The County Diagnostic: A regional environmental footprint framework for the USA

and

A comparative case study application of the County Diagnostic within the US Eastern Temperate Forest Ecoregion

By:

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This work has been developed with honest intent and to the best of my ability. I claim responsibility for all errors or misinterpretations.

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List of Abbreviations

(Arc)GIS – Geographic Information System
ABS – Abstraction
AFOs – Animal Feedlot Operations
ANOVA – Analysis of Variance
BOD – Biochemical Oxygen Demand
BPLUT – Biome Parameter Look-up Table
BTU – British Thermal Unit
C/N – Carbon / Nitrogen (Ratio)
CAFOs – Cattle and Feedlot Operations
CatPCA – Categorical Principal Component Analysis
CD – (the) County Diagnostic
CFS – Cubic Feet per Second
CO2 – Carbon Dioxide
COD – Chemical Oxygen Demand
CoEAT – Co-Digestion Economic Analysis Tool (US EPA)
CONUS - Conterminous United States
CORPS - US Army Corps of Engineers
CPM – Crude Protein Multiplier
CSO – Combined Sewer Overflow
CVR – Compost Volume Reduction
CWA – Clean Water Act
DAAD – Deutscher Akademischer Austauschdienst
DEU – Dissipative Ecological Unit
DMT – Dry Metric Tons
DW – Drinking Water
EBPR – Enhanced Biological Phosphorus Removal
EF – Ecological Footprint
ET – Evapotranspiration
ETF – Eastern Temperate Forest (Ecoregion)
ETR – Energy Transport Reaction
EUR - Ecological Urban Restructuring
EWR – Environmental Water Requirement
FAO – Food and Agriculture Organization
FDC – Flow Duration Curve
FEMA – Federal Emergency Management Agency
GFN – Global Footprint Network
GPP – Gross Primary Productivity
GWH – Gigawatt Hour
HANPP – Human Appropriation of Net Primary Productivity
HEC-HMS – Hydrologic Engineering Center Hydrologic Modeling system
HFR – High Flow Requirement
HUC – Hydrologic Unit Code
IO – Input / Output
IP – Incorporated Place
K – Potassium

kWh – Kilowatt Hour
Laf – Level of Average Frequency
LAI – Leaf Area Index
LEED – Leadership in Energy and Environmental Design
LFR – Low Flow Requirements
LiDAR – Light Detection and Ranging
M^3 – Cubic Meters
M^3/t – Cubic Meters per Ton
MAPA – Municipal Area Planning Agency (of Omaha, Nebraska, USA)
MCD – Minor Civil Division
MFA – Material Flow Analysis
Mg/l – Millegrams per liter
MGD – Million Gallons per Day
MMF – Mean Monthly Flow
MMR – Mean Monthly Runoff
MOD16 – MODIS 16
MODIS – Moderate Resolution Imaging Spectroradiometer
MOU – Memorandum of Understanding
MRIO – Multiple Region Input / Output (models)
MSW – Municipal Solid Waste
MW – Megawatt
MWH – Megawatt Hour
N – Nitrogen
N_2 – Nitrogen (Atmospheric or Organic)
NASA – National Aeronautics and Space Administration
NASS – National Agricultural Statistics Service
NDI – Normalized Difference Index
NED – National Elevation Dataset
NH^+_4 – Ammonium
NH^-_3 – Nitrate
NHD – National Hydrologic Database
NOAA – National Oceanographic and Atmospheric Administration
NPDES – National Pollutant Discharge Elimination System
NPP – Net Primary Productivity
NR – Non-Residential
NRCS – (US) Natural Resources Conservation Service
NREL – National Renewable Energy Lab
NWIS – National Water Information System
ORNL – Oak Ridge National Laboratory
P – Phosphorus
P – Probability of a Volume of Water Discharge in CFS
P/B – Production / Biomass (ratio)
PAD-US – Protected Area Database of the United States
PCA – Principal Component Analysis
Prod - Production

PP – Primary Productivity
PPD – Pounds Per Day
PV – Photovoltaic
PVGIS – Photovoltaic Geographic Information Systems
Q – A Volume of Water Discharge in CFS
REZ – Road Effect Zone
RFWS – Renewable Fresh Water Supply
RMSW – Recycled Municipal Solid Waste
ROI – Return on Investment
SAM – Sequencing Anoxic / Anaerobic Membrane Bioreactor
SPreAD - System for the Prediction of Acoustic Detectability
SPSS – Software Package (for the) Social Sciences
SSO – Sanitary Sewer Outfall
SSURGO – Soil Survey Geographic Database
SW – Service Water
SWIM – Soil and Water Integrated Model
T&E – Threatened and Endangered Species
TBEL – Technology-Based Effluent Limitations
TR-55 – Technical Release 55 (Urban Hydrology for Small Watersheds)
TWH – Terrawatt Hour
UK – United Kingdom
UN – United Nations
UN-SEEA – United Nations Strategic European Environmental Assessment
US DOE – United States Department of Energy
US EPA ECHO – United States Environmental Protection Agency Enforcement and Compliance History Online
USA – United States of America
USACOE – United States Army Corps of Engineers
USDA – United States Department of Agriculture
USEIA – United States Energy Information Administration
USGBC – United States Green Building Council
USGS - United States Geological Survey
VIC – Variable Infiltration Capacity
VWD – Vertical Waveform Diagram
WCED – World Commission on Environment and Development
WFLC – Wind Farm Locator Criteria
WPCa – Adjusted Wind Power Coefficient
WPE – Wind Power Envelope
WQBEL – Water Quality-Based Effluent Limitations

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1 Abstract

The Ecological Footprint and subsequent additions to the Footprint family of carbon and water has revealed profound truths about human consumption of resources in a globalized world, with the United States as one of the world's largest consumers. The explosion of urban development in the USA has also disconnected population and land productivity which creates urban human settlements with intense resources demands that tend to outstrip their immediate environment and rely on the global market. With global pressure and increasing costs for resources, it might be time for the USA to tighten up resource consumption and implement regional material sharing strategies with lower embedded energy and higher local economic gains than importing from the global market with hidden footprints and environmental costs. This phenomenon could be measured and compared as regional metabolism assessments using the Footprint family, but requires an expanded set of analysis factors which are related to a holistic ecological metabolism framework. If such a framework is developable, what would be the effect of ecoregions on the expanded footprint and would some geographic regions be better suited for supporting humans than others?

The County Diagnostic is an expanded component environmental footprint framework for the USA which is developed and applied to compare the influence of ecoregions on poly-factorial environmental footprints. The project brings together the methodological frameworks of the Ecological Footprint family, ecosystem services, and type 2c material flow analysis within the concept frameworks of the dissipative ecological unit and non-equilibrium thermodynamics to create a component expanded 'diagnostic assessment' that quantifies and compares the flows of food, water, energy, carbon, municipal solid waste, wastewater and spatial extent of ecosystem conservation at the county-level using publicly-available data and standard analysis tools (ArcGIS, SPSS, Excel). The annual 'snapshot' outcome of the 'County Diagnostic' method is a county-level quantification of the ecological carrying capacity compared to the human population and systems demands for resources. The results are normalized for comparison in a formula called the normalized difference index (NDI) and plotted as a 'vertical waveform diagram' that can be compared across counties.

Material fluxes are quantified using a unit-specific approach which can in-turn be used as a basis to quantify the ecological economic impacts of county-wide restructuring of infrastructure and ecosystems and the potential for a county, or a group of counties, to achieve a highly material and energy efficient level of circular metabolism in lieu of the inefficient status quo of linear urban metabolism. The project compares 6 counties in different Ecoregion level II units of the Eastern Temperate Forest in a nested ecoregion case study design with the County Diagnostic, comparing the effects of ecoregions on material flows while isolating the factors of area and population. The outcome of the case study is discussed in light of the research questions about the goal of circular metabolism or closed loop cycling of material fluxes in counties and the effect of ecoregions on how this metabolism should be managed. A discussion of the results explores the potential of the concept framework of equilibrium or non-equilibrium thermodynamics to explain county metabolism findings.

The results of the study found differences in all vertical waveform signatures across Ecoregion level II units and some similarities amongst factors of counties in adjacent units. Although only six cases were compared, statistical differences in distribution and normality between ecoregion units in the northeast USA, Midwest and Southern USA using a Kolmogorov-Smirnov test and Friedman's ANOVA were identified; significant correlations between water, food and organic material were suggested by the Spearman's R statistic; and a categorical principal component analysis summarized the NDI values into four salient dimensions which are reflected back onto the research questions and conceptual frameworks. The use of formulas to summarize the 38 capacity and demand factors resulted in a successful bottom-up county-wide material specific and spatially explicit approach enabling the integration of spatial and numeric data from myriad sources. Differences between ecoregions were identified with the County Diagnostic method. A few meaningful measures for policy regulation are made which could assist in ecosystem conservation and material flow management. Several recommendations for future research directions are made, such as application to other countries and refinement of some categories, especially sub-county CO_2 model accuracy and material recovery rates.

2 Introduction

2.1 Global Population Growth and Urbanization

More than 50% of the global human population reside in cities, with that percentage estimated to increase by 2030, while at the same time global population is estimated to grow from ~6.8 billion to ~8.8 billion by 2030. The USA is estimated to be at 80% urban population by 2030 (United Nations Population Division 2011) and in 2010 contained 29, 514 incorporated places (US Census 2010b)(ie, villages, towns, and cities) indicated in Figure 2-1. It is clear that supplying materials and energy to urban populations all over the world will be important in the future, and especially in industrialized countries where the per capita consumption rate is much higher due to technology, affluence and flows of inexpensive or subsidized petroleum and natural gas for transportation, heating and electricity. The US Department of Energy (US DOE) estimated in 2006 that peak oil production is either occurring or will occur within 10 to 20 years, after which will be an unpredictable rate of diminishing extraction returns (Almeida, Silva 2008; Hirsch 2006). To add to that, a feedback from fossil fuel combustion associated with industrialization starting around 1840 is arguably changing our climate and may affect an as yet unpredictable number of human settlements (Intergovernmental Panel on Climate Change 2013). Thus, the predicted increase of global population growth, increased percentages of urban population, possible scarcity of petroleum resources, and possible disruption of supply lines or redistribution of global bioproductivity via climate changes present future challenges to modern industrialized cities because of the intense energy and material they require, their reliance on extensive global hinterlands for supply of basic resources and energy, and the increasing global impact of urban and industrialized wastes. Indeed, this topic has been much in debate since at least the 1960s with the coining of the phrase "urban metabolism" (Wolman 1965), the emergence of systems ecology as a means to study human systems and ecosystems (Odum 1983) quantitatively and the development of various "Footprinting" methods to measure man's impact on the planet (Rees, Wackernagel 1996; Hoekstra et al. 2011).

2.2 Urban Population in the United States

Many 'cities' in the USA are in reality a cluster of incorporated places that may not have coordinated infrastructure systems designed to cycle materials; rather they are designed to receive energy and materials, metabolize them and emit wastes into the air, water, or landfill at a rate lower than what is regulated by the US Environmental Protection Agency (US EPA) and for which the cost can be politically and economically supported. To complicate the matter, there is typically a mix of public and private infrastructure ownership in the USA which makes changes to infrastructure systems and land re-allocation difficult due to the number of stakeholders involved and the possibilities for data gaps or lack of transparency. How can the USA reduce its impact and manage a growing urban population of disconnected linear metabolic units reliant on external inputs in the context of competing global demand for basic resources? This study is focused on measuring the metabolic resources required by counties in the USA to understand how urban metabolism can be structured or restructured to better manage material flows.

2.3 A Well-Studied Phenomenon?

The entire phenomenon of human impact on the environment is a huge field covering anthropology, geography, ecology, biology, economy, sociology and so on. To narrow the field down, this study focuses on recent work in the fields of spatial planning and in the ecological sub-field of landscape ecology. This work includes the Ecological Footprint and related Footprint research, a host of technical applications and spatial analyses related to remote sensing and GIS, the ideas of material flow analysis and an urban metabolism, theories for ecosystem conservation, the quantification of ecosystem services and landscape functions and advances in engineering systems technology and efficiency.

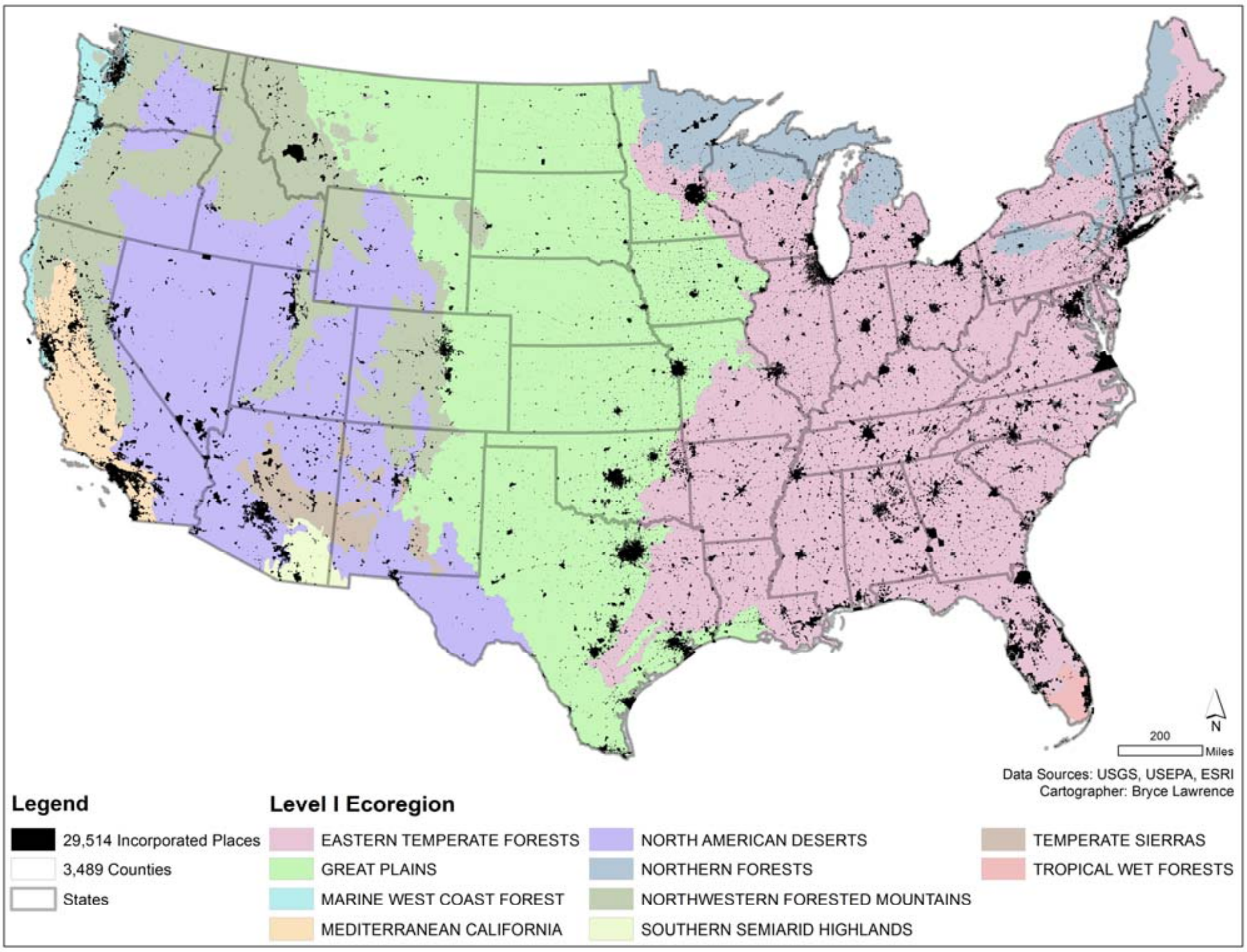

Figure 2-1: The 29, 514 Incorporated Places in the USA (US Census 2010) and Level I Ecoregion Divisions (US EPA 2007)

2.4 Refinement of Existing Methods for the USA

A city may inherently be an open non equilibrium thermodynamic dissipative structure (Prigogine, Stengers I. 1984; Pulselli et al. 2006)) and thus the goal for cities is not a closed system equilibrium, as that would equate to homeostasis with no external interactions of energy or matter (ie, death); rather the goal may be better control of detrimental entropy sinks that linear metabolic cities can impose on the surrounding ecosphere at rates which exceeds the absorption capacity of local or regional natural systems, as introduced by the Ecological Footprint (Rees, Wackernagel 1996). This transformation would manage materials more efficiently by increasing “short cycles” of matter and energy (Ripl 2003), thereby ensuring the total retention of valuable materials and energy. In terms of urban metabolism, increasing short-cycles could theoretically make a city or county more reliant on recycling of internal material and energy and less reliant on inputs of material and energy from external sources, thereby increaseing the resilience (Holling 1973) of cities to changes in supply networks, defined as the ability for relationships in a system to persist given changes to variables and parameters within the system.

Since the USA encompasses many ecoregions with different biocapacity and climates, an important step is to develop a sub-regional approach to urban metabolism assessment that utilizes sub-regional level data to capture the heterogeneity of urban material and energy demand in varying climates which ultimately determine the underlying carrying capacity of cities and regions. This work builds on a rich array of analysis methods and formulas as a starting point, including the Ecological Footprint (Rees, Wackernagel 1996), Carbon Footprint (Pandey et al. 2011), Water Footprint (Hoekstra, Chapagain 2006), urban metabolism studies (Lehmann 2011; Havránek 2008), and sustainability tools (Building Research Establishment 2004), and aims to develop a spatially explicit and unit specific macro-material flow analysis method fitted to sub-regional data available nation-wide in the USA. The resulting analysis method is a county-based diagnostic that quantifies the flows of energy, food, water and material demanded by urban populations and the ability of local ecosystems to absorb solid and organic wastes, sequester atmospheric carbon emissions, create renewable energy, and maintain a healthy underlying ecological structure. The analysis components included in the County Diagnostic are an expansion of the Footprint family as related to the fundamental components of the dissipative ecological unit (DEU) (Odum 1971; Ripl 2003), which allows for cities to be analyzed in parallel to ecosystems.

The application of the county-based diagnostic method to different ecoregion sub-units is developed to study the effects of ecoregion variations on the potential for counties or groups of counties in the USA to achieve semi-closed circular flows of material and energy.

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3 Theoretical Background

This dissertation brings together a number of fields within spatial planning, ecology and engineering. The literature review is organized into sections based on theme or methods and the part of that theme or method relevant for this study is brought forward and discussed in terms of its contributions and limitations.

3.1 The Ecological Footprint

3.1.1 The Ecological Footprint of Nations

An integrated measure of the urban metabolism that is moving in the direction of the DEU as organizing principle is the Ecological Footprint. The Ecological Footprint (EF) (Rees, Wackernagel 1996; Wackernagel, Yount 2000; Wackernagel et al. 2006; Global Footprint Network 2009) determines how much land area a nation needs to produce the basic demands of its population and absorb its wastes. When the land area required to meet these conditions is greater than the sovereign area, then a country is considered to be in a deficit known as ecological overshoot, and must rely on the global market or commons for material or energy inputs and waste absorption. The EF method has been applied to many countries and found that humanity's EF exceeded its total resources by 20% in 2002 and that the United States has the largest per capita EF of all countries, with demands exceeding biocapacity by about 50% in 2002 (Wackernagel, Kitzes 2006). However, the EF does not include some of the principle parts of the DEU, including an estimation of energy that can be derived from the sun, the creation and absorption potential of solid and organic wastes (detritus creation), the dissipation potential of organic wastes in the immediate ecosphere (decomposition), and an area-based measure for preservation of ecosystems and biodiversity (protection of producers, the basis of the food chain). The EF utilizes national-level data sources because the scale of the analysis is to compare nations; however this study is focused on the assessment of individual counties and therefore needs sub-national data sources to capture the heterogeneity of sub-regional metabolism of ecoregions across the USA.

3.1.2 Critiques of the Ecological Footprint

A number of studies have critiques and suggestions for improvement in the EF framework. Recommendations for improvement were important for this study since the unit specific flow-based approach demanded either a reworking of the EF formulas or an adoption of an integrated multi-source methodology, opening the door to integration of expanded component analysis per recommendations. The recommendations for improvement of the EF are very broad, ranging from data sources, to methods, to trade and policy applicability and integration to existing European economic analysis frameworks. Since this study is focused on developing a sub-national material flow-based adaptation of the footprint framework for the USA, the review of the critiques included in this report are limited to methodological, data source, and applicability improvements.

3.1.2.1 The German Government Summary Report of the Ecological Footprint for Germany

The Federal Environment Agency of Germany (2007) reported a number of methodological improvements or observations of the method, including 1) the need for a method to estimate the waste absorption capacity of ecosystems aside from carbon sequestration potential of forests, 2) the fact that only C02 is accounted for as a gaseous emissions when other more detailed emissions standards calculate C02 plus other different types of emissions, 3) the lack of inclusion of a direct measurement of non-renewable resources in the method, 4) the lack of a measurement of water demand or available capacity in the method, 5) the use of a land unit (global hectares) to represent impact and biocapacity, which necessitates the use of a weighted calculation and thus the identical weighting of land cover types in different climates and ecoregions which are in reality heterogeneous, 6) the inability to track changes in land use intensity or efficiency if data sets and assumptions do not also change with land use changes, 7) the lack of a definitive method for estimating areas for biodiversity conservation beyond a simple percentage, 8) the use of global yield factors when it has been shown that utilization of local yield factors in lieu of global factors can cause variations in the results of up to a factor of 2 in sub-national analysis, 9) the potential reduction of footprint based on the application of new technology such as household efficiency and renewable energy, and 10) ensuring the accuracy, consistency, and timeliness of all datasets involved.

3.1.2.2 An Interdisciplinary Evaluation Headed by the Global Footprint Network

Kitzes (Kitzes et al. 2009), included a wide array of improvements separated by subtopics, including source data, global hectare accounting, specific land type improvements, trade and international allocation, energy and carbon, other ecosystem impacts, and application and policy use. However, most of the improvements are just that, they improve the existing method by making modifications as opposed to wholesale changes to the method, data sources, or underlying assumptions. The recommendations are presented in the below table by their respective category.

Ecological Footprint Research Agenda Summary from Kitzes et al., 2009	
Source Data	**Energy and Carbon**
Accuracy of primary source data Multiple Data Sources Improvement of Key constraints Sensitivity Analysis	Nuclear footprint Carbon footprint Other greenhouse gases Emissions from land use change
Specific Land Type Improvements	**Other Major Ecosystem Impacts**
Fishing ground yields Cropland yields Built-up land Additional land types	Water use Persistent pollutants Biodiversity Future footprints and biocapacity loss
Global Hectare Accounting	**Trade and International Allocation**
Measured vs. Calculated land use Local vs global hectares Equivalence factors	Trade Producer and consumer responsibility Tourism
	Application and Policy Use
Constant Yield Calculations	Detailed written documentation Policy linkages and institutional context

Table 3-1: EF Research Agenda Summary (Kitzes et al. 2009)

3.1.2.3 Systematic Review of the Ecological Footprint Method

Wiedmann and Barrett (Wiedmann, Barrett 2010) conducted a review of over 150 papers on EF methods and applications associated with an expert survey of the "perceptions of usefulness of the EF as an indicator for sustainability (Wiedmann, Barrett 2010)". This work provides a valuable summary of the "key issues" associated with the Ecological Footprint and identifies four differing methodological approaches related to the original National Footprint Accounts from 2009 (Global Footprint Network 2009)

The main conclusions from the expert survey were that 1) the EF is a good communication tool, but does not communicate the detailed reasons for the policy, 2) it is limited in scope and does not inform about when ecological limits might be reached, 3) the aggregated nature of the EF is needed to communicate broad policy, but does not sufficiently address regenerative capacity compared to demand, 4) the EF should be aligned with the UN System of Environmental and Economic Accounting, and 5) the EF is part of a "basket" of indicators and is best when used in conjunction with other tools to achieve the comprehensiveness necessary for detailed policy-making and decision making.

The main conclusions from the methodological review include: 1) none of the existing methods can address all relevant questions alone, 2) methods that establish a link between human consumption, ecosystem functioning and bioproductivity are emerging in the form of the Dynamic EF, 3) the utilization of NPP has potential for linking human consumption and ecosystem services, 4) while interesting, the emergy approach does not appear to create a fundamental shift in the existing EF method and research base, 5) input – output analysis has promise because of its direct, unambiguous approach, flexibility of scale and system analysis and its UN-SEEA compatibility, but is based on economic input-output table availability, and 6) multiple-source trade embodied EF's can be accounted for with the MRIO method. A summary of the 4 identified methods from the method review and their key issues based on the report and tables in Wiedmann and Barrett (2010) is presented in Table 3-2 below. The table is meant as a literature review tool to succinctly relate all benefits and shortcomings of each EF-related method so as to inform and justify the research design and methods of this study.

3.1.3 The Urban Funnel: A Sub-National MFA and EF Mixed Approach

The Urban Funnel model (Luck et al. 2001) is an urban region EF model that aims to address some of the critiques mentioned in section 3.1.2, further refining the EF method by calculating separate footprints for water, water with agricultural interaction, food production and carbon assimilation (ie. the EF analysis categories) within spatially explicit units in GIS to capture the heterogeneous distribution of bioproductivity in the USA. The authors identified new data sources different than the MFA recommended UN FAO data for food production, water availability, and land cover distribution and employed a local yields and local hectares approach of the EF which also employed a tons and gallons accounting approach similar to the mass flow balance concept of the MFA type 2c approach (Ayres, Ayres 2002). The authors titled the method 'The Urban Funnel' because it was designed to identify an area of influence which 'funneled' goods to the population and which received the waste outputs of the population.

The research design employed a case study of the 20 largest US cities in which the spatially contiguous footprints extended beyond the urban region for at least one analysis category and that geographic location caused variation in the individualized footprints between cities with similar population. The urban funnel used a component approach to calculate the EF, where localized data was used to calculate the fluxes and volume of material related to a spatially explicit component category such as food, water, materials, waste and energy production. The urban funnel results suggest that sub-national component-based EFs can provide more detailed information on specific material flows in urban regions and effectively shifts the discussion from national level ecological overshoot to regionally specific material flow balances. The report falls short of a DEU analog analysis because it does not include human waste flows (detritus), renewable energy (solar radiation), waste absorption potential (decomposers) or spatially explicit ecosystem and biodiversity conservation areas (protection of producers and consumers), all of which are critically linked to infrastructure systems of industrialized cities.

Variations of EF Methodologies	Key Issues	Representative Articles / Source
Conventional EF Accounting	**1. The National Footprint Accounts Approach (Lazarus, 2014)**	
Global Hectares and Yield Factors	Compares countries at the cost of being able to compare a countries' internal heterogeneaty	Rees and Wackernagel et al; GFN et al.
National Footprint Account Method and UNFAO Data	National production, imports, exports, yeilds; top-down accounting	Lazarus, Zokai et al, 2014
Biocapacity Based on UNFAO Data	Loss of sub-national resolution with national data and yield factors; sustainable versus unsustainable yields; ecosystem degradation not accounted for	UN FAO Data
Variations of the Conventional Account (non IO based)	**2. Official NFA Data and Framework, but with a Modification**	
Actual Land Units / Local Yield Factors	Local yields can differ by a factor of two compared to global yeilds	Wiedmann and Lenzen, 2007; Haberl, 2001; Haberl, Erb et al, 2007; Erb, 2004
Land Disturbance	Includes a measure of future land disturbance in the NFA framework	Lenzen and Murray, 2001
Human Appropriation of Net Primary Productivity (HANPP)	Proposed as alternative to 'bioproductivity'; determines total use of primary productivity for humans (HANPP); HANPP is a macro-measure and resolution of primary and secondary products requred is eliminated with the NPP method; creates specific link between human consumption and ecosystem services; eHANPP links consumption from one region to NPP appropriation in another; useful pressure indicator for biodiversity loss	Haberl, Erb et al, 2007; Erb, Krausmann et al, 2009; Haberl and Wackernagel, 2004; Venetoulis and Talberth, 2008; Gaston, 2000; Wright, 1990; Haberl, Schulz et al, 2004; Waide, Wllig, Steiner et al, 1999.
Emergy	Based on solar radiation; highly abstract mass-balance approach; detrimental loss of accuracy calculating transformities between solar radiation and product / production	Zhao, 2005; Liu, 2008
Inclusion of Further Emissions and Resources	CO_2 emissions from sources other than energy use; inclusion of a new category of 'emissions land' which embodies the effects of climate change and sea level rise; inclusion of toxic pollutants; inclusion of methane; inclusion of other non-methan and non-carbon atmospheric pollutants; incorporation of non-renewable or abiotic resources such as metals and minearal resources.	Peters, Sack, Lenzen et al, 2006; Lenzen and Murray, 2001; Holden and Hoyer, 2005
Dynamic Ecological Footprint Models	**3. Relates Consumption to Bioproductivity**	
Complementary Tool to the NFA Method	Impact pathways and variables linking human consumption and ecosystems to represent human consumption in terms of impacts to bioproductivity; based on the FAO bioproductivity data at the national level and then updated annually based on the economic, demographic, productivity, energy and emissions; does not assume more consumption than there is bioproductivity; a good direction for future biodiversity assessments which could fit into the EF framework	Lenzen and Wiedmann, 2007
Input- Output (IO) Based Methods	**4. Economically-Based Supply Chain Accounting Linked to Bioproductivity**	
Single-Region IO Models (SRIO)	Quantifies interdependence of activities wihin an economy, corporation, sub-national area, city or socio-economic group; based on relating economic data-base and bioproductivity per analysis unit; is in-line with the System of National Accounts (SNA) and accepted by the UN System of integraged Environmental and Economic Accounts (US-SEEA)	Leontif, 1936; Hubacek and Giljum, 2003; Wiedman, Minx, Barret, Wackernagel, 2006;
Multi-Region IO Models	Similar to SRIO but can account for a distinction of trade flows; necessary to link multiple countries or economies together; can calculate EF embodied in international trade; indicates high costs of energy in transport (Wiedmann, 2009); very practical for corporations and accounting of supply chain networks	Wiedman et al, 2007; Wiedman, Lenzen and Wood, 2008

Table 3-2: Variations, Sources, and Key Issues for Footprint Methods, Adapted from (Wiedmann, Barrett 2010)

3.1.4 Component and Compound; Top Down and Bottom Up

One of the fundamental contributions of the urban funnel model was to recognize that explicit volumes of demand and biocapacity could be calculated as individual unit specific components, especially with the help of GIS. Research indicates that non-aggregated component approaches, where specific components remain broken down, may be more useful at the regional or sub-regional level. Newman and Jennings (Newman, Jennings 2008) indicate that compound methods are appropriate for national level and some sub-national level comparisons and tend to utilize national level input-output economic and trade data tables as a basis. In contrast, component-based methods are more appropriate for regional and urban-region focused studies where detailed regional data may be available and where unit specific and spatially explicit results can guide sector specific comprehensive or county-wide planning. While component-based sub-national methods may utilize more accurate localized data, it may also be harder to obtain consistent data across large areas, in which cases regional comparison could be difficult. This research supports the conclusion that component-based EFs may be best for urban regions provided consistent data is available.

In addition to the level of aggregation or dis-aggregation in a footprint or material flow analysis approach, data must be collected for each individual unit and then summed for an entire case study area or data must be collected for the whole case study area and then distributed to determine a per capita value. This is known as the 'bottom up or top down' data approach. The top-down EF method using national level data sources was compared to the bottom-up EF method using local data for an island off the east coast of Great Britain and found that the two measures came to within 10% of each other (Simmons 2000). The research review indicates that aggregate and component, top down and bottom up EF methods may yield similar results and that bottom up component approaches are recommended for regional and sub-regional analysis.

3.1.5 Geographic and Per Capita Approaches

The approach and data utilized is often dictated by what process or product the EF or material flow is trying to encapsulate and ascribe to people or areas. This has resulted in two types of footprint in the research: the "geographic principle" where material flows within a discrete area are computed and the "responsibility principle" where the material flows per capita are computed (Simmons 2004; 2000). Both of these approaches can be calculated with the value of the other, dividing total area consumption by population or multiplying per capita consumption by total population of an area, but the outcomes can be different. The key difference lies in what a material flow analysis or EF variation is designed to account for.

A footprint which calculates per capita impacts and includes consumption of products or pollution which occurs in another part of the world can be very detailed and based on good nationally available data, making international comparisons and "total accounting" possible. However, this type of per capita approach may have a hard time comparing that material or pollution load with the local ecosphere because it would require that an entire globally-based product chain fit within the comparatively smaller local ecosystem or ecoregion area. Per capita approaches which want to compare localized demand with localized resource availability/production must therefore be limited in what is attributed to the per capita sum, excluding the consumption of products produced in a global process chain. This basically results in a split of per capita accounting as "internal" and "external," where internal refers to consumption of goods with locally embedded resources or pollution and external refers to consumption of goods with non-locally embedded resources or pollution (Hoekstra et al. 2011). Per capita accounting can theoretically be adapted to several different intended approaches utilizing control of internal and external accounting from top down or bottom up data expressed in individual components or compound (Simmons 2000).

Footprints or material flows which resort to the geographic measure have been applied in material flow assessments of the urban metabolism (section 3.2.2) and are concerned with emissions and consumption related to explicit spatial boundaries due to data availability or desire to encapsulate the impact of a city and report in unit specific components, such as water used, carbon emitted or material cycled. This approach can be beneficial for cities or urban regions that wish to set targets to offset various internal impacts or evaluate the capacity of systems to provide demanded resources internally ('locally'). However, this approach does not account for the total material throughput of a lifestyle and may therefore under-represent the intensity of impact for the tradeoff of being able to evaluate the impacts of internal consumption on local ecosystems. Surprisingly, as of 2001 few examples of the geographic approach have tried to compare local biocapacity with localized demand (Lewan, Simmons 2001), and I believe that is because the primarily applied method, the GFN National Footprints method, must be modified to do so.

The conversion of geographic footprints into per capita footprints can be problematic because it may account for industry or services which are not directly consumed by any of the population and may not be included in internal or external per capita components. When a geographic approach indicates an undersupply of resources or pollution absorption capacity, that area shortfall can be computed into an area demanded to reach a balance between demand and supply. Geographic approaches can also have some variation depending on the component or compound approach calculating internal and external impacts using bottom up or top down data sources.

The current EF national accounts method (Lazarus et al. 2014) is a per capita approach which defines the geographic area needed for internal and external per capita demand with top down data, reporting the results as land areas demanded in an inverse geographic approach which does not restrict the results to any area but rather defines an area demanded for supply and sequestration. Therefore the EF approach is to quantify by per capita and then convert into geographic units. The potential flaw in this approach is to try and rectify waste emissions from a population which includes external consumption via local environmental regulation or modification because it would impose the load of multiple ecosystems or ecoregions onto one ecosystem or ecoregion. However, the utilization of only internal per capita emissions and inclusion of specific local process and product impacts could likely identify direct emissions within a defined area so that local ecosystem comparisons can be made. However, this approach then veers away from the official GFN national accounts method and becomes a variation on the Footprint.

3.1.6 The Water Footprint

The Water Footprint was presented per capita in 2006, methodologically crystalized in 2011 (Hoekstra et al. 2011) and followed up with a national comparison in 2012 (Chapagain et al. 2006; Hoekstra, Mekonnen 2012) that defined the Water Footprints of modern consumer society and the concept of "virtual water." The Water Footprint splits per capita consumption up into the 2 broad categories of A) internal Water Footprint (water from one's own nation) with sub categories of agricultural products, industrial products, and domestic water consumption and B) external Water Footprint (water contained in imported goods) with the two sub categories of agricultural products and industrial products. The 2012 report indicates that the per capita water consumption of Americans is estimated at 2500 m^3 / year split by 81.3% internal (48% agriculture, 24.5% industrial goods, 8.7% domestic water consumption) and 18.4 percent external sources (10.8% agriculture, 7.9% industrial goods). The Water Footprint analysis defines not only internal and external water sources, but describes the water resources as blue water (surface and ground), green water (rainwater or water vapor), and gray water (the volume of freshwater required to assimilate a pollutant load based on existing water quality standards).

3.1.7 The Carbon Footprint

There are several varieties of Carbon Footprint in the literature, aside from the method utilized by the EF guidebook to national accounts (Lazarus et al. 2014), and several frameworks have been developed to characterize the variations in the Carbon Footprint, including tier/scope based (Pandey et al. 2011), material flow based stemming from analysis type 1 and 2 (Table 3-3; Bringezu, Moriguchi 2002), and the idea of geographic and per capita reporting.

Tier/scope frameworks (Pandey et al. 2011) consist of tier I including direct onsite fuel consumption from sectors or units; tier II including embodied emissions of purchased electricity, steam, heat, or others; tier III including embodied life-cycle emissions not included up to tier II. This type of tier systems opens the door for different interpretations of a Carbon Footprint based on the application of the research design or methodology. For example in a "geographic principle" type of meta-footprint approach it may be most beneficial to split out tier I and tier II to compare sequestration rates of a specific geographic extent and not include tier III where emissions are likely to have occurred in another part of the globe which could make local ecosystem balance equations difficult to directly compare. Inversely in the case of "responsibility" or per capita footprints at a national or international level such disaggregation may not be important. A fundamental point with different Carbon Footprint types is to clarify the time scale of the impact and if it is singular or re-occurring.

3.1.8 The Footprint Family

Very recent literature has broached the idea of integrating the EF, Carbon Footprint and Water Footprint to create a Footprint family (Galli et al. 2012). Galli argues that there is not one indicator which is the best to track pressure on the planet and in fact a suite of tools may be the best approach to track impacts, especially since different tools have different policy implications. One of the troubles with integrating the three approaches is that the carbon and Water Footprints are unit specific and present direct quantitative results as volumes of water or tons of carbon; however the EF utilizes the final indicator of global hectares which can hide the individual pressures per category. Thus, the 'members of the family' cannot currently be directly integrated.

3.2 Industrial Ecology and Material Flow Analysis (MFA)

3.2.1 The Origins of MFA

MFA is a method based in the field of industrial ecology (Ayres, Ayres 2002), and can be described as the understanding of the structure and function of a system metabolism or process chain. While it may seem like industrial ecology is a different or broader topic than what should be covered in this study related to county-wide planning and ecology, it is in fact critical to address human industrial systems in order to ascertain the balance between human and ecological systems as a whole. Bringezu and Moriguchi (Bringezu, Moriguchi 2002) explain that MFA (MFA) is "the analysis of the throughput of process chains comprising extraction or harvest, chemical transformation, manufacturing, consumption, recycling and disposal of materials," and is quantified in tons of material or energy inputs and outputs within those processes (Bringezu, Moriguchi 2002, pp. p. 79). The authors sub-divide MFA into 2 types, each with 3 variations as shown in Table 3-3.

Type of Analysis	A	B	C
Type 1: Specific environmental problems related to certain impacts per unit of flow of...	**Substances**: Cd, Cl, Pb, Zn, Hg, N, P, C, CO_2, CFC's	**Materials:** Wood products, energy, biomass, raw materials	**Products:** Cell Phones, Cars, Washing Machines, Products made of compund materials
Type 2: Problems of environmental concern related to the throughput of...	**Firms:** Companies, Manufacturing Plants	**Sectors**: Military complex, construction industry, food industry, energy sector	**Regions:** Mass flow balance, total material requirement, total throughput

Table 3-3: Types of Material Flow-Related Analysis (adapted from Bringezu, Moriguchi 2002, p.81)

Specifically, the analysis methods employed within industrial ecology have wide ranging applications for this study and are linked through the study of the urban metabolism, a topic which was initially broached in the works of Wolman (Wolman 1965). Studies of urban metabolism, one of the main focuses of this study, are aided by the breakdown of metabolism types and can be couched conceptually in MFA Type 2c.

3.2.2 The Urban Metabolism and Flows of the Anthroposphere

Human demanded material and energy that flows through cities is called the urban metabolism (Wolman 1965) and has evolved in most industrialized countries as a linear flow of material and energy inputs that create material and waste stocks in the environment that can be detrimental to human and ecosystem health. Rees (Rees 1992) and Grimm (Grimm et al. 2008) have argued that the current paradigm of fossil fuel based, globally open, linear metabolism cities is having negative effects on natural systems surrounding and within cities. Studies of urban metabolism have been conducted for a few handfuls of large cities, including Brussels, Hong-Kong, Sydney, Tokyo, Vienna, London, Cape Town, Tippery Town Ireland, Prague, Taipei, Shenzhen, Amsterdam, Ann Arbor Michigan, Hamburg, Toronto, and Nantong (Havránek 2008), which generally conclude that the largest fluxes of material in the urban metabolism are heating, electricity and transportation fuels and their associated carbon emissions; creation of organic solid and liquid waste from food and humans and associated systems of recycling or liquid/solid waste disposal; food production or import and associated water usage and/or fertilizers; water utilization for domestic and industrial applications and its associated liquid and chemical wastes. These material and energy flows disrupt all levels of ecological systems around and within cities by increasing energy, waste, nutrient, and solid material flows while reducing biocapacity and waste dissipation capacity via urban land cover conversion (Brabec et al. 2002; Grimm et al. 2008).

3.2.3 Semi-Closed and Closed Metabolism

In contrast to the linear urban metabolism, healthy ecosystems have interdependent species relationships which operate as highly efficient dissipative ecological units (DEU) (Ripl 2003) where close coupling of material flows between organisms or populations becomes more effective and efficient than linear material flow management. The close coupling of material flows is done because it is beneficial for both organisms and when this becomes required by two species' life cycles it becomes a mutualistic relationship (Odum 1971; Barrett, Odum 2000). Mutualism is a form of symbiosis, where two or more organisms rely on each other for life processes, but so is parasitism. The difference is that mutualistic symbiosis is beneficial for both organisms' life cycles and parasitic symbiosis is beneficial for one organism at the expense of another.

I argue that the current formation of material and energy flows of cities is parasitic because the conversion and maintenance of urban land cover degrades land productivity, fluvial system health and atmospheric quality and the material and energy demand of cities depletes global resources at a rate faster than can be renewed ('overshoot'). Analysis of the potential for semi-closed metabolism in cities to change this paradigm has been regarded as a key for evaluation of fundamental environmental performance (Odum 1969; Ripl, Hildmann 2000; Alberti 2007; Forman 2008) and a possible underpinning for any evaluation of urban region carrying capacity or 'sustainability.' To do this, we need to quantify the main flows of human and natural systems so that they can be balanced with the localized ecosphere, interrelated and coupled with other counties if needed, or separated out and fed back into industrial processes. I propose using the DEU as an organizing principle of urban region analysis because it will ensure that any analysis covers enough material and energy flows to evaluate mutualistic alternatives and scenarios.

3.2.4 Biocybernetics

Frederic Vester (Vester 1976) developed an idea similar to the EF called Biocybernetics, which is the analysis of flows of the technosphere and the flows of natural systems for the purposes of creating mutualistic technosphere and ecosphere relationships. Vester's work is remarkable because it proposes a material flow approach that is unit specific and was focused on trying to address every human system as integrated with ecosystems in a balance. This work influenced the component expansion to human systems of water, wastewater and energy.

3.3 Ecosystem Services and Landscape Functions

3.3.1 Ecosystem Goods and Services

Ecosystem goods are substances or mixtures of substances having values assigned by man (Brunner, Rechberger 2003) and in light of biocapacity assessments may be best described as landscape functions that have a value for man or the biosphere (Krönert et al. 2001). In the framework of mutualistic symbiosis, ecosystem goods and services need to be managed in a way that does not cause degradation of the ecosystem and reductions of the annual yields of goods and services; in fact the goal for mutually symbiotic cities should be to strengthen the ecological systems upon which human settlement is enabled which in turn strengthens the human settlement by increasing resilience to natural disasters and possibly to some climate change effects. Biocapacity in the EF method is the term used to describe the productive capacity of an area for the purposes of supporting humans and is the measure used in EFs.

Research into ecosystem services has revealed that many ecosystem service metrics and precedent 'real world' studies also quantify different aspects of biocapacity and typically employ regionally specific computer models to estimate fluxes of materials as opposed to aggregate indices (Gruehn 2006; Alberti 2007). Ecosystem service case studies have quantified flows provided by connectivity and conservation of natural systems, including the number and quality distribution of plant and animal species, flood protection potential or air quality (Chan et al. 2006; Zhang et al. 2010; Norberg 1999) and can be assessed for a number of categories of measurement related to urban metabolism such as carbon sequestration, food biocapacity, waste absorption, and solar or wind energy (Obermeyer et al. 2011) availability.

Integration of computer modeling to quantify ecoregion specific goods and services may improve the biocapacity assessment of an EF, and at the same time, the EF may be an effective framework to integrate component-based ecosystem service models to measure goods and services in real world spatially explicit units. Management of the spatially explicit component EF and ecosystem services models in a GIS meta-model streamlines the process and essentially produces and manages much of the information that would be needed for a comprehensive plan for cities or long-range plan for regions. Thus, an expanded component spatially explicit and unit specific EF framework brings the concept down to a scale where regionally specific infrastructure recommendations and planning can be carried out and then re-analyzed to validate reductions in EF.

3.3.2 Landscape Functions

This section covers the ecological functions which are preserved or harnessed via land conservation. The basic functions are described by Gruehn as habitat, visual quality / recreation, landscape history, erosion protection, biotic protection, groundwater protection, groundwater recharge area preservation, water retention and detention, surface water quality and restoration, bioclimatological function, air regeneration, and noise attenuation (Gruehn 2006). Preservation of ecosystem areas should be aimed at supporting landscape functions.

3.4 Landscape and Urban Ecology

3.4.1 Patch Corridor Network Structure and Function

To determine if a county has sufficient area set aside for ecosystem preservation, a zone of conservation (ZOC) should be included in an expanded EF analysis. The ZOC concept was developed from the landscape ecology principles of patch, corridor and network preservation (Forman, Godron 1986; Forman 1995), the meta-population dynamics theory which includes protection of heterogeneous patch sizes, types, and positions in the landscape based on the needs of various species and their life-cycles (Opdam 1991), the concept of ecosystem services which protects a portion of natural habitat for primary production, the potential integration of net primary production to offset human and urban metabolic processes (Norberg 1999; Zhang et al. 2010; Chan et al. 2006), and the German "Landschaftsökologie"-based concept of landscape functions which define the basic functioning characteristics of ecosystems as a counterpart to spatial conservation of the patch and corridor network (Gruehn 2006; Krönert et al. 2001).

In general, this approach defines a county-wide area of potential protection based on existing conditions and the theoretical frameworks above and compares it to both the existing regulated protection areas within a county and the current terrestrial biodiversity targets for nations of 17% land area (Tittensor et al. 2014), a percentage based on recommendations from the International Convention on Biodiversity and The Water Footprint method (Hoekstra et al. 2011, p.81). The definition of a ZOC enables a determination that a county is meeting this target, not meeting this target but capable of meeting the target or simply unable to meet this target based on extensive human land use appropriation. The method does not rely on field work, but rather relies on an existing array of rich GIS-based datasets developed by US federal government agencies or produced by government funded scientific research, both of which are legally required to be available to the public since they are funded by the US taxation system. This method makes it possible to define a "broad-brush" zone for conservation which can address floodplain and water-cycle management, biodiversity protection, parks system planning, ecosystem services / landscape function protection and aesthetic values of landscapes within the limited time and monetary budgets typical of professional American environmental planning and design practice.

3.4.2 Ecological Urban Restructuring

The concept of restructuring of cities or human settlement to be more ecologically sound by one unit at a time is an idea called ecological urban restructuring (EUR) (Hahn 1991). Studies of urban metabolism as mentioned in section 3.2.2 indicate that cities and city regions are putting strain on the immediate ecological resources, but often these quantitative studies fall short of proposing exactly how to fix the problems. The EUR concept takes a greater than material flow approach and puts the entire problem in context of guiding principles, fields of action to achieve the principles and defines ecological neighborhood development as an example of the unit based improvements envisioned by this approach. Guiding principles and proposed action to achieve the goal makes the implementation of the whole an "ecologically restructured city," more achievable. I would add that since the early 1990s there has been a realization that units of improvement do not have to be only neighborhoods, but can be non-spatial sectors of urban metabolism as proposed by Type 2 MFA (Bringezu, Moriguchi 2002) in section 3.2.1.

3.5 Water

3.5.1 Water Quality

3.5.1.1 Ambient Water Quality and Pollution Prevention Overview

Water quality in the USA is regulated under the US Clean Water Act 33 U.S.C § 1251 et seq. (1972)(US EPA 1972), which was originally enacted in 1948 as the Water Pollution Control Act and later in 1972 re-enacted with significant modifications to control and enforcement programs as the Clean Water Act (CWA). The purpose of the CWA is to set water quality standards for all waters of the United States, defined as "all waters which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide (US Environmental Protection Agency 6/29/2015)," which includes essentially all interstate waters and wetlands, territorial seas, impoundments of water, tributary areas with indicators of bed, banks and a high water mark, all waters adjacent to the waters above, and any other water which is deemed to have a significant nexus to a water identified above. The CWA made unregulated pollution discharges into "navigable waters" of the United States illegal, defined as "Waters of the United States that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or may be susceptible for use to transport interstate or foreign commerce. A determination of navigability, once made, applies literally over the entire surface of the waterbody, and is not extinguished by later actions or events which impede or destroy navigable capacity (US Environmental Protection Agency 11/13/1986)." While this definition does not include every piece of surface water in the US, it includes all streams in the National Hydrologic Database (NHD) which is the basis of fluvial system spatial information in this study.

3.5.1.2 Establishment of Water Quality Standards

The US EPA gives the power to most States in the USA to set water quality standards (WQS), which have to be developed and enforced at the state level while complying with Federal regulations (CWA) (US EPA 1972). State water quality standards are a multi-tier definition including:

Designated Uses – Identification of how human and biotic communities use our waterways (water supply, propagation of aquatic life, recreation)

Water Quality Criteria – Numeric limits (acceptable concentrations in a body of water) or narratives (description of unacceptable conditions) designed to protect the designated uses

Anti-degradation Policies – Protection of existing uses and extra protection for high quality or unique waters

3.5.1.3 WQS Enforcement

Several categories of enforcement are delineated under the CWA pertaining to locations where WQS are not met, including 1) wastewater management and animal waste from feed operations (CAFOs) which are covered under the national pollution discharge elimination system (NPDES) program, 2) oil and hazardous substances which are investigated on a case by case basis or after a spill, and 3) wetlands and fill material in wetland, lakes, streams or estuaries covered under CWA §

404 and which is regulated jointly by the US EPA and the US Army Corps of Engineers (Corps) per a 1989 memorandum of understanding (MOU) (US EPA 1972).

3.5.1.3.1 The National Pollution Discharge Elimination System (NPDES) Program

The NPDES Program is developed as the primary compliance and enforcement mechanism to regulate 'point source' pollutant discharges into navigable waters so that the waters do not exceed state level water quality standards. The NPDES permits are required in a broad number of program areas, including animal feedlot operations (AFOs), aquaculture, forest roads, industrial and municipal wastewater including combined sewer overflows (CSOs), wastewater treatment plant (WWTP) peak outflows and sanitary sewer overflows (SSOs), pesticide applications, and stormwater generated from construction, industrial, municipal, transport and oil and gas areas. For each of the point source pollutant discharge types above, the NPDES is in-charge of setting the regulated discharge limit and enforcing that limit (US EPA 2016).

The NPDES limit is a two-tiered system with 1) technology-based effluent limitations (TBELs) aimed at wastewater treatment processes and technology which can eliminate or reduce discharges given the available technology, cost and receiving water body quality and use objective, and 2) water quality-based effluent limitations (WQBELs) aimed at setting limits to cumulative loadings of specific pollutants. NPDES TBELs and WQBELs are developed and regulated at the State level for 46 states and by the EPA directly for the other 4 states. Permits are issued as either 1) individual permits for single facilities with a given type of activity, nature of discharge and receiving water quality or 2) general permits which covers a group of dischargers with similar qualities within a given geographical location. All NPDES permits in the categories described above are listed with effluent limitations and often historical compliance records by the US EPA ECHO on-line database (US EPA 2015), which makes it possible to find all point discharges (and cumulative annual loadings) to navigable waters of the United States at the county scale over the internet (US EPA 2016).

3.5.1.3.2 Water Quality-based Effluent Limitations (WQBELs)

The CWA § 303(d) establishes a process for States to identify waters where TBELs will not be sufficient to achieve state water quality standards. Following this process, waters are ranked based on ability to meet water quality standards and total maximum daily loads (TMDLs) are developed for priority waters by pollutant type. TMDLs identify the amount of specific pollutant(s) which may be discharged while still allowing the water of the United States in question to meet State water quality standards and take into account point, non-point and background sources of pollutants to derive a total maximum daily load (TMDL) for specific pollutants in specific receiving waters, known as a wasteload allocation. In absence of a TMDL a wasteload allocation must still be established based on State water quality standards, which can be developed at a flexible scale, from an individual reach or water body to an entire watershed or basin (US EPA 2016).

When a TMDL or WQBEL has not been calculated for a county or watershed, it is necessary to step back to the state-level water quality standards described in 3.5.1.2 and find a numeric limit in mg/l (typically) for specific pollutants. This number will be different for every state and often differs by season and is typically set by the State department of natural resources, ecology, fisheries & wildlife, or another state-based conservation agency that has been tasked with CWA compliance and monitoring. In the case that state levels of ambient water quality standards cannot be found, the Quality Criteria for Water 1986 publication released by the US EPA covers all waters nationally (US Environmental Protection Agency 5/1/1986).

3.5.2 Environmental Water Requirement

The environmental water requirement (EWR) is the volume of water allotted to ecosystems. There is a high degree of uncertainty in this value and it is somewhat complicated to account for, with no clear study indicating a proven value or method at the scales of this study in the USA. Smakhtin (2004) advocates for a low flow requirement (LFR) and high flow requirement (HFR) estimate, where the LFR is derived from a flow-duration curve (FDC)(Oregon State University 2002-2005) set at a representative flow return percentage (Q90, Q75, Q50, N/A) and the HFR is set as a range from 5% to 23% of the mean monthly runoff (MMR) in the river basin based on the volume of Q90 flows related to the MAR (Smakhtin, Revenga, C. and Döll P. 2004; Hughes, Hannart 2003). Hoekstra et al. (2011) recommends working toward a simplified global method with available data that can capture variation within the year until more complicated reference reach based regional estimates such as ELOHA are available (Poff et al. 2010). The simplified method should calculate a volume of 'base flow' and 'runoff' needed to support ecosystems where a greater percentage of deviation from natural flows occurs in basins with the greatest "levels of river basin modification (Hoekstra et al. 2011)," such as dams, land cover changes or channel modification where measured mean monthly flows will be further distorted from the natural condition and thus harder to estimate with the simplified method.

The County Diagnostic approach mixes elements of the Smakhtin (2004) and Hoekstra et al. (2011) approaches ultimately calculating a LFR and HFR in cubic meters per year which are subtracted from the total available streamflow (W1c) and total available runoff (W3c) to arrive at adjusted streamflow and runoff values. The approach estimates base flow with the USGS percentage probability-based method from the entire record of monthly stream flow records for each station sampled, setting the LFR at P25-value (U.S. Department of the Interior 2016) based on a tiered ranking of the percentage of actual riparian corridor preservation derived from the ZOC area (section 5.3.1) and utilizes Smakhtin's (2004) HFR method to estimate a percentage of MAR to be set aside, which is also recommended in Hoekstra et al. (2011).

Critiques of Smakhtin's method from Poff et al. (Poff et al. 2010) that global datasets cannot accurately predict local variations and that reference reaches should be used to understand the deviation of a stream flow from its natural flow condition, are partially addressed by using localized daily time-step data to calculate monthly mean flows for counties and by breaking up the ZOC area into tiers of land cover based on international biodiversity standards as a baseline for extent of existing modification. Since the purpose of the County Diagnostic is to reach a symbiosis between humans and ecosystems, a return to pristine land cover and flow conditions might not be the best approach or even possible. Rather, the identification of responsible targets for ecosystem flow allocation given sufficient habitat conservation area is the main concern. On this basis, the ZOC categories recommended allow for a current flow allocation to be estimated and for higher quality and lower quality habitat area flow allocation targets to be estimated if a county wants to increase their conservation area or if imminent development impacts need to be estimated

3.6 Wastewater Systems

3.6.1 History of Wastewater Systems and Purposes

The history of water supply and wastewater management goes back at least 1500 years to the Mohenjo-Daro near the river Indus in Pakistan where archeologists have discovered a site with basins for running water, toilets, and grooves to carry waste water away, out of the settlement, and into receiving river water (Weismann et al. 2007). The Mayan civilization in Guatemala and Belize also developed water supply and wastewater systems which relied on channelization of freshwater into basins and cisterns and tilted plazas to flow runoff water into canals which carried water into chinampa systems where multiple annual food harvests were realized. The Roman civilization developed elaborate water supply systems which were pressurized to carry supply water uphill and included underground vaulted wastewater conveyance to carry wastewater out of building complexes where the wastes were simply deposited into nearby streams or open lands.

In Middle Ages Europe, somewhat more sophisticated systems were developed by monks in Germany where water sources were brought in to carefully sited abbey complexes near rivers and a whole system of freshwater settling tanks, supply wells, latrines, mills, fish ponds, agriculture, and breweries were established, all based on the principle of bringing in fresh water for consumption, directing, utilizing waste for productive purposes (fish feed and fertilizer), and harnessing the work of downhill flowing water in well-designed canal matrices to keep the system flowing from fresh water to human uses and back to receiving waters (Weismann et al. 2007).

In the 1600's, the first studies in microbiology were conducted and the discovery of bacteria ensued. However, due to the belief at the time of spontaneous generation of life from decaying matter, it took a few centuries worth of experiments until in the late 1800s the matter of spontaneous generation was discredited and the reality of biological processes as the culprit for breakdown of fecal matter in wastewater was realized. Much of the driving force behind the discoveries was the simple need for improvement in river and canal systems in European cities, where water had become so polluted that it was a vector for disease. In the 1880s and later, successful biological wastewater treatments were set up via irrigation canals where wastewater was pumped in and allowed to seep in to soils where the groundwater table was low enough to allow oxygen into soil pores so that microbial action could break down organic material. This process proved successful in Berlin, Massachusetts and London in the late 1880s and 1890s, laying the ground work for further soil irrigation treatment systems outside of cities elsewhere and proving that wastewater purification was an aerobic and anaerobic bacterial process and not simply a chemical process. These early systems achieved nearly complete organic matter removal and ammonium oxidation (Weismann et al. 2007).

In 1883 Robert Koch discovered that Cholera was a bacterium that entered into the human population through water supplies contaminated with wastewater and in response sand filters were added on the front end of water supply systems (Weismann et al. 2007), representing the potential for water systems with intake filters and outflow treatment by the late 1800's. However, the reality is that water treatment and wastewater quality standards were not regulated in the USA until the 1960s (Weismann et al. 2007).

3.6.2 Wastewater System Intake and Sedimentation Basins

Wastewater intakes may consist of a screen or filter used to isolate large debris prior to system inflow. Typically a "primary" sedimentation basin is used to allow large matter to settle to the bottom and be removed as sludge before entering into the activated sludge treatment. Systems without activated sludge treatment may consist of several sedimentation basins in-line with each successive basin removing finer particles (Weismann 2007).

3.6.3 Activated Sludge Treatment

Activated sludge treatment is a process in which wastewater sludge is recirculated through an aeration basin in order to facilitate microbial breakdown of organic material, which demands oxygen. This treatment method developed after 1913, during the period of irrigation fields and trickling filters which evolved to treat a greater specific inflow load and treatment rate between 1860 and 1960 (Weismann et al. 2007, p. 15), and since then several variations of the method have developed to address efficiency and treatment efficacy concerns. Variations of this process are discussed below.

Conventional activated sludge treatment process consists of a wastewater inflow to a primary clarifier or sedimentation tank where sludge is removed, which flows to a linear aeration tank (for a specified time based on the effluent load) fed with oxygen from piping along the bottom length of the tank, then into a secondary clarifier where sludge is removed and recirculated back to the head of the aeration tank and water on the surface released as treated effluent. Tapered aeration is a value engineering adaptation identical to conventional treatment except that more air is pumped into the aeration tank at the head where the oxygen demand is the greatest (ie, the measure of dissolved oxygen due to microbial processes is the greatest) and decreases along the length of the tank where oxygen demand decreases. Step aeration modifies the process by modifying the aeration tank as described, as a stacked aeration tank with wastewater from the first clarifier is flowing in at two levels and return sludge from the secondary clarifier flowing in from the bottom and being pushed upwards where it recirculates to the secondary clarifier (Benefield, Randall 1980, p. 153).

High rate activated sludge treatment applies a low mixed liquor suspended solids concentration in the aeration tank to maximize the rate of oxygen utilization and in doing so maximizes the breakdown of organic material per unit of oxygen. This process however still requires a high volume of oxygen and is only efficient for low-flow rate systems, being unable to adequately create a continuous liquor suspension in plants which require a high flow rate or variant rates depending on ecoregion-based precipitation regimes (Benefield, Randall 1980, p. 153).

Complete mixing employs specific tank geometries, feeding arrangement, and aeration equipment to produce feeding and discharge along the entire length of the tank, establishing a constant oxygen demand and uniform solids concentration throughout the tank volume. This process is resistant to initial shock loadings, which can occur in simple linear aeration tanks, because of the sufficient and rapid blending of tank inflow. While this process requires more up-front investment in the activated sludge process, it can eliminate the need for a primary clarifier due to the effective mixing of primary influent by employing mechanical aerators (rotating arms which break up larger suspended solids into smaller pieces and with greater surface area for microbial breakdown) thereby representing a cost savings in some situations (Benefield, Randall 1980, p. 153).

Extended aeration is a variation on complete mixing for smaller inflow systems (less than 1 MGD) which generally omits primary clarifier tanks and uses an extensive aeration so that all sludge is broken down before being released as effluent. This method minimizes sludge handling and compressed oxygen use and reduces system footprint and cost, which may be desirable for smaller systems or systems where sludge handling should be minimized. The negative aspect of this system is that there will be a buildup of inorganic elements in the extended aeration tank over time due to the lack of primary sludge settling, which requires a periodic clean-out of the extended aeration tank to keep efficiency high and prevent a “dead zone” at effluent outflow locations (Benefield, Randall 1980, p. 153).

3.6.4 WWTP Outflows

Regardless of the type of activated sludge treatment, the end result is treated sewage effluent which has undergone a change of chemical state represented by the “amount of dissolved oxygen consumed by chemical and microbial action when a sample is incubated at 20 degrees Celsius for a period of time; known as the BOD and measured in mg/l and which can be referred to as carbonaceous oxidation. Inversely, this number can be represented by the chemical oxygen demand (COD) of a volume of water in mg/l over time required for the breakdown in carbon matter by specific bacteria and processes to a certain level of BOD (Benefield, Randall 1980, p. 304).” In essence, carbonaceous treatment by microbes and bacteria means that carbon is used for cell building process by the reduction of CO2 and in doing so all potential putrescent organic matter is removed from the wastewater, leaving only inorganic elements (and the microbes) but also depleting the water with oxygen through the process, which can be harmful for aquatic life which relies on dissolved oxygen in water for their own metabolic survival.

Nitrification refers to the process of conversion of ammonia into nitrogen which occurs parallel to carbonaceous oxidation and is also measured in mg/l. While carbon is used as the cell building blocks for bacteria, nitrogen is the primary nutrient in bacterial metabolism (Benefield, Randall 1980).

When the nitrification and carbon oxidization processes are complete a liquid effluent is considered “treated” and assumed ready for input into receiving streams and water bodies while the drained and fully nitrified sludge can be fed into other processes such as gasification, compost or agricultural reuse. A ‘cleaned’ liquid effluent with a BOD and N measure in mg/l, as well as a host of other particles, minerals, surfactants, pharmaceuticals, microscopic particles of inorganic matter, polymers and inhibitors to nitrification (as documented in Bartlett (Bartlett 1971, p. 104)) referred to as suspended solids (SS) and measured in mg/l. The USA must meet certain standards based on the intended use of water in the stream or pool which receives the outflow (US EPA 1972; Eckenfelder 1969) and on a final volume of “sludge” measured in percent water, nitrogen, carbon and oxygen in cubic meters over time (m^3/t). The activated sludge system is designed to run its course of BOD reduction and efficient nitrification within 3 to 4 days (Bartlett 1971).

3.6.5 Polishing and Tertiary Treatment

Often, to meet regulations of BOD and suspended solids, secondarily treated effluent must go through a process of tertiary treatment where minerals, surfactants, inorganic matter and polymers are captured and not released with the effluent. Polishing is not considered a substitute for activated sludge treatment, rather it is intended to make biologically and chemically "cleaned" water which has undergone microbial action breakdown in an activated sludge system with and a very high percent of organic matter removal better based on ecological, regulatory, or human health grounds. Tertiary treatment systems include lagoons, grass plots, sprinkler installations, micro-strainers, sand filters, coagulation, carbon adsorption, ion exchange, reverse-osmosis, and electro dialysis and typically represent treatment plant initial cost increases by 15% (Bartlett 1971, p. 104).

3.6.6 Composting Process

Wastewater, when separated into black water, yellow water, and grey water, has also been shown to be compostable in smaller quantities with living machines and sub-surface wetlands (Todd, Todd 1993) to a point where it can be used as organic compost for agriculture which may be of value for counties with smaller populations that have no tertiary treatment or that cannot afford an enhanced biological phosphorus removal system. Research also indicates that some ancient cultures practiced an agriculture, integrated version of this technique for centuries, including the Mayan chinampa system (Wilken 1971) and Chinese permaculture systems (Paull 2011), which relied on composted wastewater sludge as the fundament of highly enriched soils, specifically soils with enriched nitrogen and phosphorus. The potential application of the waste water wetland system or underground wetland treatment systems for smaller communities may also be a valuable addition to the assessment.

Composting is defined as the aerobic degradation of solid organic matter, which occurs normally in nature with plant residues and animal bodies and waste, typically forming the organic (A) horizon of a soil profile. The multi-step process is a microbial community succession starting at the mesophilic phase where aerobic bacterial decomposition releases heat energy (exothermic) from the ingestion of putrescible material (animal or vegetable matter capable of quick decay) initiating the thermophilic phase where 70 degree Celsius temperatures reduce pathogens in the waste contained in the putrescible material as well as most of the bacteria which flourished in the mesophilic phase. The final maturation stage can last several weeks and includes the conversion of dry plant matter (ie, lignocellulosic biomass) into humus and the mineralization of materials with slower degradation rates; work which is usually carried out by actinomycetes (filamentous organisms forming cloudy blue-green formations on quickly degradable matter) and fungus, both of which can degrade long polymers and benefit from the decrease in temperature, pH and water content of the compost. In this sense, compost can be divided into the category of stabilized compost which has gone through the first stage of bacterial ingestion of quick degrading material, and mature compost which has gone through all three stages and substantial humification has occurred (Stentiford, Bertoldi 2011)

Organic material actually has a range of degradability, with sugars, lipids, amino & nucleic acids and proteins degrading quickly and cellulose and lignocellulose being the most resistant to degradation. Mature compost has predominantly lost carbon and hydrogen from the original solid organic matter and Tchobanoglous et al. (from Christensen 2011) estimate that mature compost generally weighs 40% of the original solid organic matter, a percent which decreases as time of compost process increases. In addition to the length of time the compost process is allowed to run, the rate at which different materials can decay is variable, with pine sawdust decaying in 90 days, raw sludge decaying in 242 days, and hardwood sawdust taking 368 days (Haug 1993). Temperature variation of the decaying material also varies by material with straw composting at 40 degrees Celsius and sewage sludge / wood chip slurry having the highest temperature ratings of over 70 degrees Celsius (Christensen 2011).

Pathogens in organic material may include bacteria, viruses, fungi, and parasites, and if these pathogens are present in compost that is applied to the land, then they may make it into the human food supply and cause diseases or food borne illnesses. Thankfully sanitation occurs naturally during the compost process, but that process needs to be monitored to ensure sufficient heat was reached by the compost for long enough, and reached consistently throughout the composting mass. The highest rates of pathogen removal occur between 55-65 degrees Celsius and the recommended duration to sufficiently kill most pathogens ranges from 24 hours to 3 days depending on the temperature (hotter = shorter duration). To ensure pathogens have been removed, indicator microorganisms such as fecal coliforms, fecal streptococci, enterobacteriaceae, certain viruses, and parasite eggs are used with reliable results to determine if compost has been sanitized. An indicator microorganism should be present in the raw organic material, less sensitive to thermal changes than some other pathogens but none the less have a thermal limit less than 65 degrees Celsius, must be easily testable and must not itself be pathogenic (Christensen 2011).

Aside from carbon and water, nitrogen losses also occur during the compost process as a result of ammonia volatilization where organic nitrogen (N_2) is converted to ammonia gas (NH^-_3) and released into the atmosphere (Killpack, Buchholz 1993). However, with the loss of more than 50% of original carbon in typical compost processes, nitrogen percent effectively increases by overall dry weight in mature compost. Sulfur (S) also undergoes transformations during the compost process when an assimilative sulfate reduction converts organic sulfur into hydrogen sulfide (HS) gas that is then released into the atmosphere. This process occurs in the thermophilic phase and is the source of sulfurous odors typical of decaying organic material. In addition to HS from S, compost material can produce reduced molecules during the fermentation and anaerobic degradation of proteins, amino acids, nitrogen, and phosphorous which spread as volatile organic compounds in the atmosphere and results in undesirable odors (Stentiford, Bertoldi 2011)

Moisture, oxygen and a wide range of nutrients (to support biological activity) are needed for successful compost. As is theorized in the DEU concept where water is analogized as “the bloodstream of the biosphere (Ripl 1995),” so too is water a key element in compost as the evaporation of water creates the heat necessary for pathogenic reduction. The carbon and nitrogen ratio (C/N) is also a critical factor in compost where the C/N ratio is generally considered good when it is in the 20-35 range (ie, 20-35% nitrogen to 65-80% Carbon), but too little N results in limited compost action and too much nitrogen results in ammonia volatilization (and a corresponding loss of available nitrogen in mature compost) or molecule reduction which produces odors (Stentiford, Bertoldi 2011).

3.6.1 Modern Treatment Systems Overview

An awareness of environmental concerns came to a point in the 1960s with the help of Silent Spring (Carson 1960s), which resulted ultimately in the Clean Water Act and the EPA and the partition of water regulations based on use of the water, the regulation of water supply system quality and the regulation of wastewater system effluent quality. To meet regulations, wastewater treatment systems today consist of a multistep process aimed at meeting the water use requirements of the receiving water body (US EPA 2016).

3.6.1.1 Advanced Nitrogen and Phosphorous Controls

Modern sanitary sewerage systems with waste water treatment plants (WWTPs) are viewed as a beneficial anthropogenic flow system that helps collect and divert organic material, and a county-wide assessment of this potential could become part of the diagnostic approach. Drawing a parallel to mature ecosystems where detritus is used as fuel inputs for decomposers or producers in tight (short-cycled) nutrient cycles, Eugene P. Odum proposed that human civilization may be justified in employing a detritus based agriculture system, which could be interpreted to include properly reclaimed nutrients in waste water sludge as agricultural fertilizers (Odum 1969). In fact, the controlling of this waste and tightening up of this human induced nutrient plume could be considered part of the natural evolution of human dominated ecosystems from one of parasitic mutualism with high production, growth, and quantity which destabilize nutrient balances and is typical of young ecosystems to one of symbiotic mutualism where protection, stability, and quality create beneficial positive feedbacks typical of mature ecosystems.

One of the technological advances that could make this possible is a process called enhanced biological phosphorus removal (EBPR) (Oehmen et al. 2007) where microbes are injected into separated waste water sludge. In this process, microbes bind with phosphorous and then are removed, yielding P but no other non-P waste water particulates, which is then converted to Phosphorus based fertilizers. The EBPR process has been widely applied across the United States with success, although inconsistencies in the removal efficiency of this method have been reported (Oehmen et al. 2007). However, this method does not remove nitrogen and still relies on processes that convert nitrogen to a flammable gas which is then volatized into the atmosphere. Another method called a sequencing anoxic/anaerobic membrane bioreactor (SAM) is reportedly capable of removing P to a level of 93% and N to a level of about 60% in laboratory experiments (Ahn et al. 2003), but has not been widely applied beyond the laboratory. Both of these methods indicate that it may be possible to extract N and P from waste water and thus it makes sense to assess counties on the basis of presence or absence of these systems, and to estimate how the application of this technology could divert the macro-material flows of waste water nutrients away from receiving waters and towards agricultural fields. However, natural systems also need N and P and thus the question still arises as to the natural or background levels of N and P in fluvial systems and whether or not such a N and P cycling systems would be beneficial for receiving waters or if it could starve natural systems of an important nutrient.

Existing research on N and P absorption capacities of wetlands in agricultural landscape indicates that wetlands can eliminate 68% of nitrate-nitrogen and 43% of phosphorous from agricultural runoff via plant uptake (Woltemade 2000). Thus, there is an existing potential of ecosystems to provide this service and dilute human waste water flows and possibly helps to justify the preservation and expansion of wetland systems in urban hinterlands. Additionally, the multi-spectral remote sensing platform Landsat TM has been used to estimate N and P concentrations in rivers and lakes (Andersson 2012; Chen, Quan 2012) and may be a viable tool to estimate natural background levels of N and P in ecosystems and set an ecological baseline for waste water emissions as opposed to a regulation baseline which may or may not correspond to healthy ecoregion values of N and P. If baseline N and P nutrient levels were known, then removal efficiencies of N and P from sludge could be tailored so as not to starve fluvial systems of needed nutrients.

3.6.1.2 Application of Biosolids to Agricultural Land

Biosolids vary in composition of N, P, organic and inorganic content and at the same time, each crop has a different demand in terms of annual N, P and organic material application (known loosely as agronomic application rates of fertilizers). Further, the existing condition of soils in consideration of biosolids application is heterogeneous and dependent on ecological and environmental conditions as well as current and historic land-use practices. For this reason, simple calculations of composted or de-gasified biosolid rates for use in agricultural applications, such as Royte's 9.6 tons per acre figure for diverse crop types (Royte 2005), can only be used for rough estimates. More detailed multi-step methods which are more accurate have been developed to calculate the biosolids agronomic rates (Cogger, Sullivan 2007; National Biosolids Partnership 2005), however, these method require considerably more location specific data and are essentially their own spreadsheet-based meta-models. In summary, application of single value rates based on broad agricultural production from sources like the USDA Cropscape program can give a very rough number of dry biosolids demand, but detailed demand requires specific field studies. The difference between the two types of estimates for county-level assessments is not directly addressed in the literature.

3.6.1.3 Dilution as a Solution to Pollution

The Water Footprint of humanity includes a measure of waste called "grey water" which is quantified as the amount of freshwater necessary to dilute the pollutant load from direct consumers and indirect consumption and agricultural and industrial commodities (Hoekstra, Mekonnen 2012, p. 1) so as to conform to regulatory thresholds of water pollution such as those set by the US EPA. However, the Water Footprint method combines wastes related to indirect agricultural and industrial products and direct consumer waste flows which convolutes the understanding of what grey water wastes actually contain and whether or not ecosystems are able to absorb said outflows without negative effects on receiving waters. As with other measures proposed in the DEU-based County Diagnostic concept, a unit-based dis-aggregation approach may work better because it would focus attention on the nitrogen and phosphorous cycles between human populations and ecosystems, as opposed to using a regulatory measure to control aggregated wastes which may or may not exceed absorption capacity or capability (in the case of non-biodegradable wastes such as pharmaceuticals or manufacturing byproducts for example) of specific ecoregions. Thus, a method that approximates the annual N and P absorption potential of fluvial systems on a county-wide basis and compares that with the annual outflow of N and P reclaimed from WWTP sludge may be a valuable tool in assessing the underlying capacity of ecosystems to absorb human wastes, which is likely to be heterogeneous across ecoregions and climates. This method also inherently quantifies the amount of N and P based fertilizer that can be removed from WWTP outflows and redirected all together to agricultural lands, replacing some of the need for imported petroleum-based fertilizers and further tightening N and P cycles between human settlements and ecosystems.

3.7 Climates

3.7.1 Global Climates

Spatial delineations of homogenous global precipitation and temperature characteristics are typically referred to as climates (Strahler, Strahler 1996). Climates classification systems were first defined in 1900 based on observations of major differences between vegetation groups around the globe, including the equatorial zone (A), arid zone (B), warm temperate zone (C), snow zone (D), and the polar zone (E). These divisions, referred to as major divisions and which generally correspond to latitude and longitude within continents, are further subdivided where a second letter corresponds to variations in annual precipitation and a third letter corresponds to annual variations in air temperature (Köppen 1900). Köppen's climate classification system was updated in 1954 (Geiger 1954), applied to the entire globe in 1961 (Geiger 1961) and has since been the most widely used climate classification system referred to as the Köppen-Geiger climate classification . New leaps in remotely sensed data has allowed modern climatologists and agencies to update global climate distributions annually utilizing the Köppen-Geiger method, which currently stands at 31 possible climate types utilizing a pixel resolution of 56 square kilometers (Kottek et al. 2006).

Köppen-Geiger System of Climate Classification		
First Letter	**Short Description**	**Details**
A	Tropical Climate	All monthly mean temperatures over 64.4 degrees F
B	Dry Climate	Boundaries determined by formula using mean annual temperature and mean annual precipitation
C	Warm Climate	Mean temperature of coldest month between 64.4 degrees F and 26.6 degrees F
D	Snow Climate	Warmest month mean over 50 degrees F; coldest month mean under 26.6 degrees F
E	Ice Climates	Warmest month mean under 50 degrees F
Second Letter	**Description**	
S	Steppe climate	
W	Desert climate	
f	Sufficient precipitation in all months	
m	Rainforest despite a dry season (i.e., monsoon cycle)	
s	Dry season in summer of the respective hemisphere	
w	Dry season in winter of the respective hemisphere	
Third Letter	**Description**	
a	Warmest month mean temperature over 71.6 degrees F	
b	Warmest month mean under 71.6 degrees F; at least 4 months have means over 50 degrees F	
c	Fewer than 4 months with means over 50 degrees F	
d	Fewer than 4 months with means over 50 degrees F; coldest mean month under -36.4 degrees F	
h	Dry and hot; mean annual temperature over 64.4 degrees F	
k	Dry and cold; mean annual temperature under 64.4 degrees F	

Table 3-4: Köppen-Geiger Climate Classification System (Adapted from Strahler, Strahler 1996)

3.7.2 Climates in the USA

Rubel and Kottek updated their 2006 climate classification release due to the widespread application of the system after the initial 2006 digital (pdf, shape file, raw data) release, and included 4 different climate change scenarios based on Special Report on Emissions Scenarios (SRES) storylines depicting the future choices of humanity in terms of population growth, economic development, energy use, efficiency of energy use, and mixes of energy technology (Arnell et al. 2004). The most conservative (change intensive) scenario assuming a world with quick economic growth and a quick launch of new and efficient technologies which remain fossil fuel intensive (A1F1) predicts 20 climate classifications within the USA between the years 2001 and 2025 and is presented in Figure 3-1 below.

3.7.3 Areas Expected to Experience Climate Change in the USA

Figure 3-1 and Figure 3-2 indicate that the distributions of climates by the year 2100 for the A1F1 scenario (do nothing, continue using fossil fuels) will change rather significantly. In reality there are 4 different scenarios of climate change calculated by (Rubel, Kottek 2010) and these two maps compare the worst case scenario. The general trend is that the USA east of the Rocky Mountains (where two-thirds of the American population is located according to the United States Census Bureau (2010)) will become warmer, wetter and more frequent, expanding the Eastern Temperate Forest ecoregion up to 33%. This is predicted to eliminate the Cfb climate area in the Appalachian mountains and bring the sub-tropical A climates northward up the Florida panhandle, eliminate the cold continental Dfa climate as it moves northward to Canada, bringing more moisture up into the Midwest with the expansion of the BSh climate and shrink the Boreal Forest to the north central and extreme northeast of the USA.

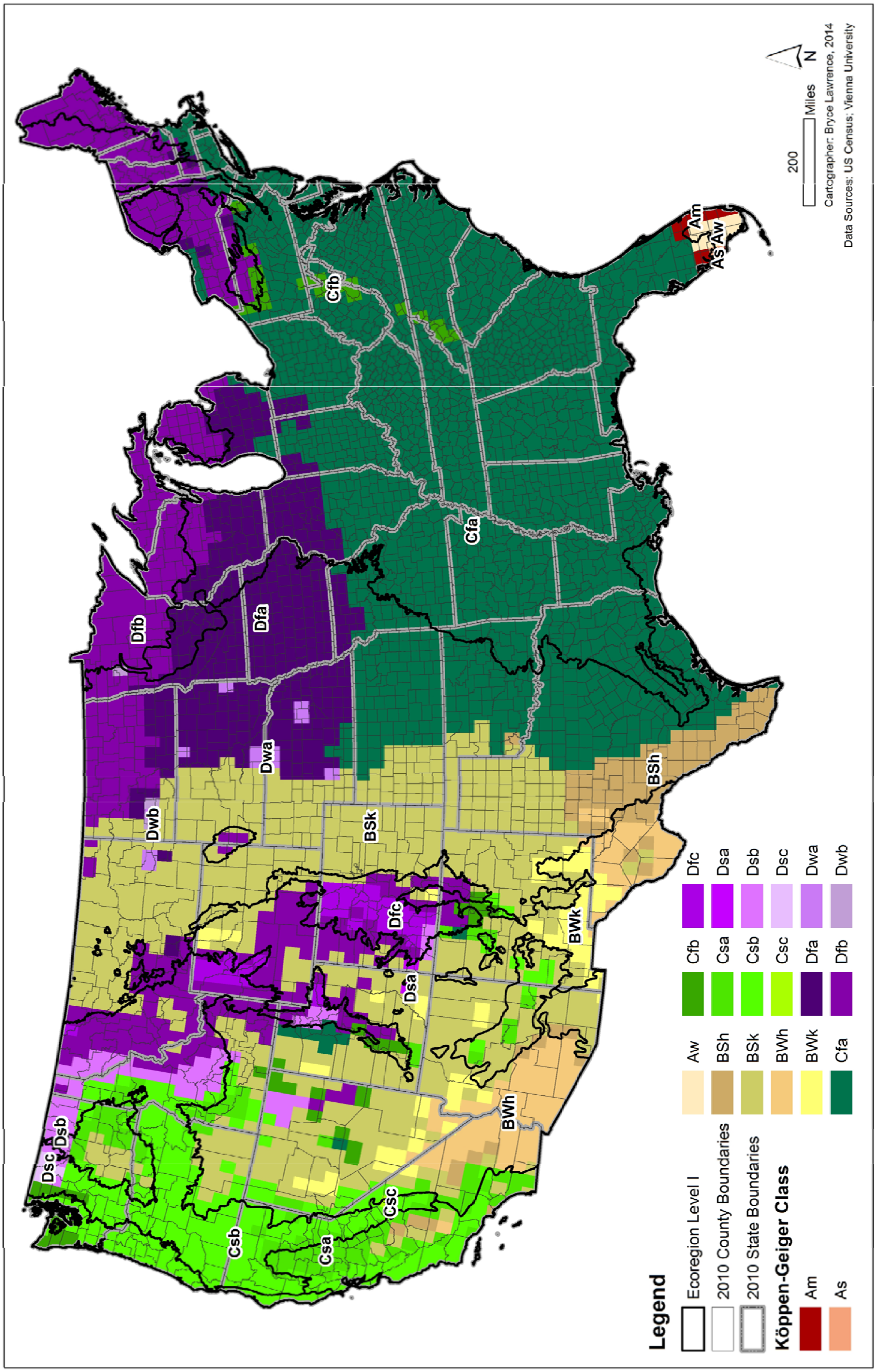

Figure 3-1: Projected USA Climates Based on the A1F1 Scenario from 2001 to 2025 (Rubel, Kottek 2010)

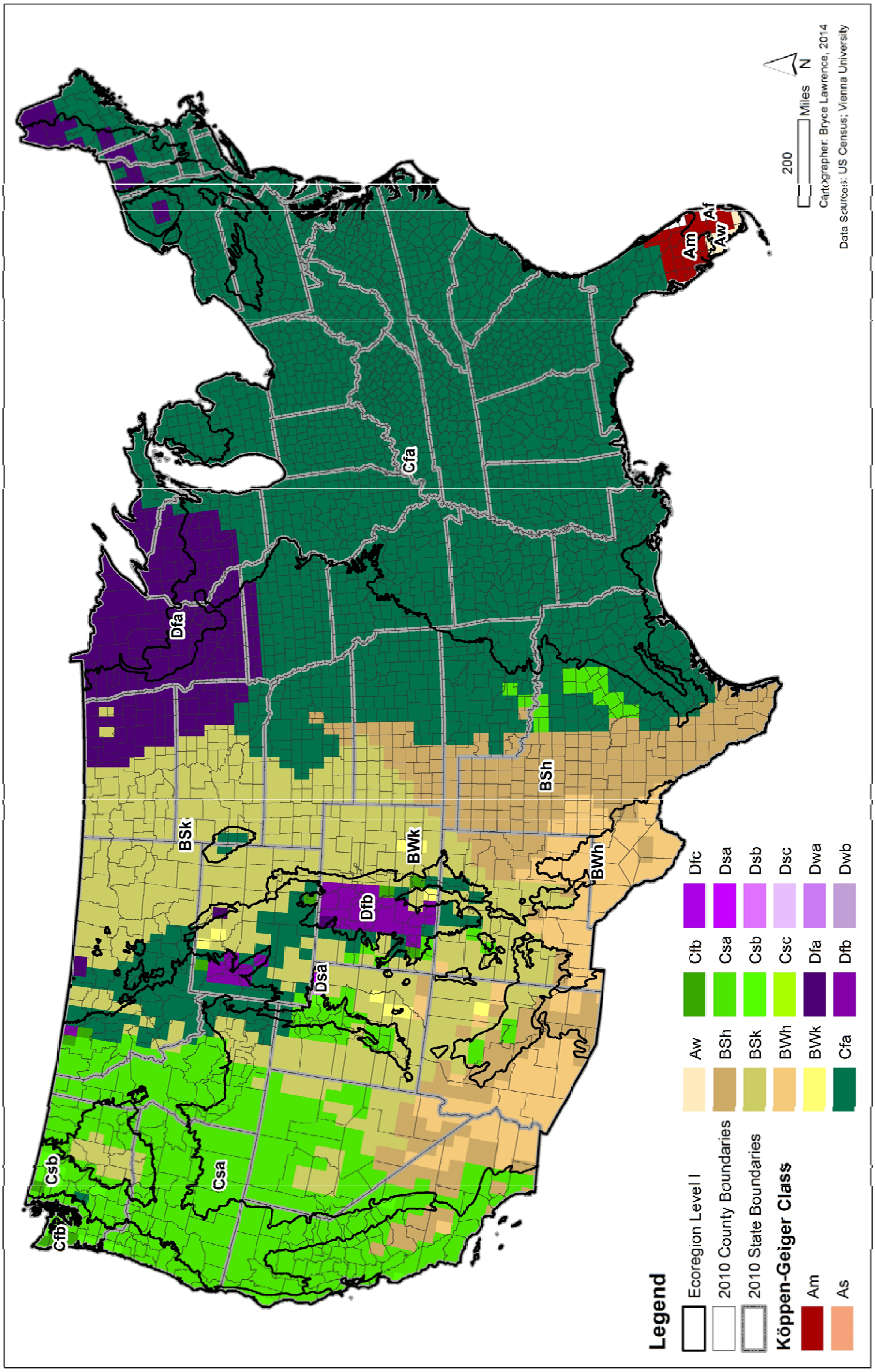

Figure 3-2: Projected USA Climates Based on the A1F1 Scenario from 2076 to 2100 (Rubel, Kottek 2010)

3.8 Ecoregions, Population and Incorporated Places

3.8.1 Ecoregions of the USA

Climates are a very useful designation for broad differences between regions in the USA, but as management units they are quite large, cross jurisdictions of states and counties and in reality there is considerable heterogeneity between vegetation types, soil types, hydrologic structure, physical geography, and settlement patterns within each climate classification. Therefore, this project needs to find a smaller and more homogeneous physical unit for county comparisons so that results can be confidently extrapolated to a region of sufficient scale to ensure ecological homogeneity amongst the data utilized in the diagnostic methods. Fortunately, a sub-climate classification system has been delineated and analyzed for North America, which is the Ecoregion classification system.

The ecoregion concept, coined by Sir Arthur George Tansley in 1935 and popularized by Eugene P. Odum and his brother (Odum 1971; Odum 1983) proposes that flora and fauna interact together to form a complex in which the sum of the parts is greater than the whole. Ecoregions are defined as ecosystems of regional extent that contain a number of smaller ecosystems (Bailey 1983). At the heart of the ecosystem concept is the dissipative ecological unit (Ripl, Hildmann 2000; Odum 1971) where producers, consumers, detritus, and decomposers work together to form a cycle of resource-use efficiency with extremely minimal entropy and where material and energy resides in the system to form mature ecosystem units (Odum 1969) with high material flow through, equally distributed but minimal growth and the capacity to metabolize large amounts of entropy. Since this work is focused on describing the potential of cities (tiled by county for political and administrative purposes) to achieve semi-closed metabolisms similar to a DEU and how this potential differs in counties across the USA, it is important to ensure that case study data come from similar ecosystems so that DEU components are not compared between vastly different climates. The question for this study is: What sub-climate level extent of ecoregion is appropriate?

3.8.2 The EPA Classification Method

While efforts at ecoregion classification have been around for over 100 years (Herbertson 1905), the breakthrough of the first widespread and successful classification systems in the USA started in 1976 with the work of Bailey, who developed an inland ecoregion map for the USA as a counterpart to concurrent work on marine and estuarine systems from other researchers (Bailey 1983). Bailey followed up this work with a written description and justification of the ecoregion concept, in which he noted that, the “purpose of ecological land classification is to divide the landscape into variously sized ecosystem units that have significance both for development of resources and for conservation of environment (Bailey 1983, p. 1).” To make these estimates, Bailey proposed that ecosystems needed to be classified by “rules” which can be replicated and extrapolated across major climatic divisions.

Bailey divided the United States into four classes based on the concept of biogeography by Canadian geographer Crowley (Crowley 1967) with a hierarchical order to simulate the nested ecosystem theory within his ecoregion classification system. The largest group, *domain*, is based on broad climate similarity, such as wet or dry, which Bailey believed has overriding effects on vegetation composition and land productivity but ultimately can be quite heterogeneous. The next level down in scale is the *division*, which corresponds to areas having different vegetation types within a domain, such as forest or prairie, which were drawn from and most closely spatially associated with major climate types per Köppen (Köppen 1900), as discussed above. The next smaller unit is the *province*, which Bailey delineated based on the climax plant formations which dominate uplands and which often coincide with major soil zones (U.S. Department of Agriculture, National Resources Conservation Service (NRCS) 1850 - 2014) and served as a data source for the delineation of provinces. The final and smallest unit in Bailey's system is the *section*, which corresponds to specific vegetation climax communities that can be identified from north to south or east to west across provinces, such as the Oak-Hickory or Maple-Basswood forest, and which generally corresponds to the major natural vegetation of the United States as delineated by Küchler (Küchler 1964). While Bailey laid the groundwork for ecoregion classifications, his rules were criticized for relying primarily on existing datasets (Köppen, NRCS Soils, Küchler) in the delineation of domains, divisions, provinces, and sections, thus the intent of Bailey to create a multi-factor delineation scheme actually proved to be a single factor delineation system at each ecoregion level.

The next step of refinement came from Omernik, who was utilizing Bailey's ecoregion system to classify streams for water quality and found that the reliance of Bailey's systems on Küchler's work at the section level was inadequate to describe the differences in water quality that Omernik found in the field (Omernik 1987). Omernik's hypothesis was that "ecosystems and their components display regional patterns that are reflected in spatially variable combinations of causal factors…including climate, mineral availability (soils and geology), vegetation, and physiography (Omernik 1987, p. 119). To inventory and combine these factors, Omernik utilized four small-scale maps as his data sources (a strategy similar to that of Bailey, but which differed based on the smaller geographic scale of the data sources) which ultimately were more related to land uses than Bailey's climates and vegetation data sources, and included *Major Land Uses* (Anderson 1970), *Classes of Land-Surface Form* (US Geological Survey, Hammond 1969); *Potential Natural Vegetation* (Küchler 1964) and soils maps from the US Geological Survey(U.S. Department of Agriculture, National Resources Conservation Service (NRCS) 1850 - 2014). Omernik's method identified ecoregions commonly on the order of 130,000 square kilometers and are a function of within-region homogeneity relative to between-region heterogeneity. These large units were further subdivided into regions of 500 square kilometers which were large enough to contain entire topographic watersheds but not large enough to combine contrasting homogeneous areas.

This process was documented in conjunction with the US EPA and all countries within North America to create a multi-level ecoregion delineation system based on the phenomena of geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology with classification based on orders from roman numeral I to IV, where : Level I corresponds to 15 broad continental level climates similar to Köppen's delineation and is appropriate for analysis at a global or intercontinental scale; Level II corresponds to 52 continental level ecological regions which are useful for national and sub-continental overviews of physiography, wildlife, and land use; Level III corresponds to 104 ecological regions in the continental United States which are appropriate for regional analysis and decision making; and Level IV corresponds to 968 sub-units in North America which were developed primarily to define stream reference sites and include detailed hydrologic unit and soils variations which are useful for sub-regional localized management. This work has been digitized and is available via the US EPA as ArcGIS shape files, and is presented below in Figure 3-3 (US EPA 2007).

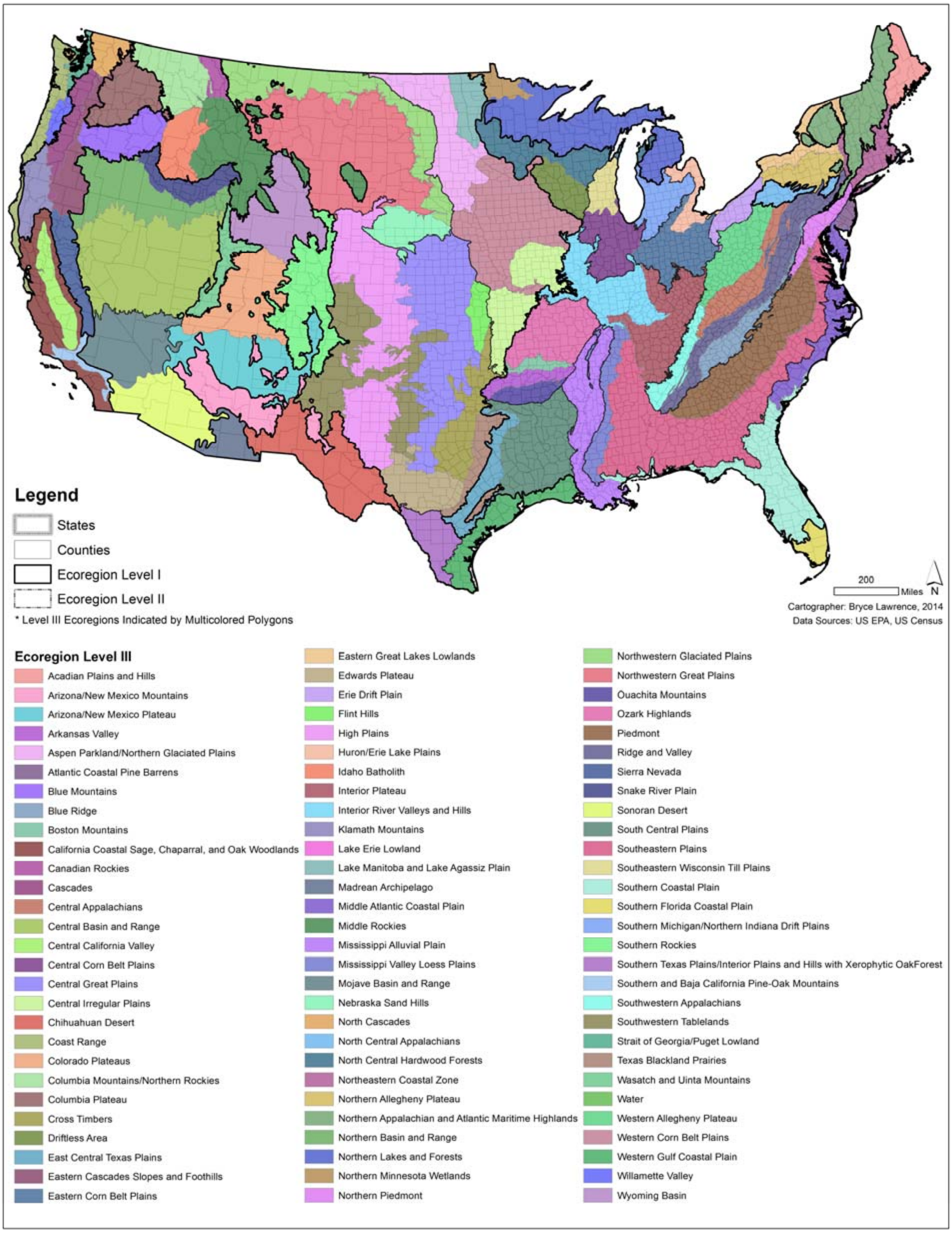

Figure 3-3: Figure 3: Ecoregion levels I – III in the USA (US EPA 2007)

3.8.3 Population Distributions within Ecoregions in the USA

An analysis of population distribution within ecoregion levels I and level II was created as a means of focusing the case study comparison to regions of the USA with the greatest population. The ecoregion levels I and II were chosen for this distribution because ecoregion level III units are so small that very few counties are completely contained by this ecoregion level, which may have falsely indicates population density in relatively uninhabited ecoregions which share a boundary with highly population ecoregions. The ArcGIS summary statistics tool was utilized for this analysis and populations within counties which crossed the level I and II ecoregion boundaries were counted in both adjacent ecoregions, resulting in a 'fuzzy' distribution of population. The fuzzy distribution method indicates a distinct pattern of distribution, but because of the county overlap cannot be used to quantitatively summarize the exact population per ecoregion level I and II units. Therefore, the results are expressed in an ordinal/nominal gradient from low to high.

The ecoregion level I population distribution indicates that ecoregion level I units generally corresponding to the Eastern Temperate Forest, Great Plains, and Mediterranean California are the most densely populated areas of the USA (Figure 3-4).

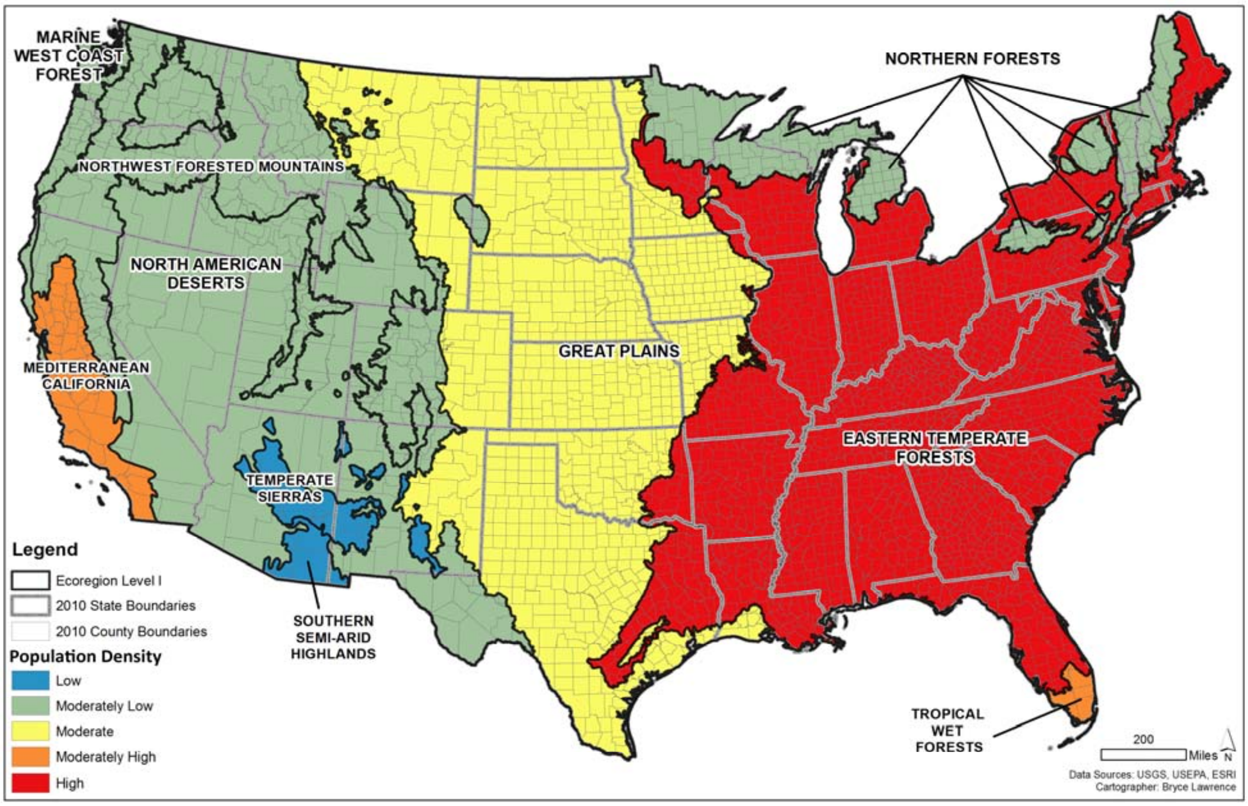

Figure 3-4: 2010 Population density within Level I Ecoregion Units (US EPA 2007; United States Census Bureau 2010)

Drilling down one more spatial scale to ecoregion level II we find that the greatest US population within the Eastern Temperate Forest is distributed towards the Mississippi alluvial and Southeast USA Coastal Plains (8.5), followed by the Mixed Wood Plains (8.1) and Southeastern USA Plains (8.3), with moderate population in the Central USA Plains (8.2) and Ozark / Ouachita-Appalachian Forests (8.4). The Everglades region (15.4) within the Tropical Wet Forests has a moderately high population, the Northern Forests within the Atlantic Highlands (5.3) has a moderately low population and the Mixed Wood Shield (5.2) has a low population density. The Great Plains region shifted from moderate population at the continental level to moderately low population in the South Central Semiarid Prairies (9.4) and low population in all other Great Plains ecoregion level II sub-units (Temperate Prairies 9.2; West-Central Semiarid Prairies 9.3; Texas-Louisiana Coastal Plain 9.5; and Tamaulipas-Texas Semiarid Plain 9.6). The ecoregion level II analysis also downgraded the population density in Cold Deserts (10.1) from moderately low to low but the Warm Deserts region (10.2) remained a moderately low populated region. The Northwest Forested Mountains (6.2) and the Marine West Coast (7.1) remained a moderately low population and the Western Sierra Madre Piedmont (12.1) and Upper Gila Mountains (10.2) remained a region with low population. Mediterranean California (11.1) remained the only moderately high area of population on the American West Coast (Figure 3-5).

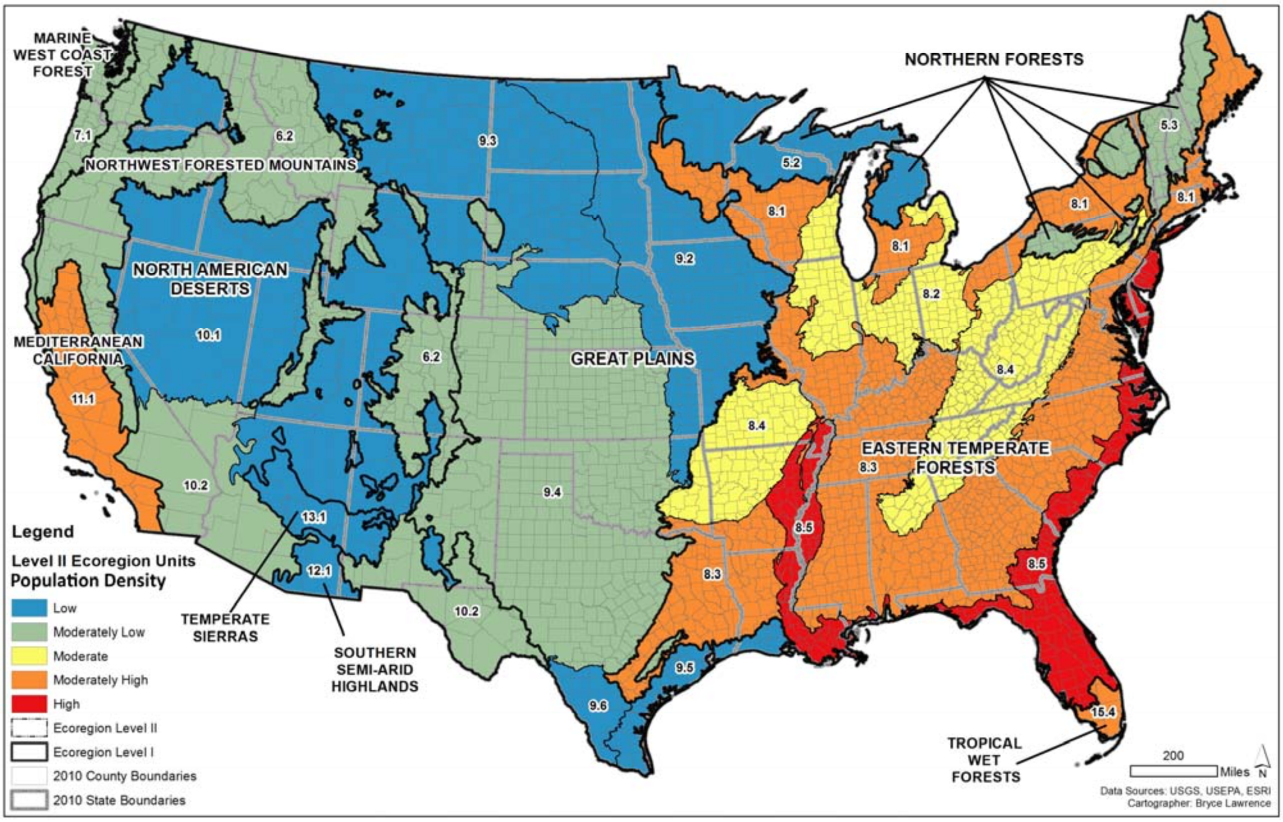

Figure 3-5: 2010 Population density within Level II Ecoregion Units (US EPA 2007; United States Census Bureau 2010)

Based on the distribution of population by ecoregion, I conclude that greatest population demands for resources is primarily within the Eastern Temperate Forests ecoregions, Mediterranean California, Tropical Wet Forests, and to a lesser extent the Great Plains. Additionally, the Great Plains, Eastern Temperate Forests and Northern Forests Ecoregions have county areas which are much more similar to each other than areas west of the Great Plains where county areas are significantly larger. Therefore, for sake of simplicity, the case study pool will be revised to only include the Eastern Temperate Forests. This choice simplifies the case study selection process and will ensure that all case comparisons are within the same ecoregion level I unit and between ecoregion II levels.

3.8.4 Geographic Entities in the USA

The US Census divides the United States into a number of geographic entities which can be broadly classified as "legal and administrative entities" and "statistical entities (US Census 1994a, p. 1)." Legal and administrative entities originate from legal actions and require a legally recognized boundary and an administrative entity to manage a wide variety of programs, including infrastructure, voting, tax collection and school districts, among other things. Statistical entities, on the other hand are developed by the US Census Bureau and are used to delineate and describe spatial statistical phenomenon in the USA on a decennial or sub-decennial basis. Statistical entities do not have any legal or economic powers of organization. Since this study is focused on infrastructure organization or re-organization then the most important geographic divisions to utilize in the study are legal and administrative entities so that recommendations can be directed to governing bodies that have the power to levee taxes, create binding plans and implement infrastructure projects. The general hierarchy of legal and administrative geographic entities in the USA is Nation, State, County, Municipal County Division and Incorporated Place, which are described from the smallest unit to the largest unit below.

The term "incorporated place (or Census places; or place)" is used by the US Census Bureau as the descriptor for a grouping of population in the landscape. For the most part, places are classified as a municipality, city, town, village, or borough, although they can have other names, and must be locally recognized, have a name and must not be part of any other census designated place (US Census 1994a). The purpose of creating legally recognized places is to provide governmental functions with legally prescribed limits, powers, and functions to a group of people, which includes infrastructure. Places must be incorporated in just one state and when a place crosses a state boundary then the territory which has crossed state boundaries must incorporate itself, sometimes with the same name, within the new state (US Census 2010b). Although infrequent statistically, this situation can become problematic for regional population centers with places and populations flowing between state boundaries where infrastructure money may be allocated differently per voting outcomes, or hydro-geographic conditions which may require one state to receive rainwater or wastewater flows of another legal entity, or for transportation infrastructure sharing issues such as mass transit lines or for park and land conservation systems which need to be managed between states.

If an area is not incorporated into a place, it may be within a larger sub-county legal designation, including a Town/Township, which is specific to the Northeast USA and are recognized as municipalities which have legal governments and boundaries or a Minor Civil Division (MCD) which are legal sub-county divisions in 29 states and may have a formal government with elected officials. If a location is not incorporated, in a Town/Township or in an MCD, then the governance functions default to the responsibility of the county within which the unincorporated place or land is located. Areas within this unincorporated county jurisdiction may include small farming community centers which have not incorporated for various reasons, vast expanses of agricultural land, land owned by national or state parks where settlement is prohibited, land owned by the US Bureau of Land Reclamation which includes large tracts of desert or mountainous land that is not agriculturally productive or is inhospitable for human habitation or land areas owned by the US Military (US Census 1994b).

The primary political and administrative units in the USA are States and counties, and given the variability of sub-county geographic units in the USA touched on above, States and Counties are also the primary statistical unit managed by the US Census. Except for the naming of county-like areas as Parishes in Louisiana and as Bouroughs in Alaska, Counties and States are continuous and consistent across the entire USA. Counties have evolved in administrative importance throughout the history of the United States. In the decades following 1776 (the creation of the USA) the original New England Colonies defined counties as jurisdictional boundaries which contained a number of towns that had their own administrative units; however in the south where land was more sparsely populated counties became important administrative and jurisdictional units that knitted disparate places together. As the USA expanded to the West between 1850 and 1920 the Northwest Ordinance encouraged the establishment of local government in newly settled territories as States and the sub-division of States into Counties. By 1920 the continental USA had been fully divided into 48 states and sub-divided into 3,041 counties with administrative and jurisdictional powers. This division has remained essentially the same since that period, with 3,109 Counties reported in the 2010 Census (Figure 3-6) (US Census 1994b).

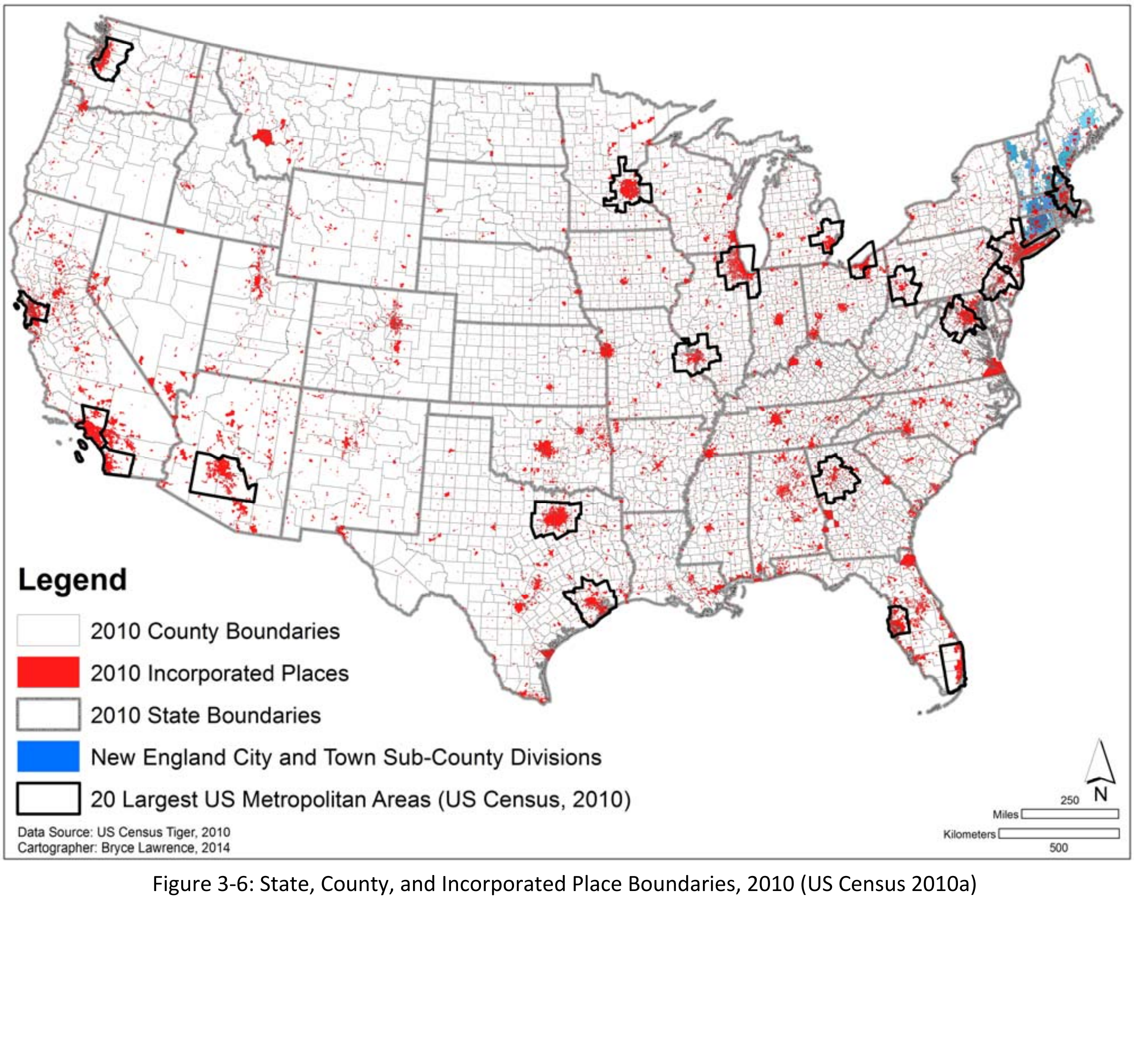

Figure 3-6: State, County, and Incorporated Place Boundaries, 2010 (US Census 2010a)

3.8.5 Area and Population Characteristics of US Counties and Incorporated Places

The 2010 US Census reported 3,109 counties that have a mean area of 619,118 acres (967 square miles; 250,548 hectares) with a mode of 585,908 acres (915 square miles; 237,109 hectares). The mean population of counties in the USA is 98,641 with a mode of 21,720 (US Census 2010; United States Census Bureau 2010). Looking at the distribution of the mean area, we find that 2,387 of the 3,109 counties in the USA have an area less than the mean (76.7%) and 2,522 of the 3,109 counties have population sizes less than the mean (81.1%). According to the 2010 US Census there are 29,514 incorporated places in the USA with a mean population of 7,811 (US Census 2010b) per incorporated place and a mean of 17 incorporated places per county but a mode of 4 incorporated places per county. This means that most counties in the USA are large, sparsely populated areas with the majority of the population residing in small incorporated places that are geographically scattered throughout the county. Therefore, I believe that the focus of this study should be on the most common and numerous population condition across the United States, between 21,000 and 100,000 people, which will statistically include 3 to 5 incorporated places per county where potential for semi-closed metabolism should be relatively high considering the large land area (biocapacity) to population ratio and will include incorporated places with infrastructure systems that can be analyzed.

Research regarding EF and material flow demands of places in the United States has already indicated that the 20 largest cities of the USA (See Figure 3-6) by population require resources far beyond city boundaries (Luck et al. 2001), which echoes the findings of Footprint researchers who found that large international cities have EFs that exceed their jurisdictional boundary (Wackernagel et al. 2006). Any focus on counties of large population would presumably repeat the findings of these previous studies and not necessarily add to the literature regarding how to achieve ecological balance between human and natural systems in the USA. Therefore, this research project couches itself under these mega-city analyses to analyze the most common demographic situations of the United States so that analysis results will be the most widely applicable to counties in the USA. In professional practice in the Midwest we call this “the low hanging fruit approach” because these counties seem like the most likely candidates for successful metabolism restructuring.

3.9 Sustainability Tools

Architecture and green building, urban planning and design, life-cycle assessment, transportation planning have also built substantial toolkits for the assessment of problem-specific or infrastructure-specific situations, called sustainability tools (Building Research Establishment 2004; Ness et al. 2007). These tools are valuable working models to pull from because they often utilize a diagnostic approach where the existing condition is identified, future goals are defined, and then alternatives are developed to meet the desired future goals or ‘optimum’ condition. This is a pragmatic approach which can help shape the work so that the end product is directly applicable in professional planning.

3.9.1 Locators for Wind and Solar Electricity

Since the 1970’s the USA has steadily ramped up the internal dialogue regarding renewable energy in several key areas, including ecological or sustainable design and planning (Todd, Todd 1993; McHarg 1992; Van der Ryn, Sim, Cowan 1996; Coates 1981), the green building movement and the

US Green Building Council (USGBC) LEED program for new and existing buildings and communities, analysis of industrial material flows and the possibilities of an industrial ecology (McDonough, Braungart 2002; Ayres, Ayres 2002). These concepts emerged in publications around the year 2000 as methodological development of automated wind power and solar power locators, which is relevant to this study since the focus is on the potential of the US to supply itself with renewable electricity.

3.9.1.1 Photovoltaic (PV) Locators

Measurements of macro-scale and micro-scale PV estimates exist, but regional meso-scale estimates with reliable results represent a potential research area. At the macro-scale, global horizontal, direct normal and diffuse horizontal irradiance have been recorded by the US Energy Administration's National Renewable Energy Lab (NREL) as the National Solar Radiation Data Base (NSRDB) since at least 1961 and have been used as the basis for calculating the Photovoltaic Solar Resource of the USA in kilowatt-hour per square meter per day (kWh/m^2/day) (Roberts 2012; Nguyen, Pearce 2012). Micro scale estimates for buildings or urban blocks have been estimated by extrapolating macro scale PV resource values from 90m or 30m monthly and more recently online site scale calculators such as PVGIS or *r.sun* in the statistics program R. Some detailed analyses are carried out in professional practice and may not have published repeatable methodologies (Nguyen, Pearce 2012, p. 1247).

Meso-scale PV estimators typically include similar steps, such as sampling the PV resource on a temporal square meter (m^2) basis, delineation of suitable areas in the urban environment for PV panel placement (roof areas), a correction for shading, orientation or other environmental factors and a final monthly or annual estimate of electricity production in MWH or GWH (Wiginton et al. 2010; Nguyen, Pearce 2012). Wiginton (2010) creates a useable m^2 per capita estimate and compares the supra-regional GW capacity estimate in Ontario, Canada to the regional demand, although the region straddles two ecoregion level III units (which might produce different monthly irradiation on that basis alone). An improvement to this method is the use of LiDAR data to optimize PV placement on roof areas with the best orientation and least shading. Nguyen and Pearce (2012) found that the use of higher resolution 0.55m LiDAR data as compared to 90m resolution data as the basis for kWh/m^2 estimate caused a 28.8% reduction in kWh/m^2 values and that the larger pixel size overestimates global horizontal irradiation. Once optimal areas are located, connection models have been developed to model the load on regional grids (Tang et al. 2012). Most recently, Bocca et al. presented a rapid method which steps back from the LiDAR complexity and uses yearly radiation, average temperature, type of installation, PVGIS, field sampling and a statistical fitting function to estimate a regional kWh/m^2 estimate. However, this method does not account for shading or roof orientation factors, focusing only on development of an accurate irradiation value per m^2 which was shown to predict PV performance within 2 percent (Bocca et al. 2015).

3.9.1.2 Wind Power Locator

The background on GIS-based wind turbine locators starts at least as early as 2001 where Baban and Parry (Baban, Parry 2001) describe a basic weighted overlay method in GIS for regional wind turbine location suitability which uses buffer zones from physical, economic, environmental and visual impact areas to delineate a wind farm location criteria (WFLC) in the UK, but do not estimate annual or monthly production in MWH or GWH. Rodman and Meentemeyer (Rodman, Meentemeyer 2006) used a similar suitability approach in GIS, using Truewind 50 height wind speed values to rank northern California for electricity production potential with buffers zones to define a suitable area. Acker et al (Acker et al. 2007) used the overlay and buffer methods from Baban and Parry (2001) and Rodman et al (2006) and refined the 50m wind speed estimates by transforming them to a speed at 100m height using a Weibull distribution as a nod to international methods (Federal Environmental Agency of Germany 2013) that incorporated seasonal variance in total potential Watts per square meter (W/m^2) and better available wind speed at 100m hub height. In addition, Acker et al (2007) presents a list of protection areas which is relevant for the USA and which protects landscape functions and habitat. However, the report focus was on cost per kWh and so a demand and capacity comparison framework was not presented in this study. Hoesen and Letendre (van Hoesen, Letendre 2010) introduce a visual analysis in GIS to prioritize social acceptance of suitable wind turbine locations. Van Haaren and Fthenakis (van Haaren, Fthenakis 2011) introduce a multi-stage suitability model to estimate spatial cost-revenue optimization that includes protection of bird habitat and a sound buffer, a research topic in the US Midwest (Obermeyer et al. 2011) that was subsequently developed further (Reed et al. 2010). Most relevant to this study, a GIS wind power locator for the USA was presented by Grassi et al. (Grassi et al. 2012) which uses extensive buffers to define a suitable wind power area with administrative, political, ecological, elevation and land uses; transforms the 50m height/30m raster resolution wind speed values to 80m height using the Weibull frequency distribution; and corrects for surface roughness to estimate an annual GWH and return on investment (ROI). However, it did not include any type of visual suitability assessment or noise propagation assessment.

Distance to or from roadways and distance away from transmission lines are included in many of the suitability analyses (Watson, Hudson 2015; Latinopoulos, Kechagia 2015; van Haaren, Fthenakis 2011; Acker et al. 2007; Baban, Parry 2001). The use of buffers to keep wind turbines away from sensitive areas is well developed, but it could be improved with the integration of sensitive area connectivity analysis, noise propagation modelling and visual analysis in one platform as an integrated ‘zone of conservation’ which is restricted from wind turbines.

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4 Research Design

4.1 Research Questions

This section lays out a two-step quantitative case study research design process which is guided by a main research question inset below and three basic research questions which follow.

How can the USA supply the basic resource and energy demands of a growing urban population in the context of climate change and competing global demand for basic resources, when footprint and urban metabolism studies indicate the US is consuming more resources than what the sovereign land produces?

This guiding question is addressed through three main research questions. The first question is addressed through the development of a diagnostic assessment which mixes EF, MFA, and ecosystem services in a conceptual framework that results in the County Diagnostic as an expanded quantitative capacity and demand framework needed to analyze cities as ecosystems. Along with the method itself, any difficulties or shortcomings are discussed in the development and feasibility of the method as supported by the literature review. To answer the second question about the influence of ecoregions on circular metabolism potential, the diagnostic assessment is applied in a 6 county case study comparison with counties from 6 different ecoregion units while controlling for population and area. The results of the case study comparison sheds light on the potential for thermodynamic theories, circular metabolism, ecoregions or ecosystems to explain the findings, which address the third research question and reflects the findings back on to the original conceptual frameworks. These questions are listed below for clarity.

1. Does the development of a sub-national environmental footprint with unit specific and spatially explicit values emulating the DEU result in a robust and useful analysis for regional planning?
    a. Can the development of a sub-national component expanded unit specific framework help quantify the gap between linear and circular metabolism on a county basis?
    b. Which factors are the most salient factors to such an analysis and which factors can be grouped together?
    c. What is the appropriate level of data acquisition or aggregation to answer the question accurately?
    d. How do variations in input data affect model outputs?
2. How might material and energy balance potential differ by ecoregion in the USA?
    a. Do certain ecoregions help make balance possible whereas other ecoregions make balance unattainable?
    b. How comparable are different ecoregions in the United States regarding the supply and demand of salient factors for minimum human carrying capacity?
    c. Which ecoregions are well suited to satisfy population demands or absorb emissions, and in which categories?
    d. Which regions are not well suited to satisfy population demands, and why?
    e. What role do small cities or counties play in counterbalancing the consumption of large urban centers, if any?

3. Can material flow balances be explained by the concept framework of equilibrium and non-equilibrium thermodynamics theories?
    a. If not, what other concept frameworks might be useful to explain the findings?

4.1.1 Hypothesis and Null Hypothesis for Research Question 1

H1 = It is possible for the USA to reduce material consumption and increase sub-regional level material balance if a method is developed to clearly diagnose the resource demands and availability at a sufficiently detailed scale so that inefficiencies and opportunities can be identified and implemented at a manageable scale.

H1ø = The development of a consistent tool is not feasible at levels of resolution less than what currently exists; the development and deployment of highly complex models in abstract units that are not directly transferrable to the general public are preferred.

Such a diagnostic should be simple enough to use so that planning and engineering practitioners can integrate it into comprehensive plans and the results of such an approach should be easily understandable by the public, politicians, and professional practitioners of all types. It would be helpful if the diagnostic reported results in unit-specific measurements separated by planning and engineering sectors, so that results can be directly equated to infrastructure improvements or planning actions with realistic cost estimates. Existing methods and models will need to be integrated to achieve such a diagnostic approach at regional or sub-regional resolution.

4.1.2 Hypothesis and Null Hypothesis for Research Question 2

H2 = The natural variation of bioproductivity and resource availability between ecoregions will have a varied effect on the county to provide the basic minimum human demands from within their jurisdictions.

H2ø = Ecoregion divisions will make no differences on the availability and type of biocapacity or the potential carrying capacity

The relationship between overall material and energy demand and population is assumed to be linear where increases in demands and entropy increase as population increases. However, the ability of ecoregions to absorb wastes may be non-linear which could affect the continual (regular; non-periodic; homeostatic) supply of material and energy demanded by human populations in developed industrialized countries, which manifests as a demand for trade. The capacity of ecosystems to absorb wastes and create beneficial net primary productivity for humans can be expressed as a limiting factor or facilitator of mutual symbiosis potential between human system flows and ecosystem flows at the community and landscape ecology levels. I hypothesize that this study will discover heterogeneity across the USA at the county level in regards to bioproductive capacity and waste absorption potential.

4.1.3 Hypothesis and Null Hypothesis for Research Question 3

H3 = The thermodynamic paradigm of closed-loop cycling, or linear thermodynamics, may have a limited applicability regarding planning of regional and supra-regional material flows.

H3ø = Closed loop systems, completely balanced demand and capacity in terms of the County Diagnostic model, are the ecological norm at the county level.

In this sense, I hypothesize that the theory of a non-linear thermodynamic may truly be the best way to characterize regional material flows, because it would explain the fact that major cities in the USA thrive even though their footprints are larger than their sovereign area. This reality must mean by definition that areas with excessive productivity exist to counterbalance areas of excessive consumption. Money and political investment will certainly play a role in achieving closed loop systems, along with ecological constraints. Closed loop county systems may also be found to have negative impacts or undesirable side effects.

4.1.4 Categorization of Research Design

The research design can be characterized as post positivist pragmatic advocacy (Creswell 2003) because it utilizes an analysis tool developed out of observed need in professional practice in the USA (pragmatic) to understand the usefulness of theoretical lenses such as ecology, landscape ecology, the dissipative ecological unit, the EF, thermodynamics, dissipative structures, ecosystem services, and MFA to help reduce the global phenomenon of massive resource and energy consumption of the USA through application of a quantitative statistical comparison (post positivist) of regional metabolism. The results of the study are funneled back into professional practice, students or publications to promote popular simplified understanding of complex issues so that effective and adaptive management can be employed for direct feedback control (ie, design or flow modifications) of human and natural systems (advocatory/participatory).

4.2 Two-Part Project Design

The research design is split into two parts, which include 1) the development of a county wide spatial and material accounting systems built on existing theories and frameworks and which addresses many of the previously perceived shortcomings of existing Footprint and material flow methods tailored for application at the regional level in the USA, and 2) the application of this method in a quantitative case study comparison across ecoregions in the United States to test the variation in parameters and analysis outcomes when isolating ecoregions apart from population and the potential for circular metabolism given the resources and demands of the county. Part 1, The County Diagnostic, directly addresses the first research question by developing a high resolution tool, which is then employed in part 2, the case study design, to answer research questions 2 and 3.

4.2.1 Part 1: The County Diagnostic Conceptual Framework

Utilizing the conceptual and methodological frameworks of the EF, MFA, and ecosystem services and pulling from the theoretical building blocks of the dissipative ecological unit (Ripl 2003), cities as dissipative structures (Prigogine, Stengers I. 1984; Pulselli et al. 2006), and the need for resilience to natural ecological oscillation (Holling 1973; Odum 1969), a new "hybrid" method is presented here as "The County Diagnostic," which analyzes A) the major material and energy flows demanded by a county's population, infrastructure, commerce, and industry needed for basic human survival and industrial operations, and B) the efficiency of human infrastructure systems and production/absorption capacity of landscape functions within a county.

Given the significant conceptual and methodological developments regarding sustainability and human and ecosystem balance which already exists, it was necessary to identify a conceptual framework capable of tying together existing bodies of research, theories of organization, methods of analysis and state of professional practice. The conceptual framework was used as an intermediate common element to understand how different fields of research came together around an organizing concept and what methods each field brought with them. Ultimately, the concept framework justifies the need for a new integrated regional approach which is used to answer research questions 1 and 2. The concept framework itself will be tested with research question 3, thus creating a feedback loop for the dissertation research to support, rebuke or propose augmentation of existing concepts and theories of human / ecosystem relationships.

The concept framework also acts as a bridge from the initial exploratory research questions to the more mature questions presented in the research design. The utilization of a conceptual framework for the purposes of defining the research problem in professional contexts, establishing theoretical coherence between research fields, organization of research questions and methods, and as a way to frame the feedback into conceptual and theoretical conclusions (Berman 2013). Other studies have demonstrated that the utilization of a conceptual framework enhances doctoral studies and acts as a way to convince other researchers that there is a need for new or additional conceptual and theoretical lenses (Leshem 2007).

4.2.1.1 The DEU as Organizing Principle for Metabolic Analysis of Cities

In this basic mutualistic symbiotic unit, the DEU, sunlight drives a cycle of production, consumption, detritus creation and detritus breakdown or dissipation (Figure 4-1) of a material (ie, nitrogen, carbon dioxide, phosphorus). Water is the prime transport, erosive, and temperature regulation agent in the DEU (Ripl, Hildmann 2000). This basic unit explains the optimum operating condition for several scales of life typically associated with the study of ecology or systems ecology, including individual organisms, communities, ecosystems, and the ecosphere (Odum 1971, p. 73; Naveh 2000, p. 15). Each system level is nested into the next higher system level and generally these systems adjust together by self-organization or self-regulation, thus when material and energy flows of the highest level (ecosphere) are balanced it means that material and energy flows at the ecosystem and community levels are also balanced. Conversely, when flows at the organism or community level become unbalanced then changes occur that must travel through the food chain, fluvial systems, erosional processes, or land cover to arrive at an adjusted ecosphere. Human activities at the local scale are arguably causing the global phenomenon of climate change. I propose that by analyzing all the material and energy flows of an urban region that are analogous to components in the DEU, a target of flow balances can be identified and a greater percentage of a countie's material and energy flow can be reused or dissipated and thereby converted from a linear to circular or semi-closed metabolism with corresponding increases in efficiency and reduction of EF. This leads to the research question: What components of urban metabolism need to be analyzed to define a level of human and ecological mutualism at the county scale and what are the best methods for this analysis?

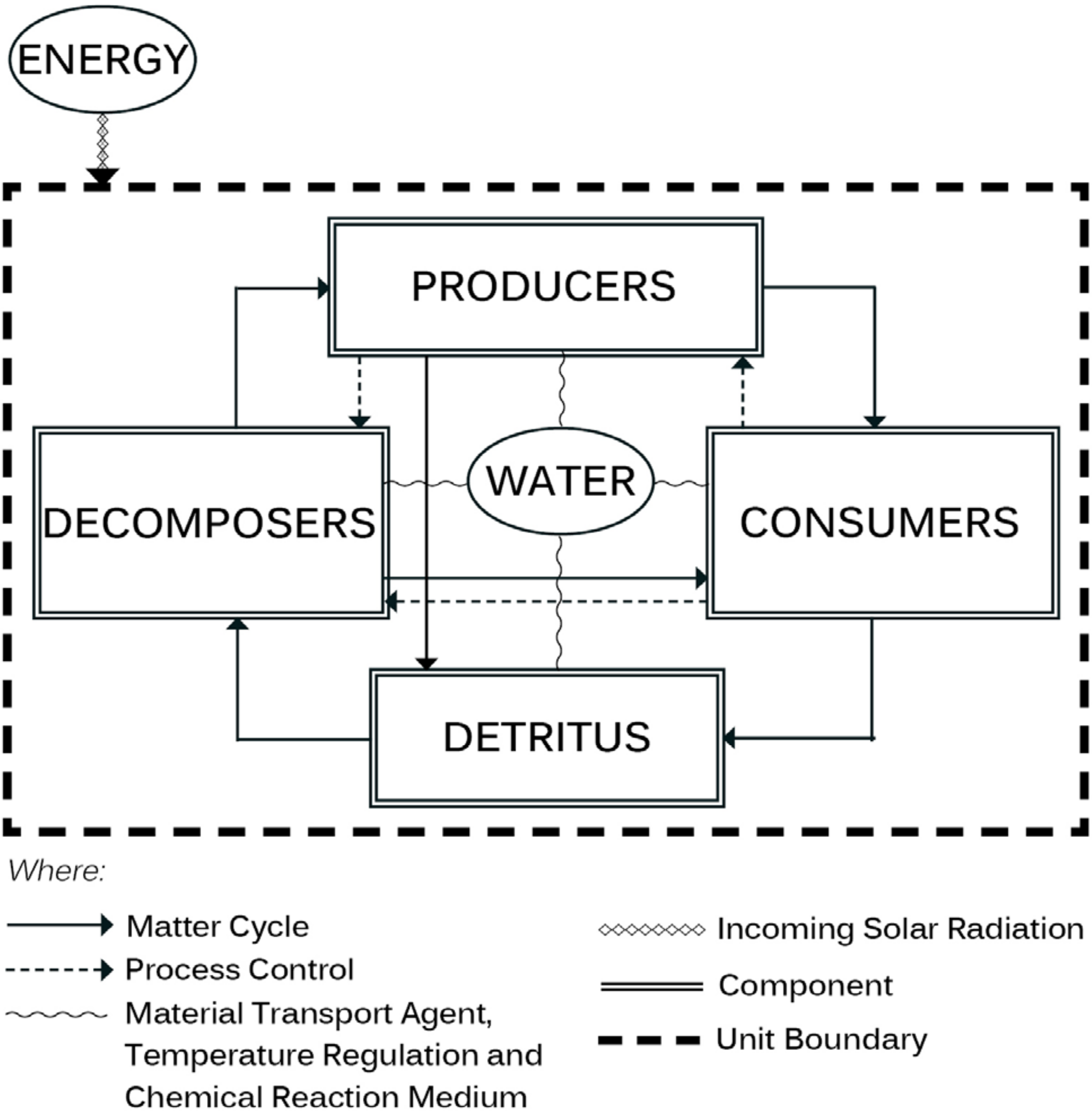


Figure 4-1: The Dissipative Ecological Unit (DEU) (Ripl, Hildmann 2000, p. 376)

4.2.1.2 Analysis Component Expansion at Regional Levels

Related fields of Footprint research are summarized into a flow diagram (Figure 4-2) where the ellipses indicate distinct fields of research, the rectangles with dotted outlines represent methods derived from their respective fields of research and the solid rectangles at the center of the diagram indicate the contribution of each method to this study. The diagram indicates that within the framework of existing research it is possible to create a unit specific and spatially explicit diagnostic approach with expanded methods to address all components of the DEU. I call this analysis method "the County Diagnostic" because it is developed to analyze the existing condition of regions in the USA with the county jurisdiction as analysis unit which can be aggregated and diagnose the potential for reform of urban metabolism. This abstract idea is the core of the third research question with the null hypothesis that linear and non-linear thermodynamics theories both explain the potential for circular metabolism potential equally well.

The County Diagnostic builds on fundamental methods and calculations such as those in the EF, Water Footprint, Carbon Footprint, urban metabolism, ecosystem services assessment, and sustainability tools, but utilizes localized datasets which eliminate many assumptions contained in global yield and equivalency factors. The County Diagnostic differs from existing analysis because it is developed around the components of the DEU (solar energy, producers, consumers, detritus, decomposers and water as transport and heat exchange system) which in turn makes it possible to evaluate alternatives, visions or scenarios in which cities have semi-closed metabolisms parallel to a DEU.

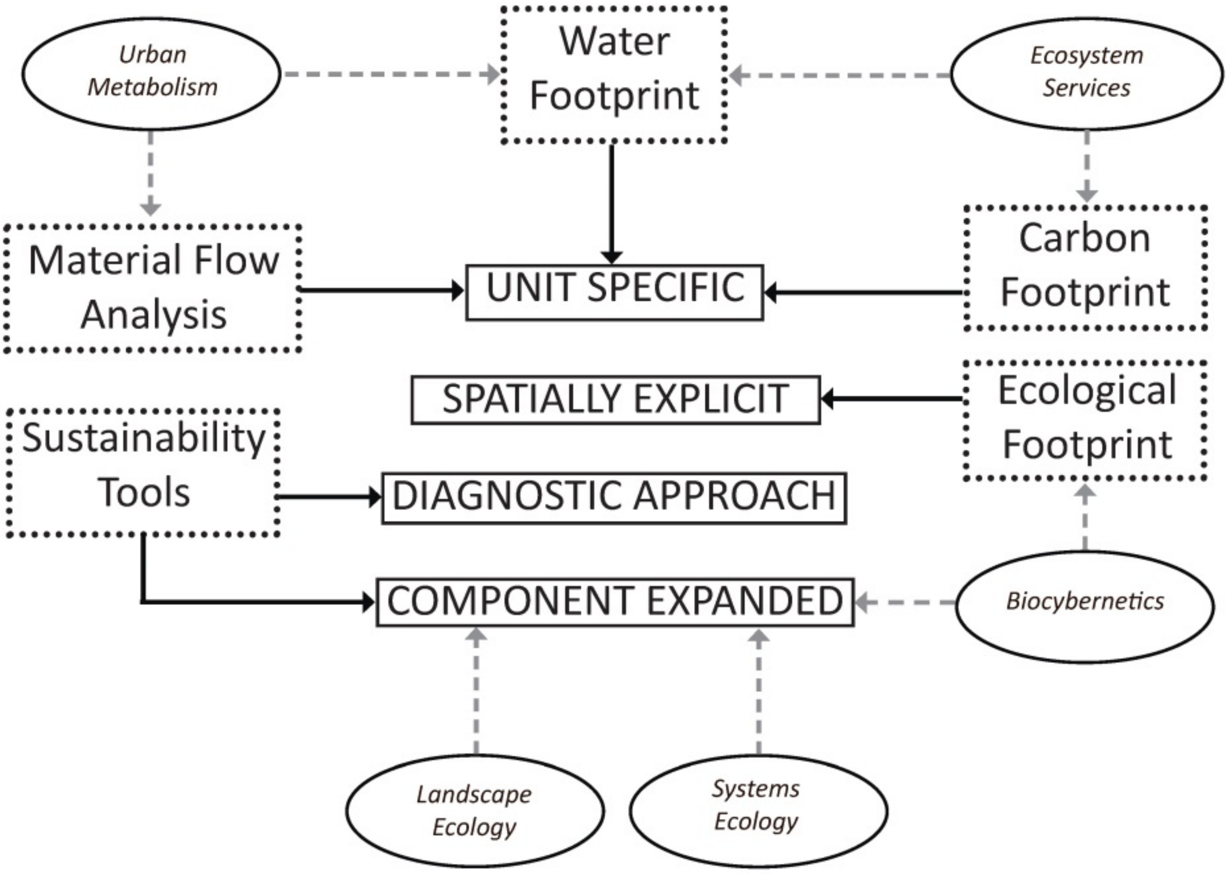


Figure 4-2: The Component Expanded Spatially Explicit Unit Specific Diagnostic Approach to Analyzing Counties in the USA (where ellipses are fields of research and dotted rectangles are methods derived from linked research fields)

The expanded analysis components analyze 'all important components' of a county metabolism, which is defined from the DEU concept to include measures of producers, consumers, detritus, decomposers, sun energy and fluvial systems. The reason for the expansion is that humans cannot realistically understand how to achieve mutualism at the urban-region level unless the analysis includes all the important components of mutualistic relationships at the appropriate scale and level of detail. I argue that the DEU defined 'all important components' translate into the components of food, water, energy, carbon, solid and organic wastes and underlying ecosystem and fluvial system preservation. These components encompass the necessary material and energy demands that support modern human settlements as well as the capacity of the biosphere to supply goods and services such as food, waste absorption and fresh water. These material flows can be considered as 'macro-material flows' where we do not need to detail the exact embedded energy of every product consumed in a county metabolism to determine "sustainability (World Commission on Environment and Development 1987)", rather we need to quantify the total food demand and food biocapacity of regions to determine the human carrying capacity of a region or sub-region and then design the population and procurement systems around that capacity. The production of completely organic food supply is irrelevant if the quantity of supply only satisfies half of the population demand and the other half of the food supply must be flown in from Chile.

The existing Footprint-family of methods, the EF, Carbon Footprint, and Water Footprint, have shown the way in regards to quantifying macro-material flows, but there is not yet one indicator which encompasses all the components of the DEU. The EF method for example only includes greenhouse gas emissions as wastes, however, humans emit organic food wastes and processed effluent into fluvial systems which remains unquantified in the EF, and thus the EF cannot assess the ecosystem-based potential for dissipation of human created detritus of N and P, an important nutrient in the ecosphere and one which can affects water quality if not properly managed. The US Green Building Council's LEED assessments are very good at estimating building energy use and creating walkable mass transit oriented urbanism, but do not address regional ecosystem services potential or consider building energy reduction standards in light of the total energy demand and production capacity of a region. Type II urban metabolism assessments are the closest type of analysis related to the County Diagnostic approach, but they actually strive to assess what the Water Footprint terms internal and external energy and material demand factors, such as air travel emissions or trade imports, which confound the idea of a regionalized demand and capacity assessment by being fundamentally supra-regional. Type I MFA is potentially the most detailed type of analysis and is described essentially as the flow all materials through a unit down to the chemical level. This level of assessment, such as the flow of lead in an urban region, is simply too detailed to be meaningful in terms of regional analysis.

Therefore, the County Diagnostic takes a macro-material flow approach to quantifying flows of urban metabolism analogous to the components of the DEU in a unit specific and spatially explicit framework with consistent and available data at the county level so that analysis can be done relatively quickly and results are directly applicable towards reformation of the urban metabolism. Since the diagnostic approach indicates the existing demands and capacities of DEU-related material flows, scenarios or alternatives which create semi-closed material, nutrient or energy cycles can be evaluated and cost estimated, thus placing the method firmly in the realm of regional planning and spatial planning. Figure 4-3 illustrates the level of complexity of the "County Diagnostic" approach compared to other approaches.

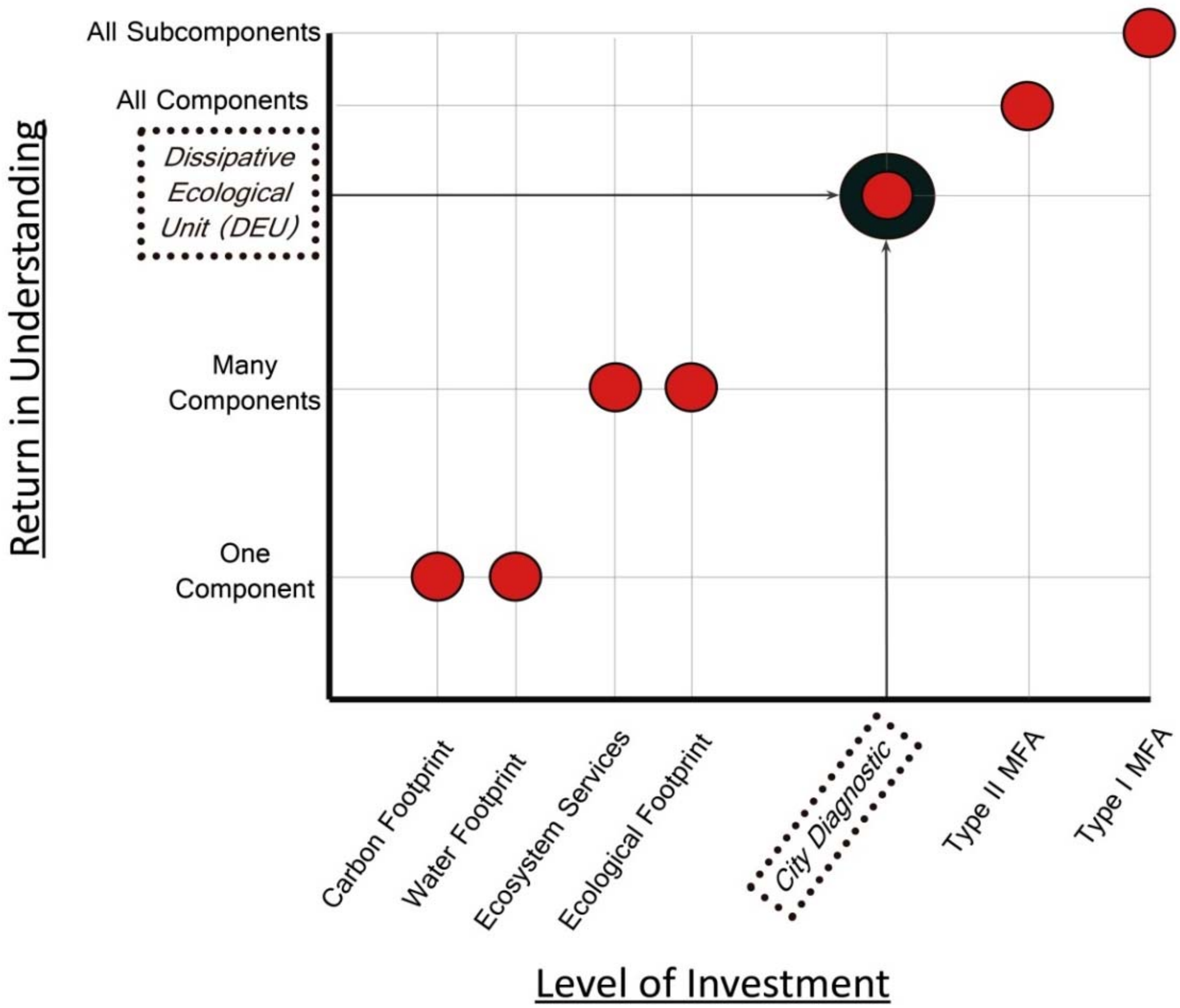


Figure 4-3: The County Diagnostic Expands the Footprint Family Approach (Galli et al. 2012) to Include all Components of the DEU and is Simpler to Apply than MFA or Detailed Urban Metabolism Studies.

4.2.1.3 Expanding the EF Framework into a DEU Diagnostic for Cities

The current research leads to the conclusion that there is a place for refinement of the EF framework into an assessment of regional metabolism, which can assess material flow performance of cities in relationship to an optimum dissipative ecological unit. The biggest task for refining the EF to the sub-regional scale is adapting the formulas of the Footprint methods (Global Footprint Network 2009) from national datasets with global equivalency factors to sub-regional datasets available in the USA and the elimination of equivalency factors in favor of direct quantitative estimates from local primary data which may be more locally accurate by capturing heterogeneity of consumption or bioproductivity at the local level that is generalized by national or international datasets (Kitzes et al. 2009). Other recommended improvements in the EF include: manuals for regional and sub-regional assessment (Venetoulis 2001; Dakhia, Berezowska-Azzag 2010), EF method improvement in regards to global yield equivalency (Wiedmann, Barrett 2010; Nijkamp et al. 2004), natural capital depletion rate and organic waste inclusion (Browne et al. 2005), leveraging GIS with the EF, sustainable vs. industrial yields assessments, assessment of cost of ecological capacity loss, measures of human satisfaction (Federal Environment Agency of Germany (Federal Environment Agency of Germany 2007), better resource consumption database and better baseline biodiversity estimates (Haberl et al. 2004b). These reports indicate there is room for improvement of the Footprint methods to bring it down to the sub-national level and to encompass an increased number of components which accurately reflect material and energy flows of dissipative ecological units. However, it is likely that such a change will require altering the EF calculation framework and components.

Studies in landscape ecology have focused on understanding mutualism in communities and ecosystems so that related plant and animal communities can be protected and properly interconnected (Forman, Godron 1986, 1981, 1981; McHarg 1992; M G Turner 1989; Opdam 1991). This approach preserves many short cycles (Ripl, Hildmann 2000) and the literal flows of flora and fauna across landscapes, which is a critical part of preserving bioproductivity and biodiversity. GIS and overlay analysis can be used in these assessments as spatially-explicit baseline biodiversity preservation estimates and require inclusion in the diagnostic as a conservation area. Current USA policy-based biodiversity estimates in the Brundtland report (World Commission on Environment and Development 1987) or quantitative estimates of 20% HANPP preservation as the area needed to perform minimum ecological function and preserve biodiversity regardless of climate or ecoregion variations (Haberl et al. 2004b, p. 283). In reality this area is dependent upon a host of ecoregion and climate-based factors and the method should allow for each application of the diagnostic to be tailored to the ecoregion or sub-ecoregion level in which the analysis occurs.

4.2.1.4 The County Diagnostic

Figure 4-4 operationalizes the ideas from Figure 4-1, Figure 4-2 and Figure 4-3 into real world units showing how the County Diagnostic is interpreted from the DEU based 6 components of producers, consumers, detritus, decomposers, water and energy into 9 basic components of food, water, carbon, solid waste, organic waste, wastewater, renewable electricity, existing electricity and a zone of conservation (habitat). In this interpretation producers and consumers are translated into the single category of food with the balance of capacity and demand acting as a controlling feedback between plant primary production and human food demand. Water is translated directly through and is measured in surface and atmospheric water scarcity assessments as it relates to human demands for water in municipal supply and agricultural production. Detritus is translated into gas, liquid and solid material outflows of carbon, solid waste, organic waste, and nutrient waste loads which are compared to the capacity of the immediate ecosphere to break down and either assimilate or make available the human system outflows back into the building blocks needed for primary production, which is the definition of the decomposers group (Odum 1971, p. 28). The single factor of solar energy in the DEU is replaced with two factors, renewable electricity and existing electricity, to represent the need for conversion of direct insolation into useable electricity in the human settlement metabolism. Splitting electricity into renewable and existing supply also enables the comparison of presently available *in-situ* renewable electricity potential in a geographic area (the pure ecological view where only immediate insolation supply is available for plant photosynthesis) with the existing electricity supply of human systems which is often reliant on historical insolation (fossil fuels; fossil insolation) to run the urban metabolism because the demand has outpaced the presently available in-situ solar supply or because of other economic or political factors driven by human decisions and technology (thus sidestepping a feedback control which is otherwise limiting to most other species in the plant, fungi and animal kingdoms). The ability to harness, save and direct electrical energy with fossil or renewable energy is one of the main differences between ecological systems and human systems. Finally, primary production requires a habitat zone for plant communities, and this is translated from the DEU into a zone of ecosystem conservation (herein described as the zone of conservation or ZOC) within the County Diagnostic. Since the DEU is a unit-less concept describing the necessary components of a system and the County Diagnostic is a method aimed at informing land use planning directly, it was necessary to integrate a unit specific measure of primary production preservation as a ZOC set aside for biodiversity and landscape function preservation. The ZOC is split into two subcomponents: 1) the current level of legal protection of ecosystems within a county and 2) the total potential for ecosystem protection in a county given the existing land use.

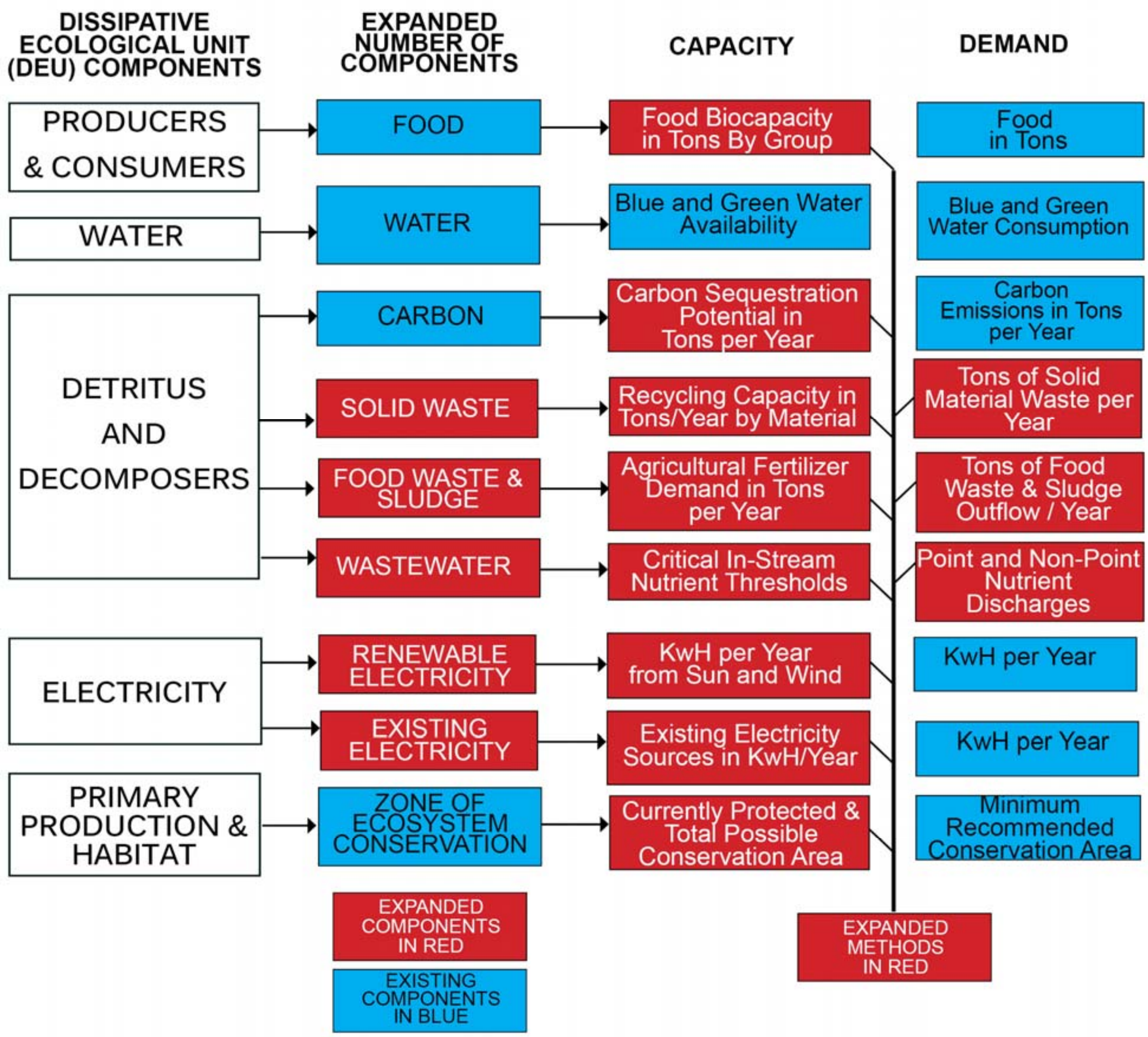


Figure 4-4: Justification of Expanded Component Selection to Include all Components of the DEU (where blue indicates components and methods which are already addressed in the literature and red indicates components and methods which would need to be developed in order to opreationalize a DEU-based expanded environmental footprint)

4.2.1.5 The County Diagnostic Interpreted as DEU

The exploded view of the County Diagnostic and its components (Figure 4-4) can be tied back to the original DEU diagram (Figure 4-1) by bringing the capacity and demand sub-components into the simple DEU diagram framework (Figure 4-5) indicating: material flows where nutrients, water, energy and waste are moved between components; feedback controls to material flows which in-turn influence populations and habitat quality; connectivity of water as a transport agent, temperature control and chemical reaction medium as well as its influence as a limiting factor in habitat extent and production potential; the spatial connections to an ecosystem conservation area where non-agriculturally related primary production, habitat, population biodiversity protection and many ecosystem services occur; political decision making which can influence the extent of protection of total potential ecosystem conservation areas and the flow of wastes to conservation areas; boundaries for the DEU components which links back to Figure 4-1; and the county boundary, which serves as the extent of the County Diagnostic related metabolic processes and is influenced by underlying physical and abiotic factors that differ by ecoregions.

In addition to the relationships between the components and sub-components within the county boundary, in flows of energy from both renewable and non-renewable resources are required to power the county metabolism. Outflows of organic and municipal solid waste products are also part of the county metabolism which result from insufficient nutrient recapture, pollution prevention or material recycling systems that can cause a material sink and should not be allowed to interfere with protected conservation areas.

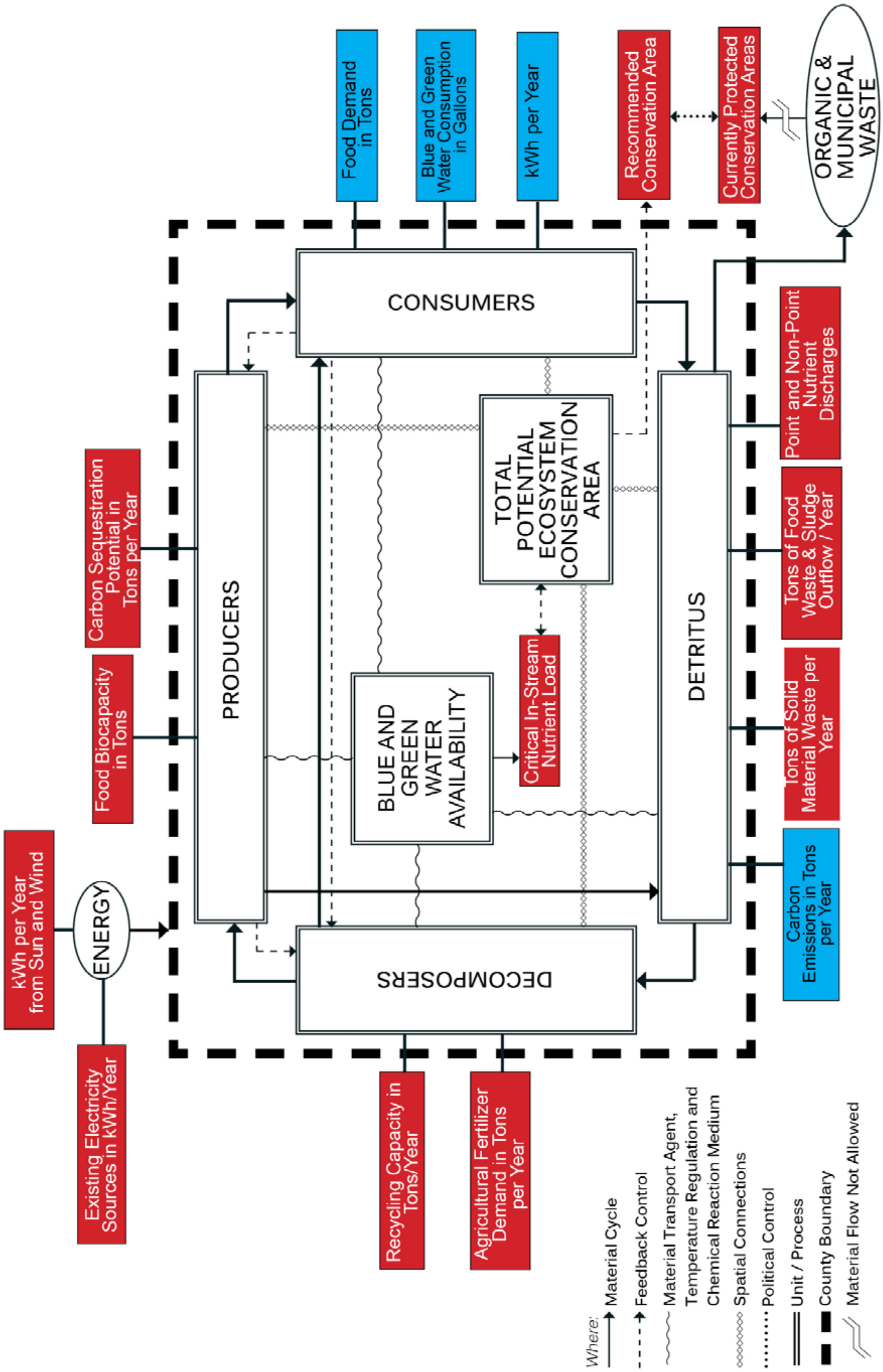


Figure 4-5: County Diagnostic Interpreted in the DEU Framework (where blue indicates components and methods which are already addressed in the literature and red indicates components and methods which would need to be developed in order to opreationalize a DEU-based expanded environmental footprint)

4.2.1.6 Material and Energy Flows in the County Diagnostic

The quantification of capacity and demand factors in the diagnostic method require empirical observations of material and energy flows. The movement of energy and materials through the Earth and Space over time is considerably more complicated than can be addressed here and the following sub-sections identify relevant cycles and define how they pertain to the County Diagnostic. It is relevant to describe these cycles in the concept framework because it links the work to the fundamentals of ecology and geography. The translation of County Diagnostic factors into cycles is not a 1 to 1 ratio where each of the 19 factors or 6 categories has a specific cycle; rather, categories and factors are often included in a number of interdependent cycles and is a key point for the diagnostic ecosystems approach where a change in one factor may lead to changes in other factors.

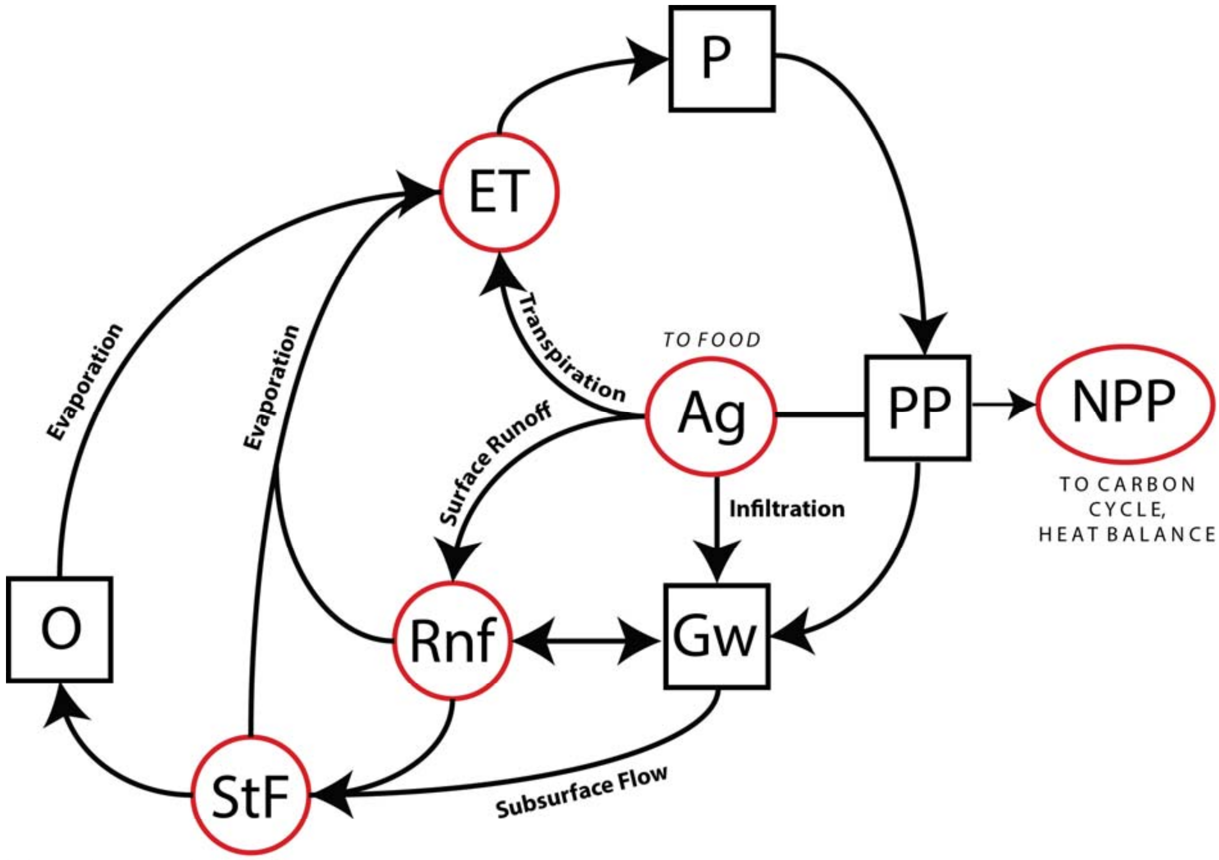
4.2.1.6.1 Water Quantity

Factors related to water ultimately measure certain points in the hydrological cycle, adapted below in Figure 4-6 from (Odum 1971, p. 97). The diagram presents the factors to be quantified in the County Diagnostic method in red circles, including evapotranspiration (ET), runoff (Rnf) and streamflow (StF) and other factors within the hydrological cycle that are not measured as black squares. In addition, agriculture (Ag) and net primary production (NPP), which are measured in food production capacity and CO2 absorption capacity, also affect outcomes on ET, Rnf and StF.

4.2.1.6.2 Water Quality

The water quality components of the diagnostic assessment fit into the nitrogen Figure 4-7 and phosphorus Figure 4-8 cycles. The nitrogen cycle in nature begins with atmospheric nitrogen (AN_2) which is fixed from the atmosphere to the soil and thereby converted to organic nitrogen. The byproduct soil fixation, ammonium (NH^+_4), is then available to plants and animals that cycle the nutrients terrestrially via consumption and excretion. The final phase in the cycle is the bacterial conversion of nitrogen and ammonium to nitrate (NO^-_3) that is then gasified back to the atmosphere (adapted from Odum 1971, p. 88). Human point and non-point loads of N from wastewater treatment plants, agricultural fertilizers or industries can increase the load of nitrogen or ammonium to the point that bacterial conversion and gasification rates cannot keep up, resulting in excess loads of nitrogen or ammonium into surface or ground water via the erosion process which can be measured. The County Diagnostic measures the point source (PS) and non-point source (NPS) nitrogen discharges which load runoff (Rnf) and compares those loads to water quality standards as discussed in section 3.5.1. The N cycle is linked to the hydrological cycle via runoff (Rnf).

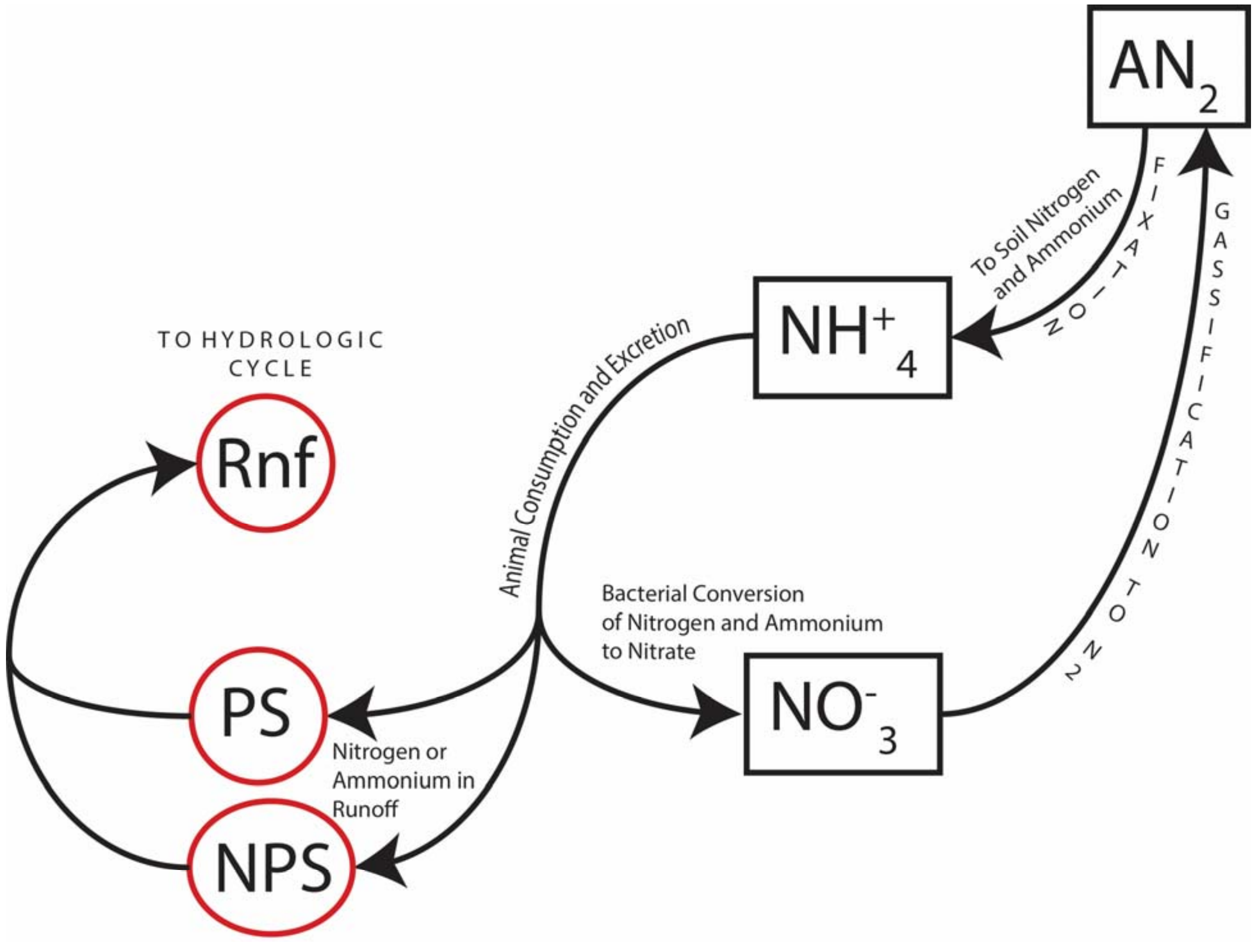
While phosphorus is an important element in biotic life, it is not overly abundant and has a long cycle with the main source of P coming from rocks containing P (PR) which are broken down via erosion and mass wasting and made available in fresh and salt water solution (DP). As a solution, P is available for biological synthesis and eventually deposited into deep marine sediments where geological uplift brings the sediment back to the surface for the cycle to begin again (adapted from Odum 1971, p. 88). As in the nitrogen cycle, humans load phosphorus into surface waters as point sources (PS) and non-point source (NPS) loads from agriculture and industrial processes, thereby increasing the natural background load which can exceed the biological synthesis capacity of local ecosystems.



Hydrological Cycle

Where:
P = Precipitation
PP = Primary Productivity
NPP = Net Primary Productivity
Ag = Human Agricultural production
Gw = Groundwater
Rnf = Runoff
StF = Streamflow
O = Ocean basin
ET = Evapotranspiration

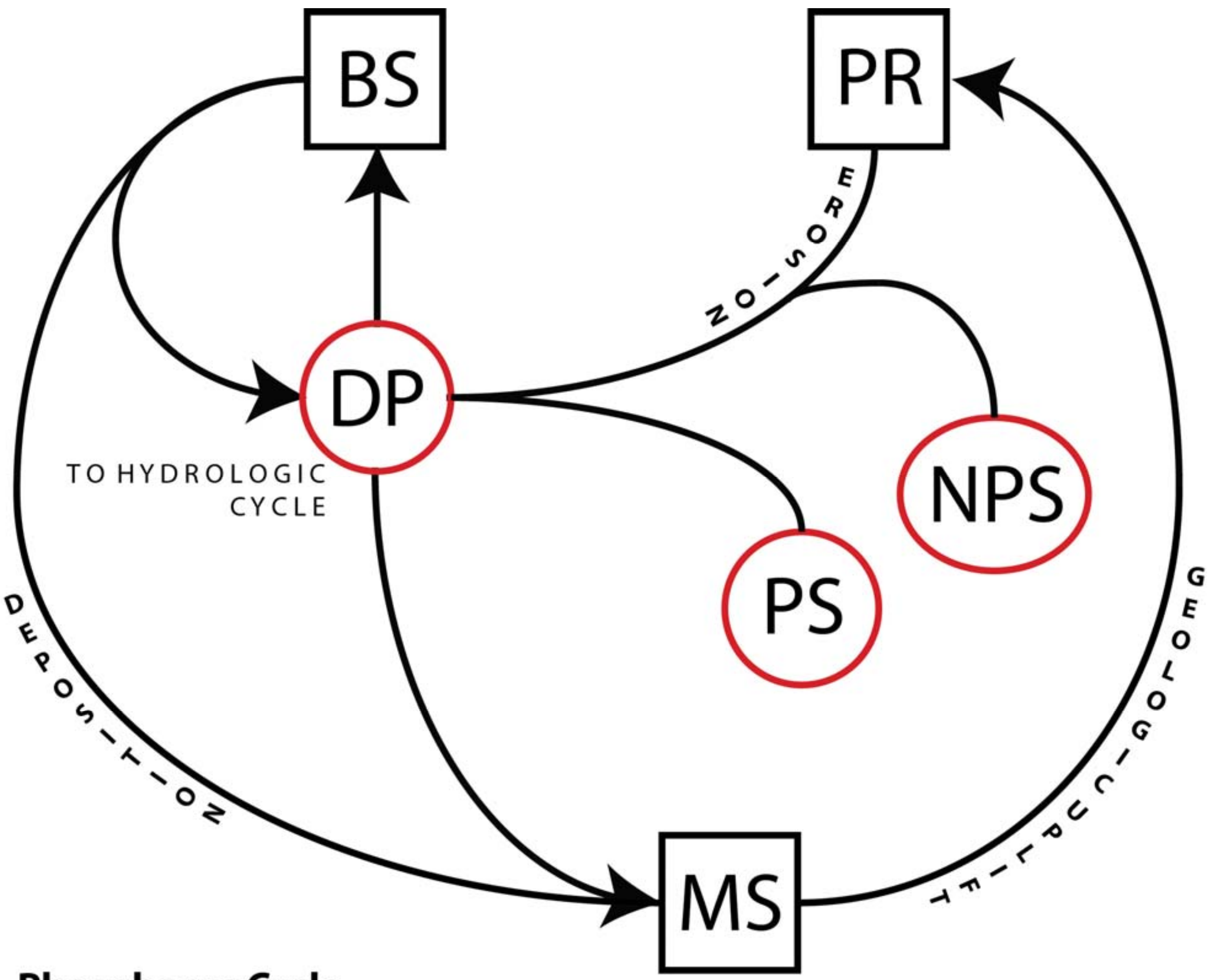
Figure 4-6: The Hydrological Cycle as Adapted for the County Diagnostic from (Odum 1971, p. 97) Where Components in Red Indicate a Point of Measurement in the County Diagnostic



Nitrogen Cycle

Where:
AN_2 = Nitrogen in the Atmosphere
NH^+_4= Plants fix nitrogen and create ammonium
NPS = Non-Point Source nitrogen load before gassification
PS = Point Source nitrogen load before gassification
NO^-_3= Ammonium is converted to nitrate
Rnf = Runoff

Figure 4-7: The Nitrogen Cycle in the County Diagnostic as Adapted from (Odum 1971, p. 88) Where Components in Red Indicate a Point of Measurement in the County Diagnostic



Phosphorus Cycle

Where:
PR = Phosphate Rocks
NPS = Non-Point Source phosphorus load
PS = Point Source phosphorus load
DP = Dissolved Phosphates in fresh and salt water
BS = Biological Synthesis of phosphorus
MS = Marine Sedimentation of phosphates

Figure 4-8: The Phosphorus Cycle in the County Diagnostic as Adapted from (Odum 1971, p. 88) Where Components in Red Indicate a Point of Measurement in the County Diagnostic

4.2.1.6.3 The Carbon Cycle

Another important cycle in the County Diagnostic is the carbon cycle (Figure 4-9), where carbon dioxide in the atmosphere is used during photosynthesis and chemosynthesis for respiration or maintenance that is defined as primary productivity (PP) with excess carbon beyond what is needed for respiration stored as plant matter and called net primary production (NPP). Net primary production (ie, plants and cellulose matter) is consumed in animal metabolism (AM) to produce energy and animal respiration releases the carbon back into the atmosphere. This process occurs in the ocean (O) as well as on land via dissolved carbon (Odum 1971, p. 43). Humans have arguably augmented this system by loading fossil fuel (stored carbon) emissions (Em) into the atmosphere at a rate greater than plants can sequester the additional AC. The County Diagnostic measures human emissions and net primary productivity as a measure of how intensely human activities might be augmenting this cycle locally. Net primary productivity has effects on the hydrological cycle and heat balance, and while the use of fossil fuels (FF) as existing energy capacity is measured as part of the County Diagnostic, the actual long-term production or availability of FF on a county-basis is not directly quantified.

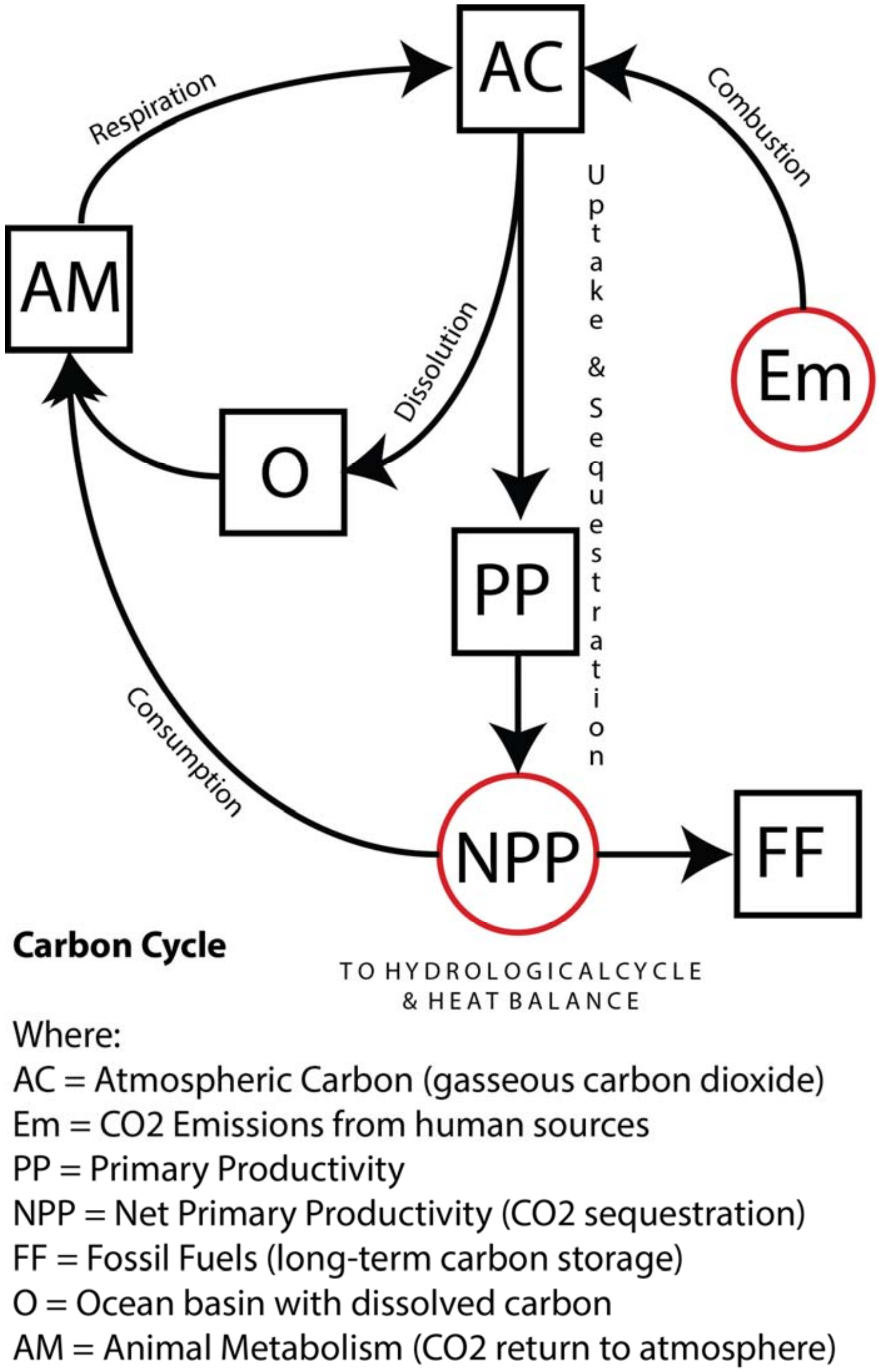


Figure 4-9: The Carbon Cycle in the County Diagnostic as Adapted from (Odum 1971, p. 97) Where Components in Red Indicate a Point of Measurement in the County Diagnostic

4.2.1.6.4 Energy Balance

Energy balance is the measure of shortwave incoming solar radiation hitting the Earth and the outgoing longwave radiation which is emitted back out to space. As shortwave radiation (SWR) enters the Earth's atmosphere, a small portion of it is scattered before being used in photosynthesis for ecosystems (PP) and human systems (Ag) or absorbed by the Earth's surface (Strahler, Strahler 1996, p. 44). Absorbed energy is released as longwave radiation (LWR) back out to space but some of it is absorbed by clouds or atmospheric particulates or reflected back to the Earth's surface from gasses and water vapor to create the 'greenhouse gas' effect. In the County Diagnostic, SWR is quantified in kWh/m^2/day to derive a total electricity production from photovoltaic (PV) panels, NPP and human use of primary productivity as Ag that could more generally could be referred to as HANPP Haberl 1997) (Figure 4-10).

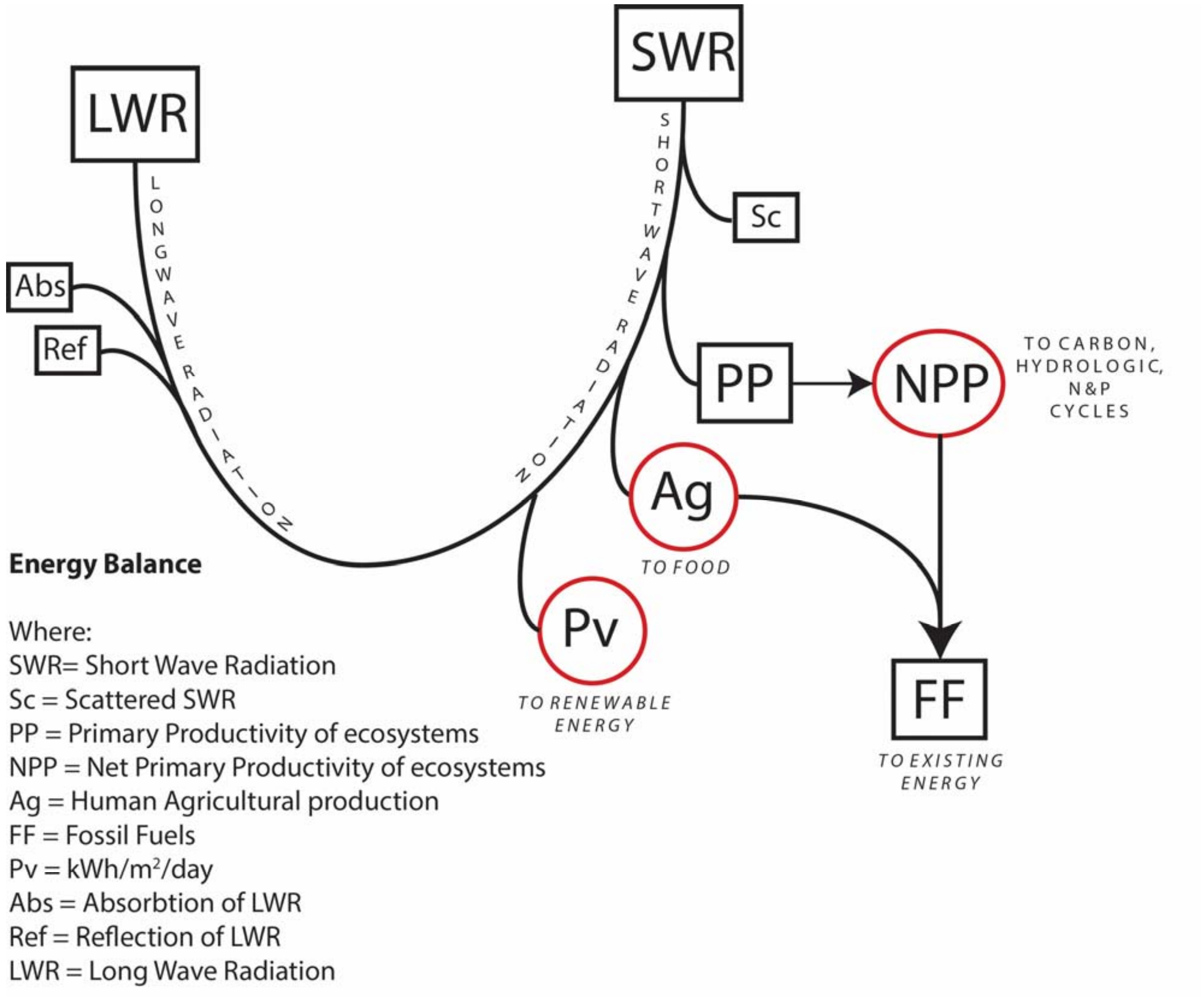


Figure 4-10: The Energy Balance in the County Diagnostic as Adapted from (Strahler, Strahler 1996, p. 44) Where Components in Red Indicate a Point of Measurement in the County Diagnostic

4.2.1.6.5 Municipal Solid Waste and Organic Waste

Municipal Solid Waste (MSW) represents detritus in the urban system and MSW is composed of organic and inorganic materials. While there is no direct ecological or Earth cycle presented to describe this flow, although the geologic cycle responsible for the creation of in-organic materials at a very large scale, there is a cycle in human systems of material recovery which is relevant and is presented as the MSW and Organic Material Cycle in Figure 4-11. The cycle is especially relevant to and driven by human actions. It begins as materials imported to urban regions from the global (Gl) or local market (Lo), where MSW is generated (Gen) as a byproduct of consumption. For simplicity's sake, organic material is included in (Gen) within the diagram. MSW and organic materials are then recovered and broken down into their basic components for uptake in local or global processes, both of which may have a carbon emission (Em) if energy or liquid fuel is used in the recovery or re-use process. The County Diagnostic is a spatially explicit environmental footprint and therefore does not quantify the emissions in production or remanufacturing of raw materials that occur outside of the county, but does quantify industrial and energy emissions which occur in the county as well as generation and recovery of MSW in the county. MSW which is not recovered generally ends up in a landfill, but LF diversion or capacity is not counted in the County Diagnostic and instead is focused on the percentage of recovery as the inverse measure of MSW waste. Organic wastes which are not recycled as sludge can end up as N or P in surface waters, which is quantified in water quality measurements. Although all local reuses for recovered materials is not quantified in the method, the ability of local agricultural production to use recovered organic materials is quantified and thus is a red square indicating a point in the cycle which is partially diagnosed.

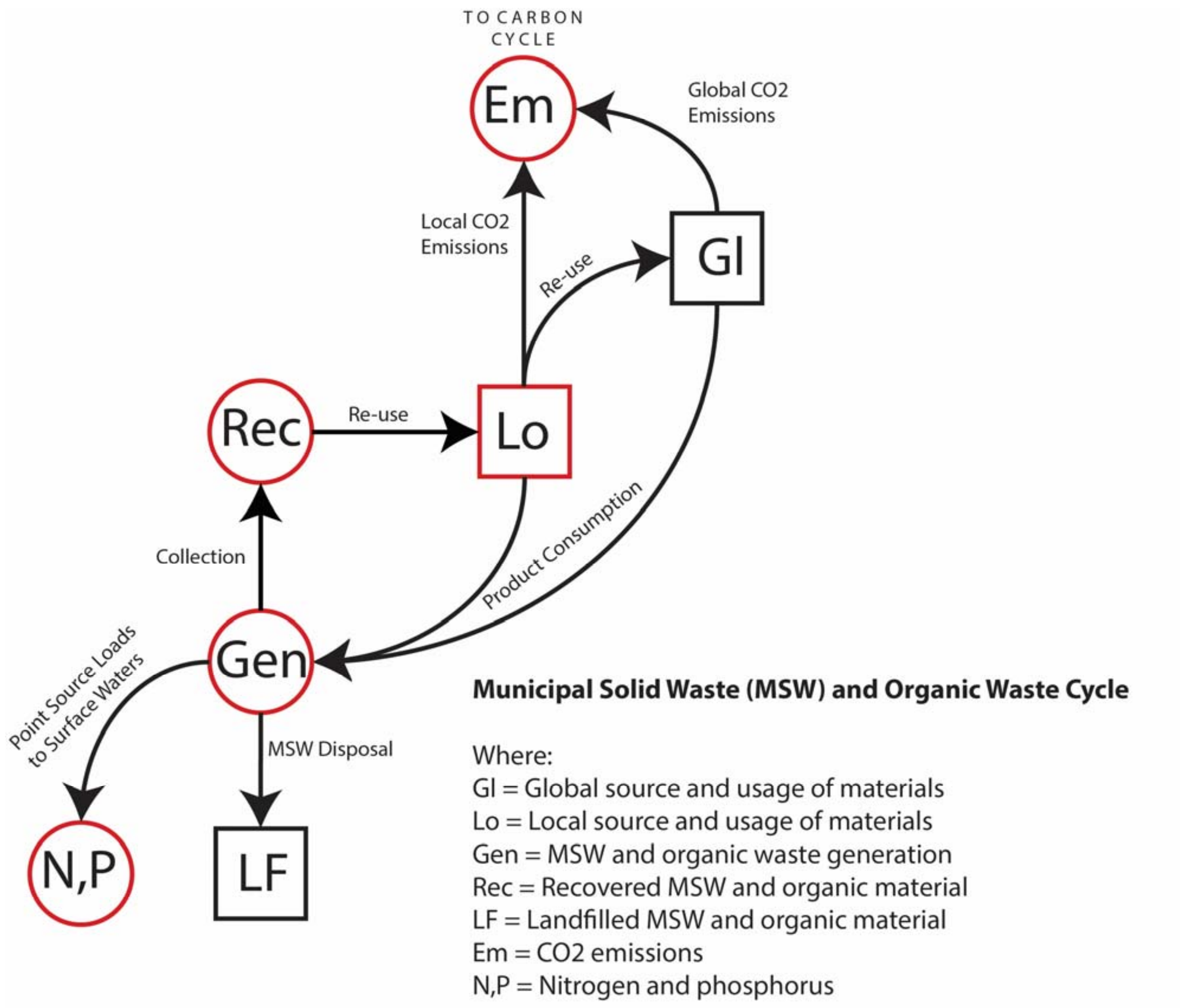


Figure 4-11: Municipal Solid Waste and Organic Material Cycle in the County Diagnostic (own depiction) Where Components in Red Indicate a Point of Measurement in the County Diagnostic

4.2.1.7 Dissipative Structures, Ecosystem Maturity & the County Diagnostic

The DEU is also related to the theory of cities as dissipative structures which was proposed by Ilia Prigogine (Prigogine, Stengers I. 1984) and has been discussed by other authors (Pulselli et al. 2006; Johnson 1981). This theory suggests that cities are non-equilibrium thermodynamic structures and that they naturally self-organize by keeping internal order and in doing so create entropy, which is characterized by solid and liquid waste flows and gaseous emissions. Prigogine suggests that cities behave as open non-equilibrium thermodynamic systems which operate on the basis of being able to receive, metabolize, and dissipate energy and materials in wide ranges of temperature and material composition. Without pulses of energy and materials, the structure would not be able to maintain this state and would revert to a thermodynamic equilibrium which would be relational to the natural flows of the region (Prigogine, Stengers I. 1984). The theory is furthered by considering ecosystems as dissipative structures characterized by differences in the ratio of production and biomass (P/B) between young high producing systems, with young systems characterized by high rates of energy flow and entropy production and mature systems characterized by “a state of least dissipation at maturity (Johnson 1981, p. 579)” with the ability to metabolize high quantities of material and energy with highly efficient individuals and low system-wide entropy production.

Good quality mature systems are known to have a higher number of “short cycles” (Ripl, Hildmann 2000) which are evident in root-level nutrient capture typical of mature prairie ecosystems due to deep and interconnected root systems which can share resources; the vertical dissipation of rainfall in the multi-tiered canopy of tropical forests where rainfall is progressively absorbed into animal and vegetation layers as it moves down the canopy; and the reduction of peak flow events in urban watersheds with extensive preserved riparian and upland vegetation. These examples can be considered idealized contexts that are the theoretical equivalent of achieving an urbanized DEU structure. Johnson proposes that such a structure has to be composed of two parts: 1) individuals which trend towards a state of least dissipation possible (highest efficiency of material use) and 2) the system which trends toward the greatest rate of dissipation possible (highest material and energy circulation potential) (Johnson 1981, p. 580). The County Diagnostic approach is designed to test whether or not counties in the USA (and aggregated counties into regions) function as linear thermodynamic structures (having the capacity to maintain themselves to a very high percentage without external input aside from solar radiation input and water flow) or if they function as non-linear structures that require areas outside of the county level jurisdiction to maintain an energy and material flow balance.

4.2.1.8 The County Diagnostic in Context of Ecological Urban Restructuring

The County Diagnostic can be understood in terms of its place within the ecological urban restructuring concept from section 3.4.2, that also acts as guide to mobilization of the results of the diagnostic. Table 4-1 indicates that the CD approach overlaps with 6 of the 8 points of orientation, leaving only participation and democratization and orientation to qualified density outside of the scope of the current study. The action matrix (Figure 4-12) indicates that the CD approach overlaps most with the urban technology and urban design fields of action in the EUR concept based on the basic environmental footprinting categories included in the CD, but also provides environmental accounting in the capacity and demand format and informs the public and decision makers about the existing balances, which can be useful in the third column of urban economy and political administration as well by setting targets for ecological or metabolic balances and environmental accounting. Outside the scope of the CD is the synthesis of findings to realistic changes in infrastructure or material and energy supply, as well as any input to building arrangement or urban design, a strategy which allows the CD to be flexible to human design responses which are different at the ecoregion level and amongst different political and economic contexts.

Points of Orientation	**CD**
Human-Ethological Orientation	x
Orientation to Cycles and Networks	x
Orientation to Nature and the Senses	x
Orientation to the "Genius Loci"	x
Ecology and Economy	x
Internation Orientation	x
Participation and Democratisation	N/A
Orientation to Qualified Density	N/A

Table 4-1: Overlap with EUR 8 Points of Orientation indicated by “x” (Hahn, 1991)

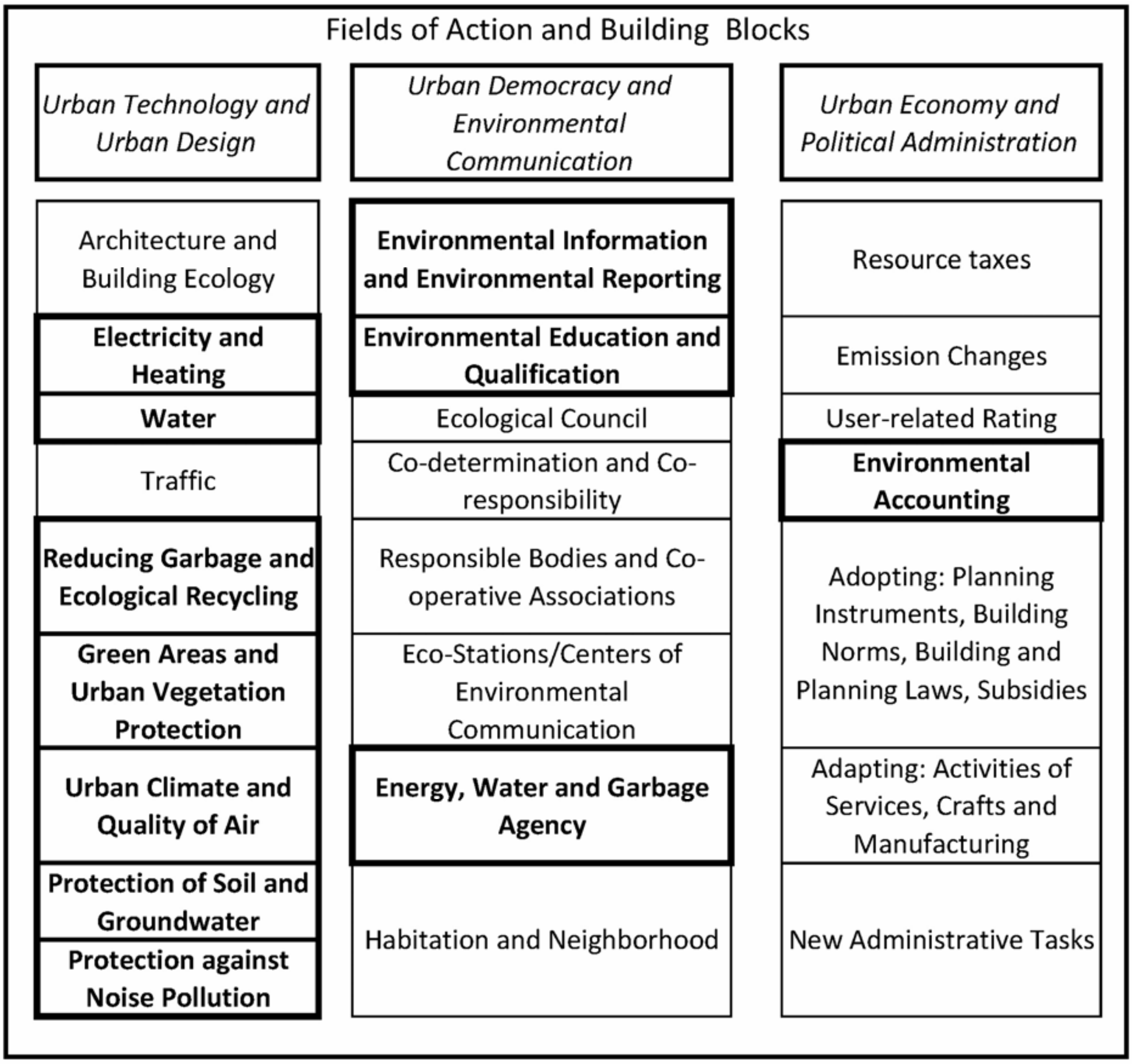


Figure 4-12: Overlap with EUR 'Fields of Action' and 'Building Blocks' Surrounded by Bold Outline (adapted from Hahn 1991)

4.2.1.9 County-Wide / Aggregated Region

Finally, since we are interested in analyzing settlements in the USA, a regional or sub-regional analysis unit should be utilized which has consistent data and can meaningfully introduce policy, leverage funding or integrate infrastructure. I propose that the best unit for this in the USA is the county unit due to consistent population Census, agricultural Census, USGS satellite imagery, and vector-based GIS data availability for the conterminous United States at the county level. Cities are analyzed in context of their county-based hinterland and all counties that intersect a large city are combined for analysis of a supra-county urban-region. The fact is that the mean population of 98% of all counties in the USA is 61,000 or less and typically contains 1 to 3 incorporated places (US Census 2010a, 2010b, United States Census Bureau 2010). Except for the 20 largest cities in the USA, which Luck and Jenerette (Luck et al. 2001) showed utilize resources far beyond the county boundary, for most of the USA the county is a small enough unit with enough hinterlands around incorporated places to be meaningful in analysis.

4.2.1.10 Strengths of the County Diagnostic Approach

The County Diagnostic output is not an aggregated spatial 'footprint,' rather it is a measure of the capacity of the county to produce the demands of population and industry. When the ratio of demand is greater than capacity it represents a shortfall of production, absorption or capacity of a county to supply the demand, meaning that materials need to be more efficiently managed or goods must be imported. When the capacity is greater than demand it represents a material or energy abundance that can be traded or sold to other counties or allowed to build up into a beneficial material stock such as a forest preserve to sequester carbon. Since each component category is individually analyzed, alternative scenarios for balancing/cycling individual components can be developed. The assessment method is composed from EF, MFA and ecosystem services assessment methodologies and adds the dimension of a regional United States specific approach as a means to reduce the excessive consumption of the USA in comparison to other industrialized countries as pointed out in the body of research. The USA is data rich and that data richness is capitalized on with the project to achieve a county-level material and energy-based diagnostic method that can be consistently applied across the USA, grouped together to create urban region analysis and which relates directly to material and energy units commonly used in all major sectors of infrastructure planning and engineering thereby being immediately applicable to engineering cost estimates and spatial planning.

I also hope that the increased resolution of the analysis made possible by focusing on a data rich country with a wide array of sub-state resolution spatial and material flow data at the regional scale and in material units will give insight into the spatial heterogeneity of resource use and biocapacity across ecoregions in the USA compared to the National Footprint Accounts method (Lazarus et al. 2014), particularly in regards to food, biodiversity, energy, waste and water. The approach is in line with adaptive ecosystem management (Haney, Power 1996) in that it uses empirical ecosystem analysis to guide human decision making which in turn control ecosystem and earth feedbacks, in lieu of modeling the effects of human action or multiple actors actions into the future based a set of assumptions. Basically, we don't need a model to tell us that outstripping our resources leads to a bleak future; rather we need an analysis method that can assess our current systems and consumption patterns quickly and accurately enough to guide human decision making to realistic infrastructure solutions that reduce our footprint.

4.2.1.11 New Methods and Approaches Needed for the County Diagnostic

Considering the background research presented in the previous section, there are still shortcomings within the research literature in regards to assessing material flows and energy flows within the USA at the regional level and translating those assessments into direct quantitative planning and engineering recommendations (Federal Environment Agency of Germany 2007; Kitzes et al. 2009; Wiedmann, Barrett 2010; Wiedmann, Lenzen 2007). These shortcomings represent the potential contributions of this work to the literature in the interdisciplinary fields of EF, material flow, ecosystems services, urban metabolism and landscape ecology and thus are justified as the focus of this dissertation. These areas for improvement are tied back to the background literature review in section 3 on a topic by topic basis below, explaining how the addition or modification of components and the changes of calculation methods and data sources is justified to address critiques.

To carry out part 1 of the research design, the County Diagnostic conceptual framework (section 4.2.1) needs to use quantitative data for all analysis components listed in Figure 4-4 which can be collected at the county level consistently across the entire USA. The specific categories in which data is collected come from a synthesis of previous methodological frameworks, including the EF (Rees, Wackernagel 1996; Wackernagel 2009; Wackernagel et al. 2006; Global Footprint Network 2009; Simmons 2000; Wiedmann, Barrett 2010; Federal Environment Agency of Germany 2007) and Footprint family (Galli et al. 2012), including the Water Footprint (Hoekstra, Chapagain 2006; Hoekstra et al. 2011) and Carbon Footprint (Pandey et al. 2011; Rees, Wackernagel 1996; Minx et al. 2009) MFA (Brunner, Rechberger 2003; Decker et al. 2000; Lehmann 2011; Haberl et al. 2004a), the urban metabolism assessments of cities (Havránek 2008; Vester 1976; Rees 1997; Luck et al. 2001; Forman 2008; Wegener 2011), ecosystem services (Chan et al. 2006; Zhang et al. 2010; Norberg 1999), landscape functions (Leibowitz et al. 2000; Gruehn 2006) and ecosystem functions (Ripl 1995; Alberti 2007; Forman 1995).

The synthesis expands the number and type of components beyond any one of the above methodological frameworks alone, defining the necessary number of analysis components within the theoretical framework of the dissipative ecological unit (Ripl 2003) and dissipative ecosystem (Odum 1971), where the paradigm of a stable system trends towards circular material and energy flows in a metabolism composed of producers, consumers, decomposers and detritus with each component held in check by feedbacks, with a metabolism run via solar energy as prime input and water as the main material and energy transport, temperature regulation and chemical reaction medium. This motivation purposely roots the analysis within the field of landscape ecology, seeking to understand cities as the sum of interactions between human and ecological systems and flows and champions the emulation of natural systems as the conceptual way forward in the creation of ecological cities. Human material fluxes are crucial in the analysis since they are essential in shaping ecological systems (Alberti 2007) and are used as a counterpoint to ecological systems to frame the concept of human and ecosystem balance in post-industrial civilization (Vester 1976; Naveh 1987, 2000).

The County Diagnostic addresses many of the shortcomings mentioned by previous authors in section 3.1.2, however, no one tool or assessment methodology can address every need and therefore the County Diagnostic should be interpreted as a type of regional ecologically based carrying capacity assessment for human populations which utilizes a high level Footprint accounting (Hoekstra, Wiedmann 2014) methodological approach. Additionally, the first research question is addressed by proposing that the USA can better manage its material flow present and future by starting at the county level building block and creating a material flow accounting system which provides a "diagnostic assessment" of capacity and demand at a manageable spatial and jurisdictional scale, highlighting the need for material and energy inputs or management of entropy outflows given the number of people and land area and providing quantitative goals to guide infrastructure or policy planning.

4.2.1.11.1 Regional Data Sets for Regional Analysis

The utilization of nation-wide datasets and equivalence factors is an effective way to compare nations, but not sensitive enough to compare regions or sub-regions within one country where yield levels may vary by ecoregion or sub-ecoregion unit. Thus the improvement of the Footprint for sub-regional analysis was mentioned by numerous authors (Gruehn 2003; Kitzes et al. 2009; Wiedmann, Barrett 2010). Wiedmann and Barrett have shown that this factor alone can influence the final footprint outcome by as much as a factor of two (Wiedmann, Lenzen 2007, p. 676). Therefore county-wide or sub-county datasets are used in the County Diagnostic method.

4.2.1.11.2 A Zone of Conservation for Ecosystem and Landscape Functions

An evaluation method to define a spatially explicit area to be set aside for habitat conservation and biodiversity preservation is not consistently defined in the research, resulting in a range of values presented by different authors. From these sources a recommendation for ecosystem and landscape functions should be developed and operationalized.

Wackernagel & Yount reference the World Commission on Environment & Development (WCED, also known as the Brundtland report from the United Nations) policy recommendation of 12% land area for biodiversity protection (Wackernagel, Yount 2000, p. 38), basing the recommendation on the WCED's consensus that 10-15% of total land should be preserved to protect biodiversity. However, no indication of where land should be set aside or the comparative biodiversity protection value between different potential land areas is addressed in this broad policy recommendation. Within the framework of the EF method, 10 and 20 percent land area set-asides have generally been recommended in past EF applications but in practice this number has been left for local authorities to define (Kitzes et al. 2009, p. 2001). The approach in the EF method has it benefits because it is open to flexibility and local expert ecological assessments to define specific land set aside areas, but without any direct guidance for habitat conservation or biodiversity preservation within the current EF methods the approach is inconsistent (Lazarus et al. 2014).

Hoekstra & Chapagain (Hoekstra et al. 2011, p. 81) interpret the WCED's 12% recommendation not as direct land area as Wackernagel & Yount and Kitzes et al. does, but as the percent of all ecosystem types which need to be preserved to achieve biodiversity preservation. While effectively protecting 12% of all land at the country level will result in equal area of preservation compared to protecting

12% of all sub-national ecosystem types, the recommendation effectively changes the concept from simply protecting land to protecting specific ecosystems, which requires the delineation of different ecoregion types to come to a practical plan for ecosystem conservation at the regional level. The Convention on Biological Diversity (United Nations 2010) also moved the discussion into an ecoregion context suggesting 10% of each of the world's ecological regions should be protected and 50% of the most important ecological regions preserved to achieve plant diversity preservation. From this ecoregion-based preservation standpoint, Noss and Cooperrider (1994) estimate that preservation should be more on the order of 25-75% of land preservation to secure biodiversity. Svancara et al (2005) concluded after comparing 200 biodiversity protection reports that evidence-based preservation targets are likely to be three times as high as policy based targets, ultimately leading Hoekstra and Chapagain to a recommendation of 30% of land area set aside, distributed by evidence based studies of ecoregions, to achieve biodiversity preservation(Hoekstra et al. 2011, p. 81).

Recently, the Convention on Biological Diversity came to an international consensus suggesting a total earth area preservation in context of EF analysis include terrestrial preservation of 17% land area and added the category of marine area conservation of 10% (Tittensor et al. 2014), successfully bringing in the concept of protecting aquatic biodiversity as well as land area biodiversity. While this approach preserves less land area than Hoekstra's recommendation, the inclusion of a marine area (which can be interpreted as inland "freshwater aquatic" areas) further refines the discussion. Therefore I conclude that footprint-based analysis should aim for 17% to 30% land area preservation plus 10% marine area preservation which includes fresh water areas (such as floodplains, alluvial aquifer zones, streams, lakes and wetlands) for counties which are not on the coast. Ultimately, I choose to use the target of 17% land and aquatic habitat protection targets in the methodology of this study because based on pilot studies in professional practice (Vireo Planning and Design 2014) I found that preservation of 12%, let alone 17% or 30% is significantly higher than existing land area conservation and that a middle-ground target may be more politically attainable than a high target.

However, simply having an area target for preservation does not ensure that meaningful high quality or well-distributed habitat will be or has been selected for conservation. For this I turn to the work of landscape ecologist Richard TT. Forman's "patch and corridor" preservation concept, where the backbone of fluvial corridors create opportunities for habitat patches (Forman, Godron 1981, 1986), and landscape connectivity networks (via water) ultimately determines the quality of habitat preserved. In addition to identifying networks for preservation based on their contiguity to water resources, the metapopulation dynamic theory (Opdam 1991) is pulled in to identify a variety of patch sizes which may not be connected to the largest contiguous patch and corridor structure in a county but nonetheless acts as important stepping stones for mammals and birds or life-cycle habitat locations for fishes and amphibians (Felix Eigenbrod, Stephen J. Hecnar, Lenore Fahrig 2009). And lastly, roadway ecology theory (Forman, Alexander 1998; Forman et al. 2002) is pulled in to identify soil, vegetation, stream and wetland areas (Shilling, Waetjen 2012) which are experiencing negative effects from roads via road habitat dissection, noise propagation (Parris, Schneider 2009; Reed et al. 2010) or toxic material outflows (Backsrom et al. 2003).

Therefore, this research seeks to strengthen the definition of biodiversity conservation in environmental footprint methods and integrate measures of ecosystem services or landscape functions by proposing a “Zone of Conservation” which can be spatially defined and quantitatively evaluated at the County level. Wiedmann and Barrett (2010) found that strengthening the link between ecosystem services, EF and bioproductivity is one of the key issues discussed over the past decade of EF research. They proposed that a dynamic EF approach is arguably the strongest model for inter-linkage, in which footprints are not reported in global hectares used, but rather in the ultimate degradation of ecosystems which supply materials and sink wastes. The zone of conservation borrows from the idea of the dynamic EF approach by defining the area and extent of connected non-agricultural and non-urbanized vegetative land cover to determine the current or future potential for ecosystem degradation or level of policy-embedded ecosystem protection. The Zone of Conservation is quantitatively and spatially compared with the land area protected under federal or state regulations and the 17% terrestrial area and 10% marine area guidelines to determine if there is enough area set aside, and if not where conservation would help reinforce ecosystem services and landscape functions. The ZOC method and detailed data sources are discussed in detail in section 5.3 below.

4.2.1.11.3 Inclusion of Water Demand and Availability

The Inclusion of water demand and capacity analysis fills a gap from the EF identified as an important component inclusion (Federal Environment Agency of Germany 2007 p. 47; Kitzes et al. 2009, p. 1994). However, filling the gap in a way that made sense required mixing the two basic frameworks for water balance assessments of “extraction” and “consumption” which leads to a mass balance equation for the former to measure the total water throughput versus the total water availability and a green and blue Water Footprint for the latter (Hoekstra et al. 2011) to measure water actually lost or consumed from the local water cycle. A policy target based greywater Footprint is also integrated into the water demand and availability assessment to account for outflows of nutrients and organic materials from human populations, industry and agriculture in comparison to legal limits standards.

Water extraction refers to removal of available freshwater from a surface or groundwater source via a distribution system for input into municipal, agricultural, industrial or open space uses. Postel defines total available freshwater as “the terrestrial renewable freshwater supply (RFWS)” that is subdivided into evaporation and runoff and are both derived from precipitation (Postel, Daily 1996, p. 785). Much focus on water conservation in the USA is geared toward reducing the extraction[1] of water from a county supply system (ie, reducing the use of potable water) and therefore reducing the percent of the RFWS needed to support the population and economy of a county. While many countries focus on reducing water extractions from the system in an effort to conserve water, Hoekstra actually found that 96.4% of municipal water “extracted” (aka. served to consumers in the municipal supply system) returns to surface waters via runoff or permitted outflows from municipal waterwater systems, storm sewer outflows or industrial outflows (Hoekstra, Mekonnen 2012, p. 2), all of which are permitted and can be quantitatively accounted for via the US EPA ECHO compliance

[1] Water extraction in the municipal supply system comes from surface water, which is generated by runoff, or groundwater, which is defined as “fossil water” and not considered part of the RFWS.

systems. This means that strategies aimed to reduce consumption in sewered urban areas where water is “extracted” but then returned via sewer or facility outflows may only be affecting a very small proportion of actual water losses in a county. In other words, conserving water at the tap in counties with sewerage systems will reduce the volume of water extracted from sources (waterways, reservoirs or groundwater) but less than 4% of that water is actually evaporated and leaves the local hydrologic cycle, making water saving strategies somewhat misleading because the water is simply moved in a loop from the source back to the source. For this reason it is also important to measure water consumption.

Water consumption refers to water which is consumed, embodied or evaporated in products from or processes within a county and can be quantified for green and blue water with the Water Footprint assessment framework (Hoekstra et al. 2011). The combination of these frameworks helps clarify the difference between the volume of water which is moving in a circle within a county (extraction and return) and the water which is potentially leaving the system as an export or as water vapor (consumption).

The graywater Footprint method as described by Hoekstra (Hoekstra, Mekonnen 2012) uses a multiplier of blue water necessary to “dilute” the pollutants to regulated levels, thereby deriving an annual volume of blue water needed per year to keep surface water quality in accordance to permitted levels and which can be compared to local water availability (ie, runoff or RFWS). The County Diagnostic utilizes the greywater Footprint concept to account for organic and nutrient wastes from human systems but instead of quantifying the total volume of blue water needed to dilute pollutant outflows, the method compares the actual reported outflows via the EPA ECHO database of nitrogen and phosphorus with the annual regulatory limits of nitrogen and phosphorus loads.

To date, no Footprint or MFA studies account for groundwater withdraws, which is clearly occurring at the county-wide level based on preliminary data review for the United States and for which annual county-wide withdraws and aquifer level data is available (USGS 1900-2014, 2010). Groundwater levels are typically reported as depth to surface of the subterranean water supply, rather than in gallons used per year as reported by the USGS 2010 Water. Due to the complexity of estimating the total available gallons in an aquifer based on a conversion from depth to surface, groundwater is not included in the water availability side of the equation but is included in the water extraction number (ie, lumping surface water and ground water extraction together to derive a single number for water abstraction). Since groundwater availability cannot be accurately determined in this study, only runoff and streamflow are accounted for as “available water” and therefore the actual amount of water available in a county could be greater when groundwater reserves are considered.

However, Postel characterizes groundwater as “fossil water” and it is well-known that surface runoff recharges groundwater in specific locations based on soil and geology (Dunne, Leopold 1978). Therefore, groundwater demand is ultimately derived from surface water and if water extraction demand of a county exceeds available runoff then logically groundwater recharge is not occurring and any withdraws from groundwater are considered un-sustainable. If a county’s water demand does not exceed the RFWS, then groundwater withdraws may be justified. Since the County Diagnostic includes a recommended zone of conservation (section 4.2.1.11.2) which identifies soil and topographic areas where groundwater recharge typically occurs, thereby providing spatial definition of areas for general soil or groundwater recharge functions, recharge areas could be scrutinized in counties where groundwater is an important source of water supply.

Since the USGS reports the percent of water extraction from surface and groundwater, and these numbers are combined in the water demand calculations, it is possible with the County Diagnostic to un-separate the two numbers in the case that annual sustainable groundwater extraction rates in gallons is known and to calculate a percentage of surface water and groundwater utilization. This means that water availability in the County Diagnostic method is conservative and is also flexible enough to allow further more detailed study when detailed groundwater data is available.

In summary, water analysis in the County Diagnostic is a hybrid approach that employs both the Water Footprint approach accounting for internal water consumption of blue and green water (demand) based on sectors, the greywater Footprint based on reported outflows and regulatory limits of N and P and employs the human appropriation of freshwater approach that calculates a defensible annual renewable freshwater supply (blue water and green water) that is adjusted for ecosystem water requirements. To determine a unit specific balance, surface and groundwater demands are directly compared to the RFWS using the NDI formula and the values are plotted on the vertical waveform diagram (Figure 4-13).

4.2.1.11.4 Organic and Municipal Solid Waste (MSW)

The inclusion of organic and solid waste processing and recycling facilities in the EF was identified by the Global Footprint Network research assessment (Kitzes et al. 2009) and the German government assessment (Federal Environment Agency of Germany 2007) as an area for improvement and thus is identified as an area for inclusion in this study.

In 2012 yard trimmings and food wastes represented 28% of typical American household wastes with only 2% of food waste recovered and 22.6% of yard waste recovered (US EPA 2012, p. 5), representing untapped resources which can be used as a source for biological compost. In addition, waste water treatment plant sludge output can also be composted when properly treated for heavy metals and can also be a source of biological compost. Biological compost, as an agricultural fertilizer, is in high demand in the United States and can be used as a substitute to nitrogen (N) and phosphorous (P) based industrial fertilizers, with research indicating that biological compost and sludge slurry may actually be a better method of P recapture, long-term organic N availability in soil and water retention capacity than industrialized chemical fertilizers (Lundin et al. 2004, p. 265) and is actually an encouraged practice by the US EPA when heavy metal and N loading limits are observed (U.S. EPA 5/1/2015). Food wastes, yard trimmings and WWTP sludge is quantified at the county level utilizing the CoEat digester sizing tool from the US EPA (US EPA 2010), which is based on per capita and facility assumptions. The benefit to this strategy is that it does not only estimate the potential volume of organic waste which can be converted to compost, it also quantifies the economic viability of installing a WWTP co-digestion facility in a county and energy co-generation potential of extracted bio-gas.

The counterpoint to the production of organic compost from organic waste and sludge slurry is the capacity of the land to receive the finished organic compost without exceeding US EPA heavy metal or nutrient loads (U.S. EPA 5/1/2015). This capacity calculation is done using standard loading rates and total area of agricultural productivity in the county. The inclusion of this factor is based loosely in the reference of a "detritus agriculture" system (Odum 1969) where man makes use of ecosystem detritus to obtain food. This study uses that concept as a base to assert that human waste and organic waste actually represent detritus of the human system and therefore the potential transformation of this material into agricultural fertilizers to replace fossil fuel and chemical based fertilizers is a step in the ecological direction. These methods are presented in detail in the methods section.

Inorganic materials in the United States represents the remaining 72% of the MSW load annually, of which about 35% of that material is recycled (US EPA 2012, p. 5). Estimating the shares of MSW by material on a per county basis in the US is somewhat trickier than organic waste to calculate, as exploratory county case study research revealed that many counties do not list the total recycling capacity or annual recycling throughput and there is currently no national level dataset with this information. None the less, the USA EPA annually tracks the per capita MSW production rates by material type and the 2012 federal level average figures are used in this study via a bottom up summarization by capita in each county to supplement when a county-wide estimate is not available. Essentially this mixes top down and bottom up approaches to derive an annual production of MSW in tons. In the MSW worksheet the total tons is broken down by material type, but ultimately only the final total combined tons of material is utilized in the final NDI calculation. The capacity side of the equation for MSW is the estimate of recycling percentage where the top down national figures are used in the case that regional or county estimates are not reported.

While landfilling is a common practice in the United States to manage un-recycled materials, I do not personally believe that it is a viable long term solution to MSW and instead counties should aim to create a '*Kreislauf Wirtschaft*,' which translates from German into English as a "circular material flow economy" which includes recycling and reuse that aims for zero waste or 100% reuse (the ecological analogy to material and nutrients in healthy ecosystems where short cycles ensure total capture of materials). For this reason the generation and recovery measurements are used as opposed to an estimate of landfill capacity, as that would be continuing to support a human system which has no place in the DEU.

4.2.1.11.5 Renewable Electricity Potential

Neither the EF nor the Footprint family assessment include an estimate of renewable energy potential and it is not typically included as an ecosystem service (Chan et al. 2006; Norberg 1999). Pulling from existing solar and wind potential placement and generation estimate methods in the German planning system (Umweltbundesamt 2013; Nohl 1993), detailed meteorological data available for the USA at the sub-county scale via the US Department of Energy (United States Department of Energy (US DOE) National Renewable Energy Laboratory (NREL) 2010), NOAA (Anthony Lopez, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro: NREL 2013) and detailed land cover data available at the sub-county scale (United States Department of Agriculture 2012a) an estimate of the potential annual MWH of renewable electricity generation is developed. This component is not truly a new method per se because a number of federal governments and private consultants are currently performing these services. However, it illuminates the calculations used for this type of estimate and in doing so provides access of this information to the public and makes it available for inclusion under the County Diagnostic umbrella.

The renewable electricity potential is used as a counterpoint to annual county-wide electricity demand and existing electricity production estimates (which are already at the heart of many existing urban metabolism studies such as Pérez-Lombard et al. 2008; Vringer, Blok 1995; Sims et al. 2003; Congressional Research Service 1/3/2014; Fuerst, Wegener 2013; Grimm et al. 2008; Decker et al. 2000; Barrett et al. 2002 and thus are not presented as new additions) to couch the potential for 1) sustainable renewable energy to support existing demand levels and 2) how that translates into a total percentage of renewable electricity generation at the county infrastructure level. It may seem that point 2 would be the same as point 1, however, some counties produce more energy than needed by the population (which feeds the US Electrical Grid), and thus to satisfy the local population energy demand it may be that only a portion of the existing fossil fuel production would need to be converted to renewable sources.

4.2.1.11.6 Accounting for the Environmental Water Requirement (EWR)

As discussed in section 3.5.2, the quantity of water to devote to ecosystem services needs to be included in the County Diagnostic, known as the environmental water requirement (EWR). The EWR is accounted for in the estimation of available surface runoff, streamflow and evapotranspiration (see section 5.2).

4.2.1.12 Modification of Existing Methods for the County Diagnostic

Many of the methods used for the County Diagnostic are not new, rather they take advantage of existing material flow and ecosystem services methods where available, drawing from existing urban metabolism, Carbon Footprint, ecosystem services, urban ecology and renewable energy research and case studies. However, due to the constraint of data availability some existing methods presented in the literature review are modified to accommodate existing data. The sources and modifications of existing methods used in the County Diagnostic are discussed below to give the reader an overview of how background research was synthesized. A full discussion of each method source with data sources is presented in the following methods section (Chapter 5).

4.2.1.12.1 Energy Demand and Carbon Footprint

The methodology for calculating energy demand and Carbon Footprint is linked, as the primary source of carbon emissions is kWh electricity demand per year, which is converted to a CO2 emissions rate per year. Energy demand is collected by sector and each sector has a slightly different calculation method. However, building-level datasets with accurate total floor areas is not available at the national level for all counties as this data is typically gathered and managed by municipalities in their detailed parcel level datasets. And while the US Energy Information Administration reports MWH usage by fuel source for states, it does not report these statistics at the sub-state level. Therefore, based on data availability it is not possible to develop a county-based bottom up estimate of total MWH by fuel types without a painstaking data gathering and coordination of parcel-level building data for every municipality in a county, which also precludes a bottom up estimate of carbon emissions at the county level. The need to digress to disparate datasets for these calculations is also against the premise of the County Diagnostic, which aims to develop a repeatable methodology which can be applied without the need for extensive time-consuming data collection work.

Thankfully, a database known as "Vulcan" addresses exactly this problem and went through the effort of piecing all of this information together for the 2002 sample year and which estimates the total MWH of electricity demand and the corresponding C02 emissions (Gurney et al. 2009). The Vulcan database estimates electricity demand and C02 emissions by county for the residential, commercial, industrial, municipal and transportation sectors and is utilized in this project to estimate total electricity demand an total carbon dioxide emissions. It is recognized that this data is not for the study year 2012, and in an effort to reduce the potential error of using data 10-years older than the study year data, the total population growth of the county between 2002 and 2012 is estimated and the C02 emissions are adjusted up or down based on the percent of growth or contraction. In the case that a county provides all of the building level data necessary, detailed energy and carbon emissions estimates can be calculated utilizing methods illuminated in other research papers and consultant studies (Padgett et al. 2008; Pandey et al. 2011; Minx et al. 2009), which is not discussed in this study.

4.2.1.12.2 Carbon Sequestration

The EF includes a measure of the quantity of forests to absorb human generated carbon emissions (Lazarus et al. 2014), but forests are not the only land cover type which can sequester carbon. In fact, all vegetative matter sequesters carbon and research into carbon sequestration indicates that above ground and below ground carbon sequestration is greatest in agriculture land cover (Jarecki et al. 2005; Post, Kwon 2000). Thus, the carbon sequestration estimates needed a heterogeneous approach which could accommodate a number of different land cover types above and below ground and this project takes a remote sensing-based approach.

The method utilizes the MODIS 16 remote sensing annual NPP estimates to estimate total carbon sequestration which is calculated for every square kilometer in North America on an annual basis in tons (Li 2012). This is essentially an estimate of the total biomass produced per year and is a sub-county measure equivalent to total sequestration. NPP has in fact been used by other researchers in variations of the EF Method (Haberl et al. 2004) and has been proposed as one method of estimating humanities appropriation of the products of photosynthesis (Haberl 1997). Therefore, there is a precedent to the use of this dataset in the literature for biomass accumulation and the source of this dataset is very robust being a multi-year NASA funded project.

4.2.1.12.3 Food Demand and Capacity

The EF applied a food analysis, but it's based on yield and equivalence factors so the authors could compare nations (Lazarus et al. 2014). This is a good strategy for national comparisons, but for sub national or county-wide footprints, there is simply too much diversity in production capacity across the USA to use this method. Luck and Generette (Luck et al. 2001) utilized a calories-based assessment in production capacity and demand, but this does not break down the production into food groups and the reality is that some counties produce more calories than the population demands, but it may all only be in grain and therefore the method is not sensitive enough to the realities of monocrop production in the USA. Therefore, a new method was developed specifically for counties in the USA to estimate food production. The method uses the US Agricultural Census NASS database, which is a material flow based production record of fruits, vegetables, grains, dairy, livestock and aquiculture harvests reported annually at the county-wide basis (United States Department of Agriculture 2012b). This database is utilized to estimate the production capacity per year in tons and is categorized into USDA "My Plate" recommended 5 food groups of fruit, vegetables, dairy, grains and protein to compare it with demand (United States Department of Agriculture 2012).

Inversely, the total demand of each county for food group items in tons was calculated using the USDA my plate daily servings estimate for adults in a bottom up per capita approach. The NDI between capacity and demand is calculated for each of the 5 food groups and then plotted on the vertical waveform. This method uses no equivalence factors and the few assumptions that are necessary (such as estimated live weight versus dressed weight of livestock and poultry; conversion ratios from tons to gallons; annual egg production of chickens; a handful of yield per acre values) are derived from University-based agricultural extensions to ensure that the most regionally accurate assumptions are used.

The benefit to this approach is that it illuminates the comparative advantages in agricultural production that have characterized the industrial agricultural systems of the USA by identifying regions which focus on production of only one or two categories of the USDA my plate recommended daily food intake. The implicit understanding in this approach is that counties which cannot produce certain categories or sufficient quantity of food groups to meet demand must rely on import of this deficit from regional sources or from national or global food networks. The utilization of national or global networks for food increases the food miles per capita embodied within basic food resources (and per urban metabolism when scaled up per capita) (Weber, Matthews 2008), which in-turn acts as an increased transport fuel demand and corresponding greenhouse gas emission which can affect climate change and I argue is an un-necessary burden. In addition, the reliance of populations on global networks for basic resources may force some communities to accept inferior quality foods (especially fruits and vegetables) simply because the proper food infrastructure investments were not made, which could be considered a social injustice and could give a true ecological perspective to the somewhat misleading idea of food deserts (Beaulac et al. 2009), which really only addresses location of retailers as opposed to a lack of underlying bioproductivity.

The drawback to this approach is that it only works for the USA and that the summarization of the USDA NASS database must be consistently applied across all counties to be effective. In addition, this method breaks from the well-established EF biocapacity assessment utilizing direct tons of food without equivalence or yield factors and is accommodated by the direct material flow unit approach in lieu of the land area approach. However, it allows for a more accurate picture of inter-regional food demand and capacity to emerge within the USA, a picture based on quantity of biomass produced and compared to per capita standard summaries of daily consumption by food group for the county population. Equivalency factors and yield factors could still be derived from the NASS data to estimate a ‘footprint’ in accordance with the current EF Standards (Lazarus et al. 2014) which can be compared on a county to county basis to quantitatively determine if the direct food tons approach is more sensitive than national level yield factors (Federal Environment Agency of Germany 2007, p. 47) (Kitzes 2009, p. 1994). However, such a comparison is outside of the scope of this study.

4.2.1.13 Creation of the Vertical Waveform Diagram for a County

The summary of all analyzed components in each county is created in a three-step process where first the directionality of the relationship between capacity and demand is defined for each factor, then a normalized difference index is calculated for each factor (called the NDI value) and finally the values are plotted sequentially by category as a vertical bar graph with a 6^{th} order polynomial regression trend line overlain on the bar graph. All together the vertical bar graph and parabolic trend line are called the “vertical waveform diagram” or VWD. The VWD captures the existing condition, balance and relationship between the six categories in the diagnostic, essentially boiling down all the analysis with different units into a single infographic measured in a unit-less statistical ratio so that the VWD can be categorized and compared to other counties. The bar graphs for each NDI factor are included under the trend line because the application of the polynomial trend line for all 19 factors finds a best fit for the NDI values regardless of factor category, thus the trend line is a mathematical interpretation of all values independent of categories; this means that the regression trend line cuts across categories so that NDI values from one category can influence the trend line shape and intensity of another category.

The concept of a graphical / statistical diagram to represent the condition or interconnection of factors in the landscape is not a new idea. The idea of a “landscape signature” has been proposed by Alberti (Alberti 2007, p. 93), where form, density, heterogeneity and connectivity are analyzed across a gradient of land-use types from rural to urban using a number of spatial equations (Alberti 2007, p. 114). Each land-use type then has a parabolic signature which can be defined when land cover types and percentages are plotted against each other on an axis. In addition to a landscape signature, Forman developed spatial comparisons for 38 urban regions across the world and compared their spatial, demographic, locational and land cover characteristics in a series of quantitative and descriptive statistics (Forman 2008, p. 113). Forman goes on to derive a typology of urbanization (models) from the case study comparisons, including centric-rings models, satellite-cities model, transportation corridors model and dispersed sites model. However, similar to the Alberti study, material flows are not addressed and thus the important dimension of urban material flows and human system / ecoregion system relationship is not directly assessed.

Step 1: Directionality

Since the method returns single values for material flows of capacity and demand, the direction of the waveform is determined by the larger value. This can be mathematically represented by a simple greater than less than expression below (Equation 1).

$$Direction = Capacity \text{ IF } Capacity > Demand$$

$$Direction = Demand \text{ IF } Capacity < Demand$$

Equation 1: Greater than Less than Expression of Directionality

Step 2: the NDI

Calculate the normalized difference index (NDI) where the numerator of capacity minus demand is divided by the denominator of capacity plus demand (Equation 2). The results of the NDI are from 1.00 to negative 1.00, where positive 1.00 is an overwhelming abundance of capacity compared to demand and negative 1.00 is an overwhelming demand compared to capacity. The quartiles of 0.25, 0.5, 0.75 and 1 are described as weak, moderate, strong and exponential respectively with zero (0) described as balanced (Equation 2). The NDI is based on the NDVI calculation (Rouse 1973).

$$NDI = \frac{(capacity - demand)}{(capacity + \ demand)}$$

Where:

$$Capacity = Decimal\ value\ calculated\ from\ Methodology$$

$$Demand = Decimal\ value\ calculated\ from\ Methodology$$

Equation 2: Calculation of the Normalized Difference Index (NDI)

Step 3: Create the Vertical Waveform

To plot the vertical waveform, the NDI data for all factors is calculated and graphed on a vertical bar chart in excel with positive 1 on the right and negative 1 on the left. The NDI values are plotted for each factor and labeled. To simplify the creation of the vertical waveform diagram the polynomial trend line with six orders is plotted over the individual NDI values. The selection of six orders results in vertical waveform with six curves where each curve indicates the magnitude and directionality of approximately every three NDI values (specifically every 3.16 NDI values), resulting in a smooth line that can be easily compared by county (Figure 4-13).

The benefit to this method is that 1) all 19 factors are used to create the vertical waveform 2) no resolution is lost from collapsing NDI values by category 3) the vertical waveform is easily created in Excel where the NDI values are plotted 4) the resulting waveform simply conveys the differences between all NDI values within a county and between counties. The drawback to this method is that 1) the waveform and the NDI values do not always graphically coincide since the polynomial regression equation is a best fit without respect to the County Diagnostic categories and 2) rearranging the order of the categories in the vertical bar graph will change the shape of the waveform. Given the drawbacks, users should understand that the vertical waveform is a way to simply explain the general pattern amongst all NDI values and that individual balances should be interpreted using the NDI values represented by the bar graph.

The use of the NDI as comparative final value may seem counter- intuitive considering the unit specific approach of the method; however, it is exactly the NDI value which allows for the comparison between components with vastly different values, essentially normalizing the waveform into quartile deviations so all component results are visible and comparable, while also retaining their underlying differences in material units and type.

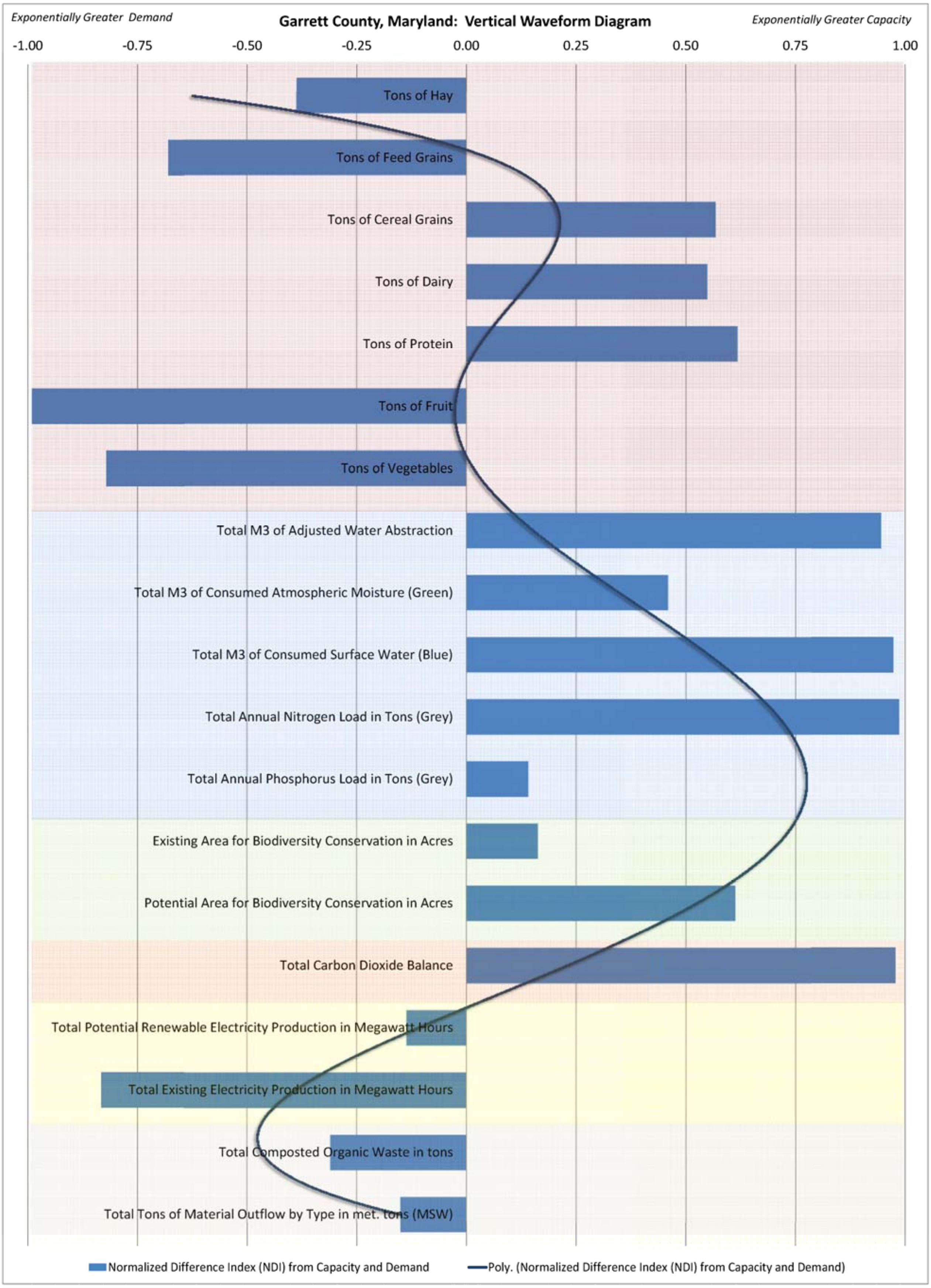


Figure 4-13: Example Vertical Waveform for Garrett County, Maryland with Each NDI Factor Graphed Individually and the Six Category Polynomial Plotted Above the NDI Values.

4.2.2 Part 2: The Quantitative Case Study Comparison and Site Selection Process

Using the County Diagnostic method as described above and refined from the case study, a project has been designed to evaluate similar sized counties with similar populations distributed in different ecoregion units across the USA to isolate and quantify how ecoregions affect County Diagnostic results. This research design configuration allows for assessment of the macro-material flows of energy, food, water, emissions and organic material annually demanded from human systems and ecosystems in equal area and equal population county units and evaluates the demand against natural variations of biocapacity within and between ecoregion levels and level sub-divisions. This balance of capacity and demand effects the potential for regional subsistence and low entropy dissipative structures (Johnson 1981; Pulselli et al. 2006) as well as a counties' reliance on distributed networks for life-goods and resilience to change of distribution networks or climate. In the big picture, this project will provide insight to the potential and roadblocks of restructuring counties in the United States towards semi-circular flow metabolism frameworks, which in-turn would reduce EF of the nation.

Conceptually, the case study pulls from both Forman's multiple case study approach of regions by employing a quantitative multiple case study research design approach and from Alberti's signature by graphically and conceptually employing the concept of 'waveform' as a representation of distinct patterns. However, by assessing the quantitative comparison of unit specific and spatially explicit material flows together the diagnostic approach derives a different summary assessment than Forman's because the quantitative capacity and demand framework evaluates counties or regions in terms of probable cost to attain balance or minimize perturbations at a jurisdictional level which can legally organize capital improvements, create policy, and develop planning targets or capital improvement plans. The use of the waveform to represent a unique capacity and demand 'signature' echo the "landscape signature'' concept but substitutes material flow balance for land cover and urbanization relationships. However, the vertical waveform in the County Diagnostic is used as a way to represent the distance from relative homeostasis in standard deviations for each component (Figure 4-13), where a single vertical line with no perturbations toward capacity or demand would indicate an equilibrium or balance in the components, and thereby indicating that the county analyzed could achieve a semi-circular metabolism. In this sense, the case study section is a proof of concept of the County Diagnostic section.

Methodologically, the case study is comparative and exploratory in the sense that it seeks to understand the phenemona of real-world flows and balances between different limited geographic areas (Yin 2011; Tellis 1997). The case study area is narrowed to the Eastern Temperate Forest because that is where most of the US population lives and the greatest number of equal area counties exist, then the case selection parameters are further narrowed to counties contained completely by Ecoregion level II units within the ETF and then more further narrowed to the most common area and population size counties (calculated out of all 3,177 counties) across the USA to maximize the number of counties for which the results might be representative. After the above three parameters are met, a group of cases with the least deviation away from the USA-wide mode population and county area were selected. The number of cases which could be completed within the time limit of the study precluded any statistically valid sampling methodology, as that would have resulted in hundreds of cases. Even with a small number of cases, some descriptive and inferential statistics are still valid and are applied in this study to shed light on the research questions and lay down a template for future studies which could employ a sampling methodology.

4.2.2.1 Justification of Counties as the Analysis Unit

The complexity, diversity, and inconsistency of sub-county legal and jurisdictional boundaries across the USA as described above makes Incorporated places, MCD's and Town/Townships non-ideal analysis unit choices for large scale geographic case study comparisons. Additionally, data sources and consistency vary between these three legal entities which could make consistent comparisons difficult when data is present for one unit but not for another. Counties, on the other hand, are consistent across the entire USA, generally include urbanized land and a surrounding hinterland, are legally and jurisdictionally capable of organizing infrastructure systems between Incorporated Places, Towns/Townships, and MCD's within a county boundary, and have government datasets consistently available across the wide range of topics covered in this study. Therefore, I believe that counties are the best analysis unit to select for this research design.

This analysis returns to one of the central questions in geography, carrying capacity, to characterize counties in terms of regional subsistence potential which simultaneously defines the reliance on import of basic life goods from other counties, regions or markets. I am not suggesting that counties should all be self-sufficient; rather I am acknowledging that counties often contain multiple small cities and can be used as a legal entity to organize or restructure infrastructure networks between cities within the county or between counties in the case of larger regions. Data sources at the county level ensure a greater degree of heterogeneity between case study comparison sites than state or national level datasets used in the EF method (Global Footprint Network 2009) and other recent EF analysis variations (Wiedmann, Barrett 2010). The diagnostic approach consistently applied across the entire United States at the county level opens up a potential sub-field of EF research as 'intra-national footprinting,' where the goal is not to compare the global hectares per capita consumption between nations, but rather to quantify the spatially explicit material and energy specific fluxes within and between counties at a level of detail that can guide comprehensive planning.

4.2.2.2 Equal Area County Selection and Definition

In order to determine the effects of ecoregions on the potential for circular metabolism of counties, equal area and equal population counties need to be selected and isolated within different ecoregions to be compared against one another. However, counties of exactly the same area and population distributed in all different ecoregions do not exist in the USA. In addition, the distribution of county sizes in the USA varies widely, with a clear difference in county sizes east of the Rocky Mountains and Deserts, and west of them (Figure 4-14). Therefore, the study will rely on counties of 'similar size and population' as opposed to counties of exactly the same size and population. The definition of 'similar' is defined as counties with areas and populations that have a maximum spread of plus or minus 10% from the mean or mode area and population values. In the selection procedure, a group of similar sized area counties are identified first and then from that selection counties are grouped by population and compared against the ecoregion level II sub-units until an area and population combination results in a sample in each ecoregion sub-unit. This process can be utilized from ecoregion level I units to ecoregion level III units.

After trying variations of plus or minus 2% to 10% area and population from both the mean and the mode of the county area, the option of 10% from the mode was selected. While my initial expectation was that finding equal area counties in the USA would not be a problem, it turned out that the quantity and distribution of counties with an area of 5% or less area and population difference was quite low and/or was not widely geographically distributed. And while a selection of counties with area differences of plus or minus 10% resulted in a sufficient number of cases which were widely geographically distributed, the difference between cases could be up to 20% of the land area, which I felt was too great a difference for this study and could skew the ability of the case study comparison to accurately represent differences in biocapacity caused by ecoregions as compared to differences of biocapacity caused simply by a greater number of productive acres. Therefore, I chose to define 'similar area' counties as counties within 10% of the Clementini county pool mode. Using the mode (most common number) as opposed to the arithmetic mean (number in the middle of the distribution) was logical in this case because it reduced the influence of highly population counties on the statistical population count.

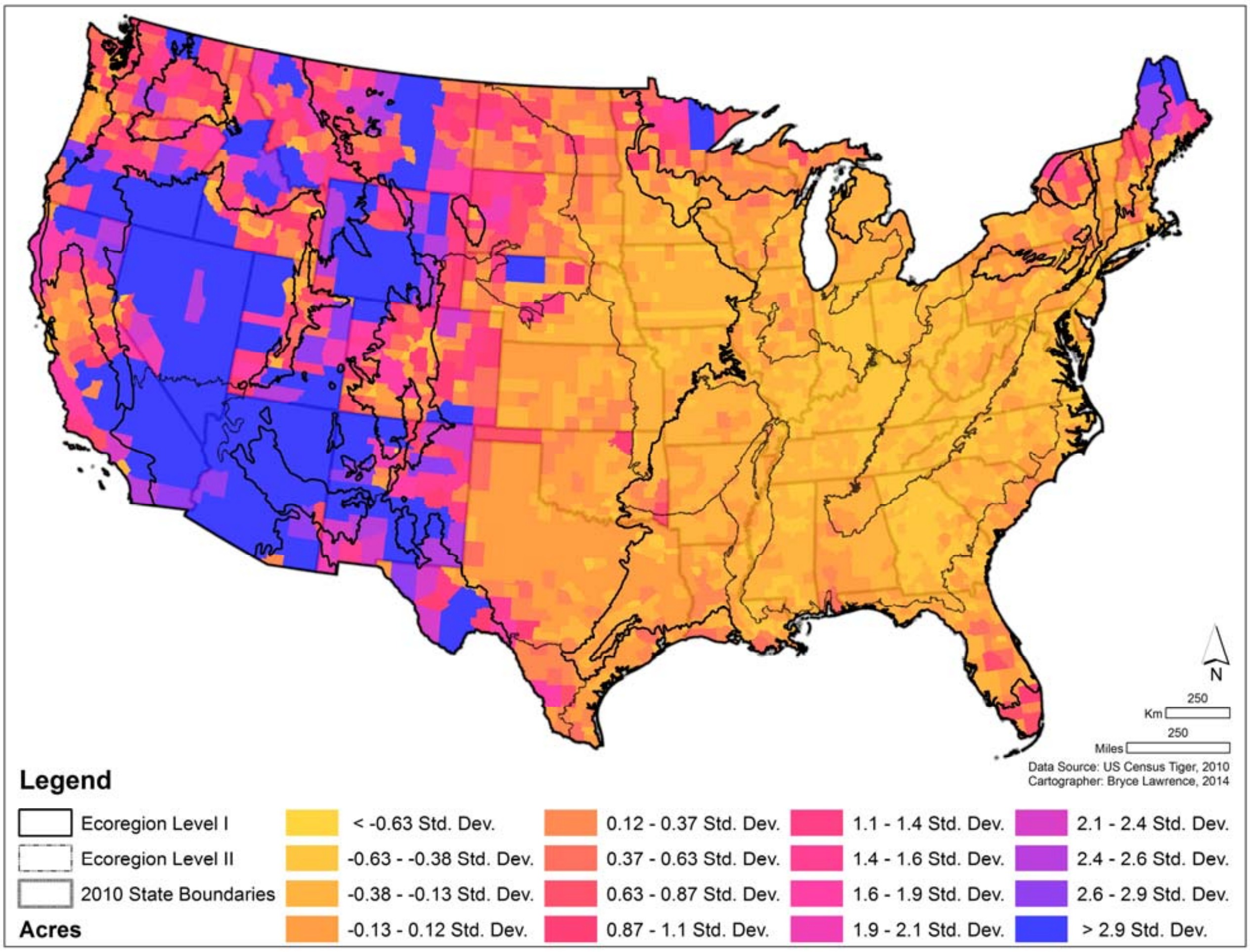


Figure 4-14: USA County Area Standard Deviation

4.2.2.3 Spatial Data Processing and Cleaning

The 2010 County boundary shapefile (US Census 2010) was clipped by the terrestrial boundary of the lower United States (not Alaska or Hawaii) to remove any county areas which extended over water and might skew the actual available land area (a situation which existed for counties adjacent to the great lakes where the county boundary extended over water to the middle of the adjacent water body, and to a lesser extent coastal counties). The clipped county shapefile was linked with the 2010 US Census housing and demographic DP1 database containing 2010 population (United States Census Bureau 2010) and acres were calculated for every county, effectively creating a cleaned county boundary database (n=3,109) with the total land area calculated in acres and the 2010 population total summarized by named counties.

A process of area and population outlier removal was conducted to narrow down the pool of potential cases. During initial investigations it was discovered that the extremely large size of counties west of the Rocky Mountains were skewing the average area when calculated for all counties in the USA, which resulted in relatively few counties of similar area distributed mainly across the American West in areas of low population. When area outliers were removed I found that a significantly greater number of equal area counties were detected and the center of equal area distribution shifted from the American West to the American Midwest and East Coast where a majority of population exists. This process made the identification of similar area counties much easier, but also effectively eliminated the analysis of large relatively unpopulated areas west of the Rocky Mountains. The outlier removal was not conducted to remove values that I could not explain, but rather to help identify the largest pool of equal area counties as possible. Therefore I do not feel that the application of outlier removal in this case is an example of scientific misconduct, but rather part of the “narrowing down” process which lead me to the final case study selections.

To conduct the outlier removal, the population and area linked county shapefile was exported as a .dbf table to SPSS, z-scores were computed for the area variable and outliers with a Z-score over 3 were removed. This processes was repeated a second time for area due to the wide range of county areas in the USA to further define the pool of relatively equal area counties available and reduce the standard deviation of area amongst all counties. With area outliers removed, a z-score analysis was conducted for the variable population and again any counties with a z-score greater than 3 were removed so as to eliminate counties with extremely high populations, which brought the maximum population by county amongst the pool down to 809, 858. Since the project was designed to assess counties less than 1 million in population then only one outlier removal step was necessary to bring the maximum population value down below the analysis target. The data cleaning described above resulted in a subset of counties in the USA (n=2,905) with mean acres of 468,992 and mean population of 67,447 (Figure 4-15, Figure 4-16).

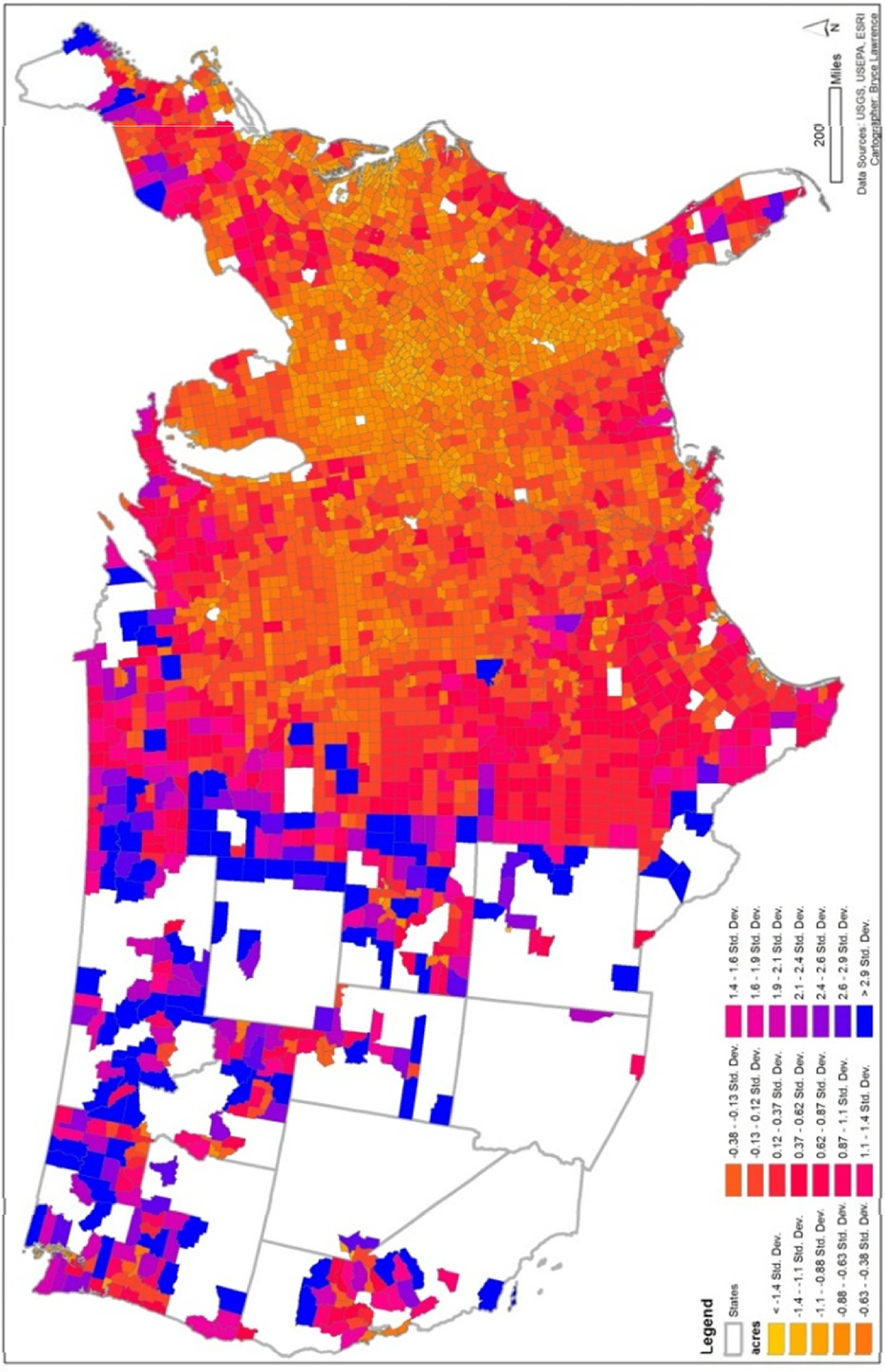


Figure 4-15: County Pool with Area and Population Outliers Removed (US Census 2010)

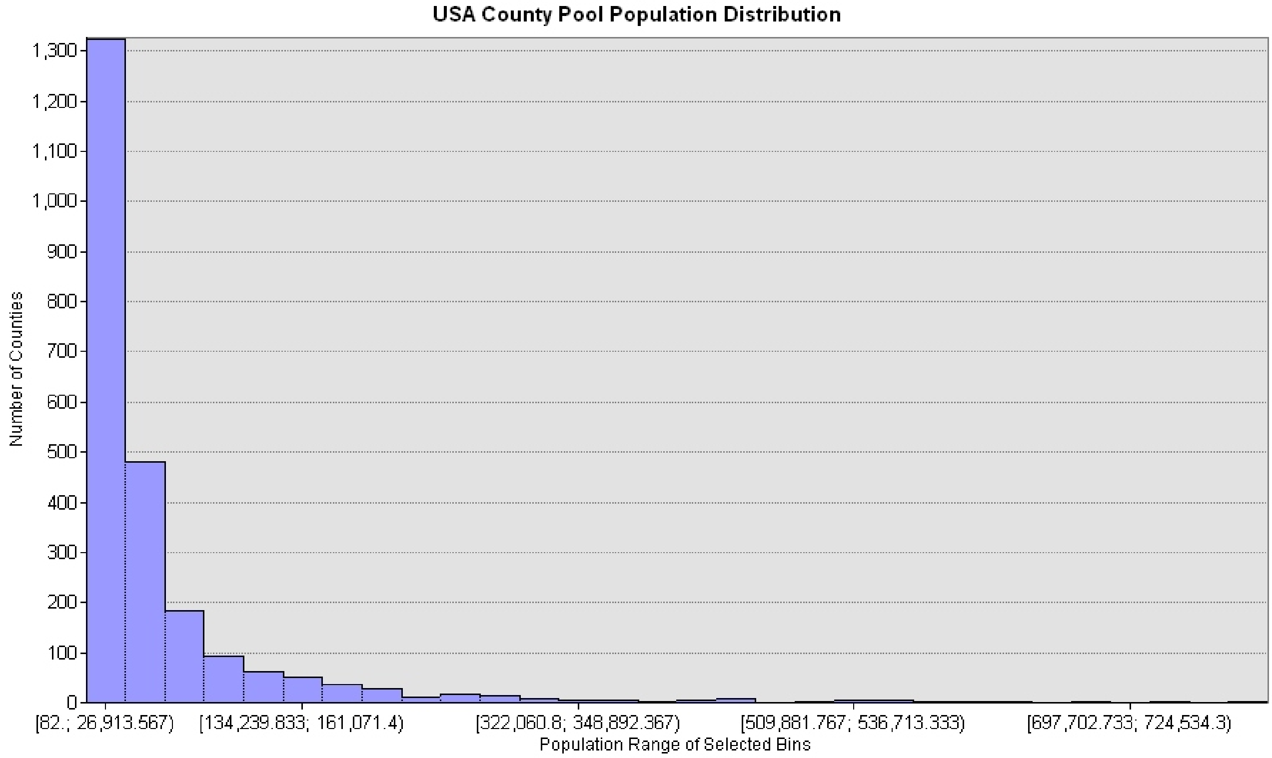


Figure 4-16: Cleaned USA County Pool Population Histogram

4.2.2.4 Clementini Selection and Ecoregion level I County Pool

To further prepare the county dataset for analysis, the USA county pool was cleaned using ArcGIS in a two-step process of selecting counties completely contained by an ecoregion and then visually inspecting the selection. In the first step, all counties from the USA county pool (Figure 4-15) were selected which were "completely within" the ecoregion level I boundary, meaning that counties did not contain more than one ecoregion I type. This selection found 2,204 county observations. This selection, however, did not select counties which shared a boundary with ecoregion level I but which for all intents and purposes were contained by the ecoregion and therefore are acceptable for this study, since 'sharing a boundary' does not constitute 'being within' another region.

This problem was addressed in the second step, where the 'completely within' selection was manually inspected and all counties which shared a boundary or digitization relic, but were not actually within another ecoregion, were added to the selected features. These additions included 312 counties to the selection and were mostly concentrated on the coasts and Canadian border where the county was just touching the boundary of the ecoregion and the 'completely within' tool could not distinguish between an edge boundary with no data on the other side and a boundary between ecoregion units. A handful of counties were added based on my personal judgment where it appeared that an extremely minimal line overlap occurred due to digitization errors or between physiographic regions where similar undulating lines representing rivers or mountain boundaries appeared to have been offset unintentionally just due to differences in the census 2010 counties dataset and the EPA ecoregions spatial dataset. In all the latter cases, I used the 2011 National Land Cover Dataset (Jin et al. 2011) to visually verify this decision. The total selection, referred to as the Ecoregion I county pool, has 2,375 observations with a mean area of 441,264 acres, a mode acreage of 585,908, a mean population of 54,056, and a mode population of 21,720 (Figure 4-17).

To further refine the county selection, the 20 largest metropolitan areas in the USA were removed as these areas have already been analyzed in Luck and Jenerette (2001). These areas are presented above in Figure 4-17.

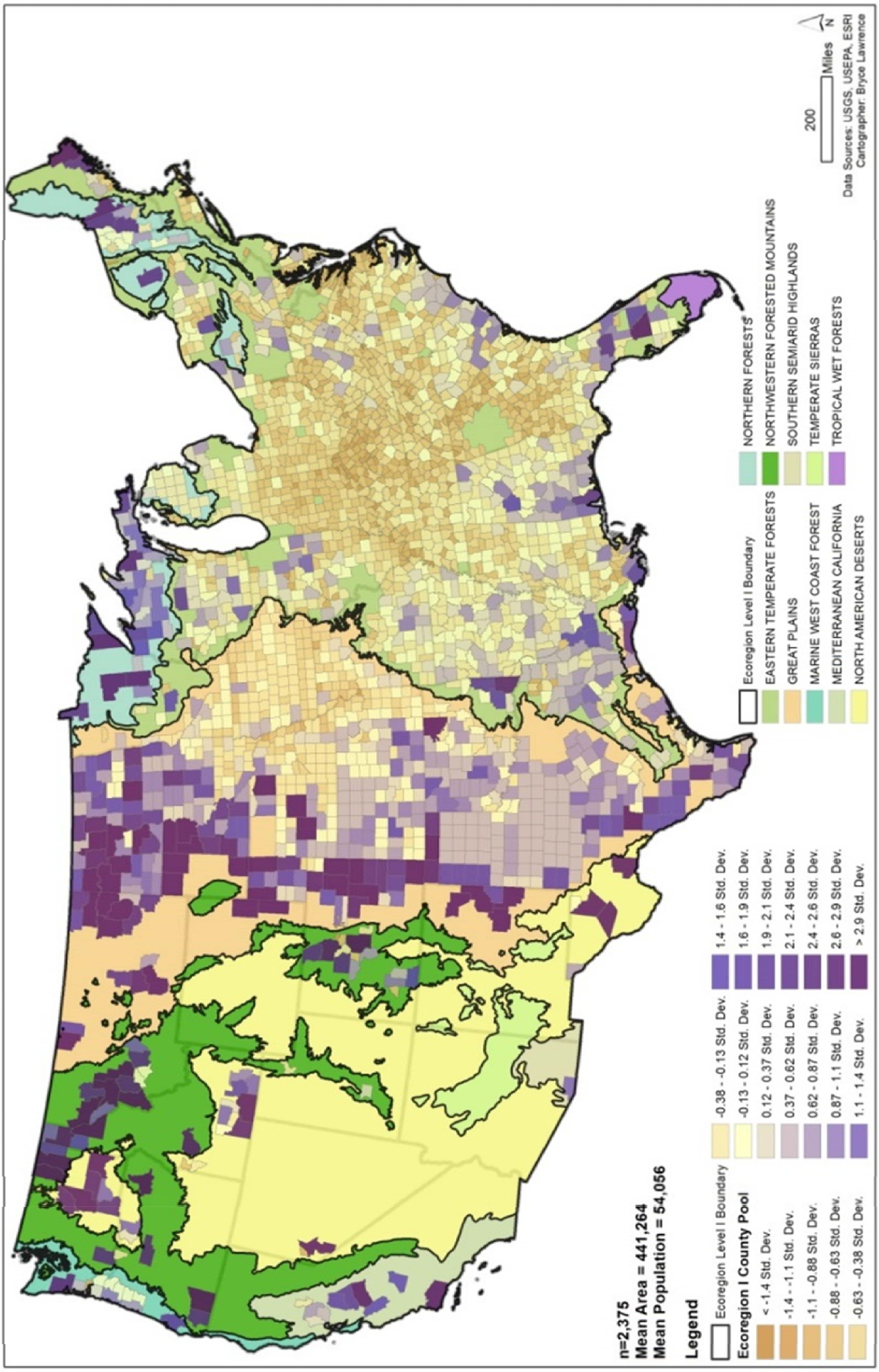


Figure 4-17: Ecoregion I County Pool

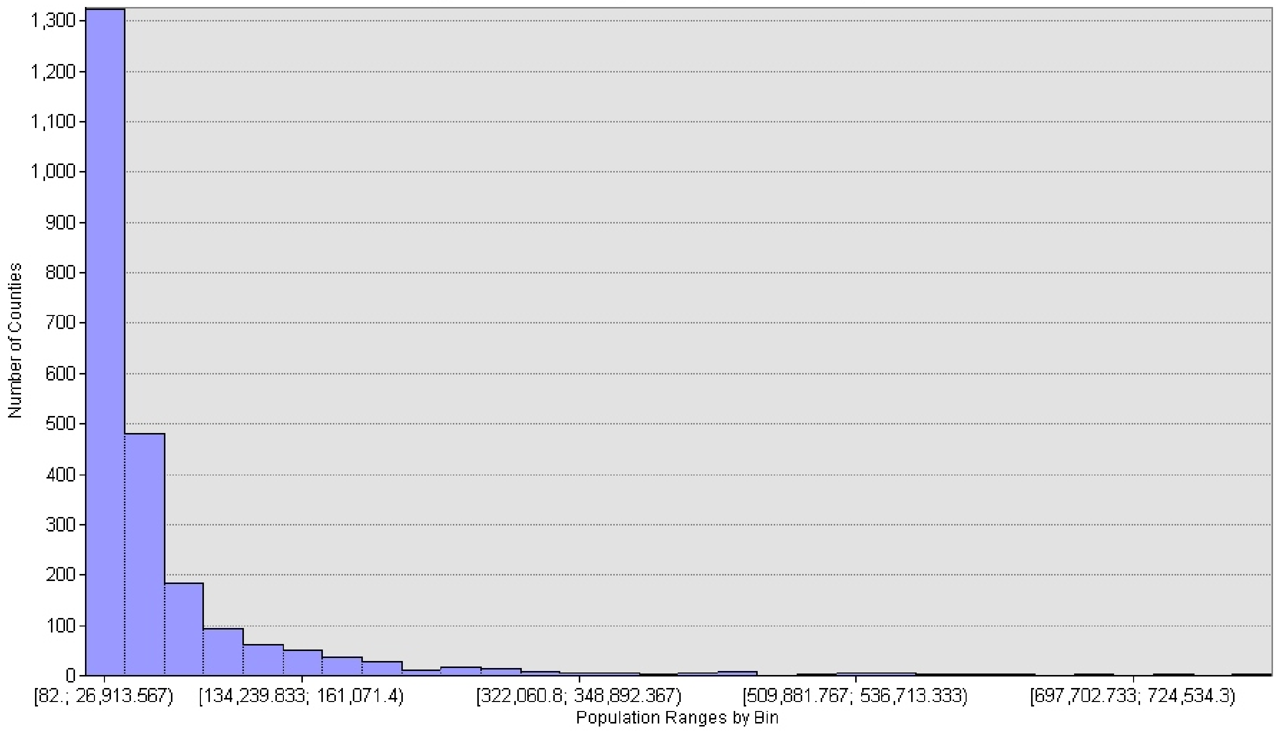


Figure 4-18: Ecoregion level I County Pool Population Histogram

4.2.2.5 Final Case Study Selection: Eastern Temperate Forest Level II

The population distribution results in section 3.8.3 and the expansion of eastern temperate forest ecoregion discussed in section 3.7.3 support the decision to focus this study on the different ecoregion level II units of the Eastern Temperate Forest ecoregion I level outlined in Figure 4-21 because this is the ecoregion which will expand with climate change this century and must support the largest population, therefore understanding the circular metabolism potential within this ecoregion's sub-units will help create a framework for climate change adaptation and resilience measures which will likely be needed over the long-term planning horizon.

Utilizing the ecoregion I county pool as a starting point the dataset was reduced to only the Eastern Temperate Forest Ecoregion and a Clementini area selection (section 4.2.2.4) was used to eliminate counties which contained more than one ecoregion level II unit. The population for the new selection, referred to as the 'ecoregion level II county pool (Figure 4-19),' was re-tabulated with a mean population of 62,395, a population mode of 27,721 and a mean area of 332,647.

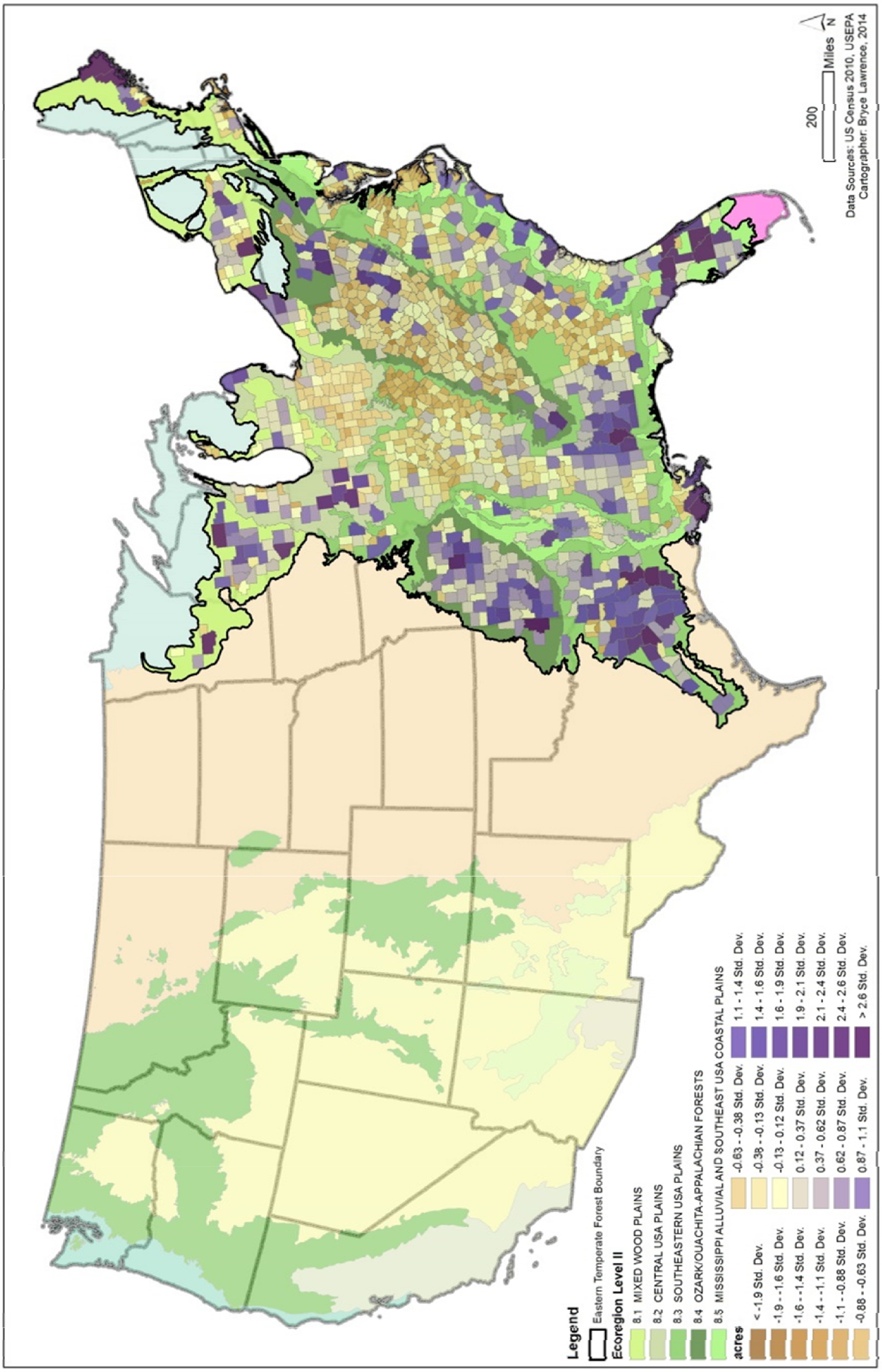


Figure 4-19: Ecoregion level II County Pool

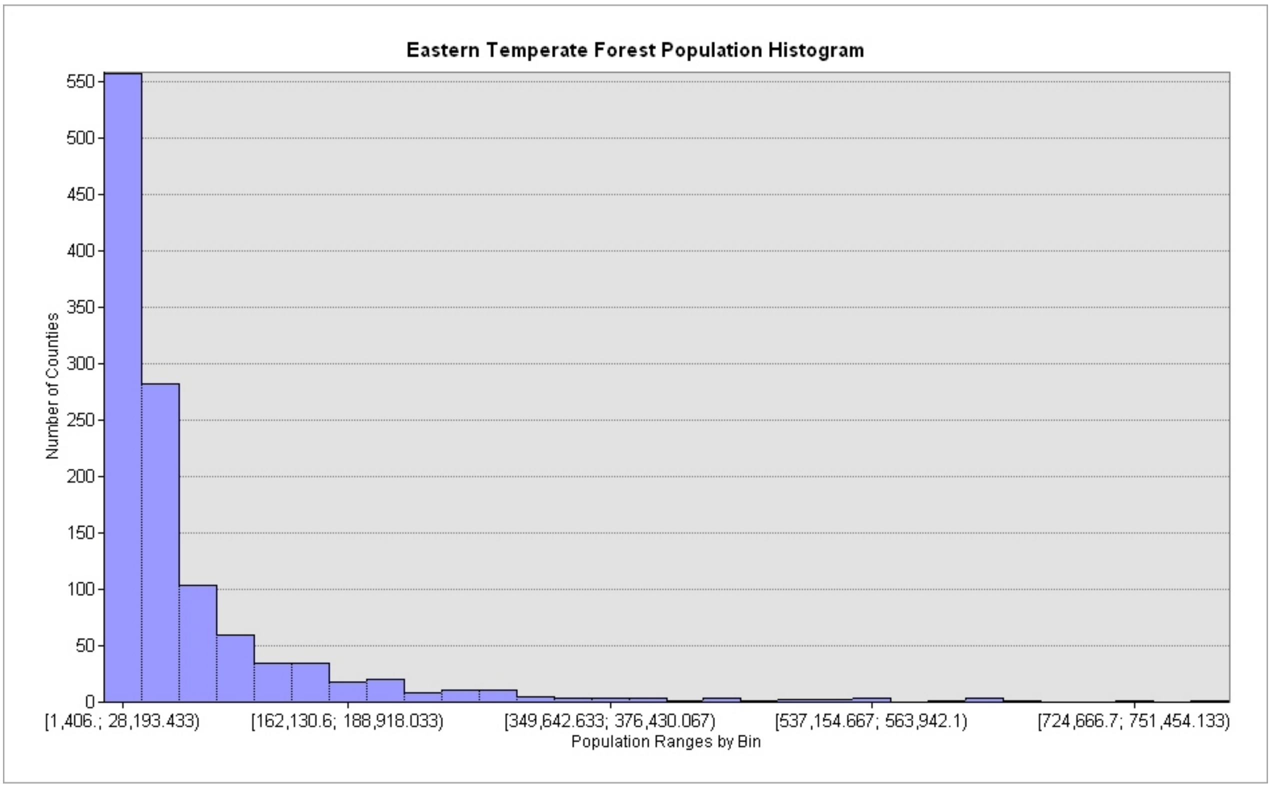


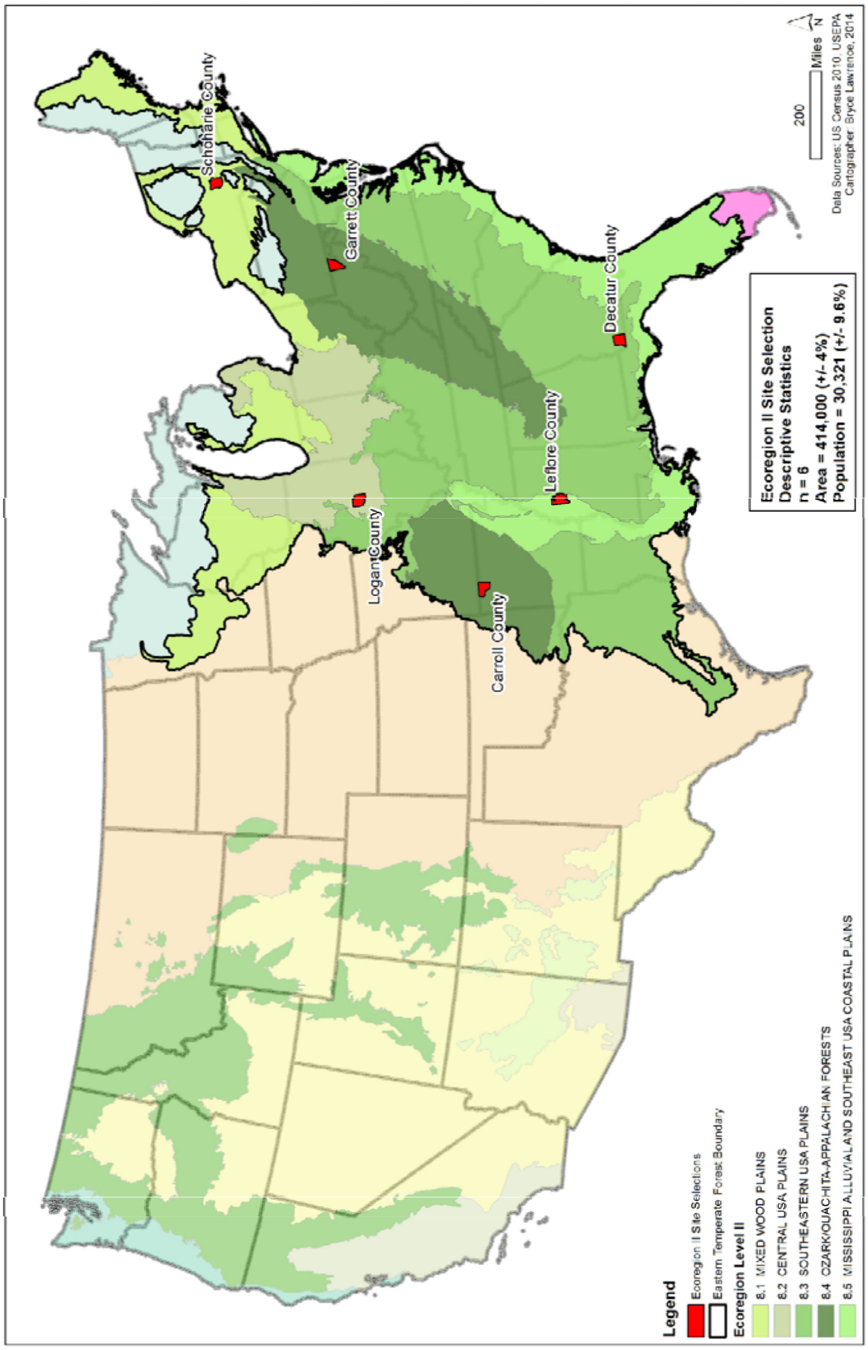
Figure 4-20: Eastern Temperate Forest Population Histogram

Using the county selection method described in section 4.2.2.2 and starting with the mode population value of the Eastern Temperate Forest (27,721), increments were tested by 1% above and below the mode until arriving at a value in which a case study site appears in each level II sub-unit (pop. 30,321). The strategy of utilizing the same area but different populations keeps the ecoregion level analysis pools similar in area so that the effects of can be compared in the statistical analysis of results. The formula for the ecoregion level II site selection is presented below in Equation 3.

"acres" >=(414000*.9) AND "acres" <=(414000*1.1) AND "DP0010001" >=(30321*.9) AND "DP0010001" <=(30321*1.1)

Equation 3: Level II Site Selection Parameters

The case study selection methodology for ecoregion level II yielded 14 potential sites and one site in every ecoregion level II sub-division. This selection is reduced to only 6 sites by choosing the sites with the smallest area and population spread of +/- 4% and +/- 9.6% respectively (Figure 4-21).



Ecoregion Level II Site Selections

County Name	Population	Acres	Ecoregion Level I	Ecoregion Level II	Ecoregion Level III
Carroll County	27,446	408,832	8 EASTERN TEMPERATE FORESTS	8.4 OZARK/OUACHITA-APPALACHIAN FORESTS	8.4.5 Ozark Highlands
Garrett County	30,097	419,672	8 EASTERN TEMPERATE FORESTS	8.4 OZARK/OUACHITA-APPALACHIAN FORESTS	8.4.1 Ridge and Valley
Logan County	30,305	396,113	8 EASTERN TEMPERATE FORESTS	8.2 CENTRAL USA PLAINS	8.2.3 Central Corn Belt Plains
Schoharie County	32,749	400,850	8 EASTERN TEMPERATE FORESTS	8.1 MIXED WOOD PLAINS	8.1.3 Northern Allegheny Plateau
Leflore County	32,317	388,083	8 EASTERN TEMPERATE FORESTS	8.5 MISSISSIPPI ALLUVIAL AND SOUTHEAST USA COASTAL PLAINS	8.5.2 Mississippi Alluvial Plain
Decatur County	27,842	398,827	8 EASTERN TEMPERATE FORESTS	8.3 SOUTHEASTERN USA PLAINS	8.3.5 Southeastern Plains

Figure 4-21: Final Case Selection Based on an Exploratory Case Study Method with Cases Completely (Clementini) Contained by Ecoregion Level II Units and Variance of Area and Population Across Cases Minimized

4.2.2.6 Case Study Evaluation

This section evaluates the overall satisfactory nature and robustness of the County Diagnostic to answer the main research questions (section 4.1) by analyzing the vertical waveform, specific factor results and descriptive statistical differences between cases. This section supports the discussion in section 7 about how the County Diagnostic contributes to sub-regional environmental footprint to help the USA trend towards circular metabolism at the regional level.

4.2.2.6.1 Conclusions and Interpretation for Each County Case Study

The NDI factor summary sheet, vertical waveform diagrams and a supporting data appendix (with all supporting graphs, tables and maps) is used to support written results for each factor in each county, with a discussion or interpretation of why the vertical waveform takes the shape it does and what that means in regards to the idea of a material flow or capacity and demand balance for a county. The mixing of results and discussion in Chapter 6 serves the purpose of tying together specific factor formulas, data and the analysis outcomes to support a discussion of the effect of each formula on the specific outcomes in each county independent of the broader discussion of how the research design answered the overall project research questions.

4.2.2.6.2 Conclusions across Counties with the Vertical Waveform Diagram

All NDI values will be graphed together and all vertical waveforms diagrams (VWDs) overlaid to visualize the differences between counties. A categorical discussion of the differences between waveforms and counties summarizes the use of the VWD to discern fundamental differences between counties and acts as a comparative baseline for the descriptive and inferential statistical analysis.

4.2.2.6.3 Conclusions across Counties using Statistics

Descriptive statistics of all NDI values will include frequency statistics, boxplots, histograms to determine the distribution and shape of NDI variable distribution between counties to address the second research question: How does ecoregion affect the County Diagnostic results?

4.2.2.6.3.1 Kolmogorov-Smirnov Test for Normality

The Kolmogorov-Smirnov (K-S) is an alternative chi-square used for testing the similarity between frequency distributions, which in this case follows up the histograms to determine if the NDI value frequency distributions between each county are normally or non-normally distributed (Field 2013, p. 185; McGrew, Monroe 2000, p. 156). The K-S test compares a cumulative relative frequency and differences, D, (Equation 4) and converted to a Z-value, where $Z > 0$ signifies values greater than the mean; $Z = 0$ signifies values equal to the mean and $Z < 0$ signifies values below the mean, in the p-value approach (McGrew, Monroe 2000, p. 157). In the p-value approach of the K-S test the null hypothesis that all cases are the same can be rejected if the p-value is below .05 (denoting significant difference).

$$D = maximum\ |CRF_0\ (X) - \ CRF_e\ (X)|$$

Where:

$CRF_0\ (X)$ *= Cumulative relative frequencies (observed) for variable X*

$CRF_e\ (X)$ *= Cumulative relative frequencies (expected) for variable X*

Equation 4: Calculation of the K-S Test Statistic (D), the Maximum Absolute Difference.

The discovery of differences in NDI distribution between the six cases could indicate the influence of ecoregion on NDI values, addressing the second research question. To help understand the K-S results, P-P plots of Z scores for each county are plotted so that the frequency distributions can be visualized (Vali et al. 2005, p. 183).

4.2.2.6.3.2 Friedman's ANOVA

Friedman's ANOVA is a ranked data test that determines if the mean NDI value between counties is significantly different, indicated by a *p-value* of less than 0.05. The Friedman's ANOVA test statistic [F_r] is calculated in Equation 5 below (Field 2013, p. 251-2). The null hypothesis is that mean values between cases are all the same since they all come from the Eastern Temperate Forest Ecoregion, which would be indicated by *p-values* over 0.05. If any of the counties analyzed in the Friedman' ANOVA indicate a significant *p-value* below 0.05 it could be attributed to differences explained by the ecoregion level II sub-division.

$$F_r = \left[\frac{12}{Nk\ (k+1)} \sum_{i=1}^{k} R_i^2\right] - 3N(k+1)$$

Where:

R_i^2*= The sum of ranks for each group*

N = is the total sample size

k = the number of conditions

Equation 5: Formula for Friedman's ANOVA

4.2.2.6.3.3 Spearman's Rank-Order Correlation

The Spearman's Rank-Order correlation (McGrew, JR., Monroe 2000) analysis is used to determine if correlations exist between different NDI factors. The Spearman's Correlation is well suited for the data set since it is non-parametric. The assumptions are listed below (Laerd Statistics 2014; Field 2013, p. 274):

1) Random sample of paired variables
2) Two values which are ordinal, interval or ratio (in this case they will be interval / interval or interval / ordinal combinations)
3) There is a monotonic relationship between variables (either increasing or decreasing)

The formula for Spearman's Rho (r_s) is presented in Equation 6 below (Field 2013, p. 276; Gruehn 2003, p. 103).

$$r_{s} = 1 - \frac{6 * \sum_{i=1}^{n} d_i^2}{n(n^2 - 1)}$$

Where:

r_s = the overall value or rank

d^2 = the difference between ranks of variables calculated as $d_{i=} |x_i - y_i|$ with variables x and y

n= the number of samples

Equation 6: Formula for Spearman's Rho (r_s)

The results of the Spearman's Rank-Order correlation in r_s is between -1 and +1 where the nearer to value 1 indicates a strong correlation and the nearer to 0 the weaker the correlation, with positive values indicating that when one value increases the other increase and a negative value indicating an inverse relationship where the increase of one value results in the decrease of another value (Field 2013 p. 267). The strength of values is categorized where values below 0.2 indicate a very low correlation; values between 0.21 and 0.5 indicate a low correlation; values between 0.51 and 0.7 indicate a moderate correlation; values between 0.71 and 0.9 indicate a high correlation and values over 0.9 indicate a very high correlation (Bühl 2012, p. 420).

4.2.2.6.3.4 Categorical Principal Component Analysis

The NDI values can be analyzed further with a categorical principal component analysis (CatPCA). The CatPCA is a variable reduction technique with the aim to reduce larger sets of variables into smaller artificial variables called 'principal components' which account for the variability amongst all of the original variables (Laerd Statistics 2013; Field 2013, p.673). The CatPCA is well suited for analyzing the County Diagnostic because it meets the 5 assumptions:

1. Multiple continuous level variables (ratio or interval)
2. A linear relationship between variables is preferred, which is determined by the Pearson correlation coefficients
3. Sampling adequacy: Laerd (Laerd Statistics 2013) recommends 5 to 10 cases per factor
4. The data should be suitable for reduction (factors may need to be transformed)
5. No significant outliers

The CatPCA is reported as Cronbach's Alpha (α) which describes the degrees of variance within a dataset reported in a value ranging from 0 to 1, where 0 indicates no correlation between values and 1 indicates a perfect correlation between all values. The Cronbach's alpha can be described as a measure of internal consistency calculated in Equation 7 below (Cronbach 1951, p. 299), where levels of internal consistency are rated as unacceptable below 0.5; poor between 0.51 and 0.6; questionable between 0.61 and 0.7; acceptable between 0.71 and 0.8; good between 0.81 and 0.9 and excellent over 0.9 (George, Mallery 2003). When α is calculated for a dataset the internal measures of consistency of that data is what is being described, and that measure of internal consistency is based on eigenvectors and eigenvalues, where eigenvectors describe the shape of the data when plotted on a Cartesian plain and eigenvalues describe the length of a vector from the central distribution of the data. When a dataset has multiple eigenvectors that do not have a perfect central distribution then an eigenvalue with a corresponding α above 0.5 indicates that the distance or clustering of a group of values away from perfect central distribution has resulted in a new dimension (Field 2013, p. 343-344). Dimensions in a CatPCA indicate an external condition which explains why values correlate and may or may not relate to any specific categories or factors within the data, rather, these dimension must be interpreted using the reported 'component loading table' of each r_s value by variable and dimension. When eigenvalues amongst a certain number of dimensions account for almost all of the data values, then the total variance of the dataset is explained as a percent of variance and one can reasonably assume that further dimensions would not further explain the internal consistency or heterogeneity between all values (Field 2013, p. 666-682).

$$\alpha = \frac{n}{n-1}\left(1 - \frac{\sum_i V_i}{V_t}\right)$$

Where:

n = The number of items (test scores)

V_t*= The variance of test scores*

V_i *= The variance of item scores after weighting*

Equation 7: Calculation of Cronbach's Alpha (α)

The CatPCA analysis in this study is valuable because it can provide insight into overarching conditions, such as different ecoregions or political affluence, which might have an effect on the total NDI value distribution. This 'dimensional insight' is an abstract and conceptual approach to understanding central salient conditions which drive the underlying factor balances or VWD in a county.

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5 Methods and Data Sources

All data is collected via the internet or has been compiled from published research sources. No field studies are conducted in the preparation of this analysis. Quantitative data from each component is summarized on a standardized data sheet as capacity and demand in tons of specified materials so the data set can be imported into SPSS, Excel, or ArcGIS for analysis. A data collection template called the NDI Factor Summary Sheet (Table 5-1: NDI Factor Summary SheetTable 5-1) is utilized to keep all summarized integer values in one place and ascribed with a numeric identifier (ie, F1c or W1d), which are then fed into their respective NDI formulas.

ASD FACTOR SUMMARY SHEET							
	CAPACITY		Decimal Value	Decimal Value		DEMAND	
FOOD	Tons of Hay	F1c			F1d	Tons of Hay	FOOD
FOOD	Tons of Feed Grains	F2c			F2d	Tons of Feed Grains	FOOD
FOOD	Tons of Cereal Grains	F3c			F3d	Tons of Cereal Grains	FOOD
FOOD	Tons of Dairy	F4c			F4d	Tons of Dairy	FOOD
FOOD	Tons of Protein	F5c			F5d	Tons of Protein	FOOD
FOOD	Tons of Fruit	F6c			F6d	Tons of Fruit	FOOD
FOOD	Tons of Vegetables	F7c			F7d	Tons of Vegetables	FOOD
WATER	Total Available M^3 of Stream Flow	W1c			W1d	Total M^3 of Adjusted Abstraction	WATER
WATER	Total M^3 of Available Atmospheric Moisture (Green)	W2c			W2d	Total M^3 of Consumed Atmospheric Moisture (Green)	WATER
WATER	Total Available M^3 of Surface Runoff (Blue)	W3c			W3d	Total M^3 of Consumed Surface Water (Blue)	WATER
WATER	Critical Annual Nitrogen Load in Tons (Grey)	W4c			W4d	Total Annual Nitrogen Load in Tons (Grey)	WATER
WATER	Critical Annual Phosphorus Load in Tons (Grey)	W5c			W5d	Total Annual Phosphorus Load in Tons (Grey)	WATER
ELECTRICITY	Total Potential Renewable Electricity in Megawatt Hours	E1c			E1d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
ELECTRICITY	Total Existing Electricity Production in Megawatt Hours	E2c			E2d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
CO_2	Total Carbon Sequestration Potential in Tons	C1c			C1d	Total Carbon Dioxide Emissions in Tons	CO_2
MATERIALS	Total Potential Compost Application Load in Tons	M1c			M1d	Total Composted Organic Waste in Tons	MATERIALS
MATERIALS	Recycling Capacity by Material Type	M2c			M2d	Total Tons of Material Outflow by Type (MSW)	MATERIALS
ECOSYSTEM CONSERVATION	Total Existing Area of Conservation in Acres	EC1c			EC1d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
ECOSYSTEM CONSERVATION	Total Potential Area of Conservation in Acres	EC2c			EC2d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION

Table 5-1: NDI Factor Summary Sheet

5.1 Food

The food section is divided into capacity values F1c-F7c and demand values F1d-F7d. Capacity and demand values are fed into the NDI formulation and summarized into NDI-F1 through NDI-F7 values, each with a direction and magnitude as defined in section 4.2.1.13 (Figure 5-1). Each of the integer values are summarized using a specific methodology, which is discussed in detail within this section.

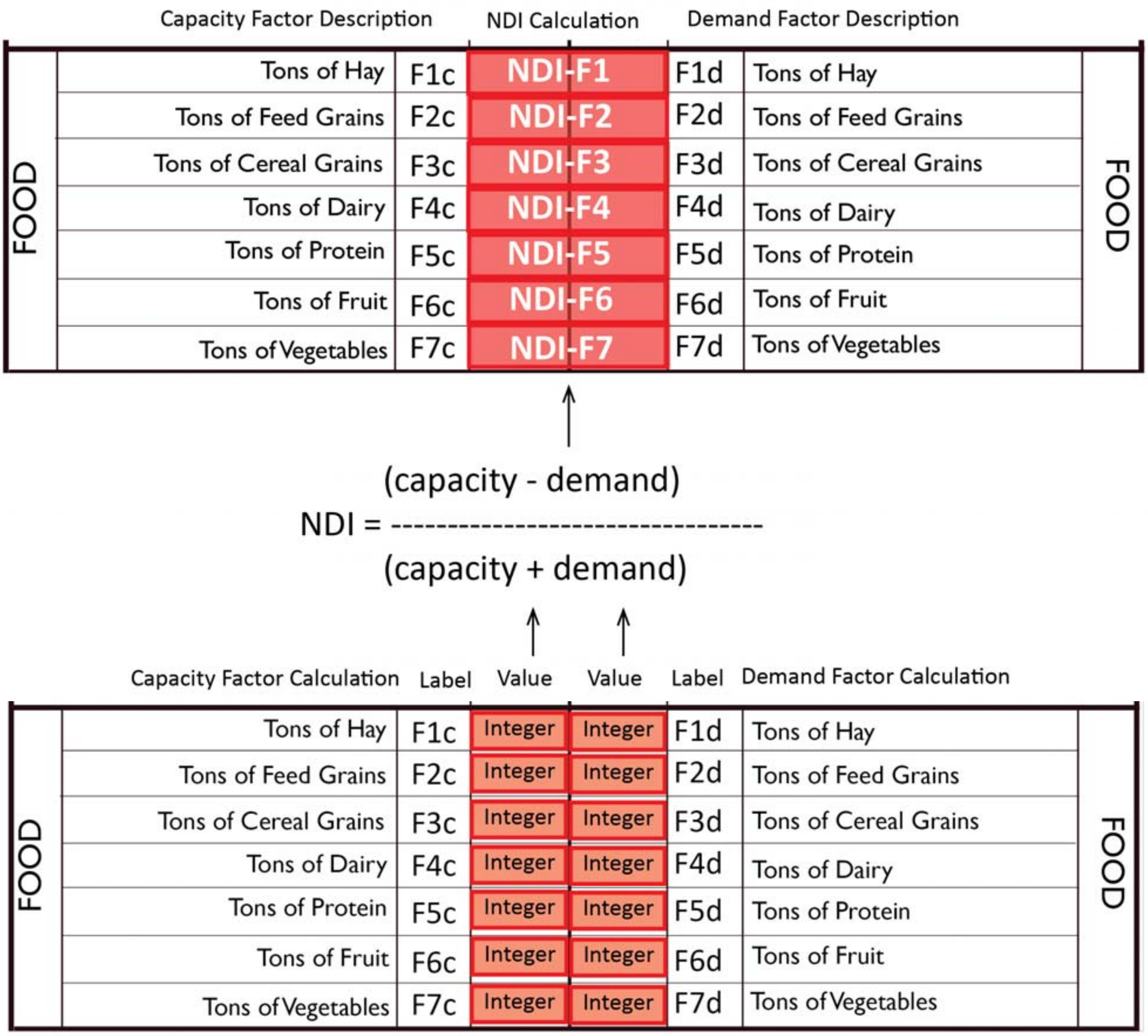

Figure 5-1: Food Factors Overview

5.1.1 Food Capacity Data Source

Food production (ie, existing capacity; food biocapacity) is calculated from county-based USDA national agricultural statistics service (NASS) 2012 agricultural census farmer reported crop, animal and aquaculture products production tables (United States Department of Agriculture 2012). The latest available complete agricultural census is 2012, which has been used in this study and a new agricultural census is produced every 5 years. The Agricultural Census sampling method starts with the classification of the entire land US land mass into land use categories by intensity of cultivation using satellite imagery, map products and software. This dataset is then divided by gridded segments of 1 square mile in agricultural areas to .01 square miles in urban areas and 10,000 samples are selected at varying rates and across all land use classifications in the USA, and approximately 50,000 operators ranging from farmers to canning operations managers are interviewed via mail surveys, telephone interviews, face-to-face interviews, and field observations (USDA 2012).

Collection of data through the NASS Quickstats Portal (http://quickstats.nass.usda.gov) is documented by the use of a data collection template which documents the data fields collected for each selection category within the 2012 Agricultural Census (Figure 5-2) and helps to ensure consistent data collection across different counties, enables the ability to backtrack from finished cleaned data to raw data and avoids downloading excessive non-critical data fields. It should be noted that to comply with *Title V of the E-Government Act, Confidential Information Protection and Statistical Efficiency Act of 2002* (United States Department of Agriculture 2007) some data is withheld to avoid disclosing data for individual operations. This is done by the USDA to protect the identity of individual farm operators who could be identified via the survey process, in which case only the crop type and operator is reported with a quantity of production listed as (D) for not disclosed, however the production is included in the county total. This method ensures that an accurate total is produced by group (ie, livestock, field crops, vegetables) in tons or acres harvested and the total variety of crops is accounted for even though some crop varieties do not have individually listed production or acres harvested totals. For the purposes of this study the data is accurate enough and at the appropriate scale. In cases where the data is withheld, no attempt is made to quantify the production of the withheld item and the data. This method 1) assures consistent reporting to the best of the capability of the US Agricultural Census, 2) reduces the possibility of errors trying to estimate the production capacity of average operators and 3) does not rely on excessive time trying to identify individual undisclosed operators (United States Department of Agriculture 2014).

FIELD CROPS

NASS Data Download Template	
http://quickstats.nass.usda.gov/	
Data Field	**Selection**
Program	Census
Sector	Crops
Group	Field Crops
Commodity	All
Category	Production
Data Item	All
Domain	All
Geographic Level	County
Year	2007

LIVESTOCK

NASS Data Download Template	
http://quickstats.nass.usda.gov/	
Data Field	**Selection**
Program	Census
Sector	Animals & Products
Group	Livestock
Commodity	All
Category	Inventory
Data Item	All
Domain	Total
Geographic Level	County
Year	2007

POULTRY

NASS Data Download Template	
http://quickstats.nass.usda.gov/	
Data Field	**Selection**
Program	Census
Sector	Animals & Products
Group	Poultry
Commodity	All
Category	Inventory
Data Item	All
Domain	Total
Geographic Level	County
Year	2007

VEGETABLES

NASS Data Download Template	
http://quickstats.nass.usda.gov/	
Data Field	**Selection**
Program	Census
Sector	Crops
Group	Vegetables
Commodity	All
Category	Area Harvested
Data Item	All
Domain	All
Geographic Level	County
Year	2007

DAIRY

NASS Data Download Template	
http://quickstats.nass.usda.gov/	
Data Field	**Selection**
Program	Census
Sector	Animals & Products
Group	Dairy
Commodity	Milk
Category	Sales
Data Item	All
Domain	Total
Geographic Level	County
Year	2007

FRUIT & TREE NUTS

NASS Data Download Template	
http://quickstats.nass.usda.gov/	
Data Field	**Selection**
Program	Census
Sector	Crops
Group	Fruit & Tree Nuts
Commodity	All
Category	Area Harvested
Data Item	All
Domain	All
Geographic Level	County
Year	2007

AQUACULTURE

NASS Data Download Template	
http://quickstats.nass.usda.gov/	
Data Field	**Selection**
Program	Census
Sector	Animals & Products
Group	Aquaculture
Commodity	All
Category	All
Data Item	All
Domain	All
Geographic Level	County
Year	2007

Figure 5-2: NASS Data Download Templates by Category

5.1.2 Food Capacity

5.1.2.1 Cereal Crop Production for Human Consumption

Crop data is collected from the 2012 NASS Census (United States Department of Agriculture 2012) by both the quantity of crop production by weight for each crop type and the number of acres harvested by crop type. The category "cereal crop" in this study includes cereal grains and legumes and is called "cereal crop" for consistency and simplicity (Table 5-2).

Cereal Crops For Human Consumption	
Corn	Rye
Rice	Oats
Sweet Corn	Speltz
Pop or Orn Corn	Buckwheat
Barley	Hops
Durum Wheat	Triticale
Spring Wheat	Vetch
Winter Wheat	Other Small Grains

Table 5-2: Cereal Crops for Human Consumption, as Listed in the NASS Survey of Agriculture

In all cases when crops are reported by production in actual weight (tons, bushels, pounds, hundred pounds, etc) the production figure in weight is used and the acres harvested figures are not used. This is done to eliminate any possibility of errors which may stem from inaccurately reported yield rates. When production in weight is not reported, which is the case for some counties, the acres harvested are converted to weight utilizing state-wide corrected yield factors for the produced commodities as reported for all states in the USA via the USDA 2012 agricultural census and was collected for all states with a case study site. The utilization of statewide yield factors may be somewhat less accurate than county wide yield factors in the cases where a state may contain multiple highly diverse ecoregion types, however, state-wide yield factors from the same year as the agricultural census data should be considerably more accurate than national level yield factors from the 1992 (USDA 1992) weights and measures table, which is the most recent and complete table of all yield factors for field crops, vegetables and fruits available for the conterminous United States. The formula to derive all cereal crop types in tons is below in Equation 8.

$$NASS_{CEREALS} = \left\{ \sum_{p=1}^{n} (NASS_{CEREALCROPS}\,[p,x,t]) + \sum_{p=1}^{n} (NASS_{LEGUMES}\,[p,x,t]) \right\}$$

Where:

$NASS_{CEREALSCROPS}$ [p,x,t] = The sum of all cereal crop products [p] in tons by county [x] per year [t](United States Department of Agriculture 2012)

$NASS_{LEGUMES}$ [p,x,t] = The sum of all legume crop products [p] in tons by county [x] per year

[t](United States Department of Agriculture 2012)

Equation 8: Cereal Crop Summation in Tons

5.1.2.2 Vegetable Production

Vegetables are summarized from the 2012 NASS Census (United States Department of Agriculture 2012) by both the quantity of vegetable production by type and the number of acres harvested per vegetable type in acres. In total, 26 plant species are categorized as vegetables in this method (Table 5-3).

Vegetables			
Asparagus	Cucumbers	Lettuce	Squash
Broccoli	Dry Beans	Onions	Sugarbeets
Cabbage	Eggplants	Peas	Sweet Potatoes
Carrots	Garlic	Peppers	Tomatoes
Cauliflower	Gourds	Potatoes	Turnips
Celery	Greens	Pumpkins	
Chick Peas	Lentils	Radishes	

Table 5-3: Vegetables as Listed in the NASS Survey of Agriculture

As with field crops, when vegetables are reported by production in actual weight the production figures in weight is used and acres harvested figures are not used. However, when production in weight is not reported, as is the case in many counties regarding vegetable yields, then the acres of vegetables harvested are converted to an approximate vegetable yield using published yield factors (Table 5-4). When possible, yield factors should come from a University agricultural extension office from the state or ecoregion level II unit within which the county is located.

Conversion Rates for Vegetables (Based on Good Yields)	Bushels (Bu) / Acre (Ac)	Pounds (Lbs) / BU	Tons (T) / BU	Crates (Cr) / Ac	Lbs / Cr	T/Cr	Lbs / Ac	T / Ac	Author
Asparagus				200	30	0,015		3	Smith, 2010
Beans, Snap	300	30	0,015					4,5	Smith, 2010
Beets (Bunched)					38	0,019		24	Thomson, Parrot et. al, 1999
Brocolli				200	42	0,021		4,2	Smith, 2010
Carrots				450	75	0,038		16,88	Smith, 2010
Cucumbers	500	48	0,024					12	Smith, 2010
Canteloup				300	40		12000	6	USDA, 1992
Garlic							5600	2,8	Smith, 2010
Kale				400	25	0,013		5	Delbert, 2010
Lettuce				600	20	0,01		6	Smith, 2010
Onions							35000	17,5	Smith, 2010
Okra								5	Smith, 2010
Peas	150	30	0,015				4500	2,25	Smith, 2010
Peppers, Bell	500	25	0,0125					6,25	Smith, 2010
Peppers, Chile								6	Takele, et. al., 1995
Potatoes	400	60	0,03					12	Smith, 2010
Pumpkins								50	Smith, 2010
Squash	400	45	0,0225					9	Smith, 2010
Sweet Corn				300	42	0,021		6,3	Smith, 2010
Tomatos	300	56	0,028					8,4	Smith, 2010
Turnips								5	Smith, 2010
Watermelon							12500	6,25	Smith, 2010

Table 5-4: Yield Factors for NASS Reported Vegetables

All vegetables species are summed by year and by county following Equation 9 below.

$$NASS_{VEG} = \sum_{p=1}^{n} (NASS_{VEG}\ [p, x, t])$$

Where:

$NASS_{VEG}$ = The sum of all vegetable products [p] in tons by county [x] per year [t] (United States Department of Agriculture 2012)

Equation 9: Vegetable Group Summation in Tons

5.1.2.3 Protein Production

The total protein production is estimated from three sources: seed crops, livestock and poultry. Each of the three sources are calculated using the equations presented below and then summarized in tons for input into NDI-F5 (Equation 28).

5.1.2.3.1 Seed Crops as a Protein Source

Several varieties of reported crop types have value as dried seeds which function as a secondary source of protein and are referred to as seed crops in this study. This group, although only including 5 plant varieties and being relatively minor by weight and production distribution compared to other field crops, do play an important role in some counties productivity characterization and should be considered as sources of dietary protein. However these plants contain much less crude protein (CP) content on a dry weight basis than livestock protein and therefore require a multiplier specific to each plant to reduce the percentage of contributing weight to protein quantity as compared to the total dry weight of the seed. The CP multiplier (CPM) is derived from the USDA Nutrient Database (USDA 2015b) and has been included in Table 5-5 below for simplicity. In all cases, the CPM reflects a significant reduction in the total tons of crops reported which can be attributed to the protein category of the USDA daily recommended diet. Oil could also be estimated from seed crops, but given the small percentage of oil intake in the USDA MyPlate daily food intake recommendation I assumed that oils and fats are satisfied by livestock protein and a separate estimate of oil yields to satisfy human needs was unnecessary and thus is not included in this study.

Seed Crop Type	Dried Crude Protein Content (%)	CPM	Source
Flaxseed	18.29	0.1829	USDA SR-28
Peanuts (all types, raw)	25.8	0.258	USDA SR-28
Safflower	16.8	0.168	USDA SR-28
Soybeans	39.58	0.3958	USDA SR-28
Sunflower	20.78	0.2078	USDA SR-28

Table 5-5: Seed Crops and Their Crude Protein Multiplier (CPM)

The equation to derive the total volume of seed crops is the summation of the seed crop type [p] in tons multiplied by the seed crop type specific CPM, as indicated in Equation 10 below.

$$NASS_{SEED} = \sum_{p=1}^{n} (NASS_{SEEDCROP}[p, x, t]) * f_{CPM}[p])$$

Where:

$NASS_{SEEDCROP}$ [p,x,t] = Reported seed crop type[p] per county [x] per year [t] (United States Department of Agriculture 2012)

f_{CPM} [p] = The crude protein multiplier(CPM) per seed crop type[p] listed in Table 5-5

Equation 10: Summary of Seed Crop Types in Tons for Protein Content

5.1.2.3.2 Livestock Production

Livestock data are collected by the category of inventory and are reported in head of animals by their respective group, including beef cows, hogs, slaughter lambs, and goats. The data in head is converted to a dressed weight using the conversion factors from the most up-to date sources possible and in all cases from University-based agricultural extensions as summarized in below in Table 5-6.

Animal	Live Weight (lbs)	Percent of Live Weight	Dressed Weight (lbs)	Source
Beef Cows	1250	63.0%	787.5	Ward 2012: 2, Table 1
Hogs	240	61.7%	148.08	Ray 2005: 2, Table 1; Jesse 1993: 2, Table 2
Lambs	120	44.0%	52.8	Ward 1991: 3, Table 2; Santos-Silva 2002
Goats	38	51.4%	19.52	Wildeus 2007: 4, Table 2

Table 5-6: Live and Dressed Weight Conversion Factors for Livestock

The live and dressed weights of animals used for this report are not customized by regions and in some cases the percent utilization is based on the average of two sources if there was discrepancy between available data. I acknowledge that there may be some drawbacks in this conversion method which could be related to average weight per livestock type based on feed grain and hay nutrient richness variations per ecoregion, methods of trimming carcasses which may differ from region to region or from country to country or from the percent of carcass utilization which may also differ from country to country based on cultural values (ie, which parts of the carcass are considered for use in human food supply and which are discarded or used as base materials for the non-human food supply such as dog foods, glues, gummi bears, etc). The benefit to this conversion method is that new data can easily be folded into the conversion tables and any updates or more detailed data that may appear on a regional basis are easily re-calculated. The formula to summarize all livestock types is below in Equation 11.

$$NASS_{LIVE} = \sum_{a=1}^{n} (HEAD_{live}[a, x, t] * f_{LC}[p])$$

Where:

$HEAD_{live}$ = The total number of head of livestock type [a] per county [x] per year [t] (USDA National

Agricultural Statistics Service 2012b)

f_{LC} [p] = The dressed weight livestock conversion (f_{LC}) factor for product [p] based on Table 5-6

Equation 11: Livestock Type Summation in Tons

5.1.2.3.3 Poultry Production

Poultry data are collected by the category of inventory and are reported in head of animals by their respective group, including broiler and layer chickens from the USDA NASS County Summary Highlights Table 1 (USDA National Agricultural Statistics Service 2012b) and ducks, geese, pheasants, quail, turkeys and other game birds or waterfowl from the more detailed full Agricultural Census (United States Department of Agriculture 2012). Head of poultry is converted to dressed weight or pounds of egg yield per head per year and then summarized in tons (Ernst 1995; USDA 2008; United States Department of Agriculture 2000; USDA 1992, p. 24, Table 15; Tilki et al. 2005, Table 3; Adamski, Kuzniaca 2006, Table 2; Vali et al. 2005, p. 2, Table 2). The benefits and drawbacks to this method for poultry carcass percent utilization are the same as those for the livestock carcass utilization conversion rates. The formula to summarize all poultry types ($NASS_{POULTRY}$) is below in Equation 12 and the conversion factors (f_{PC}) are below in Table 5-7.

$$NASS_{POULTRY} = \sum_{a=1}^{n} (POULTRY_{HEAD}[a,x,t] * f_{PC}[p])$$

Where:

$POULTRY_{HEAD}$ $[a,x,t]$= The total number of head of poultry type [a] per county [x] per year [t] (USDA National Agricultural Statistics Service 2012b)

$f_{PC}[p]$ = The dressed weight conversion factor for poultry product [p] based on Table 5-7

Equation 12: Summation of Poultry Types in Tons

Animal	Live Weight (lbs)	Percent of Live Weight	Dressed Weight (Lbs)	Avg. Annual Lbs. of Eggs (no shell) / Head	Tons	Source
Chickens (Broiler)	5,15	69,9%	3,60		0,0018	Ernst 1995
Chickens (Roaster)	8,70	69,0%	6,00		0,0030	Ernst 1995
Chicken (Layer)	-	-	-	28,6	0,0143	USDA 2008; USDA 2000
Cornish Game Hen	2,15	66,5%	1,43		0,0007	Ernst 1995
Duck	6,54	70,6%	4,62		0,0023	USDA June 1992: 24, Table 15
Goose	6,40	66,6%	4,26		0,0021	Tilki 2005: 3, Table 3
Pheasant	2,35	73,6%	1,73		0,0009	Adamski 2006: 15, Table 2
Quail	0,40	65,0%	0,26		0,0001	Vali 2005: 2, Table 2
Turkey	20,56	79,3%	16,30		0,0082	USDA June 1992: 24, Table 15

Table 5-7: Live and Dressed Weight Conversion Factors for Poultry

5.1.2.3.4 Protein Summary

The calculated protein sources from seed crops, livestock, poultry and tree nut production are summarized by tons to derive the total protein capacity for a county using Equation 13.

$$PROTEIN_{Total} = \sum NASS_{SEED} + NASS_{LIVE} + NASS_{POULTRY} + NASS_{TREENUT} + NASS_{AQUA}$$

Where:

$NASS_{SEED}$ = Equation 10

$NASS_{LIVE}$ = Equation 11

$NASS_{POULTRY}$ = Equation 12

$NASS_{TREENUT}$ = Equation 16

$NASS_{AQUA}$ = Equation 17

Equation 13: Total Protein Summary from Seed, Livestock and Poultry Sources

5.1.2.4 Dairy Production

Dairy products are collected by the category of dollars sold annually and then converted to tons based on the dollar value of a gallon of milk in 2012 (the year of the Agricultural Census) as tabulated by regions from the USDA Agricultural Marketing Service. Dairy is done this way because I found that many dairy operations across the USA choose not to disclose the number of milk producing livestock but did submit the total dollars made per operation per county. Additionally, the dollars reported on the 2012 agricultural census divided by the regionally adjusted dollar per gallon of milk in June of 2012 (USDA 2010) divided by the tons per gallon weight (USDA 2010) equates to less tons of milk production than using the alternate version of conversion from head of combined producing livestock multiplied by tons per year production of milk per head (USDA 2010; van Saun et al. 2008) multiplied by the regionally adjusted value of milk in July 2012. Thus, I opted to use the most conservative and consistent tons per milk calculation method, with the understanding the formula can be adjusted as needed based on new findings. The formula to derive the total tons of dairy products is in Equation 14 and the conversions are found in Table 5-8.

$$NASS_{DAIRY} = \left\{ \left(\frac{DAIRY_{DOLLARS}\,[x,t]}{f_{GP}[r,x]} \right) * f_{GT} \right\}$$

Where:

$DAIRY_{DOLLARS}$ = The total dollar amount of milk sold per county [x] per year [t] (United States Department of Agriculture 2012)

$f_{GP}[r]$ = The gallon price (GP) for the region [r] in which the county[x] is located (US Department of

Labor, Bureau of Labor Statistics (BLS) 2012)

f_{GT} *= A constant (0.004325), the conversion rate from gallons to short tons [GT]*

Equation 14: Summation of Dairy in Tons

2012 Average Retail Milk Prices		
Region	Milk, fresh, whole, fortified price per gallon	Source
South Central U.S.	$ 2.17	US Bureau of Labor Statistics, 2012
Southwest U.S.	$ 2.76	
Northwest U.S.	$ 2.62	
Northeast U.S.	$ 3.55	
Southeast U.S.	$ 2.98	
Midwest U.S.	$ 2.68	
US. City Average	$ 3.49	

Table 5-8: 2012 Retail Milk Price Conversion Factors by Region

5.1.2.5 Fruit and Tree Nut Production

Fruit and tree nuts are reported in "acres harvested" and "acres bearing" from the USDA and then converted to an average yield in tons per acre based on state-wide USDA yield factors as reported in the 2012 census (United States Department of Agriculture 2012) or through detailed state or regional research often from University agricultural extension offices. Acres harvested are usually how berries are reported and acres bearing are typically how fruits and tree nuts are reported. In general, fruit and tree nuts are not typically reported in total tons of production in the mainland United States, with the exception of a few counties, whereas acres bearing or acres harvested is consistently reported at the county level in the 2012 Agricultural Census and is typically more inclusive of different crop varieties. Therefore the USDA category of acres bearing from NASS Quickstats and the yield factors were necessary to obtain the broadest sample in tons. A separate value in tons is calculated for fruit, which has its own place on the NDI Factor Summary. Tree nuts are calculated as protein and added to the protein category in the NDI Factor Summary.

The utilization of statewide yield factors may be somewhat less accurate than county wide yield factors in the cases where a state may contain multiple highly diverse ecoregion types, but it is the most consistently available yield data at the lowest resolution and is considered accurate for the purposes of this study. When for whatever reason the statewide yield factors reported for fruit and tree nuts is insufficient to cover all the county-wide reported fruit and tree crop species harvested, the national yield factors are utilized from the USDA (USDA 1992). By utilizing yield factors listed in a table, all factors can be quickly and easily updated based on new findings. The formulas to derive the total tons of fruit and tree nuts are presented below in Equation 15 and Equation 16 respectively.

$$NASS_{FRUIT} = \sum_{p=1}^{n}(FRUIT_{ACRESHARV}\ [p,x,t]\ *\ (f_{AY}[p])$$

Where:

$FRUIT_{ACRESHARV}\ [p,x,t]$ *= Reported acres of fruit harvested by county [x] and year[t] (United States Department of Agriculture 2012)*

$f_{AY}[p]$ *= A variable, tons of yield per acre of each fruit type[p] by state from the NASS database*

Equation 15: Summation of Fruit in Tons

$$NASS_{TREENUT} = \sum_{p=1}^{n}(TREENUT_{ACRESHARV}\ [p,x,t]\ *\ (f_{AY}[p]))$$

Where:

$TREENUT_{ACRESHARV}\ [p,x,t]$*= Reported acres of tree nuts harvested by county [x] and year [t] (United States Department of Agriculture 2012)*

$f_{AY}[p]$ *= A variable, tons of yield per acre of each tree nut type [p] by state from the NASS database*

Equation 16: Summation of Tree Nuts in Tons

5.1.2.6 Aquaculture Production

Aquaculture is reported in sales and distribution measured in dollars sold and then converted to tons based on the price per pound of dressed weight per type of fish. Ultimately, aquaculture is reported in the protein category in the NDI factor summary sheet (Table 5-1). It should be noted that according to the case study counties, aquaculture is not a very heavily represented food group, with most counties having only one or two producers which do not disclose either tons produced or sales and distribution in dollars. The counties that report a dollar value of aquaculture sales and distribution per year are located either on the coast, in the Mississippi Delta or in mountain areas with annual freshwater streams that can support fish populations. In short, aquaculture is highly regional. The formula to summarize fish in tons is below in Equation 17.

$$NASS_{AQUA} = \left\{\frac{(AQUA_{DOLLARS}\ [q,x,t])}{f_{DLB}[p,r]}\ *\ f_{LBT}\right\}$$

Where:

$AQUA_{DOLLARS}\ [q,x,t]$ *= The total dollar amount of aquaculture [q] sold per county [x] per year [t] (USDA National Agricultural Statistics Service 2012a)*

f_{DLB} *[p] = The price per pound in dollars (DLB) for aquaculture product [p] adjusted for region [r]*

f_{LBT} *= A constant (0.0005), the conversion rate from pounds to tons (LBT)*

Equation 17: Summation of Aquaculture Production in Tons

5.1.2.7 Hay Production for Livestock Consumption

Most counties in the USA report a value for haylage or silage production, which is important in evaluating the fitness of a county to provide feed for livestock, as livestock require both grains and hay in their diets (see Table 5-10). For this reason, hay production is included in the capacity side so that it can be compared to the livestock demand for food supplies (see section 5.1.3.2). The type of grains and percentages recommended for each livestock type in different livestock production systems can be broken down by region, a consideration included in other methods (Mekonnen, Hoekstra 2012, p. 403) but not possible to estimate at the level of this analysis with the NASS data. Therefore the simple formula of a grain and hay demand is assumed for livestock types so that the minimum characteristics for livestock survival are estimated rather than the optimal hay and grain combinations which would require much deeper investigations on a county-by-county basis to verify, which is beyond the scope of this project. The calculation for hay production is based on the NASS 2012 census just like all other categories and is presented below in Equation 18.

$$NASS_{HAY} = \left\{ \sum_{p=1}^{n} (NASS_{HAYLAGE}\,[p,x,t]) + \sum_{p=1}^{n} (NASS_{SILAGE}[p,x,t]) \right\}$$

Where:

$NASS_{HAYLAGE}$ [p,x,t] = The tons of Haylage crop [p] reported per county [x] per year [t] (United States Department of Agriculture 2012)

$NASS_{SILAGE}$ [p,x,t] = The tons of Silage crop [p] reported per county [x] per year [t] (United States Department of Agriculture 2012)

Equation 18: Summation of Hay Production in Tons

5.1.2.8 Feed Grain Production for Livestock Consumption

As mentioned in section 5.1.3.2 grains are needed for daily livestock feed rations. Therefore livestock feed grain production, which includes any different species of cereal grain other than what is listed in Table 5-2 for human consumption, are summarized to determine the capacity of a county to supply their livestock's daily grain ration demand. The calculation is based on the NASS 2012 census just like all other categories and is presented below in equation 15.

$$NASS_{FEEDGRAIN} = \sum_{p=1}^{n} (NASS_{FEEDGRAIN}[p,x,t])$$

Where:

$NASS_{FEEDGRAIN}[p,x,t]$ *= The reported tons of livestock grain crop [p] per county [x] per year [t] (United States Department of Agriculture 2012)*

Equation 19: Summation of Livestock Grain Production in Tons

5.1.2.9 Oil Crops

While the USDA NASS Agricultural Survey does include the oil crops mustard, canola, rapeseed and camelina, these crops are not included in the food capacity and demand balance because oils are not included as a major part of a daily diet in the My Daily Plan, amounting to only a few teaspoons per day for adults, which is typically satisfied by oils contained in the daily allowances of livestock products, fish, nuts and dairy products (USDA 2015a). Therefore, oil crops are not included in this study.

5.1.3 Food Demand

5.1.3.1 Human Food Demand

Quantity of food demand is based on per capita food needs of the county population as reported by the 2010 US Census (United States Census Bureau 2010). All reported individual demand is calculated with the “adult” age group and equates to a 2000 calorie per day diet (Table 5-9). The diet is split into a portion by weight of the food groups grains (referred to herein as “cereals”), protein, dairy, fruit and as reported by the USDA My Plate daily food recommendations (USDA 2015a).

My Daily Food Plan

Based on the information you provided, this is your daily recommended amount for each food group.

GRAINS 6 ounces	VEGETABLES 2 1/2 cups	FRUITS 2 cups	DAIRY 3 cups	PROTEIN FOODS 5 1/2 ounces
Make half your grains whole Aim for at least **3 ounces** of whole grains a day	**Vary your veggies** Aim for these amounts **each week:** **Dark green veggies** = 1 1/2 cups **Red & orange veggies** = 5 1/2 cups **Beans & peas** = 1 1/2 cups **Starchy veggies** = 5 cups **Other veggies** = 4 cups	**Focus on fruits** Eat a variety of fruit Choose whole or cut-up fruits more often than fruit juice	**Get your calcium-rich foods** Drink fat-free or low-fat (1%) milk, for the same amount of calcium and other nutrients as whole milk, but less fat and Calories Select fat-free or low-fat yogurt and cheese, or try calcium-fortified soy products	**Go lean with protein** Twice a week, make seafood the protein on your plate Vary your protein routine—choose beans, peas, nuts, and seeds more often Keep meat and poultry portions small and lean

Find your balance between food and physical activity	Know your limits on fats, sugars, and sodium
Be physically active for at least **150 minutes** each week.	Your allowance for oils is **6 teaspoons** a day. Limit Calories from solid fats and added sugars to **260 Calories** a day. Reduce sodium intake to less than **2300 mg** a day.

Your results are based on a 2000 Calorie pattern. **Name:** __________

Table 5-9: 2000 Calorie per Day Food Plan (United States Department of Agriculture)

$$CEREALS_{DEM} = ((6 \text{ ounces per day} * 365 \text{ days}) / 32000 \text{ ounces per ton}) * \text{Adult Pop.}$$

$$VEG_{DEM} = (((2.5 \text{ cups} * 8 \text{ ounces per cup}) * 365) / 32000 \text{ ounces per ton}) * \text{Adult Pop.}$$

$$FRUIT_{DEM} = (((2 \text{ cups} * 8 \text{ ounces per cup}) * 365) / 32000 \text{ ounces per ton}) * \text{Adult Pop.}$$

$$DAIRY_{DEM} = (((3 \text{ cups} * 8 \text{ ounces per cup}) * 365) / 32000 \text{ ounces per ton}) * \text{Adult Pop.}$$

$$PROTEIN_{DEM} = (((5.5 \text{ ounces} * 365 \text{ days}) / 32000 \text{ ounces per ton}) * \text{Adult Pop.}$$

Equation 20: 2000 Calorie Food Demand by Food Group per Year

The total demand in tons is calculated per food group for the population (Equation 20) and then summarized into the total annual combined demand by food groups (Equation 21).

$$CEREALS_{HUMAN} = \sum_{p=2}^{n} GRAIN_{DEM}\,[P, x, t]$$

$$VEG_{HUMAN} = \sum_{p=2}^{n} VEG_{DEM}\,[P, x, t]$$

$$FRUIT_{HUMAN} = \sum_{p=2}^{n} FRUIT_{DEM}\,[P, x, t]$$

$$DAIRY_{HUMAN} = \sum_{p=2}^{n} DAIRY_{DEM}\,[P, x, t]$$

$$PROTIEN_{HUMAN} = \sum_{p=2}^{n} PROTIEN_{DEM}\,[P, x, t]$$

Where:

P = population, from (US Census, 2012)

x = County area

t = Time, by year

Equation 21: Food Demand Summary by Food Group for Human Supply

This method assumes that there are no differences in food groups based on age, regional identity or culture and is the most basic assumption that can be made and is considered by the USDA to be the minimum standard daily requirements which should be attained / attainable by all Americans. Since this is considered the minimum standard, then the logic of using this value is that all Americans should have access to the minimum standard, not a regional or cultural variation on the standard. It is also acknowledged that 2000 calories per day for adult may be more than a child or adult under 18-years old requires based on their activity level. But, considering that this value was also used in a related study (Luck et al. 2001), then there is a precedent for its use and therefore is justified. And finally, since this method is modeled in Excel, then the daily food intake calculations can be easily changed based on new research or the addition of regionally adjusted information when available.

5.1.3.2 Livestock Hay and Feed Demand

In addition to the demand per capita of food for humans, the per capita food demand of livestock needs to be calculated, which in this study consist of hay and grain-based feed. The livestock food demand for hay (Equation 22) and feed grain is calculated separately by livestock type, as the sum of meat animals raised plus the sum of milk animals raised multiplied by the annual hay and grain demand per livestock type respectively as listed in Table 5-10, then summarized into a total tons of hay and feed demand annually.

$$HAY_{LIVE} = \sum_{a=1}^{n} (HEAD_{LIVE}[a, x, t] \ * HAY_{DEM}\ [a]) * 365$$

Where:

$HEAD_{LIVE}\ [a, x, t]$ *= The total head of livestock type [a], produced per county [x] per year [t] as indicated in Equation 11 from (USDA National Agricultural Statistics Service 2012b)*

$HAY_{DEM}\ [a]$ *= The listed daily hay feed ration for livestock type [a] per day (Table 5-10)*

Equation 22: Livestock Hay Demand

$$FEEDGRAIN_{LIVE} = \sum_{a=1}^{n} ((HEAD_{LIVE}[a, x, t] \ * FEEDGRAIN_{DEM}\ [a]) * 365$$

Where:

$HEAD_{LIVE}\ [a, x, t]$ *= The total head of livestock type [a], produced per county [x] per year [t] as indicated in Equation 11 from (USDA National Agricultural Statistics Service 2012b)*

$FEEDGRAIN_{DEM}\ [a]$ *= The listed daily feed grain ration for livestock type [a] per day (Table 5-10)*

Equation 23: Livestock Feed Grain Demand

Daily Feed Rations for Livestock			
Livestock Type	Feed Type (lb / day)		Source
	Hay	Corn/Grain	
Milk Cows	71.25	0.75	Janke, 2012
Meat Cows	55	55	Janke, 2012
Goats	5	1	Stevens and Rickets, 1993
Pork	-	8	Jesse, 1993
Chicken	-	0.5	Lyons, 1997
Sheep/Lamb	10	1	Santos-Silva, 2002

Table 5-10: Daily Feed Rations for Livestock

5.1.4 Calculation of Food Balances

With the summary for all food factors (F1c-F7c and F1d-F7d) calculated as explained above, the integer variables are fed into their assigned NDI equation formulas (NDI-F1-NDI-F7) so that a direction and magnitude can be calculated for each of the food factors. The results of the NDI are from 1.00 to -1.00, where 1.00 is an overwhelming abundance of capacity compared to demand, -1.00 is an overwhelming demand compared to capacity and zero (0) means equal capacity and demand.

$$NDI - F1 = \frac{F1c\ (hay\ capacity) - F1d\ (hay\ demand)}{(F1c + F1d)}$$

Equation 24: NDI-F1 Calculation for Hay

$$NDI - F2 = \frac{F2c\ (feed\ grain\ capacity) - F2d\ (feed\ grain\ demand)}{(F2c + F2d)}$$

Equation 25: NDI-F2 Calculation for Feed Grain

$$NDI - F3 = \frac{F3c\ (cereals\ capacity) - F3d\ (cereals\ demand)}{(F3c + F3d)}$$

Equation 26: NDI-F3 Calculation for Cereal Grain

$$NDI - F4 = \frac{F4c\ (dairy\ capacity) - F4d\ (dairy\ demand)}{(F4c + F4d)}$$

Equation 27: NDI-F4 Calculation for Dairy

$$NDI - F5 = \frac{F5c\ (protein\ capacity) - F5d\ (protein\ demand)}{(F5c + F5d)}$$

Equation 28: NDI-F5 Calculation for Protein

$$NDI - F6 = \frac{F6c\ (fruit\ capacity) - F6d\ (fruit\ demand)}{(F6c + F6d)}$$

Equation 29: NDI-F6 Calculation for Fruit

$$NDI - F7 = \frac{F7c\ (vegetable\ capacity) - F7d\ (vegetable\ demand)}{(F7c + F7d)}$$

Equation 30: NDI-F7 Calculation for Vegetables

5.2 Water

Water in each county is divided into the two basic categories of water demand and capacity like the other component categories, however, water is the only category which borrows a methodology from two different frameworks, in this case the Water Footprint (Hoekstra et al. 2011) and the renewable freshwater demand (RFWD) (Postel, Daily 1996). The RFWD approach splits precipitation over land into evapotranspiration and runoff, for which runoff is used as the renewable water capacity and a corrected evapotranspiration capacity is used in the green water analysis. Water abstraction is water which is pulled through the municipal system, of which part of it is ultimately returned via WWTP, part of it returns to surface streams via runoff or subsurface flow and some of it is evaporated or metabolized by flora or fauna. Abstraction differs from the Water Footprint's method of defining water consumption which is metabolized water from the surface, ground or atmosphere by livestock and crop products, thus effectively leaving the local water cycle and reducing the total quantity available for human abstraction and consumption, be it surface runoff directly or indirectly from crop products. Thus, the blue and green Water Footprint methods are used to calculate the consumption of surface and atmospheric water by crop, livestock and ecosystems, alongside of the abstraction and availability of water in human systems.

A variation of the grey Water Footprint is used to determine if the point and non-point waters returned to the surface exceed US EPA total maximum daily loads (TMDL's) for nitrogen (N) or phosphorus (P). Grey water is used here to assess human waste loads since water is one of the components in the DEU where human systems input wastes. The water analysis includes ten calculations that are calculated for directionality and magnitude with 5 NDI calculations (Table 5-11), then plotted on the waveform diagram.

The water analysis in the County Diagnostic is the only part of the County Diagnostic to be calculated at the monthly time step. This is because annual summaries of water balances do not accurately portray the documented seasonality of fluvial systems and flows, which is especially relevant to identify temporal "hot spots" where demand may exceed capacity for a few months of the year but remain with excess capacity by annual calculation. Since water consumption is calculated on the monthly time step specific crop growing seasons must be evaluated on a crop by crop and county by county basis for all crops to determine the area of crop in active production and area not in active production for each month. Crop activity or inactivity on a monthly basis affects the blue and green water availability, consumption and pollutant concentrations.

Growing seasons for field crops are reported by the USDA (USDA 1997) and fruits and vegetables growing seasons are estimated using historical average spring and fall frost dates by location from USDA (USDA 1994) or from the 2010 published 1981-2010 NOAA climate normal (Arguez et al. 2010), which is accessed via county search with the NOAA Climate Data Online Mapper. Green water consumption for livestock is assumed to be a monthly constant. Field crops reported in the CropScape image (United States Department of Agriculture 2012a) are generalized into the categories of hay, feed, cereals, and pulses per the FAO FertiStat (FAO 2006) categorization to estimate non-point source N and P loads from field crops which is assumed to occur one time per year. After all monthly calculations have been created, they area summed for the year bottom-up and used in the proper NDI equation (NDI-W1 through NDI-W5).

The 10 factor calculations for water and their derivative formulas and data sources are presented individually below starting with the 5 capacity factor calculations and the 5 demand factor calculations (Table 5-11).

	Capacity Factor Description		NDI Calculation		Demand Factor Description	
WATER	Total Available M^3 of Stream Flow	W1c	NDI-W1	W1d	Total M^3 of Adjusted Abstraction	WATER
WATER	Total M^3 of Available Atmospheric Moisture (Green)	W2c	NDI-W2	W2d	Total M^3 of Consumed Atmospheric Moisture (Green)	WATER
WATER	Total Available M^3 of Surface Runoff (Blue)	W3c	NDI-W3	W3d	Total M^3 of Consumed Surface Water (Blue)	WATER
WATER	Critical Annual Nitrogen Load in Tons (Grey)	W4c	NDI-W4	W4d	Total Annual Nitrogen Load in Tons (Grey)	WATER
WATER	Critical Annual Phosphorus Load in Tons (Grey)	W5c	NDI-W5	W5d	Total Annual Phosphorus Load in Tons (Grey)	WATER

$$NDI = \frac{(capacity - demand)}{(capacity + demand)}$$

	Capacity Factor Calculation	Label	Value	Value	Label	Demand Factor Calculation	
WATER	Total Available M^3 of Stream Flow	W1c	Floating Point	Floating Point	W1d	Total M^3 of Adjusted Abstraction	WATER
WATER	Total M^3 of Available Atmospheric Moisture (Green)	W2c	Floating Point	Floating Point	W2d	Total M^3 of Consumed Atmospheric Moisture (Green)	WATER
WATER	Total Available M^3 of Surface Runoff (Blue)	W3c	Floating Point	Floating Point	W3d	Total M^3 of Consumed Surface Water (Blue)	WATER
WATER	Critical Annual Nitrogen Load in Tons (Grey)	W4c	Floating Point	Floating Point	W4d	Total Annual Nitrogen Load in Tons (Grey)	WATER
WATER	Critical Annual Phosphorus Load in Tons (Grey)	W5c	Floating Point	Floating Point	W5d	Total Annual Phosphorus Load in Tons (Grey)	WATER

Table 5-11: Water Analysis Method Overview

5.2.1 Water Capacity

Water capacity calculations, specifically W1c-W5c in Table 5-11, are derived from a number of different data sources which are individually summarized in their own unique processes based on the complexity of the underlying data to derive each final factor value. These five calculations are discussed in detail below. All components are calculated at the monthly time-step and then used in their respective NDI calculations.

5.2.1.1 Total Available Streamflow (W1c)

As a counterpoint to the total monthly extraction from surface or ground water sources for human uses (W1d) the total annual stream flow availability for the county is estimated. While it is assumed that most counties rarely run out of surface water to extract at their respective water treatment plants at any time of the year, the inclusion of this calculation also takes into account an estimate of water needed to support ecosystems, known as the environmental water requirement (EWRs or EWR) (Smakhtin, Revenga, C. and Döll P. 2004, p. 308) or environmental flow requirements (EFR) (Hoekstra et al. 2011, p. 151) which vary drainage basin roughly equivalent to the USGS HUC 02 designation and is called the EWR for clarity from here on the text. Thus, the total available streamflow is a 'corrected' value where the EWR is subtracted from the estimated monthly flow to arrive at an available monthly flow for human abstraction at water treatment plants which accounts for the continuation of ecosystem services and aquatic life supported by streams in the county (represented in part by the ZOC in section 5.3). Since streamflow is variable throughout the year, it is possible that human extractions on a monthly basis could exceed the corrected availability (while not actually abstracting so much water that the stream runs dry), especially in summer months when extractions for agricultural production are high and often rainfall is at its lowest.

Streamflow, or discharge (Q), can be summarized in a number of different ways, including mean monthly flow where all recorded flows are simply averaged; as an exceedance probability (P) where a volume of Q is expected to return at certain probabilities such as 90% of all flows will equal a certain Q(Dunne, Leopold 1978, p. 52), with Q10 or Q1.5 often times considered a typical base-flow volume (Keane et al. 2013); and in percentile where a given percentage of flow observations in a group of observations will fall below a certain Q (for example, the 10th percentile is the value below which 10 percent of the observations may be found). The USGS describes percentiles above 75% as 'above normal' flows, flows between the 25^{th} and 75^{th} percentile as 'normal' flows and flows below 25% as 'below normal' flows (USGS 2011). For the purposes of this study, the mean daily 25^{th} percentile is utilized as the baseline flow volume because this value is automatically provided by the USGS for the stream gage stations of interest for this study and because the percentile estimate meets given the objectives of estimating 'statistically normal' flows for a location, as "normal flows" are categorized with the USGS percentile method between 25th and 75th percentile. The 25^{th} percentile is used to most closely match the Q10 "low-flow" value utilized to in Smakhtin et al. as the flow value for which all EWRs were calculated. Mean values are not used because a mean daily flow value would account for high flows which can often times be exponents greater than typical low flows and therefore would significantly over-estimate typical stream flows. In this study, the value of P25 is used as a proxy for the value of Q90, which is important when determining the EWR to be deducted from streamflow and mean monthly runoff in section 5.2.1.3.

Based on the logic of the County Diagnostic, accounting for material flows within geographic boundaries, this factor (W1c) breaks the rules because measuring stream flow is accounting for water which flows into the county from upstream areas, which is quite different than total available runoff (W3c) that only accounts for runoff generated from within the county itself. The reason streamflow is included is because accounting for total streamflow and total runoff separately provides a broader picture of water availability, giving insights into the dependency of a county on its receiving flows and not just the runoff generated in the county, two values which can vary significantly. And as mentioned in the literature review section 3.5.2 the EWR demands that environmental requirements be subtracted from both stream flow and runoff to account for both vegetative and aquatic communities.

5.2.1.1.1 Calculation of Total Available Streamflow

The first step to calculate the total monthly stream flow is identification of all the pertinent USGS stream gage stations in a county of interest so that flow data can be downloaded. This is done by mapping out the HUC 8 level basins in GIS from the National Hydrography Dataset (NHD) (U.S. Department of the Interior, U.S. Geological Survey) or NHDPlus (U.S. Department of the Interior et al. 2012) that cover the county. Next the flow direction is determined the USGS stream gauges point files from the US National Water Information System (NWIS) (U.S. Department of the Interior, U.S. Geological Survey) are overlaid to isolate stations of interest (ie, stations within given HUC 8 jurisdictions) and then those numbers are using the NWIS system to download summarized mean monthly discharge in cubic feet per second (CFS) for the station.

Stations within a county are selected by location with ArcGIS and the resulting in-county stream gage stations are evaluated to reduce the selection to the fewest stations with drainage areas that cover the largest percentage of the county as possible, without including significant area outside of the county boundary or not accounting for areas within the county. The best case is when there is one HUC 8 basin completely covering a county and a single gage station is located where the main stream flows out of the county requiring only one gage station, however this rarely, if ever, happens. The more likely case is that average or representative flows (the P25 in this case as discussed above) from multiple gages need to be summed to achieve a representative volume reflecting “streamflow availability.”

An example below (A,B,C,D in Figure 5-3) indicates a typical gage sampling decision making process, where gage samples B, C and D are chosen, but not A because gage station B accounts for flows in the entire tributary area where station A is located. In the Muskingum, Ohio example, the stream area from E to D, E to C and E to B are not accounted for and given the stream gage stations available cannot really be accounted for without further field sampling. In this sense, the method can be flawed for some counties and is really an estimate of the types of flows typical in the county. Given the objectives of the calculation, to determine available mean monthly stream flow representative to the county, this level of error is accepted and can be improved in the future with better computer modelling application or field studies.

Calculation corrections for area could be done by subtracting the discharge of site B from the discharge of site E (if it were available) or site F (although that would introduce extra-county flows between site E and F which may be equivalent to flow errors arriving from the lack of a gage station between C,B,D and E. Ultimately, the calculation of available discharge using a county boundary may be flawed and it might be better calculated using the HUC 08 boundary or other watershed boundary, however, given the spatial framework of the county jurisdiction in this study it is not possible to account for water at the HUC 08 scale as that would estimate significantly more water availability (since a large land area outside of the county would be included) which would then have to be corrected in itself.

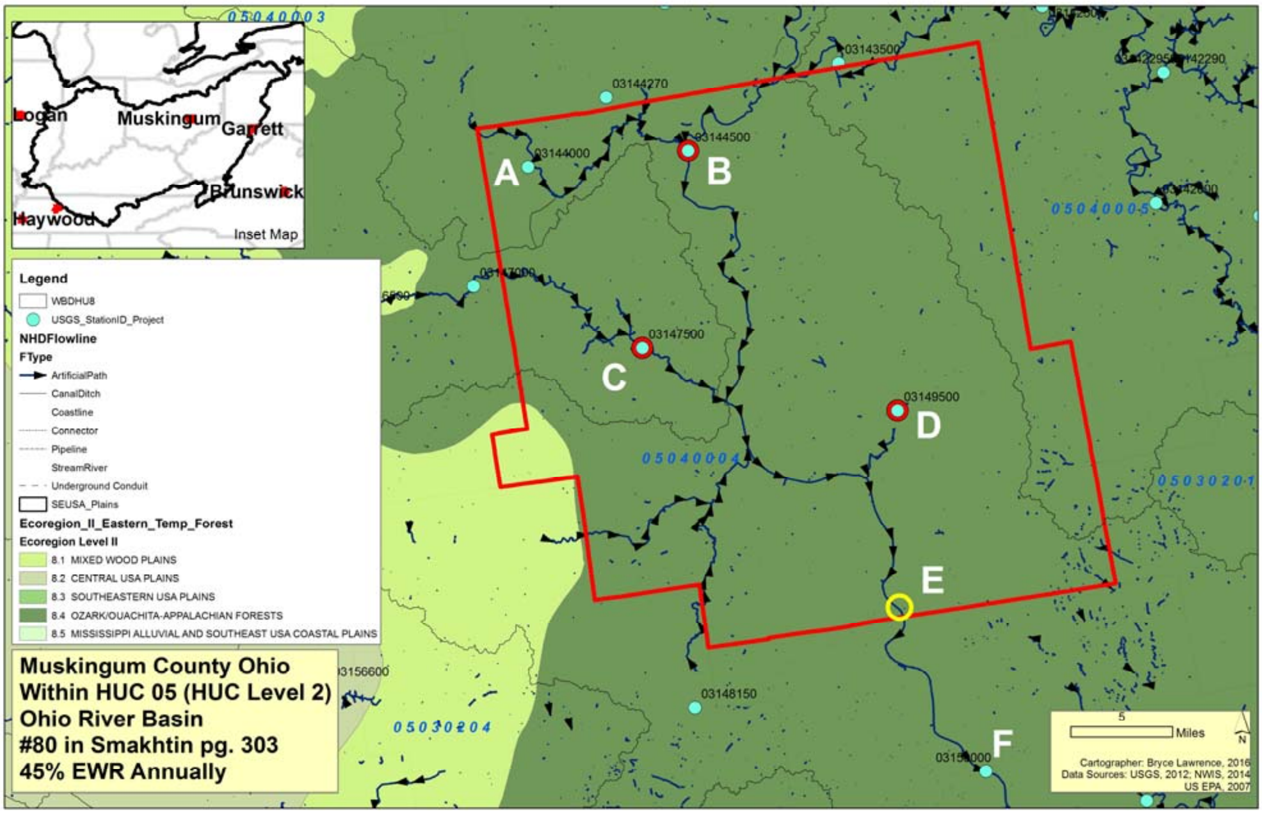

Figure 5-3: USGS Stream Gage Selection Process

For each station identified in the station selection method described above, the NWIS P25 mean stream flow for each day in every month of all years on record in CFS are downloaded using the station identifier as the link to search within the NWIS system (U.S. Department of the Interior, U.S. Geological Survey). The total cubic meters per month is summed from the annual flow records for all stations to arrive at a total mean monthly P25 volume of available stream flow in cubic meters for each station. The total monthly flow in cubic meters for each station identified is summed to estimate the total monthly stream flow in cubic meters for the county (Equation 31) which is summed by months to derive annual streamflow availability. In the case that a stream of interest has 2 stream gages, the average of the two gage records is used.

5.2.1.1.2 Derivation of the EWR from Monthly Streamflow Records

The derivation of the EWR is based on the percent of discharge required for environmental water requirements from a previous global study (Smakhtin, Revenga, C. and Döll P. 2004) at the low-flow exceedance probability of Q90, for which the P25 is used as a proxy in this study. The percentage calculated by Smakhtin et al. accounts for both low and high flow requirements and is easily derived by multiplying the percentage requirement by the monthly mean discharge (F_{nat}) Equation 31. The

EWR requirement is calculated at a "status quo" level where water requirements are estimated corresponding to the Q90 low-flow level, assuming fair quality ecosystems (Table 5-12). In terms of the ZOC (section 5.3) the Q90 is calibrated to a basic level of percentage-based protection of 12-17% area preservation (Table 5-12). A larger percentage of EWR from total discharges could be allocated for areas where higher ecosystem quality standards are derived. The EWR percentage is subtracted from the P25 mean monthly streamflow to account for water use in ecosystems.

Categorization of Environmental Water Management Objectives with the Zone of Conservation (ZOC)			
Conservation status or management objective	**Ecological Description**	**Corresponding low-flow charactaristic as a measure of LFR**	**Recommended corresponding ZOC land cover percentages as proxy for biodiversity protection**
Natural (Unmodified)	Pristine condition or negligible modification of in-stream and riparian habitat	Q50	30%+ ZOC intact
Good (slightly or moderately modified)	Largely intact biodiversity and habitats despite water resources development and/or basin modifications	Q75	17.1% - 30% ZOC intact
Fair (moderately or considerable modified	The dynamics of the biota have been disturbed. Some sensitive species are lost and /or reduced in extent. Alien species may occur	Q90	12% - 17% ZOC intact
Poor (critically modified and degraded)	Habitat diversity and availability have declined. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem	No Allocation / Not Acceptable	0-12% ZOC intact / US EPA 303(d) streams present

Table 5-12: Q-Value Selection Matrix, Reproduced and Adapted from (Smakhtin, Revenga, C. and Döll P. 2004, p.309)

$$Total\ Adjusted\ Available\ Streamflow\ in\ M^3\ (W1c) =$$
$$= \sum_{t_m=12}^{n} \left\{ \left(\sum_{s=1}^{s} F_{nat}[s, x, t_m] \right) - \left(\sum_{t_m=1}^{n} EWR\ [s, t_m, x] \right) \right\}$$

Where:

$F_{nat}[s, x, t_m]$ *= The monthly [t_m] P25 streamflow in cubic meters from each gage station [s] for county [x] (U.S. Department of the Interior, U.S. Geological Survey NWIS)*

$\sum_{t_m=1}^{n} EWR\ [s, t_m, x]$ *= The sum of monthly [t_m] EWR in cubic meters from each gage station [s] for each county [x], based on previously calculated EWR percentages by HUC 02 level drainage basin explained in section 5.2.1.1.2 below*

Equation 31: Calculation of Raw Monthly Cubic Meters of Stream Flow Availability

5.2.1.2 Green Water Availability (W2c)

Total available green water, that is water from precipitation which is stored in the upper soil layer and is available to plant transpiration through capillary root processes and evaporation from wind, is used as the counterpoint to the total demand for green water (W2d) and is calculated at the monthly time step in cubic meters. Months are summarized to derive a total annual availability for use in the NDI-W2 formula and monthly NDI-W2 values are calculated and graphed for use as supporting information to identify temporal "hot spots" where green water consumption might exceed the availability for a few months but remains in excess capacity annually.

The formula for green water availability (W2c) is equal to the measured green water for a given location and time (ET_{green} [x,t_m]) minus the green water needed for environmental processes that is estimated using the zone of conservation(ZOC) from section 5.3.1.2 (ZOC)[x]). Hoekstra propose also subtracting agricultural areas out of production as green water "lost" or "unharnessed for human purpose" via soil evaporation for each month of the year (Hoekstra et al. 2011), which is already accounted for on the demand side of the equation as not calculating agricultural green water demand for unproductive months; subtracting unproductive areas for unproductive months would thereby indicate no demand and no capacity for unproductive months rather than no demand with existing capacity, as is the case in reality, and thus undervalue the available capacity on an annual basis. This formula is indicated below in Equation 32.

In Equation 32, the measured evapotranspiration (ET_{green}) dataset comes from the University of Montana / National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) Moderate-Resolution Imaging Spectroradiometer (MODIS) Satellite mission 16. The MOD16 global ET dataset is a regular 1 Km^2 dataset covering the 109.03 Million Km^2 global vegetation land area at 8-day, monthly and annual intervals. The MOD 16 ET dataset is estimated using an improved ET algorithm (Mu et al. 2011) based on the Pennman-Monteith equation (Monteith). The MOD16 ET dataset includes evaporation from soil, from rainwater intercepted by leaf canopy, and transpiration through plant leaf and stem stomata. Leaf area index (LAI) is used to scale stomatal conductance and temperature and vapor pressure deficit effects on stoma opening times is also adjusted in the Mu e. al. improvement (2011).

For this study, the 1 Km^2 resolution MOD16 dataset is downloaded and isolated by month and county via help of the ArcGIS MODIS Toolbox from ESRI's HydroTeamRC. The monthly raster data is converted to points (one point in the centroid of each 858,782 m^2 cell) and points that lie within the ZOC are erased for all months. All ET volumes are calculated for each raster cell remaining in the county area to derive a total volume in cubic meters (m^3) per month. An example of the EWR adjusted sample locations for annual available ET from the MODIS16 dataset is given in Figure 5-4.

$$Available\ Annual\ M^3\ Green\ Water\ (W2c) = \sum_{t_m=12}^{n} \left\{ \left(\frac{ET_{green}[x, t_m]}{1000} \right) \langle ERASE \rangle\ ZOC[x] \right\} * (858782)$$

Where:

W2c = Total Adjusted Green Water Availability in cubic meters (M3)

ET_{green}[x,tm] = Monthly [t_m] estimated evapotranspiration (ET_{green}) for a ~1km (858,872 m^2) raster cell within county [x] in mm(The University of Montana 2010), converted to meters[t_m] via division by 1000

ZOC [x] = The total spatial extent [x] of the final Zone of Conservation (ZOC) (Equation 48)

$\langle ERASE \rangle$ = The defined spatial extent to the right of the $\langle ERASE \rangle$ symbol is erased from the spatial extent on the left of the symbol, performed in ArcGIS.

858782 = The area of each raster cell for which an ET point value is representative

Equation 32: Total Available Atmospheric Moiosture (Green Water Availability); adapted from (Hoekstra et al. 2011, p. 79)

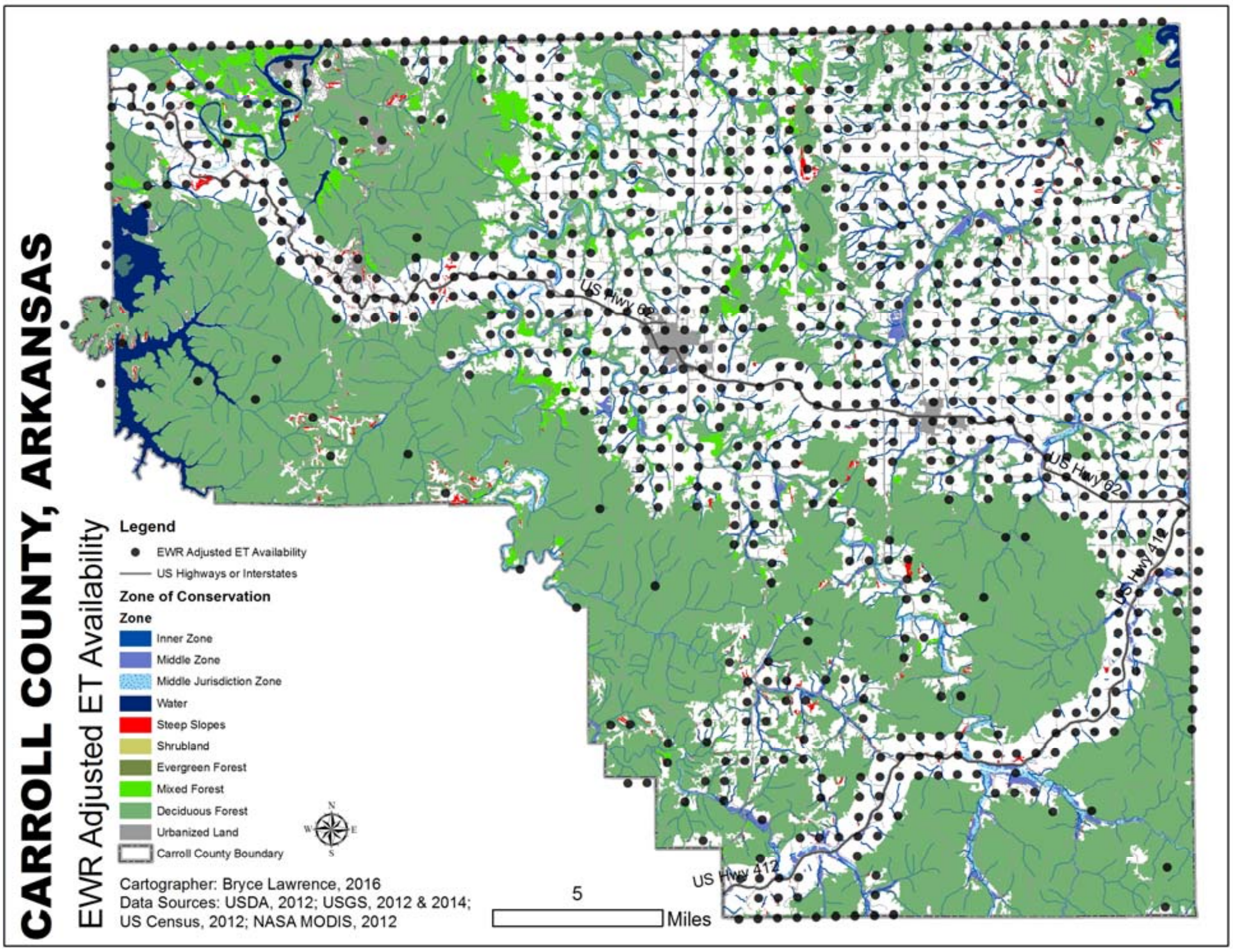

Figure 5-4: EWR Corrected Points for Sampling Evapotranspiration (ET) from MODIS 16 (Mu et al., 2011)

5.2.1.3 Total Available Runoff (W3c)

Total available runoff, or the renewable freshwater supply (RWFS) as described in Postel 1996, is derived from a high-resolution hydrological model used for climate analysis developed in recent research by the Oak Ridge National Laboratory (ORNL) and University of Alabama (Oubeidillah et al. 2014). The ORNL model is based on the variable infiltration capacity (VIC) hydrologic model and includes several factors, including the baseline required inputs for hydrologic modelling (meteorological forcings) such as precipitation, temperature, wind speed, soil characteristics from CONUS-SOIL dataset (USGS, 1998), land classification, vegetation from the MODIS 15AC le af area index (LAI) dataset, topography from the USGS NED dataset. The model produces a 4 kilometer gridded dataset of adjusted runoff in mm/month which is calibrated with runoff and stream flow observations (NWIS) and statistically grouped around HUC 8 subbasins (Oubeidillah et al. 2014). For sake of consistency with the other water components the formula for total available runoff is included below in Equation 33.

Another possible solution to arrive at a defensible RFWS is to calculate runoff for each case in this study using a hydrology model such as Hec-HMS, ArcHydro, ArcL-THIA, USGS TR-55, SWIM, etc or using a locally available and accepted runoff model such as one recently developed for a county from a stormwater, sewer, wastewater or other hydrologically related project. In this case, I contacted the Oak Ridge National Laboratory and they agreed to provide the geodata at a monthly time step from their 4x4 kilometer adjusted runoff model, which I believe is one of the best and most reliable datasets I could have used for the County Diagnostic. It is better than what I could have produced myself, is a smart time-savings to use existing datasets which help work through the water calculations quicker and above all is already a defensible peer reviewed data source.

The data was provided in the NetCDF format and was converted to a raster dataset using the Make NetCDF Raster Layer tool in ArcGIS and subsequently to points using the Raster to Points tool in GIS with all points in the centroid of each $4km^2$ raster cell. All points within the county boundary are selected and concatenated per month to arrive at a monthly runoff volume for the county (Figure 5-5). This method only includes raster tiles which are at least 50% within the county and as such some areas in the county are not attributed runoff and some areas outside of the county are attributed to runoff within the county. The logic in the method is that areas not accounted for in the county are offset by areas accounted for outside of the county.

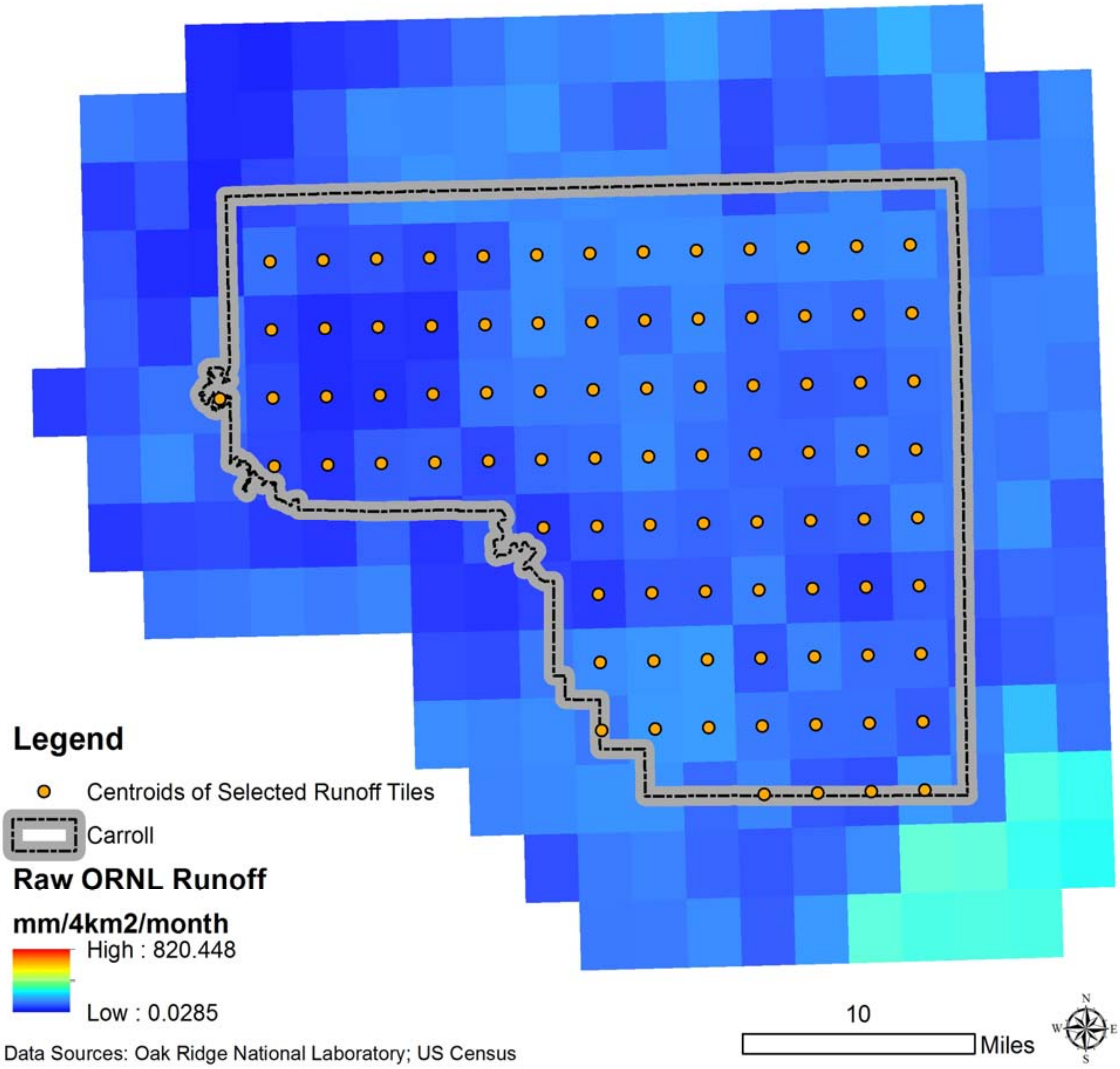

Figure 5-5: ORNL January 2012 Runoff Summary for Benton County, Oregon (Oubeidillah et al. 2014)

5.2.1.3.1 Total Adjusted Available Runoff (Blue Water)

The total available runoff quantity needs to be adjusted for ecosystem by subtracting the EWR from the ORNL runoff estimate (R_{nat}). A monthly volume of runoff in cubic meters needed to support basin-level ecosystems, known as environmental water requirements (EWR) (Smakhtin, Revenga, C. and Döll P. 2004, p. 308; Hoekstra et al. 2011, p. 151) as discussed in 5.2.1.1.2.

The calculation of the EWR is a two-step process where the monthly mean P25 volume of flow converted to a percentage of the mean annual runoff (MAR), which in turn is used to classify the stream into one of four categories in Table 5-13 with a corresponding percentage of mean monthly runoff (MMR) set aside for ecosystems. The P25 measure is used as a proxy to estimate the basin response to rainfall and allocates more water to basins with 'flashy' flow responses, indicated by relatively low flows for normal rainfalls and conversely few high intensity rainfalls accounting for a larger portion of monthly flow. In this case, the method allocates a larger percentage of MMR's to natural systems in basins with small relative P25 flows to the MAR because the time periods between saturation is longer than systems with stable flow patterns where water saturation in the vegetation, organic, soil and subsurface layers is more constant and available to ecosystems.

EWR Ratings as Percentage of P25 Compared to the Mean Annual Runoff (MAR) and Corresponding Allocation of EWR as percent of Mean Monthly Runoff (MMR)	
P25 as Percent of MAR	Percentage of MMR Alloted to EWR
P25 > 30% MAR	0% of MMR
20% MAR < P25 < 30% MAR	7% of MMR
10% MAR < P25 < 20% MAR	15% of MMR
P25 < 10% MAR	20% of MMR

Table 5-13: Categorization of MMF to Estimate Percentage of MMR allotted to EWR, Adapted from (Smakhtin, Revenga, C. and Döll P. 2004, p. 310)

The EWR is calculated on a monthly basis by multiplying the MMR (Oubeidillah et al. 2014) by the allotted EWR percent to derive a total cubic meters of runoff demanded by ecosystems monthly. Finally, EWR is subtracted from R_{nat} to derive the adjusted available runoff.

$$Annual\ Blue\ Water\ Availability\ in\ M^3\ (W3c) = \sum_{t_m=12}^{n}\left[\left(\sum_{s=1}^{n}((R_{nat}[x,t_m]/1000)*17241687.52)\right)-\left(\sum_{t_m=1}^{n}EWR\,[t_m,x]\right)\right]$$

Where:

$R_{nat}[x, t_m]$ *= The monthly [t_m] runoff estimate from (Oubeidillah et al. 2014) for county [x] in cubic meters*

$\sum_{t_m=1}^{n} EWR\,[t_m, x]$ *= A monthly percentage of R_{nat} which is subtracted from the raw R_{nat} value, based on a percent of MMR defined in Table 5-13*

1000 = Conversion of raw mm/month into meters/month

17241687.52 = Area of each grid cell in square meters, (17.24 Km^2) based on a 1/24th degree grid interval (4.623728 Km longitude x 3.728958 Km latitude).

Equation 33: Adjusted Annual Blue Water Availability

5.2.1.4 Critical Annual Nitrogen Load (W4c)

The critical annual nitrogen (N) load is a bottom-up calculation summed by month to reach the critical annual load, a load which would violate state ambient water quality standards according to the US CWA as discussed in section 3.5. To calculate this load, the ambient water quality standard for N is identified from the state level resource which is typically reported in the US EPA ECHO database (US EPA 2015) or from the Quality Criteria for Water as discussed in section 3.5.1.3.2 in the case that a TMDL has not been calculated for any basins in the county. In the case that there is more than one critical load, which is the case for counties with more than one HUC 8 basin, an average of critical loads is created for the county.

The formula for calculating the critical load is presented following Hoekstra (Hoekstra et al. 2011, pp. p.34) in Equation 34 below, where the critical load is equal to the natural runoff times the product of the maximum allowable load minus the natural background concentration. The total value in tons is added to the NDI factor summary sheet in box W4c as total tons per year, but the monthly averages are graphed and used as supplemental information in the discussion.

$$Critical\ Annual\ Nitrogen\ Load\ in\ Tons\ (W4c) =$$

$$\sum_{t_m=12}^{n} \left\langle \frac{\left\{\left(\frac{R_{nat}\,[x,t_m]}{f_5}\right) * \bar{N}_{max}[x,t_m]\right\} - \left\{\left(\frac{R_{nat}\,[x,t_m]}{f_5}\right) * N_{nat}[\bar{r}]\right\}}{f_4} \right\rangle$$

Where:

$R_{nat}[x, t_m]$ *= Runoff at the county scale [x] per month[t_m] from the Oak Ridge National Laboratory (Oubeidillah et al. 2014) in cubic meters per month.*

$\bar{N}_{max}[x, t_m]$ *= The average monthly maximum allowable concentration of nitrogen for all reported facilities based on US EPA state or national regulations (US Environmental Protection Agency 5/1/1986; US EPA 2015), scaled up from mg/l to metric tons per month. The critical load can also be based on a calculated TMDL or WQBEL by basin if existing.*

$N_{nat}[\bar{r}]$ *= The natural regional background concentration of N as published by (Smith et al. 2003, p. 3046) in mg/l.*

f_4 *= A constant,* 1000000000 *(milligrams per metric ton)*

f_5 *= A constant, 0.001 (liters to cubic meters)*

Equation 34: Critical Annual Nitrogen Load Calculation, Adapted from Hoekstra (Hoekstra et al. 2011)

5.2.1.5 Critical Annual Phosphorus Load (W5c)

The critical annual phosphorus load is a bottom-up monthly calculation that is summed by month to reach the critical annual load, a load which would violate state ambient water quality standards according to the US CWA as discussed in section 3.5. To calculate this load, the ambient water quality standard for phosphorus (P) is identified from the State level resource calculated as a TMDL by HUC 8 basin, which is typically reported in the US EPA ECHO database (US EPA 2015), or from the Quality Criteria for Water as discussed in section 3.5.1.3.2 in the case that a TMDL has not been calculated for any basins in the county. In the case that there is more than one critical load in mg/l reported, an average of critical loads is created for the county.

The formula for calculating the critical load is presented following Hoekstra (Hoekstra et al. 2011, p. 34) in Equation 35 below, where the critical load is equal to the natural runoff times the product of the maximum allowable load minus the natural background concentration. The total value in tons is added to the NDI factor summary sheet in box W5c as total tons per year, but the monthly averages are graphed and used as supplemental information in the discussion.

$$Critical\ Annual\ Phosphorus\ Load\ in\ Tons\ (W5c) =$$

$$\sum_{t_m=12}^{n} \langle \frac{\left\{\left(\frac{R_{nat}\ [x, t_m]}{f_5}\right) * \ \bar{P}_{max}[x, t_m]\right\} - \left\{\left(\frac{R_{nat}\ [x, t_m]}{f_5}\right) * P_{nat}[\bar{r}]\ \right\}}{f_4} \rangle$$

Where:

$R_{nat}[x, t_m]$ *= Runoff at the county scale [x] per month [t_m] from the Oak Ridge National Laboratory (Oubeidillah et al. 2014)*

$\bar{P}_{max}[x, t_m]$ *= The average maximum monthly allowable concentration of phosphorus for all reported facilities per month based on US EPA state or national regulations (US Environmental Protection Agency 5/1/1986), scaled up from mg/l to metric tons per month, Or from a calculated TMDL or WQBEL if existing (US EPA 2015).*

$P_{nat}[\bar{r}]$ *= The natural regional background concentration of P as published by (Smith et al. 2003, p. 3046) in mg/l.*

f_4 *= A constant,* 1000000000 *(milligrams per metric ton)*

f_5 *= A constant, 0.001 (liters to cubic meters)*

Equation 35: Critical Annual Phosphorus Load Calculation, Adapted from Hoekstra (Hoekstra et al. 2011)

5.2.2 Water Demand

Water demand in the County Diagnostic is calculated in a similar way to the Capacity, where a number of sub-formulas or models are used to derive five single floating point values (W1d – W5d) quantifying the water demand of the county in terms of total water demanded, green water and blue water demand and grey water loads for N and P (Table 5-11).

5.2.2.1 Total Adjusted Water Abstractions (W1d)

Total gallons of water abstraction (W1d) is an adjusted value based on water abstraction derived from the USGS National Water Information System (NWIS) Water Use Data for the Nation (United States Geological Survey (USGS) 1985-2010) and on reported WWTP return flows from the US EPA Enforcement and Compliance History Online (ECHO) system (https://echo.epa.gov/facilities/facility-search). Total returns are subtracted from total abstraction to calculate the total adjusted human abstraction of water in gallons (W1d) annually for use in the NDI-W1 equation, however the renewable runoff capacity (W1c) is also compared to the total water abstraction (w1d) on a monthly basis (since water abstractions and water availability (runoff) data are available at the monthly time step) as supporting data to help identify temporal "hot spots" where demand may exceed capacity in a couple months but indicate excess capacity in the NDI-W1 calculation.

The formula to calculate the total adjusted water abstractions (Equation 36) includes USGS National Water Information System NWIS reported abstractions in million gallons per day (MGD) for surface and ground water in the categories of public supply[2], mining, livestock, aquaculture, and irrigation[3](USGS 2010). Water returns from human systems are estimated as the sum of all reported returns for all permitted facility types in the US EPA ECHO database and subtracted from the abstractions to derive an adjusted rate of water abstraction per month. A sample summary table from Benton County, Oregon is included below (Table 5-14), indicating how the data from the USGS NWIS and US EPA ECHO/NPDES is summarized.

[2] Which includes commercial, domestic, industrial, and power generation demands

[3] For irrigation, water-use data from the entire year is divided by the number of days per year and do not represent actual daily rates. Irrigation in reality is only applied during a portion of the year, which is variant in each county based on seasonality, and therefore the actual rates of application per day during periods demanding irrigation are greater than the reported rates. However, for comparative purposes between boundary types, the daily average rate is computed United States Geological Survey (USGS) 1985-2005.

$$Total\ Adjusted\ Annual\ Water\ Abstractions\ in\ M^3\ (W1d) = \sum_{t_m=12}^{n} \langle \left\{ \left(ABS_{pub}[x,t_m] + ABS_{mining}[x,t_m] + ABS_{live}[x,t_m] + ABS_{aqua}[x,t_m] + ABS_{irr}[x,t_m] - \left(\sum_{pt=1}^{n} RET[ft,x,t_m] \right) \right) * f_7 \right\} * D_m \rangle$$

Where:

ABS_{pub} [x, t_m] = Public Supply abstractions in MGD for surface and groundwater per county [x] and month [t_m] (USGS 2010)

ABS_{mining} [x, t_m] = Mining abstractions in MGD for surface and groundwater (USGS 2010)

ABS_{live} [x, t_m] = Livestock abstractions in MGD for surface and groundwater (USGS 2010)

ABS_{aqua} [x, t_m] = Aquaculture abstractions in MGD for surface and groundwater (USGS 2010)

ABS_{irr} [x, t_m] = Abstractions for crop irrigation in MGD for surface and groundwater (USGS 2010)

RET [ft,x, t_m] = Return surface flows from all reported NPDES regulated facility types [ft] in MGD(US EPA 2015)

f7 = A constant, MGD to cubic meters per day conversion (4546.09)

D_m = Number of days [D] per month [m]

Equation 36: Total Adjusted Water Abstractions Calculation (W1D)

The NWIS dataset that is currently available is 2010, not the 2012 case study year as with most other data sets, which is due to the fact that water abstraction by the USGS is reported on a 5-year basis and thus 2010 is the closest year to 2012 which can be evaluated. This does introduce some potential error and no attempt is made to correct this issue since water abstraction and land uses are likely substantially unchanged between 2010 and 2012 for a majority of counties. For all categories in the NWIS data, the reported value utilized in this study is the sub-category of 'Total Use,' which is summarized separately by surface and ground water sources for each category. Surface and ground water source abstractions are combined in all of the abstraction categories with the ABS prefix in Equation 36.

Benton County, Oregon 2010 Adjusted Water Abstraction		
Category	**Mgal/D Surface**	**Mgal/D Ground**
Public Supply	9.49	0.11
Mining	-	0.76
Livestock	0.1	0.07
Aquaculture	6.62	-
Irrigation	16.1	9.11
Daily Total	*32.31*	*10.05*
Annual Abstraction Projection by Source (USGS NWIS)	11,793	3,668
Total Annual Abstraction in Mgal	15,461	
Total Annual Returns (US EPA ECHO / NPDES)	4,736	
Total Adjusted Abstraction in Mgal	**10,725**	

Table 5-14: Benton County, Oregon Annual Municipal Water Abstraction (USGS 2010)

5.2.2.2 Total Green Water Consumption (W2d)

Total cubic meters of consumed green water, defined as "precipitation that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation (Hoekstra et al. 2011, p. 189)," is calculated in demand factor calculation W2d. The green water consumption estimate includes the green water consumed from all crop types and from all feed crops (limited to corn in this method). The estimation of the total amount of green water used by plant and animal transpiration and respiration is estimated with the NASS 2012 crop and livestock data summarized in section 5.1.2, which provides a quantity of production in tons for all crop types per county (United States Department of Agriculture 2012a), which are multiplied by published green water consumption rates in M^3/Ton/year of plant and animal products (Mekonnen, Hoekstra 2010a)[4]. Annual green water demand is extrapolated monthly based on active growing seasons because the NASS data on crop production and blue water values are reported annually and thus the monthly time step requires production to be distributed as an average throughout the growing season.

[4] It should be noted that the reported green and blue water consumption figures from Mekonnen and Hoekstra (2010) are specific to geographic sub-regions for the United States, meaning blue and green water is reported by state. For this reason, it is necessary to update numbers in the crosswalk for each State when computing green and blue water consumption.

The formula for green water consumption (Equation 37 below) includes an estimate of all crop production in the county defined by $CROP_{type}$ [p,x,$t_{(t,f)}$] of crop type [p] by county [x] per month [t] for all 80 crop types from the 2012 NASS survey of agriculture (United States Department of Agriculture 2012a) multiplied by the GWF_{cons} [p,s] green water consumption of each crop type [p] in cultivation system [s] (Mekonnen, Hoekstra 2010a) to derive a total cubic meters of green water consumption of all crop types in a county per month. This is added to the product of $FEED_{type}$ [p,x,t_m] in tons per month times the green water requirement for feed types, which in this case include hay (calculated as pasture (USDA 1994, p. 22) and corn (calculated as fodder crops USDA 1994, pp. p. 22). All green water demands, except for livestock feed, are summarized by crop and by month based on crop type growing season, resulting in a heterogeneous distribution of green water demand annually. Green water demand for feed is assumed to be a monthly constant and thus the total green water demand for feed was divided by 12 and added to each month. The monthly green water values are summarized to derive the annual green water demand in cubic meters.

$$Annual\ Green\ Water\ Demand\ in\ M^3\ (W2d) = \sum_{t_{m=12}}^{n} \left\{ \sum_{p=1}^{n} \left(CROP_{type}\left[p, x, t_{m(t,f)}\right] * GWF_{cons}[p] \right) + \sum_{p=1}^{n} \left(FEED_{type}\left[p, x, t_{m(t,f)}\right] * GWF_{cons}\,[p] \right) \right\}$$

Where:

$CROP_{type}\left[p, x, t_{m(t,f)}\right]$ *= Tons of crop type [p] per county [x] (USDA 1994) per month [$t_{m(t,f)}$] with active [t_m(t)] or inactive [t_m(f)] growing season of crop type [p] (USDA 1997)*

FEEDtype [p,x, t_m] = Tons of feed type [p] demanded per county [x], derived from 5.1.3.2 (F2d) above per month [t_m] (USDA 1997)

GWFcons [p] = The green water consumption of crop type [p] in M^3 (Mekonnen, Hoekstra 2010a, 2010c)

Equation 37: Green Water Consumption of Crop and Livestock Products in Mgal / Year

5.2.2.3 Total Consumed Surface Water: Blue Water (W3d)

Total cubic meters of consumed surface water, also referred to as blue water (Hoekstra et al. 2011), is calculated in demand factor calculation W3d. Blue water consumption is defined as the water consumption of internal processes within the county, expressed as $WF_{cons,county,int}$ in the Water Footprint terminology for administrative units or national accounting(Hoekstra et al. 2011, p. 55;63), and includes the water consumption of crops, the water consumption of drinking and service water used for livestock and the water consumption in livestock feed (corn and crop fodder in this case). This accounting method is defined as the "use of domestic water resources to produce goods and services consumed by inhabitants of the country (Hoekstra, Chapagain 2006, p.2)," with county in this method instead of country. The County Diagnostic method does not currently account for industrial or public supply blue water consumption, which has been estimated at 4.4% and 3.6% of the total blue water consumption of nations respectively (Hoekstra, Mekonnen 2012, p. 2), which means the blue water consumption presented here could be conservative by about eight percent. These two factors could be included in Equation 38 if new data or methods become available.

The estimation of the total amount of surface or ground water used by plant and animal metabolism is estimated with the NASS 2012 crop and livestock data summarized in section 5.1.2, which provides a quantity of production in tons for all crop types per county (United States Department of Agriculture 2012a) and published blue water consumption rates in M^3/Ton/year of plant and livestock products (Chapagain, Hoekstra 2003, Mekonnen, Hoekstra 2010a, 2010a)[5].

The formula for blue water consumption (Equation 38 below) includes an estimate of all crop production $CROP_{type}$ [p,x,$t_{(t,f)}$] in the county [s] by crop type [p] for all 80 crop types from the 2012 NASS survey of agriculture(United States Department of Agriculture 2012a) during each month[t_m] of the active growing season [$t_{m(t,f)}$] (USDA 1997; Arguez et al. 2010) multiplied by each crop type specific blue water consumption BWF_{crop}[p] of crop type [p] in cubic meters (Mekonnen, Hoekstra 2010a) to derive a total cubic meters of blue water consumption for all crop types in a county per month. If the crop is not in its growing season [t_f] then there is no blue water demand for that crop for the inactive month. The total blue water demand is calculated for livestock by multiplying the total tons of $FEED_{type}$ [p,x,t_m] type[p] per month [m] per county [x] for all head of livestock POP [a,x,t] type[a] per county [x] raised per year [t] (Mekonnen, Hoekstra 2010a). Blue water consumption is summarized for each month with blue water crop demands being distributed by growing season and livestock demands distributed by monthly average.[6] Insolation percentages between average spring and fall frost dates could also be used to artificially allot monthly values.

Drinking water consumption for livestock is calculated by multiplying POP [a,x,t] the number of livestock type per head[a] per county [x] per month [t], times the DW_{cons} [a,s] drinking water consumption of animal type[a] calculated as the average value from all system types[s] in liters per day (Mekonnen, Hoekstra 2010b) multiplied by the number of days per month. Service water consumption for livestock is calculated by multiplying POP [a,x,t] the number of livestock type per head [a] per county [x] per month [t], times the SW_{cons} [a, $\bar{s}$] service water consumption of animal type [a] calculated as the average value from all system types [$\bar{s}$] in liters per day (Mekonnen, Hoekstra 2010b), summarized by month. All DW and SW values are for adult livestock and poultry and the average between industrial and grazing system values are used because NASS does not

[5] It should be noted that the reported green and blue water consumption figures from Mekonnen and Hoekstra (2010) are specific to geographic sub-regions for the United States, meaning blue and green water is reported by state. For this reason, it is necessary to update numbers in the crosswalk for each State when computing green and blue water consumption.

[6] This means that feed crop utilization in months when the crop is not growing in the county (ie. winter) will incur additional blue water demand for a product that may have been counted already in the summer production and then stockpiled if there is excess feed crop production capacity in the county; If the county falls short of feed crop production compared to their livestock feed demand, then the winter month blue water footprint of livestock crop products rightly represents an additional blue water demand which should have occurred in the county during the summer, but did not and thus feed was imported. This can be evaluated and adjusted on a case by case basis.

report on specific system types. Drinking and service water are summed to derive the total blue water consumption per county annually in cubic meters.

$$
\begin{aligned}
&Annual\ Blue\ Water\ Demand\ in\ M^3\ (W3d) \\
&\quad = \sum_{t_m=12}^{n} \langle \left\{ \sum_{p=1}^{N} \left(CROP_{type}\left[p, x, t_{m(t,f)}\right] *\ BWF_{crop}[p] \right) \right\} \\
&\quad + \left\{ \sum_{p=1}^{N} \left(FEED_{type}[p, x, t_m] *\ BWF_{crop}[p] \right) \right\} \\
&\quad + \left\{ \sum_{a=1}^{N} (POP[a, x, t] *\ (DW_{cons}[a, \bar{s}] * D_m *\ f_5)) \right\} \\
&\quad + \left\{ \sum_{a=1}^{N} (POP[a, x, t] *\ (SW_{cons}[a, \bar{s}] * D_m *\ f_5)) \right\} \rangle
\end{aligned}
$$

Where:

$CROP_{type}$ *[p,x,$t_{m(t,f)}$] = Tons of crop type [p] per county [x] (United States Department of Agriculture 2012b) per month [$t_{(t,f)}$] with active [t] or inactive [f] growing season of crop type [p] (USDA 1997).*

BWFcrop[p] = The blue water consumption in cubic meters (M^3) per ton for crop type [p] (Mekonnen, Hoekstra 2010a).

$FEED_{type}[p, x, t_m]$ *= Tons of feed crop [p] per county [x] from 5.1.3.2 above per month [t_m] (USDA 1997).*

POP[a,x,t] = Head of livestock type [a] per county [x] per year [t] from section 5.1.3.2.

$DW_{cons}[a, \bar{s}]$ *= Drinking water consumption of livestock type [a] assuming values from the average of industrial and grazing system types* $[\bar{s}]$ *in liters/day (Chapagain, Hoekstra 2003, p. 29)*

$SW_{cons}[a, \bar{s}]$ *= Service water consumption of livestock type [a] assuming values from the average of industrial and grazing system types* $[\bar{s}]$ *in liters/day (Chapagain, Hoekstra 2003, p. 30)*

f_5 *= A constant, 0.001 (liters to cubic meters)*

Dm = Number of days [D] per month [m]

Equation 38: Blue Water Consumption of Crop and Livestock Products in M^3 / Year Adapted from (Hoekstra, Mekonnen 2012, SI p. 1; Mekonnen, Hoekstra 2012, p. 403).

5.2.2.4 Total Annual Nitrogen Load in Tons (W4d)

The total annual nitrogen load is calculated from point and non-point sources. Non-point sources include nitrogen contained in agricultural crop and feed runoff and point source loads of nitrogen are summarized from all NPDES water emissions permits in a county reported via the EPA Enforcement and Compliance History Online (Echo) (US EPA 2015).

The total non-point source derived nitrogen load is calculated using a fixed fraction approach where a percentage of the total volume of applied nitrogen from crop products is assumed to enter surface water via a diffuse runoff source and thereby is difficult to measure without a complex land cover and runoff model which also estimates pollutant loads or field measurements. Since this study relies on an existing dataset for runoff volumes (Oubeidillah et al. 2014), detailed food production volumes and areas are known (United States Department of Agriculture 2012b, 2012b, 2012a) and nitrogen application rates by crop type and country are estimated (FAO 2006), it was chosen to use the fixed fraction approach to calculate the N load based on a decision matrix in the Water Footprint accounting method (Hoekstra et al. 2011, p. 37) in absence of detailed models or field observations.

The fixed fraction approach assumes leaching of 10% of applied nitrogen fertilizer in crop fields, a number taken from an international study on Cotton crops and not specifically corrected for different crops or different areas of the United States (Chapagain et al. 2006, pp. p. 192), which introduces an unknown level of error but is based on the best available data and recommendations from previous studies. This assumption can be changed within the framework if leeching rates are known for a specific county or new research emerges. The N load is assumed to be distributed once per year.[7] A nitrogen runoff estimate is not included for hay feed production under the assumption that hay fields are not typically fertilized.

The formula for the N load (Equation 39 below) includes the load from crops and from reported point sources. N loads (N_{load}[p,C]) per crop type [p] in country [C] in kg/Hectare are reported in the FAO Fertistat database (FAO 2006) for all crop types at the global level (which includes estimates for the USA). The N_{load} is multiplied by $CROP_{cover}$ [pHa,x,t_y] for each specific crop type in Hectares land cover[pHa] in the county[x] per year[t_y] from the 2012 US Census of Agriculture (United States Department of Agriculture 2012b) to derive a total kg/year. The total estimated non-point source loads are multiplied by a 10% leaching multiplier to estimate the volume of nutrient that enters surface or subsurface flow.

$N_{pointload}$ [ft,t_m] is the sum of all point source reported N discharges in milligram per liter (mg/l) (US EPA 2015) by facility type [ft] per month[t_m] which are multiplied by Q [ft,t_m] the total discharge (Q) for each facility type [ft] in MGD transformed to million liters month. Months are summarized and converted from total milligrams to total tons per year.

$$Total\ Annual\ Nitrogen\ Load\ in\ Tons\ (W4d) =$$

$$\{((N_{load}[p,C]) * CROP_{cover}[pHa,x,t_{\mathrm{y}}]) * 0.10\} + \left\{ \sum_{t_{m=12}}^{N} \langle \{N_{pointload}\ [ft,t_m] * (Q[ft,t_d] * f_3) * D_m\} \ / f_4 \rangle \right\}$$

[7] In reality, the temporal application of N fertilizers varies based on individual farm practices and could vary from equal monthly applications to heavy early applications with planning to detailed monitoring with applications later in the growing season when N is most demanded by cropsScharf, P., Lory, J. 2006.

Where:

N_{load} *[p,C] = Nitrogen load of crop type [p] in metric ton per hectare (Mt/Ha) in country [C] (FAO 2006)*

$CROP_{cover}[pHa, x, t_y]$ *= Total crop type coverage in hectares [pHa] adjusted per county [x] per year* $[t_y]$ *(United States Department of Agriculture 2012b)*

$N_{pointload}$ *[ft,t_m] = All reported point source loads in milligrams per liter (mg/l) of N for facility type [ft] monthly [t_m] (US EPA 2015)*

Q [ft,t_m] = Sum of total water discharge for facility type [ft] per day [t_d] in million gallons per day (MGD), converted to million liters per day (US EPA 2015)

f_3 *= A constant: 3.78541178 (Gallons to Liters)*

f_4 *= A constant:* 1000000000 *(milligrams per metric ton)*

D_m = Number of days [D] per month [m]

Equation 39: Total Annual Nitrogen Load in Tons (W4d) Adapted from (Hoekstra et al. 2011, p. 147)

5.2.2.5 Total Annual Phosphorus Load in Tons (W5d)

The total annual phosphorus load is calculated from point and non-point sources. Non-point sources include phosphorus contained in agricultural runoff from fields which grow feed crops. Point source loads of phosphorus are summarized from all NPDES water emissions permits in a county via the EPA Enforcement and Compliance History Online (Echo) (US EPA 2015).

The total non-point source derived phosphorus load is calculated using a fixed fraction approach where a percentage of the total volume of applied phosphorus from crop products is assumed to enter surface water via a diffuse runoff source and thereby is difficult to measure without a complex land cover and runoff model which also estimates pollutant loads or field measurements. Since this study relies on an existing dataset for runoff volumes (Oubeidillah et al. 2014), detailed food production volumes and areas are known (United States Department of Agriculture 2012b, 2012b, 2012a) and phosphorus application rates by crop type are already estimated (FAO 2006), it was chosen to use the fixed fraction approach to calculate the P load based on a decision matrix in the Water Footprint accounting method (Hoekstra et al. 2011, p. 37) in absence of detailed models or field observations.

The fixed fraction approach assumes leaching of 10% of applied phosphorus fertilizer in crop fields, a number taken from an international study on Cotton crops and not specifically corrected or analyzed for areas of the United States (Chapagain et al. 2006, p. 192), which introduces an unknown level of error but is based on the best available data and recommendations from previous studies. This assumption can be changed within the framework if leeching rates are known for a specific county or new research emerges. A phosphorus runoff estimate is not included for hay feed production under the assumption that hay fields are not typically fertilized.

The formula for the P load (Equation 40 below) includes the load from crops and from reported point sources. P loads (P_{load}[p,C]) per crop type [p] in country [C] and system type [s] in kg/Hectare are reported in the FAO Fertistat database (FAO 2006) for all crop types at the global level (which includes the USA). The P_{load} [p,c] is multiplied by $CROP_{cover}$ [pHa,x,t_y] the specific crop type in hectares land cover [pHa] in the county [x] per year [t_y] from the 2012 US Census of Agriculture (United States Department of Agriculture 2012b). The total estimated non-point source loads are multiplied by a 10% leaching multiplier to estimate the volume of nutrient that enters surface or subsurface flow.

This is added to $P_{pointload}$ [ft,t_m], the sum of all point source reported P discharges in mg/l (US EPA 2015) by facility type [ft] per month [t_m] which are multiplied by Q [ft,t_m] the total discharge (Q) per facility type [ft] in liters transformed to million liters month. Months are summarized and converted from milligrams to metric tons per year.

$$Total\ Annual\ Phosphorus\ Load\ in\ Tons (W5d) =$$

$$\left\{\left((P_{load}[p,C]) * CROP_{cover}[pHa,x,t_y]\right) * 0.10\right\} + \left\{\sum_{t_{m=12}}^{P} \langle \{P_{pointload}\ [ft,t_m] * (Q[ft,t_d] * f_3) * D_m\} \ / f_4 \rangle \right\}$$

Where:

P_{load} *[p,C] = Phosphorus load of crop type[p] in metric ton per hectare (Mt/Ha) in country [C] (FAO 2006)*

$CROP_{cover}$ $[pHa, x, t_y]$ *= Total crop type coverage in hectares [pHa] adjusted per county [x] per year [t_y] (USDA 1997)*

$P_{pointload}$ *[ft,t_m] = All reported point source loads (mg/l) of P for facility type [ft] monthly [t_m] (US EPA 2015)*

Q[ft,t_m] = Sum of water discharge for facility type [ft] per month [t_m] in million gallons, converted to million liters (US EPA 2015)

f_4 *= A constant:* 1000000000 *(milligrams per metric ton)*

D_m = Number of days [D] per month [m]

Equation 40: Total Annual Phosphorus Load in Tons (W5d) Adapted from (Hoekstra et al. 2011, p. 147)

5.2.3 Calculation of Water Balances

With the summary for all water factors (W1c-W5c and W1d-W5d) calculated as explained above, the integer variables are fed into their assigned NDI equation formulas (NDI-W1 through NDI-W5) so that a direction and magnitude can be calculated for each of the water factor balances. The results of the NDI are from 1.00 to -1.00, where 1.00 is an overwhelming abundance of capacity compared to demand, -1.00 is an overwhelming demand compared to capacity and zero (0) means equal capacity and demand.

$$NDI - W1 = \frac{W1c\ (Runoff\ Capacity) - W1d\ (Water\ Abstraction)}{(W1c + W1d)}$$

Equation 41: NDI-W1 - Available Water Balance

$$NDI - W2 = \frac{W2c\ (Green\ Water\ Availability) - W2d\ (Green\ Water\ Demand)}{(W2c + W2d)}$$

Equation 42: NDI-W2 – Green Water Balance

$$NDI - W3 = \frac{W3c\ (Blue\ Water\ Availability) - W3d\ (Blue\ Water\ Demand\ )}{(W3c + W3d)}$$

Equation 43: NDI-W3 – Blue Water Demand

$$NDI - W4 = \frac{W4c\ (Critical\ Nitrogen\ Load) - W4d\ (Annual\ Nitrogen\ Load)}{(W4c + W4d)}$$

Equation 44: NDI-W4 – Nitrogen Balance

$$NDI - W5 = \frac{W5c\ (Critical\ Phosphorus\ Load) - W5d\ (Annual\ Phosphorus\ Load)}{(W5c + W5d)}$$

Equation 45: NDI-W5 – Phosphorus Balance

5.3 Zone of Ecosystem Conservation

The feasibility of a county to create a circular metabolism and meet the demands of the county population or urban metabolism has considerably less meaning and resilience to environmental change if the areas for net primary production, ecosystem services some level of plant and animal habitat and biodiversity protection is not included. To address this concern and estimate an area-based land conservation strategy, the zone of conservation (ZOC) is included in the County Diagnostic which measures the underlying protection of natural systems afforded by a county's land use arrangement. The total potential area in a county identified in the ZOC analysis (EC2c) is compared to a policy-based target of 17% strategic land area conservation (EC1 & 2d) (Tittensor et al. 2014, p.242), which is also compared to the national Protected Areas Database (PAD-US) conservation areas (EC1c). As in the other components, the NDI equation is used to summarize the two relationships (See Figure 5-6) and the values are plotted on the vertical or circular waveform. The methods used are discussed in detail in this section below.

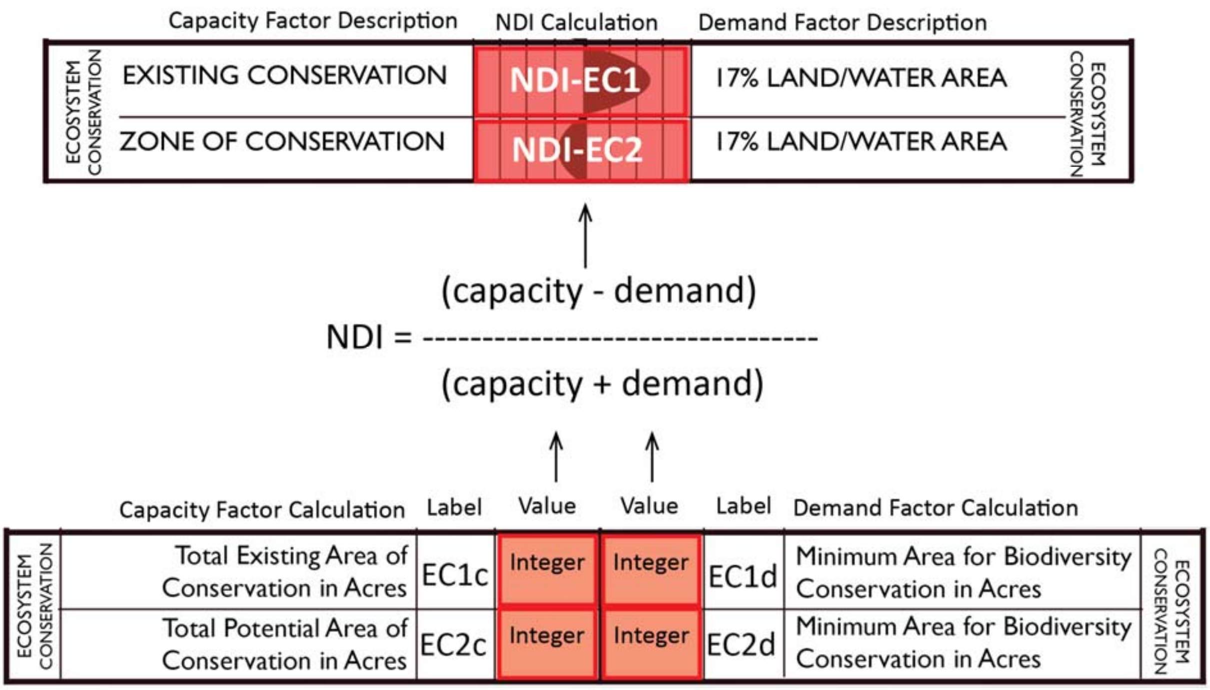

Figure 5-6: Zone of Conservation Method Overview

5.3.1 Ecosystem Area Capacity

5.3.1.1 Jurisdictional Conservation (EC1c)

The current legally conserved areas defined by the USGS are used as a measure of existing ecosystem area 'capacity' with the logic that this is the area that will be protected from development or land-use alterations. This measure is taken from the USGS Protected Area Database of the United States (PAD-US) (US Geological Survey, Gap Analysis Program (GAP) 2012). The PAD-US database (Ver. 1.3) represents the most up-to-date understanding of protected areas in the USA and their status as (1 & 2) managed for biodiversity, (3) managed for multiple uses and (4) no known mandate for protection. All other areas in the USA have no protection, even though many areas are parts of species habitat ranges (Howie et al. 2012). Within the PAD-US are threatened and endangered (T&E) amphibian, bird, mammal and reptile habitat areas. The datasets is summarized by county to derive the capacity factor (EC1c), which can be expressed as Equation 46 below, and is presented in Figure 5-7.

$$Existing\ Conservation\ Area = PADUS[x]$$

Where:

PAD-US [x] = The clipped area in the PAD-US database by county [x] (US Geological Survey, Gap Analysis Program (GAP) 2012)

Equation 46: Calculation of Existing Jurisdictional Conservation Areas (EC1c)

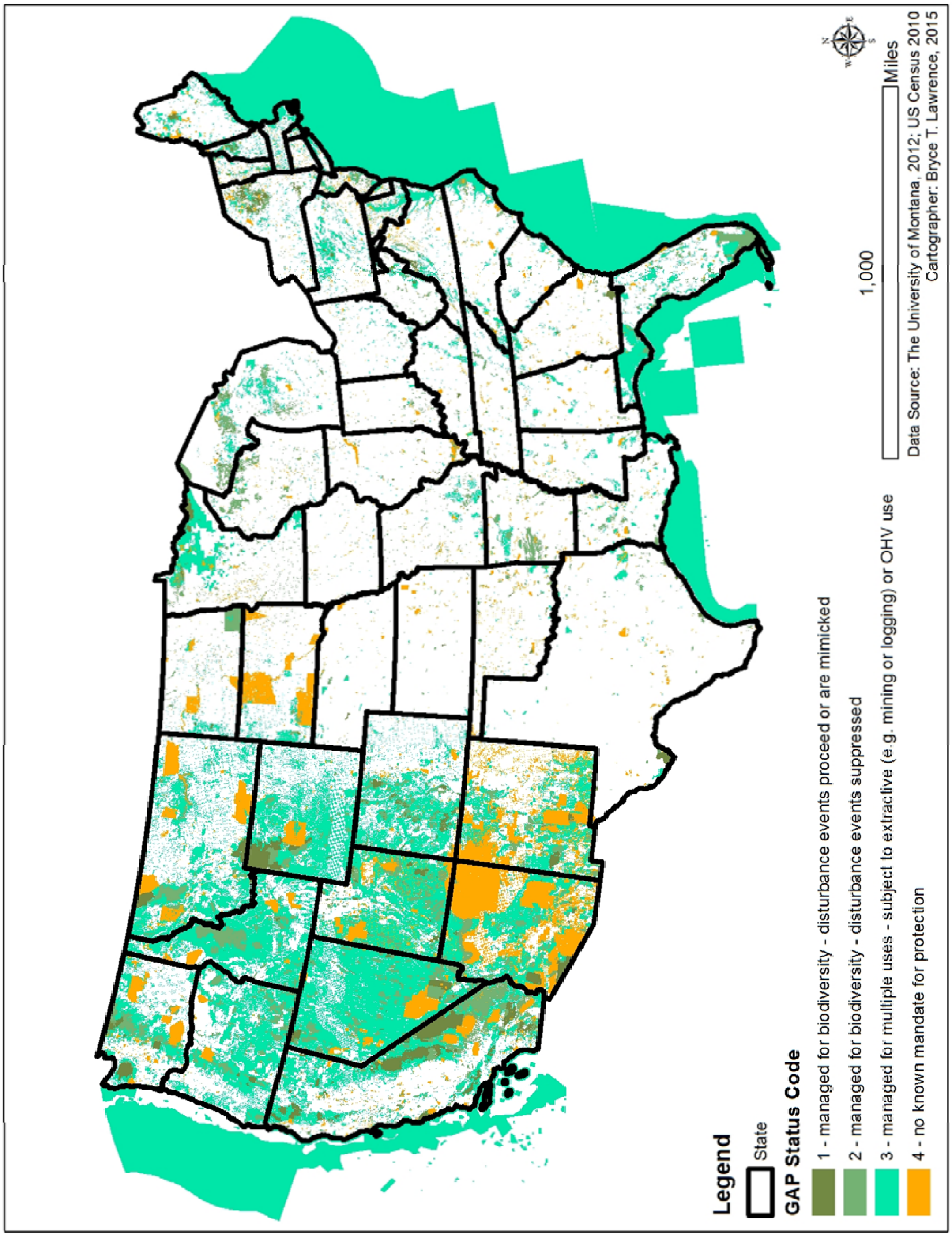

Figure 5-7: PAD-US Database of Protected Areas in the United States

5.3.1.2 Ecological Conservation (EC2c)

To operationalize an ecological conservation approach different from the jurisdictional approach, Forman's patch, corridor and network theory is subdivided into a tiered approach using the work of Brown (Brown 2010), who defines inner, middle, and outer "stream setback zones" that transforms the theoretical area for preservation into zones, an approach that has had success transferring this defined conservation area into adopted stream setback policy and ordinances in the Midwest United States (Vireo et. al). This three tiered approach is further subdivided into a 5 zones of protection discussed in the next paragraph. From a data standpoint, the ZOC includes 1) a hydrologic resource network (streams, floodplains, wetlands, alluvium), 2) the contiguous non-urban and non-agricultural vegetation cover that intersect the hydrologic resource network and are within 100' of the hydrologic network or sensitive soil resources, 3) the sensitive soil resources and topographic situations which underlie the hydrologic resource network and patch/corridor structure (hydric soils, steep slopes, non-FEMA protected geomorphic flood terraces), 4) the identified habitats of threatened and endangered fishes, amphibians, birds, vegetation, and terrestrial wildlife (USGS T&E Species), and places already set aside for conservation through state and federal regulations.

The ZOC relates directly to two hydrologic-based ecosystem management strategies, including 1) the watershed level of the "Triple Barrier Approach" (Marsalek, Schreier 2009) which creates wide riparian buffers with wetlands to retain sediment and resist pulses of flood energy, helps maintain natural channel and facilitates increases of soil moisture in the zone where plant roots require it, and avoids channelization of flood corridors which can push energy and materials downstream where it can be a detriment to human settlements, and 2) the energy-transport-reaction (ETR) model developed by Wilhelm Ripl which proposes a "sustainable restitution of a catchment" that restores forests in uplands, provides vegetative breaks downslope from human developments, and positions agriculture in the low lying flood zones with the intended consequences of improving vegetative cover, improving soils structure via mineral and nutrient retention (as opposed to soil losses via wind and water erosion), enhances micro-climates and hydrologic "short-cycles," detoxifies soils via vegetative growth, and protects groundwater recharge and supply (Ripl 1995).

This approach translates into a ZOC with 5 zones, including:

1) An inner zone of USGS perennial streams and waterbodies (lakes and probably wetlands) with an applied 100' buffer representing the direct area of surface water flow. Most counties have a minimum stream buffer or stream setback regulation which prohibit development or modification of this area, which has been recommended at 100-feet by the EPA (Brown 2010, p. 51). When applied to individual counties, existing stream setback ordinances should be reviewed and the correct setback distance should be used for the inner zone. When no ordinance exists, a 100-meter value (tripled for a factor of safety) should be used or field studies should be conducted to create an appropriate buffer zone.

2) A middle jurisdictional zone which is the area defined by FEMA as a regulated floodplain, and for which the US Army Core of Engineers (USACOE) and FEMA have calculated a HEC-RAS-based flood risk model that determines the 100-year (.1% chance) and 500-year (.05% chance) flood elevation,

thereby requiring flood insurance. This area typically corresponds to wide geomorphic floodplains at the lower elevations of a sub-basin and which often coincide with glacially deposited unconsolidated alluvial aquifers that underlie the floodplain, thereby acting as an aquifer recharge zone. However, the regulations for uses of floodplains does not bar development, rather it typically only requires that a commerce, industry, or homeowner purchase flood insurance and/or elevate the finished floor elevation of a building which lies in this area for new development to occur. Therefore, even though FEMA floodplains represent one of the largest aquifer recharge zones within a county, there are no regulations requiring that these zones remain undeveloped or that natural vegetation should be restored or enhanced within the boundary. Therefore, the zone is considered "jurisdictional" in that there are some regulations, but unfortunately the regulations often times do not require conservation due to their status as aquifer recharge zones or as prime terrestrial habitat corridors.

3) A middle zone of soils with the geomorphic description of channel, flood plain, or stream terraces on uplands outside of the middle jurisdictional zone, which is the USGS SSURGO soil database descriptor for soils which are frequently inundated and are characterized as geomorphic floodplains. In lower elevations within basins or watersheds, this area is often already included within the FEMA flood zone (the middle jurisdictional), however, in higher elevations within basins or in small tributaries without development pressure the FEMA floodzone sometimes does not include these areas. Therefore, the "middle extended zone" indicates stream valleys and other geomorphically connected fluvial zones with infiltration capacity which might be missed otherwise by using only the FEMA extents. In addition, some highly rural counties or counties dominated by agricultural land cover have no FEMA floodzone defined, and the middle zone replaces the FEMA flood zone in these cases.

4). Areas of steep slopes over 15% that are spatially summarized as contiguous patches from the original raster data and then selected when they intersect the middle and/or middle jurisdictional zones. These areas typically run between the inner and middle zones where steep stream banks exist, and between the middle/middle jurisdictional zone and outer zone where the stream valley is separated from the upland areas by a bluff or down-cut slope.

5) An outer zone of non-agricultural vegetation which intersects zones 1 through 4 or are within 100-feet of the merged zone outer boundary, which includes upper woodland forest, native grasslands, wetland patches, evergreen forests, lower hardwood deciduous forests, etc. which identifies the direct terrestrial habitat, aquatic linkages and NPP.

This 5 zone ZOC can be expressed in a formula, where the first 4 zones are summarized in a direct overlay process which is called the ZØ (Equation 47), which is then used in an iterative process to select all vegetation types summarized ("exploded" or "dissolved") by the smallest patch size possible ($VEGTYPE_p$) which intersect or are within 100-meters of intersecting the boundary (**∂**) of total spatial extent (perimeter resulting in a dissolved union) of Z (Equation 48), referred to here as **∂**ZØ.

$$\boldsymbol{\partial} Z\emptyset = \sum_{g=1}^{n} SOILS_g + STREAM_{100} + WB_{100} + FEMA_{fz} + (DEM_{sl} > 0.15)$$

Where:

$\sum_{g=1}^{n} SOILS_g$ *= All Geomorphic valleys, alluvium or fluvially categorized soils (U.S. Department of Agriculture, National Resources Conservation Service (NRCS) 1850 - 2014)*

$STREAM_{100}$ *=A 100-meter buffer on all USGS perennial streams (U.S. Department of the Interior et al. 2012)*

$FEMA_{fz}$ *= The spatial extent of the FEMA Floodzone (Federal Emergency Management Agency (FEMA) 2012)*

WB_{100} *= A waterbody, lake or probable wetland with a 100-meter buffer (U.S. Department of the Interior, U.S. Fish and Wildlife Services 2016)*

DEM_{sl} *= A digital elevation model (DEM) converted to slope (sl) (United States Geological Survey (USGS) 2012)*

Equation 47: Summarization of the Intermediate $\boldsymbol{\partial} Z\emptyset$ Step Summary of Zones 1- 4

$$ZOC = \boldsymbol{\partial}\left\{\sum_{p=1}^{n} VEGTYPE_p < INTERSECT > \boldsymbol{\partial} Z\emptyset_{100}\right\} + \boldsymbol{\partial} Z\emptyset$$

Where:

$\sum_{p=1}^{n} VEGTYPE_p =$ *All dissolved vegetation types intersecting vegetation layers listed in section 5.3.1.2, the "outer zone"*

$\boldsymbol{\partial} Z\emptyset_{\mathbf{100}}$ *=The spatial overlay summation of zones 1 through 4 with a 100-meter buffer*

$\boldsymbol{\partial} =$ *The total spatial extent of a layer, union or overlay*

$\langle INTERSECT \rangle$ *= The symbol for spatial intersect, where layer A spatially intersects layer B*

Equation 48: Calculation of the 5th (Outer) Zone of the ZOC

5.3.1.3 Road Effect Zone (EC2c)

In addition to the patch, corridor, network theory and the summarized ZOC, a road effect zone (REZ) is utilized to identify areas which are disconnected from the main patch-corridor network by roadway effects. The road effect zone is defined by Forman as the study which "explores and addresses the relationship between the natural environment and the road system (Forman et al. 2002, p. 7)." A number of authors have conducted studies which studied vegetative, terrestrial and aquatic animal, and avifauna impacts from roadways including noise impacts, migration impacts, life-cycle impacts, mortality incidents, and pollution (Forman, Alexander 1998; Trombulak, Frissell 2000; Parris, Schneider 2009), and recently models to spatially define the "road effect zone" have been developed and released as free-ware (Reed et al. 2010; Shilling, Waetjen 2012). This project utilizes the road effect zone GIS model to define areas where road zone effects occur and uses it as a limit to the extent of the ZOC by eliminating patches within the road effect zone.

The effects of roadways included in this study are pulled from Shilling and Waetjen (2012) but with some modifications. Firstly, the zone of human impacts at 400 meters in the original 2012 text is exchanged for direct stream effects as suggested by Forman (Trombulak, Frissell 2000) since human health impacts from roadways is not in the scope of this study. In addition, the impact for sensitive birds of 1200 meters is exchanged for the SPreAD raster model, that is used to identify an area which is experiencing an L_{af} decibel of over 30db in all vegetation cover types where the frequencies of bird calls can be become garbled and result in reduced mating pairs (Forman et al. 2002, pp. p793). Amphibian impacts only impact areas where amphibian habitats exist, namely low-lying wet areas and the immediate forested vegetation within travel distance estimated at 100-feet. Large mammal impacts only affect vegetation areas and rocky outcrops where mammal habitat is likely to exist in trees or caves. Soil contamination only affects the middle zones where contaminants can stay embedded in the soil. And finally, stream impacts, which alter the fluvial dynamics of the stream, affect the inner and middle zones (Table 5-15).

Road Effect	Effect Distance (m)	Zones and Vegetation Affected	Citation
Amphibians	1000	Inner and Middle Zones, Wetlands and Deciduous & Evergreen Forests within 100-Feet of the Effect Distance	Eigenbrod et al., 2009
Sensitive Birds	Varies based on SPreAD model	All Vegetation Types	The Wilderness Society, 2011
Large Mammals	600	All Forest and Grasslands and Rocky Outcrops	Backstrom et al., 2003
Soil Contamination	30	Middle and Middle Jurisdictional Zones	Findlayand and Houlahan, 1996
Stream Impacts	400	Inner, Middle, Middle Jurisdictional Zones	Forman and Alexander, 1998

Table 5-15: Road Effect Zones as Adapted and Augmented from (Shilling, Waetjen 2012).

The spatial relationships that define each road effect zone can be summarized in the formulas included below in equations 45-50 below. For simplicity, each road effect factor shown separately and can be spatially merged to indicate a binary envelope of impact or converted to raster and integrated with a weighted overlay to indicate areas of overlapping road zone effects. In the end, all of the individual impact areas area summarized and denoted as the Road Effect Zone (REZ).

$$RZ\emptyset_{Amphibian} = ROAD_{1000} \langle INTERSECT \rangle \left[\sum_{p=1}^{n} VEGTYPE_p \langle INTERSECT \rangle \boldsymbol{\partial} \left\{ \sum_{g=1}^{n} SOILS_g + STREAM_{100} + WB_{100}\ FEMA_{fz} \right\} \right] + \boldsymbol{\partial} \left\{ \sum_{g=1}^{n} SOILS_g + STREAM_{100} + FEMA_{fz} \right\}$$

Where:

$\langle INTERSECT \rangle$ *= The symbol for spatial intersect, where layer A spatially intersects layer B*

$\boldsymbol{\partial} =$ *The total spatial extent of a layer, union or overlay*

$ROAD_{1000} =$ *A 1000-meter buffer on highways and interstates (USGS 2014)*

$\sum_{p=1}^{n} VEGTYPE_p =$ *All dissolved vegetation types from section 5.3.1.2*

$\sum_{g=1}^{n} SOILS_g$ *= All Geomorhic valley, alluvium or fluvially categorized soils (U.S. Department of Agriculture, National Resources Conservation Service (NRCS) 1850 - 2014)*

$STREAM_{100} =$ *A 100-meter buffer on all USGS perennial streams (U.S. Department of the Interior 2012)*

$FEMA_{fz}$ *= The spatial extent of the FEMA Floodzone (Federal Emergency Management Agency (FEMA) 2012)*

$WB_{100} =$ *A waterbody, lake or probable wetland with a 100-meter buffer (U.S. Department of the Interior, U.S. Fish and Wildlife Services 2016)*

Equation 49: The Road Effect Zone for Amphibians

$$RZ\emptyset_{Birds} = (SPreAD\ \geq 30_{Db}) \langle INTERSECT \rangle \sum_{p=1}^{n} VEGTYPE_p$$

Where:

SPreAD = The outcome of the SPreAD spatial sound modelling software in Db at 500Hz

$\langle INTERSECT \rangle$ *= The symbol for spatial intersect, where layer A spatially intersects layer B*

$\sum_{p=1}^{n} VEGTYPE_p =$ *All dissolved vegetation types from section 5.3.1.2*

Equation 50: The Road Effect Zone for Birds

$$\text{RZ}\emptyset_{\text{Mammals}} = ROAD_{600}\ \langle INTERSECT\rangle\ \boldsymbol{\partial}\left\{\sum_{p=1}^{n} VEGTYPE_p\ + (DEM_{sl} \geq 0.15)\right\} +\ STREAM_{100} +\ WB_{100}$$

Where:

$ROAD_{600}$ *= A 600-meter buffer to highways and interstates*
DEM_{sl} *= A digital elevation model (DEM) converted to slope (sl)*

$STREAM_{100}$ *= A 100-meter buffer on all USGS perennial streams (U.S. Department of the Interior 2012)*

WB_{100} *= A waterbody, lake or probable wetland with a 100-meter buffer (U.S. Department of the Interior, U.S. Fish and Wildlife Services 2016)*

Equation 51: The Road Effect Zone for Mammals

$$RZ\emptyset_{Soil\ Contamination} =\ ROAD_{30}\ \langle INTERSECT\rangle\ \boldsymbol{\partial}\left\{\sum_{g=1}^{n} SOILS_g +\ FEMA_{fz}\right\}$$

Where:

$ROAD_{30}$ *= A 30-meter buffer on highways and interstates*

$\sum_{g=1}^{n} SOILS_g$ *= All Geomorhic valley, alluvium or fluvially categorized soils (U.S. Department of Agriculture, National Resources Conservation Service (NRCS) 1850 - 2014)*

$FEMA_{fz}$ *= The spatial extent of the FEMA Floodzone (Federal Emergency Management Agency (FEMA) 2012)*

Equation 52: The Road Effect Zone for Soil Contamination

$$\text{RZ}\emptyset_{Stream\ Impacts} =\ ROAD_{400}\ \langle INTERSECT\rangle\ \boldsymbol{\partial}\left\{\sum_{g=1}^{n} SOILS_g + STREAM_{100} + FEMA_{fz}\right\}$$

Where:

$ROAD_{400}$ *= A 400-meter buffer on highways and interstates*

$\sum_{g=1}^{n} SOILS_g$ *= All Geomorhic valley, alluvium or fluvially categorized soils {U.S. Department*

$STREAM_{100}$ *= A 100-meter buffer on all USGS perennial streams (U.S. Department of the Interior 2012)*

$FEMA_{fz}$ *= The spatial extent of the FEMA Floodzone (Federal Emergency Management Agency*

FEMA) 2012)

Equation 53: The Road Effect Zone for Stream Impacts

The total road effect zone (REZ) is the intersection of all summary layers included above in section 5.3.1.3 and is summarized with Equation 54below.

$$\boldsymbol{\partial} REZ \ = \ \langle INTERSECT \rangle \ \boldsymbol{\partial} \left\{ \mathrm{RZ\emptyset}_{\mathrm{Amphibian}} + \mathrm{RZ\emptyset}_{\mathrm{Birds}} + \mathrm{RZ\emptyset}_{\mathrm{Mammals}} + \mathrm{RZ\emptyset}_{\mathrm{Soil\ Contamination}} + \mathrm{RZ\emptyset}_{Stream\ Impacts} \right\}$$

Where:

$RZ\emptyset_{Amphibian}$ *= Equation 49*

$RZ\emptyset_{Birds}$ *= Equation 50*

$RZ\emptyset_{Mammals}$ *= Equation 51*

$RZ\emptyset_{Soil\ Contamination}$ *= Equation 52*

$RZ\emptyset_{Stream\ Impacts}$ *= Equation 53*

Equation 54: The Road Effect Zone $\boldsymbol{\partial} REZ$

5.3.1.4 ZOC and REZ Integration (EC2c)

As a final step, the REZ is erased from the ZOC to derive an estimated area where the patch corridor structure and function are in-tact and where road effects are not inhibiting any natural processes or habitats. This can be represented by Equation 55 where the final area of the REZ is erased from the total area of the ZOC.

$$\boldsymbol{\partial} ZOC = ZOC - \boldsymbol{\partial} REZ$$

Where:

ZOC *= Equation 48*

$\boldsymbol{\partial} REZ$ *= Equation 54*

Equation 55: The Final Zone of Conservation Formula

The zone of conservation formulas displayed above are deployed as a multi-step GIS based method that allows almost the entire process to be automated for a county once the 10 input data sources are linked and parameters are defined.

5.3.2 Ecosystem Area Demand (EC1d & EC2d)

Current terrestrial biodiversity targets for developed nations is estimated at of 17% land area and 10% of marine areas (section 4.2.1.11.2), a percentage based on recommendations from the International Convention on Biodiversity. The EF has used numbers of 12% land area set aside for biodiversity function (US Geological Survey, Gap Analysis Program (GAP) 2012; United Nations) and Hoekstra in the Water Footprint method (Hoekstra et al. 2011, p.81) reports from Svancara et al

(2005) that 25 to 50% of diverse ecosystem areas may be needed to truly preserve ecosystem function to settle on a recommendation of 30% area preserved for biodiversity and ecosystem function. A percentage echoed in Smakhtin et al. (2004) which indicates that water demand for ecosystems can be up to 40% of total annual flow.

Given the data provided, this study recommends a 17% of land and water area preserved as a county target in the United States. Given pilot studies in the Omaha NE region, Kansas City MO region, in counties across rural Missouri, Iowa and Kansas this target seems appropriate and defensible as a middle point in the potential recommendations. The preservation area can also be borrowed from an existing conservation area plan if it exists as an adopted plan by the county, although if the county plan is less than 17% it might be an opportunity to use the ZOC as infill recommendation areas. The ecosystem area is calculated for EC1d and EC2d (the same number, but compared to different capacity assessments) with Equation 56 below.

$$Ecosystem\ Area\ Target = COUNTY_{area} * 0.17$$

Where:

$COUNTY_{area}$ = *The total county area in Acres*

Equation 56: Equation for EC1d and EC2d, Conservation Area Target

5.3.3 Ecosystem Area Balance

The final result of the method is a summary Excel file which allows the existing area of conservation according to the PAD-US database and the proposed 'ideal' zone of conservation to be compared to the proposed terrestrial conservation area of 17% (Tittensor et al. 2014) using an NDI formula for both comparisons (Equation 57, Equation 58) so that the results can be plotted on the vertical waveform.

$$NDI - EC1 = \frac{(PADUS\ Area - 17\%\ Terrestrial\ Area)}{(PADUS\ Area +\ 17\%\ Terrestrial\ Area)}$$

Equation 57: Existing Conservation Area Compared to the 17% of Terrestrial Area Target

$$NDI - EC2 = \frac{(ZOC\ Area - 17\%\ Terrestrial\ Area)}{(ZOC\ Area + 17\%\ Terrestrial\ Area)}$$

Equation 58: Zone of Conservation Area Compared to the 17% of Terrestrial Area Target (NDI-EC1 & NDI-EC2)

5.4 Carbon

The carbon category estimates the balance between the total annual carbon emissions in the county and the annual carbon sequestration capacity. This category has the most direct calculation methodology as the capacity and demand datasets are based on existing high-level data which are discussed in detail below. The final calculations from the carbon emissions calculation (C1d) and carbons sequestration calculation (C1c) are used in the NDI-C1 calculation to determine the final normalized balance between carbon emissions and sequestration capacity (Figure 5-8). This process is discussed below.

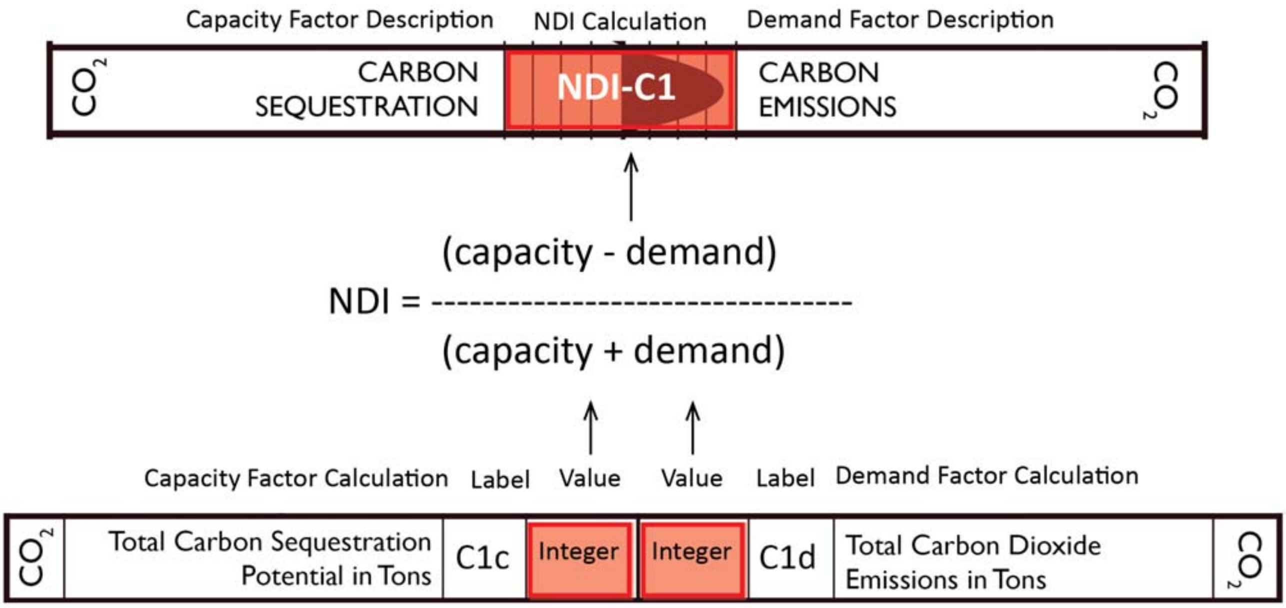

Figure 5-8: Carbon Factors Overview

5.4.1 Carbon Sequestration Capacity (C1c)

The land and vegetation can sequester at least a portion of anthropogenic carbon emissions through carbon sequestration, which occurs during the normal respiration and leaf production stage of gross primary production (GPP), also known as total photosynthesis or total assimilation, and in the storage of plant matter and tissues which occur when there is a surplus of primary production, called net primary production (NPP) (Odum 1971, p. 43). Odum describes these components to carbon sequestration in a compartmental model of biomass change in grassland ecosystems where photosynthetic input drives live vegetation root and foliage growth via respiration, which in-turn produces standing dead vegetation that becomes litter for future respiration (Odum 1971, p. 286). Given the model described by Odum it might make sense to include both GPP and NPP in estimates of carbon sequestration, however a closer look at plant respiration reveals that about half of the carbon sequestered in GPP is given off during respiration, which leaves NPP as a corrected measurement of short-term carbon storage (Watson et al. 2000, p. s1.3).

Above ground and below ground annual carbon sequestration capacity can be estimated for forestland, grassland, and cropland per acre based on compilations of past empirical field studies (Post, Kwon 2000; Nowak, Crane D.E. 2002; Follett 2001). The method of estimating biomass as NPP from land cover and agricultural harvest rates has been used by other authors successfully (Haberl 1997; Ayres 1998). Considering that this study relies on detailed agricultural production for the food summary, it would seem logical to utilize recorded field data as the basis for carbon sequestration. Unfortunately, the current state of data availability on field measured NPP does not include all vegetation cover types, especially that of non-agricultural products, which would requiring that some land cover types be processed in coarse land cover groups (ie, agriculture, forest, grassland), which could lead to inaccuracy or error.

As an alternative, remote sensing based platforms have shown usefulness in carbon cycle assessments due to the high spatial and temporal resolution which can be achieved with space-based observations. One example is the Lund-Postdam-Jena managed Land (LPJmL) model (Ayers 2000), which models land-atmosphere exchange flows of carbon and water as well as quantifying stocks within an agro-ecosystem and is based on a previous Dynamic Global Vegetation Model. Another possible source for remote sensing-based carbon sequestration is the MODIS 17 NPP dataset (Zhao et al. 2006). The MODIS 17 NPP dataset was developed to aid in carbon cycle analysis and NPP/GPP estimates and has been identified as a potential remote sensing tool for evaluation of carbon sequestration (Ferguson 1999; Li 2012) and has been empirically evaluated against another EVI and surface temperature based NPP estimation method which indicated that the MODIS 17 NPP results are statistically very similar and thus validated (Rahman 2005). Following the criticisms from Rahman 2005, the MODIS 17 Biome Parameter Look-Up Table (BPLUT) was improved (Zhao et al. 2005), further increasing the pixel-based accuracy of the dataset.

Given the approach and scale of this study, the MODIS 17 NPP dataset is utilized to estimate short-term terrestrial carbon sequestration potential, as this dataset is readily available at the global level, has a pixel resolution of approximately 1km x 1km (sub-county) and can be summarized in GIS. The dataset is available from The University of Montana Numerical Terradynamic Simulation Group (http://www.ntsg.umt.edu/project/mod17) and is shown for the lower United States (Figure 5-9) with NPP data reported in grams of carbon per square meter per year (gC/m^2/yr).

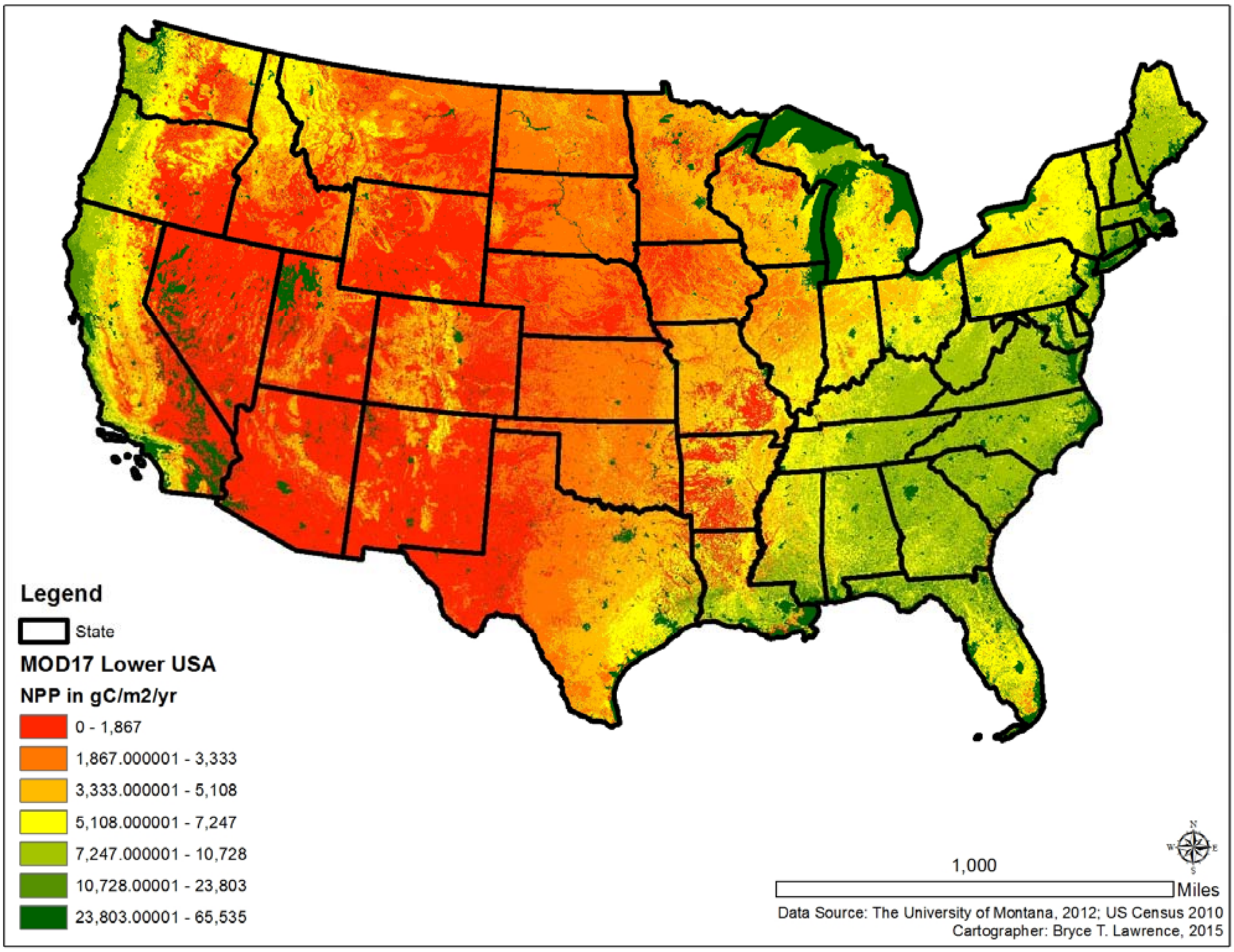

Figure 5-9: MODIS 17 Net Primary Productivity

A clip mask of the county boundary is used to extract the MOD17 NPP data by county. Raster data is converted to points with ArcGIS and the Add Field and Calculate Field tools are used to calculate the total tons of carbon for the county area (Equation 59).

$$CARBON_{SEQ} = \left\{ \sum \frac{MODIS17_{NPP}\,[px, x, t] * 691129.8}{1000000} \right\}$$

Where:

$MODIS17_{NPP}\,[px, x, t]$*= The summary of all pixel values [px] per county [x] per year [t[, representing total NPP in gC/m*^{2}*/year (Zhao et al. 2005)*

691129.8 = The area in meters of each raster pixel

1000000 = The conversion from grams to metric tons

Equation 59: Carbon Sequestration Calculation

5.4.2 Carbon Emissions (C1d)

Carbon emissions on a county-wide basis are calculated using a Tier I sector-based accounting method (as discussed in section 3.1.7), for the subdivided sectors of commercial, industrial, residential, transportation[8] and other[9]. This high-resolution subdivision is in line with the geographic approach of the County Diagnostic and these subdivisions are summarized in million tons of carbon annually from the "Vulcan" High resolution fossil fuel combustion C02 database (Gurney et al. 2009). The Vulcan database is available for download at http://vulcan.project.asu.edu/research.php and is summarized nationally by county for the year 2002.

Since the study year is 2012 and the data is provided for the year 2002, a transformation is needed to transform the 2002 emissions data into a population corrected assumption for 2012. Fortunately, the Vulcan database emissions are reported per county and per capita mean/max for all sectors. To make the adjustment the Vulcan database reported per capita mean value for each sector is multiplied by the increase or decrease of per capita population as indicated by the difference between the 2002 population estimates and 2012 population estimates (United States Census Bureau 2010). The formula for this calculation is indicated below:

$$CARBON_{EMISS} = \sum \left\{ \sum_{s-5}^{n} (CARBON_{TONS}[s,x,t]) * (POP_{\left[\frac{t_{12}}{t_{02}}\right]}) \right\}$$

Where:

$CARBON_{TONS}\,[s,x,t]$= *Tons of Carbon emissions per sector [s] per county [x] per year [t] (Gurney et al. 2009)*

$POP_{\,[t_{12}-t_{02}]}$ = *The difference in per capita population between 2012 [t_{12}] and 2002 [t_{02}] as a percentage of growth or reduction.*

Equation 60: Calculation of Adjusted Carbon Emissions per County (W1D)

5.4.3 Carbon Balance

With the summary for carbon factors (C1c and C1d) calculated as explained above, the integer variables are fed into their assigned NDI equation formulas (NDI-C1) so that a direction and magnitude can be calculated. The results in standard deviations are then plotted on the vertical waveform diagram. The formula for NDI-C1 equation is as presented below in Equation 61.

$$NDI - C1\ (Carbon\ Balance) = \frac{C1c\ (Carbon\ Sequestration) - C1d\ (Carbon\ Emissions)}{(C1c + C1d)}$$

Equation 61: Carbon Balance Formula

[8] Transportation sectors includes the sub-categories of Onroad, Aircraft, Airborne, Nonroad
[9] Other includes Electricity Production and Cement Production

5.5 Electricity

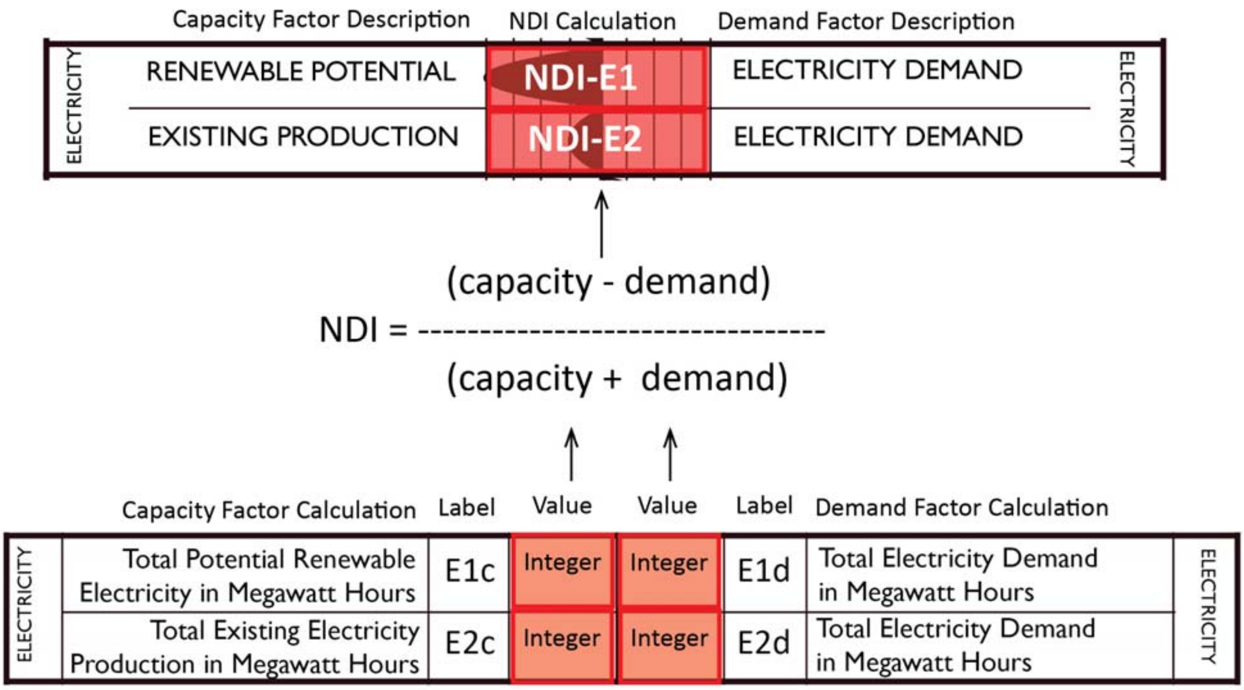

Figure 5-10: Electricity Method Overview

5.5.1 Renewable Electricity Capacity (E1c)[10]

Cities and households are to a large degree based on electricity for lighting, appliances, heating and cooling and construction and maintenance. Since renewable electricity can directly power city-based electricity demand it makes sense to analyze the annual renewable electricity potential with the County Diagnostic. From an infrastructure standpoint, wind farms and photovoltaic panels in the United States have the combined potential to supplement or replace fossil fuel based power plants (34,900 TWH urban solar and on-shore wind Anthony Lopez, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro: NREL 2013, p. iv), which in-turn reduces a percentage of county-wide fossil fuel demand and associated GHG emissions. The renewable electricity potential is calculated for wind turbines and solar photovoltaic (PV) panels in this analysis.

Renewable electricity capacity is calculated for both wind turbines and photovoltaic panels in separate processes which both include 1) the definition of an envelope, 2) the quantification of a reasonable number of wind or photovoltaic units within the envelope and 3) the calculation of the total annual MWH production potential using specific algorithms and the number of estimated units. An industry standard PV panel and wind turbine is used in the unit spacing and annual MWH calculations to ensure that electricity production estimates are related to the current energy market. The renewable electricity capacity estimates can be directly translated into engineering

[10] Section 5.5.1 was first published with the permission of the TU Dortmund University as: B.T. Lawrence (2015): Renewable energy independence in the USA: Myth or potential reality? Towards a sub-regional quantitative evaluation methodology. In: Fakultät Raumplanung (Hrsg.): Raummuster. Struktur, Dynamik, Planung. Book of abstracts der 3. Dortmunder Konferenz für Raum- und Planungsforschung, Dortmund, 22.-23. Februar 2016: S.82-84.

cost estimates by summarizing turbines or panels, infrastructure costs to connect sources to the grid, and construction and maintenance costs.

5.5.1.1 Solar Electricity Production Potential

Solar electricity production potential (SEPP) is measured using a bottom-up multi-step approach which 1) defines a spatial envelope for PV installation, 2) estimates the area within the envelope which can be allotted to photovoltaic panels, and 3) multiplies the combined panel area by the annual average solar resource for PV panels tilted toward the angle of the sun (Roberts 2012) in kWh/m^2/day, presented in Figure 5-11 and as (PG_v) in Equation 63. Given this simple framework, many possible spatial envelopes could be developed depending on the political and social will of the community. Two alternatives possibilities for deriving the SEPP are presented below and their applications briefly discussed.

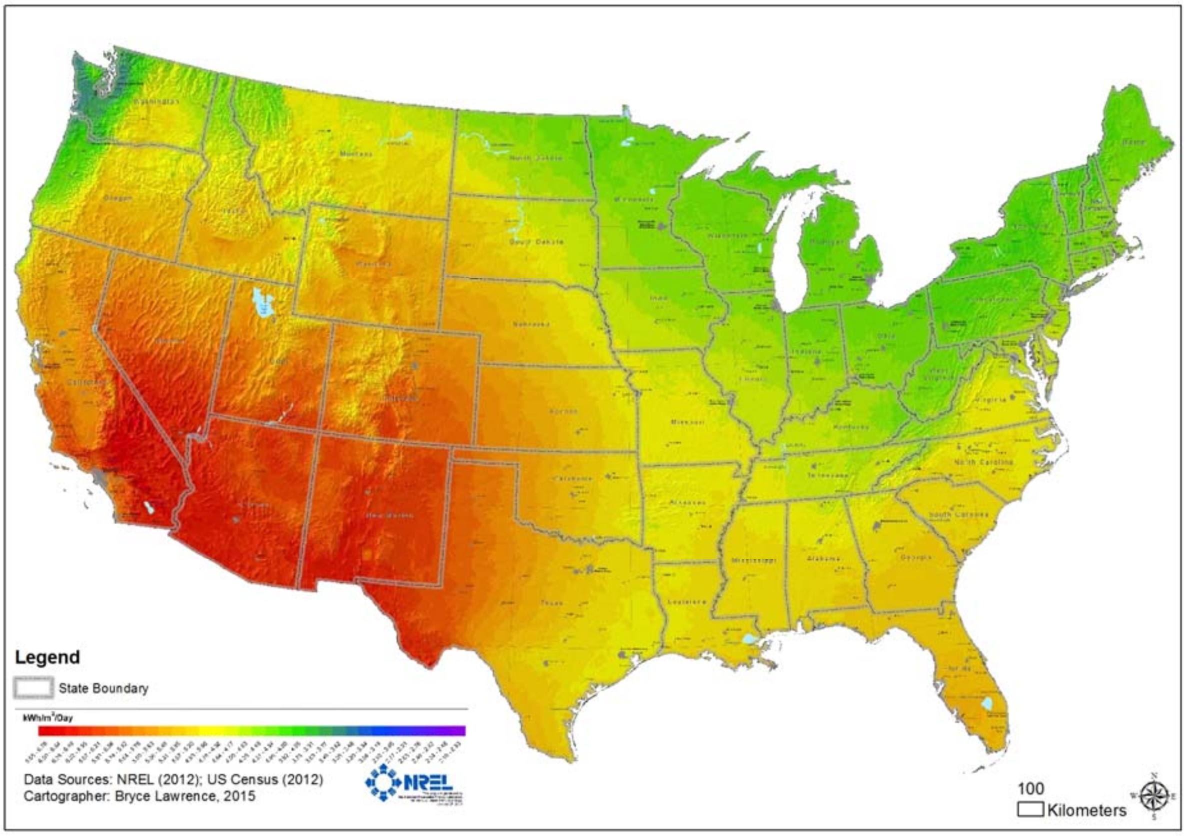

Figure 5-11: Solar Energy Resource in the United States (Roberts 2012).

5.5.1.1.1 Alternative 1: Existing Building Roof-Area

In this approach, the number of estimated residential units from the US Census Selected Housing Characteristics (United States Census Bureau 2012) and non-residential establishments[11] from US Census County & ZIP Code Business Patterns (US Census Bureau 2012) are used to define the total spatial envelope in terms of the total number of buildings available as surfaces to mount PV panels. Within the residential envelope, it is assumed that only 2/3rds of roof areas would be suitable for PV installation given their dead load capacity and positions on the landscape or within urban

[11] An establishment is a single physical location at which business is conducted or services or industrial operations are performed. It is not necessarily identical with a company or enterprise, which may consist of one or more establishments.

structure. Of the remaining 2/3rds, it is assumed that a 1.5 m^2 solar panel array could be installed on the roof and tied to the electricity grid with a grid tie system which allows the panel to feed the grid or be stored. For non-residential establishments, a larger roof area is typical of the commercial and manufacturing industry and that they are much fewer than residential units, thus a 5 m^2 solar array is assumed for commercial and industrial building stock. The total estimated available roof area in square meters is summarized and multiplied by the Photovoltaic Resource adjusted by month and region of study in $kWh/m^2/day$ ($P_{\alpha R}$) (Roberts 2012), summarize in Equation 62: Annual Solar Electricity Production Potential (SEPP) in MWH Using Alternative 1 Equation 62 below.

$$Annual\ SEPP_{a1} in\ MWh = \sum_{t_m=12}^{n} \langle \frac{\{((R[b] * 0.667) * 1.5) + ((NR[b] * 0.667) * 6) * (P_{\alpha R})\}}{1000} \rangle * D_{m[x]}$$

Where:

$R[b]$*= Residential Buildings (United States Census Bureau 2012)*

$NR[b]$*= Non-Residential Establishments (US Census Bureau 2012)*

$P_{\alpha R}$*= Photovoltaic Resource in* $kWh/m^2/day$*) (Roberts 2012)*

$D_{m[x]}$*= Days per Month [x]*

Equation 62: Annual Solar Electricity Production Potential (SEPP) in MWH Using Alternative 1

5.5.1.1.2 Alternative 2: Percentage of Urban Landcover

The urban envelope approach in the County Diagnostic method is to allocate urban roof areas as the solar panel envelope, which assumes roof mounting of array systems and proximity to the electricity grid and therefore no need to define grid tie suitability as all potential areas would be suitable. To define the extent of 'urban' areas, the CropScape land cover image (United States Department of Agriculture 2012) classification of low, medium and high developed density urban land cover area extracted and reclassified as 'urban' with a single area in acres. From the total urban area an assumption of 10% area-wide installation of solar panel arrays is extracted and used as the total area of solar panel installation. The 10% area in acres is multiplied by a monthly power generation value from NREL. This process is expressed in Equation 63 below.

$$Annual\ SEPP_{a2}\ in\ MWh = \sum_{t_{m=12}}^{n} \left\{ \left((\partial URB * X) * \frac{P_{\alpha R}}{1000} \right) * D_{m[x]} \right\}$$

Where:

∂URB *= The Urban Envelope (United States Department of Agriculture 2012)*

X = Percent of Urban Cover Needed to Satisfy Total Electricity Demand

$P_{\alpha R}$*= Photovoltaic Resource in kWh/m²/day) (Roberts 2012)*

$D_{m\ [x]}$ *= Days per Month [x]*

Equation 63: Solar Electricity Production Potential (SEPP) Calculation

5.5.1.1.3 Discussion of PV Estimation Alternatives

In a university pilot study of Jackson County, Missouri and professional practice application in the Omaha, Nebraska region[12] I found that using the building-based method (Alt.1) ended up being able to produce about 10% of the County or regional demand while taking up less than 1% of the total defined urban area (United States Department of Agriculture 2012). This suggests that the sizing of solar panels or the total coverage is a factor of 10 too low if the target for PV installation is 100% renewable energy. While this number may correspond to two Midwestern cities with moderate to low population density and a high number of individual residential dwellings, it may not correspond as well to counties with higher urban population density where there are a much greater number of per capita energy consumers under a single statistical roof area. For this reason, the total urban area (Alt. 2) is proposed. Further studies could reveal some type of rule of thumb percentage and most likely each region and community have a different percentage given economic power, community acceptance, environmental conditions and built environment. All calculations in the case study are done with Alt. 1.

5.5.1.2 Wind Power Envelope (WPE)

The wind power envelope (WPE) is calculated entirely in GIS. The method is explained here using abbreviations and then is put together in formulaic notation after the verbal description to express this factor consistently with all other factors. The WPE begins with the total county area (TCA) and then begins a process of spatial elimination using the Erase tool in ArcGIS, to eliminate the areas below which are unsuitable for wind turbine installations. The included datasets are derived from various sources such as direct secondary data served by the US Government, created from a spatial model, or derived from a cross-tabulation between secondary datasets using specific algorithms. The base datasets for the WPE are:

1) Urban land cover (UL) derived from the most recent Cropscape image (United States Department of Agriculture 2012)

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[12] Jackson County, Missouri pilot study was from Kansas State University BLA program's LAR 704 course in Landscape and Ecological Planning and the Omaha, Nebraska study was with Vireo Planning and Design (2014)

2) The zone of conservation (ZOC; see Section 5.3.1.2)

3) All Federal, State and County parks and registered protection areas per the PAD-US database (US Geological Survey, Gap Analysis Program (GAP) 2012)

4) Endangered bird and bat habitat ranges based on a summary of national and regional level habitat modelling from EPA subregions, State Fish & Wildlife Agencies and Regional Ecological Services Field Offices

5) Areas visible from within 5 kilometers (Landesregion Braunschweig, Germany 2009) from a municipal boundary vertex at 1.6m height with no azimuth or direction restriction (90 to -90 / 360 degree) (Schulte-Braucks 2011) on a 10-meter DEM (United States Geological Survey (USGS) 2012) which has been altered to reflect heights of forest, urban land, and grasslands (Landesregion Braunschweig, Germany 2009; Roth 2002)

6) Municipal boundaries (US Census 2010b)

7) Open Water (U.S. Department of the Interior, U.S. Geological Survey)with a 400m buffer (van Haaren, Fthenakis 2011)

8) Areas with slopes equal to or less than 30%, and

9) Areas of 100m high adjusted average wind power coefficients (WPC_{α}) lower than the required annual average wind speed suitable for wind turbines installations, which is considered to be less than 6 meters per second averaged wind speed. To derive the wind speed adjusted value (WPC_{α}), the original 50m state-wide NREL wind power coefficients (WPC) (United States Department of Energy (US DOE) National Renewable Energy Laboratory (NREL) 2010), which have already been adjusted to a Weibull K distribution of 2.0 with historical data (known as a Rayleigh distribution[13]) by NREL are fed through a multi-step process which includes:

> 9a) Converting the original WPC rating range to a single average wind speed at 50m height[14] which is listed in Table 5-16 below (United States Department of Energy (US DOE) National Renewable Energy Laboratory (NREL) 2010).
>
> 9b) Transferring the land cover surface roughness coefficients as described by (Bayrische Landesanstalt für Betriebswirtschaft und Agrarstruktur 2001) and summarized in Table 5-17 via reclassification of the CropScape Image (United States Department of Agriculture 2012) from surface landcover type into a surface roughness length (z) value per raster cell.
>
> 9c) Generalizing the transformed surface roughness length 30m data via the Majority Filter Generalization tool in Spatial Analyst Toolbar of ArcGIS to reduce the number of isolated land cover types, thereby better approximating the minimized effects that single patch type has within a matrix of a different cover type.

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[13] Defined as an uncorrelated, normally distributed, equal variance, zero mean distribution

[14] Averaging the high and low wind speed values is a simplification utilized in this case so that a single adjusted wind value for each raster location can be calculated as opposed to a range of values, as a range of values.

9c) A cross-column tabulation in ArcGIS for each cell within the transformed and generalized NREL 50 m wind speed value into a 100 m wind speed value estimation using Equation 64 from (Bayrische Landesanstalt für Betriebswirtschaft und Agrarstruktur 2001). This transformed value is used in section 5.5.1.4.

$$V_{h_2} = V_{h_1} * \frac{ln\left(\frac{h_2}{z}\right)}{ln\left(\frac{h_1}{z}\right)}$$

Where:

V_{h_2}*= The wind power adjusted speed in meters per second at 100m height*

h_1 $=$ *The height at which wind speed is known (50m)*

h_2 $=$ *The height at which wind speed is desired (100m)*

V_{h_1} *= The windspeed in meters per second at the known height (h1) (United States Department of Energy (US DOE) National Renewable Energy Laboratory (NREL) 2010)*

z $=$ *The surface roughness length factor Table 5-17 from (Bayerische Landesanstalt für Betriebswirtschaft und Agrarstruktur 2001)*

Equation 64: Wind Speed Transformation Formula Adapted from (Bayerische Landesanstalt für Betriebswirtschaft und Agrarstruktur 2001)

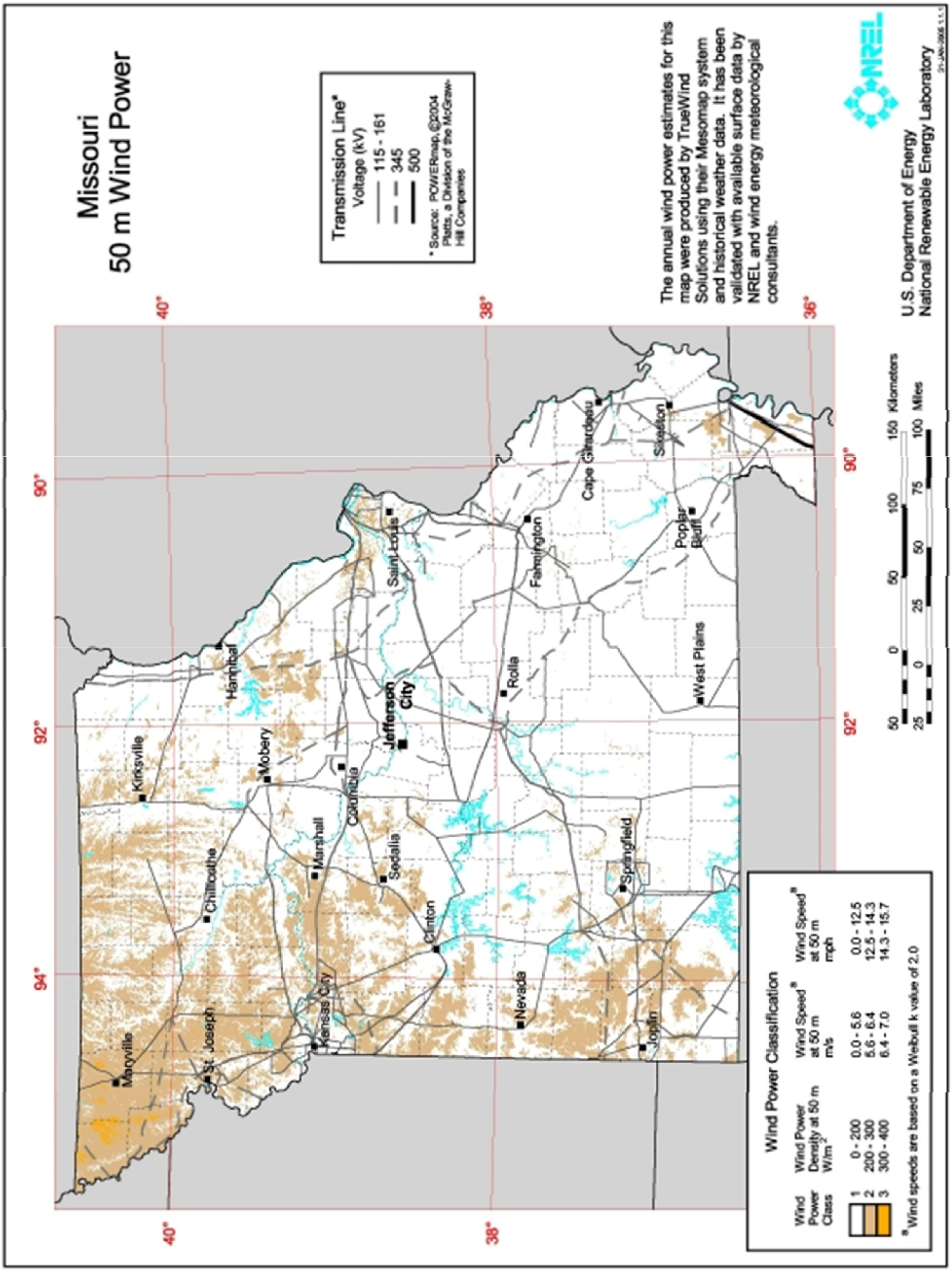


Figure 5-12: NREL 50 m Detailed Wind Speed Data (United States Department of Energy (US DOE) National Renewable Energy Laboratory (NREL) 2010)

WPC	Resource Potential	Wind Speed at 50 m Height in m/s	Average Wind Speed
1	Poor	0.00-5.6	2,85
2	Marginal	5.6-6.4	6
3	Fair	6.4-7.0	6,7
4	Good	7.0-7.5	7,25
5	Excellent	7.5-8.0	7,75
6	Outstanding	8.0-8.8	8,4
7	Superb	>8.8	8,8

Table 5-16: WPC Rating Related to Wind Speed in Meters per Second, with an Average Wind Speed Calculated for each WPC Bin (United States Department of Energy (US DOE) National Renewable Energy Laboratory (NREL) 2010).

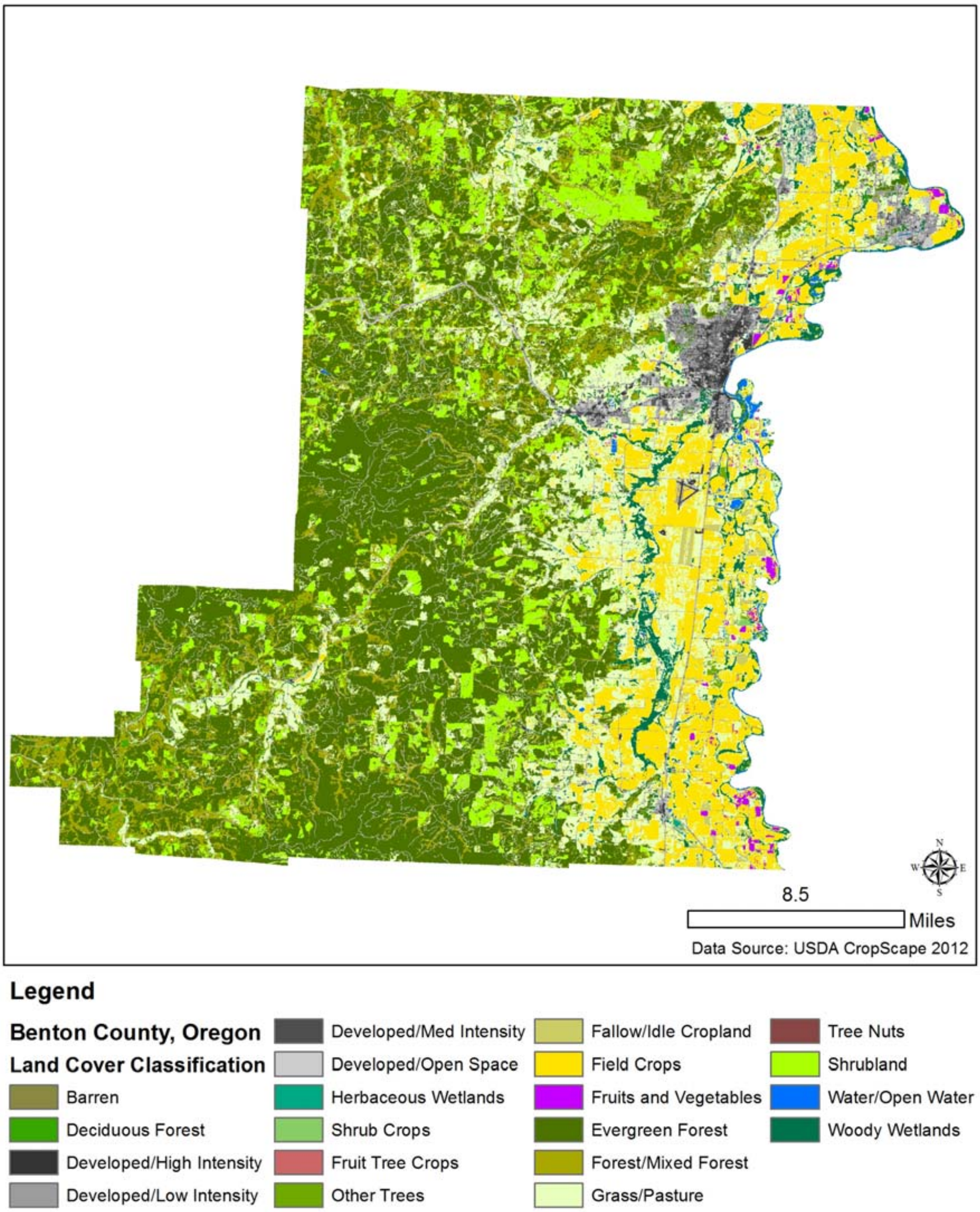


Figure 5-13: CropScape Landcover Image for Benton County, Oregon (United States Department of Agriculture 2012), Reclassified to the Surface Roughness Length (z) in Table 5-17.

Surface Roughness Length (z) in Meters (m)			
Terrain Type	*Land-Use Type*	*Roughness Length (z)*	*ArcGIS ID*
Water	Open Water	0.0002 m	1
Smooth	Mud Flats / Tidal Flat	0.0050 m	2
Open	Grasslands / Meadows	0.0300 m	3
Open to Rough	Agricultural Vegetable Production	0.1000 m	4
Rough	Agricultural Cropland Production	0.2500 m	5
Very Rough	Parkland with Shrubs and Trees; Agricultural Fruit Tree Production	0.5000 m	6
Closed	Forest; Village; Urban Fringe	1.0000 m	7
Very Closed	Urban Center	2.0000 m	8

Table 5-17: Surface Roughness Length Reproduced from (Bayerische Landesanstalt für Betriebswirtschaft und Agrarstruktur 2001)

The formula to derive the spatial extent (∂) of the WPE is expressed below in Equation 65. The outcome of the wind envelope analysis is presented in Figure 5-14, which is a professional practice application of this method from the Omaha Heartland Region 8-county 2050 Vision Plan developed from the author's method in collaboration with Vireo Planning and Design (Vireo Planning and Design 2014).

$$\boldsymbol{\partial} WPE = \boldsymbol{\partial} TCA - \boldsymbol{\partial}(UL + ZOC + PADUS + UV + MB + OW_{400} + (WPC_{\alpha} \leq 6\ m/s) + (DEM_{sl} \geq 0.30))$$

Where:

$\boldsymbol{\partial} =$ *The Total Spatial Extent, Exterior Perimeter or Boundary of a Single Layer or Combination of Layers*

TCA = Total County Area (US Census 2010a)

UL = Urban Landcover (United States Department of Agriculture 2012)

ZOC = Zone of Conservation (see section 5.3.1.4)

PAD-US = Protected Area Database of the United States (US Geological Survey, Gap Analysis Program (GAP) 2012)

UV = Urban Viewshed (see 5.5.1.1 bullet point 5)

MB = Municipal Boundaries (US Census 2010b)

OW400 = Water bodies (U.S. Department of the Interior, U.S. Fish and Wildlife Services 2016) and Blue Line Stream s(U.S. Department of the Interior et al. 2012) with a 400-Meter Buffer

$DEM_{sl} > 0.30 =$ *Areas Where the Slope is Equal to or Greater than 30%*

$WPC_{\alpha} \leq 6\ m/s$ = *Height Adjusted Wind Speed in m/s Areas Equal to or Less than 6-Meters per Second (see 5.5.1.1 bullet point 9)*

Equation 65 : Wind Power Envelope (**∂**WPE)

The remaining area, the WPE, is an area in which as many sensitive areas as possible have been removed from potential development, that produces sufficient wind quantity to make harvesting wind power reasonable and the land is flat enough that using the heavy equipment necessary to install turbines can be accommodated. However, at least one last question still needs to be addressed, namely: How much annual electricity potential does the area translate into?

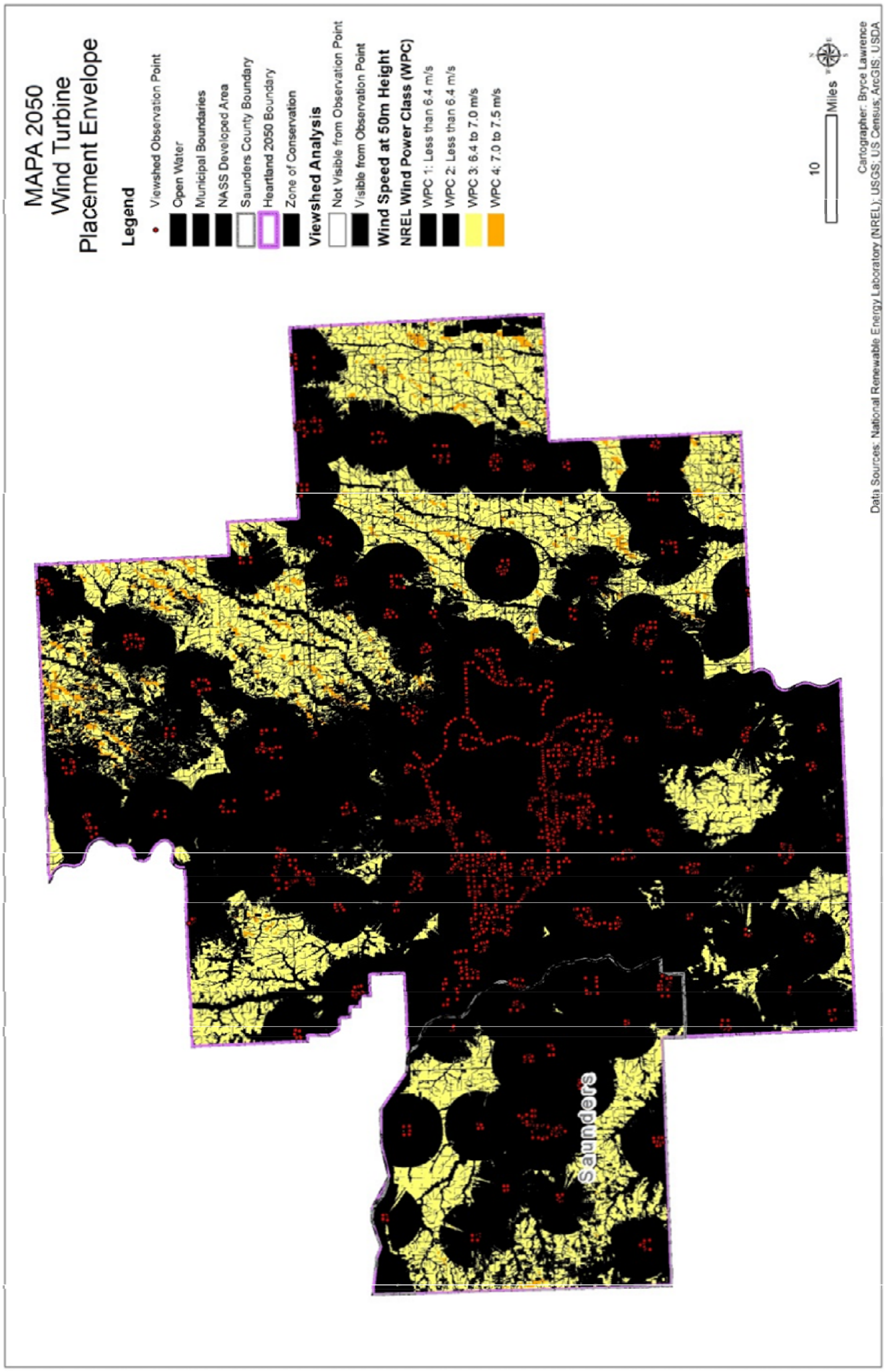


Figure 5-14: Wind Turbine Envelope (Own Depiction)

5.5.1.3 Wind Turbine Unit Spacing

Once the envelope is defined, an offset distance between each turbine hub is calculated based on rotor size, where the recommended offset is equal to 5 times the rotor diameter in the main wind direction and 3-times the rotor diameter in cross-wind direction, with 4-times the rotor diameter as spacing between rotor hubs as a recommended conservative average (Umweltbundesamt 2013, p. 16). For this project, the Gamesa G114 2.5 MW wind turbine was chosen as the representative unit from which all spacing and power generation calculations are based. From an efficiency standpoint, it is best to install the fewest number of the largest turbines possible to increase the MW per acre production and reduce or concentrate the visual impact on the landscape (Landesregion Braunschweig, Germany 2009). Therefore, smaller rotor spacing is likely feasible when a detailed facility layout plan would be developed for the envelope after the screening level analysis of the County Diagnostic. This would shrink the footprint of the envelope and create greater density amongst and production synergy between turbines, however that level of detail is out of the scope of this analysis. Therefore the turbine number estimate should be considered extremely conservative for the total area, but representative of the minimum possible potential and with significant room for increased density of turbine units and reduction of total wind turbine area. The example given here below in Table 5-18, Figure 5-14 and Figure 5-15 used a hub spacing of 5-times the rotor diameter because the regional MAPA authority wanted a conservative screening level estimate.

Wind Turbine Spacing Chart							
Turbine Type	Max Power Rating (MWR_{max})	Hub Height (m)	Rotor Diameter (m)	Hub Spacing (m)[b]	Grid Area (m^2)[c]	Unit Spacing (Ac)[d]	Unit Spacing (h)[e]
Gamesa G114[a]	2.5	100	114	570	324,900	80.28	32.49

a. http://www.gamesacorp.com/en
b. Umweltbundesampt, 2013
c. Hub Spacing ^{2}
d. Grid Area in m^2 to Acres
e. Grid Area in Hectares

Table 5-18: Wind Turbine Spacing for Gamesa G114

The mast spacing of 570 meters, calculated from the rotor diameter of 114 meters for the Gamesa G114 (Table 5-18), was utilized as input values in the CELL_SIZE_HEIGHT and CELL_SIZE_WIDTH parameters of the Fishnet tool in ArcGIS; NUMBER_OF_ROWS and NUMBER_OF_COLUMNS values are input as zero and the ∂WPE was used as the TEMPLATE_EXTENT. The fishnet tool creates a grid of rectangular points offset by 570 meters in north, south, east and west directions which fills in the ∂WPE. Areas in the ∂WPE greater than 25 acres were selected and exported to a new shapefile and then used to clip the fishnet points, which locates and quantifies a conservative number of wind turbines possible within the ∂WPE. An example output of this process is given below for Saunders County, Nebraska, which could theoretically fit 1,223 Gamesa G114 Turbines (Figure 5-15), with a detailed look at the fishnet-based spacing in Figure 5-16.

There are other more complicated and synergistic placement strategies for turbine arrays presented by the Umweltbundesamt which is no doubt useful in areas with tight envelopes (Umweltbundesamt 2013, p. 31). However in the United States we have such large open areas that a site specific turbine arrangement technique is not necessary to achieve a useful county-level screening assessment. In cases with counties that do not have large envelopes, denser turbine spacing may be of more importance and can be adjusted from the presented method as needed after envelope definition.

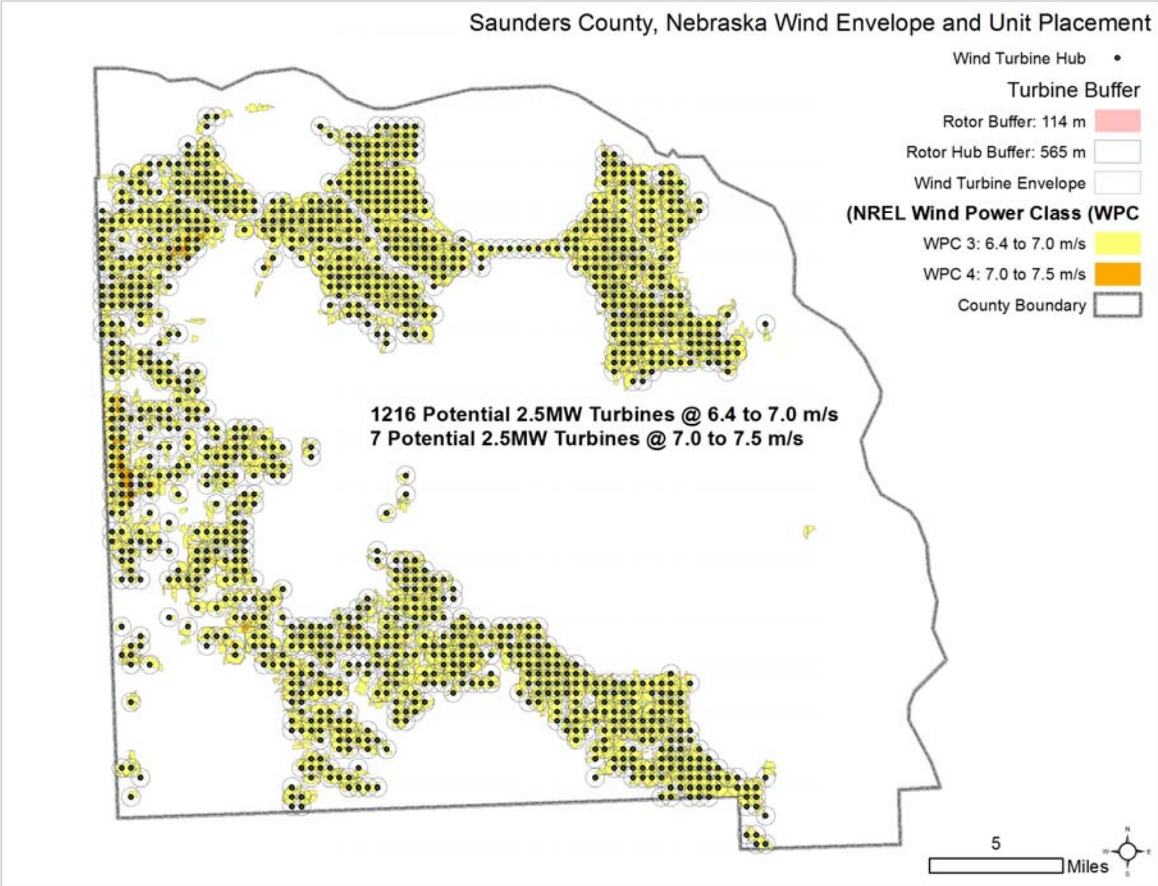


Figure 5-15: Wind Turbine Unit Spacing in Envelope: Example for Saunders County, NE (Own Depiction)

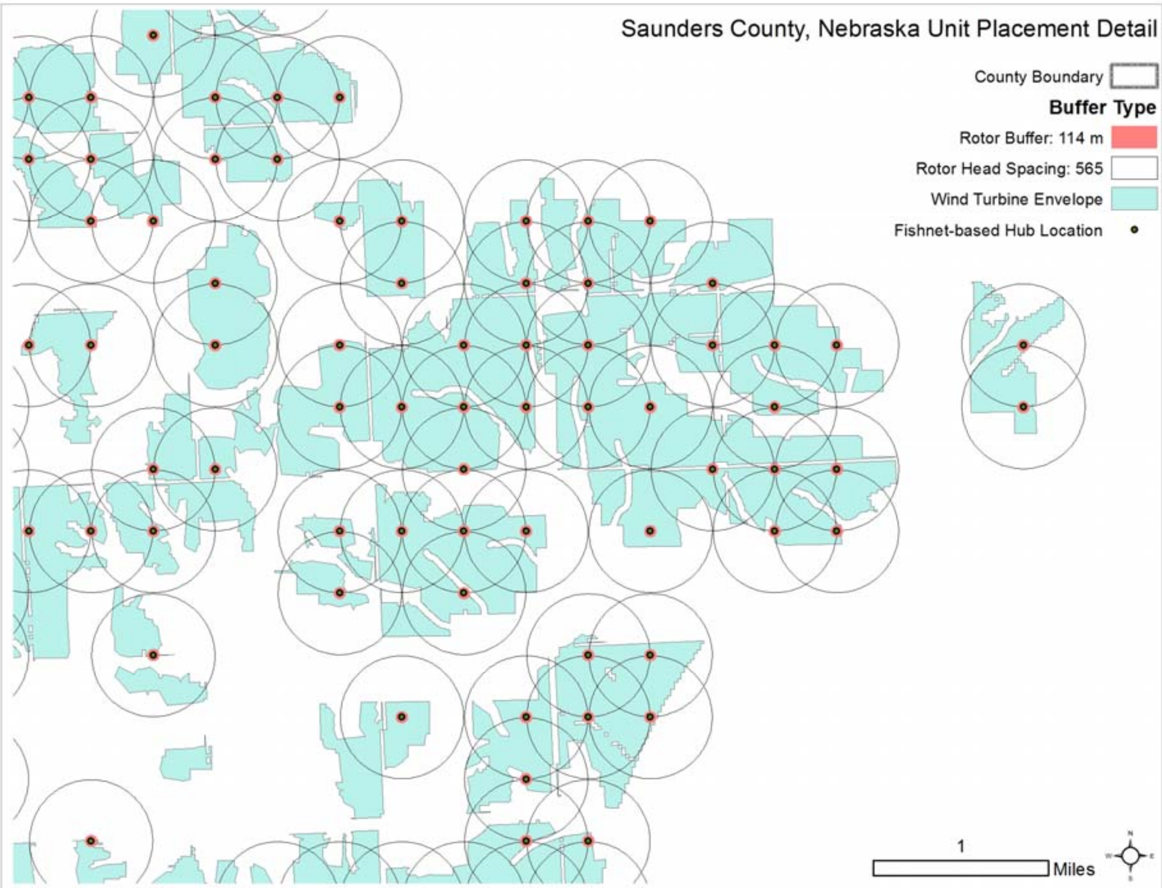


Figure 5-16: Wind Turbine Unit Spacing Detail: Example from Saunders County, NE (Own Depiction)

5.5.1.4 Calculating MWH / Year Wind Electricity Production (WPP_{MWH})

There is a multi-step process needed to calculate the MWH per year for the estimated number of potential turbines, which is described step by step below and summarized in Figure 5-18 below.

1) Pull the average wind speed for the WPC_α from table Table 5-16 and the K-value from the subtext on the 50m windspeed estimate in Figure 5-12. These are constant values for each WPC_α and should be loaded into the spreadsheet model for use in the Weibull frequency distribution function in column 3.
2) Fill out a range of theoretical wind speeds in column number 1, which for most turbine power ratings would be 1 m/s to 24 m/s.
3) Using the wind speed ratings for the sample turbine selected, in this case the Gamesa 100m high 2.5 MW rated turbine in Figure 5-17, identify the power output of the turbine at each wind speed rating along the power curve in MW and fill in the MW rating in column number 2 for each wind speed class.

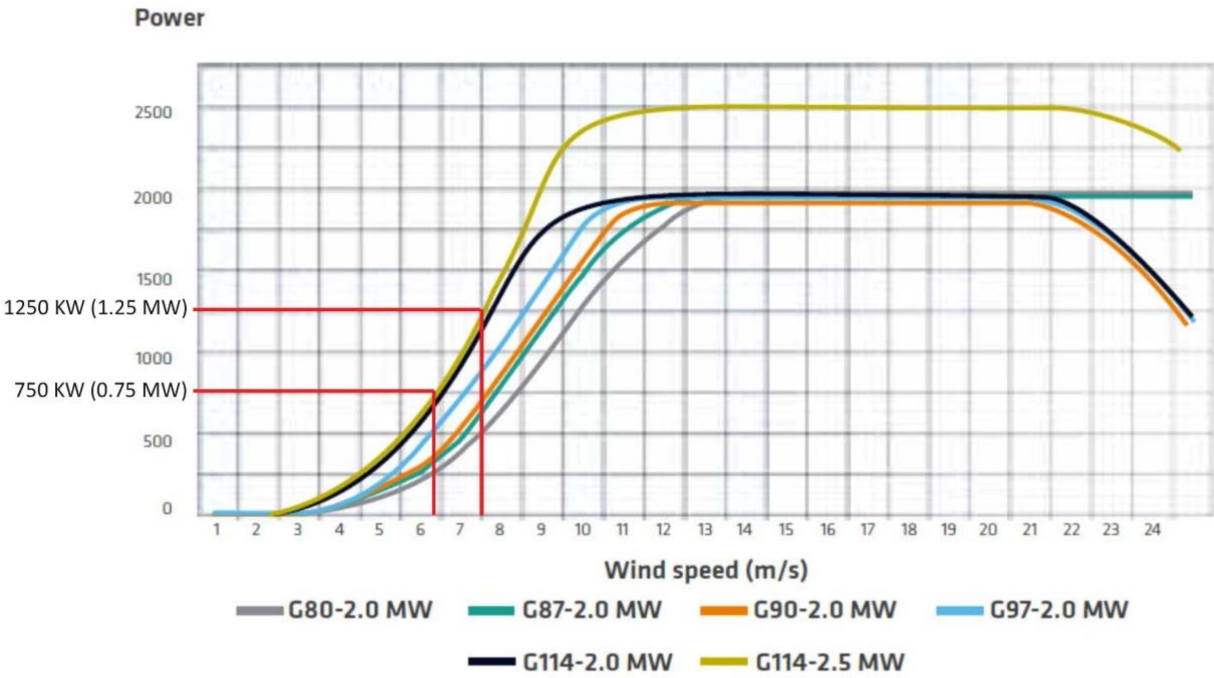


Figure 5-17: Wind Speed Ratings for Gamesa Turbines Adjusted for Saunders County, NE (www.gamesacorp.com/en)

4) Using the WPC_α value (6.7 m/s here), calculate the scaling factor (A) using the Equation 66 below from (Bayerische Landesanstalt für Betriebswirtschaft und Agrarstruktur 2001). The scaling factor is always greater than the average wind speed value listed by the NREL.

$$A = \frac{\bar{v}}{\left(0.568 + \left(\frac{0.434}{k}\right)\right)^{\frac{1}{k}}}$$

Where:

A *= The Scaling Factor*

$\bar{v}$ *= The* $WPC_{\alpha}[n]$

k *= The K-Value*

Equation 66: Scaling Factor (A) for Use in the Weibull Frequency Distribution Function

5) With (A) calculated, calculate the Weibull Frequency Distribution Function $f(V_{Wi})$ in column 3 for each windspeed (V_{Wi}) value in column 1 using Equation 67 below from (Bayrische Landesanstalt für Betriebswirtschaft und Agrarstruktur 2001). Plot the value in a bar graph.

$$f(V_{Wi}) = \frac{k}{A} * \left(\frac{V_{Wi}}{A}\right)^{(k-1)} * e^{-\left(\frac{V_{Wi}}{A}\right)^{k}}$$

Where:

$f(V_{Wi})$ *= The Weibull Frequency Distribution Function Returning a Value of 1 to 100%*

k *= The K-Value from Figure 5-12*

A *= The Scaling Factor, Product of Equation 66*

V_{Wi} *= The Wind Speed for which the f(Vwi) is to be Known*

e = The Natural Log, a Constant (2.781)

Equation 67: The Weibull Frequency Distribution Function f(Vwi)

6) With the Weibull frequency distribution calculated for each windspeed class in percentage, multiply the percentage by the number of hours per year in column 4 to derive a total number of hours per year in which the turbine will produce a specified number of megawatts.
7) In the final column 5, multiply the total number of hours at each wind speed (column 4) by the total MW potential. This effectively calculates the number of adjusted megawatt hour potential for each wind speed class.
8) Summarize column 5 as the estimate for wind turbine type[t] in location[x] within $WPC_{\alpha[n]}$. Multiply this estimate times the number of potential wind turbines in $WPC_{\alpha[n]}$ using the estimate from the WPE (Figure 5-15), the product of which is subsequently referred to here as the Wind Power Potential in megawatt hours (WPP_{MWH}). In reality, there may be several WPC_{α} within a WPE with a specific number of turbines for each WPC_{α}. In this case each $WPC_{\alpha[n]}$ would require its own WPP_{MWH} calculation table and summary, with the final figures added together to calculate the total WPP_{MWH} for a county.

K Value	2	Saunder's County, Nebraska $WPC_{\alpha1}$ MWh Wind Energy Estimation			
Average Wind Speed	6.777				
A (Scaling Factor)	7.6489647				
e (natural log)	2.7812818				
Column Number	1	2	3	4	5
Factor Name	Wind Speed	MW potential for a single turbine at wind speed listed in Column 2, based on Figure 5-22	The frequency of wind speed as determined by the Weibull-Frequency-Distribution Function (See equations 60 and 61)	Number of hours at each wind speed	Energy Estimate in MWh
Factor Unit or Formula	m/s	MW	Percent of year when wind speed in column 1 is reached	Column 4 * 8760 (hours per year)	Column 4 * Column 2
	1	0.01	3.36%	294.263	2.943
	2	0.06	6.38%	558.453	33.507
	3	0.125	8.76%	767.560	95.945
	4	0.25	10.34%	905.523	226.381
	5	0.5	11.04%	967.102	483.551
	6	0.75	10.93%	957.480	718.110
	7	1.25	10.16%	889.952	1112.440
	8	1.75	8.93%	782.461	1369.306
	9	2.25	7.46%	653.932	1471.348
	10	2.375	5.95%	521.221	1237.900
	11	2.45	4.53%	397.155	973.030
	12	2.5	3.31%	289.807	724.517
	13	2.5	2.31%	202.789	506.972
	14	2.5	1.55%	136.212	340.530
	15	2.5	1.00%	87.898	219.745
	16	2.5	0.62%	54.529	136.321
	17	2.5	0.37%	32.537	81.343
	18	2.5	0.21%	18.683	46.708
	19	2.5	0.12%	10.327	25.818
	20	2.5	0.06%	5.497	13.743
	21	2.5	0.03%	2.818	7.046
	22	2.45	0.02%	1.392	3.411
	23	2.375	0.01%	0.663	1.574
	24	2.25	0.00%	0.304	0.684
				MWh for 1 Turbine	**9,832.87**
				MWh / Year for 1216 Turbines in $WPC_{\alpha1}$	**11,956,774.04**

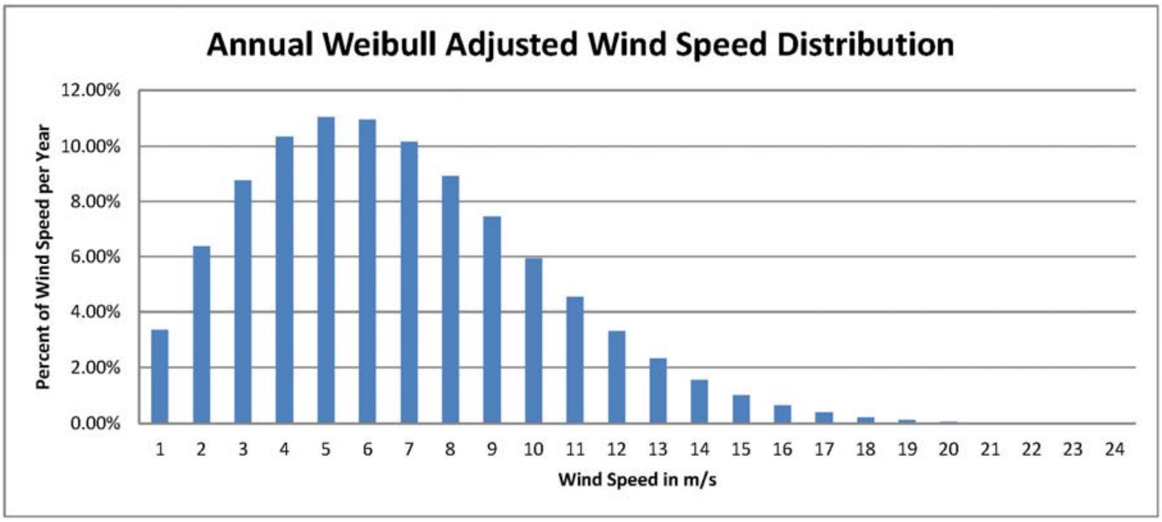


Figure 5-18: Calculation of MWH/Year for Adjusted Wind Power Area 1 ($WPE_{\alpha1}$) Adapted from (Bayerische Landesanstalt für Betriebswirtschaft und Agrarstruktur 2001; Dr.-Ing Jörg Fromme 9/12/2015)

5.5.1.5 Total Renewable Electricity Potential

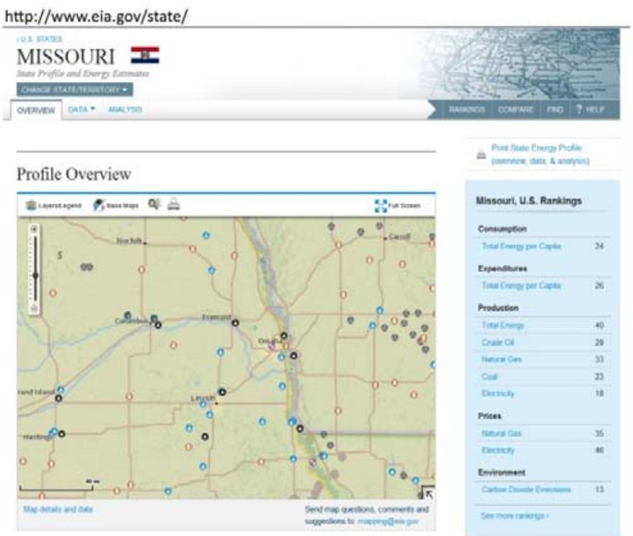
Since renewable electricity capacity in the County Diagnostic is estimated for wind and solar electricity, the two estimates need to be added together to calculate the total annual renewable electricity capacity in MWH for use in the NDI-EC1 equation in section 5.5.4. This step is illustrated in Equation 68 below. If other potential sources of renewable electricity are calculated for a county and should be included in the NDI-E1 formula, then the total annual values from other sources can be added to this equation. Wind and solar power are used here because they are the most cost-attainable technologies in use today.

$$Total\ Renewable\ Electricity\ Potential\ (E1c) = WPP_{mwh} + SEPP_{mwh}$$

Equation 68: Total Renewable Electricity Production Potential in MWH per County (EC1)

5.5.2 Existing Energy Capacity (E2c)

The existing energy capacity is estimated at the county level via data from the US Energy Information Administration (US EIA) that cover many aspects of energy generation including economic, pricing, reserves and supply, distribution and marketing, consumption and expenditures, and environmental impacts and regulations. The data download is carried out manually via the Electricity Data Browser map interface at http://www.eia.gov/state/ where all power generation stations are located with a point that links to downloaded tables of monthly productivity for the recorded lifetime of the facility (Figure 5-19) (United States Energy Information Administration (US EIA) 2012). The manual method is the only way to summarize energy generation at the county level since the smallest level of aggregation provided in prepared tables by the US EIA is the state level. Utilizing the USEIA Electricity Data Browser, county data is downloaded for each power generation plant for the sample year 2012. If all of 2012 is not reported, then the next closest 12 month period to 2012 is reported (ie, July 2012 to June 2013, or September 2011 to August 2012) and noted. In addition to the MWH produced by each prime mover at each power generation plant, the utility name, the county location and a total power generation summary is recorded in a table as indicated in Figure 5-19.



Twelve-Month Summary of Power Generation in MWH for Wahoo Station, Saunders County, Ne		
MONTH	NATURAL GAS NET GENERATION (MWH)	PETROLEUM NET GENERATION (MWH)
Dec-12	1.139	0.579
Nov-12	3.763	1.074
Oct-12	3.382	0.844
Sep-12	5.76	1.057
Aug-12	29.748	0.874
Jul-12	80.24	1.039
Jun-12	33.783	0.945
May-12	15.681	3.537
Apr-12	5.681	4.961
Mar-12	2.052	1.633
Feb-12	1.2	2.281
Jan-12	1.51	1.237
TOTAL (MWH)	**183.939**	**20.061**

Utility Name: City of Wahoo
County: Saunders
Source: http://www.eia.gov/state/

Figure 5-19: US EIA Web Interface (left); Annual MWH Summary for City of Wahoo Station, Saunders NE (right) (Vireo Planning and Design 2014)

With all prime movers [pm] collected from all plants [p] per county [x] per month[t_m] summarized in tabular format and Equation 69 is utilized to calculate a county summary of total MWH production (E2c). The monthly distribution of MWH production by all prime movers in the county is graphed.

$$Existing\ Electricity\ Capacity\ (E2c) = \sum_{t_m=12}^{n} \left\{ \sum_{p=1}^{n} NetGen[pm, t_m, x] \right\}$$

Where:

$\sum_{p=1}^{n} NetGen[pm, t_m, x]$= The total MWH generation per month[t_m] of each prime mover fuel source [pm] in a county (United States Energy Information Administration (US EIA) 2012), summarized for all months[t_m=12] to estimate annual MWH capacity.

Equation 69: County-Wide Existing Electricity Capacity Formula (E2c)

For this study it is assumed that energy demands are being met in all counties via the National Energy Grid even if all of the energy demanded in a county is not produced within the county (ie, imported via the grid), thus the main purpose is not to see if production meets demand within the county boundaries because the US Energy Grid system is designed to transfer energy between states and amongst the federation. Rather, the main purpose of this analysis is to assess the current mix of energy production physically within a county and determine the feasibility of transitioning to a full renewable electricity supply strategy.

5.5.3 Electricity Demand (E1d & E2d)

Electricity demand is calculated for residential, commercial, industrial and transportation sectors based on a top-down approach from statewide US EIA estimates, which are scaled down to the county level using population (United States Census Bureau 2010), Selected Residential Housing Characteristics (United States Census Bureau 2012) and non-residential commercial establishments (US Census Bureau 2012). The energy demand (electricity, gas, fuel oil) from these four sectors is converted to MWH of electricity using a BTU to kWh conversion factor to derive an estimated demand for electricity at the county level. Converting all energy types to electricity assumes that electricity could theoretically provide all the energy we need in the future for residential, commercial, industrial and transport and tests the hypothesis that all energy could be derived from renewable electricity sources within the county. In essence, the method converts our current fossil fuel demand into an electricity demand estimate so that current fossil demands can be compared to renewable electricity production. This strategy also assumes that all fossil fuel resources are non-renewable on the human civilization time scale and therefore should be used very sparingly where absolutely necessary to preserve the resource for future generations as well as reduce emissions from fossil fuel combustion. The formula to calculate the energy demand from scaled statewide estimates and convert the demand to electricity is presented in Equation 70.

$$Electricity\ Demand\ in\ MWh\ (E1d\ \&\ E2d) = \left\lfloor \left\langle \sum \left\{ \left(R_{TBtu}[x_{state}, t] * \frac{R[b]_{county}}{R[b]_{state}} \right) + \left(C_{TBtu}[x_{state}, t] * \frac{C[b]_{county}}{C[b]_{state}} \right) + \left(I_{TBtu}[x_{state}, t] * \frac{I[b]_{county}}{I[b]_{state}} \right) + \left(T_{TBtu}[x_{state}, t] * \frac{POP_{county}}{POP_{state}} \right) + \left(\frac{\sum_{p=1}^{n} MMbtu[pm, t_y, x]}{1000000} \right) \right\} / 0.000000000001 \right\rangle / 3412 \right\rfloor / 1000$$

Where:

$R, C, I, \& T_{TBtu}$ = Annual State-Wide Estimates of Energy use in Trillion British Thermal Units (TBtu) by End-Use sector (US Energy Information Administration 2012, Table C1).

3412 = A Constant, where 1 kWh of Electricity Equals Approximately 3,412 BTU (United States Energy Information Administration (US EIA) 2014)

x_{state}= County-Wide Boundary

t_y = Per Year

$R[b]_{county}$ = The Number of Residential Buildings in a County (United States Census Bureau 2012)

$R[b]_{state}$ =The Number of Residential Buildings in a State (United States Census Bureau 2012)

$C[b]_{county}$ = The Number of Non-Residential Buildings in a County (US Census Bureau 2012)

$C[b]_{state}$ = The Number of Non-Residential Buildings in a County (US Census Bureau 2012)

POP_{county}= US Census Population of the County (United States Census Bureau 2010)

POP_{state}= US Census Population of the State (United States Census Bureau 2010)

$MMBtu[pm, t_y, x]$= Summary of Reported in Million Btu's for all Prime Movers (United States Energy Information Administration 2012)

Equation 70: Annual Electricity Demand in MWH for Residential [R], Commercial [C], Industrial [I] and Transportation [T] Sectors

Ideally, county-wide energy demand for residential, commercial industrial and transportation sectors would be calculated bottom up based on data directly from energy suppliers at the address / owner level and then aggregated to the county level, which is the material flow technique used to calculate Tier 1 localized and internal (ie, internal to the county, not including imports embedded in goods) Carbon Footprints where energy demand by sector is summarized and then converted to GHG emissions based on fuel sources used by suppliers to produce electricity (Pandey et al. 2011). However, after significant searches I believe this data is not publically available in the United States. The reality that this data is not available forces the County Diagnostic method as outlined in this study to rely on a top-down approach for the energy demand factor calculation in lieu of the preferred bottom up approach. Future studies can rework the formulas in this section if data becomes available to calculate electricity demand from the bottom up.

5.5.4 Electricity Balance

The NDI calculation is used to determine the final electricity balance in two ways, 1) The ability of the existing electricity production in the county to satisfy demand, and 2) The ability of the renewable electricity potential in the county to satisfy demand.

$$NDI - E1 = \frac{(Elec.Capacity - Elec.Demand)}{(Elec.Capacity + Elec.Demand)}$$

Equation 71: Existing Electricity Balance

$$NDI - E2 = \frac{(Ren.Elec.Potential - Elec.Demand)}{(Ren.Elec.Potential + Elec.Demand)}$$

Equation 72: Renewable Electricity Balance

5.6 Organic and Municipal Solid Waste (MSW)

The organic and solid material waste section is an estimate of the “detritus” flowing within the urban system. As is detritus with ecosystems, organic and solid “waste” materials represent fundamental material sources for new growth, be it organic growth or human construction and artifact creation, but which need to be broken down into their constituent parts before it can be fed into new processes. Thus, this section quantifies the amount of organic material stemming from the human population, in form of food waste and human effluent and the total volume and type of solid wastes per capita per year which could be used in lieu of chemical fertilizers.

Material outflows are treated as demand in two categories, organic (M1d) and inorganic (M2d) and is assessed against the capacity of the system to re-uptake processed organic material into agricultural products (M1c), taking a theoretical cue from Odum’s proposals for detritus agriculture in mature and stable ecosystems (Odum 1969, p. 268), or break down (recycle) materials for their re-use (M2c). The capacity and demand factors are fed into their respective NDI calculations to determine the direction and magnitude of organic material balance (NDI-M1) and solid waste balance (NDI-M2) as indicated below in Figure 5-20.

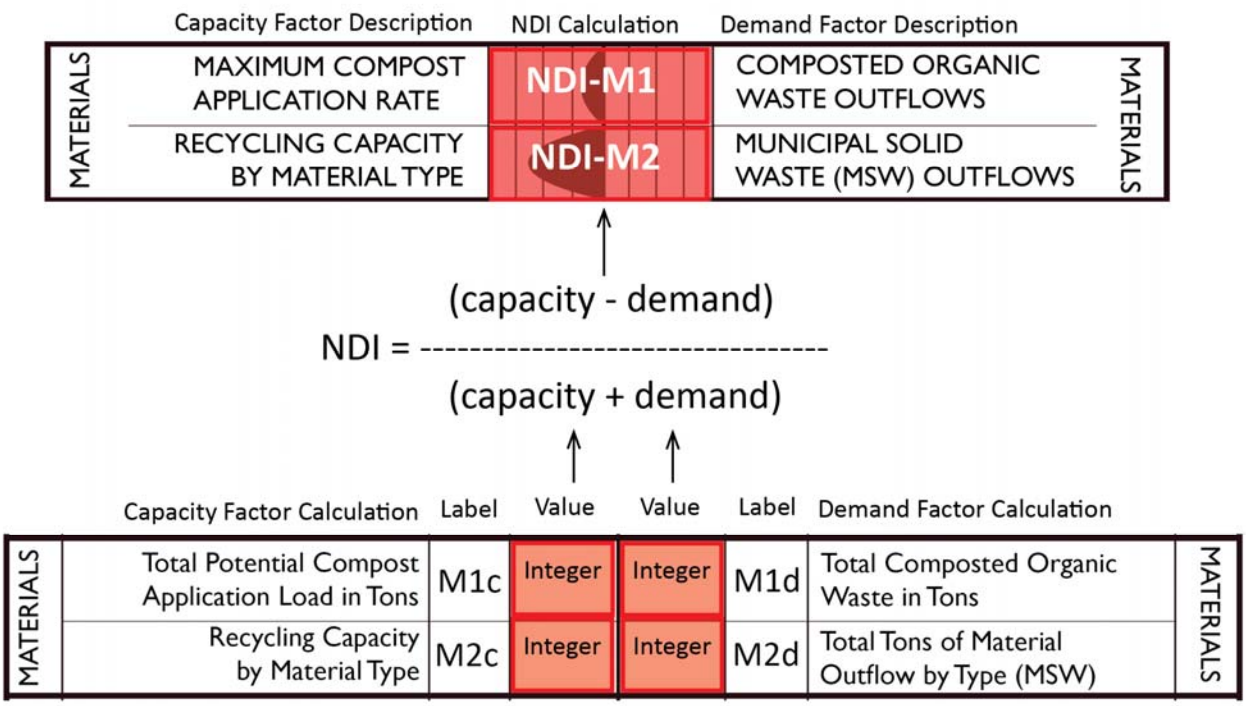


Figure 5-20: Organic and Solid Waste Materials Method Overview

5.6.1 Total Composted Organic Waste in Tons (M1d)

The organic waste outflow estimate comes from five main data sources: the US EPA ECHO database reporting of million gallons per day (MGD) of treated flow through per wastewater treatment facility (US EPA 2010a) with SIC code 4952 (Sewerage Systems) summarized in average MGD for all facilities in a county, the total population (United States Census Bureau 2010) and restaurant establishments by county (US Census Bureau 2012), the US EPA Co-Digestion Economic Analysis Tool (CoEAT) (US

EPA 2010a) which is a spreadsheet model that estimates the food waste related organic material and wastewater treatment sludge production based on the total average MGD by county, population and restaurants from the aforementioned Echo database and US Census, and the US EPA Solid Waste Generation, Recycling and Disposal Facts and Figures in the United States which estimates the quantity of yard trimmings (US EPA 2012) per capita at the national level. The underlying assumptions for the CoEAT model come from 26 different sources ranging from fixed fractions based on cited scientific reports to existing calculators and detailed model outputs from the EIA, EPA, USDA and University sources amongst others (US EPA 2010a).

To load the CoEAT spreadsheet model, population estimates from the US Census of Population (United States Census Bureau 2010) and quantity of food service establishments from the US Economic Census (US Census Bureau 2012) are gathered and the model is populated using Option 1 based on population for residential food waste and a part of Option 2 which includes the NR food waste estimates, using accommodation and food establishments only. A number of other possible NR food waste generation establishment types can be calculated in Option 2 of the COEAT model, however the data for all NR establishment types per county is not available in sufficient detail in all establishment categories to calculate every NR food waste load. Thus, the model calculation in this project is conservative (ie, low as it does not account for any facility that produces food waste aside from restaurants) but could be recalculated if additional detail of establishment types by SIC code become available. The model returns a total quantity in short tons of food and sludge waste feedstock available for a digester, which is then converted to a finished available compost value based on estimates of compost volume reduction via the compost process using a compost volume reduction [cvr] factor. The compost volume reduction factor is used because the CoEAT values are reported in wet tons of food and sludge (ie. prior to compost), where after composting much of the water weight is lost yielding a dry composted weight typically around 50% of the initial wet volume (discussed in 3.6.6 and in Stentiford, Bertoldi 2011).

The CoEAT model can also estimate the feasibility and cost of building (and feeding) a biogas facility to degasify organic wastes and capture the natural gas byproduct before being turned into compost, and as such actually estimates a total cubic meters of natural gas which could be produced. The natural gas byproduct can be compared to the natural gas consumption in the county as described in section 5.5.2 to estimate the synergy and time of payoff of installing a biogas facility, however this estimate is not included in this project because the total demand for natural gas is folded into the total electricity demand as opposed to being a stand-alone unit. In addition, the CoEAT model can calculate the tons of C02 diverted had the organic waste been landfilled, which could also be subtracted from the carbon emissions estimates from section 5.4.1. Neither of these synergistic by-products is directly utilized in the project because a full-standing account of food wastes from all non-residential types is not created, thus a full-standing cost estimate cannot be created. However, future studies may be able to take advantage of this option when more detailed establishment type data is available.

Once the dry finished compost volume in metric tons of food and sludge waste are calculated by the CoEAT model, the volumes are added to the dry metric tons composted volume of yard waste to derive a final volume of dry prepared organic matter for use in land-based fertilizer applications per

US EPA best management practices recommendations (US EPA, Office of Inspector General 2002). Aside from the factors discussed above, the CoEAT spreadsheet model includes many factors and calculations within itself which are not translated into a detailed formula here as they are self-evident in the downloadable CoEAT spreadsheet, rather an overview of the process inputs of the formula is summarized below in Equation 73.

$$(M1d)\ ORGANIC_{DEM} = \langle \left\{ \sum_{p}^{n} FW_{RES}[pop, x, t] + \sum_{p}^{n} FW_{NR}[af, x, t] + \sum_{P}^{n} SLUDGE_{wwtp}[x, t] + \Big((POP_{RES}[x, t] * \ PPD[c, n, t]) \ * \big(YARDTRIM_{pct}\big)\Big) \right\} * f_{cvr}[cp] \rangle$$

Where:

$FW_{RES}[cap, x, t]$ *= The Residential Population [pop] per County [x] for 2012 [t] (United States Census Bureau 2010), Input into and Automatically Calculated by the CoEAT Model (US EPA 2010b) to Derive Short Tons of residential Food Waste (FWRES) per Year [t]*

$FW_{NR}[af, x, t]$ *= The Number of Non-Residential Food Related Establishment Types [af], Based on Accommodation and Food Establishments per County [x] (US Census Bureau 2012), Input Into and Automatically Calculated by the CoEAT Model (US EPA 2010b) to Derive Short Tons of Non-Residential Food Waste (FWNR) per Year [t]*

$f_{cvr}[cp]$ *= The Function of Compost Volume Reduction (cvr) Based on the Compost Process Chosen [cp] (van Haaren 2009; Stentiford, Bertoldi 2011), Typically About 50% of Pre-Compost Volume.*

$SLUDGE_{wwtp}[x, t]$ *= The CoEAT Estimated Sludge Production from all WWTPs per County [x] per Year [t] Based on the MDG Flow-Through per Treatment Facility from the US EPA ECHO Database (US EPA 2015) Reported in Dry Metric Tons (DMT).*

$POP_{RES}[x, t]$*= The Residential Population per County [x] for the Study Year [t] (United States Census Bureau 2010)*

$PPD[c, n, t]$ *= The Pounds per Day (PPD) of MSW Nationally (n) per Year (t) per Capita (POP) (US EPA 2012).*

$YARDTRIM_{pct}$ *= The Percentage of Total Annual MSW Represented by Yard Waste (US EPA 2012)*

Equation 73: Organic Waste Demand Formula Based on the CoEAT Model

5.6.2 Total Tons of Municipal Solid Waste Production (M2d)

The estimate of total tons of MSW produced is calculated based on document analysis of state, regional or county MSW plans and reports, depending on availability. Given the varying nature of data availability, a matrix of calculation methodologies was developed to estimate total waste generated and recovered, which included using given PPD estimates for counties, regions or states, or PPD estimates scaled to county population from regional or state level total waste volume estimates. Recovery rate estimates also varied based on data availability and included regional recovery volumes scaled to county population, percentages of total recovery by category calculated against total waste volumes, national level recovery percentages calculated against total waste volumes and total state recovery volumes scaled to county populations. Although the M2d calculation reports wastes only in total volumes of metric tons, an effort was made to try and source separate generation by category. Equation 74 indicates how the PPD value was used to calculate total waste volume in total tons of MSW for the NDI calculations. In some cases, a county-wide plan excludes an incorporated area and therefore it is necessary to pull waste generation or PPD information from multiple municipal solid waste management plans, in which cases the average PPD between all reporting areas is utilized. Some counties may also report directly on the volume of waste produced and include a breakdown by percentage based on a detailed study, which is considered the best possible estimate as this method does not rely on scaled state or national PPD's or composition percentage. In these cases the total tons and percentages are taken directly from the report and no PPD estimate is utilized, as indicated in Equation 75. Food waste and yard waste are included in section 5.6.1 and are not included in the MSW calculations regardless of how the waste percentages were calculated.

For best results with the MSW section, it is necessary to carry out a document analysis of the county and understand how the waste collection works between the county and incorporated places within the county which may have their own collection and disposal system and waste management plan. This is the only factor which requires this type of data mining from planning documents. In all cases analyzed in this study, the county-specific document analysis method described above did yield different MSW estimates as compared to the national level top down data from the EPA (US EPA 2012, Table 4; Figure 5 2012), and thus the varied methods derived from the document analysis was justified.

$$MSW_{dem} = \sum_{p}^{n} PPD_{msw}[mswtgp] * POP[x,t]$$

Where:

$PPD_{msw}[mswtgp]$ *= The PPD of MSW as Reported from State, Regional or County MSW Planning Reports, Multiplied by the Municipal Solid Waste Type Production Percentage [mswtgp] from (US EPA 2012) or from County Reports when Available.*

$POP[x,t] =$ *The Reported Population per County for the Study Year (US Census)*

Equation 74: MSW Demand Calculation, to be Split by Material Type

$$MSW_{dem} = \sum_{p}^{n} MSWtonnes\,[C,IP]$$

Where:

$MSW_{tonnes}[C, IP]$ *= The Sum of Reported Waste Volumes by County [C] and by Incorporated Place [IP] from Detailed County-Wide or IP Specific Reports.*

Equation 75: Municipal Solid Waste Summary when Reported at the County Level by Weight per Year

5.6.3 Total Potential Compost Application Load in Tons (M1c)

The finished total composted organic waste in tons (section 5.6.1) is distributed to all of the field crop areas based on the NASS Quickstats data as reported in section 5.1 where agricultural organic compost fertilizer demand was estimated at 9.6 tons of compost per one acre of land (Royte 2005). The constant rate from Royte is used in this study for simplicity, but in reality, the N, P, K content of finished compost should be tested and the rate should be determined based on the NPK content of compost, the specific crop type demand which varies on a species by species basis, and the antecedent soil nutrient condition. However, this detail is beyond the scope of the current study and would require detailed field investigations of WWTPs and myriad agricultural fields and thus the constant rate is utilized. However, this number can be updated within the County Diagnostic framework when working with counties in specific projects and in those cases the application rate should be calculated on a field specific and crop type specific basis. The metals content of the sludge is also a consideration, fortunately many WWTPs test for metals content of sludge and this is reported in the US EPA ECHO database. When metals are reported in the sludge higher than EPA allowed concentrations, it is noted in the WWTP sludge report and in such cases sludge should not be included in Equation 73. The formula for

$$COMPOST_{LOAD} = COMPOST_{RATE} * FIELDCROP_{AC}$$

Where:

$COMPOST_{RATE}$ *= A Constant Value of Organic Compost Application Rate for Field Crops (9.6 tons per acre) (Royte 2005).*

$FIELDCROP_{AC}$ *= The Total Acres of Harvested Cropland from the USDA County Summary Highlights (Table 1) (USDA National Agricultural Statistics Service 2012).*

Equation 76: Total Potential Compost Application Load in Tons

5.6.4 Recycling Capacity by Material Type (M2c)

Similar to the MSW generation estimate, the estimate of total tons of recycled municipal solid waste recycled (RMSW) is calculated based on state, regional or county reports, depending on availability, which is translated into a percent of recovery by material category when reported by region and then summarized by county based on population (Equation 77). When county level data is available and the total recovery is reported in total tons recovered (and not broken down by category) the total tons recovered is used without any further category breakdown (Equation 78). Future studies can 'plug in' more detailed county or regional estimates if data becomes more available. The data is ultimately summarized into total tons of MSW recycled in tons for the NDI calculations.

$$RMSW_{dem} = \sum_{p}^{n} PPD_{msw}[mswtrp] * POP[x,t]$$

Where:

$RMSW_{dem}[mswtrp]$ *= The PPD of MSW Multiplied by the Municipal Solid Waste Type Recycling Percentage [mswtrp] from (US EPA 2012).*

$POP[x,t] =$ *The Reported Population per County for the Study Year from the 2012 US American Community Survey Adjusted DP1 Table.*

Equation 77: Total Tons of Recycling Capacity by Material Type

$$RMSW_{dem} = \sum_{p}^{n} RMSW_{tonnes}\,[C, IP]$$

Where:

$RMSW_{dem}[C, IP]$ *= The Sum of Reported Waste Volumes by County [C] and by Incorporated Place [IP] from Detailed County-Wide or IP Specific Reports.*

Equation 78: Recycled Material Reported in Total Tons by County

5.6.5 Organic and MSW Balances

With the summary for organic and MSW factors (M1c-M2c and M1d-M2d) calculated as explained above, the integer variables are fed into their assigned NDI equation formulas (NDI-M1 & NDI-M2) so that a direction and magnitude can be calculated. The results in standard deviations are then plotted on the vertical waveform diagram. The formula for NDI-M1 and NDI-M2 equations are as presented below in Equation 79 and Equation 80.

The total compost volume is reported in tons and is used as a counterpoint for an NDI equation measuring the total composted sludge and potential diverted household food waste produced per county compared with the total compost demand in tons.

$$NDI - M1\ (Organic\ Compost\ Balance) = \frac{M1c\ (Compost\ Limit) - M1d\ (Compost\ Demanded)}{(M1c\ +\ M1d)}$$

Equation 79: NDI-M1 Organic Wastes Balance

$$NDI - M2\ (MSW\ Balance) = \frac{M2d\ (MSW\ Created) - M1c\ (MSW\ Recycled)}{(M2d + M2c)}$$

Equation 80: NDI-M2 MSW Balance

6 County Diagnostic Results

6.1 NDI Results for all Cases by County

The factor summary sheet, NDI calculation table and vertical waveform diagrams are presented from each county case study below and are accompanied by a discussion of the results. All supporting graphs, tables and maps for relevant factors are included as an appendix and referred to in the discussion as (App. I: Figure X-x).

6.1.1 Carroll County, Arkansas

6.1.1.1 Food

As indicated in Table 6-1 Carroll County only meets the food demand of its population in the category of protein, resulting in NDI calculations listed in Table 6-2 which are all negative, with the exception of protein. This translates into a vertical waveform for food which remains in the negative over the entire category (Figure 6-1). The results indicate that food production in Carroll County is designed for export production, specifically in the category of poultry and beef and that most other foods are imported from outside the county.

6.1.1.2 Water

6.1.1.2.1 Water Quantity

As indicated in Table 6-1 Carroll County has an abundance of water compared to demand for the annual time period (W1 through W3), with green water demand (W2d) being almost equal to capacity. The results translate into positive NDI values for all three variables NDI-W1 through NDI-W3 (Table 6-2) creating a pronounced bulge in the waveform towards exponentially greater capacity for the entire water component.

The monthly results indicate that Carroll County has a pronounced wet and dry season where most of the streamflow (Appendix I: Figure 1-3) and runoff availability (App. I: Figure 1-7) occur January through April with a dry June through December. During the dry months human streamflow abstractions (which is calculated as a monthly constant via the USGS NWIS annual calculation (App. I: Table 1-2) but actually is distributed more heavily during summer months where irrigation demand is higher) comes the closest to exceeding the EWR adjusted availability, indicating that irrigation demand in the summer in Carroll County may compete with ecosystem water demand. Blue water demand actually exceeds the EWR runoff availability in July and December (App. I: Figure 1-7). To accommodate this prolonged dry season, the USCOE built a large lake in the western side of Carroll County which ensures adequate drinking water supply throughout the year (visible in App. I: Figure 1-4).

Monthly evapotranspiration availability has two peaks, in May and September respectively, with a reduction in availability during the winter and the height of the summer (App. I: Figure 1-6). When considering the reduction of evapotranspiration availability due to the EWR, human green water demand exceeds availability in February, July, August and October, and exceeds total availability in November, December and January. Annually, green water demand far exceeds blue water demand (App. I: Figure 1-5), a majority of which is accounted for from hay production.

6.1.1.2.2 Water Quality

Annually, both nitrogen and phosphorus demand (point and non-point source load)is significantly lower than the average county-wide monthly thresholds (Table 6-1) corresponding to very high positive NDI values for NDI-W4 and NDI-W5, which in-turn helps create the pronounced capacity bulge for water in the overall Carroll County vertical waveform diagram (Figure 6-1).

The monthly background adjusted load limits for N and P are 3.41 and 0.08 mg/liter respectively, which when summarized monthly based on EWR adjusted runoff volume result in monthly limits which mirror runoff volume, where a larger limit can be tolerated in months with more runoff (App. 1: Table 1-3). The annual N and P loads of 2.77 and 2.68 tons per year respectively are dominated by point source loads from EPA regulated facilities, with five facilities reporting N loads and six facilities reporting P loads (App. 1: Figure 1-8), reflecting the relative small agricultural output of fertilized cereal crops and non-fertilized hay production within the county but continual output from point sources. While the annual N load averaged over 12-months does not exceed the monthly load limit for any months of the year, the annual P load limit averaged over 12-months comes to within 50% of the limit or greater for the dry months of June, July and November.

Three permitted EPA facilities reported exceeding the total maximum daily load (TMDL) for P, which support the findings from this study for P indicating some months of low flow might increase risk for TMDL exceedance. All five EPA permitted WWTP's in the county (listed in App. I: Table 1-7) include Ammonia removal technologies, and one included both N and P removal technologies, which could indicate a reason for no reported N exceedance events and the application of P exceedance risk avoidance strategies. While the County Diagnostic method here was limited to N and P loads, Carroll County does have two 303d listed impaired streams, Kings's Creek and Leatherwood Creek, which reported causes of impairment as total dissolved solids and dissolved oxygen respectively (App. 1: Figure 1-9).

6.1.1.3 Ecosystem Conservation

The existing area of ecosystem conservation denoted by PAD-US for Carroll County is 1.8% area (EC1) and falls considerably short of the recommended 17% land and water area target (Table 6-1), resulting in a strongly negative NDI-EC1 value (Table 6-2) that pulls the waveform towards exponentially greater demand for conservation area (Figure 6-1). However, the potential area for conservation existing in Carroll county far exceeds the 17% target with a connected water and vegetation area of 59.4% remaining in the county, resulting in a strongly positive NDI-EC2 value pulling the vertical waveform for ecosystem conservation towards exponentially greater capacity than shortfall of existing conservation land.

The areas of existing conservation include the large man-made lake on the west side of the county (covering the surface water area, but not the watershed area), a small water and forested area in the northwest of the county and a small area in the extreme northeast of the county, all of which were identified as areas which should be conserved by the zone of conservation (ZOC) model. The county as a whole has an extensive area of potential conservation running northwest and southeast on the southern half of the county which is characterized by many small tributaries and narrow valleys with heavy deciduous forestation that is interrupted by linear areas of road-zone impacts from US Hwy 412 and US Hwy 62. The central, northern and northeast portions of the county are a dominated anthropic grazing land and agricultural (hay) matrix with forested riparian corridors and wooded patches (App. I: Figure 1-10).

6.1.1.4 Carbon Dioxide (CO_2)

Given the extensive area of existing forested land and land in hay production in Carroll County it is no surprise that carbon sequestration far outweighs the calculated carbon emissions for the county (Table 6-1), resulting in a highly positive NDI-C1 value (Table 6-2) which forms the tail of the parabolic positive bulge in the middle of the vertical waveform (Figure 6-1). The area of higher NPP (and hence carbon sequestration via biomass production) is distributed in the central, northern and eastern portions of the county dominated by grassland and hay production with high rates of annual above-ground and below-ground growth and individual turnover, and to a lesser extent in the southern and western areas of the county where extensive stands of mature forested lands with low annual individual turnover exist (App. I: Figure 1-11). Carbon emissions in the county are dominated by industrial and on-road sector emissions followed by residential and airborne travel emissions, a pattern not surprising considering the intensive industrial scale poultry production and generally high percentage of per capita automobile use and trucking in the USA (App. I: Figure 1-12).

6.1.1.5 Electricity

Renewable electricity production potential in Carroll County, including solar and wind sources, totals approximately 920,159 MWH or roughly 25% of the 3.59 million MWH of annual demand (Table 6-1). This creates a strongly negative NDI-E1 value (Table 6-2) and begins the negative trending tail of the vertical waveform towards exponentially greater demand (Figure 6-1). Existing electricity production is much lower than the potential renewable electricity production at 96, 335 MWH reported annually in E2c (Table 6-1) sending the NDI-E2 value further negative (Table 6-2) in the direction of exponentially greater demand for electricity than production (Figure 6-1). Essentially, Carroll County is an energy importer.

The available solar energy production is highly connected to the limited number of building roofs in the county and has an unequal monthly distribution typified by a parabola with the peak of production in August and the trough of production in December/January, reflecting annual insolation, with a total potential of 24,043 MWH production (App. I: Figure 1-13). Given the extensive area of ecosystem conservation potential in the county, the location of urban areas in broad valleys with long visibility and the limited areas of wind resources over 6 m/s, the potential for wind energy production is confined to pockets of barley suitable wind speeds over 6 m/s (App. I: Figure 1-14), although significantly higher than solar energy production at 896, 115 MWH annually and accounting for roughly 97% of the renewable energy potential. The existing energy production comes from Beaver Lake Dam on the extreme west side of County (App. I: Figure 1-16). No fossil fuel or nuclear power exists in the county, which may also attribute to the relatively low percentage of carbon emissions compared to sequestration.

Electricity demand is closely related to the number and type of buildings or power production in the county and is un-evenly distributed by building type (App. I: Figure 1-4), with industrial buildings accounting for the most energy use, mirroring the carbon emissions results in section 6.1.1.4, followed by residential and transport as the second largest categories of energy demand. Interestingly the county reports an energy usage of 268, 676 MWH of energy usage for power plants which can only be interpreted as operating energy use of the Beaver Dam hydroelectric facility or from reverse pumped storage of water which is a typical practice where water is pumped up to a storage facility in hours of the day when demand (and hence energy cost per unit) is low and then released back to the grid during hours of the day when demand is high.

6.1.1.6 Materials

Organic compost production capacity in Carroll County at 4,069 tons per year is slightly less than the land application capacity of 5,017 given the 2012 agricultural productivity profile in 6.1.1.1 (Table 6-1), resulting in slightly positive and almost balanced NDI-M1 value (Table 6-2). Inorganic materials generation, however, is roughly five times the production of organic material at 20, 130 tons annually with less than 10% material recovery rate (Table 6-1), resulting in a highly negative NDI-M2 value (Table 6-2) trending deeply towards exponentially greater demand for material recovery. Together the organic and inorganic materials finish the bottom of the vertical waveform diagram deeply into exponentially greater demand at roughly -0.60.

The organic waste production potential according to the EPA CoEAT model is roughly 65% of total generation (App. I: Figure 1-18), which is strongly influenced by the number of residential households and commercial establishments in the EPA CoEAT model (App.I: Table 1-4) and to a lesser degree the total WWTP sludge flow in MGD which represents about 25% of the estimated compostable solid mass outflow from the CoEAT model (App. I: Table 1-5). Yard waste makes up the remaining 35% of potential organic compostable material.

Total municipal solid waste generation and recovery is not homogeneously distributed, with paper and paperboard dominating the generation category, followed by the potentially compostable yard waste and food waste categories and then plastics. The roughly 10% recovery rate of materials in Carroll County is mostly plastics, followed by rubber, leather and textile, then glass, and all other material recovery negligible. As discussed in the paragraph above, yard trimmings and food waste recovery could provide a needed material stream of compost for agriculture if systems for recovery or diversion were in place, however, less than 1% these materials are recovered in the case of Carroll County according to regional reports (App. I: Figure 1-19).

CARROLL COUNTY NDI FACTOR SUMMARY SHEET								
Capacity Factor			Decimal Value	Decimal Value	Demand Factor			
FOOD	Tons of Hay	F1C	47,935	354,311	F1d	Tons of Hay	FOOD
	Tons of Feed Grains	F2c	-	1,285,405	F2d	Tons of Feed Grains	
	Tons of Cereal Grains	F3c	170	1,878	F3d	Tons of Cereal Grains	
	Tons of Dairy	F4c	3,436	7,513	F4d	Tons of Dairy	
	Tons of Protein	F5c	53,288	1,722	F5d	Tons of Protein	
	Tons of Fruit	F6c	45	5,009	F6d	Tons of Fruit	
	Tons of Vegetables	F7c	137	6,261	F7d	Tons of Vegetables	
WATER	Total Available M^3 of Stream Flow	W1c	240,723,096	8,199,808	W1d	Total M^3 of Adjusted Abstraction	WATER
	Total M3 of Available Atmospheric Moisture (Green)	W2c	475,116,614	463,379,044	W2d	Total M3 of Consumed Atmospheric Moisture (Green)	
	Total Available M3 of Surface Runoff (Blue)	W3c	271,916,173	58,115,230	W3d	Total M3 of Consumed Surface Water (Blue)	
	Critical Annual Nitrogen Load in Tons (Grey)	W4c	928	2.8	W4d	Total Annual Nitrogen Load in Tons (Grey)	
	Critical Annual Phosphorus Load in Tons (Grey)	W5c	21.75	2.7	W5d	Total Annual Phosphorus Load in Tons (Grey)	
ECOSYSTEM CONSERVATION	Total Existing Area of Conservation in Acres	EC1c	7,457	69,501	EC1d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
	Total Potential Area of Conservation in Acres	EC2c	243,066	69,501	EC2d	Minimum Area for Biodiversity Conservation in Acres	
CO_2	Total Carbon Sequestration Potential in Tons	C1c	5,547,521	103,014	C1d	Total Carbon Dioxide Emissions in Tons	CO_2
ELECTRICITY	Total Potential Renewable Electricity in Megawatt Hours	E1c	920,159	3,598,411	E1d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
	Total Existing Electricity Production in Megawatt Hours	E2c	96,335	3,598,411	E2d	Total Electricity Demand in Megawatt Hours	
MATERIALS	Total Potential Compost Application Load in Tons	M1c	5,017	4,069	M1d	Total Composted Organic Waste in tons	MATERIALS
	Recycling Capacity by Material Type in met. Tons	M2c	1,752	20,130	M2d	Total Tons of Material Outflow by Type in met. tons (MSW)	

County:	Carroll	Ecoregion I and II:	Ozark / Ouachita - Appalachian Forests of the Eastern Temperate Forests	
State:	Arkansas	Ecoregion III:	Ozark Highlands	
Acres:	408832		HUC 8:	%
Population:	27446		11010001 (Beaver Reservoir)	100

Table 6-1: Carrol County NDI Factor Summary Sheet

Carroll County NDI Calculation				
(C - D)	**(C + D)**	**NDI**	**NDI Factor Title**	**NDI ID**
(306,376)	402,246	-0.76166	Tons of Hay	NDI-F1
(1,285,405)	1,285,405	-1.00000	Tons of Feed Grains	NDI-F2
(1,708)	2,048	-0.83398	Tons of Cereal Grains	NDI-F3
(4,077)	10,949	-0.37236	Tons of Dairy	NDI-F4
51,566	55,010	0.93739	Tons of Protein	NDI-F5
(4,964)	5,054	-0.98219	Tons of Fruit	NDI-F6
(6,124)	6,398	-0.95717	Tons of Vegetables	NDI-F7
232,523,288	248,922,904	0.93412	Total M^3 of Adjusted Water Abstraction	NDI-W1
11,737,570	938,495,658	0.01251	Total M3 of Consumed Atmospheric Moisture (Green)	NDI-W2
213,800,943	330,031,403	0.64782	Total M3 of Consumed Surface Water (Blue)	NDI-W3
925	931	0.99405	Total Annual Nitrogen Load in Tons (Grey)	NDI-W4
19	24	0.78060	Total Annual Phosphorus Load in Tons (Grey)	NDI-W5
(62,044)	76,958	-0.80620	Existing Area for Biodiversity Conservation in Acres	NDI-EC1
173,565	312,567	0.55529	Potential Area for Biodiversity Conservation in Acres	NDI-EC2
5,444,507	5,650,535	0.96354	Total Carbon Dioxide Balance	NDI-C1
(2,678,252)	4,518,570	-0.59272	Total Potential Renewable Electricity Production in Megawatt Hours	NDI-E1
(3,502,076)	3,694,746	-0.94785	Total Existing Electricity Production in Megawatt Hours	NDI-E2
948	9,086	0.10434	Total Composted Organic Waste in tons	NDI-M1
(18,378)	21,882	-0.83984	Total Tons of Material Outflow by Type in met. tons (MSW)	NDI-M2

Table 6-2: Carrol County NDI Calculation Summary

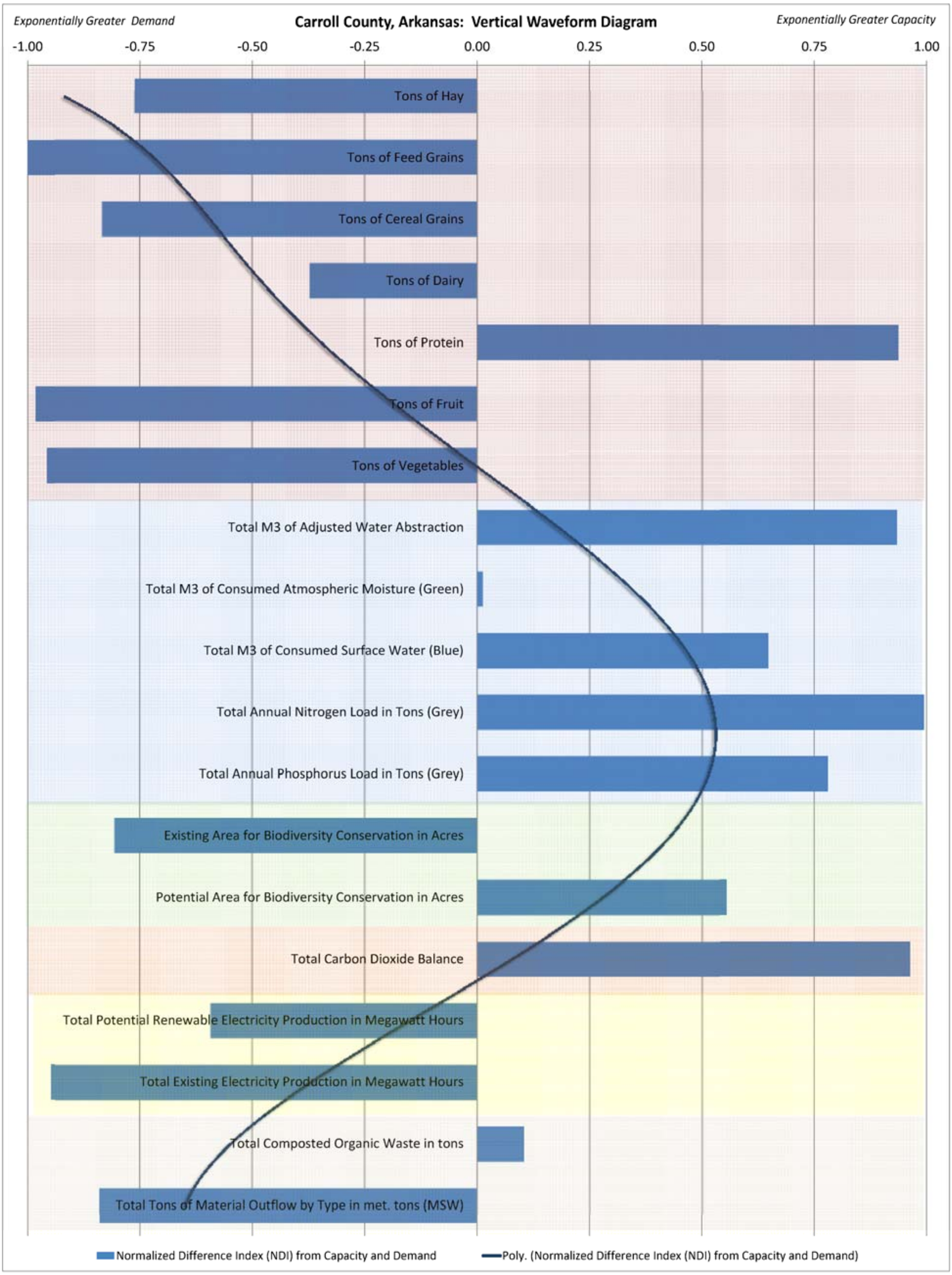


Figure 6-1: Carroll County Vertical Waveform Diagram

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6.1.2 Garrett County, Maryland

6.1.2.1 Food

Garrett County meets the food demand for the categories of cereal grains, dairy and protein, producing almost four times the demand in dairy products. County-wide production falls short in all other categories, producing less than half of the demand of hay, about 20% of the feed grain demand and roughly 10% and less than 1% of the demand for vegetables and fruits respectively (Table 7-3). This pattern of productivity results in negative values for NDI-F1, NDI-F2, NDI-F6 and NDI-F7 and positive values for NDI-F3 through NDI-F5 (Table 7-4), resulting in a variant vertical waveform pattern for food (Figure 7 2). These results indicate that food systems in Garrett County are based around cattle and grain production which require imports of hay and feed grains for livestock and fruits and vegetables for human consumption (App. I: Figure 2-1).

6.1.2.2 Water

6.1.2.2.1 Water Quantity

As indicated in Table 7-3 Garrett County has an abundance of water compared to demand for the annual time period (W1 through W3), resulting in all positive values for NDI-W1 though NDI-W3 above 0.50 (Table 7-4) and a strong directionality in all water categories trending towards exponentially greater capacity (Figure 7 2).

The monthly results indicate a pronounced wet and dry season where a majority of the streamflow (App. I: Figure 2-3) and runoff availability (App. I: Figure 2-7) occur between December and May. There are no months were the estimated human streamflow abstraction (App. I: Table 2-2) or blue water demand (App. I: Figure 2-5) exceed the EWR adjusted streamflow or runoff availability respectively. However, given the mountainous topography of the county, a reservoir was built to take advantage of the strongly seasonal rainfall for either flood protection or streamflow availability for human abstraction, or both (App. I: Figure 2-2).

Monthly evapotranspiration availability has a very pronounced peak between late April and mid-October and a significantly lower EWR adjusted availability compared to total availability (App. I: Figure 2-6) and a green water demand of more than 10 million cubic meters per month with a doubling of the demand between the May and September growing season (App. I: Figure 2-5). This distribution results in an exceedance of EWR adjusted green water availability in November and December and almost exceeds availability January through April. The high demand for green water is explained by the production of hay and feed grains in section 7.3.1 which is distributed in grassland and agricultural lands in valleys at lower elevations (App. I: Figure 2-4).

6.1.2.2.2 Water Quality

Annually, both nitrogen and phosphorus demand (point and non-point source loads) is lower than the averaged county-wide limits (Table 7-3), with N being significantly lower and P approaching about 75% of the annual limit. This results in strongly positive NDI-W4 almost approaching 1 and a weak positive NDI-W5 value which is about balanced annually (Table 7-4) and helps form the vertical waveform for water which trends towards exponentially greater capacity.

The monthly background adjusted load limits for N and P are 5.32 mg/l and 2.95 kg/day respectively, which when summarized monthly based on the EWR adjusted runoff volume results in monthly limits which mirror runoff volume, where a larger limit can be tolerated in months with more runoff (App. I: Table 2-3). The annual N and P loads of 27.8 and 10.6 tons per year respectively are dominated by fertilization from crop and oilseed fertilization, with a bit over 16% of the total percentage of the N load coming from five point sources and less than 0.01% of the P load coming from two point sources (App. I: Figure 2-8). When these annual loads are averaged over 12 months the N load well under the load limit for all months, however the P load exceeds the load limits for the months June through November when runoff and corresponding streamflow is statistically much lower.

Three permitted EPA WWTP facilities from App. I: Table 2-7 reported exceeding the allowed TMDL of N at one time in the year and no facilities reported exceeding the allowed daily loading rate of P and one WWTP facility had invested in N removal technology. This result indicates that even though the average monthly N load was lower than the calculated monthly N load limit, there still may be individual days where the TMDL for N is exceeded and may not be visible in the County Diagnostic method. Generally, the application of nutrient removal technologies for N and P is minimal or non-existent in Garrett County. Interestingly, a very high number of streams in the county are listed on the US EPA 303d list of impaired streams with the listed impairment causes of "Biological, Fecal Coliform, TSS, pH, Nutrients and Mercury (App. I: Figure 2-9)." While these impairments are not directly N or P related, they could be the outcome of eutrophication caused by N or P loading.

6.1.2.3 Ecosystem Conservation

The existing area of ecosystem conservation denoted by PAD-US for Garrett County is 23.6% of the total area (EC1) and meets the recommended 17% land and water area target for conservation (Table 6-3), resulting in a weakly positive NDI-EC1 value (Table 6-4). In addition, the potential area of ecosystem conservation significantly exceeds the 17% limit with up to 70% of the county area currently in fluvially connected contiguous forestlands and strongly positive NDI-EC2 value. These positive NDI values keep the vertical waveform diagram trending towards exponentially greater ecosystem capacity over the entire ecosystem conservation category.

The areas of existing conservation are located almost exclusively over areas identified as locations which should be conserved in the ZOC model and consist of predominantly deciduous forest and forested wetlands with some interspersed mixed forest, evergreen forest and warm season grasslands. Interestingly, there is a small percentage of conserved lands which are adjacent to highways, such as the National Pike/Hwy running east-west in the extreme north of the county which experience sound-related impacts. Most of the human development is concentrated along the roadways, a development strategy which results in maximization of connected forested areas.

6.1.2.4 Carbon Dioxide (CO_2)

With the extensive area of existing forested land and land in hay or grain production in Garrett County, it is not surprising that carbon sequestration far outweighs the calculated carbon emissions for the county (Table 6-3) with 13.09 million tons of carbon sequestered annually compared to emissions of 146, 492 tons of carbon, resulting in a highly positive NDI-C1 value (Table 6-4). This excess of carbon sequestration capacity forms the tail end of the parabolic sweep of exponentially greater capacity which trends through water, ecosystem conservation and CO2 sequestration (Figure 6-2). The entire county area has a relatively heterogeneous distribution of moderate to high carbon sequestration with a faintly discernable pattern related to higher sequestration in areas of human settlement where hay and grain production and slightly lower sequestration in the forested mountainous areas dominating the eastern side of the county (App. I: Figure 2-11). Carbon emissions in the county are dominated by transportation emissions followed by residential, commercial and industrial emissions respectively (App. I: Figure 2-12), again reflecting the highly automobile oriented nature of the USA.

6.1.2.5 Electricity

Renewable electricity production in Garrett county includes both wind and solar resources totaling 2.69 million MWH or roughly 75% of the total county demand of 3.59 million MWH annually (Table 6-3), resulting in a weakly negative NDI-E1 value of -0.13 (Table 6-4) and starting a recurve in the vertical waveform overall towards increasing demand for energy production (Figure 6-2). Existing electricity production is much lower than the potential renewable electricity production at 323, 796 MWH reported annually (Table 6-3), resulting in a highly negative NDI-E2 value (Table 6-4) pulling the vertical waveform moderately towards exponentially greater demand for energy production within the county. Garrett County is an electricity importer.

The available solar electricity production is highly connected to the number of building roofs in the county and has a monthly distribution with a parabolic peak in August and troughs in December and January, with a potential roof-based production of 31,177 MWH (App. I: Figure 2-13). With the extensive area of ecosystem conservation, placement of human settlements in low lying valleys with wide viewsheds and the patch-like nature of areas with wind resources over 6 m/s, the potential for wind generated electricity is confined to small pockets of potential turbine areas located in small open areas with hidden viewsheds from urban populations (App. I: Figure 2-14). The total wind production potential is estimated at 2.66 million MWH from 282 wind turbines over eight different adjusted wind power class areas (App. I: Table 2-4), or roughly 99% of the renewable energy potential. Interestingly, 94.6% of the existing electricity production in the county comes from wind with the remaining 5% coming from hydroelectricity and no recorded solar electricity production (App. I: Figure 2-15), which to some degree justifies the results of the County Diagnostic renewable electricity production potential model.

Electricity demand is distributed somewhat evenly over all categories with residential and power plant demand being the highest followed by almost even commercial and transport demand and industrial demand the lowest (App. I: Figure 2-16). These results reflect the carbon dioxide emissions summary in section 6.1.2.4 where residential, commercial and transportation emissions are larger than industrial emissions, but do not quite match the pattern in the pattern in power plant category where electricity demand for power plants is the second highest whereas it is the lowest in terms of carbon dioxide emissions. This could be explained by reverse pumped storage from the hydroelectric dam, where the demand for electricity is high when pumping but the emissions are low because the source is very low emissions hydroelectricity which is supplemented by some type of imported fossil fuel or liquid fuel oil with associated emissions.

6.1.2.6 Materials

Organic compost production capacity in Garrett County at 8,216 tons per year is roughly double the agricultural capacity of land-applied fertilizers at 4,326 given the non-fertilized hay dominated 2012 agricultural productivity profile in section 6.1.2.1 (Table 6-3), resulting in a moderately negative NDI-M1 value (Table 6-4) which keeps the vertical waveform in a position of moderate demand for agricultural areas to apply composted fertilizer. Municipal solid waste production of 26,907 tons per year is about 35% more than the recovery rate of 19, 867 tons per year (Table 6-3), resulting in a weakly negative NDI-M2 value (Table 6-4) which actually pulls the bottom of the vertical waveform towards a positive recurve in weakly negative territory (Figure 6-2).

The greatest category of both organic waste potential and MSW is yard waste, making up 75% of the source material for organic compost (App. I: Figure 2-17) and 45% of MSW generation (as reported by Garrett County 2012 MSW report), much higher than the national average of 14% of MSW as yard waste as reported by the EPA (App. I: Figure 2-18). The remainder of compost source material is reported as food waste from residential and commercial sources, which is ten times the amount of compost which is estimated to be generated from WWTP sludge in the county (App. I: Table 2-5 and Table 2-6).

Total Generation of MSW is dominated by yard waste as mentioned in the paragraph above, followed by yard waste, glass and other materials. Interestingly, the recovery rate for yard waste is higher than the rate of generation, which indicates that there may be a compost facility in Garrett County which receives waste inputs from other counties for the purpose of compost generation (App. I: Figure 2-18). This would explain why the generation of composted waste is higher than the demand for compost as fertilizer.

GARRETT COUNTY NDI FACTOR SUMMARY SHEET							
	Capacity Factor		Decimal Value	Decimal Value		Demand Factor	
FOOD	Tons of Hay	F1C	105,574	239,102	F1d	Tons of Hay	FOOD
	Tons of Feed Grains	F2c	38,561	202,412	F2d	Tons of Feed Grains	
	Tons of Cereal Grains	F3c	7,472	2,060	F3d	Tons of Cereal Grains	
	Tons of Dairy	F4c	28,294	8,239	F4d	Tons of Dairy	
	Tons of Protein	F5c	7,989	1,888	F5d	Tons of Protein	
	Tons of Fruit	F6c	26	5,493	F6d	Tons of Fruit	
	Tons of Vegetables	F7c	674	6,866	F7d	Tons of Vegetables	
WATER	Total Available M^3 of Stream Flow	W1c	279,227,539	7,868,319	W1d	Total M3 of Adjusted Abstraction	WATER
	Total M3 of Available Atmospheric Moisture (Green)	W2c	395,945,469	200,856,627	W2d	Total M3 of Consumed Atmospheric Moisture (Green)	
	Total Available M3 of Surface Runoff (Blue)	W3c	759,042,920	10,379,937	W3d	Total M3 of Consumed Surface Water (Blue)	
	Critical Annual Nitrogen Load in Tons (Grey)	W4c	4,038	27.8	W4d	Total Annual Nitrogen Load in Tons (Grey)	
	Critical Annual Phosphorus Load in Tons (Grey)	W5c	14	10.6	W5d	Total Annual Phosphorus Load in Tons (Grey)	
ECOSYSTEM CONSERVATION	Total Existing Area of Conservation in Acres	EC1c	99,087	71,344	EC1d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
	Total Potential Area of Conservation in Acres	EC2c	297,076	71,344	EC2d	Minimum Area for Biodiversity Conservation in Acres	
CO_2	Total Carbon Sequestration Potential in Tons	C1c	13,091,283	146,492	C1d	Total Carbon Dioxide Emissions in Tons	CO_2
ELECTRICITY	Total Potential Renewable Electricity in Megawatt Hours	E1c	2,696,758	3,549,425	E1d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
	Total Existing Electricity Production in Megawatt Hours	E2c	323,796	3,549,425	E2d	Total Electricity Demand in Megawatt Hours	
MATERIALS	Total Potential Compost Application Load in Tons	M1c	4,326	8,216	M1d	Total Composted Organic Waste in tons	MATERIALS
	Recycling Capacity by Material Type	M2c	19,867	26,907	M2d	Total Tons of Material Outflow by Type (MSW)	

County:	Garrett	Ecoregion I and II:	Ozark / Ouachita - Appalachian Forests of the Eastern Temperate Forest	
State:	Maryland	Ecoregion III:	Ridge and Valley	
Acres:	419672	HUC 8	Basin Name	%
Population:	30097	5020006	Youghiogheny	70
		2070002	North Branch Potomac	30

Table 6-3: Garrett County NDI Factor Summary Sheet

Garrett County NDI Calculation				
(C - D)	**(C + D)**	**NDI**	**NDI Factor Title**	**NDI ID**
(133,528)	344,676	-0.38740	Tons of Hay	NDI-F1
(163,851)	240,973	-0.67996	Tons of Feed Grains	NDI-F2
5,412	9,532	0.56777	Tons of Cereal Grains	NDI-F3
20,055	36,533	0.54896	Tons of Dairy	NDI-F4
6,101	9,877	0.61770	Tons of Protein	NDI-F5
(5,467)	5,519	-0.99058	Tons of Fruit	NDI-F6
(6,192)	7,540	-0.82122	Tons of Vegetables	NDI-F7
271,359,220	287,095,858	0.94519	Total M^3 of Adjusted Water Abstraction	NDI-W1
274,259,987	596,802,096	0.45955	Total M3 of Consumed Atmospheric Moisture (Green)	NDI-W2
748,662,983	769,422,857	0.97302	Total M3 of Consumed Surface Water (Blue)	NDI-W3
4,010	4,066	0.98632	Total Annual Nitrogen Load in Tons (Grey)	NDI-W4
3	25	0.14135	Total Annual Phosphorus Load in Tons (Grey)	NDI-W5
27,743	170,431	0.16278	Existing Area for Biodiversity Conservation in Acres	NDI-EC1
225,732	368,420	0.61270	Potential Area for Biodiversity Conservation in Acres	NDI-EC2
12,944,791	13,237,775	0.97787	Total Carbon Dioxide Balance	NDI-C1
(852,667)	6,246,184	-0.13651	Total Potential Renewable Electricity Production in Megawatt Hours	NDI-E1
(3,225,629)	3,873,221	-0.83280	Total Existing Electricity Production in Megawatt Hours	NDI-E2
(3,890)	12,542	-0.31021	Total Composted Organic Waste in tons	NDI-M1
(7,040)	46,774	-0.15051	Total Tons of Material Outflow by Type in met. tons (MSW)	NDI-M2

Table 6-4: Garrett County NDI Calculation Summary

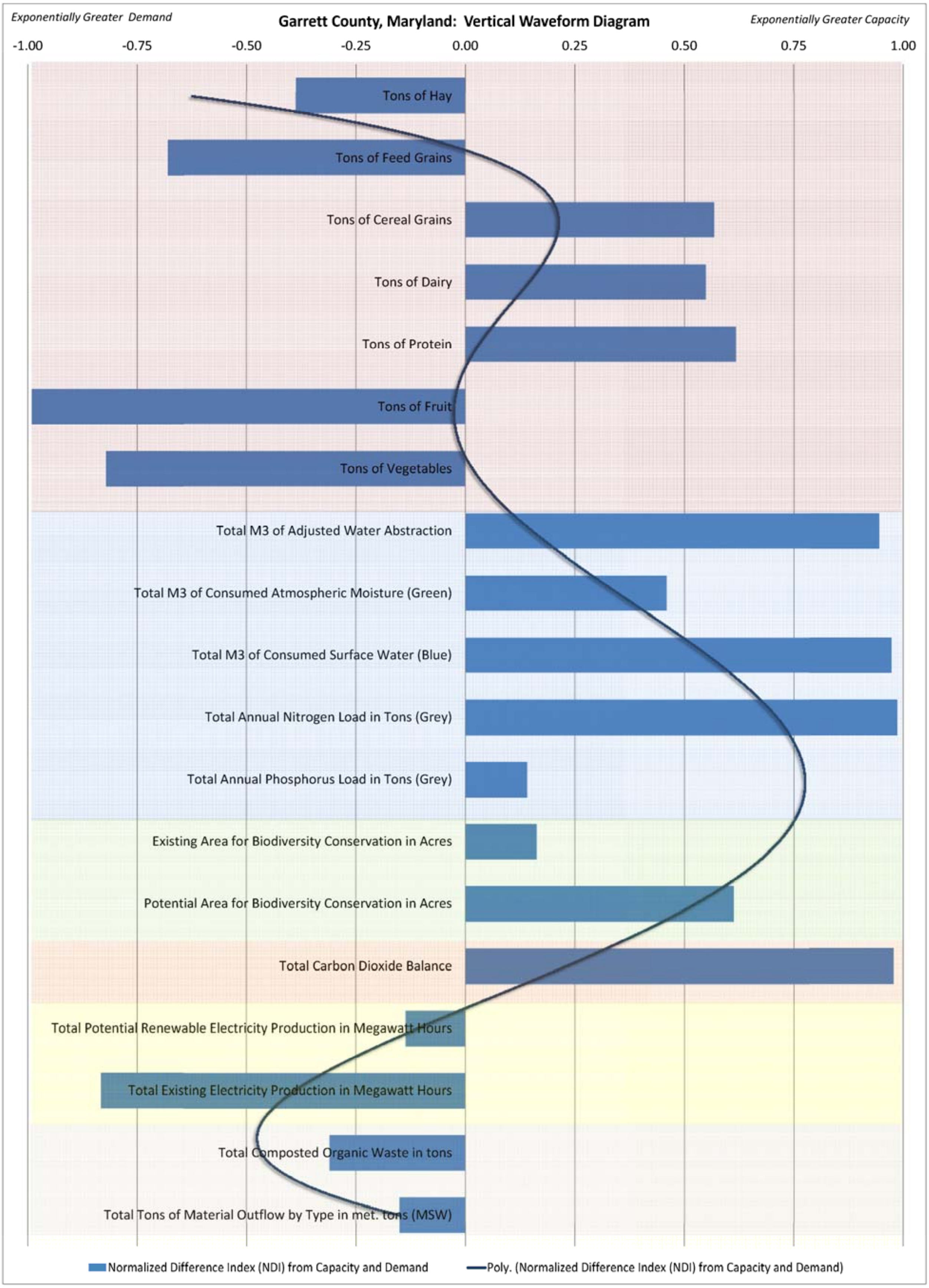

Figure 6-2: Garrett County Vertical Waveform Diagram

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6.1.3 Logan County, Illinois

6.1.3.1 Food

As indicated in Table 6-5 Logan County meets the demand for food in the categories of vegetables, protein and cereal grains, with the production of protein and cereal grains exponentially higher than demand, and does not meet the human and livestock food demands for hay, feed grains, dairy and fruit (with no fruit production recorded at all). This results in a mix of positive and negative NDI values with NDI-F1, NDI-F2, NDI-F4 and NDI-F6 all significantly negative and NDI-F3, NDI-F5 significantly positive and NDI-F7 weakly positive (Table 6-6). Even though the demand is well exceeded in two categories, the strong negative NDI values for all other categories and the weak positive NDI value for vegetables results in a vertical waveform for food generally trending towards exponentially greater demand, meaning the excessive production of cereal and protein is not enough to offset the strong shortfalls of all other categories (Figure 6-3). The quantity of production needed to meet the fruit, nut, vegetables, dairy, feed grains and hay combined is only a tiny fraction of the recorded overproduction in cereal grains. This signature reflects a monocrop system.

6.1.3.2 Water

6.1.3.2.1 Water Quantity

As indicated in Table 6-5 Logan County exhibits a mixed annual water availability, with annual stream flow availability (W1) and surface water (W3) sufficient to meet the annual water extraction and blue water demand but exceeds annual availability for green water demand (W2), resulting in a moderately positive NDI-W1 value and a strongly positive NDI-W3 value and a weakly negative NDI-W2 value (Table 6-6). This mix of positive and negative values for water quality brings the vertical waveform over towards weakly greater water capacity in the three water quantity categories.

The monthly results for Logan county reveal a different pattern than the annual results, with a pronounced wet and dry season where most of the streamflow is recorded in February through June and a dry season starting in July and running through January, with human abstraction totaling 62% to 83% of EWR adjusted availability in September through December (App. I: Figure 3-3). Monthly runoff availability does not mirror streamflow, with a double peak of rainfall recorded in April and October, typical of the US Midwest which has spring and fall cyclonic precipitation, with a very pronounced dry season peaking in July where demand for blue water actually exceeds EWR adjusted capacity (App. I: Figure 3-7). It should be noted that water extraction from groundwater accounts for half of all water extraction, with public supply taking up the majority of ground water demand (App. I: Table 3-2), which could be a response to securing drinking water during the streamflow dry season which follows a rainfall dry season in the summer.

Monthly evapotranspiration availability has a single peak in June and July, which is opposite of runoff availability causing greenwater demand to substantially exceed availability in April, May, late August, September, October, November and the first half of December (App. I: Figure 3-6), a majority of which is accounted for by the very high cereal grain production in the county as indicated in section 6.1.3.1. Evapotranspiration has been appropriated over a larger area of the county with ecosystem area minimized, presumably due to extensive field cropping (App. I: Figure 3-4) and it is worthy to note that green water demand is 70 times the demand for blue water during the growing season of May through November (App. I: Figure 3-5), another signature related to field crop monocrop systems. When all water availability observations are considered, it would make sense to hypothesize that Logan County must rely on streamflow, groundwater, runoff and evapotranspiration together throughout the year to achieve such a high field crop production rate, effectively appropriating a majority of the water from ecosystems via a strategy of extraction diversification.

6.1.3.2.2 Water Quality

Given the monocrop agricultural production strategy in Logan County it is not surprising to find that loads of nitrogen and phosphorous exceed the average N and P limits of the county listed in factors W4 and W5 (Table 6-5), resulting a moderately negative NDI-W4 value for N and a weakly negative NDI-W5 value for P. The negative NDI-W4 and NDI-W5 values pull the vertical waveform diagram back into negative territory.

The monthly background adjusted average load limits for N and P are 1.78 and 1.61 mg/l per monthly average respectively (App. I: Table 3-3), the monthly load limits of which reflect seasonal runoff availability as discussed above in section 6.1.3.2.1. The actual N and P loads themselves are dominated by field crop production of cereals and oil crops (corn and soybeans) where non-point sources from fertilizer load streams and fields with these chemicals via fertilization, with reported point sources of N and P as negligible or non-existent (App. I: Figure 3-8). This pattern results in monthly load limits for N being exceeded in all months when averaged and for all months except the peaks of runoff in April, September and October for P. In reality, N and P are field applied at the time of planning, spring for corn and soybeans, which means these loads are heavily weighted towards the spring and fall where high runoff leeches these chemicals into surface and ground water systems.

Interestingly, none of the EPA permitted point discharge sites exceeded the load limit values for N or P (App. I: Table 3-6) and while there are EPA 303d listed impaired streams in the county, the source of impairment listed for all three streams (Sugar Creek, Kickapoo Creek and Lake Fork) is Fecal Coliform (App. I: Figure 3-9) which typically stem from livestock cultivation and not N and P non-point source loads. Two of the EPA permitted sites listed treatment technologies for BOD removal but no facilities listed treatment technologies for N or P removal. In this case, the result of the County Diagnostic water quality analysis and the reported EPA water quality parameters are confounding. One factor which may support the County Diagnostic N and P results is that the source of municipal water supply is 100% ground water based (sand and gravel alluvial aquifers), which might reflect a drinking water source strategy which avoids surface water treatment and consumption due to known contamination. In addition high levels of BOD can result from excess nutrients which could be an outcome of N and P contamination (eutrophication).

6.1.3.3 Ecosystem Conservation

The existing area of conservation denoted by PAD-US for Logan County is 2.9% of the total area (EC1) represented by an area southwest of the main urbanized area in the center of the county and a small area along I-55 in the southwest corner of the county, falling considerable short of the 17%

land and water area target (Table 6-5). This shortfall results in a strongly negative value for NDI-EC1 (Table 6-6) pulling the vertical waveform further towards demand for ecosystem conservation area (Figure 6-3). The potential area of ecosystem conservation does slightly exceeds the 17% land and water area target slightly, resulting in a weakly positive NDI-EC2 value which pulls the vertical waveform towards excess capacity. However, the slight excess of ecosystem conservation potential is not due to preservation of existing vegetation, rather it is due to the inclusion of FEMA and geomorphic floodplains as part of the zone of conservation (ZOC), which in reality are used extensively for field crop cultivation in Logan County. If fluvially connected pasture land, wetlands, deciduous forests, waterbodies and steep slopes are considered independently from FEMA floodplains then the area of ecosystem conservation comes to 53,348 acres or 13.4% of the County area, falling short of the 17% target (App. I: Figure 3-10). From a landscape ecology perspective, the county can be considered an agricultural matrix with small patches of pasture and forest along narrow riparian corridors. Although there are 2 major interstates running through the County, few if any road zone impacts are recorded due to the minimal amount of existing vegetated patches.

6.1.3.4 Carbon Dioxide (CO_2)

With the intensive grain and oilseed monocrop system in Logan County creating large amounts of annual above and below ground biomass and a relatively small human population it is not surprising that carbon sequestration far outweighs carbon emissions in the county (Table 6-5), resulting in a strongly positive NDI-C1 value bringing the vertical waveform diagram back into positive (Figure 6-3). The areas of higher NPP (and hence greater carbon sequestration correspond with the main fluvial corridors and FEMA floodplains where pasture and forested vegetation exists with a spike in sequestration in the center of the county near the main urban center. The rest of the county has moderate to low carbon sequestration (App. I: Figure 3-11). Carbon emissions reflect a rural agricultural community with onroad emissions accounting for almost 60% of emissions followed by residential, nonroad, industrial and commercial sources respectively (App. I: Figure 3-12).

6.1.3.5 Electricity

Renewable electricity production in Logan County exceeds the electricity demand by a factor of almost 5, being capable of producing more than 12 million MWH (Table 6-5), resulting in a strongly positive NDI-E1 value (Table 6-6) which pulls the vertical waveform towards exponentially greater electricity capacity compared to demand (Figure 6-3). However, this trend towards greater capacity is reversed by the existing electricity production which accounts for only 4.6% of demand, resulting in a strongly negative NDI-E2 value which bends the vertical waveform towards exponentially greater energy demand than capacity (Figure 6-3). Essentially, Logan County is an electricity importer but has a very strong potential to be an energy producer and exporter, which could create long term financial stability for the County as a whole.

The available solar energy has a similar pattern to other counties with a gently arcing production curve peaking in July, and due to the limited number of industrial and commercial buildings in the county on which to mount PV panels accounts for only 20,613 MWH, or less than 1% if the renewable electricity potential (App. I: Figure 3-13). The real renewable electricity production potential lies with wind power due to the widespread areas of over 6 m/s wind resource and the relatively small ZOC area to limit wind power installations. In fact the greatest limitation to placement of wind turbines is the visibility of wind turbines on the landscape since the County has a generally homogeneous distribution of small farm communities on a relatively flat landscape, meaning that wind turbines are visible from a long distance (App. I: Figure 3-14). Nonetheless, the wind energy model estimated that a total of 81,362 acres could be suitable for installing a total of 1,243 wind turbines which results in the 12.6 million MWH hours of potential production in six different adjusted wind power class envelopes (App. I: Table 3-4).The existing energy production in the county is represented by a single wind farm, supporting the conclusion of wind power viability from the County Diagnostic method, which indicates one of the inherent factors of wind power which is inconsistency over an annual period (App. I: Figure 3-15).

The electricity demand for Logan is comprised of energy use from four sectors with industrial demand being the largest, followed by almost equal residential and transport demand, then commercial demand and power plant energy use being the lowest at zero due to the source being wind (App. I: Figure 3-16). The energy demand does not really follow the emissions as listed in section 6.1.3.4 aside from residential being large than commercial, indicating a confounding result between the County Diagnostic bottom-up building based electricity demand methodology and the large scale top down county-wide methodology used in the Vulcan 2.0 carbon emissions methodology.

6.1.3.6 Materials

Organic compost production potential in Logan County is in line with the production potential of other counties at 4,053 tons produced per year, but given the extensive agricultural lands it falls wildly short of the 35,729 ton capacity which could be field applied per year (Table 6-5), resulting in a strongly positive NDI-M1 value (Table 6-6), indicating a high capacity of the agricultural landscape to accept organic composts, and keeping the vertical waveform on the side of moderate capacity (Figure 6-3). Municipal solid waste generation at 38,131 tons per year is roughly 5 times the recovery potential (Table 6-5) resulting in a moderate to highly negative NDI-M2 value (Table 6-6) that pulls the bottom of the waveform diagram towards exponentially greater demand for MSW recovery (Figure 6-3).

The organic waste production potential from food waste and WWTP sludge according to the EPA CoEAT model (App. I: Table 3-5) is roughly 55% of total organic compost production potential; with wastewater solids mass comprising a bit over 25% of the total CoEAT estimated feedstock. Yard waste comprises the remaining 45% of organic compost feedstock material (App.I: Figure 3-17). Logan county has a task force appointed to track and manage MSW generation and recovery, which reported that paper and cardboard, plastics, yard trimmings and food waste and 'other' make up the bulk of MSW (App. I: Figure 3-18). Given the low rate of yard trimming and food waste recovery indicated in the 2015 task force report, diversion of organic material represents a potential material stream which could be harnessed for agricultural land applied compost .

LOGAN COUNTY NDI FACTOR SUMMARY SHEET							
	Capacity Factor		Decimal Value	Decimal Value		Demand Factor	
FOOD	Tons of Hay	F1C	7,174	35,293	F1d	Tons of Hay	FOOD
	Tons of Feed Grains	F2c	10,107	110,958	F2d	Tons of Feed Grains	
	Tons of Cereal Grains	F3c	539,541	2,074	F3d	Tons of Cereal Grains	
	Tons of Dairy	F4c	321	8,296	F4d	Tons of Dairy	
	Tons of Protein	F5c	63,262	1,901	F5d	Tons of Protein	
	Tons of Fruit	F6c	-	5,531	F6d	Tons of Fruit	
	Tons of Vegetables	F7c	13,097	6,913	F7d	Tons of Vegetables	
WATER	Total Available M^3 of Stream Flow	W1c	53,185,751	10,725,244	W1d	Total M3 of Adjusted Abstraction	WATER
	Total M3 of Available Atmospheric Moisture (Green)	W2c	654,382,761	742,850,415	W2d	Total M3 of Consumed Atmospheric Moisture (Green)	
	Total Available M3 of Surface Runoff (Blue)	W3c	123,688,706	11,667,512	W3d	Total M3 of Consumed Surface Water (Blue)	
	Critical Annual Nitrogen Load in Tons (Grey)	W4c	221	711.3	W4d	Total Annual Nitrogen Load in Tons (Grey)	
	Critical Annual Phosphorus Load in Tons (Grey)	W5c	199	362.4	W5d	Total Annual Phosphorus Load in Tons (Grey)	
ECOSYSTEM CONSERVATION	Total Existing Area of Conservation in Acres	EC1c	2,009	67,339	EC1d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
	Total Potential Area of Conservation in Acres	EC2c	85,408	67,339	EC2d	Minimum Area for Biodiversity Conservation in Acres	
CO_2	Total Carbon Sequestration Potential in Tons	C1c	5,741,082	125,507	C1d	Total Carbon Dioxide Emissions in Tons	CO_2
ELECTRICITY	Total Potential Renewable Electricity in Megawatt Hours	E1c	12,700,165	2,631,466	E1d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
	Total Existing Electricity Production in Megawatt Hours	E2c	121,659	2,631,466	E2d	Total Electricity Demand in Megawatt Hours	
MATERIALS	Total Potential Compost Application Load in Tons	M1c	35,729	4,053	M1d	Total Composted Organic Waste in tons	MATERIALS
	Recycling Capacity by Material Type	M2c	7,359	38,131	M2d	Total Tons of Material Outflow by Type (MSW)	

County:	Logan	Ecoregion I and II:	Central USA Plains of the Eastern Temperate Forests	
State:	Illinois	Ecoregion III:	Central Corn Belt Plains	
Acres:	396113	HUC 8	Basin Name	%
Population:	30305	7130009	Salt	98
		7130008	Lower Sangamon	2

Table 6-5: Logan County NDI Factor Summary Sheet

Logan County NDI Calculation				
(C - D)	**(C + D)**	**NDI**	**NDI Factor Title**	**NDI ID**
(28,119)	42,467	-0.6621	Tons of Hay	NDI-F1
(100,851)	121,065	-0.8330	Tons of Feed Grains	NDI-F2
537,467	541,615	0.9923	Tons of Cereal Grains	NDI-F3
(7,975)	8,617	-0.9255	Tons of Dairy	NDI-F4
61,361	65,163	0.9417	Tons of Protein	NDI-F5
(5,531)	5,531	-1.0000	Tons of Fruit	NDI-F6
6,184	20,010	0.3090	Tons of Vegetables	NDI-F7
42,460,507	63,910,995	0.6644	Total M^3 of Adjusted Water Abstraction	NDI-W1
(267,733,801)	1,397,233,176	-0.1916	Total M3 of Consumed Atmospheric Moisture (Green)	NDI-W2
112,021,194	135,356,218	0.8276	Total M3 of Consumed Surface Water (Blue)	NDI-W3
(490)	932	-0.5259	Total Annual Nitrogen Load in Tons (Grey)	NDI-W4
(163)	562	-0.2907	Total Annual Phosphorus Load in Tons (Grey)	NDI-W5
(65,330)	69,348	-0.9421	Existing Area for Biodiversity Conservation in Acres	NDI-EC1
18,069	152,747	0.1183	Potential Area for Biodiversity Conservation in Acres	NDI-EC2
5,615,575	5,866,589	0.9572	Total Carbon Dioxide Balance	NDI-C1
10,068,700	15,331,631	0.6567	Total Potential Renewable Electricity Production in Megawatt Hours	NDI-E1
(2,509,807)	2,753,125	-0.9116	Total Existing Electricity Production in Megawatt Hours	NDI-E2
31,676	39,782	0.7962	Total Composted Organic Waste in tons	NDI-M1
(30,772)	45,490	-0.6765	Total Tons of Material Outflow by Type in met. tons (MSW)	NDI-M2

Table 6-6: Logan County NDI Calculation Summary

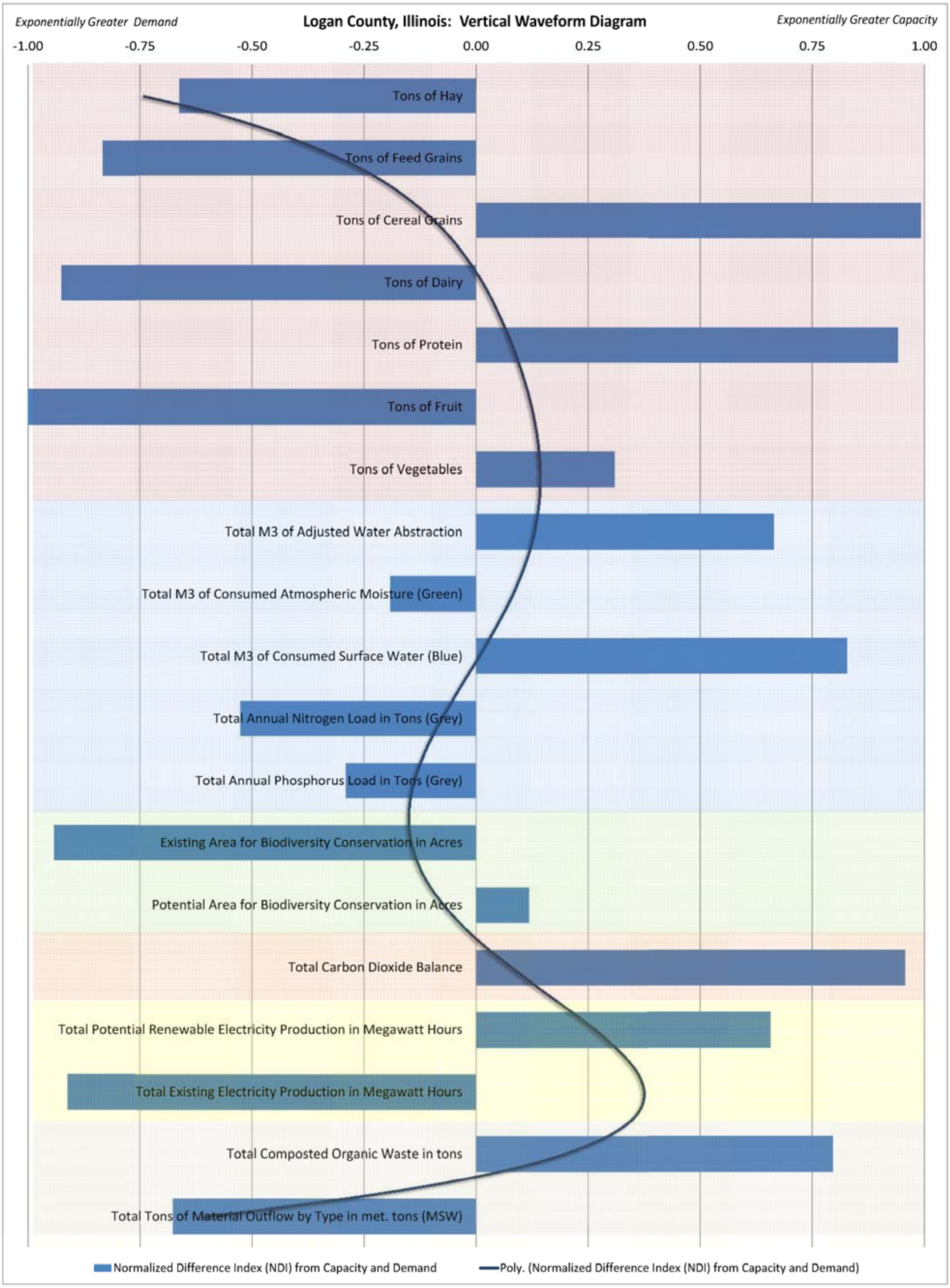

Figure 6-3: Logan County Vertical Waveform Diagram

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6.1.4 Schoharie County, New York

6.1.4.1 Food

As indicated in Table 6-7 Schoharie County meets almost all of the human food demands aside from fruits and produces about half of the livestock demand, resulting in strongly positive values for NDI-F3 and NDI-F4, a moderately positive value for NDI-F5, a weakly positive value for NDI-F7 and weak to moderately negative values for NDI-F1, NDI-F2 and NDI-F6 respectively (Table 6-8). This pattern results in a vertical waveform for food which trends towards excess food capacity. These results indicate that some import for livestock feeds and fruits are likely necessary, but that other tradeable or sellable goods such dairy products and meat products produced in excess in the county could be sold or traded to meet the weak to moderate deficits in feed and fruit categories.

6.1.4.2 Water

6.1.4.2.1 Water Quantity

In terms of water quantity, Schoharie County has an abundance of water capacity compared to demand, where annual demand for streamflow, green water or blue water do not exceed capacity (Table 6-7), resulting in a weakly positive value for NDI-W1 and strongly positive values for NDI-W2 and NDI-W3 (Table 6-8). These results continue to push the vertical waveform from the food category towards exponentially greater water capacity than demand (Figure 6-4).

The monthly results indicate that Schoharie County has a pronounced wet and dry season in streamflow (App. I: Figure 4-3), with a peak in April and a deep trough in September that could be explained by spring snow melt. In terms of human appropriation of water resources, streamflow abstraction exceeds availability considerably between July and October due to the reported use of 81.96 Mgal/day of surface water for Public Supply (App. I: Table 4-2), a number which was reported by the USGS and could be explained by the use of the P25 as a measure of streamflow availability as opposed to the P50 or a higher average P statistical flow rate. A less pronounced but still visible wet and dry season for runoff is also observed, with January through June experiencing most of the runoff and a drier period between July and November. Demand for blue water never exceeds availability of runoff availability for any months of the year (App. I: Figure 4-7).

Monthly evapotranspiration availability has a single large peak in July but given the extensive area of forest in Schoharie the EWR adjusted evapotranspiration availability is significantly lower than the total. Generally green water demand is less than the EWR adjusted evapotranspiration availability, however the analysis indicated that EWR adjusted evapotranspiration availability was exceeded by about 6% in January (App. I: Figure 4-6). Green water demand during winter months is an average of livestock hay and fodder demand per month based on total head, where livestock and poultry need these resources during winter months and thus there is a theoretical or 'stored' green water demand attributed to winter months when the reality is that the appropriation of green water to grow the plants occurred in the summer or previous season and was stored for winter use. Additionally, a large area of forested land in Schoharie County was not counted as land where evapotranspiration could be counted as available (App. I: Figure 4-4). If Nature was appropriated in uncounted areas it could change the outcome of the calculation.

6.1.4.2.2 Water Quality

Neither nitrogen nor phosphorus annual loads exceed the N and P annual load thresholds. The N and P load limits at 37 and 16 tons per year are significantly lower than the thresholds of 769 and 403 tons respectively (Table 6-7), translating into highly positive values for NDI-W4 and NDI-W5 (Table 6-8). These positive values contribute to the trend of exponentially greater water capacity than demand for all factors in the vertical waveform diagram (Figure 6-4).

A breakdown of N and P loads reveals that non-point loads from cereal crops dominate the total load, with point loads being essentially non-existent, with an N load reported for only 2 EPA permitted facilities and a P load only reported for a single facility in the county. The monthly adjusted load limit for N and P of 1.87 and .98 mg/l respectively fluctuates with the seasonal pattern of runoff (App. I: Table 4-3) as mentioned above in section 6.1.4.2.1 and the monthly average N and P loads of 3.09 and 1.3 respectively (App. I: Figure 4-8) are well under the monthly load limits.

The permitted EPA point discharge location summaries in the County support the County Diagnostic findings as no locations registered any N or P violations and no N or P tertiary treatment technologies were registered in the County, indicating no violation. However, there is one section of stream which is listed on the US EPA 303d impaired streams list, Cobleskill Creek in the northern half of the County (App. I: Figure 4-9) which listed pathogens as the cause of impairment but not N or P. Cobleskill Creek runs between two patches of urbanization that are likely the source of pathogens. One water body intersecting the south central periphery of the County, Schoharie Reservoir, did register on the EPA 303d list with excess nutrients and phosphorus as the cause of impairment. This may appear to be confounding results; they might also reflect that there are no EPA regulated point sources related to the outlet of the reservoir in the Schoharie County EPA ECHO database or other downstream reaches which register P or nutrient impairment. The P impairment in the reservoir must be to point or non-point sources which flow into the reservoir from upstream and outside of the county boundary (App. I: Figure 4-2) and is an example where the county to the south of Schoharie should also be analyzed to fully understand the cause of the 303d listing. This case illustrates the flexibility behind using counties as the main tiling unit for the County Diagnostic.

6.1.4.3 Ecosystem Conservation

The existing area of ecosystem conservation denoted by PAD-US for Schoharie County indicates that 8.5 % of the county area (EC1) is currently preserved, falling short of the recommended 17% County land and water area target (Table 6-7), resulting in a moderately negative NDI-EC1 value (Table 6-8). However, given the overwhelming number of positive NDI values in the county, this negative value does not appreciably affect the movement of the vertical waveform towards greater demand for conservation area (Figure 6-4). The minimal change in vertical waveform is also attributable to the extensive potential for ecosystem conservation of 266,777 acres totaling about 66% of the total county area, which results in a strongly positive NDI-EC2 value that keeps the vertical waveform in the range of high to exponentially high ecosystem conservation capacity.

The existing areas of conservation are located almost exclusively within the areas identified with the ZOC model and composed of mostly deciduous forest with interspersed mixed forest, evergreen forest, wetlands and woody wetlands and some small patches of shrub lands and steep slopes distributed in the central and southeast upland areas and in the northeast and southeast corners of the county. The open land north of State Route 10 have thin riparian and wetland areas connected by streams and patches of vegetation which are interspersed by open space areas attributed to human uses. There are no PAD-US conservation areas within the road effect zone of State Route 10 or I-88 on the northern half of the county (App. I: Figure 4-10).

6.1.4.4 Carbon Dioxide (CO_2)

The carbon sequestration potential of Schoharie County is more than 100 times higher than the estimated carbon emissions (C1) as indicated by Table 6-7, resulting in an exponentially positive NDI-C1 value (Table 6-8) helping to keep the vertical waveform in weak to moderate territory (Figure 6-4). The distribution of sequestration in the county is moderate overall with some indication that a greater level of sequestration occurs in the northern and eastern quadrants of the County and lesser sequestration in the central and southwest quadrants (App. I: Figure 4-11). Essentially, Schoharie County is a carbon sink. The distribution of carbon emissions resembles many of the other rural counties with about 70% of emissions coming from onroad transportation followed by residential, industrial, nonroad and commercial emissions respectively (App. I: Figure 4-12).

6.1.4.5 Electricity

Renewable electricity production potential in Schoharie County is estimated at 2.98 million MWH or close to double the 1.64 million MWH demand (Table 6-7). This creates a weak positive NDI-E1 value (Table 6-8) moving the overall waveform into a position of weakly sufficient electricity production capacity (Figure 6-4). Existing electricity production capacity within the County only meets about 6% of the electricity demand which results in a strong negative NDI-E2 value that pulls the vertical waveform overall into moderate negative territory.

The availability of solar electricity production exhibits a double parabolic arc with one apex in May and a second in July/August, and a trough in production potential between November and January (App. I: Figure 4-13) which produces a total of 24,091 MWH; less than 1% of the total renewable electricity production potential for the County. The limiting factor for Schoharie County is the number of roof areas for the application of PV panels since the solar resource value in average kWh/m^2/month has a similar range and distribution. The real powerhouse for renewable electricity production potential in Schoharie County is wind power, which produces over 99% of the potential within six different envelopes between 6.02 and 7.23 m/s adjusted wind power class areas covering 11,037 acres and estimated at 344 turbines (App. I: Table 4-4). The limitation to wind production in Schoharie County is the mountainous terrain which makes the 6 m/s wind speed areas exist in small pockets distributed mostly in the north, south and eastern areas of the county without forestation and where it is flat. In the northern areas, visibility to State Route 7 and I-88 also limit the extent to which wind power turbines can be installed (App. I: Figure 4-14).

Existing production is represented by a single pumped storage facility which is recorded as a loss of 108,533 MWH per year (App. I: Figure 4-15), which can be interpreted as the exact same gain when let out. Some research into pumped storage indicates that pumping water up and letting it back out creates a loss of about 20% of the initial energy after release, in which case the recorded loss of

108,533 would mean that the total annual production from pumped storage is in the range of 80,000 MWH. This cannot be verified without a more detailed study of pumped storage use within the county and represents a limitation of the method. Most likely, the pumped storage facility is located at the dam of the Schoharie Reservoir as discussed in section 6.1.4.2.2. Electricity demand in the county is dominated by residential and transportation energy demand followed to a lesser extent by commercial and industrial demands (App. I: Figure 4-16).

6.1.4.6 Materials

The organic compost production potential in Schoharie County of 3,470 tons per year satisfies roughly 60% of the land applied compost fertilizer demand (Table 6-7), resulting in a weakly positive NDI-M1 value (Table 6-8) which does not affect the negative trending vertical waveform diagram (Figure 6-4). Municipal solid waste production is roughly five times the recovery potential of the county which results in a strongly negative NDI-M2 value and pulls the vertical waveform diagram towards a moderate overall demand.

The organic waste production potential based on the CoEAT model represents 94% of the estimated feedstock potential with the remaining 6% from WWTP sludge (App. I: Table 4-5) from seven sewage and WW treatment facilities (App. I: Table 4-6). The remaining 45% of organic source material comes from yard wastes (App. I: Figure 4-17).

Total MSW generation and recovery is estimated from published generation and recovery figures from the New York State Department of Environmental Conservation and national EPA recovery percentages. Generation sources are mostly paper, plastics, yard and food waste and other sources ranked from highest to lowest in that order. Recovery of wastes is mostly concentrated on paper and paperboard and to a lesser extent, yard trimmings (App. I: Figure 4-18). Wood, yard trimmings and food waste in Schoharie County all represent a potential source material which could be harnessed to satisfy 60% of the demand for composted agricultural soil amendments.

SCHOHARIE COUNTY NDI FACTOR SUMMARY SHEET								
Capacity Factor			Decimal Value	Decimal Value	Demand Factor			
FOOD	Tons of Hay	F1C	100,262	189,586	F1d	Tons of Hay	FOOD
FOOD	Tons of Feed Grains	F2c	58,758	127,230	F2d	Tons of Feed Grains	FOOD
FOOD	Tons of Cereal Grains	F3c	21,216	2,241	F3d	Tons of Cereal Grains	FOOD
FOOD	Tons of Dairy	F4c	48,424	8,965	F4d	Tons of Dairy	FOOD
FOOD	Tons of Protein	F5c	5,124	2,054	F5d	Tons of Protein	FOOD
FOOD	Tons of Fruit	F6c	2,150	5,977	F6d	Tons of Fruit	FOOD
FOOD	Tons of Vegetables	F7c	11,058	7,471	F7d	Tons of Vegetables	FOOD
WATER	Total Available M^3 of Stream Flow	W1c	159,744,805	117,132,427	W1d	Total M3 of Adjusted Abstraction	WATER
WATER	Total M3 of Available Atmospheric Moisture (Green)	W2c	424,375,687	135,116,297	W2d	Total M3 of Consumed Atmospheric Moisture (Green)	WATER
WATER	Total Available M3 of Surface Runoff (Blue)	W3c	411,419,371	9,128,588	W3d	Total M3 of Consumed Surface Water (Blue)	WATER
WATER	Critical Annual Nitrogen Load in Tons (Grey)	W4c	769	37	W4d	Total Annual Nitrogen Load in Tons (Grey)	WATER
WATER	Critical Annual Phosphorus Load in Tons (Grey)	W5c	403	16	W5d	Total Annual Phosphorus Load in Tons (Grey)	WATER
ECOSYSTEM CONSERVATION	Total Existing Area of Conservation in Acres	EC1c	34,227	68,144	EC1d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
ECOSYSTEM CONSERVATION	Total Potential Area of Conservation in Acres	EC2c	266,777	68,144	EC2d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
CO_2	Total Carbon Sequestration Potential in Tons	C1c	11,779,057	111,218	C1d	Total Carbon Dioxide Emissions in Tons	CO_2
ELECTRICITY	Total Potential Renewable Electricity in Megawatt Hours	E1c	2,985,750	1,649,822	E1d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
ELECTRICITY	Total Existing Electricity Production in Megawatt Hours	E2c	108,533	1,649,822	E2d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
MATERIALS	Total Potential Compost Application Load in Tons	M1c	5,725	3,479	M1d	Total Composted Organic Waste in tons	MATERIALS
MATERIALS	Recycling Capacity by Material Type	M2c	4,589	24,398	M2d	Total Tons of Material Outflow by Type (MSW)	MATERIALS

County:	Schoharie	Ecoregion I and II:	Mixed Wood Plains of the Eastern Temperate Forests	
State:	New York	Ecoregion III:	North Allegheny Plateau	
Acres:	400850	HUC 8	Basin Name	%
Population:	32749	2020005	Schoharie	85
		2020004	Mohawk	5
		2050101	Upper Sesquehanna	5
		2020006	Middle Hudson	5

Table 6-7: Schoharie County NDI Factor Summary Sheet

Schoharie County NDI Calculation				
(C - D)	**(C + D)**	**NDI**	**NDI Factor Title**	**NDI ID**
(89,324)	289,848	-0.30818	Tons of Hay	NDI-F1
(68,472)	185,988	-0.36815	Tons of Feed Grains	NDI-F2
18,975	23,457	0.80893	Tons of Cereal Grains	NDI-F3
39,459	57,389	0.68757	Tons of Dairy	NDI-F4
3,070	7,178	0.42770	Tons of Protein	NDI-F5
(3,827)	8,127	-0.47090	Tons of Fruit	NDI-F6
3,587	18,529	0.19359	Tons of Vegetables	NDI-F7
42,612,378	276,877,232	0.15390	Total M^3 of Adjusted Water Abstraction	NDI-W1
340,000,317	559,491,984	0.60769	Total M3 of Consumed Atmospheric Moisture (Green)	NDI-W2
402,290,783	420,547,959	0.95659	Total M3 of Consumed Surface Water (Blue)	NDI-W3
732	806	0.90795	Total Annual Nitrogen Load in Tons (Grey)	NDI-W4
387	419	0.92363	Total Annual Phosphorus Load in Tons (Grey)	NDI-W5
(33,917)	102,371	-0.33131	Existing Area for Biodiversity Conservation in Acres	NDI-EC1
198,633	334,921	0.59307	Potential Area for Biodiversity Conservation in Acres	NDI-EC2
11,667,839	11,890,275	0.98129	Total Carbon Dioxide Balance	NDI-C1
1,335,928	4,635,572	0.28819	Total Potential Renewable Electricity Production in Megawatt Hours	NDI-E1
(1,541,289)	1,758,355	-0.87655	Total Existing Electricity Production in Megawatt Hours	NDI-E2
2,246	9,204	0.24402	Total Composted Organic Waste in tons	NDI-M1
(19,809)	28,987	-0.68338	Total Tons of Material Outflow by Type in met. tons (MSW)	NDI-M2

Table 6-8: Schoharie County NDI Calculation Summary

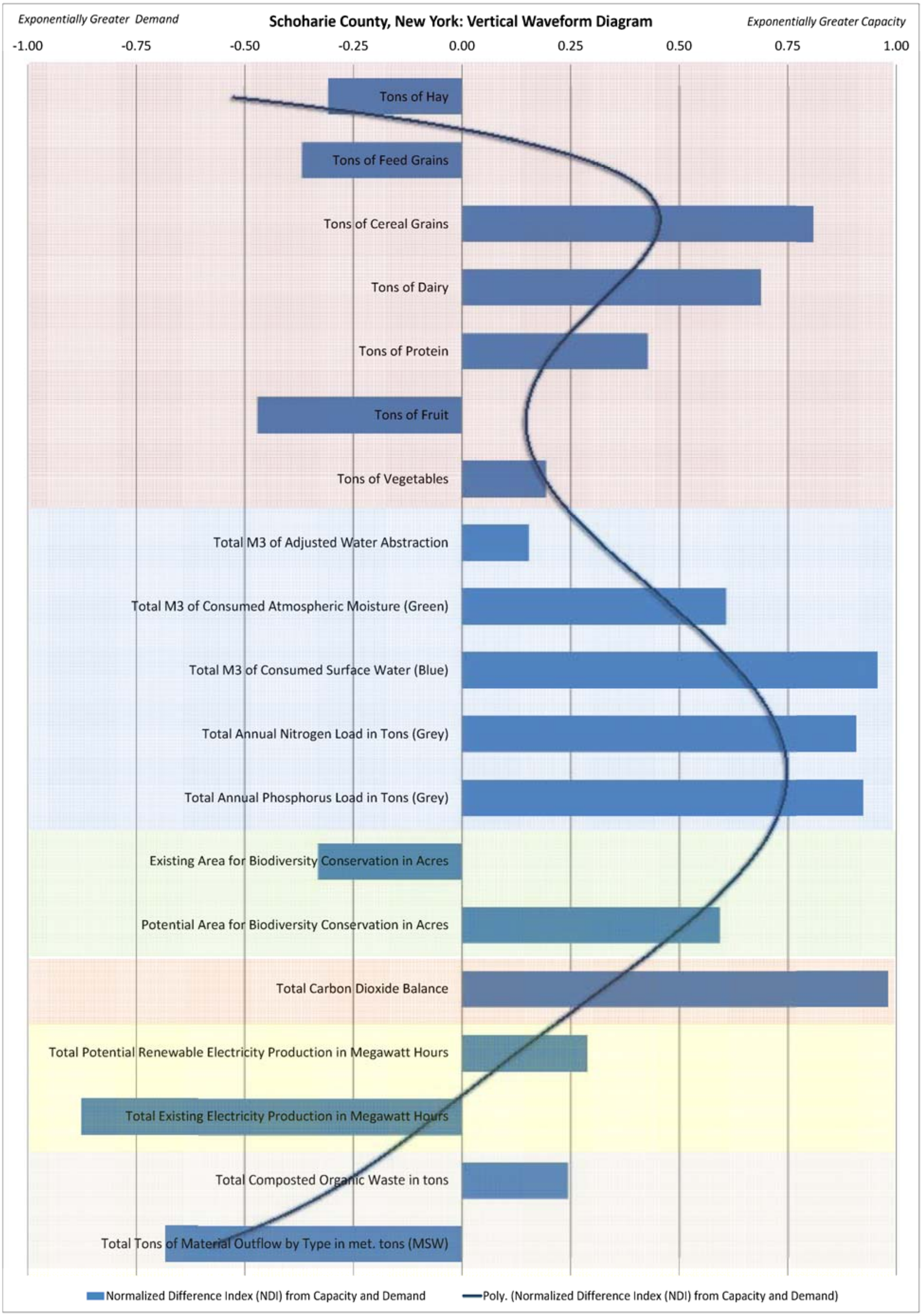

Figure 6-4: Schoharie County Vertical Waveform Diagram

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6.1.5 Leflore County, Mississippi

6.1.5.1 Food

As indicated in Table 6-9 Leflore County meets human food demands in the food factors of protein and cereal grains and produces not feed grains and only about 20% of the livestock hay demand, falling well short of demand or having no production in all other categories. The food capacity and demand values result in a stark contrast in NDI values (Table 6-10), with moderate to strong negative values for NDI-F1, NDI-F2, NDI-F4, NDI-F6 and NDI-F7 and exponentially positive values for NDI-F3 and NDI-F5, resulting in a vertical waveform which fluctuates between strong and weak demand for food production (Figure 6-5). One other notable agricultural product in Leflore County is cotton, which it produces 12,653 metric tons of annually. Given the food production results, it appears that Leflore County is a multi-crop exporting county, focusing on grains, cotton and beef cows and importing all other human and livestock foods.

6.1.5.2 Water

6.1.5.2.1 Water Quantity

In terms of water quantity, Leflore County has sufficient annual streamflow and runoff but almost consumes all of the available annual atmospheric moisture (Table 6-9), resulting in a strong positive NDI-W1 value and a moderately positive NDI-W3 value and a weakly positive NDI-W2 value (Table 6-10). The vertical waveform for water in Leflore County fluctuates on the boundary between weak overall capacity and weak overall demand (Figure 6-5).

The monthly streamflow results indicate that Leflore has a pronounced wet season peaking in March and a dry season with the lowest flows observed in October (App. I: Figure 5-3), with human appropriation of streamflow not exceeding EWR adjusted capacity in any months. In addition, there was only one available streamflow sample point in Leflore County, which is in the middle of the county and does not account for increased streamflow from runoff in about 1/3rd of the lower part of the county, which if included could indicate that more streamflow is available than recorded by the County Diagnostic method here.

Monthly runoff results indicate a drier season between May and September between a peak in March and two small peaks October and December respectively, with blue water demand exceeding availability between August and September by about 40% (App.I: Figure 5-7). Monthly atmospheric moisture availability has a broad parabolic shape peaking in June or July at 160,000,000 cubic meters of availability bookended by troughs in January and November of about 40,000,000 cubic meters. It should be noted that human appropriation of water in Leflore is only reported to be 4.1% of total abstraction, with the other 96% of abstraction from ground water sources (App. I: Table 5-2), thus the actual demand of streamflow is even lower than reported on App. I: Figure 5-3, although streamflow contributes to charging of alluvial aquifers from which groundwater in the county is extracted.

The EWR demand for evapotranspiration is very high in Leflore County, reducing availability to just over 40,000,000 cubic meters during the peak availability period in June / July, resulting in green water demand exceeding EWR availability between March and November (App. I: Figure 5-6), although only exceeding raw ET availability briefly in the middle of October. It should be mentioned that the sampling points for available ET in Leflore County only cover about half of the county area and if expanded to the entire county area would increase the availability (App. I: Figure 5-4). Overall, the demand for green water is much higher than the demand for blue water, stemming from the production of cereal grains and cotton which have very high green water demands (App. I: Figure 5-5), although these agricultural products do also require significant blue water, which is reportedly sourced via ground water extraction (App. I: Table 5-2).

In summary, the water strategy for Leflore County appears to be utilization of all water resources including ground water to ensure production of a high volume of water intensive field crops. When runoff capacity alone is exceeded, ground water or streamflow is likely used to supplement demand and in terms of ET Leflore County likely appropriates atmospheric moisture during times of high demand, where humid warm air rises off fields pulling in cooler moist air from surrounding counties.

6.1.5.2.2 Water Quality

Annually, both nitrogen and phosphorus loads exceed load limits in Leflore County. The N and P load limits at 422 and 77 tons per year are lower than the estimated 511 and 269 tons per year load estimates respectively (Table 6-9), resulting in a weakly negative NDI-W4 value and a moderately negative NDI-W5 value (Table 6-10). The negative NDI values for N and P contribute to limiting the overall vertical waveform from going any further than weakly positive and reverse its excess capacity trending direction (Figure 6-5).

The N and P load breakdown reveals that all estimated loads come from non-point oilseed, cereal and fibe crops, without any reported N or P point loads in the county that when averaged over the year by month result in monthly average loads of 42.5 and 22 tons per month for N and P respectively (App. I: Figure 5-8). The monthly load limit for N and P scaled up by total runoff from 0.77 mg/l and 0.14 mg/l respectively mirror the fluctuation in runoff which results in higher load limits in March, October and December and lower limits between May and September where less runoff is received (App. I: Table 5-3). On a monthly basis, the N load is predicted to be exceeded between May and September and in November and the P load is predicted to be exceeded every month. As discussed in the Logan County summary, the application of N and P is seasonal, corresponding with planning, and therefore the loads likely occur in the spring or in times of heavy rainfall when leaching occurs.

The EPA ECHO database did not report any permitted facilities in Leflore County, thus it is not possible to determine if any point facilities are exceeding load limits. The EPA 303d impaired waters database did indicate one impaired stream in the county, Turkey Bayou, which listed the cause of impairment as total suspended solids (App. I: Figure 5-9). Therefore, given the data available it is not possible to verify if waters in Leflore County have the excess N and P nutrients as predicted by the County Diagnostic method.

6.1.5.3 Ecosystem Conservation

The existing area of ecosystem conservation denoted by PAD-US for Leflore County indicates that 3.1% of the county area (EC1) is currently preserved, falling short of the recommended 17% land

and water area target (Table 6-9), resulting in a moderate to strongly negative NDI-EC1 value that pulls the vertical waveform into weak negative territory indicating a demand for more ecosystem conservation area (Figure 6-5). The potential conservation area far exceeds the 17% target with the ZOC model estimating that 78% of the total county area is suitable for conservation (App. I: Figure 5-10) with results in a moderate to strongly positive NDI-EC2 value. However, given the exponentially negative values in electricity production and material recycling the positive NDI-EC2 value does not change the direction of the vertical waveform.

It is worth noting that Leflore County has quite a large area of FEMA floodplains due to its location in the lower Mississippi delta. To some degree this fact confounds the ZOC model by automatically include a large amount of area in the ZOC area which is not actually covered in natural vegetation and rather is covered in croplands. If the ZOC is restricted to only floodplain areas which are covered in wetland, grassland or woodland vegetation then the total area in the ZOC would be 79,379 acres which would change the NDI-EC2 value from moderately to strongly positive to weakly positive. This result points out the differences in extent of floodplains across ecoregion types and raises the question about how floodplains in delta areas should be managed, whether they should be preserved as regional absorbers of floodwaters and thereby increase the conservation target from 17% to a target more related to the distribution of floodplains and their ecosystem service functions or if counties like Leflore have the right to appropriate these areas for human uses and stay with a conservation target of 17% like other counties which do not have such extensive floodplain areas.

6.1.5.4 Carbon Dioxide (CO_2)

The carbon sequestration potential in Leflore County is more than 100 times the reported carbon emissions (Table 6-9), resulting in an exponentially positive NDI-C1 value (Table 6-10) that bends the negative trending vertical waveform slightly towards positive but not into positive territory (Figure 6-5). The distribution of NPP is relatively homogeneous across the county with a few areas reporting very high values of NPP (App. I: Figure 5-11). The results indicate that Leflore County is a carbon sink, which is not surprising considering the very high production rate of field crops, which have high NPP values. Carbon emissions are concentrated in Onroad and Industrial sources followed by residential, non-road and commercial sources respectively (App. I: Figure 5-12), indicating that there may not be a very extensive building stock in the county and supporting the idea that the county is rural and agricultural.

6.1.5.5 Electricity

Renewable electricity production potential in Leflore County at 24, 423 MWH is much lower than the estimated 3,984,397 MWH demand (Table 6-9), resulting in an exponentially negative NDI-E1 value (Table 6-10) that pulls the vertical waveform diagram deeper towards demand for renewable energy (Figure 6-5). Existing electricity production in the county is lower than the solar resource at 12, 171 MWH annually, resulting in an exponentially negative NDI-E2 value that pulls the vertical waveform deeper into a weak negative overall position.

The reason for the low renewable production potential is that wind resources in Leflore County are consistently lower than 6 m/s and thus wind power is not suitable. This leaves only solar power on existing roofs as the only renewable production source, which has a gentle bell curve that peaks in

August to produce the 24, 424 MWH of electricity (App. I: Figure 5-15). Given that much of the county is in a FEMA floodplain it may not be the most strategic move to invest in ground-based solar panels and therefore Leflore County should probably remain an electricity importer.

Existing electricity production in the county is shared between natural gas production and petroleum use (App. I: Figure 5-16). Electricity demand in Leflore County is dominated by industrial and transport energy demand followed by residential and commercial demand respectively (App. I: Figure 5-17), which generally mirrors the sector demand relationships in carbon emissions in section 6.1.5.4.

6.1.5.6 Materials

Given the high quantity of field crops produced in Leflore County it is not surprising that the demand for organic compost exceeds the production capacity (Table 6-9), resulting in a moderately positive NDI-M1 value indicating a capacity for field application organic compost soil amendments (Table 6-10). The moderately positive NDI-M1 value has the effect of keeping the vertical waveform diagram in the weak negative position without any significant adjustments (Figure 6-5: Leflore County Vertical Waveform Diagram). Municipal solid waste generation is much higher than recovery capacity which results in an exponentially negative NDI-M2 value and plunges the vertical waveform into strong demand for more recycling capacity.

Organic compost production potential is about 65% from yard waste and the rest food waste and WWTP biosolids (App. I: Figure 5-18) with the WWTP sludge from one WWTP (App. I: Table 5-5) contributing about 15% of the total CoEAT feedstock estimate (App. I: Table 5-4). The estimated generation of waste in Leflore is scaled from US EPA national figure based on population and recovery is based on the State of Mississippi 2012 Annual MSW report, indicating that the main categories of generation are paper and paperboard, plastics, yard trimmings and food wastes (App. I: Figure 5-19).

LEFLORE COUNTY NDI FACTOR SUMMARY SHEET							
Capacity Factor			Decimal Value	Decimal Value		Demand Factor	
FOOD	Tons of Hay	F1C	551	2,686	F1d	Tons of Hay	FOOD
	Tons of Feed Grains	F2c	-	2,686	F2d	Tons of Feed Grains	
	Tons of Cereal Grains	F3c	353,087	2,212	F3d	Tons of Cereal Grains	
	Tons of Dairy	F4c		8,847	F4d	Tons of Dairy	
	Tons of Protein	F5c	68,280	1,839	F5d	Tons of Protein	
	Tons of Fruit	F6c	-	5,898	F6d	Tons of Fruit	
	Tons of Vegetables	F7c	66	7,372	F7d	Tons of Vegetables	
WATER	Total Available M^3 of Stream Flow	W1c	2,875,651,119	268,735,846	W1d	Total M3 of Adjusted Abstraction	WATER
	Total M3 of Available Atmospheric Moisture (Green)	W2c	284,784,209	449,885,864	W2d	Total M3 of Consumed Atmospheric Moisture (Green)	
	Total Available M3 of Surface Runoff (Blue)	W3c	548,673,472	144,292,803	W3d	Total M3 of Consumed Surface Water (Blue)	
	Critical Annual Nitrogen Load in Tons (Grey)	W4c	422	511	W4d	Total Annual Nitrogen Load in Tons (Grey)	
	Critical Annual Phosphorus Load in Tons (Grey)	W5c	77	269	W5d	Total Annual Phosphorus Load in Tons (Grey)	
ECOSYSTEM CONSERVATION	Total Existing Area of Conservation in Acres	EC1c	12,183	65,974	EC1d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
	Total Potential Area of Conservation in Acres	EC2c	303,586	65,974	EC2d	Minimum Area for Biodiversity Conservation in Acres	
CO_2	Total Carbon Sequestration Potential in Tons	C1c	8,690,909	83,940	C1d	Total Carbon Dioxide Emissions in Tons	CO_2
ELECTRICITY	Total Potential Renewable Electricity in Megawatt Hours	E1c	24,423	3,984,397	E1d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
	Total Existing Electricity Production in Megawatt Hours	E2c	12,171	3,984,397	E2d	Total Electricity Demand in Megawatt Hours	
MATERIALS	Total Potential Compost Application Load in Tons	M1c	24,561	6,519	M1d	Total Composted Organic Waste in tons	MATERIALS
	Recycling Capacity by Material Type	M2c	1,230	63,170	M2d	Total Tons of Material Outflow by Type (MSW)	

County:	Leflore	Ecoregion I and II:	Mississippi Alluvial and Southeast USA Coastal Plains	
State:	Mississippi	Ecoregion III:	Mississippi Alluvial Plain	
Acres:	388083	HUC 8	Basin Name	%
Population:	32317	8030207	Big Sunflower	40
		8030205	Yalobusha	30
		8030206	Upper Yazoo	20
		8030202	Tallahatchie	10

Table 6-9: Leflore County NDI Factor Summary Sheet

Leflore County NDI Calculation				
(C - D)	**(C + D)**	**NDI**	**NDI Factor Title**	**NDI ID**
(1,886)	2,988	-0.63119	Tons of Hay	NDI-F1
(2,437)	2,437	-1.00000	Tons of Feed Grains	NDI-F2
351,081	355,093	0.98870	Tons of Cereal Grains	NDI-F3
(8,026)	8,026	-1.00000	Tons of Dairy	NDI-F4
66,441	70,119	0.94755	Tons of Protein	NDI-F5
(5,350)	5,350	-1.00000	Tons of Fruit	NDI-F6
(6,622)	6,754	-0.98046	Tons of Vegetables	NDI-F7
2,606,915,273	3,144,386,965	0.82907	Total M^3 of Adjusted Water Abstraction	NDI-W1
25,230,750	734,670,073	0.03434	Total M3 of Consumed Atmospheric Moisture (Green)	NDI-W2
404,380,669	692,966,275	0.58355	Total M3 of Consumed Surface Water (Blue)	NDI-W3
(89)	933	-0.09483	Total Annual Nitrogen Load in Tons (Grey)	NDI-W4
(192)	346	-0.55576	Total Annual Phosphorus Load in Tons (Grey)	NDI-W5
(53,791)	78,157	-0.68824	Existing Area for Biodiversity Conservation in Acres	NDI-EC1
237,612	369,560	0.64296	Potential Area for Biodiversity Conservation in Acres	NDI-EC2
8,606,969	8,774,849	0.98087	Total Carbon Dioxide Balance	NDI-C1
(3,959,974)	4,008,820	-0.98782	Total Potential Renewable Electricity Production in Megawatt Hours	NDI-E1
(3,972,226)	3,996,568	-0.99391	Total Existing Electricity Production in Megawatt Hours	NDI-E2
18,042	31,080	0.58050	Total Composted Organic Waste in tons	NDI-M1
(61,940)	64,400	-0.96180	Total Tons of Material Outflow by Type in met. tons (MSW)	NDI-M2

Table 6-10: Leflore County NDI Calculation Summary

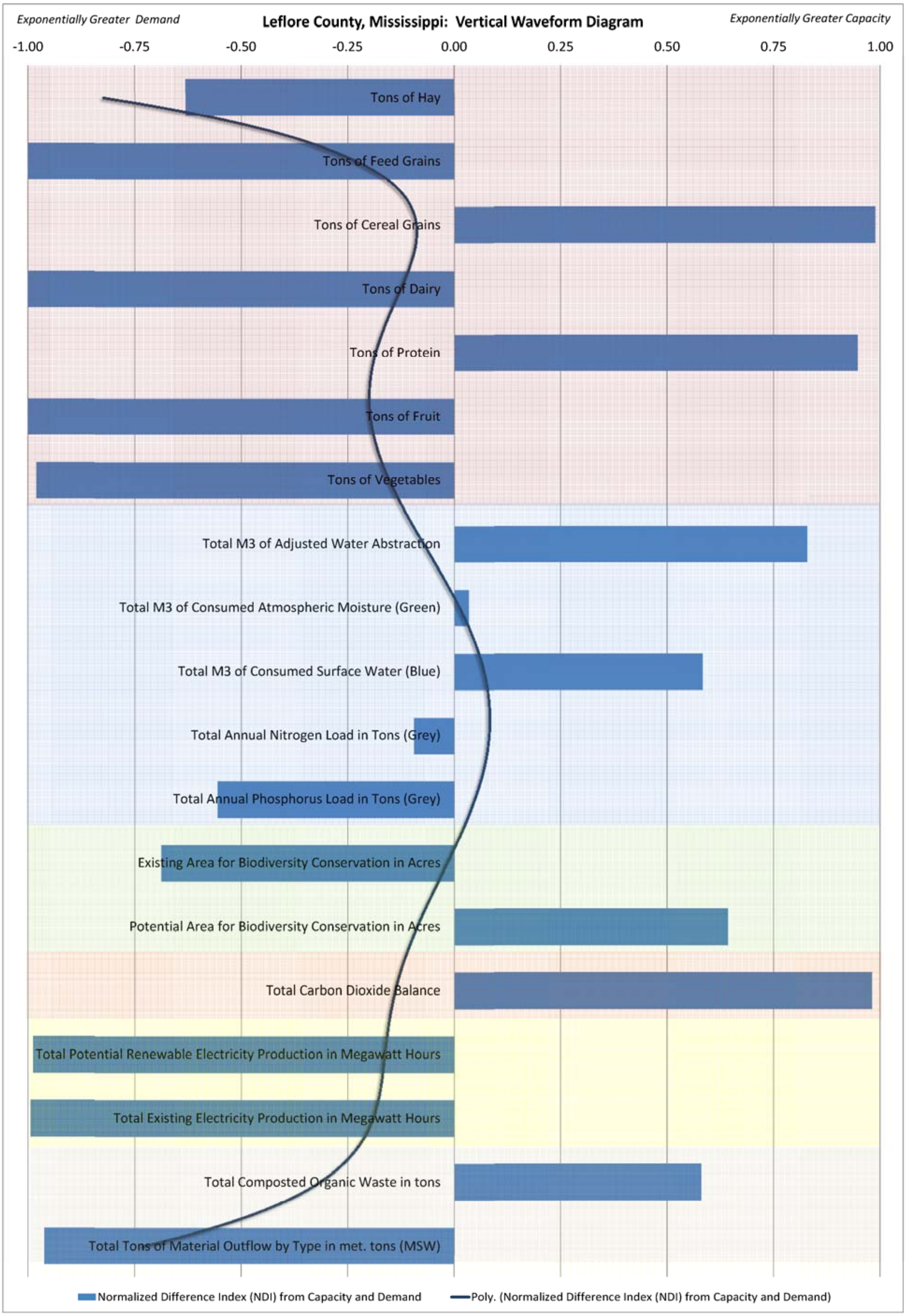

Figure 6-5: Leflore County Vertical Waveform Diagram

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6.1.6 Decatur County, Georgia

6.1.6.1 Food

As indicated in Appendix I: Figure 6-1 food production in Decatur County meets the human demands for grains, dairy, protein and vegetables, falling short in fruit production and in livestock hay and feed grain demands (Table 6-11). The NDI values for food are strongly or moderately negative for NDI-F1, NDI-F2 and NDI-F6 and moderate or strongly positive for NDI-F3, NDI-F4, NDI-F5 and NDI-F7 (Table 6-12), resulting in a vertical waveform that is negative for livestock feed and hay and then shifts to moderately positive for the remainder of the food category (Figure 6-6). The results indicate that Decatur County may be a net exporter of foods and may not be reliant on monocrop systems but is agriculturally diversified, including field crops, vegetables and fruits and cattle and dairy products.

6.1.6.2 Water

6.1.6.2.1 Water Quantity

Decatur County appears to have an abundance of water capacity compared to demand with green water demand totaling about 50% of ET availability (Table 6-11). These balances result in a strongly positive NDI-W1 and NDI-W3 values and a weakly positive NDI-W2 value, with the vertical waveform remaining at moderate overall capacity for all of the water quantity factors (Figure 6-6).

The monthly results indicate that Decatur County has a weak wet and dry season with most of the streamflow (App. I: Figure 6-3) and runoff (App. I: 6-7) recorded in March and relatively flat streamflow (but still moderate in quantity) between June and November whereas runoff fluctuates in the period but does not equal the March peak. Neither human abstraction nor blue water demand exceeds availability for any month of the year and water extraction in general is supplied 98% by ground water with irrigation accounting for 92% of total abstraction (App. I: Table 6-2).

Monthly evapotranspiration has a slow rise in availability starting in January and peaking in July through September before sharply dropping off between late September and November, with the EWR adjusted availability being sufficient to satisfy all monthly green water demands (App. I: Figure 6-6). Availability of ET is spread throughout the county with most being accounted for in the northern half of the county and a more dispersed but homogeneous availability in the southeastern quadrant (App. I: Figure 6-4). In general green water demand is much higher than blue water demand and the green water demand is spread relatively evenly amongst the various field crops and vegetables produced as opposed to being related to only a single field crop type, for example (App. I: Figure 6-5).

6.1.6.2.2 Water Quality

The estimated nitrogen load of 194 tons annual does not exceed the average county N load limit of 1,084 tons, however the estimated phosphorus load of 99 does exceed the average P load limit of 15 tons per year (Table 6-11). The load and load limit results translate into a strongly positive NDI-W4 value and and strongly negative NDI-W4 value, which have the effect of pulling the vertical waveform back from moderate water capacity to weak water capacity (Figure 6-6).

The monthly background adjusted N load limit of 3.72 mg/l reflects runoff availability with the greatest load limit tolerated in March and somewhat lower load limits between April and December with November having a noticeably lower limit than other months (App. I: Table 6-3), with the average monthly N load of 16.1 tons (App. I: Figure 6-8) not exceeding the N load limit for any month. The allowed P load based on TMDL recommendations for Decatur County were actually zero, and therefore the P load limit reflects only the background load limit of 0.05 m/l, which is the reason that P exceeds the limit. If the P limit were in-line with other counties which range between 0.1 and 2.97 mg/l the results would be different. Regardless, given this load limit and the average monthly load of 8.25 tons, the load limit is theoretically exceeded every month of the year. A breakdown of N and P load sources reveals that 99.9% of N loads and 97% of P loads are from non-point oilseed, cereal and fiber sources, with the remaining load coming from WWTP point loads (App. I: Figure 6-8).

None of the EPA regulated point sources recorded any N or P load limit violations and only one stream, Spring Creek, recorded a water quality impairment of mercury in fish tissue (App. I: Figure 6-9). These results indicated that there is no observed N or P water quality impairment in Decatur County (as observed for N) and that the prediction of P water quality impairment with the County Diagnostic method may be more related to the chosen limit value than to actual impairment.

6.1.6.3 Ecosystem Conservation

The area set aside for ecosystem conservation according to PAD-US, 28,514 acres, is about 40% of the recommended 17% EC1 conservation target (Table 6-11), resulting in a moderately negative NDI-EC1 value of -0.40790 which pulls the vertical waveform towards greater demand for ecosystem conservation (Figure 6-6). The potential area for conservation of 201,594 exceeds the 17% target by a multiple of three, resulting in a moderately positive NDI-EC2 value that produces a slight positive recurve in the overall waveform. The volume of remaining potential ecosystem conservation area indicates that even though the legally protected areas do not meet the recommendation there is still an existing interconnected area supporting habitat and landscape functions in the county (App. I: Figure 6-10).

The main portion of PAD-US conservation area is within the ZOC envelope downstream of the main urbanized land in the center of the county, with a few pieces of protected land in the northwest quadrant on a broad plain which is predominantly center-pivot groundwater irrigated cropland and then a few dispersed pieces in the northeast and southeast quadrants where a more fragmented and dissected landscape exists (App. I: Figure 6-10).

6.1.6.4 Carbon Dioxide (CO_2)

Given the diversified and intensive agricultural production coupled with a high percentage of ecosystem conservation area, it is not surprising that carbon sequestration in in Decatur County of 14,955,511 tons/year exceeds the demand of 129,784 tons/ year of emissions by more than 100-fold (Table 6-11). This high sequestration value results in a very strongly positive NDI-C1 value of 0.98279 (Table 6-12) holding the vertical waveform overall in weak demand territory and offsets the highly negative values in renewable electricity production and materials (Figure 6-6). The distribution of NPP across the county is not homogeneous, with the southern half of the county where forested wetlands, grasslands and forests on hillslopes sequester more than the agriculturally dominated northern half (App. I: Figure 6-11).

Carbon emissions in the county are dominated by on-road and industrial emissions with residential and commercial emissions surprisingly lower than non-road, airborne or aircraft emissions (App. I: Figure 6-12). The relatively small industrial carbon emissions compared to residential emissions is further confounded by the fact that Decatur County Economic Census reported 587 non-residential facilities, whereas the American Community Survey Census reported 8,343 households (App. I: Figure 6-13). With 14 times the number of residential versus industrial units it would be expected that residential units would report a higher carbon emission, however, this could be explained by the moderate climate in Georgia with a mild winter that does not require fuel or electricity for heating, or by the type of industry which may be energy intensive (a level of detail beyond the scope of County Diagnostic method to determine).

6.1.6.5 Electricity

Renewable electricity production potential in Decatur County at 20, 756 MWH per year is over 100 times lower than the county-wide demand (Table 6-11), resulting in a very negative NDI-E1 value of -0.98337 (Table 6-12) keeping the vertical waveform in weakly negative territory, with a dive into moderate or highly negative territory offset by the positive NDI-C1, NDI-EC2 and NDI-M1 values. Existing electricity production is practically non-existent in the county, with only 151 MWH of annual production reported, resulting in a NDI-E2 value of almost -1.0.

The reason for the low renewable production potential is that wind resources in Decatur County area consistently lower than 6 m/s and thus wind power is not suitable. This is a surprising fact given that Georgia is on the North American Gulf coast where one could envision a consistent wind resource from diurnal land/sea breeze exchanges; however, upon closer inspection Decatur is on the ecotone between the Southeaster Plains and Southeast Coastal Plains which could explain the lack of coastal wind resources. The lack of wind resources leaves only solar power on existing roofs as the available renewable resource, accounting for 100% of the annual 20,756 MWH production and which quickly peaks in May and slowly declines between May and December. With the distribution of building types heavily weighted towards residential roofs versus industrial roofs, which have a smaller estimated PV installation area, the total available installation area also limits production (App. I: Figure 6-13). Existing electricity production in Decatur County only reports a small amount of production in MWH from petroleum sources (App. I: Figure 6-16). In essence, Decatur County is an energy importer.

Electricity demand is reported for industrial, transport, residential and commercial in that order (App. I: Figure 6-17), which seems to be a more realistic reflection of existing building types than what is reported in section 6.1.6.4 for distribution of carbon emissions.

6.1.6.6 Materials

The relatively high food production in Decatur County translates into a demand for organic compost soil amendments of 12,875 tons / year, is three times higher than the annual production potential of 3,804 tons / year (Table 6-11). This results in a moderately positive NDI-M1 value of 0.54384 indicating that the county has excess capacity to absorb agricultural soil amendments. Municipal solid waste generation (M2d) at 29,962 tons per year is exponentially higher than the recovery capacity, resulting in a negative NDI-M2 value of -0.99600 which plunges the vertical waveform into strong demand for MSW recovery in the county (Figure 6-6).

Organic compost potential is 55% represented by yard wastes and 40% by food waste (App. I: Figure 6-18) and with a small portion of biosolids feedstock production totaling about 10% of food waste feedstock (App. I: Table 6-4) from two WWTPs sources (App. I: Table 6-5). Estimation of MSW comes from national level generation trends based on a regionally adjusted lbs/capita/day figure of MSW generation and a reported recycling capacity, which indicates that paper, plastic, yard trimmings, food waste and 'other' constitute the MSW flow in Decatur County (App. I: Figure 6-19).

DECATUR COUNTY NDI FACTOR SUMMARY SHEET							
Capacity Factor			Decimal Value	Decimal Value		Demand Factor	
FOOD	Tons of Hay	F1C	12,101	150,261	F1d	Tons of Hay	FOOD
FOOD	Tons of Feed Grains	F2c	39,216	168,177	F2d	Tons of Feed Grains	FOOD
FOOD	Tons of Cereal Grains	F3c	92,680	1,905	F3d	Tons of Cereal Grains	FOOD
FOOD	Tons of Dairy	F4c	23,841	7,622	F4d	Tons of Dairy	FOOD
FOOD	Tons of Protein	F5c	26,825	1,747	F5d	Tons of Protein	FOOD
FOOD	Tons of Fruit	F6c	399	5,081	F6d	Tons of Fruit	FOOD
FOOD	Tons of Vegetables	F7c	97,944	6,351	F7d	Tons of Vegetables	FOOD
WATER	Total Available M^3 of Stream Flow	W1c	2,925,272,131	95,670,745	W1d	Total M3 of Adjusted Abstraction	WATER
WATER	Total M3 of Available Atmospheric Moisture (Green)	W2c	638,417,342	318,329,543	W2d	Total M3 of Consumed Atmospheric Moisture (Green)	WATER
WATER	Total Available M3 of Surface Runoff (Blue)	W3c	316,287,587	44,156,527	W3d	Total M3 of Consumed Surface Water (Blue)	WATER
WATER	Critical Annual Nitrogen Load in Tons (Grey)	W4c	1,084	194	W4d	Total Annual Nitrogen Load in Tons (Grey)	WATER
WATER	Critical Annual Phosphorus Load in Tons (Grey)	W5c	15	99	W5d	Total Annual Phosphorus Load in Tons (Grey)	WATER
ECOSYSTEM CONSERVATION	Total Existing Area of Conservation in Acres	EC1c	28,514	67,800	EC1d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
ECOSYSTEM CONSERVATION	Total Potential Area of Conservation in Acres	EC2c	201,594	67,800	EC2d	Minimum Area for Biodiversity Conservation in Acres	ECOSYSTEM CONSERVATION
CO_2	Total Carbon Sequestration Potential in Tons	C1c	14,955,511	129,784	C1d	Total Carbon Dioxide Emissions in Tons	CO_2
ELECTRICITY	Total Potential Renewable Electricity in Megawatt Hours	E1c	20,756	2,475,851	E1d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
ELECTRICITY	Total Existing Electricity Production in Megawatt Hours	E2c	151	2,475,851	E2d	Total Electricity Demand in Megawatt Hours	ELECTRICITY
MATERIALS	Total Potential Compost Application Load in Tons	M1c	12,875	3,804	M1d	Total Composted Organic Waste in tons	MATERIALS
MATERIALS	Recycling Capacity by Material Type	M2c	60	29,962	M2d	Total Tons of Material Outflow by Type (MSW)	MATERIALS

County:	Decatur	Ecoregion I and II:	Southeastern USA Plains of the Eastern Temperate Forests	
State:	Georgia	Ecoregion III:	Southeastern Plans	
Acres:	398827	HUC 8	Basin Name	%
Population:	27842	3130008	Lower Flint	65
		3120003	Lower Ochochonee	20
		3130010	Spring	10
		3130011	Apalachicola	5

Table 6-11: Decatur County NDI Factor Summary Sheet

Decatur County NDI Calculation				
(C - D)	(C + D)	NDI	NDI Factor Title	NDI ID
(138,160)	162,362	-0.85094	Tons of Hay	NDI-F1
(128,961)	207,393	-0.62182	Tons of Feed Grains	NDI-F2
90,775	94,585	0.95972	Tons of Cereal Grains	NDI-F3
16,219	31,463	0.51549	Tons of Dairy	NDI-F4
25,078	28,572	0.87771	Tons of Protein	NDI-F5
(4,682)	5,480	-0.85438	Tons of Fruit	NDI-F6
91,593	104,295	0.87821	Tons of Vegetables	NDI-F7
2,829,601,386	3,020,942,876	0.93666	Total M^3 of Adjusted Water Abstraction	NDI-W1
156,787,071	956,746,885	0.16388	Total M3 of Consumed Atmospheric Moisture (Green)	NDI-W2
272,131,060	360,444,114	0.75499	Total M3 of Consumed Surface Water (Blue)	NDI-W3
890	1,278	0.69614	Total Annual Nitrogen Load in Tons (Grey)	NDI-W4
(85)	114	-0.74165	Total Annual Phosphorus Load in Tons (Grey)	NDI-W5
(39,286)	96,314	-0.40790	Existing Area for Biodiversity Conservation in Acres	NDI-EC1
133,794	269,394	0.49665	Potential Area for Biodiversity Conservation in Acres	NDI-EC2
14,825,727	15,085,295	0.98279	Total Carbon Dioxide Balance	NDI-C1
(2,455,095)	2,496,607	-0.98337	Total Potential Renewable Electricity Production in Megawatt Hours	NDI-E1
(2,475,700)	2,476,002	-0.99988	Total Existing Electricity Production in Megawatt Hours	NDI-E2
9,071	16,679	0.54384	Total Composted Organic Waste in tons	NDI-M1
(29,902)	30,022	-0.99600	Total Tons of Material Outflow by Type in met. tons (MSW)	NDI-M2

Table 6-12: Decatur County NDI Calculation Summary

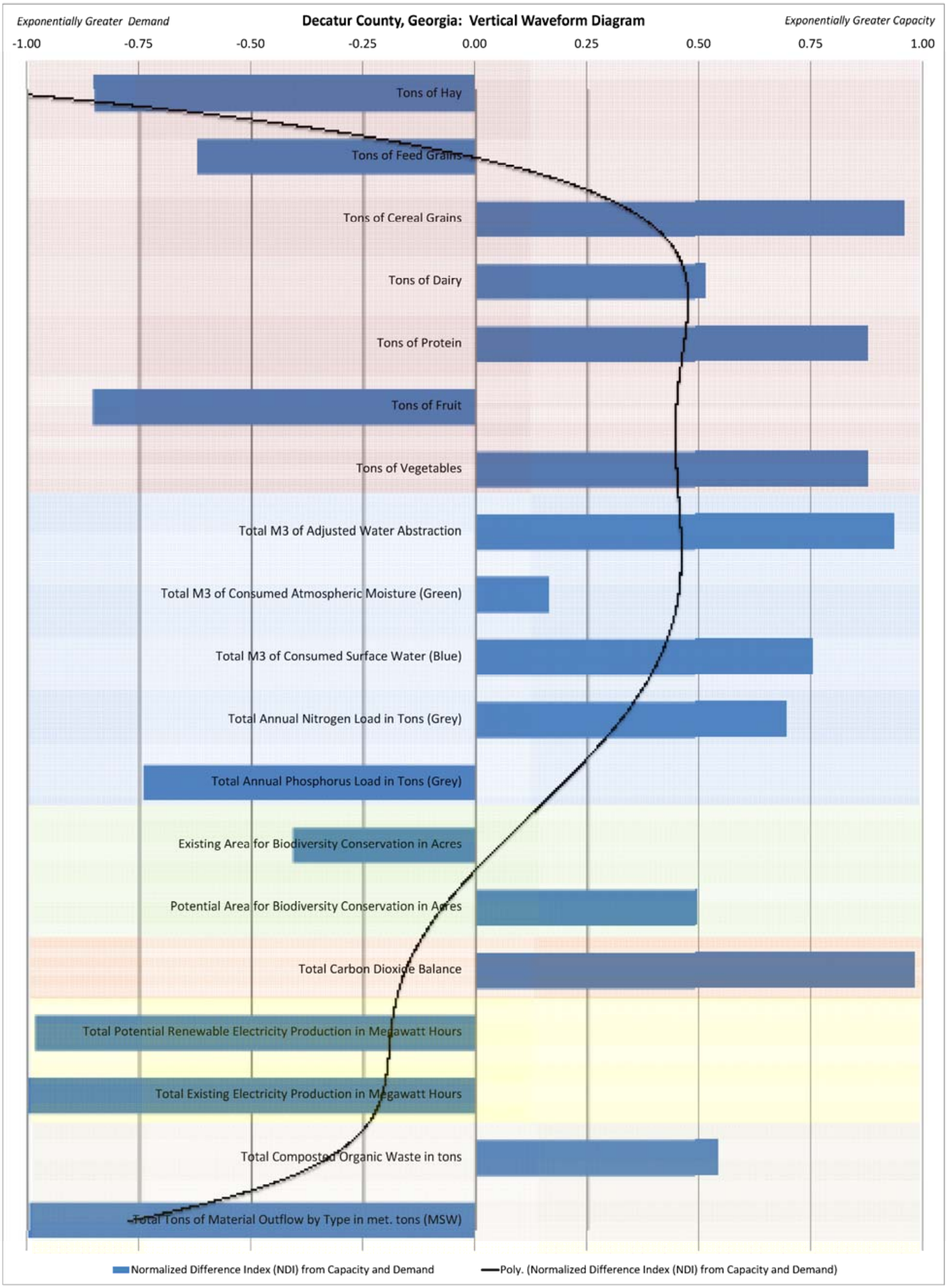

Figure 6-6: Decatur County Vertical Waveform Diagram

6.2 Vertical Waveform Diagram (VWD) Results for all Cases by Category

As one can see from the interpretation of each case above, the results for each factor within each case were not the same, resulting in distinct vertical waveform diagrams for each county. In order to derive some conclusions about the differences between counties, an overlay of all vertical waveform diagrams is presented below (Figure 6-7). As mentioned in section 4.2.1.13 the interpretation of the VWD is derived from an ungrouped polynomical regression fit line of all variables within a county.

6.2.1 Food

In the food category, the general trend was moderate to exponential demand for hay and feed grains (NDI-F1 and F2) then a shift towards weak to moderate capacity for cereal grains, dairy and protein (NDI-F3, NDI-F4 and NDI-F5) which ends in a dip in capacity for fruit and vegetable production (NDI-F6 and NDI-F7). The mean value for all NDI factors summarized across counties indicates moderate to strong demand for hay, feed grains and fruits, weak demand for dairy and vegetables and moderate to strong capacity for cereal grains and protein. The signature from Carroll County in the Ozark Highlands Ecoregion III unit, Decatur County in the Southeast USA plains and Logan County of the Central Corn Belt Plains represent the three most different signatures. Leflore County in the Mississippi Alluvial Plain, Garrett County in the Ridge and Valley Appalachian Forests and Schoharie County in the Norther Allegheny Plateau all have similar signatures but of different magnitudes. Schoharie and Garrett Counties have the closest spatial proximity of all case studies and the most similar food signatures with Logan the next closest and at roughly the same northern Latitude as Garrett County, whereas Carroll, Leflore and Decatur Counties are all located further south.

Within the calculation framework of the County Diagnostic the only firm explanation for the shortfall of hay and feed grain production is no hay or feed grains were reported in the NASS agricultural statistics, however, that does not mean that no hay or feed were produced. The result could mean that all cattle were grazed in all counties and thereby no bales of hay product were formally harvested, but the County Diagnostic method cannot sense the type of livestock or poultry system. The excess of cereal grain (NDI-F3) production may have a correlation with the excess in protein production recorded for all counties (NDI-F5) and support the conclusion that cereal grains for livestock and poultry feed may be practiced. Both Logan and Leflore Counties have monocrop food systems whereas Garrett, Decatur and Schoharie all have more diversified food systems and Carroll County produced overall very little food, which might explain the distribution of the food signatures.

6.2.2 Water

The mean NDI value for water quantity for all counties (NDI-W1, NDI-W2 and NDI-W3) was towards capacity, indicating that with the exception of Logan County all counties had enough water on an annual basis. As discussed in the individual results for all cases, a number of counties indicated that they would need to dip into environmental water requirements for ecosystems to meet demand for some months which was especially notable for the monocrop food systems in Logan and Leflore Counties. Garrett and Schoharie County continue to have similar signatures with Carroll County indicating the same trend. Decatur County has a positive for all water quantity NDI values and begins to mirror the signature of Carroll County, although Decatur has a greater magnitude of food and water capacity.

Water quality appears to be split with a moderately positive mean NDI value for nitrogen (NDI-W4) and a very weakly positive mean NDI value for phosphorus (NDI-W5). Carroll, Garrett and Schoharie Counties all have their peaks in the water category between NDI-W4 or NDI-W5 while Decatur, Logan and Leflore Counties all begin a recurve towards demand at NDI-W4. Interestingly, Carroll, Garrett and Schoharie all have a significant area for potential environmental conservation (NDI-EC2), with Decatur County having a split land use pattern of half intensive field agriculture and half high conservation potential and Logan and Leflore both having low existing conservation or potential conservation areas (see section 6.1.5.3 for a detailed discussion about Leflore's NDI-EC2 value). These results indicate that preserving natural vegetation and fluvial corridors may have a positive effect on water quality, which echoes results published by other studies (Chan 2006; Norberg 1999; Brown 2010).

6.2.3 Ecosystem Conservation

With the exception of Garrett County none of the counties met the 17% federal land protection target, with an average NDI-EC1 value of moderately negative (-0.50). However, the effective area available for ecosystem conservation remained towards weak to moderate capacity for all counties with almost the exact inverse moderately positive NDI-EC2 value. The two counties with the least PAD-US area and the least theoretically available area for environmental conservation, Logan and Leflore, predictably both had vertical waveforms indicating weak demand for ecosystem conservation. Decatur County has a mixed signature for environmental conservation which could be explained by the influence of a very negative NDI-W5 and NDI-E1 and NDI-E2 values pulling the signature towards overall negative as an effect of the polynomial trendline.

The average NDI-EC1 and NDI-EC2 values are positive for all counties with Garrett and Schoharie Counties have almost the same signatures for ecosystem conservation and Carroll County with a similar pattern but of lower capacity magnitude. The overall results indicate that many counties might rely on private land management decisions to retain ecosystem conservation and landscape connectivity, which are subject to individual will and decision making given land ownership rights in the USA, as opposed to binding federal regulations which might keep lands with high ecosystem services potential in the perpetual social commons. Land conservation rights in the Northeast United States also have a more social history dating back to colonial European settlement, which could also be a factor in the high amount of land preservation in Garrett and Schoharie. Garrett, Schoharie and Carroll Counties are also hilly or mountainous, which could explain the positive NDI-EC2 values since these lands are likely harder to develop, whereas Logan and Leflore counties are flat and are subject only to development restrictions related to flooding.

6.2.4 Carbon Dioxide (CO_2)

Without exception, the County Diagnostic estimated that carbon sequestration was exponentially greater than carbon emissions (NDI-C1) for all counties, with a mean NDI value indicating exponentially greater carbon sequestration capacity than demand. Since this category has only one NDI value, and the polynomial trend line curves are based on an average of every 3.16 factor values, this category does not have the effect of bringing every vertical waveform strongly towards positive capacity, rather it seems to be a convergence point within the waveform where all counties except for Logan County trend towards negative NDI values. A different trend line where each category was weighted with the category and not amongst the average of 3.16 categories might produce a different vertical waveform pattern for this category.

Given that the USA has one of the largest Carbon Footprints of all developed countries as discussed in the background section, this result comes as a surprise. There are a few possible explanations for this result; one could be that since counties with small populations and large areas of agriculture or forest land cover were sampled it resulted in a sample population which really represents counties with small Carbon Footprints; another explanation could be that the equations used for carbon sequestration (section 5.4) do not adequately reflect reality since carbon sequestration in the County Diagnostic is estimated by net primary productivity (NPP) based on an algorithm from space-based remote sensing while carbon emissions are based on different large scale remotely sensed measurement for the year 2002 which were scaled up to 2012 by population changes; and finally it could be that the use of top-down large scale remote sensing measurements in general result in inaccurate estimates for carbon sequestration and carbon emissions which might be fixed by employing a bottom-up material flow approach for both carbon emissions and carbon sequestration.

6.2.5 Electricity

The trend in the vertical waveform for NDI-E1 and NDI-E2 for all counties except Logan County is towards weak to moderate demand for electricity production, with mean NDI-E1 value of weak demand for renewable electricity and a mean NCI-E2 value indicating strong demand for electricity. These results indicate that all cases are in effect electricity importers. Although all counties reported photovoltaic resource capacity, the quantity of solar energy which could be produced given the restriction of roof area within the renewable electricity equations (section 5.5.1.1) was a severely limiting factor for this technology. The two counties which had positive NDI-E1 values, Logan and Schoharie, both had available wind resources which contributed to over 99% of the renewable electricity production potential. If the assumption of excluding all potential ZOC areas and areas within 5km of incorporated place boundaries were relaxed, a greater potential renewable electricity production would probably be registered for Carroll and Garrett Counties. Although close to the Gulf Coast, Leflore and Decatur Counties both had low average wind speed values, which could indicate that renewable electricity production in the American Southeast is not viable.

6.2.6 Materials

The measurement of capacity and demand of organic and municipal solid wastes across counties all followed a similar pattern, with greater field application capacity of composted organic wastes (NDI-M1) and a major shortfall in MSW recovery in all counties (NDI-M2). This results in a similar vertical waveform pattern for Carroll, Decatur, Leflore and Schoharie which plunge towards moderate to strong demand for greater material recovery than production. Logan, with a large area of monocrop farmland has a strongly capacity for organic wastes which causes a weak to strong capacity bump in the waveform before plunging into deeply negative territory in terms of MSW recovery. Garrett County actually has the potential to produce more organic compost than it can field apply and comes close to recovering all of its MSW and thereby exhibits a pretty good overall materials signature which points out that a negative NDI-M1 value within the County Diagnostic method represents a healthy signature, which is the inverse for all other factors.

The decoupling between ecoregion effects and effects of human applied technologies is especially apparent in the materials category, where I believe that every county could have a healthy or balanced NDI-M1 or NDI-M2 signature if the county chooses to implement the appropriate material recovery and composting technologies. My conclusion is that this category is more dependent on political will and economics than it is on ecoregion restrictions.

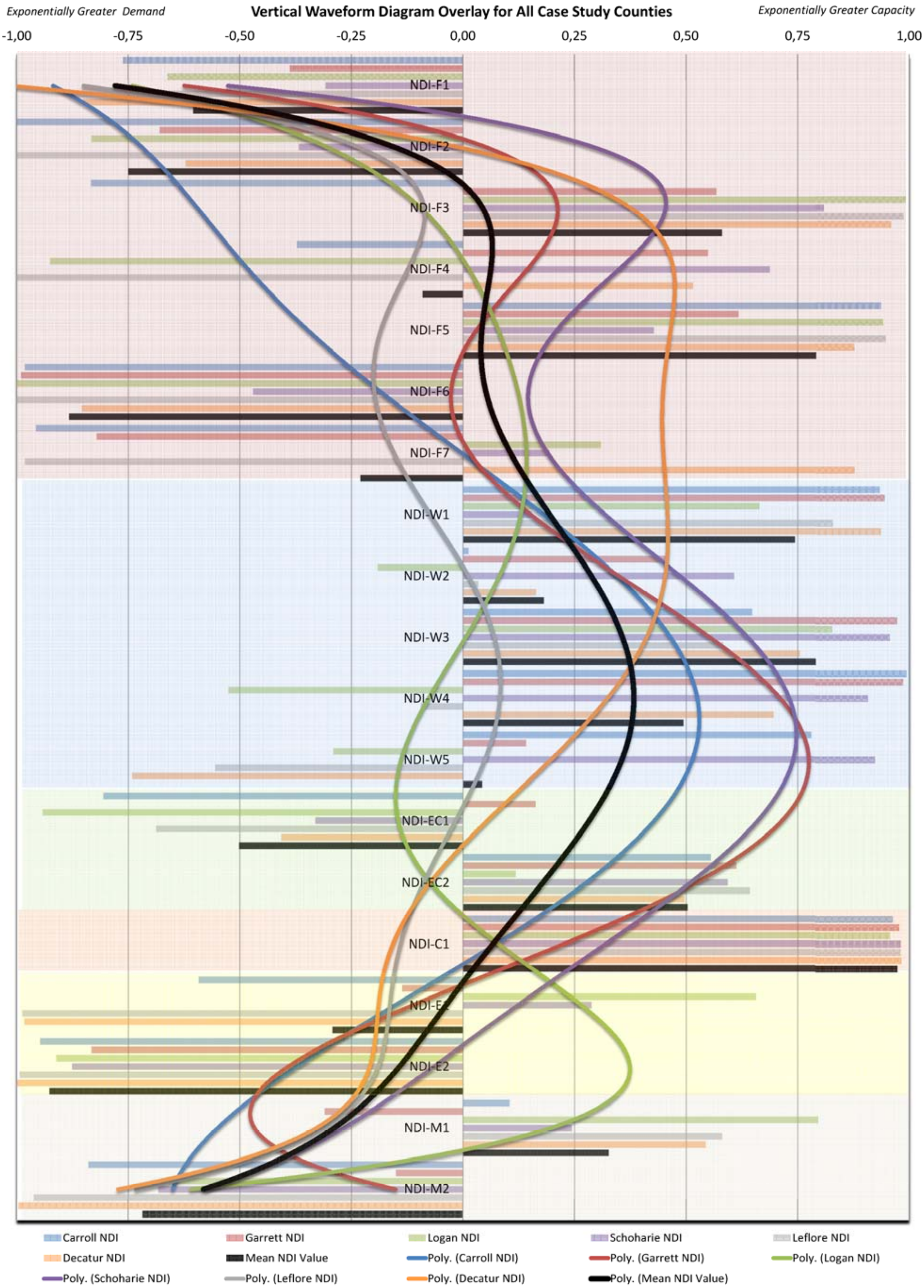

Figure 6-7: Vertical Waveform Diagram Overlay for All Case Study Counties

6.3 Statistical Results across Case Studies

To further understand the differences between counties, histograms for each county were prepared and the Kolmogorov-Smirnov test of normality was applied. The histograms and test of normality provide a statistical basepoint to compare counties against each other and to compare quantitative differences between NDI summary values per county. Table 6-13 below is a summary of all NDI values which was imported to SPSS where frequency statistics, histograms with an interpolation line, Kolmogorov-Smirnov test of normality with P-P plots of z-scores, boxplots of mean NDI values across counties, Friedmans ANOVA ("to compare groups of means that are dependent (i.e., they come from the same entities)(Field 2013 p. 250))" and correlation of NDI values were calculated for all counties. The cross-county results are discussed below.

Factor ID	Carroll	Garrett	Logan	Schoharie	Leflore	Decatur
NDI-F1	-0.76166	-0.3874	-0.66214	-0.30818	-0.65956	-0.85094
NDI-F2	-1	-0.67996	-0.83303	-0.36815	-1	-0.62182
NDI-F3	-0.83398	0.567772	0.992341	0.808927	0.987549	0.959719
NDI-F4	-0.37236	0.548956	-0.9255	0.687571	-1	0.515494
NDI-F5	0.937393	0.617698	0.941654	0.427696	0.947546	0.877712
NDI-F6	-0.98219	-0.99058	-1	-0.4709	-1	-0.85438
NDI-F7	-0.95717	-0.82122	0.309045	0.193588	-0.98225	0.878211
NDI-W1	0.934118	0.945187	0.664369	0.153904	0.829069	0.936662
NDI-W2	0.012507	0.459549	-0.19162	0.607695	0.034343	0.163875
NDI-W3	0.64782	0.973019	0.827603	0.956587	0.58355	0.754988
NDI-W4	0.994048	0.986325	-0.5259	0.907952	-0.09483	0.696135
NDI-W5	0.780598	0.141353	-0.29074	0.923628	-0.55576	-0.74165
NDI-EC1	-0.8062	0.162781	-0.94206	-0.33131	-0.68824	-0.4079
NDI-EC2	0.555289	0.612703	0.118292	0.593074	0.642959	0.496649
NDI-C1	0.963538	0.977868	0.957213	0.981293	0.980868	0.982793
NDI-E1	-0.59272	-0.13651	0.656727	0.28819	-0.98782	-0.98337
NDI-E2	-0.94785	-0.8328	-0.91162	-0.87655	-0.99391	-0.99988
NDI-M1	0.104336	-0.31021	0.79624	0.244024	0.580502	0.543845
NDI-M2	-0.83984	-0.15051	-0.67646	-0.68338	-0.9618	-0.996

Table 6-13: Descriptive Statistics Data Table

6.3.1.1 Descriptive Statistics Results

Frequency statistics in Table 6-14 indicate a wide mean distribution of NDI values across counties with Garrett, Schoharie and Decatur skewed negative. Boxplots indicate a wide distribution of NDI values in factors NDI-F4 (Dairy), NDI-F7 (Vegetables), NDI-W4 (N Water Quality), NDI-W5 (P Water Quality) and NDI-E1 (Renewable Electricity) compared to the other factors (Figure 6-8).

6.3.1.2 Inferential Statistics Results

6.3.1.2.1 Comparison between Cases

The Kolmogorov-Smirnov Test of Normality indicated that Garrett and Schoharie Counties have normal distributions with p-values above 0.2 (as interpreted with the Lillefors Significance Correlation where the hypothesis of normal distribution can be accepted with p-values above 0.2 when given a smaller number of cases (Bortz, Lienert, Boehnke 1990, p. 322)) and Leflore, Logan, Carroll and Decatur have non-normal distributions with p-values below 0.2 (Table 6-15). The non-normal distributions of Leflore, Logan, Carroll and Decatur are visible in their respective histograms where values are distributed towards the -1 and +1 edges of the histogram (right and left sides), whereas the normally distributed Garrett and Schoharie have NDI value distributions which are more centralized in the histogram (Figure 6-10).

The P-P plots of NDI Z scores show the normal distribution of Garrett and Schoharie Counties with the less pronounced 'S' shape in the Normal P-P plots and the non-normally distributed counties expressing a visible 'S' shape (Figure 6-11). Garrett and Schoharie also have a tighter distribution of min-max Z scores in the detrended P-P plots (Figure 6-12), further indicating a more normalized distribution.

The results between cases indicates that Garrett and Schoharie counties, both located in the Northeast USA in adjacent Ecoregion level II units, have a different NDI value distribution than all other counties in the case study.

6.3.1.2.2 Correlation between NDI Values

The Friedman's ANOVA results indicated a statistical difference between all NDI variables which verifies visible differences between ranges of NDI values in the Boxpots. This means that the null hypothesis that all NDI values are the same can be rejected (Figure 6-9).

The results of the Spearman's R correlation (Table 6-16) with the variables of NDI values and Counties indicated a number of significant correlations worth noting. A positive correlation between NDI-F3 and NDI-M1 indicate that as cereal grains increases so does organic compost production; a positive correlation between NDI-F4 and NDI-F2, NDI-F5 indicate that counties which produce protein and feed grains are able to produce dairy; a positive relationship between NDI-F4 and NDI-W2 indicate that dairy production increases in ecoregions with more atmospheric moisture; a negative correlation between NDI-F5 and NDI-F6 indicates that production of fruit decreases as production of protein increases; a positive correlation between NDI-F6 and NDI-F4 indicate that dairy production increases as fruit production increases; a negative relationship between NDI-W2 and NDI-F5 indicates that as runoff increases protein production decreases; a positive relationship between NDI-W2 and NDI-EC1 indicate that as atmospheric moisture increases so does legal land conservation; a positive correlation between NDI-W3 and NDI-EC2 indicate that as runoff increases so does the potential zone of conservation; a negative correlation between NDI-W4 and NDI-M1 indicates that mg/l decreases in N in the water supply correlates to a decrease in available compost volume; a positive relationship between NDI-M1 and NDI-EC2 indicate that a higher availability of organic compost correlates with increases in potential conservation area; a positive relationship between NDI-M2 and NDI-EC2 indicate that as recycling rate increases so does potential conservation area in a county.

6.3.1.2.3 Categorical Principal Component Analysis

The results of the categorical principal component analysis indicate a high level of correlations between NDI values amongst 4 dimensions with total Eigenvalues of 18.981 explaining 99.902% of the variance amongst the 19 NDI values for all six counties (Table 6-17). The first dimension has an excellent alpha value of 0.905 with an eigenvalue of 6.997 explaining 36.827% of the variance; the second dimension has a good alpha value of 0.833 with an eigenvalue of 4.742 explaining 24.958% of the variance; the third dimension has a good alpha value of 0.811 with an eigenvalue of 4.311 explaining 22.688% of the variance; and the fourth dimension has an alpha value bordering between questionable and acceptable at 0.696 with an eigenvalue of 2.931 explaining 15.428% of the variance. The CatPCA analysis was iterated multiple times to find the total number of dimensions and highest percentage of variance that could be explained and the largest number of dimensions possible after multiple iterations was four.

The component loadings in Table 6-18, reported in Spearman's r_s values, are transferred into a value matrix by dimension (Table 6-19) where significant r_s values (over 0.5) reported in the component loading table were isolated by dimension for each NDI value, where 8 of the NDI values had a significant r_s value in more than one dimension and the remaining 11 had only one significant r_s value. The value matrix was then further evaluated in a dimension interpretation table (Table 6-20) where each significant r_s value was interpreted with a written statement where the known NDI value and r_s values were interpreted against the unknown dimension with a statement such as "when dimension 1 increases the total tons of hay significantly decreases," in the case of NDI-F1 for example; or "when dimension 1 increases the total tons of protein significantly increases" in the case of NDI-F5 for example. This "interpretation statement" was created for every r_s value in every dimension and then all statements were used to develop an interpretation of what the dimension might represent.

The outcome of the dimension interpretation matrix is subjective; it is based on my understanding of the data and the interpretation of what could explain the specific grouping of positive and negative correlation values. Given the interpretation statements in Table 6-20 I interpreted the dimensions as follows:

6.3.1.2.3.1 Dimension 1: Human and Livestock Population

Given that an increase in dimension 1 equates to a decrease in resource availability, especially food and water, and that an increase in dimension 1 equates to an increase in protein, I believe this dimension represents an increase in resources demand. Given that the demand side of the County Diagnostic is calculated from human and livestock demand, it is logical to conclude that dimension 1, with the most explanation of variance in the dataset, would be explained by human and livestock demand. The result signifies that human and livestock demand on ecosystem goods and services might be a big determinant in the ability of ecosystems to support a given population. Further studies with the County Diagnostic could concentrate on comparing equal area / unequal population counties to define a breakpoint at which human and livestock demand absolutely outpaces the ability of ecosystems to produce goods and services.

6.3.1.2.3.2 Dimension 2: Areas of High Precipitation and Presence of Surface Water

Although this dimension is defined essentially as presence of water, the underlying interpretation is that presence of water restricts the potential land uses of a county, as farming, urban development and installation of renewable energy cannot occur on open water. The r_s values reflect this interpretation where surface water availability (W1), existing and potential area of ecosystem preservation (EC1 and EC2) and total carbon sequestration potential (C1) all increase as dimension 2 increases. Inversely, the area where renewable electricity and area of existing electricity (E1 and E2) decrease as dimension 2 increases. Given this interpretation one might expect significant negative r_s values to appear in the food category, but that is not the case because the significant food values generally appear in dimension 1. However, looking at the raw component loadings one finds less significant negative r_s values in all food categories except for F5 and F6, both of which are water intensive (fruit crops and livestock), and therefore increases in water would be expected to correlate with potential increases in production capacity of these two variables. The only category which does not fit this interpretation is W5, where the concentration of P in surface water would be expected to decrease as dimension 2 increases, given the 'dilution principle' of P nutrients in water.

6.3.1.2.3.3 Dimension 3: Affluence and Application of Technology

With only 22.6% variance explanation and almost 67% of the variance already explained by human and livestock population (D1) and presence of water and the corresponding limitations to land use (D2), dimension 3 is more difficult to predict given the 5 limited significant r_s values. In this case I relied on the distribution of the values to interpret the dimension, in which a significant value existed in all categories except ecosystems. Given these results it seems reasonable to conclude that affluence of human population and the willingness of a population to apply technology could explain the r_s values. As affluence goes up, so does urbanization, and people may be more reliant on vegetables imported from the global market so that year round availability of vegetables is there, thus local production of vegetables, (W7) would logically decrease. As affluence increases so does the ability to invest in water purification technologies and education regarding water quality protection, therefore water quality, represented by a positive W5 value, would also increase. As affluence and urbanization increases so would the consumption of energy intensive devices, the use of automobiles, the ability to produce energy increases (which is 89% fossil fuel based in the USA (US EIA 2008-2012) and supported by E2 which increases as dimension 3 increases) and the loss of ecosystem area occurs due to urbanization; therefore a county can no longer sequester as much carbon as it emits (C1). Finally, affluence and the ability to harness recycling networks and technology would logically increase the ability of a county to recycle its inorganic solid materials (M2). Thus, dimension 3 reflects the 'human fingerprint' and the willingness of a human population to control their systems of procurement through the application of money and technology.

6.3.1.2.3.4 Dimension 4: Area Devoted to Ecosystems or Total Available Ecosystem Area

With only 15 percent variance explained by dimension 4, all variables grouped in either the food or water categories, four of the five variables being of secondary importance in the dimensions loading table and demand for food and general availability of water already used as explanations for dimension 1 and 2, dimension 4 requires a detailed understanding of the CD model and the data results to understand. Of all the agricultural area extents, counties with high hay (F1) and cereal grain (F3) production end up having a majority of their land uses dominated by these factors, resulting in a marginalization of ecosystem areas. Additionally, since these field crops are area intensive, any dimension which reduces available area for agricultural production would have a negative effect on hay and cereal crop production. Therefore, I propose that the area devoted to ecosystems, or difficulties of terrain such as rockiness or steep topography which preclude agriculture and trend a land use towards forestation or conservation, could explain the negative r_s values for F1 and F3. With this logic, the positive W1 and W3 factors, indicating plenty of surface water and streamflow availability make sense, as increased forestation or riparian connected vegetation cover will improve water runoff regulation, groundwater regeneration and short cycling of water, thereby increasing overall local water availability by decreasing loss due to evaporation or high peak flow volumes typified by agricultural and urban development. Finally, an increase in ecosystem area does equate to an increase in green water consumption by ecosystems which is visible in the green water EWR results for all counties in the appendix. Therefore I conclude that dimension 4 can be explained by increases in existing ecosystem area footprint. This factor could be further explained by ecoregion variation, as some counties must devote more area to ecosystems given the 'lay of the land,' and thereby a secondary explanation for this factor could be explained by differences in ecoregion level II units, as supported by the findings of the Friedman's ANOVA where NDI values significantly differed across cases and thereby supports the conclusion that ecoregion variations play a role in CD outcomes.

		Carroll	Garrett	Logan	Schoharie	Leflore	Decatur
N	Valid	19	19	19	19	19	19
	Missing	0	0	0	0	0	0
Mean		-.113912812	.1412643438	-.036609246	.2492452083	-.175673035	.0710605691
Median		-.372362773	.1627814189	-.191617122	.2881904853	-.555763119	.4966488357
Mode		-1.0000000[a]	-.99057800[a]	-1.0000000[a]	-.87655168[a]	-1.00000000	-.99987803[a]
Std. Deviation		.8051878685	.6719594337	.7683388880	.5966257490	.8201750177	.8033103054
Skewness		.283	-.293	.109	-.446	.327	-.261
Std. Error of Skewness		.524	.524	.524	.524	.524	.524
Kurtosis		-1.792	-1.268	-1.777	-1.070	-1.762	-1.851
Std. Error of Kurtosis		1.014	1.014	1.014	1.014	1.014	1.014
Percentiles	25	-.839838005	-.387401502	-.833031842	-.331314532	-.987815366	-.850938027
	50	-.372362773	.1627814189	-.191617122	.2881904853	-.555763119	.4966488357
	75	.7805976259	.6176976815	.7962395053	.8089269728	.6429591947	.8777124458

a. Multiple modes exist. The smallest value is shown

Table 6-14: Frequency Statistics for all Counties

	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Carroll	.210	19	.026
Garrett	.156	19	.200*
Logan	.185	19	.086
Schoharie	.141	19	.200*
Leflore	.205	19	.035
Decatur	.228	19	.010

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 6-15: Kolmogorov-Smirnov Test of Normality for all Counties

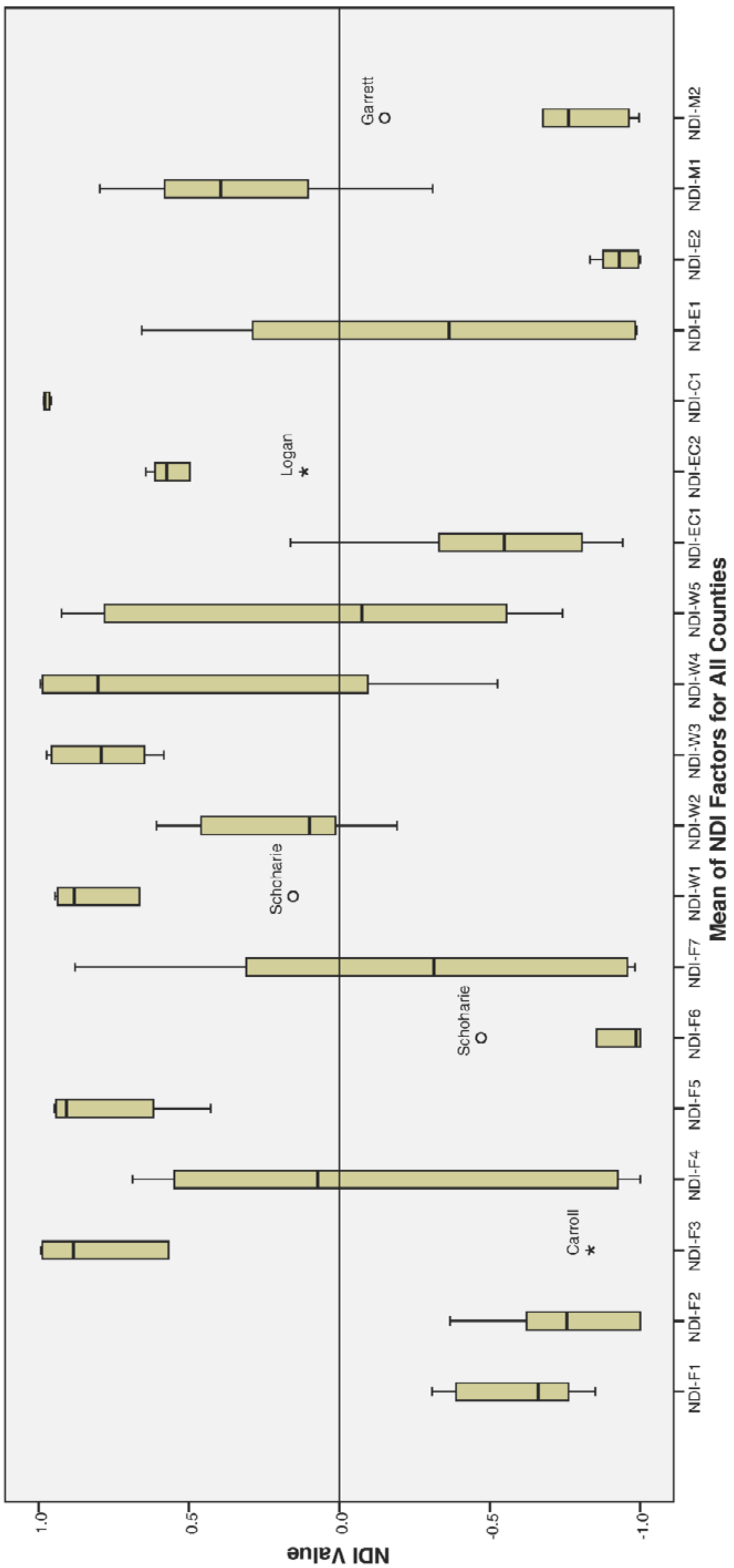

Figure 6-8: Boxplot Summary of Mean NDI Values by County

Friedman Test by Rank

	Mean Rank
NDI-F1	6.67
NDI-F2	3.83
NDI-F3	15.00
NDI-F4	8.67
NDI-F5	15.33
NDI-F6	2.17
NDI-F7	8.00
NDI-W1	14.33
NDI-W2	11.00
NDI-W3	15.50
NDI-W4	14.33
NDI-W5	11.00
NDI-EC1	6.67
NDI-EC2	12.50
NDI-C1	18.33
NDI-E1	8.00
NDI-E2	2.67
NDI-M1	11.17
NDI-M2	4.83

Test Statistics[a]

N	6
Chi-Square	78.140
df	18
Asymp. Sig.	.000

a. Friedman Test

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of NDI-F1, NDI-F2, NDI-F3, NDI-F4, NDI-F5, NDI-F6, NDI-F7, NDI-W1, NDI-W2, NDI-W3, NDI-W4, NDI-W5, NDI-EC1, NDI-EC2, NDI-C1, NDI-E1, NDI-E2, NDI-M1 and NDI-M2 are the same.	Related-Samples Friedman's Two-Way Analysis of Variance by Ranks	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 6-9: Summary of Friedman's ANOVA Test of Means from Dependent Groups

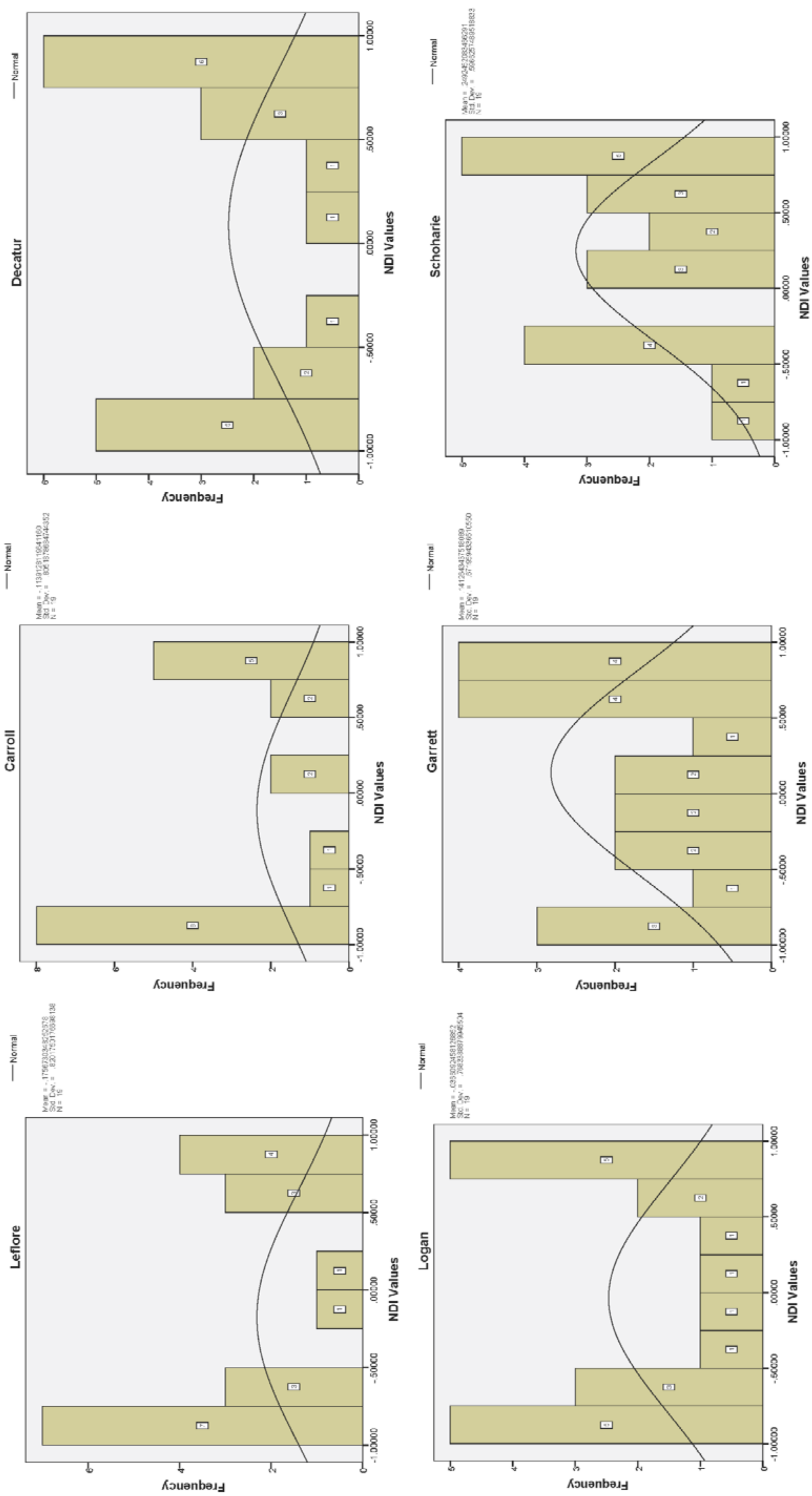

Figure 6-10: Histograms of NDI Values for All Counties

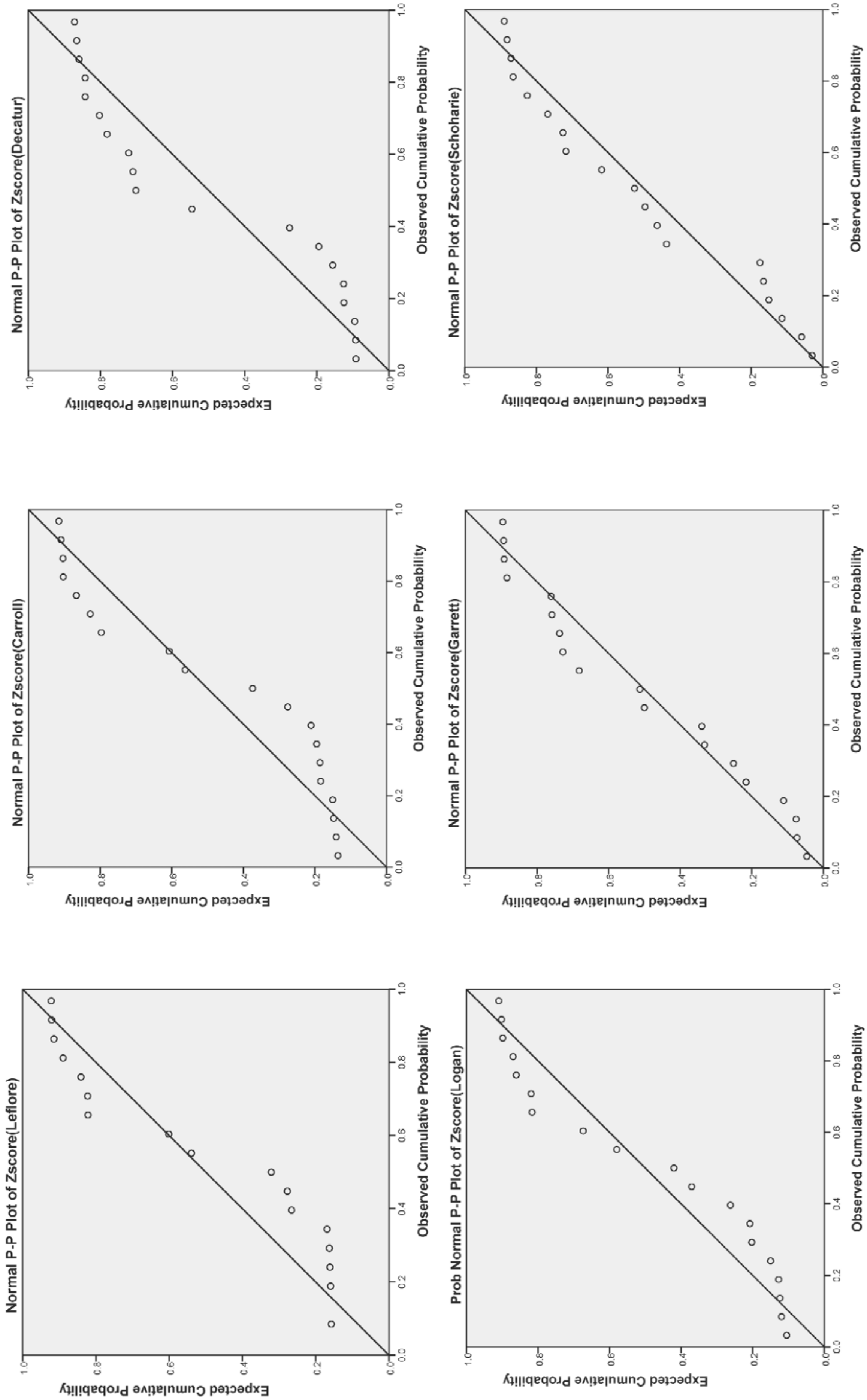

Figure 6-11: Normal P-P Plots of NDI Z Scores for all Counties

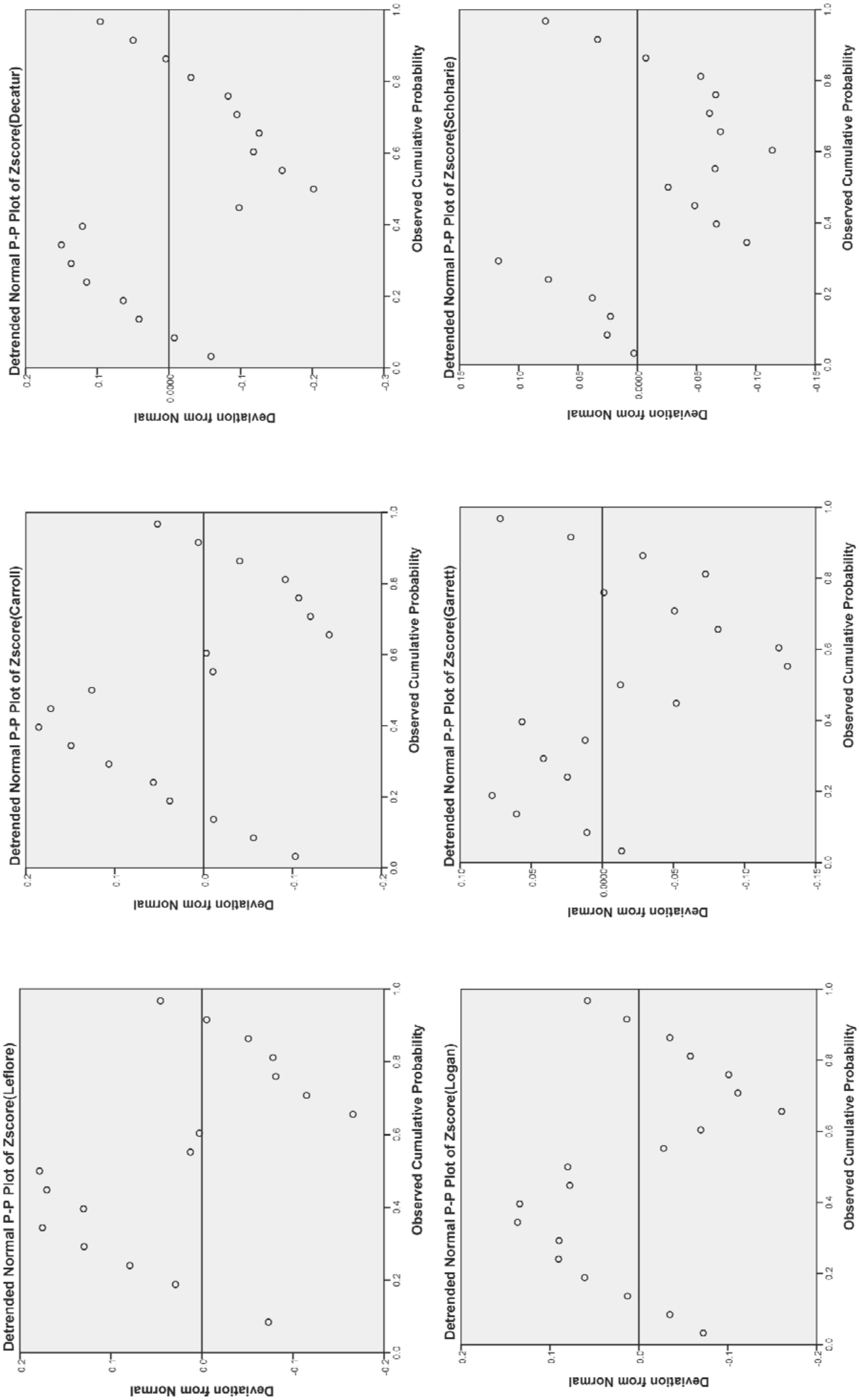

Figure 6-12: Detrended P-P Plots of NDI Z-Scores for all Counties

Type	Variables1	Statistics	Variables2																			
			NDI-F1	NDI-F2	NDI-F3	NDI-F4	NDI-F5	NDI-F6	NDI-F7	NDI-W1	NDI-W2	NDI-W3	NDI-W4	NDI-W5	NDI-EC1	NDI-EC2	NDI-C1	NDI-E1	NDI-E2	NDI-M1	NDI-M2	County
	NDI-F1	Correlation Coefficient	1.000	.319	-.086	.429	-.429	.058	-.314	-.371	.600	.543	.086	.600	.543	.600	.029	.371	.771	-.257	.600	-.143
		Sig. (2-tailed)	.	.538	.872	.397	.397	.913	.544	.468	.208	.266	.872	.208	.266	.208	.957	.468	.072	.623	.208	.787
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-F2	Correlation Coefficient	.319	1.000	-.029	.841*	-.841*	.721	.696	-.116	.754	.696	.029	.174	.638	-.174	.609	.377	.290	-.174	.116	.377
		Sig. (2-tailed)	.538	.	.957	.036	.036	.106	.125	.827	.084	.125	.957	.742	.173	.742	.200	.461	.577	.742	.827	.461
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-F3	Correlation Coefficient	-.086	-.029	1.000	-.543	.543	-.522	.314	-.429	-.371	-.200	-1.00**	-.600	-.429	-.257	-.029	.086	-.314	.943**	-.143	.600
		Sig. (2-tailed)	.872	.957	.	.266	.266	.288	.544	.397	.468	.704	.	.208	.397	.623	.957	.872	.544	.005	.787	.208
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-F4	Correlation Coefficient	.429	.841*	-.543	1.000	-1.00**	.812*	.371	.086	.829*	.771	.543	.543	.771	.029	.429	.371	.543	-.657	.314	-.086
		Sig. (2-tailed)	.397	.036	.266	.	.	.050	.468	.872	.042	.072	.266	.266	.072	.957	.397	.468	.266	.156	.544	.872
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-F5	Correlation Coefficient	-.429	-.841*	.543	-1.00**	1.000	-.812*	-.371	-.086	-.829*	-.771	-.543	-.543	-.771	-.029	-.429	-.371	-.543	.657	-.314	.086
		Sig. (2-tailed)	.397	.036	.266	.	.	.050	.468	.872	.042	.072	.266	.266	.072	.957	.397	.468	.266	.156	.544	.872
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-F6	Correlation Coefficient	.058	.721	-.522	.812*	-.812*	1.000	.377	-.058	.667	.290	.522	.406	.493	-.116	.638	.058	.029	-.464	-.232	.145
		Sig. (2-tailed)	.913	.106	.288	.050	.050	.	.461	.913	.148	.577	.288	.425	.321	.827	.173	.913	.957	.354	.658	.784
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-F7	Correlation Coefficient	-.314	.696	.314	.371	-.371	.377	1.000	-.029	.086	.429	-.314	-.257	.029	-.771	.257	.429	-.086	.257	-.029	.371
		Sig. (2-tailed)	.544	.125	.544	.468	.468	.461	.	.957	.872	.397	.544	.623	.957	.072	.623	.397	.872	.623	.957	.468
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-W1	Correlation Coefficient	-.371	-.116	-.429	.086	-.086	-.058	-.029	1.000	.086	.086	.429	-.371	.371	.143	.086	-.429	-.086	-.543	-.029	-.143
		Sig. (2-tailed)	.468	.827	.397	.872	.872	.913	.957	.	.872	.872	.397	.468	.468	.787	.872	.397	.872	.266	.957	.787
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-W2	Correlation Coefficient	.600	.754	-.371	.829*	-.829*	.667	.086	.086	1.000	.543	.371	.314	.943**	.486	.714	-.029	.371	-.543	.086	.257
		Sig. (2-tailed)	.208	.084	.468	.042	.042	.148	.872	.872	.	.266	.468	.544	.005	.329	.111	.957	.468	.266	.872	.623
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-W3	Correlation Coefficient	.543	.696	-.200	.771	-.771	.290	.429	.086	.543	1.000	.200	.429	.600	-.086	-.029	.714	.829*	-.429	.771	-.257
		Sig. (2-tailed)	.266	.125	.704	.072	.072	.577	.397	.872	.266	.	.704	.397	.208	.872	.957	.111	.042	.397	.072	.623
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-W4	Correlation Coefficient	.086	.029	-1.00**	.543	-.543	.522	-.314	.429	.371	.200	1.000	.600	.429	.257	.029	-.086	.314	-.943**	.143	-.600
		Sig. (2-tailed)	.872	.957	.	.266	.266	.288	.544	.397	.468	.704	.	.208	.397	.623	.957	.872	.544	.005	.787	.208
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-W5	Correlation Coefficient	.600	.174	-.600	.543	-.543	.406	-.257	-.371	.314	.429	.600	1.000	.200	.143	-.257	.543	.714	-.543	.543	-.657
		Sig. (2-tailed)	.208	.742	.208	.266	.266	.425	.623	.468	.544	.397	.208	.	.704	.787	.623	.266	.111	.266	.266	.156
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-EC1	Correlation Coefficient	.543	.638	-.429	.771	-.771	.493	.029	.371	.943**	.600	.429	.200	1.000	.543	.600	-.086	.429	-.657	.200	.143
		Sig. (2-tailed)	.266	.173	.397	.072	.072	.321	.957	.468	.005	.208	.397	.704	.	.266	.208	.872	.397	.156	.704	.787
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-EC2	Correlation Coefficient	.600	-.174	-.257	.029	-.029	-.116	-.771	.143	.486	-.086	.257	.143	.543	1.000	.257	-.486	.200	-.371	.029	.029
		Sig. (2-tailed)	.208	.742	.623	.957	.957	.827	.072	.787	.329	.872	.623	.787	.266	.	.623	.329	.704	.468	.957	.957
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-C1	Correlation Coefficient	.029	.609	-.029	.429	-.429	.638	.257	.086	.714	-.029	.029	-.257	.600	.257	1.000	-.486	-.371	-.086	-.600	.771
		Sig. (2-tailed)	.957	.200	.957	.397	.397	.173	.623	.872	.111	.957	.957	.623	.208	.623	.	.329	.468	.872	.208	.072
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-E1	Correlation Coefficient	.371	.377	.086	.371	-.371	.058	.429	-.429	-.029	.714	-.086	.543	-.086	-.486	-.486	1.000	.714	.029	.771	-.429
		Sig. (2-tailed)	.468	.461	.872	.468	.468	.913	.397	.397	.957	.111	.872	.266	.872	.329	.329	.	.111	.957	.072	.397
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-E2	Correlation Coefficient	.771	.290	-.314	.543	-.543	.029	-.086	-.086	.371	.829*	.314	.714	.429	.200	-.371	.714	1.000	-.486	.943**	-.600
		Sig. (2-tailed)	.072	.577	.544	.266	.266	.957	.872	.872	.468	.042	.544	.111	.397	.704	.468	.111	.	.329	.005	.208
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-M1	Correlation Coefficient	-.257	-.174	.943**	-.657	.657	-.464	.257	-.543	-.543	-.429	-.943**	-.543	-.657	-.371	-.086	.029	-.486	1.000	-.314	.543
		Sig. (2-tailed)	.623	.742	.005	.156	.156	.354	.623	.266	.266	.397	.005	.266	.156	.468	.872	.957	.329	.	.544	.266
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	NDI-M2	Correlation Coefficient	.600	.116	-.143	.314	-.314	-.232	-.029	-.029	.086	.771	.143	.543	.200	.029	-.600	.771	.943**	-.314	1.000	-.657
		Sig. (2-tailed)	.208	.827	.787	.544	.544	.658	.957	.957	.872	.072	.787	.266	.704	.957	.208	.072	.005	.544	.	.156
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	County	Correlation Coefficient	-.143	.377	.600	-.086	.086	.145	.371	-.143	.257	-.257	-.600	-.657	.143	.029	.771	-.429	-.600	.543	-.657	1.000
		Sig. (2-tailed)	.787	.461	.208	.872	.872	.784	.468	.787	.623	.623	.208	.156	.787	.957	.072	.397	.208	.266	.156	.
		N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6-16: Correlation Matrix from Spearman's R Test with NDI and Ecoregion Variables (where yellow denotes significant positive correlations and orange denotes significant negative correlations)

Model Summary

Dimension	Cronbach's Alpha	Variance Accounted For Total (Eigenvalue)	% of Variance
1	.905	6.997	36.827
2	.833	4.742	24.958
3	.811	4.311	22.688
4	.696	2.931	15.428
Total	1.000[a]	18.981	99.902

a. Total Cronbach's Alpha is based on the total Eigenvalue.

Table 6-17: Summary by NDI Values with the Categorical Principal Component Analysis, Expressed as Cronbach's Alpha, Total Eigenvalue and Total Variance Accounted For

Component Loadings

	Dimension 1	2	3	4
NDI-F1	-.733	-.333	.103	-.584
NDI-F2	-.767	-.032	-.419	-.484
NDI-F3	.720	-.217	-.401	-.520
NDI-F4	-.895	-.340	-.158	-.240
NDI-F5	.894	.379	.238	.009
NDI-F6	-.856	.313	-.135	.388
NDI-F7	-.053	-.338	-.916	.210
NDI-W1	.146	.743	.047	.646
NDI-W2	-.833	.045	.058	-.548
NDI-W3	-.566	-.442	-.411	.560
NDI-W4	-.761	.279	.357	.464
NDI-W5	-.452	-.548	.686	.158
NDI-EC1	-.510	.829	.187	-.130
NDI-EC2	-.184	.842	.389	-.326
NDI-C1	-.344	.546	-.683	-.342
NDI-E1	-.225	-.787	-.351	.455
NDI-E2	-.043	-.514	.849	-.104
NDI-M1	.855	-.378	-.186	-.302
NDI-M2	-.043	-.514	.849	-.104

Variable Principal Normalization.

Table 6-18: Summary of Spearman's R_s Values in CatPCA Dimensions

Factor	Factor ID	Dimension 1	Dimension 2	Dimension 3	Dimension 4
Tons of Hay	NDI-F1	-0.733			-0.584
Tons of Feed Grains	NDI-F2	-0.767			
Tons of Cereal Grains	NDI-F3	-0.72			-0.52
Tons of Dairy	NDI-F4	-0.895			
Tons of Protein	NDI-F5	0.894			
Tons of Fruit	NDI-F6	-0.856			
Tons of Vegetables	NDI-F7			-0.916	
Total M^3 of Adjusted Water Abstraction	NDI-W1		0.743		0.646
Total M3 of Consumed Atmospheric Moisture (Green)	NDI-W2	-0.833			-0.548
Total M3 of Consumed Surface Water (Blue)	NDI-W3	-0.566			0.56
Total Annual Nitrogen Load in Tons (Grey)	NDI-W4	-0.761			
Total Annual Phosphorus Load in Tons (Grey)	NDI-W5		-0.548	0.686	
Existing Area for Ecosystem Conservation in Acres	NDI-EC1	-0.51	0.829		
Potential Area for Ecosystem Conservation in Acres	NDI-EC2		0.842		
Total Carbon Dioxide Balance	NDI-C1		0.546	-0.683	
Total Potential Renewable Electricity Production in Megawatt Hours	NDI-E1		-0.787		
Total Existing Electricity Production in Megawatt Hours	NDI-E2		-0.514	0.849	
Total Composted Organic Waste in tons	NDI-M1	0.855			
Total Tons of Material Outflow by Type in met. tons (MSW)	NDI-M2			0.849	

Table 6-19: CatPCA r_s Value Matrix

Factor	Factor ID	Dimension 1 Interpretation	Dimension 2 Interpretation	Dimension 3 Interpretation	Dimension 4 Interpretation
		Human and Livestock Population	**Areas of High Precipitation and Presence of Surface Water**	**Affluence and Application of Technology**	**Area Deveoted to or Available for Ecosystems**
		D1 Interpretation Statement	D2 Interpretation Statement	D3 Interpretation Statement	D4 Interpretation Statement
Tons of Hay	NDI-F1	As D1 increases the availability of hay decreases			As D4 increases the availability of hay decreases
Tons of Feed Grains	NDI-F2	As D1 increases the availability of feed grains decreases			
Tons of Cereal Grains	NDI-F3	As D1 increases the availability of cereal grains decreases			As D4 increases the availability of cereal grains decreases
Tons of Dairy	NDI-F4	As D1 increases the availability of dairy decreases			
Tons of Protein	NDI-F5	As D1 increases the availability of protein increases			
Tons of Fruit	NDI-F6	As D1 increases the availability of fruit decreases			
Tons of Vegetables	NDI-F7			As D3 increases the total availability of fruits decreases	
Total M^3 of Adjusted Water Abstraction	NDI-W1		As D2 increases the availability of surface water increases		As D4 increases the availability of streamflow increases
Total M^3 of Consumed Atmospheric Moisture	NDI-W2	As D1 increases the availability of green water decreases			As D4 increases the availability of green water decreases

Table 6-20: CatPCA Dimension Interpretation Matrix (continues on next table for readability)

Total M^3 of Consumed Surface Water	NDI-W3	As D1 increases the availability of blue water decreases			As D4 increases the availability of surface water increases
Total Annual Nitrogen Load in Tons (Grey)	NDI-W4	As D1 increases the ability of ecosystems to absorb nitrogen decreases			
Total Annual Phosphorus Load in Tons	NDI-W5		As D2 increases the ability of ecosystems to absorb phosphorus decreases	As D3 increases the ability of ecosystems to absorb phosphorus increases	
Existing Area for Biodiversity Conservation in Acres	NDI-EC1	As D1 increases the existing area of ecosystems decreases	As D2 increases the existing area of ecosystems conservation increases		
Potential Area for Biodiversity Conservation in Acres	NDI-EC2		As D2 increases the potential area for biodiversity conservation area increases		
Total Carbon Dioxide Balance	NDI-C1		As D2 increases total carbon sequestration increases	As D3 increases carbon sequestration decreases	
Total Potential Renewable Electricity Production in Megawatt Hours	NDI-E1		As D2 increases the ability of the county to produce enough renewable electricity decreases		
Total Existing Electricity Production in Megawatt Hours	NDI-E2		As D2 increases the total ability a county to produce electricity decreases	As D3 increases the availability of existing electricity increases	
Total Composted Organic Waste in tons	NDI-M1	As D1 increases the availability of the land to absorb organic waste increases			
Total Tons of Material Outflow by Type in met. tons (MSW)	NDI-M2			As D3 increases the total recycling potential of a county increases	

Figure 6-13: CatPCA Dimension Interpretation Matrix (continued from Table 6-20)

7 Discussion and Conclusion

7.1 Interpretation of Results in Light of Research Questions

7.1.1 Research Question 1

7.1.1.1 Does the development of a sub-national environmental footprint with unit specific and spatially explicit values emulating the DEU result in a robust and useful analysis for regional planning?

The County Diagnostic method as described in chapter 5 and applied in chapter 6 seems to indicate that a formulaic methodology at a county-wide resolution can yield significant material specific and spatially explicit results which illuminate the differences between material and energy flows and between all of the expanded analysis categories of food, water, ecosystem conservation, carbon balance, energy and material generation and recovery (section 6.3). The NDI values used to compare capacity and demand effectively normalize a wide variety of data and factors of different minimum and maximum values so that the numbers can be fed into descriptive and inferential statistical procedures. The mathematical framework of equations for each factor value (38 in total) demonstrates a framework which can be modified as technology is applied or as new data becomes available. In this way, the formula framework distills the essence of an environmental footprint analysis down to what appear to be the most simplistic and widely applicable terms for the United States.

The DEU as an organizing framework to inform the categories of the footprint was able to guide the work to six categories where a high degree of variance percentage within the variables could be explained within 4 dimensions that also had logical explanations. The goal of using the DEU was to test the potential for a county to be a semi-closed circular metabolism independent of other counties and the results indicate that within the CD framework each county could probably be a semi-closed metabolism, but at a certain economic, social or political cost. After conducting the analysis it seems unlikely that any county in the USA would have a VWD that was a total flat line because that would mean that all systems are perfectly designed without any excess demand or excess abundance. What is more likely given the results is that resources such as water and crops, pollutants, solid materials and energy are traded between counties in a type of 'fuzzy metabolism' that is not contained by an administrative jurisdiction. Indeed, my assumptions in Section 4.1 were never that a county should be a closed metabolism, but rather that the county unit would be good for evaluation of material flows and footprint.

Certainly, no footprint or integrated analysis is going to be able to address all components possible and there is an open door to interpreting the choices of factors in the County Diagnostic as not including all factors in the DEU; two of these being availability of fibers and raw building materials for example or furthering renewable energy to include geothermal and fully developing the CoEat analysis to analyze bio-gas energy co-production. The reality is that the analysis had to draw the line somewhere while also satisfactorily employing the concept framework and as a result a set of factors with internal explanatory power was defined. Further analysis or component additions can be added on to the CD and defined as a component or process of the DEU to further refine the analysis and determine if that makes a difference in the CatPCA dimension interpretation.

The plotting of NDI values on a vertical waveform and extracting a polynomial trend line abstracts a large quantity of analysis into simple terms which are visible to laymen. In this sense, the vertical waveform diagram is the vehicle which might help transfer the complex ideas of environmental balance to the voting public and to elected officials in a simple way. This approach is well suited for regional planning where complex data and results must be simplified for decision making. The viability of the method in practice is supported by a professional practice application of the food, ecosystem, carbon and electricity categories for the 8-County Omaha, Nebraska Region in 2014 (Vireo Planning and Design 2014), where county-wide differences and region-wide summaries combined with land use planning scenarios helped to ensure land-use scenarios which maximized ecosystem services for environmental quality and critical landscape functions for humans and human settlements.

Given the few samples, unfortunately statistical robustness of County Diagnostic cannot be evaluated in this study. Past Footprint studies discussed in section 3.1.2 have indicated that Factor Analysis or Sensitivity Analysis should be applied to test new methodologies that will have to be part of another study with a larger sample size.

7.1.1.2 Can the development of a sub-national component expanded unit specific framework (ie, the DEU based County Diagnostic) help quantify the gap between linear and circular metabolism on a county basis?

I believe that the DEU applied at the county level has shown that a regional analysis composed of counties using the County Diagnostic would give insight into the social, economic and political costs of balancing a region and would improve the resolution of sub-regional internal material flows. This improved resolution picture can help restructure part of America's county-wide metabolism and would represent an increased attention to the efficiency of 'internal footprints' (Hoekstra, Chapagain 2011, p. 56) of counties where county-level system-wide efficiency and supply of basic life goods is optimized as part of a follow-up study. Indeed the existing condition, as presented by the County Diagnostic, could act as the counterpoint to the potential for an increase in efficiency of the 'internal footprint.' In this sense, the potential natural vegetation (PNV) concept as developed by Tüxen (1956) and embedded in the concepts of climate regions and ecoregions as discussed in section 3.7 and 3.8 could be a framework for further analysis, where the potential to satisfy demands is measured in social, economic and political costs as the basis for optimization. As can be seen in the results by case here, the costs to bring up recycling or water quality probably represents high economic costs of network and infrastructure and political costs of increased regulations and oversight, thus the potential system balance (as opposed to potential natural vegetation) would be limited by these costs and could be categorized much like the ecoregion categorizes potential natural vegetation.

Indeed the interpretation of the third dimension points to the influence of human decision making and application of technology as one of the primary principal components of managing food, water, ecosystems, carbon, solid and organic materials and energy (discussed separately in section 7.3). In this way, using the DEU as a concept framework led to conclusions which lie beyond the framework and could be applicable to footprint and metabolism studies outside the framework of environmental footprinting. If the internal DEU approach had not been used as a concept and method framework here, and something more akin to the EF framework with internal and external footprint related as much to availability of goods from the global market, purchasing power per capita, personal ecological responsibility and decision making then the CatPCA results would have less explanation of variance because the dimensions would have more potential confounding external influences.

Which factors are the most salient factors to (the County Diagnostic) and which factors can be grouped together?

Provided the reader agrees with my interpretation of the CatPCA in section 6.3.1.2.3, then the salient factors appear to not be a single factor within the DEU or CD, but rather represent something systematic within human-ecological-spatial relationships which transcend both frameworks. These salient factors can be described in a few ways; as ecological, terrestrial or population limiting factors per Odum (1971, p. 110, 163, 363) which restrict unlimited potential to achieve circular or semi-circular metabolism; as advantages in land or resources endowments inherent in different areas (expressed here as ecoregion level II units) which could be connected to the concept of absolute (Smith 1904) or comparative advantage (Ricardo, 1821) in further studies, where 'internal absolute or comparative advantage' is developed from the idea of international trade advantages.

7.1.1.3 What is the appropriate level of data acquisition or aggregation to answer the question accurately?

The County Diagnostic gave an answer to the environmental footprint between counties which was perceptible with inferential statistics. This means that county-level units or aggregated county units can definitely give an answer to the balance between a host of different environmental and human systems factors. The entire water category could have been collected via watershed boundaries but the county level data still reflected the expected relationships in the water cycle where runoff peaks result in streamflow increases and atmospheric moisture is less than total runoff. County-wide data actually aided in EPA data collection, NASS agricultural census and economic census data, US EIA carbon emissions by buildings and sector and for Vulcan 2.0 carbon emissions summaries. Municipal solid waste at the county level was somewhat hard to gather information for, as some counties belonged to regional MSW management groups where data was aggregated regionally (discussed in the materials section for every case in section 6). Zone of Conservation and PAD-US data was at the national level and thus could have been calculated with county or watershed boundaries.

7.1.1.4 How do variations in input data affect model outputs?

This question is somewhat addressed in each of the county summaries where there is a discussion of results in light of the calculation methodologies. The conclusion to this question is that factor calculations with more variables appear to be more sensitive to differences in data input. The PV production capacity (5.5.1.1) is a good example, where the number of structures and area of solar panel array per building is a severe limiting factor, even though the inclusion of such an envelope can be defended methodologically. However, factors such as the NASS agricultural survey (5.1.1) or

NPP sequestration in tons (5.4.1) which are directly observed values have very few if any variables in the factor equation and thus factor products represent real observed differences as opposed to a sensitivity effect of a factor equation variable. The scientific way to really answer this question would be to perform more case analysis and ultimately a sensitivity analysis for each factor equation, which will have to be addressed in another study with a larger n value.

7.1.2 Research Question 2

7.1.2.1 How might material and energy balance potential differ by region in the USA?

Based on the VWD, descriptive and inferential statistical results, it appears that two typologies of county signatures can be discerned. The two groups are 1) diversity of production and availability which include Garrett and Schoharie Counties in the Appalachian Forests and Mixed Wood Plains respectively, and 2) high productivity export-oriented counties with most NDI values located on each end of the distribution including Logan, Leflore, Carroll and Decatur Counties in the Central USA Plains, Mississippi Alluvial Plains, Ozark Forests and Southeast USA Plains respectively.

Group 1 appears to have enough sun and rainfall to have a diversified food production, have a reasonable renewable energy potential which could be increased if visibility radii in the wind turbine locator GIS model was relaxed (5.5.1.2), have plenty of ecosystem conservation area to provide the backbone for a healthy environment and have made responsible civic choices in regards to recycling. Group 2 counties in contrast have reasonably wide differences in the seasonal distribution in one or more of the water resource factors which cause abstraction, blue, or green water to exceed the EWR corrected monthly water availability. This may be a limiting factor and fundamental difference between the Northeast, Midwest and Southeast USA that points to a more balanced distribution of a primary factor (water), as is in the Northeast, as favorable. Group 2 counties also appear to have a lower material recovery potential, however this is more of a social, political or economic choice related to culture than ecoregions.

As discussed above in research question 1, the CatPCA dimensions indicate that it is not only variations inherent to ecoregions (dimensions 2 and 4) but also the total density of human population allowed and that population's reaction to human-environmental relationships with technological, economic or political intervention (dimensions 1 and 3) which influence material and energy balance potential. The extent to which these dimensions influence the potential balance cannot be addressed in this study, but point the way for future studies.

7.1.2.2 Do certain ecoregions help make balance possible whereas other ecoregions make balance unattainable?

Balance could be attainable in all regions if the materials were managed properly via increases in some factors made possible by decreases in others; or by application of technologies to increase production or material recycling. Therefore this question can only be partially answered by stating that regions with water and not overbearing ecosystem or topographic restrictions may have an easier time of achieving county-wide or regional balance at lower costs. Diversity of ecological productivity, extent of material recycling and application of renewable or energy efficiency is more due to cultural or social choices which appear to be independent of ecoregions. With more cases, these relationships can be more deeply evaluated.

7.1.2.3 How comparable are different regions in the United States regarding the supply and demand of salient factors for minimum carrying capacity?

This study was only able to evaluate six cases and therefore a meaningful answer to this question can yet be provided; it is a question which will require many more case study comparisons across different ecoregion levels which are also evaluated in terms of the economic or political costs for a population to apply technology in order to influence an as yet unknown 'absolute internal advantage.' Using the limited results of this study one could conclude that since the Friedman's ANOVA indicated a statistical difference between NDI values across counties (6.3.1.2.2) and the K-S test indicated that Garrett and Schoharie were normally distributed compared to other counties that some sort of difference was identified (sensed). However this difference cannot be meaningfully explained in the parameters of this study but offers a direction for future studies.

7.1.2.4 Which regions are well suited to satisfy population demands or absorb emissions, and in which categories?

This question is already addressed above in section 7.1.2.3 and cannot be more fully addressed without a larger sample size in a future study.

7.1.2.5 Which regions are not well suited to satisfy population demands, and why?

None of the regions studies in the ETF were poorly suited to satisfy the population demand, but a wider case study of counties would be needed to statistically clarify a range of suitability.

7.1.2.6 What role do small cities or counties play in counterbalancing the consumption of urban centers, if any?

Given the fluctuating nature of the vertical waveform and detrended P-P plots it might be logical to conclude that low population counties, such as the ones studied here, play the role of producer for a larger market where the first dimension of population and livestock demand preclude the production necessary to support food demands. This could mean that rural areas are required to offset demands in larger population counties, but without a larger regional case study consisting of many counties of varying population within an ecoregion level II unit it is not possible to quantify this potential. In addition, potential to satisfy demands is only part of the analysis because studying the actual supply chain of produced goods would be needed to determine if, once optimized for population and land, a region would actually distribute its goods internally and not ship them abroad for a higher profit based on a certain set of economic or political actors or agents. This consideration is getting beyond this study but could be an interesting direction for future studies.

What can be said within the parameters of this study is that every county analyzed here had either one centralized urban settlement or several small connected settlements. One could logically conclude then that counties must at minimum organize their material and energy flows and the spatial means of doing this is with urban settlements. The urban settlements become the synthesis nodes between human and ecosystems, where human-based technological systems are optimized between urban nodes and efficiency of production and pollution control are optimized between a node and its immediate county-wide or sub-county surrounding. If the inter-node and interecosystem relationships are optimized, then urban nodes represent the points at which the ability for rural counties to export to larger populated urban counties is quantified.

7.1.3 Research Question 3

7.1.3.1 Can Material Flow Balances be Explained by the Concept Framework of Equilibrium and Non-Equilibrium Thermodynamic Theories?

As has been touched on many times above in research questions 1 and 2, the potential for a material and energy flow balance or semi-circular metabolism at the county or region scale is likely dependent on human decisions and population size as much as it is dependent on factors inherent to ecoregions. In no cases did a county have a VWD which was flat at zero (0.00) for all counties. I think that given the results of this study it is more likely to accept the position of non-equilibrium thermodynamics as a potential model for regional planning, where each county acts as a cellular unit with demands and excess that is part of a whole living ecoregion exchanging water, food products, organic and inorganic materials, energy and gases. This type of organizational target would result in a living and dynamic bioregion with humans IN the ecological calculation. Closed system equilibrium thermodynamic systems, such as a light switch current, are probably not very good models for county-wide or regional development and material or energy management. The DEU must receive inputs from the sun and when spatially bound must include water outflows that include materials as the product of erosion. Therefore, the DEU should not be interpreted as a 'closed system metabolism' but rather as a unit of efficiency within a larger organism to which total efficiency is probably related to total variation in the unit, much like Cronbach's Alpha measured the variance of one set of variables amongst the total variance of all variables and where reduced variance would mean a more restricted non-equilibrium rather than a closed loop.

An interesting interpretation of the detrended P-Plots is that they represent 'the wave' or 'heartbeat' or 'pulse' of regional metabolism which is not dissimilar to the vertical waveform diagram if the dots in detrended P-P plots are connected. The movement up and down of the P-P wave represents alternating demand and capacity as the amplitude of non-equilibrium which also could be interpreted as the material flux in and out of the county needed for the regional human metabolism; like a breath in and out. If this 'breath' is considered in light of the DEU and thermodynamics it might indicate a dependence on a non-equilibrium thermodynamic in regional planning to sustain the life of the regional organism, where the goal is regional balance at the cost of sub-regional closed loops as opposed to individual closed loops at the cost of regional balance. If the vertical waveform or detrended P-P plots had no undulation it might represent homeostasis or death as it does in the human heartbeat. Although these ideas are tantalizing, any real concrete contribution to the concept frameworks of thermodynamics or the DEU in regional planning are limited.

7.1.3.2 What other concept frameworks might be useful to explain the findings?

The mature ecosystem concept might be another framework useful for explaining the County Diagnostic results, where mature ecosystems have a high throughput potential but also a high potential for the breakdown of entropy into basic elements for re-uptake (Odum 1969). The counties of Garrett and Schoharie which had the smallest amplitude of NDI values amongst the six counties indicate that increased MSW recovery potential, wider distribution of food production and greater area of ecosystem conservation to regulate flows of nature exhibit the properties of a mature ecosystem which has stable material and energy fluxes and a low entropy. In support of this conclusion, the NDI value distributions were normal according to the K-S test, a result which implies mathematical harmony as compared to non-normally distributed variables. All other counties have some form of an export intensive monocrop system with high production in the short term and cannot breakdown MSW or organic materials as efficiently, exhibiting the properties of the immature ecosystem with high productivity and material flow through but with low efficiency or diversity. Again, a wider number of cases in future studies might help illuminate this question.

7.2 Interpretation of the Results in Light of the EF Concept Framework

The results of the six county case study can be reflected back to the original concept frameworks of the Ecological Footprint and Footprint Family in section 3.1, the DEU and Dissipative Structures in section 4.2.1, Mature Ecosystems in Section 4.2.1.7 and Semi-Closed and Non-Equilibrium Systems in Section 3.2.2 at a conceptual level where the discussion is about principal components and not individual factors or categories.

The CatPCA first dimension interpretation, human and livestock population, supports the EF and footprint family framework because the EF also uses a footprint per capita approach to consumption as one of the central tenants of the concept framework. Since this component is sensitive in the CD model it may also be sensitive in per capita footprints, supporting the conclusion that biocapacity, per capita demand, internal or external consumption and livestock systems evaluations should trend toward higher resolution to increase understanding within the sensitive categories.

The interpretation of dimension two, areas of high precipitation and presence of surface water, supports the integration of the Water Footprint into the EF which was also a central tenant of the CD framework. The primary element of water from the DEU, which connects to every process in the production, consumption, detritus and decomposition chain in Figure 4-1 and most of the CD system diagrams (Figures 4-6 to 4-10), is reaffirmed through the dimension two interpretation. It would seem that water really is the bloodstream of the biosphere and it both enables and limits opportunities.

Dimension three touches on every concept. The internal and external footprints of consumption can affect the size of the Footprint and therefore addressing affluence and technology can affect model outcomes. In the DEU and Dissipative Structures concepts dimension three indicates that it may be up to humans to decide how much economic, social or political investment to put into a human-ecological system, thus humans are in charge of the system and measures of affluence and applications of technology are important. In the Mature Ecosystems concept a mature thinking human-environmental system will decide to invest in the technology necessary to reduce entropy in exchange for reduced short term gain, as it is linked to long-term profitability and social well-being via environmental health, as opposed to an immature system with fast growth and high production but inefficiency and high turnover. It touches on semi-closed systems because humans can decide how closed a system is if there is the expression of human will and therefore understanding how to harness and direct the human will could be one of the underling preconditions to achieving a semi-closed system. In light of dimension one and two and the VWD summary it also seems unlikely that any county would not have some gain or loss from their sovereign area in materials, water or energy supporting the conclusion that closed systems at the county or regional may not occur and may not beneficial. Given the fact that semi-closed systems are probably not possible without strict human influence on the system it would be conceivable to support the non-equilibrium thermodynamics theory for regional planning, where managing the non-equilibrium via entropy reduction of the total human-environmental system and trending towards efficiency in all individuals within the system achieves the greatest care for dimensions one and two.

The interpretation of dimension four actually sets the CD apart from all the other frameworks and champions the conclusion that the integration of a spatially explicit measure of 'ecosystem footprint' is important as a driving factor. This is certainly true in a spatially restricted footprint, as allotting more land that does not directly supply the human system will increase the footprint, in the water footprint provided that the environmental water requirement (EWR) included and possibly in the Mature Ecosystems concept because inherently a county with more natural area will have less human influence and thereby the ecosystem will trend toward its potential natural vegetation or climax equilibrium whereby the system will become mature. The findings support the inclusion of spatially explicit ecosystem conservation area in DEU and Dissipative Structure frameworks, possibly interpreted as urban metabolism studies when taken down to the application level, because the inclusion or disclusion of this factor can influence the overall system. The effect of the dimension four interpretation can only be loosely placed in semi-closed systems and non-equilibrium thermodynamics because these theories and laws are inherently to abstract to talk about in terms of physical land uses. However it could hint at an overall need for connectivity, preservation, and quality of networks within human and eco-systems which must be maintained for a system to function efficiently.

7.3 The Potential of Technology to Influence Results

As was mentioned many times above in section 7.1.1 and illuminated in the CatPCA analysis interpretation that dimension 3 is explained by affluence and the willingness of a population to apply technology, technological interventions can influence the potential for a county or region to achieve a semi-closed or semi-circular metabolism. Indeed, to a very real degree humans MUST apply technology to balance human and ecological systems, as is evidenced by the urban settlements, roads, treatment plants, buildings and factories we have built. However, the CatPCA results alone only address the abstract idea that technology application influences human-ecosystem balance and I felt it necessary to bring this abstracted idea back down to components in the County Diagnostic, and thereby back to material, water and energy flows linked to the DEU via the CD, by detailing what types of interventions and in which systems they intervene.

7.3.1 Food

Increases in agricultural production from technology applications could definitely affect all formulas F1c to F7c. Some examples of the effects of technology on food production would be the application of multi-color LED green-houses fed with 100% renewable energy or hoop houses to lengthen the growing season and enable an increased production of fruits and vegetables while not increasing the C1d measurement – this might also reduce vehicle emissions across the USA due to transport (food miles) of fruits and vegetables; the application of genetically modified or specifically bred plant or animal species could increase yields per acre or lbs. per head; the overall application of renewable electricity in the agricultural sector could reduce the C1d measurement; the application of vertical urban farming systems would increase the ecosystem conservation potential (EC1c); the improvement of processing and collection of organic wastes and the application of organic compost systems would reduce the need for chemical fertilizers which would lead to reduced non-point N and P loads and reduce the measurements W4d and W5d.

7.3.2 Water

Technology effects on W1d could come from efficiency in water uses in urban or agricultural regions and how well runoff capture and drinking water system recycling is applied. Increases in public water supply system efficiency and runoff recapture systems in urban regions should result in decreases in reported USGS 5-year demand. Technology effects on W1 could come from large scale water engineering projects, such as a dam, which regulates the flow of water and thereby could confound the measurement of streamflow (NDI-W1). Technology definitely affects formulas W4d and W5d, as the application of water purification systems and specific N and P removal systems from all point source outflows could make the point sources essentially non-existent.

7.3.3 Ecosystem Conservation

The application of dense vertical farming systems and organic / wastewater / food recycling systems could increase the overall area available for ecosystems conservation (EC2c ie. the ZOC) and decrease the number of streams on the EPA 303d list. Although not directly technology related, the application of habitat quality observation technologies could help improve target ecosystem areas for conservation which might lead to an increase in PAD-US areas (EC1c).

7.3.4 Carbon Dioxide (CO_2)

The application of renewable electricity for municipal power generation could significantly change reported carbon emissions which would change the outcome of the C1d calculation. Improvements in electric-based transport would reduce reported transport emissions. Improvements in building efficiency would reduce individual energy demand and thereby reduce overall consumption if renewable municipal power facilities are not practical or the resource does not exist. Building-based improvements alone constitute a sub-category of C1d which have a huge range from totally automated living buildings to the application of carbon neutral interior furniture, furnishings and equipment (FF&E).

7.3.5 Electricity

Within the category of renewable electricity, the improvement of PV or wind turbine MWH generation efficiency would change the E1c calculation result and not only make existing productive areas more productive but by lowering the initial viable m/s from 6 to 3 would have in the case of this study generated a result for Decatur and Leflore Counties. Improvements in electricity storage technology would increase the viability of renewable energy, which is characterized by seasonal and daily inconsistencies in production, as is visible in the annual wind production chart from Garrett County (App. I: Figure 3-15).

7.3.6 Materials

The application of technology could greatly affect calculations in the materials category. The recovery of food waste and sludge, gasification, compost of application of finished organic material would require multivariate technological applications at places along the entire process chain, not least of all being the change in perception of ‘waste’ to ‘material’ which is to be moved around in an economic cycle via the application of technology. The application of increased food and wastewater recapture and recycling would change the calculation of M1c and the improvement in collection and recycling technologies would change the calculation in M2d.

7.4 Recommendations for Planning Regulations in the USA

FEMA should include conservation of all floodplains and manage the regrowth of native riparian vegetation within floodplain areas. This would satisfy the 12-17% of land area for many counties if the expanded geomorphic description of soils is included. The program could be managed by state conservation agencies and employ professional planners who would be needed to rectify the goal of large area conservation or restoration for long-term ecosystem health and the challenges of land ownership rights in the USA and the fact that there are many existing cities or incorporated places just within the six cases studied here which are located in a FEMA designated floodplain (Decatur is a good example). This means that in places with extensive floodplain settlement this recommendation could be difficult to achieve and might need to be coupled with land conservation outside of floodplain areas.

MSW and organic material recovery, with the exception of Garrett County (6.2.6), was only a small fraction of generation, creating NDI-M2 values which were moderately to strongly negative. MSW recovery should be increased in the USA via federal regulation title 40 of the Code of Federal Regulations (CFR), parts 239 through 282, also known as the Resource Conservation and Recovery Act (RCRA), with accompanying EPA guidance documents and policy directives to clarify issues related to the implementation of the regulations. The RCRA could be used to help implement development of regional MSW and organic facilities where the economy of scale achieved from multiple county flow would probably make the necessary technology applications more affordable. County level generation and recycling data served via the internet at the national scale would be helpful for researchers in future projects who are interested in creating material specific flow analysis of MSW in a county.

Based on the six county surveys, not every county had a total maximum daily load (TMDL) calculated for N and P for every basin. The clean water act allows states to set water quality goals and TMDLs and this project should be supported and further funded to help more fully develop the US EPA 303d impaired water list.

7.5 The Global Environmental Perspective and Future Urbanization

The dissertation defense discussion covered many facets of the work and ultimately culminated in two main points of discussion regarding the CD in context of the global environmental perspective and climate change and the applicability or adaptation of the method for analysis of megacities. Since these two topics will undoubtedly be part of future planning and decisions making it is worthwhile to address these in the text.

In terms of the global perspective, the purpose of the CD method is to help the 2^{nd} largest global carbon dioxide emitter and arguably the world's largest consumption and import economy, the USA, reduce its environmental footprint and increase efficiency of regions within the USA to reduce the negative climate impact of the country. The CD is a snapshot method which can identify areas of potential improvement via planning goals, requirements and measures which can lead to resource consumption reduction and in turn reduce the global climate impacts of the USA. The CD method can also help set targets for counties or regions which are expected to experience specific climate change effects, such as decreasing or increasing annual rainfall, by calculating and comparing the CD of a county with the current condition and the expected future condition in the capacity or demand side of the NDI equations. If a region is expected to transition into a different climate classification due to climate change, such as BSa to BWa (Warm Steppe to Warm Desert), the CD can be run with all environmental parameters for the existing and expected classifications and the results can be compared to help predict what type of changes in food production, water procurement rainfall seasonality, ecosystem extent or renewable energy could be expected. Annual results of the CD can also be compared longitudinally to track or measure changes in counties or regions where climate changes are expected.

Changes in environmental parameters and ecological unit distribution are not the only future concerns where the CD can be applied, but the adaptation of regions to the growth in scale and prevalence of cities is also an important facet of the method. The demand side of the equation can be changed to account for future population growth reduction of agricultural cover due to urbanization, and in this way the CD can be used to predict how much more food, water, energy will need to be supplied and how the growth of carbon, organic and municipal solid waste would affect current detritus processing infrastructure. The largest 20 cities in the USA are all spread across several counties and thus a CD assessment of large city in the USA would include all counties within the Council of Government (CoG) or Statistical Metropolitan Area for the city in question. In this case, the urban region or megacity is viewed as a conglomerate cellular structure with each county being one part, or cell, of the whole entity. For very highly urbanized counties with none to minimal agricultural land, new definitions of productive land use would be needed, such as green roofs with food production, urban gardens or rainwater capture and use as irrigation. Often a large city is actually a conglomerate of many Incorporated Places with their own rich and accurate spatial data bases. When this is the case the CD could be run for sub-county tiles to help each single cellular metabolism tile within the megacity increase in efficiency individually and to develop directly comparable statistics for benchmarking and resource management between cells of a larger structure. If needed, the calculation flexibility of the method would allow for new factors or categories relevant to megacities to be added, such as the treatment volumes of living machines within specific buildings, the reduction of HVAC energy use in specific buildings via ground source heat exchange systems or the reduction of carbon dioxide via new atmospheric scrubbing technology.

7.6 Improvements to the County Diagnostic Method

An expanded case study comparison would be an excellent next step for further evaluation of this tool which could increase the number of cases across a wider variety of ecoregion level II units, or possibly to every county in the USA. An additional aim could be to analyze counties which have already been analyzed with the EF, Water Footprint, Carbon Footprint or other such carrying capacity or environmental footprint analyses in the past so the methods and results can be compared. Comparing results between the County Diagnostic and other methods would shed light on new research areas or areas for improvement of model resolution.

Additional case studies would also allow a statistical comparison between counties and could enable analysis of varying populations as mentioned in section 7.1.1.2. Since the primary dimension of human and livestock demand supports the conclusion that population quantity may be a serious limiting factor to county-wide or region-wide potential for metabolic balance. Further studies with the County Diagnostic should absolutely focus on this question to help understand the effect of increased demand on results.

County-level data regarding MSW generation, recovery and recycling is not easily available or consistent across regions and counties. Due to this reality, the County Diagnostic currently relies on a mix of data sources for the NDI-M2 factor demand and capacity calculations which could be creating inconsistencies across counties. To really understand MSW flows in a county I believe that field studies to the county and to all participating facilities would be necessary so that a MFA of all goods from all sectors can be more accurately created. If a databased is served under the RCRA umbrella then this data could be used here in the future.

With the Vulcan 2.0 database used for carbon emissions by county and a multivariable equation derived from the US Economic Census and Census of Population used to estimate energy demand, the chain of energy flow from production to user and the accompanying carbon emissions is interrupted. The Vulcan database was used because it was easily available at the county scale and is from a valid source. However, the difference between estimated Vulcan emissions and sequestration potential via NPP seems to be quite large. A comparison of US EIA average carbon emissions by county for Maryland indicated that carbon emissions may be more in the range of 2.6 million tons per year, which would reduce the strong capacity to a more realistic number. However, without adjusting a raw average by county to the actual population, transport, industrial and energy sector demands by type of fuel sources in a county, an adjusted carbon emission cannot be calculated. Future studies should seek to rectify this issue and create a transparent carbon calculation method using a bottom-up disaggregated building and facility-based approach.

While food data was delivered conveniently and in what appears to be a rich database, the narrow focus on food products, amongst all agricultural products which are reported in the NASS agricultural census, might be understating human demands on ecosystems. Two good examples of further categories to include are wood or timber production and textile or fiber production. These two categories come into importance in warm humid counties where cotton can be produced and in mountainous, wet or temperate northern climates where evergreen logging and boutique tree horticulture is practiced. These sources might change NDI-W2 and NDI-W3 calculations by appropriating more green and blue water into the human systems. The production of paper was one of the factors in the original EF which was not carried over into the County Diagnostic method. In hind sight, I believe that paper and paper products generation from M2d calculation could be used as a target for annual forestry and thus could be integrated into future iterations of the method.

The streamwater availability calculation (W1c) could be calculated using a number of other methods, which should be considered in future uses of the County Diagnostic. An example is that that the W1c calculation used the P25 value of long-term streamflow by county because it was automatically calculated from the US EPA at sampling stations in lieu of using a corresponding Q-value such the Q1.5 (bankflow) or the Q10 (flow after small rainfalls). A different flow availability could affect the NDI-W1 calculation.

The runoff factor W3c uses a dataset provided by the Oakridge National Laboratory (ORNL) with the MODIS NPP data in the formula to adjust for runoff which is intercepted via vegetated land cover and canopy, effectively reducing the volume of runoff within the algorithm. The EWR adjustment of runoff allocates an additional monthly volume of water to ecosystems and reduces availability. Future applications of the County Diagnostic should determine if EWR is already accounted for in the ORNL dataset or if the additional EWR allocation from the ORNL runoff dataset is actually necessary.

The estimate of stream pollution for N and P factors (W4d and W5d) is based on the compliance and reporting of point sources for one year and national level estimates of fertilizer loads by country. In addition, the mg/l or kg/month N and P limits were averaged by county based on TMDLs for all basins in a county because it was common that a county might have two adjacent basins with different load limits which could not be accommodated by the county framework. Not surprisingly, the results from the N and P loads versus the load limits were not always consistent with the US EPA 303d impaired streams list. Future studies should seek to improve the non-point fertilization rates and actual response of N and P leaching based on rainfall or specific soil properties, consider splitting all grey water evaluations out by basin, which does increase the work needed to run the method but might be more accurate, and use long term reporting trends to estimate N and P loads by regulated point sources.

7.7 Research Outlook for the County Diagnostic

The method and results in the study should be summarized and submitted to scientific journals that have published similar topics. Attempts to apply the method in the USA in professional practice should be pursued so that a larger database of counties with variant area, ecoregion types and populations become represented. Large scale ecological or urban systems research projects interested in uncovering material flows and ecosystem capacity and limits might be able to use the method as a useful regional comparative framework. The work can also be adapted to other developed countries, such as Germany, to evaluate the effectiveness of the CD approach as compared to other approaches which evaluate sustainability, footprints and human-ecosystems models; this might help the CD method improve or could help other models integrate more components in a logical way. The application of this method for developing countries has great potential for two reasons, 1) that the CD approach is a data intensive approach, which would require a country to invest in data collection methods to satisfy the CD formulas, an approach would have multi-fold benefits in other scientific studies relating to food, water, populations, spatial distributions, waste management, renewable energy and greenhouse gas emissions, and 2) that the results of the CD itself when coupled with the integrated spatial planning approach would provide a framework for social-ecological systems as a basis for the development of the country.

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9 Appendix I

Appendix I: Table of Contents

Appendix I: Table of Figures

1 Carroll County, Arkansas

Carroll County, Arkansas

FOOD CAPACITY	
FDA Daily Food Groups	Total Metric Tons Production Per Year
FRUIT AND NUTS	55
VEGETABLES	137
CEREAL GRAINS	170
HAY/GRASS	47,935
FEED GRAINS	-
PROTEIN	53,288
DAIRY	3,436

FOOD DEMAND		
*2012 ACS Population:	27446	
FDA Daily Food Groups	Annual Demand in Metric Tons	Metric Tons/Capita*/Year**
FRUIT AND NUTS	5,009	0.1825
VEGETABLES	6,261	0.228125
CEREAL GRAINS	1,878	0.0684375
HAY/GRASS	354,311	*Varies Per Livestock Type, Below*
FEED GRAINS	1,285,405	*Varies Per Livestock Type, Below*
PROTEIN	1,722	0.0627343
DAIRY	7,513	0.27375

Demand of Feed/ Hay Grains		
Livestock Type	Hay in Metric Tons / Year	Corn in Metric Tons / Year
Milk Cows	4,424	47
Beef Cows	346,360	346,360
Goats	1,392	278
Hogs	-	203
Sheep	2,136	214
Poultry	-	938,304
Total Feed(tons)	354,311.49	1,285,405.01

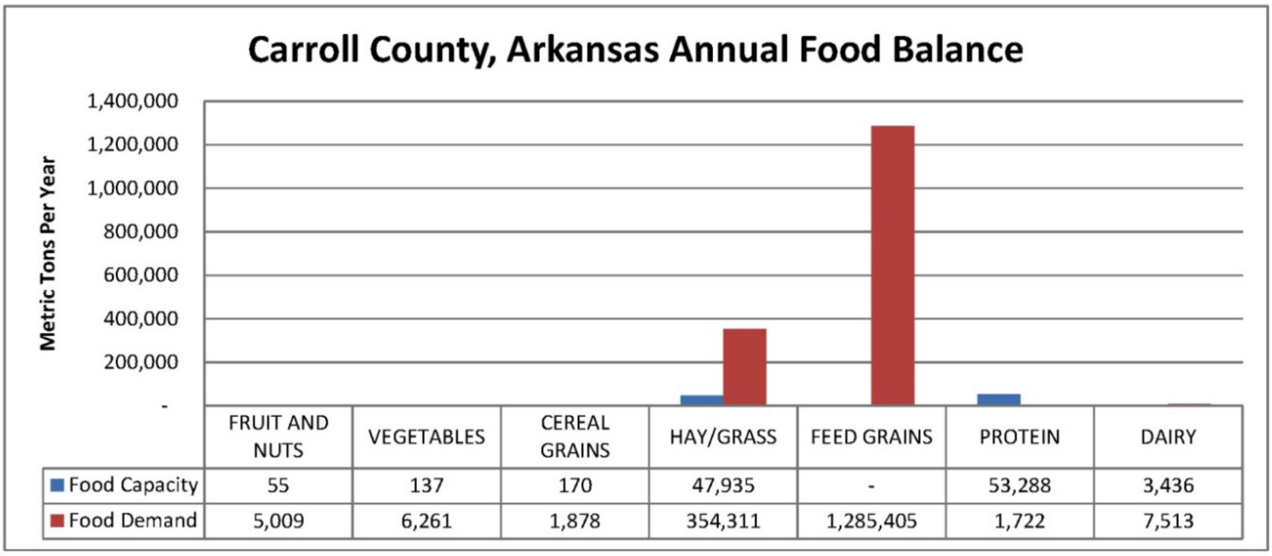


Figure 1-1: Carroll County Food Summary (F1c - F7c & F1d - F7d)

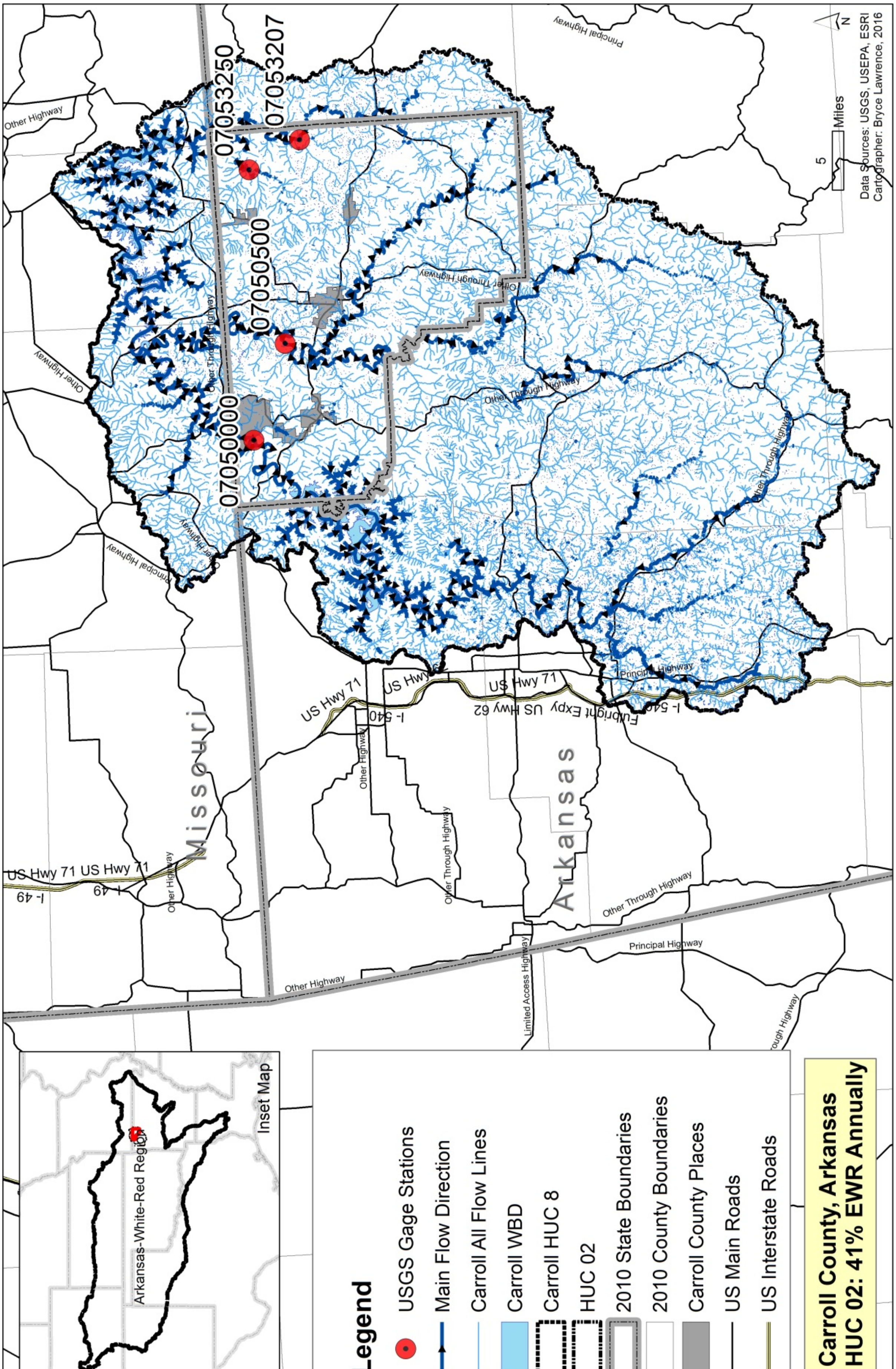


Figure 1-2: Carroll County Stream Network and Streamflow Sample Stations (W1c)

Carroll County, Arkansas

Total Available Stream Flow in Cubic Meters (W1c) with Human Abstraction (W1d)

USGS Station No. 07050000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1909-1958	296	491	687	875	688	262	117	66	51	57	124	185
EWR Requirement 41%	121	201	282	359	282	107	48	27	21	23	51	76
Available Adjusted CFS	175	290	406	516	406	154	69	39	30	33	73	109
EWR Corrected Mean Monthly Cubic Meters	13,010,270	21,553,189	30,183,089	38,421,935	30,197,252	11,485,748	5,152,554	2,904,862	2,231,876	2,487,049	5,439,924	8,106,987
EWR Requirement in Monthly Cubic Meters	9,041,035	14,977,639	20,974,689	26,699,989	20,984,531	7,981,622	3,580,588	2,018,633	1,550,965	1,728,288	3,780,286	5,633,669

USGS Station No. 07050500	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1938-2016	104	183	299	314	248	90	43	20	15	21	35	69
EWR Requirement 41%	43	77	126	132	104	38	18	8	6	9	15	29
Available Adjusted CFS	60	106	173	182	144	52	25	11	9	12	21	40
EWR Corrected Mean Monthly Cubic Meters	4,467,922	7,913,456	12,903,926	13,545,549	10,692,938	3,888,860	1,854,556	847,917	651,740	892,470	1,526,482	2,982,327
EWR Requirement in Monthly Cubic Meters	3,235,392	5,730,434	9,344,222	9,808,846	7,743,162	2,816,071	1,342,955	614,009	471,950	646,272	1,105,383	2,159,616

USGS Station No. 07053250	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1992-2016	11	20	25	23	20	13	10	9	8	8	9	11
EWR Requirement 41%	5	8	10	9	8	5	4	4	3	3	4	5
Available Adjusted CFS	7	12	15	14	12	8	6	6	5	5	5	6
EWR Corrected Mean Monthly Cubic Meters	504,775	862,673	1,093,395	1,011,296	885,197	587,020	459,877	413,564	356,222	338,783	384,029	483,388
EWR Requirement in Monthly Cubic Meters	350,776	599,484	759,817	702,765	615,137	407,929	319,576	287,392	247,544	235,425	266,868	335,914

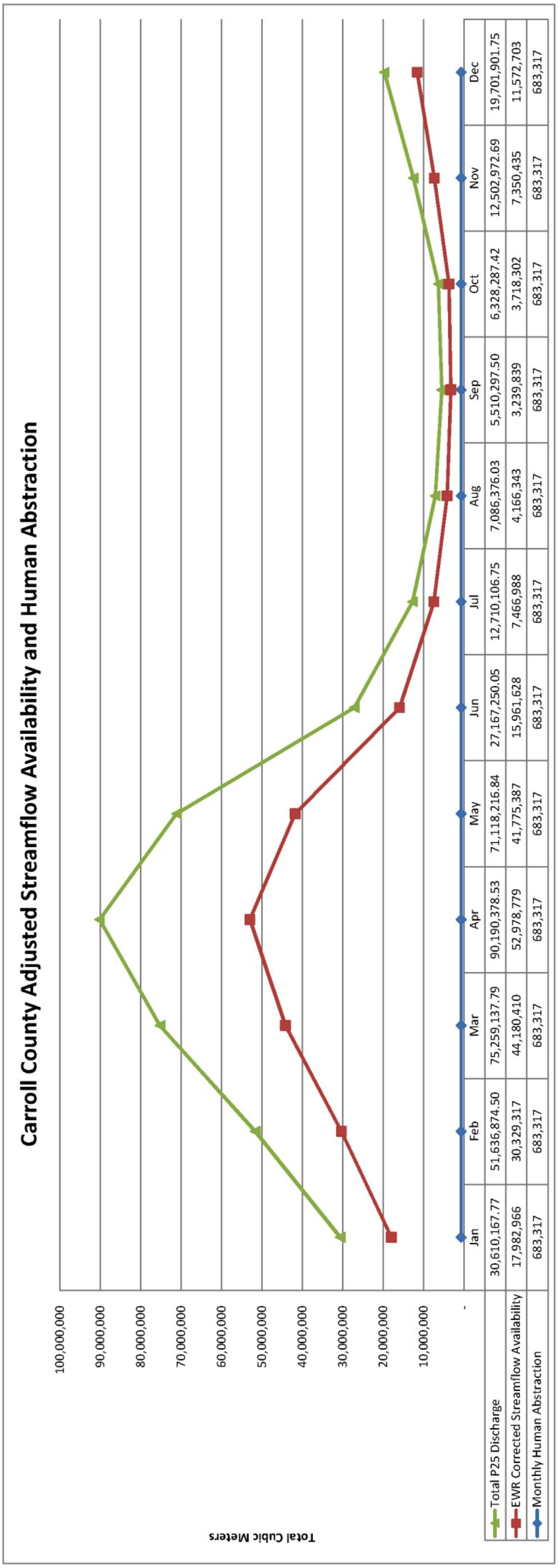
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	30,610,167.77	51,636,874.50	75,259,137.79	90,190,378.53	71,118,216.84	27,167,250.05	12,710,106.75	7,086,376.03	5,510,297.50	6,328,287.42	12,502,972.69	19,701,901.75
EWR Adjusted P25 Discharge	17,982,966	30,329,317	44,180,410	52,978,779	41,775,387	15,961,628	7,466,988	4,166,343	3,239,839	3,718,302	7,350,435	11,572,703
Human Abstraction (W1d)	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317
Human Abstraction as % EWR Adjusted	3.80%	2.25%	1.55%	1.29%	1.64%	4.28%	9.15%	16.40%	21.09%	18.38%	9.30%	5.90%

Total EWR Adjusted Annual Available Streamflow Volume in Cubic Meters	**240,723,096**

Table 1-1: Carroll County EWR Adjusted Annual P25 Streamflow Availability (W1c)

Carroll County, Arkansas 2010 Adjusted Water Abstraction		
Category	**Mgal/D Surface**	**Mgal/D Ground**
Public Supply	7.78	0.8
Mining	-	-
Livestock	1	0.67
Aquaculture	-	-
Irrigation	0.16	-
Daily Total	*8.94*	*1.47*
Annual Abstraction Projection by Source (USGS NWIS)	3,263	537
Total Annual Abstraction in Mgal	3,800	
2012 Total Annual Returns in Mgal (US EPA ECHO / NPDES)	1,633	
Total Adjusted Abstraction in Mgal/year	**2,166.16**	
Total Adjusted Abstraction in cubic meters per year / month	8,199,808	683,317

Table 1-2: Carroll County Adjusted Water Abstraction (W1d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	30,610,167.77	51,636,874.50	75,259,137.79	90,190,378.53	71,118,216.84	27,167,250.05	12,710,106.75	7,086,376.03	5,510,297.50	6,328,287.42	12,502,972.69	19,701,901.75
EWR Corrected Streamflow Availability	17,982,966	30,329,317	44,180,410	52,978,779	41,775,387	15,961,628	7,466,988	4,166,343	3,239,839	3,718,302	7,350,435	11,572,703
Monthly Human Abstraction	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317	683,317

Figure 1-3: Carroll County Adjusted Streamflow Availability and Human Abstraction (W1c & W1d)

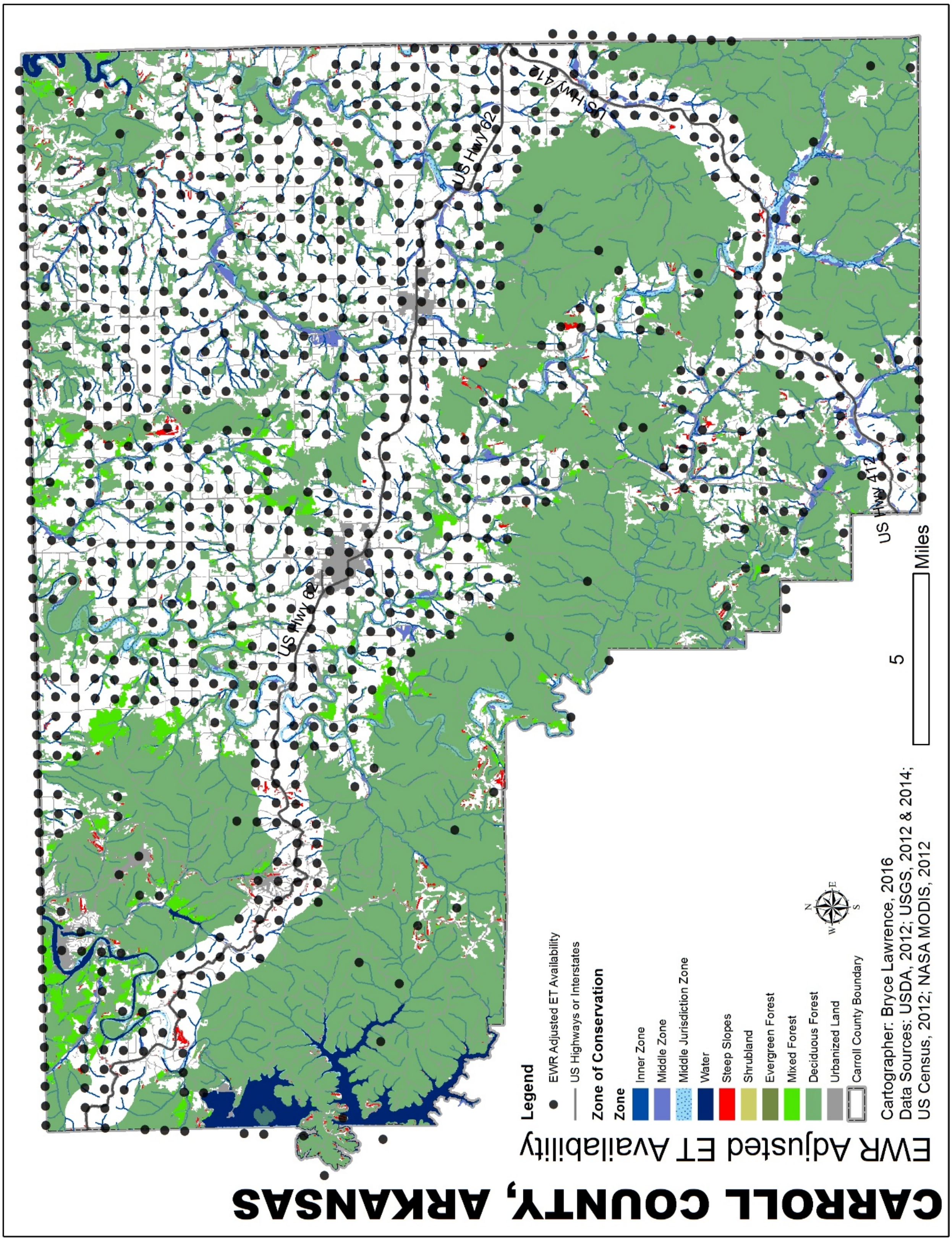
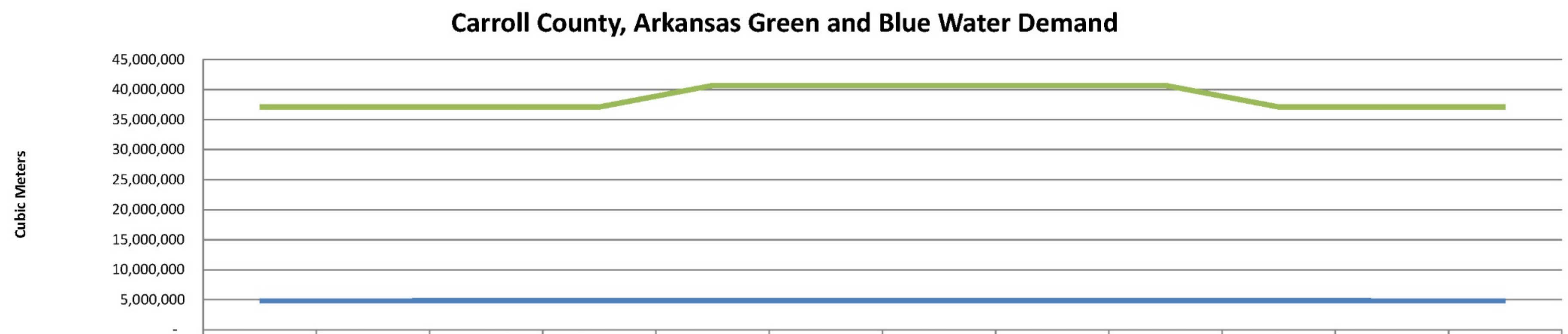


Figure 1-4: Carroll County EWR Adjusted ET Availability Sample Points (W2c)

Carroll County, Arkansas

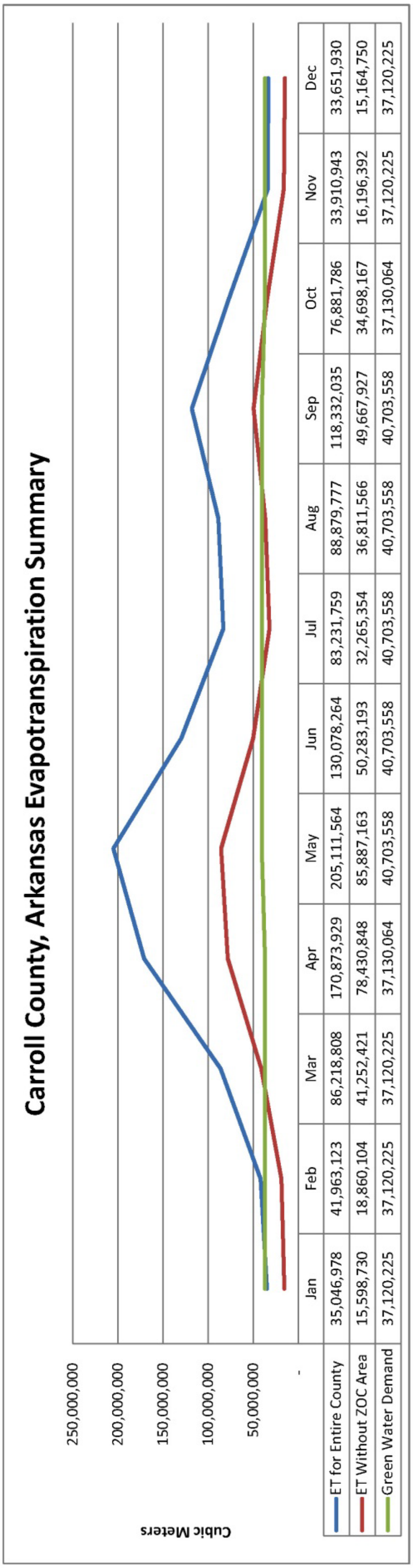
Monthly Green Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	GW Annual Total
Value in Cubic Meters	37,120,225	37,120,225	37,120,225	37,130,064	40,703,558	40,703,558	40,703,558	40,703,558	40,703,558	37,130,064	37,120,225	37,120,225	463,379,044

Monthly Blue Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	BW Annual Total
Value in Cubic Meters	4,839,553	4,827,321	4,839,553	4,840,589	4,850,519	4,846,442	4,850,519	4,850,519	4,846,442	4,844,667	4,839,553	4,839,553	58,115,230



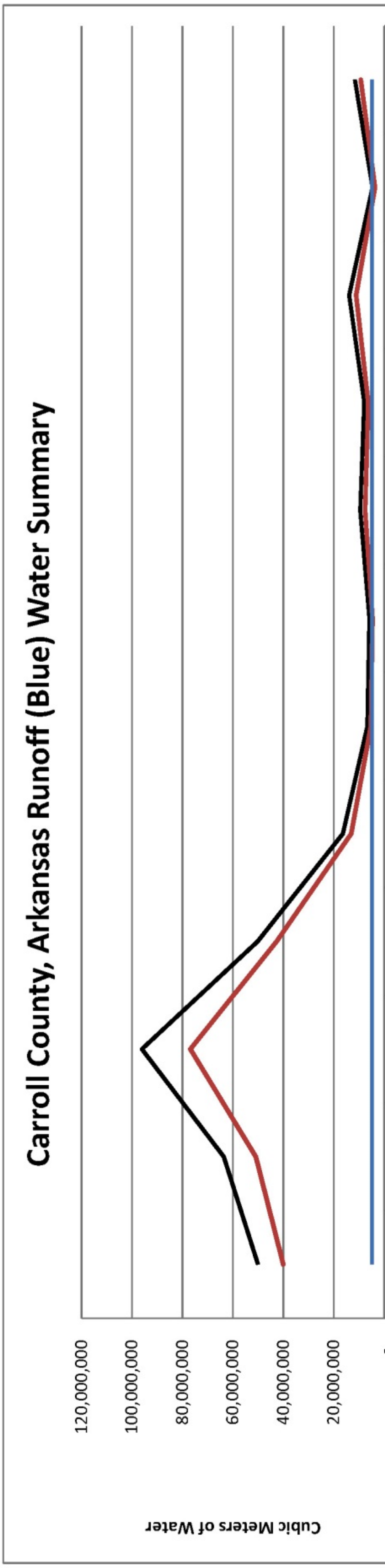
	January	February	March	April	May	June	July	August	September	October	November	December
Green Water Demand	37,120,225	37,120,225	37,120,225	37,130,064	40,703,558	40,703,558	40,703,558	40,703,558	40,703,558	37,130,064	37,120,225	37,120,225
Blue Water Demand	4,839,553	4,827,321	4,839,553	4,840,589	4,850,519	4,846,442	4,850,519	4,850,519	4,846,442	4,844,667	4,839,553	4,839,553

Figure 1-5: Carroll County ET (Green Water) and Surface (Blue Water) Demand (W2d & W3d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET for Entire County	35,046,978	41,963,123	86,218,808	170,873,929	205,111,564	130,078,264	83,231,759	88,879,777	118,332,035	76,881,786	33,910,943	33,651,930
ET Without ZOC Area	15,598,730	18,860,104	41,252,421	78,430,848	85,887,163	50,283,193	32,265,354	36,811,566	49,667,927	34,698,167	16,196,392	15,164,750
Green Water Demand	37,120,225	37,120,225	37,120,225	37,130,064	40,703,558	40,703,558	40,703,558	40,703,558	40,703,558	37,130,064	37,120,225	37,120,225

Figure 1-6: Carroll County ET (Green Water) Summary (W2c & W2d)



	January	February	March	April	May	June	July	August	September	October	November	December
Total Runoff	50,075,466	63,654,395	96,084,584	50,159,762	16,426,913	6,697,659	5,866,839	9,540,649	7,948,157	13,956,787	4,675,679	11,673,341
EWR Adjusted Runoff	40,060,373	50,923,516	76,867,667	42,635,798	13,141,530	5,358,127	4,693,472	7,632,520	6,358,526	11,165,430	3,740,543	9,338,673
Blue Water Demand	4,839,553	4,827,321	4,839,553	4,840,589	4,850,519	4,846,442	4,850,519	4,850,519	4,846,442	4,844,667	4,839,553	4,839,553

Figure 1-7: Carroll County Surface (Blue) Water Availability and Demand (W3c & W3d)

N	Carroll County, Arkansas	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month	40,060,373	50,923,516	76,867,667	42,635,798	13,141,530	5,358,127	4,693,472	7,632,520	6,358,526	11,165,430	3,740,543	9,338,673
	Liters / month	40,060,372,800	50,923,516,000	76,867,667,200	42,635,797,700	13,141,530,240	5,358,127,120	4,693,471,520	7,632,519,520	6,358,525,840	11,165,429,600	3,740,542,960	9,338,672,880
3.70	Total Allowed Mg	148,303,500,106	188,518,856,232	284,564,103,974	157,837,723,085	48,649,944,948	19,835,786,598	17,375,231,567	28,255,587,263	23,539,262,660	41,334,420,379	13,847,490,038	34,571,767,002
	Total Allowed Tons (N)	148.30	188.52	284.56	157.84	48.65	19.84	17.38	28.26	23.54	41.33	13.85	34.57
0.29	Nnat in mg/l	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	Total mg Nnat	11,617,508,112	14,767,819,640	22,291,623,488	12,364,381,333	3,811,043,770	1,553,856,865	1,361,106,741	2,213,430,661	1,843,972,494	3,237,974,584	1,084,757,458	2,708,215,135
	Tons Nnat	11.62	14.77	22.29	12.36	3.81	1.55	1.36	2.21	1.84	3.24	1.08	2.71
	Corrected Limit	136.69	173.75	262.27	145.47	44.84	18.28	16.01	26.04	21.70	38.10	12.76	31.86
	Total Annual N Load (t)	**928**											

P	Carroll County, Arkansas	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / Month	40,060,373	50,923,516	76,867,667	42,635,798	13,141,530	5,358,127	4,693,472	7,632,520	6,358,526	11,165,430	3,740,543	9,338,673
	Liters / month												
0.1	Total Allowed Mg	4,006,037,280	5,092,351,600	7,686,766,720	4,263,579,770	1,314,153,024	535,812,712	469,347,152	763,251,952	635,852,584	1,116,542,960	374,054,296	933,867,288
	Total Allowed Tons (P)	4	5	8	4	1	1	0	1	1	1	0	1
0.02	Pnat in mg/l	801,207,456	1,018,470,320	1,537,353,344	852,715,954	262,830,605	107,162,542	93,869,430	152,650,390	127,170,517	223,308,592	74,810,859	186,773,458
	Total tons bkgnd Pnat	0.80	1.02	1.54	0.85	0.26	0.11	0.09	0.15	0.13	0.22	0.07	0.19
	Corrected Limit	3.20	4.07	6.15	3.41	1.05	0.43	0.38	0.61	0.51	0.89	0.30	0.75
	Total Annual P Load (t)	**21.75**											

Table 1-3: Carroll County Critical Nitrogen and Phosphorus Load Limits (W4c & W5c)

Carroll County	Tons / Year	Tons / Year	
CROPGROUP	N Load	P Load	Hectares
Oilseed	0.00	0.00	0.09
Cereal	0.39	0.16	60.75
N and P Point Loads	2.38	2.51	
Total Annual N and P Loads	**2.77**	**2.68**	

(N)n=5, (P)n=6

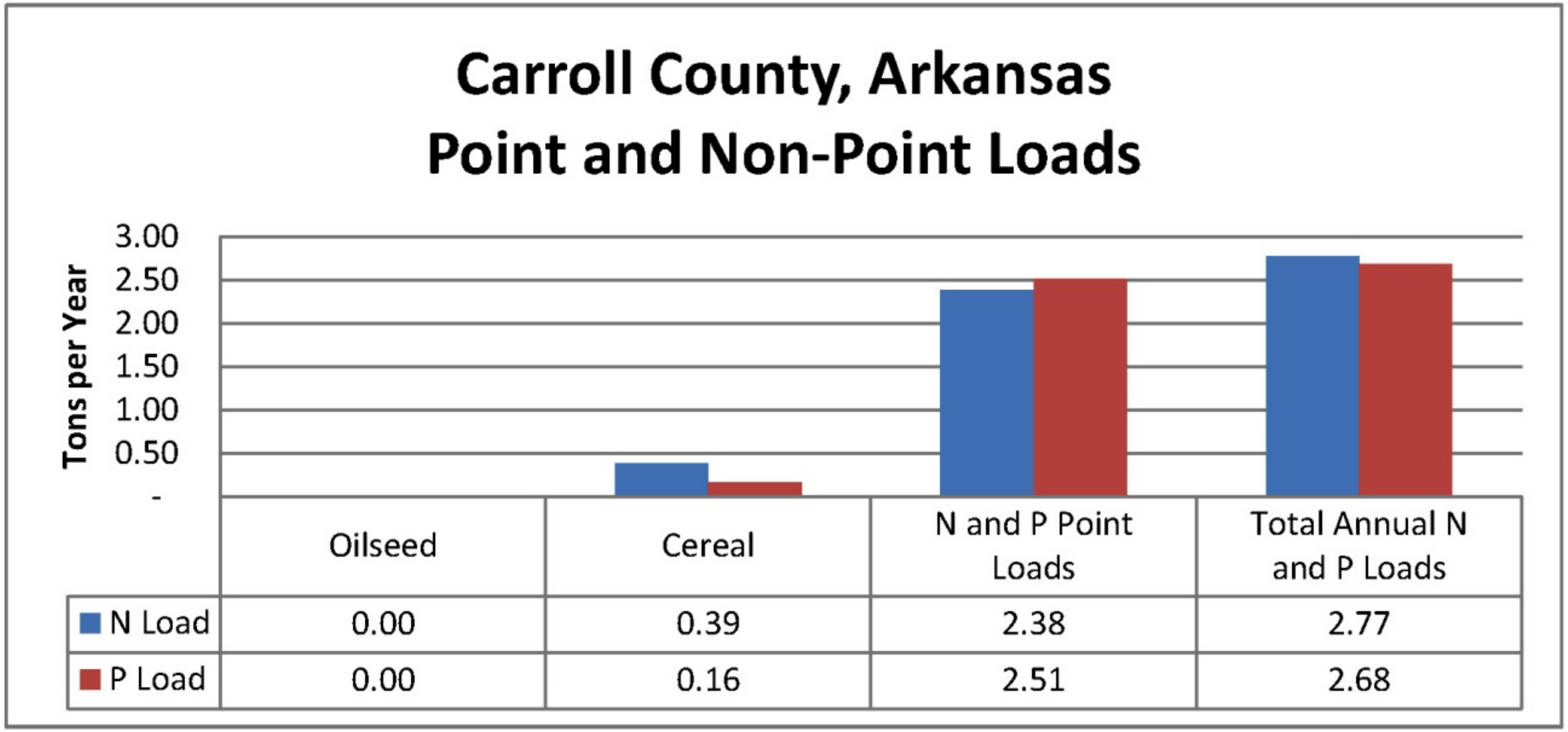


Figure 1-8: Carroll County Nitrogen and Phosphorus Point and Non-Point Source Loads (W4d & W5d)

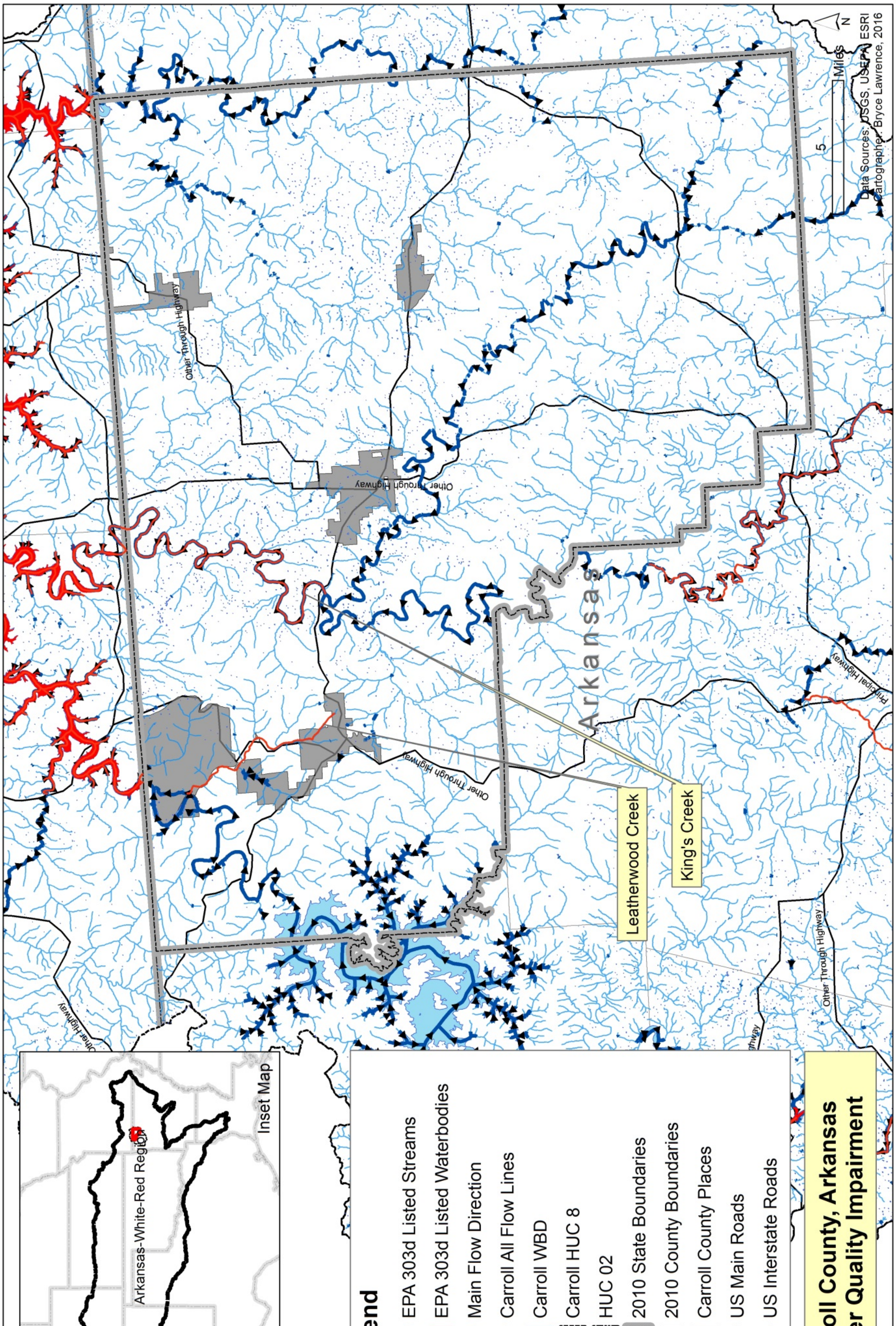


Figure 1-9: Carroll County EPA 303d Listed Streams and Waterbodies

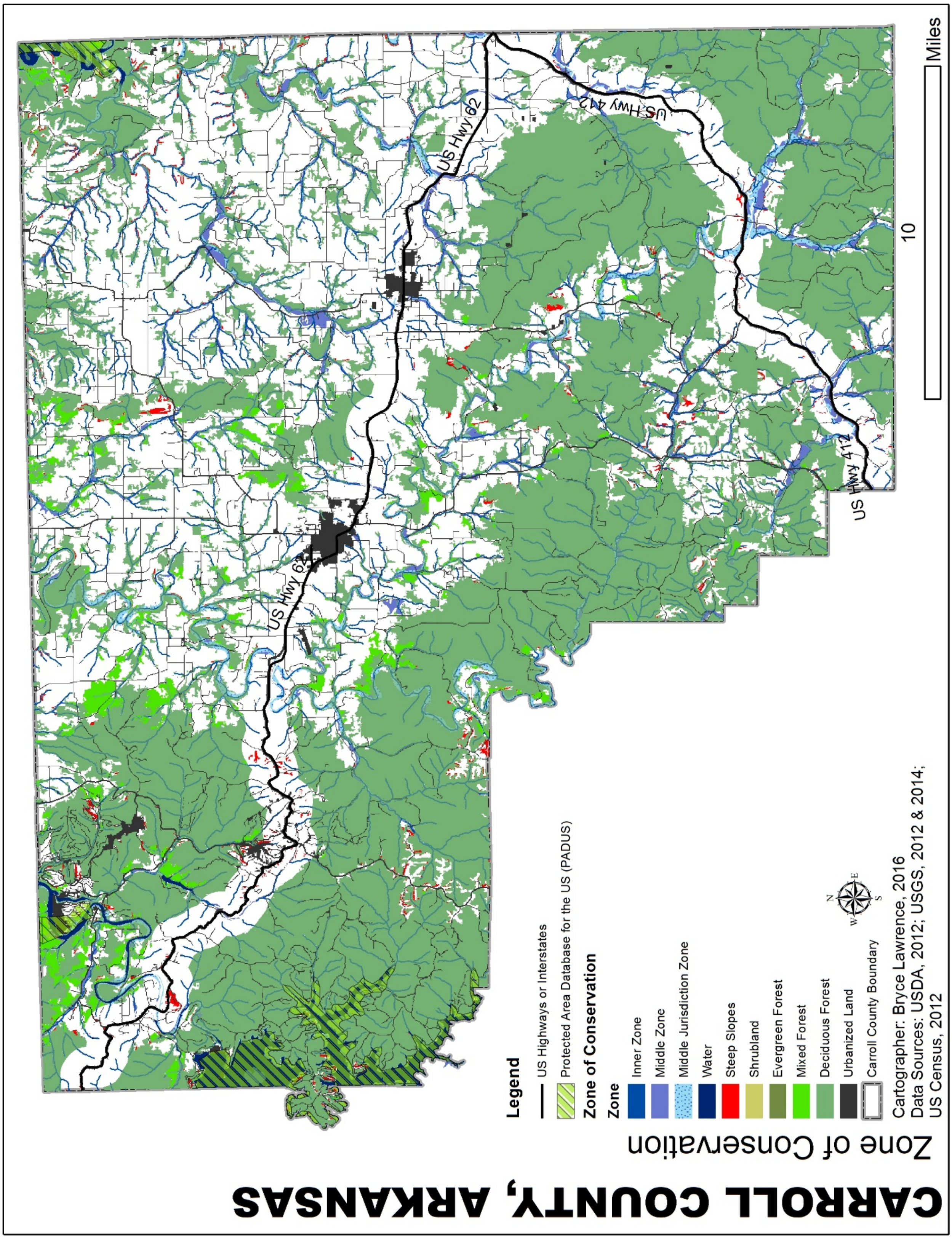


Figure 1-10: Carroll County Existing and Potential Zone of Conservation (EC1c & EC1c)

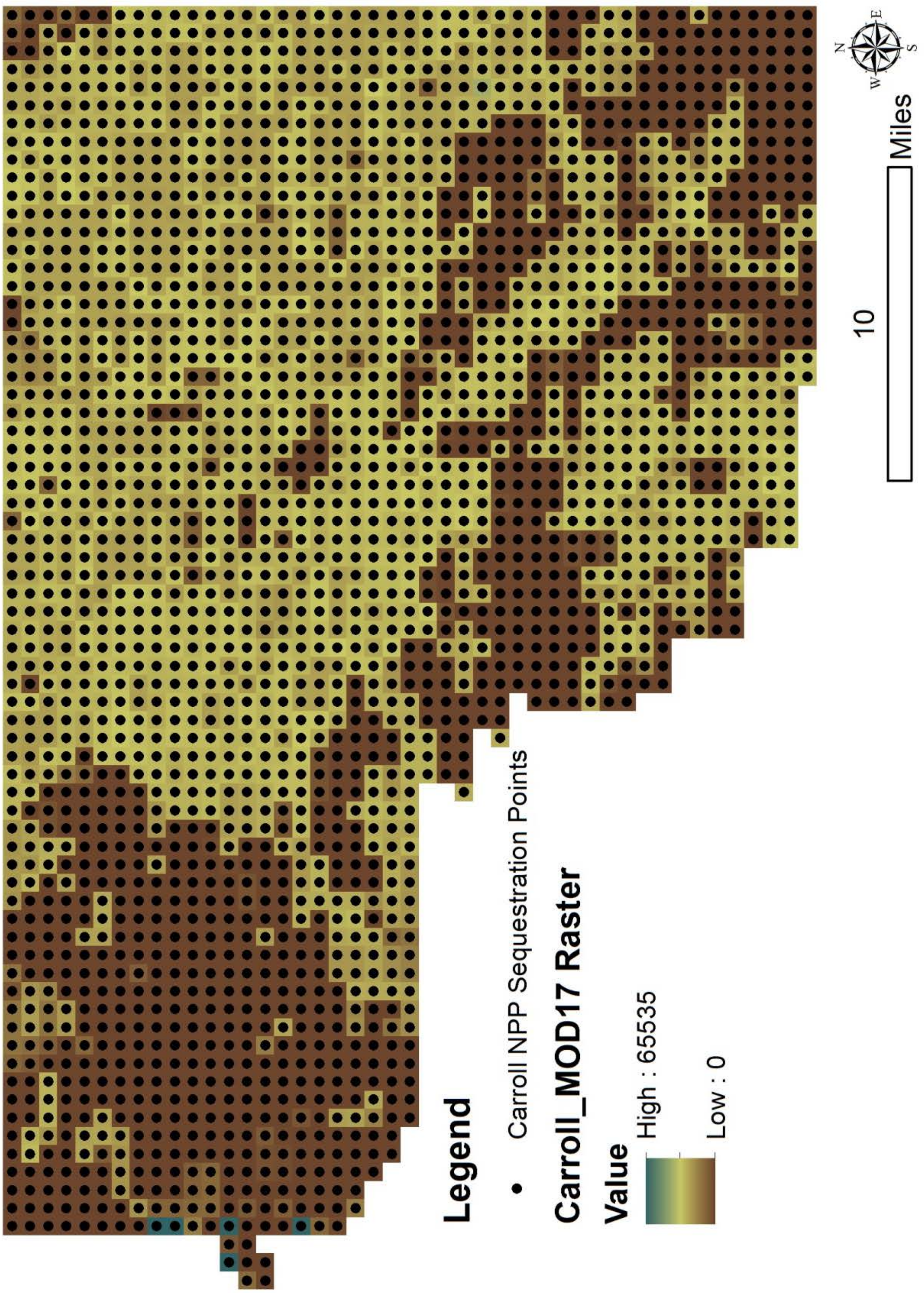
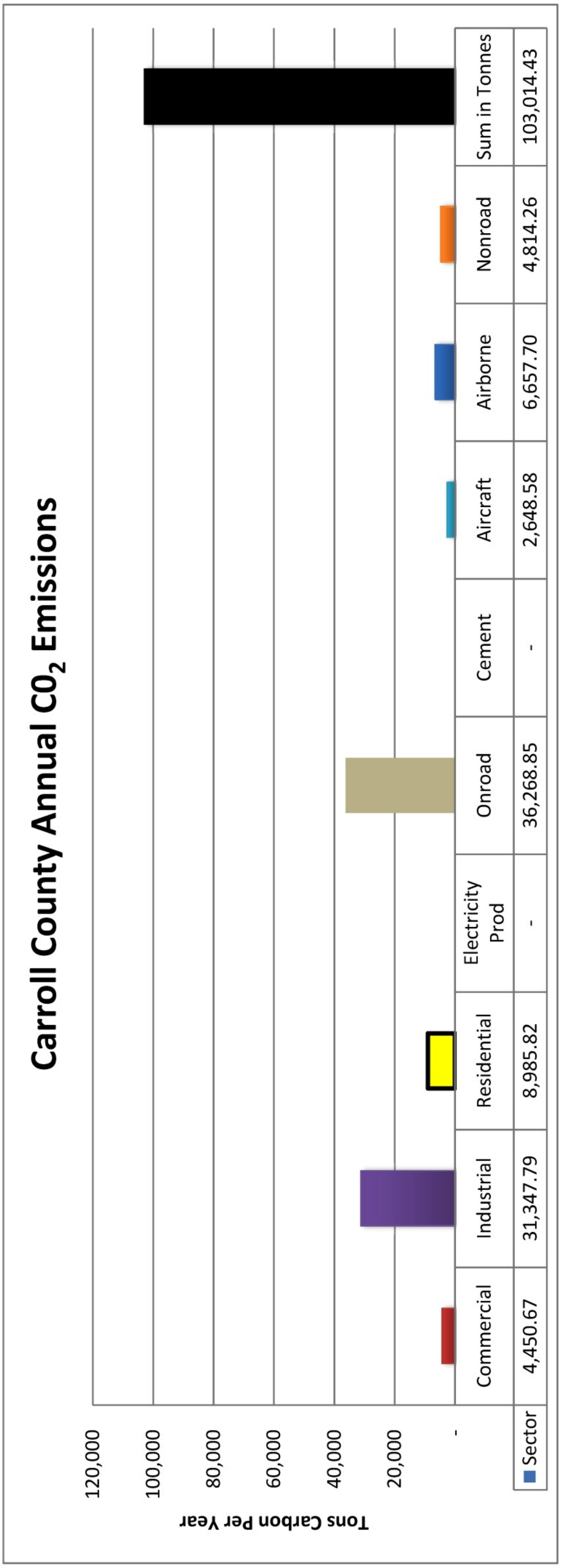


Figure 1-11: Carroll County Net Primary Productivity (NPP) in Tons of Carbon per Year, as Estimate for Carbon Sequestration Potential (C1c)



	Commercial	Industrial	Residential	Electricity Prod	Onroad	Cement	Aircraft	Airborne	Nonroad	Sum in Tonnes
Sector	4,450.67	31,347.79	8,985.82	-	36,268.85	-	2,648.58	6,657.70	4,814.26	103,014.43

Figure 1-12: Carroll County $C0_2$ Emissions in Tons per Year (C1d)

Carroll County Solar Resource Summary												
Raster Tile OID	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
87	3.872	4.231	4.876	5.473	5.360	5.686	5.990	6.100	5.641	4.832	4.090	3.801
88	3.891	4.210	4.841	5.470	5.350	5.649	5.899	6.039	5.556	4.816	4.127	3.835
89	3.918	4.241	4.879	5.531	5.364	5.670	5.870	6.034	5.577	4.820	4.156	3.842
90	3.847	4.200	4.912	5.544	5.400	5.672	5.857	6.052	5.600	4.878	4.150	3.859
91	3.804	4.119	4.874	5.565	5.385	5.673	5.865	6.090	5.608	4.856	4.163	3.797
92	3.795	4.231	4.894	5.566	5.398	5.725	5.856	6.094	5.602	4.847	4.164	3.806
93	3.828	4.156	4.896	5.542	5.410	5.691	5.827	6.048	5.589	4.869	4.139	3.828
94	3.870	4.268	4.764	5.435	5.329	5.661	6.001	6.099	5.585	4.778	4.038	3.828
95	3.882	4.291	4.861	5.485	5.370	5.639	5.948	6.063	5.618	4.862	4.165	3.871
96	3.919	4.250	4.878	5.543	5.386	5.664	5.873	6.024	5.596	4.864	4.170	3.914
97	3.882	4.287	4.918	5.575	5.403	5.693	5.858	6.082	5.643	4.894	4.149	3.882
98	3.897	4.198	4.902	5.541	5.390	5.665	5.833	6.067	5.564	4.848	4.143	3.864
99	3.860	4.276	4.979	5.606	5.415	5.686	5.821	6.074	5.560	4.857	4.170	3.877
100	3.873	4.256	4.937	5.584	5.410	5.695	5.818	6.038	5.614	4.882	4.179	3.810
101	3.932	4.291	4.845	5.542	5.370	5.640	5.888	6.006	5.570	4.848	4.139	3.857
102	3.872	4.275	4.876	5.564	5.369	5.643	5.868	6.020	5.537	4.867	4.180	3.820
103	3.891	4.217	4.920	5.565	5.387	5.655	5.847	6.050	5.545	4.840	4.168	3.861
104	3.902	4.257	4.933	5.612	5.404	5.677	5.805	6.029	5.558	4.846	4.180	3.843
105	3.901	4.217	4.913	5.605	5.377	5.655	5.789	5.978	5.541	4.852	4.175	3.862
106	3.943	4.280	4.880	5.540	5.375	5.654	5.893	6.022	5.570	4.879	4.152	3.837
107	3.891	4.217	4.889	5.601	5.344	5.653	5.876	6.040	5.589	4.857	4.139	3.842
108	3.899	4.222	4.917	5.607	5.346	5.653	5.863	6.040	5.603	4.872	4.154	3.837
109	3.924	4.274	4.966	5.630	5.357	5.624	5.792	6.033	5.606	4.863	4.170	3.862
110	3.969	4.229	4.984	5.610	5.347	5.614	5.762	5.973	5.555	4.832	4.177	3.821
Average kWh/m^2/month	3.886	4.237	4.897	5.556	5.377	5.664	5.862	6.046	5.584	4.852	4.152	3.844
Residential Units	10,404											
NR Units	691											
Annual Sum in MWH	**24,043.92**											

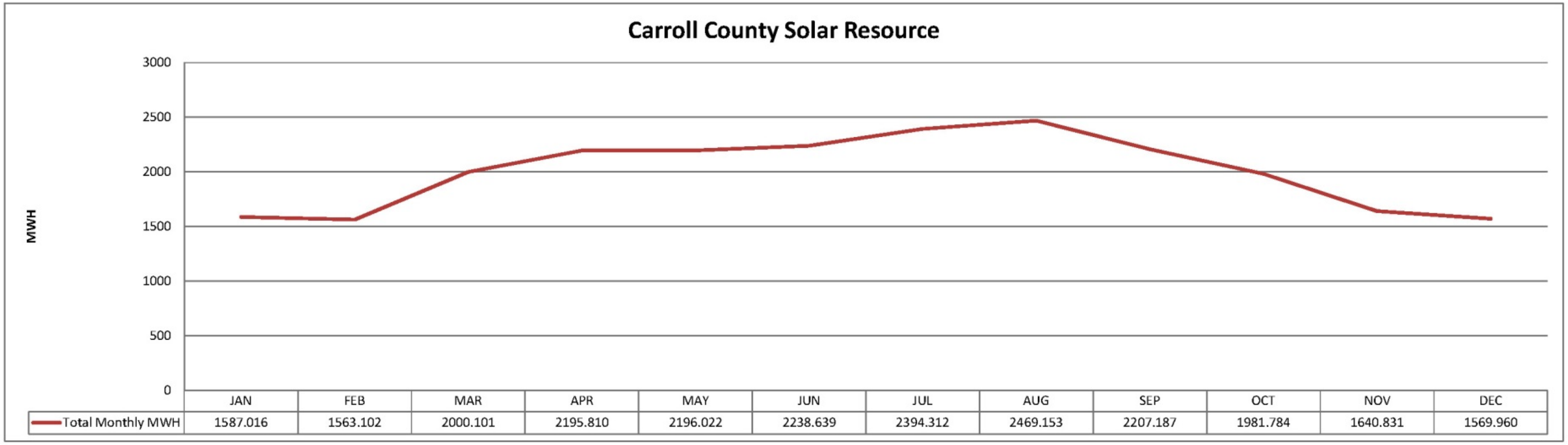


Figure 1-13: Solar (PV) Resource Potential Summary for Carroll County (E1c)

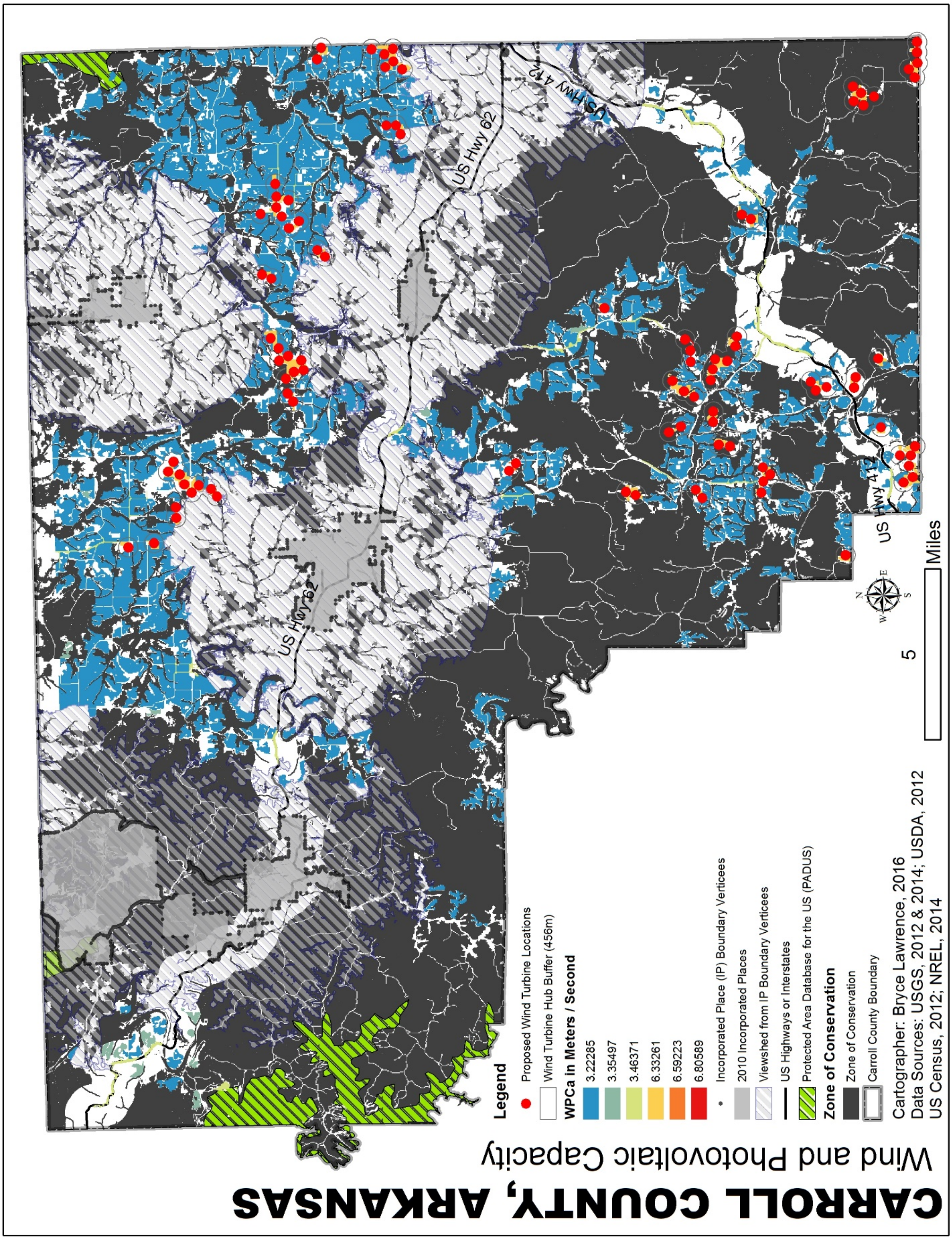


Figure 1-14: County Potential Wind and PV Renewable Electricity Locations Map (E1c)

Carroll County, Arkansas Renewable Electricity Potential				
Adjusted Wind Power Class	Wind Speed	Area in Acres	No. of Turbines	MWh
Carroll $WPC_{\alpha1}$	6.33261	2,477	95	847,522.59
Carroll $WPC_{\alpha2}$	6.59223	26	2	18,923.15
Carroll $WPC_{\alpha3}$	6.80589	25	3	29,669.72
Wind Sum	-	2,528	100	896,115.46
Solar Potential				24043.9182
Total Potential in MWh / Y				920,159.38

Figure 1-15: Carroll County Potential Wind and PV Renewable Electricity Locations (E1c)

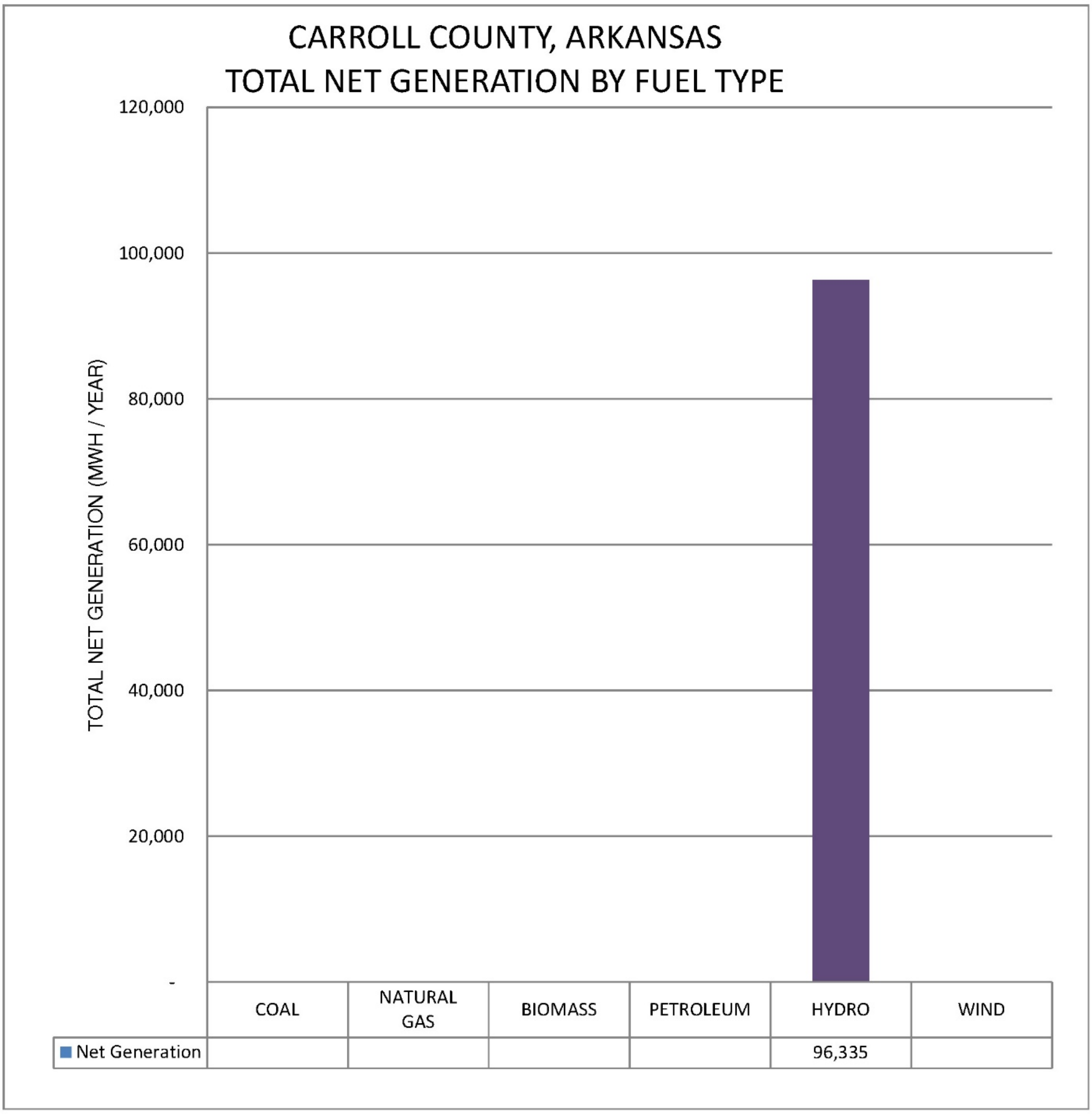


Figure 1-16: Carroll County Existing Electricity Production (E2c)

		ACS Table DP04		From Economic Census Table A1				2012 ACS	2010 Census
								County	State
County	State	County Residential Units	Statewide Res. Units	County Commercial Units	Statewide Comm. Units	County Industrial Units	Statewide Ind. Units	Population	Population
Carroll	Arkansas	13573	1316874	445	42954	246	21861	27446	2,966,000

Source:	*Econ. Census: Table C10*	*Econ. Census: Table C10*	*Econ. Census: Table C10*	*Econ. Census: Table C10*		*USEIA*
Units:	*in Trillion Btu's*	*in Trillion Btu's*	*in Trillion Btu's*	*in Trillion Btu's*		*in Million Btu's*
State	Total Residential TBtu's / Year	Total Commercial TBtu's / Year	Total Industrial Tbtu's / Year	Total Transportation Tbtu's / Year	County	All Prime Movers Btu's / Year
Arkansas	241.3	176.6	398.8	276.3	Carroll	916725

County	Residential MWH	Commercial MWH	Industrial MWH	Transport MWH	Power Plant MWH	Total MWH
Carroll	728,920.10	536,213.91	1,315,258.78	749,341.48	268,676.73	3,598,411.00

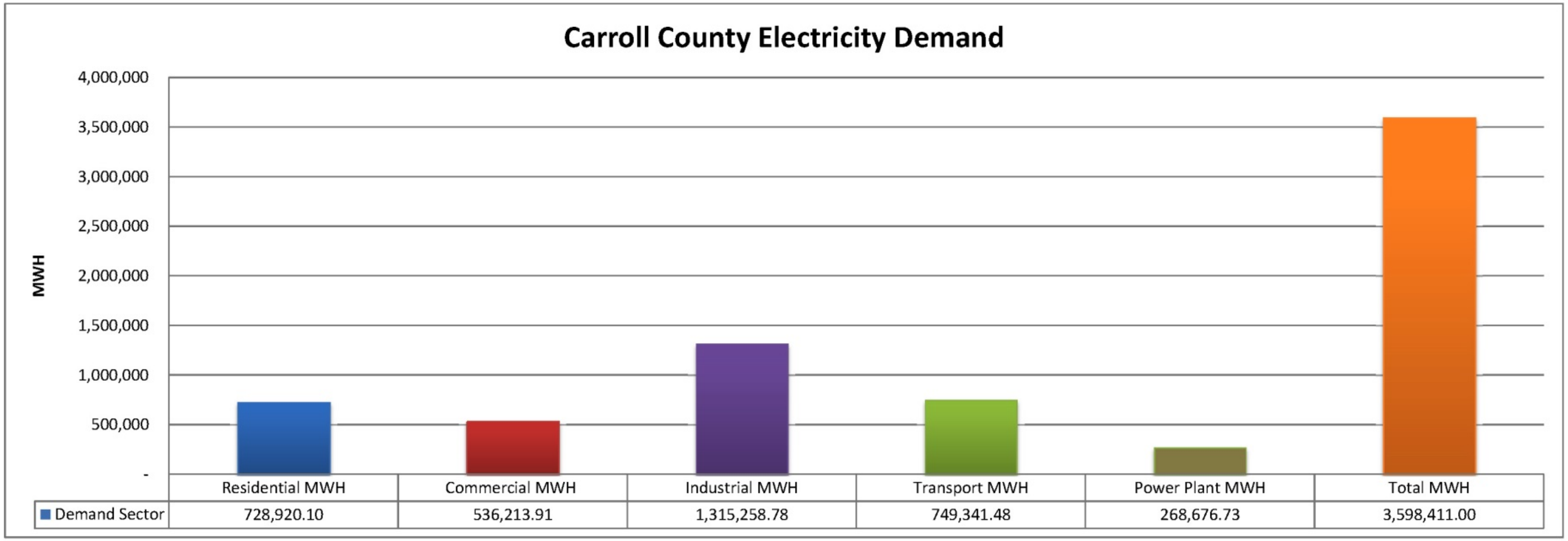


Figure 1-17: Carroll County Electricity Demand (E1d & E2d)

Carroll County Composted Organic Waste Production

Category	Wet Short Tons	Dry Short Tons	Dry Metric Tons	Data Source:
Yard Waste	2,994.0	1,497.0	1,358.1	*Carroll County MSW Spreadsheet (EPA % from Total Reported PPD)*
Food Waste Mass	4,710.9	2,355.5	2,136.8	*Co-EAT, post composting: MGD WWTP*
Biosolids (WW Solids Mass)	1,266.4	633.2	574.4	*Co-EAT, post composting; MGD WWTP*
Organic Production Summary			4,069.3	
Field Application Capacity			5,017.0	*USDA Quickstats Food Production Summary; Compost Rate/Ac*

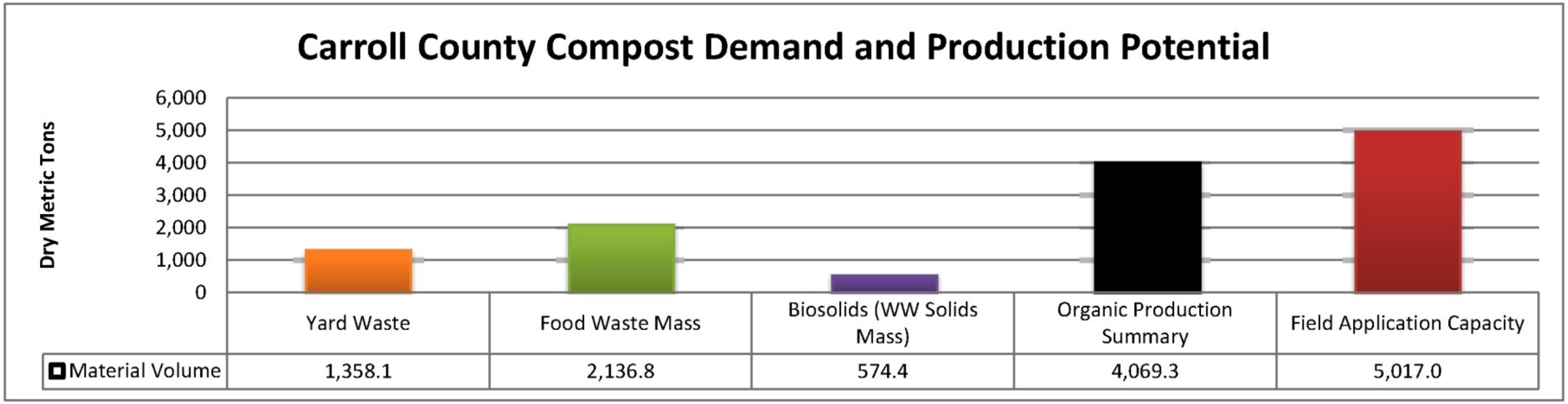


Figure 1-18: Carroll County Compost Demand and Organic Material Production Potential (M1c & M1d)

VS = volatile solids TS = total solids MCRT = mean cell residence time

Feedstock Parameter	Value	Units
Food Waste Mass	12.91	short tons/day
Food Waste Biogas Yield	6.65	ft^3 CH^4/lb TS
Food Waste Total Solids	29.99%	solids
Food Waste VS	89.60%	of total solids
Food Waste % of Total Waste	78.81%	total substrate
Weighted Total Feedstock Loading (TS)	25,813.30	lbs/day
Weighted Total Feedstock Loading (VS)	23,128.34	lbs/day
Wastewater Solids Mass	3.47	short tons/day
Wastewater Solids Yield	2.12	ft^3 CH^4/lb TS
Wastewater Total Solids	1.00%	solids
Wastewater VS	70.00%	of total solids
Wastewater % of Total Waste	21.19%	total substrate
Weighted Total Feedstock Mass	16	short tons/day
Weighted Total Feedstock Yield	5.69	ft^3 CH^4/lb TS
Weighted Total Feedstock Concentration (% TS)	23.8%	solids
Weighted VS Content of Total Feedstock	85%	volatile solids
Weighted Total Feedstock (TS)	6,939.3	lbs/day
Weighted Total Feedstock (VS)	4,857.5	lbs/day

Table 1-4: Carroll County Co-EAT Sludge Model Output (Input for M1d)

Sewerage Systems SIC 4952

Carrol County			
Plant Name	NPDES ID	Avg. Annual MGD	Total Sludge DMT/y
Berryville WWTP	AR0021792	1.632583333	
City of Green Forest WWTP	AR0021741	1.937583333	
City of Eureka Springs	AR0021865	0.452272727	
~~USA COE Beaver Powerhouse~~	ARG550214		
City of Berryville	ARL021792		151.77
City of Green Forest	ARL021741		346.54
~~Green forest Wastewater Treatment~~	ARR000015		
Holiday Island SID	AR0037249	0.203666667	
Total Annual Average MGD		4.226106061	498.31

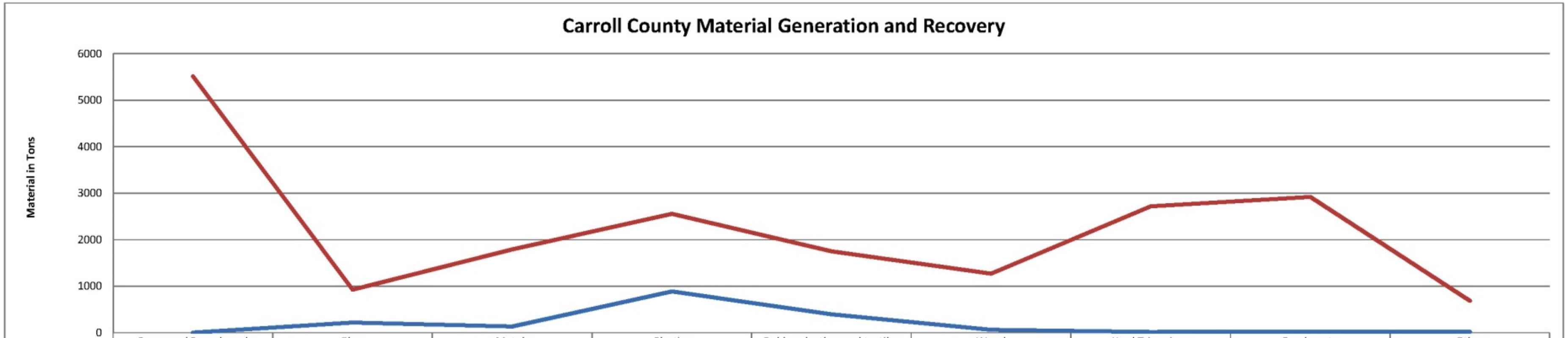
Table 1-5: Carroll County WWTPs MGD and Sludge Inputs for Co-EAT Model (Input for Input of M1d)

Carroll County MSW Generation Scaled to Volume from Given PPD and Population		
Category	EPA Percentage Generation[1]	Carroll Generation
Paper and Paperboard	27%	5515.59
Glass	5%	925.97
Metals	9%	1791.56
Plastics	13%	2556.49
Rubber, leather and textiles	9%	1751.30
Wood	6%	1268.18
Yard Trimmings	14%	2717.53
Food waste	15%	2918.83
Other	3%	684.42
Total Generation in Tons	**1**	**20,129.87**

Census and Regional MSW Overview Statistics				
County	2012 Pop	Pounds per day[2]	Total Waste (lbs/yr)	Total Waste (MT/y)
Carroll	27,446	4.43	44378809.7	20129.87305
Ozark Mountain Region (OMR)	139,040	-	-	-
Percent of Carrol to OMR	19.74%			

Sources:
[1]US EPA (2012): Municipal Solid Waste Generation, Recycling, and Disposal in the United States. Facts and Figures for 2012. US Environmental Protection Agency. Available online at www.epa.gov/wastes, updated on 2012, checked on April, 2014.
[2]Ozark Mountain Solid Waste District (2013): Ozark Mountain Needs Assessment 2013. Harrison, Arkansas. Available online at https://www.adeq.state.ar.us/sw/programs/pdfs/needs_assess/2013/ozark_mountain.pdf, checked on February 2016.

Category	Regional MSW Recovery by Facility Reports Scaled to Volume by Population										
	American Truck Repair (tons)	**Baxter Day Service (tons)**	**Ozark Mountain Solid Waste (ton)**	**Methvin Sanitation Recycling(ton)**	**Carroll County Solid Waste Authority (tons)**	**Marion Co. Transfer Station (tons)**	**City of Bull Shoals (tons)**	**NCRC (tons)**	**SCR (tons)**	**Sum by Category in Tons**	**Pop. Scaled Total by Category**
Paper and Paperboard		1007.8		1213.69	818.213	128	66.09	45.55	69.758	3349.10	661.10
Glass				74.61	418.05			6	0	498.66	98.43
Metals	3	29.8		30.75	135.23	56.5	8.41	76.6	0.3925	340.68	67.25
Plastics		61.2		33.14	88.505	12.5		7.5	7.208	210.05	41.46
Rubber, leather and textiles	1				285.255			0	10.8955	297.15	58.66
Wood					0			0	0	0.00	0.00
Yard Trimmings			672.3	3134.16	242.725			0	0	4049.19	799.29
Food waste					0			0	0	0.00	0.00
Other					19.49	113		0	0	132.49	26.15
Total Regional Recovery in Tons	4	1098.8	672.3	4486.35	2007.468	310	74.5	135.65	88.254	**8877.32**	1752.35
Percent of Recovery for Carroll County	0.79	216.90	132.71	885.59	396.27	61.19	14.71	26.78	17.42	**1752.35**	



	Paper and Paperboard	Glass	Metals	Plastics	Rubber, leather and textiles	Wood	Yard Trimmings	Food waste	Other
Generation	5515.59	925.97	1791.56	2556.49	1751.30	1268.18	2717.53	2918.83	684.42
Recovery	0.79	216.90	132.71	885.59	396.27	61.19	14.71	26.78	17.42

Figure 1-19: Carroll County Material Generation and Recovery (M2c & M2d)

2 Garrett County, Maryland

Garrett County, Maryland

FOOD CAPACITY	
FDA Daily Food Groups	Total Metric Tons Production Per Year
FRUIT AND NUTS	26
VEGETABLES	680
CEREAL GRAINS	7,472
HAY/GRASS	105,574
FEED GRAINS	38,561
PROTEIN	7,989
DAIRY	28,294

FOOD DEMAND	*2012 ACS Population:	30097
FDA Daily Food Groups	Annual Demand in Metric Tons	Metric Tons/Capita*/Year**
FRUIT AND NUTS	5,493	0.1825
VEGETABLES	6,866	0.228125
CEREAL GRAINS	2,060	0.0684375
HAY/GRASS	239,102	*Varies Per Livestock Type, Below*
FEED GRAINS	202,412	*Varies Per Livestock Type, Below*
PROTEIN	1,888	0.0627343
DAIRY	8,239	0.27375

Demand of Feed/ Hay Grains	Hay in Metric Tons / Year	Corn in Metric Tons / Year
Milk Cows	36,427	383
Beef Cows	201,076	201,076
Goats	551	110
Hogs	-	299
Sheep	1,048	105
Poultry	-	439
Total Feed(tons)	239,101.81	202,412.21

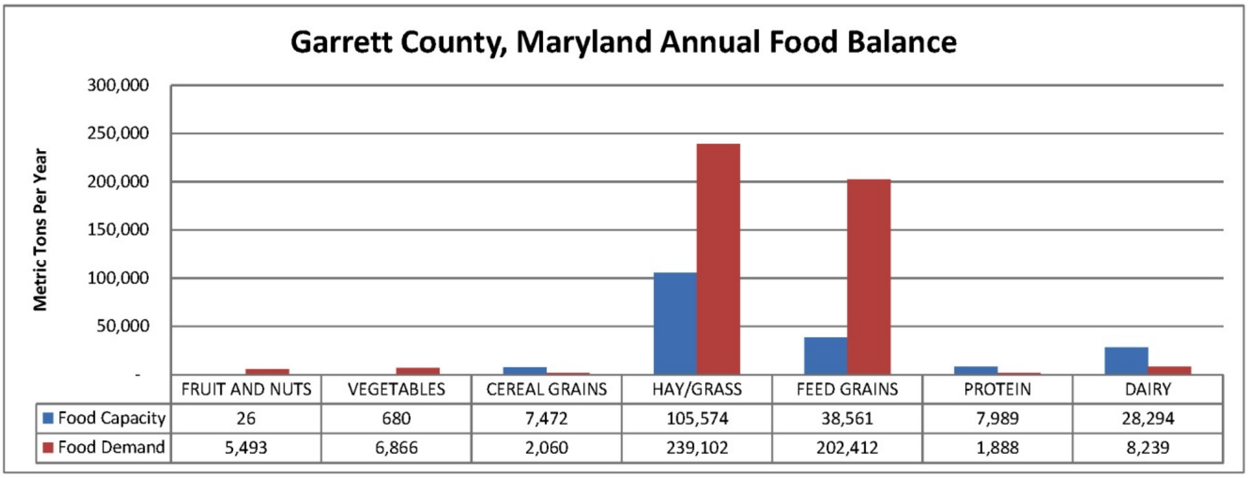


Figure 2-1: Garrett County Food Summary Page (F1c - F7c & F1d - F7d)

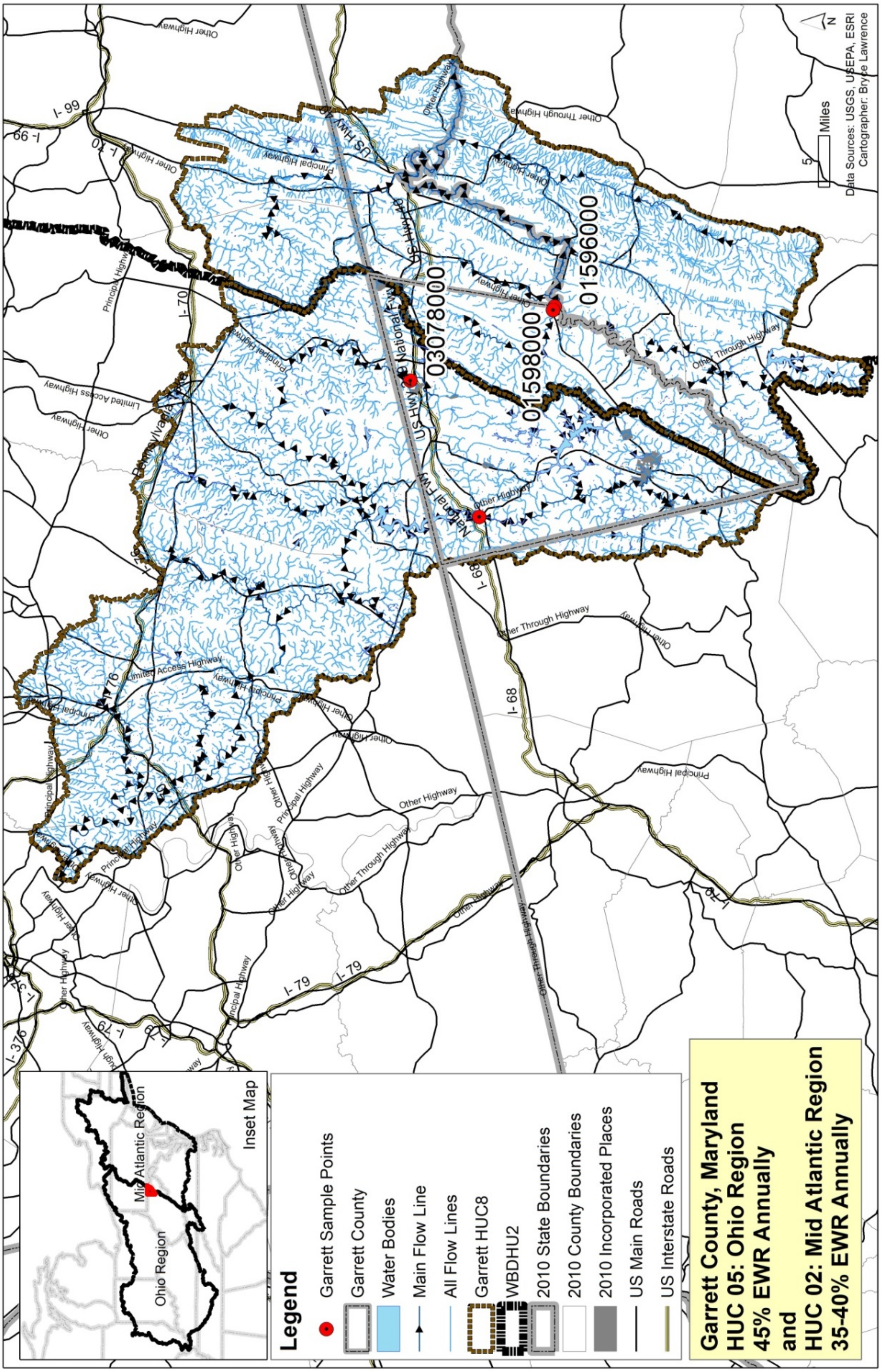


Figure 2-2: Garrett County Stream Network and Streamflow Sample Stations (W1c)

Garrett County, Maryland

Total Available Stream Flow in Cubic Meters (W1c) with Human Abstraction (W1d)

USGS Station No. 03076500	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1898-2016	382.7	421.9	592.5	456.5	310.3	183.1	131.9	115.2	82.1	105.2	203.1	374.7
EWR Requirement 41%	172.2	189.8	266.6	205.4	139.6	82.4	59.4	51.8	36.9	47.3	91.4	168.6
Available Adjusted CFS	210.5	232.0	325.9	251.1	170.7	100.7	72.6	63.4	45.1	57.8	111.7	206.1
EWR Corrected Mean Monthly Cubic Meters	15,665,284.0	17,266,436.0	24,249,833.2	18,682,771.1	12,699,904.5	7,494,118.7	5,400,001.0	4,714,768.6	3,358,915.0	4,304,157.3	8,311,336.5	15,337,851.2
Total P25 Discharge	28,482,334.5	31,393,519.9	44,090,605.8	33,968,674.7	23,090,735.4	13,625,670.4	9,818,183.6	8,572,306.5	6,107,118.2	7,825,740.5	15,111,520.8	27,887,002.1

USGS Station No. 03078000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1947-2016	62.7	75.1	117.1	98.1	58.5	24.8	11.2	7.3	4.9	8.3	25.1	61.0
EWR Requirement 41%	28.2	33.8	52.7	44.1	26.3	11.1	5.0	3.3	2.2	3.7	11.3	27.5
Available Adjusted CFS	34.5	41.3	64.4	53.9	32.2	13.6	6.2	4.0	2.7	4.6	13.8	33.6
EWR Corrected Mean Monthly Cubic Meters	2,567,971.1	3,072,505.4	4,791,345.6	4,013,780.7	2,393,692.4	1,013,677.4	458,670.0	296,802.0	202,053.3	339,315.5	1,025,956.2	2,496,675.3
Total P25 Discharge	4,669,038.4	5,586,373.5	8,711,537.5	7,297,783.0	4,352,167.9	1,843,049.9	833,945.5	539,640.0	367,369.7	616,937.2	1,865,374.9	4,539,409.6

USGS Station No. 01598000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1924-1950	62.7	95.2	151.9	123.6	73.4	27.5	12.3	7.6	4.9	7.8	15.3	32.3
EWR Requirement 41%	28.2	42.8	68.4	55.6	33.0	12.4	5.5	3.4	2.2	3.5	6.9	14.5
Available Adjusted CFS	34.5	52.3	83.5	68.0	40.4	15.1	6.7	4.2	2.7	4.3	8.4	17.8
EWR Corrected Mean Monthly Cubic Meters	2,565,330.5	3,895,321.5	6,217,262.7	5,058,837.1	3,003,668.0	1,124,186.0	501,579.6	309,476.8	200,961.9	320,435.3	626,761.0	1,321,613.9
Total P25 Discharge	4,664,237.3	7,082,402.7	11,304,114.1	9,197,885.6	5,461,214.6	2,043,974.6	911,962.8	562,685.1	365,385.3	582,609.6	1,139,565.4	2,402,934.4

USGS Station No. 01596000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1924-1950	246.2	336.5	481.6	408.8	227.4	112.0	62.6	50.0	45.5	54.7	96.7	172.8
EWR Requirement 41%	110.8	151.4	216.7	183.9	102.3	50.4	28.2	22.5	20.5	24.6	43.5	77.8
Available Adjusted CFS	135.4	185.1	264.9	224.8	125.1	61.6	34.5	27.5	25.0	30.1	53.2	95.0
EWR Corrected Mean Monthly Cubic Meters	10,076,481.0	13,773,348.7	19,713,304.3	16,730,452.9	9,308,070.1	4,582,695.2	2,564,010.2	2,046,455.1	1,860,909.9	2,237,897.7	3,957,844.2	7,072,813.0
Total P25 Discharge	18,320,874.6	25,042,452.3	35,842,371.4	30,419,005.3	16,923,763.9	8,332,173.1	4,661,836.8	3,720,827.5	3,383,472.5	4,068,904.9	7,196,080.4	12,859,660.0

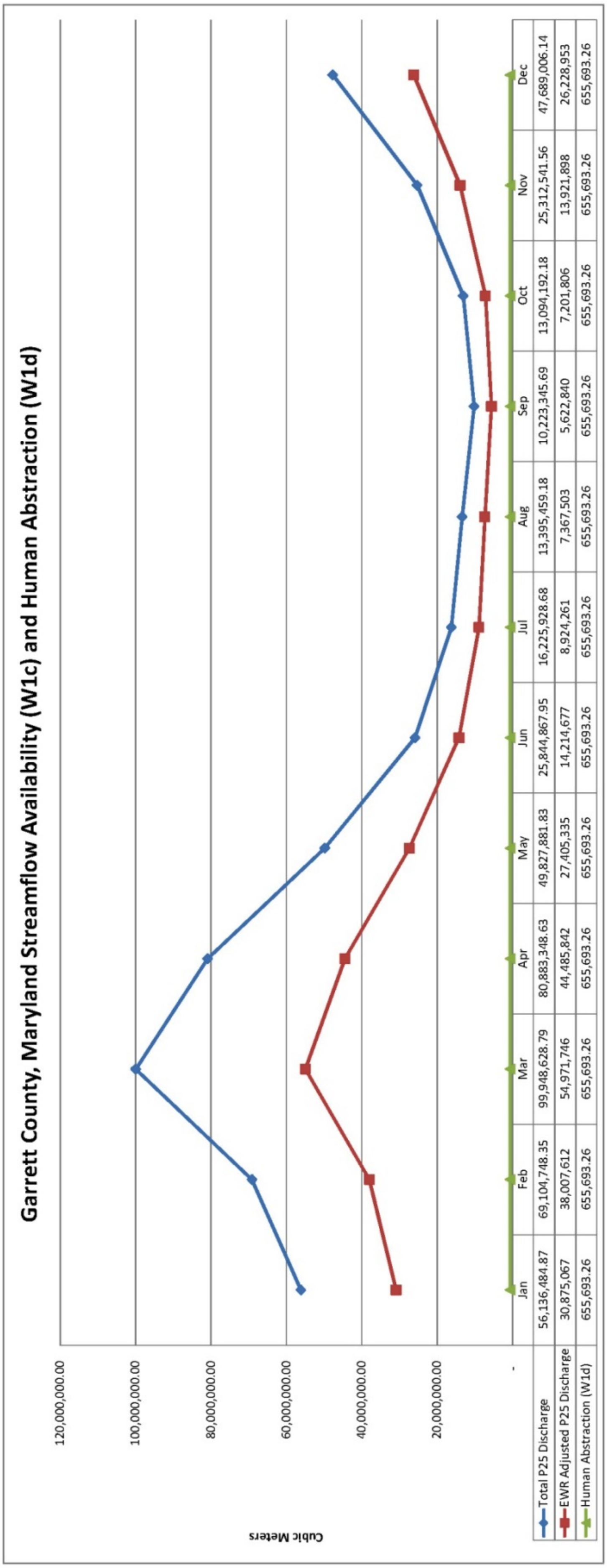
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	56,136,484.87	69,104,748.35	99,948,628.79	80,883,348.63	49,827,881.83	25,844,867.95	16,225,928.68	13,395,459.18	10,223,345.69	13,094,192.18	25,312,541.56	47,689,006.14
EWR Adjusted P25 Discharge	30,875,067	38,007,612	54,971,746	44,485,842	27,405,335	14,214,677	8,924,261	7,367,503	5,622,840	7,201,806	13,921,898	26,228,953
Human Abstraction (W1d)	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26
Human Abstraction as % EWR Adjusted	2.12%	1.73%	1.19%	1.47%	2.39%	4.61%	7.35%	8.90%	11.66%	9.10%	4.71%	2.50%

Total EWR Adjusted Annual Available Streamflow Volume in Cubic Meters	**279,227,539**

Table 2-1: Garrett County EWR adjusted Annual P25 Streamflow Availability (W1c)

Garrett County, Maryland 2010 Adjusted Water Abstraction		
Category	**Mgal/D Surface**	**Mgal/D Ground**
Public Supply	1.71	2.56
Mining	1.19	0.01
Livestock	0.19	0.14
Aquaculture	1.7	-
Irrigation	0.2	0.04
Daily Total	*4.99*	*2.75*
Annual Abstraction Projection by Source (USGS NWIS)	1,821	1,004
Total Annual Abstraction in Mgal		2,825
2012 Total Annual Returns in Mgal (US EPA ECHO / NPDES)		747
Total Adjusted Abstraction in Mgal		**2,078.59**
Total Adjusted Abstraction in cubic meter per year / month	7,868,319	655,693

Table 2-2: Garrett County Adjusted Water Abstraction (W1d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	56,136,484.87	69,104,748.35	99,948,628.79	80,883,348.63	49,827,881.83	25,844,867.95	16,225,928.68	13,395,459.18	10,223,345.69	13,094,192.18	25,312,541.56	47,689,006.14
EWR Adjusted P25 Discharge	30,875,067	38,007,612	54,971,746	44,485,842	27,405,335	14,214,677	8,924,261	7,367,503	5,622,840	7,201,806	13,921,898	26,228,953
Human Abstraction (W1d)	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26	655,693.26

Figure 2-3: Garrett County Adjusted Streamflow Availability and Human Abstraction (W1c & W1d)

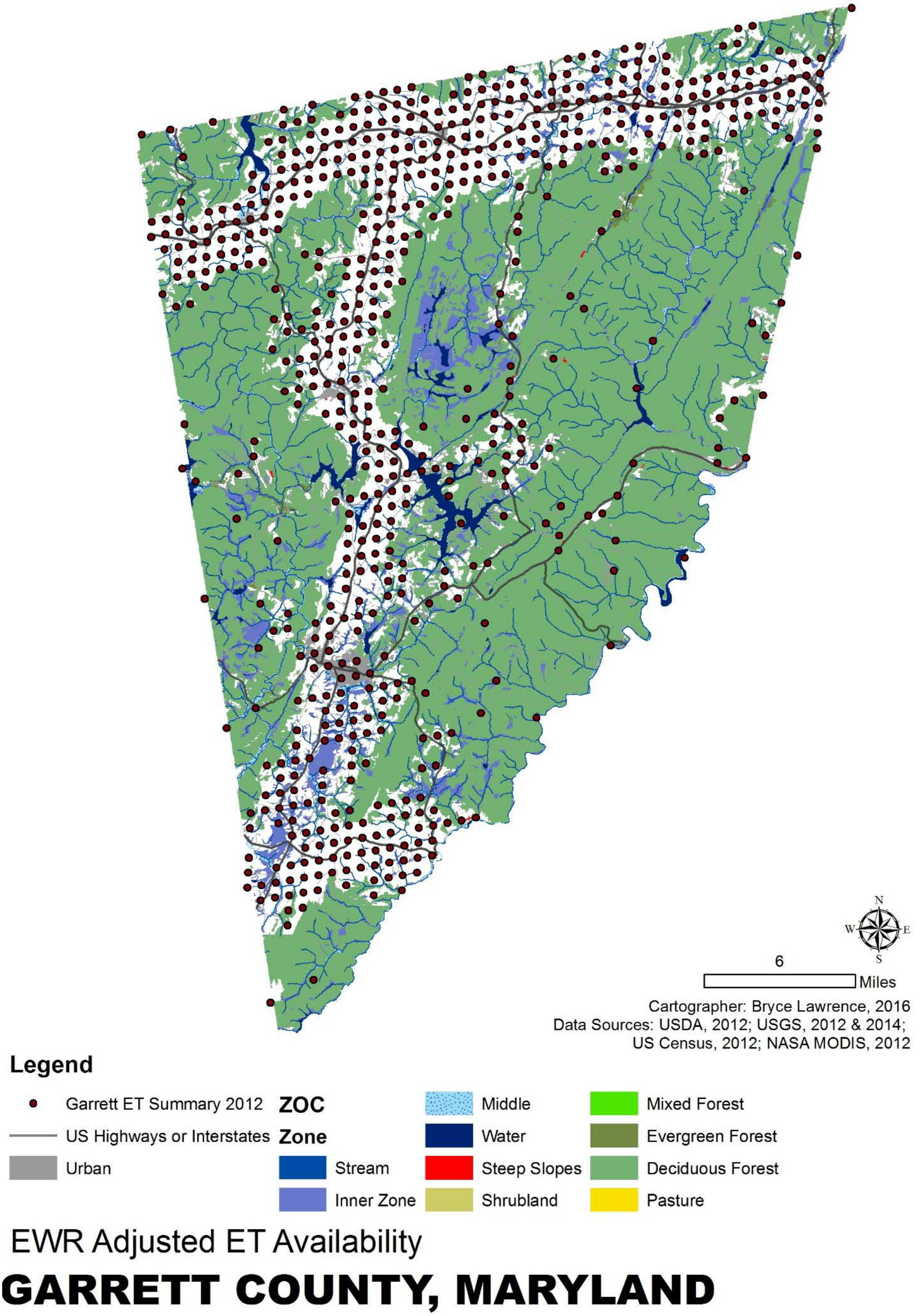


Figure 2-4: Garrett County EWR Adjusted ET Availability Sample Points (W2c)

Garrett County, Maryland

Monthly Green Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	GW Annual Total
Value in Cubic Meters	11,527,871	11,527,871	11,527,871	14,765,815	22,754,317	22,754,317	22,682,323	22,682,323	22,682,323	14,823,860	11,599,865	11,527,871	200,856,627

Monthly Blue Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	BW Annual Total
Value in Cubic Meters	769,594	766,941	769,594	795,912	988,782	987,891	988,629	988,629	987,744	796,887	769,741	769,594	10,379,937

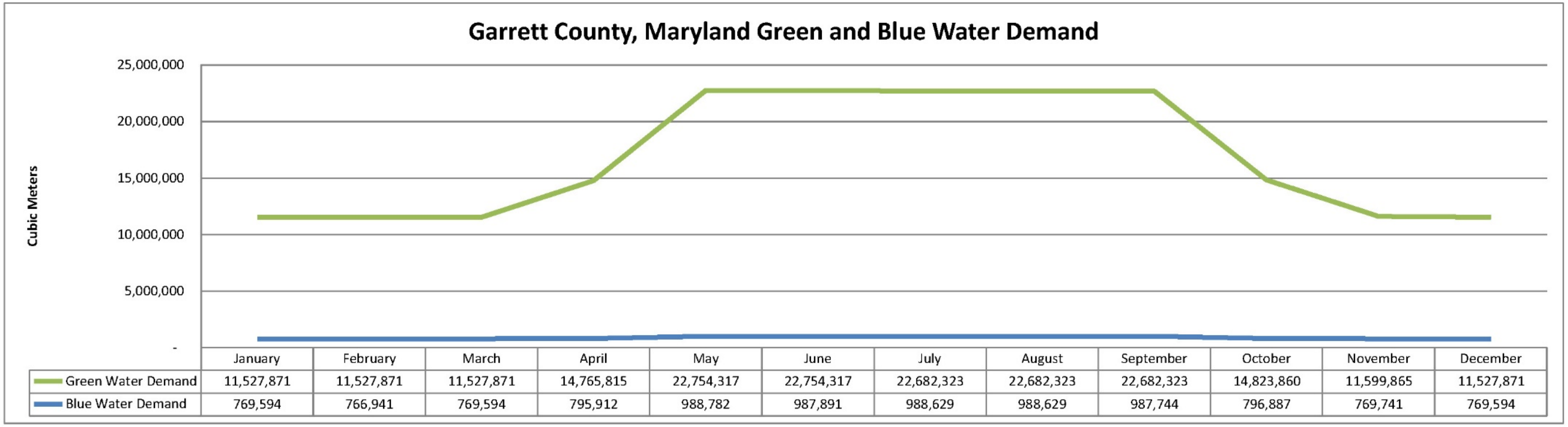
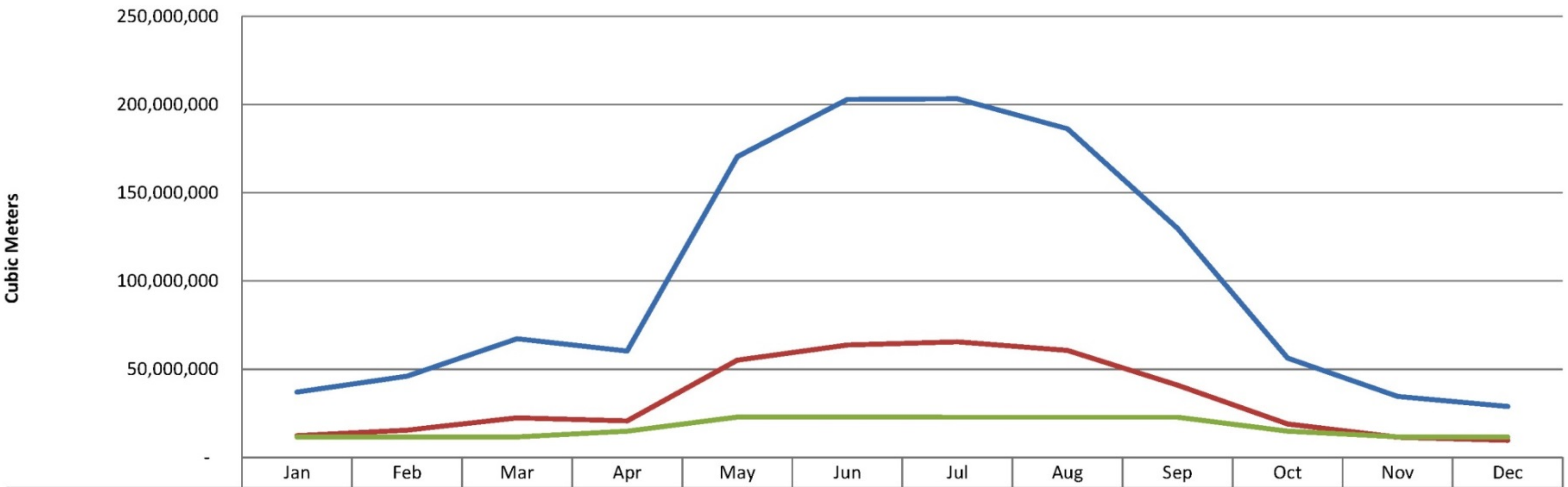


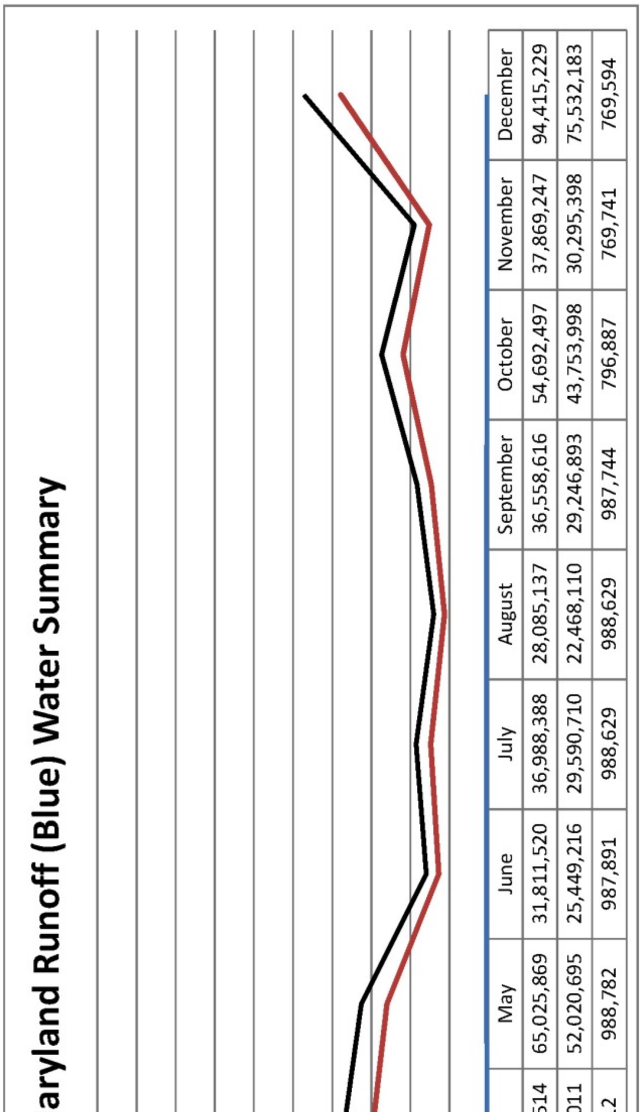
Figure 2-5: Garrett County ET (Green Water) and Surface (Blue Water) Demand (W2d & W3d)

Garrett County, Maryland Evapotranspiration Summary



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET for Entire County	36,946,333	46,003,875	67,181,801	60,239,489	170,439,36	202,875,52	203,247,54	186,240,18	129,759,19	56,242,383	34,473,040	28,814,025
ET Without ZOC Area	12,267,919	15,350,264	22,382,224	20,606,308	55,038,099	63,625,359	65,458,629	60,578,121	40,893,105	18,836,590	11,366,108	9,542,744
Green Water Demand	11,527,871	11,527,871	11,527,871	14,765,815	22,754,317	22,754,317	22,682,323	22,682,323	22,682,323	14,823,860	11,599,865	11,527,871

Figure 2-6: Garrett County ET (Green Water) Summary (W2c & W2d)



	January	February	March	April	May	June	July	August	September	October	November	December
Total Runoff	170,938,110	130,317,933	187,668,590	74,432,514	65,025,869	31,811,520	36,988,388	28,085,137	36,558,616	54,692,497	37,869,247	94,415,229
EWR Adjusted Runoff	136,750,488	104,254,346	150,134,872	59,546,011	52,020,695	25,449,216	29,590,710	22,468,110	29,246,893	43,753,998	30,295,398	75,532,183
Blue Water Demand	769,594	766,941	769,594	795,912	988,782	987,891	988,629	988,629	987,744	796,887	769,741	769,594

Figure 2-7: Garrett County Surface (Blue) Water Availability and Demand (W3c & W3d)

N	Garrett County, Maryland	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	136,750,488	104,254,346	150,134,872	59,546,011	52,020,695	25,449,216	29,590,710	22,468,110	29,246,893	43,753,998	30,295,398	75,532,183
	Liters / month	136,750,488,000	104,254,346,400	150,134,872,000	59,546,011,200	52,020,695,200	25,449,216,000	29,590,710,400	22,468,109,600	29,246,892,800	43,753,997,600	30,295,397,600	75,532,183,200
5.61	Mg/l limit	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61	5.61
	Total allowed Mg	767,170,237,680	584,866,883,304	842,256,631,920	334,053,122,832	291,836,100,072	142,770,101,760	166,003,885,344	126,046,094,856	164,075,068,608	245,459,926,536	169,957,180,536	423,735,547,752
	Total Allowed Tons (N)	767	585	842	334	292	143	166	126	164	245	170	424
0.29	Nnat in mg/l	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	Total mg Nnat	39,657,641,520	30,233,760,456	43,539,112,880	17,268,343,248	15,086,001,608	7,380,272,640	8,581,306,016	6,515,751,784	8,481,598,912	12,688,659,304	8,785,665,304	21,904,333,128
	Tons Nnat	40	30	44	17	15	7	9	7	8	13	9	22
	Corrected Limit	728	555	799	317	277	135	157	120	156	233	161	402
	Total Annual N Load (t)	**4,038.1**											

P	Garrett County, Maryland	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	136,750,488	104,254,346	150,134,872	59,546,011	52,020,695	25,449,216	29,590,710	22,468,110	29,246,893	43,753,998	30,295,398	75,532,183
	liters / month	136,750,488,000	104,254,346,400	150,134,872,000	59,546,011,200	52,020,695,200	25,449,216,000	29,590,710,400	22,468,109,600	29,246,892,800	43,753,997,600	30,295,397,600	75,532,183,200
2.97	Kg / day limit	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97
	Days / month	31	28	31	30	31	30	31	31	30	31	31	31
	Max Mo Avg P in kg	92.07	83.16	92.07	89.1	92.07	89.1	92.07	92.07	89.1	92.07	92.07	92.07
	Total Tons bkgrnd P	0.09207	0.08316	0.09207	0.0891	0.09207	0.0891	0.09207	0.09207	0.0891	0.09207	0.09207	0.09207
0.02	Mg/l background P	2,735,009,760	2,085,086,928	3,002,697,440	1,190,920,224	1,040,413,904	508,984,320	591,814,208	449,362,192	584,937,856	875,079,952	605,907,952	1,510,643,664
	Monthly bkgrnd P in tons	2.74	2.09	3.00	1.19	1.04	0.51	0.59	0.45	0.58	0.88	0.61	1.51
	Corrected P limit / mo	2.64	2.00	2.91	1.10	0.95	0.42	0.50	0.36	0.50	0.78	0.51	1.42
	Total Annual P Load (t)	**14.1**											

Table 2-3: Garrett County Critical Nitrogen and Phosphorus Load Limits (W4c & W5c)

Garrett County, Maryland N and P Load Summary			
CROPGROUP	N_load	P_load	Hectares
Oilseed	2.2	1.8	652.0
Feed	0.0	0.0	0.7
Cereal	20.6	8.7	3,239.5
N and P Point Loads	5.0	0.07	(N)n=5, (P)n=2
Total N and P Loads	**27.8**	**10.6**	

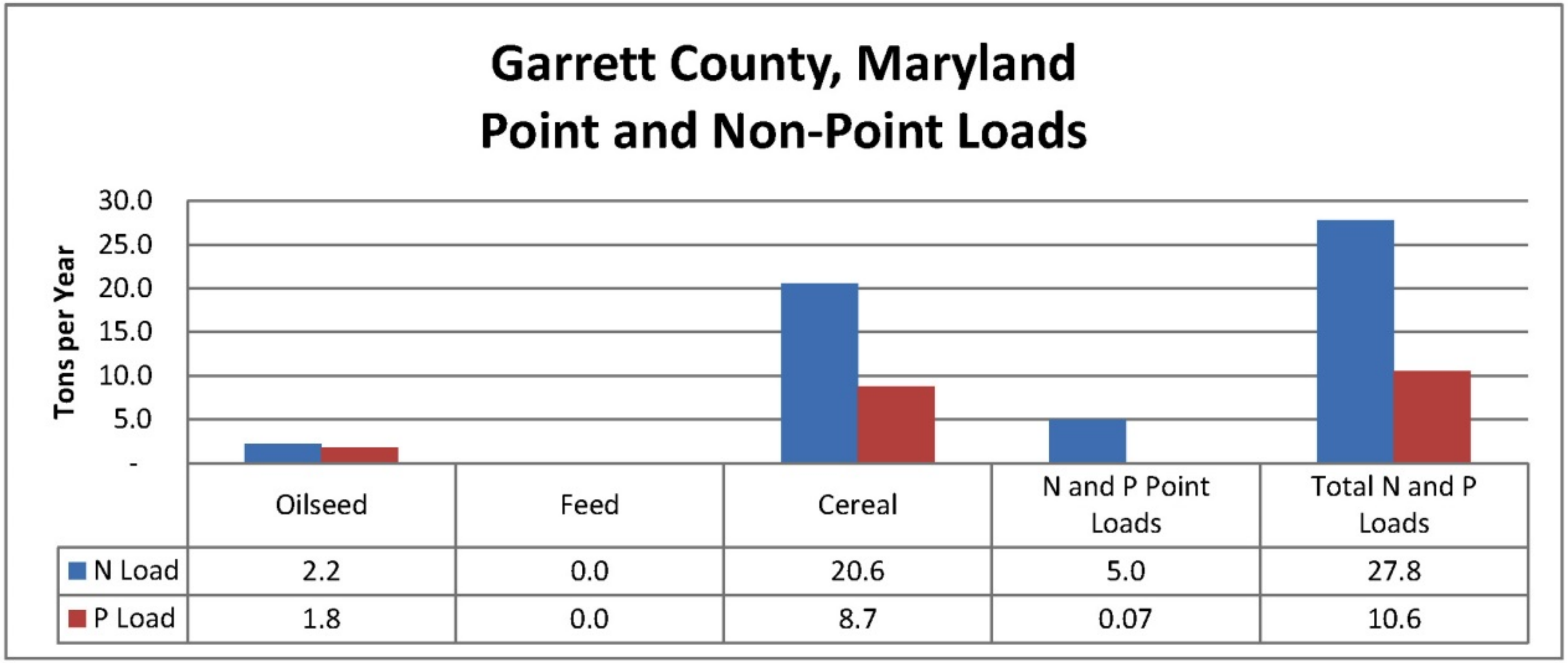


Figure 2-8: Garrett County Nitrogen and Phosphorus Point and Non-Point Source Loads (W4d & W5d)

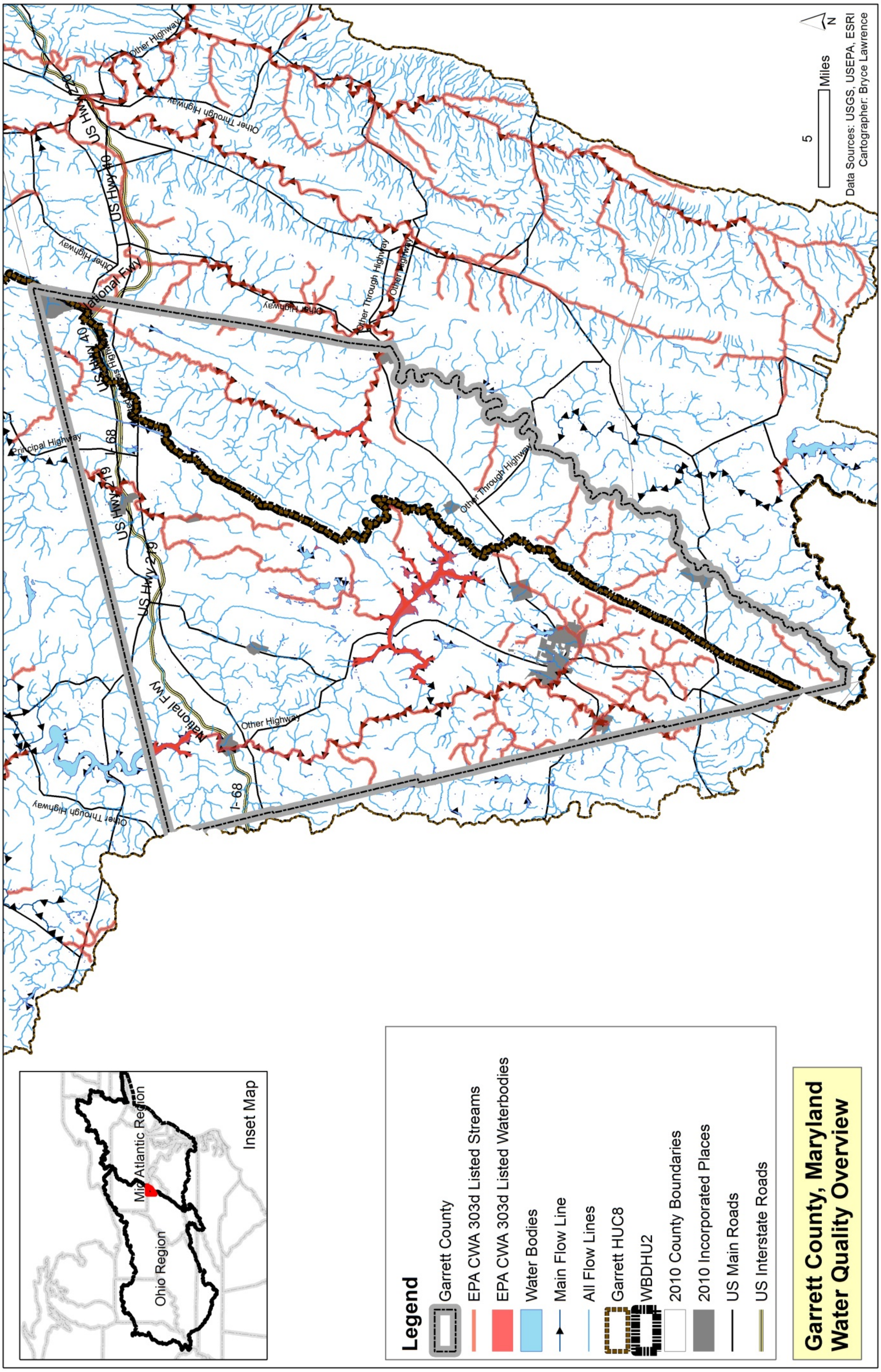


Figure 2-9: Garrett County EPA 303d Listed Streams and Waterbodies

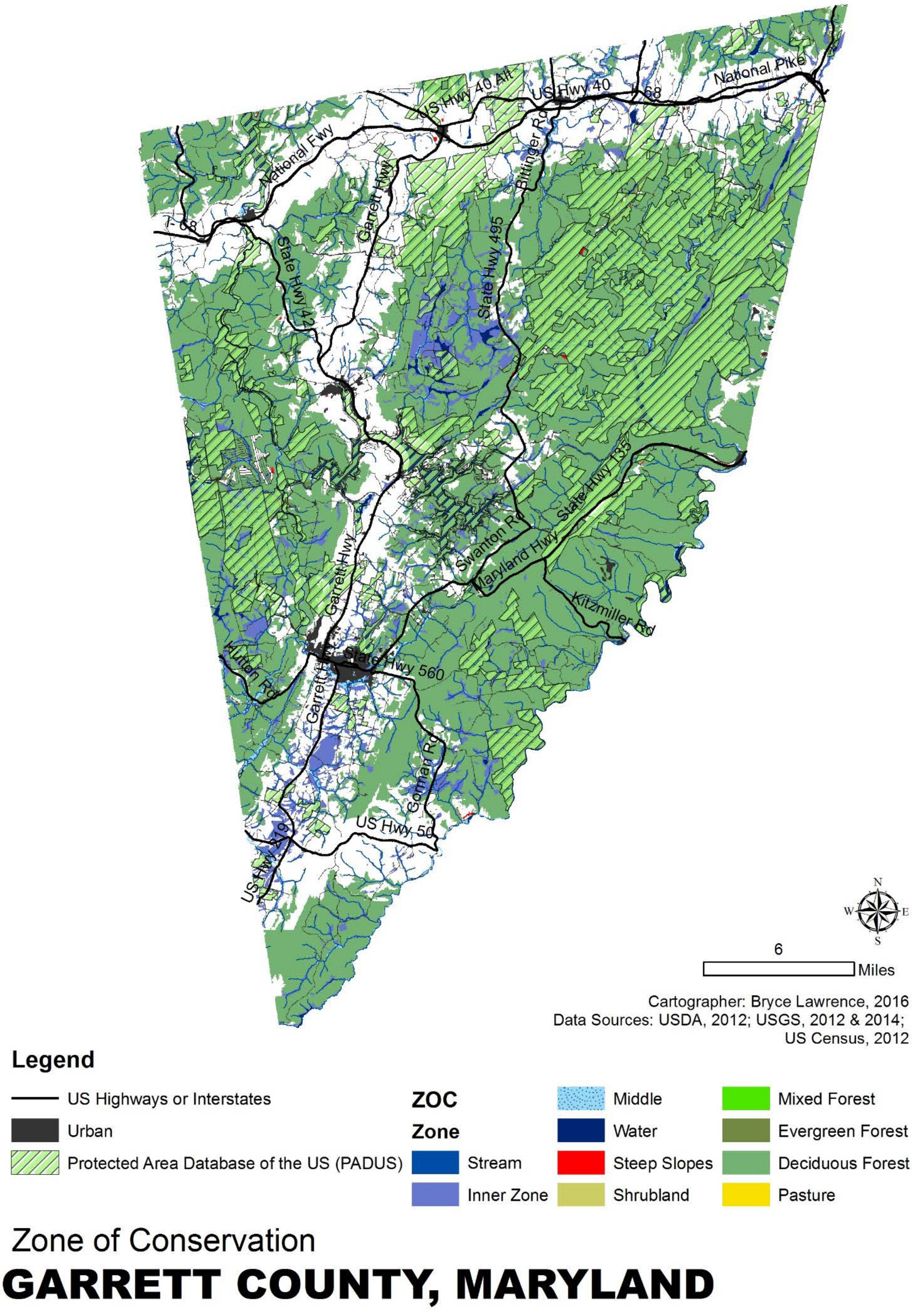


Figure 2-10: Garrett County Existing and Potential Zone of Conservation (EC1c & EC1c)

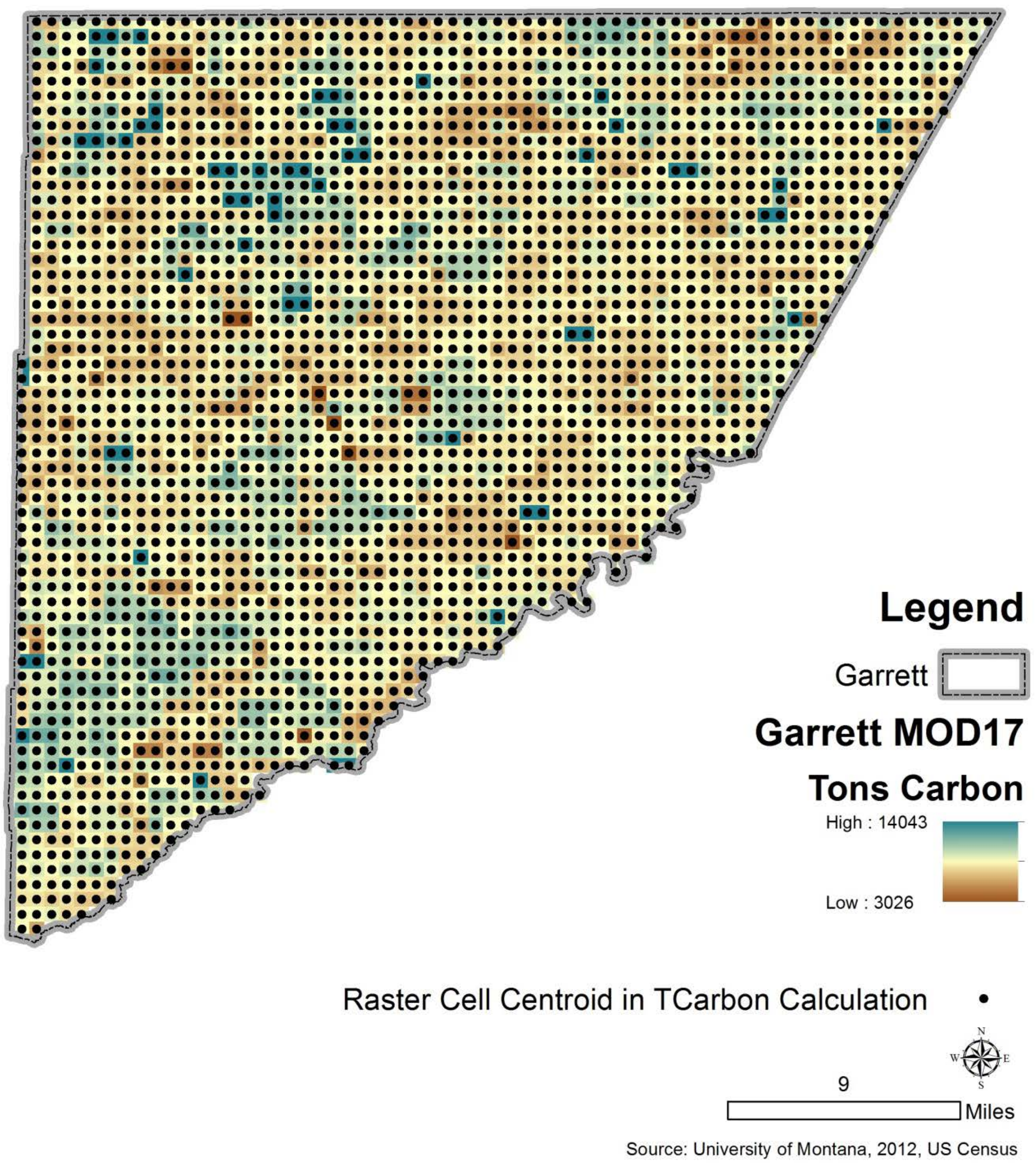


Figure 2-11: Garrett County Net Primary Productivity (NPP) in Tons of Carbon per Year, as Estimate for Carbon Sequestration Potential (C1c)

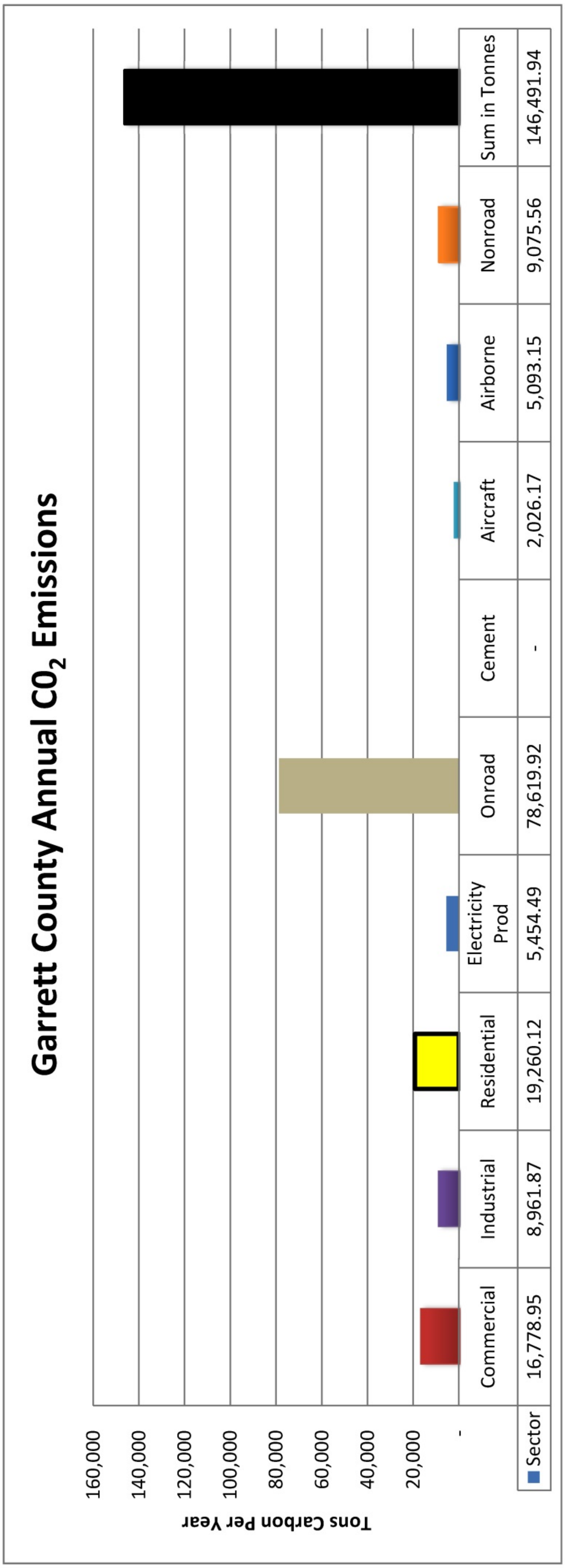


Figure 2-12: Garrett County C0$_2$ Emissions in Tons per Year (C1d)

Garrett County Solar Resouce Summary

Raster Tile OID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
58	3.017	3.610	4.379	4.976	5.066	5.221	5.150	5.213	4.898	4.141	3.092	2.857
59	3.158	3.699	4.404	4.872	5.031	5.187	5.192	5.180	4.814	4.030	3.063	2.922
60	3.180	3.727	4.673	5.018	5.022	5.185	5.092	5.144	4.861	4.106	3.150	3.001
61	3.100	3.723	4.610	4.956	5.081	5.192	5.109	5.140	4.869	4.131	3.135	3.040
62	3.240	3.633	4.708	5.011	5.061	5.198	5.206	5.216	4.900	4.223	3.222	3.053
63	3.272	3.743	4.699	5.050	5.118	5.243	5.147	5.247	4.858	4.251	3.274	3.077
64	3.149	3.718	4.405	4.988	5.012	5.223	5.160	5.155	4.919	4.152	3.153	2.910
65	3.091	3.637	4.420	4.935	4.982	5.203	5.129	5.161	4.898	4.103	3.106	2.933
66	3.227	3.849	4.592	4.910	5.013	5.178	5.074	5.164	4.847	4.145	3.164	2.982
67	3.260	3.863	4.770	5.001	5.067	5.202	5.131	5.203	4.840	4.181	3.220	3.102
68	3.411	3.998	4.823	5.025	5.068	5.229	5.152	5.212	4.822	4.214	3.287	3.205
69	3.494	3.937	4.846	5.056	5.066	5.281	5.188	5.250	4.865	4.342	3.365	3.261
70	3.157	3.838	4.503	4.977	5.016	5.222	5.085	5.129	4.870	4.164	3.140	3.002
71	3.130	3.602	4.534	4.931	4.966	5.141	5.095	5.180	4.900	4.159	3.185	2.970
72	3.159	3.698	4.692	5.105	5.102	5.230	5.113	5.181	4.920	4.147	3.192	3.073
73	3.581	3.974	4.806	5.009	5.057	5.263	5.155	5.234	4.890	4.266	3.298	3.195
74	3.471	3.992	4.832	4.997	5.133	5.284	5.238	5.298	4.976	4.294	3.371	3.307
75	3.055	3.784	4.624	5.078	5.022	5.265	5.114	5.216	4.904	4.242	3.219	3.042
76	3.119	3.863	4.505	4.989	5.021	5.223	5.148	5.251	4.876	4.232	3.217	3.011
77	3.069	3.698	4.482	4.857	4.966	5.240	5.086	5.214	4.886	4.218	3.152	2.709
78	3.456	4.200	4.885	4.985	5.100	5.235	5.179	5.239	4.934	4.331	3.355	3.160
79	3.690	4.005	4.810	4.965	5.102	5.282	5.178	5.259	4.914	4.258	3.304	3.277
80	3.219	3.811	4.489	5.017	4.998	5.285	5.167	5.238	4.916	4.280	3.242	3.085
81	3.034	3.823	4.634	4.969	5.056	5.277	5.141	5.260	4.923	4.271	3.235	3.048
82	3.369	4.006	4.649	5.018	5.067	5.295	5.113	5.279	4.936	4.306	3.327	3.205
83	3.616	4.049	4.659	5.031	5.084	5.262	5.162	5.293	4.938	4.339	3.415	3.285
84	3.314	3.988	4.761	5.079	5.030	5.211	5.093	5.216	4.927	4.272	3.236	3.189
85	3.483	4.051	4.741	4.973	5.023	5.242	5.081	5.242	4.919	4.361	3.358	3.254
86	3.503	4.127	4.762	5.078	5.025	5.246	5.052	5.213	4.900	4.407	3.455	3.338
Average kWh/m^2/month	**3.277**	**3.850**	**4.645**	**4.995**	**5.047**	**5.233**	**5.136**	**5.215**	**4.894**	**4.226**	**3.239**	**3.086**
Residential Units	15,761											
NR Units	904											
Annual Sum in MWH	31,177											

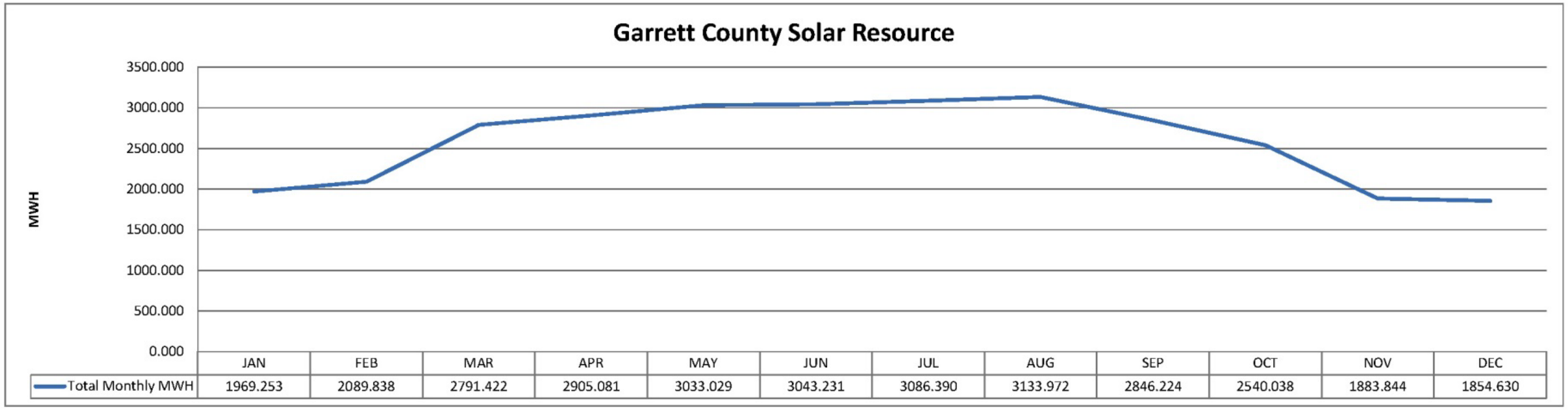


Figure 2-13: Solar (PV) Resource Potential Summary for Garrett County (E1c)

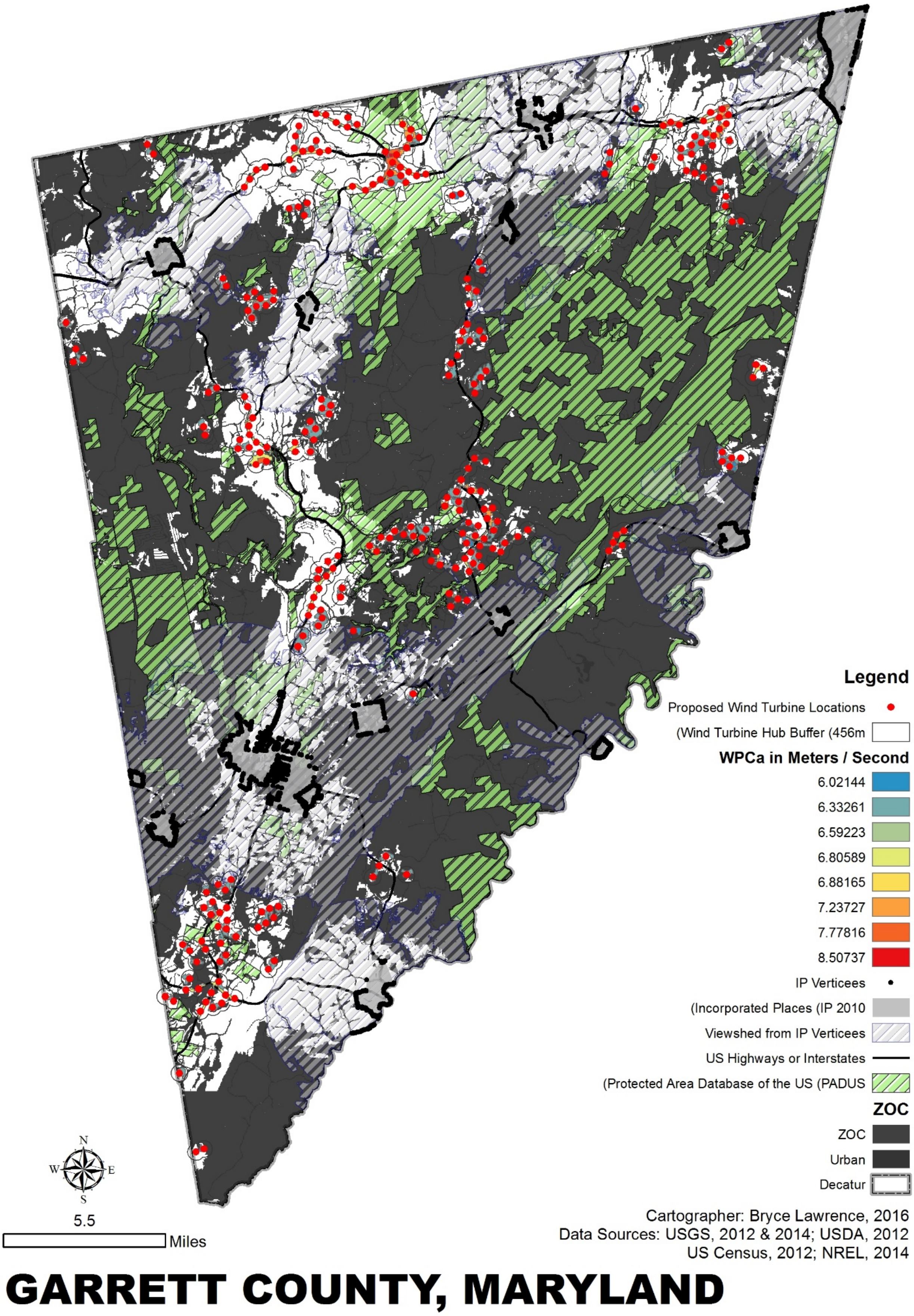


Figure 2-14: Garrett County Potential Wind and PV Renewable electricity Locations Map (E1c)

Garrett County, Maryland Wind Power Potential				
Adjusted Wind Power Class	**Wind Speed**	**Area in Acres**	**No. of Turbines**	**MWh**
Garrett $WPC_{\alpha 1}$	6.02144	292	12	98,962.89
Garrett $WPC_{\alpha 2}$	6.33261	4,224	146	1,302,508.40
Garrett $WPC_{\alpha 3}$	6.59223	27	2	18,923.15
Garrett $WPC_{\alpha 4}$	6.80589	1,584	90	890,091.67
Garrett $WPC_{\alpha 5}$	6.88165	102	4	40,152.57
Garrett $WPC_{\alpha 6}$	7.23727	427	13	139,202.69
Garrett $WPC_{\alpha 7}$	7.77816	416	14	162,998.99
Garrett $WPC_{\alpha 8}$	8.50737	25	1	12,742.07
Sum	-	7,097	282	2,665,582.43
Solar Potential				31176
Total Production Potential				2,696,758.43

Table 2-4: Garrett County Potential Wind and PV Renewable Electricity Locations (E1c)

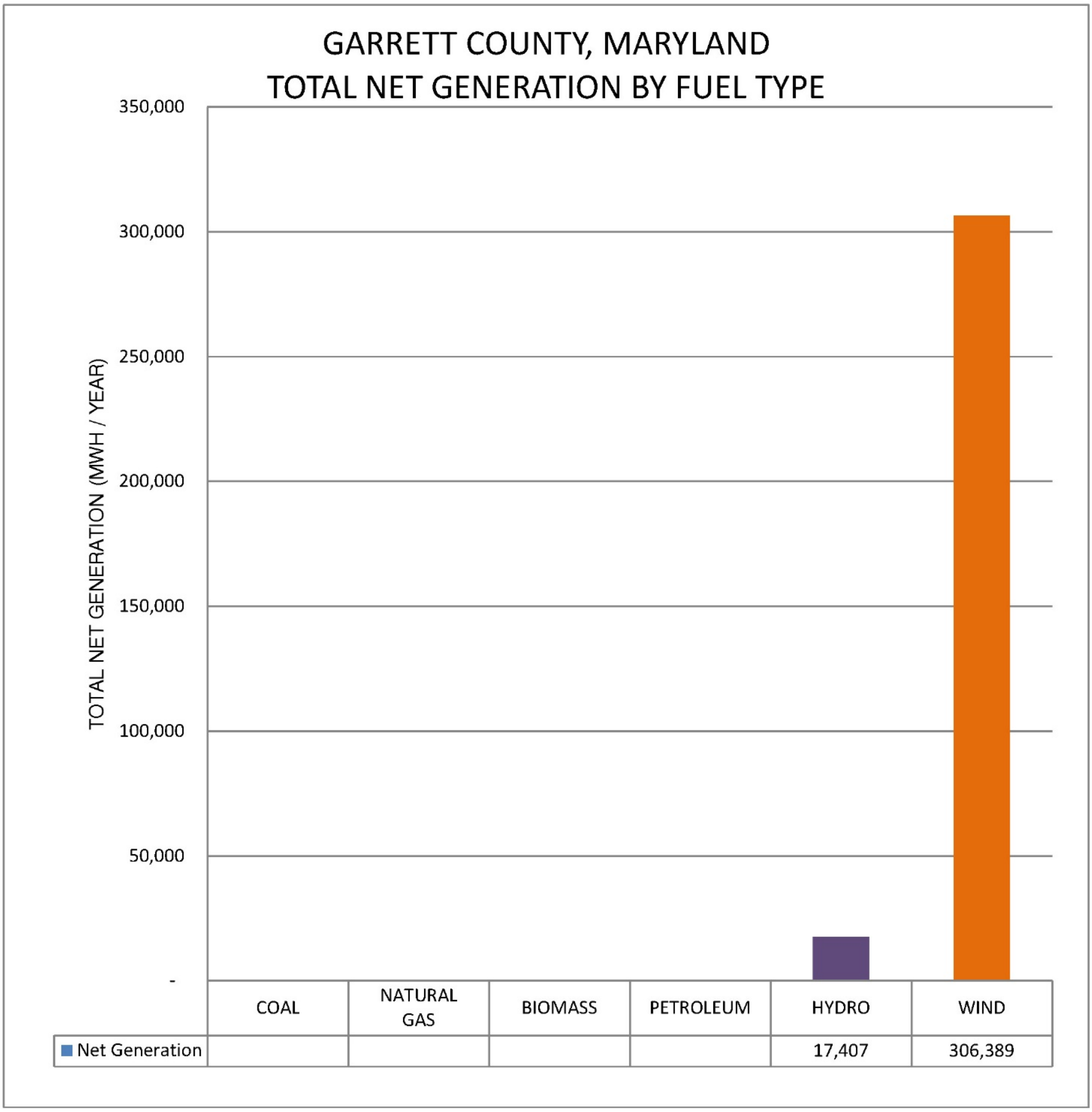


Figure 2-15: Garrett County Existing Electricity Production (E2c)

		ACS Table DP04		From Economic Census Table A1				2012 ACS	2010 Census
								County	State
County	State	County Residential Units	Statewide Res. Units	County Commercial Units	Statewide Comm. Units	County Industrial Units	Statewide Ind. Units	Population	Population
Garrett	Maryland	18920	2378932	449	94405	455	39900	30097	5,773,552

Source:	*Econ. Census: Table C10*	*Econ. Census: Table C10*	*Econ. Census: Table C10*	*Econ. Census: Table C10*		*USEIA*
Units:	*in Trillion Btu's*	*in Trillion Btu's*	*in Trillion Btu's*	*in Trillion Btu's*		*in Million Btu's*
State	Total Residential TBtu's / Year	Total Commercial TBtu's / Year	Total Industrial Tbtu's / Year	Total Transportation Tbtu's / Year	County	All Prime Movers Btu's / Year
Maryland	431.5	424.6	116.8	430.9	Garrett	3081241

County	Residential MWH	Commercial MWH	Industrial MWH	Transport MWH	Power Plant MWH	Total MWH
Garrett	1,005,798.26	591,864.53	390,366.30	658,335.99	903,060.08	3,549,425.17

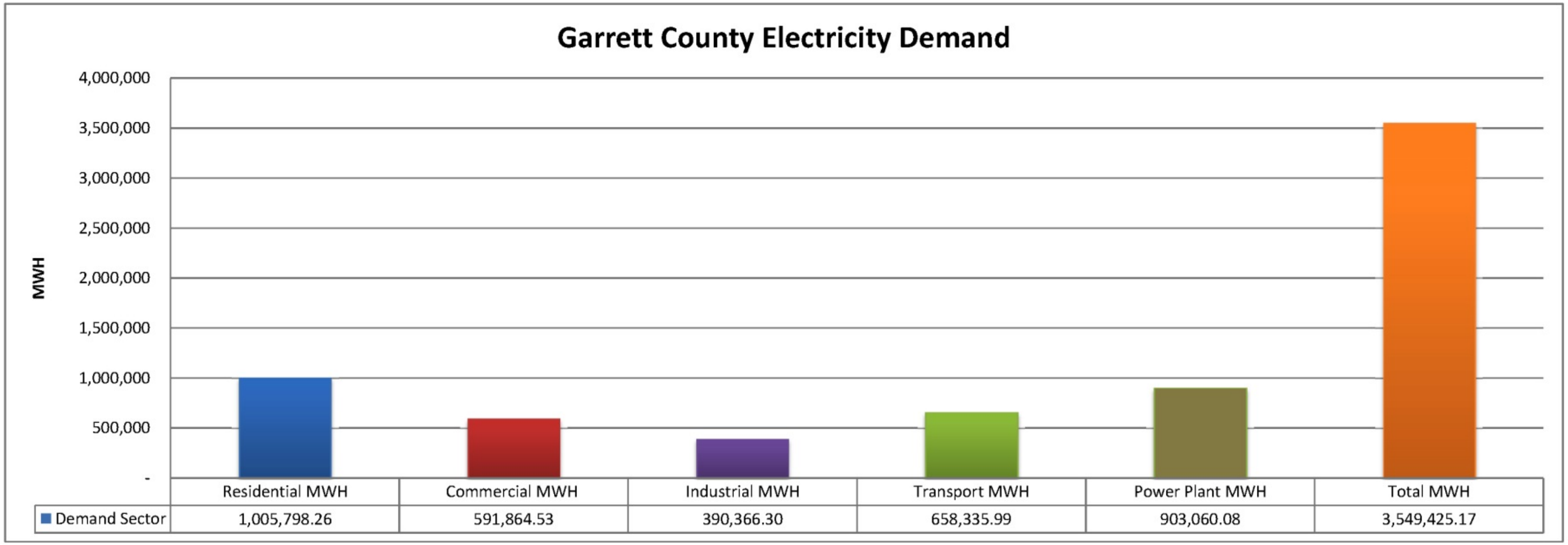


Figure 2-16: Garrett County Electricity Demand (E1d & E2d)

Garrett County Composted Organic Waste Production				
Category	Wet Short Tons	Dry Short Tons	Dry Metric Tons	*Data Source:*
Yard Waste	13,623.0	6,811.5	6,179.3	*Garrett County MSW Spreadsheet (Reported)*
Food Waste Mass	4,074.0	2,037.0	1,847.9	*Co-EAT, post composting: MGD WWTP*
Biosolids (WW Solids Mass)	418.2	209.1	189.7	*Co-EAT, post composting; MGD WWTP*
Organic Production Summary			8,216.9	
Field Application Capacity			4,326.0	*USDA Quickstats Food Production Summary; Compost Rate/Ac*

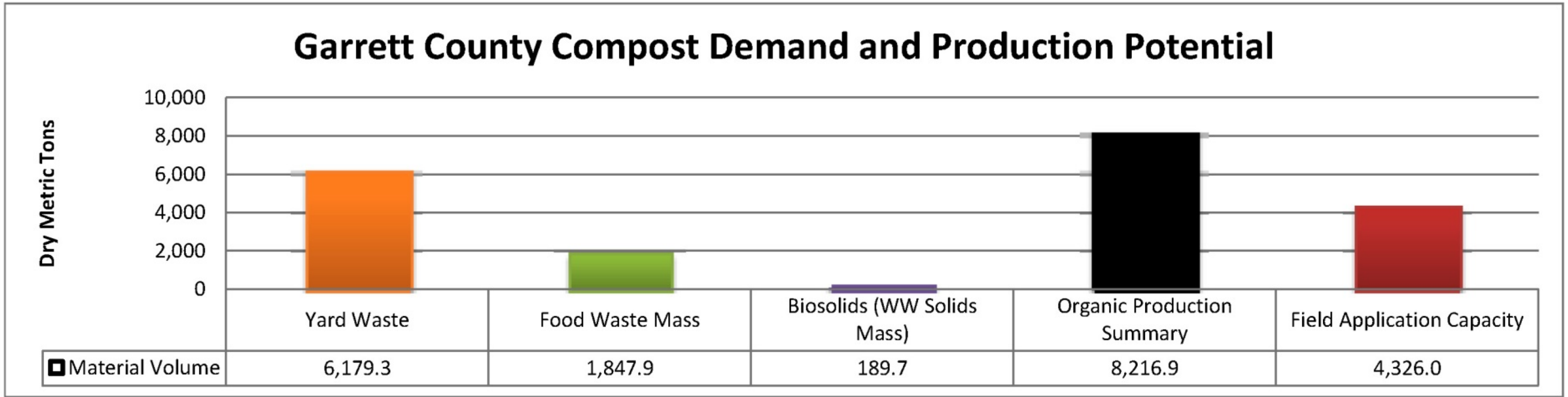


Figure 2-17: Garrett County Compost Demand and Organic Material Production Potential (M1c & M1d)

VS = volatile solids TS = total solids MCRT = mean cell residence time

Feedstock Parameter	Value	Units
Food Waste Mass	11.2	short tons/day
Food Waste Biogas Yield	6.65	ft³ CH⁴/lb TS
Food Waste Total Solids	29.98%	solids
Food Waste VS	89.62%	of total solids
Food Waste % of Total Waste	90.69%	total substrate
Weighted Total Feedstock Loading (TS)	22,323.47	lbs/day
Weighted Total Feedstock Loading (VS)	20,007.40	lbs/day
Wastewater Solids Mass	1.15	short tons/day
Wastewater Solids Yield	2.12	ft³ CH⁴/lb TS
Wastewater Total Solids	1.00%	solids
Wastewater VS	70.00%	of total solids
Wastewater % of Total Waste	9.31%	total substrate
Weighted Total Feedstock Mass	12	short tons/day
Weighted Total Feedstock Yield	6.23	ft³ CH⁴/lb TS
Weighted Total Feedstock Concentration (% TS)	27.3%	solids
Weighted VS Content of Total Feedstock	88%	volatile solids
Weighted Total Feedstock (TS)	2,291.5	lbs/day
Weighted Total Feedstock (VS)	1,604.0	lbs/day

Table 2-5: Garrett County Co-EAT Sludge Model Output (Input for M1d)

Garrett County			
Plant Name	NPDES ID	Avg. Annual MGD	Total Sludge DMT/y
Accident WWTP	MD0051721	0.078416667	
Bloomington WWTP	MD0060933	0.012416667	
Camp Sunrise MTN WWTP	MD0053074	0.0035	
Crellin WWTP	MD0052281	0.0135	
Deep Creek Lake WWTP	MD0054348	0.333333333	
Friendsville WWTP	MD0021083	0.1065	
~~Goodwill Home WWTP~~	MD0053384		
Gorman WWTP	MD0060950	0.002	
Grantsville WWTP	MD0020761	0.0775	
~~Keyser's Ridge WWTP~~	MD0069418		
Kitzmiller WWTP	MD0060941	0.008083333	
~~Mettekai Coal Corp.~~	MD0055182		
New Germany SP WWTP	MD0023981	0.00225	
Northern High and Middle School	MD0024449	0.004416667	
Oakland WWTP	MD0020648	0.387363636	
Swallow Falls WWTP	MD0052850	0.0227	
Trout Run WWTP	MD0051497	0.343545455	
~~Town Council of Oakland~~	MD0054704		
Total Annual Average MGD		1.395525758	

Table 2-6: Garrett County WWTPs MGD and Sludge Inputs for Co-EAT Model (Input for Input of M1d)

Garrett County MSW Generation by Category Based on Given Annual Volume		
Category	Garrett % Generation[3]	Garrett Generation
Paper and Paperboard	28%	7426.50
Glass	8%	2211.81
Metals	5%	1325.20
Plastics	3%	746.69
Rubber, leather and textiles	0%	0.00
Wood	0%	0.00
Yard Trimmings	46%	12350.60
Food waste	0%	0.00
Other	11%	2846.83
Total Generation in Tons	**1**	**26,907.62**

Census and Regional Overview Statistics				
County	2012 Pop	Pounds per day	Total Waste (lbs/yr)	Total Waste (MT/y)[3]
Garrett	30,097	5.40	59,321,187.00	26,907.62

Sources:

[3]Garrett County Department of Solid Waste & Recycling (2014): Ten Year Solid Waste Management Plan 2014-2024. Garrett County Government. Oakland, Maryland. Available online at https://www.garrettcounty.org/solid-waste-recycling/landfill-location-and-list-of-rates/ten-year-solid-waste-management-plan-1, checked on February 2016.

Garrett County Recovery Provided by County-Level Report				
Garrett County, Md	Res. Tons by Category[3]	Comm. Tons by Category[3]	Total Tons	Percentage
Paper and Paperboard	327	1574	1901.0	10%
Glass	143	51	194.0	1%
Metals	22	553	575.0	3%
Plastics	44	64	108.0	1%
Rubber, leather and textiles	21	889	910.0	5%
Wood			0.0	0%
Yard Trimmings	233	15035	15268.0	77%
Food waste			0.0	0%
Other	22	889	911.0	5%
Total Recovery in Tons	**812**	**19,055.0**	**19,867.0**	**100%**

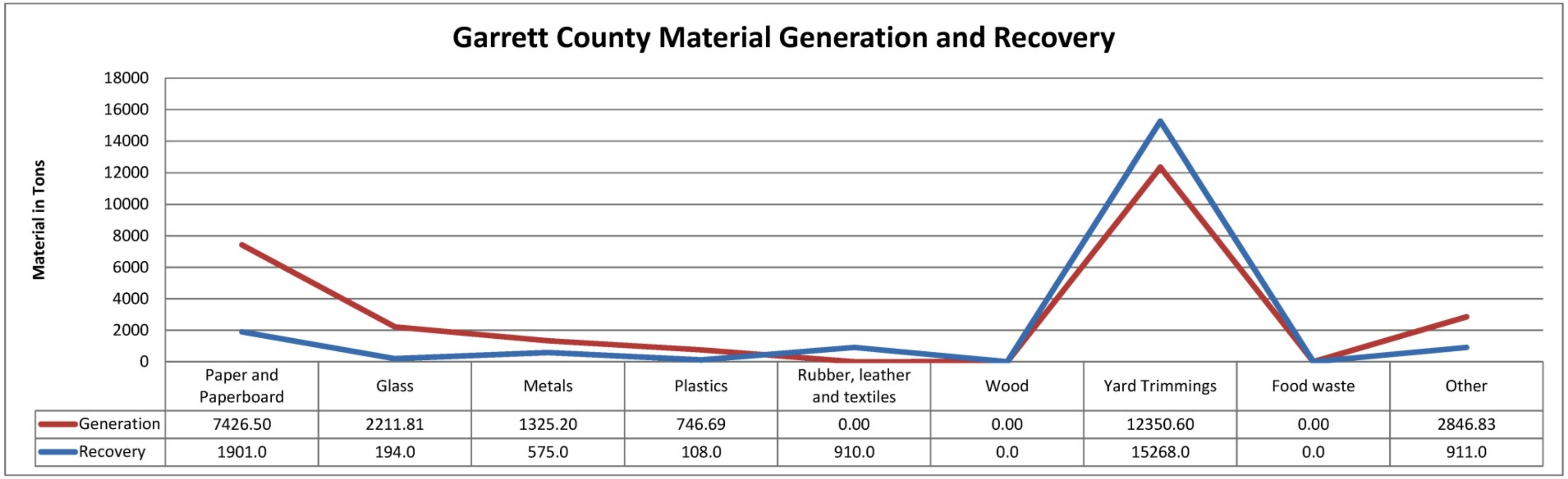


Figure 2-18: Garrett County Material Generation (M2c & M2d)

3 Logan County, Illinois

Logan County, Illinois

FOOD CAPACITY	
FDA Daily Food Groups	Total Tons Production Per Year
FRUIT AND NUTS	-
VEGETABLES	13,097
CEREAL GRAINS	539,541
HAY/GRASS	7,174
FEED GRAINS	10,107
PROTEIN	63,262
DAIRY	321

FOOD DEMAND	*2012 ACS Population:	30305
FDA Daily Food Groups	Annual Demand in Metric Tons	Metric Tons/Capita*/Year**
FRUIT AND NUTS	5,531	0.1825
VEGETABLES	6,913	0.228125
CEREAL GRAINS	2,074	0.0684375
HAY/GRASS	35,293	*Varies Per Livestock Type, Below*
FEED GRAINS	110,958	*Varies Per Livestock Type, Below*
PROTEIN	1,901	0.0627343
DAIRY	8,296	0.27375

Demand of Feed/ Hay Grains	Hay in Metric Tons / Year	Corn in Metric Tons / Year
Milk Cows	413	4
Beef Cows	33,500	33,500
Goats	276	55
Hogs	-	76,439
Sheep	1,104	110
Poultry	-	849
Total Feed(tons)	35,293.30	110,958.40

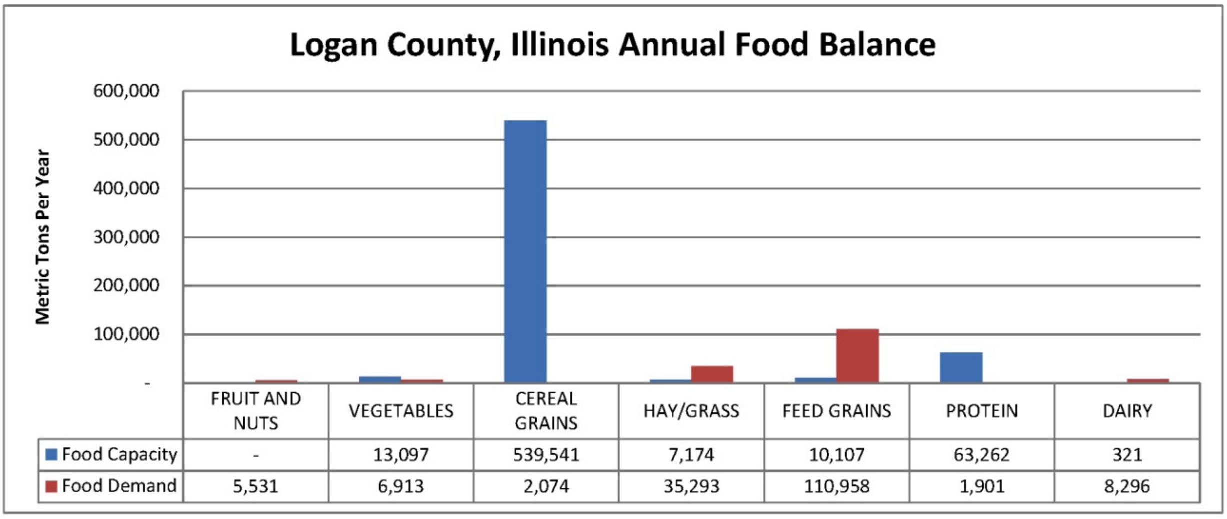


Figure 3-1: Logan County food Summary Page (F1c - F7c & F1d - F7d)

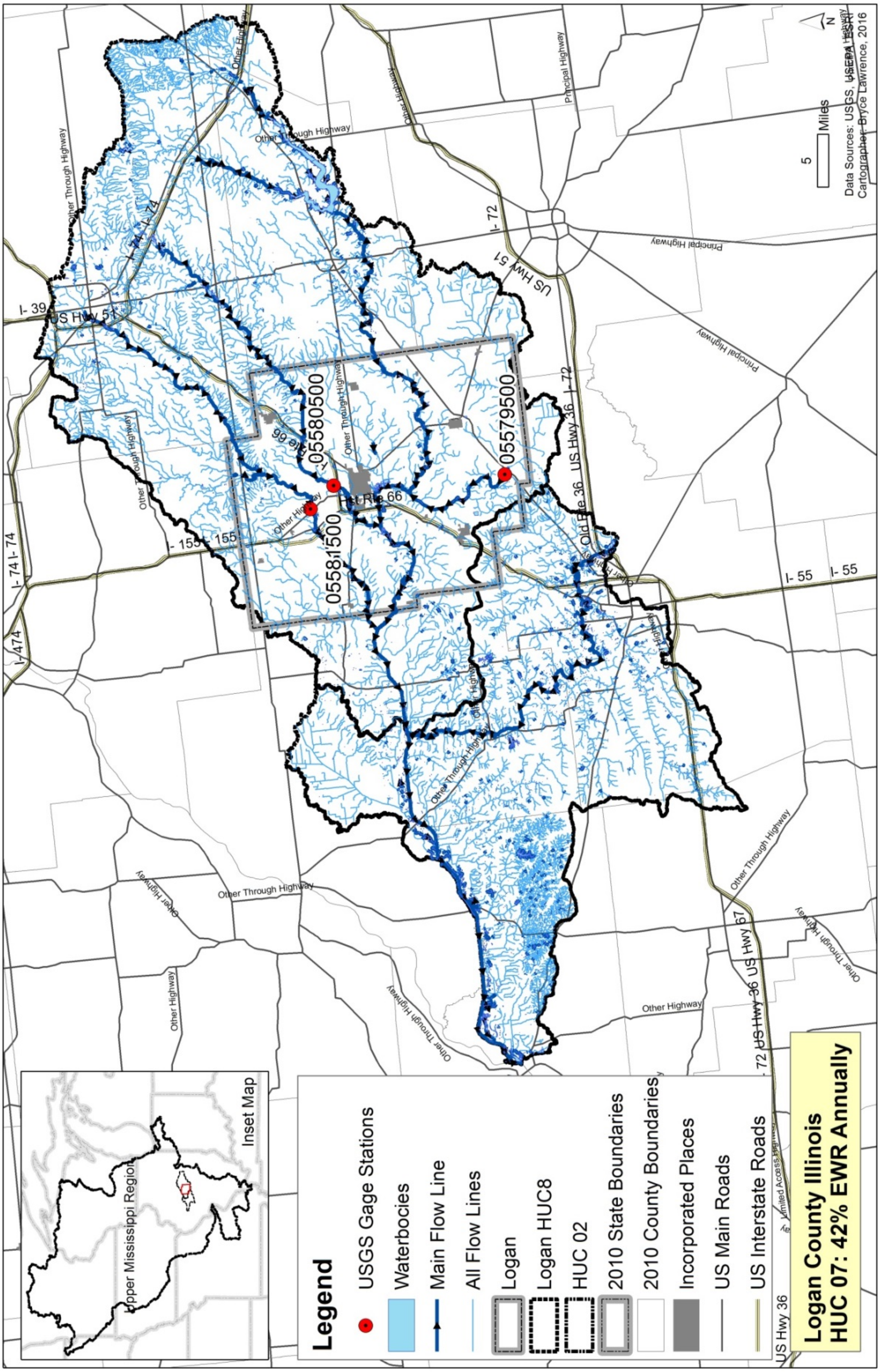


Figure 3-2: Logan County Stream Network and Streamflow Sample Stations (W1c)

Logan County, Illinois

Total Available Stream Flow in Cubic Meters (W1c) with Human Abstraction (W1d)

USGS Station No. 05581500	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge:	34	64	103	141	105	73	43	22	14	14	17	19
EWR Requirement 41%	14	27	43	59	44	30	18	9	6	6	7	8
Available Adjusted CFS	20	37	60	82	61	42	25	13	8	8	10	11
EWR Corrected Mean Monthly Cubic Meters	1,468,887	2,745,971	4,442,860	6,068,521	4,529,183	3,132,093	1,847,595	953,732	607,140	625,147	739,502	822,855
Total P25 Discharge	2,532,563	4,734,432	7,660,104	10,462,967	7,808,937	5,400,161	3,185,508	1,644,366	1,046,793	1,077,840	1,275,004	1,418,716

USGS Station No. 05580500	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1944-1971	22.0	48.1	81.6	128.1	89.1	74.7	37.7	17.7	7.9	6.7	7.9	9.5
EWR Requirement 41%	9.2	20.2	34.3	53.8	37.4	31.4	15.9	7.4	3.3	2.8	3.3	4.0
Available Adjusted CFS	12.8	27.9	47.4	74.3	51.7	43.3	21.9	10.3	4.6	3.9	4.6	5.5
EWR Corrected Mean Monthly Cubic Meters	950,251.3	2,077,710.1	3,523,935.7	5,527,562.1	3,845,559.3	3,222,732.7	1,629,002.3	762,985.7	341,696.0	287,511.9	342,127.6	411,566.7
Total P25 Discharge	1,638,364.4	3,582,258.8	6,075,751.3	9,530,279.6	6,630,274.6	5,556,435.8	2,808,624.6	1,315,492.6	589,131.0	495,710.2	589,875.2	709,597.8

USGS Station No. 05579500	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1948-2015	4.4	4.8	5.0	5.1	5.1	5.1	4.3	3.7	3.6	3.6	3.9	4.3
EWR Requirement 41%	1.9	2.0	2.1	2.1	2.1	2.1	1.8	1.5	1.5	1.5	1.6	1.8
Available Adjusted CFS	2.6	2.8	2.9	3.0	3.0	3.0	2.5	2.1	2.1	2.1	2.2	2.5
EWR Corrected Mean Monthly Cubic Meters	191,916.0	205,211.1	214,276.5	220,383.1	220,444.4	220,728.4	186,012.6	158,918.2	154,691.2	155,256.4	167,179.3	184,606.3
Total P25 Discharge	330,889.6	353,812.2	369,442.2	379,970.9	380,076.5	380,566.2	320,711.3	273,996.9	266,708.9	267,683.5	288,240.1	318,286.8

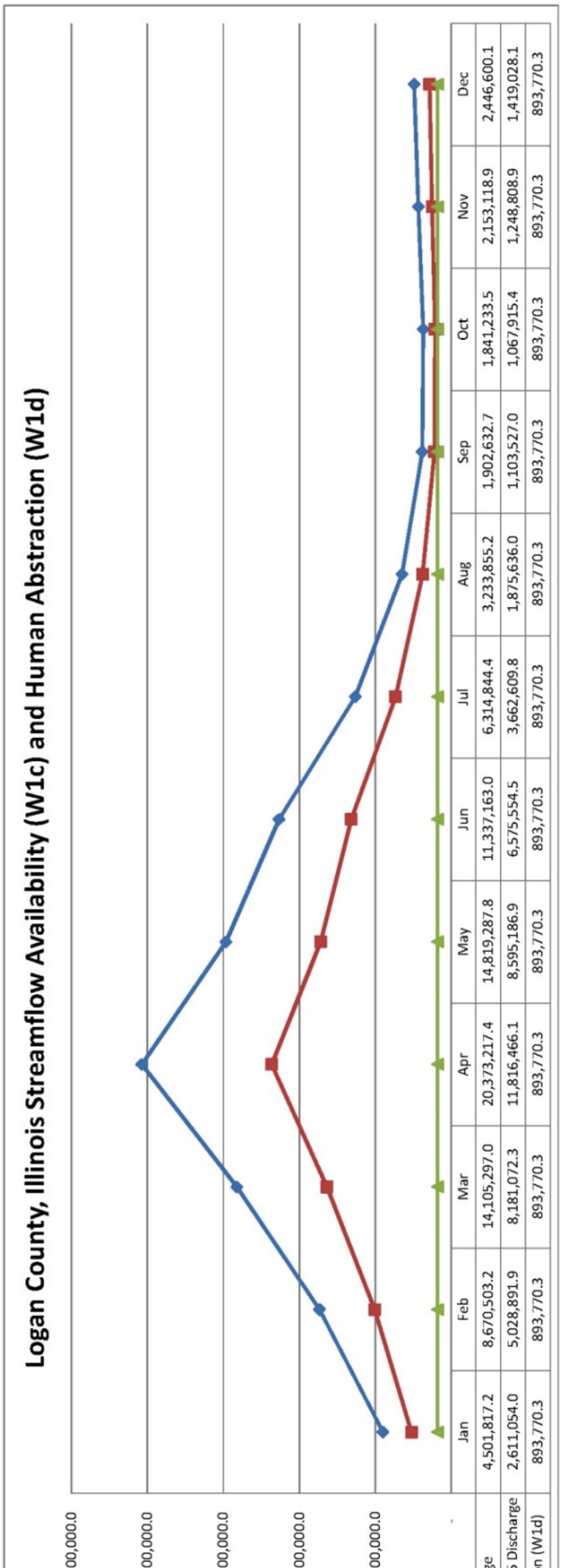
Total P25 Discharge	4,501,817.2	8,670,503.2	14,105,297.0	20,373,217.4	14,819,287.8	11,337,163.0	6,314,844.4	3,233,855.2	1,902,632.7	1,841,233.5	2,153,118.9	2,446,600.1
EWR Adjusted P25 Discharge	2,611,054.0	5,028,891.9	8,181,072.3	11,816,466.1	8,595,186.9	6,575,554.5	3,662,609.8	1,875,636.0	1,103,527.0	1,067,915.4	1,248,808.9	1,419,028.1
Human Abstraction (W1d)	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3
Human Abstraction as % EWR Adjusted	0.3	0.2	0.1	0.1	0.1	0.1	0.2	0.5	0.8	0.8	0.7	0.6

Total EWR Adjusted Annual Available Streamflow Volume in Cubic Meters	**53,185,751**

Table 3-1: Logan County EWR Adjusted Annual P25 Streamflow Availability (W1c)

Logan County, Illinois 2010 Adjusted Water Abstraction		
Category	**Mgal/D Surface**	**Mgal/D Ground**
Public Supply	-	3.58
Mining	9.47	0.02
Livestock	-	0.38
Aquaculture	-	-
Irrigation	0.03	0.03
Daily Total	*9.5*	*4.01*
Annual Abstraction Projection by Source (USGS NWIS)	3,468	1,464
Total Annual Abstraction in Mgal	4,931	
2012 Total Annual Returns in Mgal (US EPA ECHO / NPDES)	2,098	
Total Adjusted Abstraction in Mgal	**2,833.31**	
Total Adjusted Abstraction in cubic meters per year / month	10,725,244	893,770

Table 3-2: Logan County Adjusted Water Abstraction (W1d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	4,501,817.2	8,670,503.2	14,105,297.0	20,373,217.4	14,819,287.8	11,337,163.0	6,314,844.4	3,233,855.2	1,902,632.7	1,841,233.5	2,153,118.9	2,446,600.1
EWR Adjusted P25 Discharge	2,611,054.0	5,028,891.9	8,181,072.3	11,816,466.1	8,595,186.9	6,575,554.5	3,662,609.8	1,875,636.0	1,103,527.0	1,067,915.4	1,248,808.9	1,419,028.1
Human Abstraction (W1d)	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3	893,770.3

Figure 3-3: Logan County Adjusted Streamflow Availability and Human Abstraction (W1c & W1d)

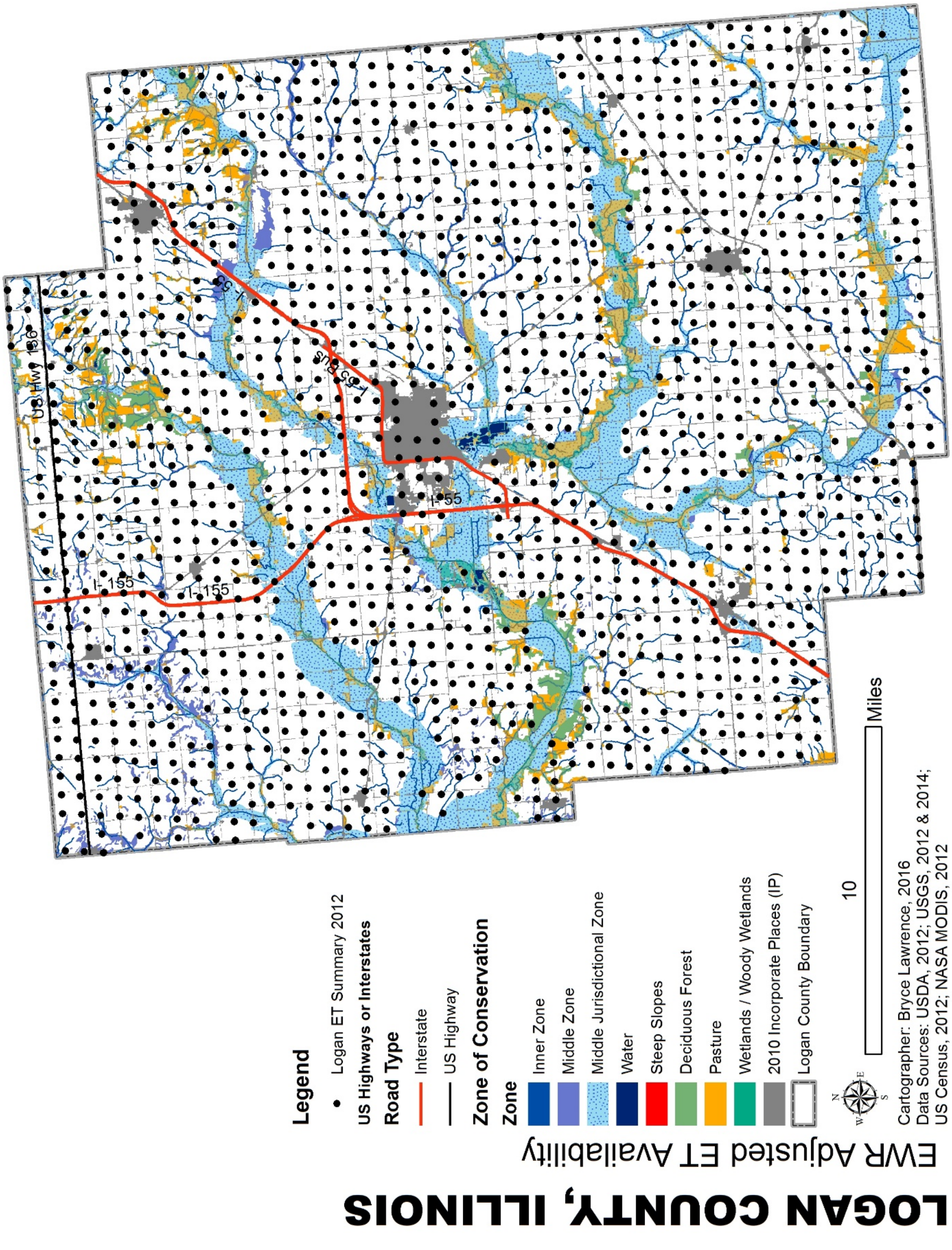


Figure 3-4: Logan County EWR Adjusted ET Availability Sample Points (W2c)

Logan County, Illinois

Monthly Green Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	GW Annual Total
Value in Cubic Meters	15,385,261	15,385,261	15,385,261	54,776,972	89,907,496	89,907,496	89,907,496	89,526,365	89,698,766	88,792,390	88,792,390	15,385,261	742,850,415

Monthly Blue Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	BW Annual Total
Value in Cubic Meters	525,294	513,832	525,294	872,580	1,266,665	1,262,844	1,266,665	1,266,402	1,247,657	1,197,492	1,197,492	525,294	11,667,512

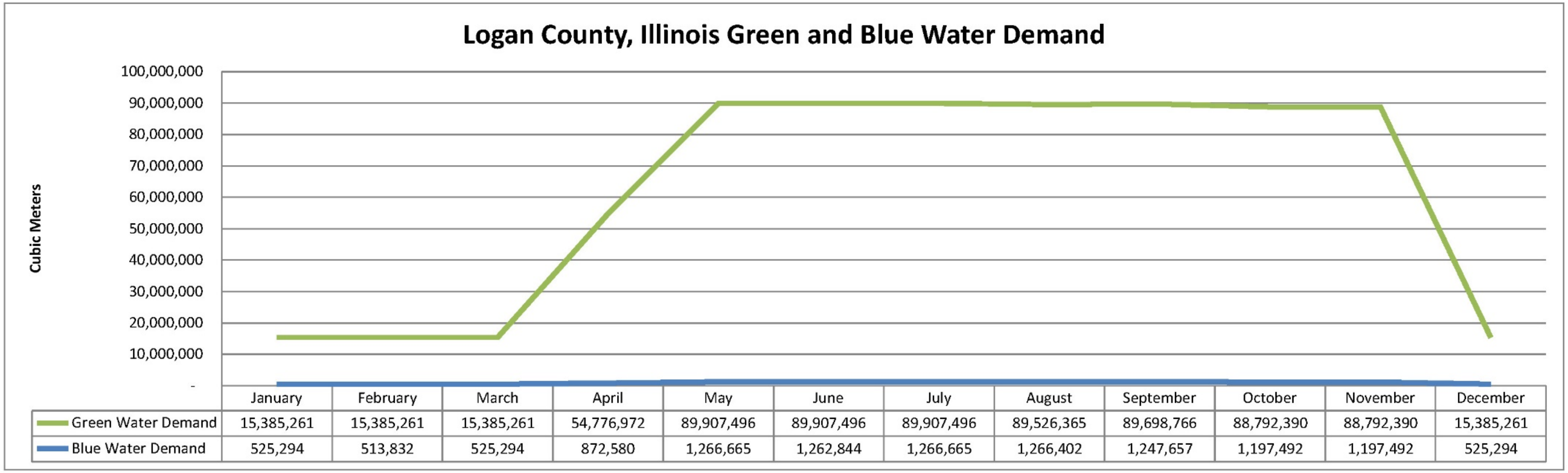
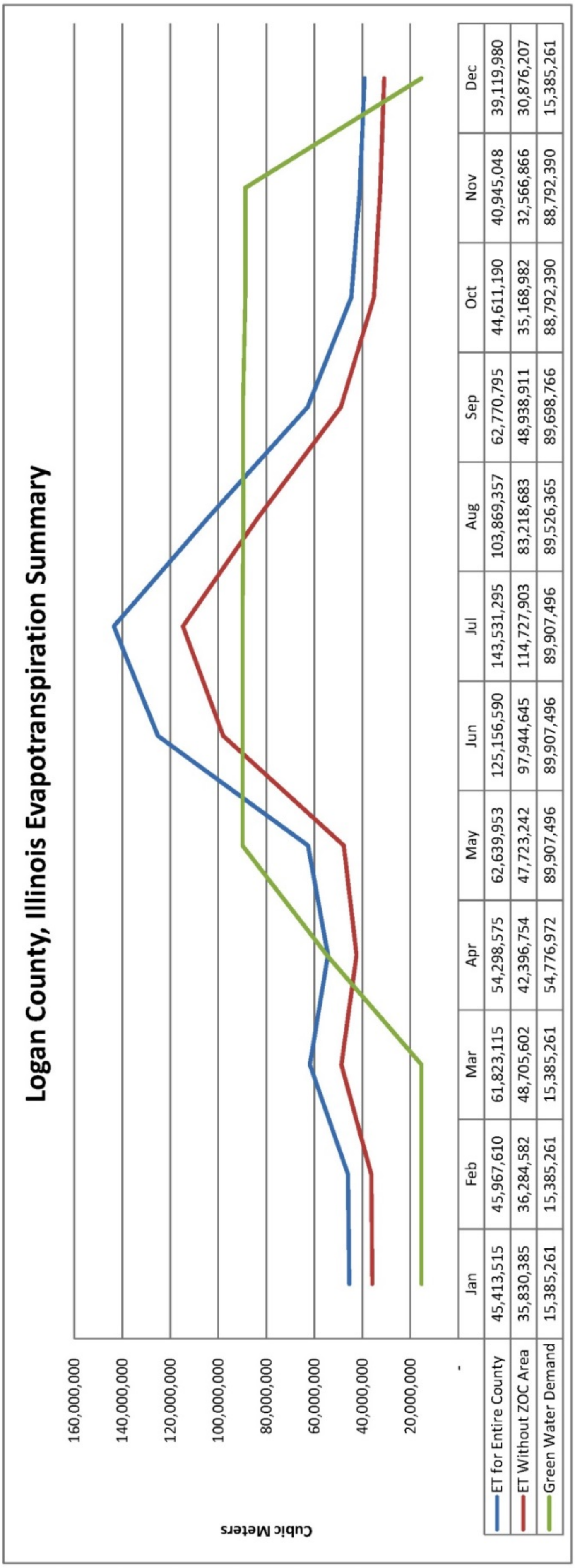
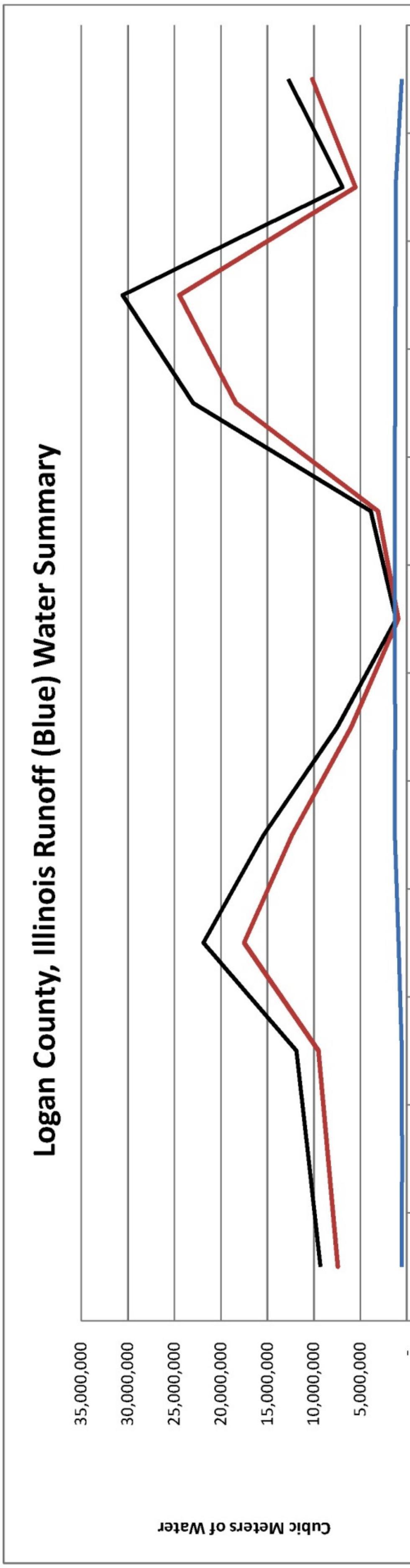


Figure 3-5: Logan County ET (Green Water) and Surface (Blue Water) Demand (W2d & W3d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET for Entire County	45,413,515	45,967,610	61,823,115	54,298,575	62,639,953	125,156,590	143,531,295	103,869,357	62,770,795	44,611,190	40,945,048	39,119,980
ET Without ZOC Area	35,830,385	36,284,582	48,705,602	42,396,754	47,723,242	97,944,645	114,727,903	83,218,683	48,938,911	35,168,982	32,566,866	30,876,207
Green Water Demand	15,385,261	15,385,261	15,385,261	54,776,972	89,907,496	89,907,496	89,907,496	89,526,365	89,698,766	88,792,390	88,792,390	15,385,261

Figure 3-6: Logan County ET (Green Water) Summary (W2c & W2d)



	January	February	March	April	May	June	July	August	September	October	November	December
Total Runoff	9,270,704	10,571,560	11,861,719	21,872,182	15,399,721	7,473,923	1,131,630	3,868,281	22,962,050	30,580,224	6,905,150	12,713,738
EWR Adjusted Runoff	7,416,563	8,457,248	9,489,375	17,497,746	12,319,777	5,979,138	905,304	3,094,625	18,369,640	24,464,179	5,524,120	10,170,990
Blue Water Demand	525,294	513,832	525,294	872,580	1,266,665	1,262,844	1,266,665	1,266,402	1,247,657	1,197,492	1,197,492	525,294

Figure 3-7: Logan County Surface (Blue) Water Availability and Demand (W3c & W3d)

N	Logan County, Illinois	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	7,416,563	8,457,248	9,489,375	17,497,746	12,319,777	5,979,138	905,304	3,094,625	18,369,640	24,464,179	5,524,120	10,170,990
	Liters / month	7,416,562,960	8,457,248,320	9,489,375,440	17,497,745,600	12,319,776,800	5,979,138,000	905,304,368	3,094,624,872	18,369,640,000	24,464,179,200	5,524,119,760	10,170,990,400
2.40833	mg/l limit	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
	Total allowed Mg	17,861,555,795	20,367,873,037	22,853,579,185	42,140,403,987	29,670,129,127	14,399,757,350	2,180,274,686	7,452,888,233	44,240,216,333	58,917,898,240	13,303,921,755	24,495,135,213
	Total allowed tons (N)	18	20	23	42	30	14	2	7	44	59	13	24
0.62	Nnat in mg/l	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
	Total mg Nnat	4,598,269,035	5,243,493,958	5,883,412,773	10,848,602,272	7,638,261,616	3,707,065,560	561,288,708	1,918,667,421	11,389,176,800	15,167,791,104	3,424,954,251	6,306,014,048
	Tons Nnat	5	5	6	11	8	4	1	2	11	15	3	6
	Corrected limit	13	15	17	31	22	11	2	6	33	44	10	18
	Total Annual N Load (t)	**221.20**											

P	Logan County, Illinois	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	7,416,563	8,457,248	9,489,375	17,497,746	12,319,777	5,979,138	905,304	3,094,625	18,369,640	24,464,179	5,524,120	10,170,990
	Liters / month	7,416,562,960	8,457,248,320	9,489,375,440	17,497,745,600	12,319,776,800	5,979,138,000	905,304,368	3,094,624,872	18,369,640,000	24,464,179,200	5,524,119,760	10,170,990,400
1.67	mg/l month avgerage limit	12,385,660,143	14,123,604,694	15,847,256,985	29,221,235,152	20,574,027,256	9,985,160,460	1,511,858,295	5,168,023,536	30,677,298,800	40,855,179,264	9,225,279,999	16,985,553,968
	Tons / Month	12.39	14.12	15.85	29.22	20.57	9.99	1.51	5.17	30.68	40.86	9.23	16.99
0.06	Pnat in mg/l	444,993,778	507,434,899	569,362,526	1,049,864,736	739,186,608	358,748,280	54,318,262	185,677,492	1,102,178,400	1,467,850,752	331,447,186	610,259,424
	Tons / month	0.44	0.51	0.57	1.05	0.74	0.36	0.05	0.19	1.10	1.47	0.33	0.61
	Corrected tons	11.94	13.62	15.28	28.17	19.83	9.63	1.46	4.98	29.58	39.39	8.89	16.38
	Total Annual P Load (t)	**199.14**											

Table 3-3: Logan County Critical Nitrogen and Phosphorus Load Limits (W4c & W5c)

Logan County N and P Load Summary			
CROPGROUP	N_load	P_load	Hectares
Oilseed	162.1	129.6	47,391.7
Cereal	548.0	232.4	86,370.9
Pulse	0.0	0.0	0.5
Veg	0.7	0.3	50.4
N and P Point Loads	0.5	-	(N)n=1, (P)n=0
Total N and P Loads per Year	**711.3**	**362.4**	

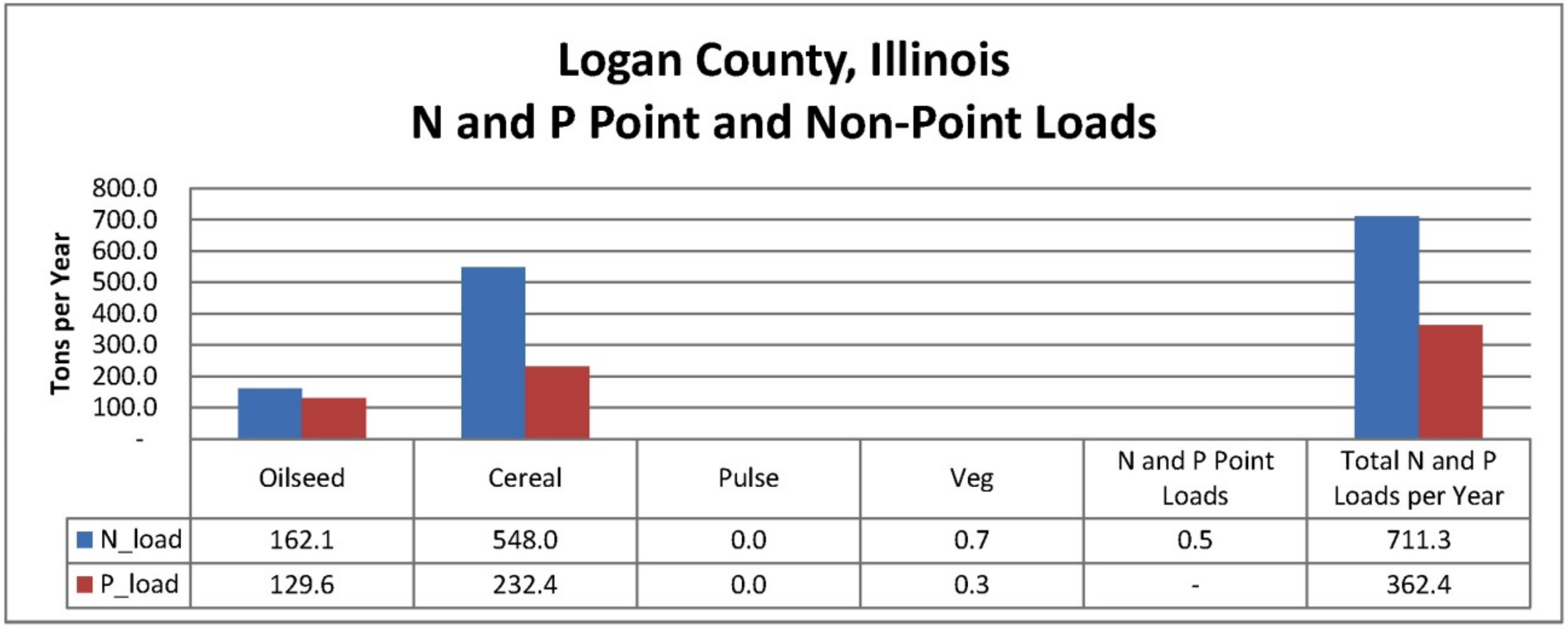


Figure 3-8: Logan County Nitrogen and Phosphorus Point and Non-Point Source Loads (W4d & W5d)

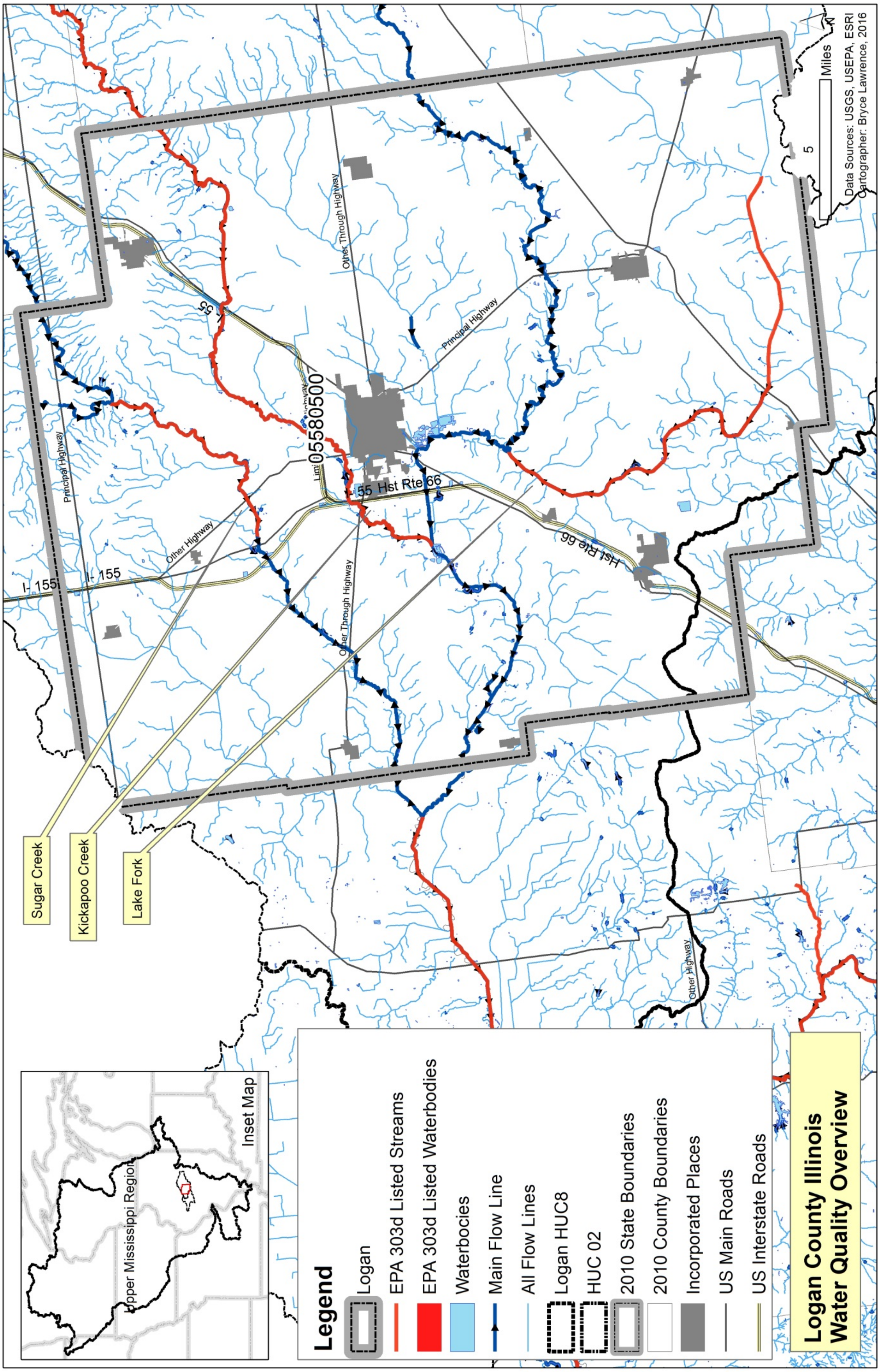


Figure 3-9: Logan County EPA 303d Listed Streams and Waterbodies

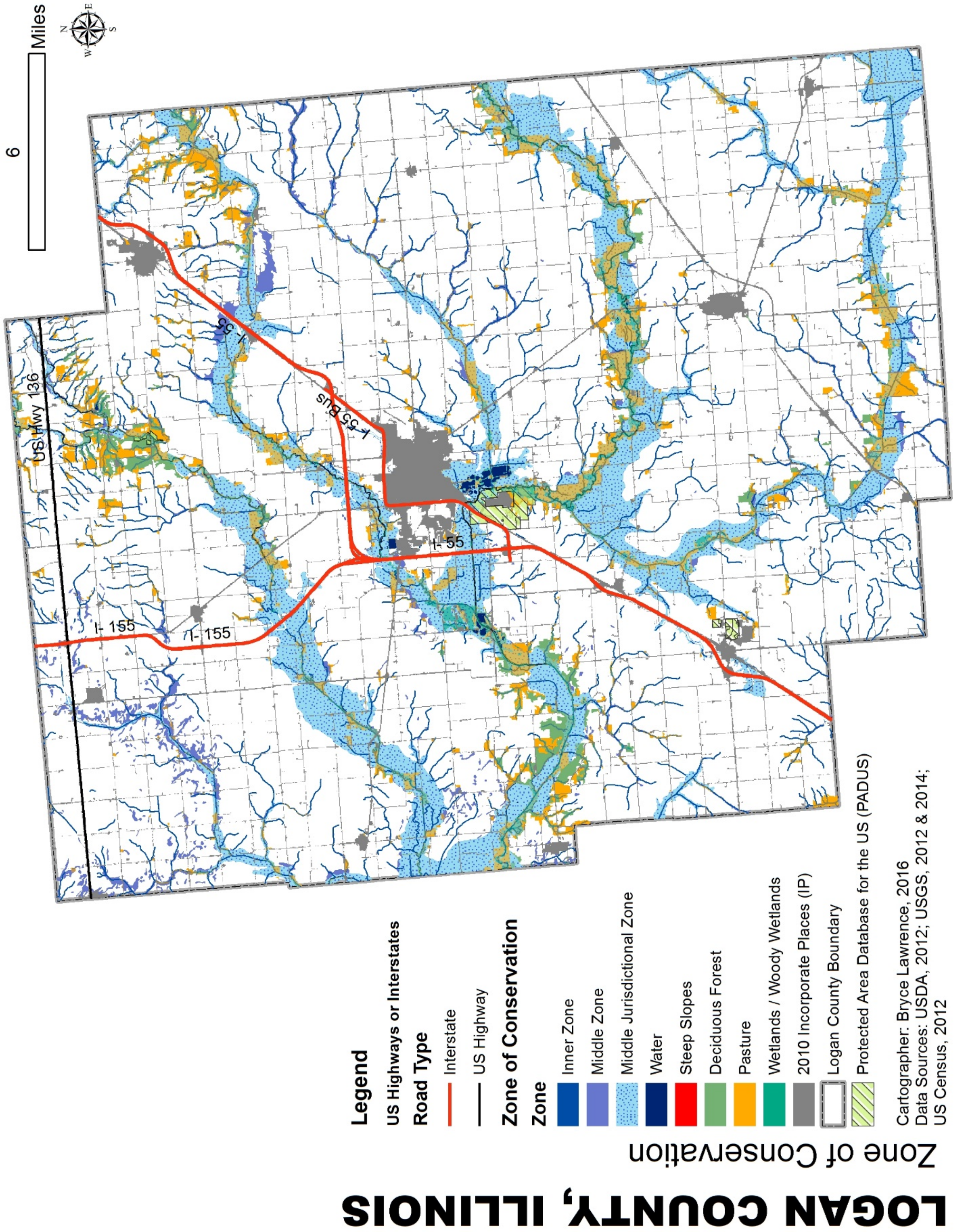


Figure 3-10: Logan County Existing and Potential Zone of Conservation (EC1c & EC1c)

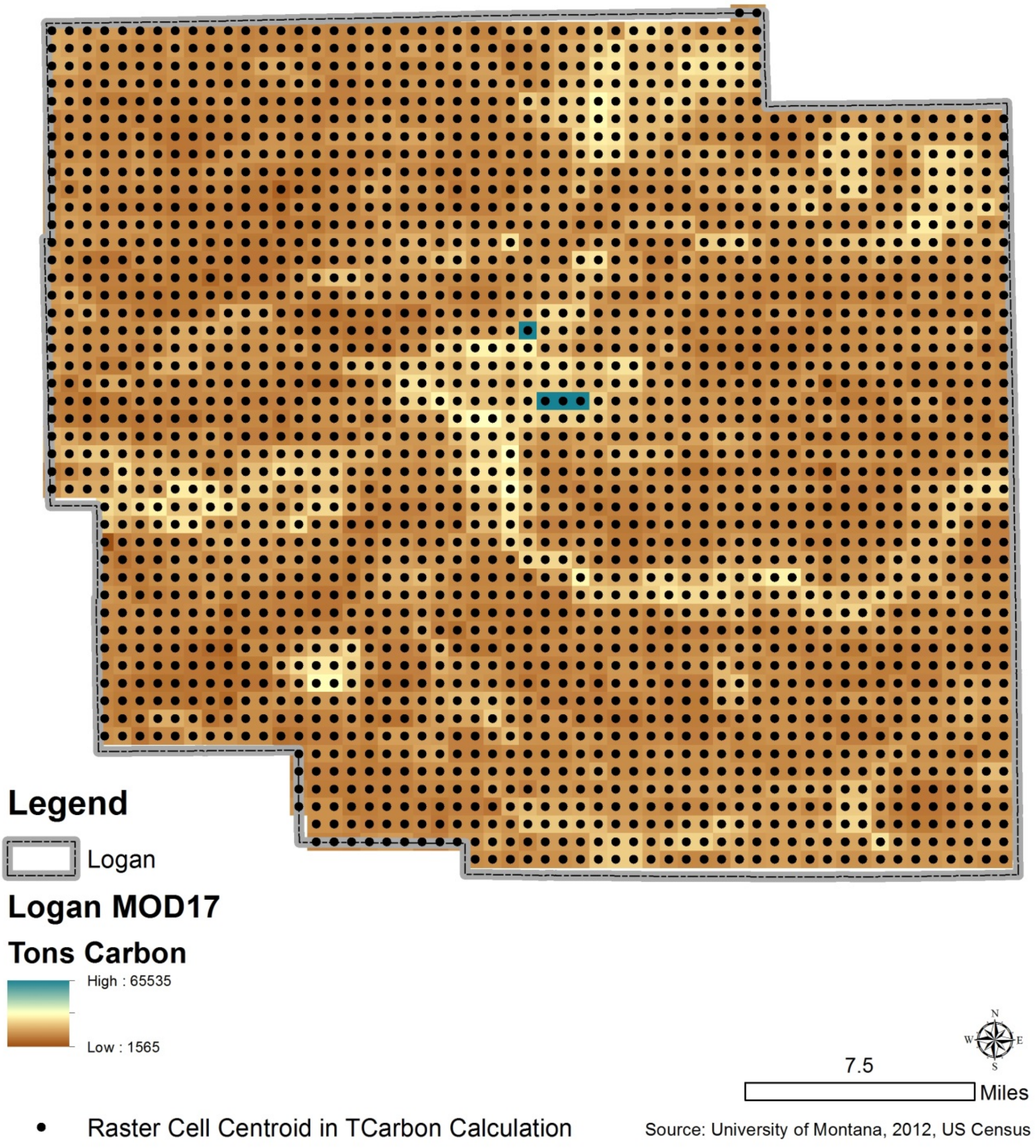


Figure 3-11: Logan County Net Primary Productivity (NPP) in Tons of Carbon per year, as Estimate for Carbon Sequestration Potential (C1c)

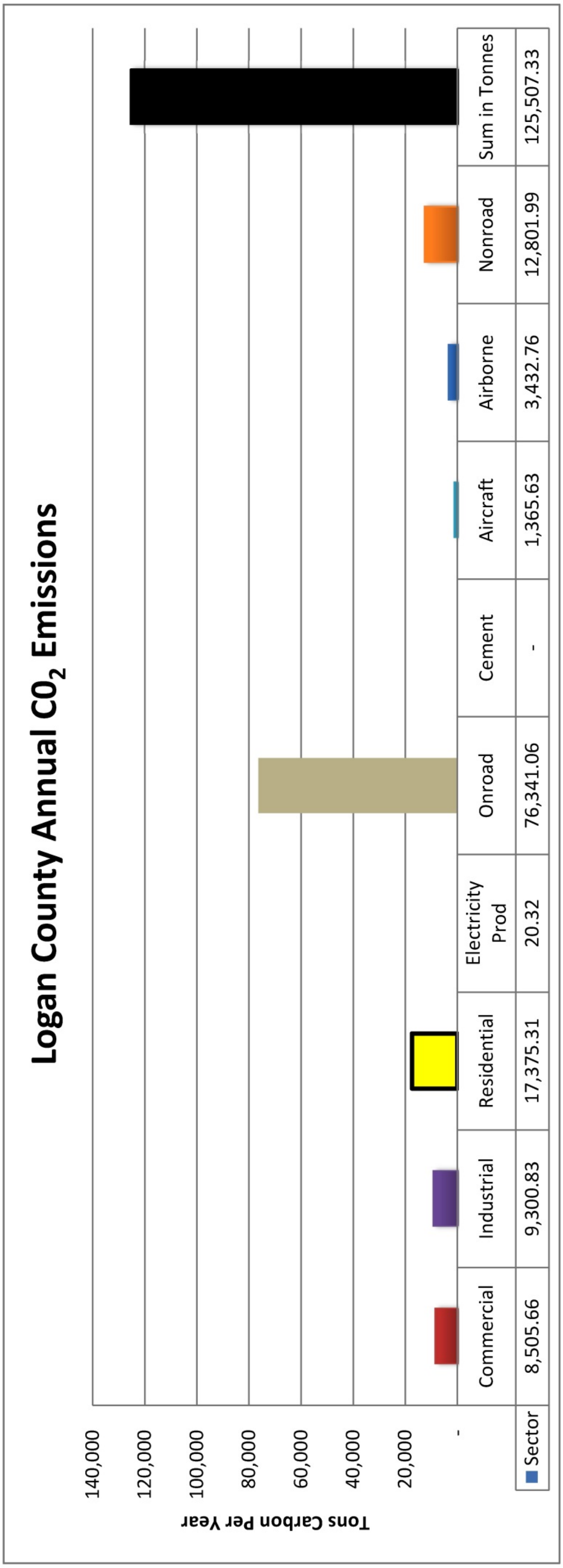
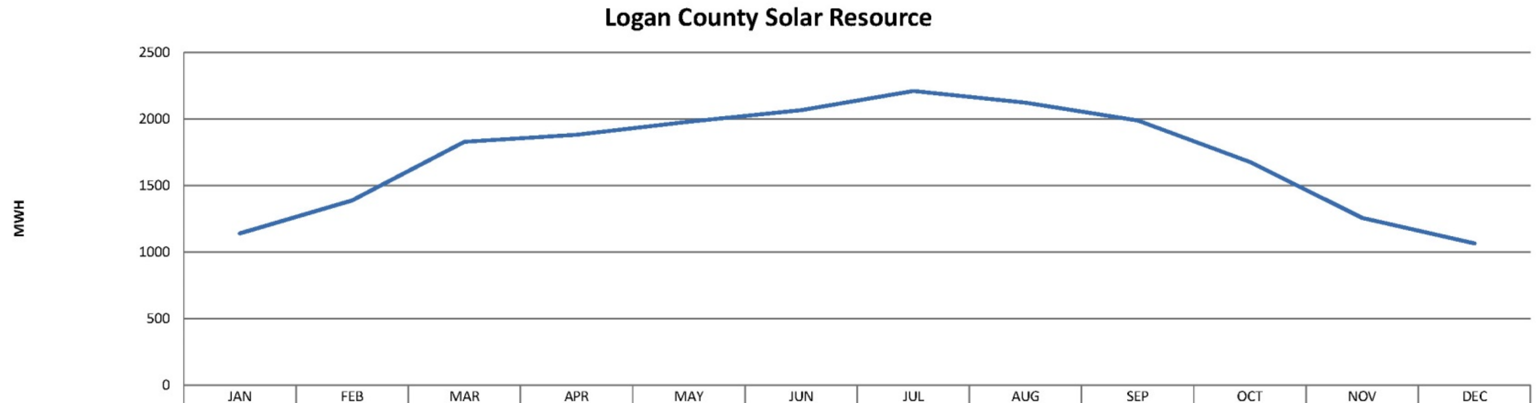


Figure 3-12: Logan County C0$_2$ Emissions in Tons per Year (C1d)

Logan County Solar Resouce Summary												
Raster Tile OID	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
30	3.047	4.202	4.895	5.200	5.254	5.707	5.943	5.663	5.543	4.411	3.455	2.847
31	3.099	4.198	4.846	5.248	5.275	5.709	5.924	5.689	5.497	4.441	3.435	2.823
32	3.024	4.078	4.920	5.257	5.289	5.710	5.926	5.700	5.491	4.420	3.430	2.801
33	3.086	4.182	4.937	5.169	5.259	5.691	5.926	5.697	5.483	4.395	3.404	2.769
34	3.052	4.067	4.926	5.181	5.287	5.707	5.912	5.661	5.512	4.449	3.413	2.804
35	3.079	4.114	4.904	5.221	5.328	5.736	5.926	5.694	5.521	4.452	3.544	2.846
36	3.028	4.057	4.892	5.162	5.275	5.715	5.917	5.697	5.477	4.531	3.483	2.833
37	3.135	4.179	4.909	5.264	5.327	5.708	5.947	5.695	5.490	4.518	3.489	2.781
38	3.046	4.068	4.925	5.173	5.319	5.691	5.926	5.669	5.507	4.465	3.458	2.829
39	3.021	4.113	4.946	5.161	5.325	5.687	5.916	5.650	5.521	4.454	3.458	2.803
40	2.994	4.036	4.869	5.143	5.312	5.706	5.895	5.662	5.517	4.441	3.441	2.798
41	3.048	4.153	4.878	5.261	5.341	5.708	5.924	5.699	5.502	4.545	3.530	2.815
42	3.091	4.107	4.893	5.216	5.355	5.705	5.927	5.693	5.502	4.527	3.510	2.850
43	3.021	4.186	4.945	5.257	5.330	5.743	5.937	5.683	5.493	4.497	3.510	2.804
44	3.133	4.110	4.829	5.155	5.327	5.728	5.906	5.633	5.548	4.484	3.472	2.926
45	3.015	4.085	4.860	5.170	5.307	5.712	5.912	5.699	5.510	4.499	3.474	2.777
46	2.943	4.165	4.947	5.189	5.279	5.717	5.926	5.694	5.495	4.486	3.429	2.783
47	3.149	4.085	4.879	5.240	5.321	5.751	5.949	5.696	5.557	4.558	3.497	2.904
48	3.159	4.130	4.981	5.266	5.327	5.742	5.952	5.703	5.499	4.559	3.533	2.924
49	3.081	4.050	4.955	5.308	5.286	5.750	5.935	5.735	5.514	4.525	3.500	2.884
50	3.044	4.068	4.899	5.267	5.341	5.747	5.928	5.696	5.507	4.506	3.494	2.901
51	3.051	4.075	4.868	5.217	5.333	5.752	5.906	5.691	5.523	4.518	3.471	2.934
52	2.983	4.099	5.006	5.238	5.313	5.753	5.909	5.679	5.485	4.530	3.482	2.836
53	3.125	4.100	4.820	5.212	5.305	5.747	5.944	5.717	5.545	4.554	3.541	2.982
54	3.111	4.201	4.872	5.220	5.286	5.755	5.932	5.725	5.503	4.559	3.543	2.892
55	3.117	4.171	4.908	5.222	5.311	5.746	5.931	5.741	5.519	4.515	3.509	2.924
56	2.987	4.137	4.908	5.180	5.322	5.752	5.928	5.722	5.508	4.518	3.518	2.922
57	2.964	4.136	4.869	5.215	5.311	5.754	5.933	5.718	5.514	4.542	3.468	2.891
Average kWh/m^2/month	3.058	4.120	4.903	5.215	5.309	5.726	5.926	5.693	5.510	4.496	3.482	2.853
Residential Units	9,581											
NR Units	612											
Annual Sum in MWH	**20,613**											



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Total Monthly MWH	1141.012	1388.244	1829.245	1882.788	1980.628	2067.388	2211.020	2123.941	1989.413	1677.517	1257.099	1064.396

Figure 3-13: Solar (PV) Resource Potential Summary for Logan County (E1c)

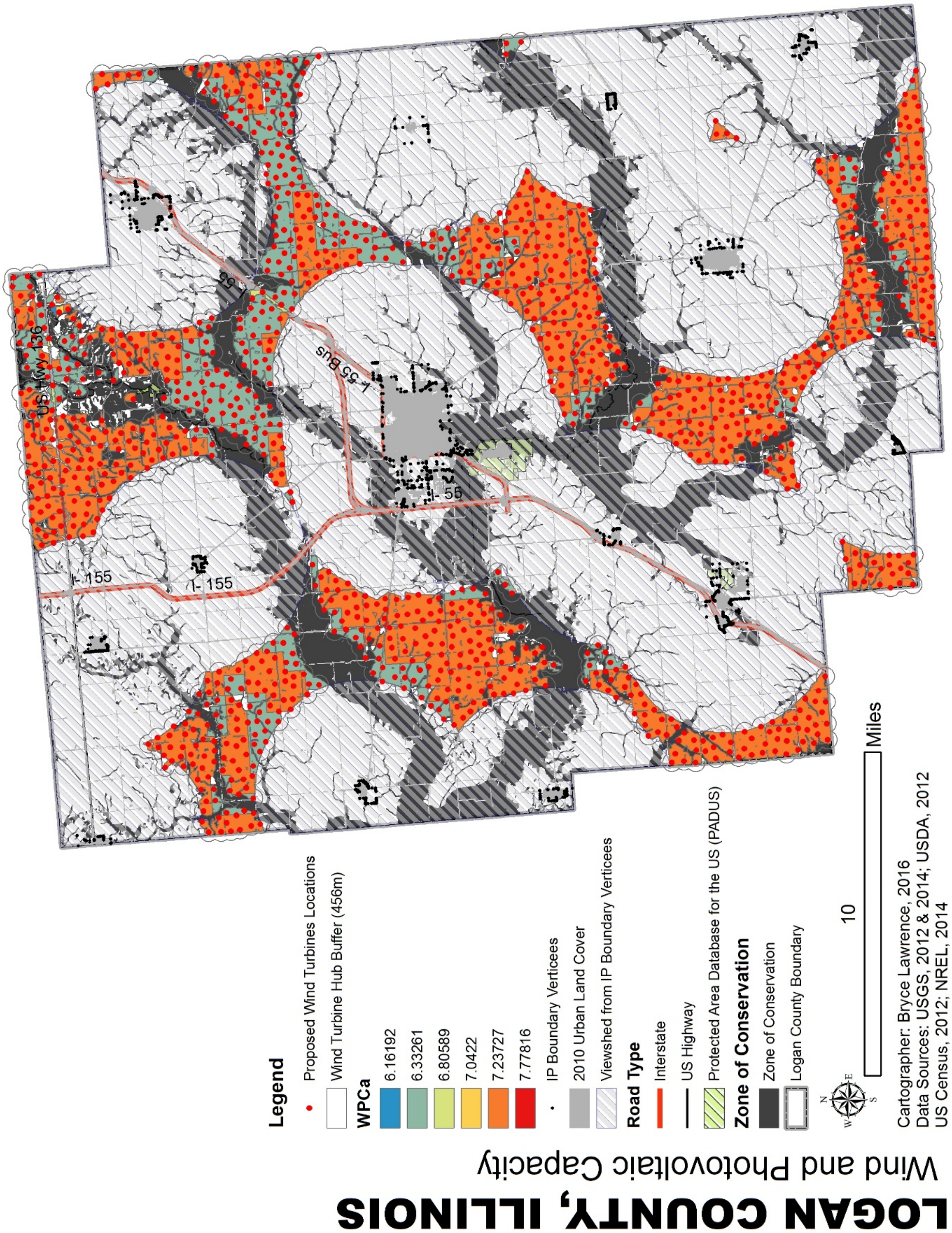


Figure 3-14: Logan County Potential Wind and PV Renewable Electricity Locations Map (E1c)

Logan County, Illinois Wind Power Potential				
Adjusted Wind Power Class	Wind Speed	Area in Acres	No. of Turbines	MWh
Logan $WPC_{\alpha 1}$	6.02144	58	2	17,110
Logan $WPC_{\alpha 2}$	6.33261	21,581	351	3,131,373
Logan $WPC_{\alpha 3}$	6.59223	257	4	39,560
Logan $WPC_{\alpha 4}$	6.80589	43	1	10,346
Logan $WPC_{\alpha 5}$	6.88165	58,988	880	9,422,951
Logan $WPC_{\alpha 6}$	7.23727	436	5	58,214
Wind Sum	-	81,362	1243	12,679,553
Solar Sum				20,612
Grand Total Renewable				12,700,165

Table 3-4: Logan County Potential Wind and PV Renewable Electricity Locations (E1c)

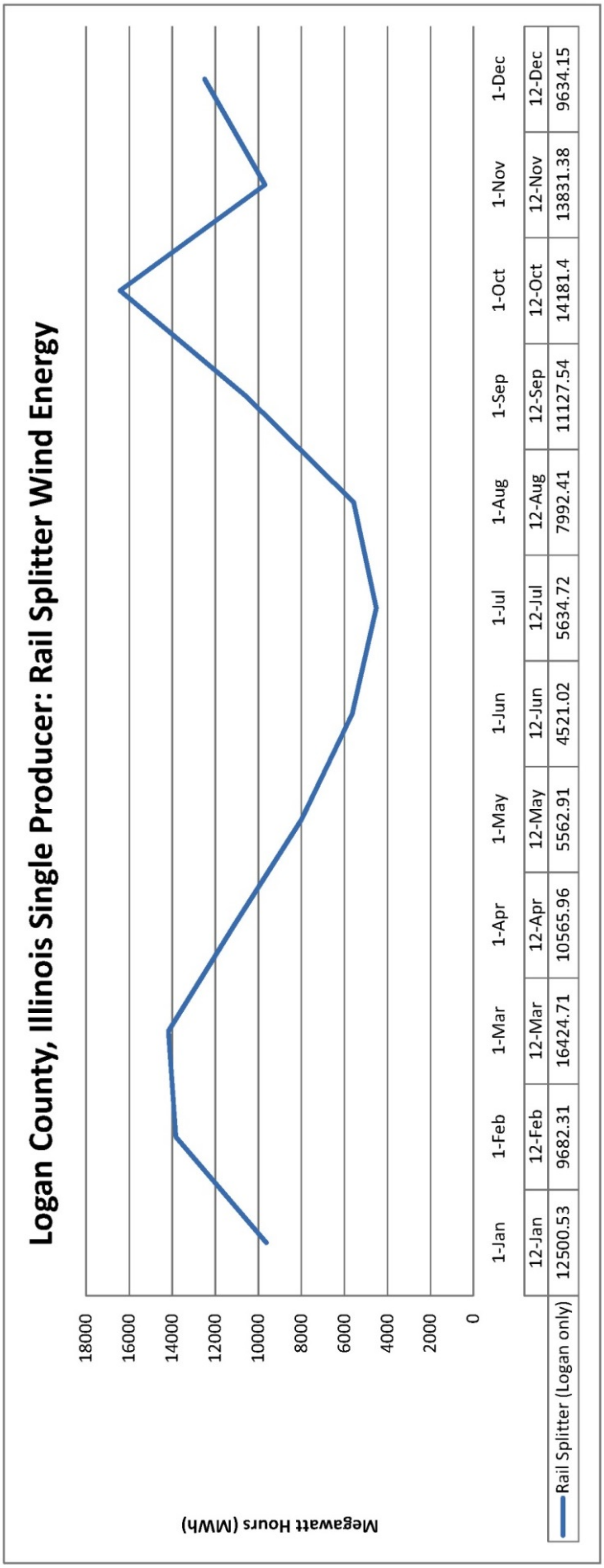


Figure 3-15: Logan County Existing Electricity Production (E2c), Wind from One Source

		ACS Table DP04		From Economic Census Table A1				2012 ACS	2010 Census
								County	State
County	State	County Residential Units	Statewide Res. Units	County Commercial Units	Statewide Comm. Units	County Industrial Units	Statewide Ind. Units	Population	Population
Logan	Illinois	11560	5239619	335	206284	277	107915	30305	12,830,632

Source:	Econ. Census: Table C10	Econ. Census: Table C10	Econ. Census: Table C10	Econ. Census: Table C10		USEIA
Units:	in Trillion Btu's	in Trillion Btu's	in Trillion Btu's	in Trillion Btu's		in Million Btu's
State	Total Residential TBtu's / Year	Total Commercial TBtu's / Year	Total Industrial Tbtu's / Year	Total Transportation Tbtu's / Year	County	All Prime Movers Btu's / Year
Illinois	1,011.90	804.4	1,244.70	950.4	Logan	0

County	Residential MWH	Commercial MWH	Industrial MWH	Transport MWH	Power Plant MWH	Total MWH
Logan	654,314.73	382,862.03	936,383.22	657,905.69	-	2,631,465.68

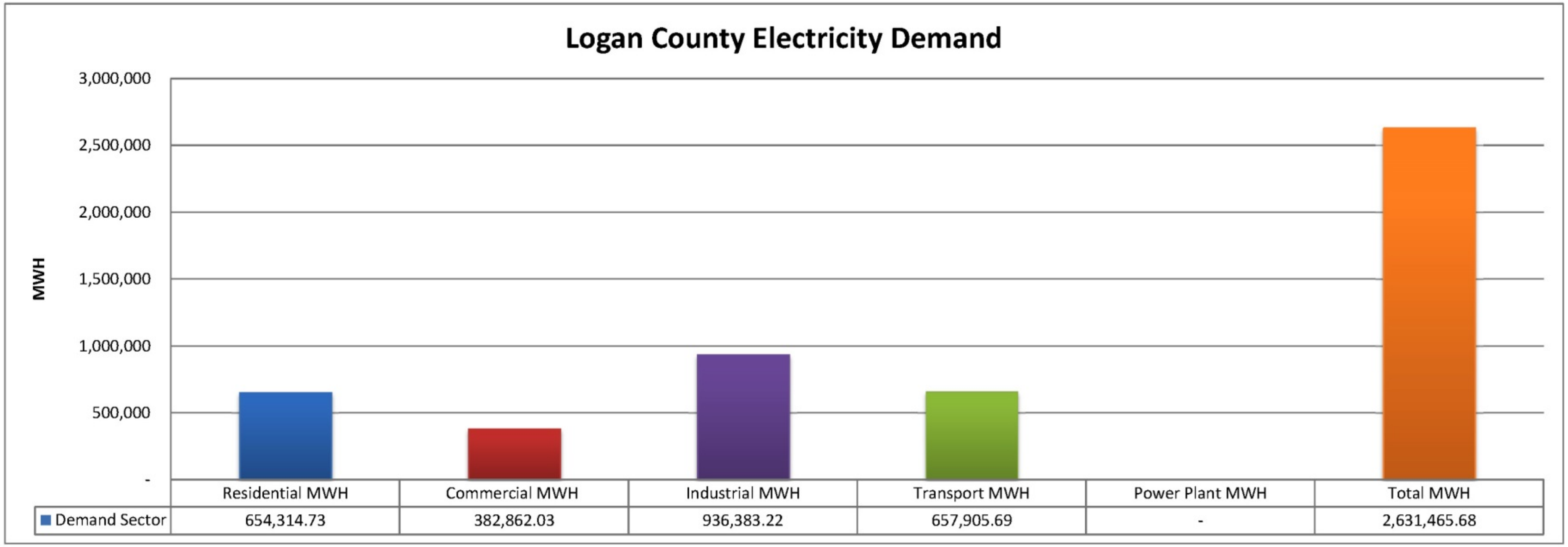


Figure 3-16: Logan County Electricity Demand (E1d & E2d)

Logan County Composted Organic Waste Production				
Category	Wet Short Tons	Dry Short Tons	Dry Metric Tons	*Data Source:*
Yard Waste	3,950.7	1,975.3	1,792.0	*Logan County MSW Spreadsheed (Reported)*
Food Waste Mass	3,927.2	1,963.6	1,781.4	*Co-EAT, post composting: MGD WWTP*
Biosolids (WW Solids Mass)	1,059.5	529.7	480.6	*Co-EAT, post composting; MGD WWTP*
Organic Production Summary			4,053.9	
Field Application Capacity			35,729.0	*USDA Quickstats Food Production Summary; Compost Rate/Ac*

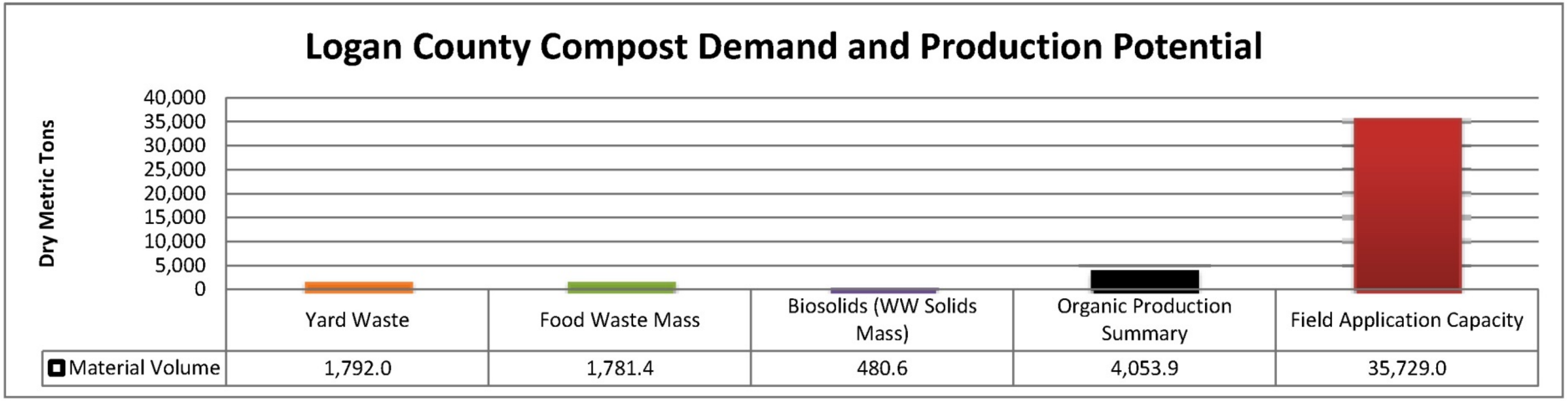


Figure 3-17: Logan County Compost Demand and Organic Material Production Potential (M1c & M1d)

VS = volatile solids TS = total solids MCRT = mean cell residence time

Feedstock Parameter	Value	Units
Food Waste Mass	10.76	short tons/day
Food Waste Biogas Yield	6.65	ft^3 CH^4/lb TS
Food Waste Total Solids	29.98%	solids
Food Waste VS	89.63%	of total solids
Food Waste % of Total Waste	78.75%	total substrate
Weighted Total Feedstock Loading (TS)	21,519.12	lbs/day
Weighted Total Feedstock Loading (VS)	19,287.70	lbs/day
Wastewater Solids Mass	2.90	short tons/day
Wastewater Solids Yield	2.12	ft^3 CH^4/lb TS
Wastewater Total Solids	1.00%	solids
Wastewater VS	70.00%	of total solids
Wastewater % of Total Waste	21.25%	total substrate
Weighted Total Feedstock Mass	14	short tons/day
Weighted Total Feedstock Yield	5.69	ft^3 CH^4/lb TS
Weighted Total Feedstock Concentration (% TS)	23.8%	solids
Weighted VS Content of Total Feedstock	85%	volatile solids
Weighted Total Feedstock (TS)	5,805.3	lbs/day
Weighted Total Feedstock (VS)	4,063.7	lbs/day

Table 3-5: Logan County Co-EAT Sludge Model Output (Input for M1d)

Logan County			
Plant Name	NPDES ID	Avg. Annual MGD	Total Sludge DMT/y
Atlanta STP	IL0059137	0.29	
City of Lincoln STP	IL0029564	2.595833333	
Emden Village	IL0078344	0.004	
San Jose STP	ILG580071	0.045666667	
Mount Pulaski STP	ILG582025	0.6	
Total Annual Average MGD		3.5355	

Table 3-6: Logan County WWTPs MGD and Sludge Inputs for Co-EAT Model (Input for Input of M1d)

Logan County Generation Derived from Given Regional PPD Statistics		
Category	Percentage Generation[4]	Logan Generation
Paper and Paperboard	28%	10791.27
Glass	3%	1105.82
Metals	5%	1792.19
Plastics	11%	4270.75
Rubber, leather and textiles	6%	2173.51
Wood		0.00
Yard Trimmings	9%	3584.38
Food waste	9%	3584.38
Other	28%	10829.40
Total Generation in Tons	**1**	**38,131.70**

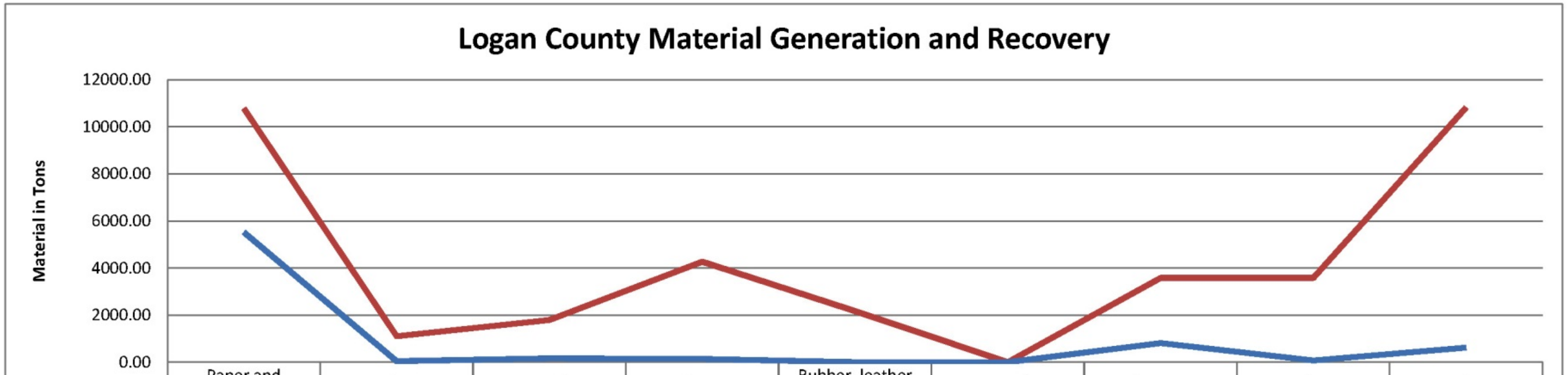
Census and Regional Overview Statistics				
County	2012 Pop	Pounds per day[4]	Total Waste (lbs/yr)	Total Waste (MT/y)
Logan	30,305	7.6	84,066,070.0	38,131.70

Sources:

[4]State of Illinois (2015): Task Force on the Advancemnt of Materials Recycling. Normal, Illinois. Available online at https://www.illinois.gov/dceo/AboutDCEO/ReportsRequiredByStatute/Approved%20Final%20Report%20-%20Recycling%20Advancement%20Task%20Force.pdf, checked on June 2016.

[1]US EPA (2012): Municipal Solid Waste Generation, Recycling, and Disposal in the United States. Facts and Figures for 2012. US Environmental Protection Agency. Available online at www.epa.gov/wastes, updated on 2012, checked on April, 2014.

Logan County Recovery from National EPA Statistics		
Category	EPA Percentage Recovery[1]	Logan Recovery
Paper and Paperboard	51%	5525.13
Glass	4%	40.92
Metals	9%	157.71
Plastics	3%	136.66
Rubber, leather and textiles	0%	0.00
Wood	3%	0.00
Yard Trimmings	23%	810.07
Food waste	2%	71.69
Other	6%	617.28
Total Recovery in Tons	**1**	**7,359.46**



	Paper and Paperboard	Glass	Metals	Plastics	Rubber, leather and textiles	Wood	Yard Trimmings	Food waste	Other
Generation	10791.27	1105.82	1792.19	4270.75	2173.51	0.00	3584.38	3584.38	10829.40
Recovery	5525.13	40.92	157.71	136.66	0.00	0.00	810.07	71.69	617.28

Figure 3-18: Logan County Material Generation and Recovery (M2c & M2d)

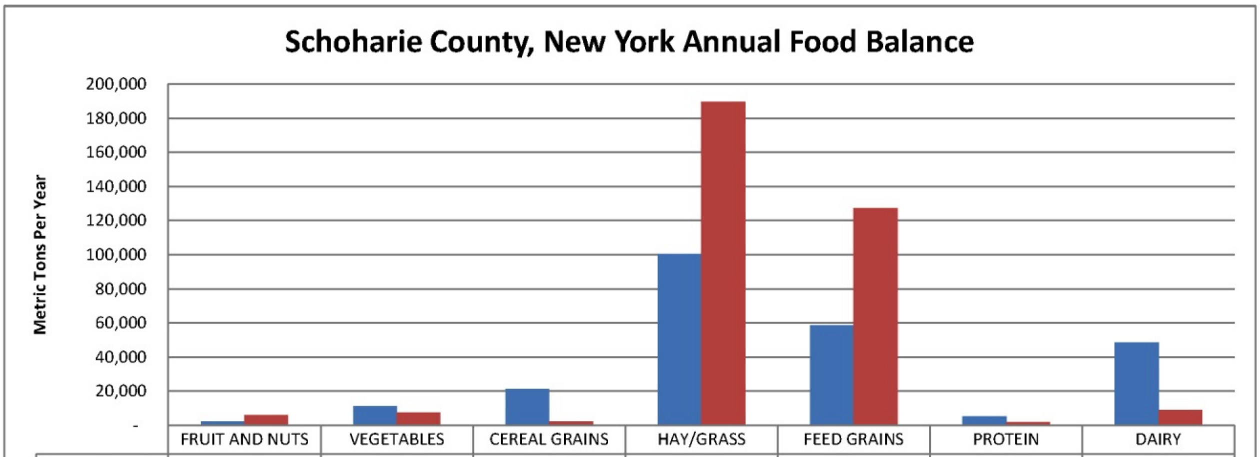
4 Schoharie County, New York

Schoharie County, New York

FOOD CAPACITY	
FDA Daily Food Groups	Total Metric Tons Production Per Year
FRUIT AND NUTS	2,150
VEGETABLES	11,058
CEREAL GRAINS	21,216
HAY/GRASS	100,262
FEED GRAINS	58,758
PROTEIN	5,135
DAIRY	48,424

FOOD DEMAND	*2012 ACS Population:	32749
FDA Daily Food Groups	Annual Demand in Metric Tons	Metric Tons/Capita*/Year**
FRUIT AND NUTS	5,977	0.1825
VEGETABLES	7,471	0.228125
CEREAL GRAINS	2,241	0.0684375
HAY/GRASS	189,586	*Varies Per Livestock Type, Below*
FEED GRAINS	127,230	*Varies Per Livestock Type, Below*
PROTEIN	2,054	0.0627343
DAIRY	8,965	0.27375

Demand of Feed/ Hay Grains	Hay in Metric Tons / Year	Corn in Metric Tons / Year
Milk Cows	62,343	656
Beef Cows	124,514	124,514
Goats	281	56
Hogs	-	1,286
Sheep	2,449	245
Poultry	-	473
Total Feed(tons)	189,585.98	127,230.25



	FRUIT AND NUTS	VEGETABLES	CEREAL GRAINS	HAY/GRASS	FEED GRAINS	PROTEIN	DAIRY
Food Capacity	2,150	11,058	21,216	100,262	58,758	5,135	48,424
Food Demand	5,977	7,471	2,241	189,586	127,230	2,054	8,965

Figure 4-1: Schoharie County food Summary (F1c - F7c & F1d - F7d)

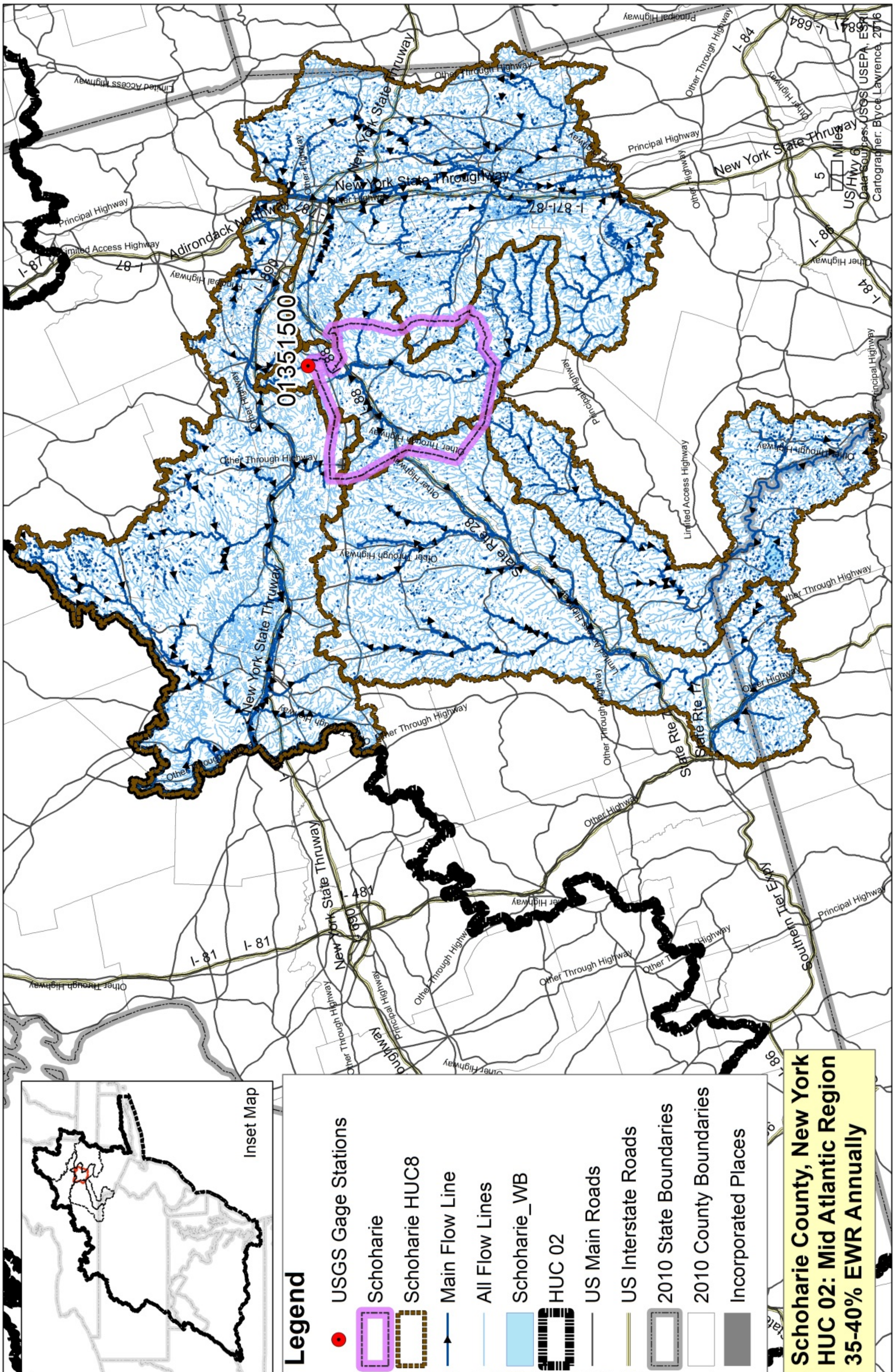


Figure 4-2: Schoharie County Stream Network and Streamflow Sample Stations (W1c)

Schoharie County, New York

Total Available Stream Flow in Cubic Meters (W1c) with Human Abstraction (W1d)

USGS Station No. 01351500	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1939-2015	256.6	274.3	682.7	1,130.9	398.2	130.0	48.1	27.8	24.5	35.9	132.9	292.8
EWR Requirement 41%	96.2	102.9	256.0	424.1	149.3	48.7	18.0	10.4	9.2	13.5	49.8	109.8
Available Adjusted CFS	160.4	171.4	426.7	706.8	248.9	81.2	30.1	17.4	15.3	22.4	83.1	183.0
EWR Corrected Mean Monthly Cubic Meters	11,935,154.4	12,756,664.7	31,753,061.9	52,598,548.0	18,518,618.6	6,044,794.4	2,236,997.5	1,291,787.3	1,141,053.8	1,668,371.0	6,181,224.7	13,618,528.8
Total P25 Discharge	19,096,247.0	20,410,663.5	50,804,899.1	84,157,676.8	29,629,789.7	9,671,671.0	3,579,196.0	2,066,859.7	1,825,686.0	2,669,393.7	9,889,959.5	21,789,646.1

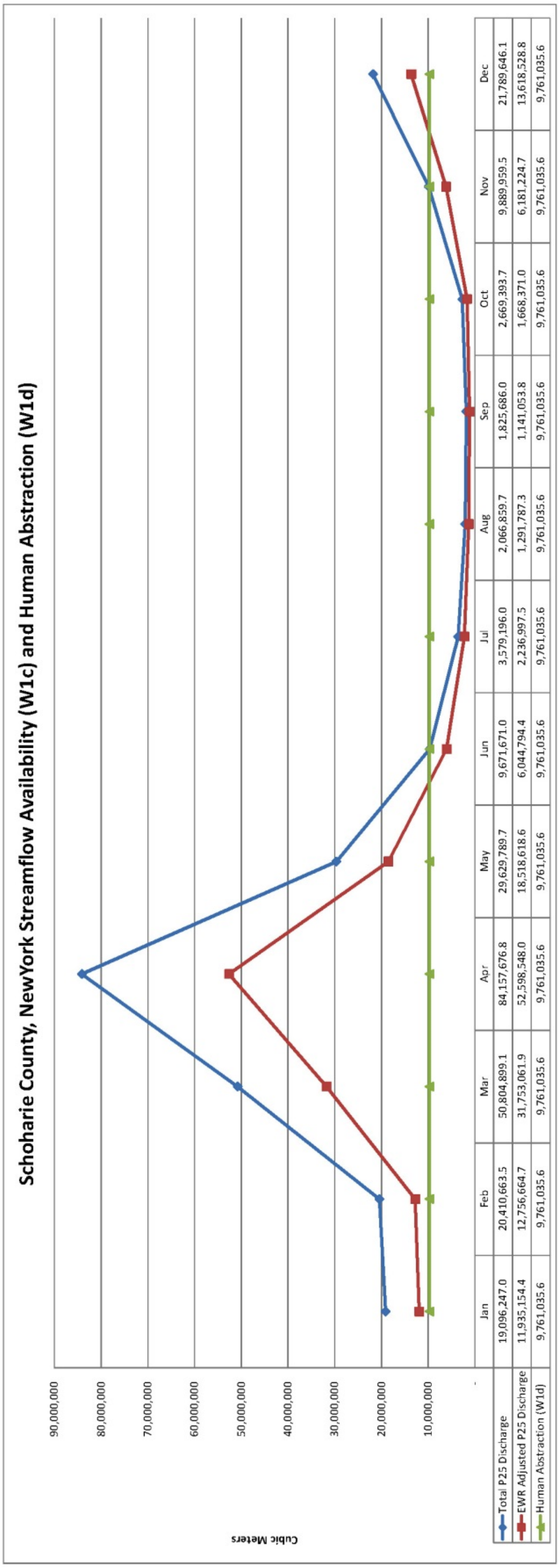
Total P25 Discharge	19,096,247.0	20,410,663.5	50,804,899.1	84,157,676.8	29,629,789.7	9,671,671.0	3,579,196.0	2,066,859.7	1,825,686.0	2,669,393.7	9,889,959.5	21,789,646.1
EWR Adjusted P25 Discharge	11,935,154.4	12,756,664.7	31,753,061.9	52,598,548.0	18,518,618.6	6,044,794.4	2,236,997.5	1,291,787.3	1,141,053.8	1,668,371.0	6,181,224.7	13,618,528.8
Human Abstraction (W1d)	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6
Human Abstraction as % EWR Adjusted	81.78%	76.52%	30.74%	18.56%	52.71%	161.48%	436.35%	755.62%	855.44%	585.06%	157.91%	71.67%

Total EWR Adjusted Annual Available Streamflow Volume in Cubic Meters	**159,744,805**

Table 4-1: Schoharie County EWR adjusted Annual P25 Streamflow Availability (W1c)

Schoharie County, New York 2010 Adjusted Water Abstraction		
Category	**Mgal/D Surface**	**Mgal/D Ground**
Public Supply	81.96	1.77
Mining	0.68	-
Livestock	0.08	0.14
Aquaculture	-	-
Irrigation	0.29	0.07
Daily Total	*83.01*	*1.98*
Annual Abstraction Projection by Source (USGS NWIS)	30,299	723
Total Annual Abstraction in Mgal	31,021	
2012 Total Annual Returns in Mgal (US EPA ECHO / NPDES)	75	
Total Adjusted Abstraction in Mgal	**30,946.48**	
Total Adjusted Abstraction in cubic meters per year / month	117,132,427	9,761,036

Table 4-2: Schoharie County Adjusted Water Abstraction (W1d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	19,096,247.0	20,410,663.5	50,804,899.1	84,157,676.8	29,629,789.7	9,671,671.0	3,579,196.0	2,066,859.7	1,825,686.0	2,669,393.7	9,889,959.5	21,789,646.1
EWR Adjusted P25 Discharge	11,935,154.4	12,756,664.7	31,753,061.9	52,598,548.0	18,518,618.6	6,044,794.4	2,236,997.5	1,291,787.3	1,141,053.8	1,668,371.0	6,181,224.7	13,618,528.8
Human Abstraction (W1d)	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6	9,761,035.6

Figure 4-3: Schoharie County Adjusted Streamflow Availability and Human Abstraction (W1c & W1d)

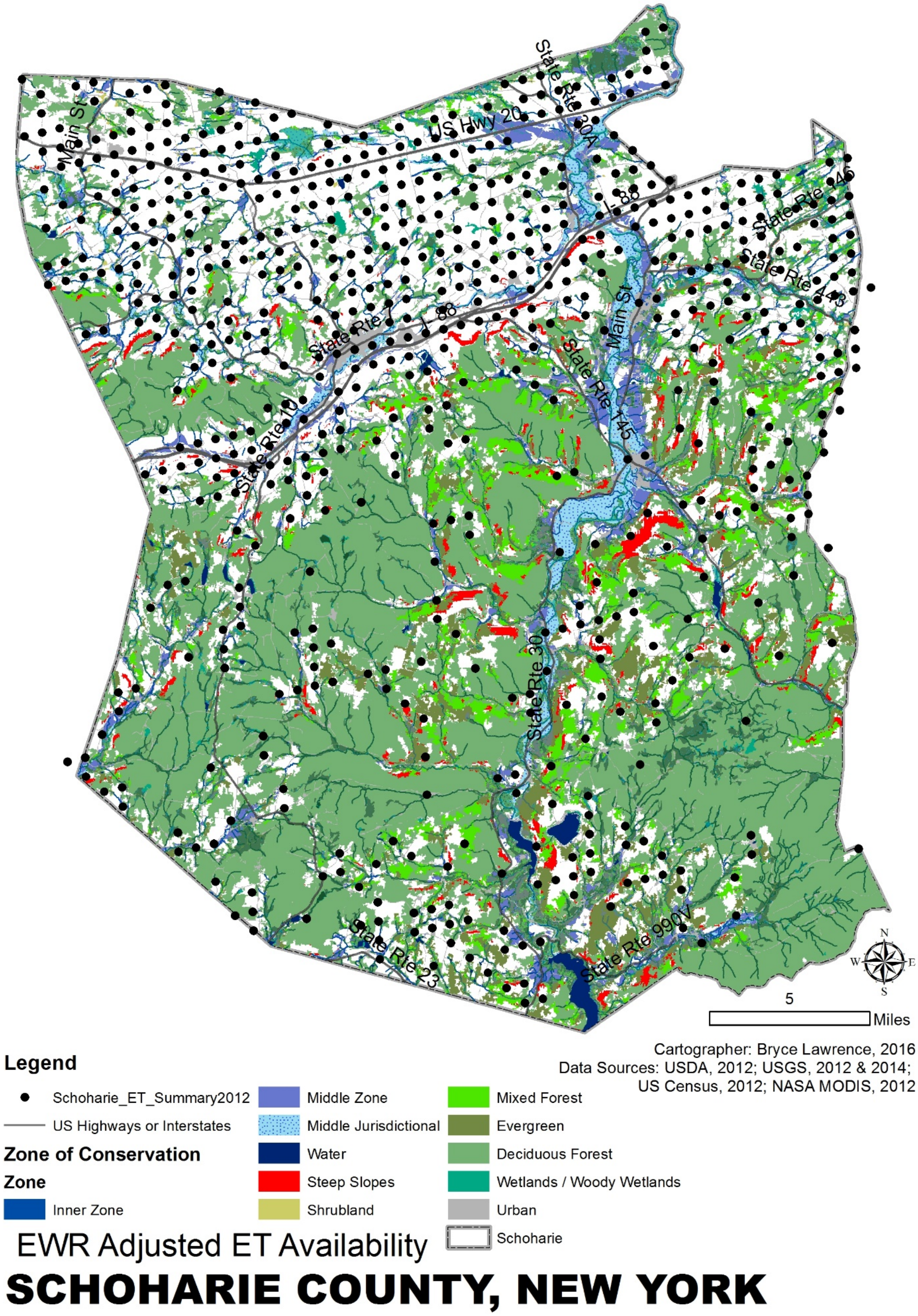
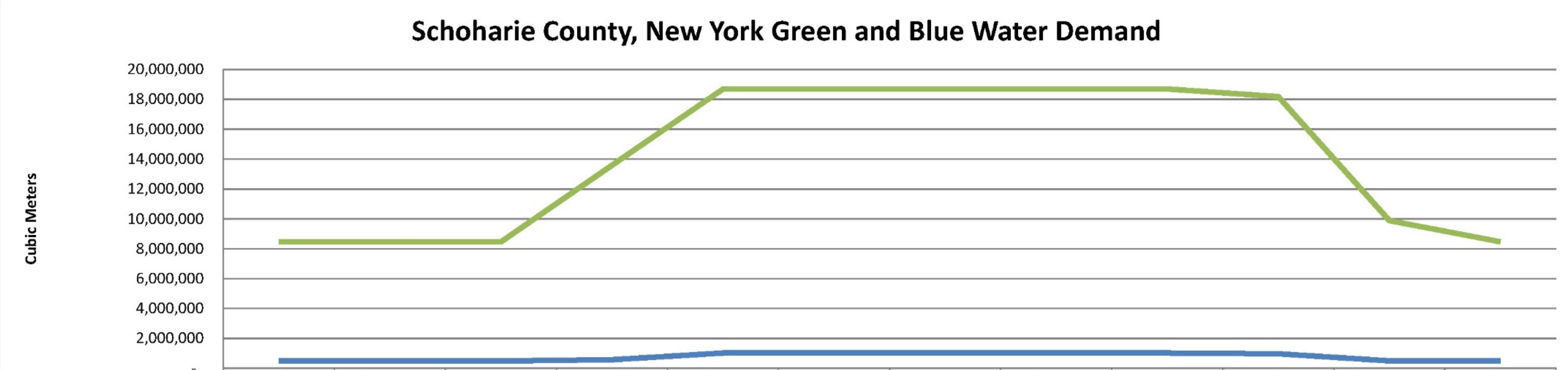


Figure 4-4: Schoharie County EWR Adjusted ET Availability Sample Points (W2c)

Schoharie County, New York

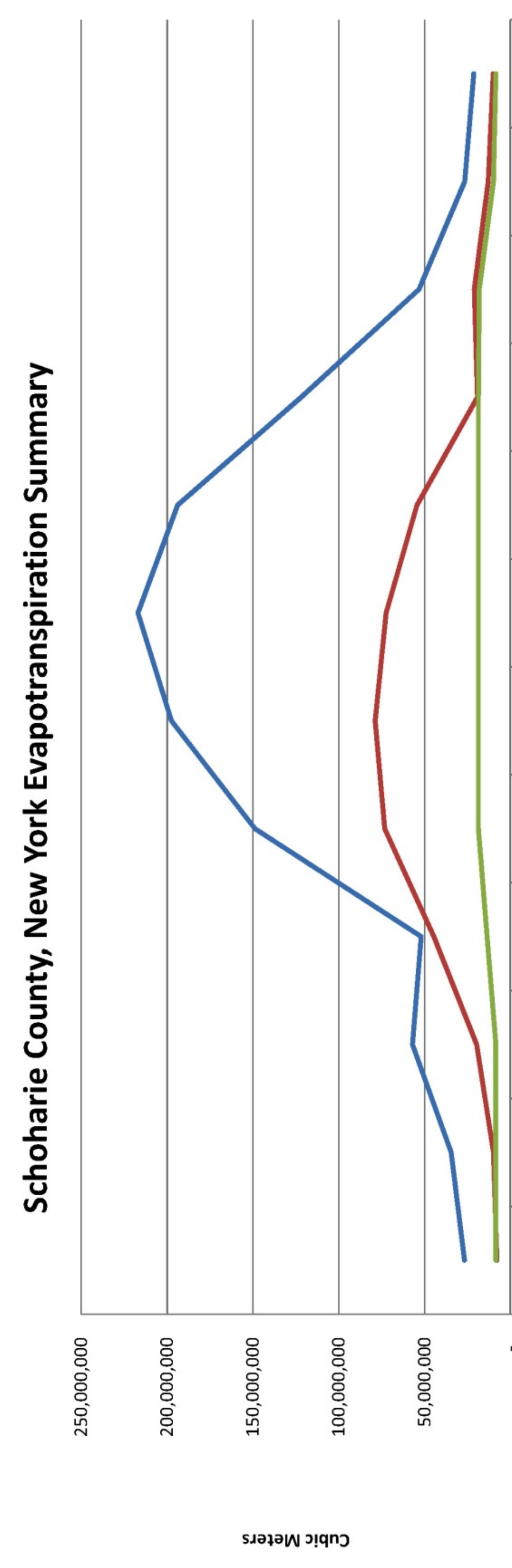
Monthly Green Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	GW Annual Sum
Value in Cubic Meters	8,464,180	8,464,180	8,464,180	13,593,824	18,692,654	18,693,214	18,693,214	18,693,214	18,693,214	18,177,442	9,879,520	8,464,180	135,116,297

Monthly Blue Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	BW Annual Sum
Value in Cubic Meters	493,187	490,606	493,187	573,398	1,024,100	1,023,360	1,024,221	1,024,221	1,023,360	969,471	496,289	493,187	9,128,588



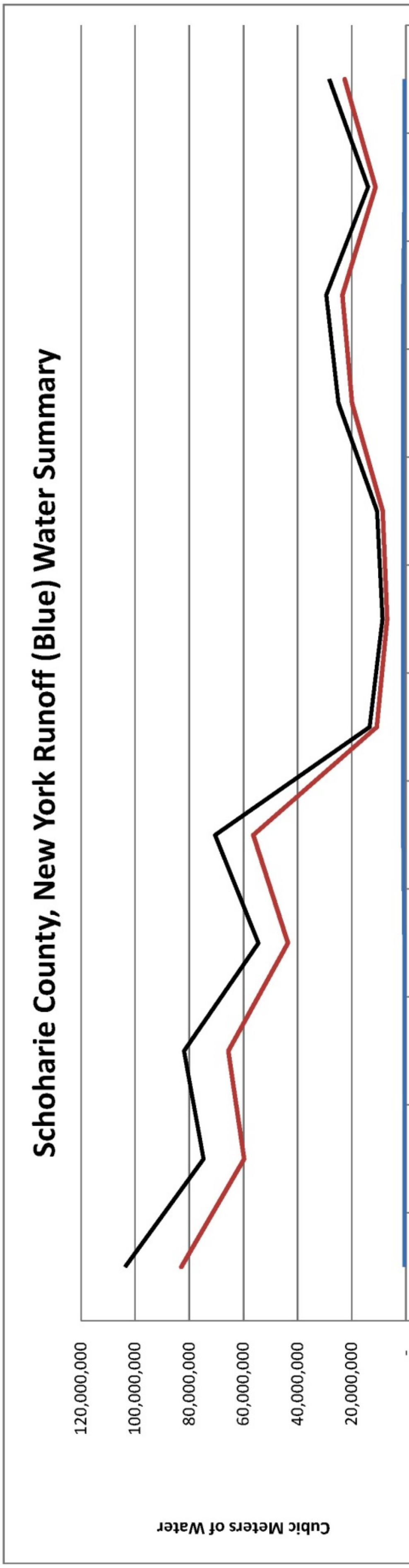
	January	February	March	April	May	June	July	August	September	October	November	December
Green Water Demand	8,464,180	8,464,180	8,464,180	13,593,824	18,692,654	18,693,214	18,693,214	18,693,214	18,693,214	18,177,442	9,879,520	8,464,180
Blue Water Demand	493,187	490,606	493,187	573,398	1,024,100	1,023,360	1,024,221	1,024,221	1,023,360	969,471	496,289	493,187

Figure 4-5: Schoharie County ET (Green Water) and Surface (Blue Water) Demand (W2d & W3d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET for Entire County	26,756,081	34,534,638	57,096,813	52,009,993	148,769,26	197,458,43	216,943,80	193,803,76	121,920,89	53,229,598	26,630,494	21,390,913
ET Without ZOC Area	7,940,908	9,890,010	19,672,709	44,605,660	73,251,982	78,761,602	72,420,869	54,454,947	19,275,399	21,100,726	12,958,210	10,042,666
Green Water Demand	8,464,180	8,464,180	8,464,180	13,593,824	18,692,654	18,693,214	18,693,214	18,693,214	18,693,214	18,177,442	9,879,520	8,464,180

Figure 4-6: Schoharie County ET (Green Water) Summary (W2c & W2d)



	January	February	March	April	May	June	July	August	September	October	November	December
Total Runoff	103,701,036	74,698,161	81,960,228	54,441,532	70,434,299	13,370,843	8,591,897	10,637,796	24,868,373	29,333,526	13,942,994	28,293,528
EWR Adjusted Runoff	82,960,829	59,758,529	65,568,182	43,553,226	56,347,439	10,696,675	6,873,518	8,510,237	19,894,698	23,466,821	11,154,395	22,634,822
Blue Water Demand	493,187	490,606	493,187	573,398	1,024,100	1,023,360	1,024,221	1,024,221	1,023,360	969,471	496,289	493,187

Figure 4-7: Schoharie County Surface (Blue) Water Availability and Demand (W3c & W3d)

N	Schoharie County, New York	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	82,960,829	59,758,529	65,568,182	43,553,226	56,347,439	10,696,675	6,873,518	8,510,237	19,894,698	23,466,821	11,154,395	22,634,822
	Liters / month	82,960,828,800	59,758,528,800	65,568,182,400	43,553,225,600	56,347,439,200	10,696,674,640	6,873,517,600	8,510,237,120	19,894,698,400	23,466,820,800	11,154,395,200	22,634,822,400
2.15	mg/l limit												
	Total Allowed Mg	178,365,781,920	128,480,836,920	140,971,592,160	93,639,435,040	121,146,994,280	22,997,850,476	14,778,062,840	18,297,009,808	42,773,601,560	50,453,664,720	23,981,949,680	48,664,868,160
	Total Allowed Tons (N)	178.4	128.5	141.0	93.6	121.1	23.0	14.8	18.3	42.8	50.5	24.0	48.7
0.28	Nnat in mg/l												
	total mg Nnat	23,229,032,064	16,732,388,064	18,359,091,072	12,194,903,168	15,777,282,976	2,995,068,899	1,924,584,928	2,382,866,394	5,570,515,552	6,570,709,824	3,123,230,656	6,337,750,272
	tons Nnat	23	17	18	12	16	3	2	2	6	7	3	6
	Corrected Limit	155	112	123	81	105	20	13	16	37	44	21	42
	Total Annual N Load (t)	**769.4**											

P	Schoharie County, New York	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	82,960,829	59,758,529	65,568,182	43,553,226	56,347,439	10,696,675	6,873,518	8,510,237	19,894,698	23,466,821	11,154,395	22,634,822
	Liters / month	82,960,828,800	59,758,528,800	65,568,182,400	43,553,225,600	56,347,439,200	10,696,674,640	6,873,517,600	8,510,237,120	19,894,698,400	23,466,820,800	11,154,395,200	22,634,822,400
1	mg/l monthly avg limit	82,960,828,800	59,758,528,800	65,568,182,400	43,553,225,600	56,347,439,200	10,696,674,640	6,873,517,600	8,510,237,120	19,894,698,400	23,466,820,800	11,154,395,200	22,634,822,400
	Max monthly tons P	82.96	59.76	65.57	43.55	56.35	10.70	6.87	8.51	19.89	23.47	11.15	22.63
0.02	mg/l Pnat background	1,659,216,576	1,195,170,576	1,311,363,648	871,064,512	1,126,948,784	213,933,493	137,470,352	170,204,742	397,893,968	469,336,416	223,087,904	452,696,448
	Avg monthly background P	1.66	1.20	1.31	0.87	1.13	0.21	0.14	0.17	0.40	0.47	0.22	0.45
	Corrected monthly P Limit	81.30	58.56	64.26	42.68	55.22	10.48	6.74	8.34	19.50	23.00	10.93	22.18
	Total Annual P Load (t)	**403.2**											

Table 4-3: Schoharie County Critical Nitrogen and Phosphorus Load Limits (W4c & W5c)

Schoharie N and P Load Summary

CROPGROUP	N_load	P_load	Hectares
Oilseed	0.7	0.6	202.4
Feed	0.0	0.0	0.7
Cereal	35.2	14.9	5,554.3
Fruit	0.7	0.3	77.3
Pulse	0.0	0.0	2.2
Veg	0.5	0.2	36.9
N and P Point Loads	0.037	0.004017	(N)n=2, (P)n=1
Total N and P Loads	**37.1**	**16.0**	

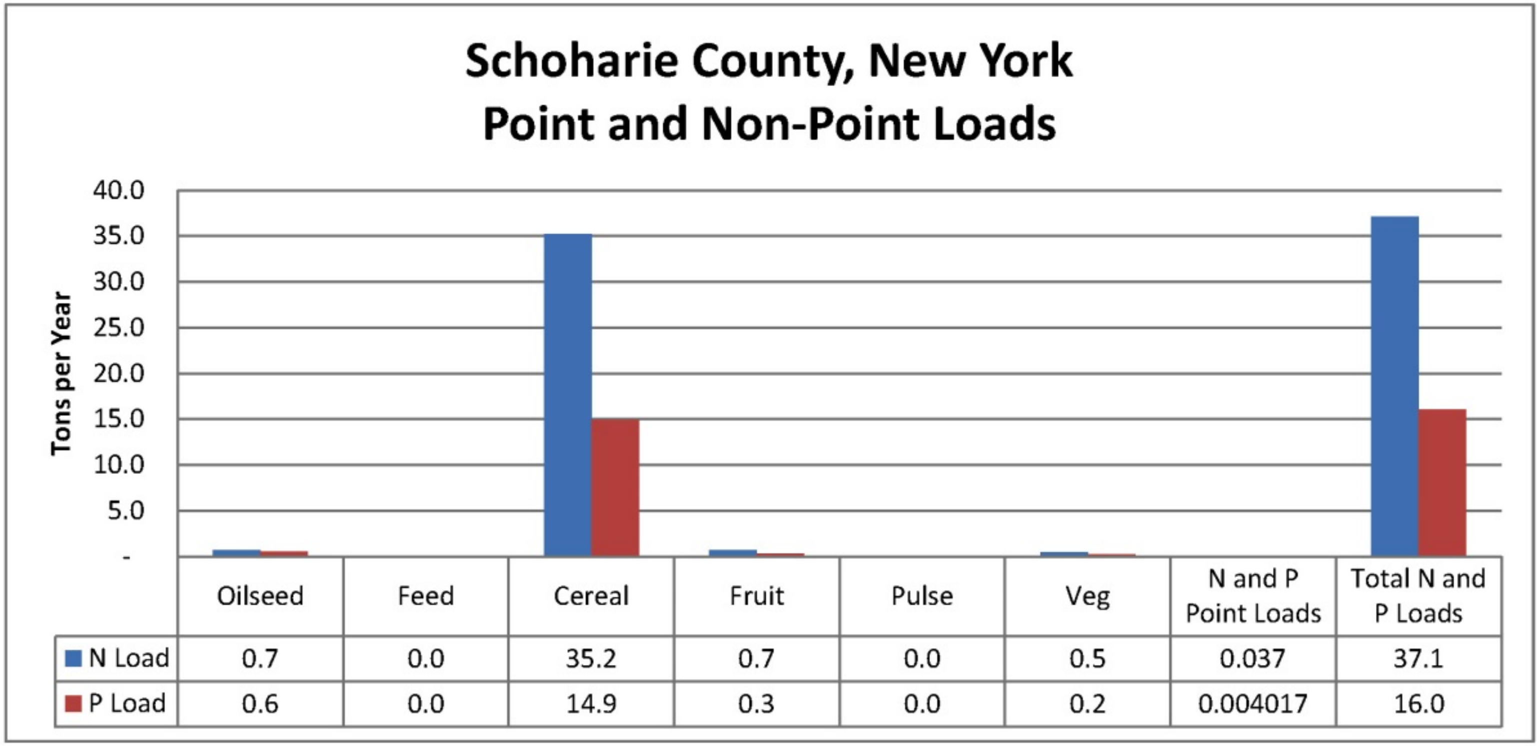


Figure 4-8: Schoharie County Nitrogen and Phosphorus Point and Non-Point Source Loads (W4d & W5d)

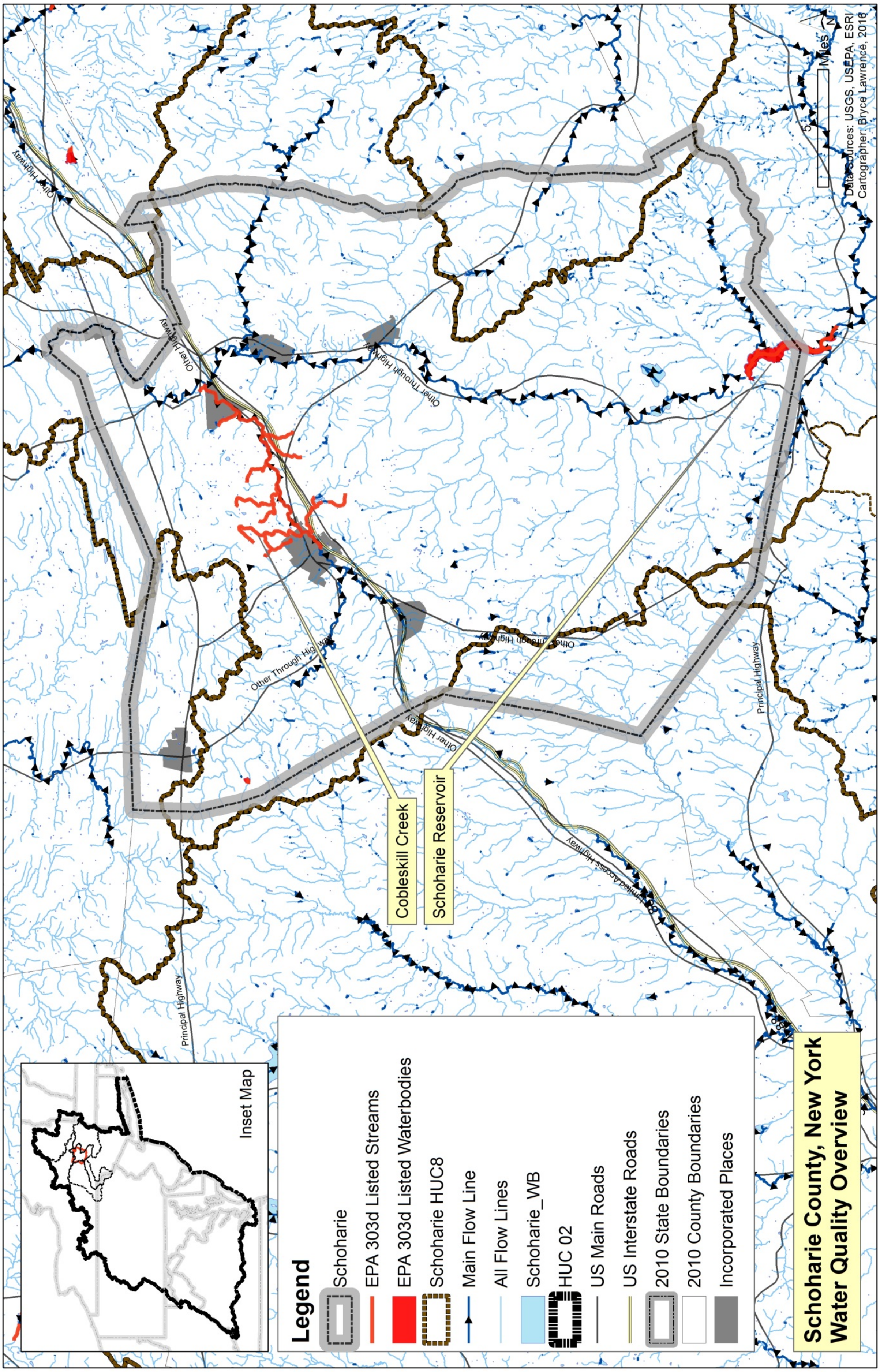


Figure 4-9: Schoharie County EPA 303d Listed Streams and Waterbodies

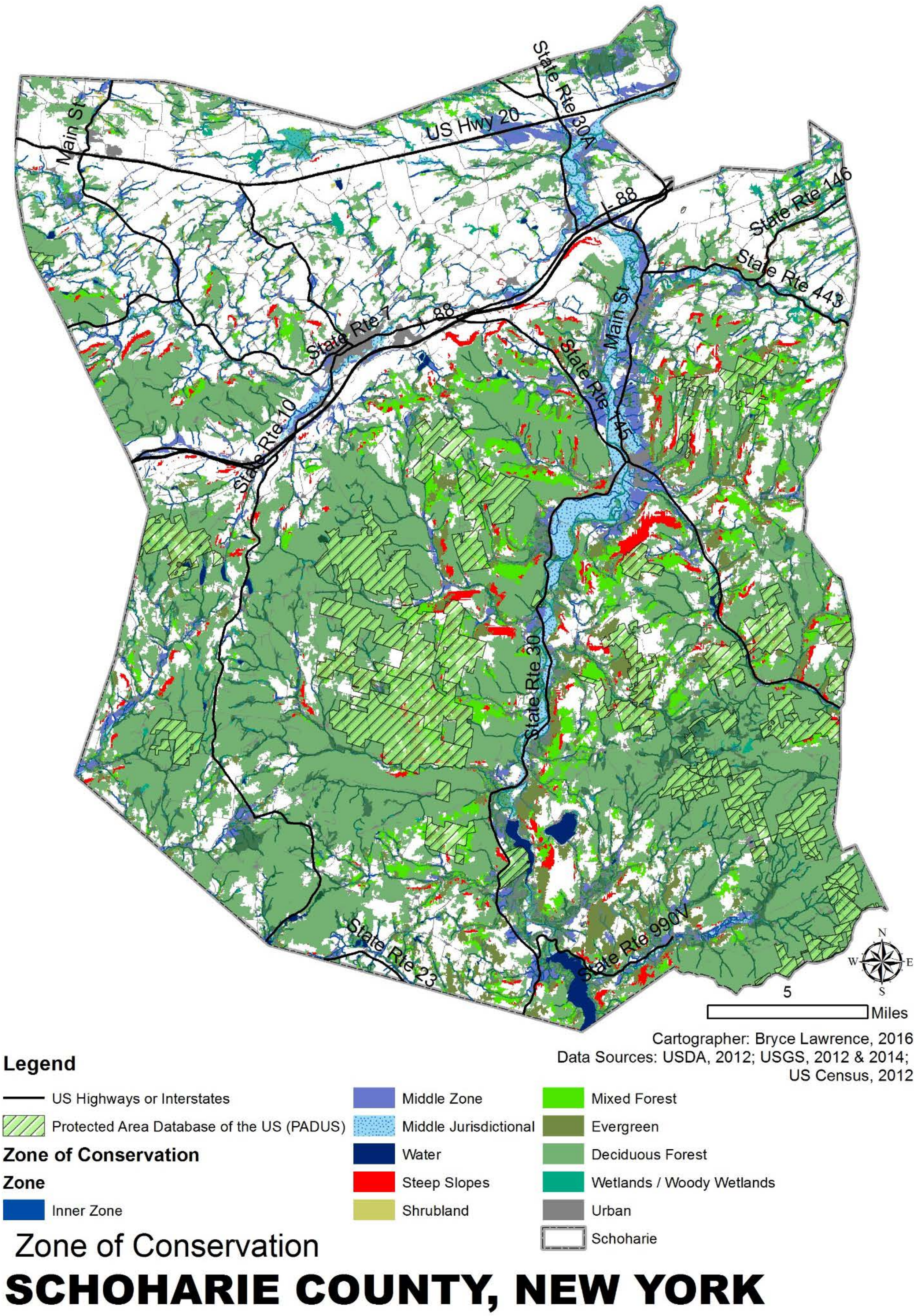


Figure 4-10: Schoharie County Existing and Potential Zone of Conservation (EC1c & EC1c)

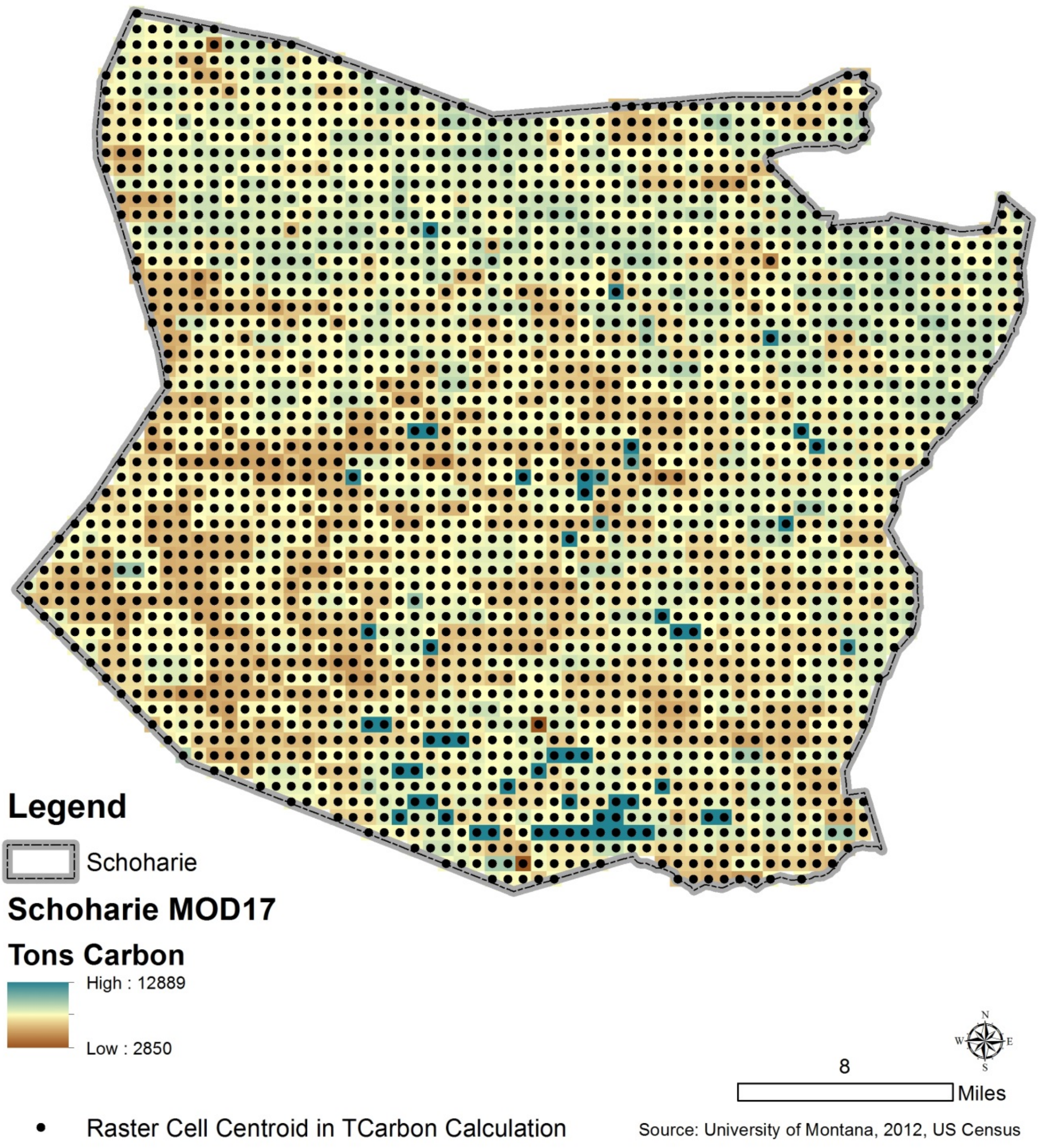


Figure 4-11: Schoharie County Net Primary Productivity (NPP) in Tons of Carbon per Year, as Estimate for Carbon Sequestration Potential (C1c)

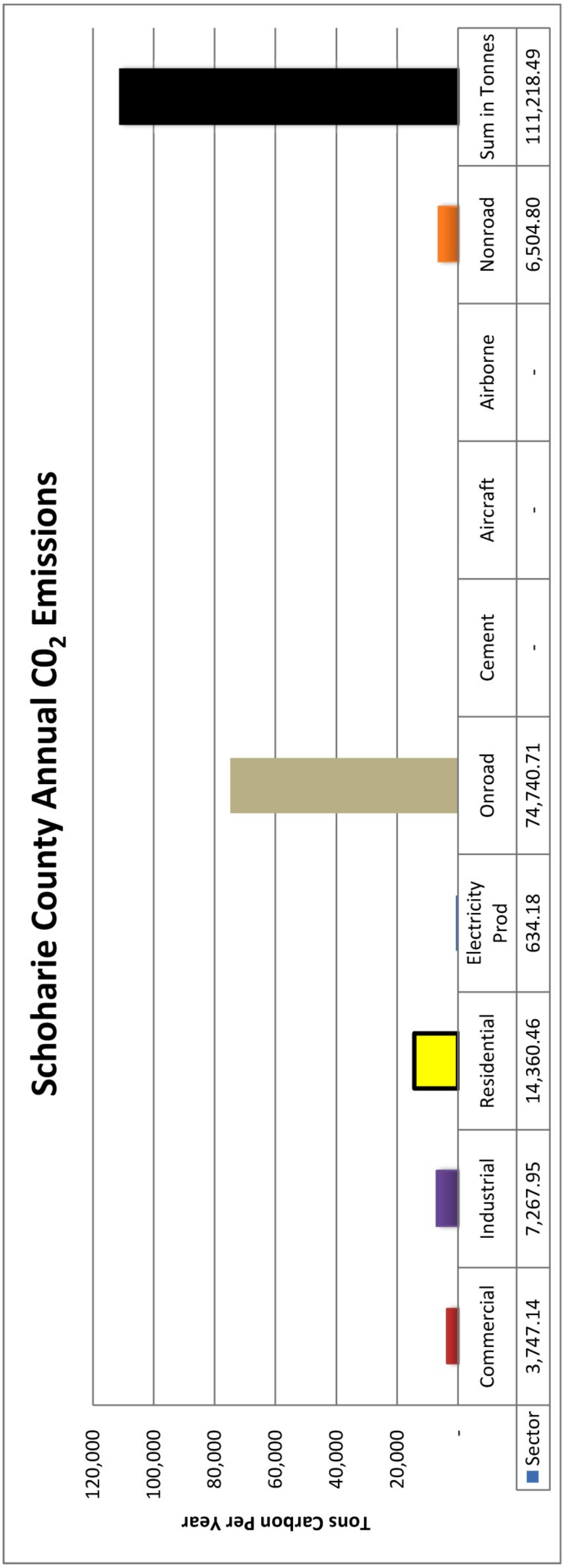


Figure 4-12: Schoharie County CO_2 Emissions in Tons per Year (C1d)

Schoharie County Solar Resouce Summary												
Raster Tile OID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	2.898	3.514	4.307	5.202	5.237	5.165	5.350	5.326	4.910	3.635	2.723	2.512
2	2.699	3.401	4.450	5.228	5.240	5.194	5.337	5.374	4.889	3.651	2.759	2.511
3	3.042	3.702	4.418	5.179	5.194	5.092	5.301	5.268	4.869	3.674	2.764	2.764
4	2.868	3.536	4.308	5.247	5.250	5.184	5.338	5.333	4.883	3.711	2.823	2.701
5	2.964	3.618	4.432	5.263	5.216	5.186	5.383	5.355	4.933	3.739	2.865	2.745
6	3.027	3.716	4.578	5.268	5.261	5.171	5.420	5.362	4.914	3.865	2.888	2.785
7	3.003	3.755	4.562	5.378	5.347	5.208	5.433	5.379	4.980	3.873	2.946	2.796
8	3.245	3.935	4.562	5.227	5.192	5.200	5.446	5.380	5.050	3.935	2.948	2.790
9	3.061	3.561	4.349	5.031	5.107	5.076	5.311	5.201	4.803	3.680	2.740	2.669
10	3.124	3.660	4.502	5.076	5.146	5.148	5.321	5.300	4.883	3.756	2.888	2.726
11	3.224	3.684	4.436	5.089	5.121	5.079	5.332	5.239	4.922	3.794	2.750	2.789
12	3.145	3.688	4.549	5.095	5.173	5.201	5.393	5.290	4.985	3.885	2.909	2.839
13	3.085	3.807	4.601	5.070	5.129	5.145	5.390	5.307	4.965	3.827	2.834	2.766
14	3.269	3.824	4.623	5.238	5.229	5.165	5.447	5.336	5.071	3.939	2.989	2.824
15	3.193	3.721	4.281	5.131	5.125	4.964	5.293	5.161	4.740	3.593	2.669	2.757
16	3.102	3.783	4.422	5.143	5.150	4.976	5.262	5.147	4.792	3.679	2.718	2.717
17	3.106	3.725	4.431	5.186	5.177	5.064	5.298	5.208	4.852	3.753	2.811	2.726
18	3.476	3.934	4.683	5.128	5.149	5.120	5.322	5.199	4.891	3.802	2.827	2.907
19	3.312	3.643	4.459	5.060	5.055	5.033	5.311	5.207	4.917	3.756	2.800	2.876
20	3.270	3.717	4.474	5.151	5.148	5.104	5.327	5.247	4.971	3.834	2.915	3.013
21	2.942	3.355	4.218	5.216	5.224	5.002	5.301	5.169	4.833	3.674	2.711	2.731
22	3.022	3.653	4.298	5.186	5.126	5.011	5.323	5.168	4.854	3.707	2.747	2.722
23	3.224	4.002	4.620	5.107	5.136	5.076	5.361	5.217	4.929	3.778	2.867	2.827
24	3.396	3.881	4.547	5.081	5.151	5.097	5.351	5.217	4.926	3.772	2.860	2.989
25	3.167	3.813	4.454	5.040	5.049	5.035	5.307	5.175	4.919	3.808	2.946	2.967
26	2.928	3.457	4.397	5.244	5.156	4.989	5.271	5.119	4.790	3.652	2.730	2.704
27	3.254	3.989	4.625	5.169	5.188	5.073	5.367	5.210	4.927	3.778	2.907	2.941
28	3.229	3.887	4.556	5.000	5.071	4.963	5.292	5.122	4.885	3.727	2.822	3.034
29	3.272	3.825	4.488	5.079	5.094	5.013	5.311	5.149	4.911	3.784	2.919	3.083
Average kWh/m^2/month	3.122	3.717	4.470	5.156	5.167	5.094	5.341	5.247	4.903	3.761	2.830	2.800
Residential Units	13,038											
NR Units	573											
Annual Sum in MWH	**24,091**											

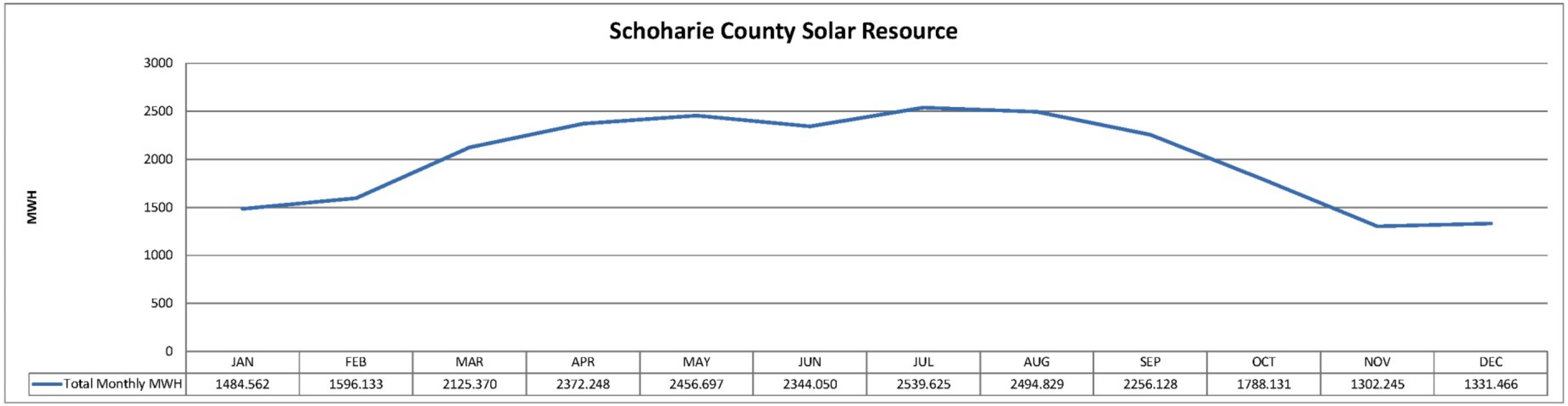


Figure 4-13: Solar (PV) Resource Potential Summary for Schoharie County (E1c)

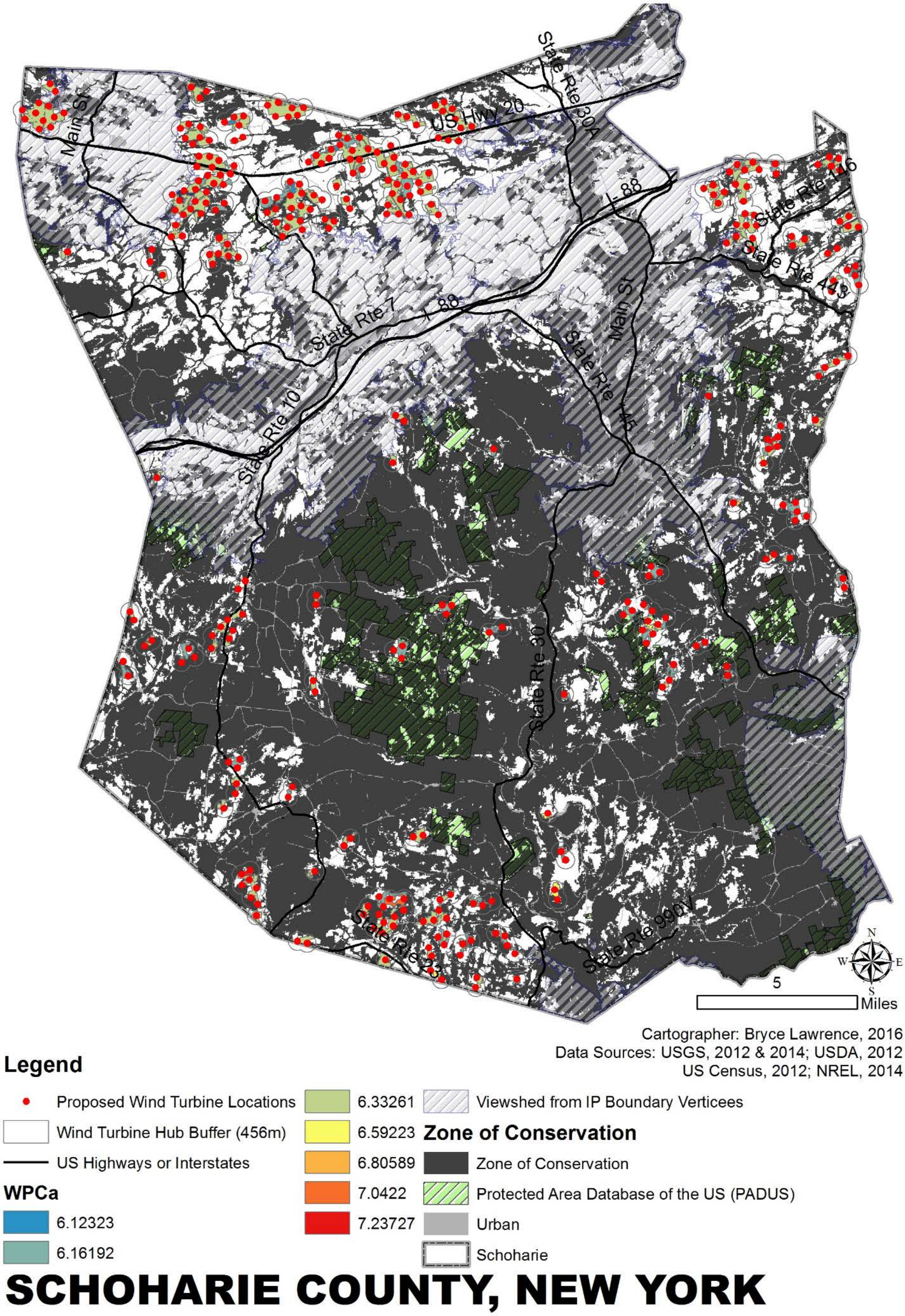


Figure 4-14: Schoharie County Potential Wind and PV Renewable Electricity Locations Map (E1c)

Schoharie County, New York Wind Power Potential				
Adjusted Wind Power Class	Wind Speed	Area in Acres	No. of Turbines	MWh
Schoharie $WPC_{\alpha 1}$	6.02144	85	3	25,411.69
Schoharie $WPC_{\alpha 2}$	6.33261	2,477	89	761,378.37
Schoharie $WPC_{\alpha 3}$	6.59223	7,965	233	1,989,447.76
Schoharie $WPC_{\alpha 4}$	6.80589	238	9	85,154.16
Schoharie $WPC_{\alpha 5}$	6.88165	185	7	69,229.35
Schoharie $WPC_{\alpha 6}$	7.23727	87	3	31,037.61
Wind Sum	-	11,037	344	2,961,658.94
PV Sum				24091
Grand Total Renewable				2,985,749.94

Table 4-4: Schoharie County Potential Wind and PV Renewable Electricity Locations (E1c)

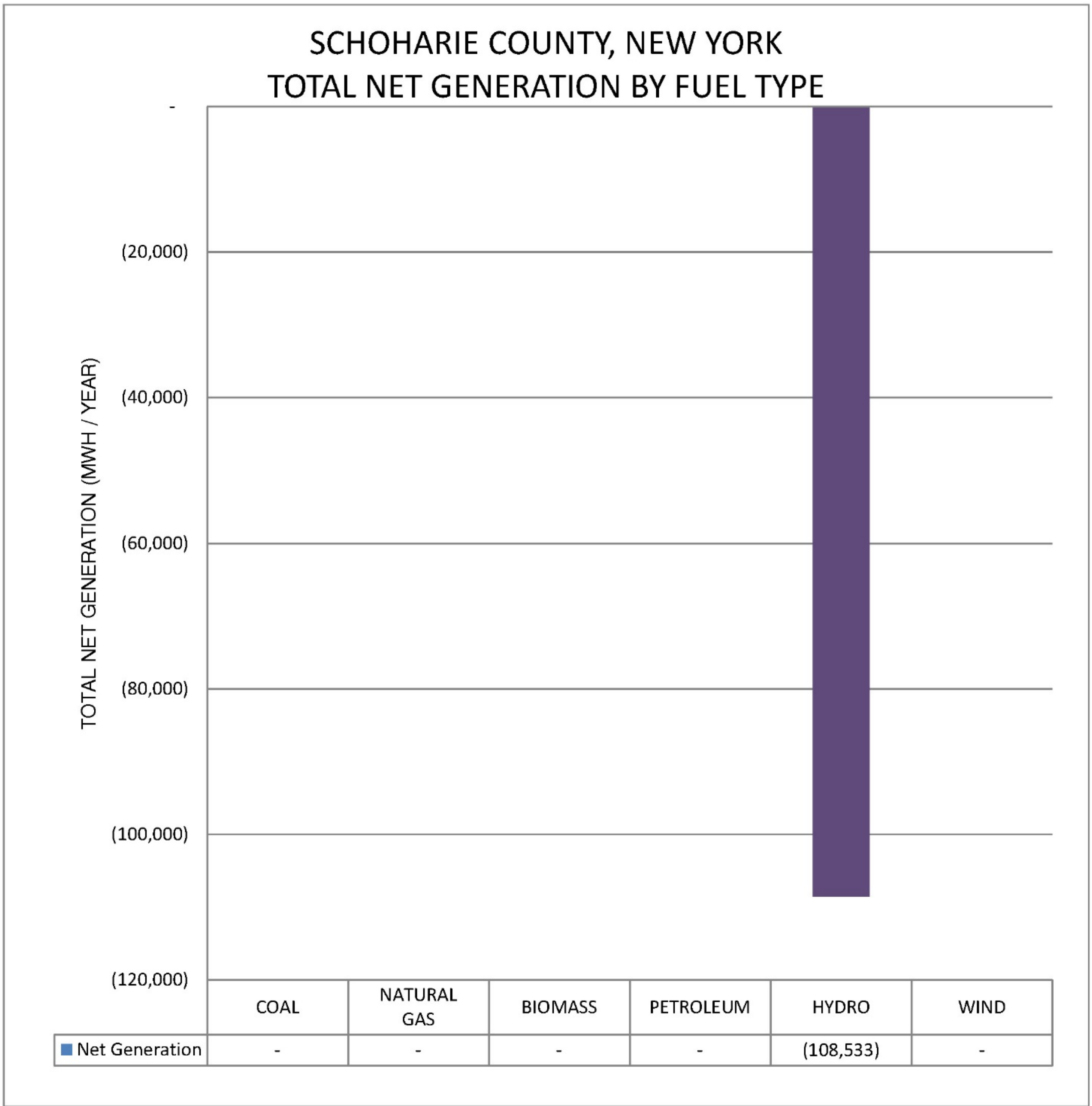


Figure 4-15: Schoharie County Existing Electricity Production (E2c), an Annual Loss due to Gravity Fed Energy Recovery System

		ACS Table DP04		From Economic Census Table A1				2012 ACS	2010 Census
								County	State
County	State	County Residential Units	Statewide Res. Units	County Commercial Units	Statewide Comm. Units	County Industrial Units	Statewide Ind. Units	Population	Population
Schoharie	New York	17230	8102223	328	362940	245	164061	32749	19,378,102

Source:	Econ. Census: Table C10	Econ. Census: Table C10	Econ. Census: Table C10	Econ. Census: Table C10		USEIA
Units:	in Trillion Btu's	in Trillion Btu's	in Trillion Btu's	in Trillion Btu's		in Million Btu's
State	Total Residential TBtu's / Year	Total Commercial TBtu's / Year	Total Industrial Tbtu's / Year	Total Transportation Tbtu's / Year	County	All Prime Movers Btu's / Year
New York	1,072.10	1,134.20	376.3	1,042.80	Schoharie	0

County	Residential MWH	Commercial MWH	Industrial MWH	Transport MWH	Power Plant MWH	Total MWH
Schoharie	668,201.37	300,413.63	164,697.09	516,510.09	-	1,649,822.17

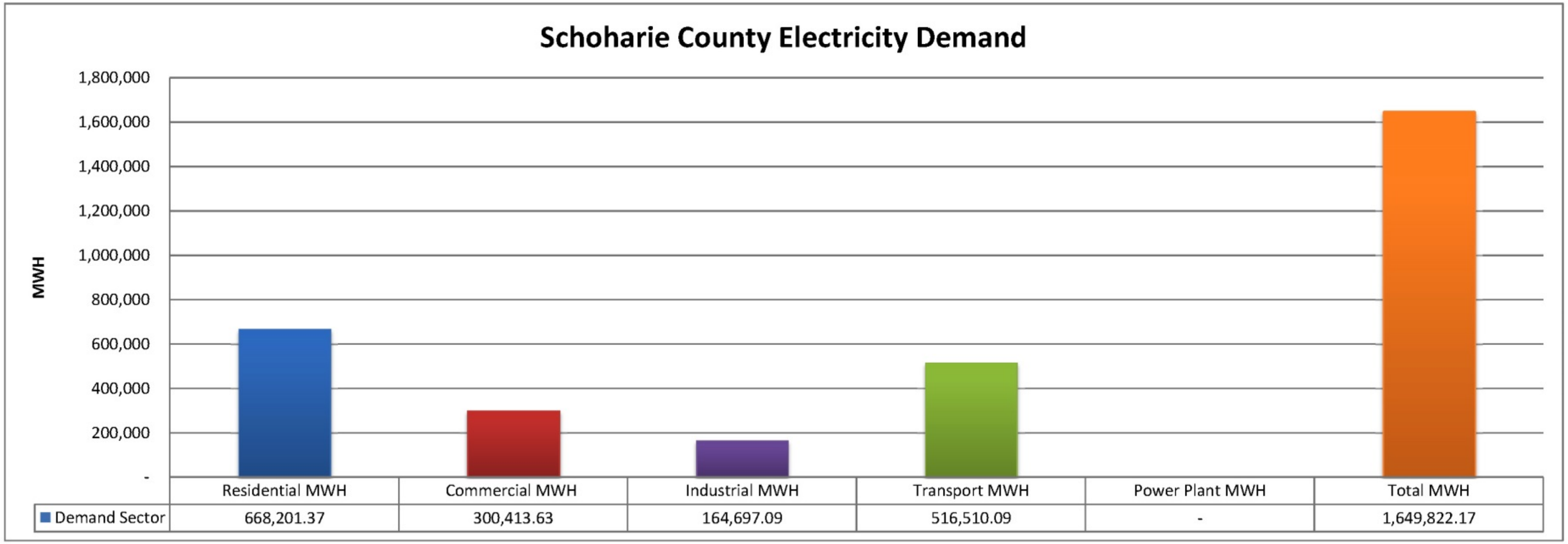


Figure 4-16: Schoharie County Electricity Demand (E1d & E2d)

Schoharie County Composted Organic Waste Production				
Category	Wet Short Tons	Dry Short Tons	Dry Metric Tons	*Data Source:*
Yard Waste	3,226.5	1,613.2	1,463.5	*Schoharie County MSW Spreadsheet (Reported)*
Food Waste Mass	4,166.7	2,083.4	1,890.0	*Co-EAT, post composting: MGD WWTP*
Biosolids (WW Solids Mass)	277.2	138.6	125.7	*Co-EAT, post composting; MGD WWTP*
Organic Production Summary			3,479.2	
Field Application Capacity			5,725.0	*USDA Quickstats Food Production Summary; Compost Rate/Ac*

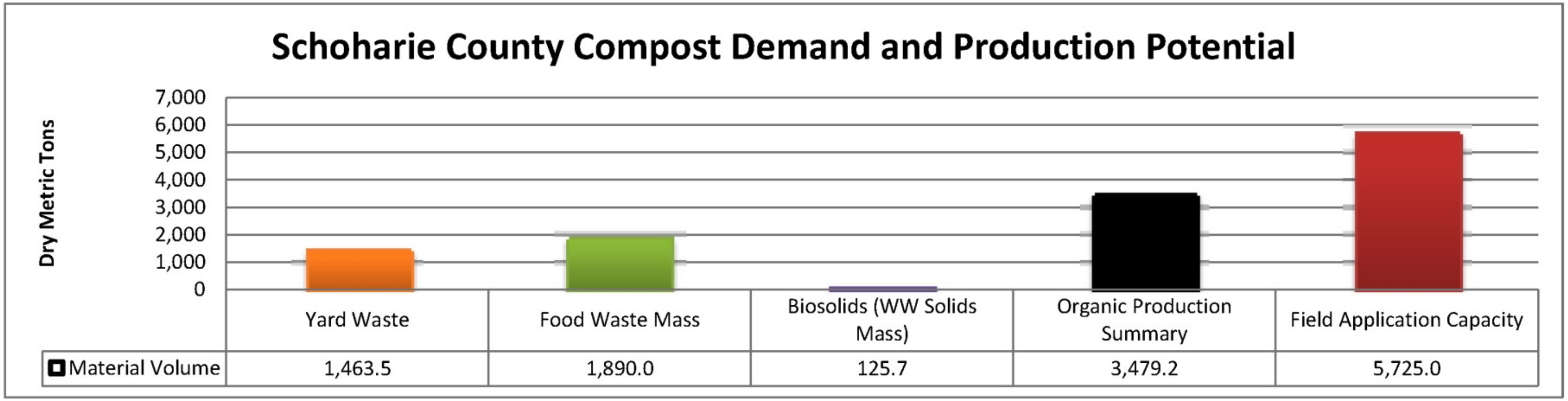


Figure 4-17: Schoharie County Compost Demand and Organic Material Production Potential (M1c & M1d)

VS = volatile solids TS = total solids MCRT = mean cell residence time

Feedstock Parameter	Value	Units
Food Waste Mass	11.42	short tons/day
Food Waste Biogas Yield	6.65	ft^3 CH^4/lb TS
Food Waste Total Solids	29.98%	solids
Food Waste VS	89.63%	of total solids
Food Waste % of Total Waste	93.76%	total substrate
Weighted Total Feedstock Loading (TS)	22,831.45	lbs/day
Weighted Total Feedstock Loading (VS)	20,464.51	lbs/day
Wastewater Solids Mass	0.76	short tons/day
Wastewater Solids Yield	2.12	ft^3 CH^4/lb TS
Wastewater Total Solids	1.00%	solids
Wastewater VS	70.00%	of total solids
Wastewater % of Total Waste	6.24%	total substrate
Weighted Total Feedstock Mass	12	short tons/day
Weighted Total Feedstock Yield	6.37	ft^3 CH^4/lb TS
Weighted Total Feedstock Concentration (% TS)	28.2%	solids
Weighted VS Content of Total Feedstock	88%	volatile solids
Weighted Total Feedstock (TS)	1,518.9	lbs/day
Weighted Total Feedstock (VS)	1,063.2	lbs/day

Table 4-5: Schoharie County Co-EAT Sludge Model Output (Input for M1d)

Schoharie County			
Plant Name	NPDES ID	Avg. Annual MGD	Total Sludge DMT/y
Richmondville STP	NY0022519	0.081666667	
Schoharie STP	NY0023655	0.061333333	
Cobleskill SPCP	NY0024201	0.55	147.54
Sharon Springs STP	NY0033588	0.1575	
Middleburgh WWTP	NY0192309	0.044916667	
Seward STP	NY0212199	0.006196417	
Central Bridge WWTP	NY0263087	0.023415	
Total Annual Average MGD		0.925028083	

Table 4-6: Schoharie County WWTPs MGD and Sludge Inputs for Co-EAT Model (Input for Input of M1d)

Schoharie County Generation Derived from State PPD Statistics		
Category	Percentage Generation[5]	Schoharie Generation
Paper and Paperboard	27%	6587.68
Glass	3%	731.96
Metals	6%	1463.93
Plastics	17%	4147.80
Rubber, leather and textiles	6%	1463.93
Wood	4%	975.95
Yard Trimmings	12%	2927.86
Food waste	12%	2927.86
Other	13%	3171.85
Total Generation in Tons	**1**	**24,398.82**

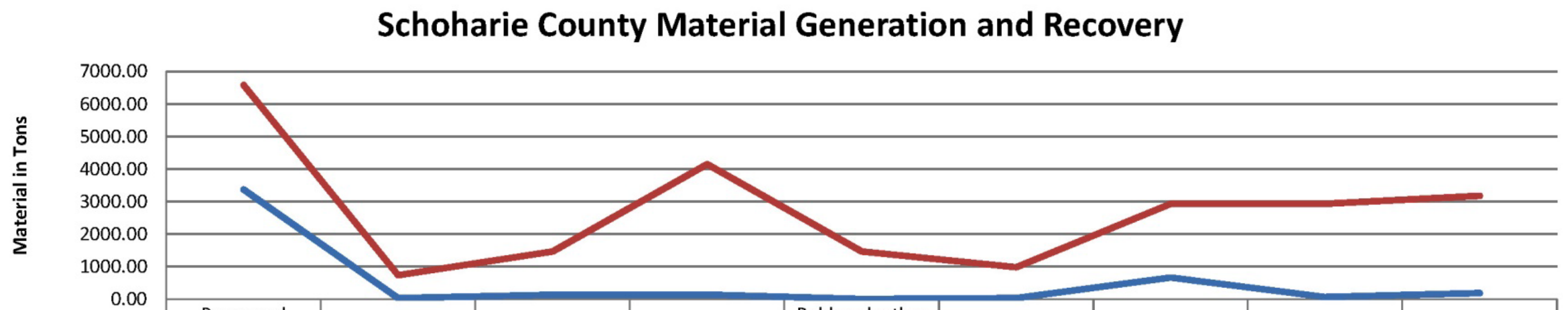
Schoharie County Recovery from National EPA Statistics		
Category	EPA Percentage Recovery[1]	Schoharie Recovery
Paper and Paperboard	51%	3372.89
Glass	4%	27.08
Metals	9%	128.83
Plastics	3%	132.73
Rubber, leather and textiles	0%	0.00
Wood	3%	27.33
Yard Trimmings	23%	661.70
Food waste	2%	58.56
Other	6%	180.80
Total Recovery in Tons	**1**	**4,589.91**

Census and Regional Overview Statistics				
County	2012 Pop	Pounds per day[5]	Total Waste (lbs/yr)	Total Waste (MT/y)
Schoharie	32,749	4.5	53790232.50	24398.82

Sources:

[5]NYS Department of Environmental Conservation (2010): NYS Beyond Waste Plan. Available online at http://www.dec.ny.gov/docs/materials_minerals_pdf/frptbeyondwaste.pdf, checked on June 2016.

[1]US EPA (2012): Municipal Solid Waste Generation, Recycling, and Disposal in the United States. Facts and Figures for 2012. US Environmental Protection Agency. Available online at www.epa.gov/wastes, updated on 2012, checked on April, 2014.



	Paper and Paperboard	Glass	Metals	Plastics	Rubber, leather and textiles	Wood	Yard Trimmings	Food waste	Other
Generation	6587.68	731.96	1463.93	4147.80	1463.93	975.95	2927.86	2927.86	3171.85
Recovery	3372.89	27.08	128.83	132.73	0.00	27.33	661.70	58.56	180.80

Figure 4-18: Schoharie County Material Generation and Recovery (M2c & M2d)

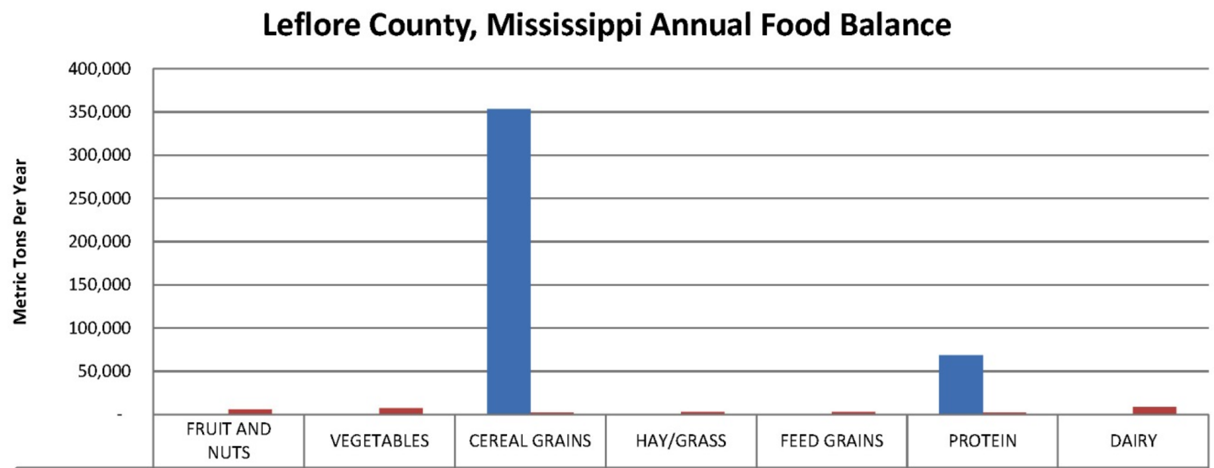
5 Leflore County, Mississippi

Leflore County, Mississippi

FOOD CAPACITY	
FDA Daily Food Groups	Total Metric Tons Production Per Year
FRUIT AND NUTS	-
VEGETABLES	66
CEREAL GRAINS	353,087
HAY/GRASS	551
FEED GRAINS	-
PROTEIN	68,280
DAIRY	-

FOOD DEMAND	*2012 ACS Population:	32317
FDA Daily Food Groups	Annual Demand in Metric Tons	Metric Tons/Capita*/Year**
FRUIT AND NUTS	5,898	0.1825
VEGETABLES	7,372	0.228125
CEREAL GRAINS	2,212	0.0684375
HAY/GRASS	2,686	*Varies Per Livestock Type*
FEED GRAINS	2,686	*Varies Per Livestock Type*
PROTEIN	2,027	0.0627343
DAIRY	8,847	0.27375

Demand of Feed/ Hay Grains	Hay in Metric Tons / Year	Corn in Metric Tons / Year
Milk Cows	-	-
Beef Cows	2,686	2,686
Goats	-	-
Hogs	-	-
Sheep	-	-
Poultry	-	-
Total Feed(tons)	2,686.23	2,686.23



	FRUIT AND NUTS	VEGETABLES	CEREAL GRAINS	HAY/GRASS	FEED GRAINS	PROTEIN	DAIRY
Food Capacity	-	66	353,087	551	-	68,280	-
Food Demand	5,898	7,372	2,212	2,686	2,686	2,027	8,847

Figure 5-1: Leflore County Food Summary (F1c - F7c & F1d - F7d)

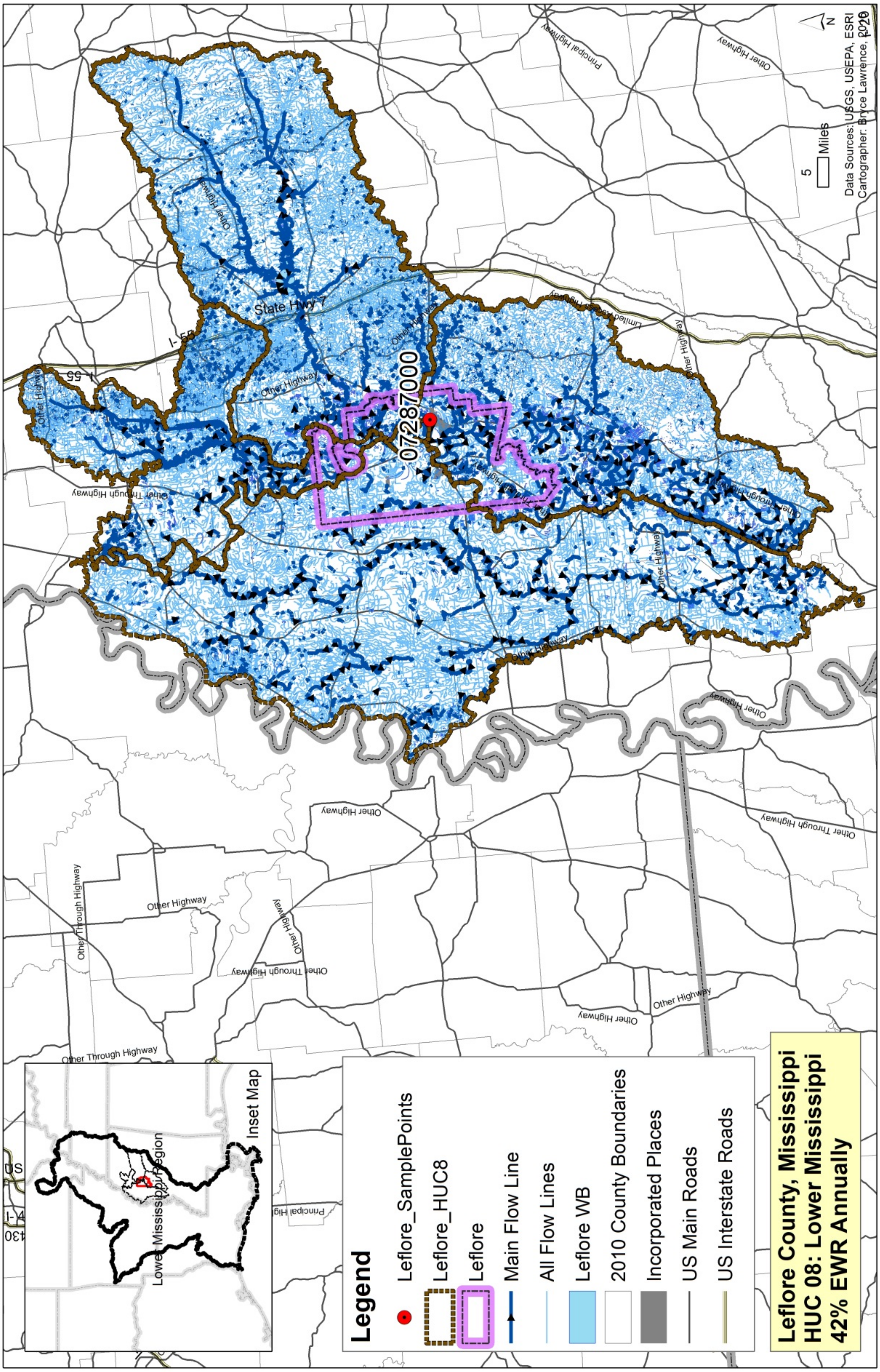


Figure 5-2: Leflore County Stream Network and Streamflow Sample Stations (W1c)

Leflore County, Mississippi

Total Available Stream Flow in Cubic Meters (W1c) with Human Abstraction (W1d)

USGS Station No. 07287000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1907-1980	5,877.4	8,723.1	12,638.7	10,786.3	8,124.2	5,528.3	4,202.3	2,865.8	1,932.7	1,452.3	1,598.3	2,895.8
EWR Requirement 41%	2,468.5	3,663.7	5,308.3	4,530.3	3,412.2	2,321.9	1,764.9	1,203.6	811.7	609.9	671.3	1,216.2
Available Adjusted CFS	3,408.9	5,059.4	7,330.5	6,256.1	4,712.0	3,206.4	2,437.3	1,662.2	1,120.9	842.3	927.0	1,679.6
EWR Corrected Mean Monthly Cubic Meters	253,678,818.7	376,503,095.1	545,506,921.9	465,555,396.5	350,653,186.0	238,611,707.8	181,376,178.5	123,692,789.5	83,416,984.1	62,681,780.6	68,986,622.8	124,987,637.5
Total P25 Discharge	437,377,273.6	649,143,267.4	940,529,175.7	802,681,718.1	604,574,458.7	411,399,496.1	312,717,549.1	213,263,430.2	143,822,386.4	108,072,035.5	118,942,453.1	215,495,926.8

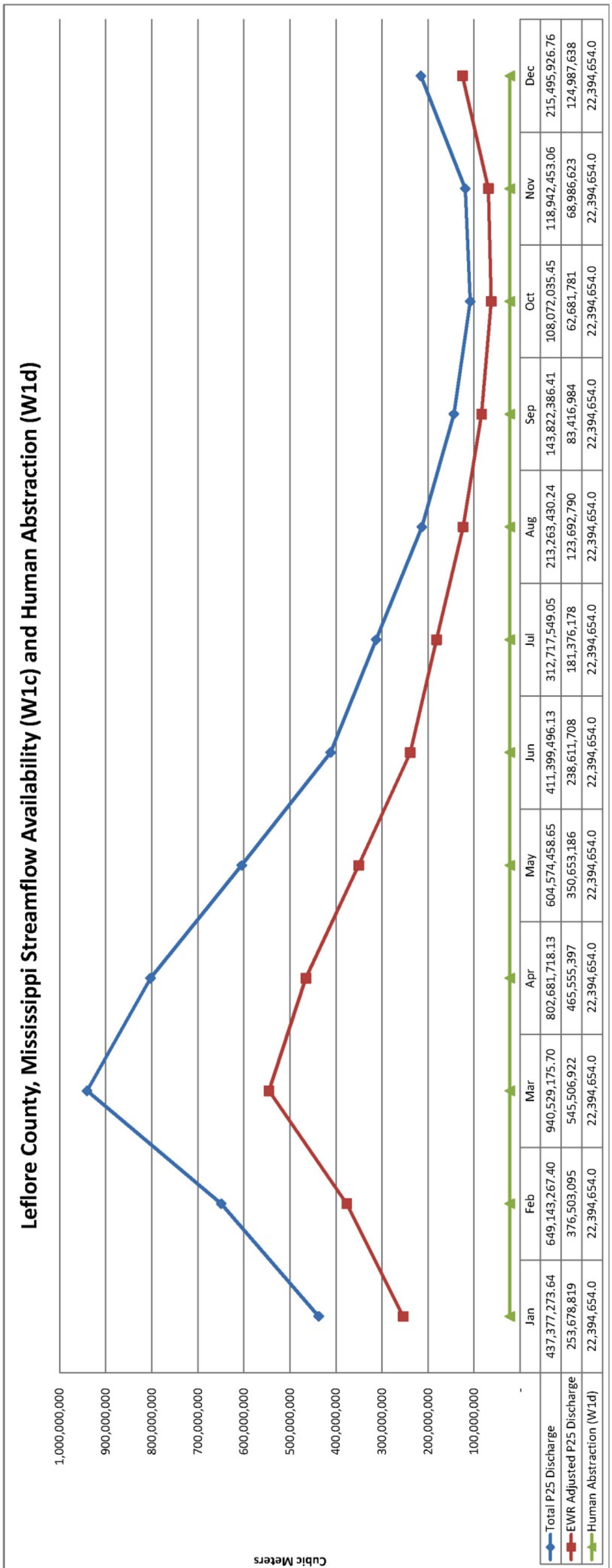
Total P25 Discharge	437,377,273.64	649,143,267.40	940,529,175.70	802,681,718.13	604,574,458.65	411,399,496.13	312,717,549.05	213,263,430.24	143,822,386.41	108,072,035.45	118,942,453.06	215,495,926.76
EWR Adjusted P25 Discharge	253,678,819	376,503,095	545,506,922	465,555,397	350,653,186	238,611,708	181,376,178	123,692,790	83,416,984	62,681,781	68,986,623	124,987,638
Human Abstraction (W1d)	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0
Human Abstraction as % EWR Adjusted	8.83%	5.95%	4.11%	4.81%	6.39%	9.39%	12.35%	18.11%	26.85%	35.73%	32.46%	17.92%

Total EWR Adjusted Annual Available Streamflow Volume in Cubic Meters	**2,875,651,119**

Table 5-1: Leflore County EWR Adjusted Annual P25 Streamflow Availability (W1c)

Leflore County, Mississippi 2010 Adjusted Water Abstraction		
Category	**Mgal/D Surface**	**Mgal/D Ground**
Public Supply	-	5.65
Mining	-	-
Livestock	-	-
Aquaculture	-	30.29
Irrigation	8.24	156.64
Daily Total	*8.24*	*192.58*
Annual Abstraction Projection by Source (USGS NWIS)	3,008	70,292
Total Annual Abstraction in Mgal	73,299	
2012 Total Annual Returns in Mgal (US EPA ECHO / NPDES)	2,307	
Total Adjusted Abstraction in Mgal	**70,993**	
Total Adjusted Abstraction in cubic meters per year / month	268,735,846	22,394,654

Table 5-2: Leflore County Adjusted Water Abstraction (W1d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	437,377,273.64	649,143,267.40	940,529,175.70	802,681,718.13	604,574,458.65	411,399,496.13	312,717,549.05	213,263,430.24	143,822,386.41	108,072,035.45	118,942,453.06	215,495,926.76
EWR Adjusted P25 Discharge	253,678,819	376,503,095	545,506,922	465,555,397	350,653,186	238,611,708	181,376,178	123,692,790	83,416,984	62,681,781	68,986,623	124,987,638
Human Abstraction (W1d)	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0	22,394,654.0

Figure 5-3: Leflore County Adjusted streamflow Availability and Human Abstraction (W1c & W1d)

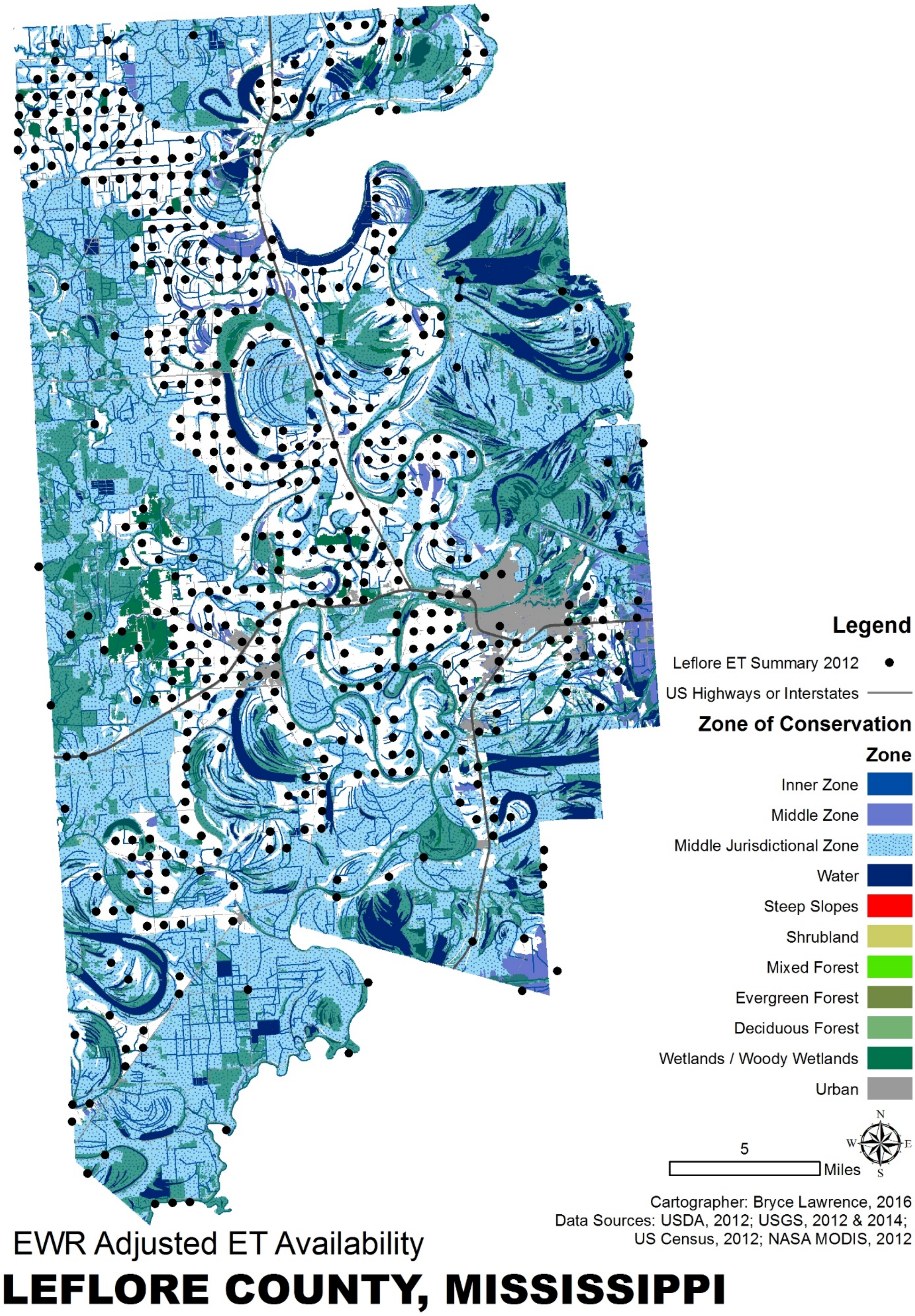
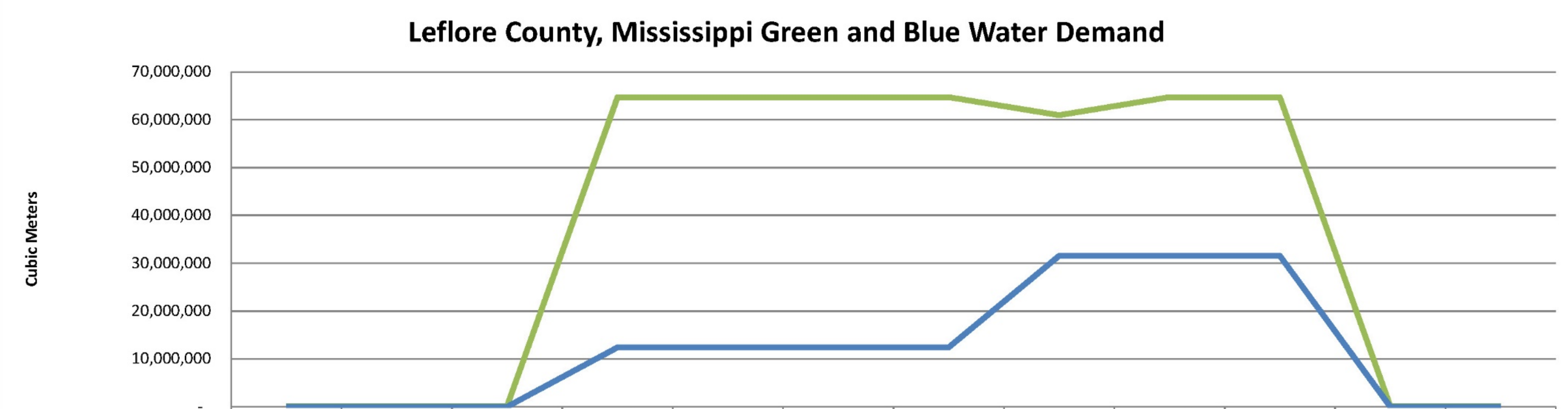


Figure 5-4: Leflore County EWR Adjusted ET Availability Sample Points (W2c)

Leflore County, Mississippi

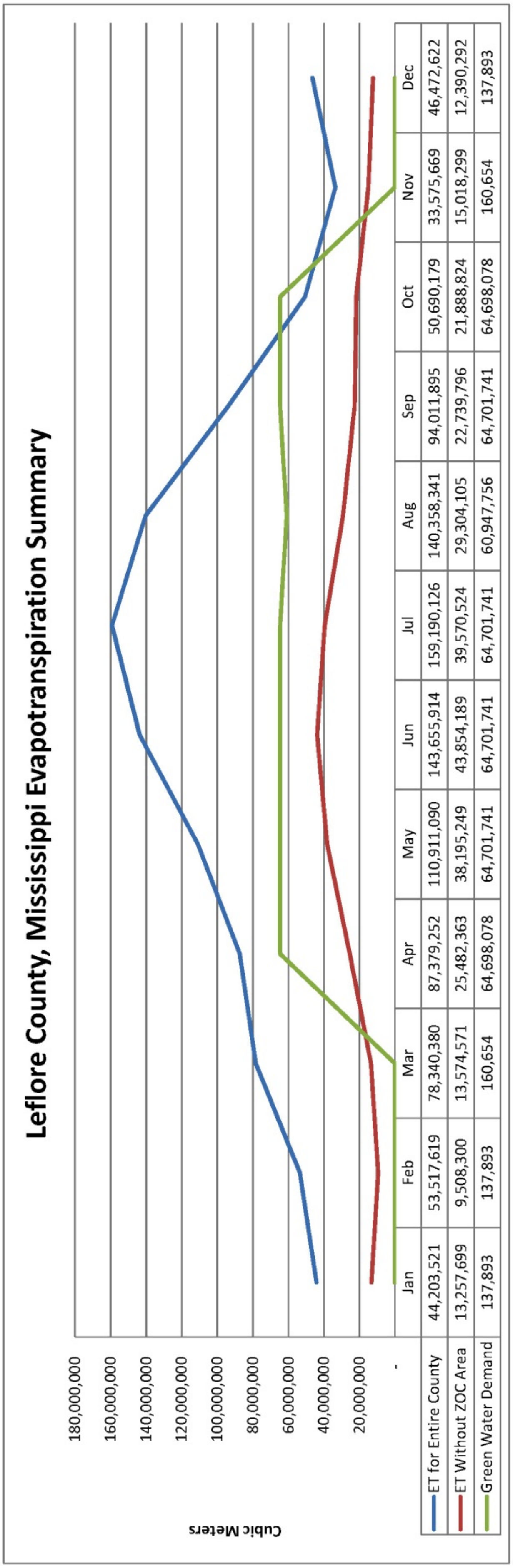
Monthly Green Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	GW Annual Total
Value in Cubic Meters	137,893	137,893	160,654	64,698,078	64,701,741	64,701,741	64,701,741	60,947,756	64,701,741	64,698,078	160,654	137,893	449,885,864

Monthly Blue Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	BW Annual Total
Value in Cubic Meters	10,134	10,106	10,134	12,399,032	12,399,311	12,399,302	12,399,311	31,529,665	31,557,901	31,557,641	10,134	10,134	144,292,803



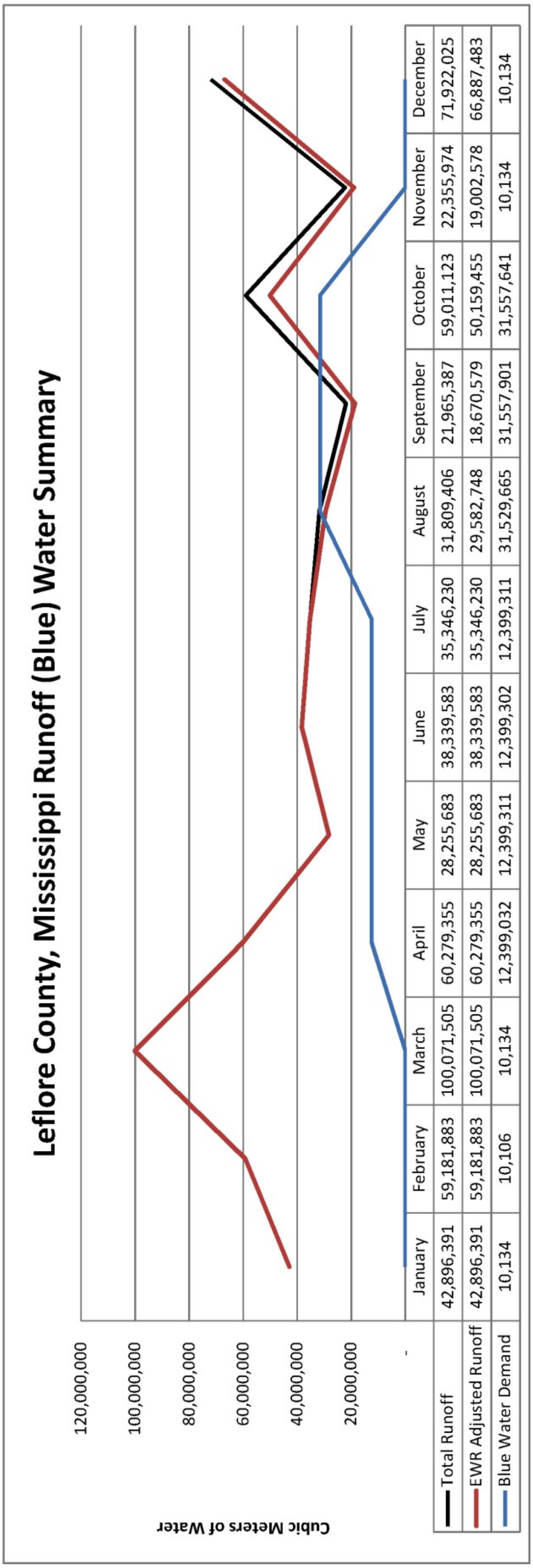
	January	February	March	April	May	June	July	August	September	October	November	December
Green Water Demand	137,893	137,893	160,654	64,698,078	64,701,741	64,701,741	64,701,741	60,947,756	64,701,741	64,698,078	160,654	137,893
Blue Water Demand	10,134	10,106	10,134	12,399,032	12,399,311	12,399,302	12,399,311	31,529,665	31,557,901	31,557,641	10,134	10,134

Figure 5-5: Leflore County ET (Green Water) and Surface (Blue Water) Demand (W2d & W3d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET for Entire County	44,203,521	53,517,619	78,340,380	87,379,252	110,911,090	143,655,914	159,190,126	140,358,341	94,011,895	50,690,179	33,575,669	46,472,622
ET Without ZOC Area	13,257,699	9,508,300	13,574,571	25,482,363	38,195,249	43,854,189	39,570,524	29,304,105	22,739,796	21,888,824	15,018,299	12,390,292
Green Water Demand	137,893	137,893	160,654	64,698,078	64,701,741	64,701,741	64,701,741	60,947,756	64,701,741	64,698,078	160,654	137,893

Figure 5-6: Leflore County ET (Green Water) Summary (W2c & W2d)



	January	February	March	April	May	June	July	August	September	October	November	December
Total Runoff	42,896,391	59,181,883	100,071,505	60,279,355	28,255,683	38,339,583	35,346,230	31,809,406	21,965,387	59,011,123	22,355,974	71,922,025
EWR Adjusted Runoff	42,896,391	59,181,883	100,071,505	60,279,355	28,255,683	38,339,583	35,346,230	29,582,748	18,670,579	50,159,455	19,002,578	66,887,483
Blue Water Demand	10,134	10,106	10,134	12,399,032	12,399,311	12,399,302	12,399,311	31,529,665	31,557,901	31,557,641	10,134	10,134

Figure 5-7: Leflore County Surface (Blue) Water Availability and Demand (W3c & W3d)

N	Leflore County, Mississippi	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	42,896,391	59,181,883	100,071,505	60,279,355	28,255,683	38,339,583	35,346,230	29,582,748	18,670,579	50,159,455	19,002,578	66,887,483
	Liters / month	42,896,391,000	59,181,883,000	100,071,505,000	60,279,355,000	28,255,683,100	38,339,583,000	35,346,230,000	29,582,747,580	18,670,578,950	50,159,454,550	19,002,577,900	66,887,483,250
1.05	Mg/l limit	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
	Total Allowed Mg	45,041,210,550	62,140,977,150	105,075,080,250	63,293,322,750	29,668,467,255	40,256,562,150	37,113,541,500	31,061,884,959	19,604,107,898	52,667,427,278	19,952,706,795	70,231,857,413
	Total Allowed Tons (N)	45.0	62.1	105.1	63.3	29.7	40.3	37.1	31.1	19.6	52.7	20.0	70.2
0.28	Nnat in mg/l	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	Total mg Nnat	12,010,989,480	16,570,927,240	28,020,021,400	16,878,219,400	7,911,591,268	10,735,083,240	9,896,944,400	8,283,169,322	5,227,762,106	14,044,647,274	5,320,721,812	18,728,495,310
	Tons Nnat	12.0	16.6	28.0	16.9	7.9	10.7	9.9	8.3	5.2	14.0	5.3	18.7
	Corrected Limit	33.0	45.6	77.1	46.4	21.8	29.5	27.2	22.8	14.4	38.6	14.6	51.5
	Total Annual N Load (t)	**422.5**											

P	Leflore County, Mississippi	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	42,896,391	59,181,883	100,071,505	60,279,355	28,255,683	38,339,583	35,346,230	29,582,748	18,670,579	50,159,455	19,002,578	66,887,483
	Liters / month	42,896,391,000	59,181,883,000	100,071,505,000	60,279,355,000	28,255,683,100	38,339,583,000	35,346,230,000	29,582,747,580	18,670,578,950	50,159,454,550	19,002,577,900	66,887,483,250
0.16	monthly P mg limit	6,863,422,560	9,469,101,280	16,011,440,800	9,644,696,800	4,520,909,296	6,134,333,280	5,655,396,800	4,733,239,613	2,987,292,632	8,025,512,728	3,040,412,464	10,701,997,320
	Total Allowed Tons (P)	6.86	9.47	16.01	9.64	4.52	6.13	5.66	4.73	2.99	8.03	3.04	10.70
0.02	Pnat in mg/l	857,927,820	1,183,637,660	2,001,430,100	1,205,587,100	565,113,662	766,791,660	706,924,600	591,654,952	373,411,579	1,003,189,091	380,051,558	1,337,749,665
	Total tons bkgnd Pnat	0.86	1.18	2.00	1.21	0.57	0.77	0.71	0.59	0.37	1.00	0.38	1.34
	Corrected Limit	6.01	8.29	14.01	8.44	3.96	5.37	4.95	4.14	2.61	7.02	2.66	9.36
	Total Annual P Load (t)	**76.8**											

Table 5-3: Leflore County Critical Nitrogen and Phosphorus Load Limits (W4c & W5c)

Leflore County N and P Load Summary			
CROPGROUP	N_load	P_load	Hectares
Oilseed	156	125	45,610
Cereal	246	104	38,743
Fruit	0	0	28
Fibre	105	38	10,970
Veg	0	0	5
Nuts	1	1	333
Feed	3	1	443
N and P Point Loads	-	-	(N)n=0, (P)n=0
Total N and P Load	**511**	**269**	

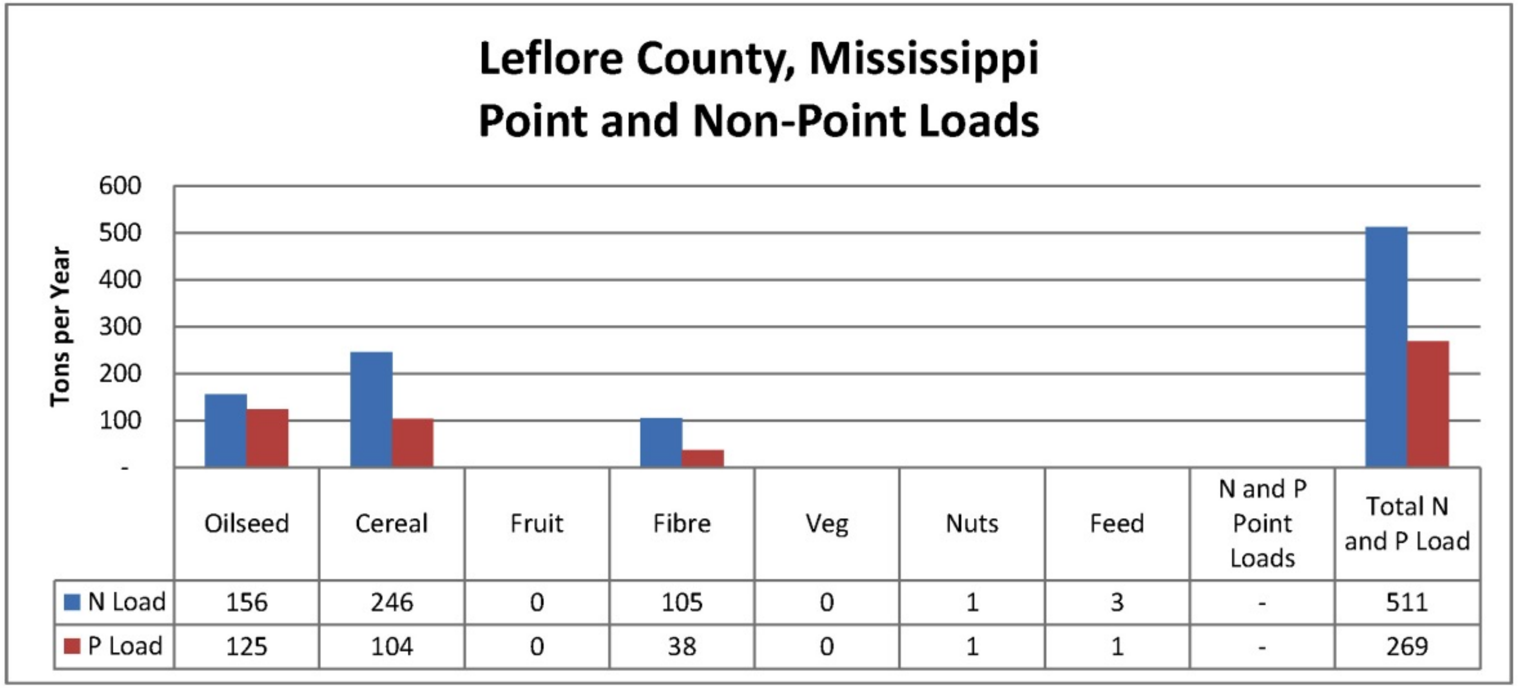


Figure 5-8: Leflore County Nitrogen and Phosphorus Point and Non-Point Source Loads (W4d & W5d)

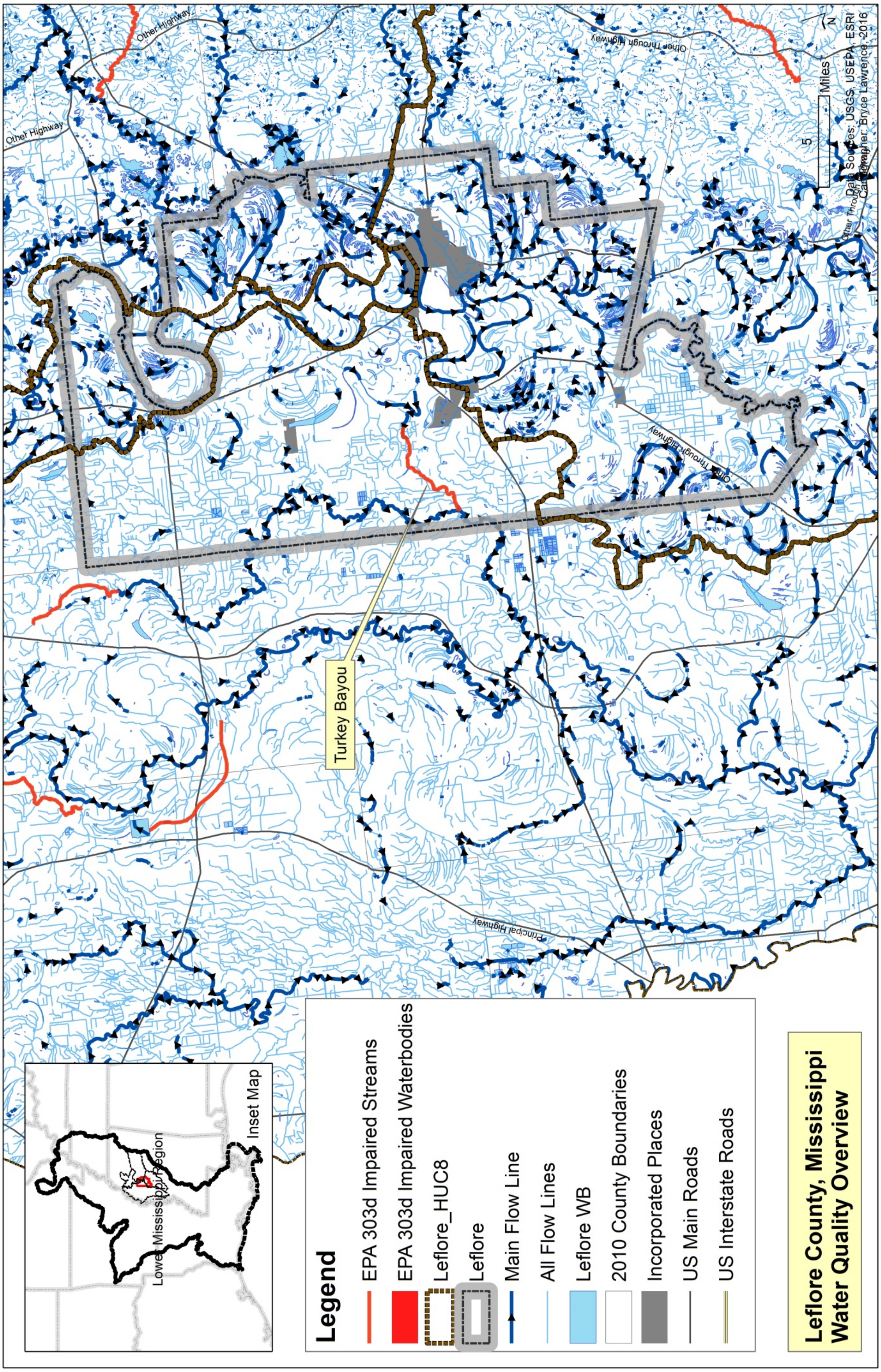


Figure 5-9: Leflore County EPA 303d Listed Streams and Waterbodies

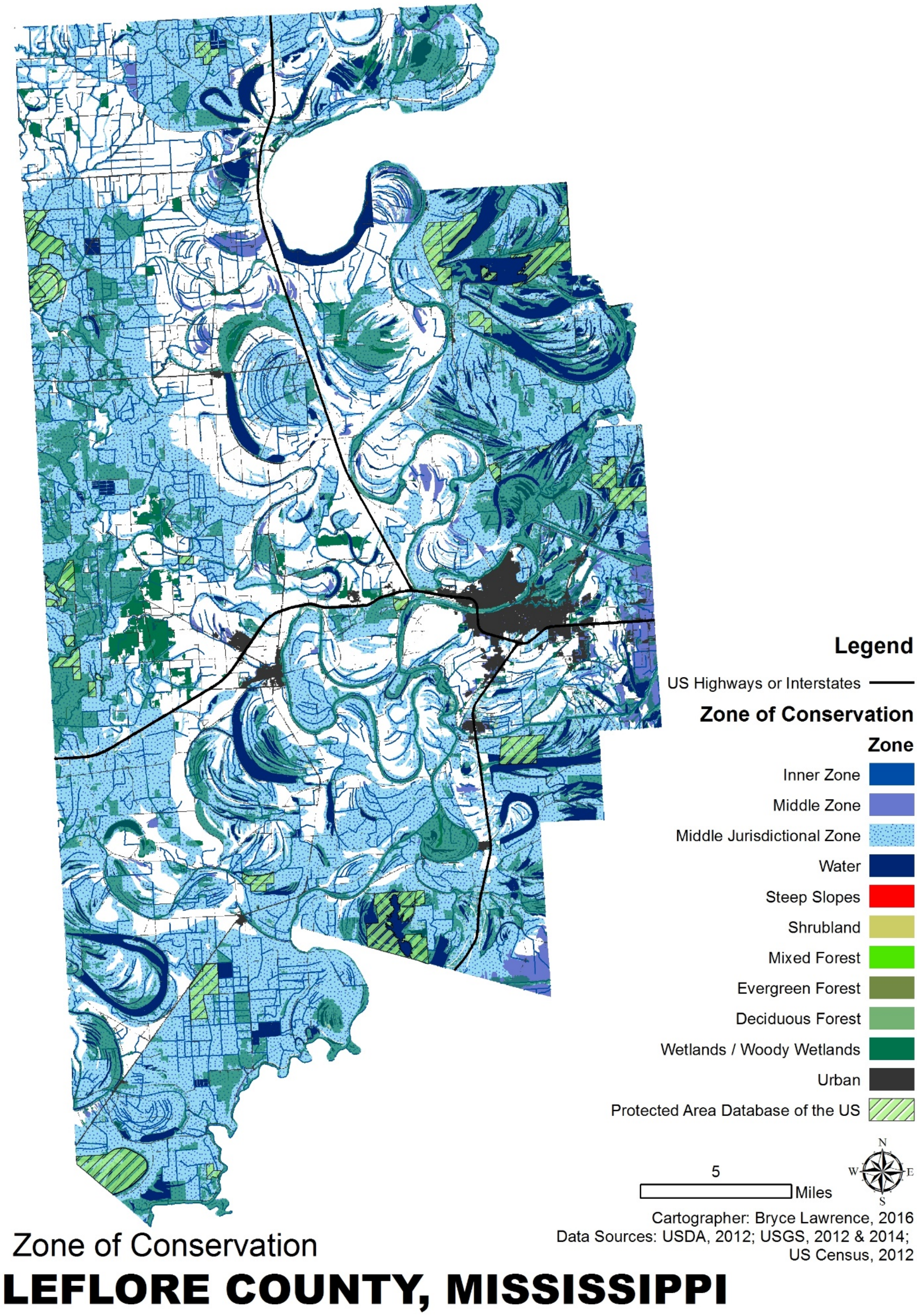


Figure 5-10: Leflore County Existing and Potential Zone of Conservation (EC1c & EC1c)

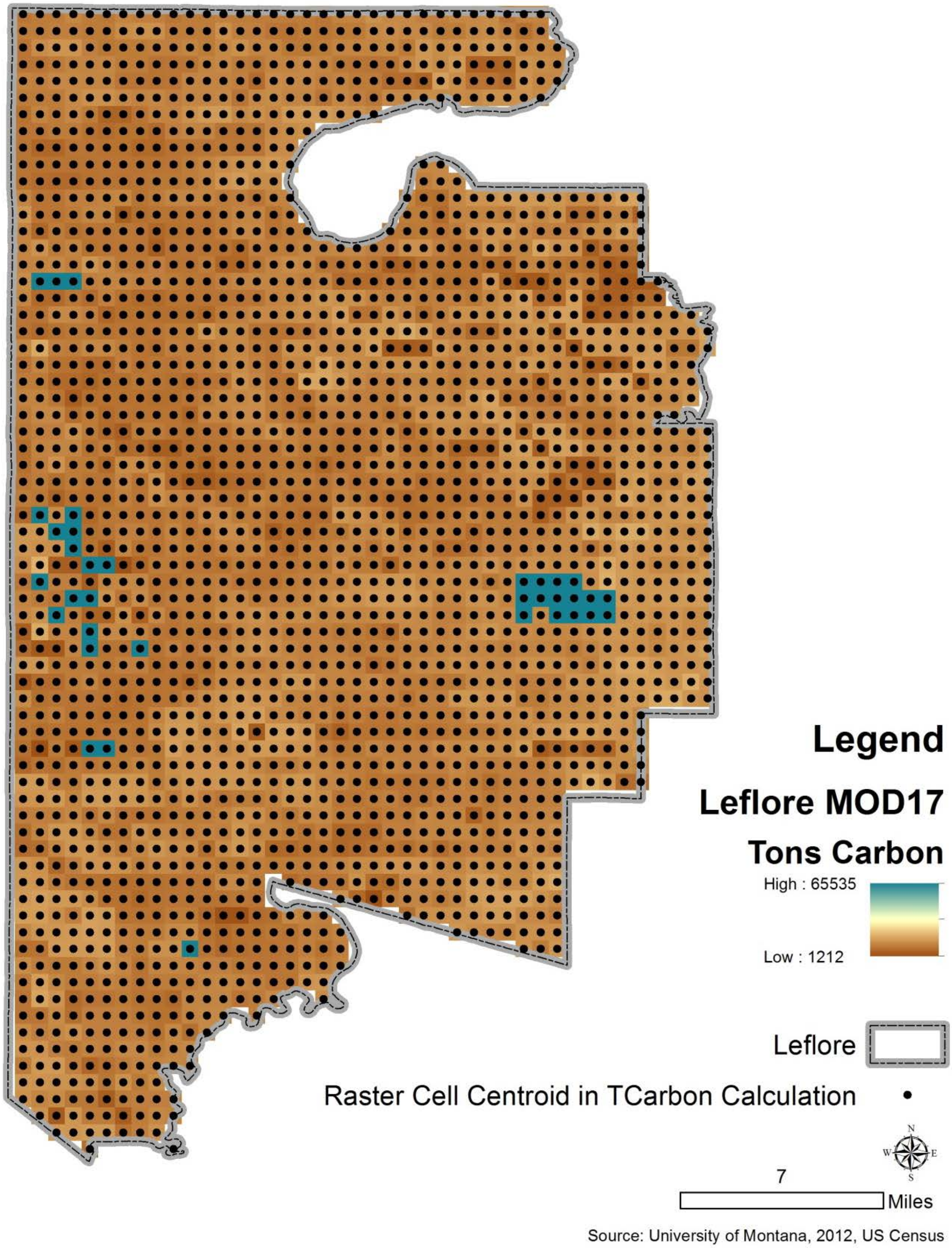


Figure 5-11: Leflore County Net Primary Productivity (NPP) in Tons of Carbon per Year, as Estimate for Carbon Sequestration Potential (C1c)

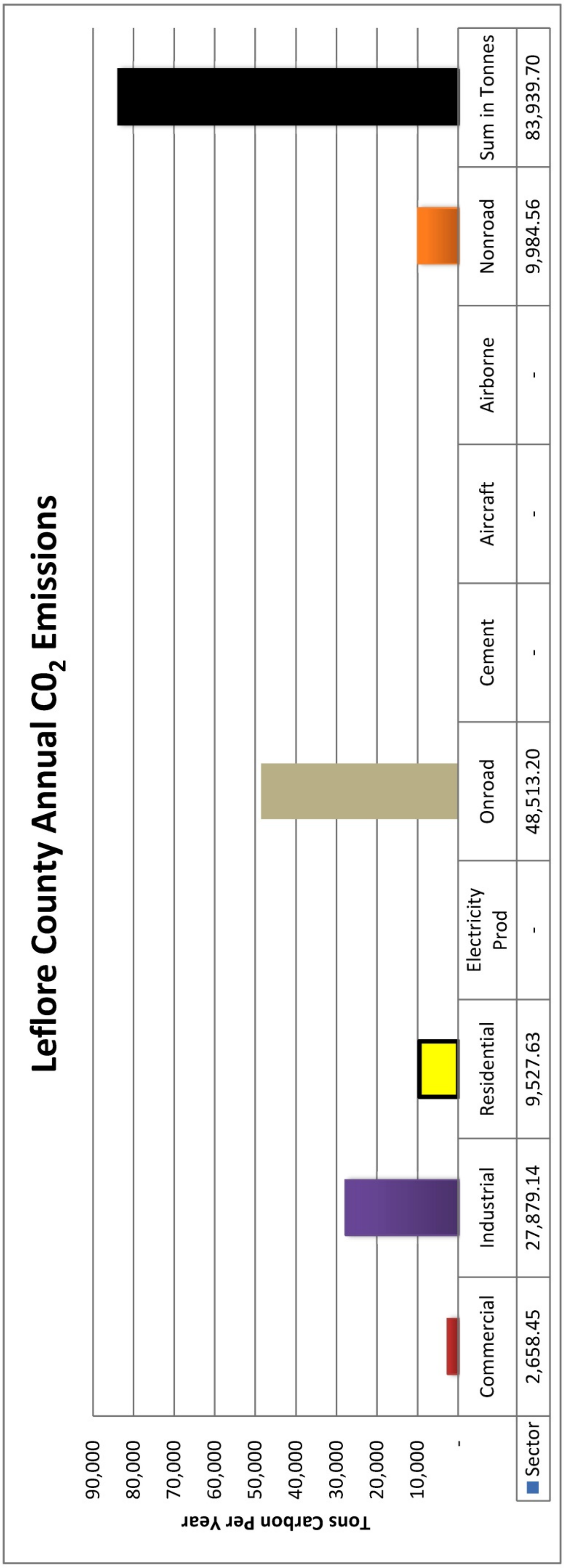


Figure 5-12: Leflore County $C0_2$ Emissions in Tons per Year (C1d)

Intentionally left blank, no wind resources in Leflore identified

Figure 5-13: Leflore County Potential Wind and PV Renewable Electricity Locations Map (E1c)

Intentionally left blank, no wind resources in Leflore identified and PV potential provided in Figure 5-15

Figure 5-14: Leflore County Potential Wind and PV Renewable Electricity Locations (E1c)

Leflore County Solar Resouce Summary

Raster Tile OID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
111	3.786	4.340	5.151	5.667	5.765	6.041	5.970	6.123	5.609	5.191	4.338	3.577
112	3.793	4.258	5.156	5.643	5.765	6.007	5.969	6.139	5.630	5.195	4.317	3.564
113	3.758	4.350	5.176	5.633	5.734	6.004	5.974	6.110	5.631	5.207	4.332	3.556
114	3.801	4.338	5.162	5.637	5.738	5.977	5.889	6.077	5.599	5.206	4.294	3.521
115	3.775	4.324	5.122	5.653	5.750	6.034	5.997	6.154	5.626	5.179	4.321	3.595
116	3.760	4.306	5.132	5.662	5.724	6.021	5.983	6.136	5.613	5.208	4.312	3.569
117	3.753	4.254	5.116	5.647	5.694	5.969	5.951	6.109	5.597	5.182	4.336	3.537
118	3.738	4.319	5.167	5.627	5.714	5.976	5.907	6.120	5.650	5.212	4.264	3.520
119	3.755	4.260	5.153	5.715	5.758	6.066	6.035	6.198	5.649	5.219	4.268	3.571
120	3.725	4.303	5.153	5.694	5.729	6.048	5.969	6.165	5.609	5.222	4.287	3.520
121	3.797	4.278	5.162	5.676	5.699	6.012	5.911	6.092	5.610	5.207	4.300	3.522
122	3.749	4.264	5.145	5.639	5.728	5.979	5.877	6.112	5.638	5.202	4.290	3.523
123	3.780	4.333	5.201	5.717	5.780	6.080	5.977	6.211	5.639	5.250	4.347	3.592
124	3.748	4.258	5.138	5.639	5.665	6.003	5.949	6.180	5.561	5.200	4.283	3.569
125	3.752	4.281	5.178	5.634	5.716	5.996	5.939	6.135	5.597	5.229	4.326	3.580
126	3.743	4.291	5.176	5.656	5.720	5.986	5.866	6.109	5.625	5.216	4.323	3.557
127	3.788	4.297	5.165	5.713	5.766	6.076	5.964	6.130	5.603	5.243	4.363	3.618
128	3.769	4.304	5.166	5.687	5.730	6.015	5.942	6.127	5.601	5.238	4.374	3.614
129	3.755	4.292	5.171	5.672	5.700	5.975	5.935	6.133	5.587	5.233	4.325	3.601
130	3.765	4.292	5.171	5.664	5.713	5.994	5.885	6.044	5.596	5.235	4.337	3.585
131	3.821	4.334	5.180	5.711	5.763	6.028	5.957	6.094	5.632	5.244	4.390	3.626
132	3.816	4.308	5.190	5.708	5.752	6.031	5.937	6.127	5.628	5.253	4.337	3.627
133	3.792	4.284	5.137	5.659	5.682	5.985	5.927	6.046	5.584	5.190	4.324	3.607
134	3.747	4.260	5.155	5.663	5.698	5.962	5.879	6.013	5.554	5.083	4.251	3.549
135	3.835	4.325	5.170	5.698	5.730	6.017	5.942	6.100	5.615	5.255	4.348	3.625
136	3.844	4.341	5.166	5.713	5.775	6.005	5.912	6.090	5.596	5.232	4.377	3.631
Average kWh/m^2/month	3.775	4.300	5.160	5.670	5.730	6.011	5.940	6.118	5.611	5.213	4.322	3.575
Residential Units	10,137											
NR Units	730											
Annual Sum in MWH	**24,424**											

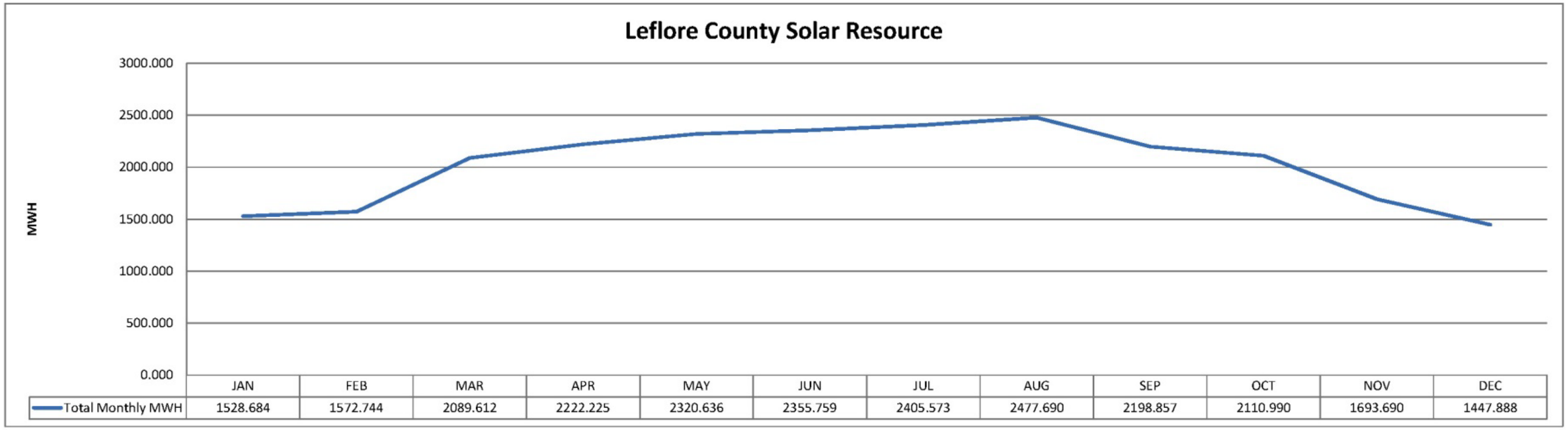


Figure 5-15: Solar (PV) Resource Potential Summary for Leflore County (E1c)

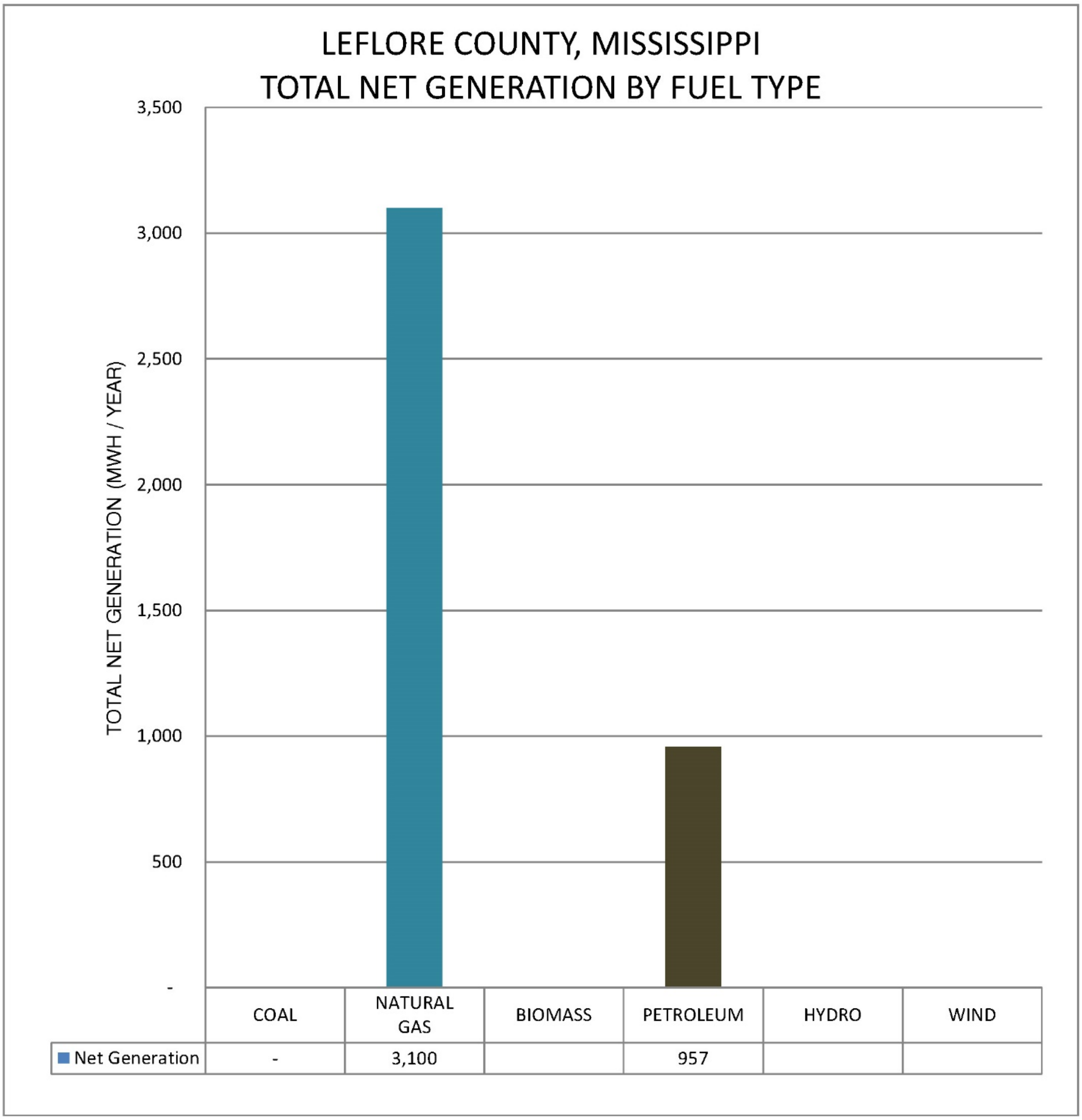


Figure 5-16: Leflore County Existing Electricity Production (E2c), an Annual Loss due to Gravity Fed Energy Recovery System

		ACS Table DP04		From Economic Census Table A1				2012 ACS	2010 Census
								County	State
County	State	County Residential Units	Statewide Res. Units	County Commercial Units	Statewide Comm. Units	County Industrial Units	Statewide Ind. Units	Population	Population
Leflore	Mississippi	13175	1272277	469	39444	261	19200	32317	2,994,079

Source:	Econ. Census: Table C10	Econ. Census: Table C10	Econ. Census: Table C10	Econ. Census: Table C10		USEIA
Units:	in Trillion Btu's	in Trillion Btu's	in Trillion Btu's	in Trillion Btu's		in Million Btu's
State	Total Residential TBtu's / Year	Total Commercial TBtu's / Year	Total Industrial Tbtu's / Year	Total Transportation Tbtu's / Year	County	All Prime Movers Btu's / Year
Mississippi	211.2	160.3	402.2	368.1	Leflore	61136

County	Residential MWH	Commercial MWH	Industrial MWH	Transport MWH	Power Plant MWH	Total MWH
Leflore	640,993.82	558,619.89	1,602,405.11	1,164,460.01	17,917.94	3,984,396.76

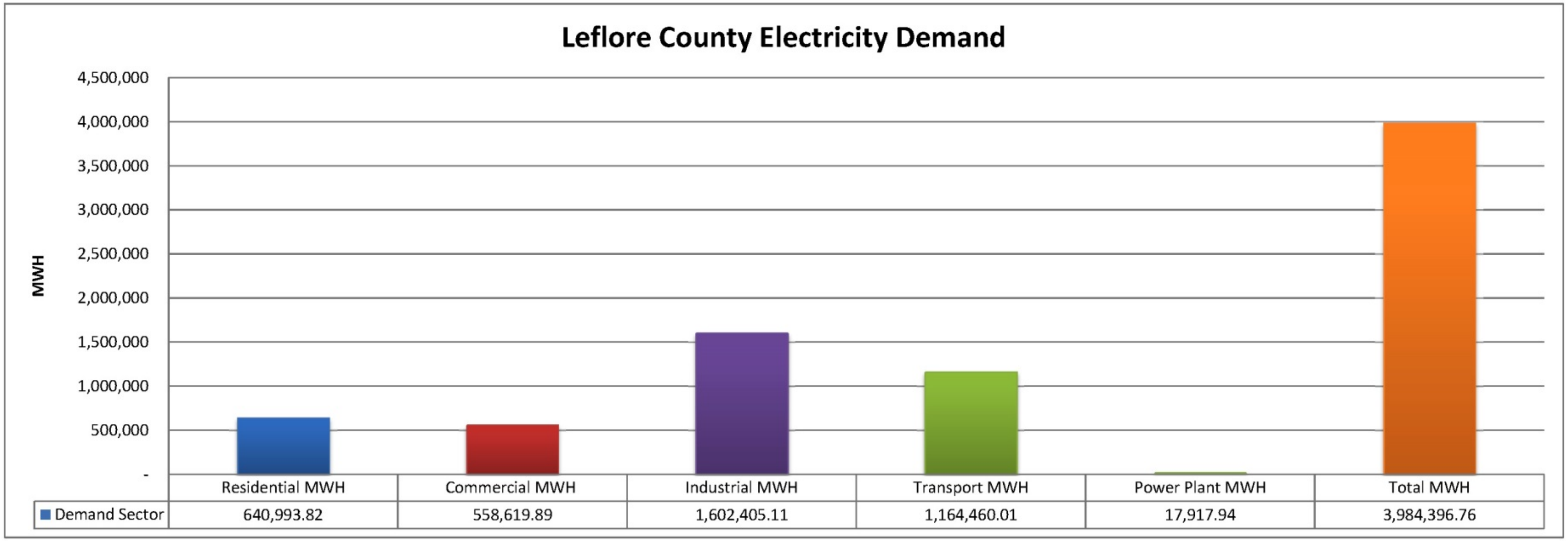


Figure 5-17: Leflore County Electricity Demand (E1d & E2d)

Leflore County Composted Organic Waste Production				
Category	Wet Short Tons	Dry Short Tons	Dry Metric Tons	*Data Source:*
Yard Waste	9,408.2	4,704.1	4,267.5	*Leflore County MSW Spreadsheet (EPA% from Reported Total)*
Food Waste Mass	4,276.4	2,138.2	1,939.7	*Co-EAT, post composting: MGD WWTP*
Biosolids (WW Solids Mass)	689.2	344.6	312.6	*Co-EAT, post composting; MGD WWTP*
Organic Production Summary			6,519.8	
Field Application Capacity			24,561.0	*USDA Quickstats Food Production Summary; Compost Rate/Ac*

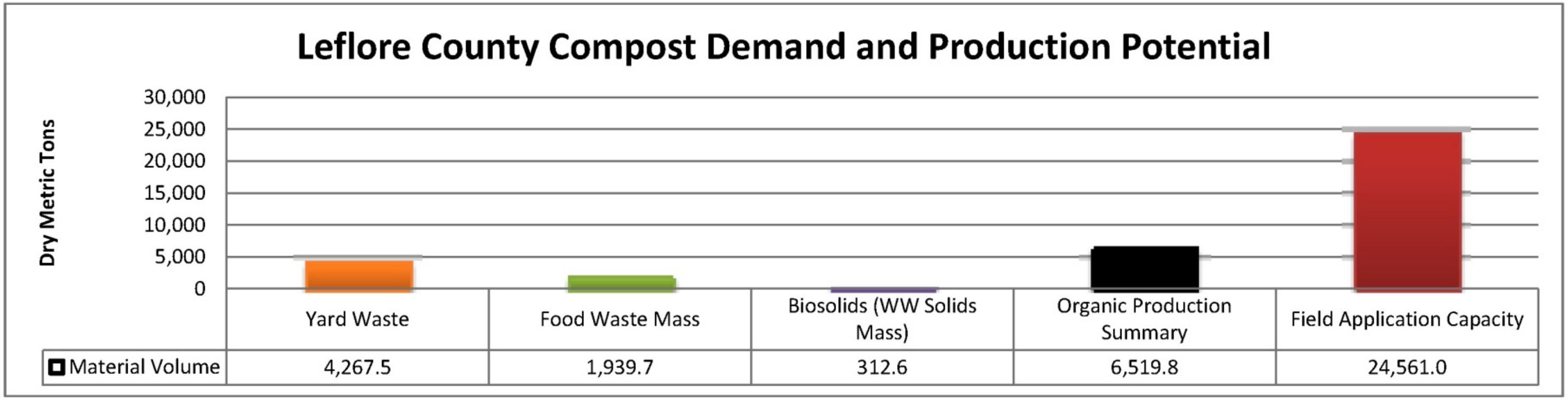


Figure 5-18: Leflore County Compost Demand and Organic Material Production Potential (M1c & M1d)

VS = volatile solids TS = total solids MCRT = mean cell residence time

Feedstock Parameter	Value	Units
Food Waste Mass	11.72	short tons/day
Food Waste Biogas Yield	6.65	ft³ CH⁴/lb TS
Food Waste Total Solids	29.98%	solids
Food Waste VS	89.63%	of total solids
Food Waste % of Total Waste	86.12%	total substrate
Weighted Total Feedstock Loading (TS)	23,432.25	lbs/day
Weighted Total Feedstock Loading (VS)	21,001.82	lbs/day
Wastewater Solids Mass	1.89	short tons/day
Wastewater Solids Yield	2.12	ft³ CH⁴/lb TS
Wastewater Total Solids	1.00%	solids
Wastewater VS	70.00%	of total solids
Wastewater % of Total Waste	13.88%	total substrate
Weighted Total Feedstock Mass	14	short tons/day
Weighted Total Feedstock Yield	6.02	ft³ CH⁴/lb TS
Weighted Total Feedstock Concentration (% TS)	26.0%	solids
Weighted VS Content of Total Feedstock	87%	volatile solids
Weighted Total Feedstock (TS)	3,776.6	lbs/day
Weighted Total Feedstock (VS)	2,643.6	lbs/day

Table 5-4: Leflore County Co-EAT Sludge Model output (Input for M1d)

Leflore County			
Plant Name	NPDES ID	Avg. Annual MGD	Total Sludge DMT/y
City of Greenwood WWTP	Unknown	2.3	
Total Annual Average MGD		2.3	

Table 5-5: Leflore County WWTPs MGD and Sludge Inputs for Co-EAT Model (Input for Input of M1d)

Leflore County Generation Derived from State PPD Statistics		
Category	EPA Percentage Generation[1]	Leflore Generation
Paper and Paperboard	27%	17308.71
Glass	5%	2905.84
Metals	9%	5622.17
Plastics	13%	8022.65
Rubber, leather and textiles	9%	5495.83
Wood	6%	3979.74
Yard Trimmings	14%	8528.01
Food waste	15%	9159.72
Other	3%	2147.80
Total Generation in Tons	**1**	**63,170.47**

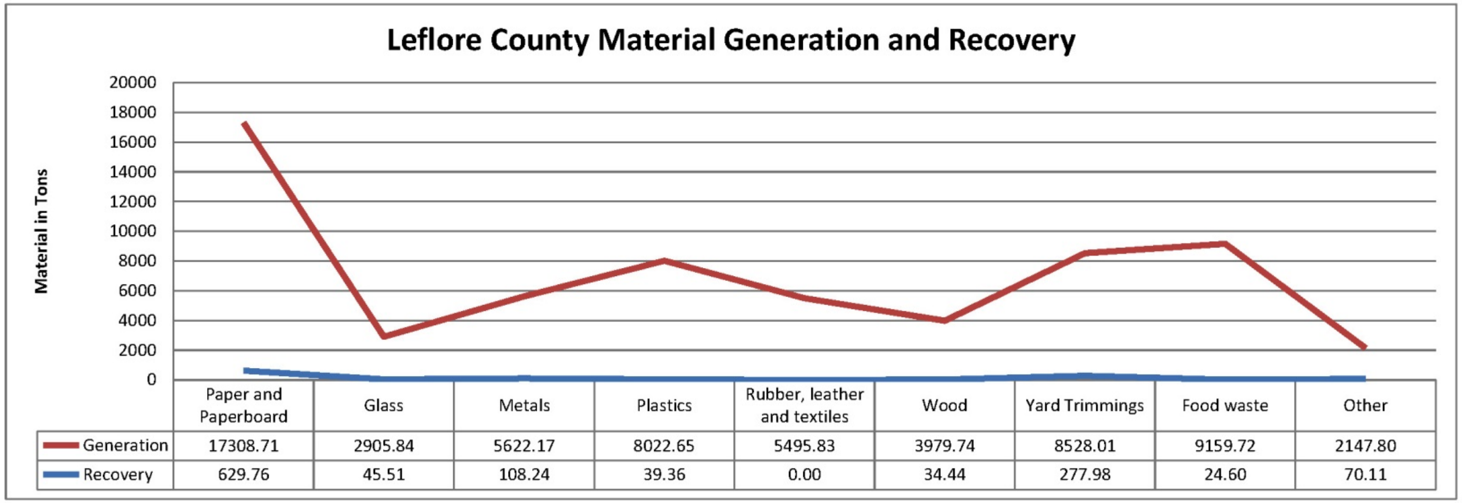
Leflore County Recovery from County MSW Report		
Category	EPA Percentage Recovery[1]	Leflore Recovery[6]
Paper and Paperboard	51%	629.76
Glass	4%	45.51
Metals	9%	108.24
Plastics	3%	39.36
Rubber, leather and textiles	0%	0.00
Wood	3%	34.44
Yard Trimmings	23%	277.98
Food waste	2%	24.60
Other	6%	70.11
Total Recovery in Tons	**1**	**1,230.00**

Census and State Overview Statistics				
County	2012 Pop	Pounds per day	Total Waste (lbs/yr)	Total Waste (MT/y)[6]
Leflore	32,317	11.81	139267170.65	63170.47

Sources:

[1]US EPA (2012): Municipal Solid Waste Generation, Recycling, and Disposal in the United States. Facts and Figures for 2012. US Environmental Protection Agency. Available online at www.epa.gov/wastes, updated on 2012, checked on April, 2014.

[6]Office of Pollution Control, MIssissippi Department of Environmental Quality (2012): State of Mississippi 2012 MSW Annual Report. Status Report on Solid Waste Management Facilities and Activities. Jackson, Mississippi. Available online at https://www.deq.state.ms.us/MDEQ.nsf/pdf/SW_2012SolidWasteAnnualReport/$File/2012%20Annual%20Report.pdf?OpenElement, checked on June 2016.



	Paper and Paperboard	Glass	Metals	Plastics	Rubber, leather and textiles	Wood	Yard Trimmings	Food waste	Other
Generation	17308.71	2905.84	5622.17	8022.65	5495.83	3979.74	8528.01	9159.72	2147.80
Recovery	629.76	45.51	108.24	39.36	0.00	34.44	277.98	24.60	70.11

Figure 5-19: Leflore County Material Generation and Recovery (M2c & M2d)

6 Decatur County, Georgia

Decatur County, Georgia

FOOD CAPACITY	
FDA Daily Food Groups	Total Metric Tons Production Per Year
FRUIT AND NUTS	399
VEGETABLES	97,944
CEREAL GRAINS	92,680
HAY/GRASS	12,101
FEED GRAINS	39,216
PROTEIN	26,825
DAIRY	23,841

FOOD DEMAND	*2012 ACS Population:	27842
FDA Daily Food Groups	Annual Demand in Metric Tons	Metric Tons/Capita*/Year**
FRUIT AND NUTS	5,081	0.1825
VEGETABLES	6,351	0.228125
CEREAL GRAINS	1,905	0.0684375
HAY/GRASS	150,261	*Varies Per Livestock Type*
FEED GRAINS	168,177	*Varies Per Livestock Type*
PROTEIN	1,747	0.0627343
DAIRY	7,622	0.27375

Demand of Feed/ Hay Grains	Hay in Metric Tons / Year	Corn in Metric Tons / Year
Milk Cows	30,694	323
Beef Cows	119,478	119,478
Goats	89	18
Hogs	-	241
Sheep	-	-
Poultry	-	48,117
Total Feed(tons)	150,261.26	168,176.64

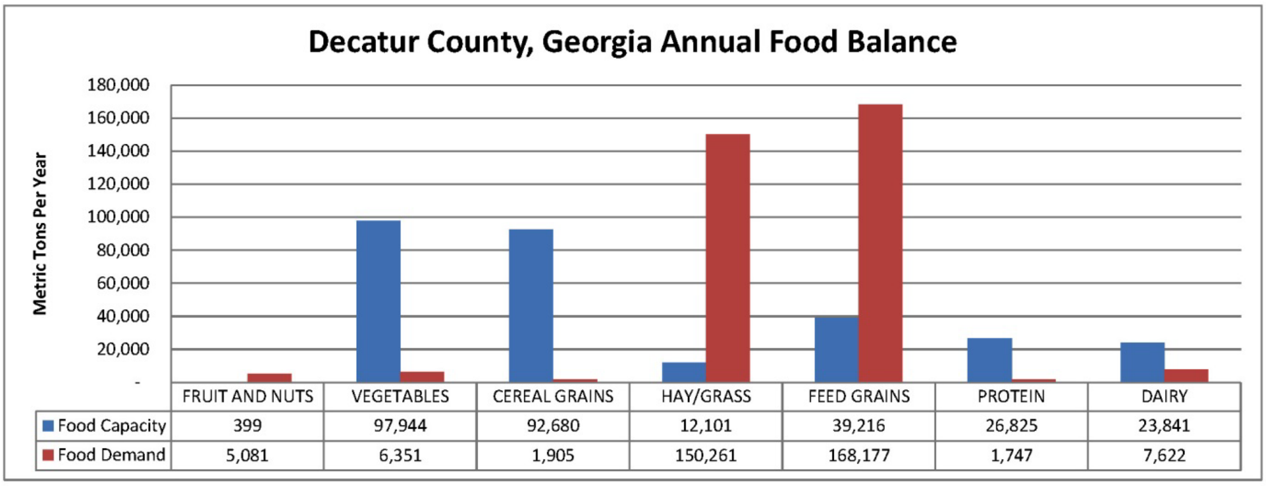


Figure 6-1: Decatur County Food Summary (F1c - F7c & F1d - F7d)

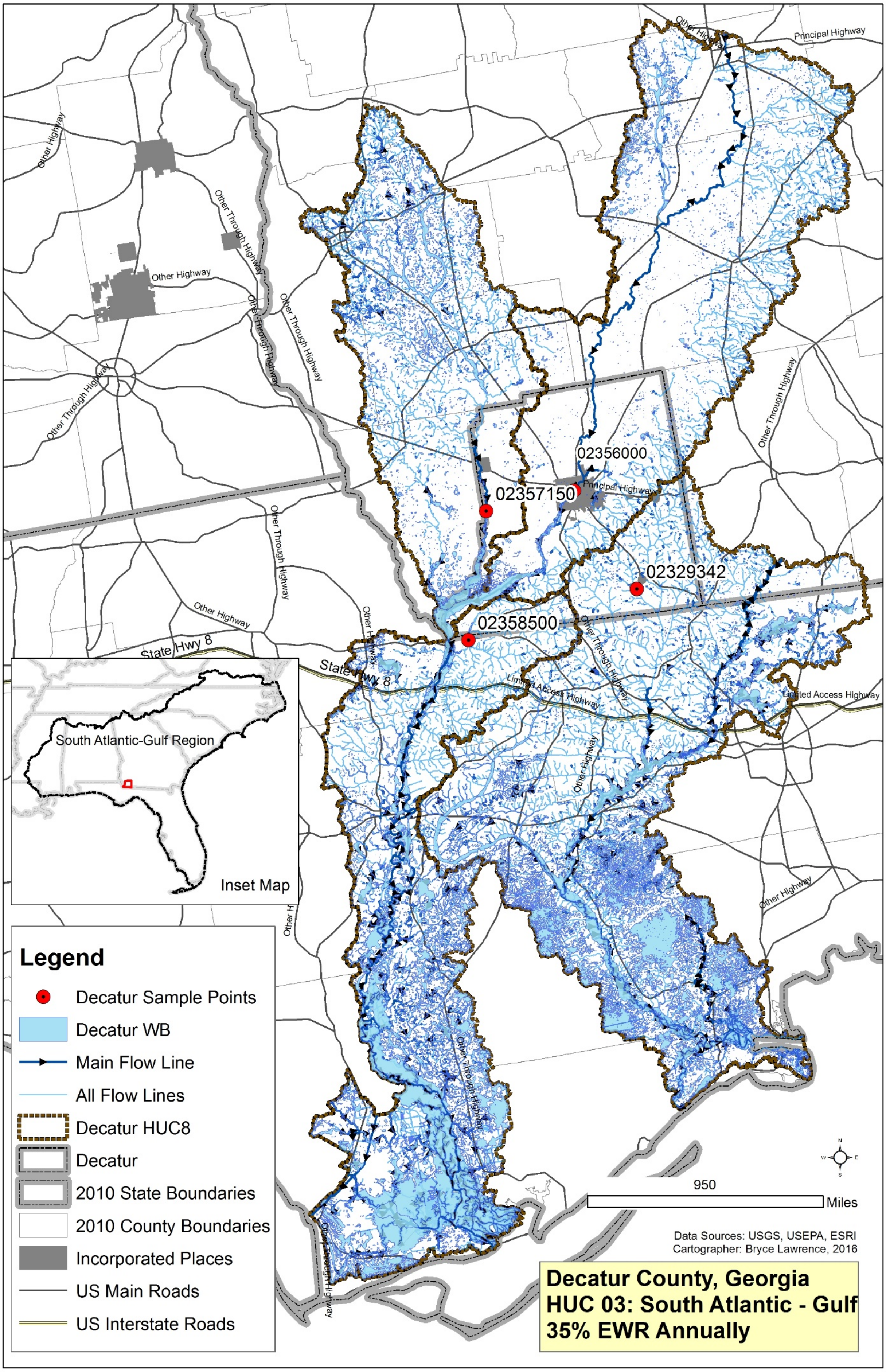


Figure 6-2: Decatur County Stream Network and Streamflow Sample Stations (W1c)

Decatur County, Georgia

Total Available Stream Flow in Cubic Meters (W1c) with Human Abstraction (W1d)

USGS Station No. 02358500	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1936-1942	25.5	31.5	32.0	31.0	12.8	10.7	17.0	18.6	12.4	11.6	13.8	23.1
EWR Requirement 41%	8.9	11.0	11.2	10.9	4.5	3.7	5.9	6.5	4.3	4.1	4.8	8.1
Available Adjusted CFS	16.6	20.5	20.8	20.2	8.3	7.0	11.0	12.1	8.0	7.5	8.9	15.0
EWR Corrected Mean Monthly Cubic Meters	1,232,674.1	1,523,678.9	1,547,552.2	1,499,493.5	617,273.3	517,567.1	821,054.6	899,228.0	598,507.5	560,757.5	665,259.2	1,118,768.8
Total P25 Discharge	1,896,421.8	2,344,121.3	2,380,849.5	2,306,913.1	949,651.2	796,257.1	1,263,160.9	1,383,427.7	920,780.8	862,703.9	1,023,475.6	1,721,182.8

USGS Station No. 02357150	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1996-2015	221.5	346.8	517.6	384.2	205.8	153.6	141.0	140.9	153.7	156.4	162.8	180.2
EWR Requirement 41%	77.5	121.4	181.2	134.5	72.0	53.8	49.4	49.3	53.8	54.7	57.0	63.1
Available Adjusted CFS	144.0	225.4	336.5	249.8	133.8	99.9	91.7	91.6	99.9	101.7	105.8	117.1
EWR Corrected Mean Monthly Cubic Meters	10,714,903.0	16,774,645.2	25,038,888.7	18,585,657.5	9,955,014.0	7,431,360.8	6,820,276.8	6,814,035.5	7,436,197.8	7,566,122.7	7,873,147.0	8,716,098.5
Total P25 Discharge	16,484,466.2	25,807,146.5	38,521,367.2	28,593,319.2	15,315,406.2	11,432,862.7	10,492,733.6	10,483,131.5	11,440,304.3	11,640,188.8	12,112,533.9	13,409,382.3

USGS Station No. 02356000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1907-2015	5,571.3	6,805.9	8,364.2	7,183.0	5,025.5	3,890.0	3,731.9	3,426.5	3,133.0	2,993.2	3,208.3	4,060.3
EWR Requirement 41%	1,950.0	2,382.1	2,927.5	2,514.1	1,758.9	1,361.5	1,306.2	1,199.3	1,096.6	1,047.6	1,122.9	1,421.1
Available Adjusted CFS	3,621.3	4,423.8	5,436.7	4,669.0	3,266.6	2,528.5	2,425.8	2,227.2	2,036.5	1,945.6	2,085.4	2,639.2
EWR Corrected Mean Monthly Cubic Meters	269,487,534.6	329,204,705.5	404,582,380.0	347,447,153.0	243,086,462.9	188,162,247.7	180,516,547.3	165,740,060.9	151,545,584.1	144,784,600.4	155,189,514.5	196,400,880.0
Total P25 Discharge	414,596,207.1	506,468,777.7	622,434,430.7	534,534,081.5	373,979,173.8	289,480,381.1	277,717,765.0	254,984,709.1	233,147,052.4	222,745,539.1	238,753,099.2	302,155,200.0

USGS Station No. 02329342	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly P25 Discharge: 1991-2015	9.6	11.2	11.4	7.3	4.1	3.7	4.0	4.4	4.7	4.8	6.2	7.1
EWR Requirement 41%	3.4	3.9	4.0	2.5	1.4	1.3	1.4	1.5	1.6	1.7	2.2	2.5
Available Adjusted CFS	6.2	7.3	7.4	4.7	2.7	2.4	2.6	2.8	3.0	3.1	4.0	4.6
EWR Corrected Mean Monthly Cubic Meters	464,047.2	541,752.5	553,299.1	351,171.7	199,100.3	181,067.9	192,390.8	211,271.0	225,730.2	231,243.4	300,543.6	344,680.7
Total P25 Discharge	713,918.8	833,465.4	851,229.3	540,264.2	306,308.1	278,566.0	295,985.8	325,032.3	347,277.2	355,759.1	462,374.8	530,277.9

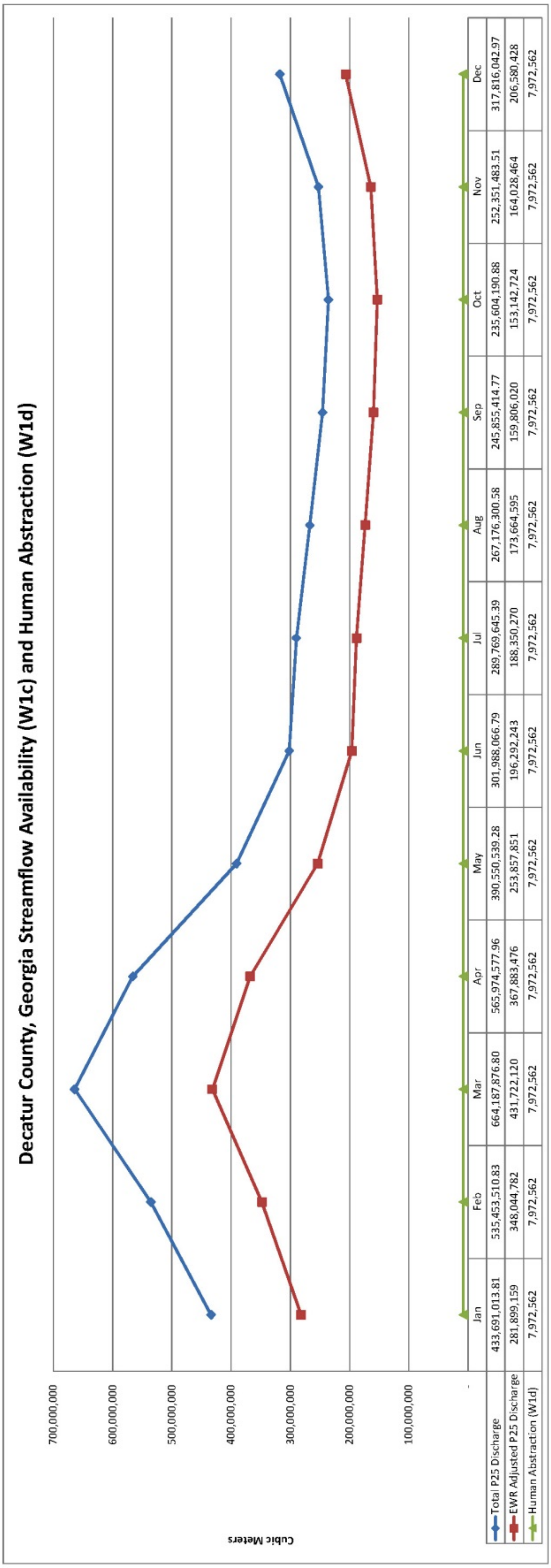
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	433,691,013.81	535,453,510.83	664,187,876.80	565,974,577.96	390,550,539.28	301,988,066.79	289,769,645.39	267,176,300.58	245,855,414.77	235,604,190.88	252,351,483.51	317,816,042.97
EWR Adjusted P25 Discharge	281,899,159	348,044,782	431,722,120	367,883,476	253,857,851	196,292,243	188,350,270	173,664,595	159,806,020	153,142,724	164,028,464	206,580,428
Human Abstraction (W1d)	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562
Human Abstraction as % EWR Adjusted	2.83%	2.29%	1.85%	2.17%	3.14%	4.06%	4.23%	4.59%	4.99%	5.21%	4.86%	3.86%

Total EWR Adjusted Annual Available Streamflow Volume in Cubic Meters	**2,925,272,131**

Table 6-1: Decatur County EWR Adjusted Annual P25 Streamflow Availability (W1c)

Decatur County, Georgia 2010 Adjusted Water Abstraction		
Category	**Mgal/D Surface**	**Mgal/D Ground**
Public Supply	0.58	4.58
Mining	-	-
Livestock	0.05	0.09
Aquaculture	-	0.06
Irrigation	1	66.58
Daily Total	*1.63*	*71.31*
Annual Abstraction Projection by Source (USGS NWIS)	595	26,028
Total Annual Abstraction in Mgal	26,623	
2012 Total Annual Returns in Mgal (US EPA ECHO / NPDES)	1,350	
Total Adjusted Abstraction in Mgal	**25,274**	
Total Adjusted Abstraction in cubic meters per year / month	95,670,745	7,972,562

Table 6-2: Decatur County Adjusted Water Abstraction (W1d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total P25 Discharge	433,691,013.81	535,453,510.83	664,187,876.80	565,974,577.96	390,550,539.28	301,988,066.79	289,769,645.39	267,176,300.58	245,855,414.77	235,604,190.88	252,351,483.51	317,816,042.97
EWR Adjusted P25 Discharge	281,899,159	348,044,782	431,722,120	367,883,476	253,857,851	196,292,243	188,350,270	173,664,595	159,806,020	153,142,724	164,028,464	206,580,428
Human Abstraction (W1d)	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562	7,972,562

Figure 6-3: Decatur County Adjusted Streamflow Availability and Human Abstraction (W1c & W1d)

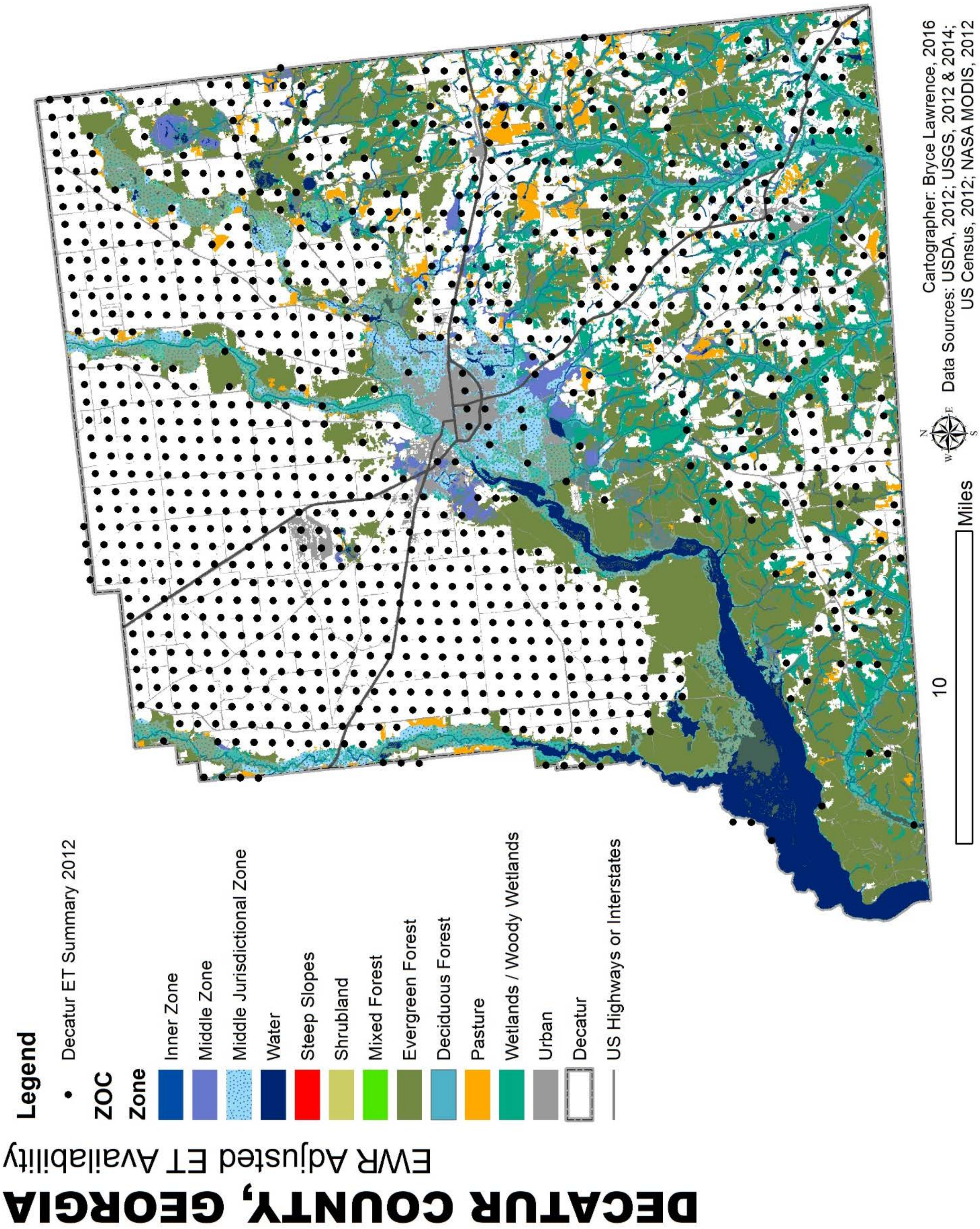
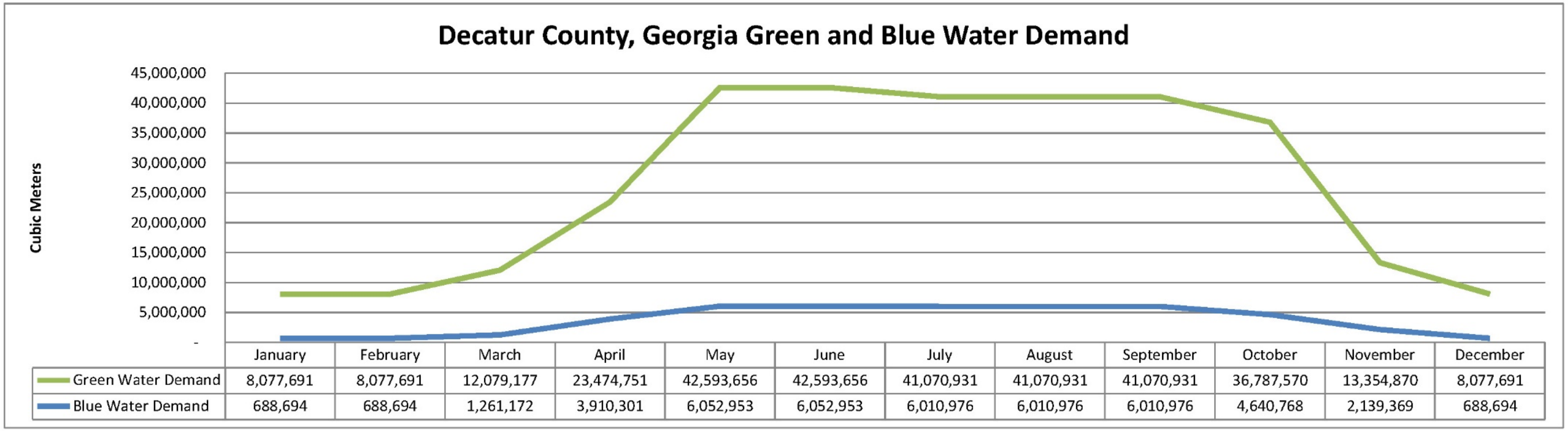


Figure 6-4: Decatur County EWR Adjusted ET Availability Sample Points (W2c)

Decatur County, Georgia

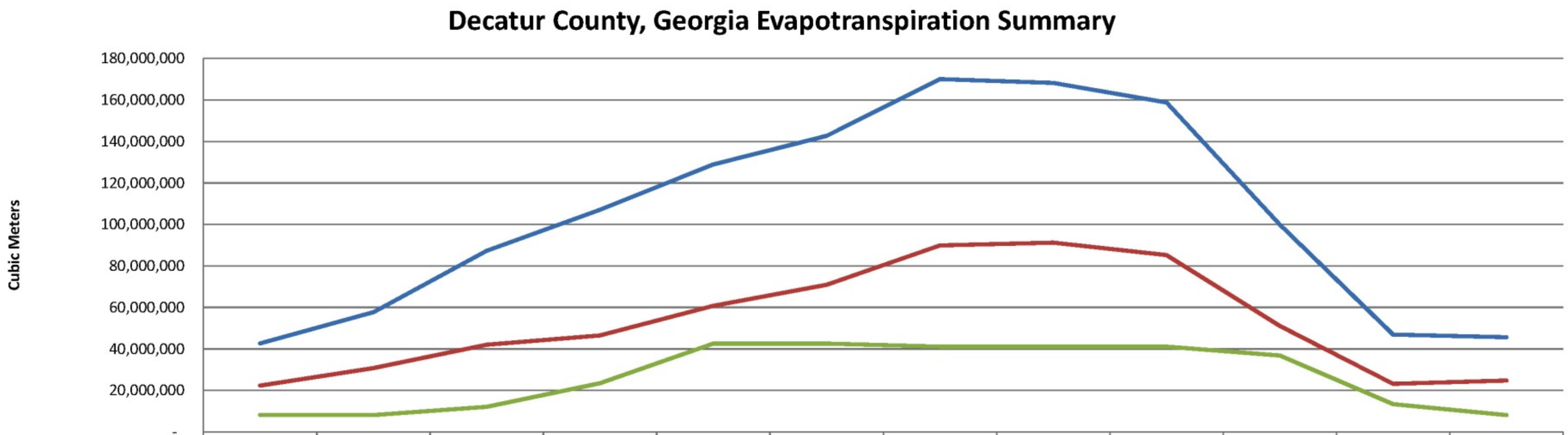
Monthly Green Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	GW Annual Sum
Value in Cubic Meters	8,077,691	8,077,691	12,079,177	23,474,751	42,593,656	42,593,656	41,070,931	41,070,931	41,070,931	36,787,570	13,354,870	8,077,691	318,329,543

Monthly Blue Water Demand													
Days of Month	31	28	31	30	31	30	31	31	30	31	30	31	
Month	January	February	March	April	May	June	July	August	September	October	November	December	BW Annual Sum
Value in Cubic Meters	688,694	688,694	1,261,172	3,910,301	6,052,953	6,052,953	6,010,976	6,010,976	6,010,976	4,640,768	2,139,369	688,694	44,156,527



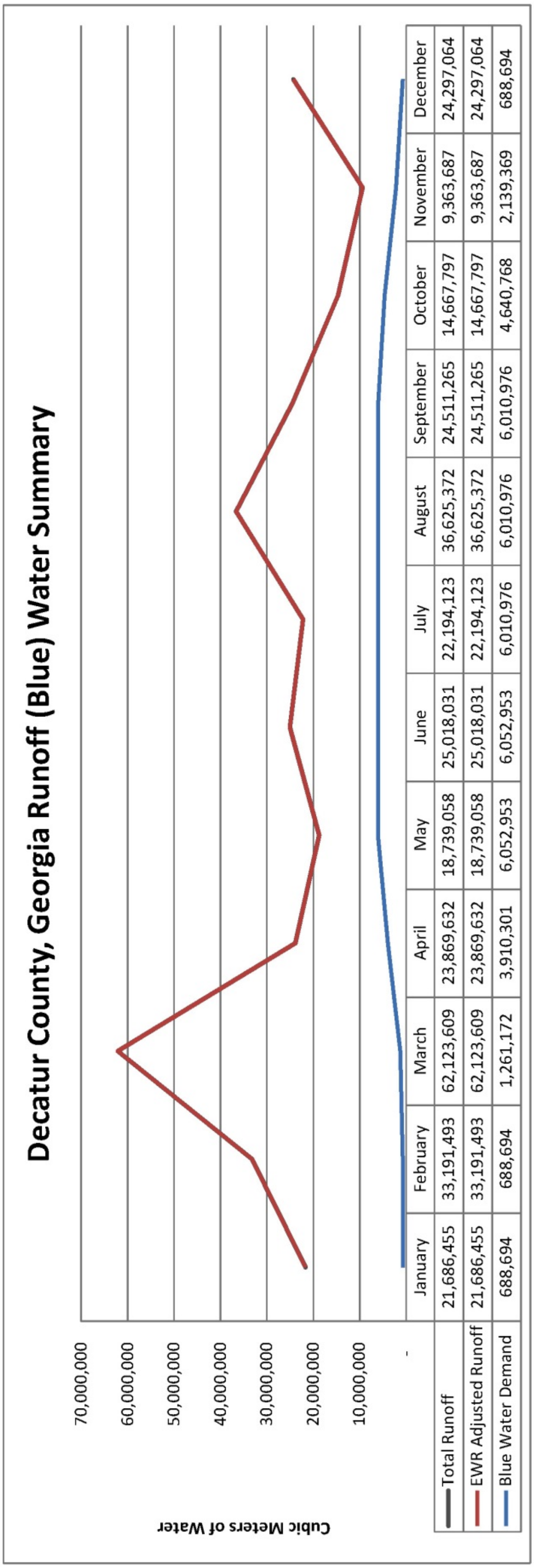
	January	February	March	April	May	June	July	August	September	October	November	December
Green Water Demand	8,077,691	8,077,691	12,079,177	23,474,751	42,593,656	42,593,656	41,070,931	41,070,931	41,070,931	36,787,570	13,354,870	8,077,691
Blue Water Demand	688,694	688,694	1,261,172	3,910,301	6,052,953	6,052,953	6,010,976	6,010,976	6,010,976	4,640,768	2,139,369	688,694

Figure 6-5: Decatur County ET (Green Water) and Surface (Blue Water) Demand (W2d & W3d)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET for Entire County	42,629,568	57,684,798	87,291,337	107,078,830	128,895,254	142,719,873	170,030,482	168,191,509	158,768,374	99,935,477	46,908,301	45,608,897
ET Without ZOC Area	22,318,399	30,737,416	42,029,631	46,475,063	60,722,987	70,877,487	89,872,445	91,193,917	85,245,839	51,059,305	23,135,599	24,749,254
Green Water Demand	8,077,691	8,077,691	12,079,177	23,474,751	42,593,656	42,593,656	41,070,931	41,070,931	41,070,931	36,787,570	13,354,870	8,077,691

Figure 6-6: Decatur County ET (Green Water) Summary (W2c & W2d)



	January	February	March	April	May	June	July	August	September	October	November	December
Total Runoff	21,686,455	33,191,493	62,123,609	23,869,632	18,739,058	25,018,031	22,194,123	36,625,372	24,511,265	14,667,797	9,363,687	24,297,064
EWR Adjusted Runoff	21,686,455	33,191,493	62,123,609	23,869,632	18,739,058	25,018,031	22,194,123	36,625,372	24,511,265	14,667,797	9,363,687	24,297,064
Blue Water Demand	688,694	688,694	1,261,172	3,910,301	6,052,953	6,052,953	6,010,976	6,010,976	6,010,976	4,640,768	2,139,369	688,694

Figure 6-7: Decatur County Surface (Blue) Water Availability and Demand (W3c & W3d)

N	Decatur County, Georgia	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	21,686,455	33,191,493	62,123,609	23,869,632	18,739,058	25,018,031	22,194,123	36,625,372	24,511,265	14,667,797	9,363,687	24,297,064
	liters/month	21,686,455,000	33,191,493,000	62,123,609,000	23,869,632,100	18,739,058,100	25,018,031,000	22,194,122,800	36,625,372,000	24,511,265,000	14,667,797,200	9,363,687,400	24,297,064,000
4	mg/l monthly avg												
	Total Allowed Mg	86,745,820,000	132,765,972,000	248,494,436,000	95,478,528,400	74,956,232,400	100,072,124,000	88,776,491,200	146,501,488,000	98,045,060,000	58,671,188,800	37,454,749,600	97,188,256,000
	Total Allowed Tons (N)	86.75	132.77	248.49	95.48	74.96	100.07	88.78	146.50	98.05	58.67	37.45	97.19
0.28	Nnat in mg/l	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	total mg Nnat	6,939,665,600	10,621,277,760	19,879,554,880	7,638,282,272	5,996,498,592	8,005,769,920	7,102,119,296	11,720,119,040	7,843,604,800	4,693,695,104	2,996,379,968	7,775,060,480
	tons Nnat	6.94	10.62	19.88	7.64	6.00	8.01	7.10	11.72	7.84	4.69	3.00	7.78
	Corrected Limit	79.81	122.14	228.61	87.84	68.96	92.07	81.67	134.78	90.20	53.98	34.46	89.41
	Total Annual N Load (t)	**1,163.9**											

P	Decatur County, Georgia	Runoff Volume from ORNL											
		Jan_vol	Feb_vol	Mar_vol	Apr_vol	May_vol	June_vol	July_vol	Aug_vol	Sept_vol	Oct_vol	Nov_vol	Dec_vol
	Cubic meters / month runoff	21,686,455	33,191,493	62,123,609	23,869,632	18,739,058	25,018,031	22,194,123	36,625,372	24,511,265	14,667,797	9,363,687	24,297,064
	liters/month	21,686,455,000	33,191,493,000	62,123,609,000	23,869,632,100	18,739,058,100	25,018,031,000	22,194,122,800	36,625,372,000	24,511,265,000	14,667,797,200	9,363,687,400	24,297,064,000
0	mg/l limit / month avg												
	Total Allowed Mg	2,168,645,500	3,319,149,300	6,212,360,900	2,386,963,210	1,873,905,810	2,501,803,100	2,219,412,280	3,662,537,200	2,451,126,500	1,466,779,720	936,368,740	2,429,706,400
	Total Allowed Tons (P)	2	3	6	2	2	3	2	4	2	1	1	2
0.05	Pnat in mg/l	1,084,322,750	1,659,574,650	3,106,180,450	1,193,481,605	936,952,905	1,250,901,550	1,109,706,140	1,831,268,600	1,225,563,250	733,389,860	468,184,370	1,214,853,200
	total tons bkgnd Pnat	1.08	1.66	3.11	1.19	0.94	1.25	1.11	1.83	1.23	0.73	0.47	1.21
	Corrected Limit	1.08	1.66	3.11	1.19	0.94	1.25	1.11	1.83	1.23	0.73	0.47	1.21
	Total Annual P Load (t)	**15.8**											

Table 6-3: Decatur County Critical Nitrogen and Phosphorus Load Limits (W4c & W5c)

Decatur N and P Load Summary			
CROPGROUP	N_load	P_load	Hectares
Oilseed	50.1	40.1	14,663.1
Feed	0.6	0.2	88.5
Cereal	42.4	18.0	6,686.2
Fruit	0.1	0.0	6.2
Fibre	97.8	34.9	10,186.1
Nuts	3.0	2.4	876.6
N and P Point Loads	0.3	3.6	N(n)=2, (P)n=2
Total N and P Loads	**194.2**	**99.3**	

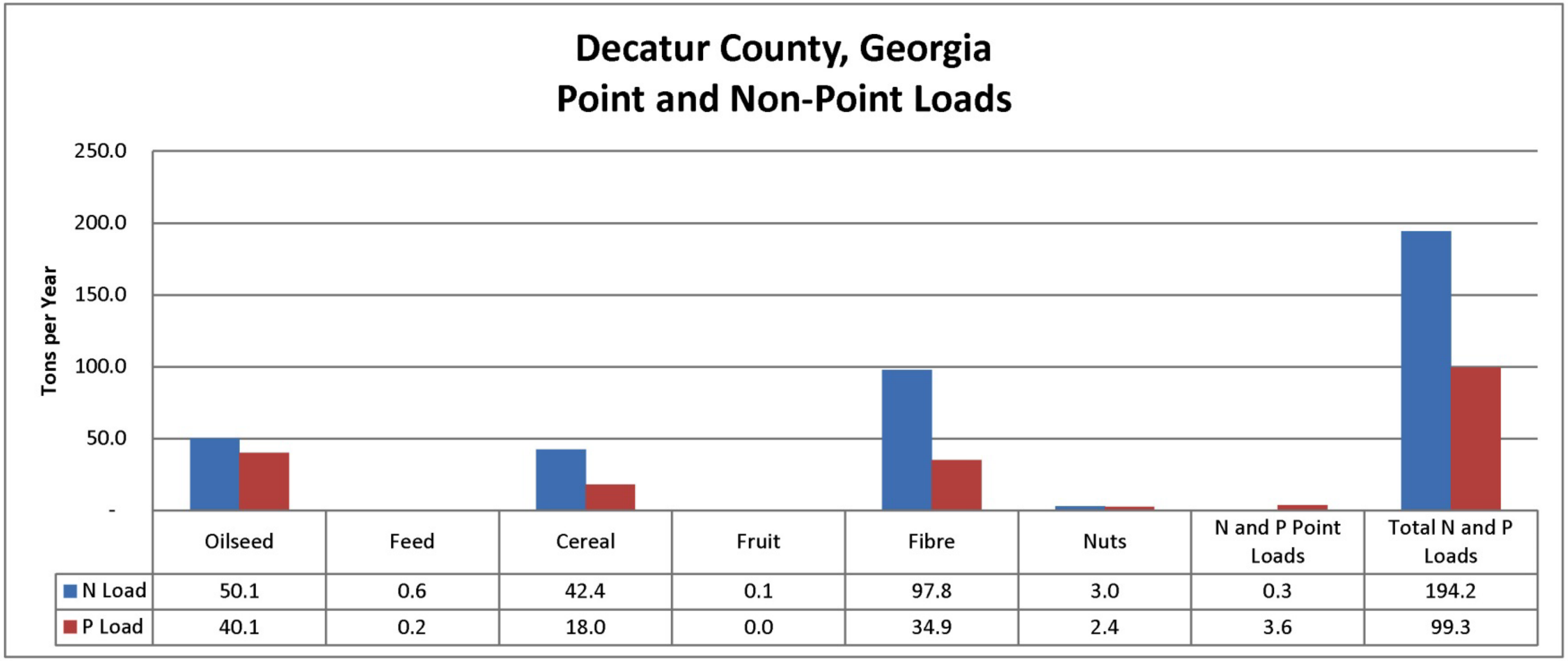


Figure 6-8: Decatur County Nitrogen and Phosphorus Point and Non-Point Source Loads (W4d & W5d)

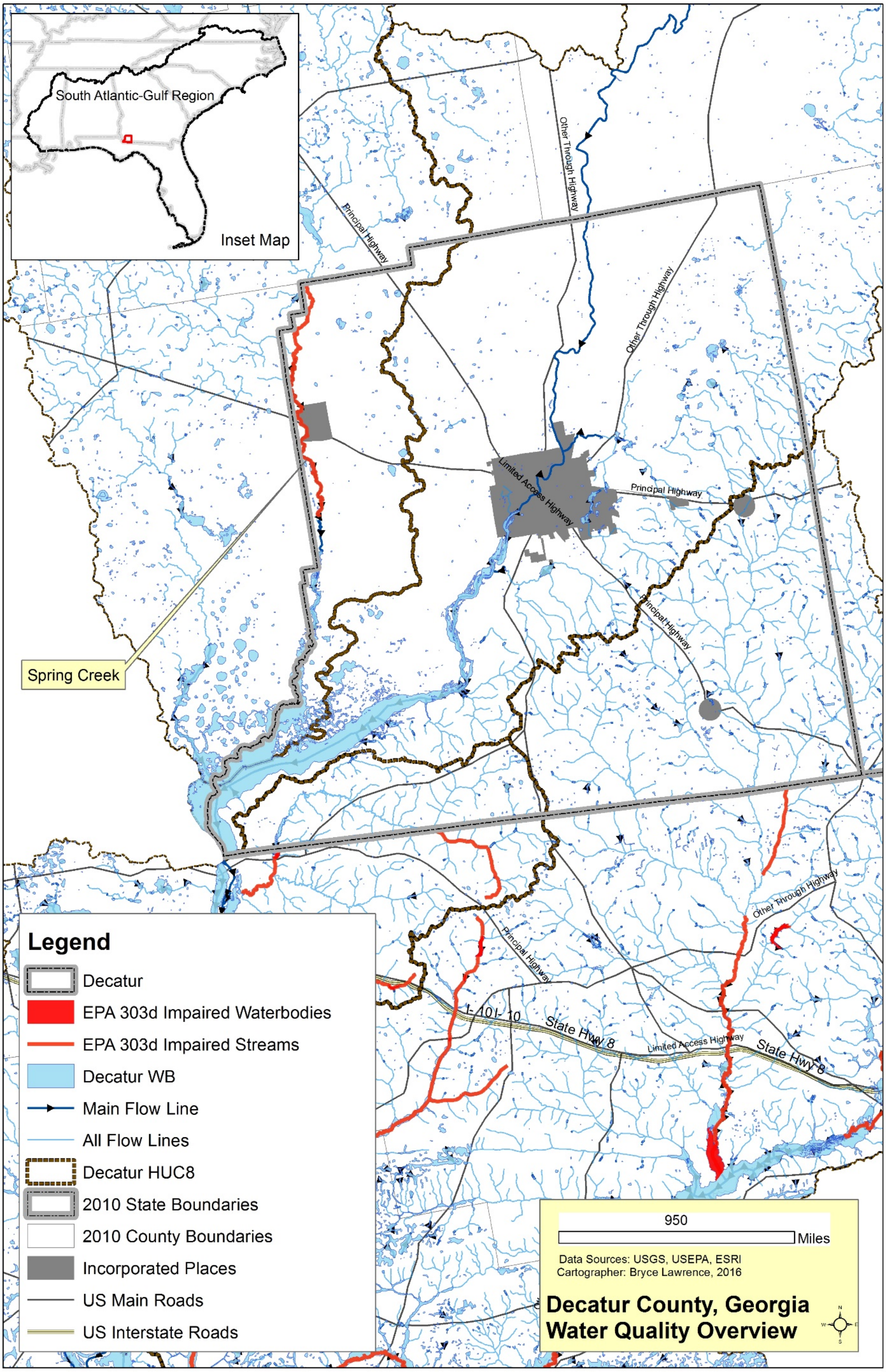


Figure 6-9: Decatur County EPA 303d Listed Streams and Waterbodies

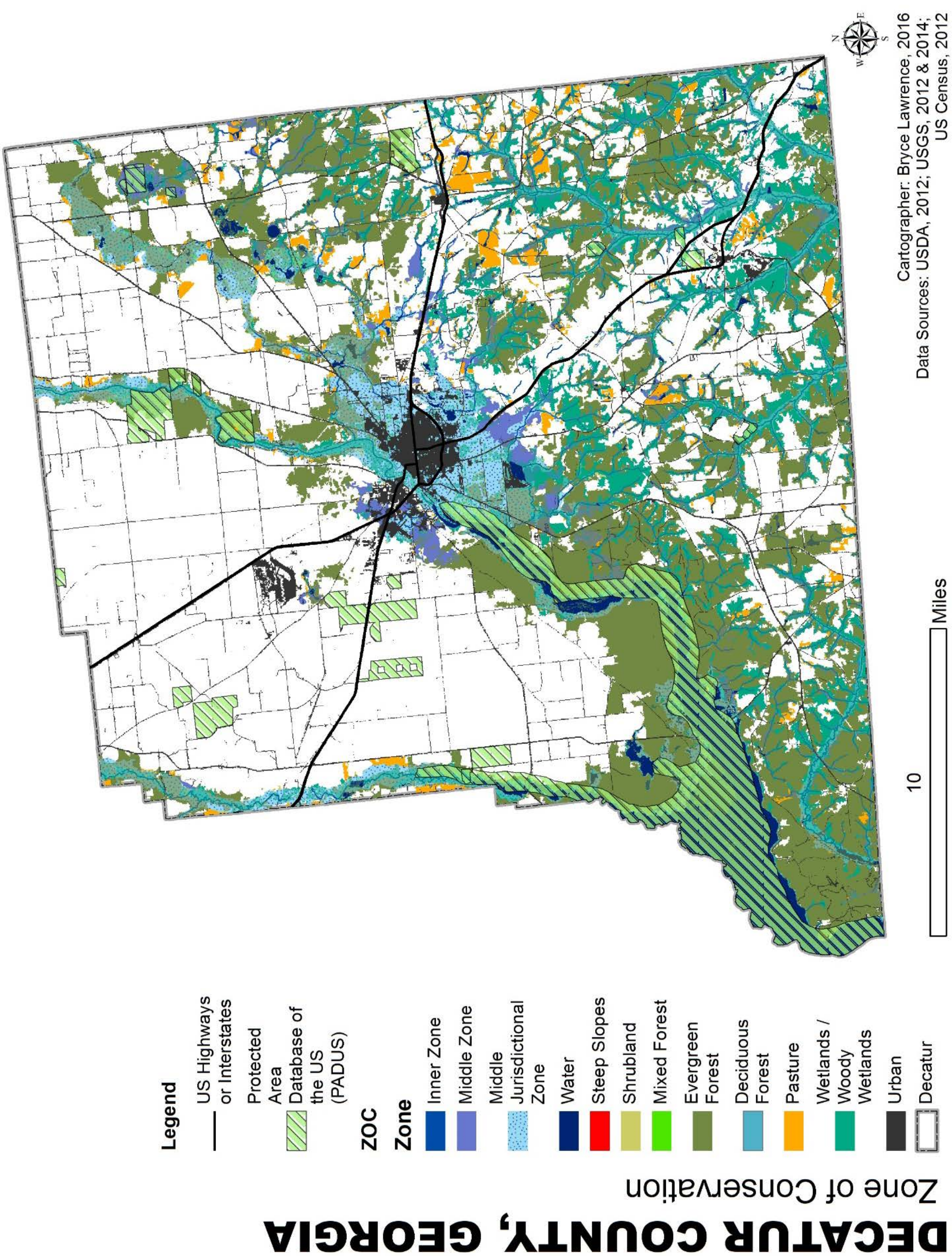


Figure 6-10: Decatur County Existing and Potential Zone of Conservation (EC1c & EC1c)

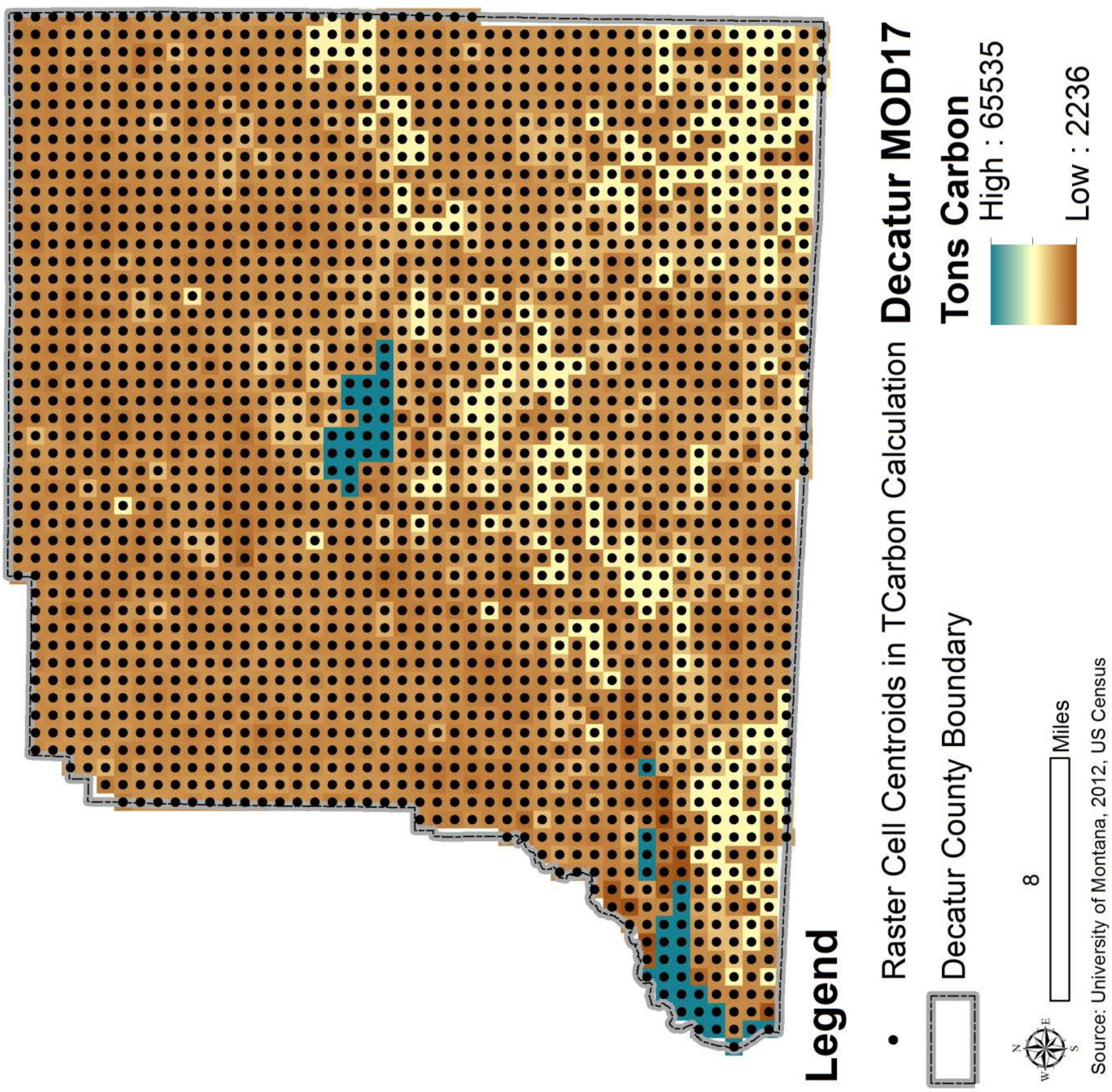
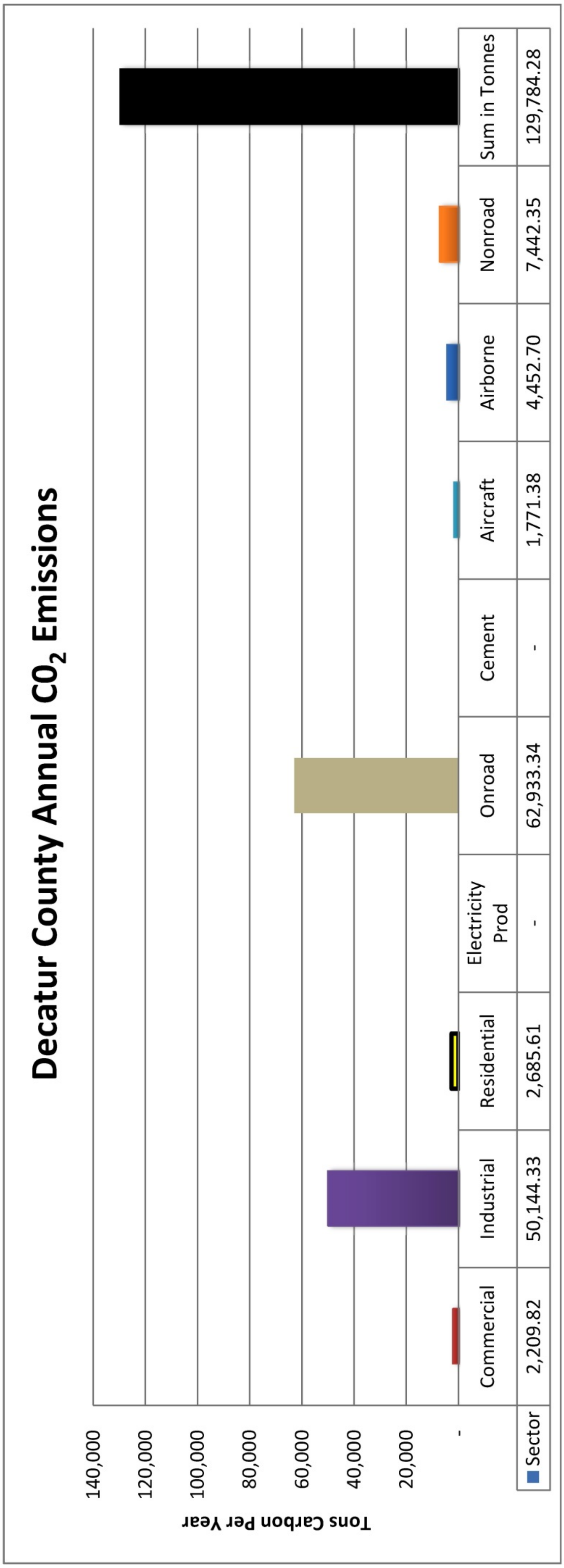


Figure 6-11: Decatur County Net Primary Productivity (NPP) in Tons of Carbon per Year, as Estimate for Carbon Sequestration Potential (C1c)



	Commercial	Industrial	Residential	Electricity Prod	Onroad	Cement	Aircraft	Airborne	Nonroad	Sum in Tonnes
Sector	2,209.82	50,144.33	2,685.61	-	62,933.34	-	1,771.38	4,452.70	7,442.35	129,784.28

Figure 6-12: Decatur County C0$_2$ Emissions in Tons Per Year (C1d)

Decatur County Solar Resouce Summary

Raster Tile OID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
137	4.413	5.005	5.716	6.157	6.205	5.673	5.646	5.679	5.365	5.227	4.805	4.138
138	4.385	5.035	5.704	6.172	6.232	5.657	5.664	5.687	5.343	5.271	4.812	4.142
139	4.376	5.017	5.725	6.128	6.161	5.592	5.672	5.615	5.311	5.242	4.765	4.135
140	4.382	5.009	5.713	6.125	6.279	5.590	5.677	5.668	5.335	5.225	4.769	4.125
141	4.367	5.020	5.673	6.121	6.227	5.606	5.659	5.647	5.314	5.225	4.808	4.125
142	4.430	4.939	5.662	6.166	6.162	5.629	5.610	5.645	5.304	5.216	4.753	4.130
143	4.437	5.064	5.730	6.148	6.212	5.605	5.616	5.644	5.316	5.225	4.805	4.137
144	4.314	4.955	5.664	6.115	6.145	5.543	5.585	5.576	5.267	5.224	4.758	4.070
145	4.433	5.076	5.683	6.124	6.237	5.590	5.620	5.595	5.292	5.227	4.750	4.113
146	4.418	5.044	5.708	6.134	6.185	5.551	5.653	5.561	5.313	5.198	4.791	4.126
147	4.433	4.989	5.705	6.205	6.187	5.586	5.595	5.647	5.341	5.240	4.802	4.130
148	4.402	4.999	5.638	6.147	6.164	5.559	5.585	5.659	5.319	5.195	4.780	4.086
149	4.435	5.046	5.726	6.153	6.197	5.561	5.592	5.625	5.297	5.209	4.771	4.137
150	4.477	5.081	5.726	6.158	6.191	5.556	5.592	5.590	5.266	5.222	4.802	4.144
151	4.402	5.057	5.746	6.177	6.215	5.555	5.561	5.608	5.293	5.267	4.819	4.138
152	4.456	5.090	5.780	6.207	6.256	5.619	5.655	5.638	5.322	5.262	4.832	4.181
153	4.408	5.014	5.721	6.150	6.201	5.594	5.522	5.600	5.278	5.275	4.783	4.075
154	4.484	5.132	5.742	6.179	6.186	5.534	5.492	5.531	5.295	5.246	4.835	4.123
155	4.437	5.054	5.706	6.143	6.124	5.519	5.479	5.531	5.269	5.194	4.774	4.120
156	4.486	5.114	5.717	6.153	6.168	5.511	5.508	5.562	5.292	5.212	4.820	4.165
157	4.489	5.113	5.738	6.152	6.211	5.524	5.502	5.568	5.270	5.294	4.859	4.172
158	4.464	5.066	5.723	6.126	6.233	5.550	5.555	5.596	5.302	5.277	4.863	4.177
159	4.474	5.111	5.750	6.140	6.123	5.483	5.478	5.537	5.229	5.268	4.852	4.163
160	4.486	5.149	5.733	6.137	6.176	5.482	5.422	5.524	5.241	5.269	4.857	4.180
161	4.475	5.165	5.748	6.146	6.228	5.507	5.485	5.573	5.306	5.318	4.881	4.170
162	4.507	5.153	5.762	6.170	6.221	5.520	5.473	5.550	5.309	5.368	4.907	4.179
Average kWh/m^2/month	4.433	5.058	5.717	6.151	6.197	5.565	5.573	5.602	5.300	5.246	4.810	4.138
Residential Units	8,343											
NR Units	587											
Annual Sum in MWH	**20,756**											

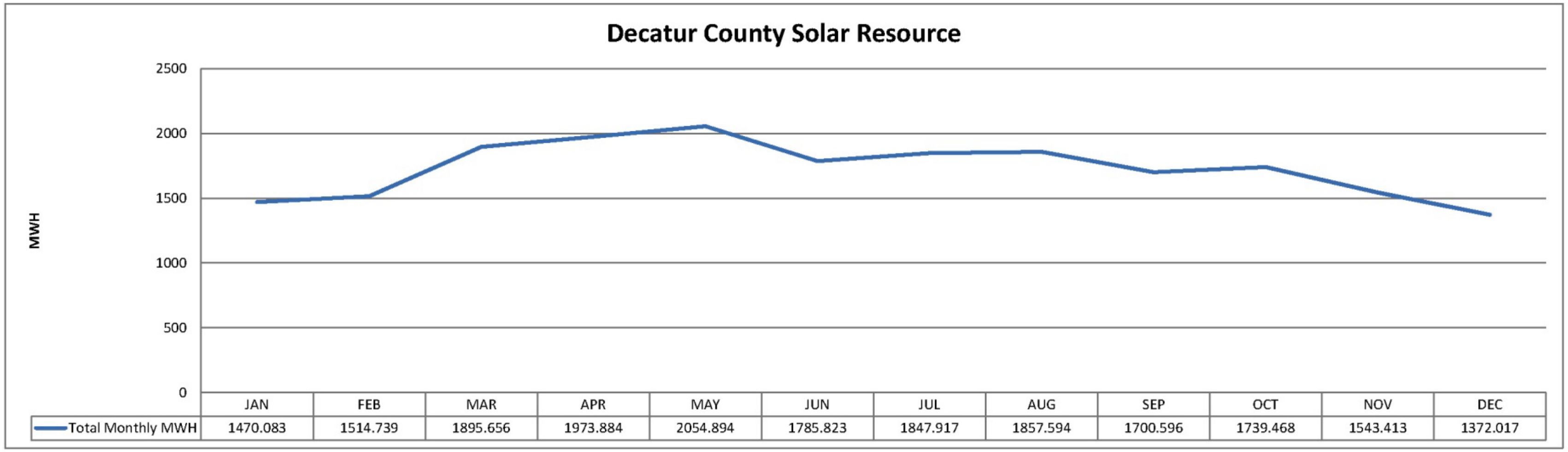


Figure 6-13: Solar (PV) Resource Potential Summary for Decatur County (E1c)

Intentionally left blank, no wind resources in Decatur identified

Figure 6-14: Decatur County Potential Wind and PV Renewable Electricity Locations Map (E1c)

Intentionally left blank, no wind resources in Decatur identified and PV potential provided in Figure 5-15

Figure 6-15: Decatur County Potential Wind and PV Renewable Electricity Summary (E1c)

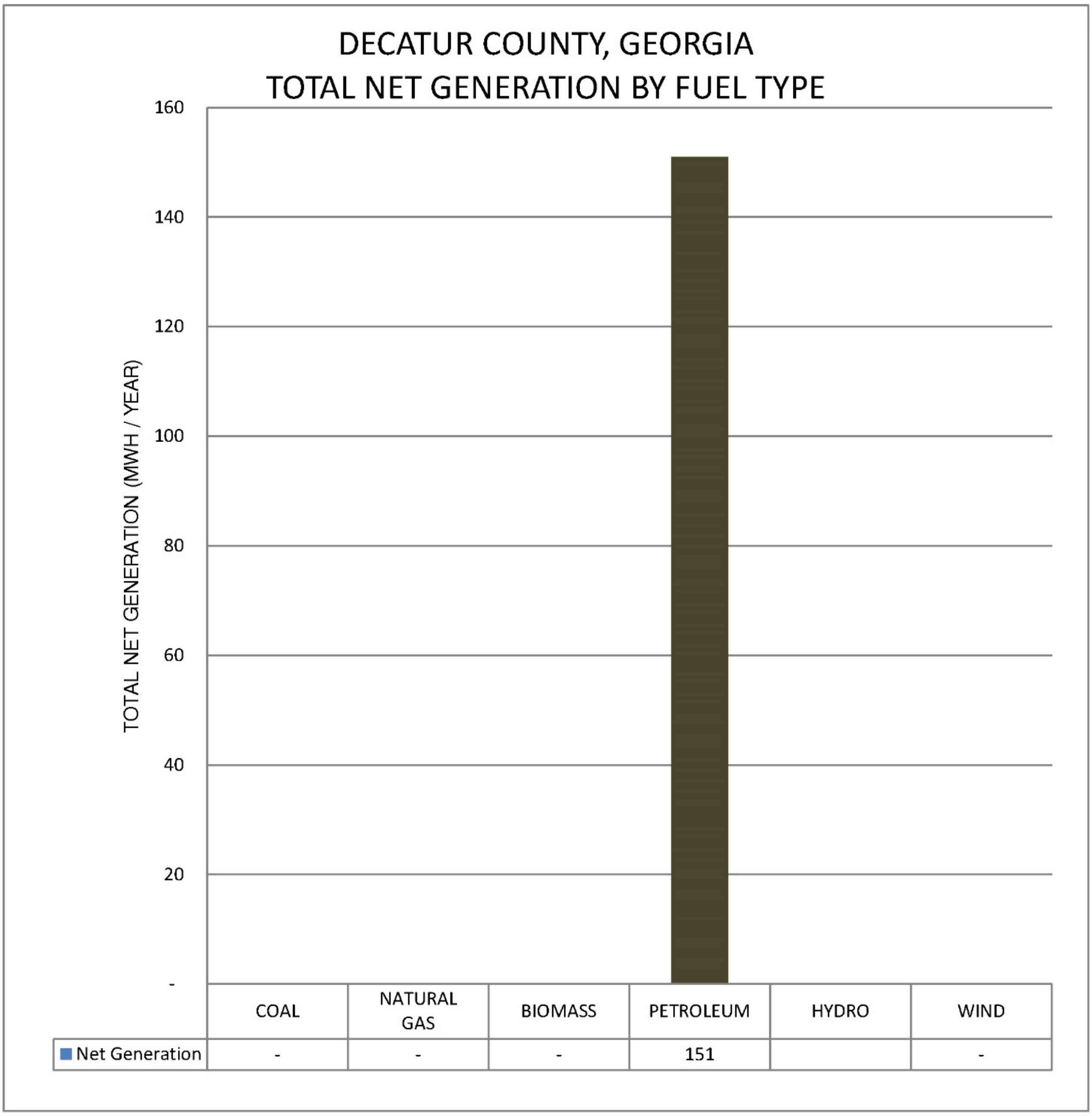


Figure 6-16: Decatur County Existing Electricity Production (E2c), an Annual Loss due to Gravity Fed Energy Recovery System

		ACS Table DP04		From Economic Census Table A1				2012 ACS	2010 Census
								County	State
County	State	County Residential Units	Statewide Res. Units	County Commercial Units	Statewide Comm. Units	County Industrial Units	Statewide Ind. Units	Population	Population
Decatur	Georgia	12150	4086231	343	151363	244	64945	27842	9,687,653

Source:	Econ. Census: Table C10	Econ. Census: Table C10	Econ. Census: Table C10	Econ. Census: Table C10		USEIA
Units:	in Trillion Btu's	in Trillion Btu's	in Trillion Btu's	in Trillion Btu's		in Million Btu's
State	Total Residential TBtu's / Year	Total Commercial TBtu's / Year	Total Industrial Tbtu's / Year	Total Transportation Tbtu's / Year	County	All Prime Movers Btu's / Year
Georgia	688.1	530.8	753.3	823.2	Decatur	2758

County	Residential MWH	Commercial MWH	Industrial MWH	Transport MWH	Power Plant MWH	Total MWH
Decatur	599,647.32	352,530.17	829,474.52	693,390.99	808.32	2,475,851.32

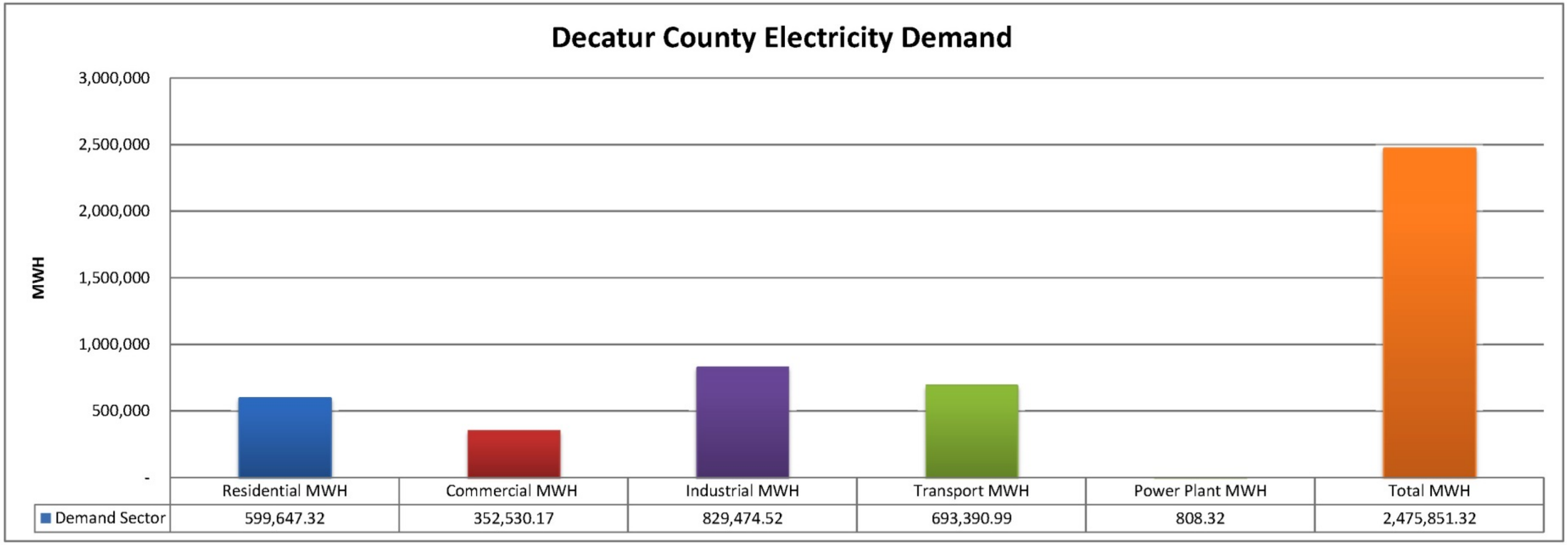


Figure 6-17: Decatur County Electricity Demand (E1d & E2d)

Decatur County Composted Organic Waste Production

Category	Wet Short Tons	Dry Short Tons	Dry Metric Tons	Data Source:
Yard Waste	4,626.9	2,313.4	2,098.7	*Decatur County MSW Spreadsheet (EPA% from Reported Total)*
Food Waste Mass	3,336.3	1,668.2	1,513.3	*Co-EAT, post composting: MGD WWTP*
Biosolids (WW Solids Mass)	423.6	211.8	192.1	*Co-EAT, post composting; MGD WWTP*
Organic Production Summary			3,804.2	
Field Application Capacity			12,875.0	*USDA Quickstats Food Production Summary; Compost Rate/Ac*

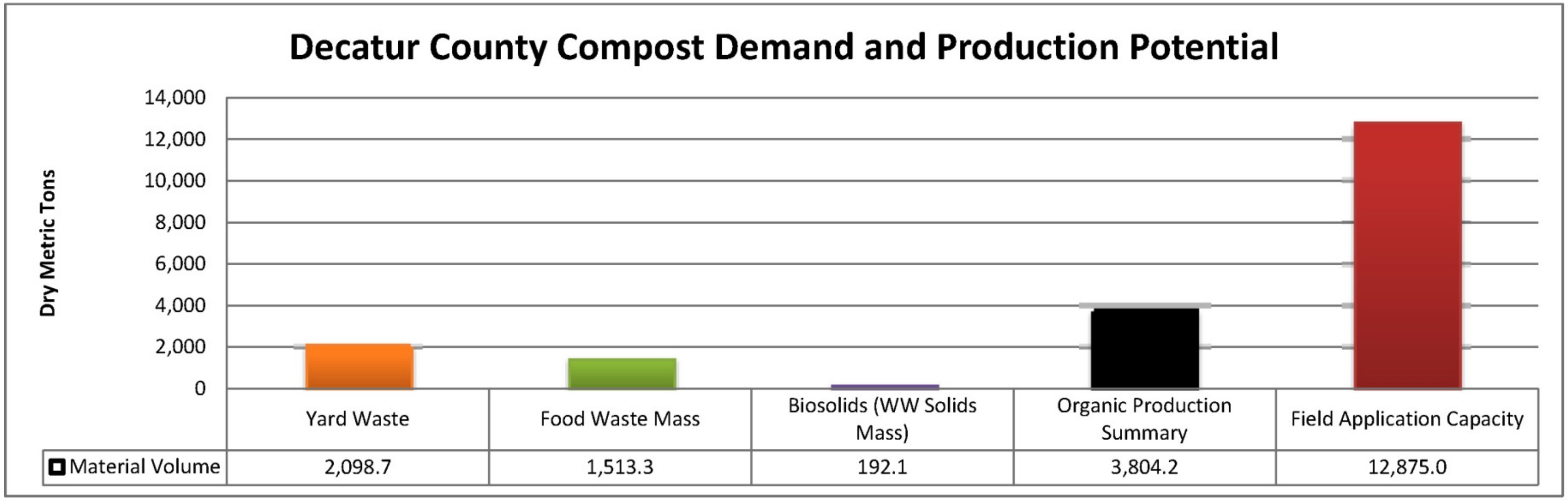


Figure 6-18: Decatur County Compost Demand and Organic Material Production Potential (M1c & M1d)

VS = volatile solids
TS = total solids
MCRT = mean cell residence time

Feedstock Parameter	Value	Units
Food Waste Mass	9.14	short tons/day
Food Waste Biogas Yield	6.65	ft^3 CH^4/lb TS
Food Waste Total Solids	29.98%	solids
Food Waste VS	89.64%	of total solids
Food Waste % of Total Waste	88.73%	total substrate
Weighted Total Feedstock Loading (TS)	18,281.21	lbs/day
Weighted Total Feedstock Loading (VS)	16,387.49	lbs/day
Wastewater Solids Mass	1.16	short tons/day
Wastewater Solids Yield	2.12	ft^3 CH^4/lb TS
Wastewater Total Solids	1.00%	solids
Wastewater VS	70.00%	of total solids
Wastewater % of Total Waste	11.27%	total substrate
Weighted Total Feedstock Mass	10	short tons/day
Weighted Total Feedstock Yield	6.14	ft^3 CH^4/lb TS
Weighted Total Feedstock Concentration (% TS)	26.7%	solids
Weighted VS Content of Total Feedstock	87%	volatile solids
Weighted Total Feedstock (TS)	2,321.1	lbs/day
Weighted Total Feedstock (VS)	1,624.8	lbs/day

Table 6-4: Decatur County Co-EAT Sludge Model Output (Input for M1d)

Decatur County			
Plant Name	NPDES ID	Avg. Annual MGD	Total Sludge DMT/y
City of Bainbridge WWTP	GA0024678	1.2155	
Decatur County Industrial Airpark WPCP	GA0033511	0.198083333	
Decatur County WWTP	GAL033511		
Shaw Ind Inc	GAU050140		
Total Annual Average MGD		1.413583333	

Table 6-5: Decatur County WWTPs MGD and Sludge Inputs for Co-EAT Model (Input for Input of M1d)

Decatur County Generation Derived from County Category Percentage Statistics		
Category	EPA Percentage Generation[1]	Decatur Generation
Paper and Paperboard	27%	10486.73
Glass	5%	1198.48
Metals	9%	1797.73
Plastics	13%	4793.93
Rubber, leather and textiles	9%	0.00
Wood	6%	0.00
Yard Trimmings	14%	4194.69
Food waste	15%	4194.69
Other	3%	3295.83
Total Generation in Tons	**1**	**29,962.09**

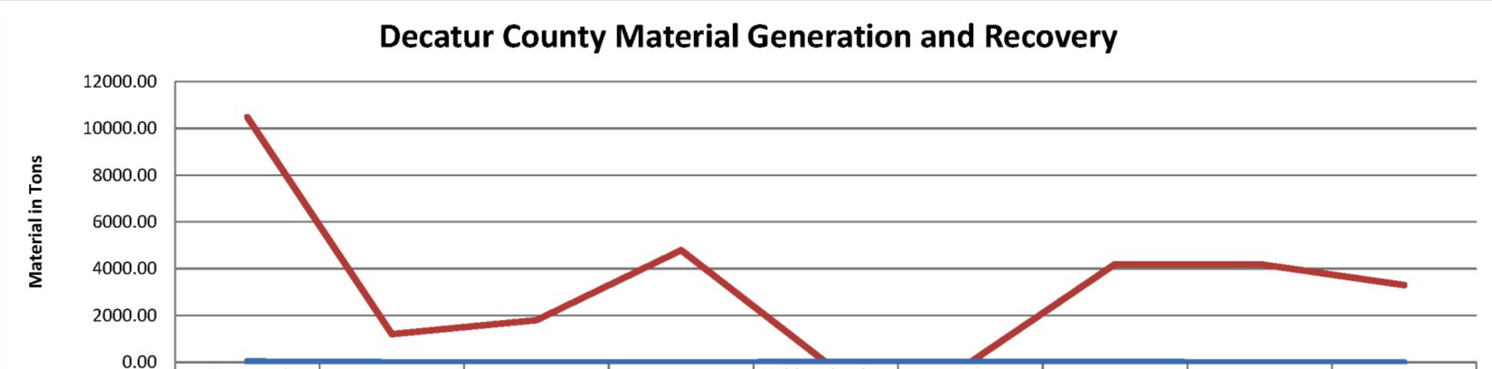
Census and State Overview Statistics				
County	2012 Pop	Pounds per day	Total Waste (lbs/yr)	Total Waste (MT/y)[7]
Decatur	27842	6.5	66055145.00	29962.09

Sources:

[1]US EPA (2012): Municipal Solid Waste Generation, Recycling, and Disposal in the United States. Facts and Figures for 2012. US Environmental Protection Agency. Available online at www.epa.gov/wastes, updated on 2012, checked on April, 2014.

[7]The Southwest Georgia Regional Development Center (2007): Decatur County Consolidated Solid Waste Management Plan 2007-2017. Decatur County, Georgia. Available online at http://www.dca.state.ga.us/development/EnvironmentalManagement/Adopted%20SWMP/Decatur_Co_Attapulgus_Ci_Brinson_Ci_Climax_Ci_SWMP2007-2017.pdf, checked on June 2016.

Decatur County Recovery from County MSW Report		
Category	EPA Percentage Recovery[1]	Decatur Recovery[7]
Paper and Paperboard	51%	30.72
Glass	4%	2.22
Metals	9%	5.28
Plastics	3%	1.92
Rubber, leather and textiles	0%	0.00
Wood	3%	1.68
Yard Trimmings	23%	13.56
Food waste	2%	1.20
Other	6%	3.42
Total Recovery in Tons	**1**	**60.00**



	Paper and Paperboard	Glass	Metals	Plastics	Rubber, leather and textiles	Wood	Yard Trimmings	Food waste	Other
Generation	10486.73	1198.48	1797.73	4793.93	0.00	0.00	4194.69	4194.69	3295.83
Recovery	30.72	2.22	5.28	1.92	0.00	1.68	13.56	1.20	3.42

Figure 6-19: Decatur County Material Generation and Recovery (M2c & M2d)