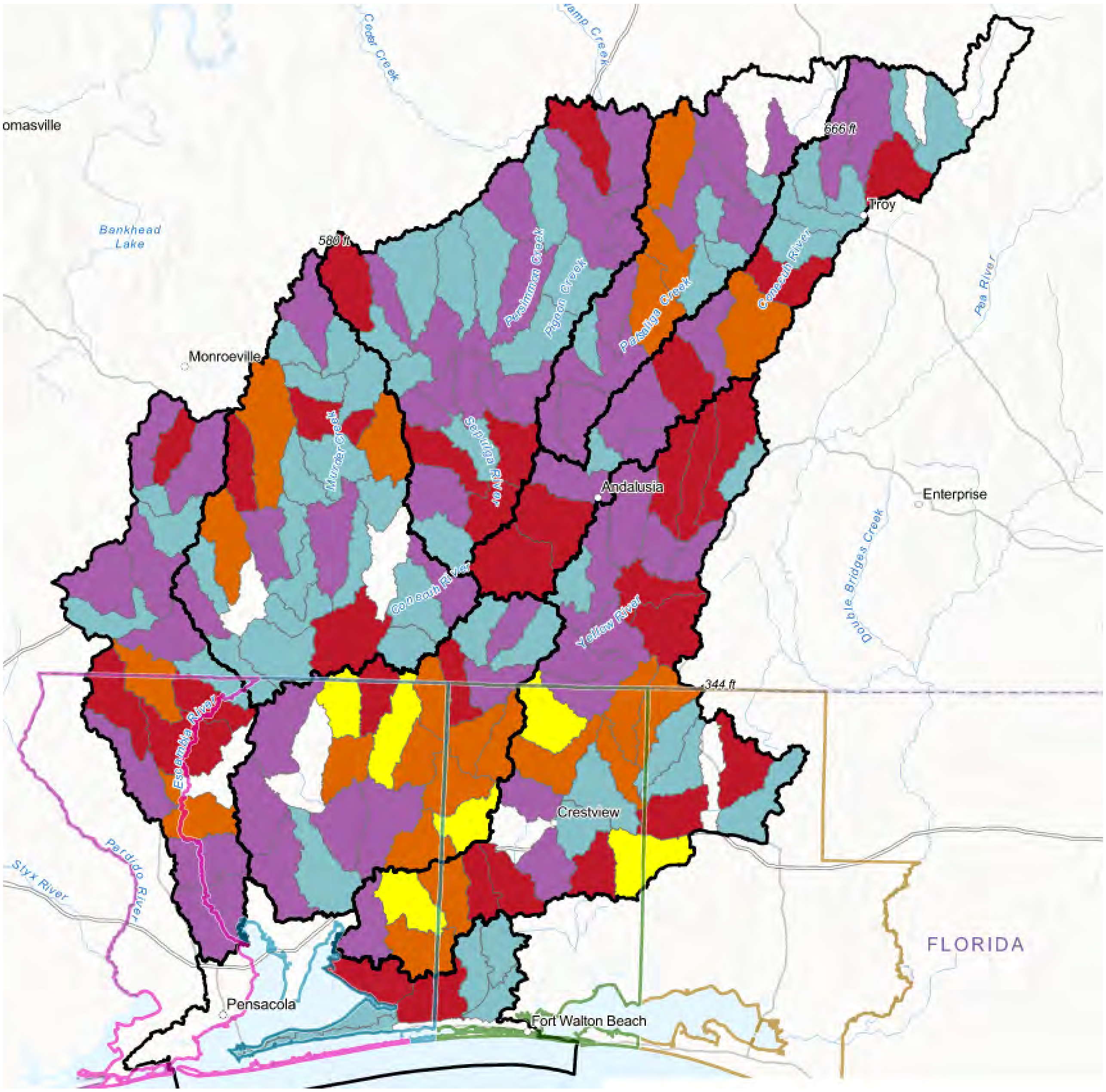
June 9, 2023

Pensacola Bay Unpaved Roads Initiative Revised Sediment Report

FDEP Contract No. DH014

Submitted to: Florida Department of the Environment



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EXECUTIVE SUMMARY

This Revised Sediment Report describes previous studies and modeling results and how they will be synthesized to:

1. Perform literature reviews and modeling to quantify the amount of sediment transport occurring upstream of the Bay.
2. Calculate an estimate of the total sediment load to Pensacola Bay and quantify contributions from each subwatershed.
3. Develop a methodology for and estimate the sediment contribution from road-stream crossings within the watershed. In-situ sampling was used to calibrate calculations.
4. Determine a sediment reduction goal for the watershed.

A synthesis of existing models and studies throughout the Pensacola Bay watershed and adjacent basins was also performed to quantity the amount of sediment occurring upstream of the Bay. Results from existing watershed models developed by USGS (Spatially Referenced Regression On Watershed [SPARROW] models) will provide estimates of **suspended sediments** and sediment sources. A series of twelve basin studies (124 sample locations) were performed by Cook Hydrogeology and the Geological Survey of Alabama (GSA) in Alabama and Florida, and some of these sample locations were within the Pensacola Bay watershed. Though **bed load sediment** is difficult to simulate and predict, data from these existing studies were analyzed and compared to estimate bed load sediment throughout the Pensacola Bay watershed. Sediment sources are summarized by land use type and subwatershed.

The Revised Report also includes calculated **sediment contributions from road-stream crossings**. An inventory of all road-stream crossings within the watershed was developed in Task 3. This inventory combined data from multiple sources, and asked stakeholders, including Escambia, Santa Rosa, Okaloosa, and Walton Counties, Eglin AFB, and Blackwater River State Forest to indicate which roads have already been improved or are programmed to be improved. The roadway approach lengths and slopes to each road-stream crossing was measured using LiDAR topography. After making several assumptions on roadway composition, width, and existing configurations, we were able to use the Revised Universal Soil Loss Equation (RUSLE) to estimate the annual soil yield from each road/stream crossing. Standard practice is to haul in a sand-clay mixture to repair and maintain unpaved roads, so the sediment source to the streams is often perpetual. Field-surveyed bed load sediment was used to calibrate the RUSLE estimates.

Finally, an estimate of the total sediment load entering Pensacola Bay is calculated, and a potential **sediment reduction goal** is provided in context of other information.

INTRODUCTION

BACKGROUND

The Florida Department of Environmental Protection (FDEP), along with other partners, is conducting a project to inventory, prioritize, and develop solutions to unpaved roads in the Pensacola Bay watershed with the goal of improving water quality. The project includes assessing and identifying unpaved road-stream crossings contributing the largest sediment loads to the watershed and developing 30% design plans of site-specific solutions at a minimum of 15 priority locations to eliminate or reduce sediment loading to water resources and associated habitat. The 15 locations will be the highest-prioritized sites based on a larger number of sites assessed.

The Pensacola Bay watershed encompasses over 7,000 square miles in northwest Florida and southern Alabama. The Florida portion of the watershed, approximately 2,300 square miles, is located within Escambia, Okaloosa, Santa Rosa, and Walton counties. The Pensacola Bay drainage area contains the Escambia, Blackwater, and Yellow River systems. The Escambia River covers over 4,200 square miles, of which about only 10 percent is in Florida. The Blackwater River has a drainage area of approximately 860 square miles, with approximately 81 percent in Okaloosa and Santa Rosa counties. The Yellow River has a drainage area of 1,365 square miles, with nearly 64 percent located in northwest Florida. Approximately 144 square miles of the Pensacola Bay drainage area is considered estuarine.

The project will help improve water quality and habitats in the Pensacola Bay watershed by assessing and identifying unpaved road-stream crossings contributing the most amount of sediment to the watershed. Unpaved roads cause significant erosion and sediment loading to nearshore waterbodies (Programmatic Damage Assessment and Restoration Plan [PDARP]/ Programmatic Environmental Impact Statement (PEIS, Sec. 2-37 5.D.2.2)). While road systems typically occupy a relatively small portion of the landscape, their construction and maintenance have a great impact on water quality in the adjacent streams and the connected, downstream aquatic ecosystems (Gucinski, Furniss, Ziemer, & Brookes, 2011) causing loss of habitat and aquatic species decline. It has been well documented that stream-bound sediment interferes with the downstream growth and development of algae, phytoplankton, and Submerged Aquatic Vegetation (SAV) by absorbing or scattering solar radiation necessary for photosynthesis. The 2017 Northwest Florida Water Management District (NWFWMD) Pensacola Bay System Surface Water Improvement and Management (SWIM) plan identifies unpaved roads as one of the challenges in the watershed contributing to nonpoint source pollution, turbidity in streams, smothering of habitats, and impacting water quality.

SEDIMENT REDUCTION GOAL

Task 1: Quality Assurance
Task 2: Compile and Compare Existing Inventories
Task 3: Geodatabase / GIS Mapping
Task 4: Modeling and Sedimentation Reduction Goal Establishment
Task 5: Preliminary Prioritization
Task 6: Field Reconnaissance
Task 7: Final Prioritization & Habitat and Resource Assessment
Task 8: Design Plans
Task 9: Project Management

In April 2022, JMT was retained by FDEP to assist in establishing a sediment reduction goal for the Pensacola Bay Watershed (Task 4). To accomplish this, JMT was authorized to perform the following subtasks:

1. Perform a literature review and modeling to quantify the amount of suspended and bed load sediment transport occurring upstream of the Bay.
2. Quantify contributions from each subwatershed.
3. Estimate the sediment contribution specifically from road-stream crossings within the watershed.
4. Use in-situ sampling to calibrate calculations.
5. Determine a sediment reduction goal for the watershed.

This Revised Report describes previous studies and modeling results and how they will be synthesized to achieve the subtasks listed above. Results from existing watershed models developed by USGS (Spatially Referenced Regression On Watershed [SPARROW] models) will provide estimates of **suspended sediments** and sediment sources. A series of studies twelve basin studies (124 sample locations) were performed by Cook Hydrogeology and GSA in Alabama and Florida, and some of these sample locations were within the Pensacola Bay watershed. Although **bed load sediment** is difficult to simulate and predict, an attempt will be made to synthesize these existing studies, some of which included bed load measurement, and estimate bed load sediment throughout the Pensacola Bay watershed. Sediment sources are summarized by land use type and subwatershed. The Revised Report also includes calculated **sediment contributions from road-stream crossings**. These calculations have been calibrated with field measurements. Finally, an estimate of the total sediment load entering Pensacola Bay is calculated, and a potential **sediment reduction goal** is provided in context of other information.

PENSACOLA BAY WATERSHED

The Pensacola Bay watershed is located within the Choctawhatchee-Escambia Basin (HUC0314). It is comprised of eight sub-basins with 8-digit Hydraulic Unit Codes (HUCs).

Figure 1: Major subwatersheds (Eight-digit HUCs) within Pensacola Basin

HUC	Watershed
03140103	– Yellow. Alabama and Florida
03140104	– Blackwater. Alabama and Florida
03140105	– Pensacola Bay. Florida
03140301	– Upper Conecuh. Alabama
03140302	– Patsaliga. Alabama
03140303	– Sepulga. Alabama
03140304	– Lower Conecuh. Alabama and Florida
03140305	– Escambia. Alabama and Florida

These eight sub-basins are collectively referred to as the study watershed in this report. Even though the Upper Conecuh, Patsaliga, and Sepulga are entirely within Alabama, the entire study watershed was assessed. This is necessary for a complete and accurate understanding of sediment sources, especially since suspended and bed sediments drain into Florida from Alabama. The watershed can be further divided into 12-digit HUCs and catchments for analysis. The study watershed contains 247 12-digit HUCs, and the area drained by each 12-digit HUC varies (mean 35.4 mi^2, min 10.9 mi^2, max 183.7 mi^2). The study watershed contains 9,396 catchments, and the area drained by each catchment varies (mean 4.9 mi^2, min 0.01 mi^2, max 114.0 mi^2). A catchment is the local drainage area to each river reach, where each reach is defined as the distance between confluences with either smaller or larger rivers. Both 12-digit HUCs and catchments were used as the resolution for the summary figures in this report.

PRIOR REPORTS & DATA COLLECTION

PENSACOLA & PERDIDO BAYS ESTUARY PROGRAM

In 2022 the Pensacola & Perdido Bays Estuary Program (PPBEP) released their first Comprehensive Conservation and Management Plan (CCMP). The CCMP is a ten-year action plan for improving the health and resilience of the Pensacola and Perdido Bays watersheds. The CCMP outlines six primary goals or priority actions, 23 objectives, and 51 actions to improve water quality and habitats within the two gulf watersheds. Goal One is to become a primary source of watershed-related information. Goal Two is to inform community planning and development decisions, ensuring the comprehensive plans and land development codes are consistent with the objectives of the CCMP. Goal Three is to improve water quality in the two watersheds through a comprehensive monitoring program to identify the root causes of water quality impairments, develop water quality targets and identify where actions are needed. Goal Four is to reduce sedimentation, through a sediment monitoring program and a sediment study to assess sources of sediment. These actions include identifying sediment sources and the impact of land use cover to sediment loading. Goal Four includes developing, designing, and implementing sediment reduction projects to directly address sources of sedimentation. Goal Five is to conserve and restore critical habitats. This goal focuses on comprehensive monitoring and restoration approach for native oyster and seagrass populations as well as critical habitats for imperiled and protected species to improve and support native ecosystems in the Pensacola and Perdido Bays watersheds. Goal Six is to restore and conserve fish and wildlife. This is collaborative goal with partner organizations and the community to monitor and identify areas where wildlife populations can be protected and expanded.

Part of Goal Four includes identification of unpaved roads, gullies, and streambank erosion. The CCMP has identified FDEP's Pensacola Unpaved Roads Initiative. Tributaries in the Pensacola Bay watershed are known sources of excess sedimentation. Projects developed by FDEP and The Nature Conservancy (TNC) have been successful in stabilizing some unpaved roads. Counties in Florida and Alabama have used a "hilltop to hilltop" program to survey and assess unpaved road conditions to develop road paving prioritization. A major action in the CCMP will be to identify all unpaved roads and prioritize them for paving or low impact designs to reduce sediment inputs. PPBEP will continue to coordinate and identify partners and funding sources for future sediment reduction projects that address unpaved roads.

SPARROW

SPARROW models were designed to estimate the mean annual streamflow and the amount of Suspended Sediment (SS), Total Nitrogen (TN), and Total Phosphorous (TP). The data also includes the incremental, accumulated, and delivered amounts to the coastal waters. There were five categories of variables used for modeling: Source, Land to Water Delivery, Aquatic Loss, Removal as Water Withdrawals, and a Conversion Factor. The resulting model was then calibrated against measured gage, sediment, and water quality measurements sequentially calibrating from upstream-to-downstream. In each calibration iteration the model coefficients were adjusted until the differences between the estimated and measured values at the calibration locations were minimized (Hoos & Roland II, 2019). The model had standard errors of over 30% for most source variables, indicating a complex relationship. Given this uncertainty, the model may predict greater sediment load from upland sources than is occurring. As long as the uncertainty is understood, this model provides useful and unique information that can be summarized by sediment source and at different spatial scales.

Note that data summarized from SPARROW are in metric units.

PRIOR BASIN STUDIES

A total of twelve other water quality and sediment studies (124 sample individual locations) were performed by Cook Hydrogeology and GSA in the Pensacola Bay and adjacent watersheds. Of those, only seven studies (31 locations in 28 catchments) included TSS and bed load data. Note that data summarized and calculated using these basin studies are in imperial units. The location of each measurement is mapped in Figure 2. The catchments for each of the measurements that included TSS and bed load data were delineated and are also shown. These seven studies included discharge, turbidity, TSS load, extrapolated bed sediment load, and other water quality measurements. These seven studies were located within or along the following watersheds:

- Bon Secour River, AL
- D’Olive Creek, AL
- Dog River, AL
- Fish River, AL
- Magnolia River, AL
- Multiple locations within the Wolf Bay Watershed, AL
- Multiple locations within the Pensacola Bay Watershed, AL and FL

The studies within the Pensacola Bay Watershed were from 2009 and were intended to establish a baseline for water quality assessments. At the time, few data were available to assess the waters and to track how the changes in land use and other factors would impact the water quality. However, the project was developed to generate a data set that can be used by stakeholders to develop, manage, and protect the surface-water resources of the Conecuh and Blackwater River Watersheds. These studies provide a basis for water quality conditions within the headwaters of the Pensacola Bay Watershed.

Within the Conecuh and Blackwater River watersheds, four primary nonpoint source constituents affect water quality including sediment, nutrients, bacteria, and metals. Those sites that were highly impacted by these primary constituents correlated well with agricultural land use activities. These land uses often result in runoff of fertilizers and animal waste which creates excessive nutrients and bacterial activity and causes deterioration of water quality (Cook, 2009).

Land use is one of the most important factors affecting water quality. Land use was divided into two major land use categories in the 2009 studies: those dominated by agriculture and those dominated by forests. Evaluations were based upon stream locations and land uses associated within a given stream reach, specifically stream reaches located on low-impact sites that drain from forested lands and those located on high-impact sites that drain from agricultural lands. Those sites within watersheds dominated by forested lands had the lowest magnitude impact on water quality, and those sites in heavily dominated agricultural watersheds had the highest magnitude impact on water quality. In these watersheds, land use practices have a significant effect on water quality, and targeted land management could improve water quality and aquatic ecosystems.

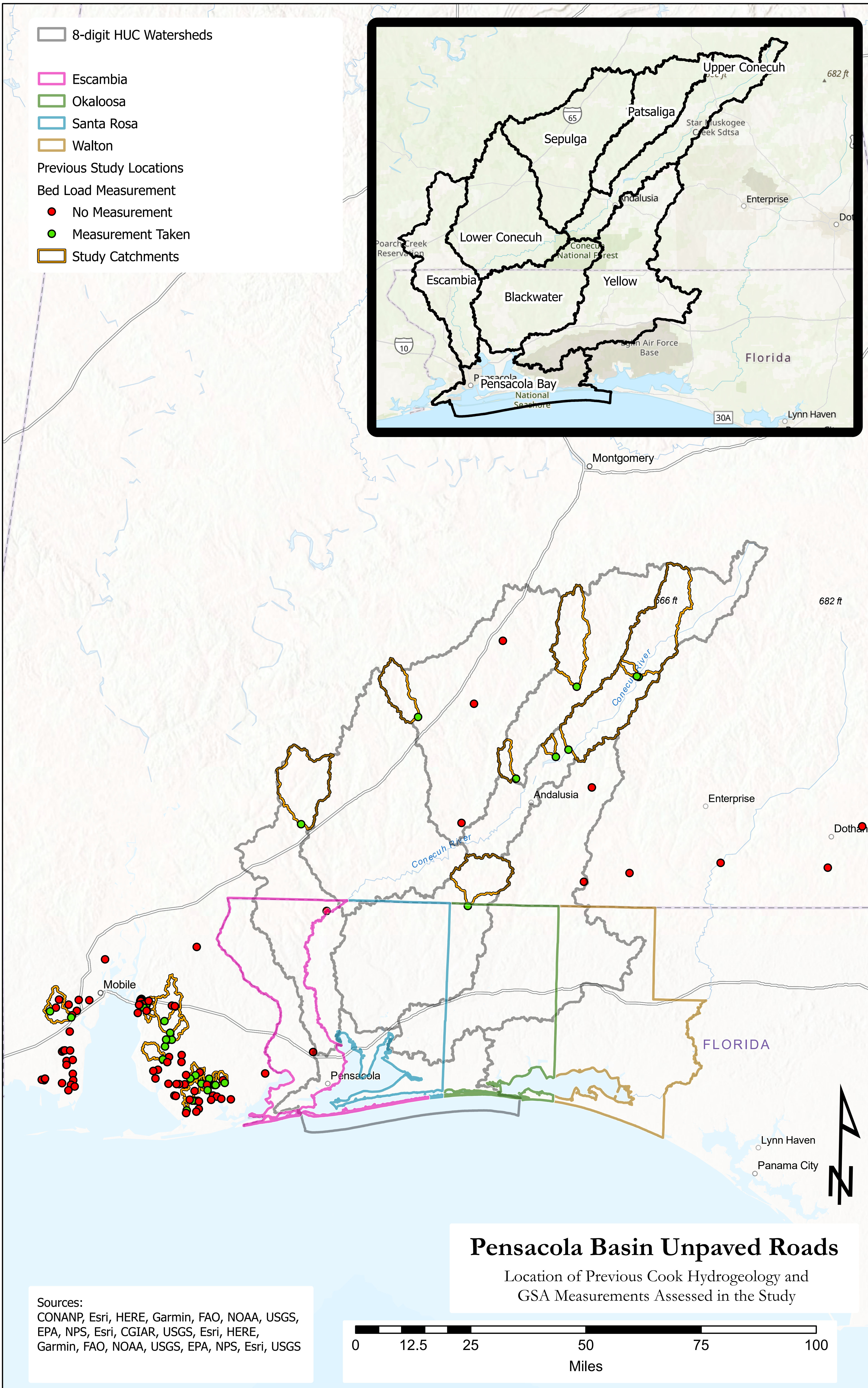

8-digit HUC Watersheds
Escambia
Okaloosa
Santa Rosa
Walton
Previous Study Locations
Bed Load Measurement
No Measurement
Measurement Taken
Study Catchments
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Andalusia
Enterprise
Florida
Lynn Haven
Montgomery
Conecuh River
Pensacola
Mobile
Dothan
FLORIDA
Panama City
Pensacola Basin Unpaved Roads
Location of Previous Cook Hydrogeology and
GSA Measurements Assessed in the Study
0 12.5 25 50 75 100
Miles
Sources:
CONANP, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, USGS

Figure 2

MODELED SUSPENDED SEDIMENT LOAD

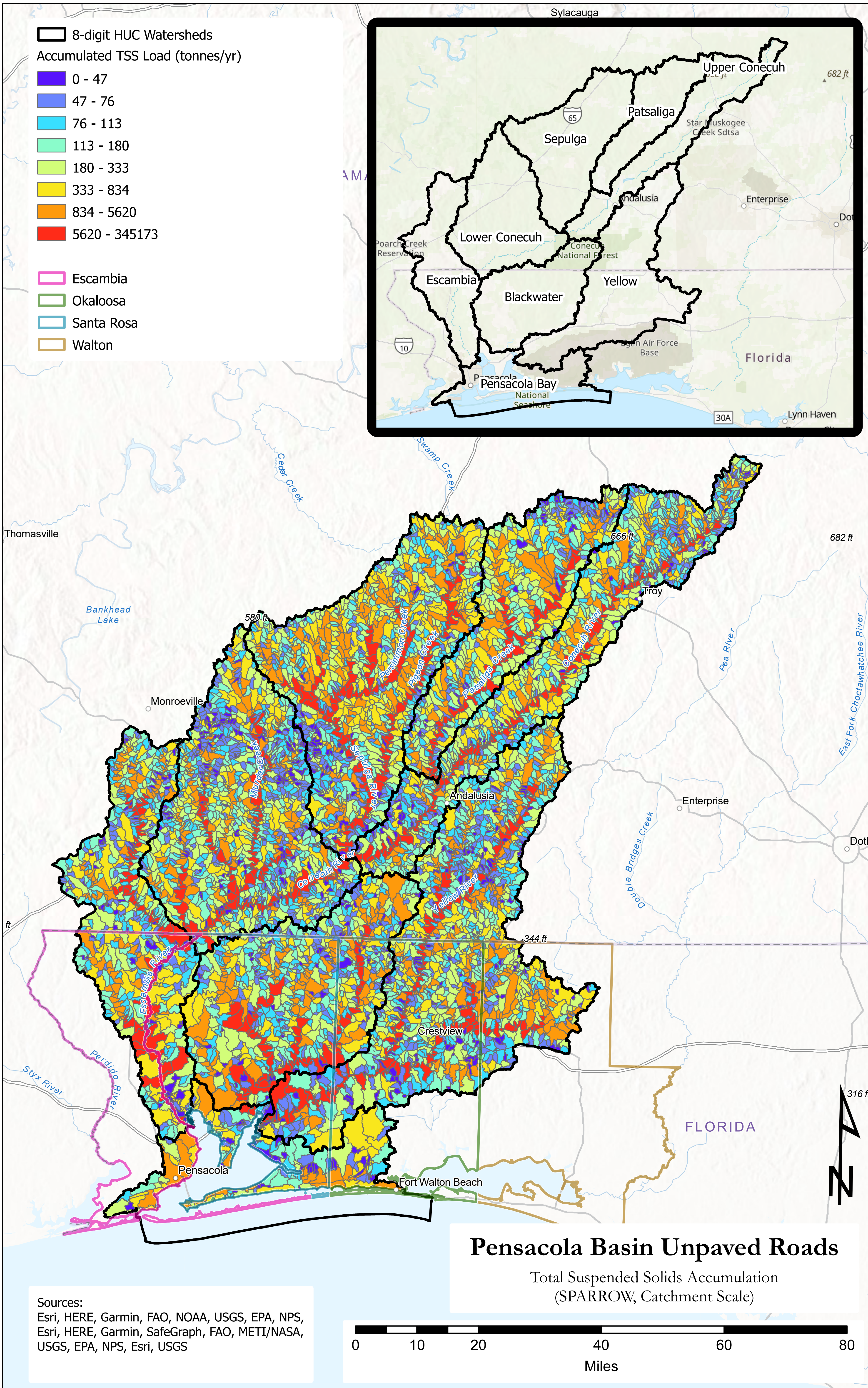
The modeled suspended sediment load results from the SPARROW model can be summarized spatially and by sediment source. Table 1 summarizes suspended sediment load by HUC 8 watershed, and the last column is a summary across all Pensacola Bay watersheds. Sediment runoff from urban sources dominates the watershed with the most urban development (03140105 Pensacola). Upland runoff from agricultural lands generates roughly a third of the suspended sediment load within the Bay watershed. Agriculture is the greatest proportional sediment source within the Sepulga HUC 8 (03140303) and is the least within the Pensacola HUC 8 (03140105). Sediment runoff from forested land represents over 22% of the suspended sediment load. This is likely a combination of what can be interpreted as natural runoff from unimpacted land and sediment runoff from silviculture. Streambank and streambed erosion (channel sources) represents approximately 13% of the suspended sediment load within the Bay. These results do not explicitly consider sediment from unpaved road-stream crossings.

Table 1: SPARROW Total Suspended Solids Source Distribution within Each HUC 8

Total Suspended Solids (TSS) Source	03140103 Yellow	03140104 Blackwater	03140105 Pensacola Bay	03140301 Upper Conecuh	03140302 Patsaliga	03140303 Sepulga	03140304 Lower Conecuh	03140305 Escambia	Pensacola Bay Watershed
Urban land (%)	5.8	6.9	70.5	4.9	3.3	3.2	5.4	8.6	8.4
Agricultural land (%)	32.7	20.4	0.8	31.5	34.2	45.5	21.8	23.7	30.1
Transitional land (%)	25.7	33.2	15.2	25.1	23.5	18.8	32.4	37.5	26.3
Forested land (%)	20.4	27.0	9.8	24.5	26.8	22.7	24.6	17.5	22.5
Channel sources (%)	15.5	12.5	3.7	14.0	12.3	9.7	15.8	12.8	12.7

The accmulated suspended sediment load is mapped by individual catchment in Figure 3. This figure depicts the suspended sediment load from each catchment and transported from all upstream catchments. Sediment load that is deposited within a catchment (such as within a reservoir) is not accumulated in the next downstream catchment. The incremental suspended sediment load is mapped by catchment in Figure 4 and by HUC 12 in Figure 5. This shows only the relative sediment load originating from each catchment, which, within Florida, is greatest within the northern parts of Santa Rosa, Okaloosa, and Walton Counties and in urban centers in the immediate vicinity of Pensacoal Bay (Pensacola, Pace, and Gulf Breeze to Navarre). Figure 6 and Figure 7 also show that channel sources (streambank and streambed erosion) are proportionally greater in the more northern parts of all Florida Counties, especially northern Okaloosa County.

Both phosphorus and nitrogen are often bound to suspended sediment, though nitrogen has other pathways for transport. Though nutrients were not the focus of this study, Figure 8, summarizing phosphorus source locations across the watershed, and Figure 9, summarizing nitrogen source locations across the watershed, are included for reference. Within Florida, the largest phosphorus source location are the urban centers in the immediate vicinity of Pensacola Bay and in Crestview. The largest nitrogen source locations are similarly distributed.



8-digit HUC Watersheds
Accumulated TSS Load (tonnes/yr)
0 - 47
47 - 76
76 - 113
113 - 180
180 - 333
333 - 834
834 - 5620
5620 - 345173
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Yellow
Blackwater
Pensacola Bay
Sylacauga
Thomasville
Monroeville
Andalusia
Enterprise
Troy
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Persimmon Creek
Pigeon Creek
Patsaliga Creek
Conecuh River
Sepulga River
Murder Creek
Yellow River
Escambia River
Perdido River
Styx River
Double Bridges Creek
Pea River
East Fork Choctawhatchee River
Cedar Creek
Swamp Creek
Bankhead Lake
Pensacola Basin Unpaved Roads
Total Suspended Solids Accumulation
(SPARROW, Catchment Scale)
Sources:
Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS,
Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA,
USGS, EPA, NPS, Esri, USGS
0 10 20 40 60 80
Miles
N

Figure 3

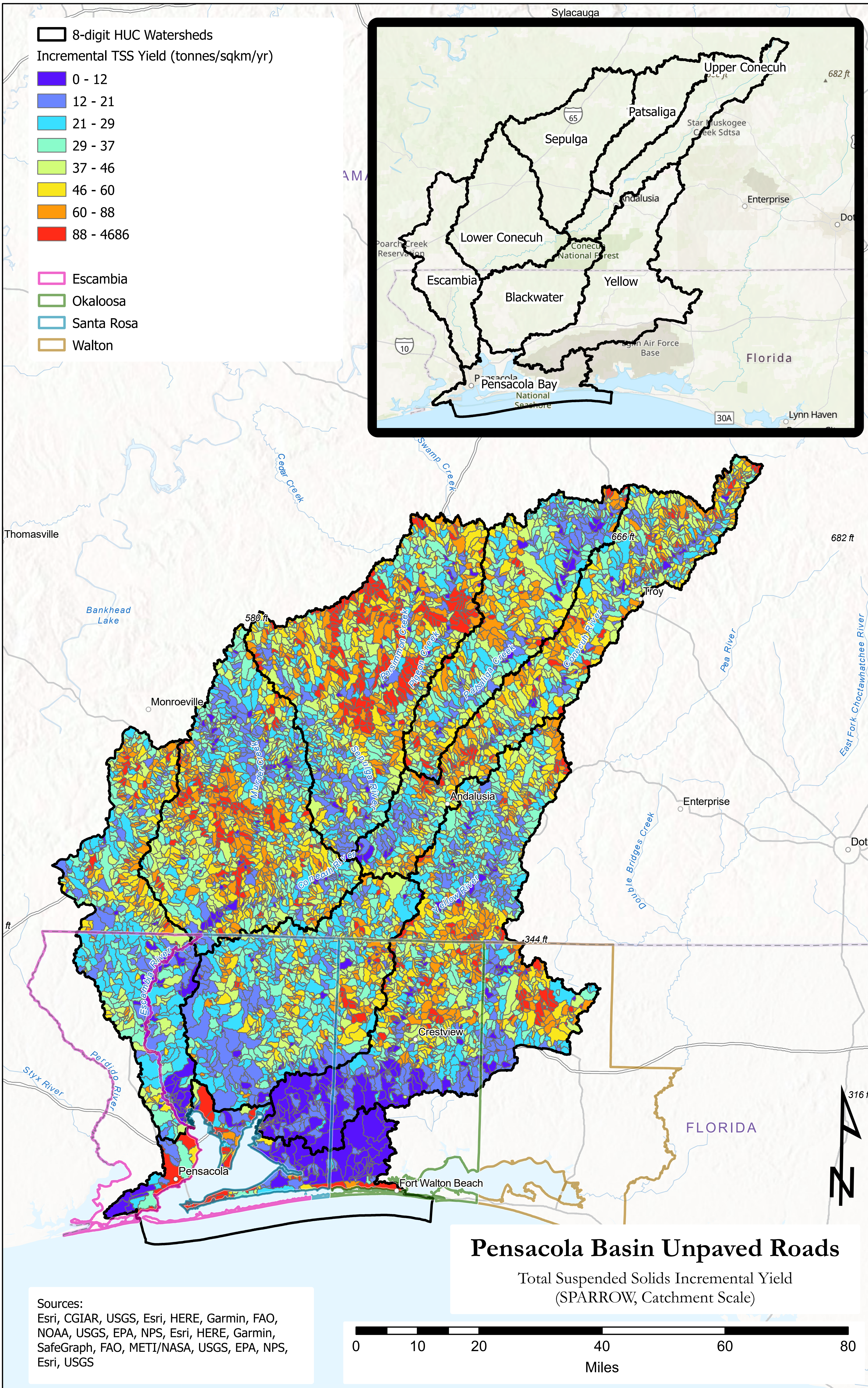
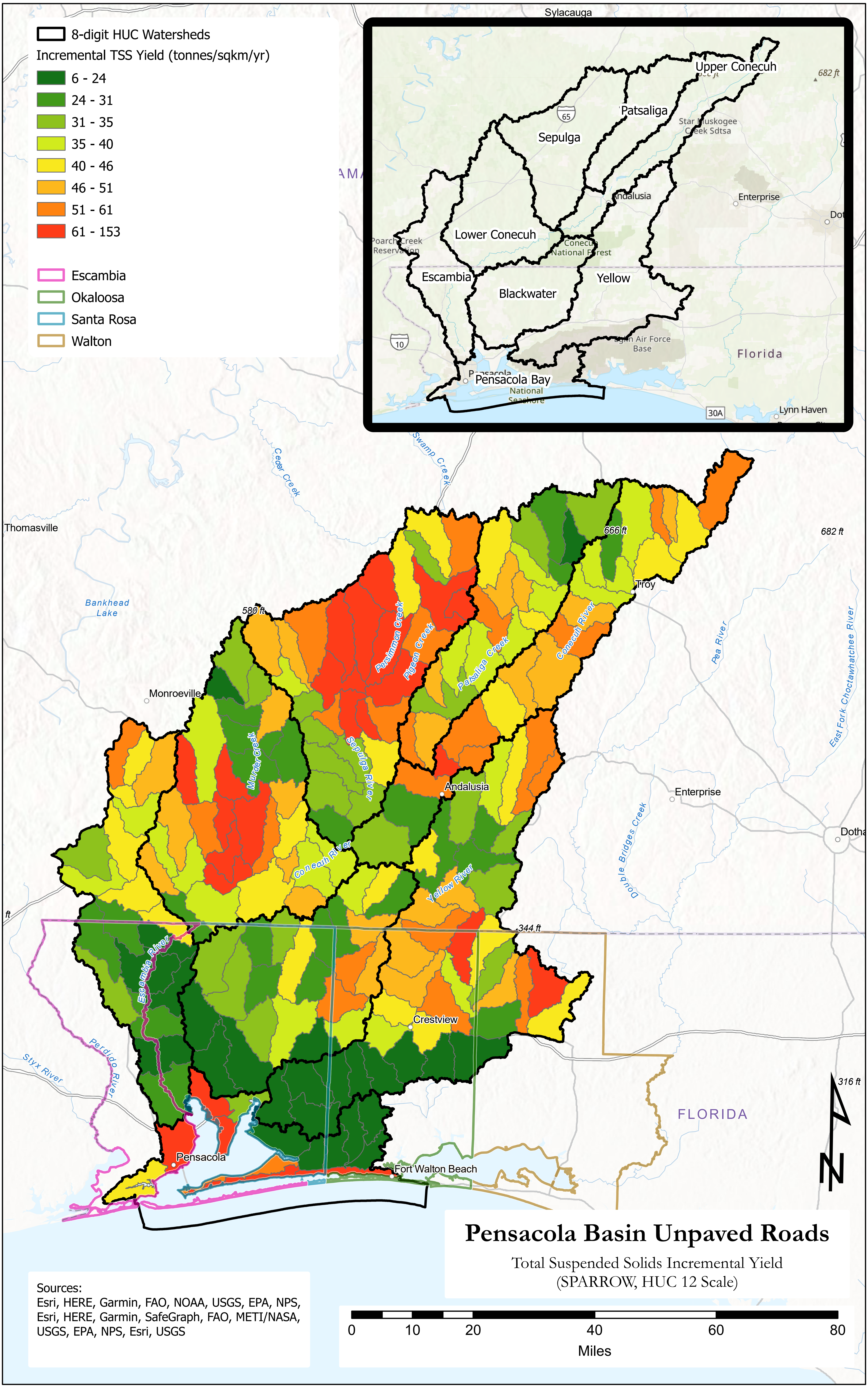

8-digit HUC Watersheds
Incremental TSS Yield (tonnes/sqkm/yr)
0 - 12
12 - 21
21 - 29
29 - 37
37 - 46
46 - 60
60 - 88
88 - 4686
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Florida
Sylacauga
Thomasville
Monroeville
Troy
Andalusia
Enterprise
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Persimmon Creek
Pigeon Creek
Patsaliga Creek
Conecuh River
Sepulga River
Murder Creek
Yellow River
Escambia River
Perdido River
Styx River
Double Bridges Creek
Pea River
East Fork Choctawhatchee River
Cedar Creek
Swamp Creek
Bankhead Lake
Pensacola Basin Unpaved Roads
Total Suspended Solids Incremental Yield
(SPARROW, Catchment Scale)
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO,
NOAA, USGS, EPA, NPS, Esri, HERE, Garmin,
SafeGraph, FAO, METI/NASA, USGS, EPA, NPS,
Esri, USGS
0 10 20 40 60 80
Miles
N

Figure 4



8-digit HUC Watersheds
Incremental TSS Yield (tonnes/sqkm/yr)
6 - 24
24 - 31
31 - 35
35 - 40
40 - 46
46 - 51
51 - 61
61 - 153
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Yellow
Blackwater
Pensacola Bay
Sylacauga
Thomasville
Monroeville
Troy
Andalusia
Enterprise
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Persimmon Creek
Pigeon Creek
Patsaliga Creek
Conecuh River
Sepulga River
Murder Creek
Yellow River
Escambia River
Perdido River
Styx River
Cedar Creek
Swamp Creek
Pea River
Double Bridges Creek
East Fork Choctawhatchee River
Bankhead Lake
N
Pensacola Basin Unpaved Roads
Total Suspended Solids Incremental Yield
(SPARROW, HUC 12 Scale)
0
10
20
40
60
80
Miles
Sources:
Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS

Figure 5

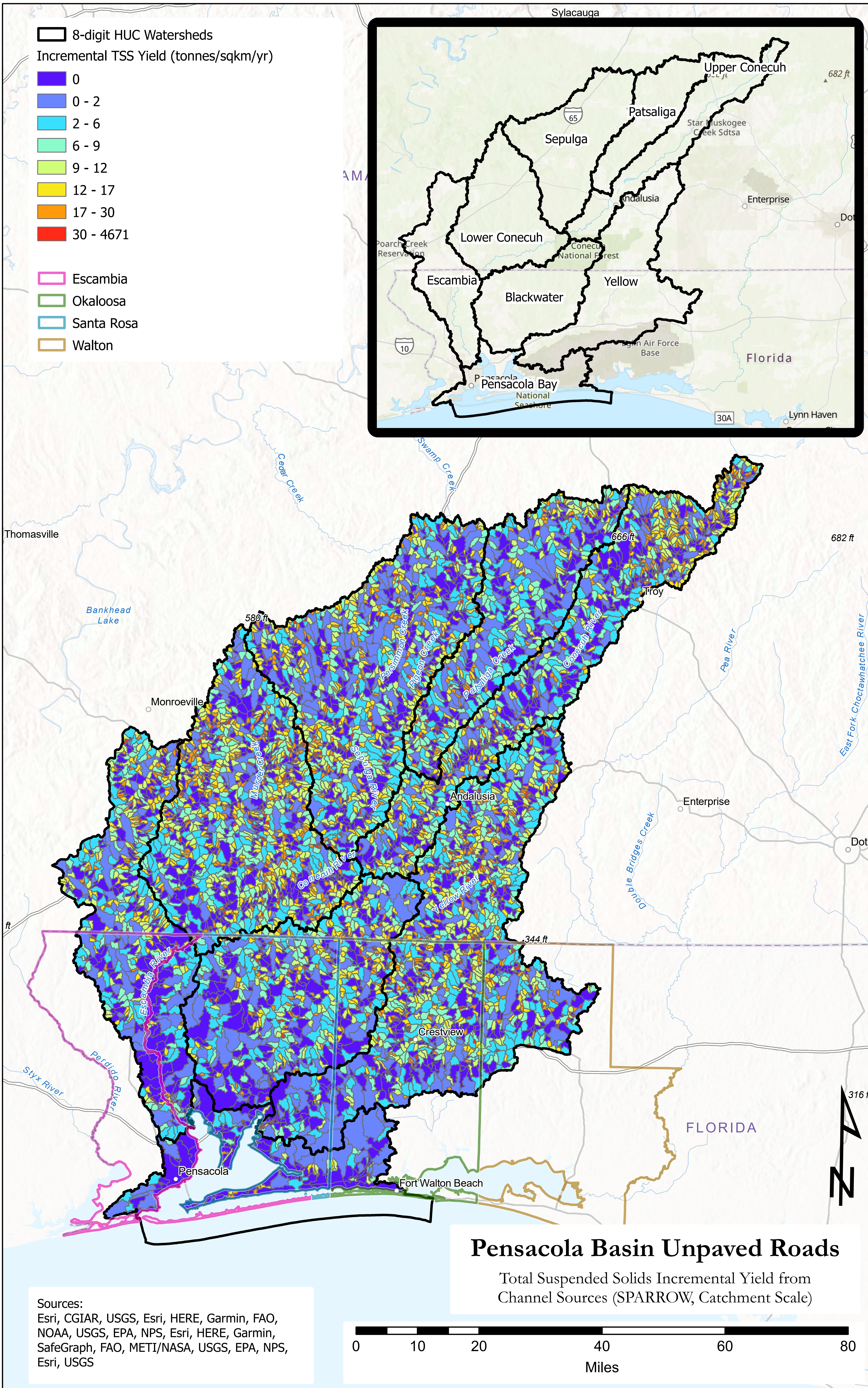
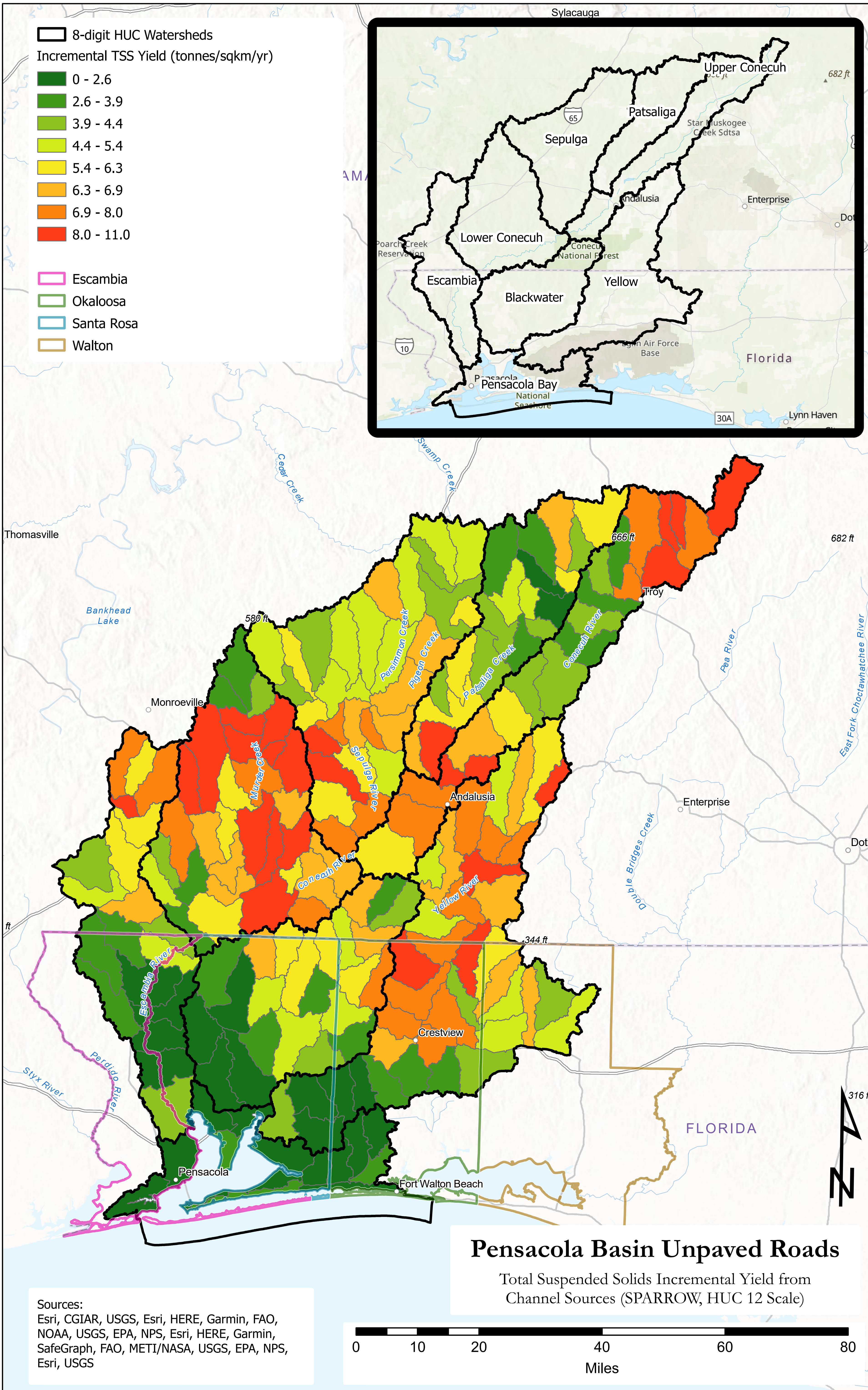

8-digit HUC Watersheds
Incremental TSS Yield (tonnes/sqkm/yr)
0
0 - 2
2 - 6
6 - 9
9 - 12
12 - 17
17 - 30
30 - 4671
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Andalusia
Enterprise
Florida
Sylacauga
Thomasville
Monroeville
Troy
Andalusia
Enterprise
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Conecuh River
Yellow River
Escambia River
Sepulga River
Patsaliga Creek
Pigeon Creek
Persimmon Creek
Murder Creek
Perdido River
Styx River
Pea River
Double Bridges Creek
East Fork Choctawhatchee River
Cedar Creek
Swamp Creek
Bankhead Lake
Pensacola Basin Unpaved Roads
Total Suspended Solids Incremental Yield from Channel Sources (SPARROW, Catchment Scale)
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
0 10 20 40 60 80
Miles
N

Figure 6



Pensacola Basin Unpaved Roads
Total Suspended Solids Incremental Yield from Channel Sources (SPARROW, HUC 12 Scale)
8-digit HUC Watersheds
Incremental TSS Yield (tonnes/sqkm/yr)
0 - 2.6
2.6 - 3.9
3.9 - 4.4
4.4 - 5.4
5.4 - 6.3
6.3 - 6.9
6.9 - 8.0
8.0 - 11.0
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Andalusia
Enterprise
Florida
Sylacauga
Thomasville
Monroeville
Troy
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Enterprise
Crestview
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Persimmon Creek
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Conecuh River
Sepulga River
Murder Creek
Yellow River
Escambia River
Perdido River
Styx River
Cedar Creek
Swamp Creek
Pea River
Double Bridges Creek
East Fork Choctawhatchee River
Bankhead Lake
N
0
10
20
40
60
80
Miles
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS

Figure 7

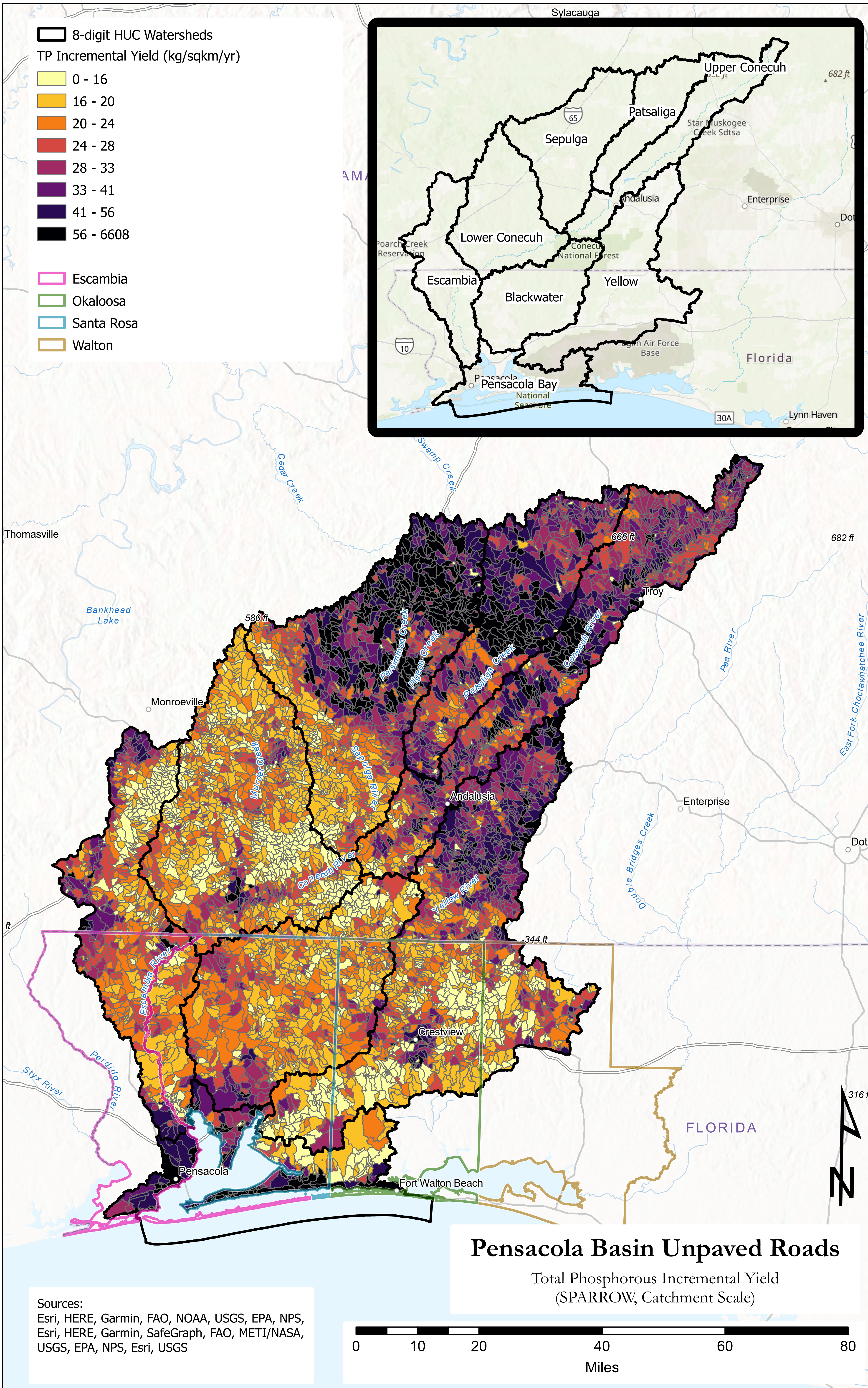

8-digit HUC Watersheds
TP Incremental Yield (kg/sqkm/yr)
0 - 16
16 - 20
20 - 24
24 - 28
28 - 33
33 - 41
41 - 56
56 - 6608
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Pensacola Basin Unpaved Roads
Total Phosphorous Incremental Yield
(SPARROW, Catchment Scale)
Sources:
Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS,
Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA,
USGS, EPA, NPS, Esri, USGS
0 10 20 40 60 80
Miles
N
Thomasville
Monroeville
Andalusia
Troy
Enterprise
Crestview
Pensacola
Fort Walton Beach
FLORIDA

Figure 8

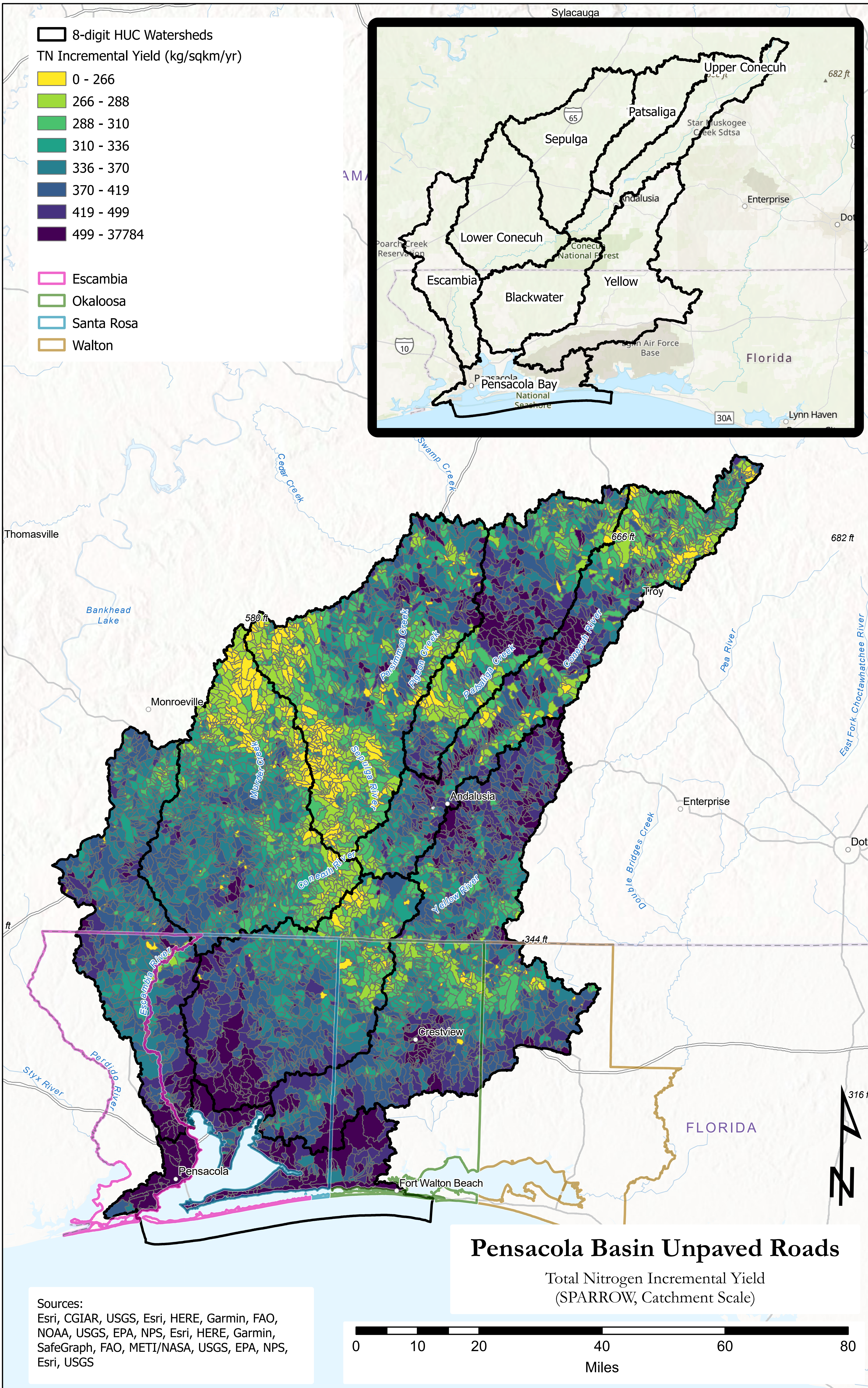

8-digit HUC Watersheds
TN Incremental Yield (kg/sqkm/yr)
0 - 266
266 - 288
288 - 310
310 - 336
336 - 370
370 - 419
419 - 499
499 - 37784
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Sylacauga
Thomasville
Monroeville
Andalusia
Enterprise
Troy
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Pensacola Basin Unpaved Roads
Total Nitrogen Incremental Yield
(SPARROW, Catchment Scale)
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
0 10 20 40 60 80
Miles

Figure 9

MODELED BED LOAD

Bed load transport is highly variable across streams, and it is often difficult to model and laborious to measure. For this project, we attempted to leverage existing data to assess if there are relationships between measured bed load and other watershed parameters. We used dozens of annual bed load estimates from studies performed by Cook Hydrogeology and GSA in Alabama and Florida and compared them against their watershed characteristics. The comparisons that were made include:

- Drainage Area
- Curve Number
- Average Soil K Factor
- Average Land Slope
- TSS Accumulation Estimated from SPARROW

Methodology and results for this analysis are included below. Ultimately, we found that TSS accumulation estimated from the SPARROW model provided the best correlation with estimates of annual bed load from previous studies. Therefore, that parameter was used to calculate an estimated bed load within each HUC 8 drainage area.

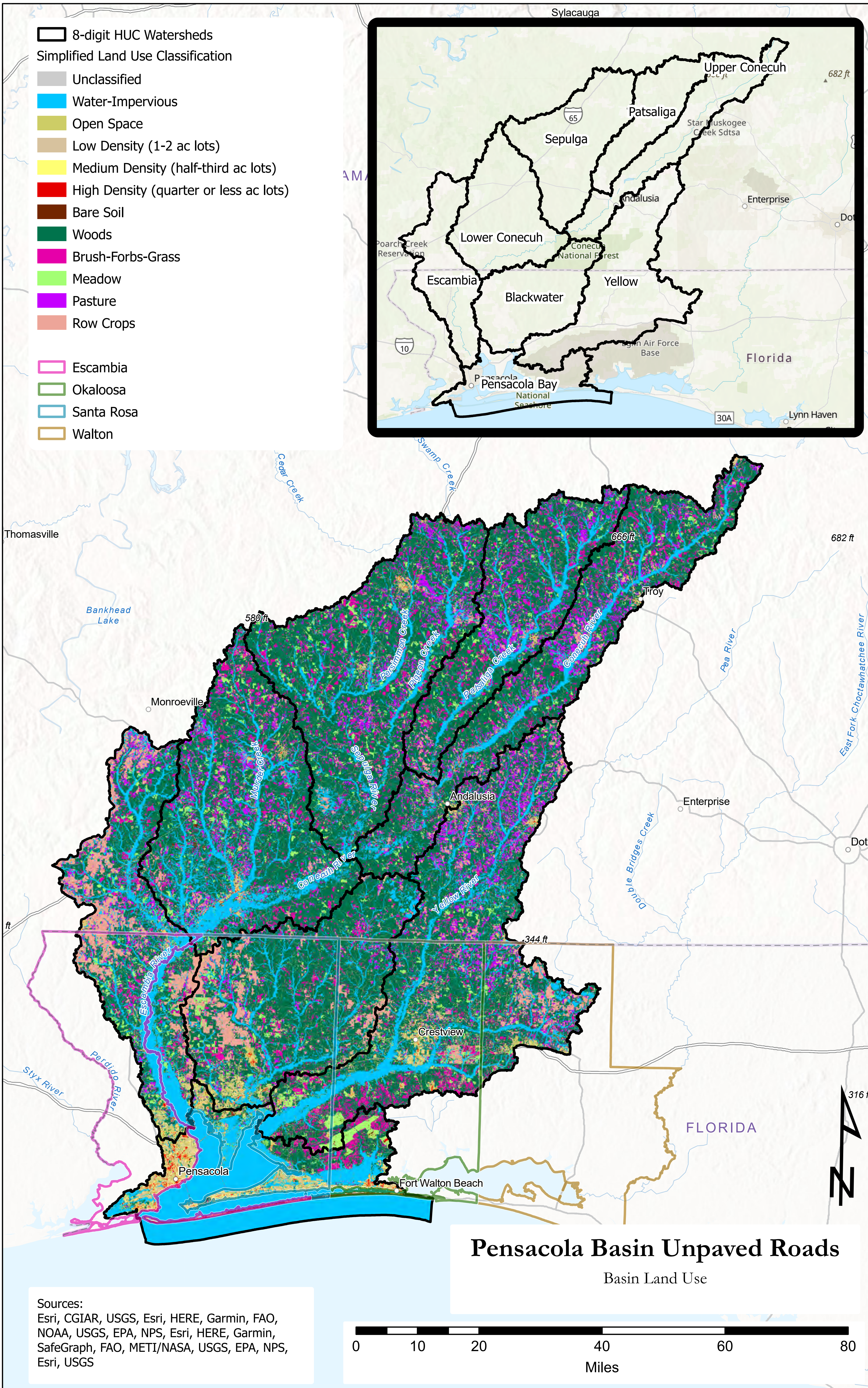
LAND USE DATA

Because the study watershed is in both Alabama and Florida, the 2019 National Land Cover Database (NLCD) was obtained and used for land use categorical consistency across the watershed. Sixteen NLCD land uses were reclassified to twelve land use classes to better match curve number categories in the National Engineers Handbook by the Natural Resources Conservation Services (NRCS) (Table 2). Land use classifications were simplified for illustration (Figure 10).

Table 2: Land Use Codes and Reclassifications

NLCD Land Use Code	NLCD Land Use Description	Model Land Use Code and Description
0	Unclassified	0: Unclassified
11	Open Water	1: Water and Wetlands
90	Woody Wetlands	1: Water and Wetlands
95	Emergent Herbaceous Wetlands	1: Water and Wetlands
21	Developed, Open Space	2: Open Space
22	Developed, Low Intensity	3: Low Density (20-49% impervious)
23	Developed, Medium Intensity	4: Medium Density (50-79% impervious)
24	Developed, High Intensity	5: High Density (80-100% impervious)
31	Barren Land	6: Bare Soil
41	Deciduous Forests	7: Woods
42	Evergreen Forests	7: Woods

NLCD Land Use Code	NLCD Land Use Description	Model Land Use Code and Description
43	Mixed Forests	7: Woods
52	Shrub/Scrub	8: Brush-Forbs-Grass
71	Herbaceous	9: Meadow
81	Hay/Pasture	10: Pasture
82	Cultivated Crops	11: Row Crops



8-digit HUC Watersheds
Simplified Land Use Classification
Unclassified
Water-Impervious
Open Space
Low Density (1-2 ac lots)
Medium Density (half-third ac lots)
High Density (quarter or less ac lots)
Bare Soil
Woods
Brush-Forbs-Grass
Meadow
Pasture
Row Crops
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Andalusia
Enterprise
Florida
Sylacauga
Thomasville
Monroeville
Troy
Enterprise
Pensacola
Crestview
Fort Walton Beach
FLORIDA
Persimmon Creek
Pigeon Creek
Patsaliga Creek
Conecuh River
Sepulga River
Murder Creek
Yellow River
Escambia River
Perdido River
Styx River
Pea River
Double Bridges Creek
East Fork Choctawhatchee River
Bankhead Lake
Cedar Creek
Swamp Creek
Pensacola Basin Unpaved Roads
Basin Land Use
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
0
10
20
40
60
80
Miles
N

Figure 10

SOIL DATA

Soil data were retrieved from the United States Department of Agriculture (USDA) Soil Survey Geographic Database (SSURGO), which is the most complete dataset available for both states. Soils were classified by their hydrologic group (HG) (Figure 11) so they could be used for curve number calculation. Some gaps were found in the available soil data, and the following assumptions were made:

- Soils identified as Water were assigned an HG of D.
- Urban land, Dams, and Gullied land were assigned the value of C in Alabama and A in Florida, corresponding to the predominate HGs in each state.
- Pits, Landfills, and Oil Wasteland were assigned HG B as a conservative measure.
- Beaches were assigned HG A.

Soil erodibility, or K factor, is a representation of the likelihood of soil particles to be detached and flow with the runoff. The K factor is also a variable of interest for areas with high sediment yield. Values ranged from 0.02 to 0.49 with a lower value being less likely to detach. The K factors were averaged across HUC 12 watersheds (Figure 12). There were some areas in the soil data where the soil characteristics abruptly changed at county or state lines, and these inconsistencies could influence results. This can be seen as abrupt transitions in the soil hydraulic group map (Figure 11).

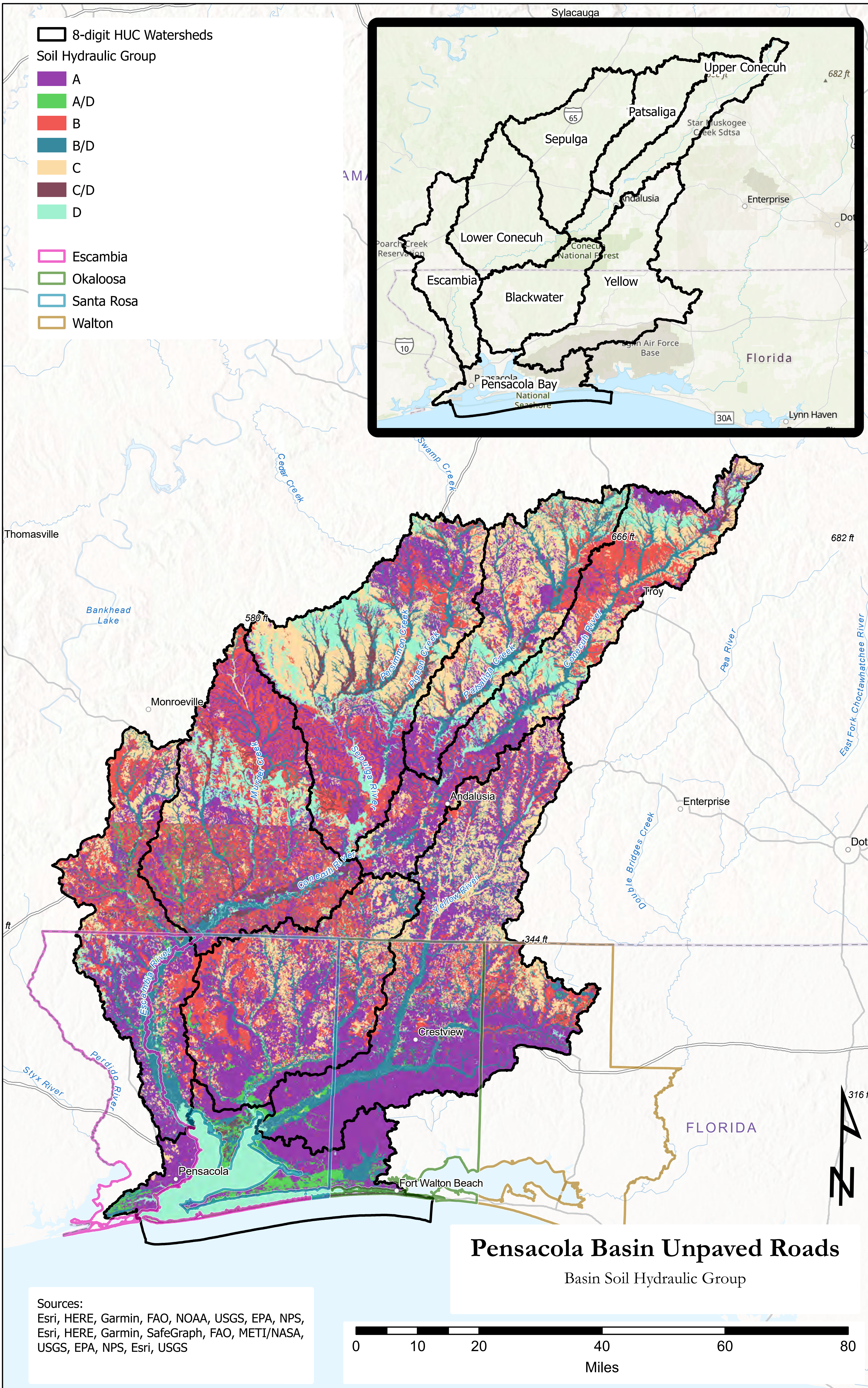

8-digit HUC Watersheds
Soil Hydraulic Group
A
A/D
B
B/D
C
C/D
D
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Yellow
Blackwater
Pensacola Bay
Florida
Enterprise
Andalusia
Sylacauga
Thomasville
Monroeville
Troy
Crestview
Pensacola
Fort Walton Beach
Dothan
FLORIDA
Bankhead Lake
Cedar Creek
Swamp Creek
Persimmon Creek
Pigeon Creek
Patsaliga Creek
Conecuh River
Sepulga River
Murder Creek
Yellow River
Escambia River
Perdido River
Styx River
Pea River
Double Bridges Creek
East Fork Choctawhatchee River
580 ft
666 ft
682 ft
344 ft
316 ft
Pensacola Basin Unpaved Roads
Basin Soil Hydraulic Group
Sources:
Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS,
Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA,
USGS, EPA, NPS, Esri, USGS
0
10
20
40
60
80
Miles

Figure 11

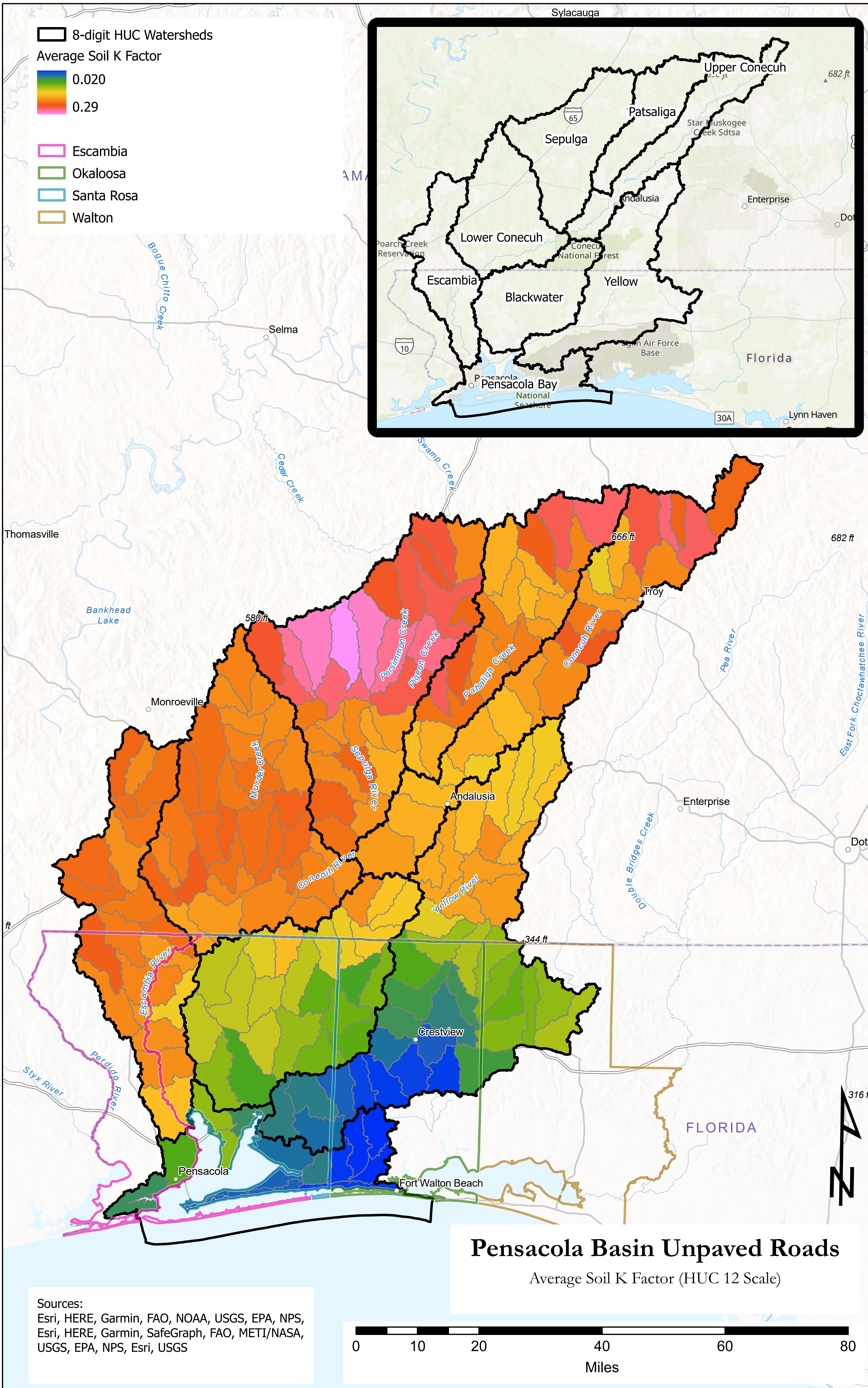
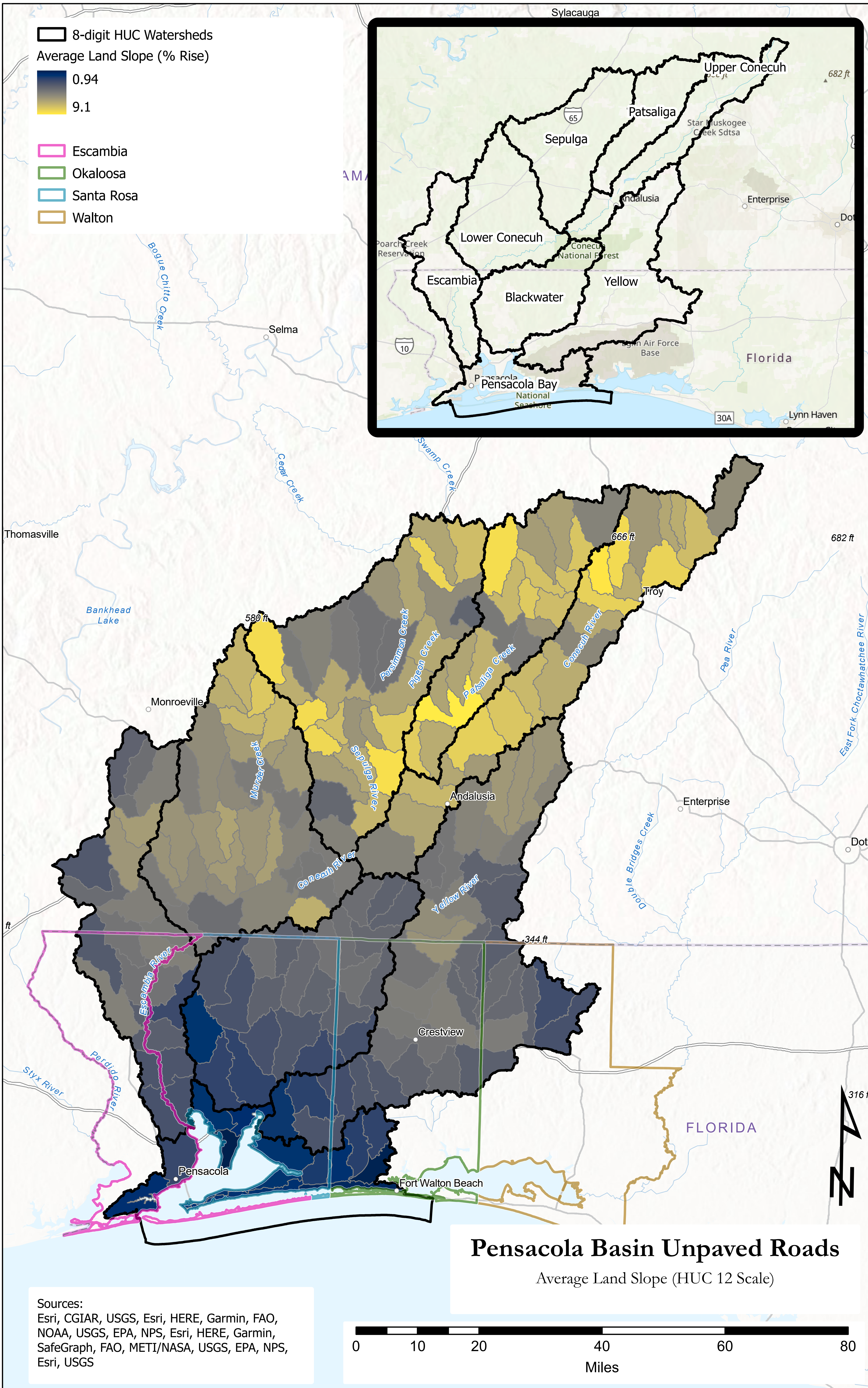

8-digit HUC Watersheds
Average Soil K Factor
0.020
0.29
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Florida
Sylacauga
Selma
Thomasville
Monroeville
Troy
Andalusia
Enterprise
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Persimmon Creek
Pigeon Creek
Patsaliga Creek
Conecuh River
Sepulga River
Murder Creek
Yellow River
Escambia River
Perdido River
Styx River
Bogue Chitto Creek
Cedar Creek
Swamp Creek
Bankhead Lake
Pea River
East Fork Choctawhatchee River
Double Bridges Creek
Pensacola Basin Unpaved Roads
Average Soil K Factor (HUC 12 Scale)
Sources:
Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS,
Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA,
USGS, EPA, NPS, Esri, USGS
0
10
20
40
60
80
Miles

Figure 12

ELEVATION DATA

There were multiple sources for elevation data due to the large area covered by the watershed. The United States Geological Survey one-third and one-ninth arcsecond LiDAR were obtained for the study watersheds. County and regional data (Florida Department of Emergency Management, Northwest Florida Water Management District) at a higher resolution were merged with other data, with the higher resolution data used wherever available. These data were used to help delineate catchments of previous data collection and for calculating average slope. Average land slope was derived from the elevation data and processed as a percent slope (ft/ft). It was then averaged across each HUC 12 watershed (Figure 13).



8-digit HUC Watersheds
Average Land Slope (% Rise)
0.94
9.1
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Florida
Enterprise
Andalusia
Sylacauga
Selma
Thomasville
Monroeville
Troy
Enterprise
Andalusia
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Pensacola Basin Unpaved Roads
Average Land Slope (HUC 12 Scale)
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
0
10
20
40
60
80
Miles
N

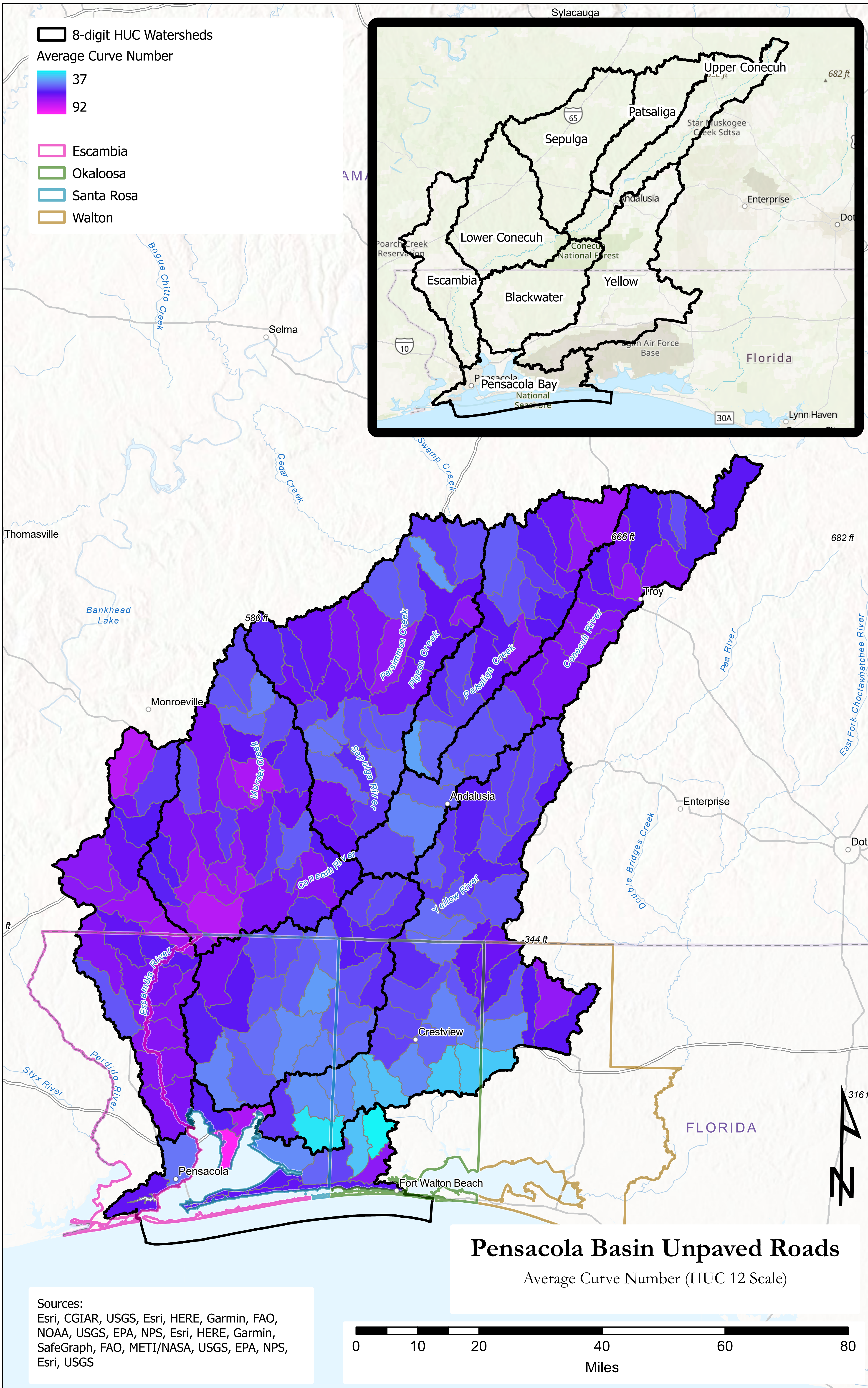
Figure 13

CURVE NUMBER

The curve numbers were calculated by intersecting Soil Hydraulic Group and Land Use. They were then classified via Table 3 to assign curve numbers. Initial values are based on the NRCS National Engineering Handbook part 630, chapter 9. Where there were combinations of hydraulic groups, the curve numbers were averaged. It was assumed all conditions were "Good;" combinations of items have averaged curve numbers (lot sizes); and the Unclassified category was an average of Open Space and Bare Soil.

Table 3: Curve Numbers Based on Land Use and Hydraulic Groups

Description	A	B	C	D	A/D	B/D	C/D
0: Unclassified	58	73.5	82.5	87	72.5	80.25	84.75
1: Water-Impervious	98	98	98	98	98	98	98
2: Open Space	39	61	74	80	59.5	70.5	77
3: Low Density (1-2 ac lots)	48.5	66.5	78	83	65.75	74.75	80.5
4: Medium Density (half-third ac lots)	55.5	71	80.5	85.5	70.5	78.25	83
5: High Density (quarter ac or less lots)	69	80	86.5	89.5	79.25	84.75	88
6: Bare Soil	77	86	91	94	85.5	90	92.5
7: Woods	30	55	70	77	53.5	66	73.5
8: Brush-Forbs-Grass	30	48	65	73	51.5	60.5	69
9: Meadow	30	58	71	78	54	68	74.5
10: Pasture	68	79	86	89	78.5	84	87.5
11: Row Crops (SR, Good)	67	78	85	89	78	83.5	87



Pensacola Basin Unpaved Roads

Average Curve Number (HUC 12 Scale)

Figure 14

PREDICTING BED LOAD FROM EXISTING DATA

Factors that were predicted to have the most impact on bed sediment load were analyzed for correlation; the results are in Table 4. As expected, large drainage areas were correlated with higher sediment loads. However, none of the other factors showed a significant correlation except for accumulated TSS load (SPARROW data). The factors that influence bed load in waterways is complex process but is reasonably well represented with accumulated TSS load (SPARROW data). Bed load was calculated based on this linear relationship assuming zero as the intercept point (Figure 15). Estimated bed load is mapped at the catchment scale in Figure 16.

Table 4: Correlation Table of Selected Factors across HUC 12 Watersheds

	Drainage Area (mi^2)	Average Curve Number	Average Soil K Factor	Average Land Slope (% rise)	Accumulated TSS Load (metric tons/yr)	Estimated Bed Sediment Load (tons/yr)
Drainage Area (mi^2)	1					
Average Curve Number	-0.02	1				
Average Soil K Factor	-0.46	0.14	1			
Average Land Slope (% rise)	0.37	-0.70	-0.40	1		
Accumulated TSS Load (metric tons/yr)	0.99	0	-0.45	0.38	1	
Estimated Bed Sediment Load (tons/yr)	0.83	0.04	-0.21	0.18	0.79	1

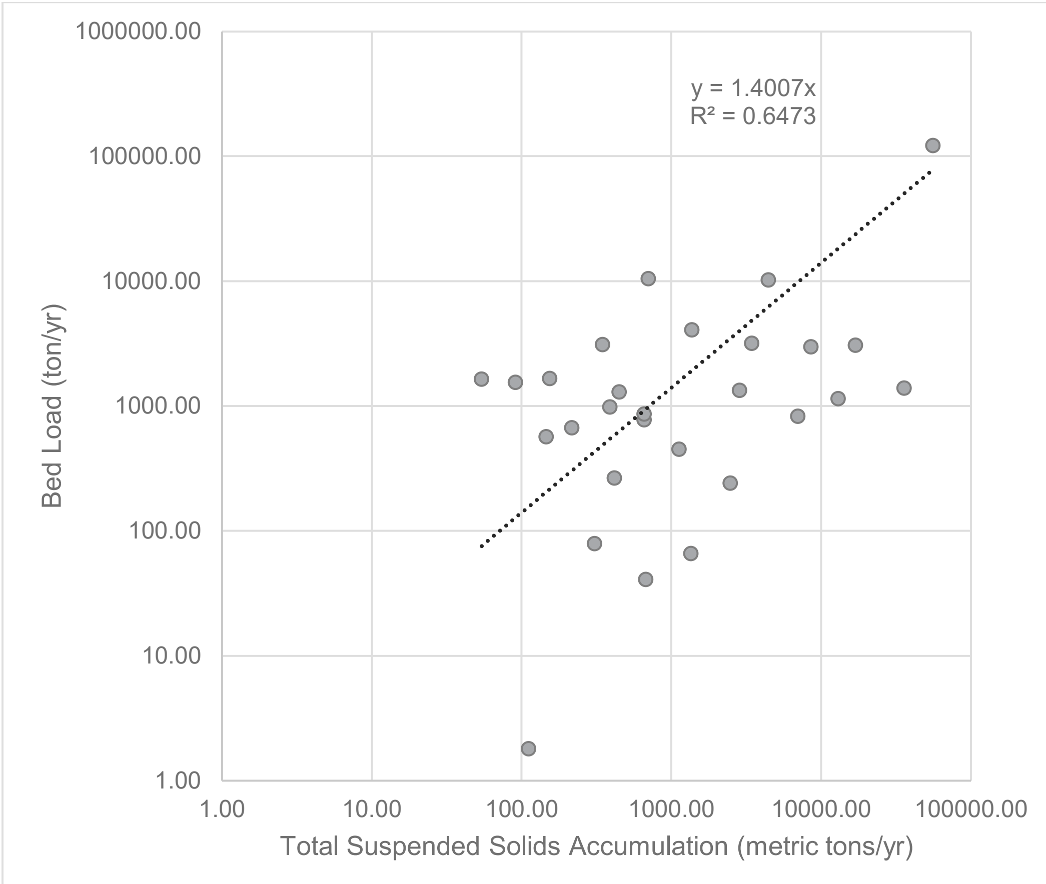


Figure 15: Total Suspended Solids Accumulation (SPARROW) Compared to Estimated Bed Load from Previous Studies (Cook Hydrogeology and GSA)

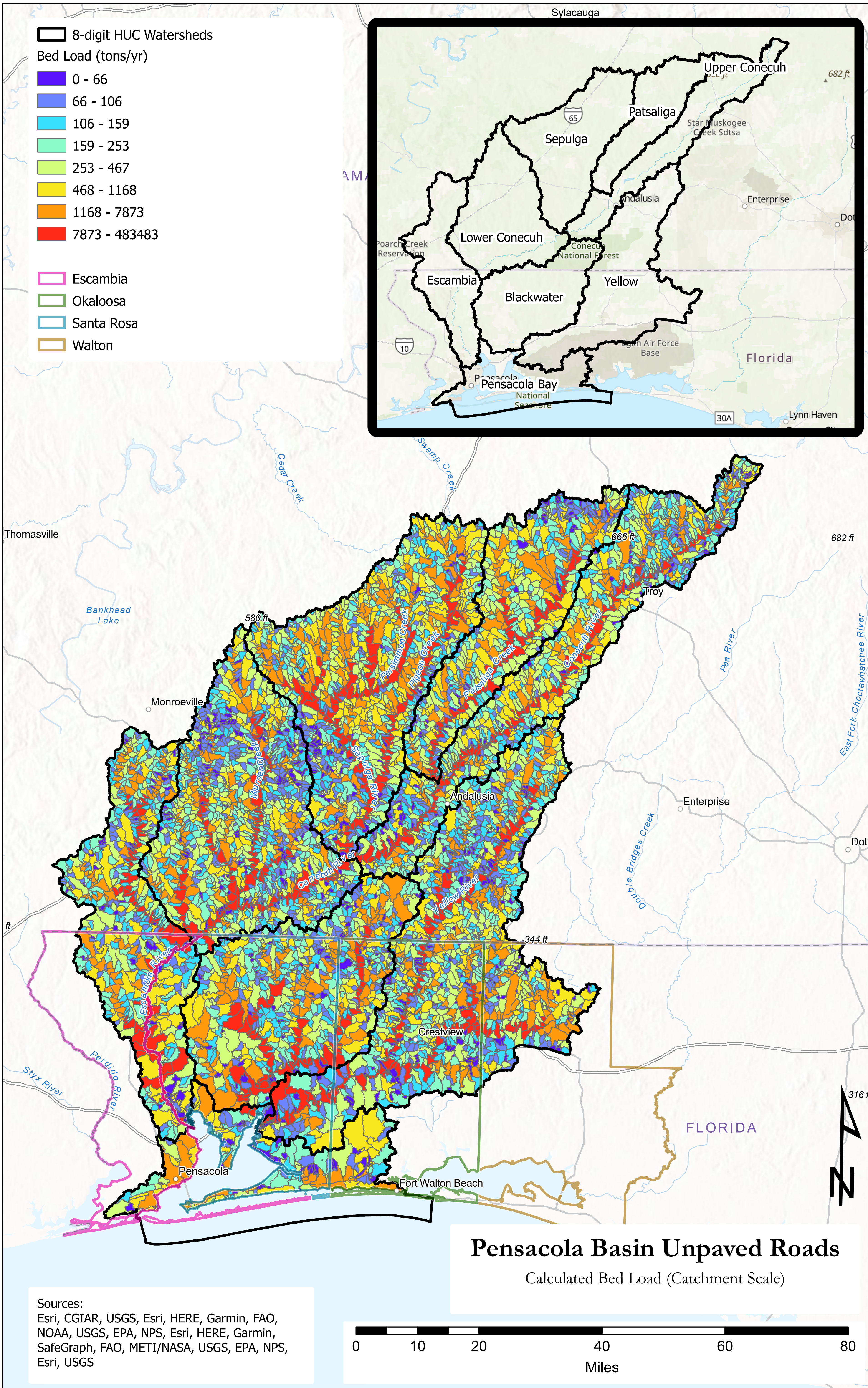

Pensacola Basin Unpaved Roads
Calculated Bed Load (Catchment Scale)
8-digit HUC Watersheds
Bed Load (tons/yr)
0 - 66
66 - 106
106 - 159
159 - 253
253 - 467
468 - 1168
1168 - 7873
7873 - 483483
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Sylacauga
Thomasville
Monroeville
Troy
Andalusia
Enterprise
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO,
NOAA, USGS, EPA, NPS, Esri, HERE, Garmin,
SafeGraph, FAO, METI/NASA, USGS, EPA, NPS,
Esri, USGS
0
10
20
40
60
80
Miles
N

Figure 16

SEDIMENT YIELD FROM UNPAVED ROAD-STREAM CROSSINGS

REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE) METHODOLOGY

There are approximately 551 unpaved crossings within the Pensacola Bay watershed in Florida, and 1,170 unpaved crossings within the Pensacola Bay watershed in Alabama (Figure 17). An unpaved road-stream crossing is defined from hillcrest to hillcrest, or the segment of roadway that drains to the crossing. The average sediment contribution from each road-stream crossing was estimated using RUSLE (Renard, 1997) and data collected as part of this study (summarized in previous deliverables). These data included roadway width, slope, slope length, and local, regional, and soil-related parameters.

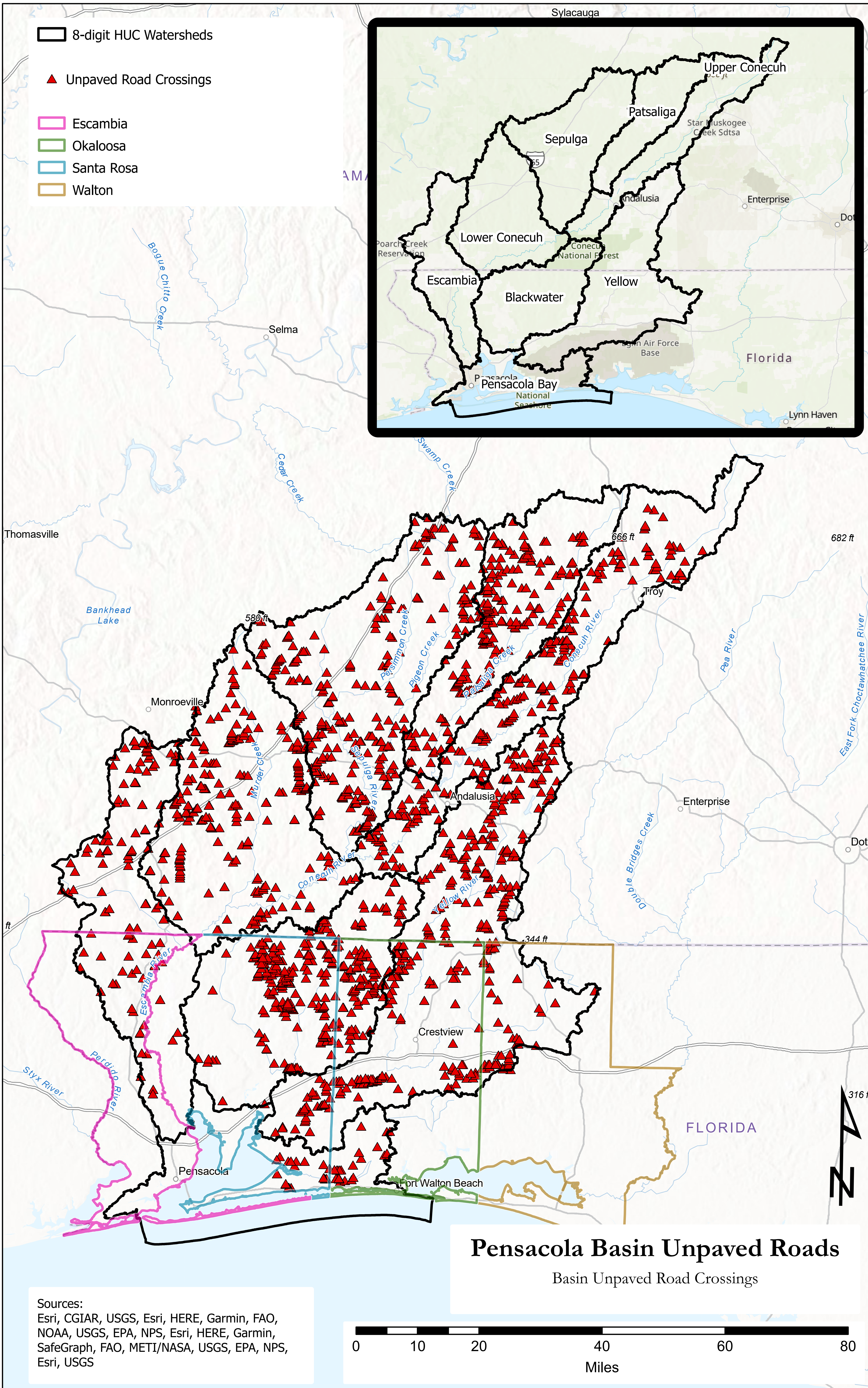
RUSLE, according to the USDA, predicts long-term, average-annual erosion by water for a broad range of farming, conservation, mining, construction, and forestry uses. An initial RUSLE calculation was performed by JMT (using existing GIS collected data and assumed values) on unpaved road-stream crossings within the Pensacola Bay Watershed to estimate the annual sediment load lost from each crossing and delivered to each corresponding stream. The equation used to compute soil loss, per the USDA Agricultural Handbook 537 (Wischmeier & Smith, 1978), is defined as: $A = RKLSCP$

Where

A = soil loss (tons per acre per year)
R = rainfall erosivity (hundreds of foot-ton-inches per acre per hour)
K = soil erodibility factor (ton-acre-hours per hundred foot-tons-per inch)
LS = slope-length and gradient factor
C = crop/vegetation and management factor
P = support practice factor

Note that parameters and results are in imperial units. By applying a few assumptions about soil type, management inputs, supporting practices, and base management, RUSLE can effectively estimate soil loss for unpaved road-stream crossings. While two of these variables remain constant within the study area (R and P), others (K, LS, and C) were assessed on a site-by-site basis and varied with roadway material, gradient, slope-length, and management factors measured by JMT.

McGehee et al. (2021) examined the R factor in RUSLE compared to benchmark studies and other estimates from erosivity. The Florida portion of the study area has an approximate R value of 650 hundreds of foot-ton-inches per acre per hour (11000 MJ-mm per ha-hr-yr).



8-digit HUC Watersheds
Unpaved Road Crossings
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Florida
Sylacauga
Selma
Thomasville
Monroeville
Andalusia
Enterprise
Troy
Dothan
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Bogue Chitto Creek
Cedar Creek
Swamp Creek
Bankhead Lake
Persimmon Creek
Pigeon Creek
Patsaliga Creek
Conecuh River
Pea River
East Fork Choctawhatchee River
Murder Creek
Sepulga River
Double Bridges Creek
Yellow River
Escambia River
Perdido River
Styx River
580 ft
666 ft
682 ft
344 ft
316 ft
Pensacola Basin Unpaved Roads
Basin Unpaved Road Crossings
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
0 10 20 40 60 80
Miles
N

Figure 17

The soil erodibility factor, or K factor, represents how susceptible soil is to detachment and transport as measured for a standard rainfall erosivity on unit plot conditions (USDA - Agricultural Research Service, 2004). Many of the roadways built across stream crossings are on sand and other soft alluvium. Because of the poor native soils, offsite materials are often imported to create a more stable road surface. For the initial RUSLE calculation at each crossing, a K factor of 0.1 was assumed. This is the approximate average of all soils within the Florida portion of the Pensacola Bay watershed.

As sites are field assessed, K factors will be assigned based on material and texture. The roadway surface types listed below are from the Sedimentation Risk Index (SRI) calculations with the additional categories of Sand and Milling/Impervious based on field observations. While many areas in the Pensacola Bay watershed have sand as the native soil, it should be noted it is counted as a separate classification since the sand and sand/clay mix have different K factors according to the NRCS rock free soil data and the Stewart et al. (1975) guidance. Since our focus is on constructed roads rather than a typical watershed analysis, the K factor needs to be adjusted for the addition of aggregate materials. If the road is assumed to be 60% aggregate/gravel, it would have a similar K factor to an impervious road after adjustment from the base sand/clay factor of 0.13 (Hu, et al., 2019). With the given data and assumptions made, the associated K factor for each type of soils in the study area are:

- Sand: 0.05
- Native Soil or Native w/ Sand/Clay mix: 0.13
- Native Soil w/ Aggregate (<60%) mix or Sand/Clay: 0.07
- Gravel/Aggregate or Aggregate (>60%) w/Sand/Clay mix: 0.01
- Milling/Impervious: 0.01

When more than one roadway material type is present on a single roadway approach, the K value will be calculated as a weighted average by length.

The "*LS*" factor is based on gradient and longitudinal length along the gradient (slope length). These values were measured along a roadway line in GIS, and an average slope was calculated for each approach from a slope raster. The slope raster was created from the best available LiDAR data, and resolution varied across the watershed. The calculated slope should be considered an approximate value.

Calculation of the *LS* factor has varied with studies, and four methods were compared.

a) The *LS* factors were obtained from a table in the USDA Agricultural Handbook No. 703 for constructed or disturbed soil with little to no cover, and by different equations (Hu, et al., 2019; Parsakhoo, Lotflain, Kavian, & Hosseini, 2014; Renard, Foster, Weesies, McCool, & Yoder, 1997). The table was limited to length of less than 1000 ft and 60% slope and slopes greater than 0.2%. For any length beyond 1000 ft, an equation was fit to the data and extrapolated out to the longest approach length. Slopes less than 0.2% were assumed to be the same as the 0.2% values. Linear interpolations were used to approximate values between listed slopes and length. The table was developed for use on uniforms slopes and may not be an accurate representation of our slopes, even though we are assuming a constant average slope across the approach.

b) Equation 1 (Parsakhoo, Lotflain, Kavian, & Hosseini, 2014) consistently calculated LS factors higher than the table method.

$$(1)\ LS = \sqrt{\frac{(0.065L) + (0.045S) + (0.0065S^2)}{22.13}} \qquad Where\ L = meters, S = slope\ in\ degrees$$

c) Equation 2 (Renard, Foster, Weesies, McCool, & Yoder, 1997), refined for sleeper slopes, also consistently calculated LS factors higher than the table method.

$$(2)\ LS = \left(\frac{\lambda}{72.6}\right)^m * S \qquad Where\ \lambda = horizontal\ length\ in\ feet, \theta = slope\ in\ degrees, s\ in\ percent\ rise$$

$$m = \frac{\beta}{1+\beta} \qquad \beta = \frac{sin\theta/0.0896}{3.0(sin\theta)^{0.8} + 0.56}$$

$$S = \begin{cases} 10.8sin\theta + 0.03 & for\ s < 9\% \\ 16.8sin\theta - 0.05 & for\ s \geq 9\% \\ 3.0(sin\theta)^{0.8} + 0.56 & for\ \lambda < 15 \end{cases}$$

d) Equation 3 (Hu, et al., 2019), further refined for steep slopes, was typically closer to the table method.

$$(3)\ LS = (\lambda/72.6)^m * S \qquad Where\ \lambda = horizontal\ length\ in\ feet, \theta = slope\ in\ degrees$$

$$m = \begin{cases} 0.5\ for\ \theta > 5 \\ 0.4\ for\ 3 < \theta \leq 5 \\ 0.3\ for\ 1 < \theta \leq 3 \\ 0.2\ for\ \theta \leq 1 \end{cases}$$

$$S = \begin{cases} 10.8sin\theta + 0.03 & for\ \theta \leq 5 \\ 16.8sin\theta - 0.05 & for\ 5 < \theta \leq 10 \\ 16.10sin\theta - 0.89 & for\ 10 < \theta \leq 25 \\ 23.82sin\theta - 2.64 & for\ \theta > 25 \end{cases}$$

By using these four methods, a range of values was calculated representing potential erosion within the study area. These were compared to field-verified data for calibration.

Only two management factors ("*C*") will be assigned to the assessed road-stream crossings. For the initial calculation, all roadway approaches were assigned a *C* of 0.45, which occurs when the roadway is bare soil.

After sites are field-assessed, roadway approaches with an aggregate top layer will be assigned a *C* of 0.37. These values for *C* were obtained from the ARS (2004) documentation.

The support practice factor ("*P*") does not apply to roadway projects (it is related to agricultural BMPs). Therefore, its value was set to "1" for each site.

After soil loss ("*A,"* in tons/acre/year) was calculated for each roadway approach at each site, it was multiplied by the area of each roadway approach to obtain the annual sediment load. For each roadway the width was assumed to be 20 feet wide for county-maintained roads (double lane), 15 feet wide for roads on Eglin AFB (lane and a half), and 12 feet wide in the Black River State Forest (single lane).

CALIBRATION OF SEDIMENT LOAD FROM ROAD-STREAM CROSSINGS

As it has been implemented in this study, the RUSLE model uses average approach slope, approach length, and assumed roadway characters to determine an annual estimate of sediment delivery to each road-stream crossing. To calibrate these estimates, the JMT team (JMT and Cook Hydrogeology) used field-measured bedload transport coupled with other data to calculate annual sediment delivery independently. This alternative method consisted of the following:

1. Measure in-stream velocity and bedload transport during rain events in study streams and ditches.
2. Develop a relation between flow velocity and bed sediment transport.
3. Use hourly rainfall data, Rational Method, and Manning's Equation to estimate flow velocities in each roadway approach ditch every hour over one year.
4. Use the velocity-transport relation to calculate transport every hour over one year.
5. Sum bed sediment transport loads

Field Measurements

In-stream velocity and bed sediment transport were measured by Cook Hydrogeology at ten locations (some were measured twice) during rain events in May 2022. Attempts were made to collect measurements through April 2023, though ditches were not flowing during all field visits. The time of concentration is very short on most roadway approaches, so ditches typically only flow during high intensity rain events, and they stop flowing shortly thereafter. A summary of all site visits associated with sediment sampling, including measurements and observations, can be found in Appendix A.

Relation between Flow Velocity and Bed Sediment Transport

Measured flow velocity and measured bed sediment transport were compared, and a power relation was fit to these data (Figure 18). Bed sediment transport increases exponentially with velocity within the conditions measured (velocities less than 3 ft/s). To compare the RUSLE results to field data, Cook Hydrogeology developed a curve from measured velocities and bed sediment loads. This relation was used for estimating bed sediment transport rate based on in-stream velocity.

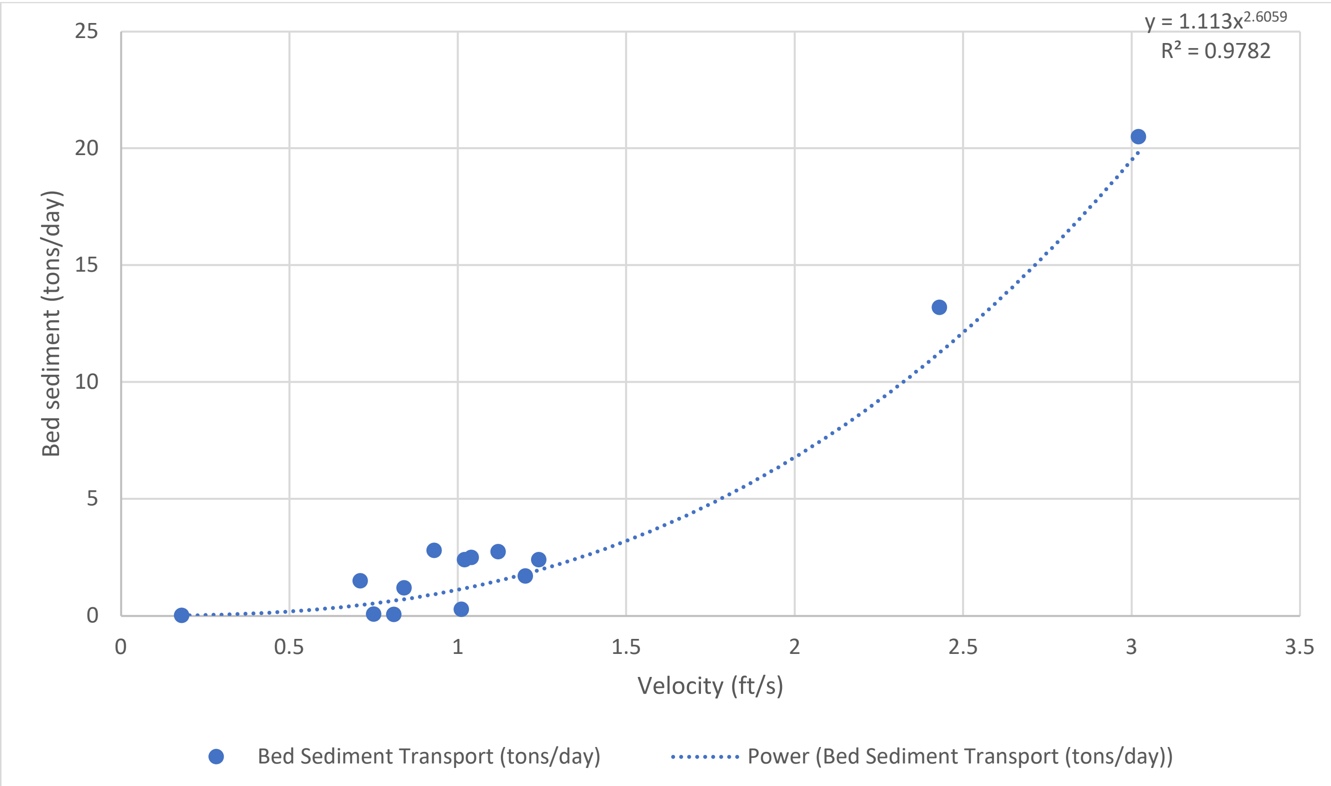


Figure 18. Bed Sediment Transport versus Flow Velocity in Pensacola Bay Streams and Ditches

Estimate of Hourly Flow Velocities in Each Roadway Approach Ditch over One Year

Hourly data were downloaded from NOAA for the Pensacola Regional Airport in 2013. These data were the most recently available data for the area in hourly increments. Hourly data were preferred since the rainfall intensity factor in the Rational Method is in inches/hour. Using a combination of the Rational Method and Manning's Equation, flow velocity in each roadway approach ditch was calculated hourly (see Appendix B for sample calculations on how the Rational Method and Manning's Equation were used).

For these calculations, the roadway was assumed to be crowned with a ditch on each side, so the drainage area was assumed to be half of the unpaved roadway approach. Each ditch was assumed to be rectangular with a 2-foot bottom. The ditch slope was assumed to be the same as the average road slope. A runoff coefficient of 0.1 was used for the Rational Method, which is in the lower range of the values used for unimproved areas. The Manning's n value for excavated clean earthen channels ranges from 0.016 as a minimum value for fresh channels to 0.025 as a maximum for weathered channels. A value of 0.022 was assumed for the calculations.

Estimate of Hourly Bed Sediment Transport

The empirical relation between flow velocity and bed sediment transport was used to estimate bed sediment transport at each hour where ditch flow velocity was estimated. These hourly estimates were then summed for each site.

Calibration Results

Across all Florida sites, the estimate of annual sediment delivery using the maximum of the four RUSLE methodologies averaged 50.7 tons/year (median 32.1 tons/year). This is equivalent to an average soil loss of 0.5 inches/year.

The calibrated estimate of erosion was about one tenth of the calculated RUSLE estimate on average (mean 6.40 tons/day, median 4.96 tons/day). It was approximately one third of the calculated RUSLE estimate using Equation 1. Multiple assumptions were made to develop estimates of annual erosion from instantaneous measurements of bed sediment transport in streams and ditches, and it is not known how reasonable they may be. The difference between the RUSLE estimates of sediment load and the calibration method was also found to be related to approach length (Figure 19). The greater the approach length, the greater the difference between the calibration and the RUSLE method.

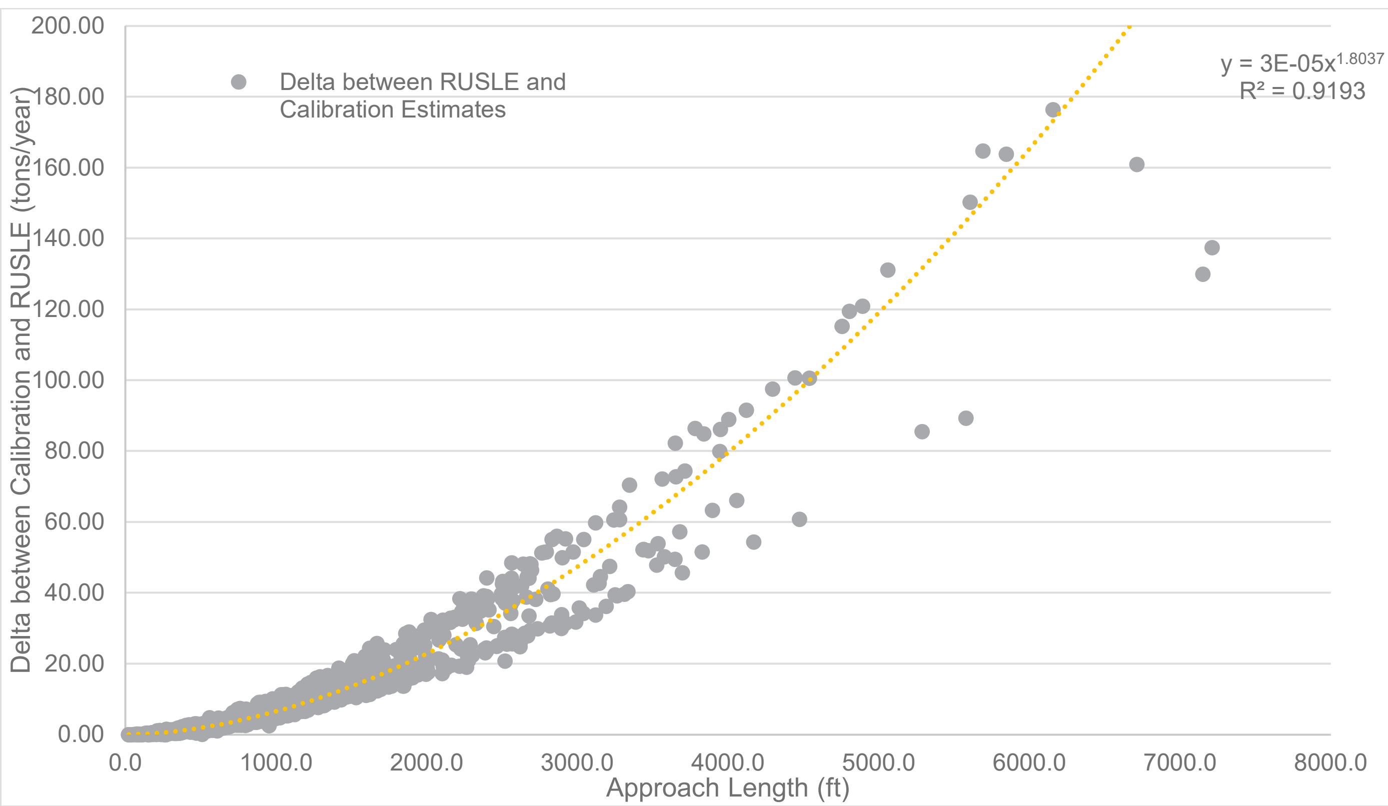


Figure 19. Difference in Sediment Load at Unpaved Road-stream Crossings Compared to Roadway Approach Length (Difference is RUSLE Method – Calibration Method)

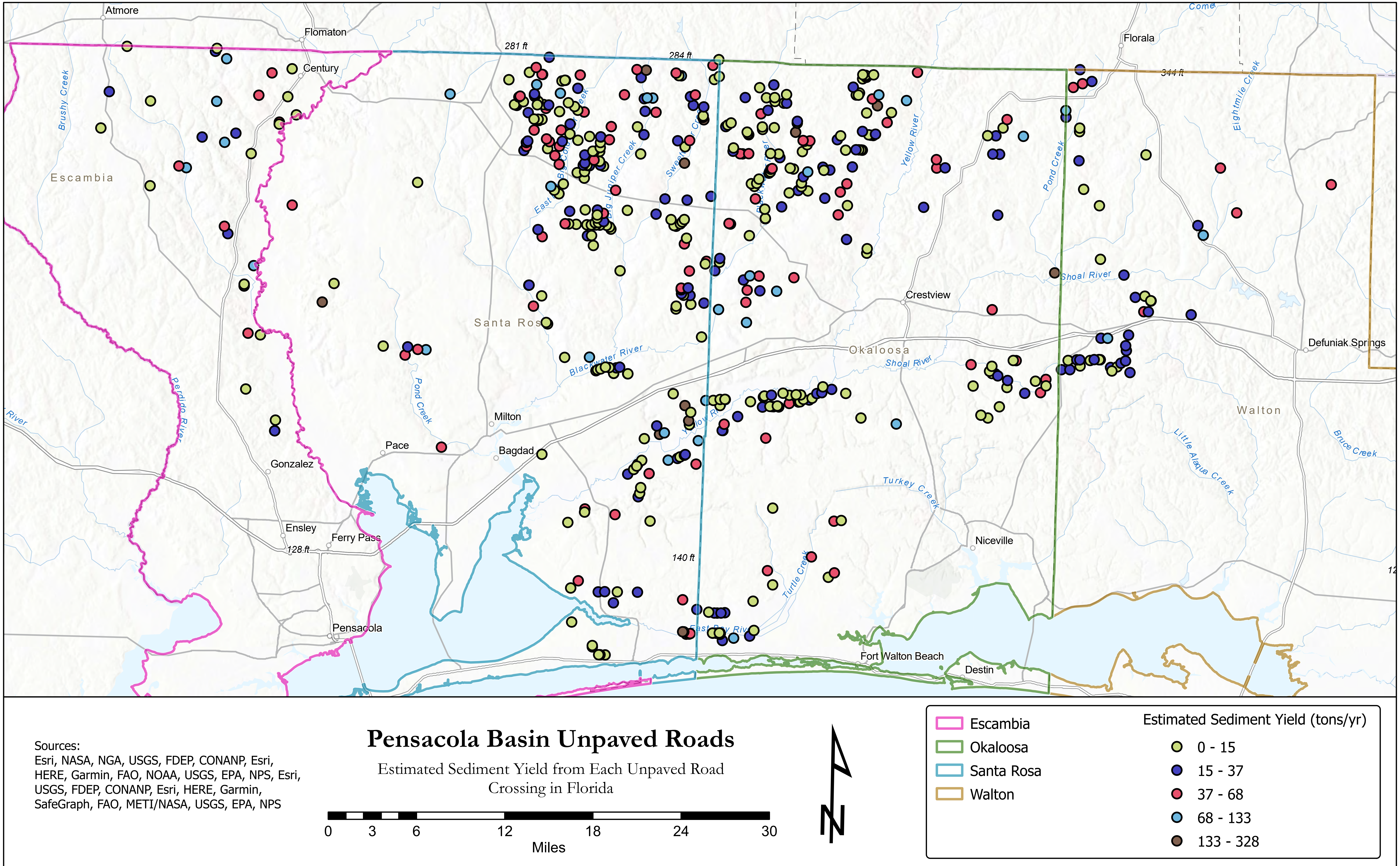
RUSLE Modification

The RUSLE methodology for estimating sediment load to road-stream crossings may be exaggerated. Of the four RUSLE methodologies, Equation 1 had sediment delivery estimates closest to the calibration method, so the results from Equation 1 will be used for the remainder of this study. The mean estimate of sediment load from unpaved road-stream crossings using Equation 1 is approximately 27.6 tons/day (median 15.9 tons/day). This is equivalent to an annual sediment loss of 0.15 inches from the road surfaces with a maximum calculated loss of approximately 0.5 inches. This seems reasonable based on observations of soil loss from crossings. The RUSLE methodology provides an estimate of annual soil loss that is based on physical factors, is easily calculated across all crossings, and can aid in the selection of road-stream crossings for improvements.

TOTAL SEDIMENT YIELD FROM UNPAVED ROAD-STREAM CROSSINGS

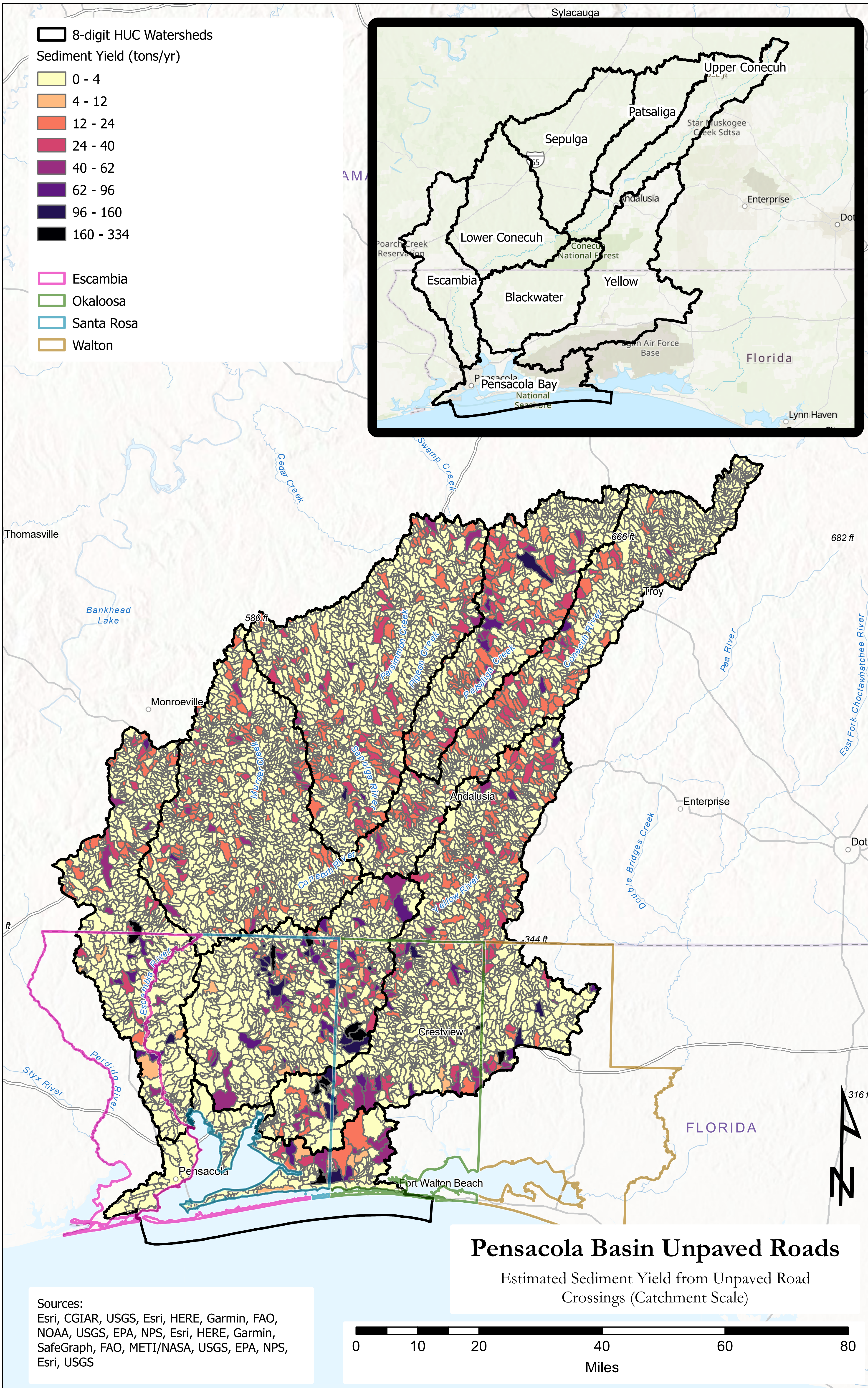
Annual soil loss from each unpaved road-stream crossing was calculated to be as high as 328 tons/year, but the median annual soil loss was 15.9 tons/year across all Florida crossings. The estimated soil loss from each unpaved road-stream crossing is mapped in Figure 20. The median soil loss of 15.9 tons/year was assumed for all 1,170 stream crossings in Alabama, since a more detailed analysis of Alabama road-stream crossings was not performed. The total sediment yield from unpaved road-stream crossings is summarized by catchment in Figure 21 and by HUC 12 in Figure 22 to provide a better illustration of where road-stream crossings are contributing the most sediment. These figures are a combination of the frequency of unpaved road-stream crossings and erosion severity because unpaved crossings are not evenly distributed. Sediment yield from unpaved road-stream crossings is also summarized by HUC 8 (Table 5).

The total sediment yield was calculated as 14,889 tons/year in Florida and 18,556 tons/year in Alabama; for a total of 33,445 tons/year across the whole watershed. Note that sediment yield from unpaved road-stream crossings is not explicitly included in catchment estimates of total suspended solids or bed load.



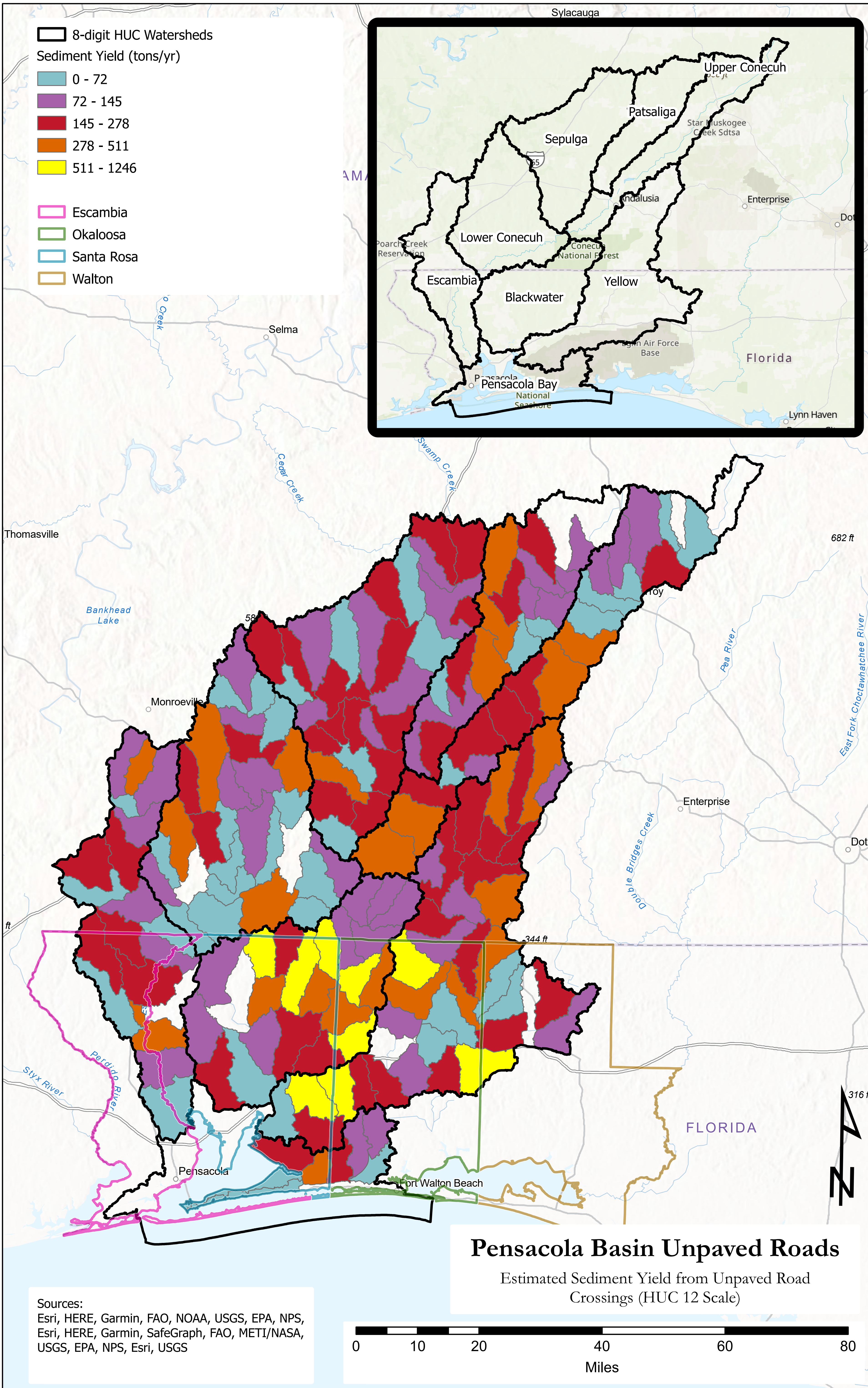
Atmore
Flomaton
Century
281 ft
284 ft
344 ft
Florala
Brushy Creek
Escambia
Santa Rosa
Okaloosa
Walton
Crestview
Defuniak Springs
Shoal River
Yellow River
Pond Creek
Eightmile Creek
Juniper Creek
Blackwater River
Milton
Pace
Bagdad
Gonzalez
Perdido River
Ensley
Ferry Pass
128 ft
140 ft
Pensacola
Turtle Creek
Turkey Creek
Niceville
Fort Walton Beach
Destin
Little Alaqua Creek
Bruce Creek
East Bay River
Pensacola Basin Unpaved Roads
Estimated Sediment Yield from Each Unpaved Road Crossing in Florida
0
3
6
12
18
24
30
Miles
N
Escambia
Okaloosa
Santa Rosa
Walton
Estimated Sediment Yield (tons/yr)
0 - 15
15 - 37
37 - 68
68 - 133
133 - 328
Sources:
Esri, NASA, NGA, USGS, FDEP, CONANP, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, USGS, FDEP, CONANP, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

Figure 20



8-digit HUC Watersheds
Sediment Yield (tons/yr)
0 - 4
4 - 12
12 - 24
24 - 40
40 - 62
62 - 96
96 - 160
160 - 334
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Enterprise
Florida
Lynn Haven
Sylacauga
Thomasville
Monroeville
Andalusia
Enterprise
Troy
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Pensacola Basin Unpaved Roads
Estimated Sediment Yield from Unpaved Road Crossings (Catchment Scale)
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
0 10 20 40 60 80
Miles
N

Figure 21



8-digit HUC Watersheds
Sediment Yield (tons/yr)
0 - 72
72 - 145
145 - 278
278 - 511
511 - 1246
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Florida
Sylacauga
Selma
Thomasville
Monroeville
Enterprise
Dotha
Pensacola
Fort Walton Beach
FLORIDA
Pea River
Double Bridges Creek
East Fork Choctawhatchee River
Cedar Creek
Swamp Creek
Styx River
Perdido River
Bankhead Lake
682 ft
344 ft
316 ft
N
Pensacola Basin Unpaved Roads
Estimated Sediment Yield from Unpaved Road Crossings (HUC 12 Scale)
Sources:
Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
0 10 20 40 60 80
Miles

Figure 22

SEDIMENT REDUCTION GOAL FOR PENSACOLA BAY

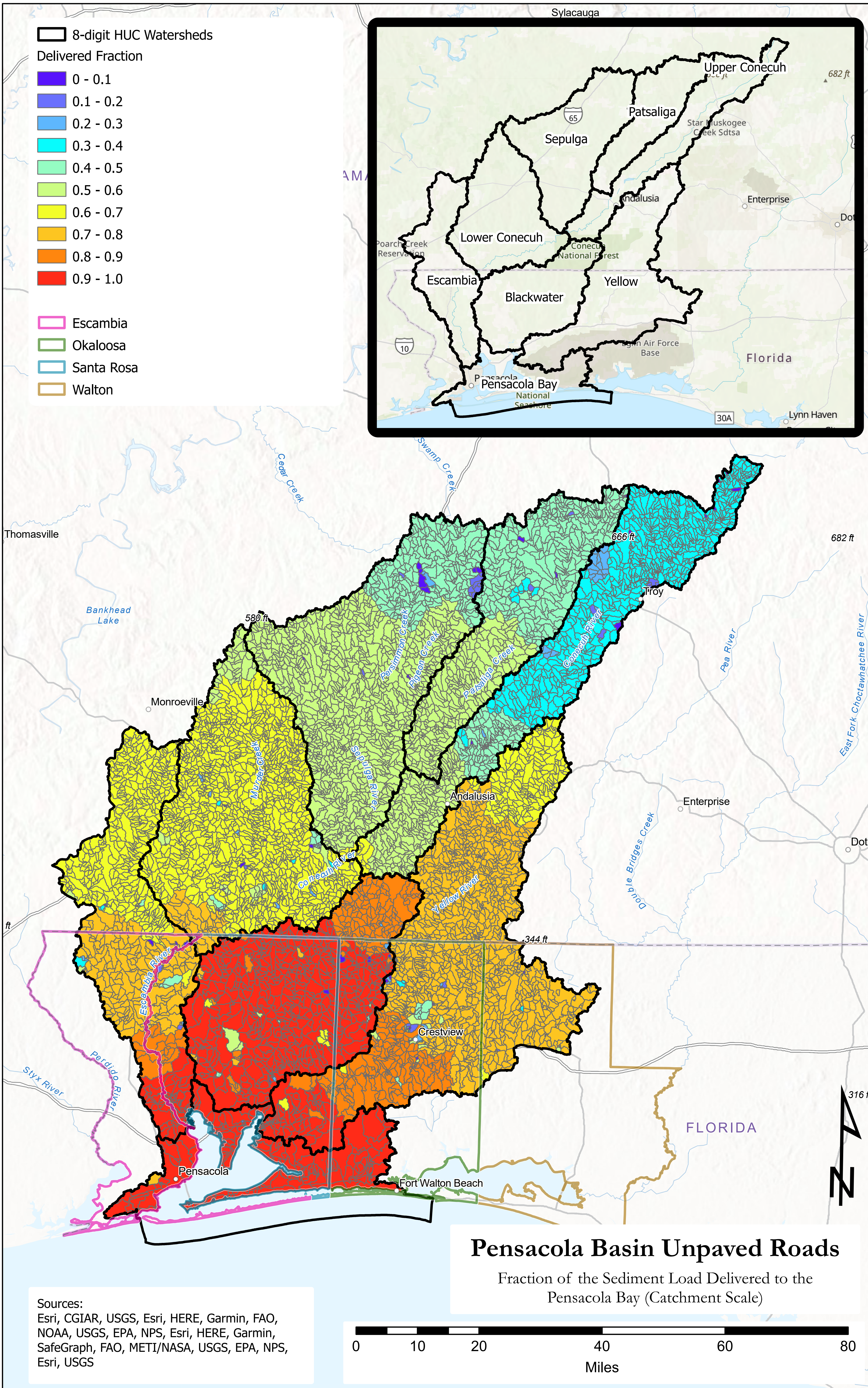
Sediment data from this study are summarized by HUC 8 watershed in Table 5. Results are summarized by incremental catchments and by accumulated load. The sum of incremental catchments includes sediment yield from various sources without considering sediment routing and storage, so any sediment source that is transported but is then stored in downstream reservoirs or within rivers is included. The accumulated loads are those at the outlet of each 8-digit HUC watershed, and these values consider sediment routing and storage. Note that the Escambia, Lower Conecuh, and Upper Conecuh 8-digit HUC basins receive runoff from upstream 8-digit HUCs, so the accumulated TSS and bedload estimates include estimates from the local watershed and from upstream. The 03140105 Pensacola Bay HUC only includes a sum of incremental loads within that HUC, because there is no defined Pensacola Bay outlet within SPARROW data.

Table 5: Summary of Sediment Data by HUC 8

HUC 8	03140103 Yellow	03140104 Blackwater	03140105 Pensacola Bay	03140301 Upper Conecuh	03140302 Patsaliga	03140303 Sepulga	03140304 Lower Conecuh	03140305 Escambia	Pensacola Bay Watershed
Sum of Incremental Catchments (not considering sediment routing and storage)									
Total Suspended Solids (TSS) (ton/yr)	146,486	83,454	40,984	106,209	67,473	176,669	129,283	73,157	823,715
TSS from Nonpoint Sources (ton/yr)	123,787	73,027	39,483	91,298	59,189	159,549	108,899	63,825	719,057
TSS from Channel Sources (ton/yr)	22,698	10,427	1,501	14,911	8,283	17,120	20,383	9,332	104,655
Total Sediment from Unpaved Road Crossings (ton/yr)	8,124	7,777	1,001	3,156	3,013	4,251	3,600	2,523	33,445
Accumulated Load at HUC Outlet (considering sediment routing and storage)									
Accumulated TSS at HUC Outlet (ton/yr)	108,754	76,613	40,984	124,271	59,050	149,035	343,742	301,801	528,153
Accumulated Bed Load at HUC Outlet (ton/yr)	138,193	97,352	52,079	157,911	75,035	189,378	436,792	383,498	671,121
Total Sediment Load at HUC Outlet (tons/yr)	246,947	173,966	93,063	282,182	134,085	338,413	780,534	685,299	1,199,274

In Table 5, TSS from Nonpoint Sources and TSS from Channel Sources sum to the Total Suspended Solids. Sediment from Unpaved Road Crossings is not explicitly included in these estimates. Sediment originating from nonpoint sources, such as overland runoff, represents 87% of TSS, sediment originating from streambank and streambed erosion represents 13%. Sediment yield from unpaved road-stream crossings is equivalent to 4% of the total TSS load in the watershed and is equivalent to 3% of all sediment (suspended load and estimated bed load) entering Pensacola Bay. When compared to total sediment, sediment yield from unpaved road-stream crossings is greatest in the Blackwater HUC 8 watershed, where it is equivalent to 9% of the total TSS load and 4% of all sediment. Note that estimated bed load is approximately 1.4 times the accumulated TSS load (see Figure 15). The greatest proportional sediment reduction from improving unpaved road-stream crossings could be realized in the Blackwater HUC 8 watershed (7,777 tons/year, or 4% of the total sediment load) and Yellow HUC 8 watershed (8,124 tons/year, or 3% of the total sediment load). These watersheds are located mostly within Santa Rosa and Okaloosa Counties, though portions of the watersheds are in Alabama. These two counties also represent the greatest proportion of the Pensacola Bay watershed within Florida. **Improving all unpaved road-stream crossings in Florida would reduce sediment yield by 14,889 tons/year.**

Because of in-stream, floodplain, and reservoir storage within each river system, not all sediment delivered to rivers is ultimately transported to the Pensacola Bay. Based on model data, a sediment load delivery fraction was mapped (Figure 23). This shows that some sediment originating from the upper watershed in Alabama (such as the headwaters of the Upper Conecuh watershed) is trapped in reservoirs and is not delivered to the Bay. Within Florida, Figure 23 also shows that 70-80% of sediment originating from northern Escambia and Walton Counties is ultimately delivered to the Bay, whereas more than 90% of sediment from much of Santa Rosa County and southern Escambia and Okaloosa Counties are delivered. This delivery fraction may be useful when prioritizing unpaved road-stream crossings for improvement.



8-digit HUC Watersheds
Delivered Fraction
0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
Escambia
Okaloosa
Santa Rosa
Walton
Upper Conecuh
Patsaliga
Sepulga
Lower Conecuh
Escambia
Blackwater
Yellow
Pensacola Bay
Thomasville
Monroeville
Troy
Andalusia
Enterprise
Crestview
Pensacola
Fort Walton Beach
FLORIDA
Pensacola Basin Unpaved Roads
Fraction of the Sediment Load Delivered to the Pensacola Bay (Catchment Scale)
Sources:
Esri, CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, USGS
0 10 20 40 60 80
Miles

Figure 23

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Appendix A - Sediment Sampling Site Visit Data

Field Visit Summary

JMT Label	Cook Label	Road Name	Stream Name	Date	Time (CST)	Sample Collected
Esc55	mrk 860	Killam Rd	Mill Creek Tributary	5/3/2022	1245	No
Esc56	mrk 861	Wawbeek Rd	Canoe Creek Tributary	5/3/2022	1310	No
Esc59	mrk 880	Crary Rd	Pritchell Mill Branch	5/3/2022	1440	No
N/A	mrk 916			5/4/2022	1010	No
N/A	mrk 902			5/4/2022	1235	No
N/A	mrk 902-1			5/4/2022	1235	Yes
sr-0223-r-001	mrk 1027	Fisher Old Mill Rd	Burnt Grocery Creek	5/5/2022	1410	No
sr-0223-r-002	mrk 1025	Garner Landing	Julian mill Creek	5/5/2022	1455	No
Esc56	mrk 861-2-1	Wawbeek Rd	Canoe Creek Tributary	5/23/2022	1420	No
Esc56	mrk 861-2-2	Wawbeek Rd	Canoe Creek Tributary	5/23/2022	1420	No
N/A	mrk 1001			5/23/2022	1215	No
SR121	mrk 1002	Mason West Rd	Pringle Branch	5/23/2022	1250	No
SR120	mrk 1003	Mason West Rd	Pringle Branch	5/23/2022	1310	Yes
Esc23	mrk 1075	Lamber Bridge Rd	Pine Barren Creek	5/23/2022	1610	No
Oka10	mrk 1084	West Kelly Rd	Big Horse Creek Tributary	5/24/2022	1330	No
ok-0526-r-009	mrk 1091	Olin Cotton Rd	Big Horse Creek	5/24/2022	815	No
ok-0526-r-001	mrk 1088	Yellow River Baptist Rd	Yellow River Tributary	5/24/2022	1300	No
ok-0526-r-001	mrk 1088-1-1	Yellow River Baptist Rd	Yellow River Tributary	5/24/2022	1300	Yes
ok-0526-r-001	mrk 1088-1-2	Yellow River Baptist Rd	Yellow River Tributary	5/24/2022	1300	Yes
Esc56	mrk 861-3	Wawbeek Rd	Canoe Creek Tributary	5/26/2022	1515	Yes
sr-0223-r-001	mrk 1027-2	Fisher Old Mill Rd	Burnt Grocery Creek	5/26/2022	1420	No
Oka10	mrk 1084-2-1	West Kelly Rd	Big Horse Creek Tributary	5/26/2022	900	Yes
Oka10	mrk 1084-2-2	West Kelly Rd	Big Horse Creek Tributary	5/26/2022	900	Yes
Oka10	mrk 1084-2-3	West Kelly Rd	Big Horse Creek Tributary	5/26/2022	900	Yes
Oka10	mrk 1084-2-4	West Kelly Rd	Big Horse Creek Tributary	5/26/2022	900	Yes
ok-0526-r-001	mrk 1088-2-1	Yellow River Baptist Rd	Yellow River Tributary	5/26/2022	1000	Yes
ok-0526-r-001	mrk 1088-2-2	Yellow River Baptist Rd	Yellow River Tributary	5/26/2022	1000	Yes
ok-0512-r-004	mrk 1095	Old River Rd	Bear Branch	5/26/2022	1230	No
ok-0512-r-004	mrk 1095-1-1	Old River Rd	Bear Branch	5/26/2022	1230	Yes
ok-0512-r-004	mrk 1095-1-2	Old River Rd	Bear Branch	5/26/2022	1230	No
ok-0512-r-004	mrk 1096	Old River Rd	Bear Branch	5/26/2022	1305	Yes
wa-0625-r-003	N/A	Varnum Rd	Fleming Creek	4/27/2023	N/A	No
ok-0528-r-001	N/A	Ludlum Rd	Horse Creek	4/27/2023	N/A	No
wa-0617-r-005	N/A	County Line Rd North	Pond Creek Tributary	4/27/2023	N/A	No
ok-0528-r-012	N/A	Millside Rd	Horsehead Creek	4/27/2023	N/A	No
ok-0429-r-012	N/A	Jack Rd	Murder Creek	4/27/2023	N/A	No

Field Visit Notes and Data

JMT Label	Cook Label	Date	Time (CST)	Road Name	Stream Name	Location	Notes	Turbidity (NTU)	Discharge (cfs)	Bed Sediment (tons/day)
Esc55	mrk 860	5/3/2022	1245	Killam Rd	Mill Creek Tributary	Unnamed tributary to Mill Creek at Killam Rd	Intermittent, no flow at time of visit. Severe bank erosion due to periodic high velocity flow on the downstream side of the crossing. Small amount of bed sediment on downstream side of crossing. No erosion on the upstream side. Rip rap armoring in channel near culvert openings. Three-five-foot culverts.			
Esc56	mrk 861	5/3/2022	1310	Wawbeek Rd	Canoe Creek Tributary	Unnamed tributary to Canoe Creek at Wawbeek Road	Small amount of flow. Alluvial fan on downstream side of bridge. Road covered with orange sand. Six wing ditches on north approach clogged with sediment. Extreme erosion. Floodplain on downstream side of road inundated with sediment to confluence with larger tributary. No sediment movement at time of visit.			
Esc59	mrk 880	5/3/2022	1440	Crary Rd	Pritchell Mill Branch	Pritchell Mill Creek at Crary Road	Deep, blackwater creek with no active sediment movement in channel. Road is paved on either side of creek but not hilltop to hilltop. Wing ditches at higher elevations with severe erosion and clogged with sediment. Sediment measurement can only be done in wing ditches during rain event.			
N/A	mrk 916	5/4/2022	1010			Elbing Street	Main N-S drainage ditch recently excavated south of Elbing St. Ditch 12 ft wide and 4 ft deep with moderate bank erosion and exposed roots with some bed sediment accumulation.			
N/A	mrk 902	5/4/2022	1235			Drainage ditch at intersection of Edgewood Dr. and Angie Dr. Ditch	Drainage ditch at intersection of Edgewood Dr. and Angie Dr. Ditch on southeast corner highly scoured, 10 ft wide and 8 ft deep. Exposed roots. Small amount of flow. Ditch flows into culvert and goes northwestward under Edgewood Dr. Moderate bed sediment at northwest end of culvert. Hard access but good measuring point			
N/A	mrk 902-1	5/4/2022	1235			Subdivision drainage divide at Codell St.	Hard access but good measuring point.		0.005	0.02
sr-0223-r-001	mrk 1027	5/5/2022	1410	Fisher Old Mill Rd	Burnt Grocery Creek	Burnt Grocery Creek at Fisher Old Mill Road	Unpaved road with 2 wing ditches on both sides of the road, east of the creek and 1 wing ditch on north side of road and west side of creek. Moderate active sediment transport. Measure sediment in wing ditches during rain events and in the stream upstream from bridge.			
sr-0223-r-002	mrk 1025	5/5/2022	1455	Garner Landing	Julian mill Creek	Julian Mill Creek at Garner Landing Road	Road covered with imported orange sand. Six active wing ditches on the north side of the creek and 2 wing ditches on the south side of the creek. Stream is slightly tannic with white sand bed. No active sediment movement in the creek on the upstream side of the bridge.			
Esc56	mrk 861-2-1	5/23/2022	1420	Wawbeek Rd	Canoe Creek Tributary	Unnamed tributary to Canoe Creek at Wawbeek Road	Increased flow after moderate rain event. Measured water quality, flow, and bed sediment immediately upstream from confluence. Combined discharge and sediment from two channels.	14	0.79	2.74
Esc56	mrk 861-2-2	5/23/2022	1420	Wawbeek Rd	Canoe Creek Tributary	Tributary upstream from Wawbeek Rd	Tributary upstream from Wawbeek Rd flows through a forested wetland with minimal observed sediment in channels. Not measurable.	2		
N/A	mrk 1001	5/23/2022	1215			Mason West Road unpaved road drainage	Large amount of sediment in ditch. Measure in ditch during rain events.			
SR121	mrk 1002	5/23/2022	1250	Mason West Rd	Pringle Branch	Pringle Branch Tributary at Mason West Road	Road serves as a dam for large impoundment on west side of road. Two wing ditches on east side of road drain into creek on the downstream side. Sediment measured in ditches or downstream in the creek.			
SR120	mrk 1003	5/23/2022	1310	Mason West Rd	Pringle Branch	Pringle Branch Tributary at Mason West Road	Floodplain upstream from road covered with orange sand. Bed sediment measured in creek, downstream from sediment inputs. No observed sediment upstream from bridge.	14	0.54	0.06
Esc23	mrk 1075	5/23/2022	1610	Lamber Bridge Rd	Pine Barren Creek	Pine Barren Creek at Lambert Bridge Rd	Pine Barren Creek is a deep, blackwater stream at this crossing with some gravel on the bed. There is an old longitudinal bar on the downstream side of the bridge. Lambert Bridge Rd is paved with concrete flumes on the east side of the creek. West side is unpaved with 9 wing ditches with severe erosion and sediment transport. Sediment measurement can only be done in wing ditches during rain event.			
Oka10	mrk 1084	5/24/2022	1330	West Kelly Rd	Big Horse Creek Tributary	Big Horse Creek at West Kelly Road	Site is at intersection of West Kelly Road and Rock Hill Road. Dry Ford Branch is a large, deep-water creek at this location so sediment must be measured in road drainage ditches. Sediment from West Kelly and Rock Hill Roads enters creek from wing ditches on the west side of creek and north and south sides of West Kelly Road, and on the east side of creek from one wing ditch on west side of Rock Hill Road and ditches on the east side of Rock Hill Road and north and south sides of West Kelly Road, which combine and flow through a 1 ft culvert to the creek. No sediment movement on 5/24/22.			

JMT Label	Cook Label	Date	Time (CST)	Road Name	Stream Name	Location	Notes	Turbidity (NTU)	Discharge (cfs)	Bed Sediment (tons/day)
ok-0526-r-009	mrk 1091	5/24/2022	815	Olin Cotton Rd	Big Horse Creek	Big Horse Creek Tributary to Dry Ford Branch at Olin Cotton Road.	Impoundment on southwest side of road. Northwest road approach is flat with no erosion. Southeast road approach has eroding ditches. Western ditch currently drains into pond at the spillway. Eastern ditch drained by wing ditch into forested area and eventually into the creek. Creek channel is scoured as expected below the dam, with only residual bed sediment. Road surface covered with crushed Paleozoic limestone, which limits road surface erosion. Sediment can be measured in wing ditch during rain events.			
ok-0526-r-001	mrk 1088	5/24/2022	1300	Yellow River Baptist Rd	Yellow River Tributary	Unnamed tributary to Yellow River at Yellow River Baptist Church Road	Four wing ditches on south side of stream and 2 wing ditches on the north side of the stream. Active road and ditch erosion and sediment transport to the stream via wing ditches. Bed sediment measurements upstream (30.96182 86.57173) and downstream (30.96069 86.57108) from the bridge.			
ok-0526-r-001	mrk 1088-1-1	5/24/2022	1300	Yellow River Baptist Rd	Yellow River Tributary	Upstream from the bridge	Four wing ditches on south side of stream and 2 wing ditches on the north side of the stream. Active road and ditch erosion and sediment transport to the stream via wing ditches.	6	2.3	0.08
ok-0526-r-001	mrk 1088-1-2	5/24/2022	1300	Yellow River Baptist Rd	Yellow River Tributary	Downstream from the bridge	Four wing ditches on south side of stream and 2 wing ditches on the north side of the stream. Active road and ditch erosion and sediment transport to the stream via wing ditches.	8	2.3	1.2
Esc56	mrk 861-3	5/26/2022	1515	Wawbeek Rd	Canoe Creek Tributary	Unnamed tributary to Canoe Creek at Wawbeek Road	Canoe Creek out of banks at monitoring site. Only one discharge channel flowing. Second channel is flooded. Visit was after heavy rain that stopped at about 1400 but wing ditches were not flowing	16	2.04	2.4
sr-0223-r-001	mrk 1027-2	5/26/2022	1420	Fisher Old Mill Rd	Burnt Grocery Creek	Burnt Grocery Creek at Fisher Old Mill Road	Unpaved road with 2 wing ditches on both sides of the road, east of the creek and 1 wing ditch on north side of road and west side of creek. Moderate active sediment transport. Measure sediment in wing ditches during rain events and in the stream upstream from bridge.			
Oka10	mrk 1084-2-1	5/26/2022	900	West Kelly Rd	Big Horse Creek Tributary	Big Horse Creek at West Kelly Road, North ditch discharge and bed sediment measurement	Moderate rain. Measured sediment in wing ditches on West Kelly Road on west side of Dry Ford Branch.	>1000	0.04	1.5
Oka10	mrk 1084-2-2	5/26/2022	900	West Kelly Rd	Big Horse Creek Tributary	Big Horse Creek at West Kelly Road, South ditch discharge and bed sediment measurement	Moderate rain. Measured sediment in wing ditches on West Kelly Road on west side of Dry Ford Branch.	>1000	0.12	1.7
Oka10	mrk 1084-2-3	5/26/2022	900	West Kelly Rd	Big Horse Creek Tributary	Big Horse Creek at West Kelly Road, Measurement of combined sediment from east side of Rock Hill Road and north side of West Kelly Road	Moderate rain. Measured sediment in wing ditches on West Kelly Road on west side of Dry Ford Branch.	>1000	0.25	2.4
Oka10	mrk 1084-2-4	5/26/2022	900	West Kelly Rd	Big Horse Creek Tributary	Big Horse Creek at West Kelly Road, West side of Rock Hill Road sediment measurement	Moderate rain. Measured sediment in wing ditches on West Kelly Road on west side of Dry Ford Branch.	>1000	0.21	2.5
ok-0526-r-001	mrk 1088-2-1	5/26/2022	1000	Yellow River Baptist Rd	Yellow River Tributary	Upstream from the bridge	Moderate to heavy rain	31	7.2	0.28
ok-0526-r-001	mrk 1088-2-2	5/26/2022	1000	Yellow River Baptist Rd	Yellow River Tributary	Downstream from the bridge	Moderate to heavy rain	74	7.1	2.8
ok-0512-r-004	mrk 1095	5/26/2022	1230	Old River Rd	Bear Branch	Bear Branch at Old River Road and Shockley Spring Road	Torrential rain. North approach of Old River Road is paved with no erosion or sediment transport. South approach of Old River Road has road surface covered with Tertiary limestone and is a long, steep slope with ditches on both sides with no wing ditches.			
ok-0512-r-004	mrk 1095-1-1	5/26/2022	1230	Old River Rd	Bear Branch	West ditch discharge and bed sediment measurement	Torrential rain. North approach of Old River Road is paved with no erosion or sediment transport. South approach of Old River Road has road surface covered with Tertiary limestone and is a long, steep slope with ditches on both sides with no wing ditches.	>1000	4.8	13.2
ok-0512-r-004	mrk 1095-1-2	5/26/2022	1230	Old River Rd	Bear Branch	East ditch filled with limestone, could not measure sediment	Torrential rain. North approach of Old River Road is paved with no erosion or sediment transport. South approach of Old River Road has road surface covered with Tertiary limestone and is a long, steep slope with ditches on both sides with no wing ditches.	>1000		

JMT Label	Cook Label	Date	Time (CST)	Road Name	Stream Name	Location	Notes	Turbidity (NTU)	Discharge (cfs)	Bed Sediment (tons/day)
ok-0512-r-004	mrk 1096	5/26/2022	1305	Old River Rd	Bear Branch	Drainage ditch on south side of Lee Cook Road at intersection with Old River Road	Torrential rain. Ditch is on long, steep slope with no wing ditches. West ditch discharge and bed sediment measurement	>1000	2.4	20.5
wa-0625-r-003	N/A	4/27/2023		Varnum Rd	Fleming Creek	Varnum Road crossing of Fleming Creek	The road was covered with imported red clayey sand, ditches were highly scoured. Creek water was highly turbid up and downstream but water was dark grayish brown, indicating that there is little impact from ditches.			
ok-0528-r-001	N/A	4/27/2023		Ludlum Rd	Horse Creek	Tributary to Horsehead Creek at Ludlum Road).	Entire road has been recently paved. Turbid plume was observed coming from upstream not related to road erosion. Ditches on south approach carrying Tertiary Limestone, which covered road prior to paving.			
wa-0617-r-005	N/A	4/27/2023		County Line Rd North	Pond Creek Tributary	Tributary to Pond Creek crossing of County Line Road near Svea	Hard, smooth limestone road surface with minor ditch scour. I walked downstream and observed no sediment in stream. Stream flows through forest upstream and downstream.			
ok-0528-r-004	N/A	4/27/2023		Millside Rd	Horsehead Creek	Horsehead Creek crossing of Millside Road	Road covered with imported red clayey sand. Broad ditches filled with sand moving to creek. Road surface highly eroded. One of the worst sites that I have seen.			
ok-0429-r-012	N/A	4/27/2023		Jack Rd	Murder Creek	Tributary to Murder Creek at Jack Road	Stream crossing is a concrete ford. Large lake upstream (Road is on the dam). Stream flows through dense forest downstream. Road surface is hard, smooth limestone. Riprap installed along downstream ditch on both sides with no observed erosion or sediment.			

Appendix B - Calibration Calculations

Project Pensacola Unpaved Roads

Subject Roadway Approach Sediment Load Calibration

Job No. 21-02307-001

Sheet No. 1 of 1

Computed By MWS Date 27 Apr 2023 Checked By SC Date 5 Jun 2023

Rational Method

$Q_p = C\,i\,A_d$

A_d: Drainage Area, ½ of road approach

$$A_d = \frac{L_R W_R}{43560} \cdot 0.5$$

Mannings Equation

$$Q = \frac{1.49}{n} A_s R^{2/3} \sqrt{S}$$

A_s: Cross sectional area, assume rectangle width × depth

$A_s = W_c D_c$

$$R = \frac{A_s}{2D_c + W_c}$$

$$\alpha = \frac{1.49}{n}$$

$$C\,i\,A_d = \alpha A_s R^{2/3} \sqrt{S}$$

Solve for D_c

$$\frac{C\,i\,A_d}{\alpha \sqrt{S}} = W_c D_c \left(\frac{W_c D_c}{2D_c + W_c} \right)^{2/3}$$

assume $W_c = 2$

$$\frac{C\,i\,A_d}{\alpha \sqrt{S}} = \frac{(2D_c)^{5/3}}{(2D_c + 2)^{2/3}}$$

simplified

$$\frac{C\,i\,A_d}{\alpha \sqrt{S}} = X \qquad \frac{(2D_c)^{5/3}}{(2D_c + 2)^{2/3}} = \Phi$$

Solve for Φ by changing D_c and plotting the results

$$\Phi = 1.8195 D_c^{1.6477}$$

$$X = \Phi \Rightarrow X = 1.8195 D_c^{1.6477} \Rightarrow D_c = \sqrt[1.6477]{\frac{X}{1.8195}}$$

$$D_c = \sqrt[1.6477]{\frac{C\,i\,A_d}{\alpha \sqrt{S}\ 1.8195}}$$

Channel velocity

$$v = \frac{Q}{A_s} \Rightarrow \frac{C\,i\,A_d}{2D_c}$$

Where:

D_c = Channel depth (ft)

$C = 0.1$ runoff coefficient

i = Rain fall intensity (in/hr)

A_d = Drainage area (ac)

S = slope (ft/ft)

$\alpha = \frac{1.49}{n}$ $n = 0.022$ Mannings coefficient