# City of Saint Charles

# Comprehensive Stormwater Masterplan

# Final Study

Revision 3.0

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**Prepared by**

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# SECTION 1 EXCUTIVE SUMMARY

## 1.1 INTRODUCTION

Communities need Stormwater Planning for a variety of reasons, including development planning, flood analysis and mitigation, and capital programming. Each community is unique, so an effective Stormwater Master Plan considers the needs and resources of that community and addresses stormwater issues based on level of risk that is acceptable to them.

*Street Flooding at the Corner of Kent and Elm on May 20, 2013*

The purpose of the study is to recommend flood mitigation measures, prioritize stream restoration and determine whether there are steps the City can take to improve water quality in streams.

### 1.1.1 FLOOD MITIGATION

The Flood Mitigation effort began with a review of flood complaints and a field inventory of structures known to flood. XP-SWMM was used to model both the open channel and enclosed systems in order to identify the root causes of flooding and to model alternatives to mitigate it. A risk-based analysis was used to determine the level of improvement that is consistent with the City's goals and budget. The proposed measures were prioritized based on cost benefit system developed in conjunction with City staff. Overall eighteen flood damage reduction projects were recommended for inclusion in the City's Capital Improvement Program

### 1.1.2 STREAM RESTORATION

M3 inspected and evaluated approximately 20 miles of stream using Rapid Geomorphic Assessment techniques. M3 prepared a Stability Index for the stream reaches, and a cost per stream-foot to address the degradation. The proposed improvements were prioritized for use in the City Capital Improvement Program. Overall nine stream restoration projects were recommended for inclusion in the Cities Capital Improvement Program. The projects provide $8.1M in benefits to the City.

*Severe bend scour on Cole Creek*

### 1.1.3 WATER QUALITY

M3 developed a GIS Tool that processes the soils, slope, land use, ground coverage and other pertinent environmental information for each Watershed to determine locations that may contribute to water quality degradation in the streams. M3 characterized each watershed using the GIS Tool and highlighted “hot spots”, or locations that exhibit a high potential for contributing to water quality degradation. Recommendations for improving the Cities water quality program were developed based on the analysis. Recommendations include enhancing the Cities Green Point System, Incorporating water quality improvements, where feasible, into flood mitigation projects, and delaying stream water quality monitoring until water quality regulations have stabilized.

## 1.2 MODEL DEVELOPMENT

The hydraulic model incorporates all sewers contained within the Cities’ GIS Database. Additionally, the model extents are developed such that significant “problem areas” due to overland flow are adequately represented. All the City structures and node points (including manholes and inlets) are included within the model extents and the model represents the connectivity of the City’s facility maps. The U.S. Army Corps of Engineers HEC-RAS model for Dardenne Creek was utilized to import the natural channel geometry Cole Creek, Sandfort and Boschert Creek. For remaining watersheds, an existing HEC-RAS model was not available, so the geometry was created developed using Geo-RAS.

Many of the inlets within the system have restricted openings due to street debris, pavement re-surfacing, and collapsed or otherwise impaired structures among other reasons. If complaints indicated inlet restriction, the model was adjusted in these areas to restrict inlet capacity using XP-SWMM’s inlet restriction capabilities. When flow isn’t allowed to enter the collection system, a mechanism for storing or conveying was added.

For the Study, seven frequency storms were used to analyze the watershed. The events used were the 2, 5, 10, 15, 25, 50, and 100-year frequency. Flowmeter data is not available for the project; therefore, calibration consisted of matching flows provided in the Corps of Engineers HEC-HMS and HEC-RAS Model and matching flood complaint records. The model was calibrated to match peak flow rates within +/- 10% of the modeled flows.

A detailed description of the model setup is provided in Section 2 of this report.

## 1.3 RAPID GEOMORPHIC ASSESSMENT

To meet the project goals, a rapid geomorphic assessment technique was utilized to incorporate a quantitative analysis of geomorphic indicators of the four primary processes by which streams change to reach dynamic equilibrium: aggredation, degredation, widening, and planform adjustment. Approximately 33.6 miles of stream within the city were evaluated using the RGA technique described in Section 3.

### 1.3.1 Blanchette Creek Watershed

7 reaches were evaluated within the Blanchette Creek Watershed. 57% of the reaches have stability index scores within the “Transitional” range, 29% have stability index scores within the “In Regime” range, and the remaining 14% have stability index scores within the “In Adjustment” range. Reach #1 at the confluence with the Missouri River has the highest stability index of 0.49 and is reflective of active widening and aggredation processes. The predominate feature of Reach #2 is a high but stable headcut into bedrock that control the grade of the channel upstream. Reach #4 and all upstream reaches are in the “Transitional” range, but only Reach #4 poses risks to adjacent properties. Note that the rapid geomorphic assessment was conducted in March 2016 after a significant flood event in December 2015 that severely impacted the streams in the City.

### 1.3.2 Boschert Creek Watershed

36 reaches were evaluated within the Boschert Creek Watershed. 61% of the reaches have stability index scores within the “Transitional” range, 22% have stability index scores within the “In Regime” range, and the remaining 17% have stability index scores within the “In Adjustment” range. Much of Boschert Creek has been straightened in the past. In response, Boschert Creek is now widening and is re-establishing meanders in several locations. In particular, the areas downstream of I-370 should be monitored. A significant portion of this area has an adjacent levee, and as the meanders and widening increase, the stability of the levee will be compromised.

### 1.3.3 Cole Creek Watershed

55 reaches were evaluated within the Cole Creek Watershed (including the East Branch of Cole Creek). Approximately 15% of the reaches have a stability index score in the “In Regime” range from below 0.25. The remaining 47 reaches are almost equally divided with stability indices in the “Transitional” and “In Adjustment” ranges. The “In Adjustment” reaches are located downstream of I-370, between Lake Forest Drive and Willow Brook Court, between Elmhurst Drive and Indian Trail Drive, and upstream of Zhumbehl Road. Upstream of Muegge Road, Cole Creek is adjusting in response to the change in flow patterns resulting from the relatively recent

construction of Spring Mill Lake. Between Lake Forest Drive and Willow Brook Court, Cole Creek has downcut and is now actively widening. Widening is also active downstream of I-370 and between Elmhurst Drive and Indian Trail Drive.

### 1.3.4 Crystal Springs Watershed

For Crystal Springs, the majority of stream reaches have a stability index score in the "Transitional" range between 0.25 and 0.40. From the Southern Oaks Subdivision at S. Fifth Street to Rio Vista Drive the stability indices are "In Regime" which is reflective of past stabilization projects on these two reaches. Between Rio Vista Drive and South River Road and upstream of the Southern Oaks Subdivision have stability indices in the "In Adjustment" range. It should be noted that upstream of Reach #4, most of the reaches lie within St. Charles County.

### 1.3.5 Sandfort Creek Watershed

49 reaches were evaluated within the Sandfort Creek Watershed. 47% of the reaches have stability index scores within the "Transitional" range, 16% have stability index scores within the "In Regime" range, and the remaining 37% have stability index scores within the "In Adjustment" range. In general, the reaches north of I-70 are in the worst condition. The majority of reaches in the watershed were severely impacted by the December 2015 flood event that resulted in widespread bank failures. Consequently, several of the reaches have accelerated rates of widening in response to the flood event. Much of the lower one-half of the watershed has wide riparian corridors that allow the stream to adjust without significantly impacting improved properties. Naturally, encroachments into the riparian corridor places improvements at a greater risk to stream adjustments.

### 1.3.6 Taylor Branch Watershed

30 reaches were evaluated within the Taylor Branch Watershed. 63% of the reaches have stability index scores within the "Transitional" range, 23% have stability index scores within the "In Regime" range, and the remaining 13% have stability index scores within the "In Adjustment" range. In the watershed, widening and degradation are the predominate, active geomorphic processes. Several of the reaches upstream of Kunze Road have downcut to bedrock. Generally, the riparian buffer along the reaches provides sufficient protection of the adjacent properties, and only two reaches appear to pose a risk to properties. Note that the rapid geomorphic assessment was conducted in March 2016 after a significant flood event in December 2015 that severely impacted the streams in the City.

### 1.3.7 Warwick Watershed (Downstream of Warwick Lake)

Two reaches downstream of Warwick Lake were assessed and found to be in the "In Regime" range. Degradation and widening are moderately active, but the wide riparian corridor along the reaches accommodates adjustment without significant impact to adjacent improved properties. Note that a sanitary manhole on the right descending bank of the reach downstream of Warwick Lake has been exposed, and the reach should be monitored for future impacts to the sewer line.

### 1.3.8 Webster Branch Watershed

6 reaches were evaluated within the Webster Branch Watershed. 33% of the reaches have stability index scores within the "Transitional" range, and 67% have stability index scores within the "In Adjustment" range. None of the reaches score in the "In Regime" range. Widening is very active in the watershed and the high banks are unstable and there have been numerous bank failures. Reach #1 immediately upstream of South River Road has the highest risk to adjacent properties and bank failures threaten the adjacent road to Webster Park. Note that the rapid geomorphic assessment was conducted in March 2016 after a significant flood event in December 2015 that severely impacted the streams in the City.

## 1.4 RISK ASSESSMENT

### 1.4.1 Flood Damage Risk

The risk of flooding and the associated damages were evaluated for the 2, 5, 10, 15, 25, 50, and 100-year return interval hydrologic events. Depths of flooding from the stream, overland flow, and inlet ponding source were calculated and compared to the elevations of habitable structures to determine the extent of flooding within the structure. Damage curves representing the cost of water damage based on the depth of flooding within the structure was used to compute the damage costs.

Critical structures were inspected and/or surveyed to determine building elevations and the presence or absence of basements. The damage caused by flooding is related to the depth of flooding and frequency of flooding with respect to an expected level of protection provided during a project's life. Project life defines the period for which all costs (construction and damages) can be compared equally. For this project, a 50 year life was used.

The structure damages for residential, commercial, and industrial buildings are a function of the flood depth and the total market value of the property, and the damage curve.

### 1.4.2 Stream Damages

A GIS tool was developed to automate the process of quantifying the risk to structures, properties, and sanitary sewer infrastructure, as well, assessing the damage potential due to stream erosion. This process is described in detail in Section 5, and a flow chart of the GIS process is included in Appendix C. The stream corridor is divided into three risks zones: Channel Zone, High Risk Zone, and Low Risk Zone. These zones are then utilized to determine the Risk for damages to Buildings, Yard and Sanitary Sewers.

Stream erosion damages are the product of the risk factor for erosion and the assessed property value for both buildings and land. This analysis is performed for buildings and land cost for each parcel as a raster calculation within GIS and summed for all pixels within a stream reach to produce a total damage cost weighted by relative risk.

## 1.5 PROJECT IDENTIFICATION

Using the tools described in Section 4, the computed damages for flooding risks and stream erosion risks were mapped in GIS. GIS assists in the analysis by providing the necessary underlying data while facilitating verification of the computed risks and associated damages with the observations and knowledge base of the Public Works staff through visualization. Additionally, visualization through mapping allows cause-and-effect sources and patterns to be more readily identified and understood, thereby leading to comprehensive solutions.

### 1.5.1 Stream Erosion

Projects were identified along entire reach lengths and not merely at the location of an identified problem area within a specific reach. The reason for this that a problem area or “hot spot” in one location is indicative of a larger set of variables that is causing the stream to adjust, and these variable must be addressed holistically to provide a comprehensive and lasting solution. Experience has demonstrated that spot repairs work for only a short time, and ultimately they shift the problem to another area along the stream. This approach leads to a series of spot repairs.

Therefore, project costs, including construction and engineering, were determined based on the linear foot of bank impacted for each reach.

### 1.5.2 Flooding

The enclosed stormsewer system and open channel flooding depths as modeled for the 2, 5, 10, 15, 25, 50, and 100-year events are mapped in GIS to identify the flooding risk to the corresponding probabilistic return interval. In addition to the mapping, the hydraulic model is used to identify the resulting cause of flooding by determining the hydraulic deficiencies within the system. Once the deficiencies are identified, alternative solutions were identified to correct the problem based on an accepted level of protection from flooding.

The alternative solutions were presented to the City's Public Works Staff in a series of workshops to identify the viability of the alternatives based of staff's direct knowledge of the how the system functions and the impact to the community.

### 1.5.3 Stream Erosion Benefit/Cost Ratio Analysis

For each reach along within the project area, the damages to yards, building and sanitary sewers were determined. These potential damages are the financial benefit the community would experience if the stream reach were to be stabilized to prevent the damage from occurring. Thus, the benefit to cost ratio was determined for each reach by dividing the potential damage costs by the estimated project costs. To determine at what point projects should be selected to be implemented, the results were analyzed to determine at what point the City would not receive a net benefit from funding projects to remediate stream erosion. This process is termed "knee of the curve analysis".

At stream reach rank 9, the cumulative benefit and cost curves cross, and there is not a net benefit to the City. This is the "knee of the curve" and is the recommended funding level for the City to use for selecting projects to include in the Capital Improvement Program.

The nine projects recommended for inclusion are summarized in the table below, and detailed summary sheets for each project are included in Appendix E.

**Table 1-1: Recommended Stream Erosion Projects**

| Stream Reach | Benefit Cost | Project Cost | B/C |
|---|---|---|---|
| West Branch of Sandfort at Harry S. Trueman | $1,640K | 950K | 1.72 |
| Cole Creek from Zumbehl Rd. Culvert to 1981 Zumbehl Rd. | $1,868K | $1,522K | 1.23 |
| Boschert Creek from 10 Le Chateaux Ct. to 4 Le Chateaux Ct. | $922K | $784K | 1.18 |
| Boschert Creek from Lindenwood Ave. to Pine St. | $959K | $889K | 1.08 |
| Crystal Springs from Rio Vista Dr. to S. River Rd. | $1,166K | $1,086K | 1.07 |
| Boschert from N. Kingshighway St. to Lindenwood Ave. | $768K | $784K | 0.98 |
| Boschert from 1008 Indian Hills Dr. to Duquette Dr. | $461K | $471K | 0.98 |
| Boschert from West Clay St. to 506 Droste Dr. | $715K | $776K | 0.92 |
| Cole Creek from 2216 Graystone Dr. to Fox Glove Dr. | $662K | $922K | 0.72 |
| Boschert from 916 Barton Pl. to Hawthorne Ave. | $613K | $872K | 0.70 |

### 1.5.4 Flood Damage Reduction Benefit/Cost Ratio Analysis

Based on the project alternative workshops with City Staff, the selected alternatives were finalized and the construction cost estimated. The project cost included the costs of engineering, property rights acquisition, and construction. The projects recommended for inclusion are summarized in the Table 1-2, and detailed summary sheets for each project are included in Appendix D.

From the flood risk analysis, the potential damage cost is computed, and the removal of the risk through a proposed project represents the benefit to the community in dollars. The benefit/cost ratio is the cost of a project divided by the benefit cost.

Many times other factors are important or influence the benefits for a given project. For this reason, a two benefit cost ratio adjustments are included to capture items beyond the flood damages.

- **End of Life Adjustment –** Storm sewer infrastructure has a finite life. If infrastructure is near the end of its useful life then a 1.0 factor is added to base benefit cost ratio. This factor accounts for the reality that the infrastructure will have to be replaced regardless of flood damages. This replacement has the benefit of extending the infrastructures life.

- **Water Quality Adjustment –** With the ever changing water quality regulations, promoting projects that have a positive water quality impact is in the best interest of the City. Projects that contain green infrastructure best management practices have a multiplier applied to the base cost benefit ratio. This water quality benefit is based on MSD standard water quality benefit calculation and is added to the overall base benefit cost ratio.

**Table 1-2: Recommended Flood Reduction Projects**

| Project | Benefit Cost | Project Cost | B/C | Infrastructure Adjustment | WQ Adjustment | Adjusted B/C |
|---|---|---|---|---|---|---|
| Foxglove Floodproofing | $ 3,000,000 | $ 340,000 | 8.82 | 1.00 | 0.00 | 9.82 |
| Lindenwood Culvert Replacement | $ 2,750,000 | $ 365,000 | 7.53 | 1.00 | 0.00 | 8.53 |
| Shelburne Drive Floodproofing | $ 2,350,000 | $ 445,000 | 5.28 | 1.00 | 0.00 | 6.28 |
| Randolph St Storm Improvements | $ 1,383,836 | $ 520,000 | 2.66 | 1.00 | 0.00 | 3.66 |
| Sunnybrook Storm Improvements | $ 6,740,000 | $ 5,900,000 | 1.14 | 1.00 | 0.00 | 2.14 |
| Buckingham Place Storm Improvements | $ 2,960,000 | $ 2,685,000 | 1.10 | 1.00 | 0.00 | 2.10 |
| Boones Lick Rd and Sixth St Storm Improvements | $ 1,375,500 | $ 1,280,000 | 1.07 | 1.00 | 0.00 | 2.07 |
| 5th Street and Rio Vista Culvert Replacement | $ 2,030,000 | $ 1,960,000 | 1.04 | 1.00 | 0.00 | 2.04 |
| Elm Sibley Culvert Replacement | $ 1,200,000 | $ 1,175,000 | 1.02 | 1.00 | 0.00 | 2.02 |
| Lawrence St and N 2nd Street Storm Improvements | $ 969,354 | $ 1,000,000 | 0.97 | 1.00 | 0.00 | 1.97 |
| Kingshighway Storm Improvements | $ 8,425,000 | $ 9,485,000 | 0.89 | 1.00 | 0.00 | 1.89 |
| Thrush Drive Storm Improvements | $ 296,000 | $ 172,000 | 1.72 | 0.00 | 0.00 | 1.72 |
| Cole and East Branch Cole Buyout | $ 3,375,000 | $ 3,210,000 | 1.05 | 0.00 | 0.59 | 1.64 |
| Clark St Storm Improvements | $ 1,270,000 | $ 2,000,000 | 0.64 | 1.00 | 0.00 | 1.64 |
| Cole Creek from Zumbehl Rd. Culvert to 1981 Zumbehl Rd. | $ 1,868,000 | $ 1,522,000 | 1.23 | 0.00 | 0.20 | 1.43 |
| Old Saybrook Regional Detention | $ - | $ 1,925,000 | 0.00 | 0.00 | 1.40 | 1.40 |
| Seventh St to Boones Lick Rd Storm Improvements | $ 1,557,650 | $ 3,950,000 | 0.39 | 1.00 | 0.00 | 1.39 |
| Boschert Creek from 10 Le Chateaux Ct. to 4 Le Chateaux Ct. | $ 922,000 | $ 784,000 | 1.18 | 0.00 | 0.20 | 1.38 |
| N Benton Ave to N Main Storm Improvements | $ 1,818,374 | $ 5,300,000 | 0.34 | 1.00 | 0.00 | 1.34 |

## 1.6 PROJECT PRIORITIZATION

### 1.6.1 Prioritization

For the projects identified in this study, the underlying basis for prioritization is the benefit to cost ratio. Initially, all projects will be ranked in order of the lowest to highest benefit/cost ratio for each project type (i.e., flood damage or stream erosion). Next, the individual projects for each project type will be mapped so that the projects can be analyzed spatially. From the spatial analysis it may be desired to group projects in the same category that in close proximity to each other together as a single project to reduce the overall project cost through economies of scale. Likewise, flood damage and stream erosion projects that overlapped each other could be combined to reduce total costs.

Working with the Public Works Staff, the projects were initially prioritized based on the benefit to cost ratio after finalization of the project scope based on the project spatial analysis and project combination processes. The ranking of projects will then be analyzed against the planning horizon of the City's current Capital Improvement Plan (CIP). Decisions can then be made if adjustments are needed within the current CIP planning horizon. For projects beyond the current CIP planning horizon, projects will be based on the benefit/cost ratio.

Table 1-3: Combined Project List

| Project | Benefit Cost ($1,000s) | Project Cost ($1,000s) | Benefit/Cost Ratio | Infrastructure Adjustment | WQ Adjustment | Adjusted B/C |
|---|---|---|---|---|---|---|
| Lindenwood Culvert Replacement | $2,750 | $365 | 7.53 | 1 | 0 | 8.53 |
| Shelburne Drive Floodproofing | $2,350 | $445 | 5.28 | 0 | 0 | 5.28 |
| Sunnybrook Storm Improvements | $6,740 | $5,900 | 1.14 | 1 | 0 | 2.14 |
| Buckingham Place Storm Improvements | $2,960 | $2,685 | 1.1 | 1 | 0 | 2.1 |
| 5th Street and Rio Vista Culvert Replacement | $2,030 | $1,960 | 1.04 | 1 | 0 | 2.04 |
| Elm Sibley Culvert Replacement | $1,200 | $1,175 | 1.02 | 1 | 0 | 2.02 |
| Kingshighway Storm Improvements | $8,425 | $9,485 | 0.89 | 1 | 0 | 1.89 |
| Thrush Drive Storm Improvements | $296 | $172 | 1.72 | 0 | 0 | 1.72 |
| Cole and East Branch Cole Buyout | $3,375 | $3,210 | 1.05 | 0 | 0.59 | 1.64 |
| Cole Creek from Zumbehl Rd. Culvert to 1981 Zumbehl Rd. | $1,868 | $1,522 | 1.23 | 0 | 0.3 | 1.53 |
| Boschert Creek from 10 Le Chateaux Ct. to 4 Le Chateaux Ct. | $922 | $784 | 1.18 | 0 | 0.3 | 1.48 |
| Crystal Springs from Rio Vista Dr. to S. River Rd. | $1,166 | $1,086 | 1.07 | 0 | 0.4 | 1.47 |
| Foxglove Floodproofing | $500 | $340 | 1.47 | 0 | 0 | 1.47 |
| Old Saybrook Regional Detention | $ | $1,925 | 0 | 0 | 1.4 | 1.4 |
| Boschert Creek from Lindenwood Ave. to Pine St. | $959 | $889 | 1.08 | 0 | 0.3 | 1.38 |
| Boschert from N. Kingshighway St. to Lindenwood Ave. | $768 | $784 | 0.98 | 0 | 0.3 | 1.28 |
| Boschert from 1008 Indian Hills Dr. to Duquette Dr. | $461 | $471 | 0.98 | 0 | 0.3 | 1.28 |
| Droste Road Regional Detention Basin | $6,300 | $7,800 | 0.81 | 0 | 0.44 | 1.25 |
| Boschert from West Clay St. to 506 Droste Dr. | $715 | $776 | 0.92 | 0 | 0.3 | 1.22 |
| Concordia Culvert Replacement | $1,100 | $926 | 1.19 | 0 | 0 | 1.19 |
| West Clay Regional Detention Basin | $1,300 | $4,600 | 0.28 | 0 | 0.81 | 1.09 |
| Cole Creek from 2216 Graystone Dr. to Fox Glove Dr. | $662 | $922 | 0.72 | 0 | 0.3 | 1.02 |
| Muegge Road Regional Detention | $ | $3,050 | 0 | 0 | 0.51 | 0.51 |

## 1.7 WATER QUALITY

There are a variety of reasons why the water quality of streams, ponds and lakes within a community is important. Water quality affects recreation, source water, public health, fish and wildlife habitat, property values and community pride. Water quality can be degraded by a number of sources, including illegal waste discharges, stormwater discharges from pavement, animal waste, agricultural activities and stream bank erosion. The source of water quality degradation can come in the form of pathogens, metals, nutrients, and sediment. The two general methods for determining water quality at specific locations are to estimate based on upstream land use (indirect, or desk-top method) and to physically sample the water body.

### 1.7.1 Regulations

St. Charles is considered a Small MS4 community and is obligated to follow the regulations for water quality as set forth by the EPA and MoDNR. The City secured an NPDES (stormwater discharge) permit from MoDNR in 2008 and it expired in 2013. The City's NPDES Permit is based on a Stormwater Management Plan to address the prescribed 6 Minimum Control Measures that should lead to reductions of pollutants discharged into receiving waterbodies. The State's own permit with EPA expired in 2013 and, as of March 2015, the permit has not been renewed. As part of the renewal process, the State has issued a set of Draft Revised Rules for public comment. Until the State has renewed its EPA Permit, the City will continue to operate under its existing NPDES permit.

### 1.7.2 Current Water Quality Programs

Existing City documents that focus on water quality include the *Green Point Rating System Guide* to incentivize sustainable development, the City's *Stormwater Management Plan* (part of the 2008-2013 NPDES Permit from MoDNR) and the City Ordinances that deal with stormwater management. The *Green Point Rating System Guide* has met with limited success. The *Stormwater Management Plan* includes measures to publicize the importance of water quality, engage the public in improving water quality, control sediment during and after construction, and to enact "good housekeeping" measures, such as street sweeping. Some of these measures are still in place, while others have gone dormant.

### 1.7.3 Future Water Quality Regulations

The Draft Rules Changes that have been issued by MoDNR, along with statements from MoDNR staff, indicate a desire to move toward a more stringent and costly system to sample and monitor water bodies and control pollutants that enter them. There has been significant resistance on the part of regulated communities, in part, because of vague proposed language. Larger communities, such as St. Louis County, have initiated programs for developers that mandate construction of Best Management Practices (BMPs) such as rain gardens, bioretention facilities and permeable pavement. Other local communities are waiting until MoDNR's Permit with EPA is renewed before committing to additional measures.

### 1.7.4 Recommendations

In regard to water quality improvements, communities often strive to balance the interests of competing interests like development, environmental responsibility, regulations and fiscal responsibility. In general, the goals of addressing the City's water quality issues should be to minimize increase in costs, while closely monitoring regulatory movement. It makes sense to implement reasonable improvements to prepare for regulatory changes, while avoiding overcommitting until State regulations stabilize.

Specific recommendation for immediate implementation include:

1. Revitalize Existing Programs – Reassess the Green Point Rating System to see if greater incentives will lead to greater utilization. Revisit the City's *Stormwater Management Plan* to ensure that the proposed measures are still effective. Revive those that have gone dormant.

2. Incorporate Water Quality Projects into Flood Mitigation Projects - As the City moves forward with flood mitigation the projects should be expanded to include water quality features.

3. Do Not Sample or Monitor Streams – If the sampling is not performed in a very structured and regulated manner, the results may be useless. The results could also become public information and then be used to officially classify streams as impaired, opening the door to stringent results-based regulation or litigation from special interest groups. The language in MoDNR's Draft Rules Changes is currently vague. No sampling is recommended until MoDNR formalizes its requirements.

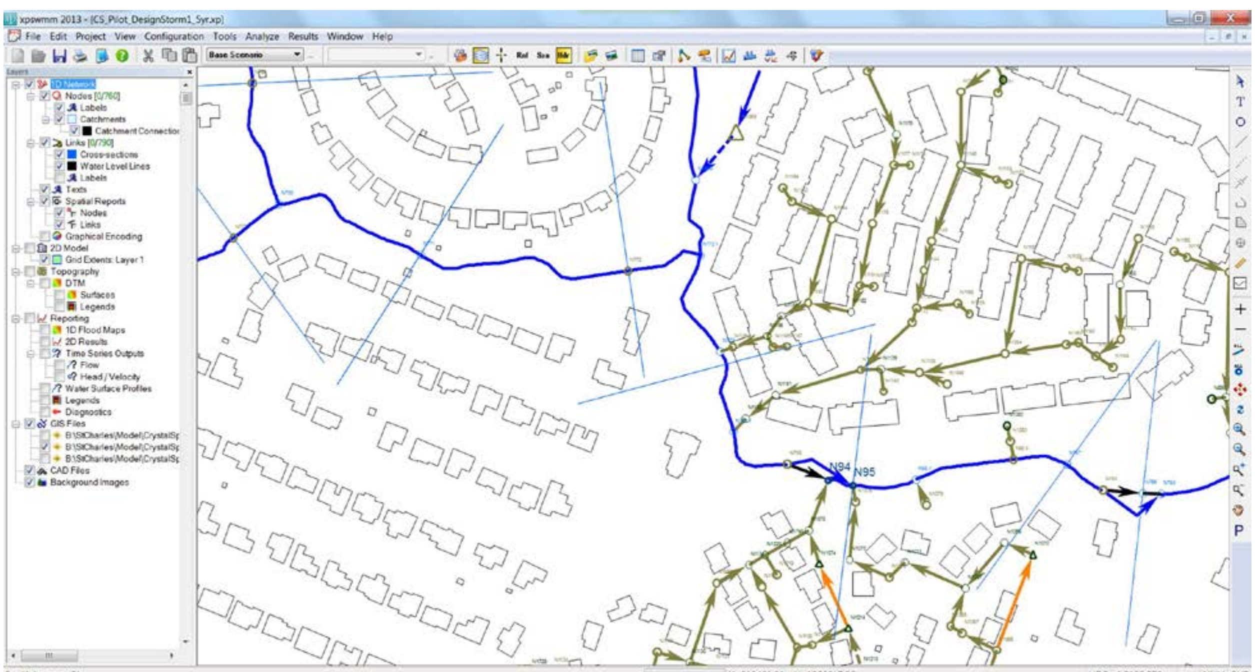
# SECTION 2 **MODEL DEVELOPMENT**

XP-SWMM, by XP Software Inc., is a link-node model used to model both open and enclosed stormwater systems. XP-SWMM is used to simulate the full hydrologic cycle from generating stormwater flows to routing resultant flows through the collection system. Two modules are used in developing a combined sewer system model. The “Runoff” module develops hydrographs for input to the hydraulic components of the model, based on user-defined rainfall hyetographs, antecedent conditions, land use and topography. The “Hydraulics” module reads the Runoff hydrographs and dynamically routes the storm and sanitary flows through the collection system.

The XP-SWMM model is capable of:

- Generating baseline sanitary and infiltration flows, and estimating storm flows given user-defined rainfall hyetographs;
- Estimating hydraulic grade lines, volumes and flow rates of water in the modeled collection system;
- Estimating flow capacity of gravity sewers;
- Estimating peak system flows during dry and wet weather periods;
- Simulating system performance using either discrete events or continuous data; and,
- Displaying model using graphical user interface, as shown in Figure 2-1.

**Figure 2-1: Example model display**

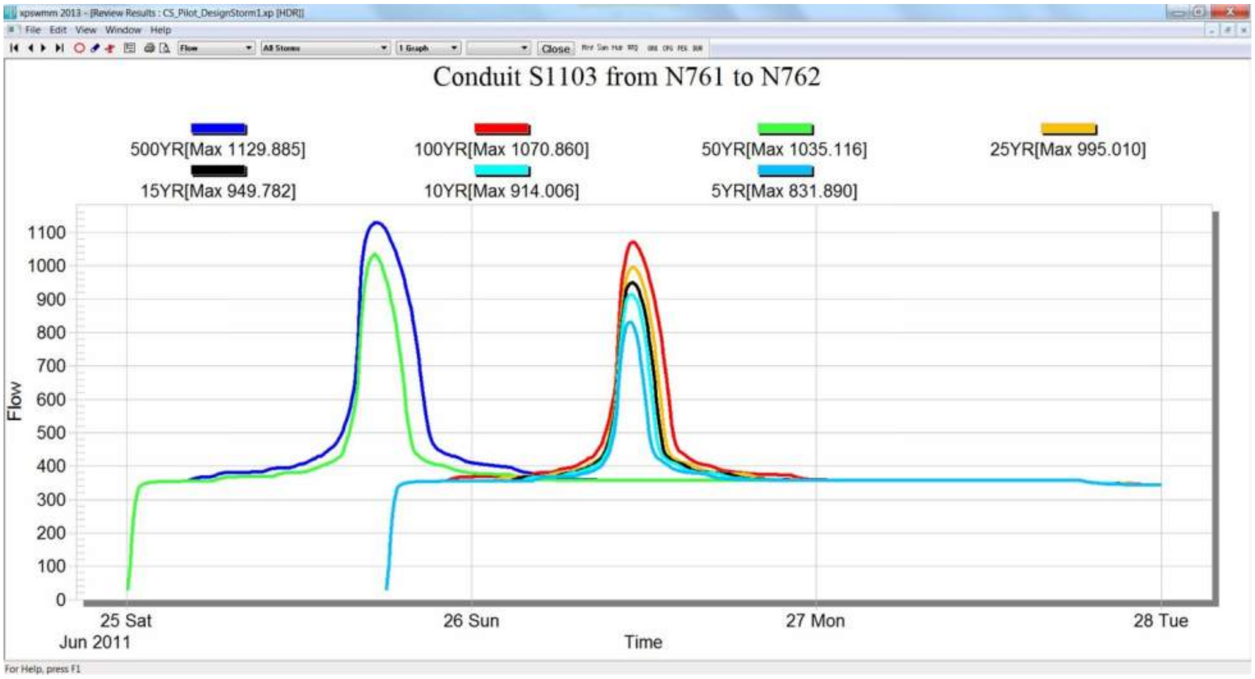


The system models use two modules within XP-SWMM: the Runoff and Hydraulics modules. This section describes the development of the inputs for the models.

## 2.1 HYDRAULICS MODULE INPUTS

The Hydraulics module simulates the hydraulic flow routing of the combined sewer system. The model is a node-link description of the combined sewer system whereby a series of node elements (*e.g.,* manholes, storage tanks, etc.) are connected by link elements (*e.g.,* sewers, pump stations, force mains). The node elements receive hydrograph input from the Runoff module or by direct user input (*e.g.,* sanitary flow). The model then dynamically routes the received flows through the combined sewer system to receiving waters. An example results file is provided in Figure 2-2.

**Figure 2-2: Example output results file in Hydraulics module**




The Dynamic Wave hydrograph method is utilized to perform the hydraulic routing. In this method, the model is based on the gradually-varied, one-dimensional, unsteady flow (St. Venant) equations for open channels. When the flow in a conduit becomes pressurized, the free surface condition is maintained by using the Preissman slot to account for compressibility effects during surcharging. The width of the narrow slot characterizes the elastic properties of the water and sewer walls. The default value is 0.005*W, where W is the conduit width. Therefore, large diameter sewers may require adjustment of this factor using the configuration parameter WSLOT.

The following are input to the Hydraulics module:

- Collection System Physical Data;
- Base (Dry Weather) Flows; and,
- Boundary Conditions.

### 2.1.1 Collection System Element Data

Collection system element data include the following:

- Open Channels
- Bridges and Culverts
- Sewer and manhole names;
- Sewer size;
- Sewer shape;
- Sewer length;
- Manhole and sewer upstream and downstream invert elevations;
- Manhole surface (rim) elevations; and
- Detention Basins.

These hydraulic parameters are developed using the City's GIS facility maps, which provide sewer locations and configurations, including diversion structure locations and flow configurations, structure top elevations, and pipe invert elevations. Additional sources, such as historical surveys, record drawings or studies may be utilized to supplement the City's facility maps. In some cases, sufficient data is not always available. In such instances, the modeler identified the data gaps and propose solutions to the City. These solutions incorporated field estimates, new surveys, interpolations, and other reasonable approaches. At a minimum, all major structures incorporated field-verified data (*e.g.,* surveys, as-built drawings). Additionally, areas with historical hydraulic issues should have a firm basis for model input. Discussions with the City provided the necessary guidance to proceed with the model development.

#### Collection System Extents

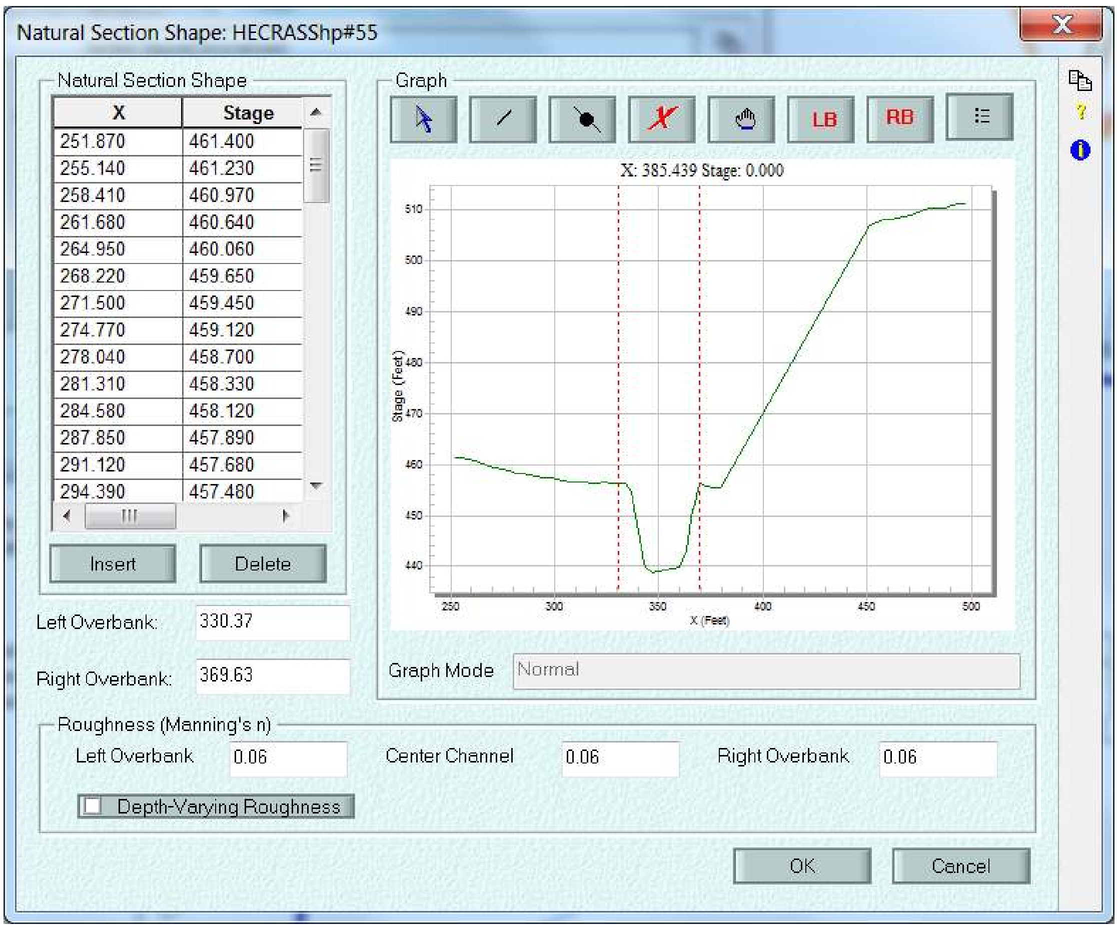
The hydraulic model incorporated all the City structures and node points (including manholes and junctions) are included within the model extents, regardless of distance between modeled nodes. In this manner, searches for specific structures or conduits are expedited, and the model will represent the connectivity of the City's facility maps.

#### Natural Channels

For the initial development of the geometry required to model natural channels, the U.S. Army Corps of Engineers HEC-RAS model for Sandfort, Cole Creek and Boschert Creek were utilized.

For remaining watersheds, an existing HEC-RAS model was not available, so the geometry was created. The HEC-RAS model geometries were then imported into XP-SWMM. The HEC-RAS geometry consists of stream reach lines with cross sections cut at strategic locations. The cross section data consist of horizontal distances (X) and corresponding elevations (Stage) to define the ground line along with Manning's n values representing the roughness of the main channel and adjacent overbank area to the left and right. Also, each cross section was coded with the distance to the next downstream cross section for the left and right overbanks. A typical cross section that has been imported into XP-SWMM is shown in Figure 2-3.

**Figure 2-3: Cross Section Editing Window in XP-SWMM**




### Pipe Roughness

The Manning's roughness coefficient for each sewer is based on the surface material of the sewer's wetted perimeter. Table 2-1 below presents the values to be initially used in the model; however, the roughness coefficient may be a calibration parameter. Where pipe material information is unavailable, a conservative value of 0.015 s/ft$^{1/3}$ is used, due to the age of the sewer system.

**Table 2-1: Manning's Roughness coefficients**

| Sewer Material | Coefficient | Sewer Material | Coefficient |
|---|---|---|---|
| Cured-in-Place (CIPP) | 0.012 | Clay (VCP) | 0.013 |
| Ductile Iron (DIP) | 0.012 | Concrete (RCP) | 0.013 |
| Plastic (PVC) | 0.012 | Brick | 0.015 |
| Cast Iron (CIP) | 0.013 | All Others | 0.015 |

## 2.2 BOUNDARY CONDITIONS

For numerous reasons, various boundary conditions are required to accurately represent existing conditions or simulate alternatives. Boundary conditions have been discussed with the City's project manager to develop a proper approach to modeling the conditions of interest.

### 2.2.1 Watershed Outfalls

Each watershed has an outfall at the downstream end of the model. Multiple boundary conditions were modeled, including: Normal Depth, Critical Depth and a rating curve based on the hydraulics in the USACE Hec-RAS model. This analysis concluded that normal depth controlled the predicted water surface.

### 2.2.2 Inlet Restrictions

Many of the inlets within the system have restricted openings due to street debris, pavement re-surfacing, and collapsed or otherwise impaired structures among other reasons. If flow meter results or other data (*e.g.,* complaints) indicate inlet restriction the modeler may need to adjust the level of model detail in these areas or restrict inlet capacity using XP-SWMM's inlet restriction capabilities. When flow isn't allowed to enter the collection system, a mechanism for storing or conveying it may be needed.

### 2.2.3 Surface Storage and Overland Flow Routing

Accounting for surface flood volumes is essential to identifying overland flooding. For example, flooding analyses require an accurate representation of existing conditions to properly understand the collection system's response to wet weather events.

Surface storage may be accomplished by using the “ponding” option within the Hydraulics node dialog box for discrete, small-scale hydraulic capacity issues in the sewer system. More sophisticated surface storage nodes may be required for large areas or hydraulic capacity issues in “problem” areas.

Overland flow routing may also be required. Similar to surface storage, simple scenarios do not require advanced routing techniques. For example, if an inlet is clogged on a paved surface with a constant slope, the flooded flows may be redirected through a surface conveyance system to downstream nodes.

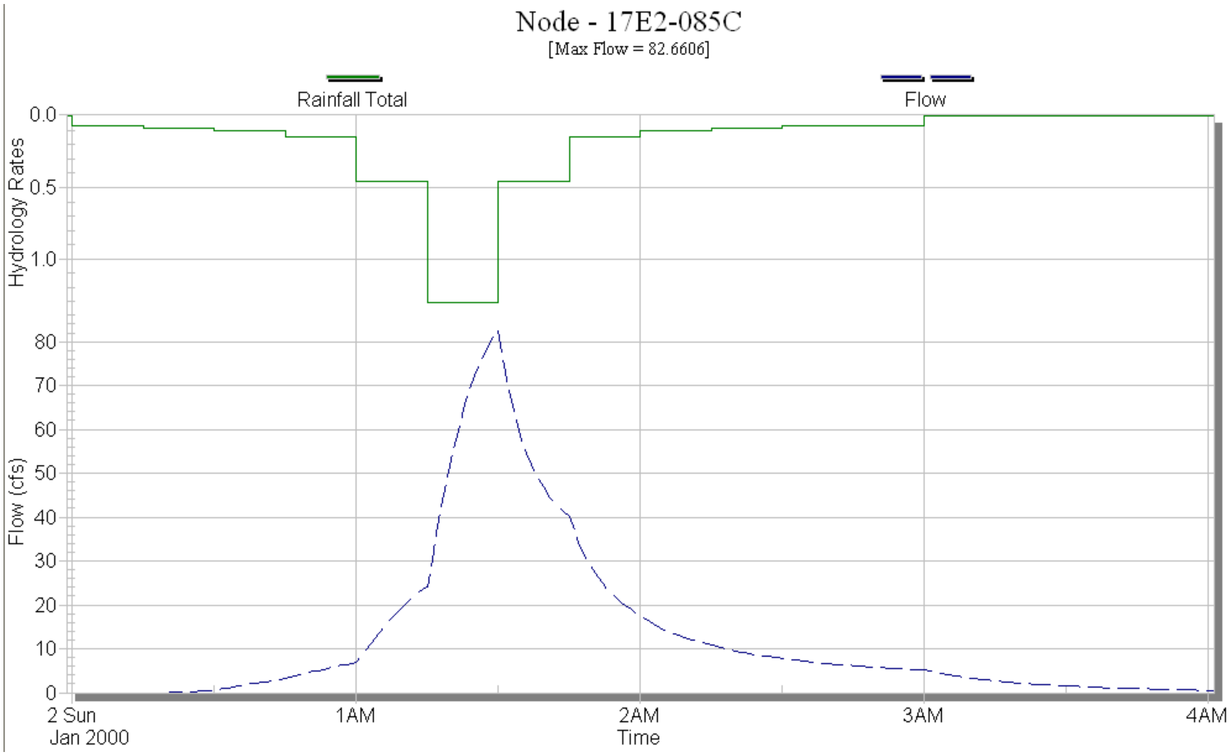
## 2.3 RUNOFF MODULE INPUTS

The Runoff module simulates the hydrology of the combined sewer system and generates the stormwater runoff quantities for input to the Hydraulics module. The model simulates runoff conditions by distributing a user-defined rainfall hyetograph over the modeled sub-catchment area. Based on the characteristics of the sub-catchment area, the program estimates overland flow quantities, surface detention, infiltration losses, and evaporation losses over a user-defined time period. The output from the Runoff module is a hydrograph, as shown in Figure 2-4 for input to the Hydraulics module.

The SWMM Runoff Non-Linear Reservoir Method is utilized to perform the hydrograph generation. In this method, overland flow hydrographs for each sub-catchment area are generated by nonlinear reservoir routing using Manning’s equation and lumped continuity equation with depression storage and impervious area parameters.

The Runoff module provides for additional input options beyond those presented herein including groundwater and snowmelt. Modeling of these parameters were discussed with the City’s project manager to evaluate a proper approach to modeling the conditions of interest.

**Figure 2-4: Example input hyetograph and output hydrograph in Runoff module**




The following parameters with their typical units in parentheses are input to the Runoff module:

- Ground Surface Area (acre);
- Ground Slope (foot/feet);
- Percent Impervious Area (percentage);
- Characteristic Width (feet);
- Ground Infiltration Parameters;
- Evaporation (inch/day);
- Ground Cover Roughness (second/feet$^{1/3}$);
- Depression Storage (inches); and,
- Precipitation (inch).

### 2.3.1 Ground Surface Area

For purposes of analyses, the service area is divided into sub-catchment areas. Estimated ground surface areas for each sub-catchment are calculated by delineating the City's facility maps (infrastructure maps) and digitizing the boundary using GIS software to create a polygon feature class. One of the inherent characteristics of a polygon feature class is calculation of the shape's area for each polygon. The areas are then compared against values found in previous studies for verification. In some instances, field verification may be necessary.

Roof areas are represented in a sub-catchment separate from other directly connected impervious areas (*e.g.,* street inlets) to facilitate modeling of anticipated scenarios (particularly roof drain disconnects). This may be accomplished using different Runoff nodes for roof and other impervious areas or by using different sub-catchments in the same Runoff node, as described in Section 2.2.3 below. The ground surface area is not a calibration parameter unless directed by the City.

### 2.3.2 Ground Slope

Ground slopes are based on the City's contour and sewer maps. Two-foot contour maps are available from the City. Since ground slopes are not expected to be uniform across a sub-catchment, this parameter may be adjusted during calibration.

### 2.3.3 Percent Impervious Area

The County maintains a building footprint database in polygon feature class format. Impervious percentages are calculated by intersecting the impervious area and paved area databases with the sub-catchment polygon feature class. Roadways, driveways and sidewalks were estimated at 85% of the impervious area and added to the building footprint area.

### 2.3.4 Characteristic Width

The characteristic width is defined as the distance over which surface flow exits the sub-catchment and enters the modeled trunk sewer. The XP-SWMM User Manual recommends that the width be initially entered as the quotient of the sub-catchment area divided by the average path length of overland flow with the knowledge that this hypothetical parameter is a key calibration parameter.

### 2.3.5 Ground Infiltration Losses

Ground infiltration losses are estimated on the basis of the Green-Ampt equation for continuous simulation purposes. St. Louis soils tend to be characterized as clays and consequently have low infiltration values. Since soil conditions are not expected to be uniform across a watershed, the ground infiltration parameters are expected to be calibration parameters. Average values and typical ranges for the input parameters are presented in Error! Reference source not found. below.

**Table 2-2: Average values and typical ranges of infiltration parameters**

| Infiltration Parameter | Average Value | Typical Range |
|---|---|---|
| Average Capillary Suction (inches) | 7 | 3 - 10 |
| Initial Moisture Deficit | 0.21 | 0.16 - 0.25 |
| Saturated Hydraulic Conductivity (in/hr) | 0.15 | 0.01 - 0.5 |

### 2.3.6 Evaporation

The model simulates the portion of precipitation that falls on the sub-catchment and evaporates prior to running off into the combined sewer system. Evaporation is also used to renew surface depression storage, which is discussed in Section 2.3.8. Evaporation is not expected to be a significant calibration parameter; consequently, the XP-SWMM default value of 0.1 inch/day may be utilized.

### 2.3.7 Ground Cover Roughness

The model uses Manning's roughness coefficients for pervious and impervious ground cover areas. Values of Manning's roughness coefficient are not as well known for overland flow compared to channel flow. The ground cover roughness values used in other the City models are 0.2 and 0.014 for pervious and impervious areas, respectively. These values generally associate to light turf for pervious surfaces and asphalt or concrete paving for impervious surfaces, according to the XP-SWMM User Manual. This description is consistent with the urban watersheds associated with the City's combined sewer service area. Ground cover roughness values are not expected to be significant calibration parameters.

### 2.3.8 Depression Storage

Depression storage is the volume that must be filled prior to the occurrence of runoff. This value represents the loss caused by phenomena such as surface ponding and allows for evaporation. Each sub-catchment has unique physical characteristics that may affect depression storage. However, to accurately characterize this parameter for each sub-catchment may not be efficient. Depression storage may be a significant calibration parameter, especially for small events, but watershed-wide values have been used successfully on other the City models.

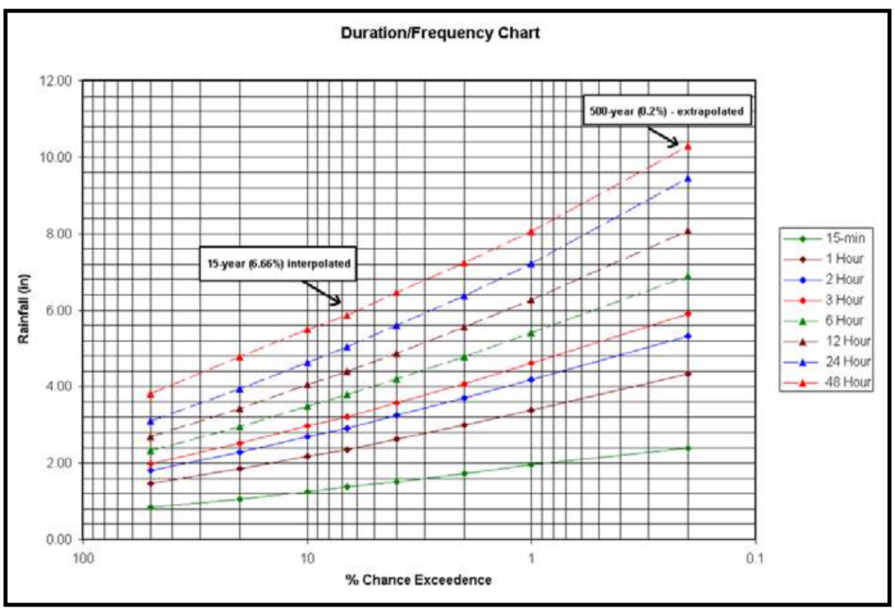
### 2.3.9 Precipitation

Precipitation data is necessary to simulate wet weather events, historical or synthetic. This data may be entered through a variety of options in the Rainfall global database. Historical data may be collected on a project-specific basis, from the City, or from another local, state, or federal agency. Synthetic design storms are provided by the City. Precipitation data, in the form of rainfall hyetographs, may be based on temporary rain gages, the City's permanent rain gages, radar rainfall data, other approved agencies, or a combination of data sets.

## 2.4 DESIGN STORMS

For the Study, seven frequency storms were to be used to analyze the watershed. The events used were the 2, 5, 10, 15, 25, 50, and 100-year frequency. The rainfall duration-frequency curves were developed from the Rainfall Atlas of the Midwest, also known as Bulletin 71. The authors of the Rainfall Atlas researched storm types, durations, and intensities throughout the Midwest, and the findings of the report are presented for specific regions within each state. The results for the Northeast Prairie region of Missouri were consulted for application to the project. The only limitation of this hypothetical storm data is that the 15-year were not included in Bulletin 71. In order to determine the appropriate rainfall amounts for these storms, the data had to be interpolated and extrapolated. A Microsoft Excel spreadsheet was used to plot and estimate the additional required rainfall amounts. The plot of the interpolated and extrapolated storm frequencies is shown here in Figure 2-5.

**Figure 2-5 Rainfall IDF Curves**



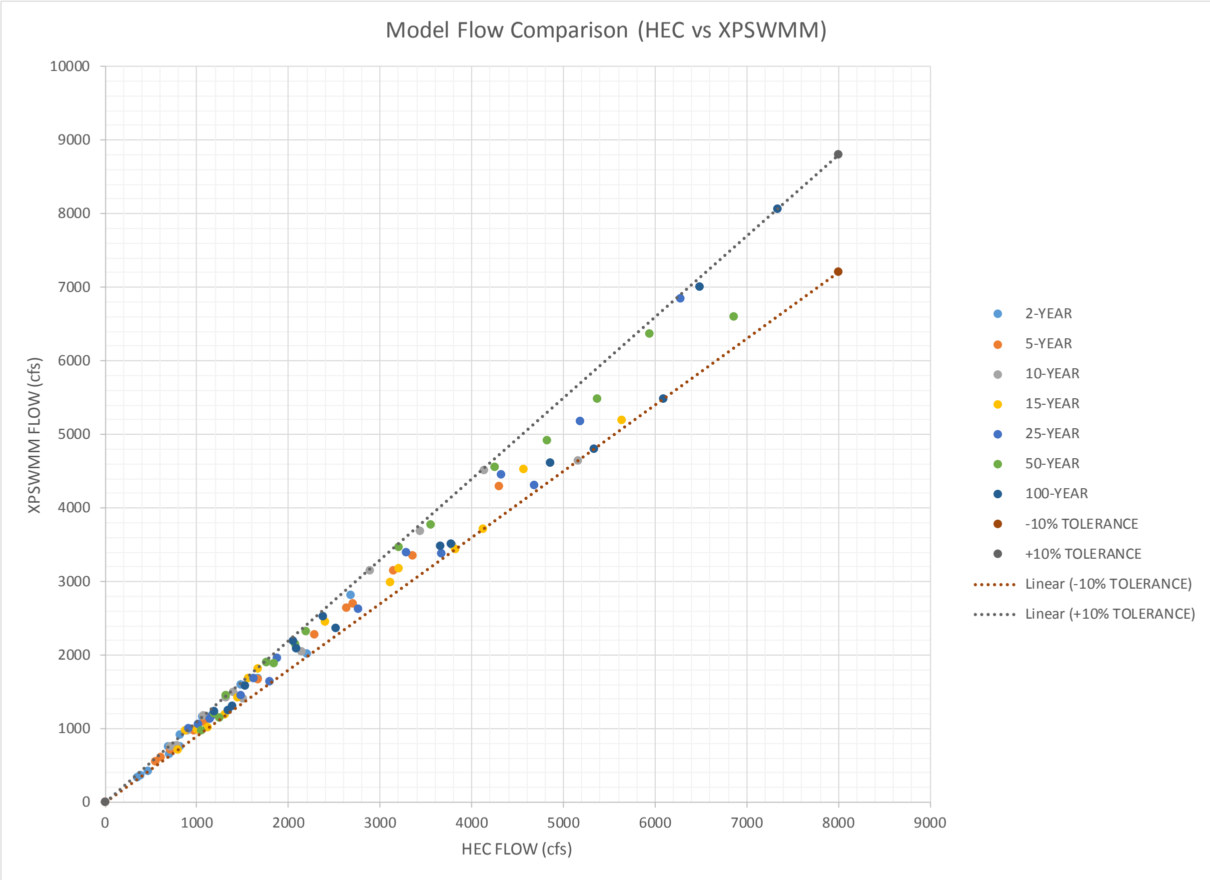
## 2.5 MODEL CALIBRATION AND VERIFICATION

Adjustment of the model's hydrologic and hydraulic parameters is necessary to better reflect field-measured results. The term "better reflect" could suggest an infinite process of adjusting the parameters. Therefore, calibration procedures and goals are established to identify the conclusion of the adjustment process.

Flowmeter data is not available project area; therefore, calibration consisted of matching flows provided in the Corps of Engineers HEC-HMS and HEC-RAS Model and verify complaints confirmed by the City. The model should be calibrated to match peak flow rates within +/- 10% of the modeled flows. A peak flow calibration plot is provided in Figure 2-6.

Model results were verified by comparing results to documented flood data collected for the May, 20, 2013 and June 25, 2011 events. Detailed flood limits and depths were determined for each of these events. Model results compare favorable to both storm events.

## Figure 2-5: Volume calibration plot



# SECTION 3 RAPID GEOMORPHIC ASSESSMENTS

## 3.1 RGA DESCRIPTION

A Rapid Geomorphic Assessments (RGA) is a field method to quantify a stability index, which is a measure of the relative stability of a stream reach. This section describes necessary background to understand what is meant by the term "stable", the field methods available for evaluating stream stability, the rationale for using the RGA technique selected for conducting this project, and explains the RGA method.

**Photo 3-1: Severe bend scour on Cole Creek**

Streams are in a constant state of flux and adjust their geometry as a response to changing stream flows, geology, vegetation, obstructions, man-made impacts, and so forth, by eroding and redistributing bed and bank materials in an attempt to reach a state of dynamic equilibrium. Dynamic equilibrium describes the state of a stream that, while still changing shape, maintains a balance between sediment transportation and the energy present in flowing water. A stream that is in a state of dynamic equilibrium will be observed to have overall dimensions that are relatively stable and is neither aggrading (building up sediment/depositional features) nor degrading (removing sediment).

Collectively, the study of how streams change their physical form in response to physical parameters is termed fluvial geomorphology and is a complex, emerging science that presently is not well understood. Consequently, the methods for assessing the stability of streams vary considerably and often lead to conflicting conclusions. Stream stability assessment techniques can be broadly grouped into two categories – qualitative and quantitative. Qualitative techniques rely on the judgment of the observer; whereas, quantitative techniques rely on measuring deterministic physical properties. Qualitative techniques can lead to accurate condition assessments, but they are highly dependent on the training, experience, and judgment of the observer. Additionally, consensus on an evaluation by multiple observers can be difficult. On the other hand, quantitative methods result in conclusions that are more uniform amongst multiple observers and provide supporting documentation, but obtaining and processing the data for quantitative analysis can be onerous and costly.

For this project the purposes of the stream stability assessments were to:

- Quantifying the relative stream stability to determine the risk to property adjacent to streams and use in prioritizing stream stabilization projects, and
- Determine a baseline condition that can be used in the future to determine how the stream is changing.

To meet the project goals, a rapid geomorphic assessment technique was selected that incorporates a quantitative analysis of geomorphic indicators of the four primary processes by which streams change to reach dynamic equilibrium: aggredation, degredation, widening, and planform adjustment. The RGA technique involved determining if individual geomorphic indicators are present, not present, or not applicable for various stream features, including:

- Channels
- Banks and Overbanks
- Bends
- Riffles
- Pools
- Bars
- Trees
- Infrastructure and Buildings

Each stream was divided into smaller segments called reaches and investigated by walking the stream and recording observations of the geomorphic indicators. Then, a stability index, SI, was computed for each reach using the following formula:

$$SI = \frac{\sum_{i=Aggredation,Degredation,Widening,Plan\ Form\ Adjustment}\left(\frac{\sum Indicators\ Present}{\sum Indicators\ Applicable}\right)_i}{4}$$

Based on the computed stability index, a stream reach was classified in one of three categories described below.

- Reaches with a stability index equal to or less than 0.25 are classified as "In Regime", which means the metrics describing the stream form are within the expected range of variance (typically accepted as on standard deviation from the mean) for stable streams of similar type.
- Reaches with a stability greater than 0.25 and less than 0.40 are classified as "Transitional", which means the metrics are within the expected variance but with evidence of stress.
- Reaches with a stability index equal to or greater than 0.40 are classified as "In Adjustment", which means the metrics are outside the expected range of variance for streams of similar type.

## 3.2 RGA FIELD ASSESSMENTS

Approximately 33.6 miles of stream in the project area were evaluated using the RGA technique described in Section 3.1 by dividing each stream into crossing and the confluence of a tributary. To document the observations of geomorphic indicators and to compute the stability index for each reach, the form in Figure 3-1 was used. Appendix A contains the Stream Field Assessment Manual which details the means and methods used.

# Figure 3-1: Sample of Completed Rapid Geomorphic Assessment

# Reach Evaluation Form

**Project:** St. Charles Comprehensive Stormwater Study
**Client:** City of St. Charles
**Date:** 4/9/2014

**Watercourse:** Cole Creek
**Reach:** #17
**Observers:** SM, JR

| Code | Geomorphic Indicators | Geomorphic Processes | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Aggregation | | | Degredation | | | Widening | | | Planimetric Form Adjustment | | |
| | | Y | N | NA | Y | N | NA | Y | N | NA | Y | N | NA |
| | **Channels** | | | | | | | | | | | | |
| D-Chan-1 | ▶ Channel incision into undisturbed overburden/bedrock | | | | 1 | | | | | | | | |
| D-Chan-2 | ▶ Headcuts (knickpoints) or knickzones | | | | | 1 | | | | | | | |
| P-Chan-3 | ▶ Evolution of single thread channel to multiple channels | | | | | | | | | | | 1 | |
| P-Chan-4 | ▶ Formation of chutes | | | | | | | | | | | 1 | |
| P-Chan-5 | ▶ Cutoff channels | | | | | | | | | | | 1 | |
| P-Chan-6 | ▶ Formation of islands | | | | | | | | | | | 1 | |
| P-Chan-7 | ▶ Evolution of pool-riffle for to low bed relief form | | | | | | | | | | | 1 | |
| P-Chan-8 | ▶ Thalweg alignment out of phase with meander geometry | | | | | | | | | | | 1 | |
| A-Chan-9 | ▶ Soft, unconsolidated bed (NOT IN POOLS) | 1 | | | | | | | | | | | |
| | **Banks & Overbanks** | | | | | | | | | | | | |
| D-Bank-1 | ▶ Bank height increases from upstream to downstream | | | | 1 | | | | | | | | |
| W-Bank-2 | ▶ Length of bank scour >50% of reach length | | | | | | | 1 | | | | | |
| W-Bank-3 | ▶ Steep bank angles (<1:1) thoughout most of the reach | | | | | | | 1 | | | | | |
| D-Bank-4 | ▶ Suspended armor layer visible in bank | | | | | 1 | | | | | | | |
| A-Bank-5 | ▶ Deposition in overbank zone | | 1 | | | | | | | | | | |
| W-Bank-6 | ▶ Bank failure/ severe bend scour / tension cracks | | | | | | | 1 | | | | | |
| | **Bends** | | | | | | | | | | | | |
| W-Bend-1 | ▶ Basal scour on the inside of meander bends | | | | | | | 1 | | | | | |
| | **Riffles** | | | | | | | | | | | | |
| A-Riff-1 | ▶ Coarse materials embedded | | 1 | | | | | | | | | | |
| W-Riff-2 | ▶ Toe erosion on both sides of channel through riffle | | | | | | | 1 | | | | | |
| | **Pools** | | | | | | | | | | | | |
| A-Pool-1 | ▶ Siltation in the bottom of pools | 1 | | | | | | | | | | | |
| | **Bars** | | | | | | | | | | | | |
| A-Bar-1 | ▶ Lobate (lateral) bars | 1 | | | | | | | | | | | |
| A-Bar-2 | ▶ Mid-channel bars | | 1 | | | | | | | | | | |
| D-Bar-3 | ▶ Absence of bars | | | | | 1 | | | | | | | |
| P-Bar-4 | ▶ Bar forms poorly formed/reworked/removed | | | | | | | | | | | 1 | |
| A-Bar-5 | ▶ Accretion on point bars | 1 | | | | | | | | | | | |
| A-Bar-6 | ▶ Poor logitudinal sorting of bar materials | 1 | | | | | | | | | | | |
| D-Bar-7 | ▶ Cut faces on bar forms | | | | | 1 | | | | | | | |
| | **Trees** | | | | | | | | | | | | |
| W-Tree-1 | ▶ Fallen/leaning trees/fence posts/etc. | | | | | | | 1 | | | | | |
| W-Tree-2 | ▶ Exposed tree roots | | | | | | | 1 | | | | | |
| W-Tree-3 | ▶ Occurrence of large organic debris | | | | | | | 1 | | | | | |
| | **Infrastructure & Buildings** | | | | | | | | | | | | |
| D-Str-1 | ▶ Stormsewers - outfalls | | | | | 1 | | | | | | | |
| D-Str-2 | ▶ Stormsewers - downstream scour pools | | | | | 1 | | | | | | | |
| D-Str-3 | ▶ Bridges/In-Line Culverts - Footings Exposed | | | | | 1 | | | | | | | |
| D-Str-4 | ▶ Perpendicular Utilites (Non-Aerial) Exposed | | | | | 1 | | | | | | | |
| W-Str-5 | ▶ Longitudinal Underground Utilities Exposed | | | | | | | | 1 | | | | |
| D-Str-6 | ▶ Structures - Undermined | | | | | | 1 | | | | | | |
| W-Str-7 | ▶ Structures - Flanked | | | | | | | | | 1 | | | |
| W-Str-8 | ▶ Structures - Building Foundations | | | | | | | | | 1 | | | |
| | **TOTALS** | **5** | **3** | **0** | **2** | **8** | **1** | **8** | **1** | **2** | **0** | **7** | **0** |
| | SUM OF PROCESS | 8 | | | 11 | | | 11 | | | 7 | | |
| | NUMBER OF APPLICABLE PROCESSES | 8 | | | 10 | | | 9 | | | 7 | | |
| | PROCESS SCORE (FRACTION) | 5/8 | | | 2/10 | | | 8/9 | | | 0/7 | | |
| | PROCESS SCORE (DECIMAL) | 0.63 | | | 0.2 | | | 0.89 | | | 0 | | |
| | **STABILITY INDEX (SI)** | **0.43** | | | | | | | | | | | |

| SI Value | Stability Class | Description |
|---|---|---|
| SI<=0.25 | In Regime | Metrics describing channel form are within the expected range of variance (typically accepted as one standard deviation from the mean) for stable channels of similar type. |
| 0.25<SI<0.4 | Transitional | Metrics are within the expected range of variance as defined above but with evidence of stress. |
| SI>0.4 | In Adjustment | Metrics are outside of the expected range of |

## 3.3 RGA RESULTS

### 3.3.1 Blanchette Creek Watershed

7 reaches were evaluated within the Blanchette Creek Watershed. 57% of the reaches have stability index scores within the "Transitional" range, 29% have stability index scores within the "In Regime" range, and the remaining 14% have stability index scores within the "In Adjustment" range. Reach #1 at the confluence with the Missouri River has the highest stability index of 0.49 and is reflective of active widening and aggredation processes. The predominate feature of Reach #2 is a high but stable headcut into bedrock that control the grade of the channel upstream. Reach #4 and all upstream reaches are in the "Transitional" range, but only Reach #4 poses risks to adjacent properties. Note that the rapid geomorphic assessment was conducted in March 2016 after a significant flood event in December 2015 that severely impacted the streams in the City.

### 3.3.2 Boschert Creek Watershed

36 reaches were evaluated within the Boschert Creek Watershed. 61% of the reaches have stability index scores within the "Transitional" range, 22% have stability index scores within the "In Regime" range, and the remaining 17% have stability index scores within the "In Adjustment" range. Much of Boschert Creek has been straightened in the past. In response, Boschert Creek is now widening and is re-establishing meanders in several locations. In particular, the areas downstream of I-370 should be monitored. A significant portion of this area has an adjacent levee, and as the meanders and widening increase, the stability of the levee will be compromised.

### 3.3.3 Cole Creek Watershed

55 reaches were evaluated within the Cole Creek Watershed (including the East Branch of Cole Creek). Approximately 15% of the reaches have a stability index score in the "In Regime" range from below 0.25. The remaining 47 reaches are almost equally divided with stability indices in the "Transitional" and "In Adjustment" ranges. The "In Adjustment" reaches are located downstream of I-370, between Lake Forest Drive and Willow Brook Court, between Elmhurst Drive and Indian Trail Drive, and upstream of Zhumbehl Road. Upstream of Muegge Road, Cole Creek is adjusting in response to the change in flow patterns resulting from the relatively recent construction of Spring Mill Lake. Between Lake Forest Drive and Willow Brook Court, Cole Creek has downcut and is now actively widening. Widening is also active downstream of I-370 and between Elmhurst Drive and Indian Trail Drive.

### 3.3.4 Crystal Springs Watershed

For Crystal Springs, the majority of stream reaches have a stability index score in the "Transitional" range between 0.25 and 0.40. From the Southern Oaks Subdivision at S. Fifth Street to Rio Vista Drive the stability indices are "In Regime" which is reflective of past stabilization projects on these two reaches. Between Rio Vista Drive and South River Road and upstream of the Southern Oaks Subdivision have stability indices in the "In Adjustment" range. It should be noted that upstream of Reach #4, most of the reaches lie within St. Charles County.

### 3.3.5 Sandfort Creek Watershed

49 reaches were evaluated within the Sandfort Creek Watershed. 47% of the reaches have stability index scores within the "Transitional" range, 16% have stability index scores within the "In Regime" range, and the remaining 37% have stability index scores within the "In Adjustment" range. In general, the reaches north of I-70 are in the worst condition. The majority of reaches in the watershed were severely impacted by the December 2015 flood event that resulted in widespread bank failures. Consequently, several of the reaches have accelerated rates of widening in response to the flood event. Much of the lower one-half of the watershed has wide riparian corridors that allow the stream to adjust without significantly impacting improved properties. Naturally, encroachments into the riparian corridor places improvements at a greater risk to stream adjustments.

### 3.3.6 Taylor Branch Watershed

30 reaches were evaluated within the Taylor Branch Watershed. 63% of the reaches have stability index scores within the "Transitional" range, 23% have stability index scores within the "In Regime" range, and the remaining 13% have stability index scores within the "In Adjustment" range. In the watershed, widening and degradation are the predominate, active geomorphic processes. Several of the reaches upstream of Kunze Road have downcut to bedrock. Generally, the riparian buffer along the reaches provides sufficient protection of the adjacent properties, and only two reaches appear to pose a risk to properties. Note that the rapid geomorphic assessment was conducted in March 2016 after a significant flood event in December 2015 that severely impacted the streams in the City.

### 3.3.7 Warwick Watershed (Downstream of Warwick Lake)

Two reaches downstream of Warwick Lake were assessed and found to be in the "In Regime" range. Degradation and widening are moderately active, but the wide riparian corridor along the reaches accommodates adjustment without significant impact to adjacent improved properties.

Note that a sanitary manhole on the right descending bank of the reach downstream of Warwick Lake has been exposed, and the reach should be monitored for future impacts to the sewer line.

### 3.3.8 Webster Branch Watershed

6 reaches were evaluated within the Webster Branch Watershed.  33% of the reaches have stability index scores within the "Transitional" range, and 67% have stability index scores within the "In Adjustment" range. None of the reaches score in the "In Regime" range. Widening is very active in the watershed and the high banks are unstable and there have been numerous bank failures.  Reach #1 immediately upstream of South River Road has the highest risk to adjacent properties and bank failures threaten the adjacent road to Webster Park. Note that the rapid geomorphic assessment was conducted in March 2016 after a significant flood event in December 2015 that severely impacted the streams in the City.

# SECTION 4 RISK ANALYSIS

## 4.1 FLOOD RISK AND DAMAGES

The risk of flooding and the associated damages were evaluated for the 2, 5, 10, 15, 25, 50, and 100-year return interval hydrologic events. The first step in the evaluation was to determine the depths of flooding from the stream, overland flow, and inlet ponding sources. Next, the depths of flooding were compared to the elevations of habitable structures to determine the extent of flooding within the structure. Damage curves representing the cost of water damage based on the depth of flooding within the structure was used to compute the damage costs. Refer to Appendix B for a flow chart depicting the processes described in this section for determining the flood damages.

## 4.2 DEPTH OF FLOODING BY SOURCE

### 4.2.1 Stream Depth of Flooding

XP-SWMM was used to model the hydraulics of the enclosed and open channel stormwater collection and conveyance system. For the streams, each reach is modeled as a “link” with an upstream and downstream water surface elevation computed for each return interval evaluated. For each return interval, the depth of flooding is computed by importing the XP-SWMM node water surface elevation (WSEL) into GIS as 3-D points. The 3-D point is converted to a digital elevation model (DEM) representing the WSEL. Then, the DEM is limited (also called clipped) to a polygon that represents the limits of the waterway valley. This limits the influence of nodes in other parts of the system in the surface calculation. The existing surface DEM is then subtracted from the WSEL DEM and all negative values are removed. The resulting DEM is the depth of flooding.

### 4.2.2 Inlet and Overland Flow Depth of Flooding

When the flowrate of a rain event exceeds the inlet capacity, water will pond, and when the ponding depth overtops the depression, the ponding area will the water will follow an overland flow path until it re-enters the sewer system at an inlet or discharges into a stream. The computed water surface elevations (WSEL) for each node in the sewer system and overland flow paths are imported into GIS as 3-D points. The 3-D WSEL points are then used to create a digital elevation model (DEM) representing the WSEL and the DEM is bounded by a polygon that represents the limits of flooding impacts based on the terrain. The existing surface DEM is then subtracted from the WSEL DEM and all negative values are removed. The resulting DEM is the depth of flooding for inlet surcharging and overland flow.

### 4.2.3 Composite Depth of Flooding

The digital elevation models (DEMs) for streams and for inlets and overland flows are useful for identifying the source of flooding at a location, but to simplify and the analysis, the two DEMs by flooding source are composited into a single DEM. This is accomplished in GIS using the "Mosiac" tool that combines two raster datasets, in this case the two DEMs. Where the pixels from each DEM overlap each other, the larger of the two values is retained. Thus, the composited DEM is the max depth of flooding for a particular event resulting from all flooding sources. This same process is also applied to create a composite water surface elevation DEM for use in the habitable structure damage analysis.

## 4.3 INHABITABLE STRUCTURE FLOODING

The term inhabitable structure refers to buildings that are used by people, such as homes and buildings used for commercial and industrial purposes. For the sake of brevity, these will simply be called "structures". A key to determining the flooding impact to a structure is understanding the depth of flooding relative to the configuration of the structure to the existing ground surface. That is, does the structure have a basement or is on an at-grade slab. The St. Charles parcel database lacks the basic data to determine if basements are present for structures. Therefore, assumptions for the analysis were developed and are documented in the following section.

### 4.3.1 Initial Inhabitable Structure Floor Elevation Assessment

St. Charles County maintains a GIS database of all building footprints in the county. The building footprints are intersected with the ground terrain digital elevation model, and tools within GIS are used to extract the maximum and minimum elevations that intersect the building. Using these elevations, the following assumptions are made in determining the building configuration.

**Finished Floor Elevations**

- For all structures, except mobile homes, the finished floor elevation is determined by adding 1 foot to the maximum ground elevation within the footprint of the structure.
- For mobile homes, the finished floor is determined by adding 4 feet to the average of the maximum and minimum ground elevations within the footprint of the mobile home.

**Low Sill Elevations**

- For mobile homes and structures without basements, the low sill elevation was set to the finished floor elevation. A structure was assumed to not have a basement if the difference between the maximum and minimum ground elevation within the structure footprint is less than or equal to 2 feet.
- For structures with a walkout basement, the low sill elevation was set to 0.5 feet above the minimum ground elevation within the structure footprint. A structure was assumed to have a walkout basement if the difference between the maximum and minimum ground elevation within the structure footprint is greater than 6 feet.
- For structures with a basement but without a walkout, the low sill elevation was set based on one of two conditions:
  - If the difference between the maximum and minimum ground elevations is between 2 and 4 feet, the low sill elevation was set to 1 foot plus the minimum ground elevation.
  - If the difference between the maximum and minimum ground elevations is between 4 and 6 feet, the low sill elevation was set to 3 feet plus the minimum ground elevation.

Critical to this analysis is evaluating the validity of the above assumption, particularly when the flood elevation is at or near the elevation that would allow the building to begin flooding given the accuracy of the digital terrain model is plus or minus 1 foot. For this reason, 306 buildings were inspected and/or surveyed to determine building elevations and the presence or absence of basements.

## 4.4 FLOOD DAMAGES

The damage caused by flooding is related to the depth of flooding and frequency of flooding with respect to an expected level of protection provided during a project's life.

### 4.4.1 Project Life

Project life defines the period for which all costs (construction and damages) can be compared equally. The project life is decided upon at the beginning of the project based on the typical engineering life of the proposed solution. For this project, a 50 year life will be used.

### 4.4.2 Flood Return Periods and Probability

If a particular magnitude, or greater, flood occurs on average once every *T* years, then *T* is called the return period. The probability, *P*, of such an event in any year is determined by $P=1/T$. For example, a flood with a magnitude that occurs on average once every 5 years is referred to as a 5-year flood (or event) and has the probability of being exceeded in any given year of 20%. The idea of a return period is useful for evaluating the risk for a structure to be damaged from flooding. For the study, the following return intervals were evaluated: 2-year, 5-year, 10-year, 15-year, 25-year, 50-year, and 100-year.

### 4.4.3 Depth of Structure Flooding

The depth of structure flooding for each analyzed flood return period is computed for each structure by subtracting the structure finished floor elevation from the maximum water surface elevation intersecting the structure for the respective return period.

### 4.4.4 Structure Damage

Flood damage to a building is related to two factors: How much does it cost to restore the building and what is the cost to replace the contents of the building. Both the restoration and content replacement costs are related to the depth of flooding, and the content replacement cost is dependent on the type of the building use (residential, commercial, industrial, etc.). Using guidance from studies by the U.S. Army Corps of Engineers, the contents replacement cost is evaluated at 50% of the assessed value of the building regardless of usage type, unless local surveys are conducted. For this study, content replacement cost will be assessed at 50% of the assessed building cost. The structure damage (restoration cost) is determined by applying a damage curve where the percent cost of the assessed value increases based on the depth of flooding in the structure by floor type. For each building the structure cost and contents replacement cost will be determined accordantly to estimate the total damage cost caused by the flood depth for each respective return interval event over the determined project life. For example, if the damage cost for a 5-year event is $10,000 and the project life is 50 years, then the total damage cost for a 5-year event over 50 years is 50 years/5 year times $10,000 which equals $100,000. Likewise the damage costs for the other return intervals in the evaluation would be calculated and summed to determine the total structure damage of the project life.

The structure damages for residential, commercial, and industrial buildings are a function of the flood depth and the total market value of the property, and the damage curve tables are shown below. However, damages for other types of structures were determined as follows:

- Sheds – flood damages were not determined
- Detached Garages - $3,000 per flooding occurrence
- Basements - $25,000 per flooding occurrence
- Mobile Homes - $52,500 per flooding occurrence (includes a 1.5 multiplier for contents replacement)

**Table 4-1: Flood Depth Damage Curves for Structure Types**

| | Damage Cost of Assessed Total Market Value | | |
|---|---|---|---|
| **Flood Depth from 1st Floor** | **Single Family Residential** | **Multi-Family Residential** | **Commercial or Industrial** |
| -1 feet ≤ Depth < 0 feet | 8% | 0 | 0 |
| 0 feet ≤ Depth < 1 feet | 11% | 6% | 8% |
| 1 feet ≤ Depth < 2 feet | 18% | 16% | 45% |
| 2 feet ≤ Depth < 3 feet | 20% | 19% | 64% |
| 3 feet ≤ Depth < 4 feet | 23% | 22% | 74% |
| 4 feet ≤ Depth < 5 feet | 28% | 27% | 76% |
| 5 feet ≤ Depth < 6 feet | 33% | 32% | 80% |
| 6 feet ≤ Depth < 7 feet | 38% | 35% | 81% |
| 7 feet ≤ Depth < 8 feet | 44% | 36% | 82% |
| 8 feet ≤ Depth < 9 feet | 49% | 44% | 82% |
| 9 feet ≤ Depth < 10 feet | 51% | 48% | 82% |
| Depth ≥ 10 feet | 53% | 50% | 82% |

### 4.4.5 Flood Damage Results

Maps summarizing the flood damages for the watersheds are included in Appendix D.

## 4.5 STREAM EROSION RISK

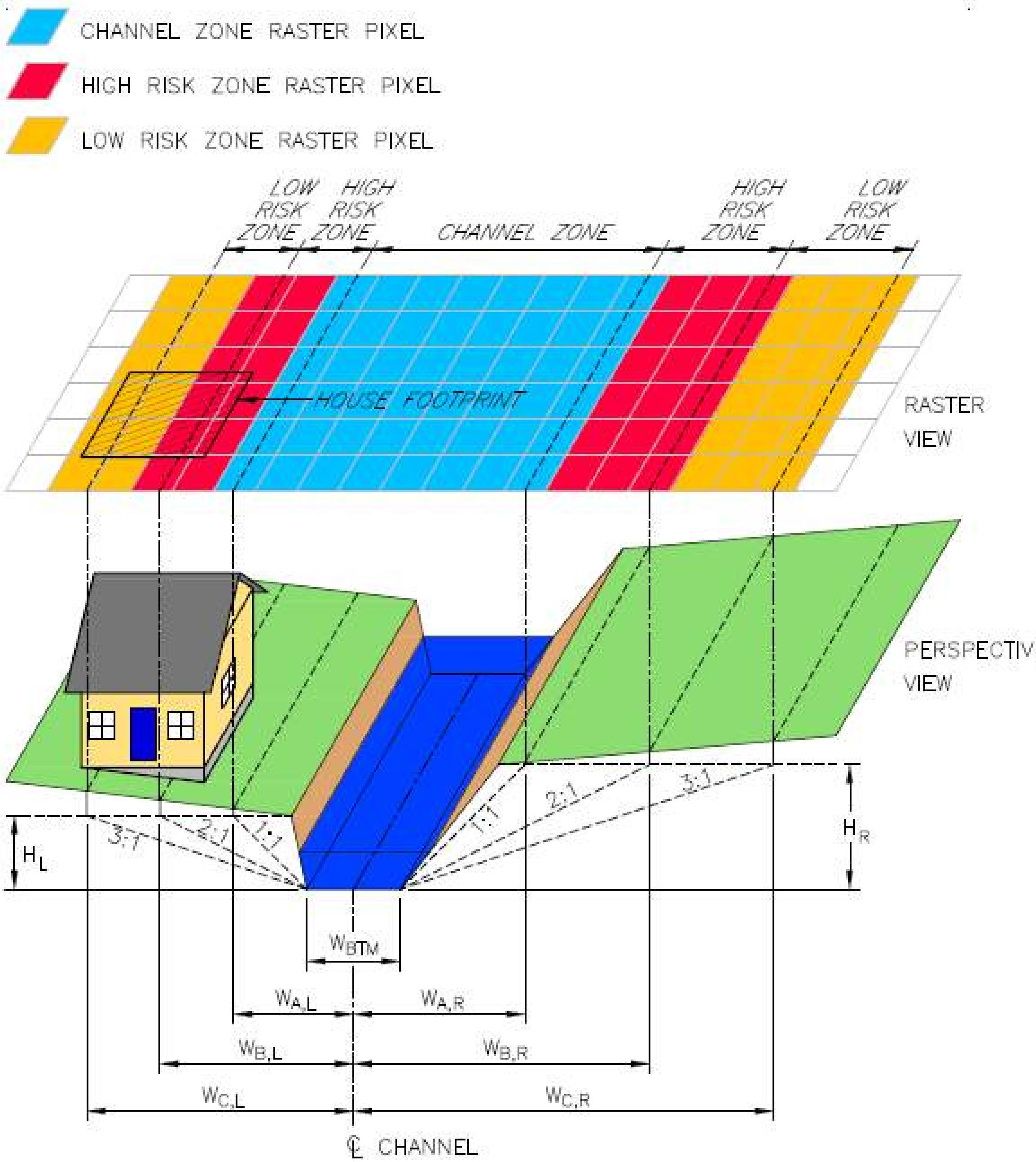
GIS was used to develop a tool to automate the process of quantifying the risk to structures, properties, and sanitary sewer infrastructure, as well, assessing the damage potential due to stream erosion. This process is described in detail in the following sections, and a flow chart of the GIS process is included in Appendix C.

### 4.5.1 Define Stream Risk Zones

The first step in analyzing the potential risk of eroding streams is to identify risk zones in the stream corridor. Figure 4-1 illustrates the methodology. Defining the risk zones involves the following steps:

- Define the approximate centerline of the stream channel in GIS for each reach
- For each reach populate the GIS database with the average bank heights for each bank and the average distance between the toe of the banks (i.e, the bottom width of the channel).
- Determine the extents of the "Channel Zone". The Channel Zone is defined as the area within the channel that actively conveys flow along with the portion of the top of banks that lie within the limits of a minimally stable bank slope. Bank slopes within a channel vary, but are generally between a vertical face to a slope of 1 horizontal to 1 vertical (or 45 degrees measured from a horizontal plane). Therefore, the Channel Zone for each side of the reach is determined by offsetting the reach centerline by a distance computed by the respective average bank height multiplied by the horizontal component of the maximum slope (1) plus one-half the average channel width. The offset line is then converted to a polygonal feature.
- Determine the extent of the "High Risk Zone". The High Risk Zone is the overbank area that is adjacent to the Channel Zone and is at high risk for stream erosion based on the potential for the bank slope to adjust to a minimally stable slope based on typical geotechnical parameters. Based on M3's experience of performing stream stabilization projects in St. Charles and the surrounding region, the minimally stable slope for natural channel banks is typically 2 horizontal to 1 vertical (or 26.6 degrees measured from a horizontal plane). Thus, the High Risk Zone can be determined in GIS by offsetting the reach centerline by a distance computed by the respective average bank height multiplied by the horizontal component of the High Risk Bank Slope (2) plus one-half the average channel width. The offset line is then converted to a polygonal feature, and a ring feature is created by subtracting the High Risk Zone polygon from the Channel Zone polygon.

- Determine the extent of the “Low Risk Zone”. The Low Risk Zone is the overbank area adjacent to the High Risk Zone that has potential for erosion in the future as the stream continues to adjust to reach a dynamically stable plan form. To determine the Low Risk Zone outer boundary, the decision was made to base the limit on a bank with a slope of 3 horizontal to 1 vertical (18.4 degrees measured from a horizontal plane) from the toe of slope for the respective bank. The computation for determining the distance from the reach centerline to the outer boundary of the Low Risk Zone is similar to the method for the High Risk Zone. The reach centerline is offset by a distance computed by the respective average bank height multiplied by the horizontal component of the Low Risk Bank Slope (3) plus one-half the average channel width. The offset line is then converted to a polygonal feature, and a ring feature is created by subtracting the Low Risk Zone polygon from the High Risk Zone polygon.
- Once the polygon feature for the Channel Zone and the ring features for the High Risk Zone and the Low Risk Zone have been defined, the features are converted to a raster to assist in future calculations. A raster is a two-dimensional, horizontal grid onto which the polygon and ring features are projected. The grid is made up of uniformly sized squares, or pixels, with a user defined resolution (i.e., a resolution of 5 produces squares that measure 5 units along each side). Each pixel has a value that corresponds spatially to the projected risk zone.




| ANALYSIS ZONE | LEFT BANK | RIGHT BANK |
|---|---|---|
| CHANNEL ZONE | $W_{A,L}=\frac{1}{2}W_{BTM}+H_L$ | $W_{A,R}=\frac{1}{2}W_{BTM}+H_R$ |
| HIGH RISK ZONE | $W_{B,L}=\frac{1}{2}W_{BTM}+2H_L$ | $W_{B,R}=\frac{1}{2}W_{BTM}+2H_R$ |
| CHANNEL ZONE | $W_{C,L}=\frac{1}{2}W_{BTM}+3H_L$ | $W_{C,R}=\frac{1}{2}W_{BTM}+3H_R$ |

**Figure 4-1: Visualization for determining stream erosion risk zones and projecting onto a raster.**

### 4.5.2 Building Risk

The closer a building (structure) is to the stream channel, the greater the potential risk for damage. This is quantified by creating a raster with the same resolution as the raster that defines the stream erosion risk zones. Next each raster is populated by location within a stream erosion risk zone as follows:

- Buildings in the Channel Zone are assigned to be at 100% risk (1.00 multiplier)
- Buildings in the High Risk Zones are assigned to be at 100% risk (1.00 multiplier)
- Buildings in the Low Risk Zones are assigned to be at 90% risk (0.90 multiplier)

### 4.5.3 Yard Erosion Risk

The risk of properties to yard erosion along streams varies depending on the stream erosion risk zone. The rationale for assigning risk for yard erosion is that property within the Channel Zone is within an area of creek where loss should be expected to occur as a natural condition of the stream dynamics. Outside the Channel Zone, the risk decreases with increasing distance from the stream centerline. This is quantified by creating a raster with the same resolution as the raster that defines the stream erosion risk zones. Next each raster is populated by location within a stream erosion risk zone as follows:

- Property in the Channel Zone are assigned to be at 0% risk (0 multiplier)
- Property in the High Risk Zones are assigned to be at 100% risk (1.00 multiplier)
- Property in the Low Risk Zones are assigned to be at 90% risk (0.90 multiplier)

### 4.5.4 Sanitary Sewer Risk

Because of the natural terrain, sanitary sewers typically follow streams and are in close proximity to the stream banks. Consequently, sewers can be at risk is the stream begin to downcut, widen, or meander. The risk for each pipe segment contained within the polygonal boundary for each of the risk zones was assigned as follows:

- Sewers in the Channel Zone are assigned to be at 100% risk (1.00 multiplier)
- Sewers in the High Risk Zones are assigned to be at 100% risk (1.00 multiplier)
- Sewers in the Low Risk Zones are assigned to be at 90% risk (0.90 multiplier)

## 4.6 STREAM EROSION DAMAGES

Stream erosion damages are the product of the risk factor for erosion and the assessed property value for both buildings and land. This analysis is performed for buildings and land cost for each parcel as a raster calculation within GIS and summed for all pixels within a stream reach to produce a total damage cost weighted by relative risk.

### 4.6.1 Yard Erosion Damages Computation

To determine the yard erosion damages, the following steps are followed:

- The St. Charles County GIS parcel dataset is modified to create a new field that calculates the land cost per square foot for each parcel.
- The polygons that represent each parcel in the County's parcel database is converted to a raster dataset with the pixel resolution set to the same resolution as the stream erosion risk zone dataset, and the pixel value is populated with the land cost per square foot.
- Next, the Yard Damage raster dataset is created and contains the product of the Property Risk Factor and the Land Cost per square foot in each pixel (see Figure 4-2).

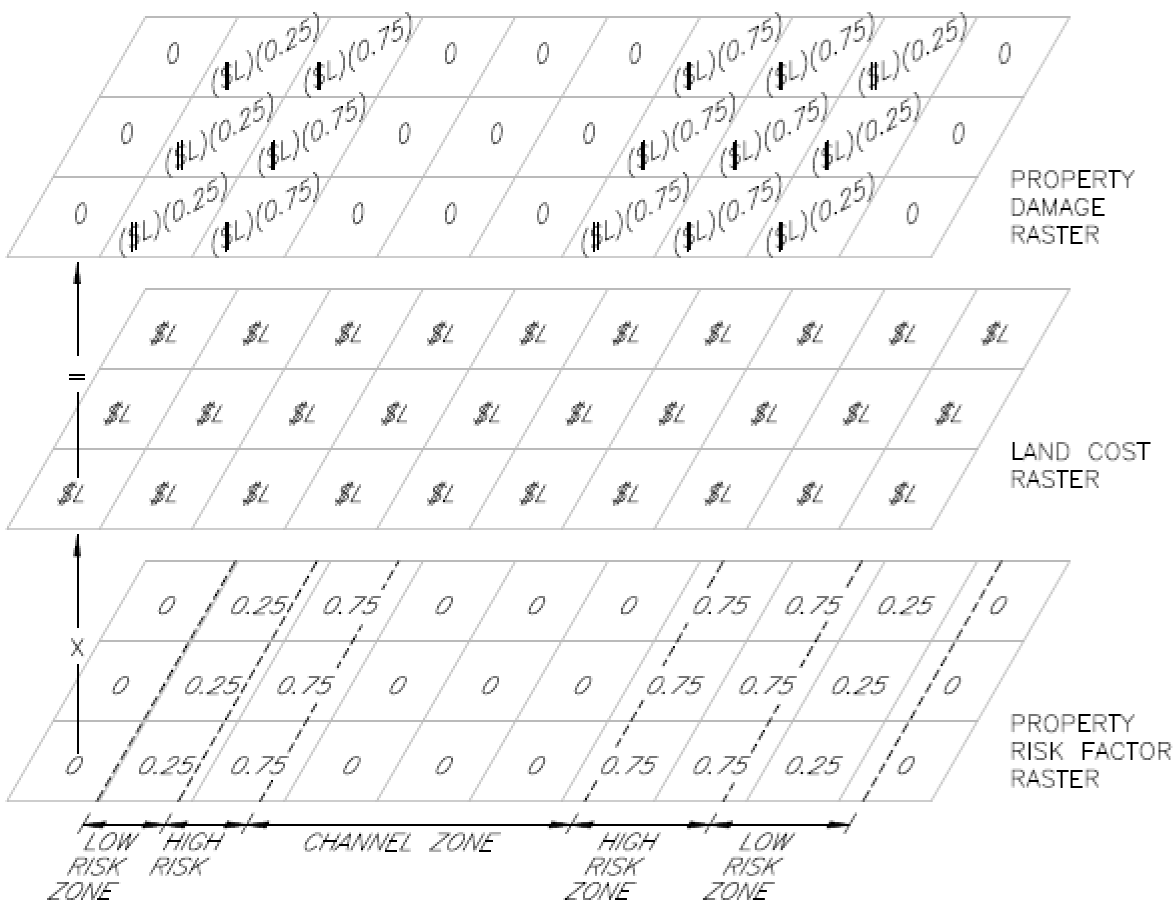



**Figure 4-2: Raster Computation of Yard Damage**

### 4.6.2 Building Damages Computation

To determine the building damages, the following steps are followed:

- The St. Charles County GIS Parcel and Building Footprint datasets are joined together.
- For each building except sheds, the building cost is computed by dividing the appraised value by the area of the building footprint. Sheds are assigned a cost of $5,000 each.
- The polygons that represent each building footprint is converted to a raster dataset with the pixel resolution set to the same resolution as the stream erosion risk zone dataset, and the pixel value is populated with the building cost per square foot.
- Next, the Building Damage raster dataset is created and contains the product of the Building Risk Factor and the Building Cost per square foot in each pixel (see Figure 4-3).

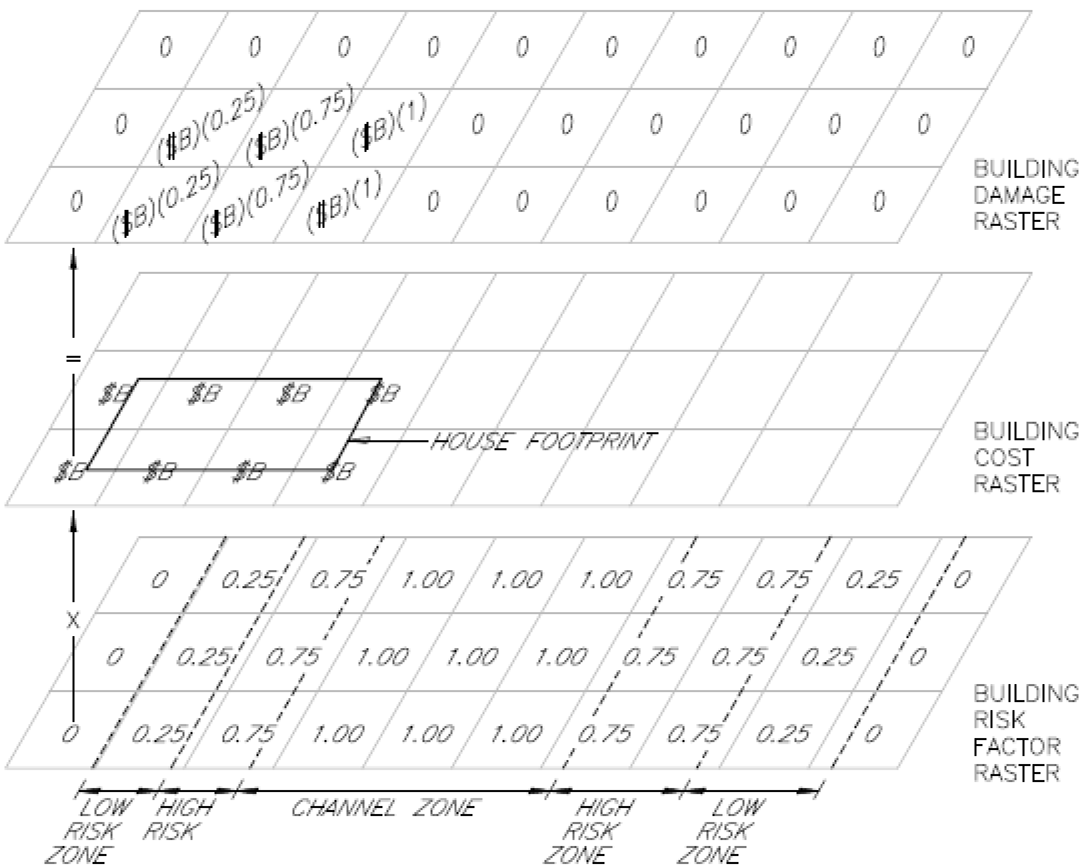



**Figure 4-3: Raster Computation of Building Damage**

### 4.6.3 Sanitary Sewer Infrastructure Damage

The potential damaged to sanitary sewers was determined by multiplying the risk factor based on in which risk zone the pipe is located, the length of pipe potentially impacted, the unit cost of pipe based on the diameter, and a factor of 1.5 for incidental construction.

### 4.6.4 Stream Erosion Damages Computation

Finally, to determine the total stream damages for each reach, the property damage raster and the building data raster datasets are added together and multiplied by the number of pixels with a non-zero value and then multiplied by the square of the pixel resolution to yield a total dollar cost in potential damages caused by stream erosion.  Then, the sanitary construction costs were added to determine the total damage cost per reach.

### 4.6.5 Stream Erosion Damages Results

Maps summarizing the stream erosion damages for the watersheds are included in Appendix E.

# SECTION 5 PROJECT IDENTIFICATION

## 5.1 IDENTIFYING THE PROBLEM AND THE SOLUTION

Using the tools described in Section 4, the computed damages for flooding risks and stream erosion risks will be mapped in GIS. GIS assists in the analysis by providing the necessary underlying data while facilitating verification of the computed risks and associated damages with the observations and knowledge base of the Public Works staff through visualization. Additionally, visualization through mapping allows cause-and-effect sources and patterns to be more readily identified and understood, thereby leading to comprehensive solutions.

### 5.1.1 Stream Erosion

As discussed in Section 3, all streams are in various states of change as they adjust to be in dynamic equilibrium. The Stability Index computed for the reaches through the rapid geomorphic assessment help identify the underlying driving process(es) and quantify the relative stability. The four principal driving processes are planimetric form adjustment, aggedation, degedation, and widening. Each of the processes were scored in the rapid geomorphic assessment and the processes with high scores are indicative of the forces driving the adjustment of the reach. Generally speaking, the streams in St. Charles are primarily driven by degredation and/or widening.

Projects were identified along entire reach lengths and not merely at the location of an identified problem area within a specific reach. The reason for this that a problem area or “hot spot” in one location is indicative of a larger set of variables that is causing the stream to adjust, and these variable must be addressed holistically to provide a comprehensive and lasting solution. Experience has demonstrated that spot repairs work for only a short time, and ultimately they shift the problem to another area along the stream. This approach leads to a series of spot repairs. Therefore, project costs, including construction and engineering, were determined based on the linear foot of bank impacted for each reach. The construction estimate is based on stabilizing impacted stream banks using biostabilization techniques at a cost of $500 per linear foot of bank. However, in some confined areas retaining walls will be required and were estimated at a cost of $70 per square foot of wall face. Engineering costs were estimated at 30% of the construction costs. The lengths of each type of construction technique along with costs and engineering estimates are included in the project preliminaries contained in Appendix G.

### 5.1.2 Flooding

The enclosed stormsewer system and open channel flooding depths as modeled for the 2, 5, 10, 15, 25, 50, and 100-year events are mapped in GIS to identify the flooding risk to the corresponding probabilistic return interval. In addition to the mapping, the hydraulic model is used to identify the resulting cause of flooding by determining the hydraulic deficiencies within the system. Once the deficiencies are identified, alternative solutions can be identified to correct the problem based on an accepted level of protection from flooding.

The complete elimination of flooding risk is not typically financially feasible, but reasonable levels of protection can be obtained. For this reason probabilistic design is the standard for addressing what level of protection is desired for a relative risk. For example, dwellings adjacent to streams and rivers are expected to have a low level of risk where in any year there is only a 1% chance of flood waters coming within one foot of flooding a structure. The 1% flood risk is termed the exceedance probability but is more commonly called the 100-year flood event. The accepted exceedance probabilities for corresponding design levels of infrastructure are summarized in Table 5-1.

**Table 5-1: Flood Risk Design Standards**

| Criteria | Exceedance Probability | Return Interval |
|---|---|---|
| Stormsewer Inlet Capacity | 6.67% | 15-Year |
| Stormsewer Conduit Hydraulic Grade Line Less Than or Equal to One Foot Below Low Sill Elevation of Sewer Structures | 6.67% | 15-Year |
| Stormsewer Overflow to Provide Protection of Habitable Structures from Flooding | 1.00% | 100-Year |
| Roadway Culverts to Pass Flow with a Flood Elevation One Foot Below the Roadway Shoulder Elevation | Varies | Varies |
| Roadway Bridges to Pass Flow with a Flood Elevation Not to Exceed the Low Chord Elevation of the Structure | 1.00% | 100-Year |

The alternative solutions will be presented to the City's Public Works Staff in a series of workshops to identify the viability of the alternatives based of staff's direct knowledge of the how the system functions and the impact to the community.

## 5.2 FLOOD DAMAGE REDUCTION PROJECTS

Based on workshops with City Staff, several types of flood damage reduction projects were considered when trying reduce the flood damages. Each project type is summarized below:

### 5.2.1 Floodproofing

Floodproofing is any combination of structural and non-structural additions, changes, or adjustments to structures which reduce or eliminate flood damage to real estate or improved real property, structures and their contents. It is recommended that floodproofing be implemented up to one foot above 100-year flood elevation for a factor of safety and to receive full credit for flood insurance rating for properties within the FEMA floodplain limits. In general, floodproofing provides good value, especially in cases where flooding is isolated. Typically, floodproofing is offered on a voluntary basis. Funding could be administered using a similar approach as the City's lateral insurance program.

### 5.2.2 Culvert Replacement

Culvert replacement is an effective measure for reducing stream flooding. Analysis should account for the impact of the new culvert on downstream water surface elevations. In some cases, increased water levels downstream can be mitigated by providing additional flood plain storage through benching the channel.

### 5.2.3 Storm Sewer Improvements

Portions of the system do not meet the City's design criteria. In these instances, the system is upgraded to meet City design standards, including pipe sizing, material and inlet capacities. Storm sewer improvements typically have the most impact on property owners during construction.

### 5.2.4 Regional Detention

Regional detention can be an effective method for reducing flood damages. Detention provides the greatest benefit in the upper third of the watershed.

### 5.2.5 Buyouts

Buyouts of private property alone do not reduce flood damages, however, when combined with other reduction measures they can be eliminate future flood damages. In order for Buyouts to be successful, the structures on the property will need to demolished or floodproofed. If demolished, the property can then be used for as park land or regional detention. In certain instances, a property can be bought, floodproofed, and then resold. Buyouts are typically only considered in instances where other flood reduction measures are not feasible.

## 5.3 FLOODING ALTERNATIVES

M3 conducted several project alternatives workshops to identify projects and develop potential solutions. Past flooding occurrences and model identified flooding were discussed in detail to develop alternatives. The top alternatives are presented below.

## 5.4 DETERMINING THE BENEFIT/COST RATIO

Based on the project alternative workshops with City Staff, the selected alternatives will be finalized and the construction cost estimated. The project cost included the costs of engineering, property rights acquisition, and construction. The project cost is determined by the cost to initially construct the project and multiplied by the number service lives needed to meet the project life. The service life of a project is the time that the infrastructure can be expected to be physically viable, and the project life is the duration the entire project is expected to function. For example, a corrugated steel pipe has a service life of 25 years, but the desired project life is 50 years. Therefore, the pipe would need to be replaced once during the project life, and the replacement cost would be factored into the project cost.

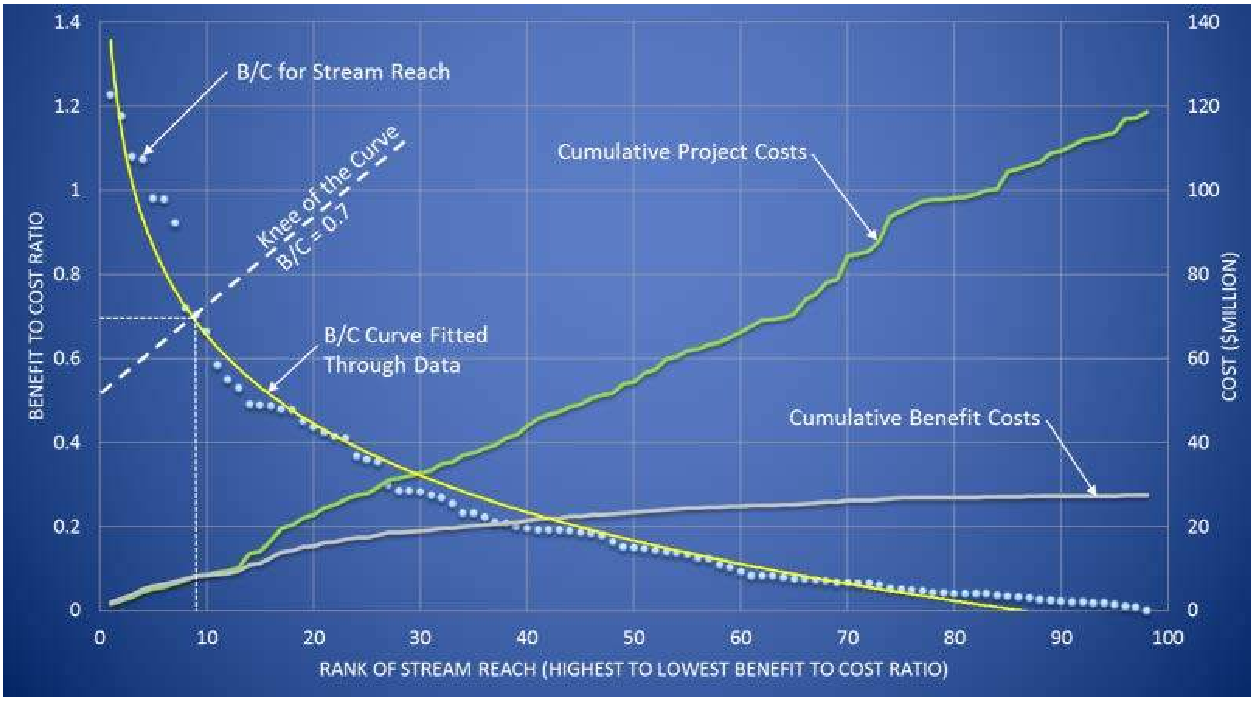
From the flood risk analysis, the potential damage cost is computed, and the removal of the risk through a proposed project represents the benefit to the community in dollars. The benefit/cost ratio is the cost of a project divided by the benefit cost. For example, a reach along a stream has been identified to cause $1,000,000 dollars in damage over the project life, and the cost to construct a project to correct the flooding is $2,000,000. The corresponding benefit/cost ratio is

0.5. If the benefit/cost ratio is less than 1, the project cost exceeds the benefit provided by constructing the project. Conversely, a benefit/cost ratio greater than 1 means the construction cost is less than the corresponding benefit, which is desirable. By looking at the benefit/cost ratio for a range of project alternatives, the optimum alternative can be determined as the one that provides the highest benefit to cost ratio.

### 5.4.1 Stream Erosion Benefit/Cost Ratio Analysis

For each reach, the damages to yards, building and sanitary sewers were determined. These potential damages are the financial benefit the community would experience if the stream reach were to be stabilized to prevent the damage from occurring. Thus, the benefit to cost ratio was determined for each reach by dividing the potential damage costs by the estimated project costs. Next, the reaches were plotted in descending order of benefit to cost ratio (see Figure below).

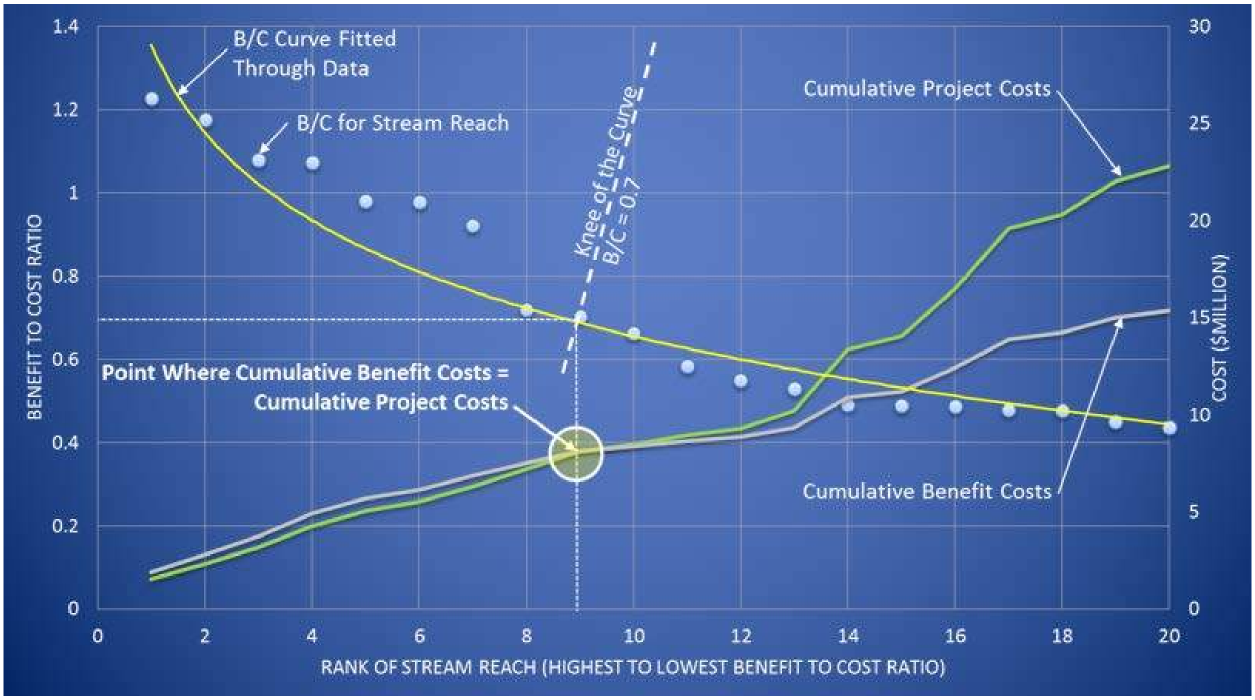
**Figure 5-1: Project Benefit to Cost Ratio Analysis (All Reaches)**




Additionally, the cumulative project costs and benefit costs were plotted. From the graph, it can be seen that the majority of projects have a benefit to cost ratio less than one (meaning the project cost exceeds the benefit cost). Also, the total project costs are $119 million and the total benefit costs are $27 million. To determine at what point projects should be selected to be implemented, the results were analyzed to determine at what point the City would not receive a net benefit from funding projects to remediate stream erosion. This process is termed “knee of the curve analysis”.

If the above figure is looked at using a smaller set of data, as shown below, it becomes apparent that initially the curve for the cumulative benefit is above the cumulative project cost curve. This means that for those projects, the cumulative benefits are greater than the cumulative costs and there is a net benefit to the City. However, at stream reach rank 9, the cumulative benefit and cost curves cross, and there is not a net benefit to the City. This is the “knee of the curve” and is the recommended funding level for the City to use for selecting projects to include in the Capital Improvement Program.

**Figure 5-2: Stream Project Benefit to Cost Ratio Analysis (Top 20 Ranked Reaches)**




The nine projects recommended for inclusion are summarized in the table below, and detailed summary sheets for each project are included in Appendix G.

**Table 5-2: Recommended Stream Erosion Projects**

| Stream Reach | Benefit Cost | Project Cost | B/C |
|---|---|---|---|
| West Branch of Sandfort at Harry S. Trueman | $1,640K | 950K | 1.72 |
| Cole Creek from Zumbehl Rd. Culvert to 1981 Zumbehl Rd. | $1,868K | $1,522K | 1.23 |
| Boschert Creek from 10 Le Chateaux Ct. to 4 Le Chateaux Ct. | $922K | $784K | 1.18 |
| Boschert Creek from Lindenwood Ave. to Pine St. | $959K | $889K | 1.08 |
| Crystal Springs from Rio Vista Dr. to S. River Rd. | $1,166K | $1,086K | 1.07 |
| Boschert from N. Kingshighway St. to Lindenwood Ave. | $768K | $784K | 0.98 |
| Boschert from 1008 Indian Hills Dr. to Duquette Dr. | $461K | $471K | 0.98 |
| Boschert from West Clay St. to 506 Droste Dr. | $715K | $776K | 0.92 |
| Cole Creek from 2216 Graystone Dr. to Fox Glove Dr. | $662K | $922K | 0.72 |
| Boschert from 916 Barton Pl. to Hawthorne Ave. | $613K | $872K | 0.70 |
| | | | |

## 5.5 FLOOD DAMAGE BENEFIT/COST RATIO ANALYSIS

### 5.5.1 Adjustments to the Benefit Cost Ratios

Many times other factors are important or influence the benefits for a given project. For this reason, a two benefit cost ratio adjustments are included to capture items beyond the flood damages.

- **End of Life Adjustment –** Storm sewer infrastructure has a finite life. If infrastructure is near the end of its useful life then a 1.0 factor is added to base benefit cost ratio. This factor accounts for the reality that the infrastructure will have to be replaced regardless of flood damages. This replacement has the benefit of extending the infrastructures life.

- **Water Quality Adjustment –** With the ever changing water quality regulations, promoting projects that have a positive water quality impact is in the best interest of the City. Projects that contain green infrastructure best management practices have a multiplier applied to the base cost benefit ratio. This water quality benefit is based on MSD standard water quality benefit calculation and is added to the overall base benefit cost ratio.

**Table 5-3: Water Quality Adjustment Calculation**

| SOLUTION WQ BENEFIT CATEGORY | | | | | | |
|---|---|---|---|---|---|---|
| 3.0 REGIONAL | 3.1. Reduction of flowrate leaving site | % reduction of peak flowrate : | | Max points: | 1000 | |
| | 3.2. Combines smaller projects into regional solution (see note) | No. Add'l Projects: | | Points per Add'l Proj.: | 50 | |
| 4.0 ENVIRONMENTAL / WATER QUALITY | 4.1. Addresses pollutants: | No. Units | | Points per Unit | | |
| | Bioswales | | PER 100 LF | 10 | | |
| | Forebays | | AC | 200 | | |
| | Wet Ponds | | AC | 100 | | |
| | Wetlands | | AC | 50 | | |
| | Biostabilization of banks (per bank) | | PER 100 LF | 10 | | |
| | Riffle Pool Complex | | PER 100 LF | 10 | | |
| | 4.2. Eliminates combined sewer (per project) | | EA | 100 | | |
| | 4.3. Eliminates inflow into sanitary system (1 each per basement flooded, yard vent overtopped, street inlet or driveway drain connected to sanitary/combined system, etc.) | | EA | 10 | | |
| 5.0 MISC. | 5.1. Ease of Implementation (No. of Easements) | 0-5 (20 pts) | 6-10 (10 pts) | 11-15 (5 pts) | >15 (0 pts) | |
| | Points for Easements | | | 5 | | 5 |
| | 5.2. Recreational/Educational | Yes = 100, no = 0 pts | | | | |
| | | | | | | |
| | | TOTAL WQ BENEFIT POINTS | | | | |

Note: A regional solution combines several smaller projects into a watershed or subwatershed solution.

| | |
|---|---|
| **TOTAL COST IN THOUSANDS=** | **0** |
| **BENEFIT/ COST RATIO= TOTAL POINTS/ TOTAL COST IN THOUSANDS=** | |

**Table 5-4: Recommended Flood Reduction Projects**

| Project | Benefit Cost | Project Cost | B/C | Infrastructure Adjustment | WQ Adjustment | Adjusted B/C |
|---|---|---|---|---|---|---|
| Foxglove Floodproofing | $ 3,000,000 | $ 340,000 | 8.82 | 1.00 | 0.00 | 9.82 |
| Lindenwood Culvert Replacement | $ 2,750,000 | $ 365,000 | 7.53 | 1.00 | 0.00 | 8.53 |
| Shelburne Drive Floodproofing | $ 2,350,000 | $ 445,000 | 5.28 | 1.00 | 0.00 | 6.28 |
| Randolph St Storm Improvements | $ 1,383,836 | $ 520,000 | 2.66 | 1.00 | 0.00 | 3.66 |
| Sunnybrook Storm Improvements | $ 6,740,000 | $ 5,900,000 | 1.14 | 1.00 | 0.00 | 2.14 |
| Buckingham Place Storm Improvements | $ 2,960,000 | $ 2,685,000 | 1.10 | 1.00 | 0.00 | 2.10 |
| Boones Lick Rd and Sixth St Storm Improvements | $ 1,375,500 | $ 1,280,000 | 1.07 | 1.00 | 0.00 | 2.07 |
| 5th Street and Rio Vista Culvert Replacement | $ 2,030,000 | $ 1,960,000 | 1.04 | 1.00 | 0.00 | 2.04 |
| Elm Sibley Culvert Replacement | $ 1,200,000 | $ 1,175,000 | 1.02 | 1.00 | 0.00 | 2.02 |
| Lawrence St and N 2nd Street Storm Improvements | $ 969,354 | $ 1,000,000 | 0.97 | 1.00 | 0.00 | 1.97 |
| Kingshighway Storm Improvements | $ 8,425,000 | $ 9,485,000 | 0.89 | 1.00 | 0.00 | 1.89 |
| Thrush Drive Storm Improvements | $ 296,000 | $ 172,000 | 1.72 | 0.00 | 0.00 | 1.72 |
| Cole and East Branch Cole Buyout | $ 3,375,000 | $ 3,210,000 | 1.05 | 0.00 | 0.59 | 1.64 |
| Clark St Storm Improvements | $ 1,270,000 | $ 2,000,000 | 0.64 | 1.00 | 0.00 | 1.64 |
| Cole Creek from Zumbehl Rd. Culvert to 1981 Zumbehl Rd. | $ 1,868,000 | $ 1,522,000 | 1.23 | 0.00 | 0.20 | 1.43 |
| Old Saybrook Regional Detention | $ - | $ 1,925,000 | 0.00 | 0.00 | 1.40 | 1.40 |
| Seventh St to Boones Lick Rd Storm Improvements | $ 1,557,650 | $ 3,950,000 | 0.39 | 1.00 | 0.00 | 1.39 |
| Boschert Creek from 10 Le Chateaux Ct. to 4 Le Chateaux Ct. | $ 922,000 | $ 784,000 | 1.18 | 0.00 | 0.20 | 1.38 |
| N Benton Ave to N Main Storm Improvements | $ 1,818,374 | $ 5,300,000 | 0.34 | 1.00 | 0.00 | 1.34 |

## 5.6 PROJECT PRELIMINARIES

Each project is summarized in a brief report that identifies the problem the project is intended to address along with the alternatives and corresponding benefit/cost versus risk reduction curves used to identify the selected alternative. The selective alternative is the project that is recommended, and the support information describing the project scope and cost is detailed.

# SECTION 6 PROJECT PRIORITIZATION

## 6.1 PROJECT PRIORITIZATION PROCESS

For the projects identified in this study, the underlying basis for prioritization is the benefit to cost ratio. Initially, all projects will be ranked in order of the lowest to highest benefit/cost ratio for each project type (i.e., flood damage or stream erosion). Next, the individual projects for each project type will be mapped so that the projects can be analyzed spatially. From the spatial analysis it may be desired to group projects in the same category that in close proximity to each other together as a single project to reduce the overall project cost through economies of scale. Likewise, flood damage and stream erosion projects that overlapped each other could be combined to reduce total costs.

## 6.2 PRIORITIZATION

Working with the Public Works Staff, the projects will be initially prioritized based on the benefit to cost ratio after finalization of the project scope based on the project spatial analysis and project combination processes. The ranking of projects will then be analyzed against the planning horizon of the City's current Capital Improvement Plan (CIP). Decisions will then be made if adjustments are needed within the current CIP planning horizon. For projects beyond the current CIP planning horizon, projects will be based on the benefit/cost ratio.

## Table 6-1: Prioritized Capital Projects

| Project | Benefit Cost | Project Cost | B/C | Infrastructure Adjustment | WQ Adjustment | Adjusted B/C |
|---|---|---|---|---|---|---|
| Foxglove Floodproofing | $ 3,000,000 | $ 340,000 | 8.82 | 1.00 | 0.00 | 9.82 |
| Lindenwood Culvert Replacement | $ 2,750,000 | $ 365,000 | 7.53 | 1.00 | 0.00 | 8.53 |
| Shelburne Drive Floodproofing | $ 2,350,000 | $ 445,000 | 5.28 | 1.00 | 0.00 | 6.28 |
| Randolph St Storm Improvements | $ 1,383,836 | $ 520,000 | 2.66 | 1.00 | 0.00 | 3.66 |
| Sunnybrook Storm Improvements | $ 6,740,000 | $ 5,900,000 | 1.14 | 1.00 | 0.00 | 2.14 |
| Buckingham Place Storm Improvements | $ 2,960,000 | $ 2,685,000 | 1.10 | 1.00 | 0.00 | 2.10 |
| Boones Lick Rd and Sixth St Storm Improvements | $ 1,375,500 | $ 1,280,000 | 1.07 | 1.00 | 0.00 | 2.07 |
| 5th Street and Rio Vista Culvert Replacement | $ 2,030,000 | $ 1,960,000 | 1.04 | 1.00 | 0.00 | 2.04 |
| Elm Sibley Culvert Replacement | $ 1,200,000 | $ 1,175,000 | 1.02 | 1.00 | 0.00 | 2.02 |
| Lawrence St and N 2nd Street Storm Improvements | $ 969,354 | $ 1,000,000 | 0.97 | 1.00 | 0.00 | 1.97 |
| Kingshighway Storm Improvements | $ 8,425,000 | $ 9,485,000 | 0.89 | 1.00 | 0.00 | 1.89 |
| Thrush Drive Storm Improvements | $ 296,000 | $ 172,000 | 1.72 | 0.00 | 0.00 | 1.72 |
| Cole and East Branch Cole Buyout | $ 3,375,000 | $ 3,210,000 | 1.05 | 0.00 | 0.59 | 1.64 |
| Clark St Storm Improvements | $ 1,270,000 | $ 2,000,000 | 0.64 | 1.00 | 0.00 | 1.64 |
| Cole Creek from Zumbehl Rd. Culvert to 1981 Zumbehl Rd. | $ 1,868,000 | $ 1,522,000 | 1.23 | 0.00 | 0.20 | 1.43 |
| Old Saybrook Regional Detention | $ - | $ 1,925,000 | 0.00 | 0.00 | 1.40 | 1.40 |
| Seventh St to Boones Lick Rd Storm Improvements | $ 1,557,650 | $ 3,950,000 | 0.39 | 1.00 | 0.00 | 1.39 |
| Boschert Creek from 10 Le Chateaux Ct. to 4 Le Chateaux Ct. | $ 922,000 | $ 784,000 | 1.18 | 0.00 | 0.20 | 1.38 |
| N Benton Ave to N Main Storm Improvements | $ 1,818,374 | $ 5,300,000 | 0.34 | 1.00 | 0.00 | 1.34 |
| Transit St Storm Improvements | $ 949,298 | $ 2,850,000 | 0.33 | 1.00 | 0.00 | 1.33 |
| Boschert Creek from Lindenwood Ave. to Pine St. | $ 959,000 | $ 889,000 | 1.08 | 0.00 | 0.20 | 1.28 |
| Crystal Springs from Rio Vista Dr. to S. River Rd. | $ 1,166,000 | $ 1,086,000 | 1.07 | 0.00 | 0.20 | 1.27 |
| Perry St to Reverside Dr Storm Sewer Improvements | $ 688,575 | $ 2,750,000 | 0.25 | 1.00 | 0.00 | 1.25 |
| Droste Road Regional Detention Basin | $ 6,300,000 | $ 7,800,000 | 0.81 | 0.00 | 0.44 | 1.25 |
| Concordia Culvert Replacement | $ 1,100,000 | $ 926,000 | 1.19 | 0.00 | 0.00 | 1.19 |
| Boschert from N. Kingshighway St. to Lindenwood Ave. | $ 768,000 | $ 784,000 | 0.98 | 0.00 | 0.20 | 1.18 |
| Boschert from 1008 Indian Hills Dr. to Duquette Dr. | $ 461,000 | $ 471,000 | 0.98 | 0.00 | 0.20 | 1.18 |
| Nathan, Gustane and Woodlawn Storm Improvements | $ 404,567 | $ 2,380,000 | 0.17 | 1.00 | 0.00 | 1.17 |
| Boschert from West Clay St. to 506 Droste Dr. | $ 715,000 | $ 776,000 | 0.92 | 0.00 | 0.20 | 1.12 |
| West Clay Regional Detention Basin | $ 1,300,000 | $ 4,600,000 | 0.28 | 0.00 | 0.81 | 1.09 |
| Howard St Storm Improvements | $ - | $ 260,000 | 0.00 | 1.00 | 0.00 | 1.00 |
| Nantucket Detention Basin | $ - | $ 210,000 | 0.00 | 1.00 | 0.00 | 1.00 |
| Cole Creek from 2216 Graystone Dr. to Fox Glove Dr. | $ 662,000 | $ 922,000 | 0.72 | 0.00 | 0.20 | 0.92 |
| Boschert from 916 Barton Pl. to Hawthorne Ave. | $ 613,000 | $ 872,000 | 0.70 | 0.00 | 0.20 | 0.90 |
| Muegge Road Regional Detention | $ - | $ 3,050,000 | 0.00 | 0.00 | 0.51 | 0.51 |
| Hawthorne Culvert Replacement | $ 250,000 | $ 926,000 | 0.27 | 0.00 | 0.00 | 0.27 |
| Hawthorne Floodproofing | $ 37,500 | $ 160,000 | 0.23 | 0.00 | 0.00 | 0.23 |
| Duchesne Culvert Replacement | $ 37,500 | $ 926,000 | 0.04 | 0.00 | 0.00 | 0.04 |

# SECTION 7 WATER QUALITY

## 7.1 WHY SHOULD A COMMUNITY CARE ABOUT WATER QUALITY?

### 7.1.1 Recreation

Stormwater pollution is a serious problem for wildlife dependent on our waterways and for the people who live near polluted rivers, lakes and streams. It can cause a decline in fish populations, disturb habitats and limit water recreation activities. E. Coli (Escherichia coli) bacteria from human and animal waste is often carried in polluted stormwater runoff posing a threat to humans and the overall health of the ecosystem.

### 7.1.2 Source Water

Stormwater pollution can impact our surface waters which directly impacts the source of our drinking water. Water is a staple in our daily lives. We use it for drinking, washing our clothes, showering, watering our lawns and more. As pollution continues to impact drinking water supplies, there will be continued efforts to test and treat contaminants, leading to increasing prices for clean and safe drinking water.Public Health

### 7.1.3 Fish and Wildlife Habitat

Urban development can alter their habitat by polluting water, changing water temperature, degrading in-stream and riparian habitat, and altering the natural flow of rivers and streams. Water pollution creates an unhealthy environment for habitat and wildlife that live in and around waterways. The erosion of sediment into rivers and streams can be detrimental to fish and other aquatic life that need gravel and rocks to spawn and rear their young (i.e. fish and frogs). Sediment can also fill in pools that are an important part of fish habitat.

### 7.1.4 Community Pride

Uncontrolled stormwater pollution affects the way a stream or other water body looks and smells, making it unpleasant to be near. This can impact the quality of life for everyone living in and around a community. Increased nutrients, usually from fertilizers, may cause algae blooms, particularly on ponds and small lakes. These algae blooms not only make the pond look bad, they choke out the other vegetation and aquatic life. Trash and debris in the drainage system can lead to foul odors and may attract rats and other pests. Large amounts of sediment can harm the quality of life and reduce opportunities for recreation due to infilling of creeks, ponds and lakes. If trash reaches the stream, it ruins the beauty for everyone.

### 7.1.5 Regulations

An important cornerstone of the Clean Water Act is the requirement that states, tribes, and territories adopt water quality standards to protect public health, support wildlife, and enhance the quality of life within their jurisdictions. Water quality standards serve as the basis for assessing waters, establishing TMDLs, and setting attainment limits in NPDES permits. Attaining these standards helps to ensure that waters will remain useful to both humans and aquatic life. Standards also drive water quality restoration activities because they help to determine which waterbodies must be addressed, what level of restoration is necessary, and which activities need to be modified to ensure that the waterbody meets its minimum standards.

Standards are developed by designating one or more beneficial uses for each waterbody and establishing a set of criteria that protect those uses. Standards also include an antidegradation policy.

## 7.2 WHAT CONTRIBUTES TO THE DEGREDATION OF WATER QUALITY?

### 7.2.1 Point Sources

Point source pollution, on the most basic level, is water pollution that comes from a single, discrete place, typically a pipe. The Clean Water Act specifically defines a "point source" in section 502(14) of the Act. That definition states:

> *The term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture.*

It is important to remember that not all pipes create point source pollution. Federal and state laws exist that require permits and place limits on many different types of businesses, cities, and industry that may discharge water containing pollutants to a pipe that, in turn, may flow to a river, stream or lake. These limits are set at levels protective of both the aquatic life in the waters which receive the discharge and protective of human health. These laws require water that comes from point sources be treated in modern facilities called wastewater treatment plants. This technology treats and removes pollutants from wastewater so that when the process is completed, the water is safe enough to put back into nearby rivers and streams.

### 7.2.2 Non-Point Sources

Nonpoint source pollution comes from oil, pet waste, pesticide, herbicide, fertilizer, road salt, bacteria, sediment, and any other contaminant that ends up on the ground naturally or from human activity. Rainwater and snowmelt picks up these contaminants as it washes over yards, sidewalks, driveways, parking lots, and fields and deposits them into Missouri's lakes and streams as nonpoint source pollution. Common sources of nonpoint source pollution in Missouri include:

- animal production operations and feedlots;
- agricultural activities;
- stream bank and shoreline erosion;
- timber harvesting;
- land development;
- on-site sewage disposal units;
- solid waste disposal landfills;
- transportation-related facilities;
- coal mining;
- oil and gas production;
- non-energy mineral extraction; and,
- atmospheric deposition.

We tend to group together these sources of nonpoint source pollution into two major categories based on land use – agricultural and urban. Agricultural land is defined as land that is currently in production such as cropland, pastureland, rangeland, native pastureland, other land used to support livestock production, and tree farms. Urban land, in contrast, is forests, wetlands, minelands, and any other area that is developed for housing, roads and businesses (not used for agriculture). Many programs that provide assistance to clean-up nonpoint source pollution rely on these classifications

## Table 7-1 – Typical Pollutant Sources

| Pollutant | Potential Sources | | Impacts on Waterbody Uses |
|---|---|---|---|
| | Point Sources | Nonpoint Sources | |
| Pathogens | • WWTPs | • Animals (domestic, wildlife, livestock) | • Primarily human health risks |
| | • CSOs/SSOs | • Malfunctioning septic systems | • Risk of illness from ingestion or from contact with contaminated water through recreation |
| | • Permitted CAFOs | • Pastures | • Increased cost of treatment of drinking water supplies |
| | • Discharges from meatprocessing | • Boat pumpout facilities | • Shellfish bed closures |
| | facilities | • Land application of | |
| | • Landfills | • Land application of wastewater | |
| Metals | • Urban runoff | • Abandoned mine drainage | • Aquatic life impairments (e.g., reduced fish populations due to acute/chronic concentrations or contaminated sediment) |
| | • WWTPs | • Hazardous waste sites (unknown or partially treated sources) | • Drinking water supplies (elevated concentrations in source water) |
| | • CSO/SSOs | • Marinas | • Fish contamination (e.g., mercury) |
| | • Landfills | • Atmospheric deposition | |
| | • Industrial facilities | | |
| | • Mine discharges | | |
| Nutrients | • WWTPs | • Cropland (fertilizer application) | • Aquatic life impairments (e.g., effects from excess plant growth, low DO) |
| | • CSOs/SSOs | • Landscaped spaces in developed areas (e.g., lawns, golf courses) | • Direct drinking water supply impacts (e.g., dangers to human health from high levels of nitrates) |
| | • CAFOs | • Animals (domestic, wildlife, livestock) | • Indirect drinking water supply impacts (e.g., effects from excess plant growth clogging drinking water facility filters) |
| | • Discharge from foodprocessing facilities | • Malfunctioning septic systems | • Recreational impacts (indirect impacts from excess plant growth on fisheries, boat/swimming access, appearance, and odors) |
| | | • Pastures | • Human health impacts |
| | | • Boat pumpout | |
| | | • Land application of manure or wastewater | |
| | | • Atmospheric deposition | |

**Table 7-1 – Typical Pollutant Sources (Con't)**

| Pollutant | Potential Sources | | Impacts on Waterbody Uses |
|---|---|---|---|
| | Point Sources | Nonpoint Sources | |
| Sediment | • WWTPs | • Agriculture (cropland and pastureland erosion) | • Fills pools used for refuge and rearing |
| | • Urban stormwater systems | • Silviculture and timber harvesting | • Fills interstitial spaces between gravel (reduces spawning habitat by trapping emerging fish and reducing oxygen exchange) |
| | | • Rangeland erosion | • When suspended, prevents fish from seeing food and can clog gills; high levels of suspended sediment can cause fish to avoid the stream |
| | | • Excessive streambank erosion | • Taste/odor problems in drinking water |
| | | • Construction | • Impairs swimming/boating because of physical alteration of the channel |
| | | • Roads | • Indirect impacts on recreational fishing |
| | | • Urban runoff | |
| | | • Landslides | |
| | | • Abandoned mine drainage | |
| | | • Stream channel | |
| Temperature | • WWTPs | • Lack of riparian shading | • Causes lethal effects when temperature exceeds tolerance limit |
| | • Cooling water discharges (power plants and other | • Shallow or wide channels (due to hydrologic modification) | • Increases metabolism (results in higher oxygen demand for aquatic organisms) |
| | • Urban stormwater | • Hydroelectric dams | • Increases food requirements |
| | | • Urban runoff (warmer runoff from impervious | • Decreases growth rates and DO |
| | | • Sediment (cloudy water absorbs more heat than clear water) | • Influences timing of migration |
| | | • Abandoned mine drainage | • Increases sensitivity to disease |
| | | | • Increases rates of photosynthesis (increases algal growth, depletes oxygen through plant decomposition) |
| | | | • Causes excess plant growth |

## 7.3 WHAT IS THE STATUS OF THE EXISTING WATER QUALITY PROGRAM

The City has taken moderate steps in the last decade to address regulatory water quality requirements. However, a more cohesive and enforceable program may be warranted in order to effectively address water quality issues. City documents that focus on water quality include the *Green Point Rating System Guide* to incentivize sustainable development, the City's *Stormwater Management Plan* (part of the 2008-2013 NPDES Permit from MoDNR) and the City Ordinances that deal with stormwater management. The *Green Point Rating System Guide* has met with limited success. The *Stormwater Management Plan* follows MoDNR's guidelines for the 6 Minimum Control Measures and pledges to create ordinances to: promote low impact development, green infrastructure and water quality detention; reduce impervious area and;

require riparian buffers.  The status of the ordinance modifications is unknown, but presumed to be incomplete.  The City's existing ordinance refers to MoDNR Water Quality guidelines that promote green infrastructure, but it is unclear as to exactly what will be required by the City and what the enforcement mechanism is.

### 7.3.1 NPDES Permit

The City of St. Charles, defined as a Small MS4 (Municipal Separate Storm Sewer System) is required to apply for an NPDES (Nation Pollutant Discharge Elimination System) permit under the *Missouri State Operating Permit, General Permit MO-R00400* in order to discharge into waters of the State.  The State's *General Permit MO-R00400*, however, expired on June 12, 2013 and, as of March 2015, the permit has not been renewed.  As part of the renewal process, the State has issued a set of Draft Revised Rules for public comment.  Until the State has renewed its *General Permit MO-R00400,* the City will continue to operate under its existing NPDES permit.

### 7.3.2 City of St. Charles Stormwater Management Plan

The City of St. Charles' existing *Stormwater Management Plan* (SWMP) was developed as part of the requirements for the City's NPDES permit.  As with the NPDES, the City will continue to operate under the current SWMP until the State renews its own *General Permit MO-R00400*. Following are some of the areas covered under the existing SWMP:

#### 7.3.2.1 Six Minimum Control Measures

There are six minimum control measures that operators of regulated Small MS4s must incorporate into stormwater management programs.  These measures are intended to cause significant reductions of pollutants discharged into receiving waterbodies.  The Six Minimum Control Measures are:

1. Public Education and Outreach
2. Public Participation/Involvement
3. Illicit Discharge Detection and Elimination
4. Construction Site Runoff Control
5. Post-Construction Runoff Control
6. Pollution Prevention/Good Housekeeping

In September 2007, the City developed their plan to implement and monitor the control measures.  It appears that the City's control measures have only been partially implemented.

Specifically, several proposed ordinance changes to promote green infrastructure have not yet been implemented.

#### 7.3.2.2 Sustainable Development

On December 8, 2009, the City adopted the *Green Point Rating System Guide*. The purpose of the Green Point Rating System is to provide development incentives for building innovation and sustainable practices. The practices that are encouraged include: runoff reduction, energy efficiency, water use efficiency, access to public transit, recycled materials, sustainable product use, indoor air quality and indigenous plantings. Based on the number of "Green Points" awarded, incentive include:

- Building setback reductions
- Increased allowable building heights
- Increased maximum floor area
- Sign setback reduction
- Parking requirement reductions
- Expedited permit process
- Building permit fee reduction

The *Green Point Rating System Guide* has had limited success in promoting sustainable development practices.

#### 7.3.2.3 Green Infrastructure/Water Quality Detention/ Reduction of Impervious Area/Riparian Buffers

The City has attempted to address these areas through the Six Minimum Control Measures included in the SWMP, specifically *Post-Construction Runoff Control*. The SWMP pledges to:

- Create a Post Construction ordinance that will allow low impact development, utilize water quality enhancing detention practices and reduce impervious area.
- Modify creek bank setback ordinance to include a riparian buffer component and possibly a conservation easement overlay.
- Create an ordinance to specifically address water quality and quantity concerns for redevelopment of existing sites to include micro/bio detention, porous pavement, turf pavement for overflow parking and other low impact elements.
- Review existing detention ordinances and recommend changes to include water quality requirements such as forebays, extended detention and pre vs. post development hydrologic emulation.

The status or these ordinance changes is unknown, but presumed to be incomplete.

### 7.6.3 City Stormwater Ordinances

The following existing City ordinances reference water quality, primarily stomwater management during construction.  There is little reference to post construction water quality practices.

City of St. Charles, MO Ordinance CHAPTER 510: EXCAVATION, GRADING AND STORMWATER CONTROL, ARTICLE V. STORMWATER

SECTION 510.200: PURPOSE –
“The management of stormwater will reduce the erosion on land and creek channels, will reduce the possibility of damage to public and private property, will assist in the attainment and maintenance of water quality standards and will preserve the environmental quality of the watercourses in the City.”

SECTION 510.300: STORMWATER MANAGEMENT PLANS –
“A. Anyone contemplating any construction work within the City shall prepare, or cause to be prepared, for review and approval by the Director of Public Works or his/her designee, a storm water management plan for each site being developed, re-developed or maintained. This plan shall follow the guidelines presented in the manual "Protecting Water Quality", January 2000 by the Missouri Department of Natural Resources and be stamped by a registered professional engineer within the State of Missouri. The plan shall contain, among other things, recommendations for potential locations and sizes of on-site or off-site storm water management facilities and an evaluation of the existing streams and creeks within the site for stabilization and grade (erosion) control issues. If approved by the Director of Public Works or his/her designee, sites under one (1) acre may be exempted from this rule and be given a written exemption from the Director of Public Works or his/her designee.

B. The plan shall be designed to minimize the amount of erosion of the site during the construction of the project. Failure to have adequate erosion protection on the site or failure to maintain erosion protection throughout the construction of the project shall be considered a violation of this Article and will result in penalties per Sections 510.330 and 510.340.
(R.O. 2009 §151.70; Ord. No. 02-175, 7-19-02)”

SECTION 510.310: REQUIRED DOCUMENTS –

> “As part of the review process for the permitting of construction activities, the following items will have to be submitted to the Director of Public Works or his/her designee for review. These items will have to be adjusted by the applicant as necessary to meet the requirements of the City prior to the issuance of a permit for the work…. 2. Storm Water Management Plan and Erosion/Sedimentation Control Plan stamped by a professional engineer per Chapter 3 of "Protecting Water Quality", January 2000 by the Missouri Department of Natural Resources.”

Note that the "Protecting Water Quality", January 2000 by the Missouri Department of Natural Resources referenced in the ordinance has been replaced by “Protecting Water Quality: A field guide to erosion, sediment and stormwater best management practices for development sites in Missouri and Kansas” Revised January 2011.

## 7.4 LEVEL OF EXISTING WATER QUALITY

### 7.6.4 Indirect Measurement (Desktop Analysis)

During a storm event, runoff occurs when the volume and/or rate of rain that falls onto a surface exceeds the ability of the surface to pond and infiltrate the water. The resulting runoff has the potential to degrade the water quality of receiving bodies of water through transport of sediments (erosion) and surface pollutants (floatables, soluble chemicals, heavy metals, etc.). Consequently, the land use changes that result from urbanization are directly related to water quality. Quantifying the range of pollutant loadings of receiving streams has proved difficult due to the diffuse nature of stormwater discharges, but through the EPA’s Nationwide Urban Runoff Program (NURP), data has been collected on ten pollutants. Analysis of the NURP and other data published in the paper *Fundamentals of Urban Runoff Management: Technical and Institutional Issues* in 1994 by Horner, Skupien and Shaver led to the summary of pollutant loading based on land use as shown in the table below.

**Table 7-2: Typical Pollutant Loadings from Runoff by Urban Land Use (lbs/acre-yr)**

| Pollutant Constituent | Land Use | | | | | | |
|---|---|---|---|---|---|---|---|
| | Commercial | Industrial | High Density Residential | Medium Density Residential | Low Density Residential | Roadway | Park/Cemetery |
| Total Suspended Solids (TSS) | 1000 | 860 | 420 | 190 | 10 | 880 | 3 |
| Total Phosphorus (TS) | 1.5 | 1.3 | 1 | 0.5 | 0.04 | 0.9 | 0.03 |
| Total Kjeldahl Nitrogen (TKN) | 6.7 | 3.8 | 4.2 | 2.5 | 0.03 | 7.9 | 1.5 |
| Total Ammonia as Nitrogen ($NH_3$-N) | 1.9 | 0.2 | 0.8 | 0.5 | 0.02 | 1.5 | NA |
| Nitrite and Nitrate as Nitrogen ($NO_2$+$NO_3$-N) | 3.1 | 1.3 | 2 | 1.4 | 0.1 | 4.2 | 0.3 |
| Biological Oxygen Demand (BOD) | 62 | NA | 27 | 13 | NA | NA | NA |
| Chemical Oxygen Demand (COD | 420 | NA | 170 | 72 | NA | NA | 2 |
| Lead (Pb) | 2.7 | 2.4 | 0.8 | 0.2 | 0.01 | 4.5 | 0 |
| Zinc (Zn) | 2.1 | 7.3 | 0.7 | 0.2 | 0.04 | 2.1 | NA |
| Copper (Cu) | 0.4 | 0.5 | 0.03 | 0.14 | 0.01 | 0.37 | NA |

Notes:

NA: Not available; insufficient data to characterize loadings

Source: Adapted from *Fundamentals of Urban Runoff Management: Technical and Institutional Issues* by Horner, Skupien and Shaver (1994)

Using the data in Table 7-1, a GIS tool was created to quantify and analyze the annual pollutant loadings for each of the constituent pollutants. For each parcel in the study area, the GIS tool multiplies the annual loading rate for the pollutant constituent by the parcel area to yield the annual loading in pounds for the parcel. The data is then summed for each sub-watershed. The results of the annual loading computations allows regions of high pollutant loadings to be quickly analyzed to determine where to implement Best Management Practices to address water quality with the greatest effect and efficiency. See Appendix H for mapping of the water quality analysis.

### 7.4.1 Sampling/Monitoring at Water Bodies

The limitations of indirect pollution loading estimates described in section 7.4.1 is they are, at best, approximations and are intended to for general characterization only. In order to quantify the actual pollutant loadings in a community, water sampling and monitoring is required. The data from water sampling is used to establish a baseline of current conditions and then monitor the effectiveness of the implementation of Best Management Practices for improving water quality. Furthermore, sampling and monitoring can be used by regulatory agencies in the enforcement of water quality standards.

The quality of a monitoring plan is only as good as the data that is collected. To that end, the selection of sampling locations should be chosen with care to ensure that they are representative of the water quality of the stream segment. Additionally, the quality of the sampling techniques is important to ensure the integrity of the data.

## 7.5 WHAT IS THE FUTURE OF WATER QUALITY REGULATIONS?

### 7.5.1 Local

Environmental Compliance engineers at St. Louis MSD were contacted to discuss their opinion of the future of water quality regulations in the St. Louis region. MSD has extensive experience in addressing water quality issues and is partnered with 60 municipalities (co-permittees) to comply with stormwater regulations for their St. Louis Metropolitan Small MS4 2013 – 2018 Permit. MSD was able to renew their Phase II Permit in 2013 in part because of a moderate water quality sampling program and their commitment to Minimum Control Measure 5, Post-Construction Stormwater Management. Their MSD's Phase II Stormwater Management Plan (SWMP) for St. Louis County includes enforceable BMPs (Best Management Practices) that address potential sources of pollutants in stormwater as required by the federal and state regulations. The program requires that BMPs are in place to prevent or minimize water quality impacts for development or redevelopment projects with over 1 acre of impact. Educational information on planning and zoning strategies to protect water quality and post-construction BMP guidance, including an on-line BMP Toolbox, have also been developed. MSD's SWMP can be found online at http://www.stlmsd.com/sites/default/files/education/478686.PDF.

Section 303(d) of the federal Clean Water Act requires states to identify water bodies that do not meet water quality standards after applying the existing regulations. For waters on this list (impaired waters), a plan must be developed to fix the problem. Such plans will include a Total Maximum Daily Load (TMDL) calculation of the maximum amount of a pollutant a water body can absorb without being impaired. While MSD has several streams within its jurisdiction that are on the 303(d) list, TMDLs have not yet been approved by EPA, and MSD's streams are not yet subject to them.

In general, it is MSD's opinion that regulators will continue to try and make stormwater quality regulations more stringent.

### 7.5.2 State of Missouri

According to Missouri's 10 CSR 20-7.031, No water contaminant, by itself or in combination with other substances, shall prevent the waters of the state from meeting the following conditions: Waters shall be free from substances in sufficient amounts to cause the formation of putrescent, unsightly or harmful bottom deposits or prevent full maintenance of beneficial uses.

1. Waters shall be free from oil, scum, and floating debris in sufficient amounts to be unsightly or prevent full maintenance of beneficial uses.
2. Waters shall be free from substances in sufficient amounts to cause unsightly color or turbidity, offensive odor or prevent full maintenance of beneficial uses.
3. Waters shall be free from substances or conditions in sufficient amounts to result in toxicity to human, animal, or aquatic life.
4. There shall be no significant human health hazard from incidental contact with the water.
5. There shall be no acute toxicity to livestock or wildlife watering.
6. Waters shall be free from physical, chemical, or hydrologic changes that would impair the natural biological community.
7. Waters shall be free from used tires, car bodies, appliances, demolition debris, used vehicles or equipment and solid waste as defined in Missouri's Solid Waste Law, section 260.200, RSMo, except as the use of such materials is specifically permitted pursuant to section 260.200-260.247

These are some of the basic criteria that guide MoDNR's water quality regulations. Not all of these are currently enforced with all permitted communities, but MoDNR continues to push to more comprehensively address the criteria through their MS4 permitting process. TMDLs for streams on the 303 (d) list may be imposed at some point, but the timing is unknown. Ambient water quality standards for nutrients may also be a possibility. A Draft Rules Change for MoDNR's General Permit MO-R00400 was issued to affected MS4s. Among other things, the Draft Permit suggests a move away from Best Management Practices (BMPs) implemented to the Maximum Extent Practicable (MEP) and a move toward TMDL Waste Load Allocations. This move would require MS4s to implement a rigorous sampling and monitoring program. Numerous communities throughout Missouri have submitted comments in opposition to many of the proposed changes.

John Hoke, Chief of the Watershed Protection Section at MDNR, was contacted for his opinion. He said "Recent updates to ammonia, pathogen and toxics are areas that we intend to incorporate in the current or a future rulemaking. We are also attempting to satisfy a disapproval of Missouri's numeric nutrient criteria for lakes with the current effort. Other longer term Water Quality Standard updates include development of numeric nutrient criteria for streams, as well as more holistic ways to manage pollutants on a watershed scale (e.g., watershed pollutant trading). Cities and regulated entities can stay engaged through the Department's Water Protection Forum. They can also carefully review and comment on their Missouri State Operating Permit applications and take advantage of regulatory mechanisms such as compliance schedules and variances to achieve compliance with water quality standards."

MoDNR recently issued a Public Notice for *Missouri Aquatic Habitat Use Attainability Analyses (UAA): Stream Survey and Assessment Protocol.* According to MoDNR: *The UAA protocol is intended as guidance for any party interested in conducting investigations to provide scientifically defensible information on existing and attainable warm water aquatic life uses of waters included in Missouri's Water Quality Standards at Tables G and H, including the Missouri Use Designation Dataset (referenced at 10 CSR 20-7.031(2)(E)). These waters are afforded specific protections by regulation and are subject to numeric and narrative criteria and antidegradation requirements to protect water quality and designated uses. The protocol offers factors to consider and minimum requirements necessary for conducting a UAA to identify appropriate aquatic habitat designated uses and, where applicable, address the removal or modification of such uses.*

Many communities on MoDNR's MS4 regulated list do not currently have stringent water quality enforcement mechanisms. Based on discussions, observations and proposed rules however, MoDNR appears to be attempting to correct this.

### 7.5.3 Federal

The objective of the Federal Clean Water Act of 1972 along with its amendments are to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The first national set of water quality standards were published in 1983 and codified in 40 CFR Part 131. These regulations allow individual states to construct their own water quality standards framework providing there is no reduction in protection compared to federal guidelines. The CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Changes in the CWA are highly political and unpredictable. Enforcement of the CWA sometimes involves federal lawsuits involving the Department of Justice who negotiates Consent Decrees with communities, such as their Consent Decree with St. Louis MSD. It appears unlikely that any near term changes in federal water quality regulations will directly affect the City of St. Charles.

## 7.6 WHAT MEASURES CAN BE TAKEN TO IMPROVE WATER QUALITY?

### 7.6.1 Identify High Risk Areas

High risk water bodies typically include streams and lakes near high traffic roadways, industrial complexes and dense commercial development. Receiving streams near farmland are susceptible to high nutrient content (ammonia and phosphates) which can lead to oxygen depletion. Sanitary sewer overflows and unidentified point discharges near commercial areas can also have a significant effect on water quality. High risk areas can identified without physical sampling by using a "desk-top" analysis involving mapping, point discharge records and complaint records.

### 7.6.2 Focus Available Resources

If resources are limited, then it makes sense to focus them on the high risk water bodies. A prioritization plan can be developed and phased over time. Another sensible approach includes combining water quality improvements as a secondary benefit to other projects, such as flood mitigation or roadway replacement projects.

## 7.7 GREEN INFRASTRUCTURE

Green Infrastructure is a term used to describe Best Management Practices (BMPs) that control stormwater runoff and pollution by introducing a treatment method or technique that allows infiltration into the soil, storage of runoff to reduce hydraulic impact on receiving waters, or both.

### 7.7.1 Goal of Green Infrastructure

The goal of Green Infrastructure BMPs is to improve water quality by either removing stormwater runoff from a system (through infiltration) or filtering runoff before releasing it into a system.

### 7.7.2 Techniques

There are a variety of BMPs that can be used to improve water quality. Some of the most common techniques are listed below.

#### 7.7.2.1 Permeable Pavements

There are three types of permeable pavement: Permeable Interlocking Concrete Pavement (PICP), Porous Asphalt, and Pervious Concrete. The pavement is designed to absorb rainfall and filter it through a reverse-graded aggregate sub base which is above a storage area consisting of large aggregate with 40% voids. The stormwater that does not infiltrate into the native soil is carried away through a perforated underdrain.

#### 7.7.2.2 Bioretention Facilities

Bioretention facilities reduce stormwater runoff and improve water quality. They consist of a depressed landscaped area that can store runoff above grade and allow it to infiltrate through prepared soils that filter out pollutants. The facility includes plantings that remove the pollutants from the soil through the root structure. Bioretention facilities should be strategically located to accept runoff from impervious areas on the site. Flows that exceed the above-grade capacity of the facility are directed into an overflow inlet. Infiltration that exceeds the below-grade capacity is directed into a perforated underdrain.

#### 7.7.2.3 Rain Gardens

Rain gardens are a great way to filter out pollutants in stormwater runoff before entering the stormwater system or groundwater. The garden can become an attractive addition to the neighborhood that not only can increase property value but also provides a habitat for local wildlife.

#### 7.7.2.4 Rainwater Harvesting

Rainwater harvesting captures runoff (typically from roofs) and stores it for future uses such as irrigation. Rain barrels are a typical example of this, but larger and more ornate facilities have been used in urban areas and can be used as an aesthetic feature or as a water quality educational tool.

#### 7.7.2.5 Buffer Strips

Buffer strips are strips of vegetation (grassy area, for example) that are placed at the downstream edge of an impervious surface. The runoff is forced to cross the strip, where infiltration reduces volume and filters pollutants. Removal of existing pavement may be required to accommodate a Buffer Strip.

#### 7.7.2.6 Green Roofs

Living roofs, or in more common terms green roofs, are roofs that are partially or fully covered with vegetation. They provide advantages to the building itself, such as climate control, and also absorb rainfall to reduce the amount of runoff and improve water quality.

#### 7.7.2.7 Retrofit Detention Basins

A detention basin that has a concrete channel, or short turf-type vegetation, or any other unnatural elements may originally have been designed just to prevent flooding. Detention basins primarily are now used for flood control and filtration. To retrofit a detention, one may remove the concrete channel and replace it with stone, or substitute the turf with natural soils and grasses native to the area. This allows for basins to not only be capable of filtering out more pollutants, but can also provide a place for wildlife to live and eat.

## 7.8 ESTIMATED COSTS

Based on recent local projects, the following are estimates for construction of various BMPs:

- Bioretention Facilities – $20 to $25/sf
- Permeable Pavement – $15 to $20/sf
- Rainwater Harvesting –$150 and up (depends on the aesthetic nature of the BMP)
- Green Roofs – $15 to $20/sf
- Disconnection – $500 to $1,000 per disconnection
- Buffer Strips – $5 to $10/sy

### 7.8.1 Funding Possibilities

Expanding the City's existing water quality program, which may be necessary in order to secure the future NPDES Phase II Permit, will almost certainly increase costs required to construct water quality BMPs and to perform sampling and monitoring of streams. The City would likely be required to pay for the cost of sampling/monitoring, but there are options for funding the BMPs. Options include:

- The City constructs and maintains region-wide BMPs.
- Developers construct local BMPs and owners maintain the BMPs.
- Developers construct local BMPs and the City maintains the BMPs.
- Developers contribute to a "bank" and the City uses the money to construct and maintain region-wide BMPs.

Requiring developers to construct the BMPs or contribute to a bank may discourage future development in the City. Securing funding for the City to construct and/or maintain the BMPs also presents challenges. All BMPs will require maintenance. Decisions should account for the reality that there is a poor track record of maintenance of BMPs by the private sector.

## 7.9 WHAT ARE OTHER COMMUNITIES DOING?

### 7.9.1 St. Louis

St. Louis MSD, under their current Consent Decree, has pledged $100M over 23 years to build or fund green infrastructure in Bissell Watershed (combined sewer) since Bissell discharges directly to the Mississippi River. In all separate sewer watersheds, MSD's NPDES permit requires development that disturbs over 1 acre to implement green infrastructure or other BMPs to capture and process 90% of the annual rainfall.

### 7.9.2 New York

New York City is embarking on a similarly ambitious effort. Their "Green Infrastructure Plan," released in 2010, calls for spending $2.4 billion in public and private funding for targeted green infrastructure installations, as well as $2.9 billion in cost-effective grey infrastructure upgrades over 20 years. This plan replaced a previous all-grey stormwater infrastructure approach that would have resulted in the construction of several "deep tunnel" projects and other costly traditional grey stormwater projects. By integrating green stormwater infrastructure into their overall stormwater management strategy, the City of New York expects a savings of $1.4 billion from substituting grey infrastructure with green infrastructure and an additional $2 billion in deferred costs.

### 7.9.3 Philadelphia

The City of Philadelphia is implementing a $2.5 billion, 25-year stormwater management plan called "Green City, Clean Waters." Philadelphia developed this plan primarily to fulfill their legal obligations to reduce CSOs under the U.S. Clean Water Act. Of the $2.5 billion in this plan, Philadelphia anticipates that 85 percent will fund green stormwater infrastructure. Their plan requires the retrofit of nearly 10,000 acres to manage runoff before it enters their sewer system. This will be done by building public green infrastructure in streets, sidewalks, schoolyards, and public building rooftops. Their plan also heavily relies on private green infrastructure construction through increased development regulations and private property incentive programs. Philadelphia expects the water quality benefits from their strategy to be equivalent to building a $10 billion "deep tunnel."

### 7.9.4 Chicago

The City of Chicago, while not under a Consent Decree, has chosen to spend $50M over 5 years to implement green infrastructure in an attempt to reduce basement backups and improve overall water quality. The majority of the projects will be administered directly by the City on public property.

## 7.10 ENFORCE THE SIX MINIMUM CONTROL

The NPDES Phase II Permit identifies six minimum control measures that MS4 operators must incorporate into their Storm Water Management Plan (SWMP). The City of St. Charles' SWMP addresses the measures, but the City may be required to modify their plan in order to renew the Phase II Permit. Following are general descriptions of the requirements for each control measure.

### 7.10.1 Public Education and Outreach

Implement a public education program to distribute educational materials to the community and conduct outreach activities about the impacts of stormwater discharges on water bodies and the steps that the public can take to reduce pollutants in stormwater runoff.

### 7.10.2 Public Participation and Involvement

Provide opportunities for citizens to participate in program development and implementation, including effectively publicizing public hearings and/or encouraging citizen representatives on a stormwater management panel. A permittee may also encourage third party groups (such as the River Des Peres Watershed Coalition in St. Louis) to conduct meetings, seminars and arrange annual cleanup events.

### 7.10.3 Illicit Discharge Detection and Elimination

Develop and implement a plan to detect and eliminate illicit discharges to the storm sewer system (includes developing a system map and informing the community about hazards associated with illegal discharges and improper disposal of waste).

### 7.10.4 Construction Site Stormwater Runoff Control

Develop, implement, and enforce an erosion and sediment control program for construction activities that disturb 1 or more acres of land (controls could include silt fences and temporary stormwater detention ponds).

### 7.10.5 Post-Construction Stormwater Runoff Control

Develop, implement, and enforce a program to address discharges of post-construction stormwater runoff from new development and redevelopment areas. Applicable controls could include preventative actions such as protecting sensitive areas (e.g., wetlands) or the use of structural BMPs such as grassed swales or porous pavement.

### 7.10.6 Pollution Prevention and Good Housekeeping

Develop and implement a program with the goal of preventing or reducing pollutant runoff from municipal operations. The program must include municipal staff training on pollution prevention measures and techniques (e.g., regular street sweeping, reduction in the use of pesticides or street salt, or frequent catch-basin cleaning).

### 7.10.7 Address Dumping at Specific Locations

Stream inspections can reveal locations where solid waste dumping frequently occurs. Dumped yard waste onto a stream bank will inhibit vegetative growth and could lead to bank erosion. Signage discouraging this behavior may have some effect, as will locating and addressing the responsible parties. A more effective approach may be to emphasize the negative impact of this behavior as part of the Public Education and Outreach effort.

## 7.11 RECOMMENDATIONS FOR THE CITY OF ST. CHARLES

### 7.11.1 Goals

In general, the goals of addressing the City's water quality issues should be to:

- Minimize increase in costs
- Closely monitor regulatory movement
- Implement reasonable improvements to prepare for regulatory changes
- Avoid overcommitting until regulations stabilize

### 7.11.2 Balance Competing Interests

The reality of improving water quality is that it can be a painstaking and expensive effort. There are many competing interests for a community such as St. Charles, including:

- Being pro-business and pro-development
- Being environmentally responsible
- Being regulatory compliant
- Identifying a sustainable funding source for construction and maintenance
- Being fiscally responsible to the St. Charles taxpayers
- Respecting private property rights

Ideally, the City should seek an approach that provides a balance among the interests, since they are all important components in a healthy community.

### 7.11.3 Regulatory Considerations

On a state level, the immediate future of water quality regulations appears to be uncertain. MoDNR is promoting stream sampling and monitoring and the construction of stormwater Best Management Practices (BMPs) such as rain gardens, bioretention facilities and permeable pavement. In larger communities, MoDNR is not just promoting, but requiring constructed BMPs. There is currently, however, a lack of clear direction regarding future requirements for communities such as St. Charles. As referenced previously in this document, the City will be renewing its NPDES Phase II Permit, which includes a Stormwater Management Plan (SWMP) based on implementing 6 Minimum Control Measures. The implementation of the City's existing

SWMP has had limited success, but the permit renewal process will provide an opportunity to strategically address as many of the competing interests as is reasonable. In this case, “strategic” could mean:

- Focusing on watersheds where there are likely water quality issues.
- Focus on no/low cost BMPs.
- Expand future City projects to include water quality improvements.
- Showing progress on non-structural Minimum Control Measures (such as public awareness).
- Highlighting unrecognized accomplishments that contribute to improved water quality (such as stream biostabilization).

Even though the City’s permit renewal schedule is unknown, it will be important to avoid stagnation on the water quality program. Reasonable measures should be implemented to avoid becoming reactionary (to developers or regulators) when the permit is finally issued.

### 7.11.4 Recommendations for Immediate Implementation

#### Revitalize Existing Programs

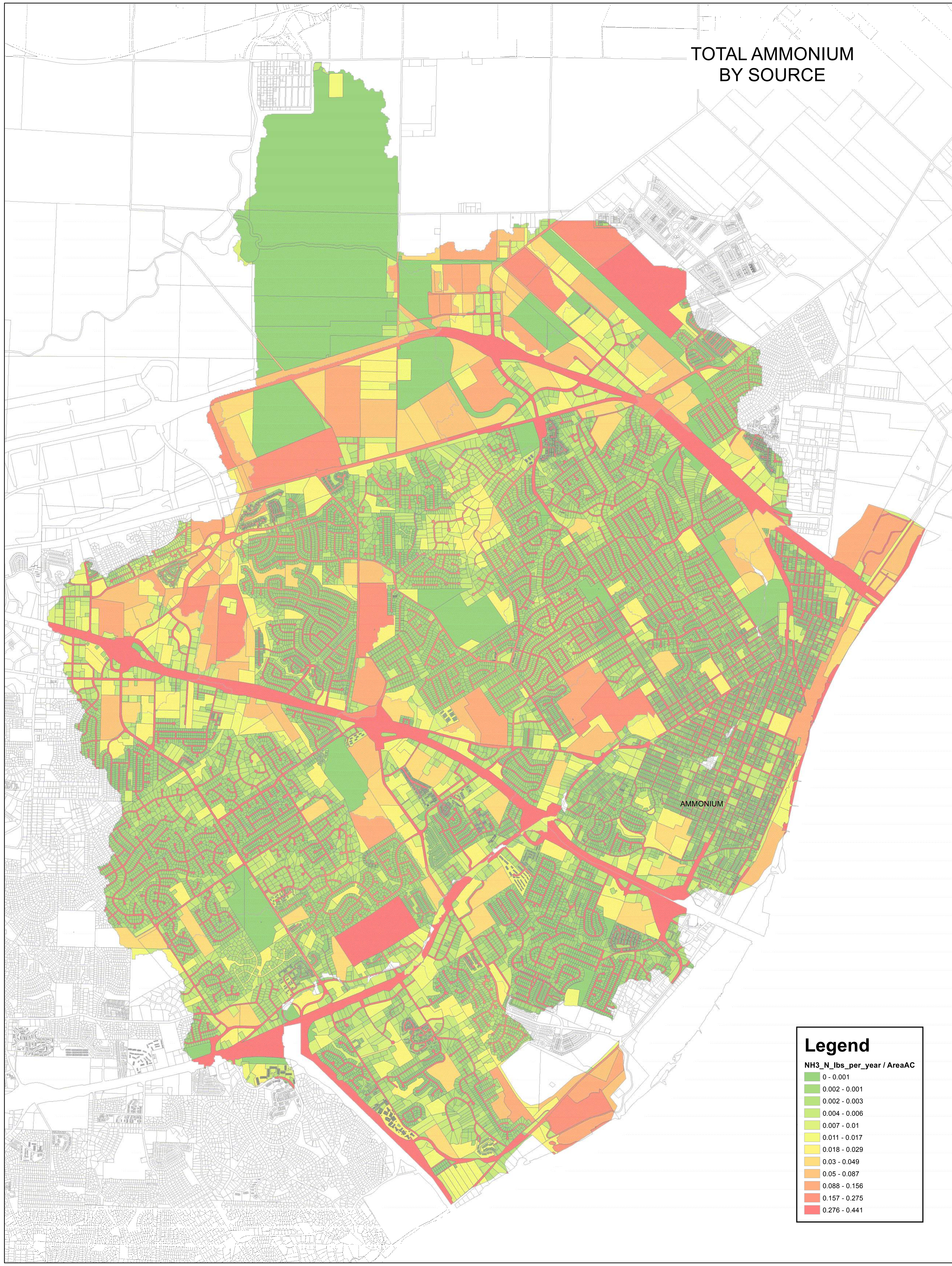
The City has authorized and implemented several programs with various degrees of success. In order to enhance their effectiveness, each should be assessed for the status of implementation and for possible improvements. Examples include the Green Point Rating System, which could be better utilized if the incentives were more attractive. Many activities from the City’s existing SWMP have either gone dormant or have never been implemented. Again, these should be assessed for effectiveness and improved where possible.

#### Incorporate Water Quality Projects into Flood Mitigation Projects

As the City moves forward with flood mitigation projectsCiol, the projects should be expanded to include water quality features. An example would be to include filter forebays, vegetation and extended detention in regional detention basins. The projects should be recommended in areas that have shown a risk of lower water quality based on a desktop analysis. Publicly maintained facilities will increase the longevity of water quality effectiveness since there is a poor track record of maintenance of BMPs by the private sector.

### Do Not Sample or Monitor Streams

Intuitively, stream sampling would yield results that could be used to demonstrate which streams do or do not require attention. However, if the sampling is not performed in a very structured and regulated manner, the results may be useless.  The results could also become public information and then be used to officially classify streams as impaired, opening the door to stringent results-based regulation or litigation form special interest groups.  The current sampling recommendations in MoDNR's Draft Rules Changes do not appear that they will lead to useful results.  No sampling is recommended until MoDNR formalizes its requirements.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BY SOURCE
AMMONIUM
Legend
NH3_N_lbs_per_year / AreaAC
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0.002 - 0.003
0.004 - 0.006
0.007 - 0.01
0.011 - 0.017
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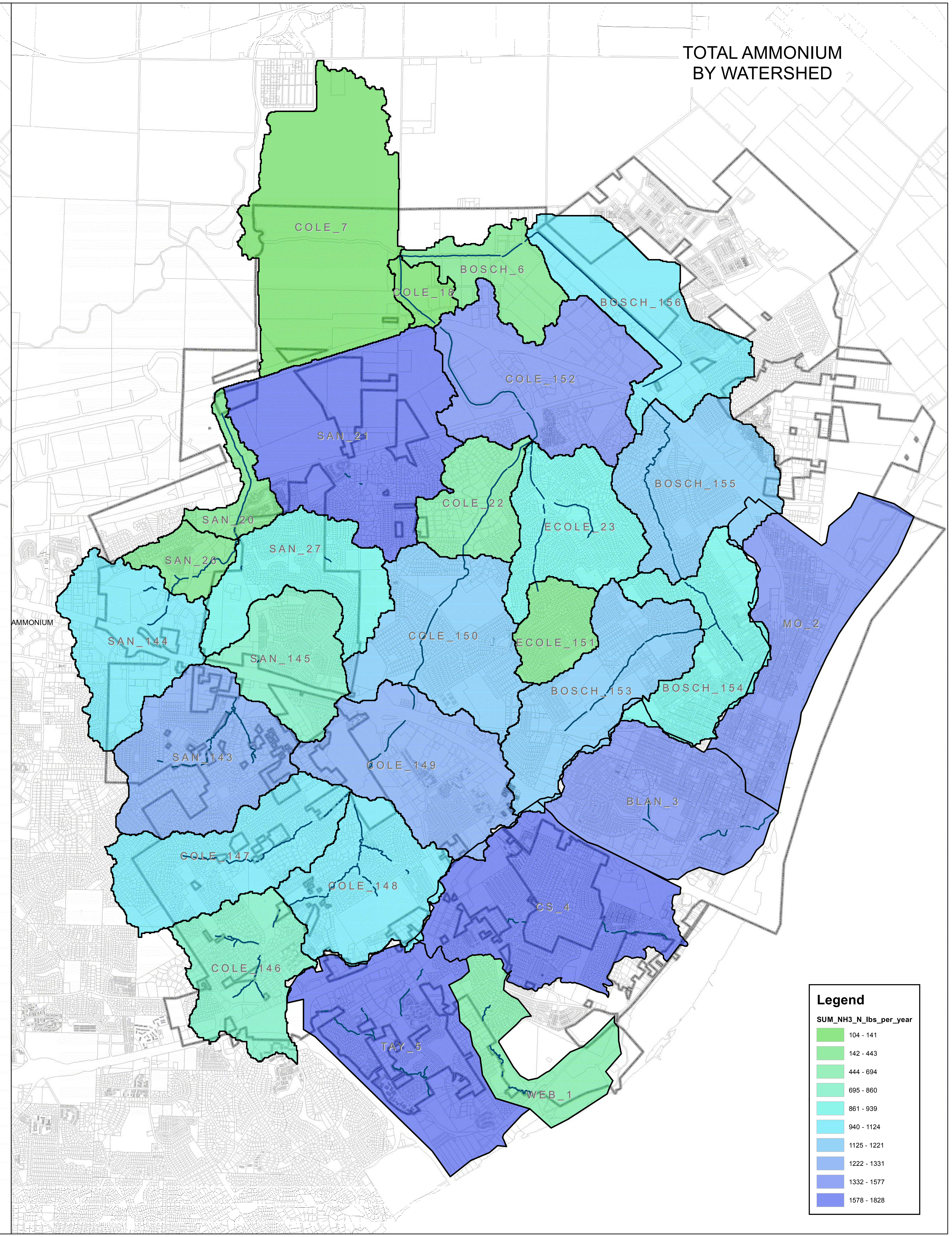
0.05 - 0.087
0.088 - 0.156
0.157 - 0.275
0.276 - 0.441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BY WATERSHED
AMMONIUM
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BOSCH_156
COLE_152
SAN_21
COLE_22
ECOLE_23
BOSCH_155
SAN_20
SAN_27
MO_2
SAN_144
COLE_150
ECOLE_151
SAN_145
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
WEB_1
Legend
SUM_NH3_N_lbs_per_year
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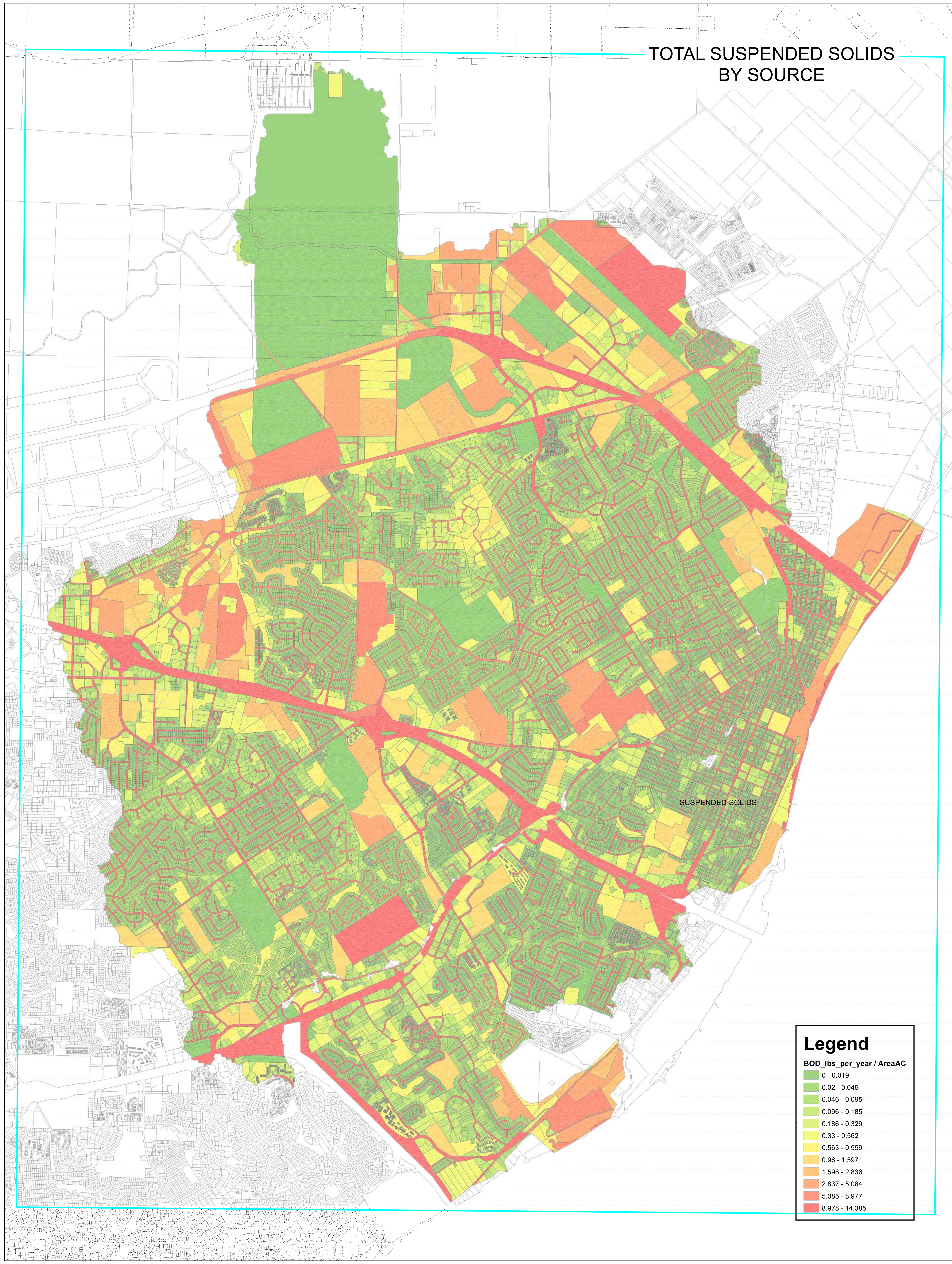
142 - 443
444 - 694
695 - 860
861 - 939
940 - 1124
1125 - 1221
1222 - 1331
1332 - 1577
1578 - 1828



TOTAL SUSPENDED SOLIDS
BY SOURCE
SUSPENDED SOLIDS
Legend
BOD_lbs_per_year / AreaAC
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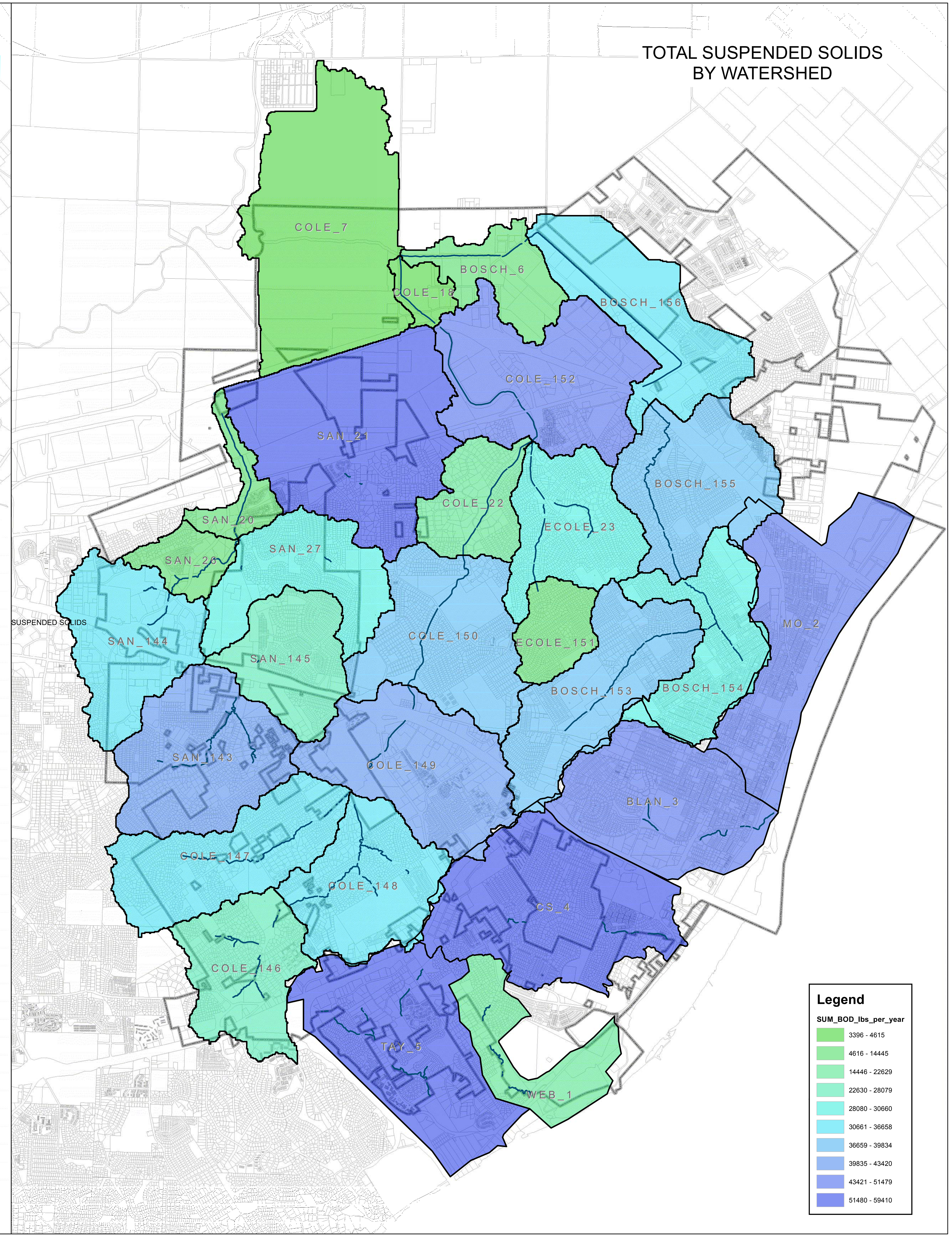
0.02 - 0.045
0.046 - 0.095
0.096 - 0.185
0.186 - 0.329
0.33 - 0.562
0.563 - 0.959
0.96 - 1.597
1.598 - 2.836
2.837 - 5.084
5.085 - 8.977
8.978 - 14.385

TOTAL SUSPENDED SOLIDS
BY WATERSHED
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BOSCH_6
COLE_18
BOSCH_156
COLE_152
SAN_21
COLE_22
BOSCH_155
ECOLE_23
SAN_20
SAN_27
SAN_26
SUSPENDED SOLIDS
SAN_144
SAN_145
COLE_150
ECOLE_151
MO_2
BOSCH_153
BOSCH_154
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COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
Legend
SUM_BOD_lbs_per_year
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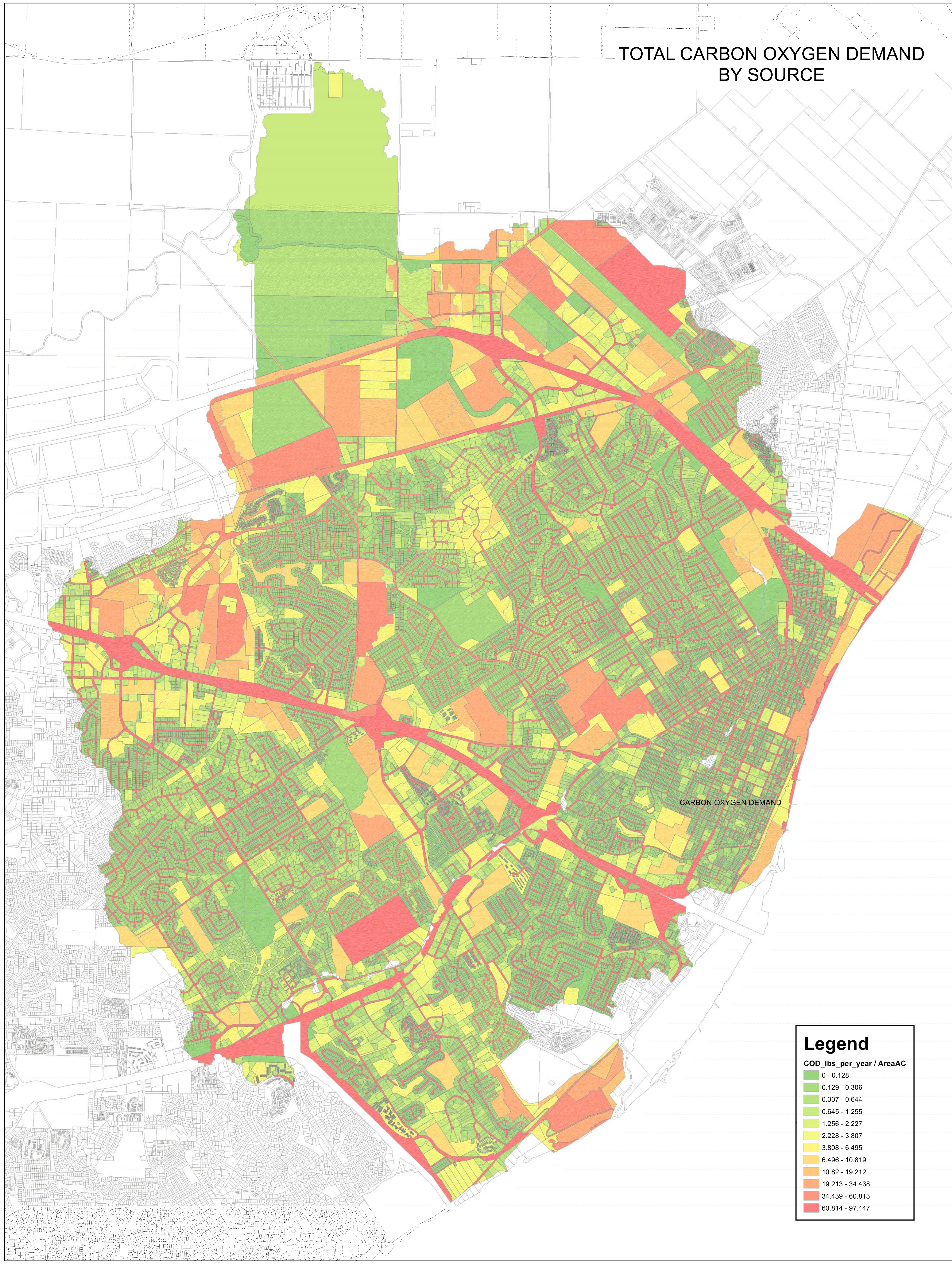
4616 - 14445
14446 - 22629
22630 - 28079
28080 - 30660
30661 - 36658
36659 - 39834
39835 - 43420
43421 - 51479
51480 - 59410


TOTAL CARBON OXYGEN DEMAND
BY SOURCE
CARBON OXYGEN DEMAND
Legend
COD_lbs_per_year / AreaAC
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0.307 - 0.644
0.645 - 1.255
1.256 - 2.227
2.228 - 3.807
3.808 - 6.495
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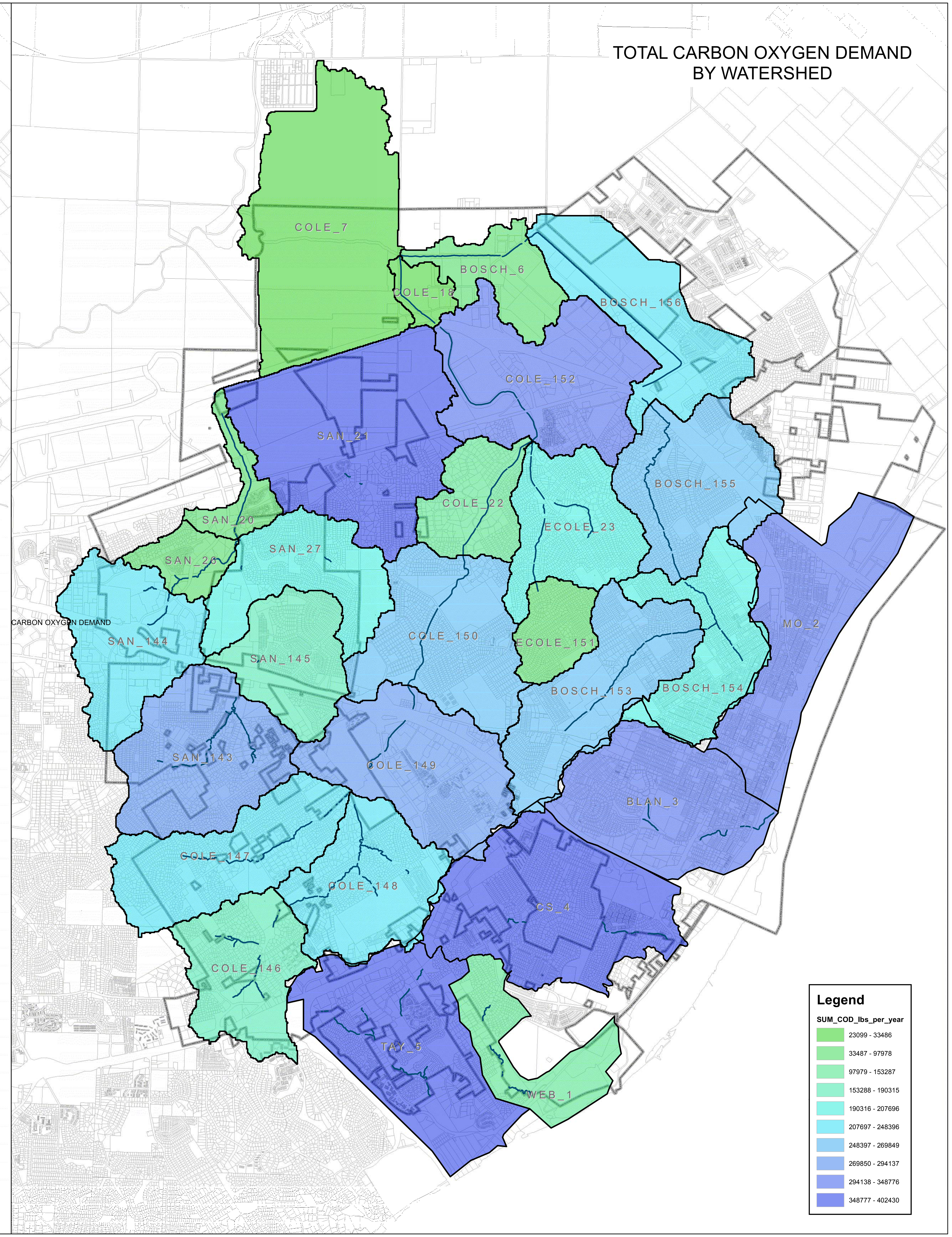
60.814 - 97.447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BY WATERSHED
CARBON OXYGEN DEMAND
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BOSCH_156
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SAN_21
COLE_22
ECOLE_23
BOSCH_155
SAN_20
SAN_26
SAN_27
SAN_144
SAN_145
COLE_150
ECOLE_151
MO_2
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
Legend
SUM_COD_lbs_per_year
23099 - 33486
33487 - 97978
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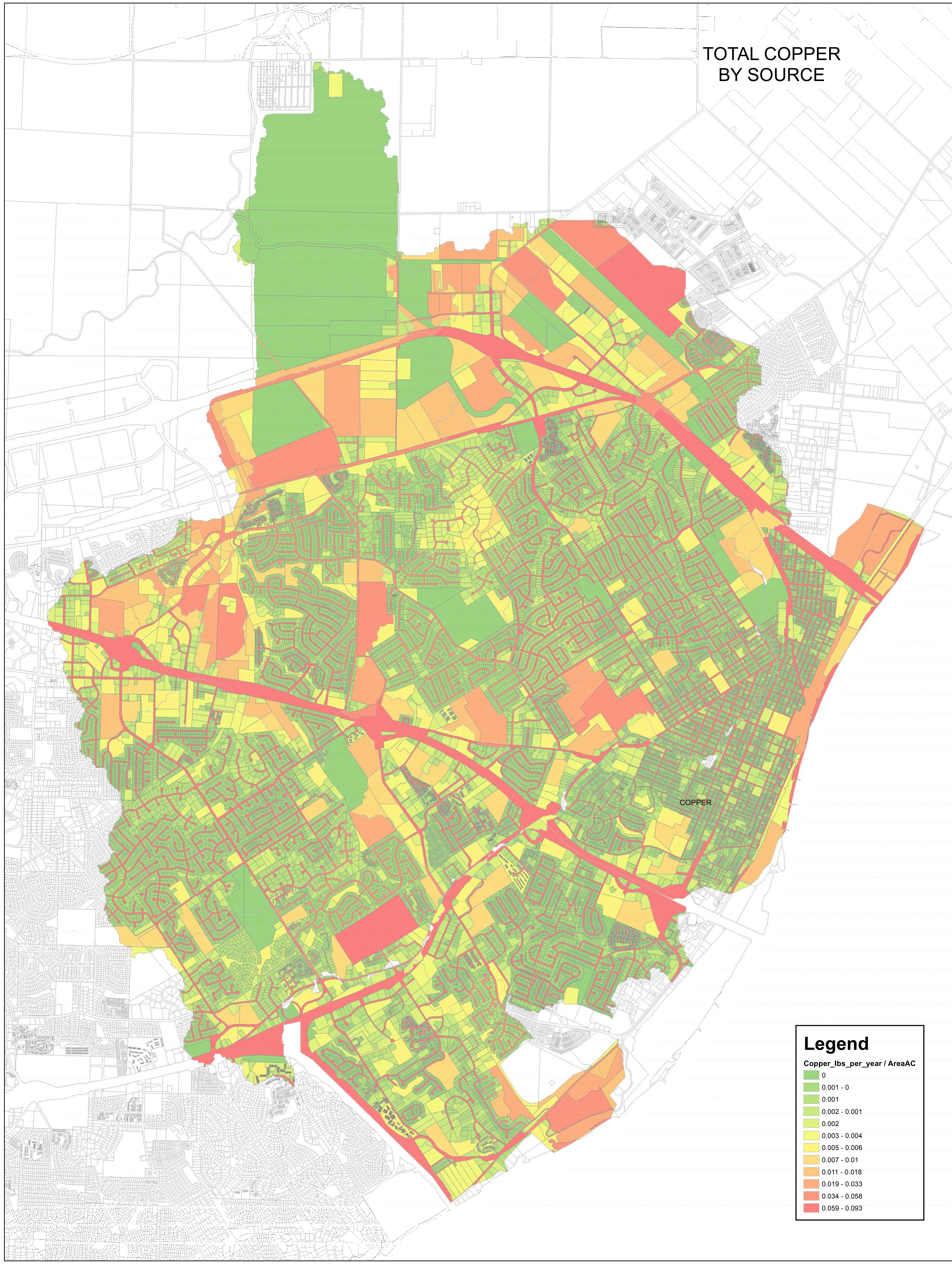
348777 - 402430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BY SOURCE
COPPER
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Copper_lbs_per_year / AreaAC
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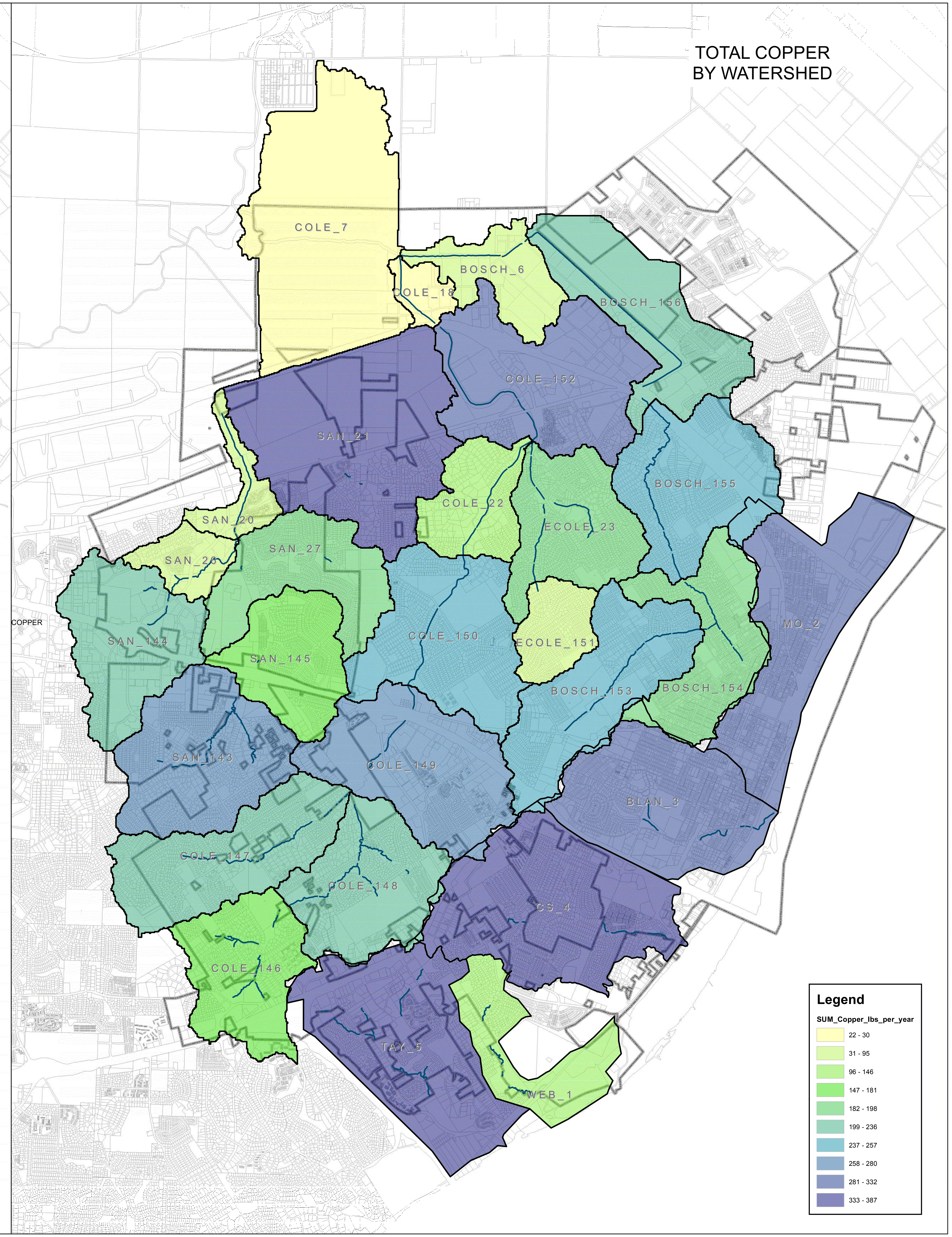
0.001 - 0
0.001
0.002 - 0.001
0.002
0.003 - 0.004
0.005 - 0.006
0.007 - 0.01
0.011 - 0.018
0.019 - 0.033
0.034 - 0.058
0.059 - 0.093


TOTAL COPPER
BY WATERSHED
COPPER
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COLE_18
BOSCH_156
COLE_152
SAN_21
BOSCH_155
COLE_22
ECOLE_23
SAN_20
SAN_27
SAN_26
SAN_144
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COLE_150
ECOLE_151
MO_2
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
Legend
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237 - 257
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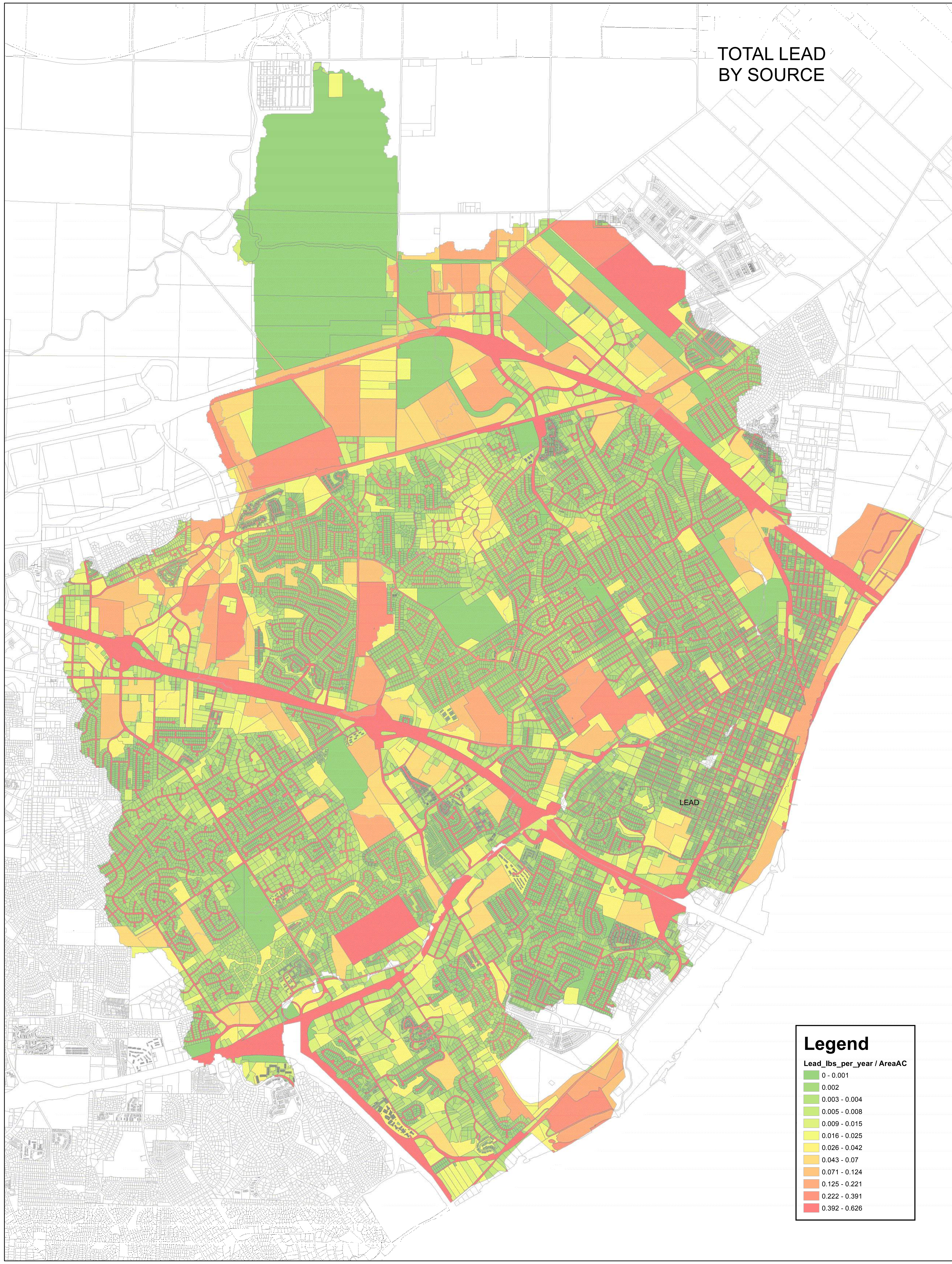
281 - 332
333 - 387


TOTAL LEAD
BY SOURCE
LEAD
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Lead_lbs_per_year / AreaAC
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0.003 - 0.004
0.005 - 0.008
0.009 - 0.015
0.016 - 0.025
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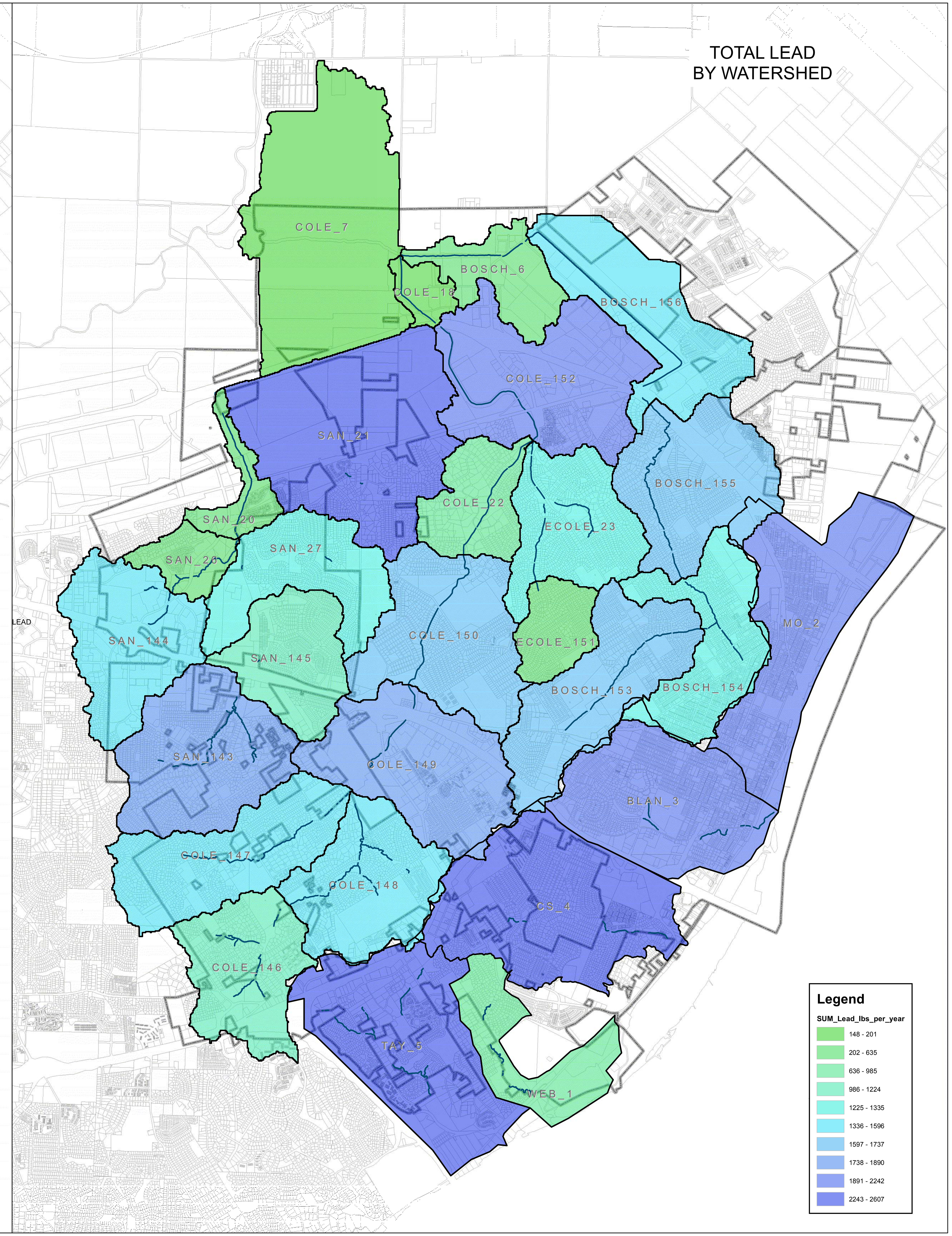
0.043 - 0.07
0.071 - 0.124
0.125 - 0.221
0.222 - 0.391
0.392 - 0.626


TOTAL LEAD
BY WATERSHED
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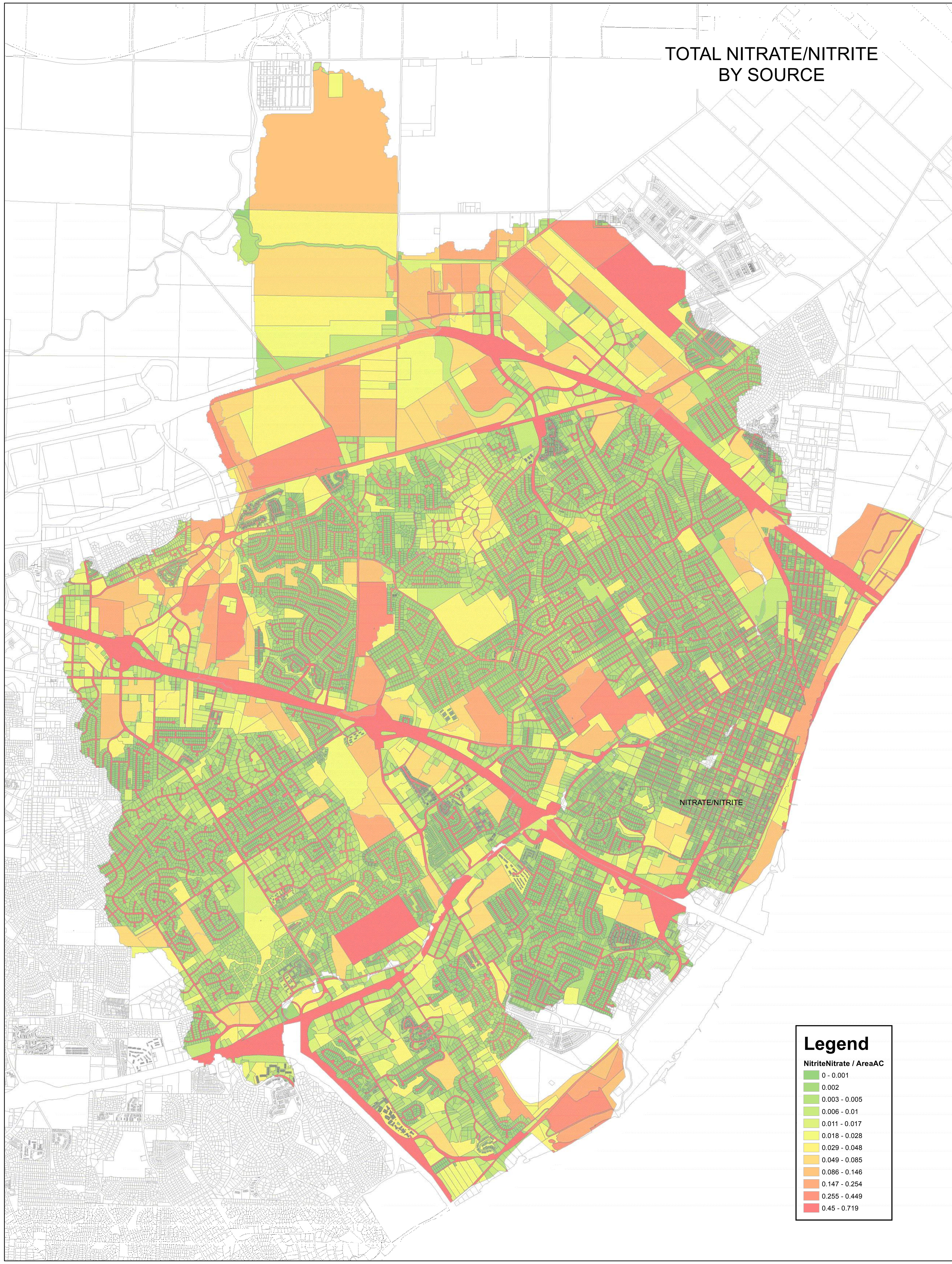
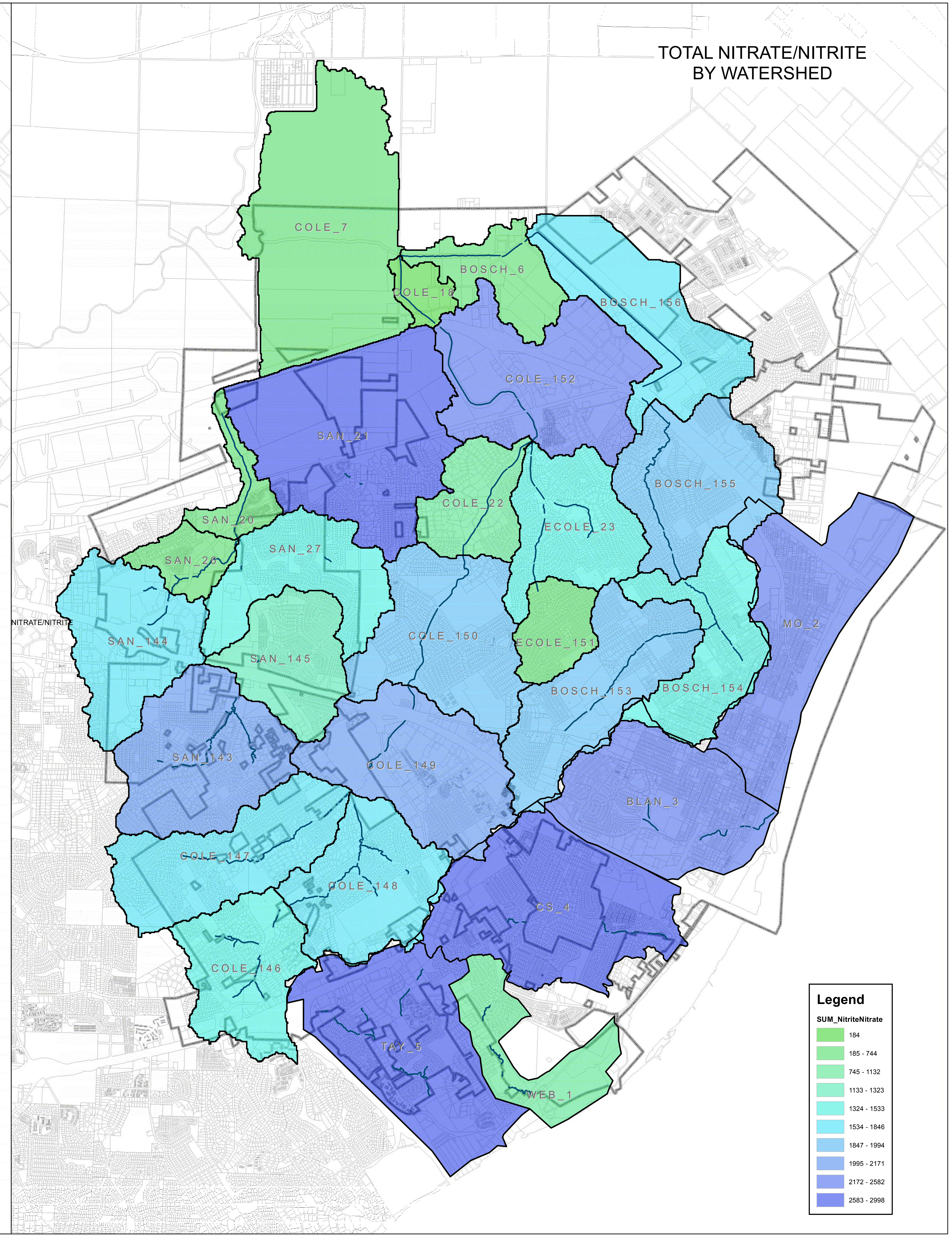
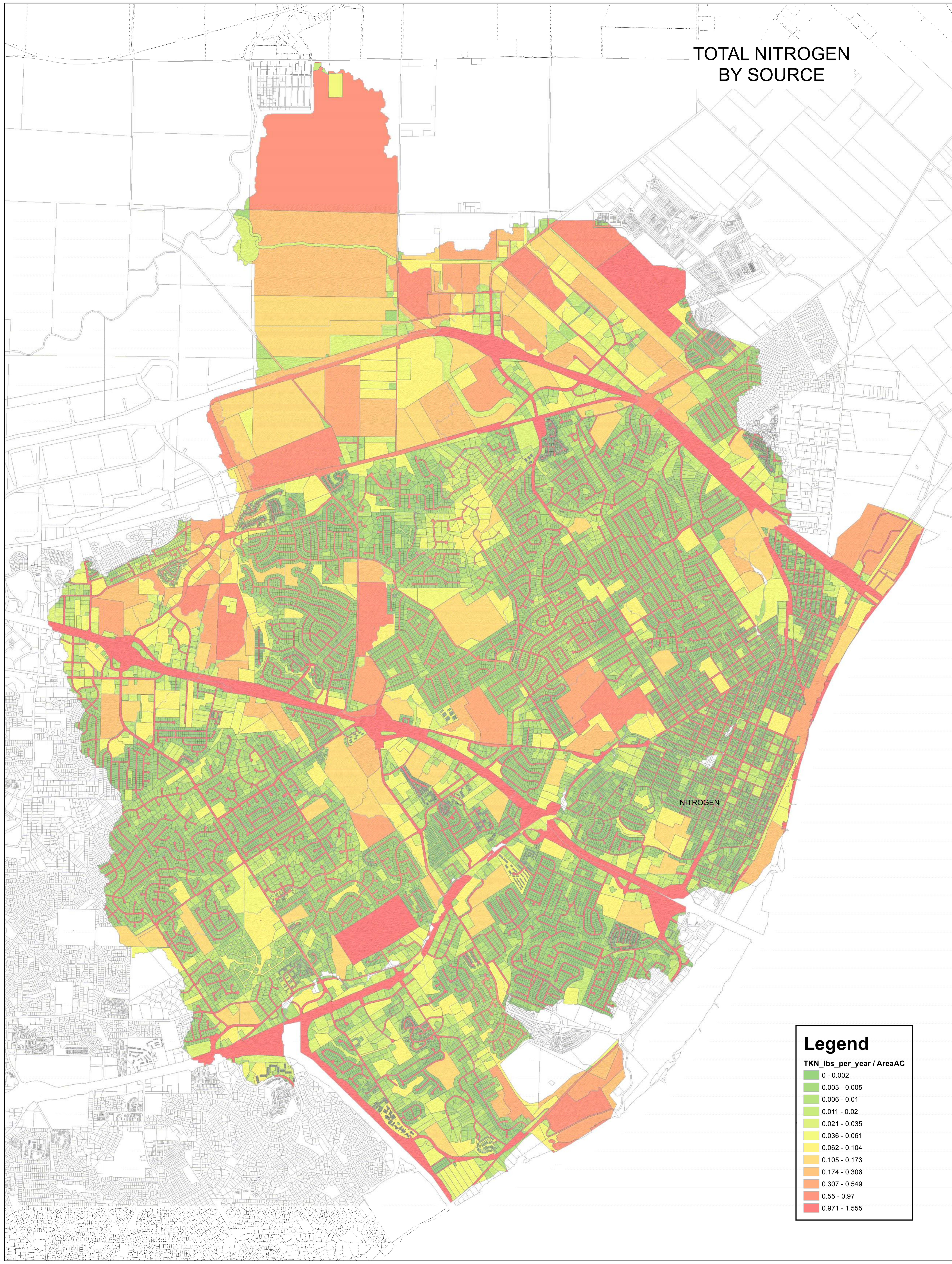
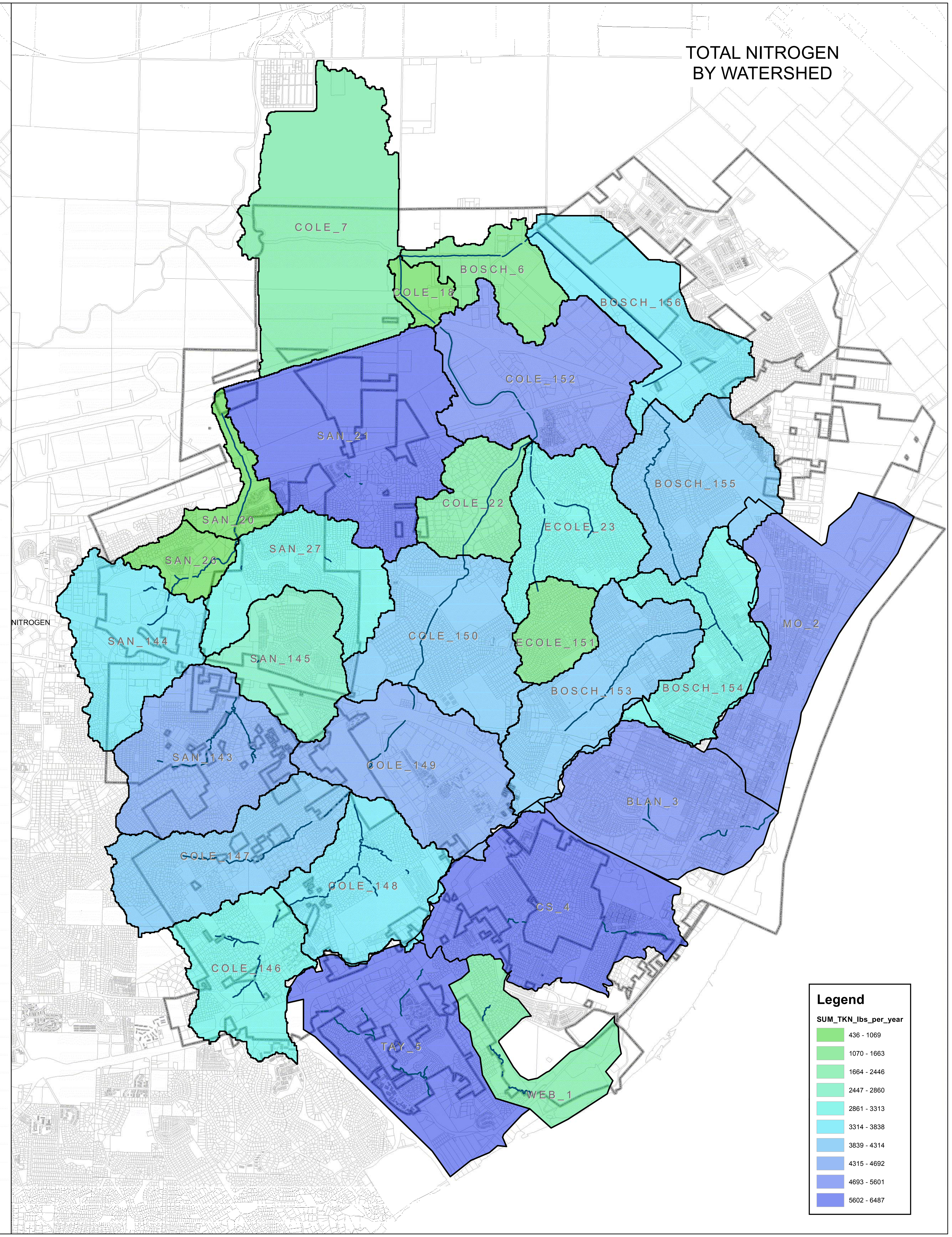
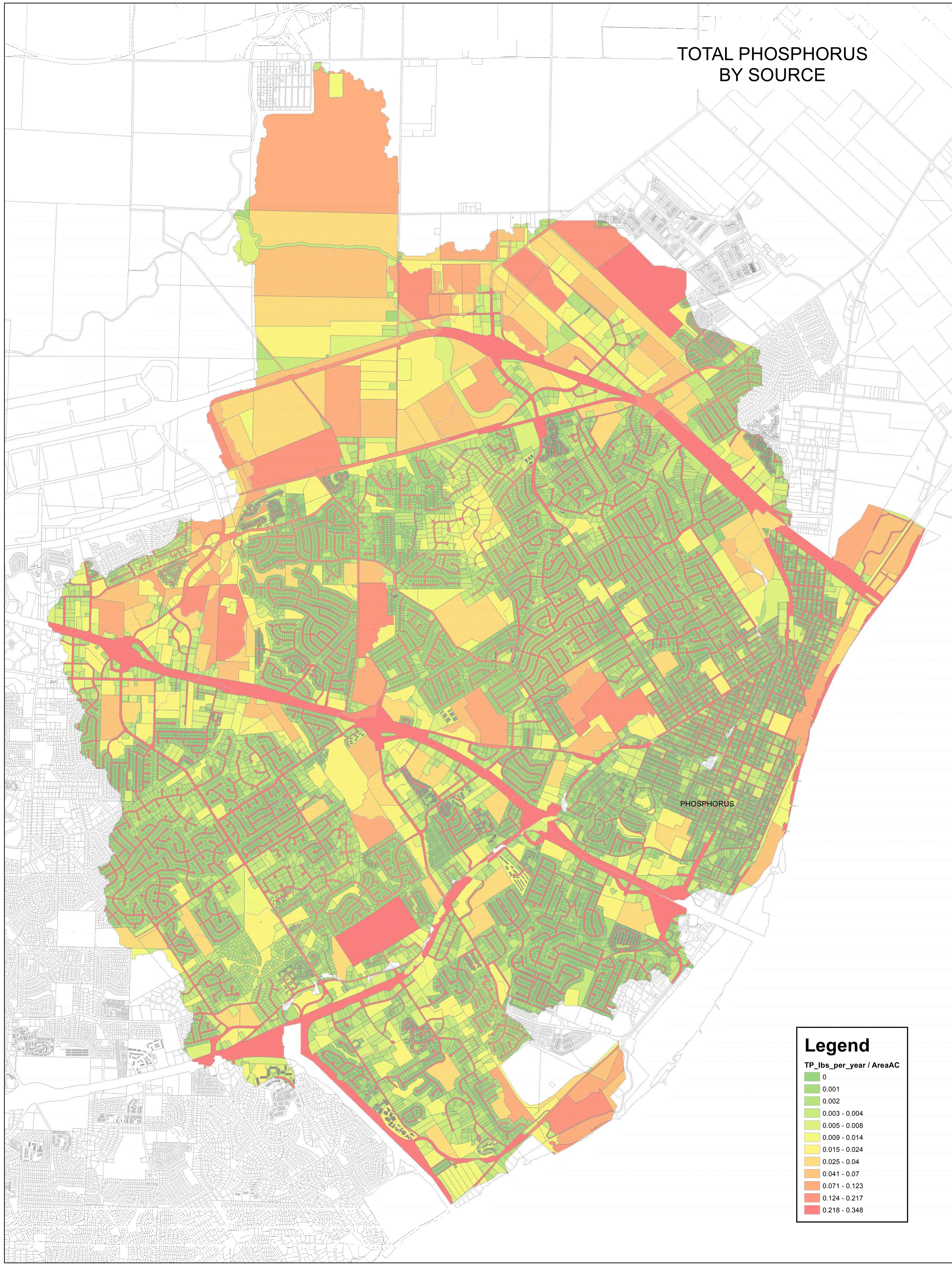
BOSCH_6
COLE_18
BOSCH_156
COLE_152
SAN_21
BOSCH_155
COLE_22
ECOLE_23
SAN_20
SAN_27
SAN_26
MO_2
SAN_144
COLE_150
ECOLE_151
SAN_145
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
LEAD
Legend
SUM_Lead_lbs_per_year
148 - 201
202 - 635
636 - 985
986 - 1224
1225 - 1335
1336 - 1596
1597 - 1737
1738 - 1890
1891 - 2242
2243 - 2607

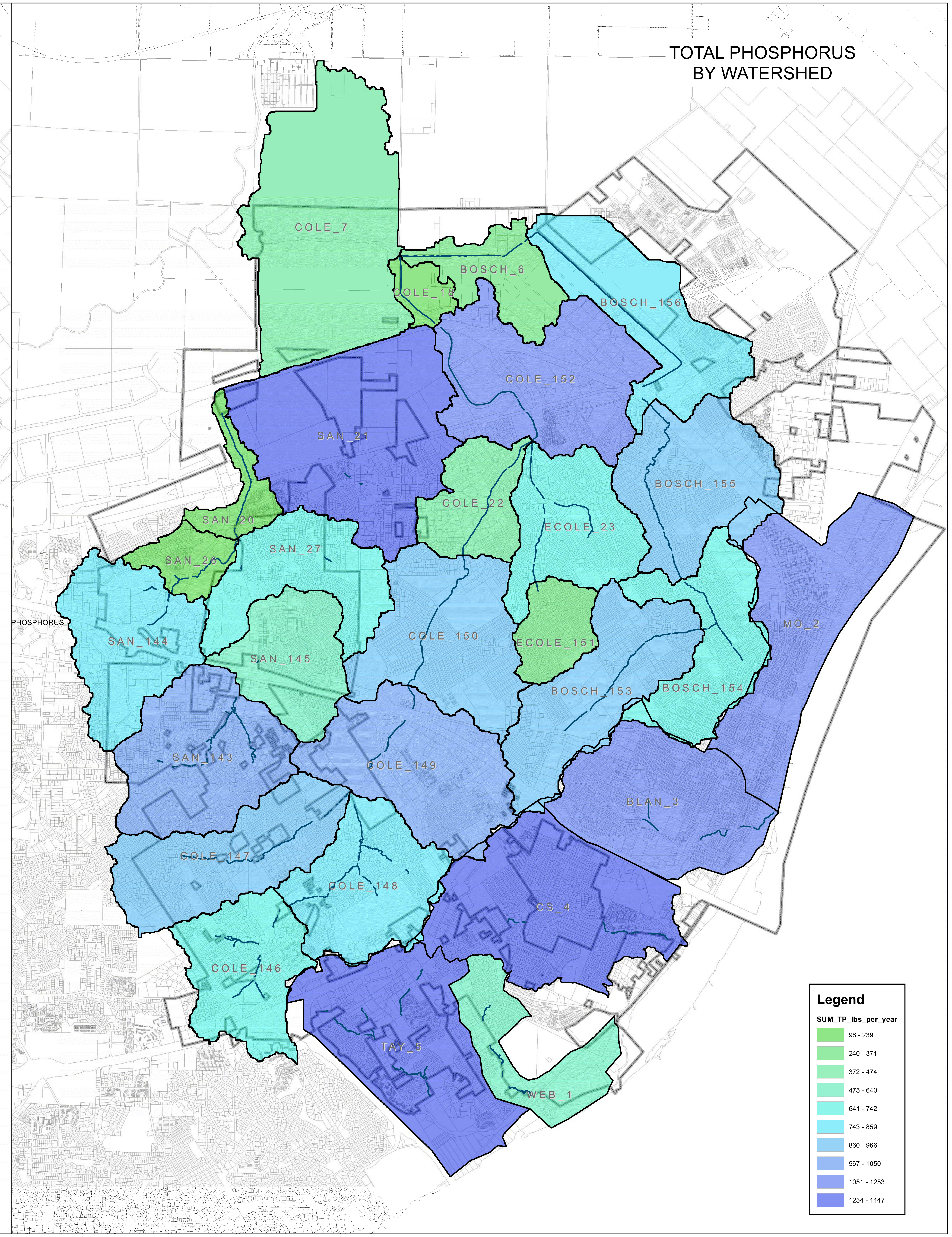

TOTAL NITRATE/NITRITE
BY SOURCE
NITRATE/NITRITE
Legend
NitriteNitrate / AreaAC
0 - 0.001
0.002
0.003 - 0.005
0.006 - 0.01
0.011 - 0.017
0.018 - 0.028
0.029 - 0.048
0.049 - 0.085
0.086 - 0.146
0.147 - 0.254
0.255 - 0.449
0.45 - 0.719

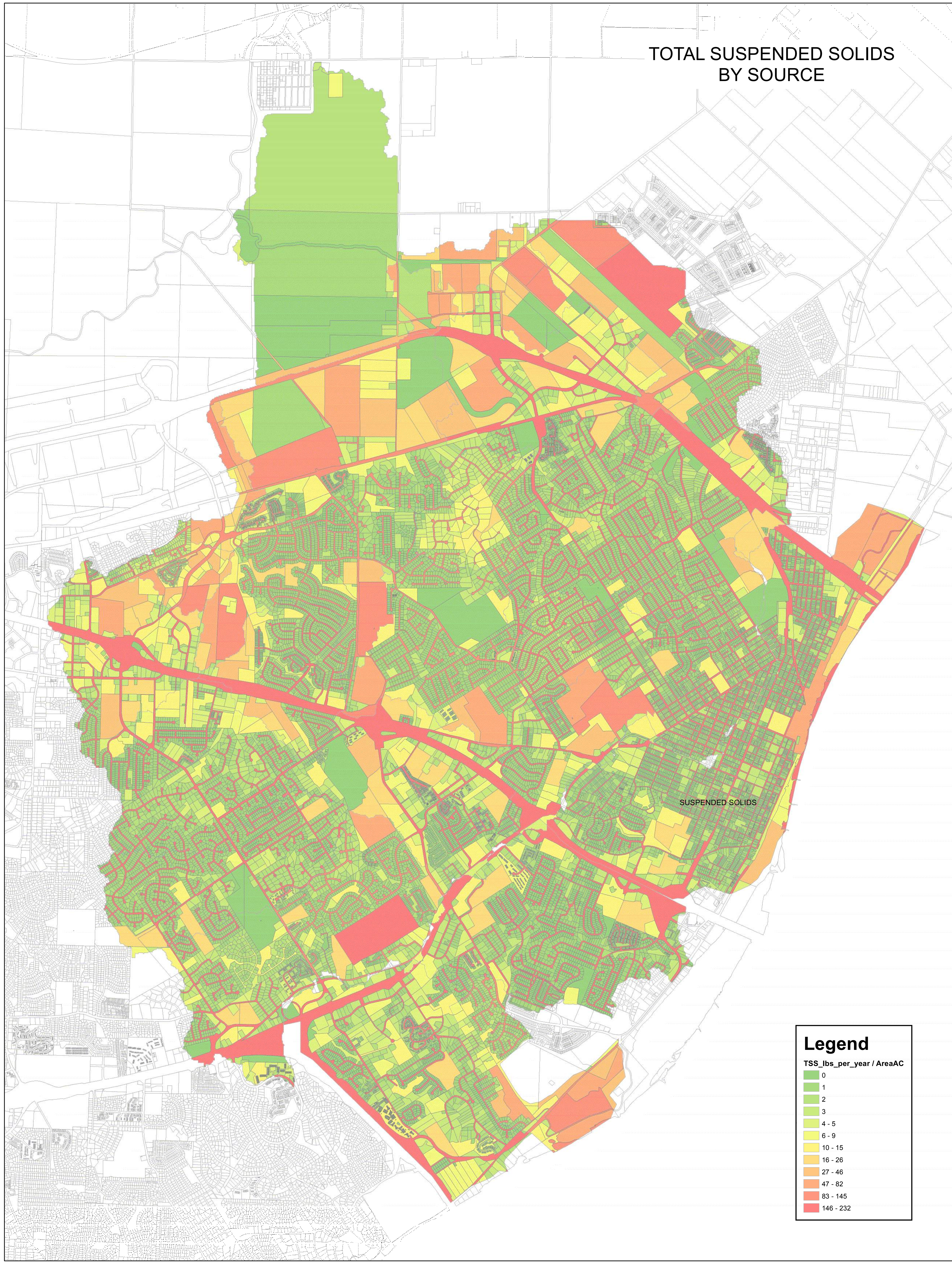

TOTAL NITRATE/NITRITE
BY WATERSHED
COLE_7
BOSCH_6
COLE_18
BOSCH_156
COLE_152
SAN_21
BOSCH_155
COLE_22
ECOLE_23
SAN_20
SAN_26
SAN_27
MO_2
NITRATE/NITRITE
SAN_144
SAN_145
COLE_150
ECOLE_151
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
Legend
SUM_NitriteNitrate
184
185 - 744
745 - 1132
1133 - 1323
1324 - 1533
1534 - 1846
1847 - 1994
1995 - 2171
2172 - 2582
2583 - 2998

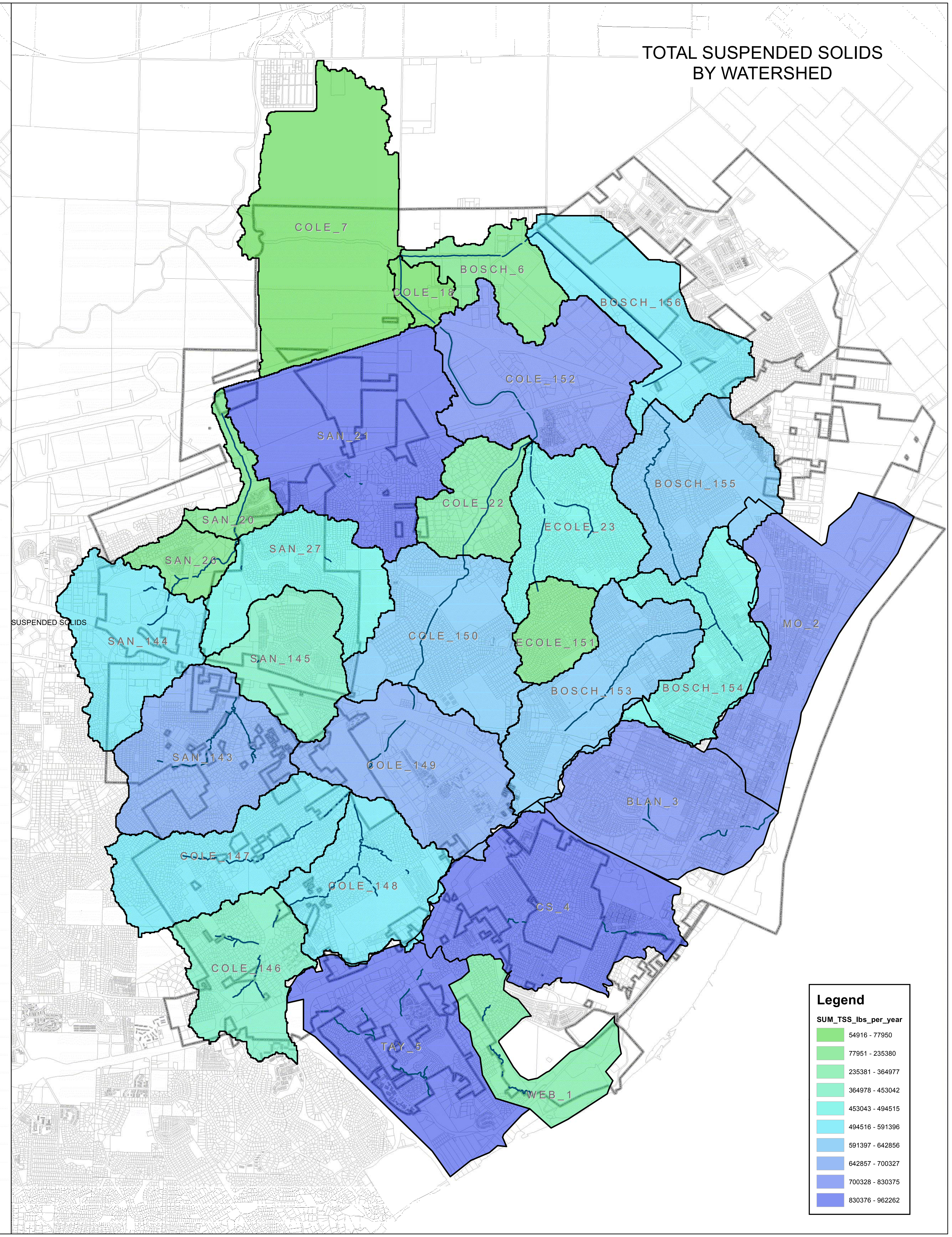

TOTAL NITROGEN
BY SOURCE
NITROGEN
Legend
TKN_lbs_per_year / AreaAC
0 - 0.002
0.003 - 0.005
0.006 - 0.01
0.011 - 0.02
0.021 - 0.035
0.036 - 0.061
0.062 - 0.104
0.105 - 0.173
0.174 - 0.306
0.307 - 0.549
0.55 - 0.97
0.971 - 1.555

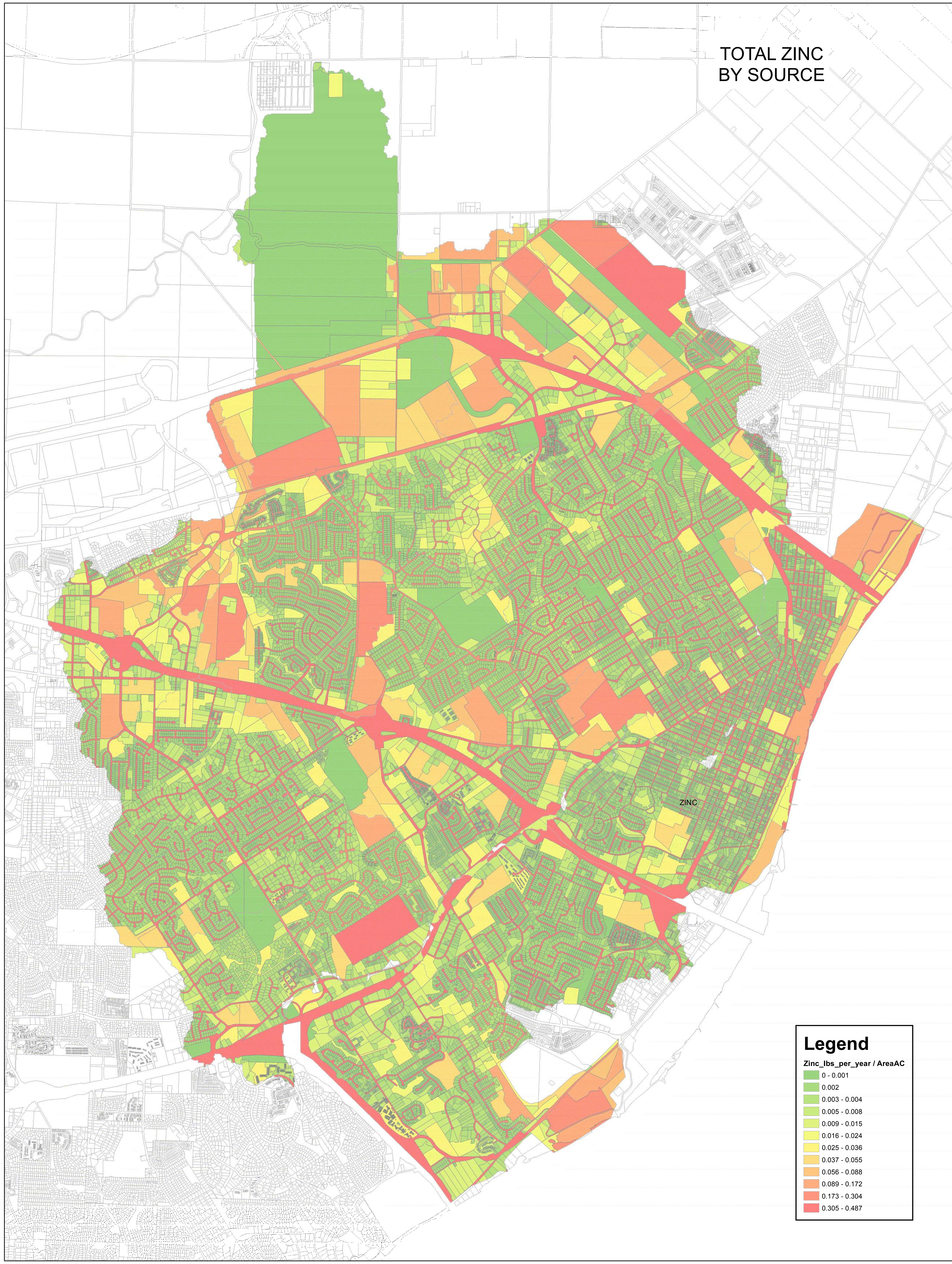

TOTAL NITROGEN
BY WATERSHED
COLE_7
BOSCH_6
COLE_18
BOSCH_156
COLE_152
SAN_21
COLE_22
ECOLE_23
BOSCH_155
SAN_20
SAN_27
SAN_26
SAN_144
SAN_145
COLE_150
ECOLE_151
MO_2
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
NITROGEN
Legend
SUM_TKN_lbs_per_year
436 - 1069
1070 - 1663
1664 - 2446
2447 - 2860
2861 - 3313
3314 - 3838
3839 - 4314
4315 - 4692
4693 - 5601
5602 - 6487


TOTAL PHOSPHORUS
BY SOURCE
PHOSPHORUS
Legend
TP_lbs_per_year / AreaAC
0
0.001
0.002
0.003 - 0.004
0.005 - 0.008
0.009 - 0.014
0.015 - 0.024
0.025 - 0.04
0.041 - 0.07
0.071 - 0.123
0.124 - 0.217
0.218 - 0.348

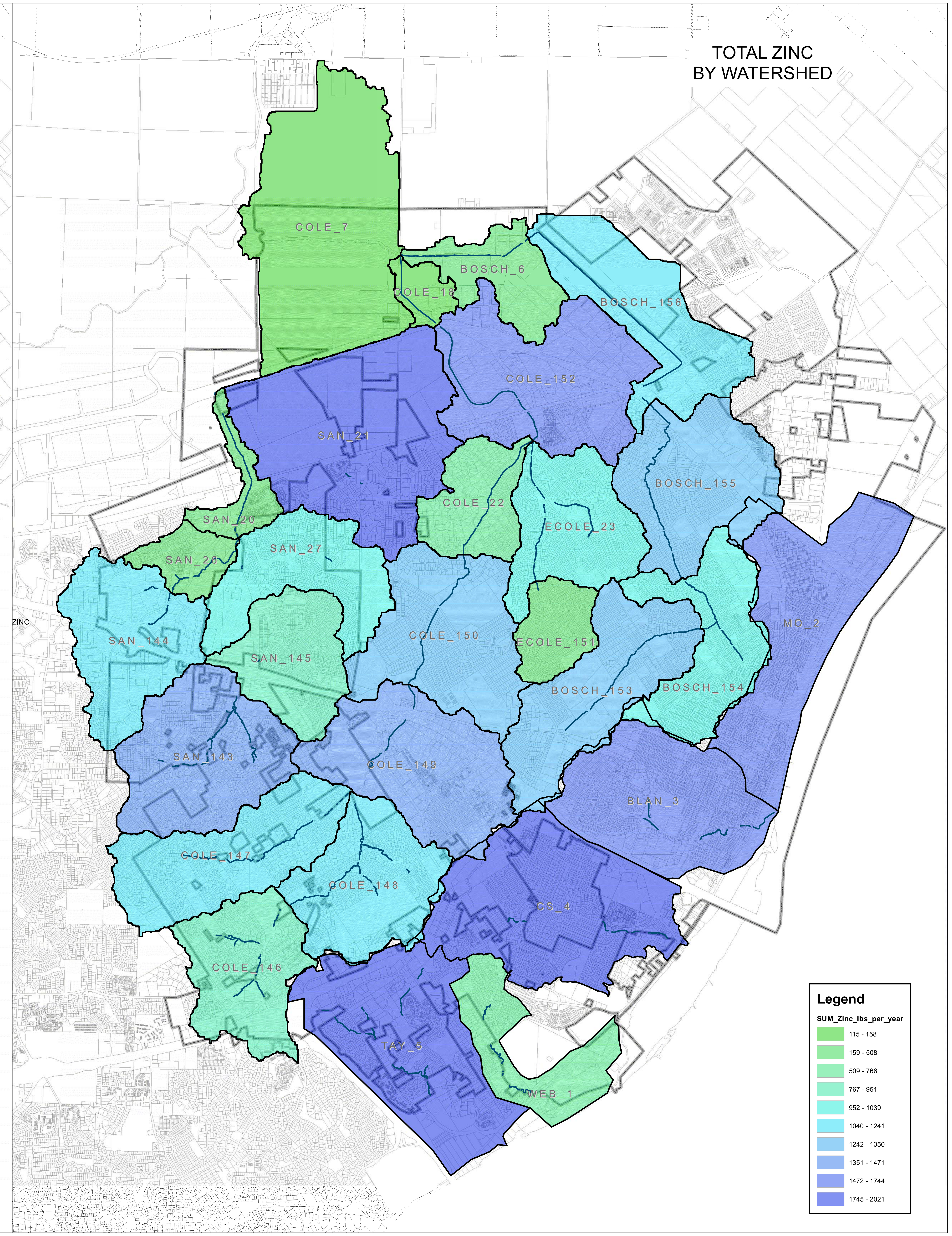

TOTAL PHOSPHORUS
BY WATERSHED
COLE_7
BOSCH_6
COLE_18
BOSCH_156
COLE_152
SAN_21
COLE_22
ECOLE_23
BOSCH_155
SAN_20
SAN_27
SAN_26
PHOSPHORUS
SAN_144
SAN_145
COLE_150
ECOLE_151
MO_2
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
Legend
SUM_TP_lbs_per_year
96 - 239
240 - 371
372 - 474
475 - 640
641 - 742
743 - 859
860 - 966
967 - 1050
1051 - 1253
1254 - 1447


TOTAL SUSPENDED SOLIDS
BY SOURCE
SUSPENDED SOLIDS
Legend
TSS_lbs_per_year / AreaAC
0
1
2
3
4 - 5
6 - 9
10 - 15
16 - 26
27 - 46
47 - 82
83 - 145
146 - 232


TOTAL SUSPENDED SOLIDS
BY WATERSHED
COLE_7
BOSCH_6
COLE_18
BOSCH_156
COLE_152
SAN_21
BOSCH_155
COLE_22
ECOLE_23
SAN_20
SAN_26
SAN_27
SUSPENDED SOLIDS
SAN_144
SAN_145
COLE_150
ECOLE_151
MO_2
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
Legend
SUM_TSS_lbs_per_year
54916 - 77950
77951 - 235380
235381 - 364977
364978 - 453042
453043 - 494515
494516 - 591396
591397 - 642856
642857 - 700327
700328 - 830375
830376 - 962262



TOTAL ZINC
BY SOURCE
ZINC
Legend
Zinc_lbs_per_year / AreaAC
0 - 0.001
0.002
0.003 - 0.004
0.005 - 0.008
0.009 - 0.015
0.016 - 0.024
0.025 - 0.036
0.037 - 0.055
0.056 - 0.088
0.089 - 0.172
0.173 - 0.304
0.305 - 0.487

TOTAL ZINC
BY WATERSHED
COLE_7
BOSCH_6
COLE_18
BOSCH_156
COLE_152
SAN_21
COLE_22
BOSCH_155
SAN_20
ECOLE_23
SAN_27
SAN_26
SAN_144
SAN_145
COLE_150
ECOLE_151
MO_2
BOSCH_153
BOSCH_154
SAN_143
COLE_149
BLAN_3
COLE_147
COLE_148
CS_4
COLE_146
TAY_5
WEB_1
ZINC
Legend
SUM_Zinc_lbs_per_year
115 - 158
159 - 508
509 - 766
767 - 951
952 - 1039
1040 - 1241
1242 - 1350
1351 - 1471
1472 - 1744
1745 - 2021