STREAM WATER QUALITY CORRIDOR ASSESSMENT AND MANAGEMENT USING SPATIAL ANALYSIS TECHNIQUES: INTRODUCTION, EVALUATION AND IMPLEMENTATION OF THE WQCM MODEL

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The rapid development of once-rural landscapes often produces detrimental effects on surface water quality entering local reservoirs through vulnerable stream channels. This study presents a methodology that incorporates geographic information systems (GIS) and remote sensing techniques for the creation of a stream corridor evaluation mechanism, coined the water quality corridor management (WQCM) model. Specifically, the study focuses on determining the viability of the WQCM model in assessing the stream corridor conditions within a northern Denton County pilot study region. These results will aid in the prediction and evaluation of the quality of stream water entering reservoirs that serve as the primary drinking water source for local municipalities.

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CHAPTER 1

INTRODUCTION

Dramatic increases in urbanization are occurring throughout the North Central Texas region. Denton and Collin Counties alone showed a population increase from 1990 to 2000 of 58.3% and 86.2%, respectively (US Census Bureau). With a current population of just over half a million and a 2030 projected population of approximately one million, expansion throughout Denton County shows no sign of slowing down (NCTCOG). Increasingly, freshwater resources are facing immense pressure from this urban expansion.

The Texas State Water Plan issued by the Texas Water Development Board (TWDB, 2006) predicts the population of Texas to increase from approximately 20.9 million in 2000 to 45.6 million by 2060. Specifically, the total population within the TWDB designated region C, which is encompassing of the Lake Lewisville drainage basin, is expected to increase from approximately 5.25 million in 2000 to 13 million by 2060, a percent population increase of 149.1%. The same report by the TWDB foretells somewhat moderate increases in water demand for several planning regions throughout Texas, with notable exception to planning region C. Water demands for this expanse are expected to increase 139.8% from 2000 to 2060. Such water requirements for the ever-increasing urbanized regions of North Central Texas indicate a decreasing availability for agricultural irrigation water and a dramatic increase in municipal water demand (TWDB, 2006).

Illegal dumping, chemical runoff, clear-cutting, grazing, and other human influences are just a few of the detrimental factors affecting the dynamic balance between streams, their surrounding corridors, and their encompassing catchments. As one of the most diverse and multifarious terrestrial habitats, riparian corridors influence water quality, flood prevention, wildlife habitat, economics and various other ecological, physical, biological, and chemical processes (Wagner, 2004). Effective assessment and management techniques are necessary to protect the vast array of diversity of ecosystem services found within fluvial ecosystems and to mitigate current and future conditions of environmental distress amplified by urban development.

The use of various spatial analysis techniques in environmental assessment present more expedient, cost effective, and broader ranging methods of evaluation than traditional field techniques. One such novel evaluation technique is the water quality corridor management (WQCM) model, developed by Samuel Atkinson, Ph.D., of the University of North Texas, in cooperation with the Upper Trinity Regional Water District (UTRWD). The WQCM model is a geospatial database that utilizes geographic information systems (GIS) and remote sensing techniques to assess and prioritize stream reaches according to their overall health and sustainability. This research assessed the viability of the WQCM model in reviewing the status of stream systems, and ultimately, established an accurate mechanism for evaluating the stream corridor and surface water quality leading into Lake Lewisville, a popular recreation site and drinking water source for Dallas and Denton municipalities.

To accomplish this task, the following objectives were met:

- Selected a field evaluation technique that best paralleled the parameters of the WQCM model

- Conducted field evaluations within the pilot study area (portions of Denton, Collin, and Grayson Counties) using the chosen field methodology
- Utilized Statistical Analysis System® software (SAS 9.1.3, SAS Institute, Inc., Cary, NC, www.sas.com) to perform univariate statistical tests comparing the field evaluation results to the data obtained via the WQCM model for the pilot study region
- Applied the WQCM model to the Lake Lewisville watershed
- Paired the parameters outlined by the WQCM model with best management practices for the goal of stream water and corridor protection

A comprehensive knowledge of the current stressors facing stream ecosystems and the existing assessment techniques is needed in order to understand the necessity of a far-reaching riparian evaluation methodology, such as the WQCM model. Chapter 2 of this study highlights, through literature review, the everyday functions, importance, and damaging impacts applying pressure to streams and their surrounding corridors. Chapter 2 also describes the WQCM model in relation to preservation versus restoration practices, the usefulness of spatial analysis techniques, a detailed description of the WQCM model, and a summation of the field assessments considered for the on-site verification of the WQCM model. The methods used to complete the project's objectives are described thoroughly within Chapter 3, including specific details on the field assessment technique chosen, modifications made to these procedures, and the statistical analyses performed in the evaluation of the WQCM model. The study results are described in Chapter 4 and Chapter 5 presents a comprehensive presentation and discussion of these results, including a summation of the project findings, various strategies of stream corridor protection as paired with the WQCM model parameters, and recommendations for future study.

CHAPTER 2

LITERATURE REVIEW

To gain insight into the scope of this project, it is important to examine the current environmental state of riparian ecosystems, recognizing how such conditions affect, and are affected by all physical, chemical, and human behavioral interactions. This chapter focuses on gathering that broad knowledge base via the analysis of published experimental and review studies. Topics addressed include exploring the benefits of streams and their surrounding corridors and the consequences of urbanization and misguided land management practices on such environments. This chapter also discusses the water quality corridor management (WQCM) model's goal of preservation in relation to restoration practices, along with the influence of spatial analysis techniques, including the WQCM model, on the identification of areas in need of preservation and the ensuing implementation of protective measures. Finally, analysis of various field assessment techniques is presented for the purpose of identifying the best field-based or in situ methodology to evaluate the effectiveness of the WQCM model.

2.1 Stream Ecosystems

Riparian corridors are forested and/or vegetative buffers that link aquatic and terrestrial environments, typically extending from the edge of a waterway onto a neighboring landscape (Correll 2005; Lovell and Sullivan, 2006). Healthy riparian stream corridors perform a multitude of valuable tasks for their adjacent waterways, influencing overall water quality, biological diversity, and ecosystem maintenance. Nutrient cycling, contaminant filtration, water purification, bank stabilization, stream temperature maintenance, flow stabilization, flood attenuation, and habitat preservation are some of the numerous functions carried out by riparian zones (Lovell and Sullivan, 2006; NRC, 2002). In addition, riparian corridors help sustain clean waterways which not only serve as recreational grounds, but also have been reported to increase home aesthetic worth and economic value by as much as 22% (Henry Jr. et al., 1999; NCTCOG, 2006). Unfortunately, urbanization and the consequent insurgence of detrimental anthropogenic activities have led to the degradation of streams and their corridors, inhibiting the natural cycles of biological and physical activities normally carried out within riparian ecosystems (Correll, 2005). Furthermore, everyday agricultural practices, such as grazing and the direct access of cattle to streams, have resulted in increased erosion of stream banks due to trampling, as well as direct deposition and indirect flow of animal waste into waterways, a principal component of non-point source pollution (Hamilton and Miller, 2002).

Throughout North Texas, what was once considered rural is now a part of an increasing urban landscape. As residential developments, commercial properties, and industrial services proliferate, they cover the natural landscape with roads, buildings, parking lots, and other impervious surfaces (NRC, 2002). Stream health is directly linked to urbanization, the effects of which simultaneously decrease bank stability and increase pollutant presence and transfer. Healthy riparian buffer zones have been shown to filter out up to 97% of soil sediment prior to stream entrance (Lee et al., 2003). Unfortunately, clear-cutting of riparian zones is one of the first by-products of urban and suburban development, leading to increased soil erosion. Increased erosivity generates a decrease in the depth of fertile topsoil and an increase of sediment within streams, containing such contaminants as metals, dichloro-diphenyl-trichlorethane (DDT), polychlorinated biphenyls (PCB), and polycyclic aromatic hydrocarbons (PAH). These pollutants are toxic to aquatic and terrestrial plant and animal species and are linked to human health via the food chain (France 1997; Kennedy, 2005).

De-forestation of riparian zones also affects the presence of other non-point source pollutants within stream systems, such as fertilizers, pesticides, pharmaceuticals, hormones and everyday household chemicals (Vellidis and Lowrance, 2004). In a study by Hamilton and Miller (2002), streams within urban settings contained higher levels of commercial and industrial solvents than did streams within agricultural areas, with 36% of the urban streams exceeding regulated guidelines. Riparian corridors help protect the water supply by removing the volatile chemicals that often enter streams via overland flow, a damaging process resulting from the increased presence of impermeable surfaces. Not only do riparian corridors play an important role in improving water quality and decreasing possible health risks resulting from contaminated water, but they also help ameliorate extensive water treatment costs (Lovell and Sullivan, 2006). An Environmental Protection Agency (EPA) National Water Quality Inventory (2000) assessing 19% of the waterways in the United States found that pathogens were a pollutant in over 93,000 miles of streams and rivers. Ultimately, the dynamic equilibrium of stream ecosystems is altered detrimentally by the cumulative effects of channelization, clear-cutting, illegal dumping, and increased chemical usage, all consequences of urbanization surrounding riparian zones. Urban sprawl, bad land management practices, and the negligent use and disposal of pollutants have placed stream ecosystems in a state of emergency and in dire need of protection.

The use of land for poorly managed agricultural and farming practices can have devastating effects on stream systems that are comparable to those caused by urban expansion.   A comparison study by Zaimes et al. (2004) determined that stream bank erosion was lowest along healthy riparian corridors and highest along streams with neighboring row-crop fields, followed by streams surrounded by continuously grazed pastures. In addition, had the streams bordered by high agricultural activity been buffered by riparian zones, erosion of stream bank soil would have decreased by roughly 72%. Healthy riparian buffers increase the amount of sediment being removed from cropland surface runoff by anywhere from 92% to 97%, depending on buffer width and vegetation type (Lee et al., 2003).

An extensive review of the literature found no citations of positive impacts from the open grazing of riparian ecosystems. Direct access to stream corridors by grazing livestock tramples in-stream and stream bank vegetation, decreases the amount of detritus for aquatic organisms, diminishes natural habitat for both fish and wildlife species, compacts underlying soils, redistributes nutrients, reduces bank stability and sediment trapping, and fractures delicate ecological niches susceptible to invasive species (Belsky et al., 1999; NRC, 2002; Zaimes et al., 2004). Furthermore, the deposition of manure and urine into stream systems has been shown to reduce dissolved oxygen levels and spread pathogenic microbial contaminants throughout the water supply (NRCS, 1995).

Stream water quality is directly related to the condition of stream corridors and the overall stream ecosystem. The number of beneficial functions carried out by riparian buffers is disproportionate to their oftentimes diminutive breadth. In order to help meet the goals set forth by the Clean Water Act of 1972, stream and stream corridor assessment and management strategies need to be available not only to scientists working to protect the streams, but to the landowners and developers utilizing their properties daily (NRC, 2002). With so many encroaching pressures, the protection of riparian corridors is critical for the sustainability of stream ecosystems and the safeguarding of water entering local reservoirs.

2.2 WQCM Model Preservation vs. Restoration Practices

The purpose set forth by the WQCM model is that of stream corridor and water quality protection. The WQCM model classifies areas on a qualitative scale for which the streams of highest quality warrant preservation. The protection of intact riparian zones is multi-dimensional, incorporating various passive and active management and abatement practices. Before analyzing specific methods for stream corridor protection, it is important to explore the fundamental idea behind the WQCM model, preservation.

As previously discussed, increased sediment load, illegal dumping, channelization, and the clear-cutting and trampling of natural riparian vegetation are just a few of the anthropogenic vestiges bringing about the degradation of stream ecosystems. Ecological restoration involves re-establishing the biological and physical disconnects among streams that occur from such damaging practices (Kauffman et al., 1997). Restoring the complicated network of biotic interactions is tedious, requires a detailed knowledge base, and is a potentially-expensive endeavor for any institution, whether private, government, or academic (Scholz and Booth, 2001). A viable alternative to the restoration of degraded stream systems is the protection and preservation of waterways and their surrounding corridors. The maintenance of healthy riparian ecosystems not only provides example environments by which restoration practices can be modeled, but is also a more economical alternative when funding is limited and efforts need to be focused on a less intensive methodology (Kauffman et al., 1997).

It is the ultimate goal of preservation strategies to curtail the loss of valuable resources. An improvement in resource conditions, however, is dependent on the eventual enactment of restoration practices. Protection strategies provide the solid foundation by which more politically and environmentally complicated restoration efforts can be evolved over time (Figure 1). The WQCM model establishes the underpinning for such a continuum management project by identifying and prioritizing stream segments based on the need for protection. For all of the reasons described, this study will focus on management strategies specific to the purpose of stream ecosystem preservation. Specific protection strategies, identified in coordination with the parameters of the WQCM model, are discussed in Chapter 5.

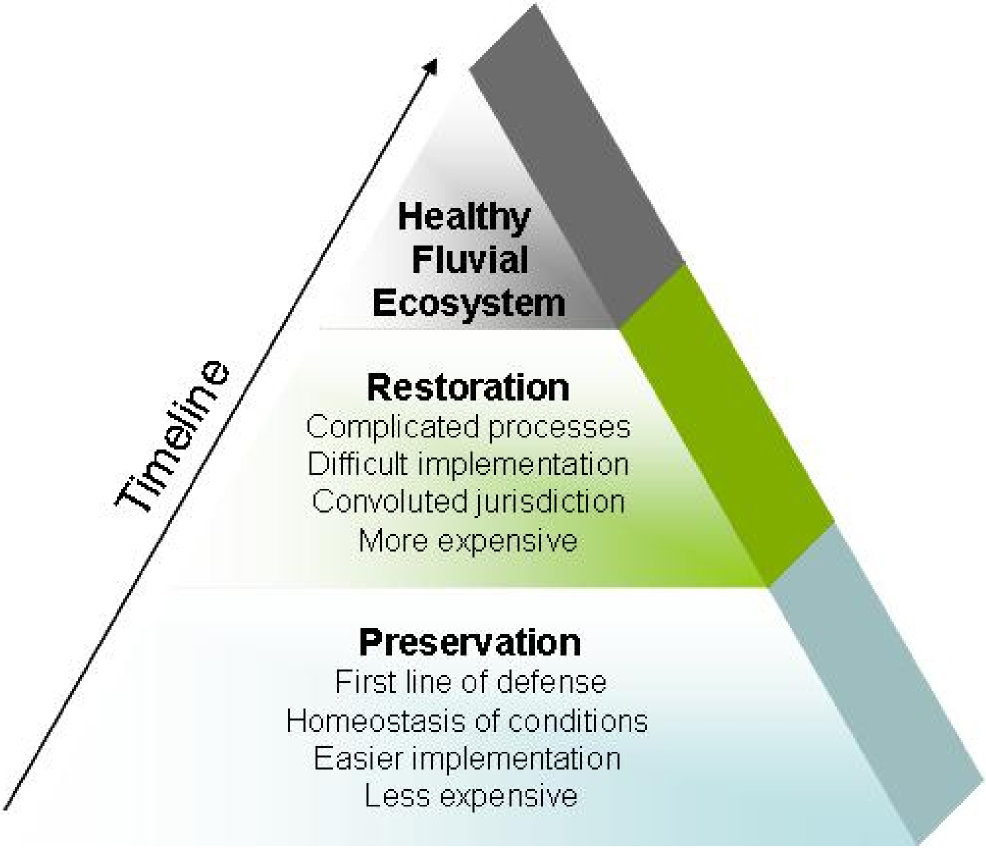


Figure 1. Continuum concept of stream ecosystem maintenance with comparison between preservation and restoration strategies (Alan Plummer Associates, 2006).

2.3 Spatial Analysis Techniques

In terms of water quality monitoring and protection, a watershed approach has been widely suggested and supported as the premier level of investigation (EPA Introduction, 2005). This methodology is based on the understanding that stream biological processes are interrelated and connected, therefore necessitating a holistic approach when attempting to curtail damaging impacts, whether direct or indirect. Although this tactic often relies on the integration of multiple individuals and organizations, and thus is more difficult to implement on smaller monetary scales and over large topographic areas, the guiding principles are key to identifying and prioritizing the state of fluvial ecosystems. Spatial analysis techniques, such as geographic information systems (GIS) and remote sensing, enable the monitoring of environmental conditions on various scales of measure (Harris et al., 1997; Turner, 1989).

GIS and remote sensing have modernized the monitoring and implementation of best management practices for the protection of stream ecosystems. Such techniques allow for the manipulation of large and complex datasets, while providing easy access to data retrieval. In addition, complex interactions can be evaluated through the GIS layering of various data montages, such as land use classifications via remote sensing, satellite images, feature files, and raster datasets (Wood and Smith, 2006). GIS technology also allows for simplified data sharing, making it logistically easier and more cost-effective to employ interdisciplinary teams working towards the goal of environmental sustainability (EPA Measure 12, 2005).

Furthermore, it is through computerized analysis that the practice of landscape ecology has flourished. Landscape ecology deals with the complex and dynamic interactions among ecosystems and their relation to spatial and temporal distributions across heterogeneous topography (Turner 1989). Data over such broad and widespread scales are often cumbersome and difficult to analyze in a cost effective, time efficient, and comprehensive manner. In fact, stream and stream corridor field assessment techniques are problematic in their inability to adequately incorporate all the various ecological regions of the United States. North Central Texas alone includes the Blackland Prairie, the Eastern and Western Cross Timbers, the Grand Prairie, and the Red River area, all highly diversified regions with contrasting land usage, soil type, vegetation, and other differentiating parameters (Diggs et al., 1999). Without a cohesive field assessment guide, it has fallen upon private and federal agencies to develop highly specific, and oftentimes costly, regionalized inventories. Not only has the use of GIS and remote sensing streamlined the process of evaluating spatial relationships across different geographical regions, but the pairing of such techniques with environmental and ecological models has broadened the range of intricate analyses being performed in landscape studies (Turner 1989).

2.4 The WQCM Model

Using GIS and remote sensing technology, a stream water quality corridor management (WQCM) model was designed to identify potential water quality issues and to prioritize stream segments. To establish the relative priority of stream reaches, five parameters were chosen based on their availability and capacity for manipulation within spatial analysis software, as well as their ability to predict current reach conditions. These parameters included vegetation type, erosion potential, surface slope, percent of the stream defined by the Federal Emergency Management Agency (FEMA) 100-year floodplain, and amount of the stream corridor contained within the subwatershed. Each parameter consisted of an importance weight and scaling function, which was determined based on the delineation of parameter magnitude. Importance weights (i) and scaling functions (f) assigned to each WQCM component ranged from 1 to 5, with 5 indicating a greater need for protection. Values were calculated and summed for each stream segment, generating an overall WQCM score for each subwatershed (Table 1). Based on the WQCM score, each subwatershed was classified into one of four preservation priority groupings: low, moderate, high, and highest priority. WQCM results ranged from 0 to 50, with the highest scores assigned to the highest preservation priority category and indicating the greater need for protection of a stream corridor under future development.

Table 1. Description of the WQCM model, broken down by components.

WQCM model = $V_iV_f + E_iE_f + S_iS_f + F_iF_f + C_iC_f$	
WQCM Component	Brief Description
Vegetation (V)	Eight classes were generated. The more the native the vegetative cover (forested riparian zones) within the stream corridor, the greater need for protection
Erosivity (E)	Kffact (Kw) scores range from 0 to .43; The higher the Kw, the higher the erosion potential and the greater need for protection
Slope (S)	Slope range from <1% to 5%; The higher the slope percentage, the greater need for protection
Floodplain (F)	Ratio of the FEMA 100-year floodplain area to stream buffer area; Since the floodplain (defined by FEMA) provides inherent protection, the greater the area outside the floodplain, the greater need for protection
Corridor (C)	Ratio of the corridor area to the subwatershed area; The larger the stream corridor area within the subwatershed, the greater need for protection

To forecast the predictability of the WQCM model, a field assessment methodology was chosen for the physical evaluation of stream segments within the pilot study area. Time, budget, complexity of the procedures, protocol objectives, and regional climatic constraints all factored into the choice for a suitable field assessment methodology.

2.5 Field Assessment Selection

The WQCM model analyzes stream water and corridor quality using a combination of elements not entirely paralleled by standard field assessment protocols. The selection of a field inventory technique to test the predictability power of the WQCM model that was appropriate for the North Central Texas region and that also addressed the parameters outlined by the WQCM model, posed a challenge. Field assessments analyzing everything from wildlife habitat, wetlands, riparian corridors, stream channels, and floodplains were evaluated on their functionality, individual assessment parameters, and overall fit to the WQCM model's objectives. A series of field procedures, their specializations, and potential as a WQCM model assessment technique are outlined below.

The parameters of two habitat-based assessment protocols were evaluated in relation to the WQCM model: the wildlife habitat appraisal procedure (WHAP) and the habitat evaluation procedure (HEP). WHAP (Frye, 1995) specializes in evaluating habitat quality, impacts on wildlife habitat from water development projects, and wildlife management potential. Applicable to bottomland and wetland areas, this visual, quantitative inventory focuses on land cover type; a similar parameter to that of the WQCM model. In contrast, HEP (USFWS, 1980) measures the quality and quantity of available habitat for a few selected species known to inhabit the land cover types of the proposed study area. For each species under evaluation, HEP requires the development of a habitat suitability model that can be both time consuming and labor intensive if not already in existence. Although highly specific in their delineations and analyses of land cover types, both WHAP and HEP methodologies do not include parameters associated with water quality and stream corridor conditions. The use of either protocol to test the WQCM model would have required an additional protocol that included stream assessment parameters. Consequently, in an effort to find the most efficient field evaluation possible, both WHAP and HEP were abandoned as options.

Several wetland appraisal methods were considered with similar parameters to those of the WQCM model, including the wetland evaluation technique (WET) and the hydrogeomorphic approach (HGM). Both the WET (Adamus et al., 1987) and the HGM (USACE, 1996) protocols use various qualitative and quantitative techniques to assess landscape, hydrologic conditions, soil type, and vegetation. These parameters are, however, designed exclusively for wetland areas, and are not easily adapted to streams and riparian corridors. In addition, the HGM has not yet been developed for North Central Texas, making it unsuitable for use at this time.

Over 30 stream corridor inventory and assessment techniques focusing on channel-floodplain, riparian areas, water quality (contaminants), and/or aquatic habitat were included in the search for a field verification methodology. Priority was placed on techniques which (1) concentrated on channel-floodplain and riparian areas, (2) did not require complex field and/or laboratory measurements, (3) were not region specific and/or could be easily locally modified, and (4) did not need a reference site for comparison analysis. With these and various other elements in mind, the list of protocols was narrowed to 4 possible candidates: stream*a*syst, riparian area management: process for assessing proper functioning condition, the adopt-a-stream shoreline survey, and the stream visual assessment protocol.

Stream*a*syst (S*A*S), developed by the Oregon State University Extension Service (Andrews and Townsend, 2000), was designed to help landowners evaluate stream corridor conditions on their property. A series of fifteen “yes” and “no” questions are used to identify potential concerns, such as water pollution, algae presence, floodplain and channel condition, agricultural influences on vegetation, and streambank condition. An action plan is employed in conjunction with the questionnaire to more specifically address landowner concerns and includes recommended mitigation steps and agency contact information. Although this methodology contained parameters more closely related to the WQCM model's objectives, and was the easiest to perform, it lacked a defined numerical scale of stream condition, requiring the evaluator to assign a qualitative value on overall stream health.

The U.S. Department of the Interior Bureau of Land Management's protocol, riparian area management (RAM): process for assessing proper functioning conditions (Prichard et al., 1998), is a highly specialized assessment that works best with the cooperation of an inter-disciplinary team of vegetation, soil, and hydrology specialists. Although areas could be qualitatively categorized as "functional at risk," "nonfunctional," and "unknown," it lacked a quantitative scoring range for these groupings. Consequently, the inability of this methodology to be statistically compared to the WQCM model, coupled with its complicated and staff intensive nature, excluded its use within the project.

The adopt-a-stream shoreline survey, prepared by the Massachusetts Riverways Programs (Kimball and Van Dusen, 1996), uses a questionnaire format to evaluate current instream, corridor, vegetation, and fish and wildlife conditions, as well as bridge and pipeline stability. The assessment categories correlated somewhat with the WQCM model's parameters, and the procedure itself fit within the time frame and expertise levels for the project at hand. As with the S*A*S and RAM techniques, however, the lack of a quantitative measurement scale of stream health negated the use of this assessment.

As both an inventory and evaluation methodology, the stream visual assessment protocol (SVAP, 1998), developed by United States Department of Agriculture (USDA)

National Resource Conservation Service (NRCS), quantitatively scores, via set scales, the physical conditions evaluated for stream aquatic ecosystems. Accordingly, correlation and regression analyses can be performed between the SVAP and WQCM scores to evaluate the accuracy of the WQCM model to real world conditions. The following 15 assessment elements are evaluated within the protocol, not all of which must be used for each stream segment: channel condition, hydrologic alteration, riparian zone, bank stability, water appearance, nutrient enrichment, barriers to fish movement, instream fish cover, pools, invertebrate habitat, canopy cover, manure presence, salinity, rifle embeddedness, and macroinvertebrates observed. The adjustable applicability of the evaluation parameters to each stream reach gives this protocol flexibility to region and individual stream conditions not present in other techniques. Although the SVAP assesses stream health using several parameters and objectives not directly correlated with the WQCM model, it does share elements that parallel the WQCM model's focus on channel, bank, water, and soil conditions in relation to stream water and corridor quality. In addition, the ease and timeliness in which the SVAP protocol could be implemented made it an ideal choice for use within this study.

CHAPTER 3

METHODOLOGY

This chapter details the procedures employed throughout the various phases of research. A geographical description of the Lake Lewisville watershed and pilot study area is also presented, along with an accounting of the data origins utilized within the water quality corridor management (WQCM) model. Also described are the parameters and directives of the stream visual assessment protocol (SVAP) field methodology, chosen following the comprehensive review process outlined in chapter 2.5, as well as the considerations for field verification site selection. Chapter 3 concludes with a description of the statistical analyses used in comparing the WQCM model to real-world conditions assessed by the field verification methodology.

3.1 Description of Study Area

The Lake Lewisville watershed was the overall region of focus, extending between north latitudes 30°44’ and 32°42’ and west longitudes 96°43’ and 97°50’. The area south of Lake Ray Roberts spans approximately 867 square miles (2,245,519 square meters). The watershed extends throughout portions of Montague, Cooke, Grayson, Wise, Denton, and Collin Counties.   The pilot study area, in which field verifications were performed, extends throughout portions of Denton, Collin, and Grayson Counties (Figure 2). Of the top ten fastest growing cities in North Central Texas for 2005-2006, Collin County contained seven and Denton County one, including the cities of Celina, Prosper, and Little Elm, all located within the pilot study area (Figure 3). The principal tributaries contributing to the Lake Lewisville watershed include Clear

Creek and Hickory Creek on the west side of the catchment and Pecan Creek, Mustang Creek, and Little Elm Creek to the east.

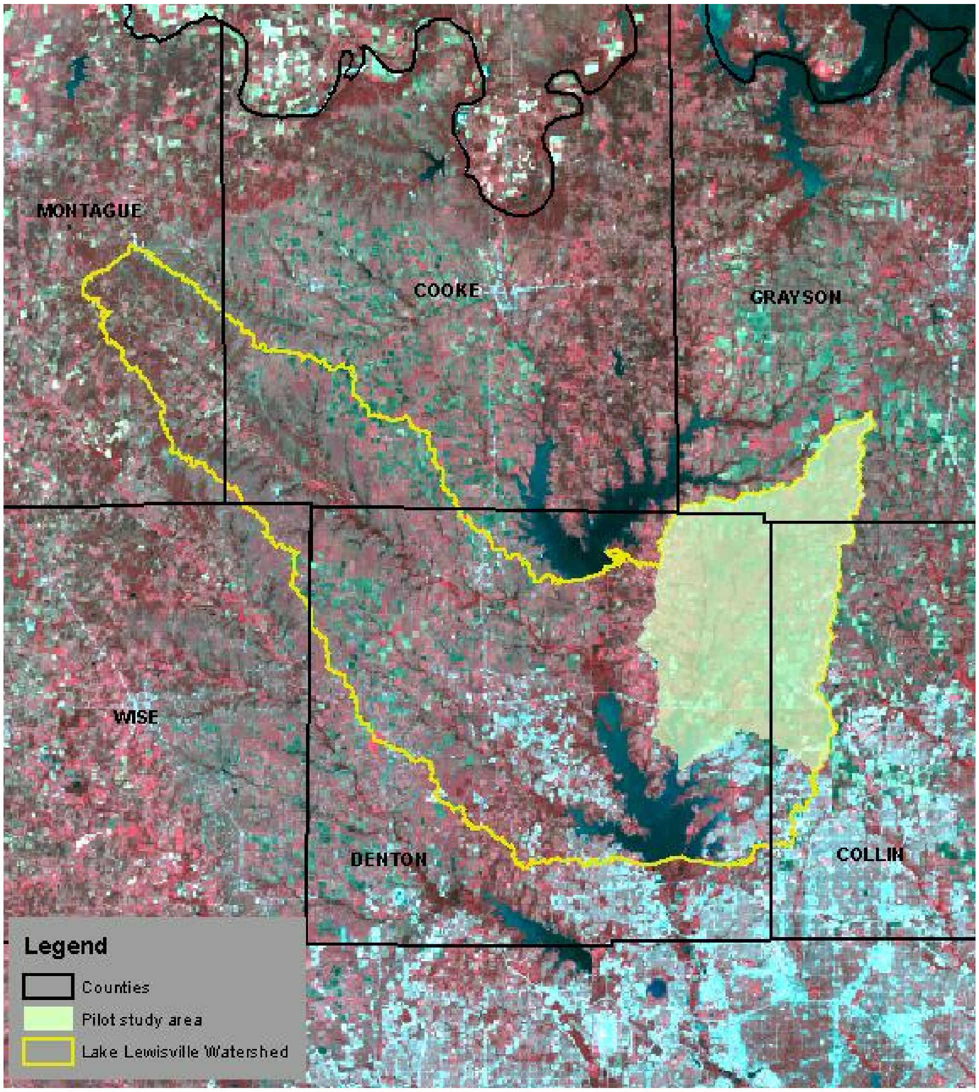


Figure 2. Lake Lewisville watershed and pilot project study area.

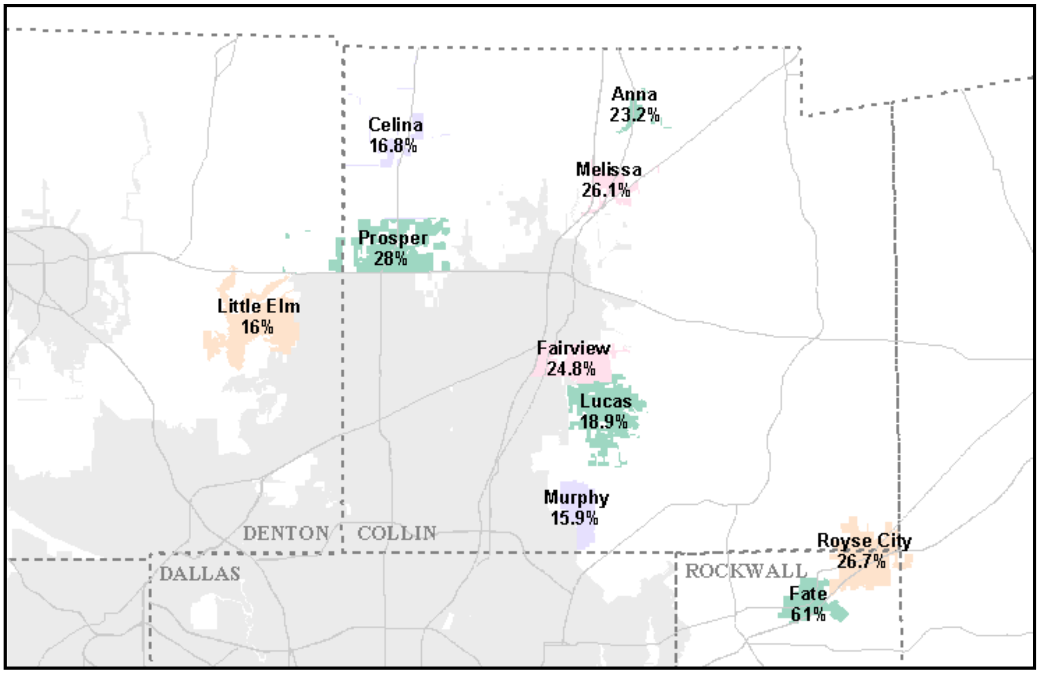


Figure 3. Fastest growing cities of North Central Texas, 2005-2006 (NCTCOG, Population Estimates). Percentages represent overall percent growth and are based on current housing inventories within cities with populations of 1000 or more people.

The Cross Timbers and Blackland Prairie make up the two main physiographic regions of the Lake Lewisville watershed. The Cross Timbers are transitional areas of forest, woodland savannah, and prairie that can be further subdivided into the Western Cross Timbers of the northwestern and western areas of the watershed, Grand Prairie of the central region, and Eastern Cross Timbers of the eastern most watershed counties, inclusive of the pilot study region. The fine, sandy loams of the Western Cross Timbers and red and yellow sandy soils of the Eastern Cross Timbers are dominated by an overstory of post oak and blackjack oak and an understory of various grasses. Located immediately between the Western and Eastern Cross Timbers lies a sliver of upland, tall grass area called the Grand Prairie. To the east, and in stark contrast to the Cross Timbers, lies the dark, clay soil of the Blackland Prairie. This region makes up the eastern-most portion of the pilot study area and is wooded with bur oak, Shumard oak, elm, ash, eastern cottonwoods, and pecans, while historically vegetated with grasses such as little and big bluestem. All of the North Central Texas physiographic regions are predominantly utilized for grazing, farming, and most recently, urban development (Diggs et al., 1999; Griffith et al., 2003).

The climate of the study area is humid subtropical with hot summers, mostly mild winters, and occasional short-lived winter storms. The average length of the warm season is about 249 days. The area is accustom to heavy thunderstorms during the spring months and scattered rainfall of varying intensity throughout the year, with an average annual precipitation of approximately 36 inches (0.91 meters) over the watershed. However, the drought conditions of 2005-2006 have limited the natural plant cover along the Blackland Prairie and significantly reduced the water retention ability of the clay soil, leading to increased erosion. Similarly, erosion is a problem among the sandy, loose soil of the Cross Timbers. These soil susceptibilities, along with rapid commercial development and residential growth around the streams and tributaries flowing directly into Lake Lewisville, made the pilot study region and overall Lake Lewisville watershed ideal for the stream water and corridor quality assessment project (Griffith et al., 2003; USACE, 1999).

3.2 Data Acquisition and Modification for the WQCM Model

Various spatial data layers were utilized in the generation of the WQCM model for both the pilot study area and the Lake Lewisville watershed. The origin and creation of the GIS layers for each of the WQCM model components is described below:

- Vegetation Parameter: Land use classifications were created from 2004, 30-meter resolution LANDSAT® ETM satellite imagery (U.S. Geological Survey, Reston, VA, http://landsat.usgs.gov) using Definiens eCognition 4.0^{TM} software (Definiens, Munich, Germany, www.definiens.com). The following eight classifications were generated: barren, cropland/pasture, forested, residential, shrub/brush rangeland, urban, water, and unclassified. An area summary in acres for each subwatershed was created for all eight vegetation classes within the stream buffer region and imported into the WQCM model

- Soil Erosivity Parameter: The National Resource Conservation Service (NRCS) soil survey geographic (SSURGO) database dataset was obtained for all study area counties and used to create the soil erosion potential layer. A polygon shapefile of the county soil surveys was joined with the 'kffact' erosivity factor database file, enabling the display of soil erodibility in ESRI ArcGIS® software (Environmental Systems Research Institute, Redlands, CA, www.esri.com) via the 'kffact' field. Eight erosivity 'kffact' categories were generated: Kw = 0, Kw = 0.17, Kw = 0.20, Kw = 0.24, Kw = 0.28, Kw = 0.32, Kw = 0.37, and Kw = 0.43. An area summary in acres for each subwatershed was created for each erosivity class within the stream buffer region and imported into the WQCM model
- Slope Parameter: ESRI ArcGIS software was used to convert a digital elevation model (DEM), obtained from the USGS National Elevation Dataset (NED), to a raster format. The grid file was then used to create a percent slope raster file using the slope tool via the ArcInfo® 9.1 software (ESRI, Redlands, CA, www.esri.com) spatial analyst extension. Five slope categories were generated: <1%, 1% to 2%, 2% to 3%, 3% to 4%, and 4% to <5%. An area summary in

acres for each subwatershed was created for each slope class within the stream buffer region and imported into the WQCM model

- Floodplain Parameter: The Federal Emergency Management Agency (FEMA) 100-year floodplain layer was obtained from the Denton County Appraisal District for the pilot study region. As the FEMA 100-year floodplain data was not available for all of the counties within the Lake Lewisville watershed, the floodplain was alternatively delineated using frequently and occasionally “flooded soils” data available from the NRCS SSURGO database. The floodplain component within the WQCM model was generated by dividing the area of the floodplain within each subwatershed by the overall stream buffer area within each subwatershed. An area summary in acres for each subwatershed was created and imported into the WQCM model
- Corridor Component: The ESRI ArcInfo 9.1 buffer tool was used to generate a 66-foot (20 meters) wide buffer zone around a stream shapefile obtained from the USGS National Hydrography Dataset (NHD). The stream buffer was then exported as a separate shapefile to be used as the extent from which the vegetation, soil erosivity, slope, and floodplain layers were clipped. The WQCM model corridor component was generated by dividing the area of stream buffer within each subwatershed by the total area of each subwatershed. A summary in acres for each subwatershed was created and imported into the WQCM model
- The subwatershed boundaries were produced using the ArcView® 3.1 software (ESRI, Redlands, CA, www.esri.com) automated geospatial watershed assessment (AGWA) application and the soil and water assessment tool (SWAT)

for basin subdivision. The pilot study area was divided into 133 subwatersheds (Figure 4), and the Lake Lewisville watershed was divided into 90 subwatersheds (Figure 5). All geographic information systems (GIS) data layers were obtained and created with the assistance of Brian Boe, M.S. Environmental Science from UNT

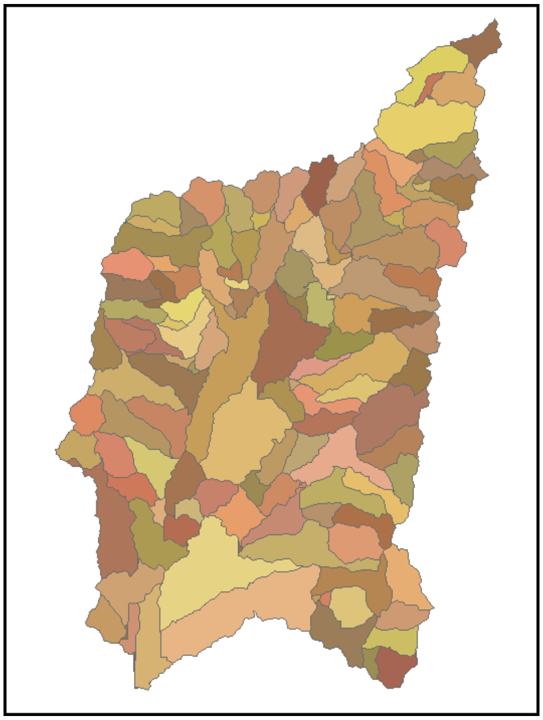


Figure 4. Individual subwatersheds (133) for the pilot study area.

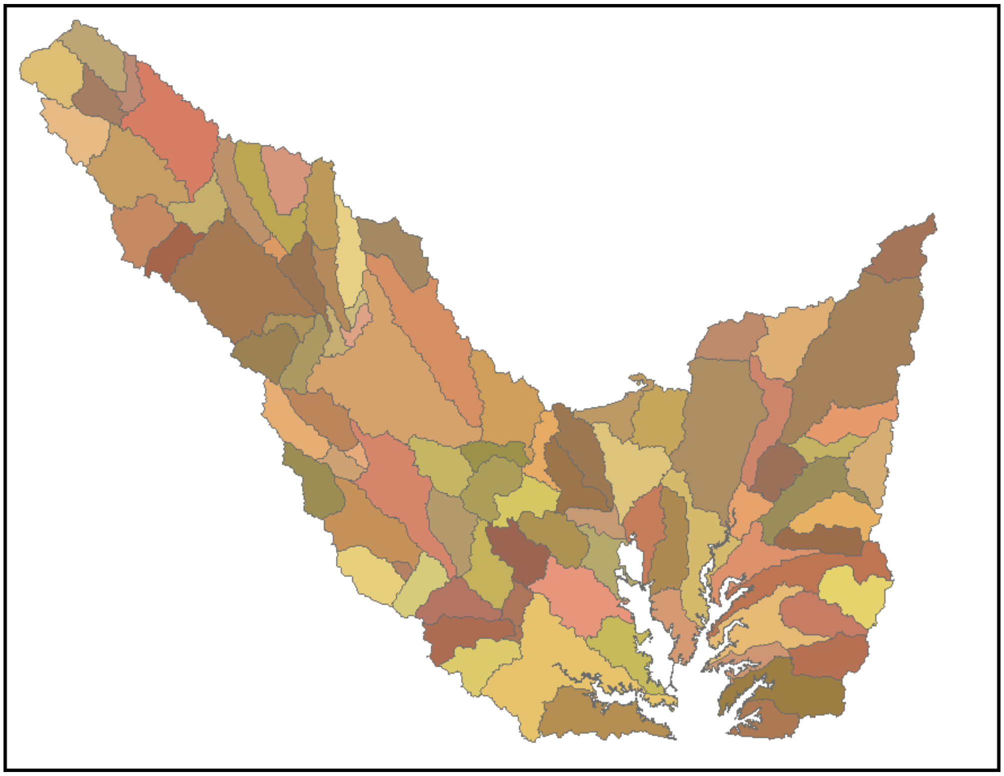
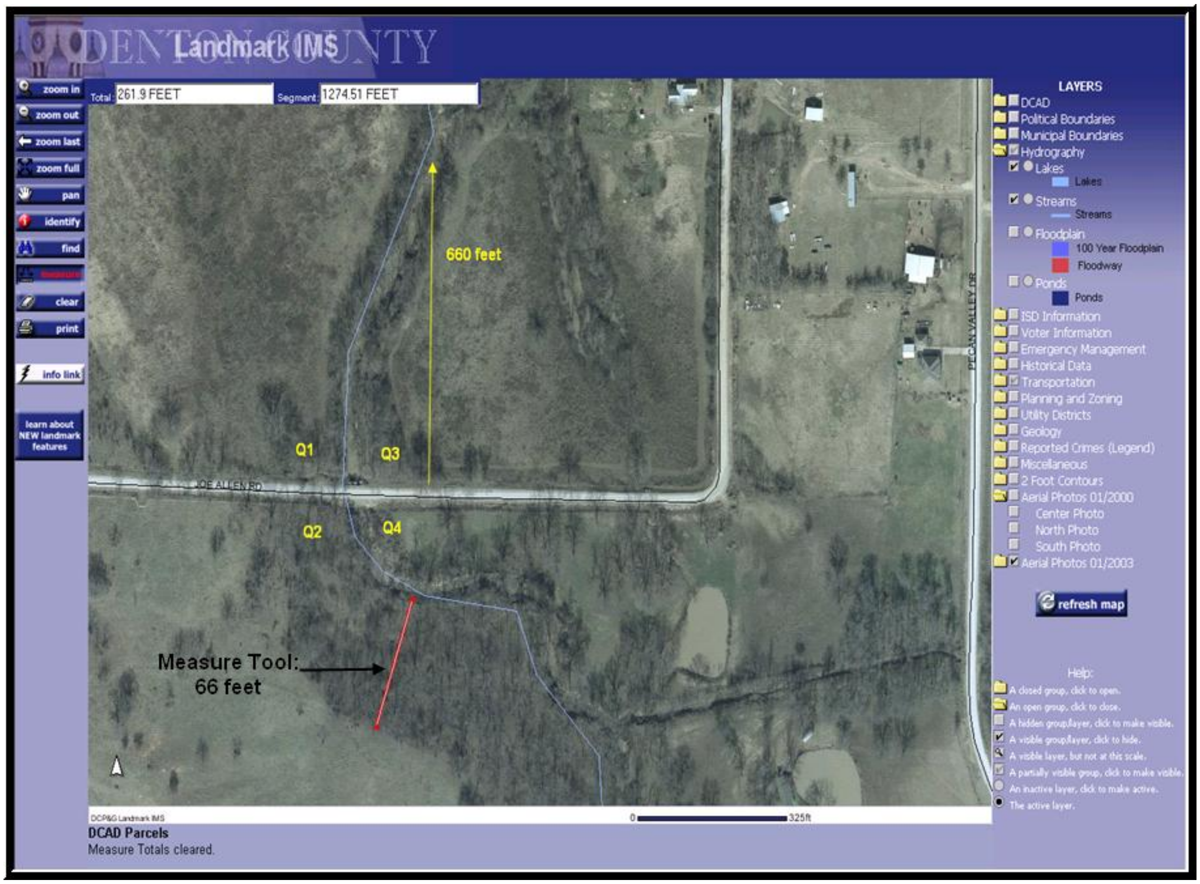


Figure 5. Individual subwatersheds (90) for the Lake Lewisville watershed.

3.3 Field Verification Methodology

As previously described, the SVAP was chosen as the evaluation technique used in the field for a comparison of stream conditions assessed remotely by the WQCM model. The two sections of the SVAP include a stream identification worksheet and a stream assessment section. Basic information was recorded about each stream segment on the stream identification worksheet, including site number, stream name, stream location within the catchment, land use type, active channel width, and dominant channel substrate. The stream assessment section of the SVAP is comprised of an evaluation worksheet with 15 assessment elements. These elements were recorded for the test river segments using pre-defined scales for scoring. Since the protocol does not require all elements to be assessed for each stream reach, the SVAP can be customized to better fit the conditions of the study area. Of the 15 parameters listed previously, channel condition, riparian zone, bank stability, water appearance, nutrient enrichment, invertebrate habitat, manure presence, and canopy cover were scored for each test stream segment. These parameters were graded on a scale of 1-10 by comparing visual observations to the descriptions outlined for each element in the protocol. The descriptive scales for the parameters of bank stability, canopy cover, and manure presence were inversed from that given in the SVAP protocol in order to directionally correspond with the parameter scales of the WQCM model.

An additional parameter was added to the SVAP guidelines in order to ensure a comprehensive evaluation of the WQCM model's assessment of land cover conditions within the stream buffer regions. For this component, aerial photos of the pilot study area were reviewed using Denton and Collin County interactive GIS sites (Denton County Planning Division, Collin County). Streams were evaluated in the same location that the field verifications occurred and broken down into four quadrants for easier visualization. The measure tool was used to outline the areas of assessment, which extended 66-feet (20 meters) wide by 660-feet (201 meters) long for each stream reach (Figure 6). The buffer width was established in accordance with Environmental Protection Agency (EPA) requirements limiting the application of the agricultural herbicide atrazine from within 66-feet (20 meters) of streams. Atrazine is one of the most common herbicides used on major U.S. crops annually and a primary pollutant found in groundwater discharge (EPA, 1994; PMEP, 1992). From there, a descriptive buffer condition scale ranging from 1-10 was established to parallel the scales presented in the SVAP protocol.

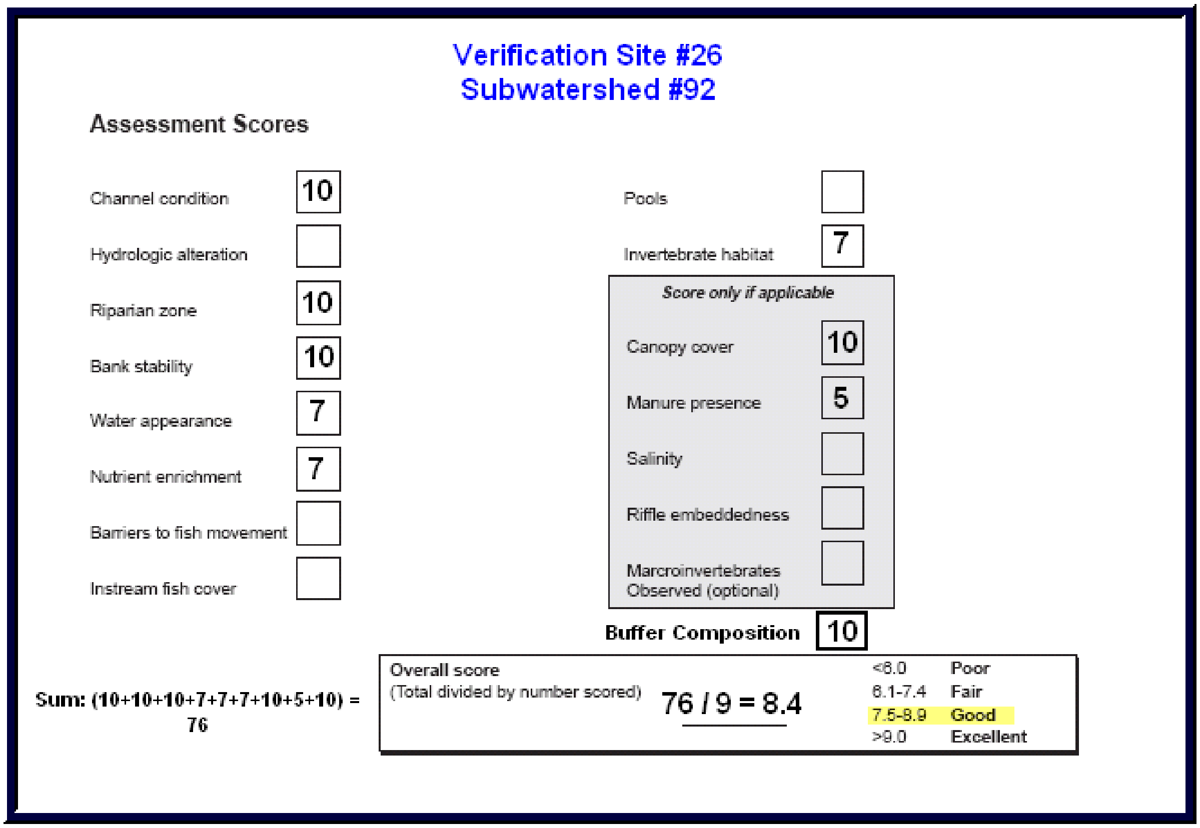


Total 261.9 FEET
Segment 1274.51 FEET

DCAD Parcels
Measure Totals cleared.

Figure 6. Denton County Landmark IMS, used to assess land cover type within stream buffer zones in Denton County (Source: Denton County Planning Division).

An overall assessment score was calculated for each site by summing the individual parameter scores and dividing that value by the number of parameters analyzed. Comparisons were then made between the overall assessment scores, ranging from 0 to 10, and the four SVAP categories of stream health: poor, fair, good, and excellent (Figure 7).



Verification Site #26
Subwatershed #92

Assessment Scores

Channel condition	10
Hydrologic alteration	
Riparian zone	10
Bank stability	10
Water appearance	7
Nutrient enrichment	7
Barriers to fish movement	
Instream fish cover	

Pools	
Invertebrate habitat	7

Score only if applicable

Canopy cover	10
Manure presence	5
Salinity	
Riffle embeddedness	
Marcroinvertebrates Observed (optional)	

Buffer Composition 10

Sum: (10+10+10+7+7+7+10+5+10) = 76

Overall score
(Total divided by number scored) 76 / 9 = 8.4

<6.0	Poor
6.1-7.4	Fair
7.5-8.9	Good
>9.0	Excellent

Figure 7. Example field verification assessment of a stream reach (site #26) within subwatershed #92 of the pilot study area (USDA, 1998); Highlighted is the SVAP conditional scale assigned to the stream reach.

3.4 Field Verification Site Selection

Output from the WQCM model includes an overall subwatershed score (based on the conditions of the encompassing stream reaches) and the subsequent classification of each subwatershed into low, moderate, high, or highest preservation priority categories. Ten sampling sites, spread throughout the entire study area, were selected from each of the four WQCM prioritizations, for a total of 40 sites evaluated using the SVAP (Figure 8). Sites were chosen based on roadway access points, taking care not to trespass on the large expanses of private property that extend throughout the study region. Field verification took place during the months of January and February 2007. To decrease the likelihood of evaluator bias, two researchers participated in the field verification, one with prior knowledge of the WQCM priority category assigned to the stream reach under assessment, and the other unaware of its categorization. The two sets of evaluation scores were then compared and finalized for each stream segment.

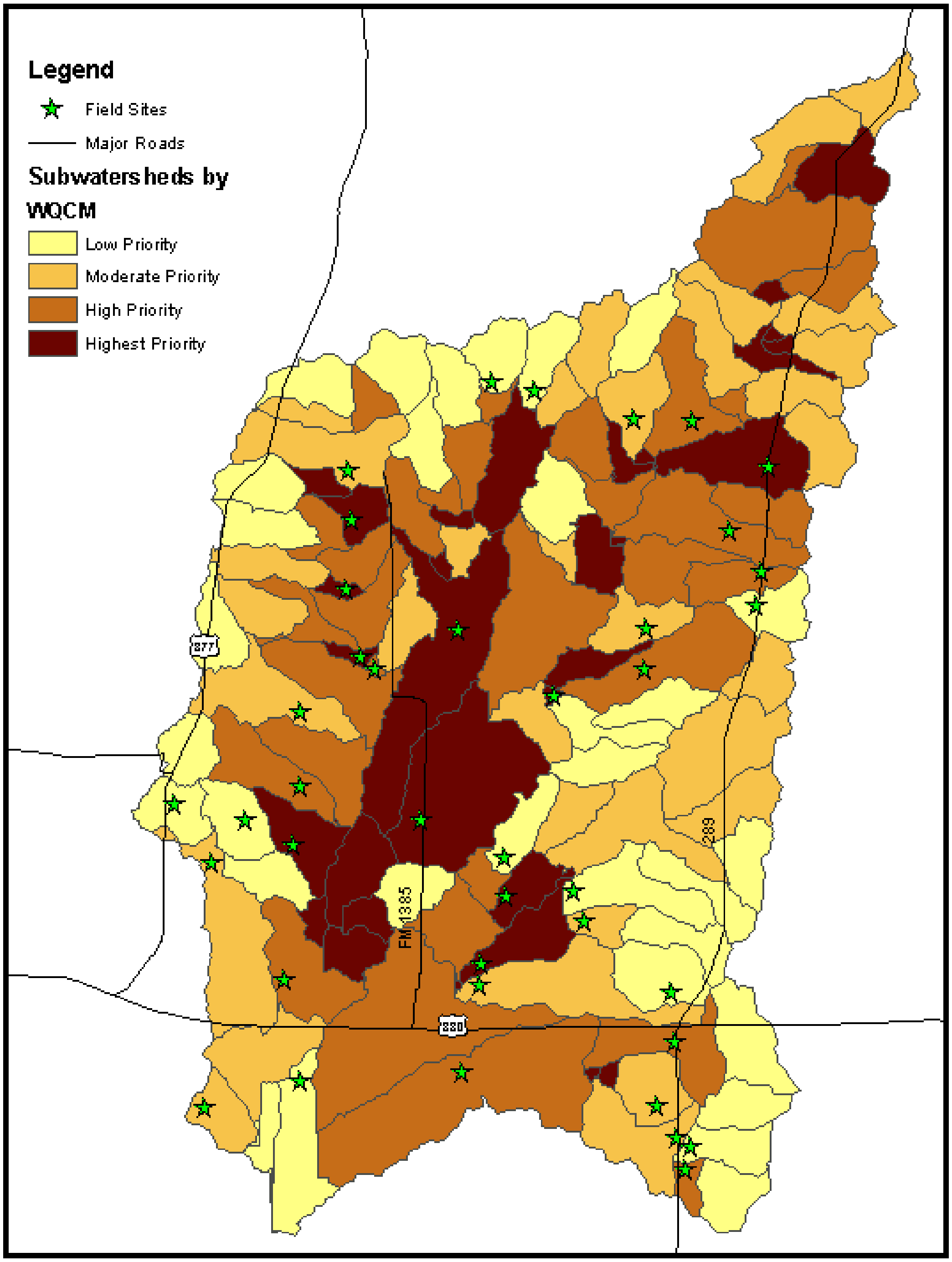


Figure 8. Field verification site locations within the pilot study area.

3.5 Statistical Analyses

The results from the WQCM and the SVAP analyses of the pilot study area were subjected to both correlation and multiple regression tests using the Statistical Analysis System® software (SAS 9.1.3, SAS Institute, Inc., Cary, NC, www.sas.com). First, in order to determine if the WQCM model and SVAP were associated and, if so, measure the intensity of that association, a non-parametric Spearman-rank correlation analysis was performed on the four WQCM priority quartiles (low, moderate, high, and highest) and the four SVAP stream quality categories (poor, fair, good, and excellent). A non-parametric test was used instead of a parametric analysis because of the practical constraints described in section 3.4 that limited the random selection of field verification sites.

In addition, a multiple regression analysis was performed to determine if the WQCM model was influenced importantly by any of the same parameters evaluated using the SVAP field assessment. Only those SVAP components scored for each of the 40 field verification sites were regressed against the WQCM model. These elements included channel condition, riparian zone, bank stability, water appearance, nutrient enrichment, invertebrate habitat, canopy cover, and buffer composition. Using the maximum R^2 improvement (MAXR) regression analysis, the simplest model describing the relationship between the WQCM model and the eight SVAP elements was established.

CHAPTER 4

RESULTS

This chapter addresses the output from the water quality corridor management (WQCM) model as applied to the pilot study area and the Lake Lewisville watershed region. In addition, a detailed description of the statistical analyses is included, with specific attention paid to the direct or indirect relationships between the components of the stream visual assessment protocol (SVAP) and the WQCM model.

4.1 WQCM Model Output

A final WQCM score was calculated and a coordinating WQCM priority quartile (low, moderate, high, or highest) was designated for the stream corridors within each of the 133 subwatersheds of the pilot study area and 90 subwatersheds of the Lake Lewisville watershed. Figure 9 displays the stream segments of the pilot study area according to their WQCM quartile assignment. In contrast, and for ease of visualization, the subwatersheds of the Lake Lewisville watershed are overlaid with their inclusive stream corridors and are displayed according to their WQCM quartile assignment (Figure 10). The 90 subwatersheds of the Lake Lewisville watershed study area are featured in Appendix A. Each map includes the subwatershed's overall WQCM score, as well as the individual scores for the five WQCM parameters paired with corresponding importance weights.

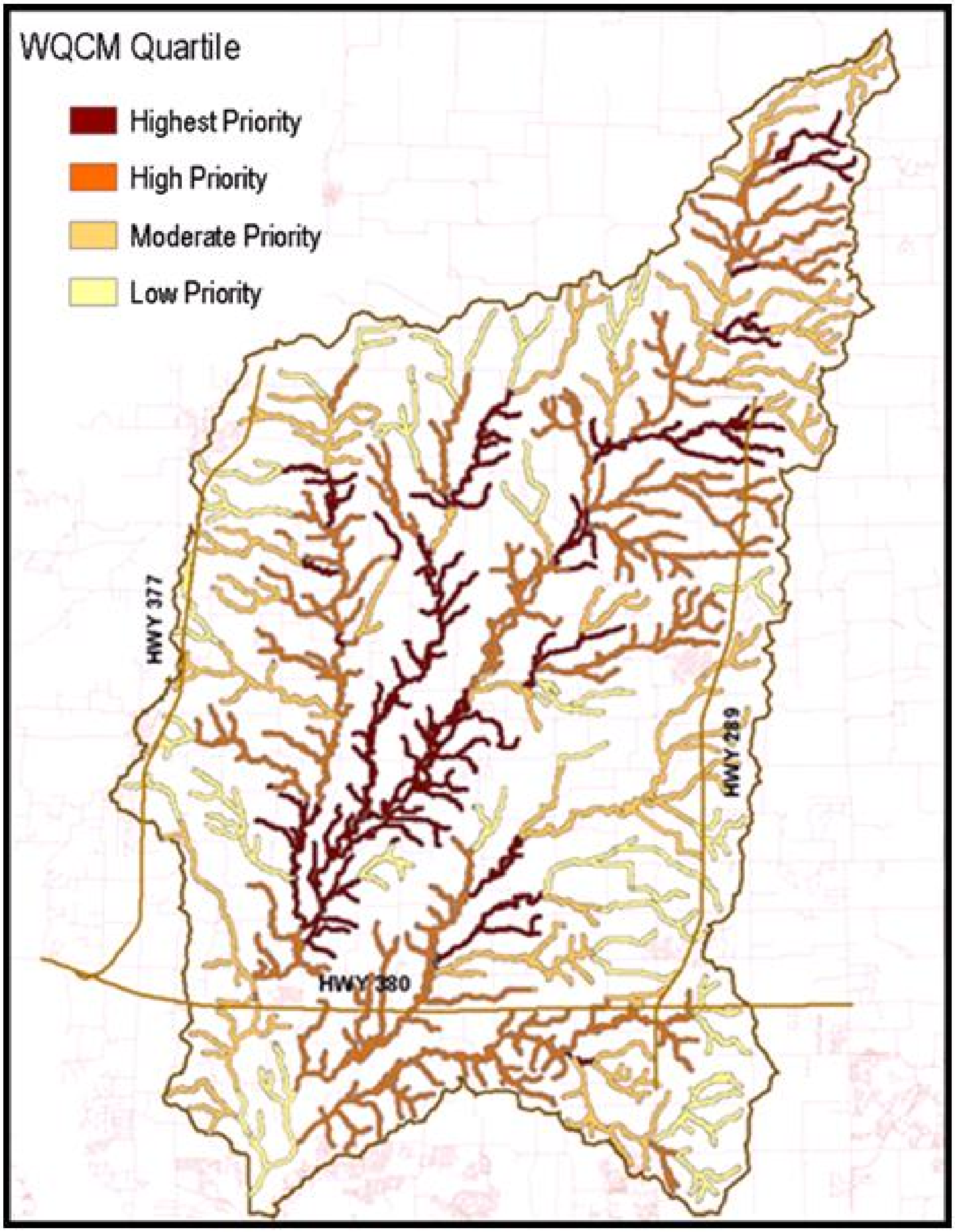


Figure 9. GIS representation of the WQCM model results for the pilot study area.

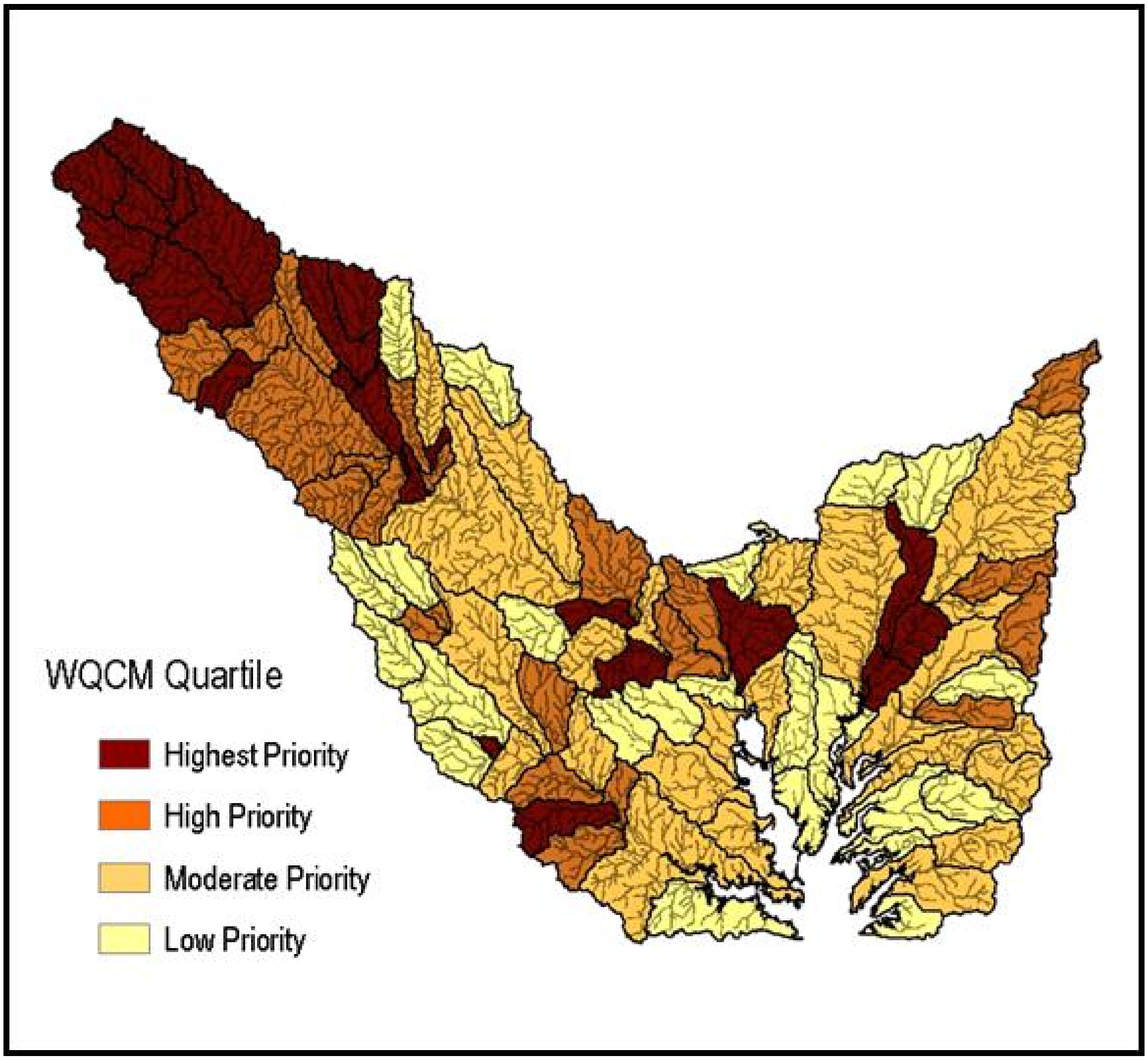


Figure 10. GIS representation of the WQCM model results for the Lake Lewisville watershed.

4.2 Statistical Findings

A positive trend was observed between the WQCM model scores and the SVAP scores for the 40 field observation sites (Figure 11). In addition, a significant correlation was determined to exist between the quartiles generated by the WQCM model and the four field verification SVAP categories (Spearman-rank correlation, $r_s = 0.58$, $p<0.0001$).

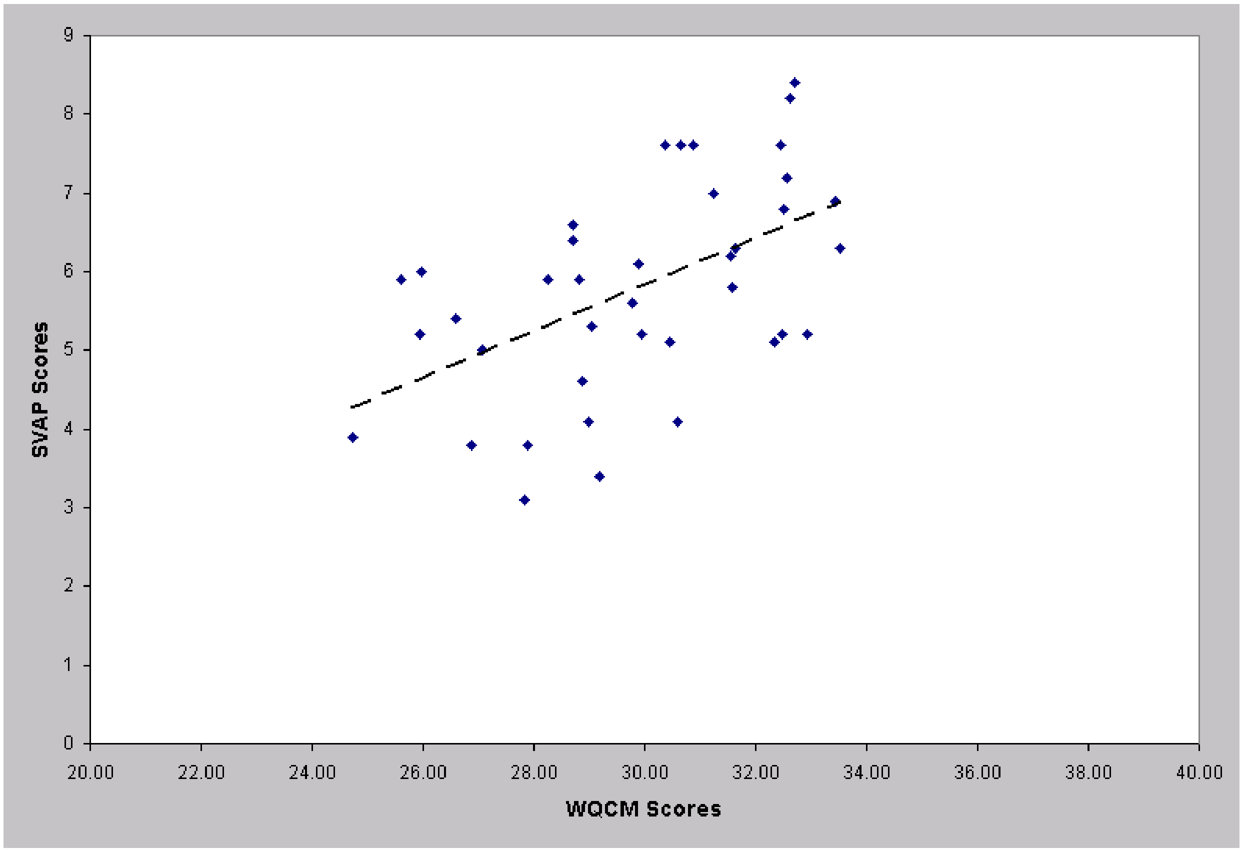


Figure 11. WQCM scores versus SVAP field assessment scores for the 133 subwatersheds of the pilot study area.

A MaxR regression analysis of the WQCM quartiles to the eight parameters evaluated for each stream reach by the SVAP revealed that five of the components, bank stability (BS), water appearance (WA), nutrient enrichment (NE), canopy cover (CC), and manure presence (MP), were influential elements to the priority designation of the stream reaches. The relationship between the WQCM model quartiles and the 5 SVAP predictor variables is as follows:

$$\text{WQCM Quartile} = 0.51 + 0.11\ \text{BS} - 0.09\ \text{WA} + .12\ \text{NE} + 0.17\ \text{CC} + 0.12\ \text{MP}$$

- Bank Stability (BS): There is a direct relation between the BS parameter assessed by the SVAP and four designated WQCM quartiles. Higher scores are given to actively eroding stream banks in both the SVAP and the WQCM model

Thus, the less stable the stream bank, the higher the WQCM score and the greater need for protection

- Water Appearance (WA): There is an inverse relation between the WA parameter assessed by the SVAP and four designated WQCM quartiles. The SVAP assigns higher scores to clear water, whereas the WQCM model assigns higher scores and priority to turbid water resulting from the presence of erosion manifested suspended solids
- Nutrient Enrichment (NE): There is a direct relation between the NE parameter assessed by the SVAP and four designated WQCM quartiles. Eutrification results in decreased aquatic plant diversity and the increased presence of macrophytes and algal blooms. Thus, the less nutrient enriched the steam, the higher the SVAP score and the higher the WQCM score, indicating the greater need for protection
- Canopy Cover (CC): There is a direct relation between the CC parameter assessed by the SVAP and four designated WQCM quartiles. Streams having more forested coverage are scored higher in both the SVAP and WQCM model, and thus, have a greater need for protection
- Manure Presence (MP): There is a direct relation between the MP parameter assessed by the SVAP and four designated WQCM quartiles. Agriculture is a primary means of land usage throughout the region, resulting in the presence of manure in and around streams. The SVAP (scale inversed for this project) and the WQCM model assign higher scores to streams in the presence of animal waste, and thus, have a greater need for protection

CHAPTER 5

DISCUSSION

This chapter discusses the statistical findings, as well as the visual analyses of the water quality corridor management (WQCM) model's results for the pilot and Lake Lewisville study areas. Also addressed are observations made throughout the field verification process and preservation strategies paired with the components of the WQCM model. This chapter concludes with possible future opportunities incorporating the WQCM model and final observations regarding the research.

5.1 Statistical Analyses

The significant correlation ($p<0.0001$) between the WQCM quartiles and the stream visual assessment protocol (SVAP) categories for the pilot study area highlights the functionality of the WQCM model in assessing real-world conditions. It is probable that the relatively low correlation coefficient ($r_s = 0.58$) for the Spearman-rank analysis was due to sample size. The scope of the field verification analysis was limited to 40 sites, 10 per WQCM quartile, due to time constraints and a lack of accessibility to many of the stream reaches located on private property throughout the pilot study area.

In addition, a regression analysis showed that the SVAP components assessing bank condition and composition (bank stability, canopy cover, manure presence) and water quality (water appearance and nutrient enrichment) were the best predictors of stream assignments to the four WQCM quartiles. The focus of these five SVAP parameters parallels the WQCM components' focus on water quality assessment via the analysis of stream bank conditions (vegetation, erosivity, slope, floodplain, and corridor components). Furthermore, as described in the results section, each predictor variable of the SVAP directionally corresponded with the components of the WQCM model.

5.2 Visual Analysis

Upon visual analysis of the pilot study area (Figure 12), it is evident that a majority of the subwatersheds assigned to the highest priority quartile were located within the center of the analysis region. These WQCM results are consistent with the less urbanized topographical features of the central study area as compared to the more developed regions along the borders. Specifically, the center of the expanse is comprised primarily of county and farm roads that do not receive as much traffic as the state and business highways (HWY 380, HWY 377, 287/Business 287/Preston Road) on the outskirts of the study area. Moreover, the majority of municipalities within the pilot territory are located on and around low and moderate priority subwatersheds, with no municipalities situated within any of the highest priority subwatersheds. The rapidly expanding urbanized areas were found to have, in general, less natural vegetation and riparian cover, more channelized streams within suburban developments, poorer water quality due to increased sedimentation from nearby construction sites, and low stream banks, all conditions which resulted in the placement of these “urbanized” subwatersheds into lower WQCM priority categories.

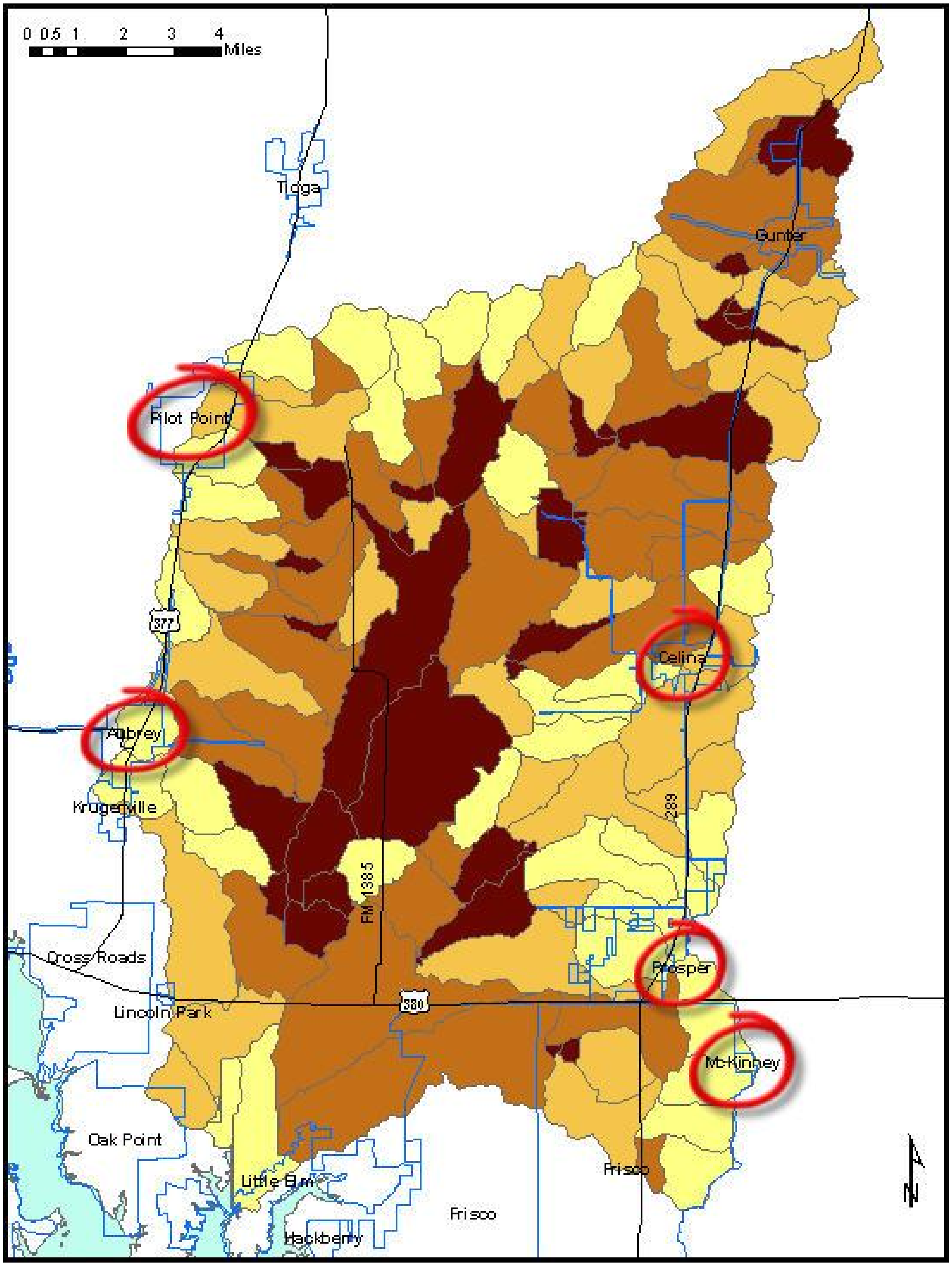


Figure 12. Pilot study WQCM results in relation to cities and major roads.

The majority of streams designated of highest protection priority within the Lake Lewisville watershed (Figure 13) were located in the northwestern region, an area characterized by loose and sandy soil, steep sloping banks, and little urban development. In fact, no major roads traverse this region and the closest towns are the small communities of St. Jo and Muenster. It is within these relatively undeveloped landscapes that protection strategies would be most beneficial. In contrast, many of the stream reaches within the subwatersheds more proximate to Lake Lewisville were assigned to the lowest and moderate protection priority categories (Figure 13). Again, the lower WQCM scores are indicative of both the longer established communities and the rapid urban and residential development occurring in these regions, where detrimental landscape alterations are foregone and protection strategies are of little use.

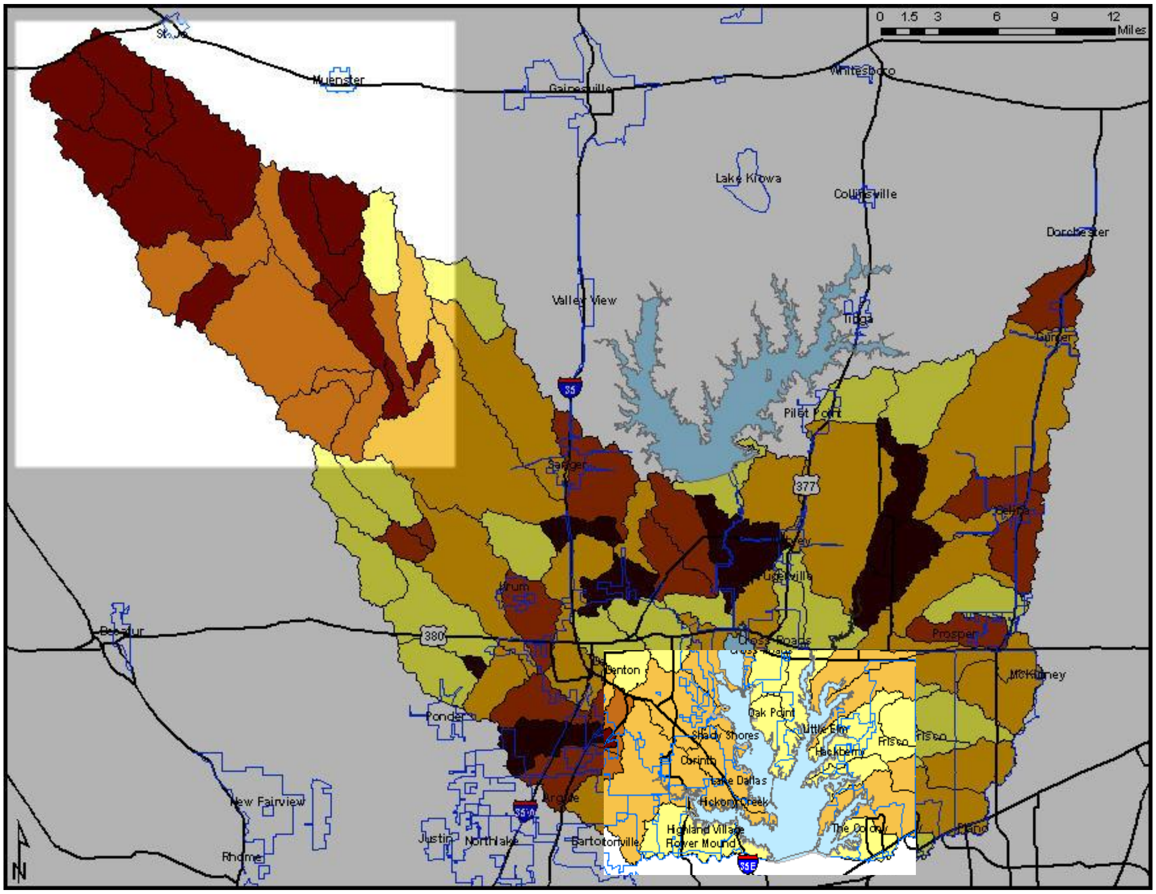


Figure 13. Lewisville watershed WQCM results in relation to cities and major roads.

5.3 Field Evaluations

As was statistically evident, many of the field conditions observed were consistent with those described by the WQCM model. For instance, largely erosive and high sloping banks (Figure 14, Figure 15) and thick vegetated riparian zones (Figure 16) were indicative of the stream channels assigned to the high and highest WQCM priority categories. Conversely, low sloping banks and little to no riparian zone (Figure 17) where characteristic of low priority stream reaches. The WQCM model also proved to be accurate in its assessment of streams within rapidly developing areas. A stream reach within the expanding town of Aubrey, TX, for example, was assigned by the WQCM model to a low priority designation, a categorization indicative of the residential construction surrounding the area and a complete lack of riparian zone (Figure 18).

Figure 14. Field site #31, designated WQCM highest priority.


Figure 15. Field site #36, designated WQCM highest priority.


Figure 16. Field site #28, designated WQCM highest priority.


Figure 17. Field site #23, designated WQCM lowest priority.


Figure 18. Field site #34, designated WQCM lowest priority.

Even with such precision, there were anomalies and noteworthy conditions encountered during the field verification portion of the project. As was sometimes the case at road crossings, vast differences were observed between upstream and downstream conditions (Figure 19, Figure 20). In such cases, one field analysis was conducted for the upstream portion, another for the downstream, and the average was taken. It was also interesting to encounter stream segments in relatively good condition according to both the SVAP and WQCM model's standards, but heavily polluted by illegal dumping (Figure 21). Unfortunately, it would be difficult to include a parameter within the WQCM model accounting for the affect of illegal dumping on stream corridor and water conditions. The location and intensity of litter is impossible to predict without visual inspection, a task that would require on site verification or very high resolution imagery that is expensive and often inaccessible to stakeholders.

Figure 19. Field site #25, designated WQCM highest priority, upstream perspective.

Figure 20. Field site #25, designated WQCM highest priority, downstream perspective.

Figure 21. Field site #13, designated WQCM highest priority.

5.4 Protection Strategies

The ease with which the WQCM model can be implemented lends itself for use in any ecological region, within any institution, and in situations where monetary constraints limit the field work. As the goal of the WQCM model is protection, its usefulness is amplified by the pairing of best management practices associated with the WQCM parameters. By doing so, the WQCM model not only identifies the areas in need of protection, but it also presents cost effective strategies to achieve the goal of ecological sustainability within stream ecosystems.

Prior to beginning any preservation endeavors, it is first necessary to delineate stream systems by their current physical condition in order to determine a proper course of action. One of the advantages of the WQCM model is that, by categorizing stream segment quality, it is possible to review the five different components of the model and determine which element is driving the WQCM score for each stream segment. Best management practices associated with these WQCM components can then be put into practice.

A comparison analysis of the five WQCM model components, applied to both the pilot study region and the Lake Lewisville watershed, showed that the parameters most likely to influence the WQCM model’s scores were vegetation, followed by the erosivity and floodplain components. The slope and corridor parameters were not driving factors for any of the WQCM model’s scores within either of the studies. These findings were as expected, since the importance weight given to the vegetation component of the WQCM model (5) is higher than the weight assigned to any of the other four components. Furthermore, the vegetation, erosivity, and floodplain components were the predominant parameters influencing the WQCM scores even without including the corresponding importance weights. Due to these consistent comparison results, the pairing of protection strategies will be discussed for the three primary driving WQCM components of vegetation/land use type, the bank stability parameter of erosivity, and the floodplain component.

In relation to vegetation/land use type, the encroachment of suburban communities and commercial developments factors prominently into the degradation of stream ecosystems. In fact, the primary source of sediment runoff originates from the vast number of construction sites so commonly found among developing areas. Accordingly, simple protective measures need to be enforced at all construction zones. For example, the cessation of vegetation clear-cutting around construction sites leaves buffer zones intact and able to entrap harmful non-point source pollutants before they enter stream systems (EPA Measure 8, 2005). Furthermore, negligent lawn care and waste disposal habits throughout residential communities necessitates better management practices, such as using organic compost to treat lawns instead of the toxic chemicals found in fertilizers and pesticides that are easily swept away in rainfall events (EPA Measure 9, 2005). Stream bank erosion, vegetation trampling, and the presence of manure are just a few of the detrimental impacts caused by the grazing of livestock in and near streams on pastureland, the most effective remedy for which being the total exclusion of cattle from accessing streams and their surrounding corridors (Belsky et al., 1999). Table 2 outlines these and other management practices for three land types commonly affected by outside impacts: urban, residential, and pasture.

Just as the complex interactions of ecosystems are intertwined, so are the parameters outlined in the WQCM model. The stability of a stream bank, measured in the WQCM model by erosion potential, is both directly and indirectly affected by land use. For instance, stream channelization to improve aesthetics in residential developments disturbs the delicate balance among stream ecosystems, leading to amplified water flow and the subsequent increase in stream bank erosion, channel incision, and habitat degradation (Pirim et. al, 2000). In other words, if erosivity is an implicating parameter for a particular WQCM score, the first step in establishing abatement practices is analyzing how the stream bank failure is related to the land use practices surrounding the stream and on the neighboring land parcels. Once the relationship between land usage and channel break down has been established, the appropriate management practices, as outlined in Table 2, can be implemented.

In a similar way, if a WQCM score is being driven by the floodplain component, those stream reaches encompassed within the subwatershed have less protection from the inherent preservation regulations of the Federal Emergency Management Agency (FEMA) 100-year floodplain. Accordingly, the implementation of preservation strategies begins with the analysis of the given stream conditions and how the utilization of that area (Table 2) is affecting the state of the stream reaches.

Table 2 Impact sources and management practices for stream water quality and corridor *protection* based on land use.

WQCM Land Use Type	Sources	Impacts to Stream Water and Corridor Quality	Suggested Management Practices	References
Urban/ Residential	Construction sites	Presence of sediment, pesticides, fertilizers, trash, and other harmful chemicals in streams	Protect natural vegetative buffers; Stabilize construction site entrance & exit locations; Install silt or fabric filter fences in areas of non-concentrated flow around site; Install sediment basins	EPA, 2005, Measure 8
Urban/ Residential	Impervious Cover, Negligent waste disposal and landscape practices	Increased flooding risk; Increased transport of non-point source pollutants to water sources; Runoff pollutants such as lawn fertilizers, household chemicals, and pet waste; Increased algae presence in streams; Increased stream bank erosion	Public education outreach programs; Protect natural vegetative buffers; Limit the use of pesticides and fertilizers; Increase the use of organic compost; Recycle yard clippings into organic compost; If use fertilizer, use organic or encapsulated nitrogen fertilizer; Plant vegetation native to the regional climatic conditions; Water lawns only when necessary; Properly dispose of pet waste; Do not wash cars at home; Label storm drains; Post “no pollution signs” warning of legal ramifications	EPA, 2005, Measure 9; Kennedy, 2005; NCTCOG, 2006
Pasture	Cattle grazing	Trampling and disturbance of stream banks and vegetation; Increased soil compaction; Increased erosion; Decrease in detritus for aquatic organisms; Decrease in stream biodiversity; Presence of livestock urine and manure in stream; Increase in disease causing bacteria and oxygen-depleting organics	Fence off cattle access to streams and riparian corridors; Decrease or tightly regulate cattle access to streams and riparian corridors; Rotate areas subjected to cattle grazing	Agouridis, 2004; Belsky et al., 1999; Correll, 2005; NRCS, 1995

5.5 Future Opportunities

The implementation of protection strategies is dependent on teaching through public outreach. The problem, as in any attempt to instigate change, is finding an effective method of instruction that can reach as many people as possible and communicate its strategies successfully. One possible mechanism of public outreach is an interactive compact disc (CD) highlighting the results of the WQCM model, made available to local municipalities and other stakeholders within the area of analysis. As a continuation of this research, a hypothetical expert system for this study would include links to each Lake Lewisville subwatershed, their accompanying WQCM scores, and scores for the five WQCM components of vegetation, erosivity, slope, floodplain and stream corridor. Links to visual representations of all five components would also be available for each subwatershed. In addition, after determining which WQCM parameter was driving the final WQCM score, the user could click on a link to protection strategies associated with that specific WQCM parameter. An interactive CD is slated for completion on the Lake Lewisville watershed study area for use by the University of North Texas and the Upper Trinity Regional Water District (UTRWD). Such an expert system could be created for any region evaluated by the WQCM model, a useful tool for any stakeholder interested in the protection of stream corridor and water quality. Several example interfaces for the prospective Lake Lewisville watershed interactive CD are displayed in Appendix B.

Ideally, the greatest effects will be procured from a widespread approach to maintaining and improving water quality; one that involves not only a protective methodology, but a restoration approach as well. The database structure of the WQCM model can be re-worked easily to parallel the goal of stream corridor restoration for the purpose of water quality improvement. A benefit of using both the current preservation WQCM model and a prospective WQCM restoration model is the ability to identify and enact mitigation measures. A developer, for instance, needing to alter an area identified by the WQCM model to be in the highest protection quartile, may mitigate these actions by using the proposed WQCM restoration model to identify an area in highest need of restoration and then enacting management and restoration practices on this area. Perhaps most important, the combination of the WQCM models, made available to stakeholders, could serve as a “policing” mechanism for all organizations, protecting water quality from the many facets of urban development occurring throughout rural areas.

5.6 Conclusions

Based on the pilot study research, the conclusion is that the WQCM model is a reliable system for predicting stream corridor and water quality within both the pilot study area and the Lake Lewisville watershed region and will prove to be a valuable resource for the UTRWD. Ideally, the project would have benefited from a wider ranging pilot study in which more field verifications could have been performed, had a time constraint not been in place. In addition, as the WQCM model’s usage is expanded over different geographic regions, it will be necessary to further develop the corresponding management practices for the goal of preservation. The accessibility and availability of input data make the WQCM model flexible to varying topographic and climatic regions. Consequently, the WQCM model is ideal for both initial stream corridor assessment and as a primary evaluation technique.

APPENDIX A

WQCM RESULTS FOR THE LAKE LEWISVILLE WATERSHED

Appendix A Index

Overview Map 56

Low Priority Sites

Subwatershed (SW) 10 66
SW 16 72
SW 25 81
SW 31 87
SW 39 95
SW 41 97
SW 43 99
SW 44 100
SW 47 103
SW 48 104
SW 52 108
SW 53 109
SW 59 115
SW 62 118
SW 68 124
SW 71 127
SW 73 129
SW 77 133
SW 80 136
SW 81 137
SW 83 139
SW 84 140
SW 88 144

Moderate Priority Sites

SW 17 73
SW 28 84
SW 30 86
SW 32 88
SW 38 94
SW 45 101
SW 50 106
SW 54 110
SW 55 111
SW 56 112
SW 57 113
SW 60 116
SW 63 119
SW 65 121

Moderate Priority

SW 67 123
SW 70 126
SW 74 130
SW 78 134
SW 79 135
SW 82 138
SW 85 141
SW 86 142
SW 90 146

High Priority

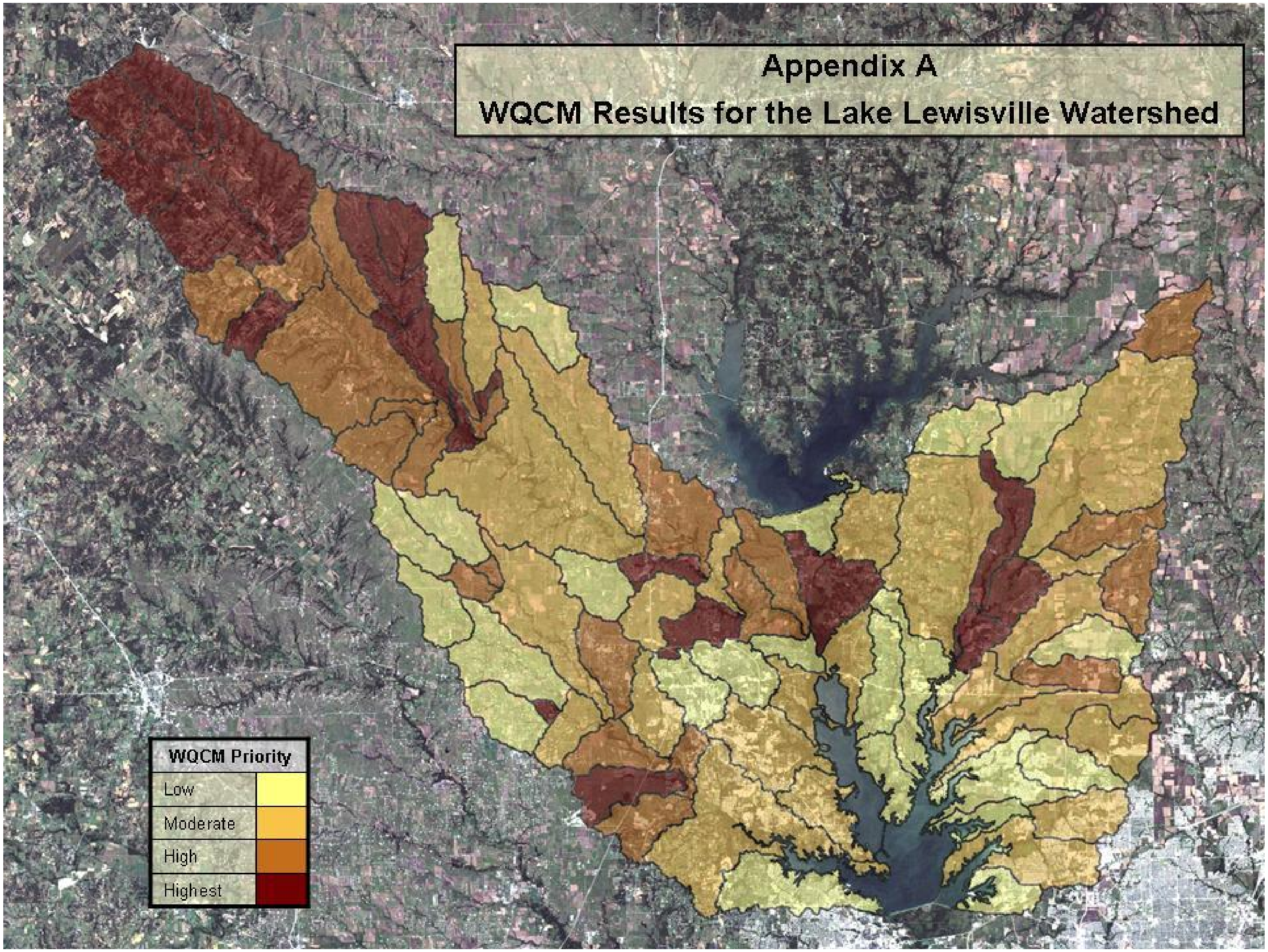
SW 9 65
SW 13 69
SW 15 71
SW 18 74
SW 21 77
SW 22 78
SW 23 79
SW 26 82
SW 27 83
SW 29 85
SW 33 89
SW 35 91
SW 36 92
SW 40 96
SW 46 102
SW 49 105
SW 58 114
SW 61 117
SW 66 122
SW 69 125
SW 72 128
SW 75 131

Highest Priority

SW 1 57
SW 2 58
SW 3 59
SW 4 60
SW 5 61
SW 6 62
SW 7 63

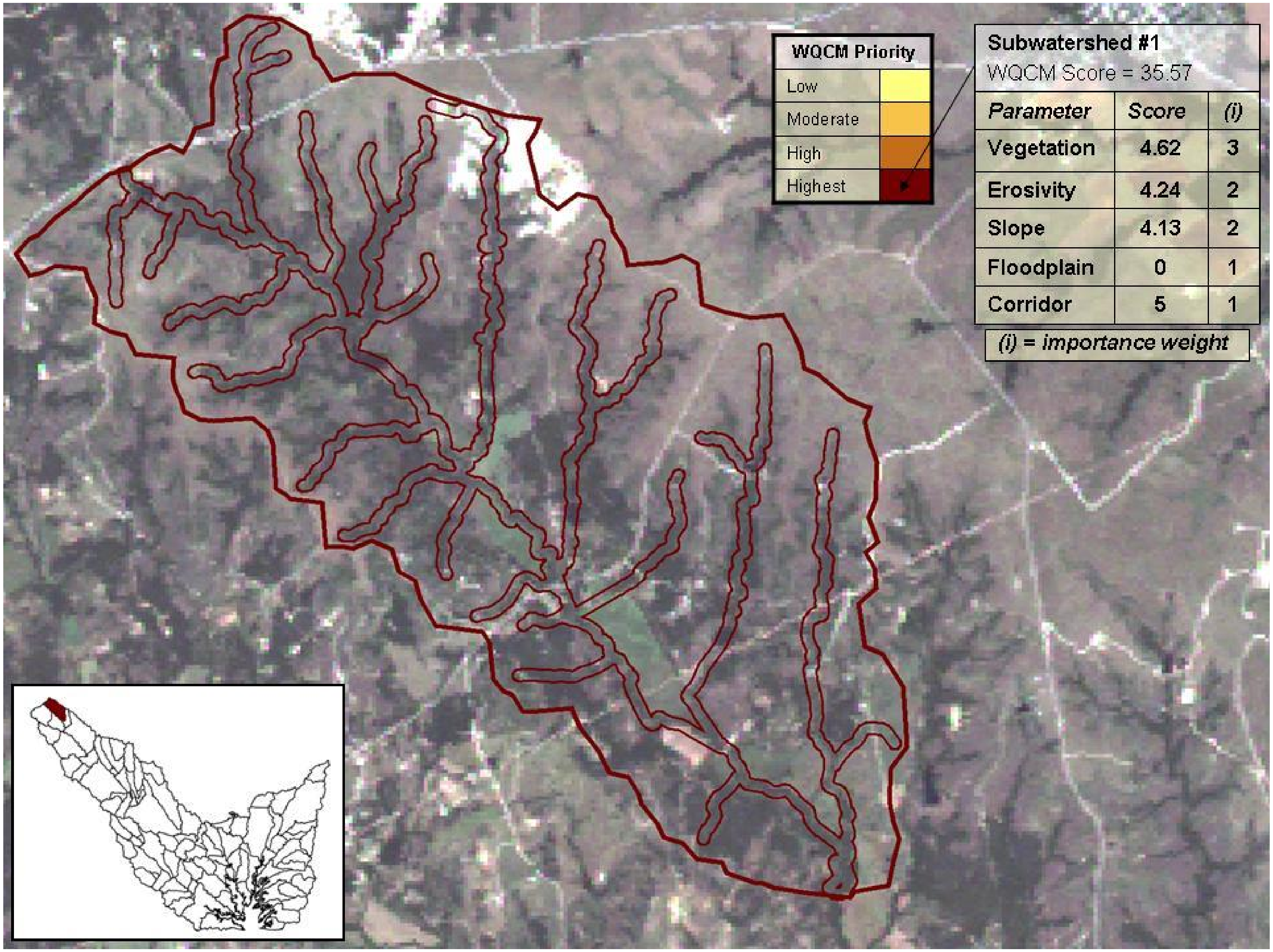
Highest Priority

SW 8 64
SW 11 67
SW 12 68
SW 14 70
SW 19 75
SW 20 76
SW 24 80
SW 34 90
SW 37 93
SW 42 98
SW 51 107
SW 64 120
SW 76 132
SW 87 143
SW 89 145



Appendix A

WQCM Results for the Lake Lewisville Watershed

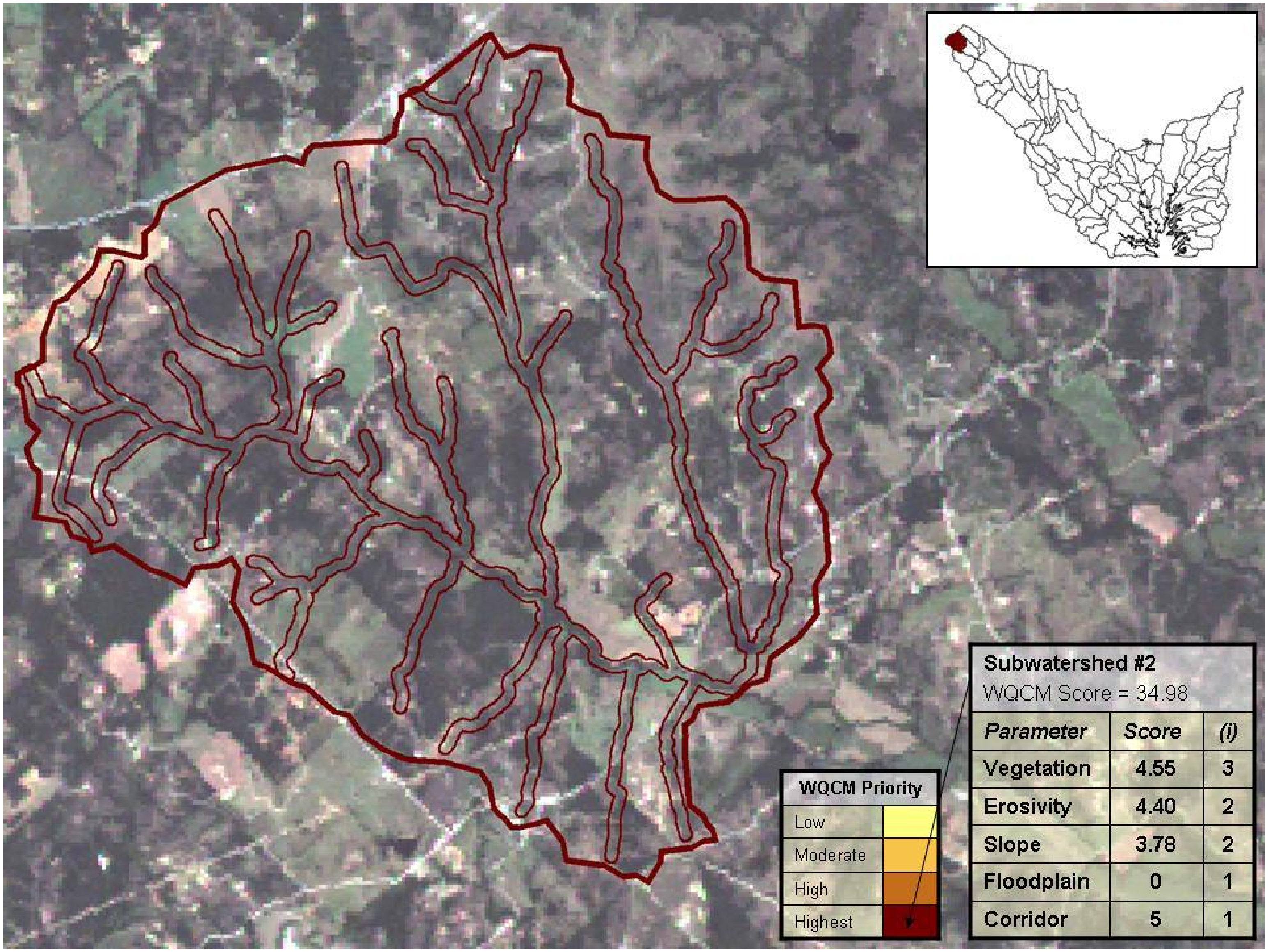


Subwatershed #1

WQCM Score = 35.57

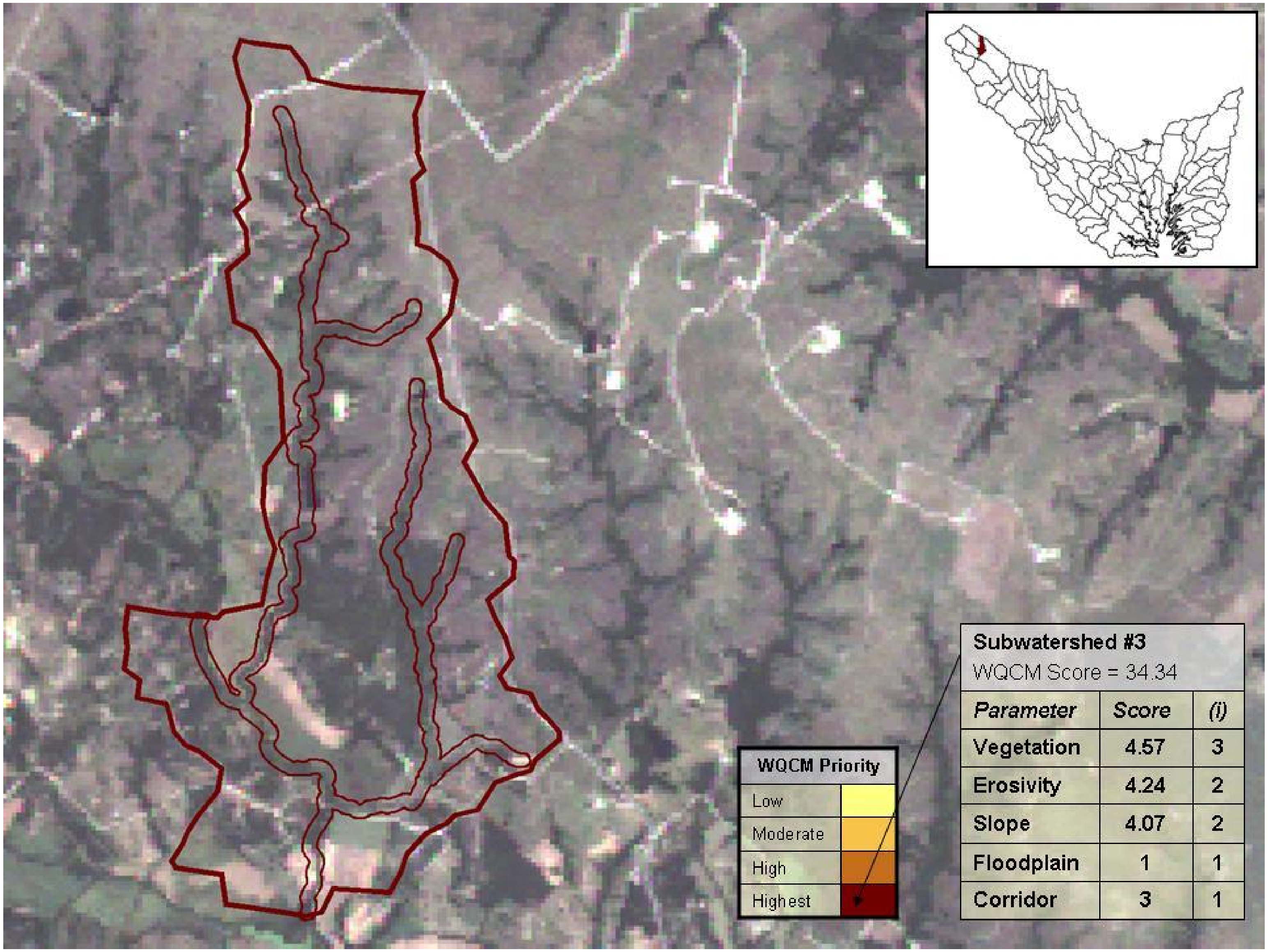
Parameter	*Score*	*(i)*
Vegetation	4.62	3
Erosivity	4.24	2
Slope	4.13	2
Floodplain	0	1
Corridor	5	1

(i) = importance weight



Subwatershed #2
WQCM Score = 34.98

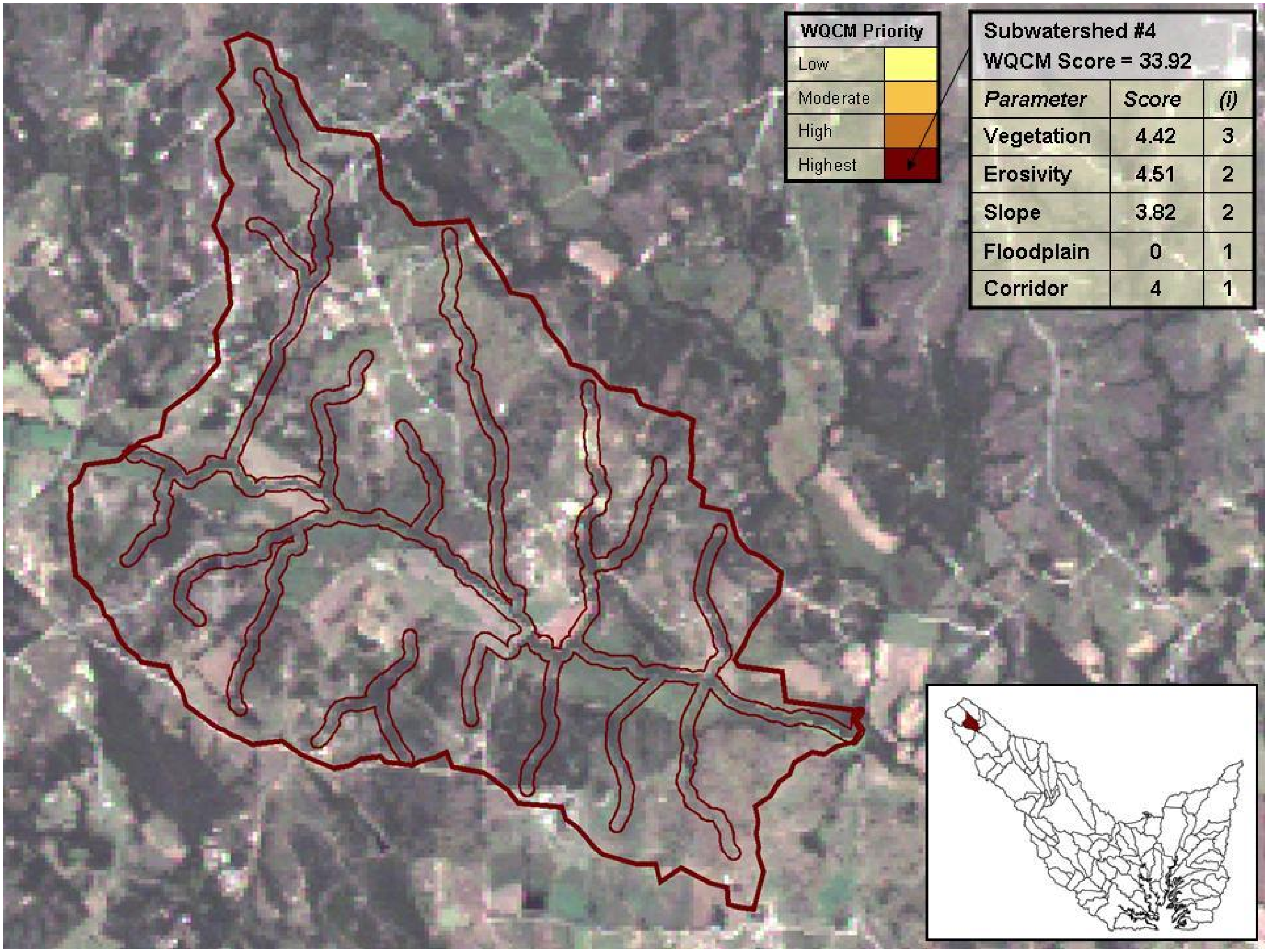
Parameter	*Score*	*(i)*
Vegetation	4.55	3
Erosivity	4.40	2
Slope	3.78	2
Floodplain	0	1
Corridor	5	1



Subwatershed #3

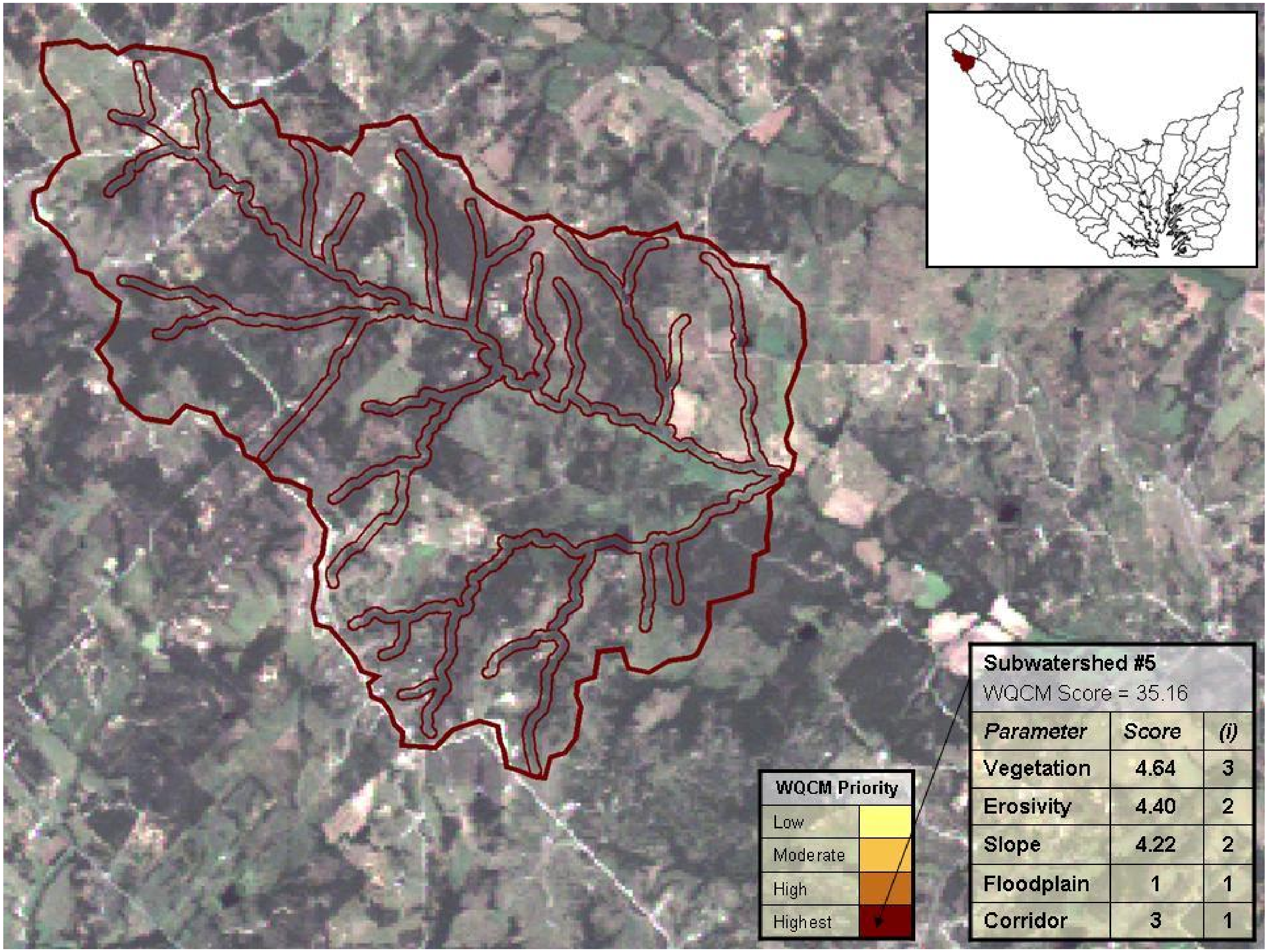
WQCM Score = 34.34

Parameter	*Score*	*(i)*
Vegetation	4.57	3
Erosivity	4.24	2
Slope	4.07	2
Floodplain	1	1
Corridor	3	1



Subwatershed #4
WQCM Score = 33.92

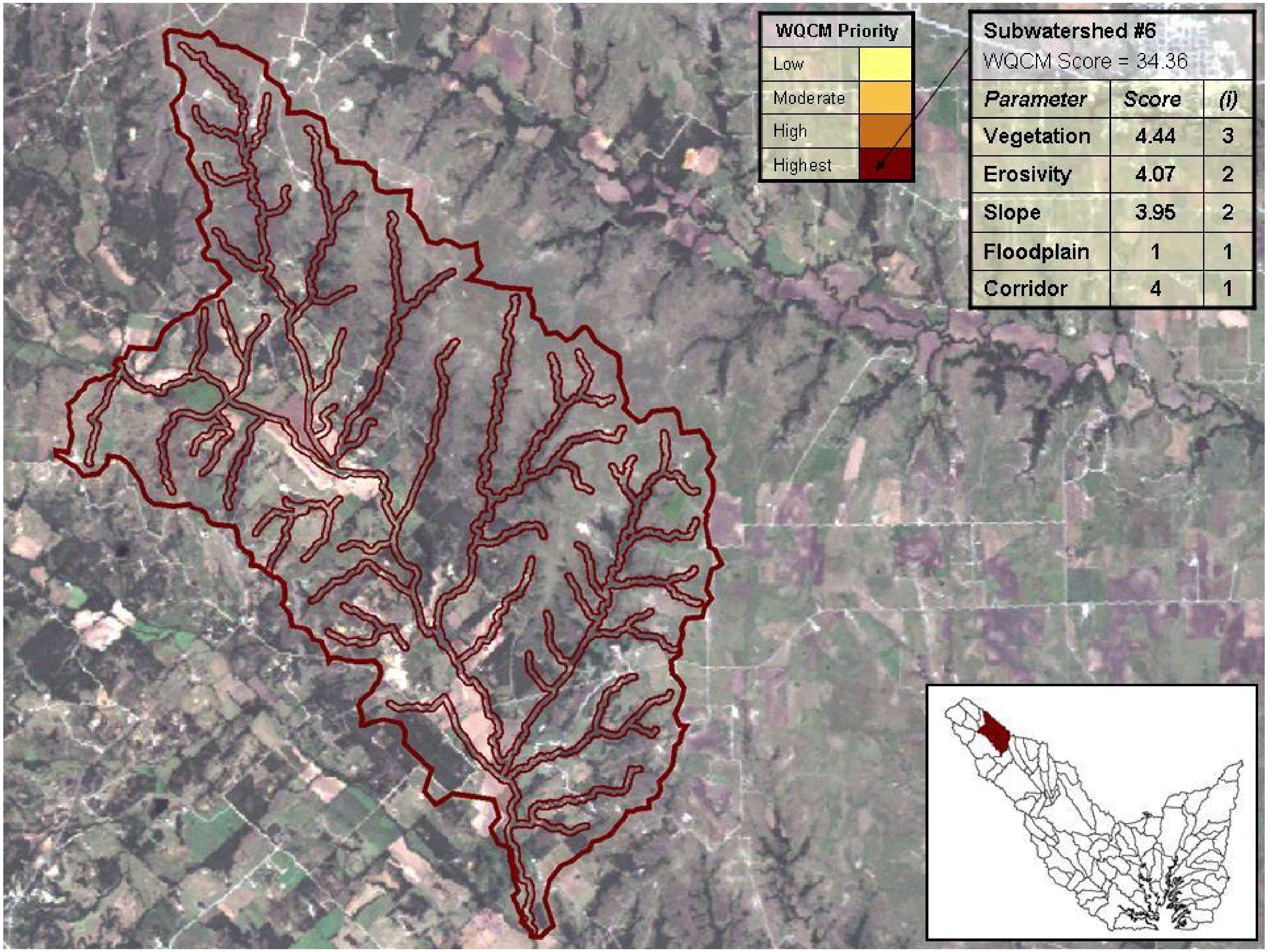
Parameter	*Score*	*(i)*
Vegetation	4.42	3
Erosivity	4.51	2
Slope	3.82	2
Floodplain	0	1
Corridor	4	1



Subwatershed #5

WQCM Score = 35.16

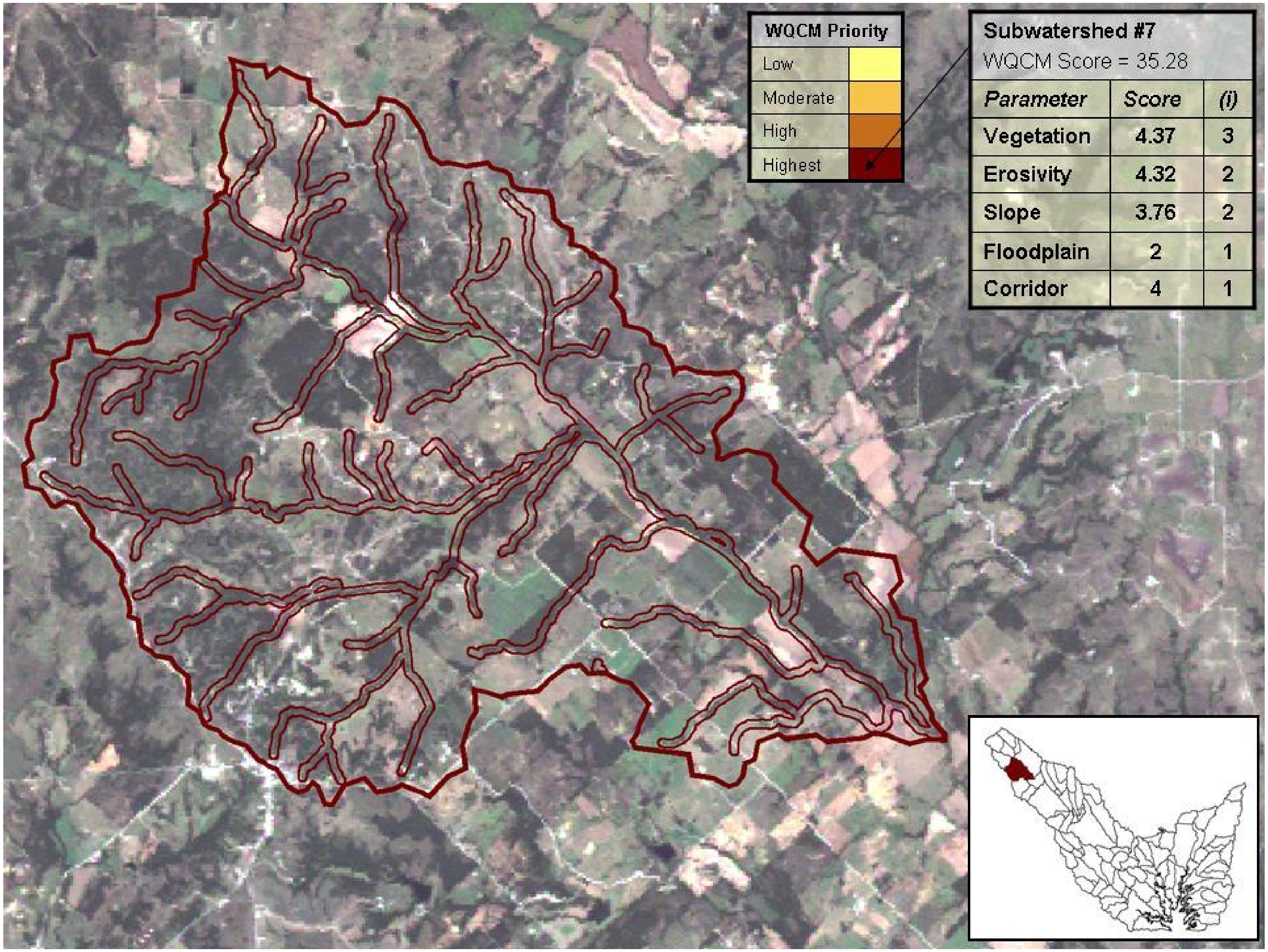
Parameter	*Score*	*(i)*
Vegetation	4.64	3
Erosivity	4.40	2
Slope	4.22	2
Floodplain	1	1
Corridor	3	1



Subwatershed #6

WQCM Score = 34.36

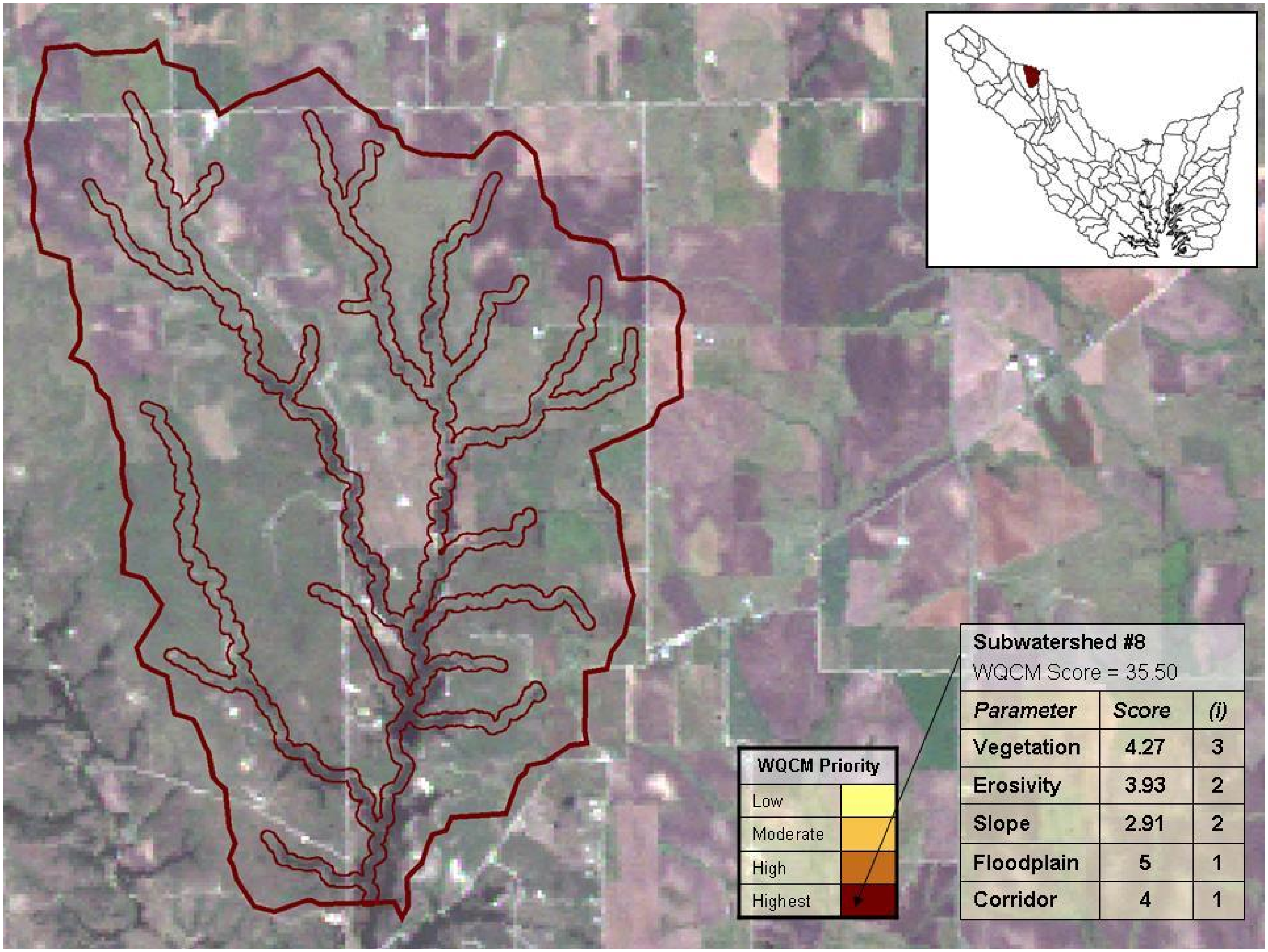
Parameter	*Score*	*(i)*
Vegetation	4.44	3
Erosivity	4.07	2
Slope	3.95	2
Floodplain	1	1
Corridor	4	1



Subwatershed #7

WQCM Score = 35.28

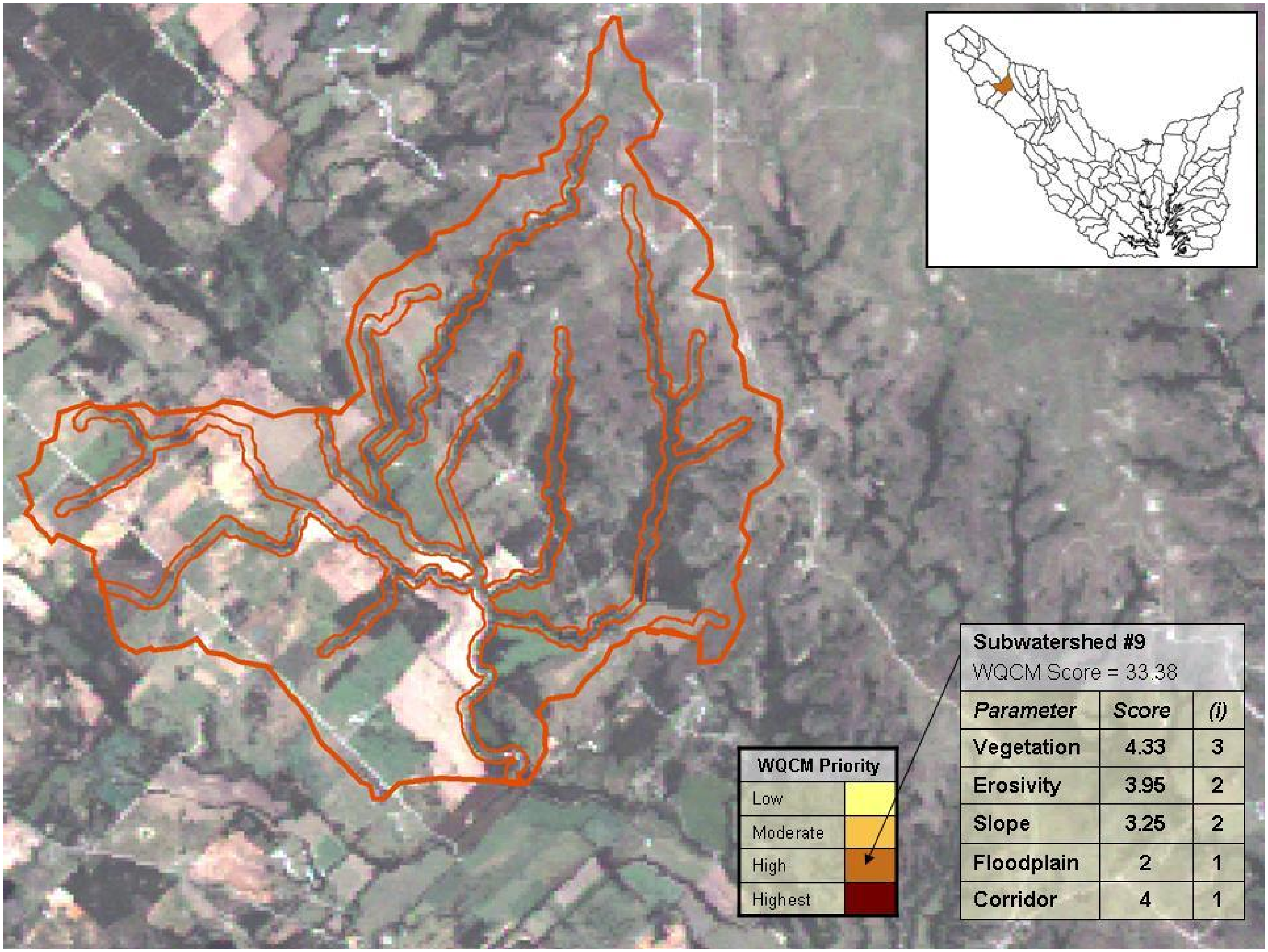
Parameter	Score	(i)
Vegetation	4.37	3
Erosivity	4.32	2
Slope	3.76	2
Floodplain	2	1
Corridor	4	1



Subwatershed #8

WQCM Score = 35.50

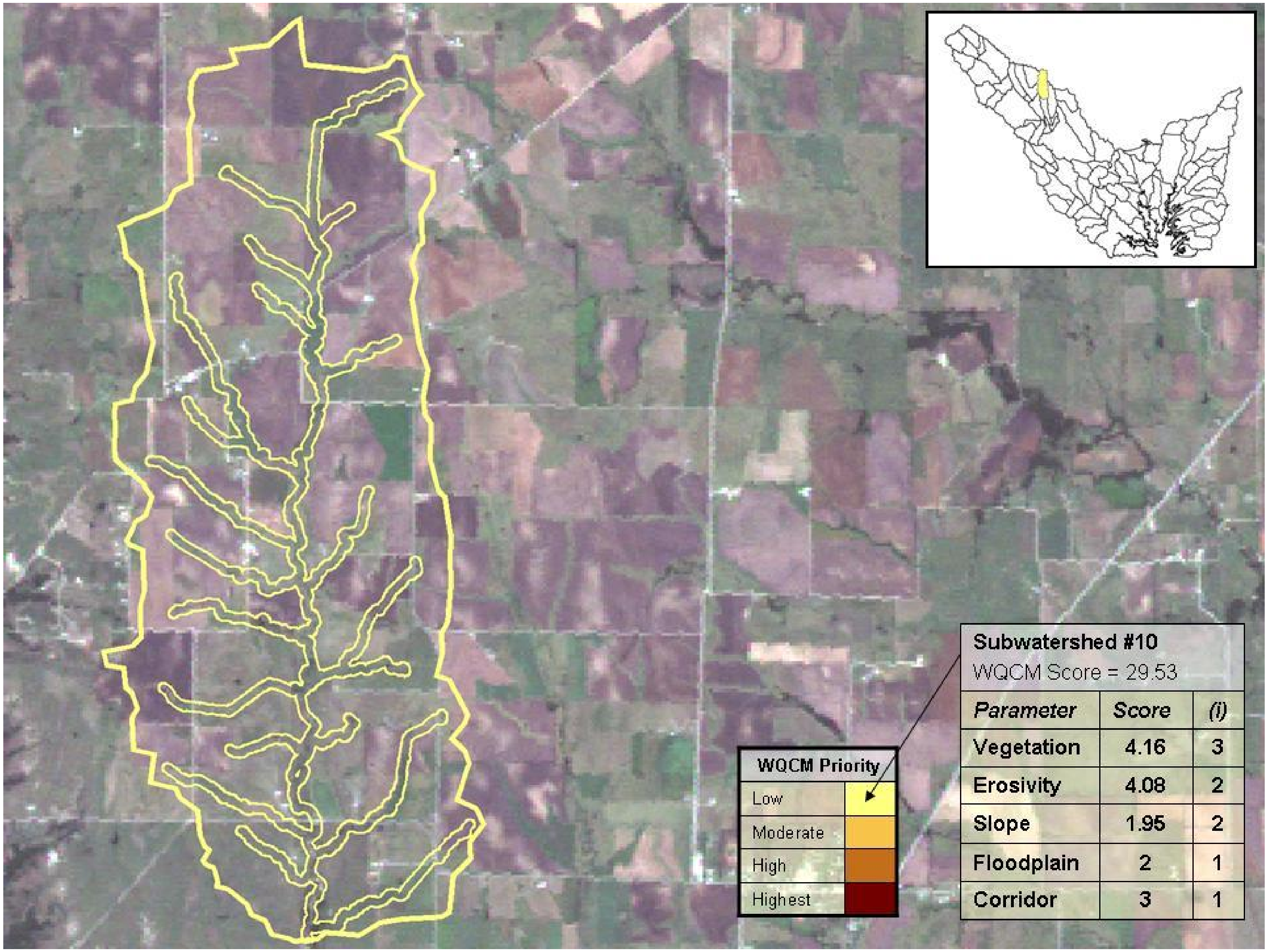
Parameter	*Score*	*(i)*
Vegetation	4.27	3
Erosivity	3.93	2
Slope	2.91	2
Floodplain	5	1
Corridor	4	1



Subwatershed #9

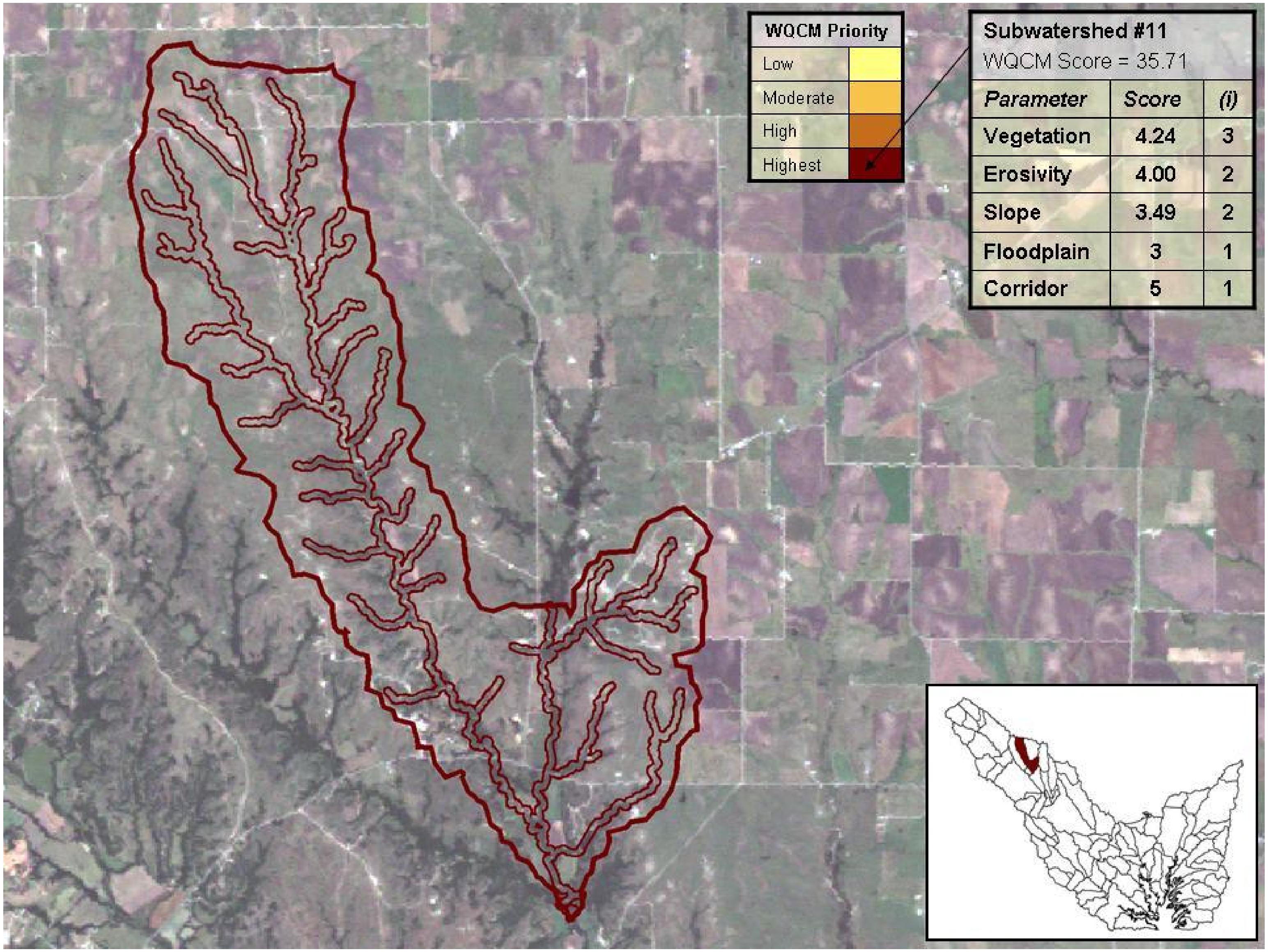
WQCM Score = 33.38

Parameter	*Score*	*(i)*
Vegetation	**4.33**	**3**
Erosivity	**3.95**	**2**
Slope	**3.25**	**2**
Floodplain	**2**	**1**
Corridor	**4**	**1**



Subwatershed #10
WQCM Score = 29.53

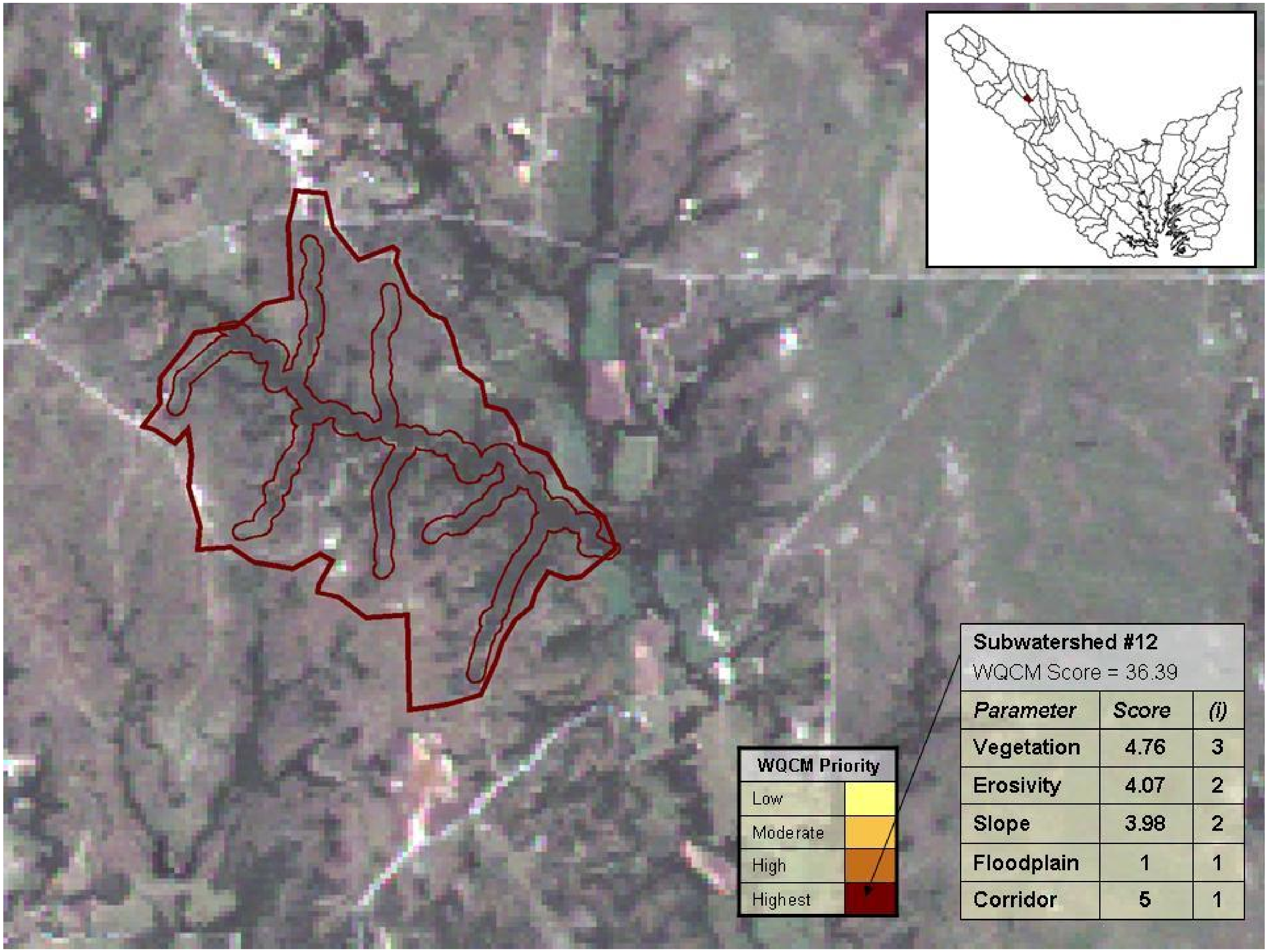
Parameter	*Score*	*(i)*
Vegetation	4.16	3
Erosivity	4.08	2
Slope	1.95	2
Floodplain	2	1
Corridor	3	1



Subwatershed #11

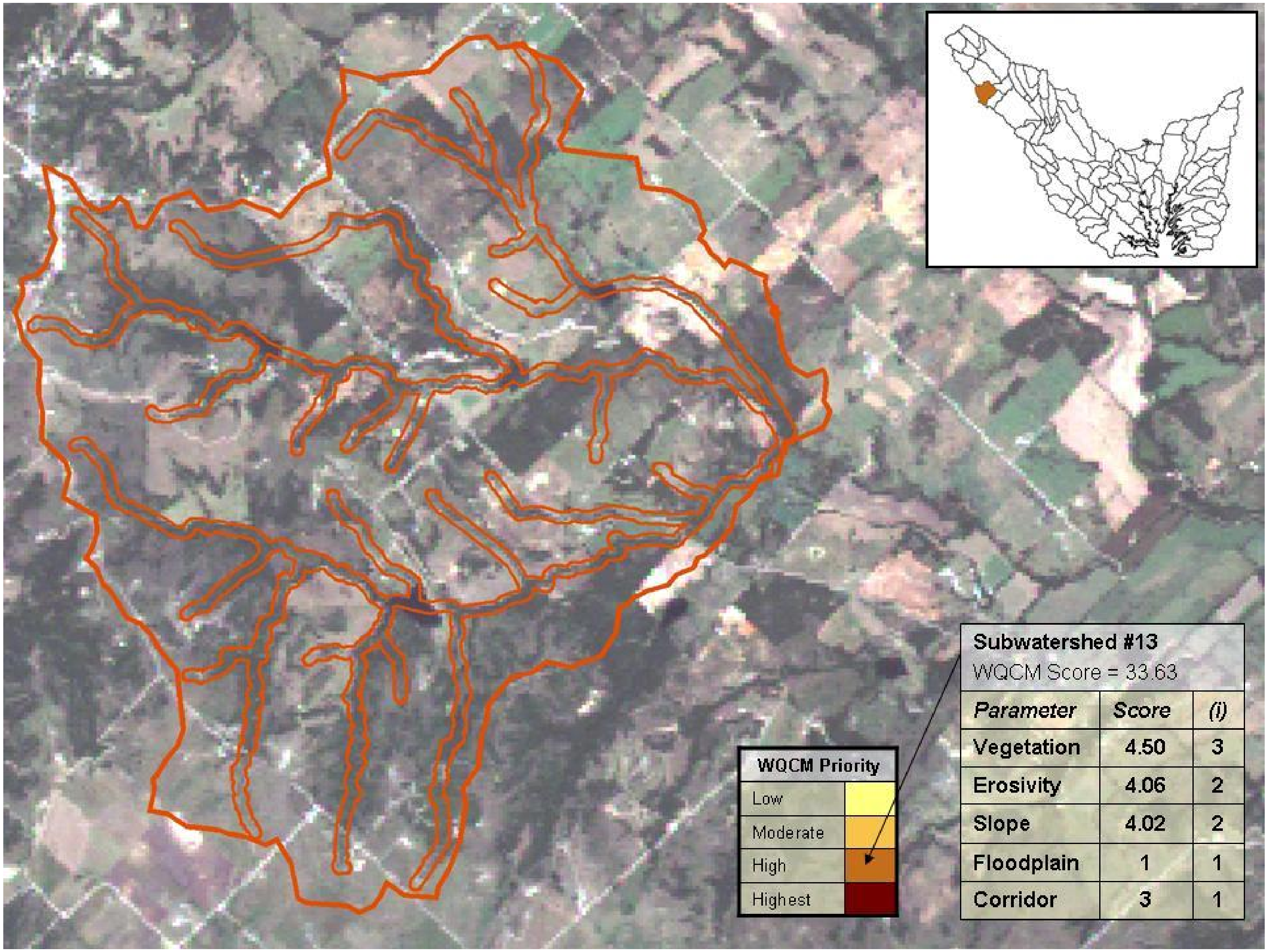
WQCM Score = 35.71

Parameter	*Score*	*(i)*
Vegetation	**4.24**	**3**
Erosivity	**4.00**	**2**
Slope	**3.49**	**2**
Floodplain	**3**	**1**
Corridor	**5**	**1**



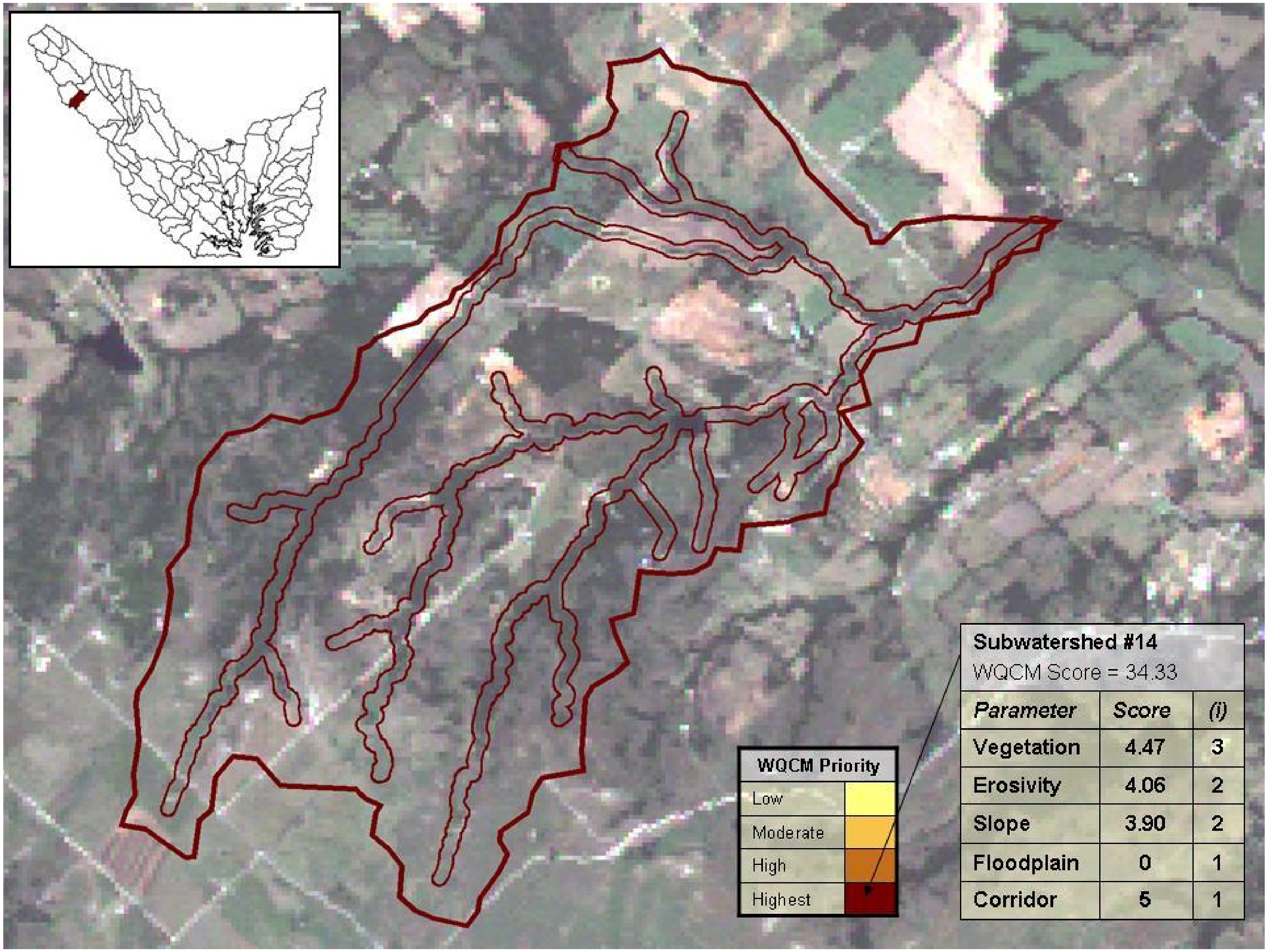
Subwatershed #12
WQCM Score = 36.39

Parameter	*Score*	*(i)*
Vegetation	4.76	3
Erosivity	4.07	2
Slope	3.98	2
Floodplain	1	1
Corridor	5	1



Subwatershed #13
WQCM Score = 33.63

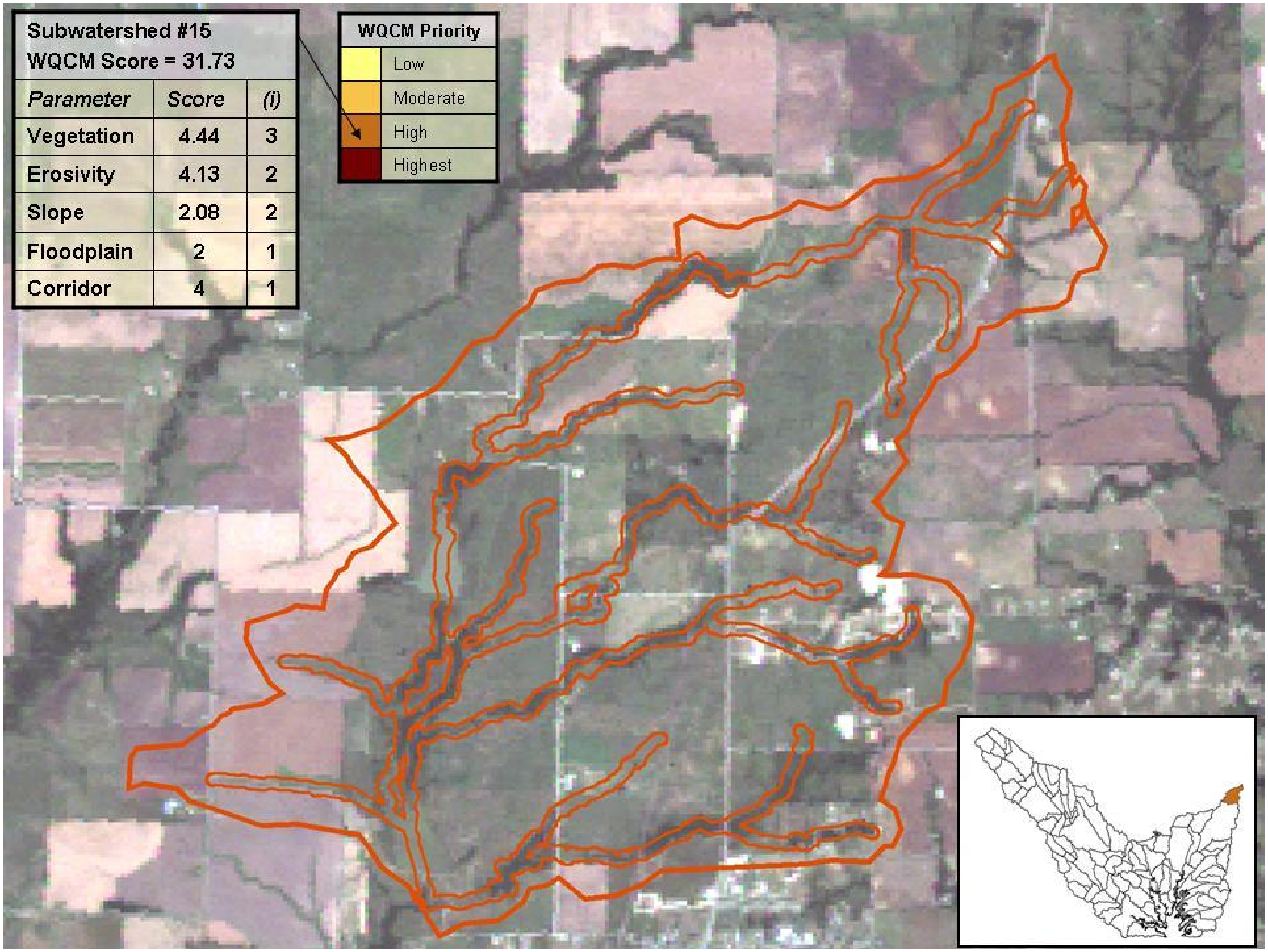
Parameter	*Score*	*(i)*
Vegetation	4.50	3
Erosivity	4.06	2
Slope	4.02	2
Floodplain	1	1
Corridor	3	1



Subwatershed #14

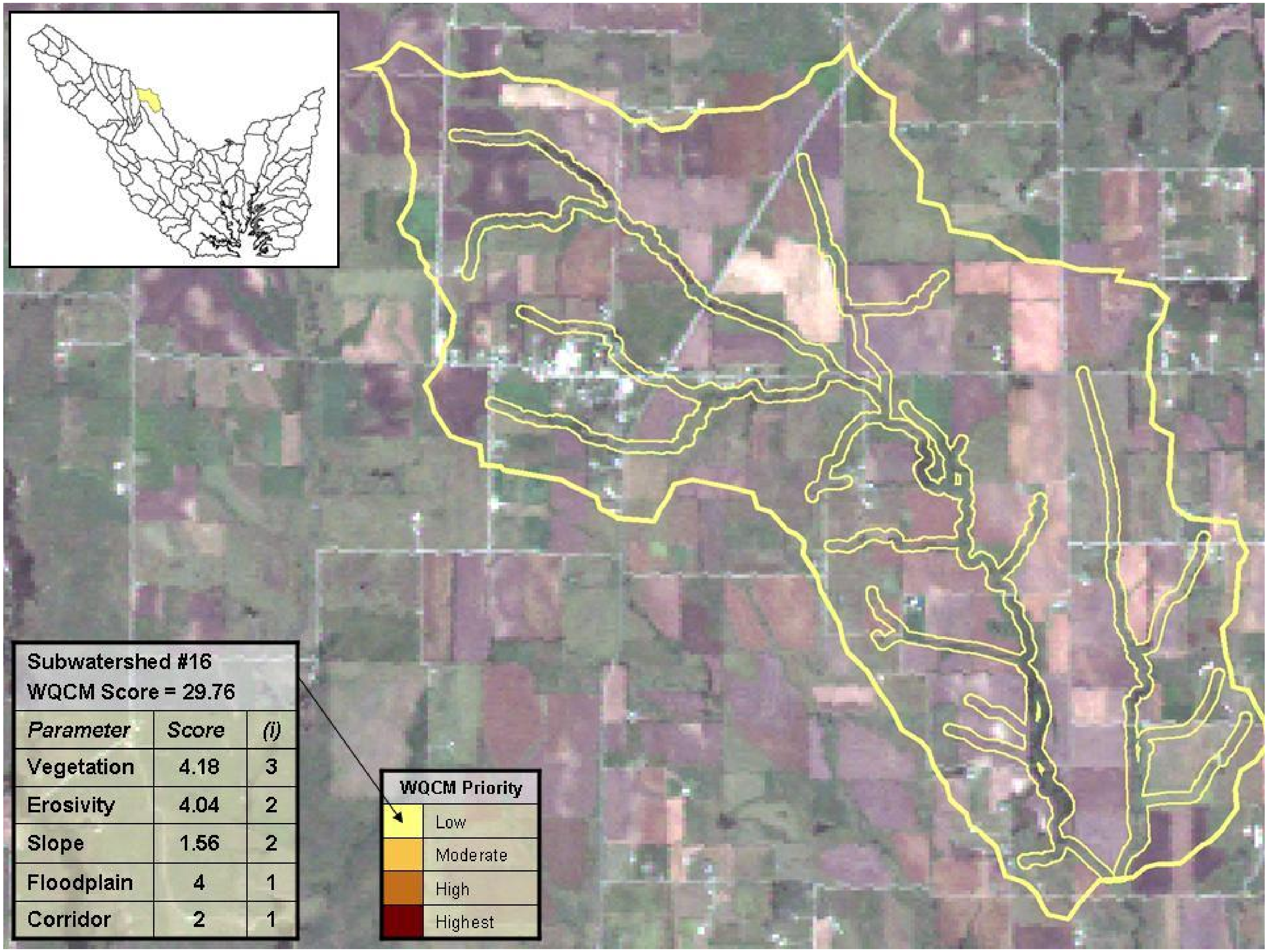
WQCM Score = 34.33

Parameter	*Score*	*(i)*
Vegetation	**4.47**	**3**
Erosivity	**4.06**	**2**
Slope	**3.90**	**2**
Floodplain	**0**	**1**
Corridor	**5**	**1**



Subwatershed #15
WQCM Score = 31.73

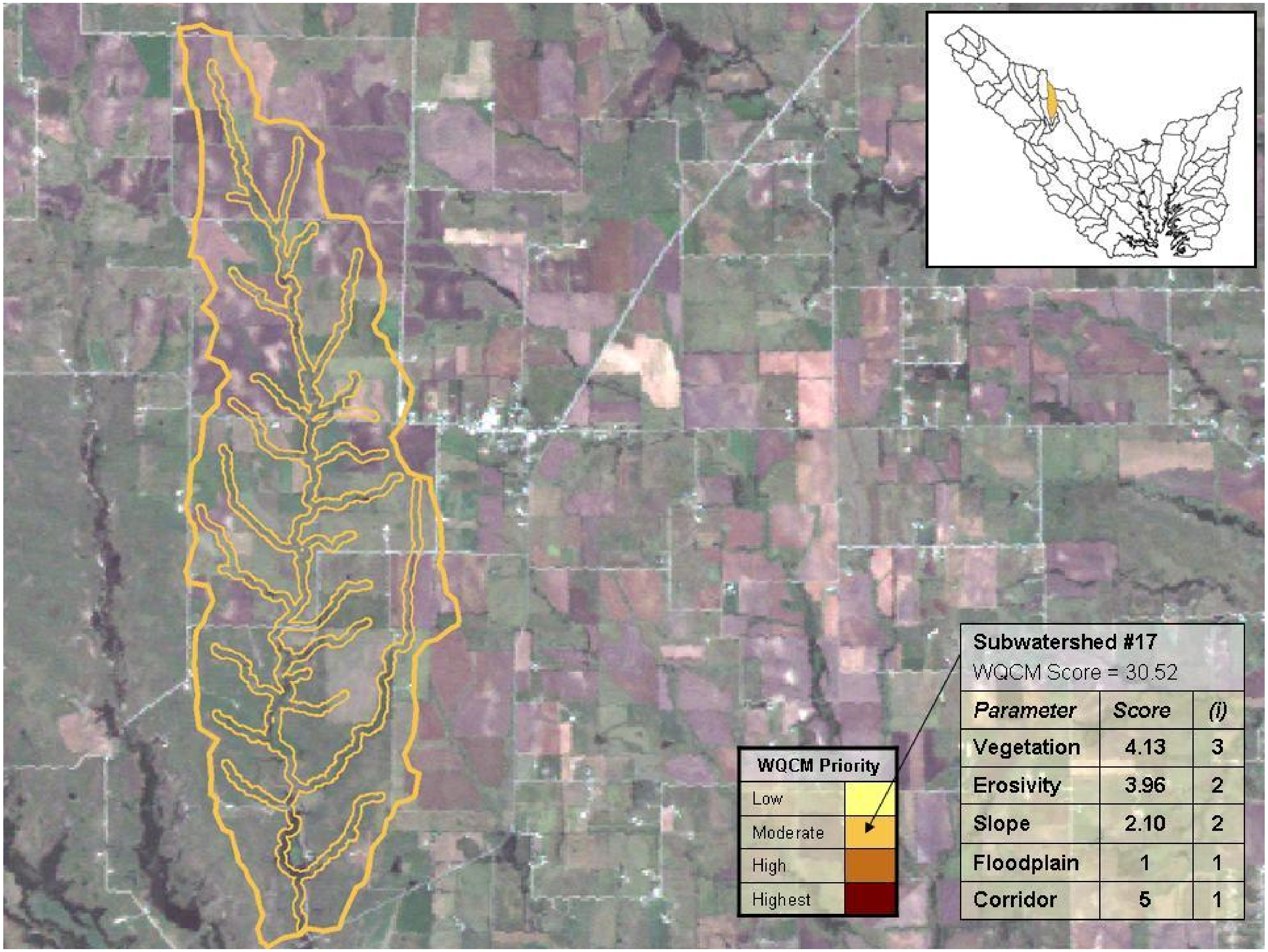
Parameter	*Score*	*(i)*
Vegetation	4.44	3
Erosivity	4.13	2
Slope	2.08	2
Floodplain	2	1
Corridor	4	1



Subwatershed #16

WQCM Score = 29.76

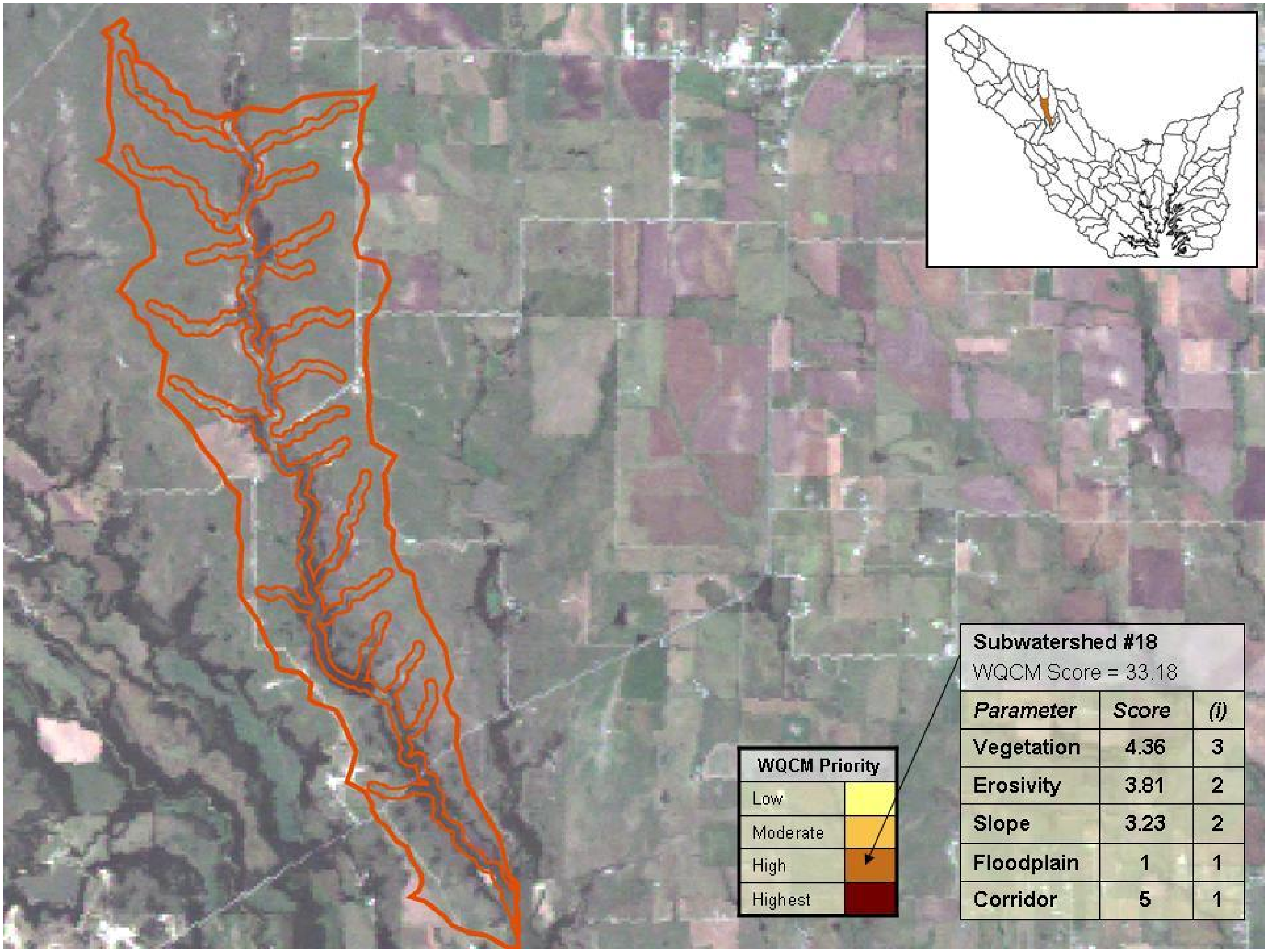
Parameter	*Score*	*(i)*
Vegetation	4.18	3
Erosivity	4.04	2
Slope	1.56	2
Floodplain	4	1
Corridor	2	1



Subwatershed #17

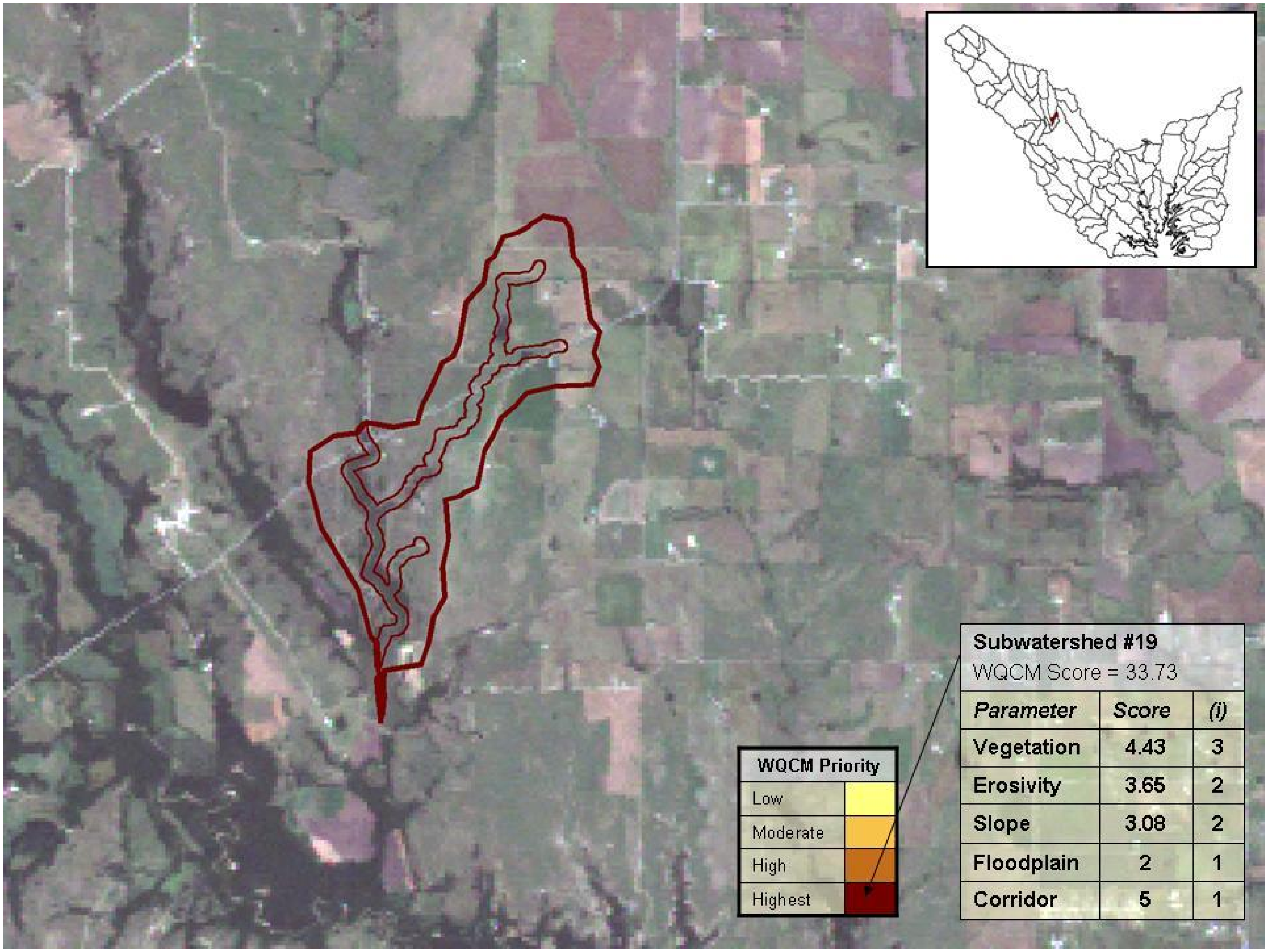
WQCM Score = 30.52

Parameter	*Score*	*(i)*
Vegetation	4.13	3
Erosivity	3.96	2
Slope	2.10	2
Floodplain	1	1
Corridor	5	1



Subwatershed #18
WQCM Score = 33.18

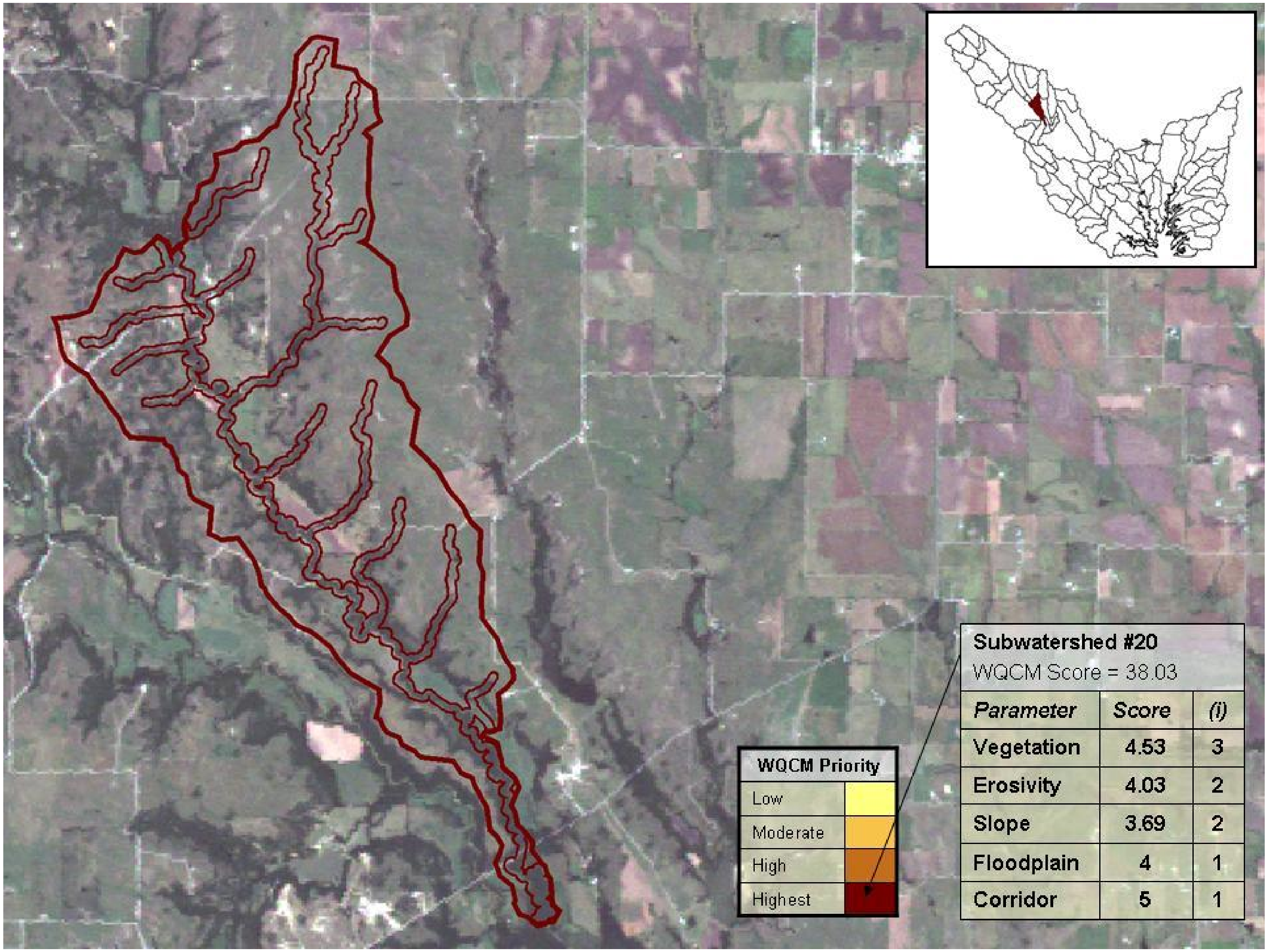
Parameter	*Score*	*(i)*
Vegetation	**4.36**	**3**
Erosivity	**3.81**	**2**
Slope	**3.23**	**2**
Floodplain	**1**	**1**
Corridor	**5**	**1**



Subwatershed #19

WQCM Score = 33.73

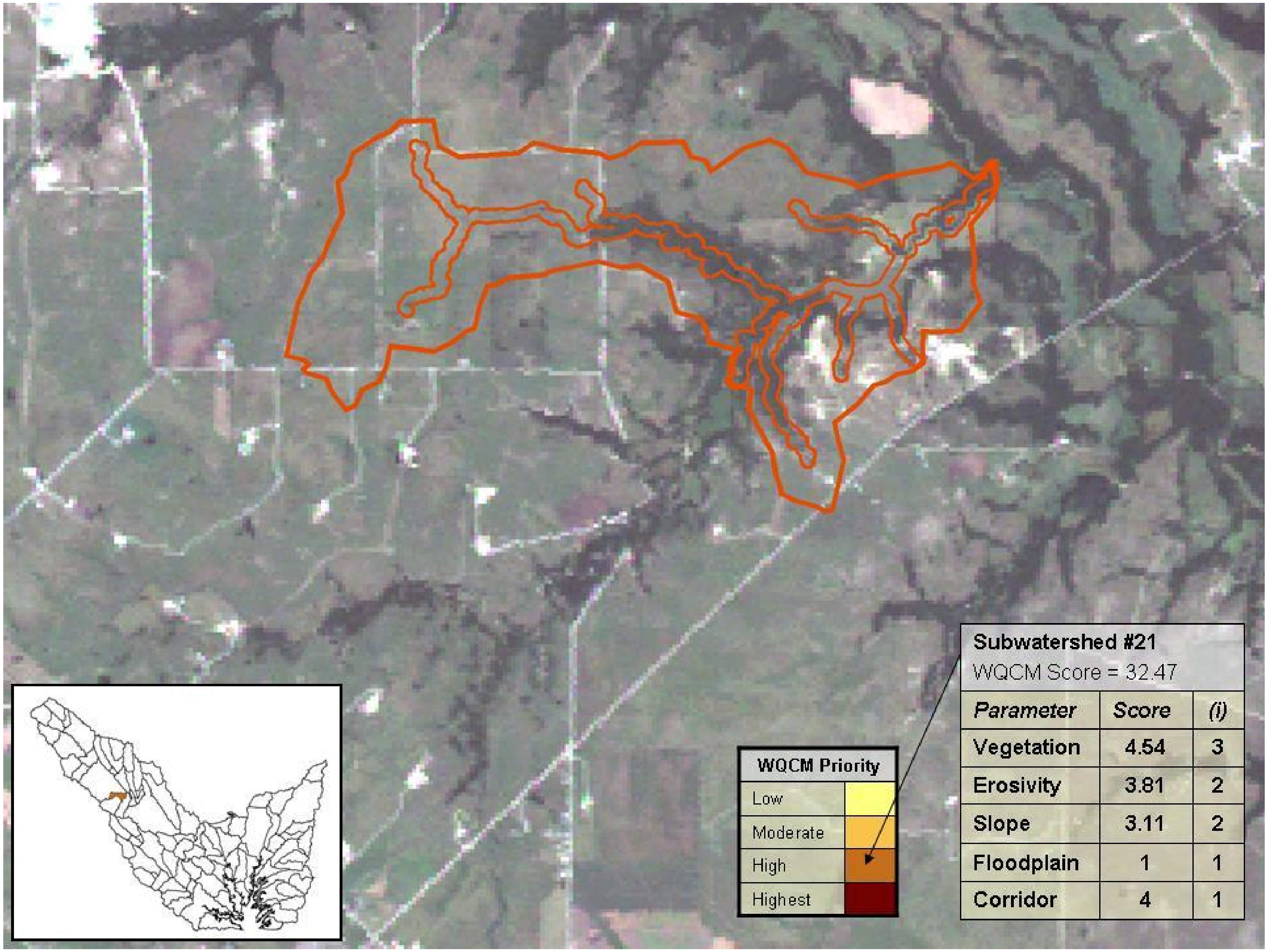
Parameter	*Score*	*(i)*
Vegetation	4.43	3
Erosivity	3.65	2
Slope	3.08	2
Floodplain	2	1
Corridor	5	1



Subwatershed #20

WQCM Score = 38.03

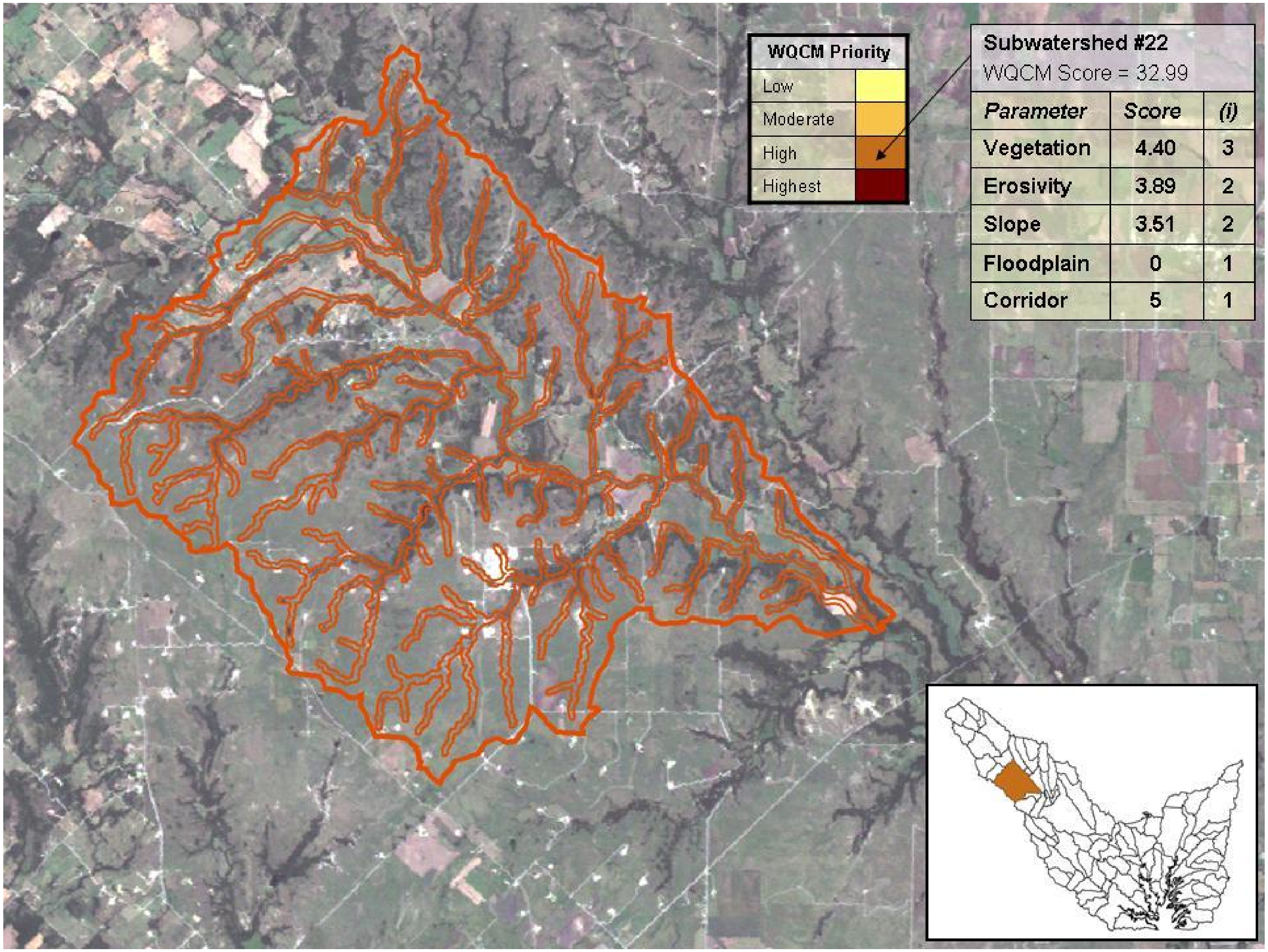
Parameter	*Score*	*(i)*
Vegetation	**4.53**	**3**
Erosivity	**4.03**	**2**
Slope	**3.69**	**2**
Floodplain	**4**	**1**
Corridor	**5**	**1**



Subwatershed #21

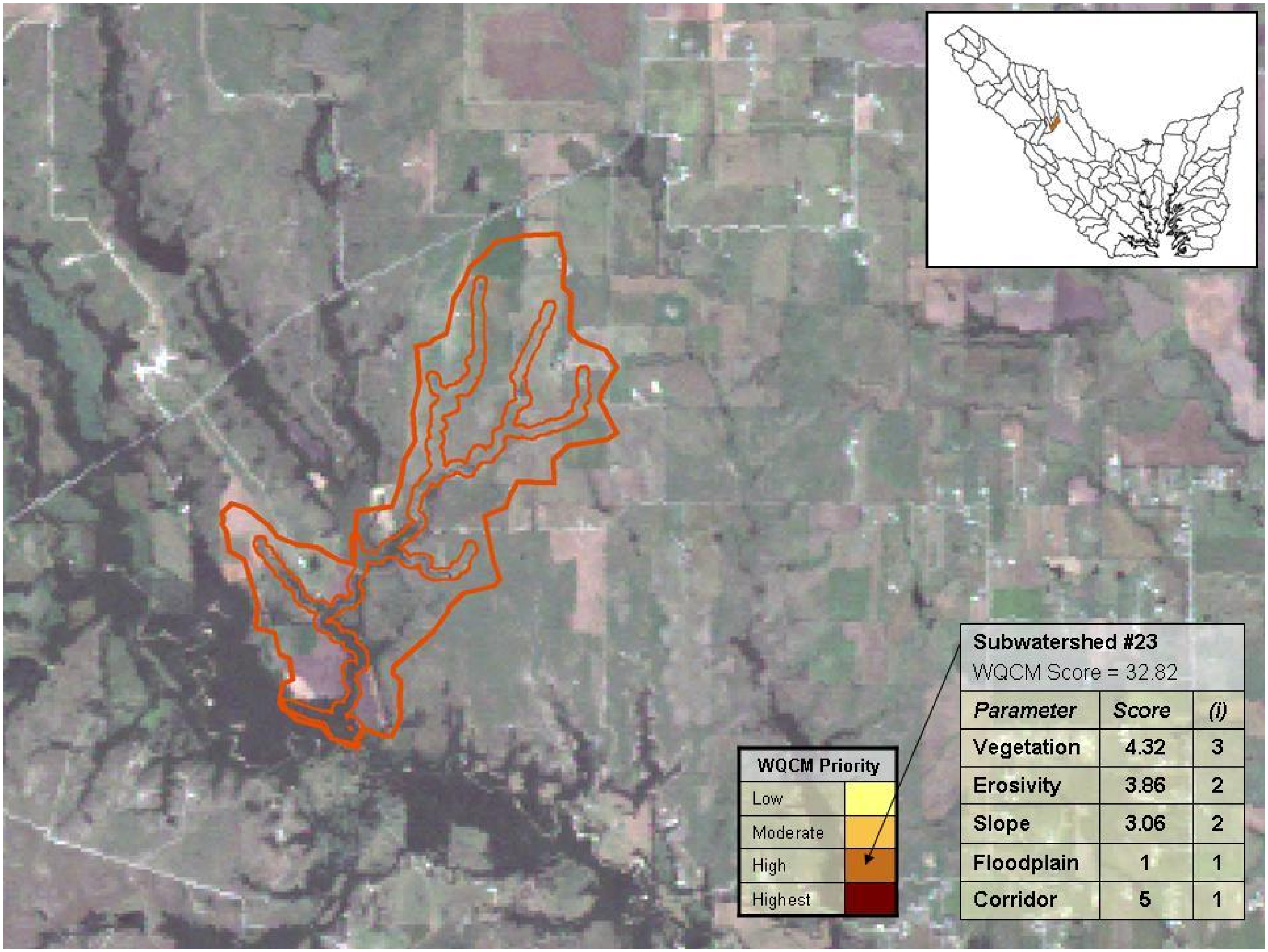
WQCM Score = 32.47

Parameter	*Score*	*(i)*
Vegetation	**4.54**	**3**
Erosivity	**3.81**	**2**
Slope	**3.11**	**2**
Floodplain	**1**	**1**
Corridor	**4**	**1**



Subwatershed #22
WQCM Score = 32.99

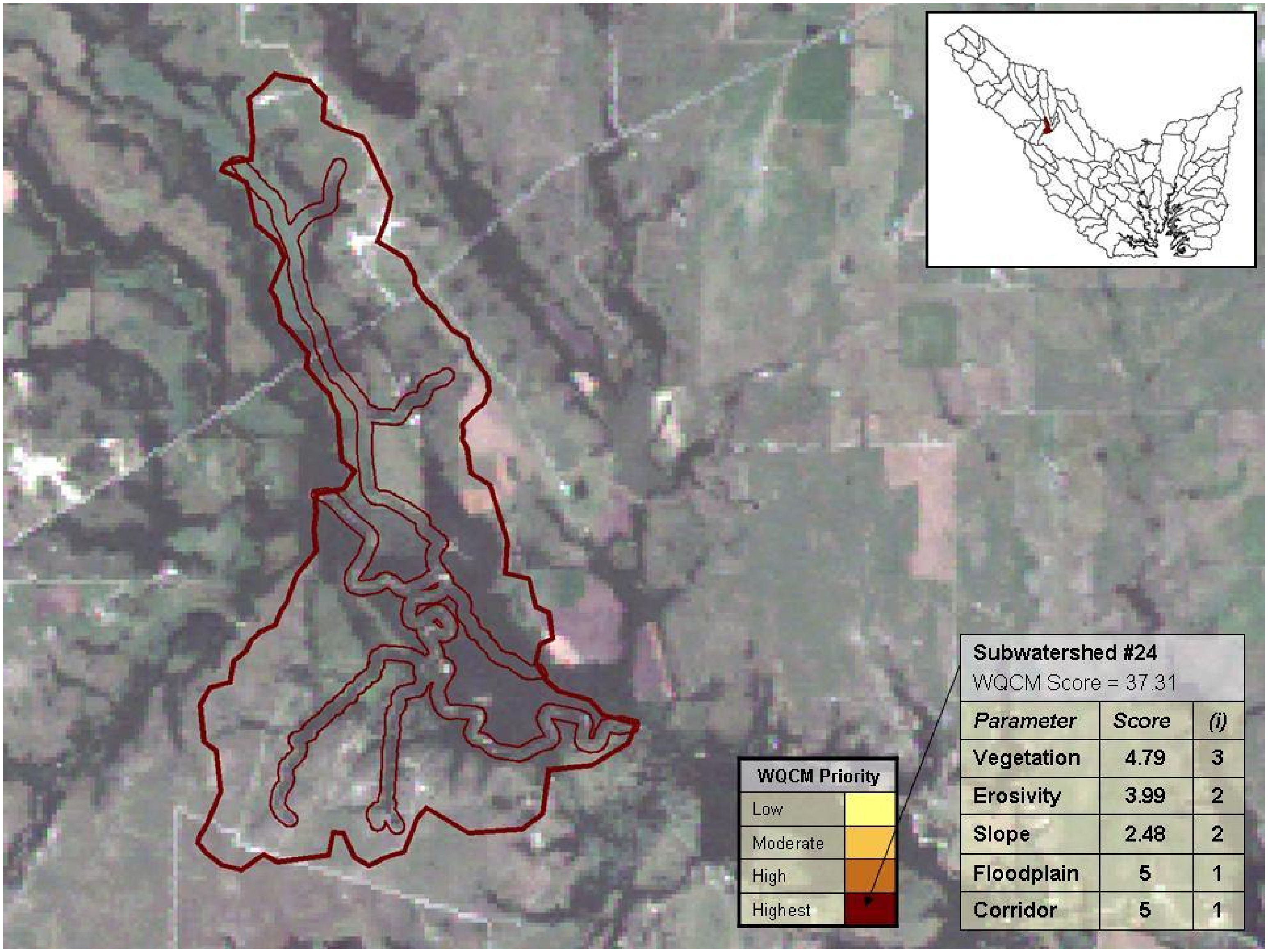
Parameter	*Score*	*(i)*
Vegetation	4.40	3
Erosivity	3.89	2
Slope	3.51	2
Floodplain	0	1
Corridor	5	1



Subwatershed #23

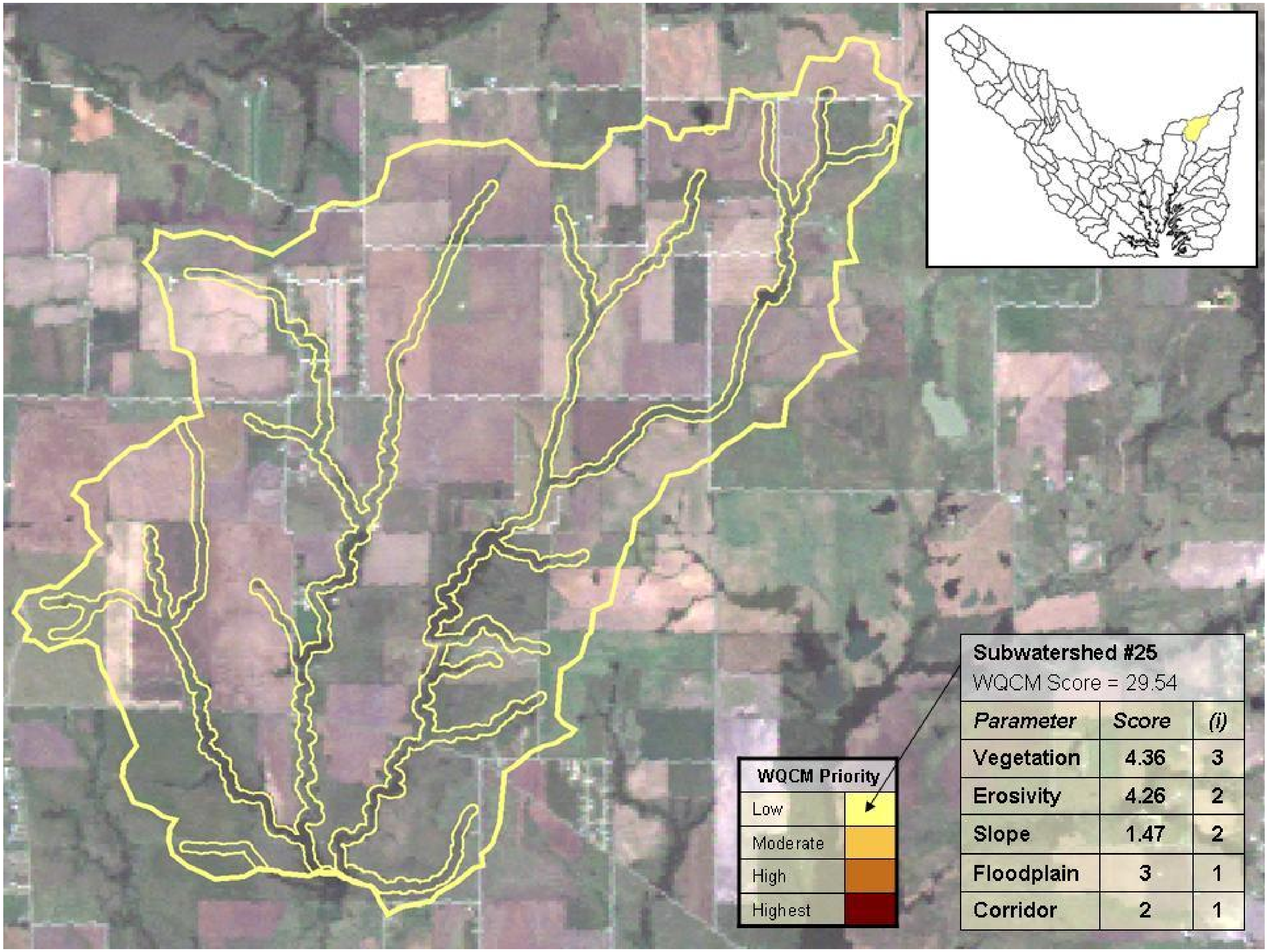
WQCM Score = 32.82

Parameter	*Score*	*(i)*
Vegetation	4.32	3
Erosivity	3.86	2
Slope	3.06	2
Floodplain	1	1
Corridor	5	1



Subwatershed #24
WQCM Score = 37.31

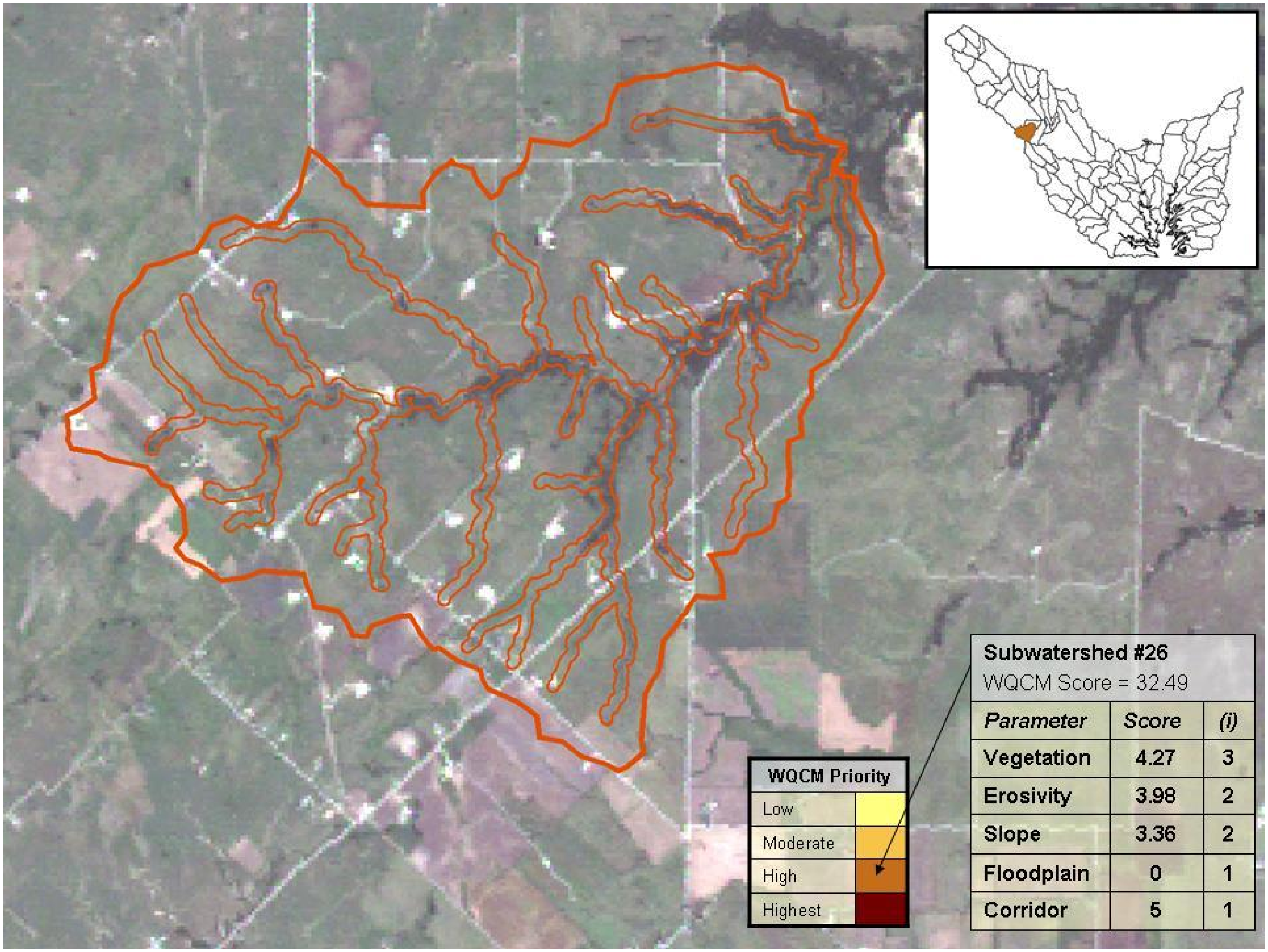
Parameter	*Score*	*(i)*
Vegetation	**4.79**	**3**
Erosivity	**3.99**	**2**
Slope	**2.48**	**2**
Floodplain	**5**	**1**
Corridor	**5**	**1**



Subwatershed #25

WQCM Score = 29.54

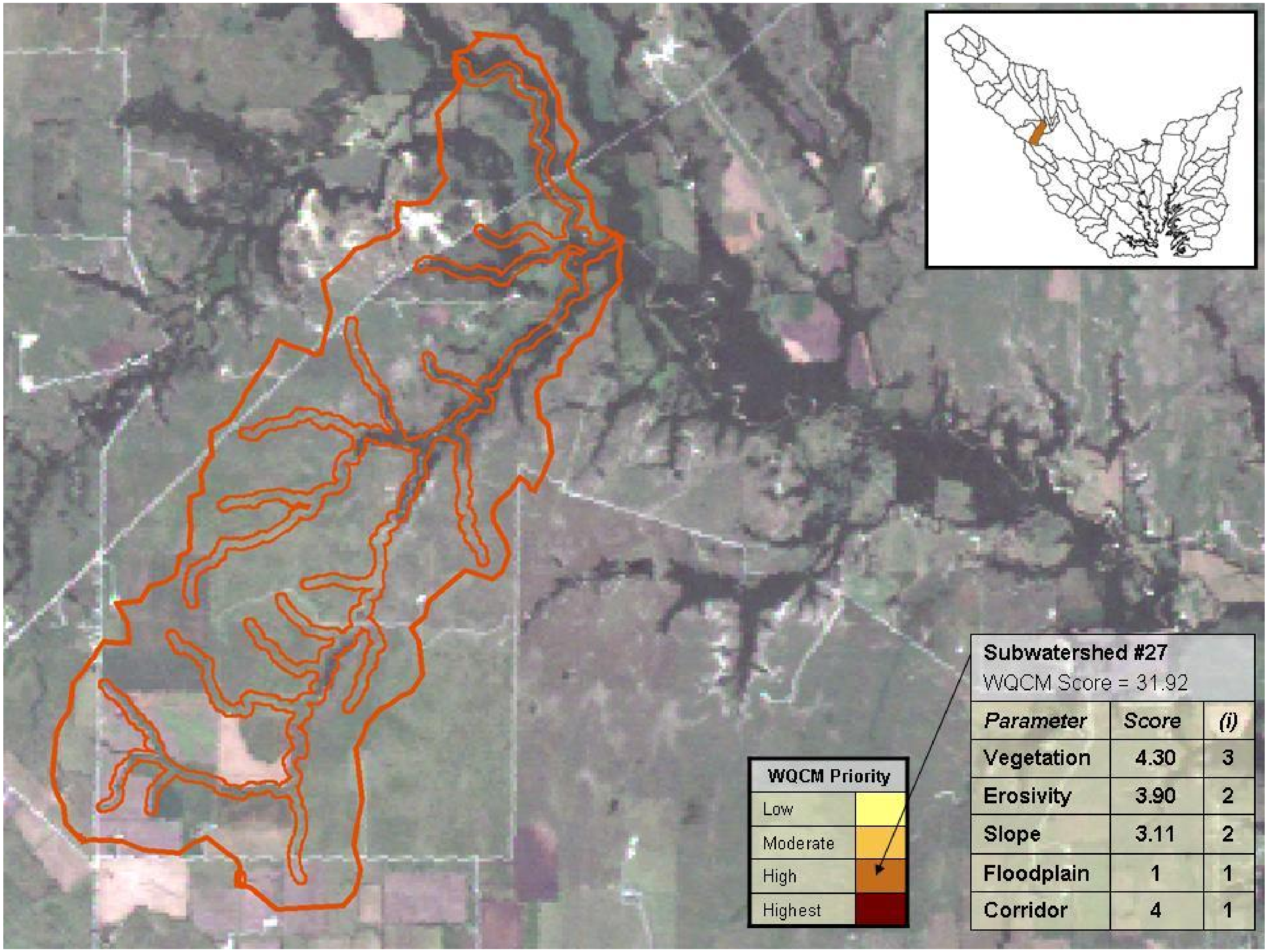
Parameter	*Score*	*(i)*
Vegetation	**4.36**	**3**
Erosivity	**4.26**	**2**
Slope	**1.47**	**2**
Floodplain	**3**	**1**
Corridor	**2**	**1**



Subwatershed #26

WQCM Score = 32.49

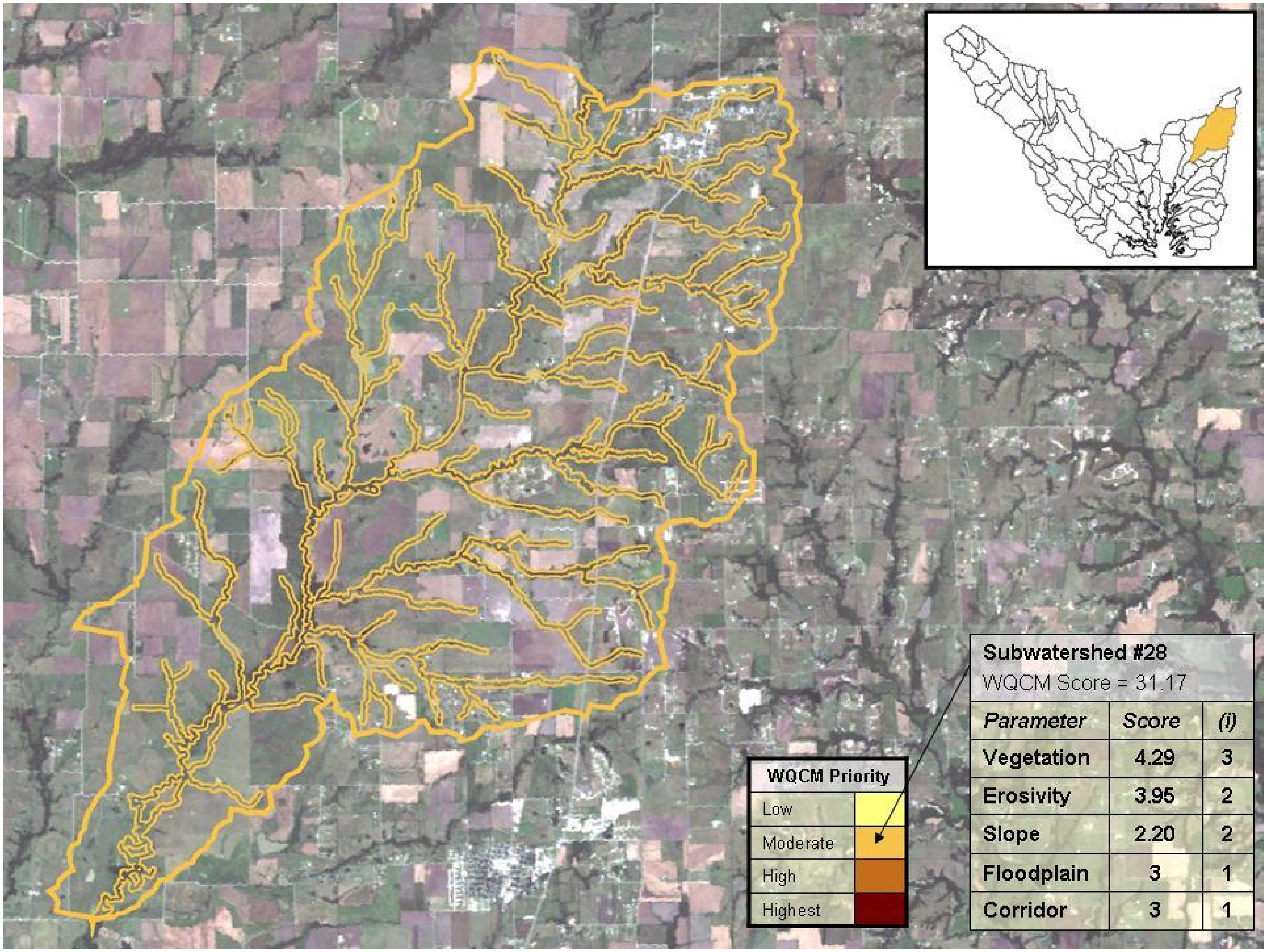
Parameter	*Score*	*(i)*
Vegetation	4.27	3
Erosivity	3.98	2
Slope	3.36	2
Floodplain	0	1
Corridor	5	1



Subwatershed #27

WQCM Score = 31.92

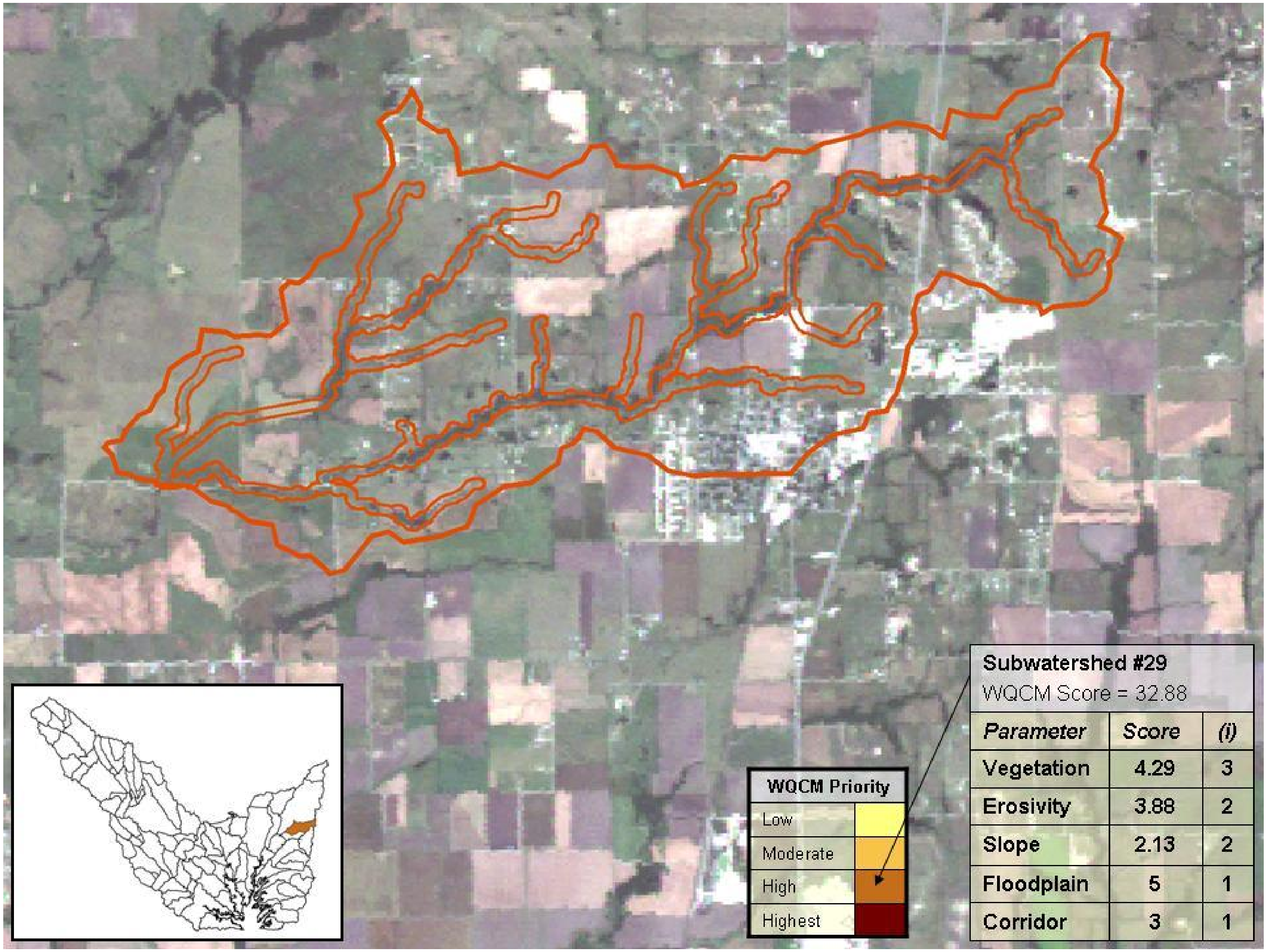
Parameter	*Score*	*(i)*
Vegetation	**4.30**	**3**
Erosivity	**3.90**	**2**
Slope	**3.11**	**2**
Floodplain	**1**	**1**
Corridor	**4**	**1**



Subwatershed #28

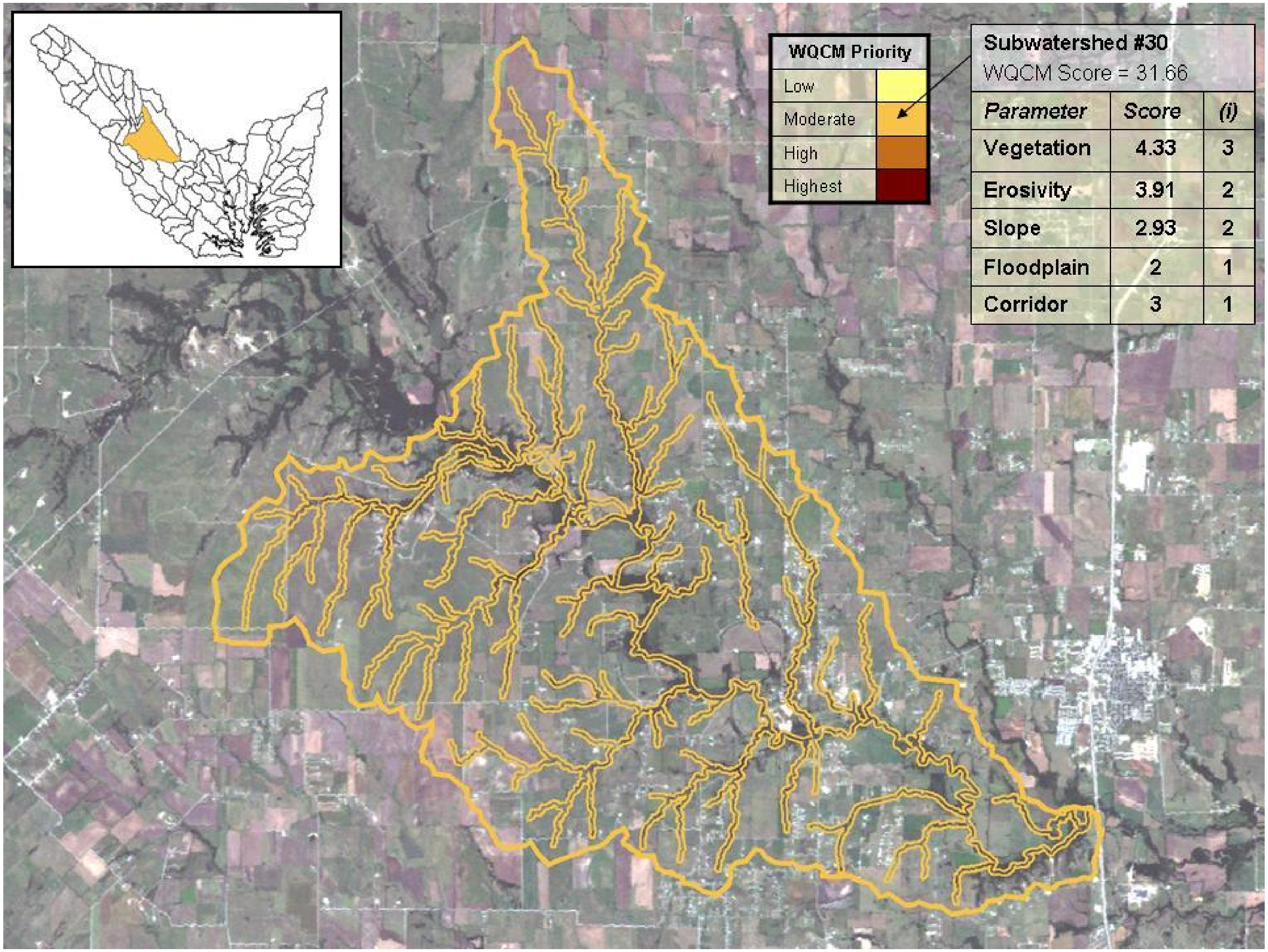
WQCM Score = 31.17

Parameter	*Score*	*(i)*
Vegetation	4.29	3
Erosivity	3.95	2
Slope	2.20	2
Floodplain	3	1
Corridor	3	1



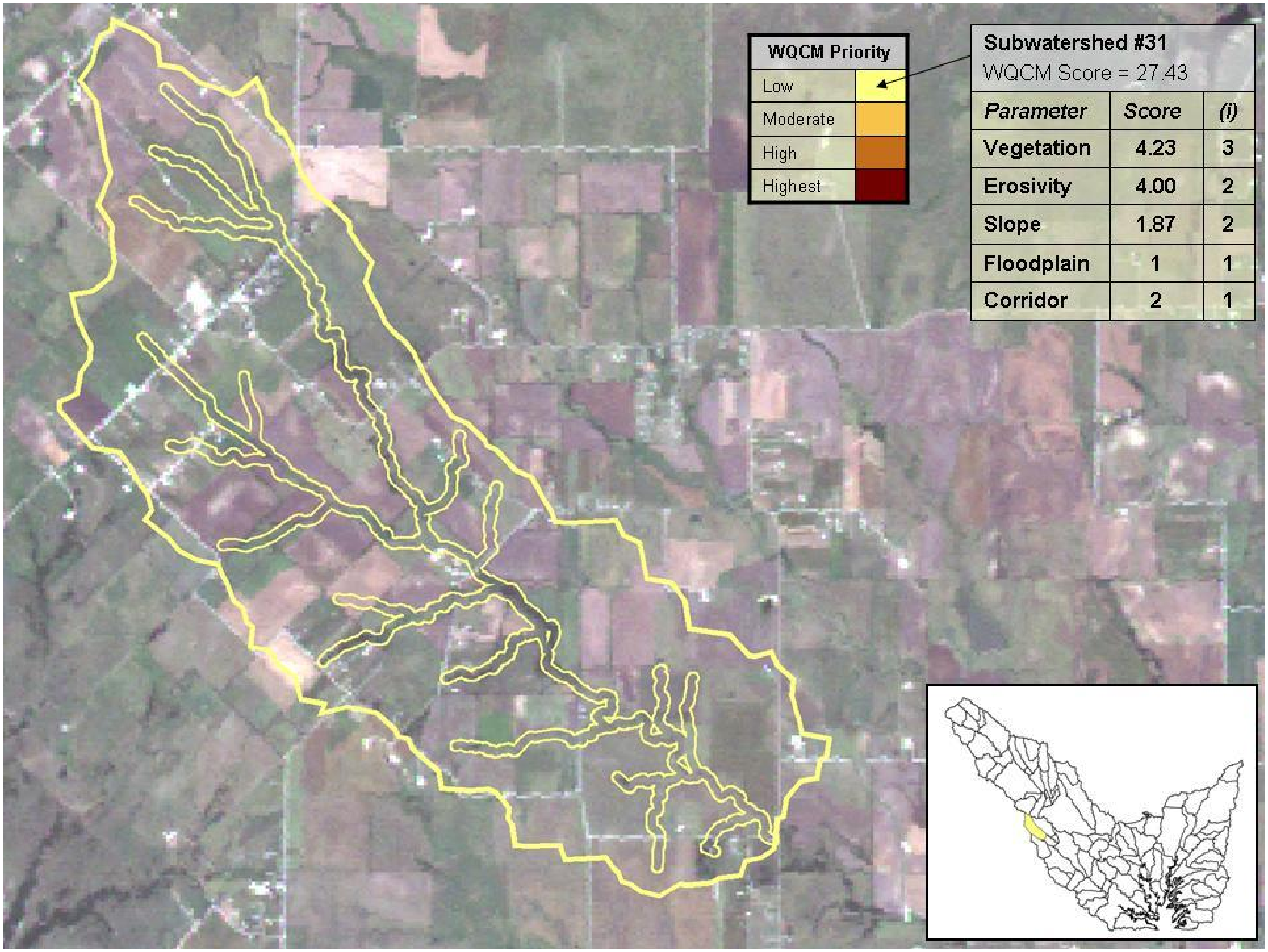
Subwatershed #29
WQCM Score = 32.88

Parameter	*Score*	*(i)*
Vegetation	4.29	3
Erosivity	3.88	2
Slope	2.13	2
Floodplain	5	1
Corridor	3	1



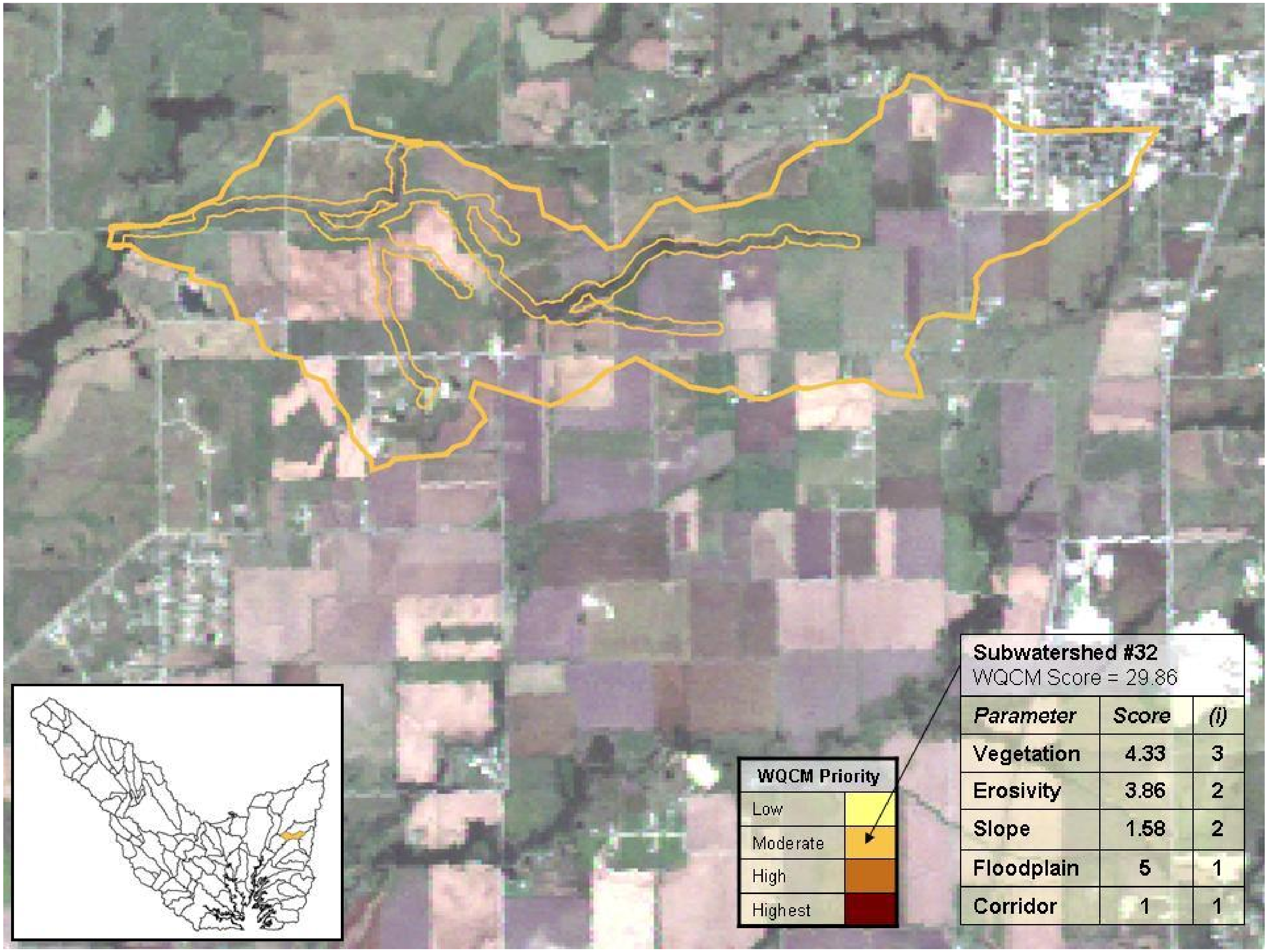
Subwatershed #30
WQCM Score = 31.66

Parameter	*Score*	*(i)*
Vegetation	4.33	3
Erosivity	3.91	2
Slope	2.93	2
Floodplain	2	1
Corridor	3	1



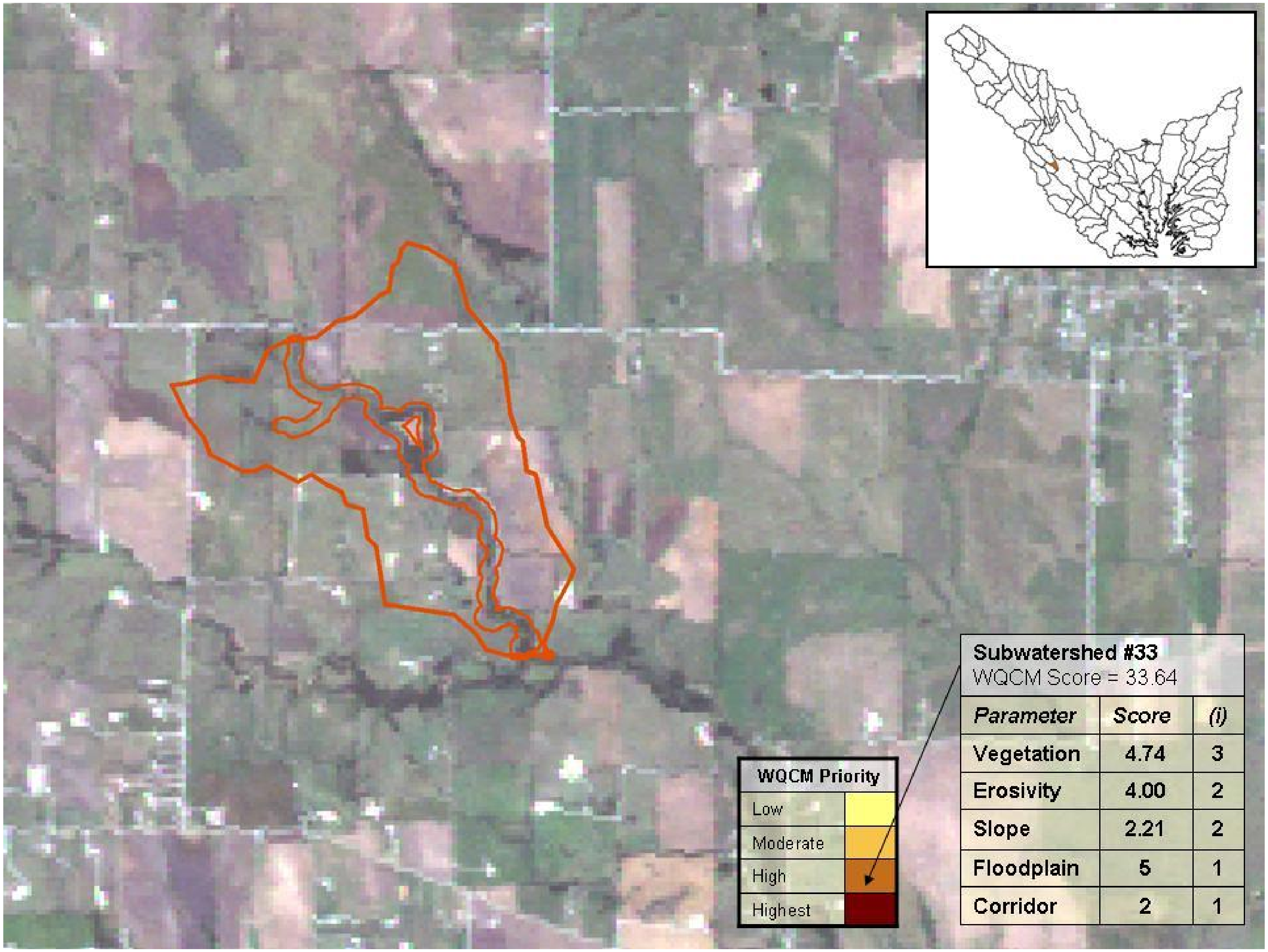
Subwatershed #31
WQCM Score = 27.43

Parameter	*Score*	*(i)*
Vegetation	**4.23**	**3**
Erosivity	**4.00**	**2**
Slope	**1.87**	**2**
Floodplain	**1**	**1**
Corridor	**2**	**1**



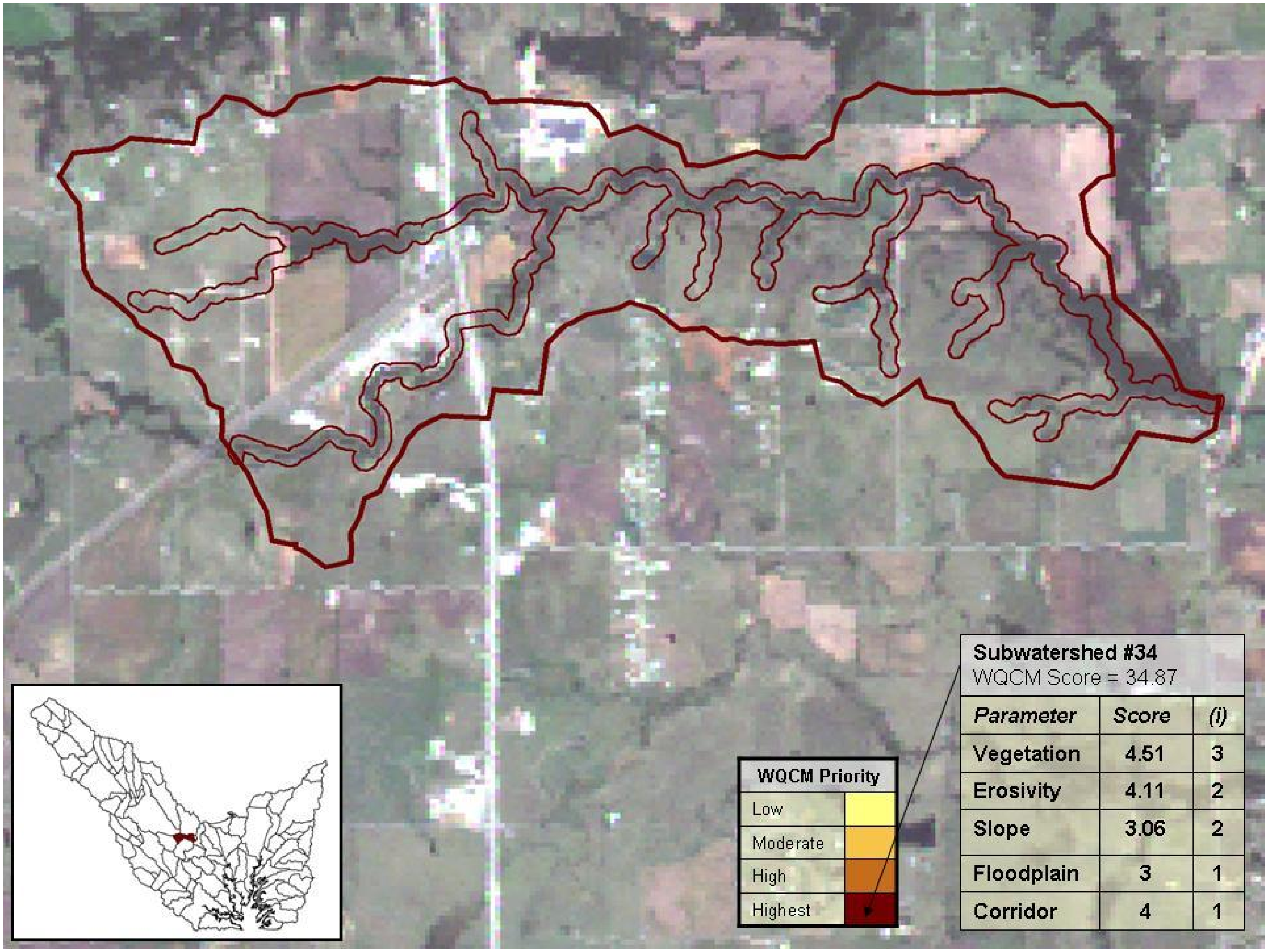
Subwatershed #32
WQCM Score = 29.86

Parameter	*Score*	*(i)*
Vegetation	4.33	3
Erosivity	3.86	2
Slope	1.58	2
Floodplain	5	1
Corridor	1	1



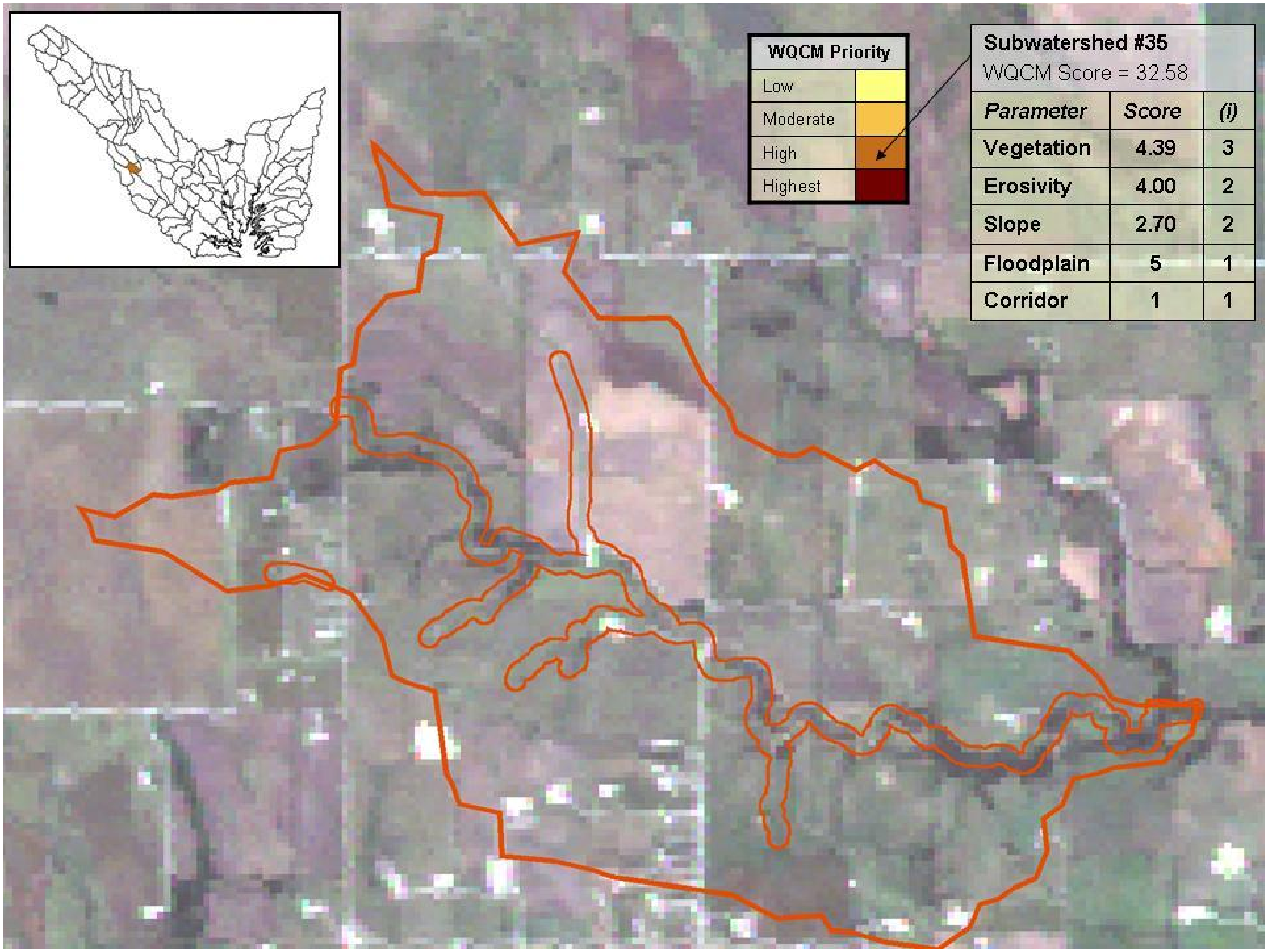
Subwatershed #33
WQCM Score = 33.64

Parameter	*Score*	*(i)*
Vegetation	**4.74**	**3**
Erosivity	**4.00**	**2**
Slope	**2.21**	**2**
Floodplain	**5**	**1**
Corridor	**2**	**1**



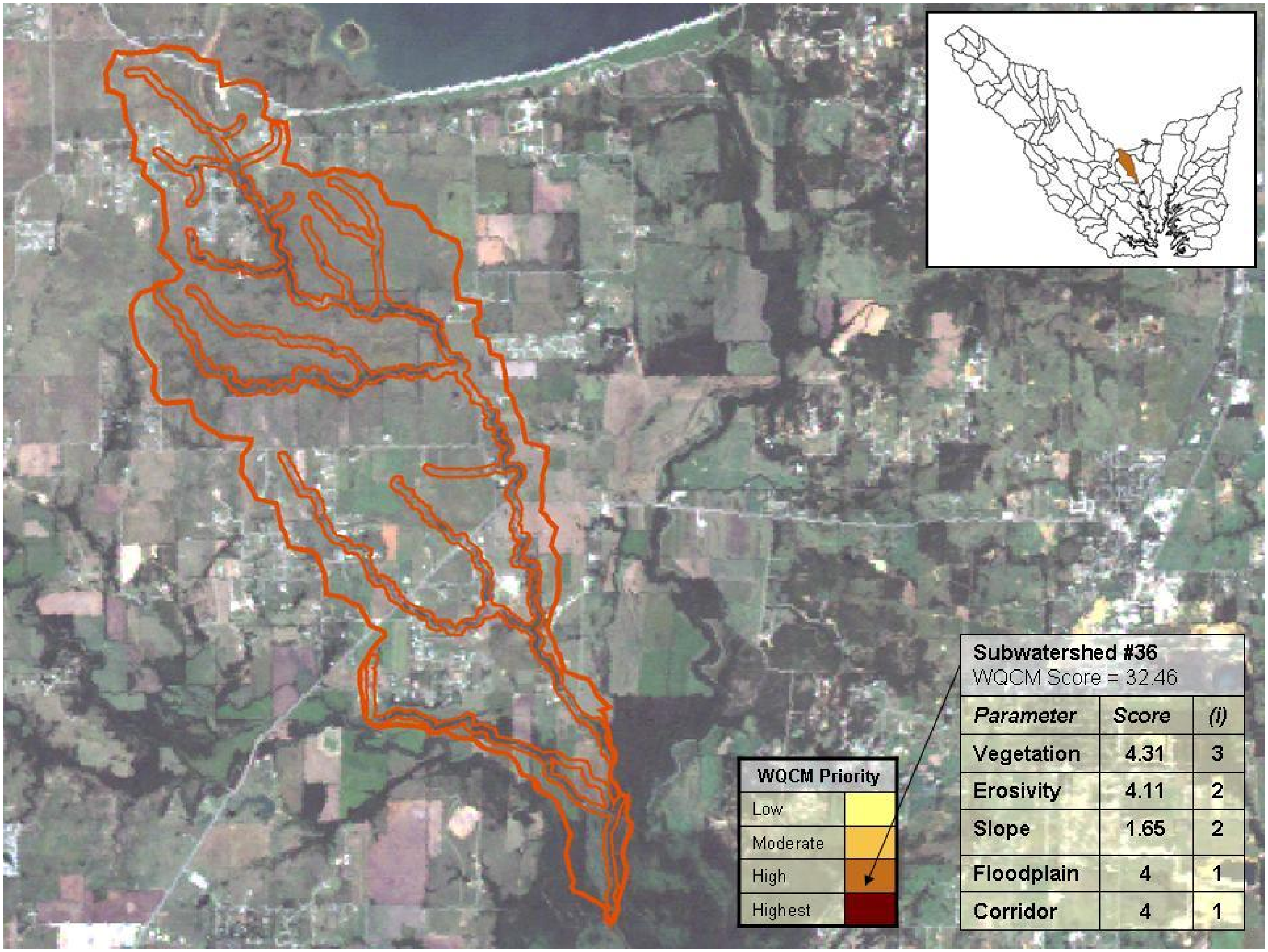
Subwatershed #34
WQCM Score = 34.87

Parameter	*Score*	*(i)*
Vegetation	4.51	3
Erosivity	4.11	2
Slope	3.06	2
Floodplain	3	1
Corridor	4	1



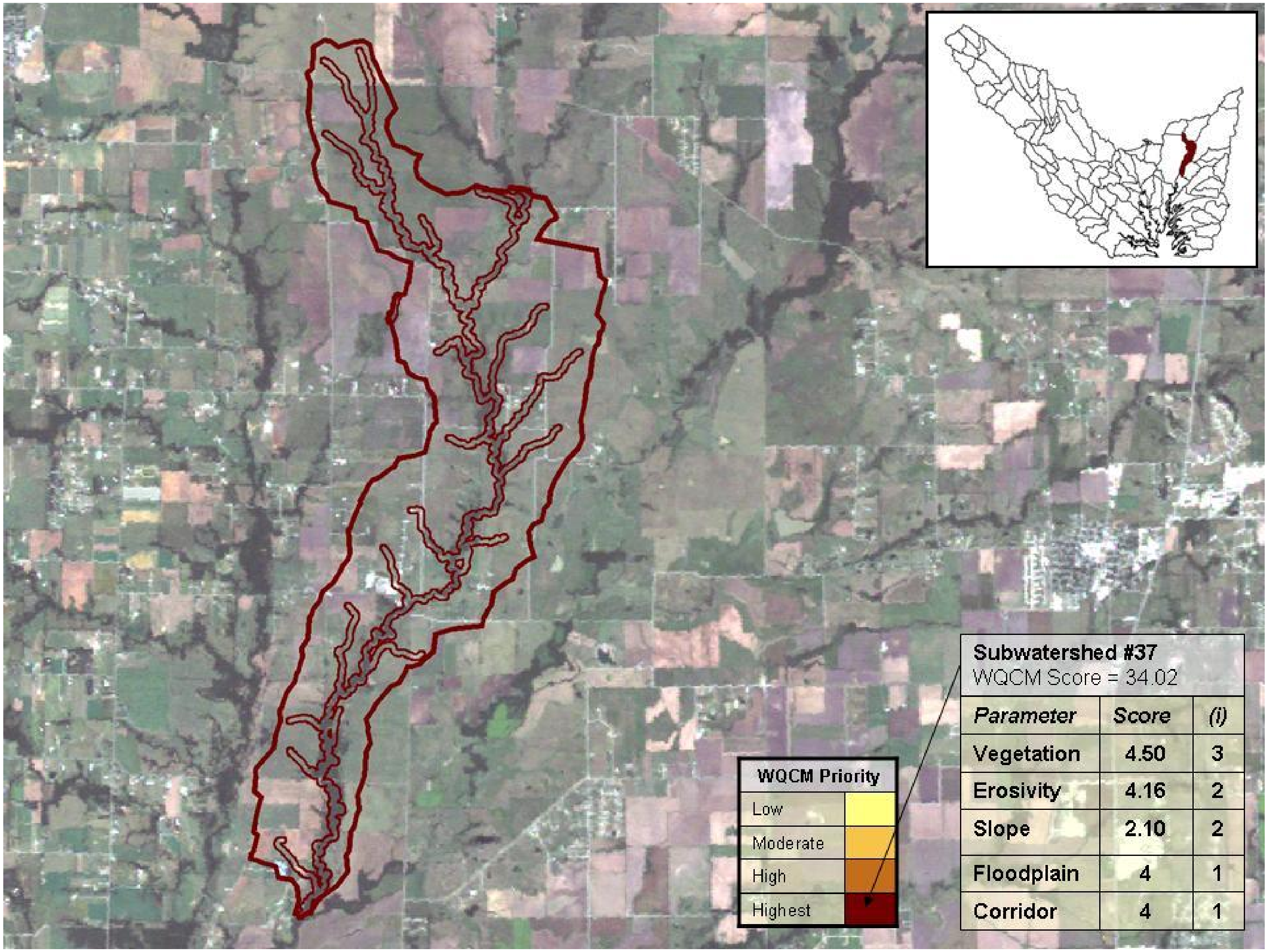
Subwatershed #35
WQCM Score = 32.58

Parameter	*Score*	*(i)*
Vegetation	4.39	3
Erosivity	4.00	2
Slope	2.70	2
Floodplain	5	1
Corridor	1	1



Subwatershed #36
WQCM Score = 32.46

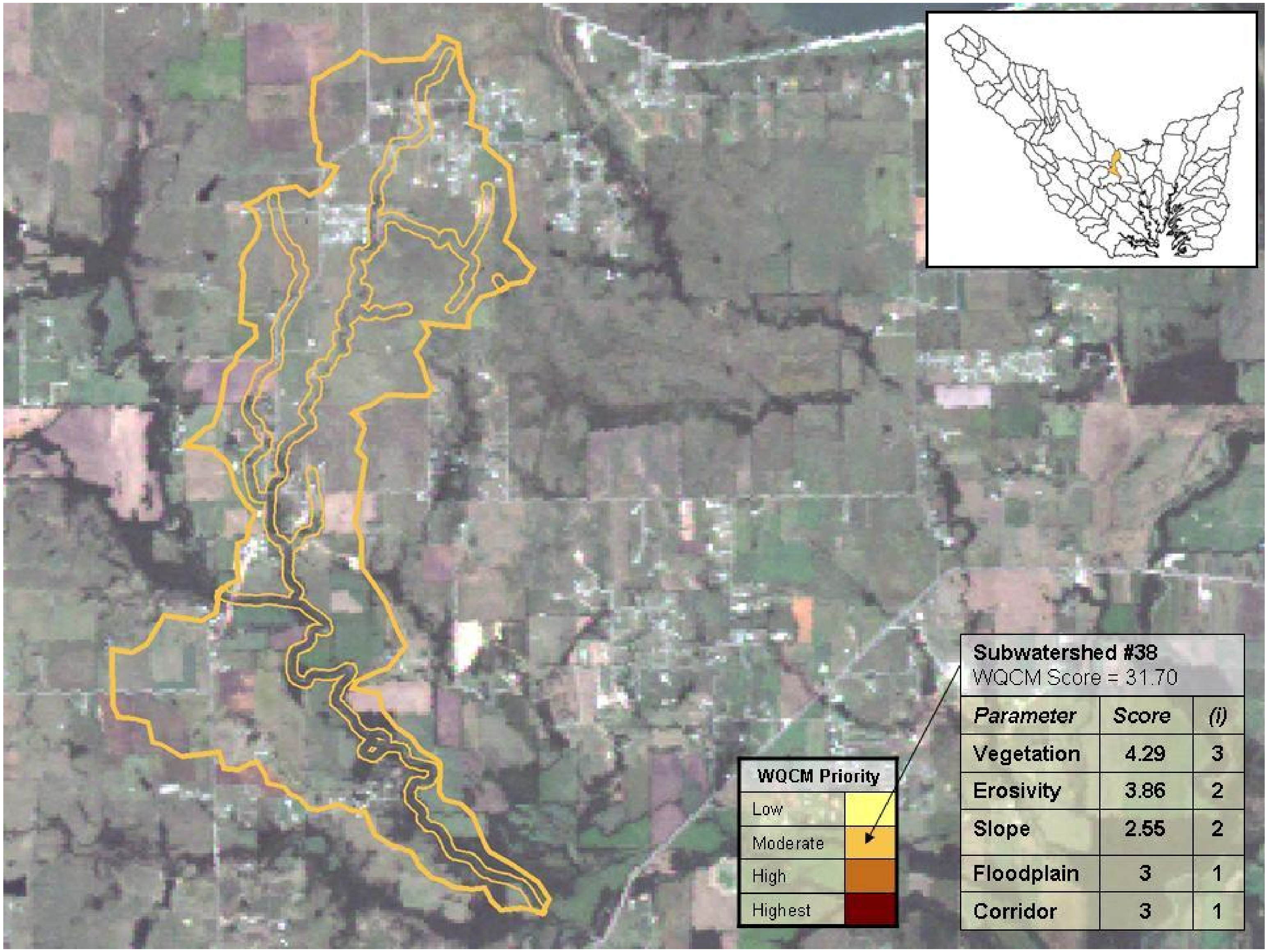
Parameter	*Score*	*(i)*
Vegetation	4.31	3
Erosivity	4.11	2
Slope	1.65	2
Floodplain	4	1
Corridor	4	1



Subwatershed #37

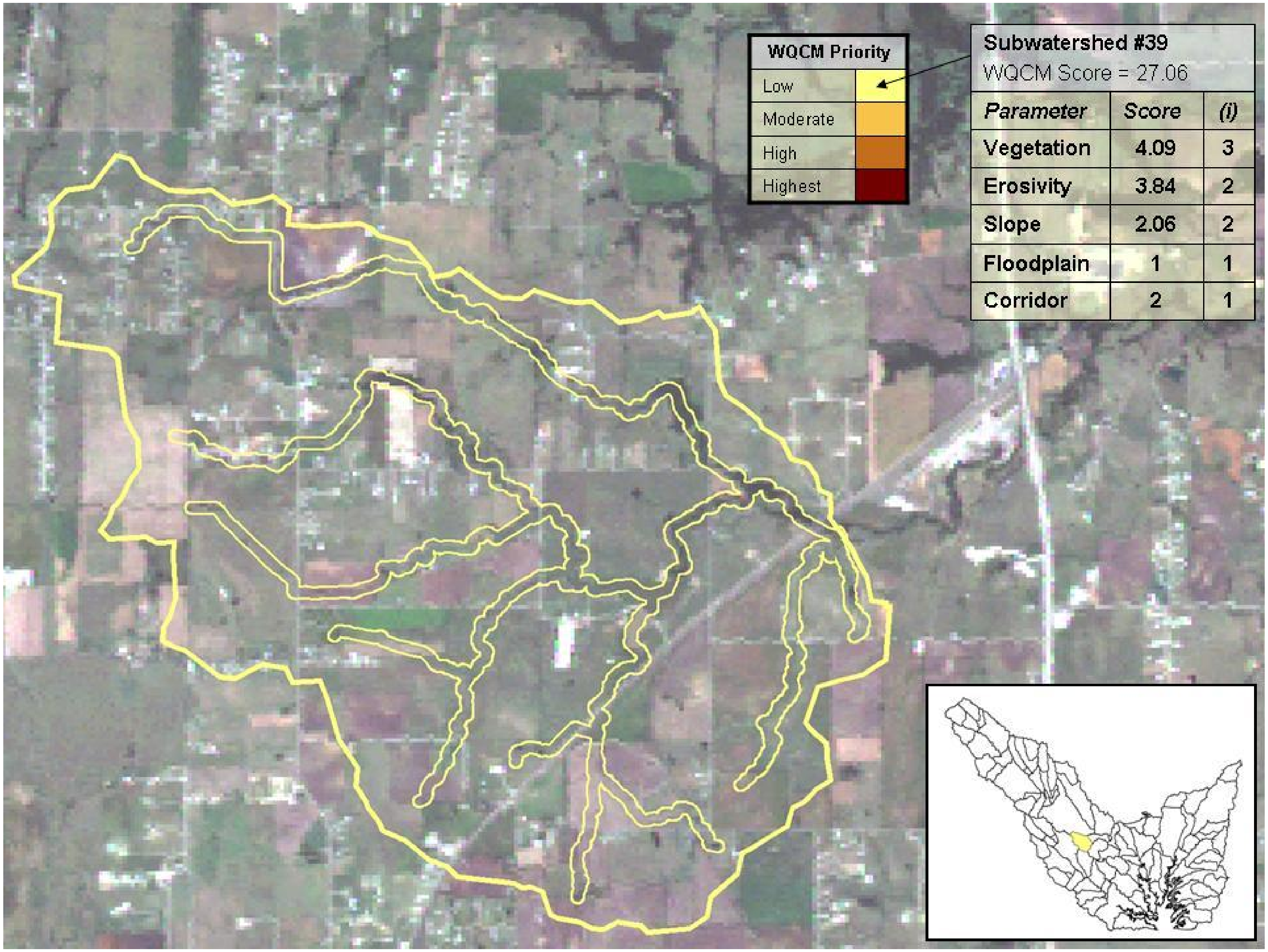
WQCM Score = 34.02

Parameter	*Score*	*(i)*
Vegetation	**4.50**	**3**
Erosivity	**4.16**	**2**
Slope	**2.10**	**2**
Floodplain	**4**	**1**
Corridor	**4**	**1**



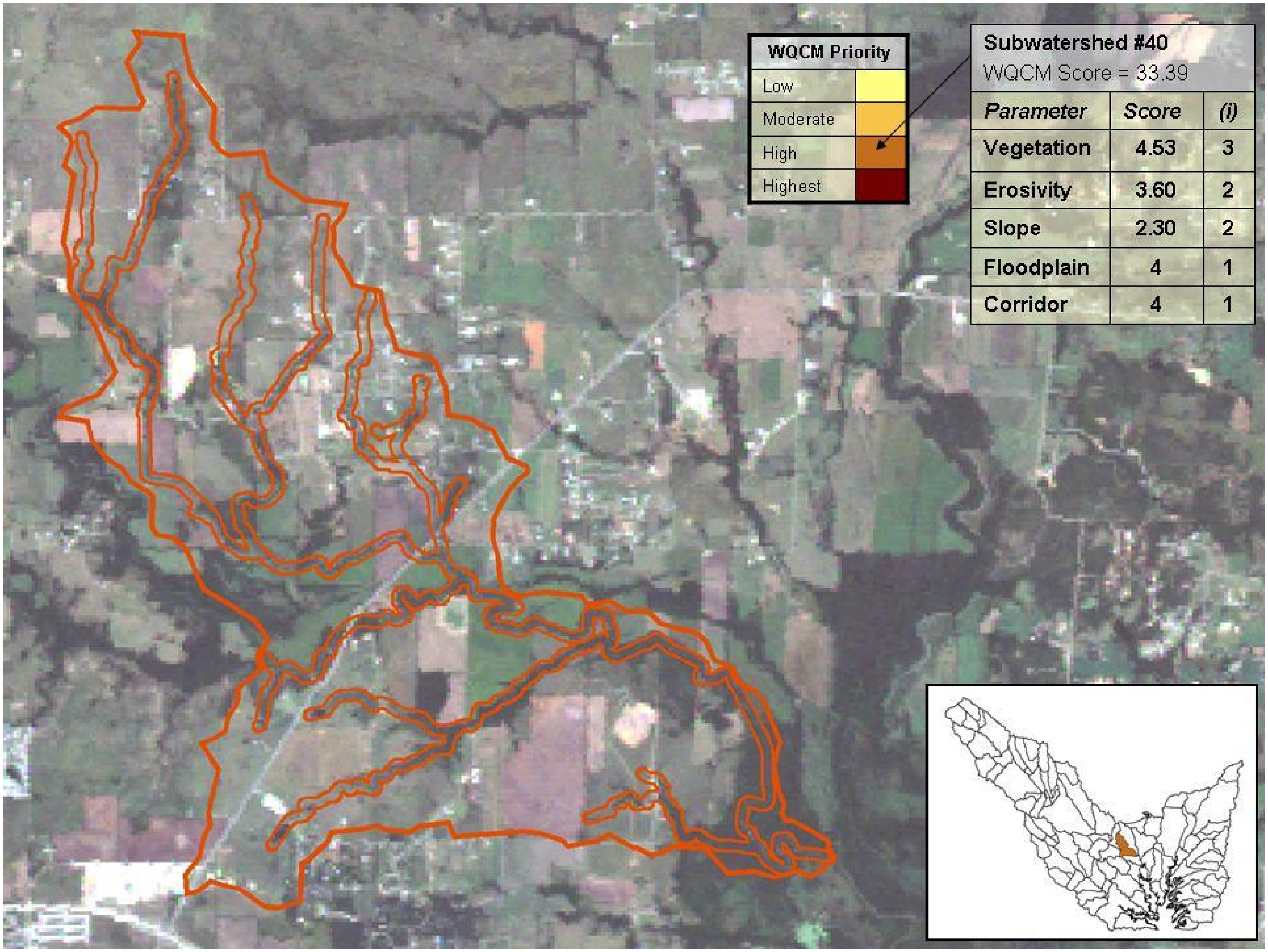
Subwatershed #38
WQCM Score = 31.70

Parameter	*Score*	*(i)*
Vegetation	4.29	3
Erosivity	3.86	2
Slope	2.55	2
Floodplain	3	1
Corridor	3	1



Subwatershed #39
WQCM Score = 27.06

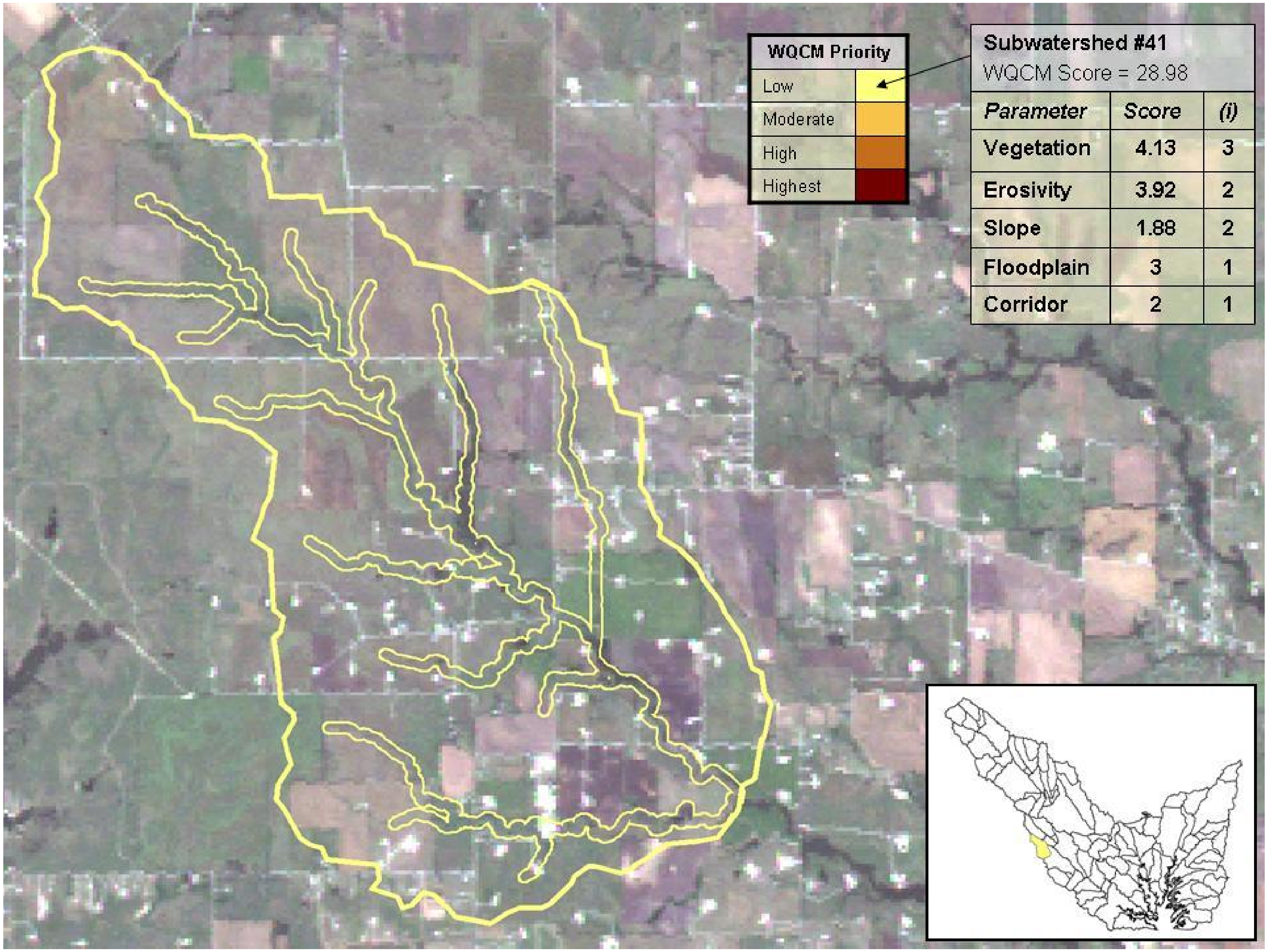
Parameter	*Score*	*(i)*
Vegetation	4.09	3
Erosivity	3.84	2
Slope	2.06	2
Floodplain	1	1
Corridor	2	1



Subwatershed #40

WQCM Score = 33.39

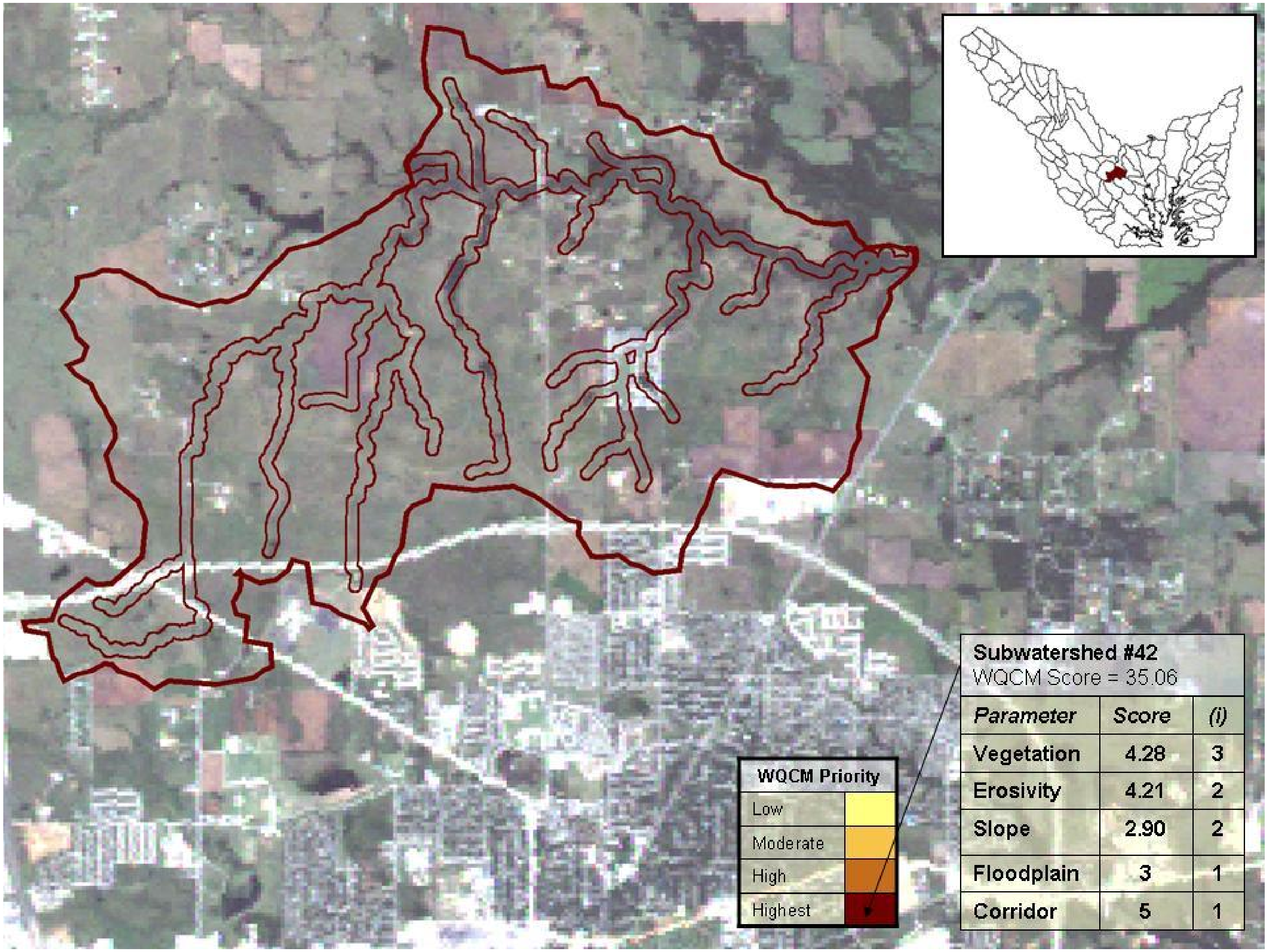
Parameter	*Score*	*(i)*
Vegetation	4.53	3
Erosivity	3.60	2
Slope	2.30	2
Floodplain	4	1
Corridor	4	1



Subwatershed #41

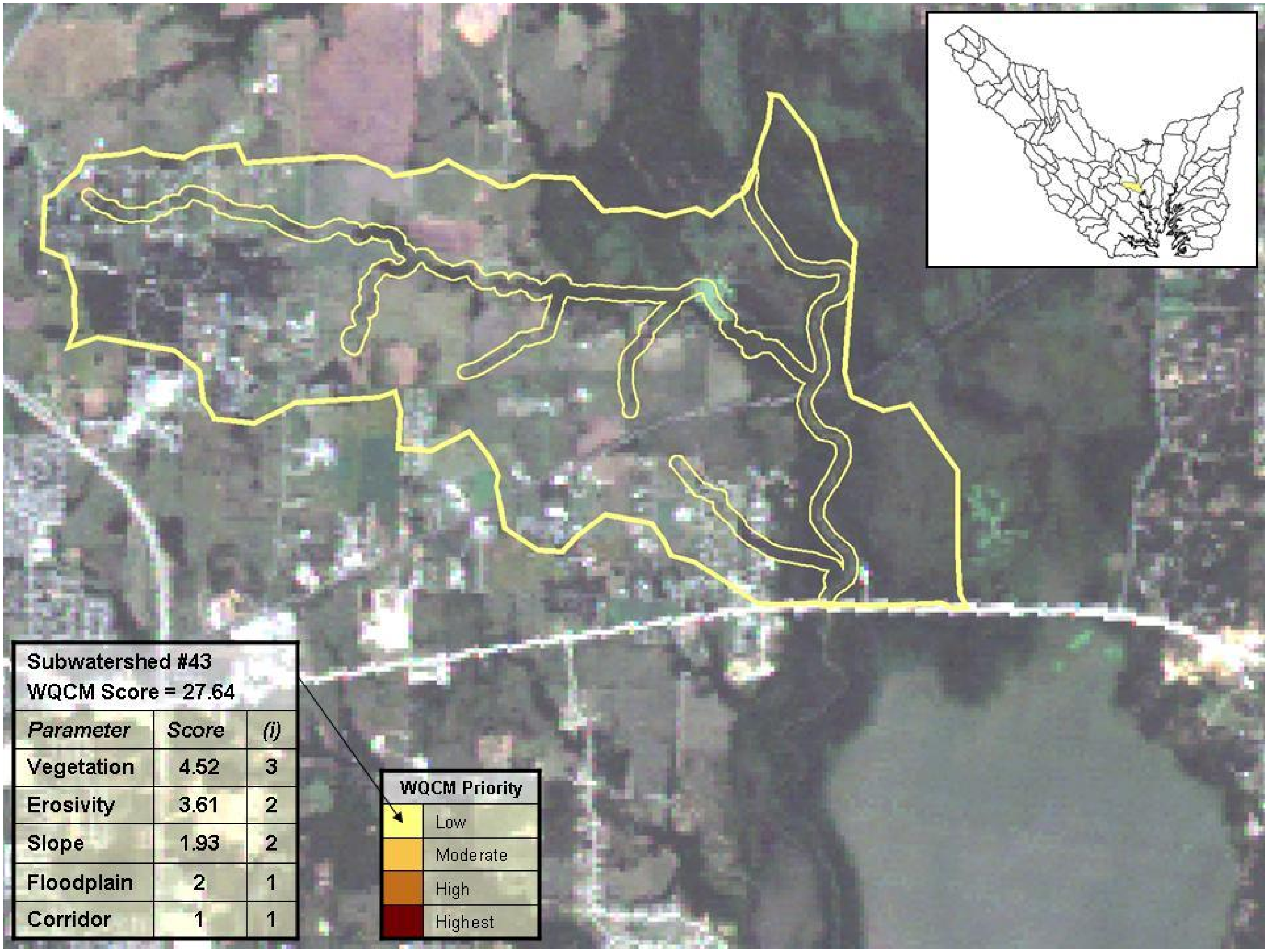
WQCM Score = 28.98

Parameter	*Score*	*(i)*
Vegetation	**4.13**	**3**
Erosivity	**3.92**	**2**
Slope	**1.88**	**2**
Floodplain	**3**	**1**
Corridor	**2**	**1**



Subwatershed #42
WQCM Score = 35.06

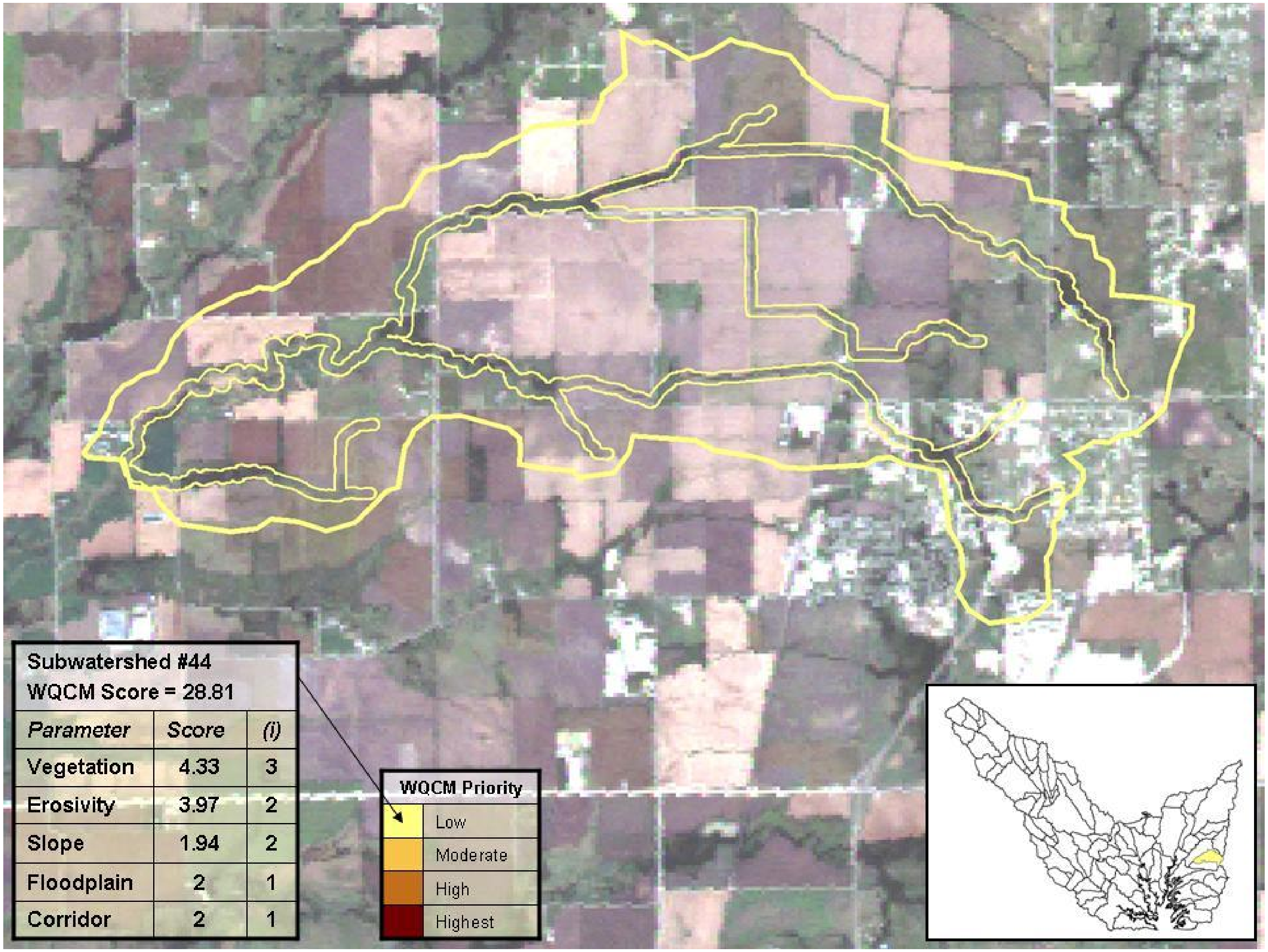
Parameter	*Score*	*(i)*
Vegetation	**4.28**	**3**
Erosivity	**4.21**	**2**
Slope	**2.90**	**2**
Floodplain	**3**	**1**
Corridor	**5**	**1**



Subwatershed #43

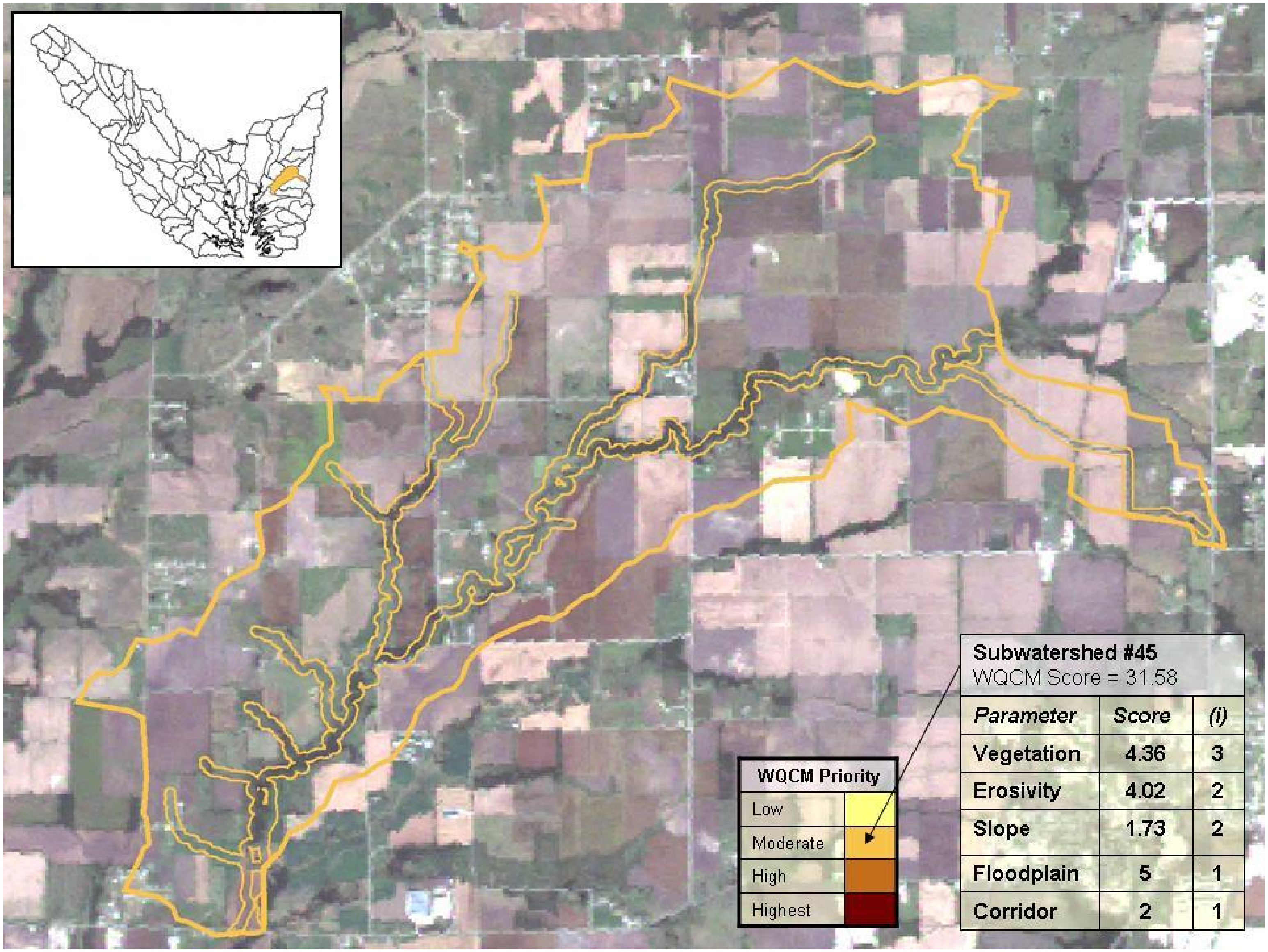
WQCM Score = 27.64

Parameter	*Score*	*(i)*
Vegetation	4.52	3
Erosivity	3.61	2
Slope	1.93	2
Floodplain	2	1
Corridor	1	1



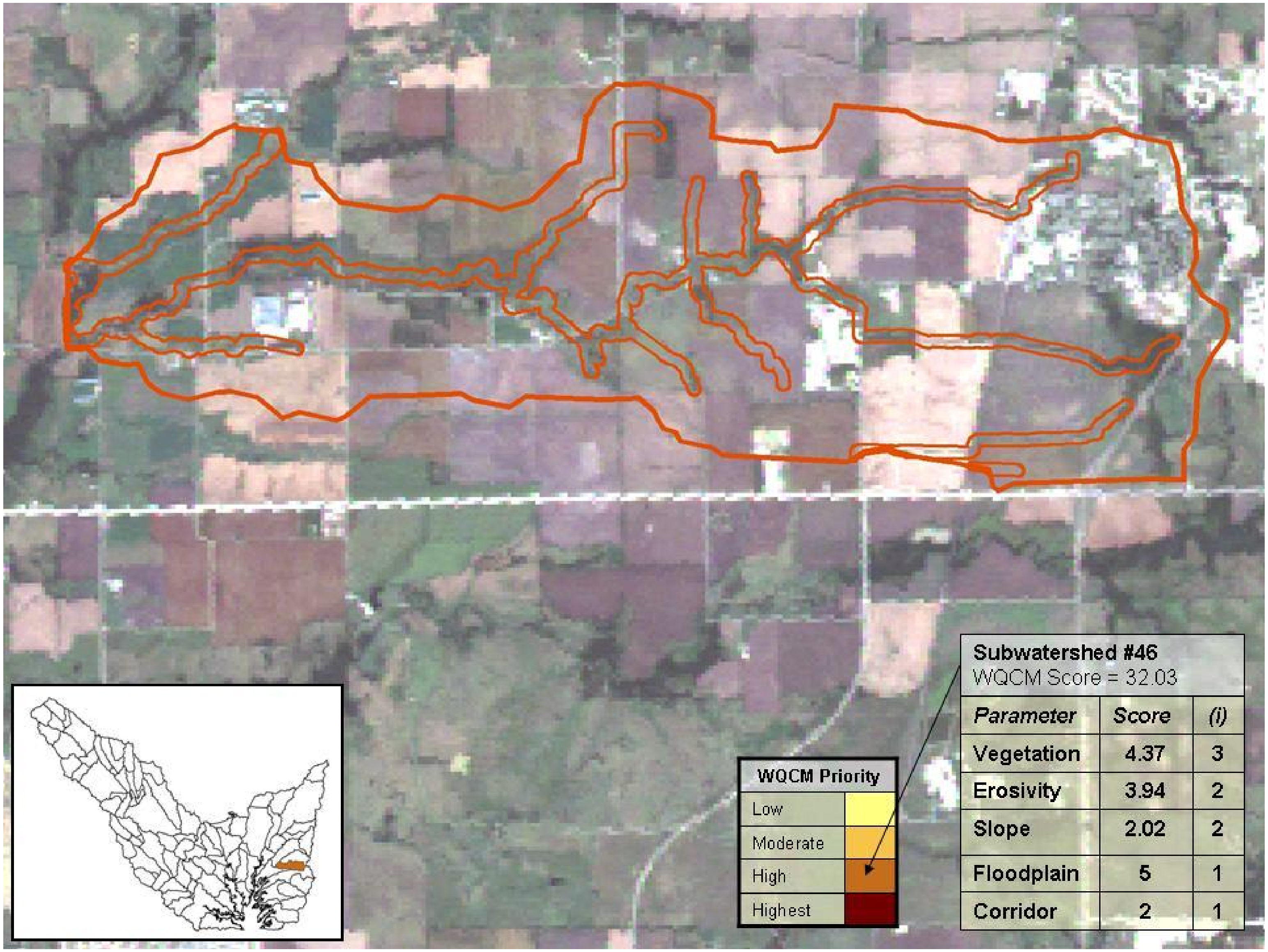
Subwatershed #44
WQCM Score = 28.81

Parameter	*Score*	*(i)*
Vegetation	4.33	3
Erosivity	3.97	2
Slope	1.94	2
Floodplain	2	1
Corridor	2	1



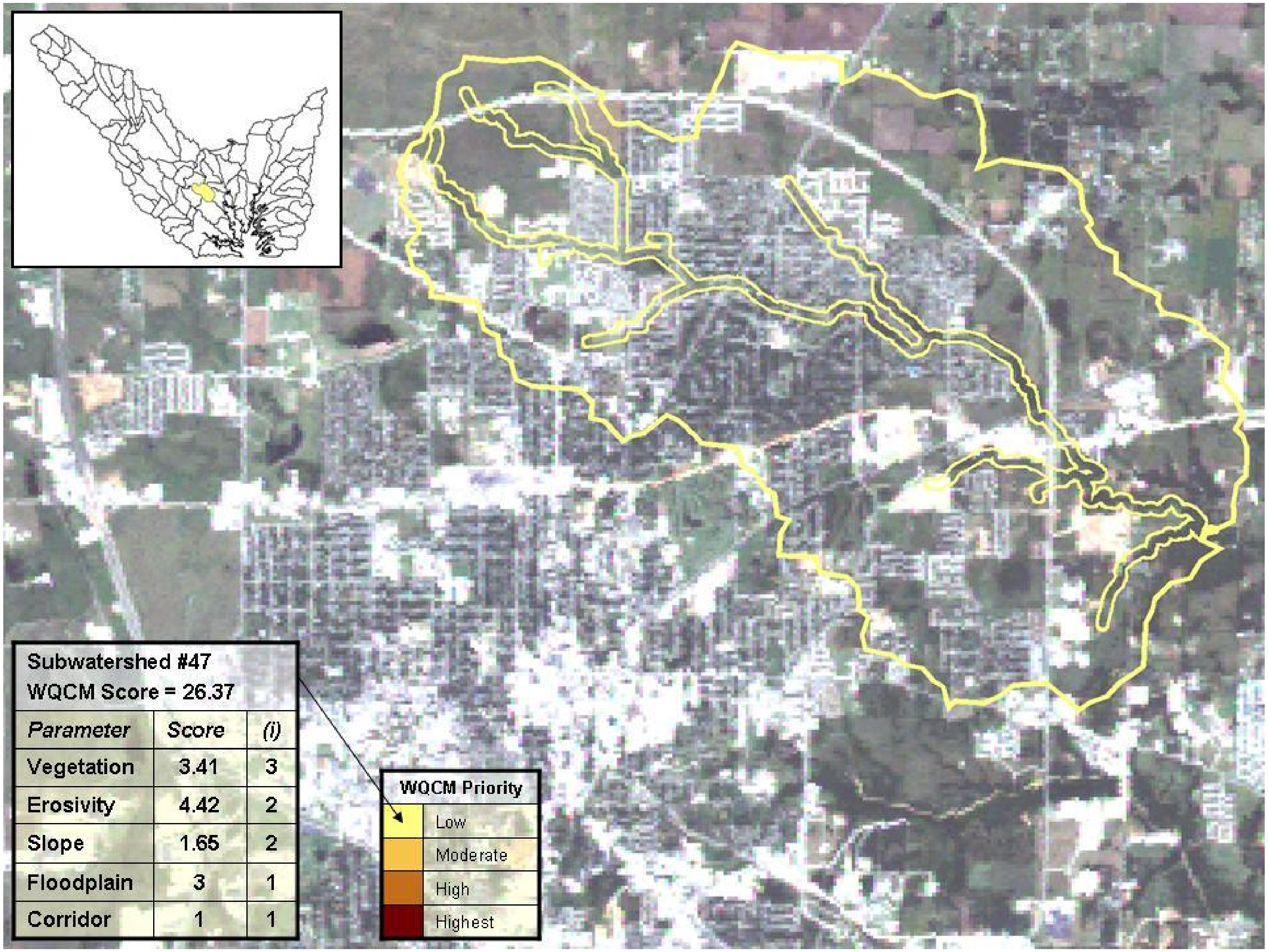
Subwatershed #45
WQCM Score = 31.58

Parameter	*Score*	*(i)*
Vegetation	4.36	3
Erosivity	4.02	2
Slope	1.73	2
Floodplain	5	1
Corridor	2	1



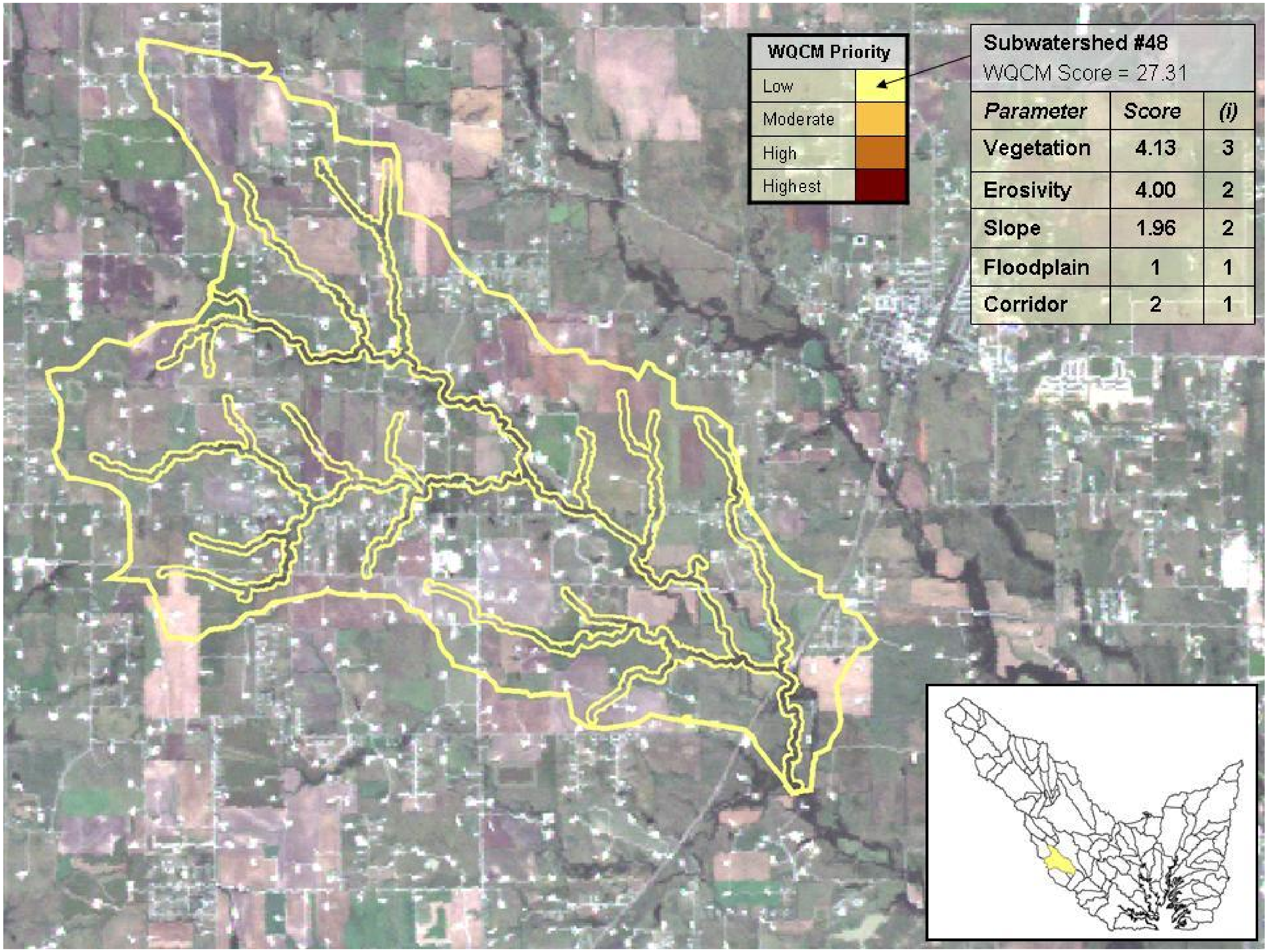
Subwatershed #46
WQCM Score = 32.03

Parameter	*Score*	*(i)*
Vegetation	**4.37**	**3**
Erosivity	**3.94**	**2**
Slope	**2.02**	**2**
Floodplain	**5**	**1**
Corridor	**2**	**1**



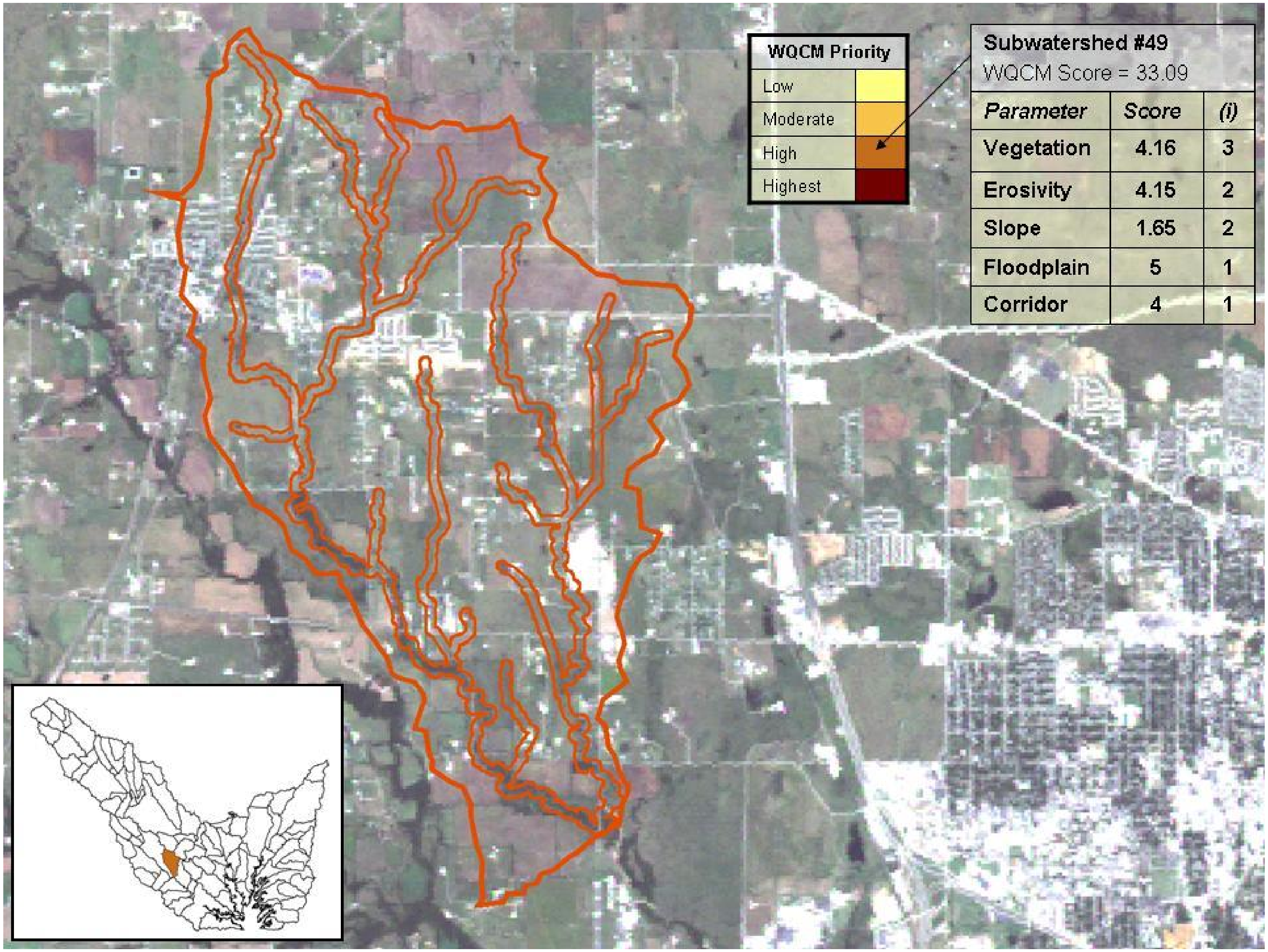
Subwatershed #47
WQCM Score = 26.37

Parameter	*Score*	*(i)*
Vegetation	3.41	3
Erosivity	4.42	2
Slope	1.65	2
Floodplain	3	1
Corridor	1	1



Subwatershed #48
WQCM Score = 27.31

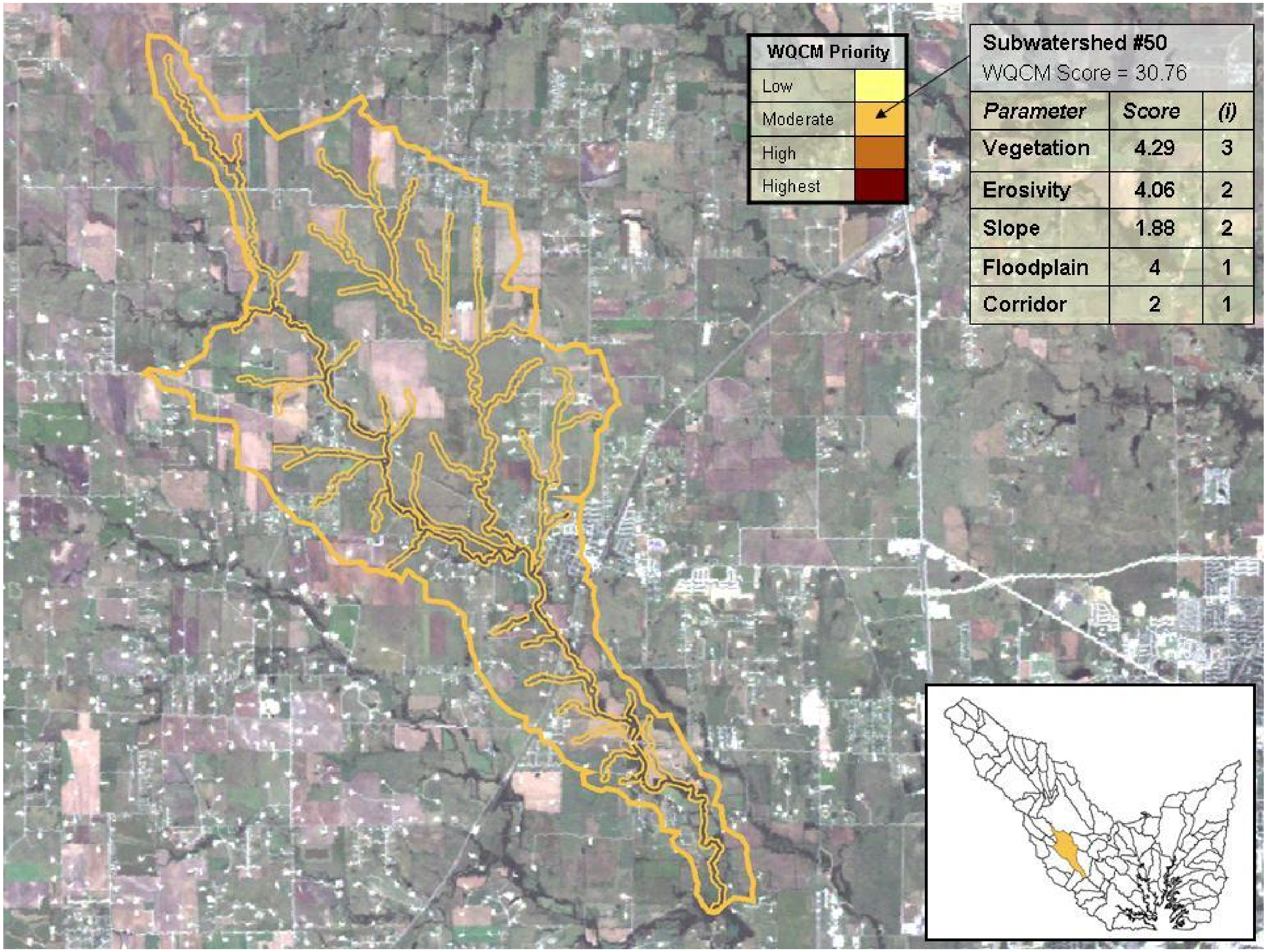
Parameter	*Score*	*(i)*
Vegetation	4.13	3
Erosivity	4.00	2
Slope	1.96	2
Floodplain	1	1
Corridor	2	1



Subwatershed #49

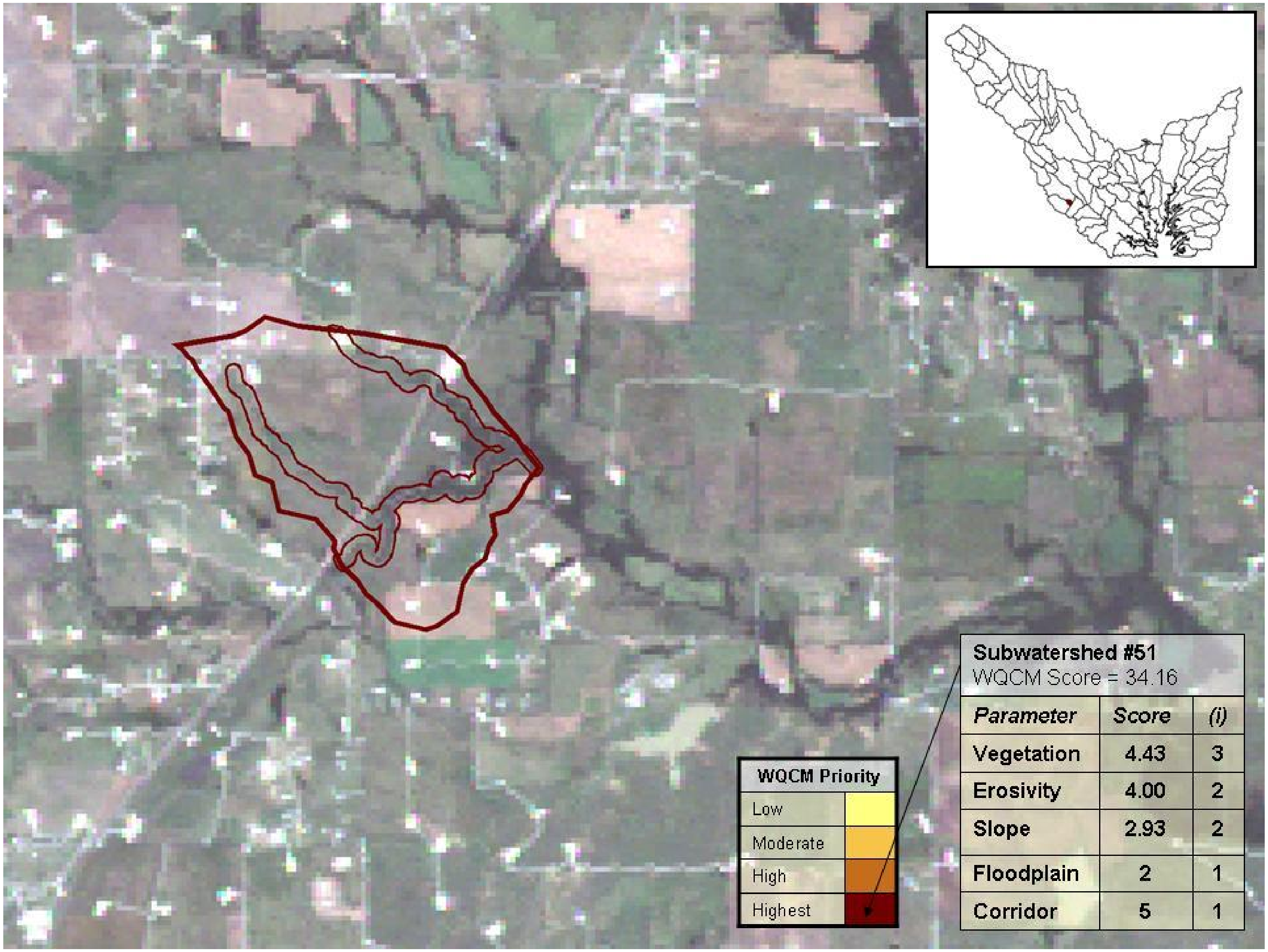
WQCM Score = 33.09

Parameter	*Score*	*(i)*
Vegetation	**4.16**	**3**
Erosivity	**4.15**	**2**
Slope	**1.65**	**2**
Floodplain	**5**	**1**
Corridor	**4**	**1**



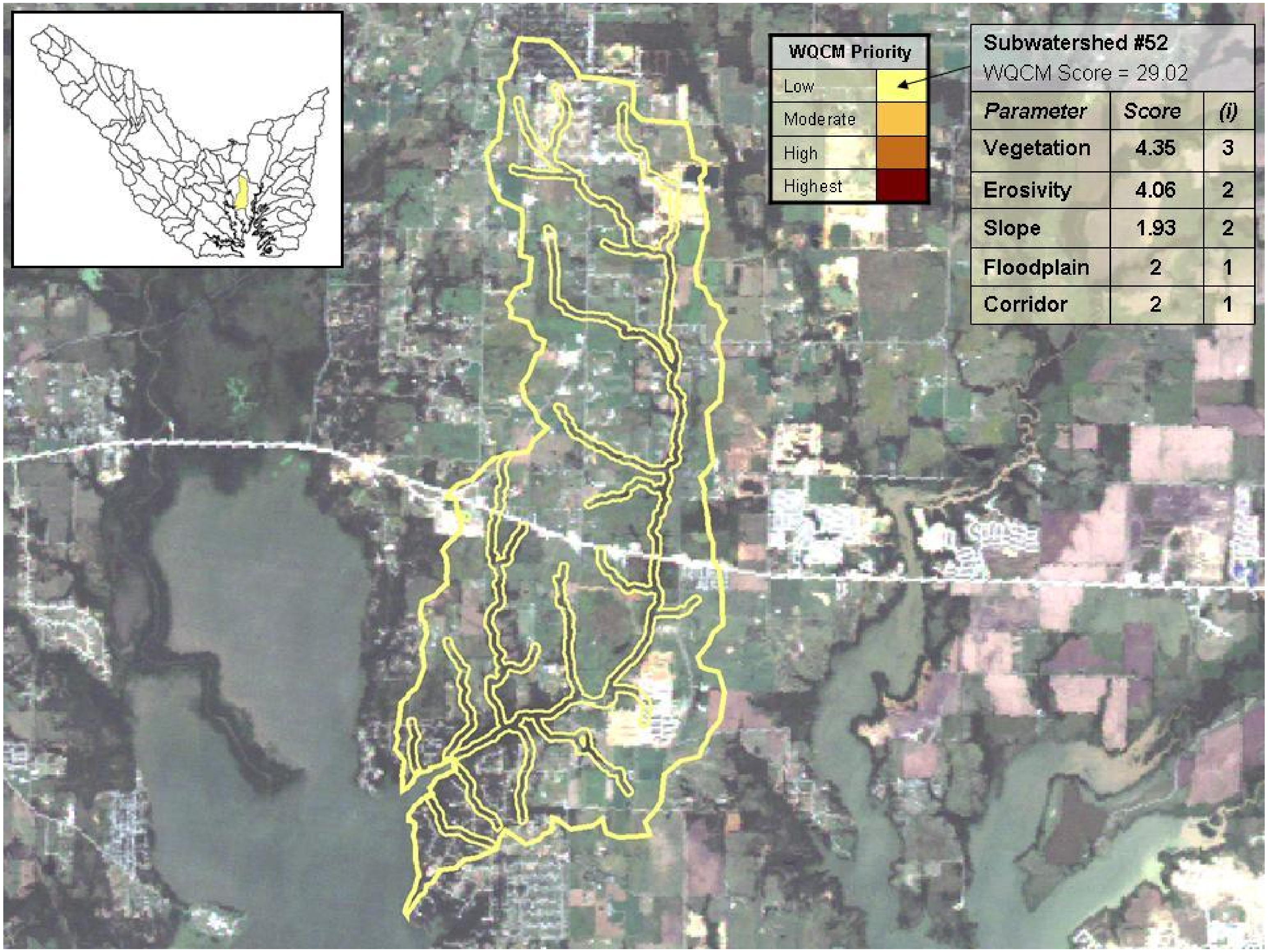
Subwatershed #50
WQCM Score = 30.76

Parameter	*Score*	*(i)*
Vegetation	4.29	3
Erosivity	4.06	2
Slope	1.88	2
Floodplain	4	1
Corridor	2	1



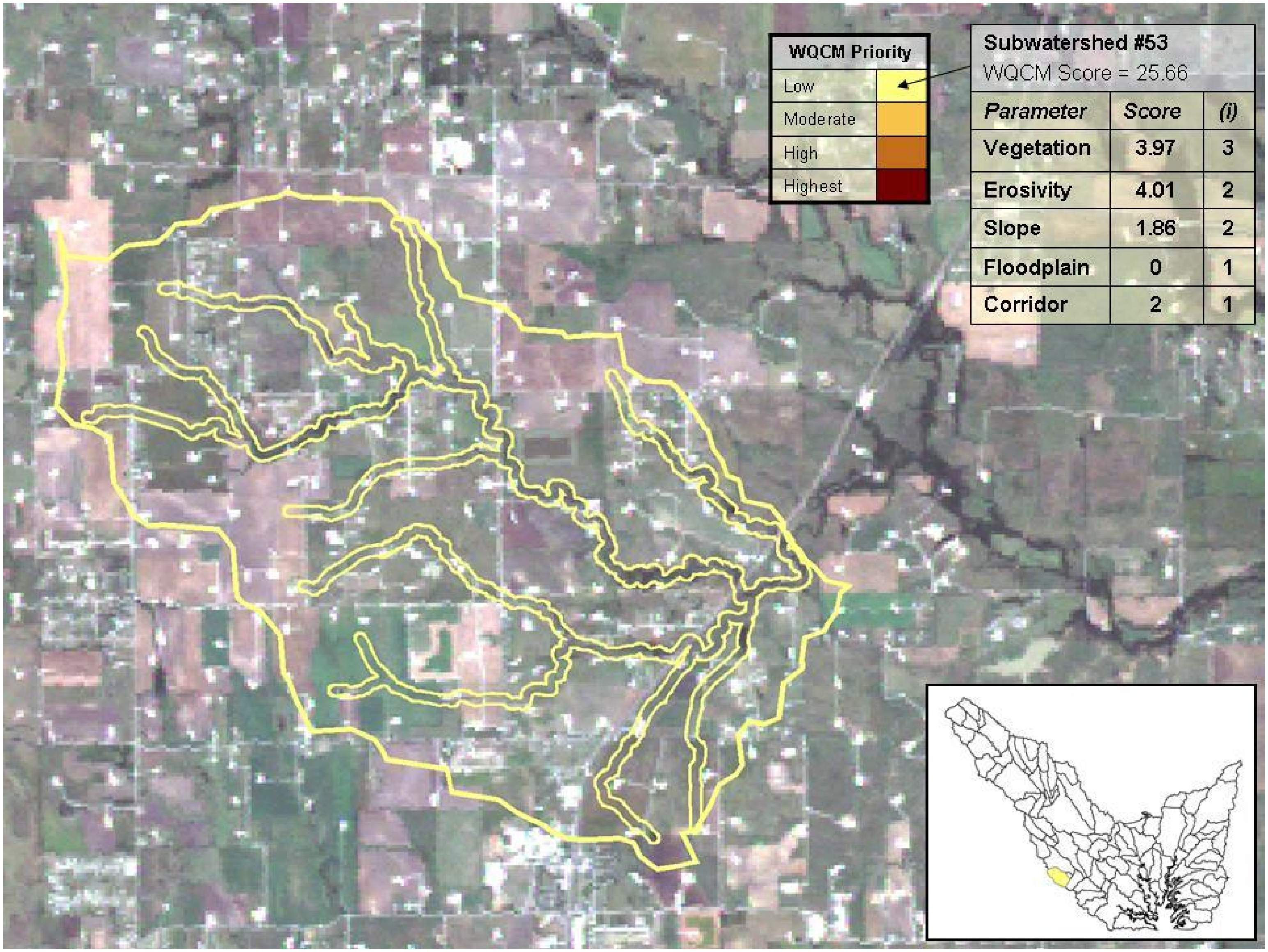
Subwatershed #51
WQCM Score = 34.16

Parameter	*Score*	*(i)*
Vegetation	4.43	3
Erosivity	4.00	2
Slope	2.93	2
Floodplain	2	1
Corridor	5	1



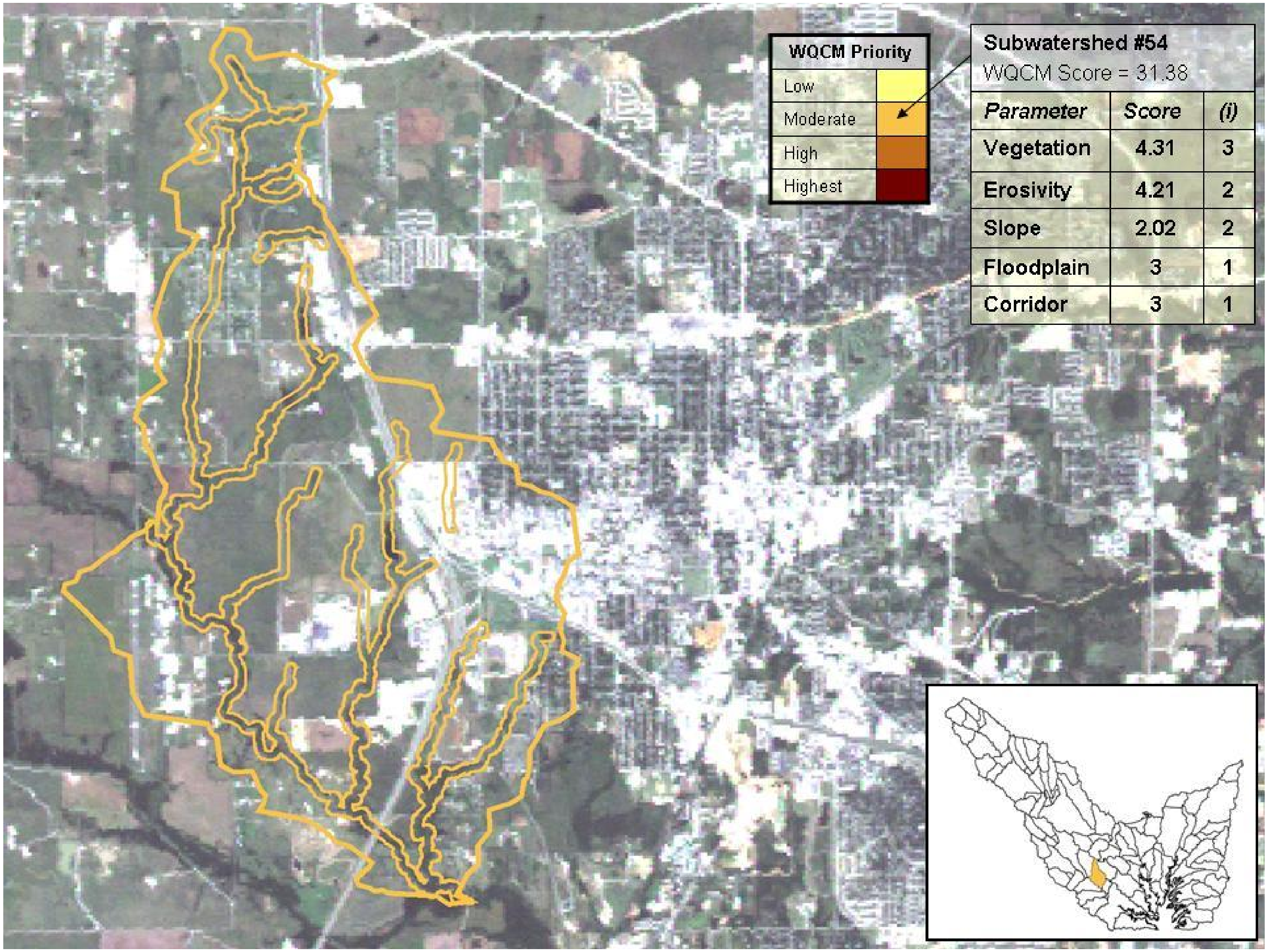
Subwatershed #52
WQCM Score = 29.02

Parameter	*Score*	*(i)*
Vegetation	4.35	3
Erosivity	4.06	2
Slope	1.93	2
Floodplain	2	1
Corridor	2	1



Subwatershed #53
WQCM Score = 25.66

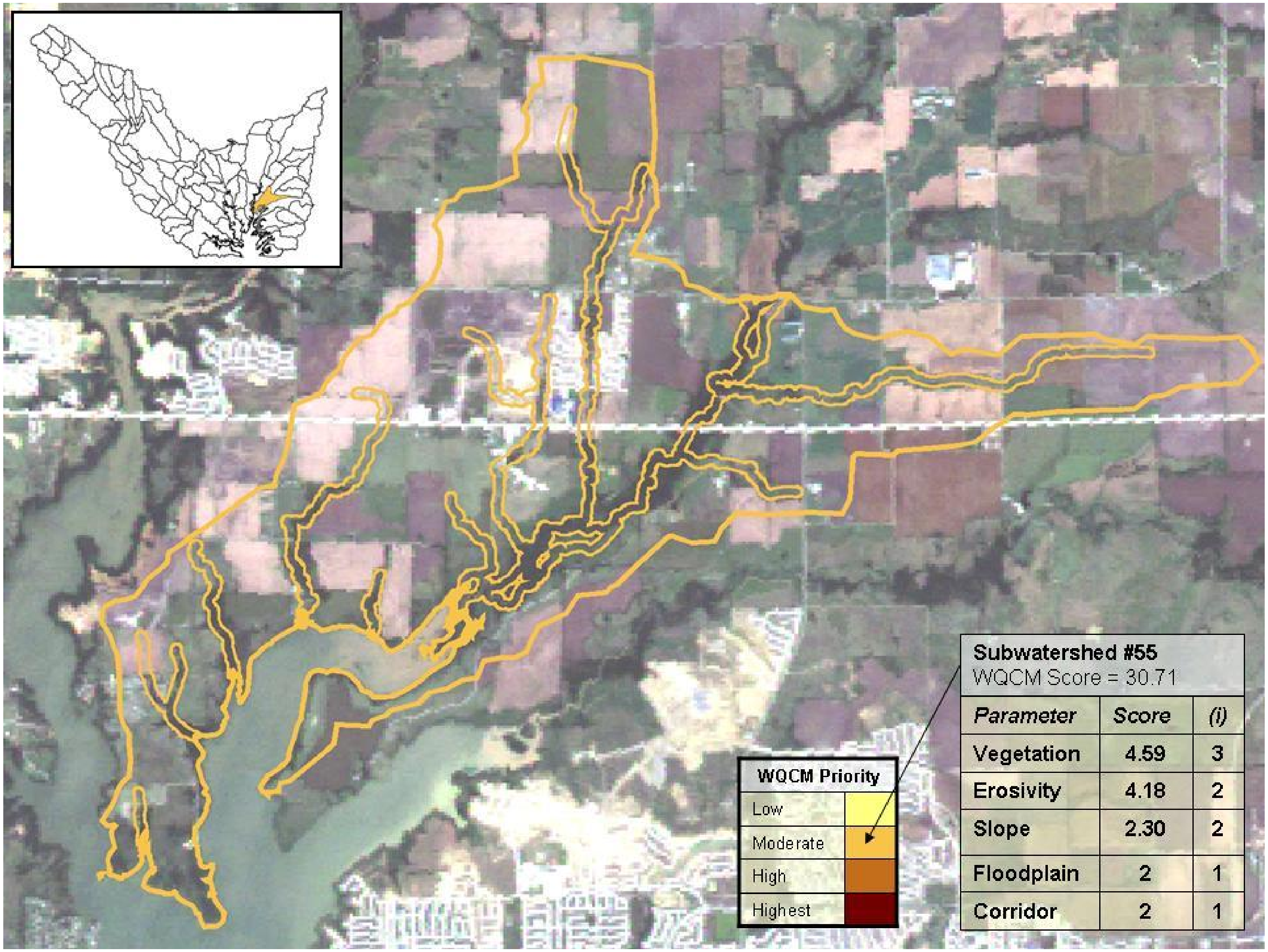
Parameter	*Score*	*(i)*
Vegetation	3.97	3
Erosivity	4.01	2
Slope	1.86	2
Floodplain	0	1
Corridor	2	1



Subwatershed #54

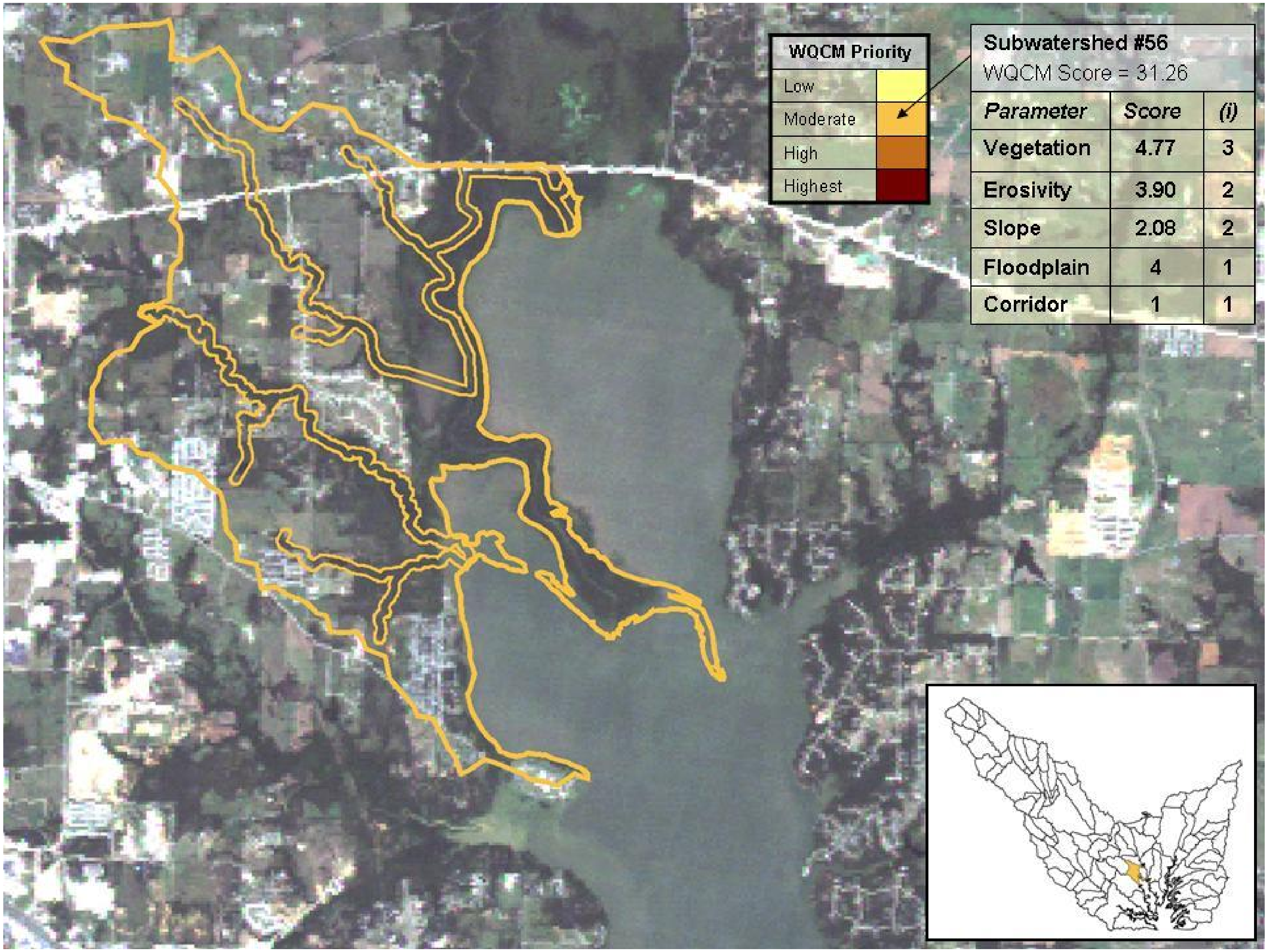
WQCM Score = 31.38

Parameter	*Score*	*(i)*
Vegetation	4.31	3
Erosivity	4.21	2
Slope	2.02	2
Floodplain	3	1
Corridor	3	1



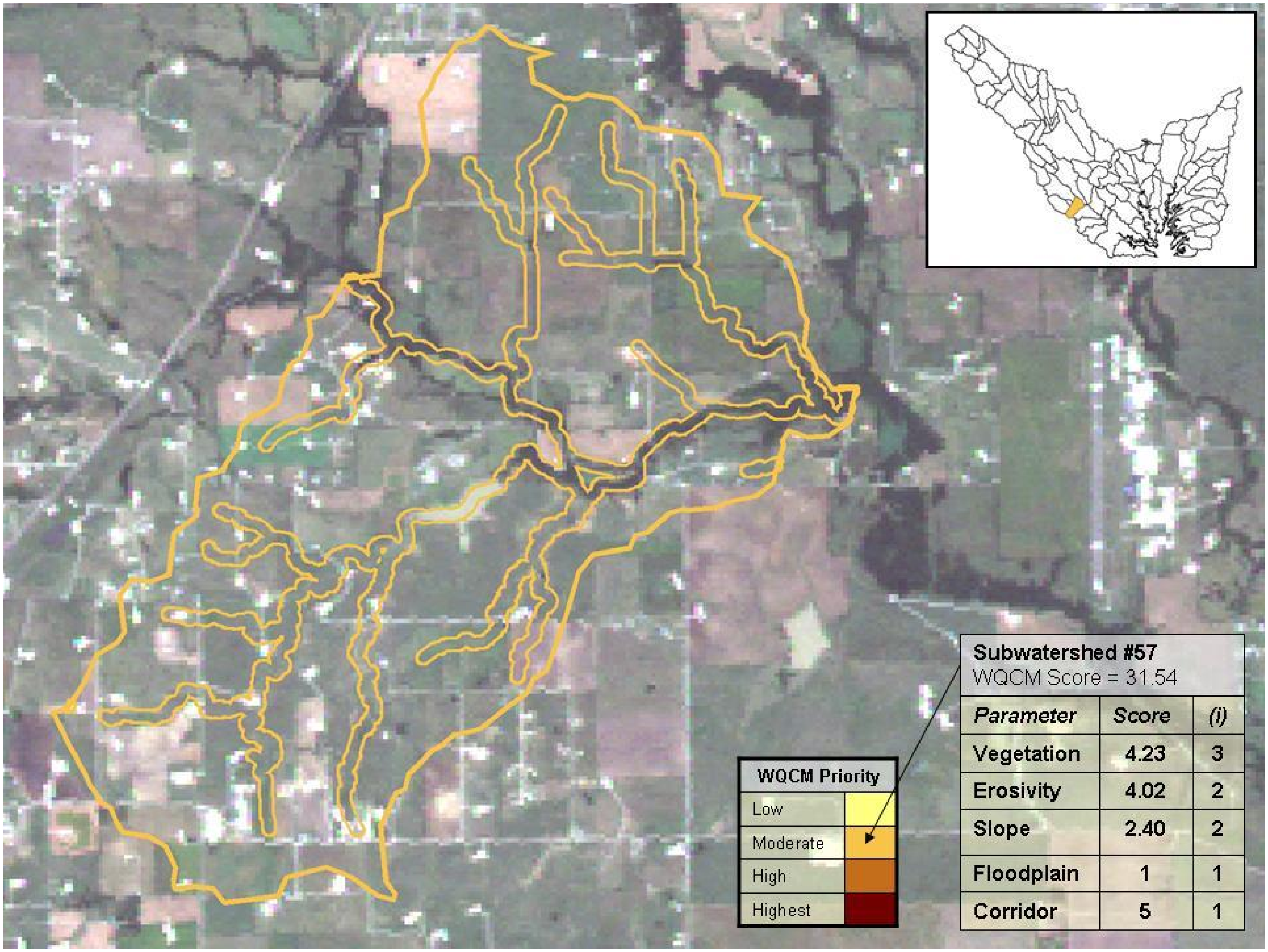
Subwatershed #55
WQCM Score = 30.71

Parameter	*Score*	*(i)*
Vegetation	4.59	3
Erosivity	4.18	2
Slope	2.30	2
Floodplain	2	1
Corridor	2	1



Subwatershed #56
WQCM Score = 31.26

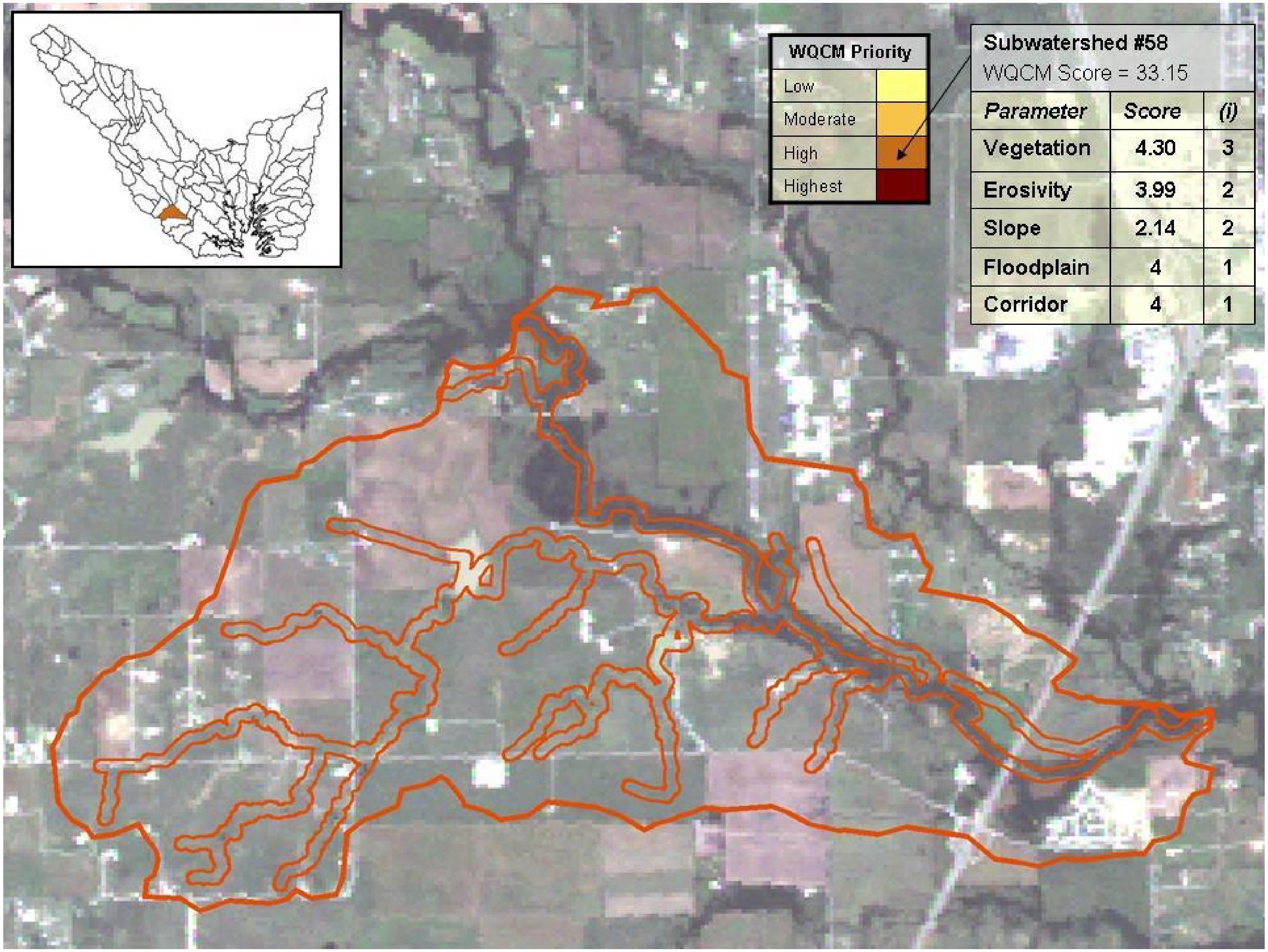
Parameter	*Score*	*(i)*
Vegetation	**4.77**	**3**
Erosivity	**3.90**	**2**
Slope	**2.08**	**2**
Floodplain	**4**	**1**
Corridor	**1**	**1**



Subwatershed #57

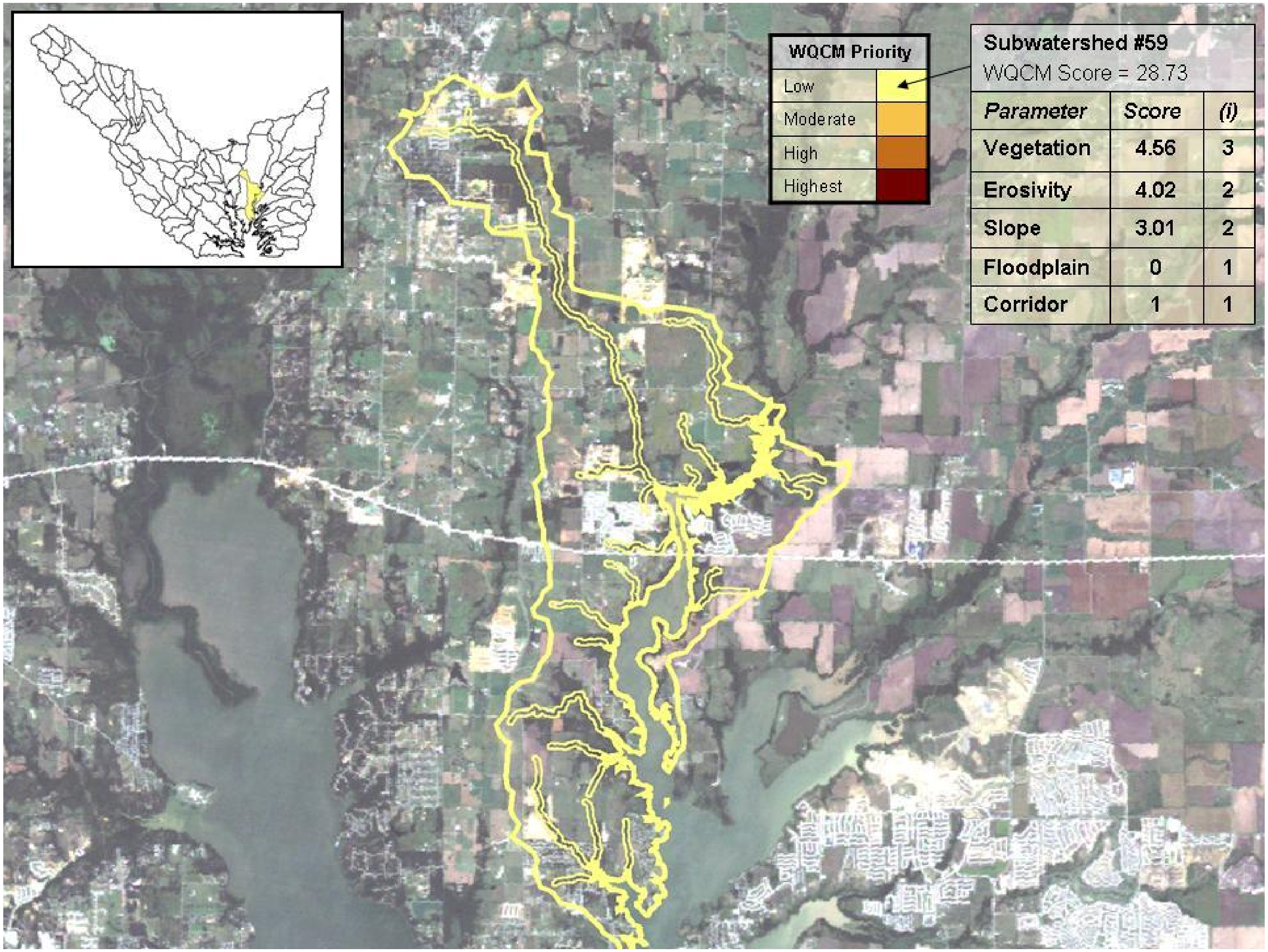
WQCM Score = 31.54

Parameter	*Score*	*(i)*
Vegetation	**4.23**	**3**
Erosivity	**4.02**	**2**
Slope	**2.40**	**2**
Floodplain	**1**	**1**
Corridor	**5**	**1**



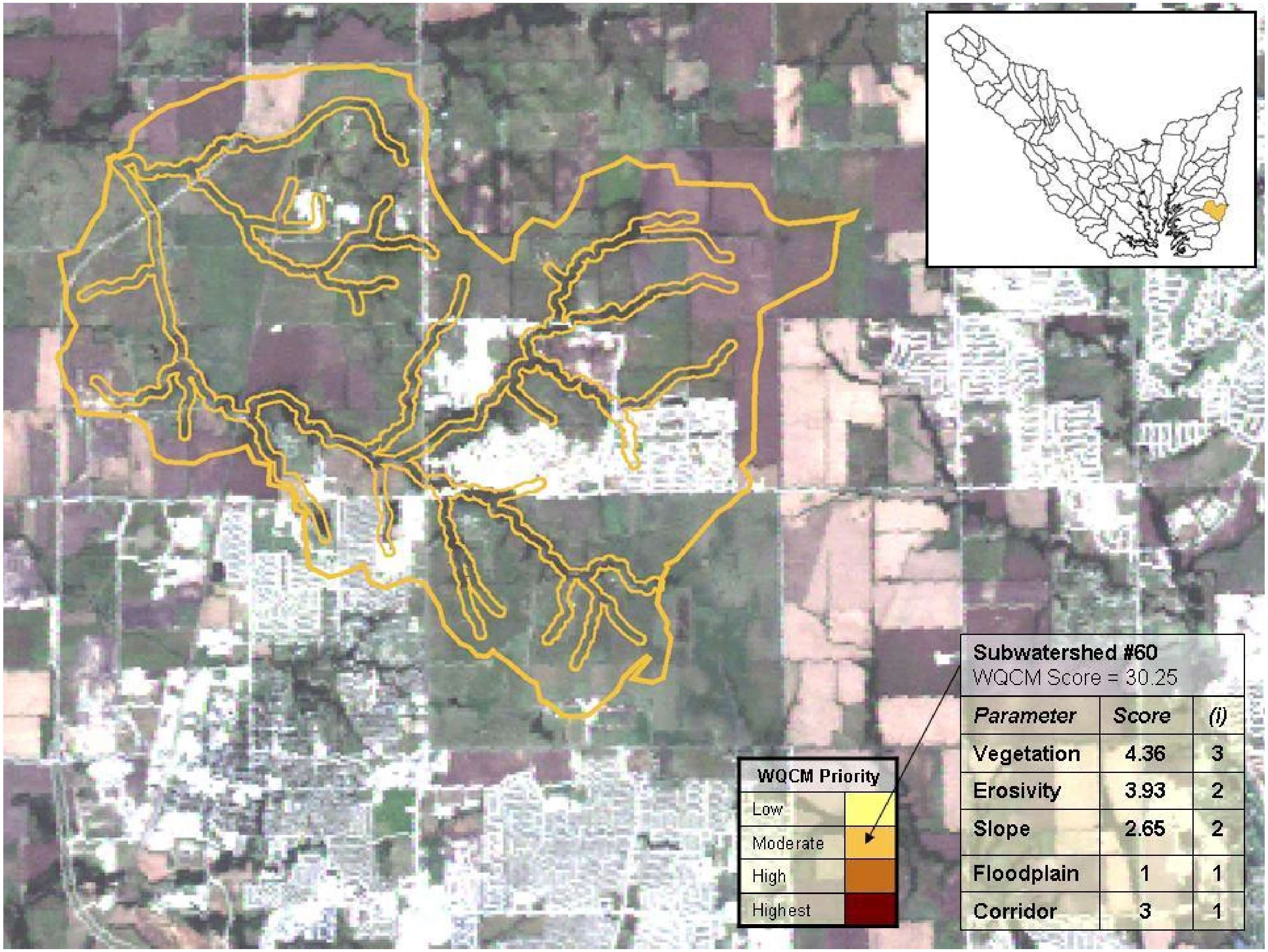
Subwatershed #58
WQCM Score = 33.15

Parameter	*Score*	*(i)*
Vegetation	**4.30**	**3**
Erosivity	**3.99**	**2**
Slope	**2.14**	**2**
Floodplain	**4**	**1**
Corridor	**4**	**1**



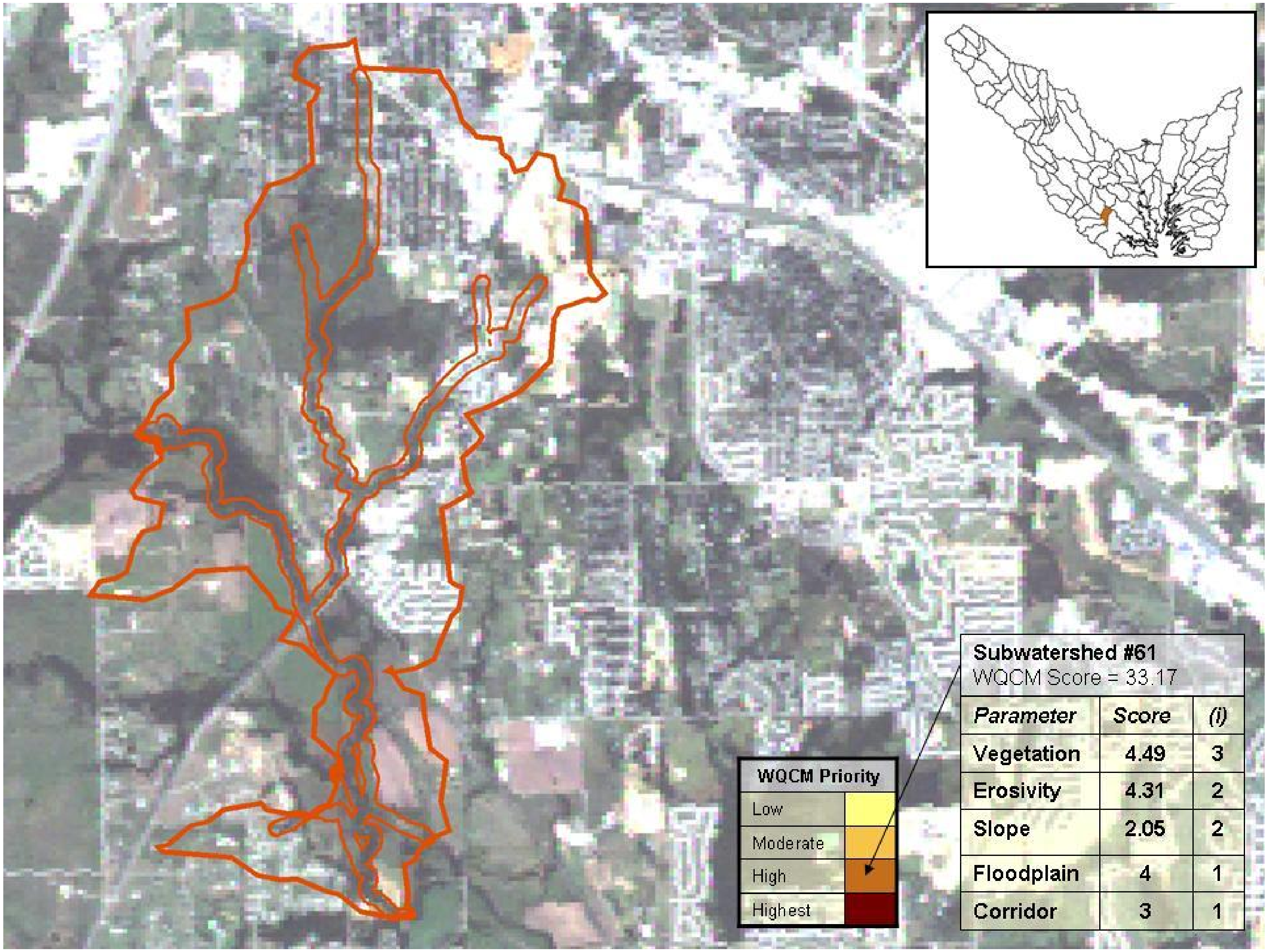
Subwatershed #59
WQCM Score = 28.73

Parameter	*Score*	*(i)*
Vegetation	4.56	3
Erosivity	4.02	2
Slope	3.01	2
Floodplain	0	1
Corridor	1	1



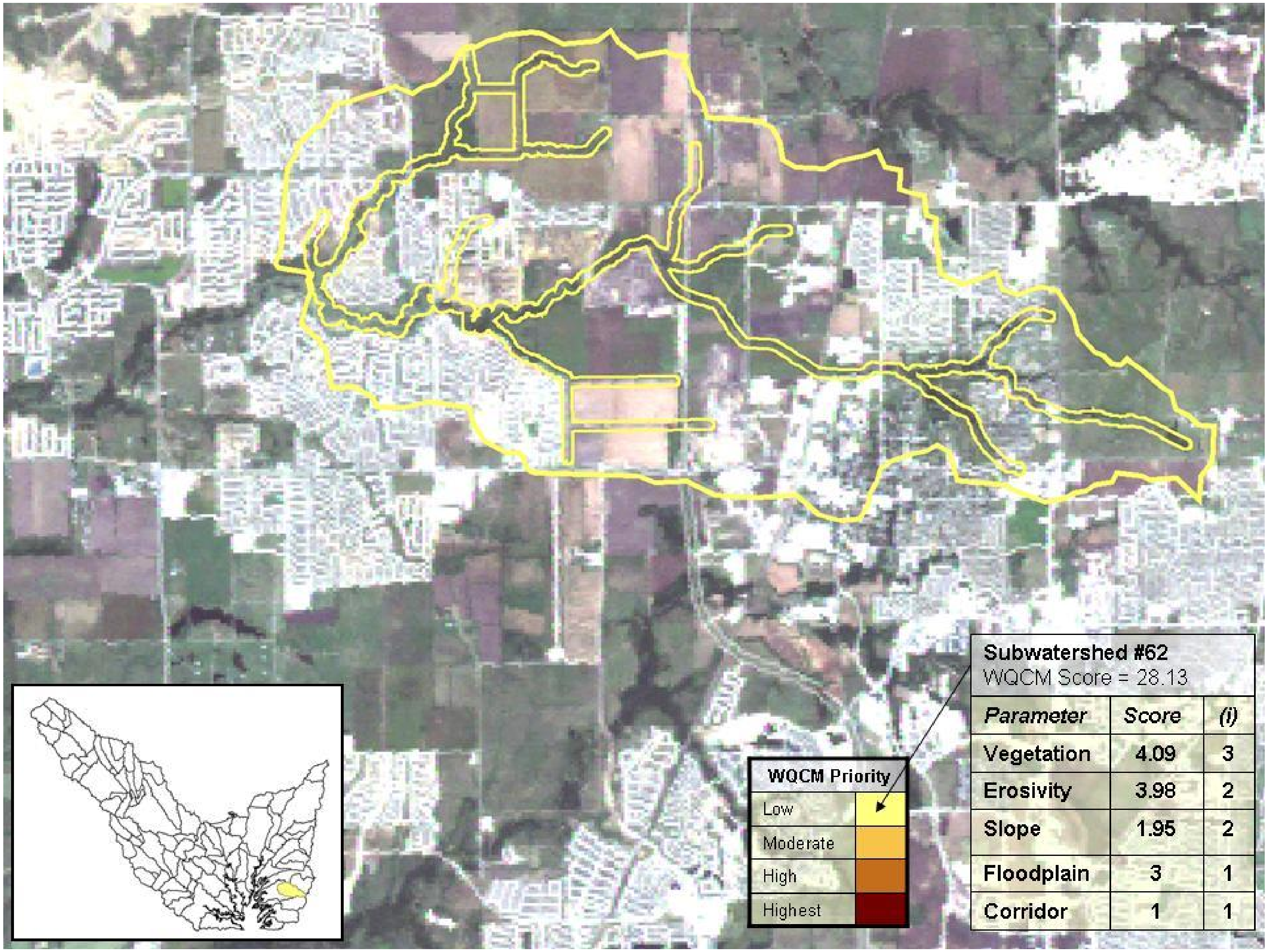
Subwatershed #60
WQCM Score = 30.25

Parameter	*Score*	*(i)*
Vegetation	**4.36**	**3**
Erosivity	**3.93**	**2**
Slope	**2.65**	**2**
Floodplain	**1**	**1**
Corridor	**3**	**1**



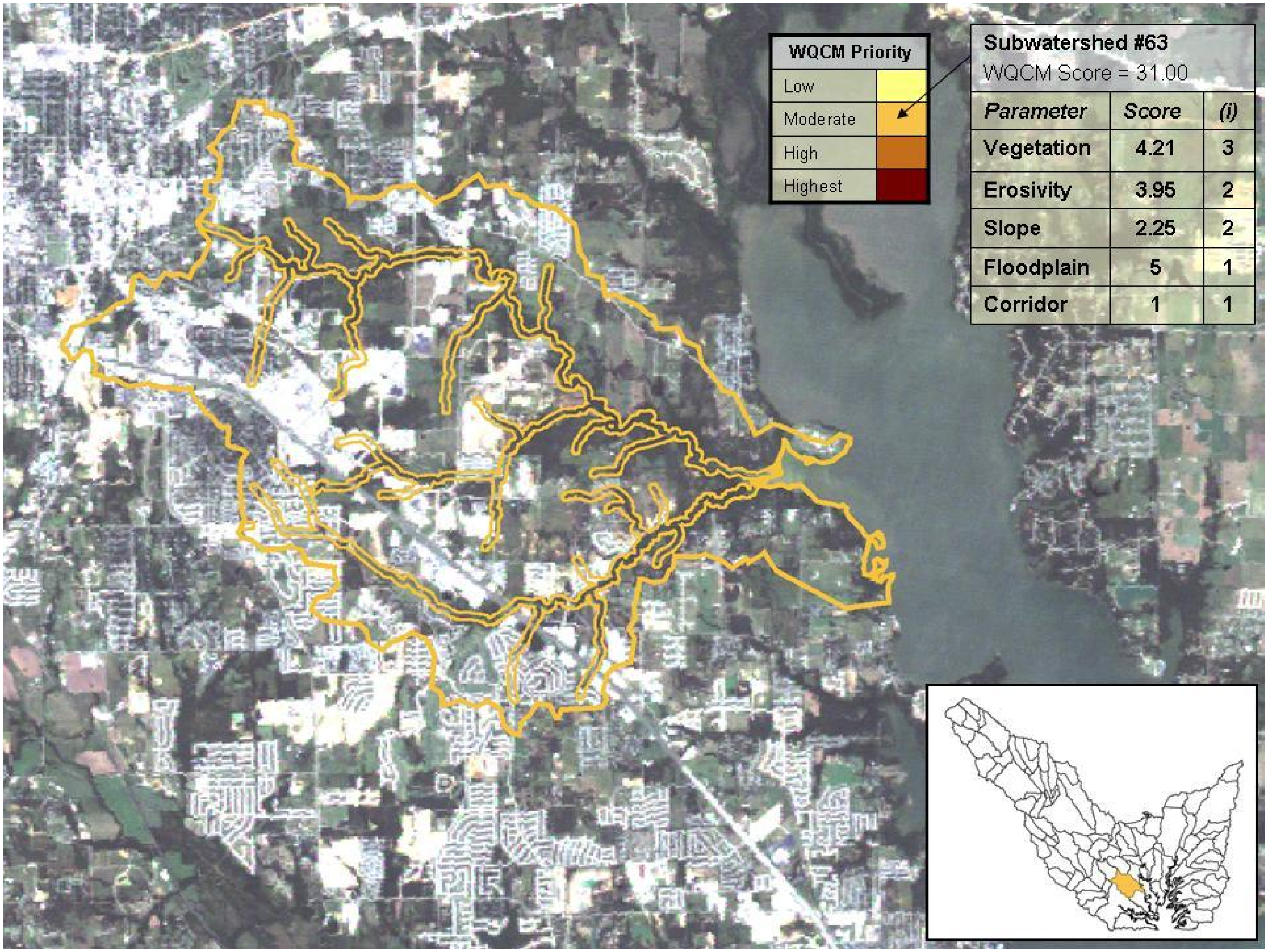
Subwatershed #61
WQCM Score = 33.17

Parameter	*Score*	*(i)*
Vegetation	4.49	3
Erosivity	4.31	2
Slope	2.05	2
Floodplain	4	1
Corridor	3	1



Subwatershed #62
WQCM Score = 28.13

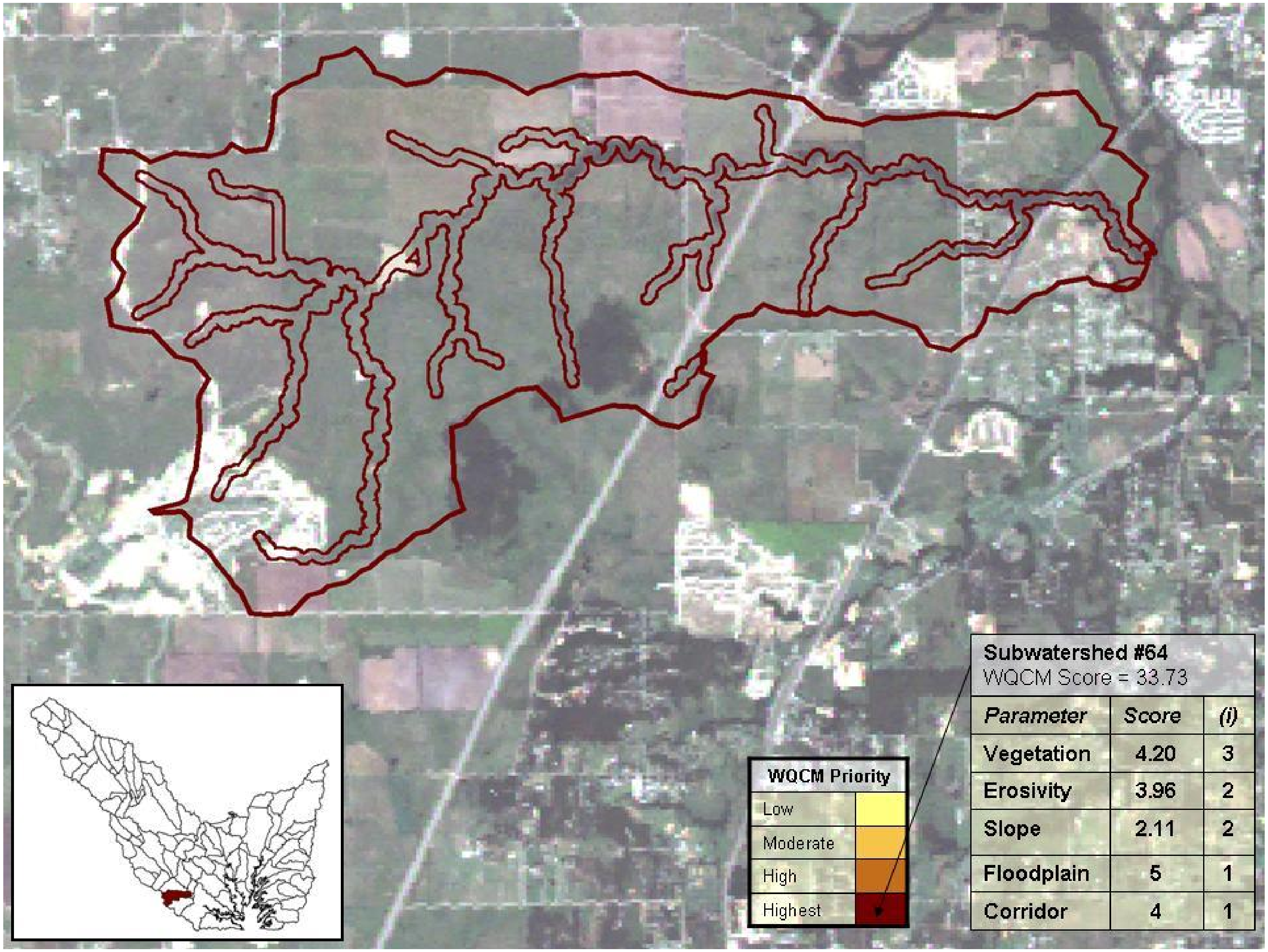
Parameter	*Score*	*(i)*
Vegetation	**4.09**	**3**
Erosivity	**3.98**	**2**
Slope	**1.95**	**2**
Floodplain	**3**	**1**
Corridor	**1**	**1**



Subwatershed #63

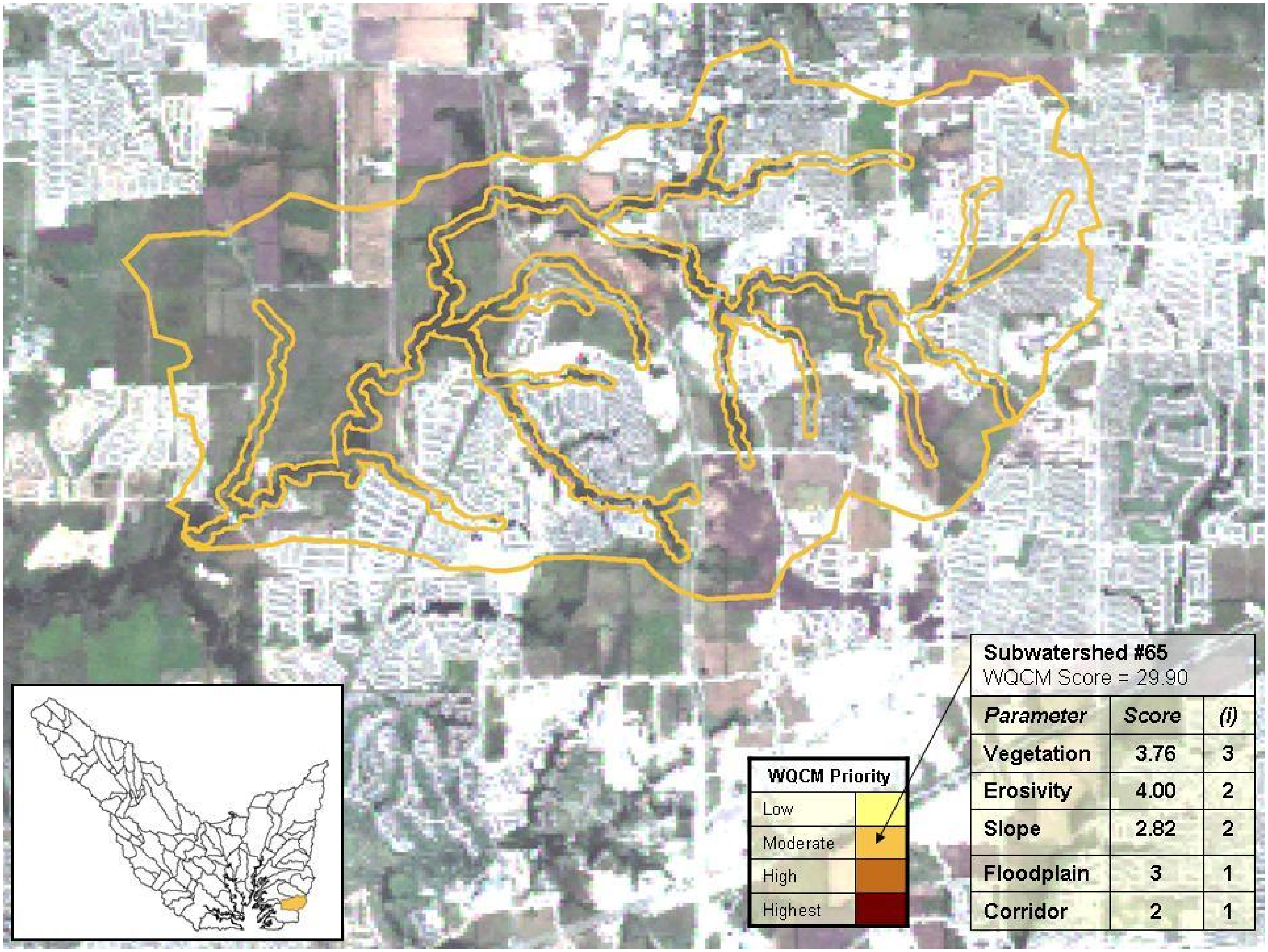
WQCM Score = 31.00

Parameter	*Score*	*(i)*
Vegetation	4.21	3
Erosivity	3.95	2
Slope	2.25	2
Floodplain	5	1
Corridor	1	1



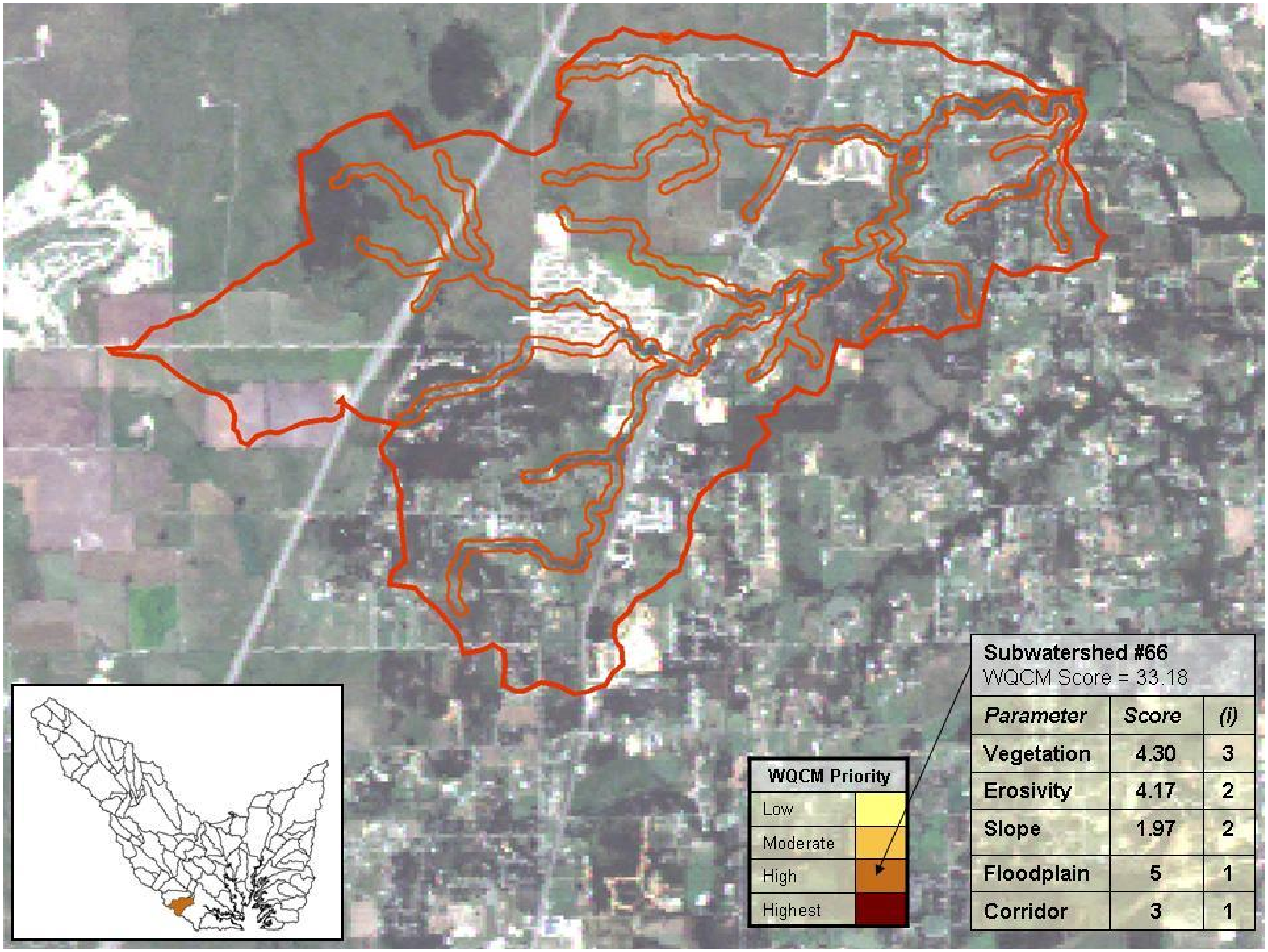
Subwatershed #64
WQCM Score = 33.73

Parameter	*Score*	*(i)*
Vegetation	**4.20**	**3**
Erosivity	**3.96**	**2**
Slope	**2.11**	**2**
Floodplain	**5**	**1**
Corridor	**4**	**1**



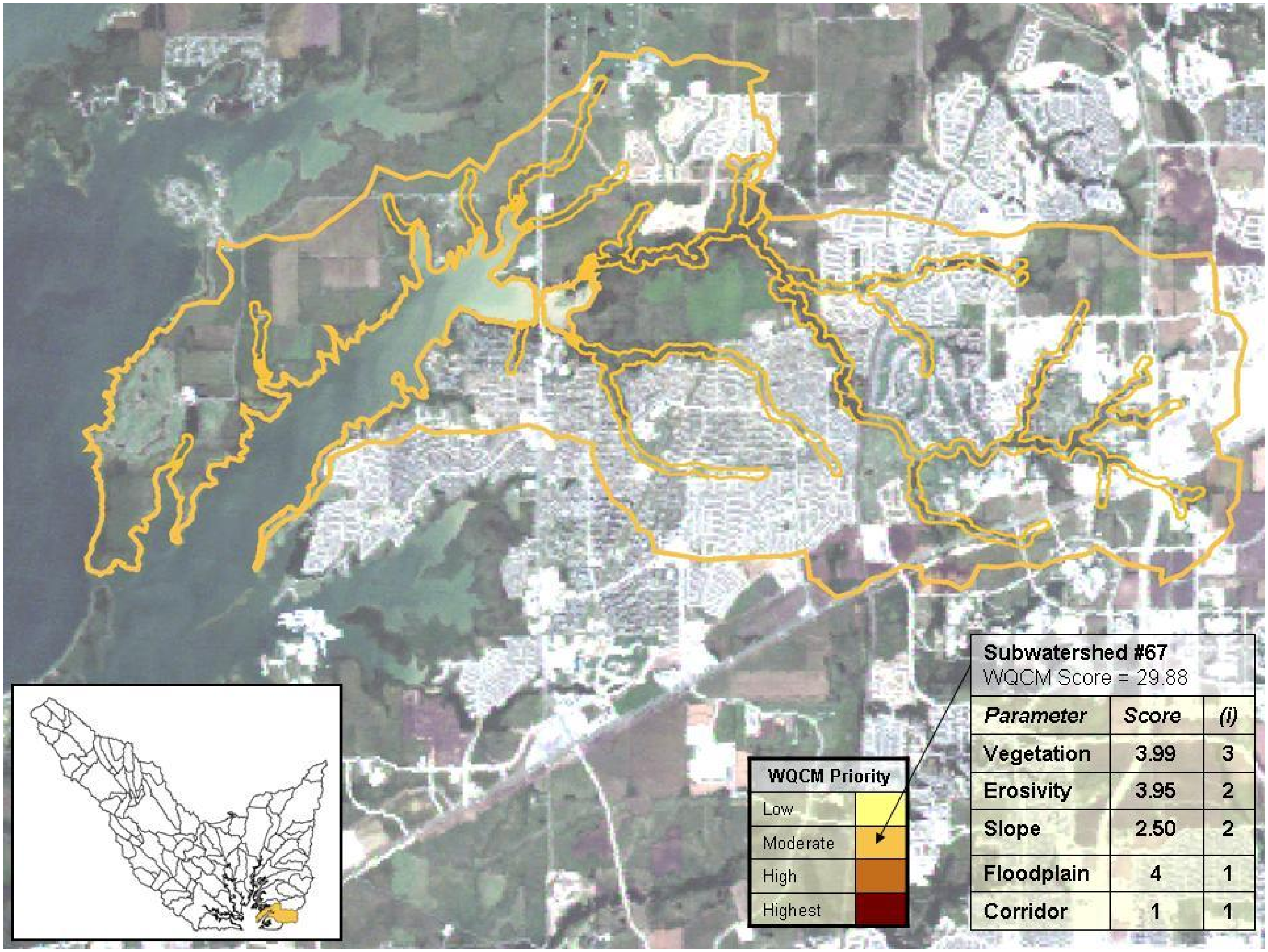
Subwatershed #65
WQCM Score = 29.90

Parameter	*Score*	*(i)*
Vegetation	3.76	3
Erosivity	4.00	2
Slope	2.82	2
Floodplain	3	1
Corridor	2	1



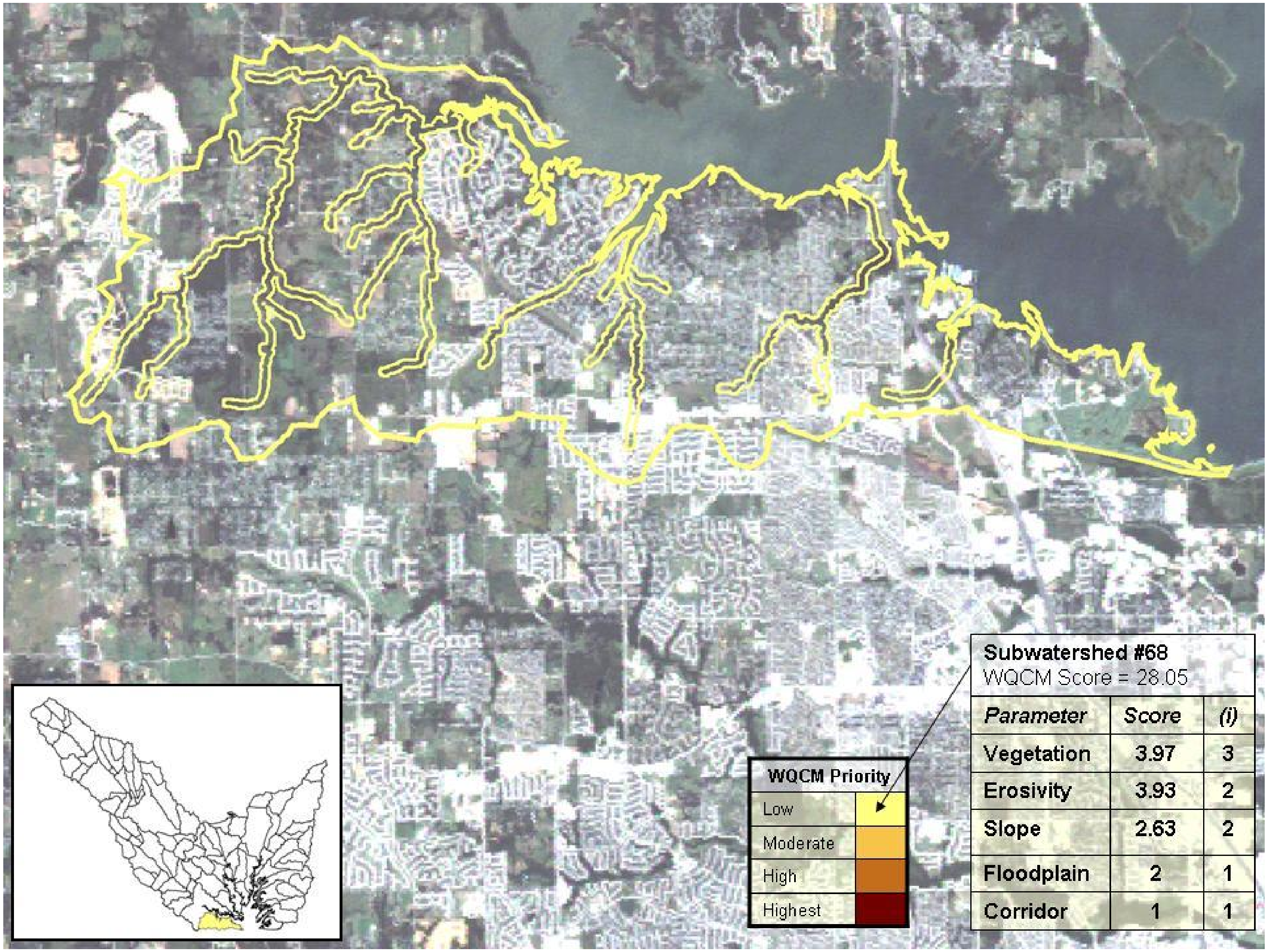
Subwatershed #66
WQCM Score = 33.18

Parameter	*Score*	*(i)*
Vegetation	**4.30**	**3**
Erosivity	**4.17**	**2**
Slope	**1.97**	**2**
Floodplain	**5**	**1**
Corridor	**3**	**1**



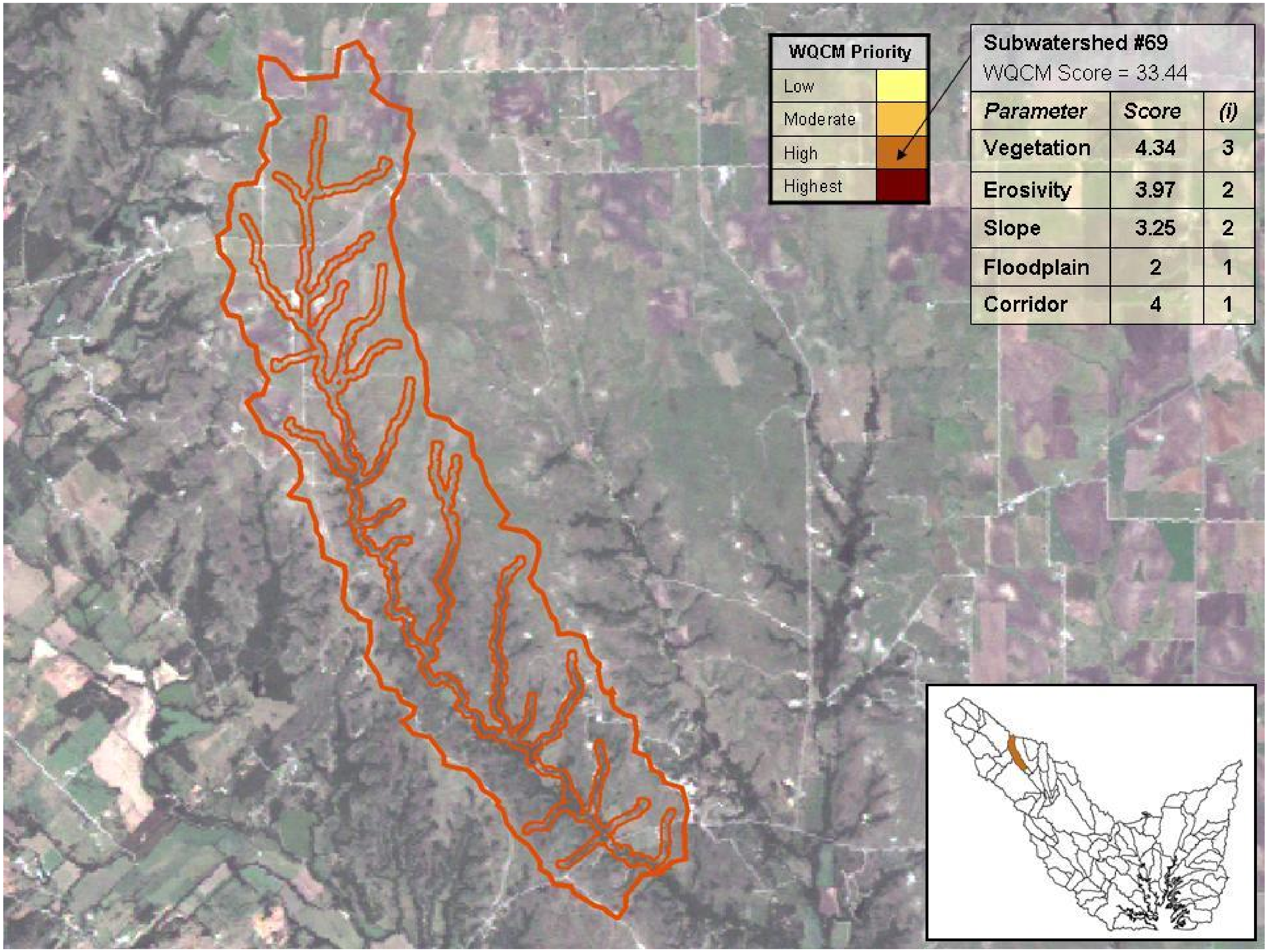
Subwatershed #67
WQCM Score = 29.88

Parameter	*Score*	*(i)*
Vegetation	**3.99**	**3**
Erosivity	**3.95**	**2**
Slope	**2.50**	**2**
Floodplain	**4**	**1**
Corridor	**1**	**1**



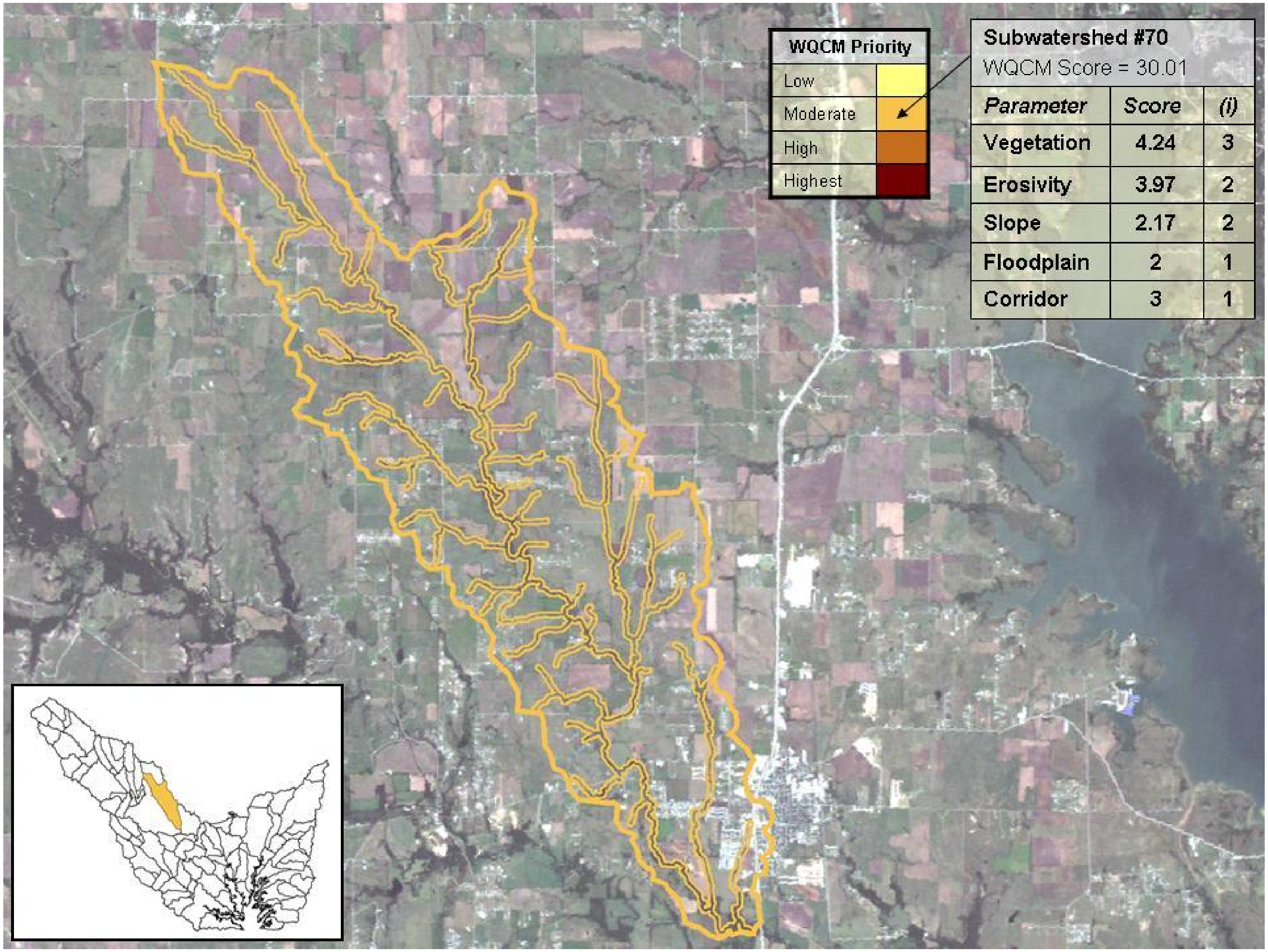
Subwatershed #68
WQCM Score = 28.05

Parameter	*Score*	*(i)*
Vegetation	**3.97**	**3**
Erosivity	**3.93**	**2**
Slope	**2.63**	**2**
Floodplain	**2**	**1**
Corridor	**1**	**1**



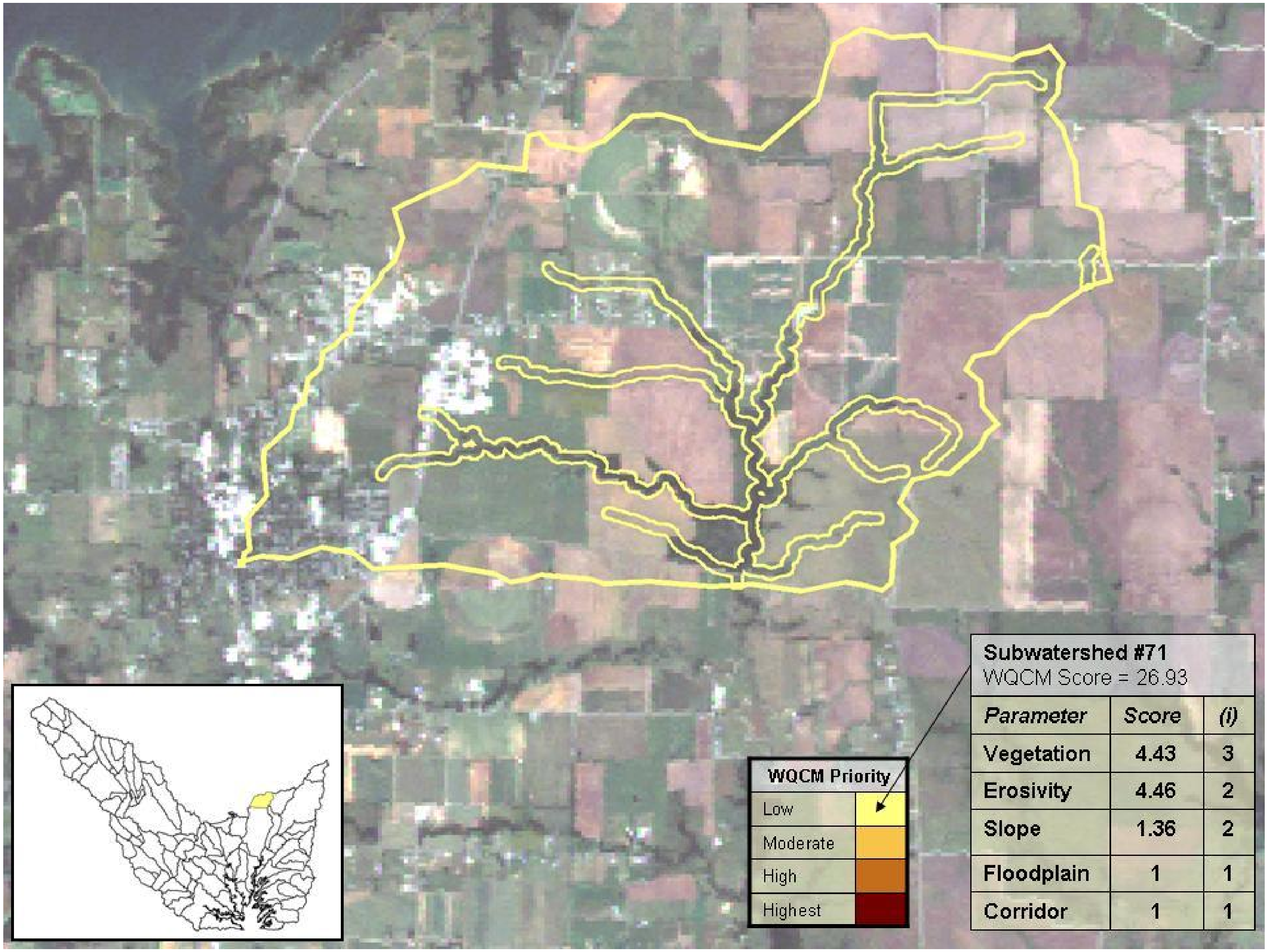
Subwatershed #69
WQCM Score = 33.44

Parameter	*Score*	*(i)*
Vegetation	**4.34**	**3**
Erosivity	**3.97**	**2**
Slope	**3.25**	**2**
Floodplain	**2**	**1**
Corridor	**4**	**1**



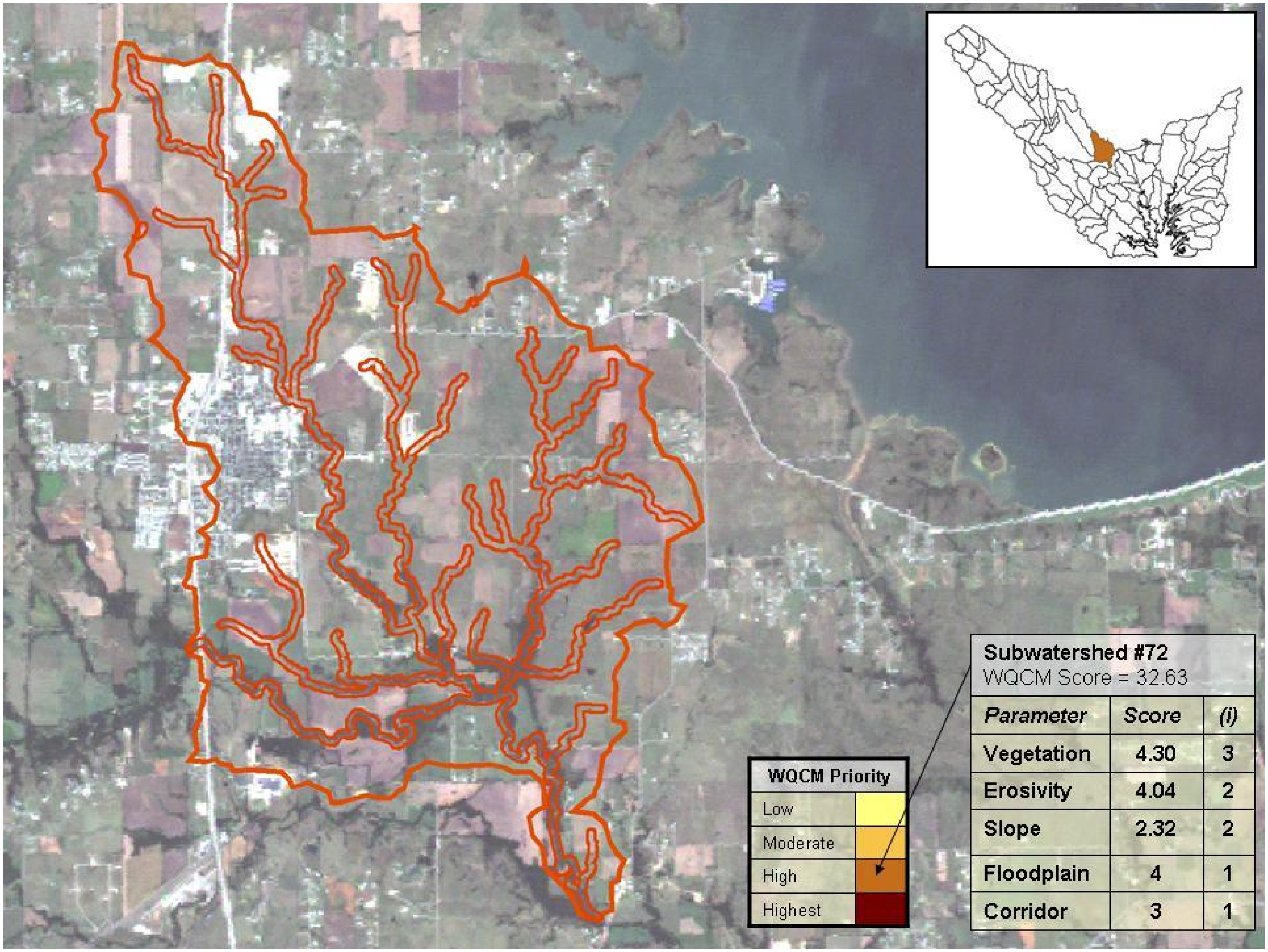
Subwatershed #70
WQCM Score = 30.01

Parameter	*Score*	*(i)*
Vegetation	**4.24**	**3**
Erosivity	**3.97**	**2**
Slope	**2.17**	**2**
Floodplain	**2**	**1**
Corridor	**3**	**1**



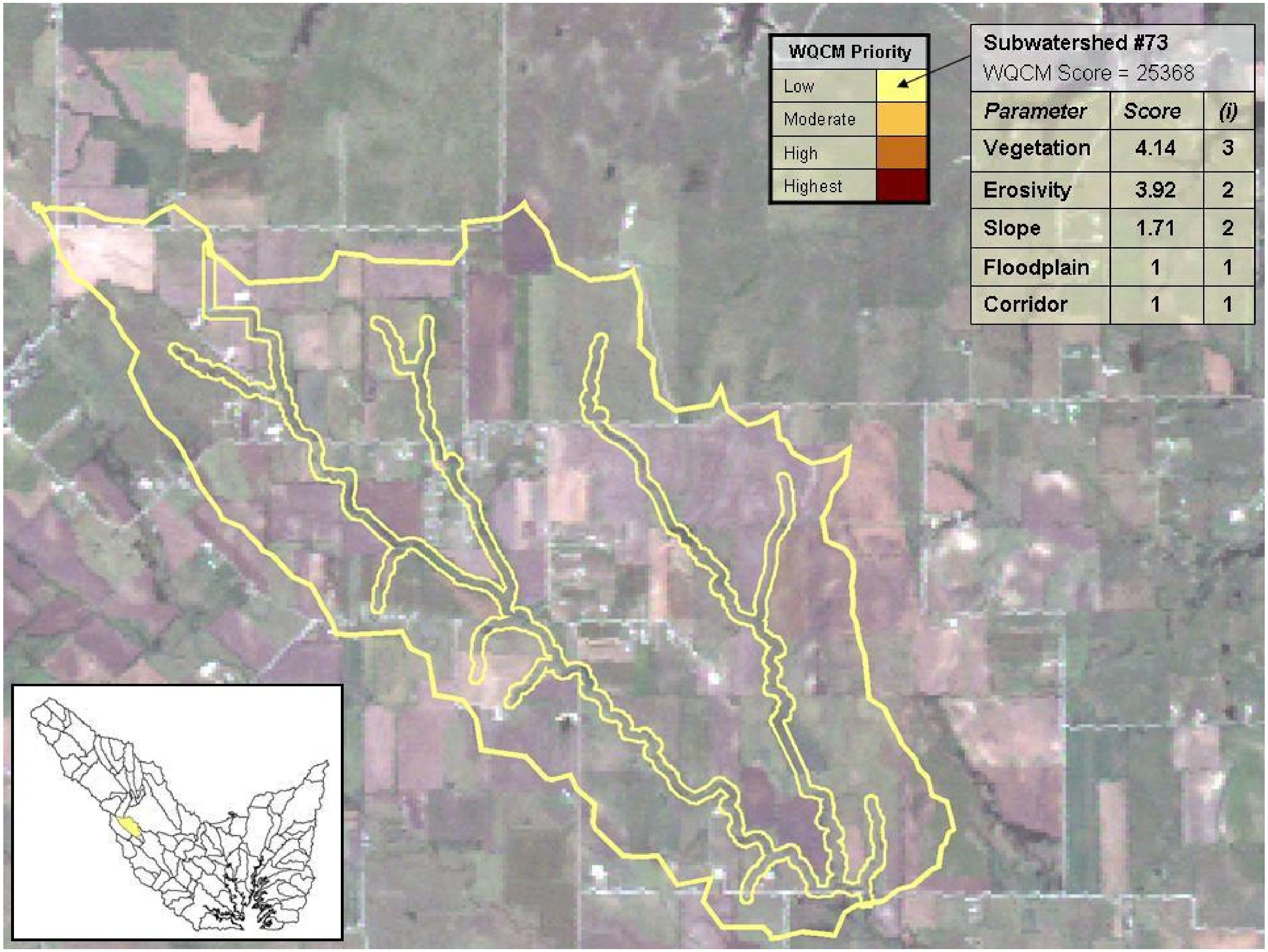
Subwatershed #71
WQCM Score = 26.93

Parameter	*Score*	*(i)*
Vegetation	**4.43**	**3**
Erosivity	**4.46**	**2**
Slope	**1.36**	**2**
Floodplain	**1**	**1**
Corridor	**1**	**1**



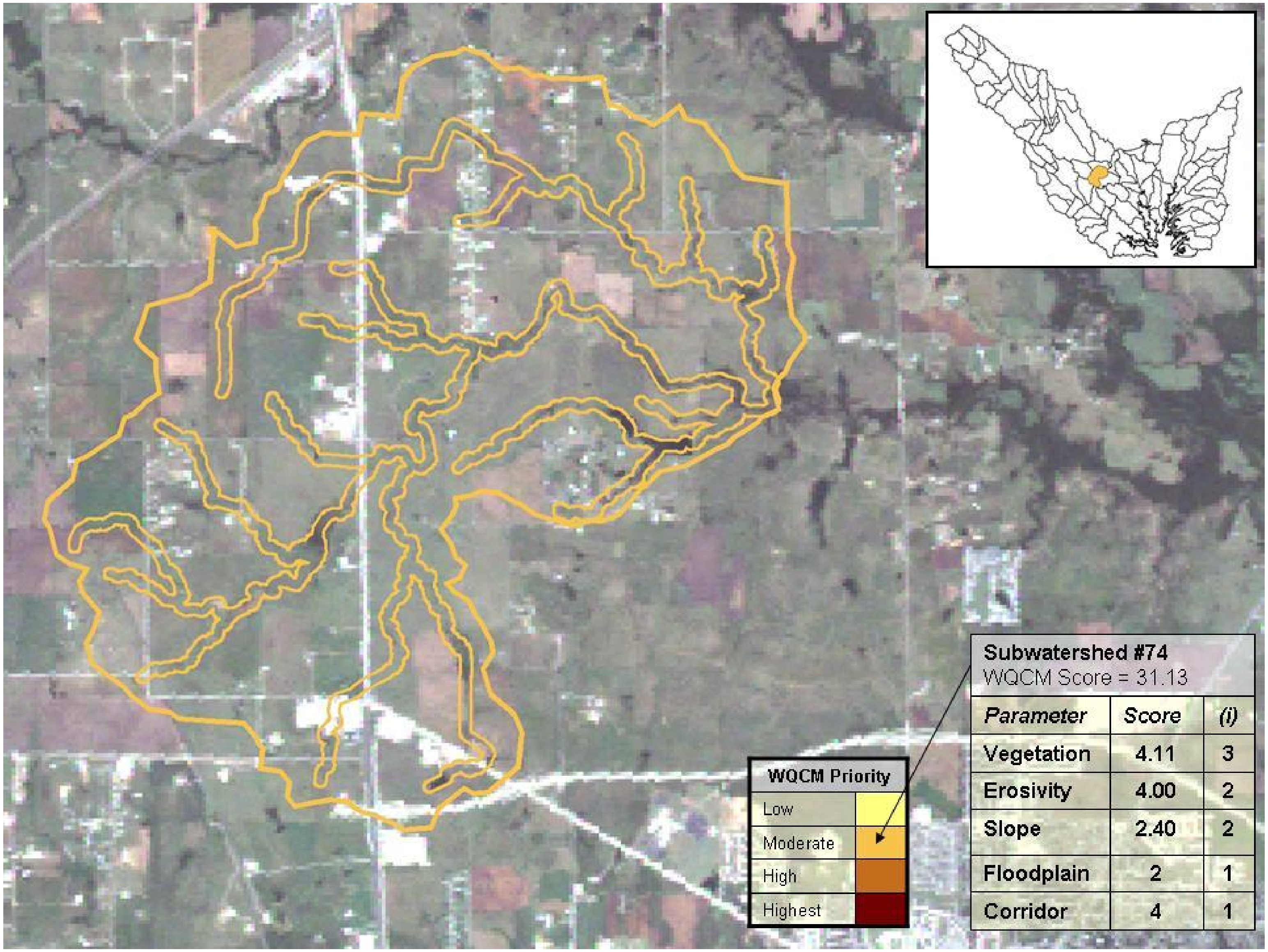
Subwatershed #72
WQCM Score = 32.63

Parameter	*Score*	*(i)*
Vegetation	4.30	3
Erosivity	4.04	2
Slope	2.32	2
Floodplain	4	1
Corridor	3	1



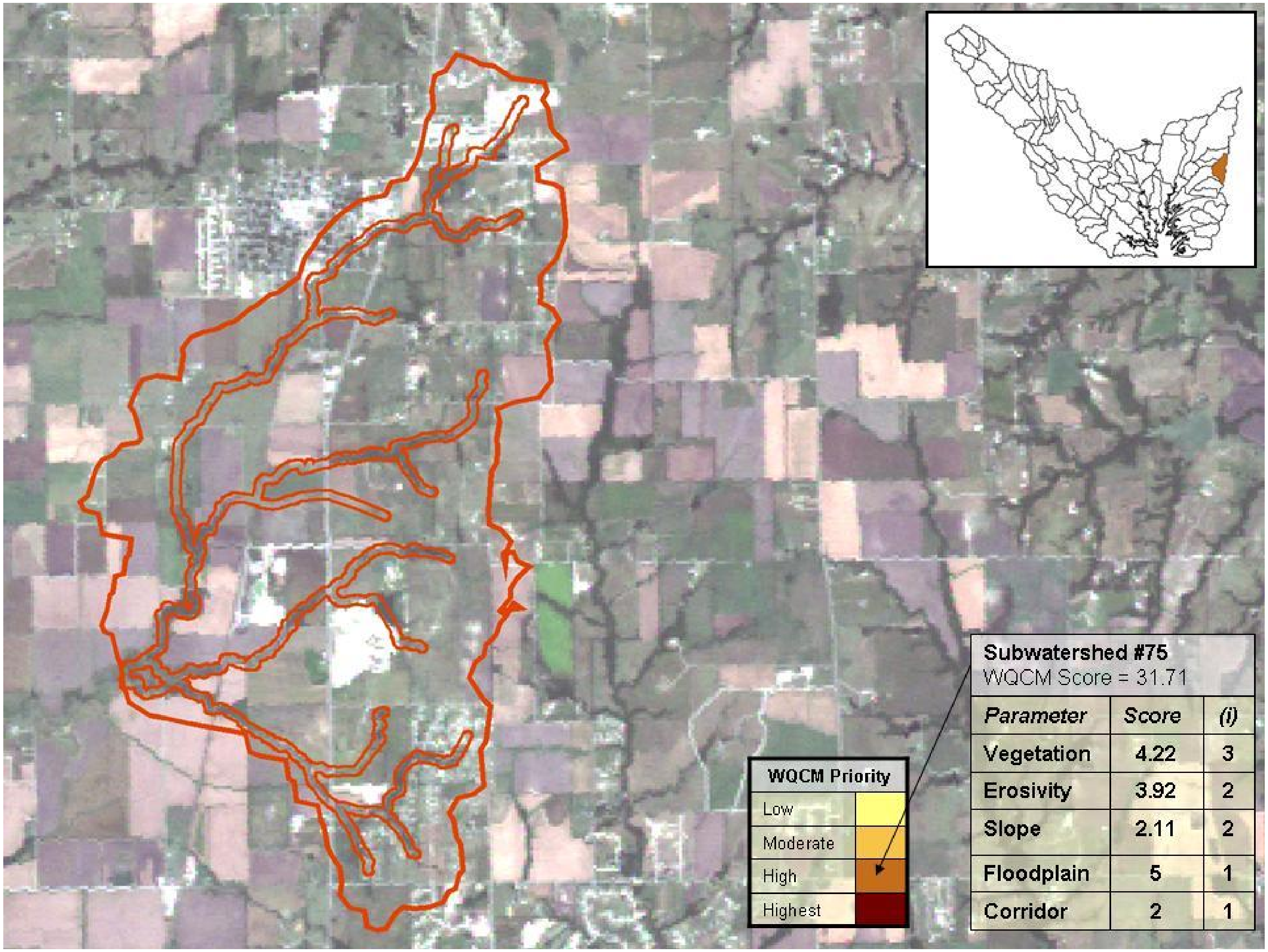
Subwatershed #73
WQCM Score = 25368

Parameter	*Score*	*(i)*
Vegetation	4.14	3
Erosivity	3.92	2
Slope	1.71	2
Floodplain	1	1
Corridor	1	1



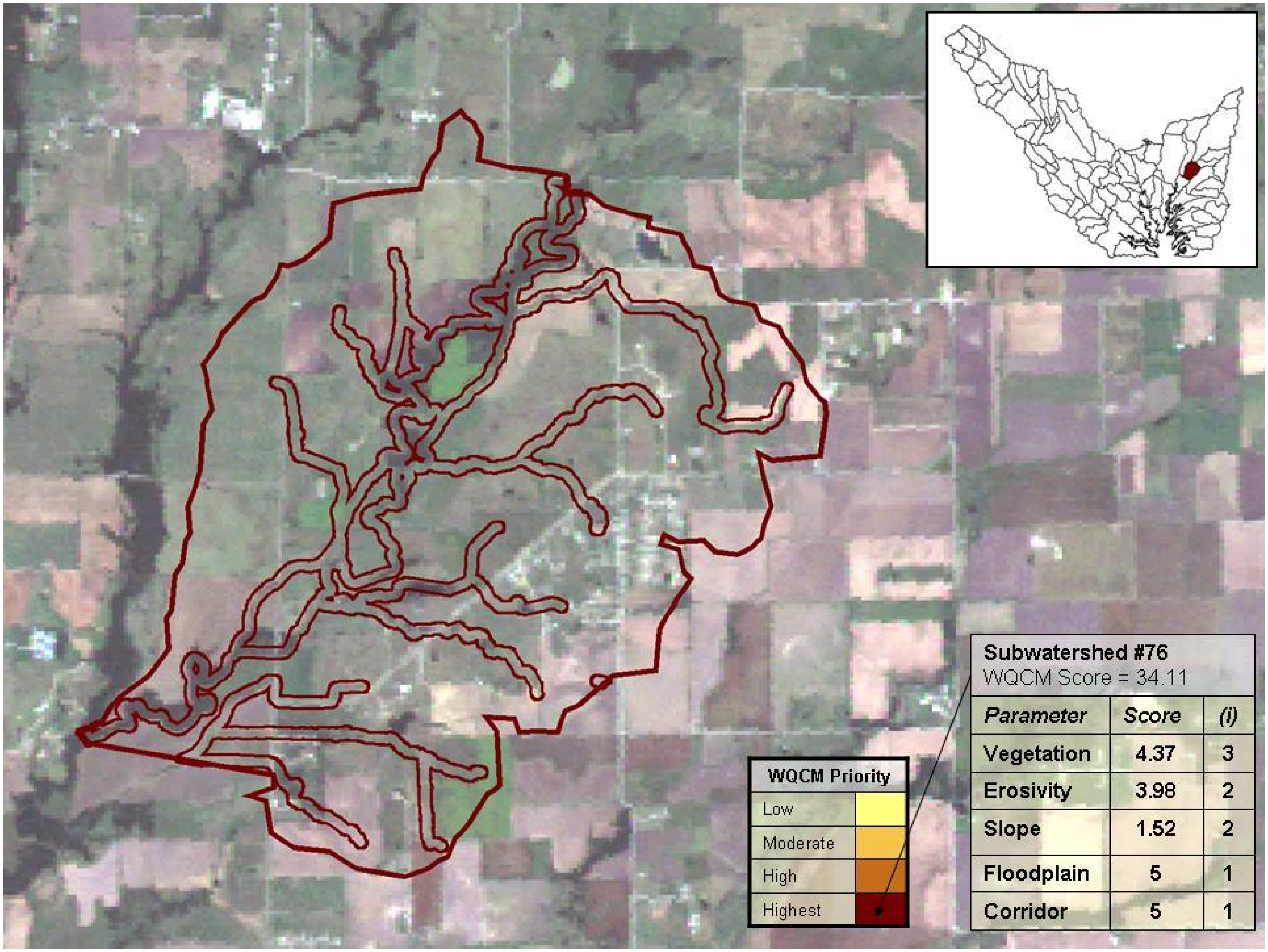
Subwatershed #74
WQCM Score = 31.13

Parameter	*Score*	*(i)*
Vegetation	4.11	3
Erosivity	4.00	2
Slope	2.40	2
Floodplain	2	1
Corridor	4	1



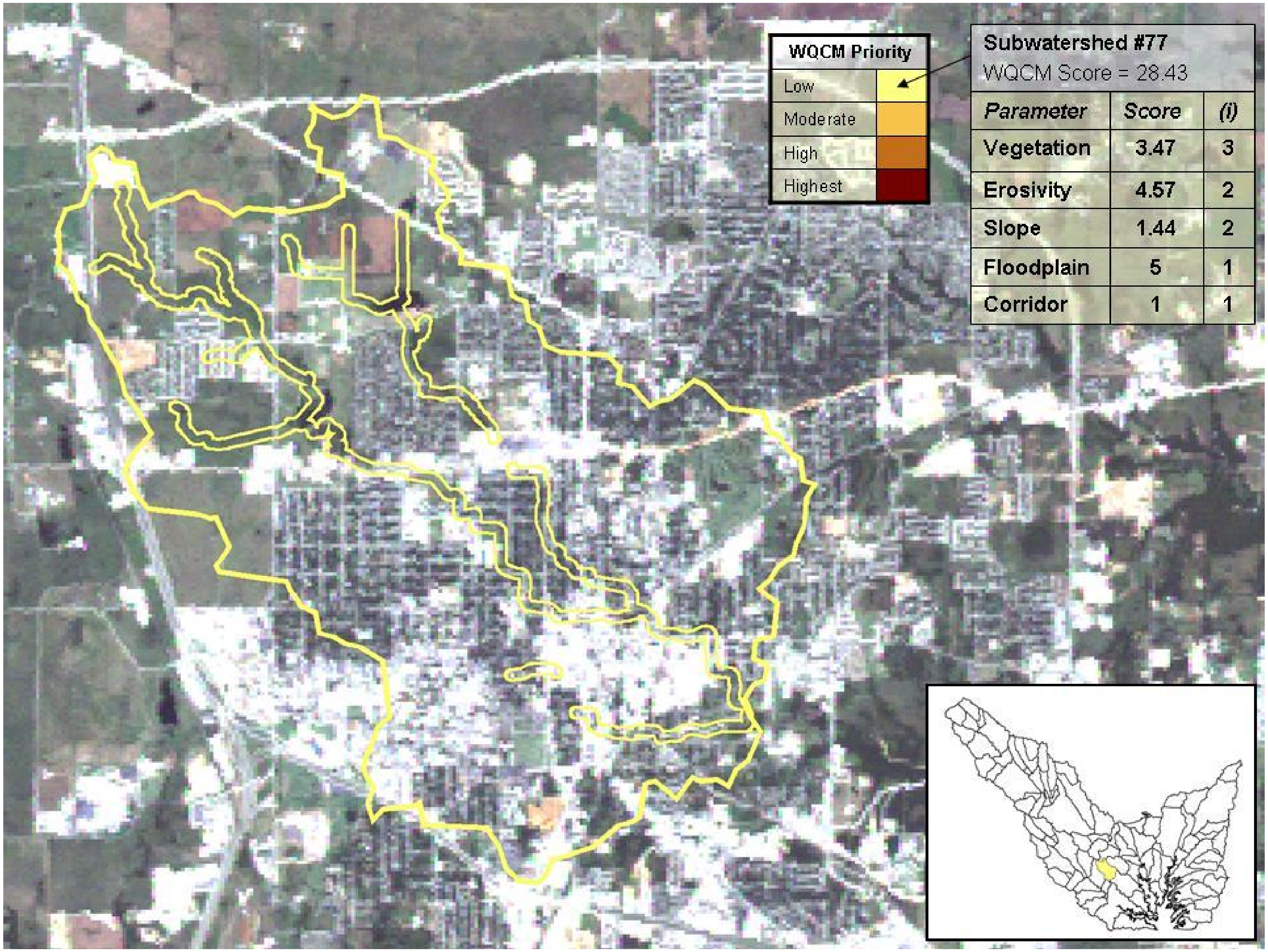
Subwatershed #75
WQCM Score = 31.71

Parameter	*Score*	*(i)*
Vegetation	4.22	3
Erosivity	3.92	2
Slope	2.11	2
Floodplain	5	1
Corridor	2	1



Subwatershed #76
WQCM Score = 34.11

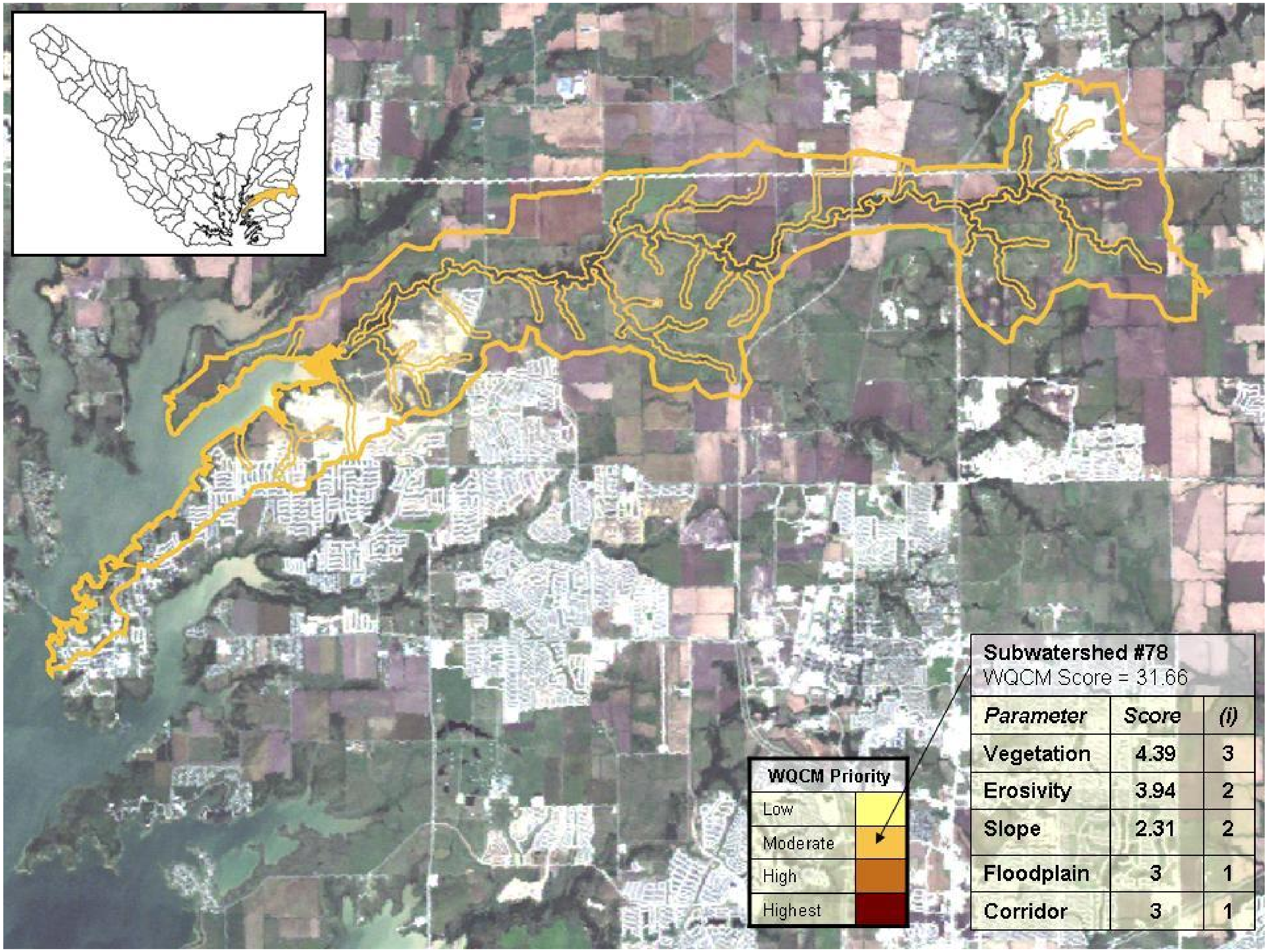
Parameter	*Score*	*(i)*
Vegetation	4.37	3
Erosivity	3.98	2
Slope	1.52	2
Floodplain	5	1
Corridor	5	1



Subwatershed #77

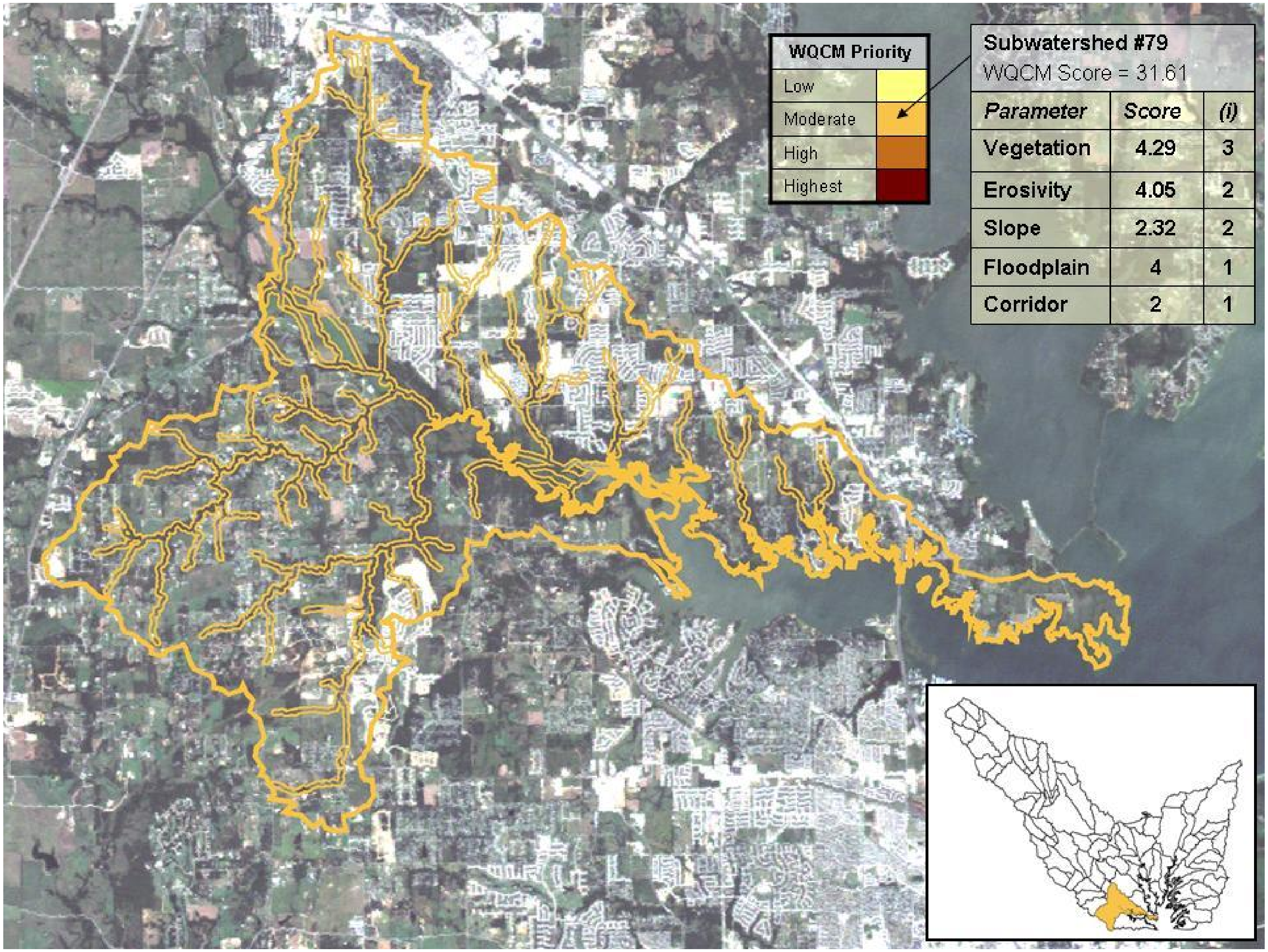
WQCM Score = 28.43

Parameter	*Score*	*(i)*
Vegetation	3.47	3
Erosivity	4.57	2
Slope	1.44	2
Floodplain	5	1
Corridor	1	1



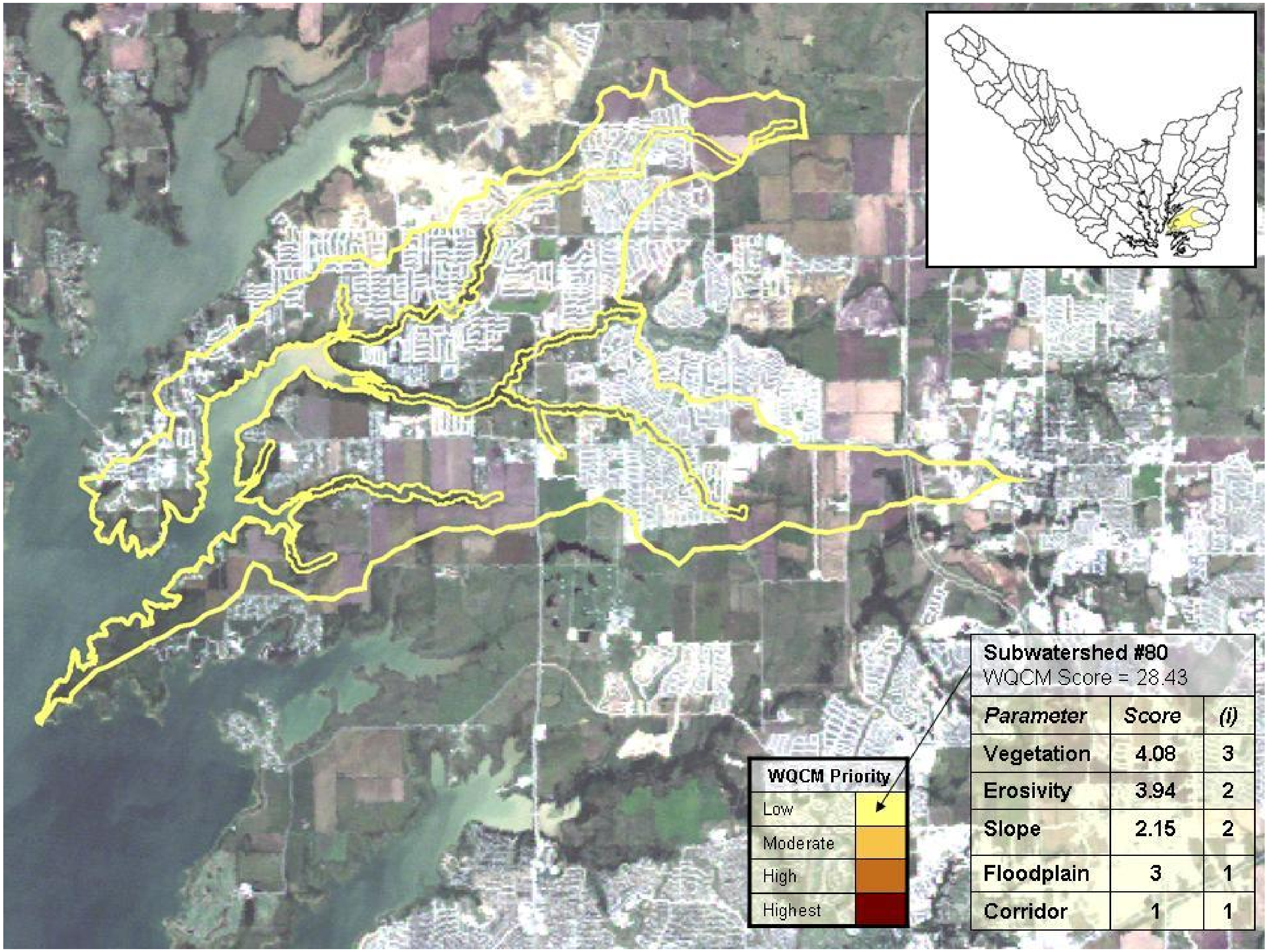
Subwatershed #78
WQCM Score = 31.66

Parameter	*Score*	*(i)*
Vegetation	4.39	3
Erosivity	3.94	2
Slope	2.31	2
Floodplain	3	1
Corridor	3	1



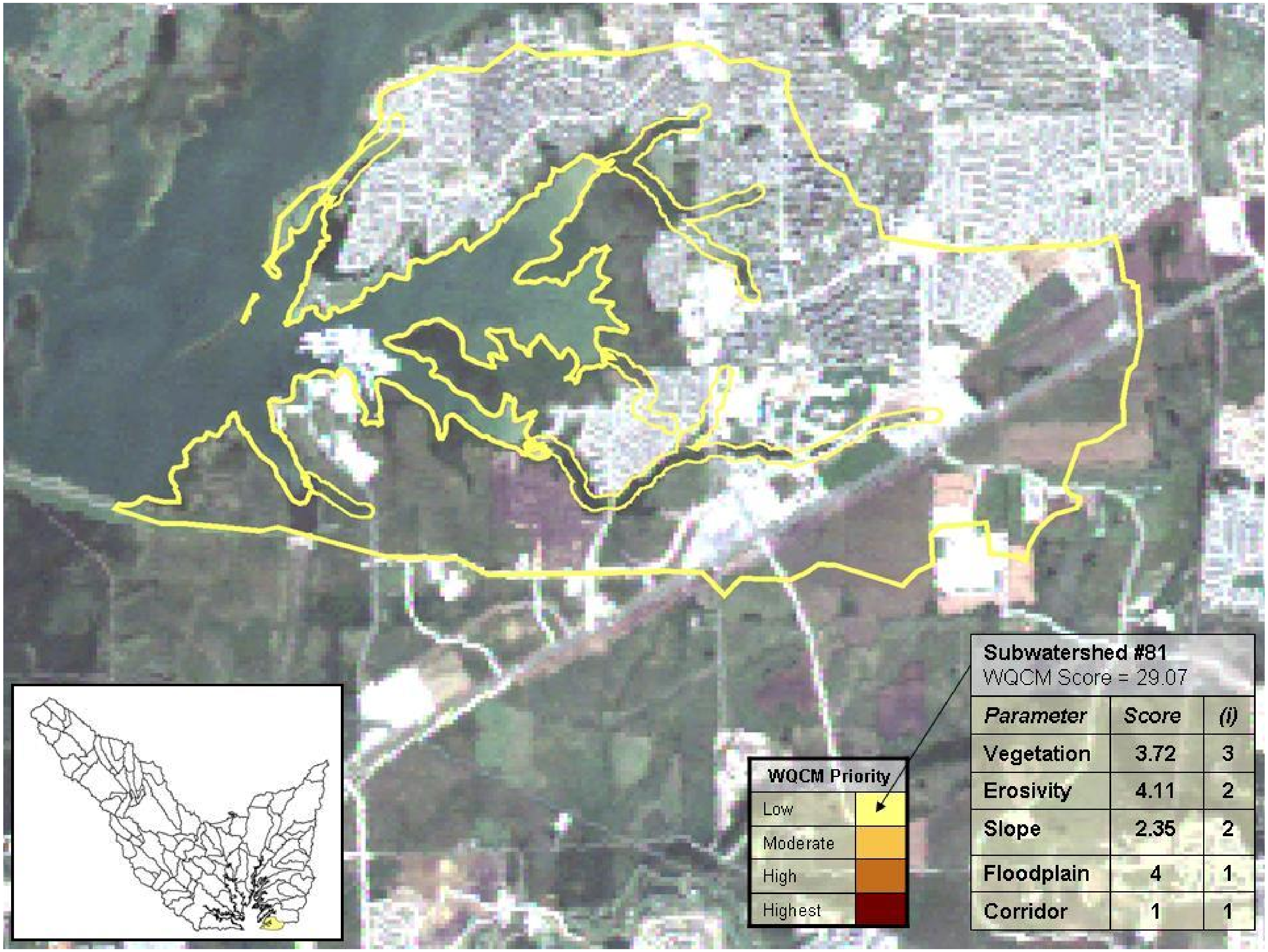
Subwatershed #79
WQCM Score = 31.61

Parameter	*Score*	*(i)*
Vegetation	4.29	3
Erosivity	4.05	2
Slope	2.32	2
Floodplain	4	1
Corridor	2	1



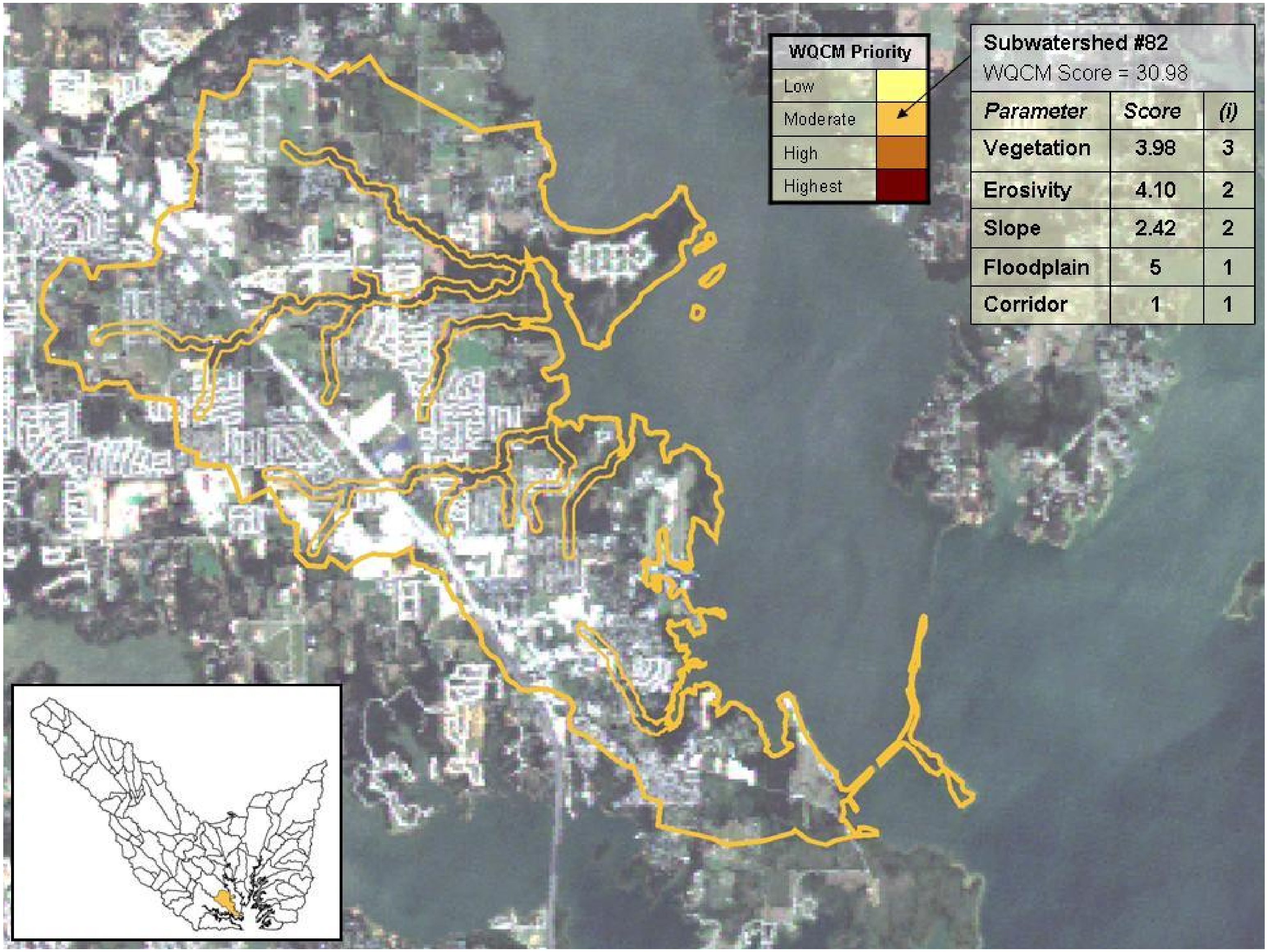
Subwatershed #80
WQCM Score = 28.43

Parameter	*Score*	*(i)*
Vegetation	4.08	3
Erosivity	3.94	2
Slope	2.15	2
Floodplain	3	1
Corridor	1	1



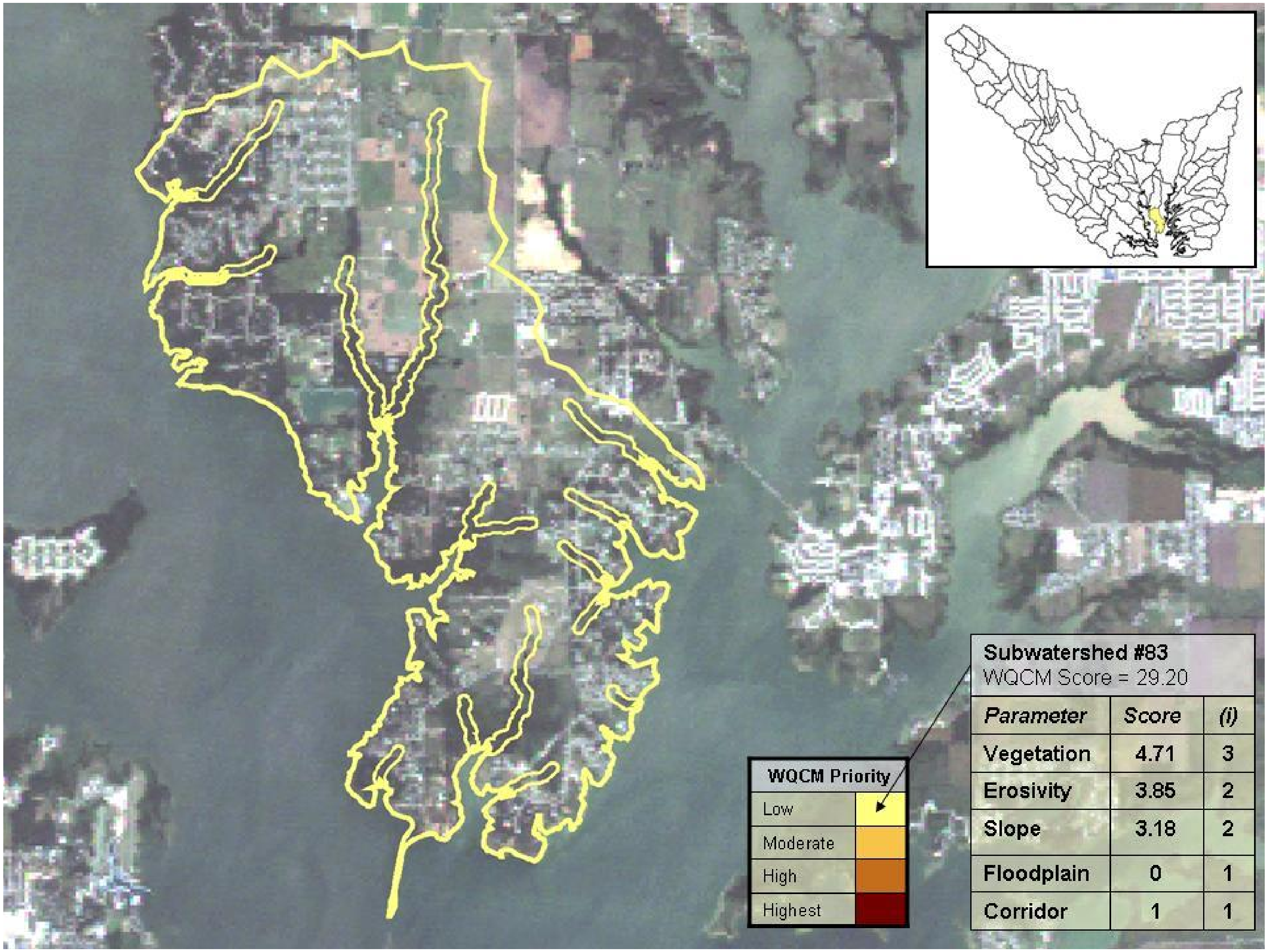
Subwatershed #81
WQCM Score = 29.07

Parameter	*Score*	*(i)*
Vegetation	**3.72**	**3**
Erosivity	**4.11**	**2**
Slope	**2.35**	**2**
Floodplain	**4**	**1**
Corridor	**1**	**1**



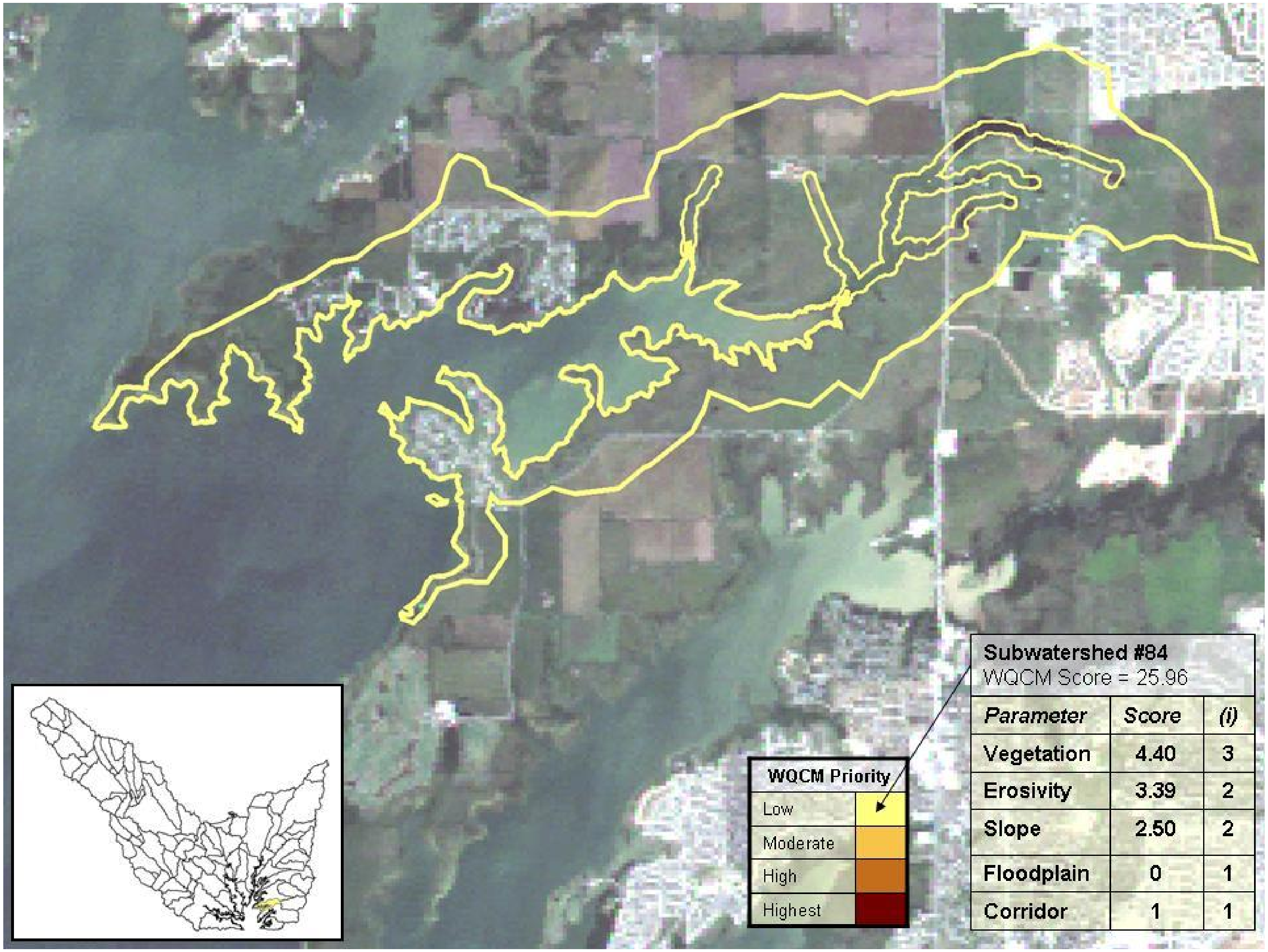
Subwatershed #82
WQCM Score = 30.98

Parameter	*Score*	*(i)*
Vegetation	3.98	3
Erosivity	4.10	2
Slope	2.42	2
Floodplain	5	1
Corridor	1	1



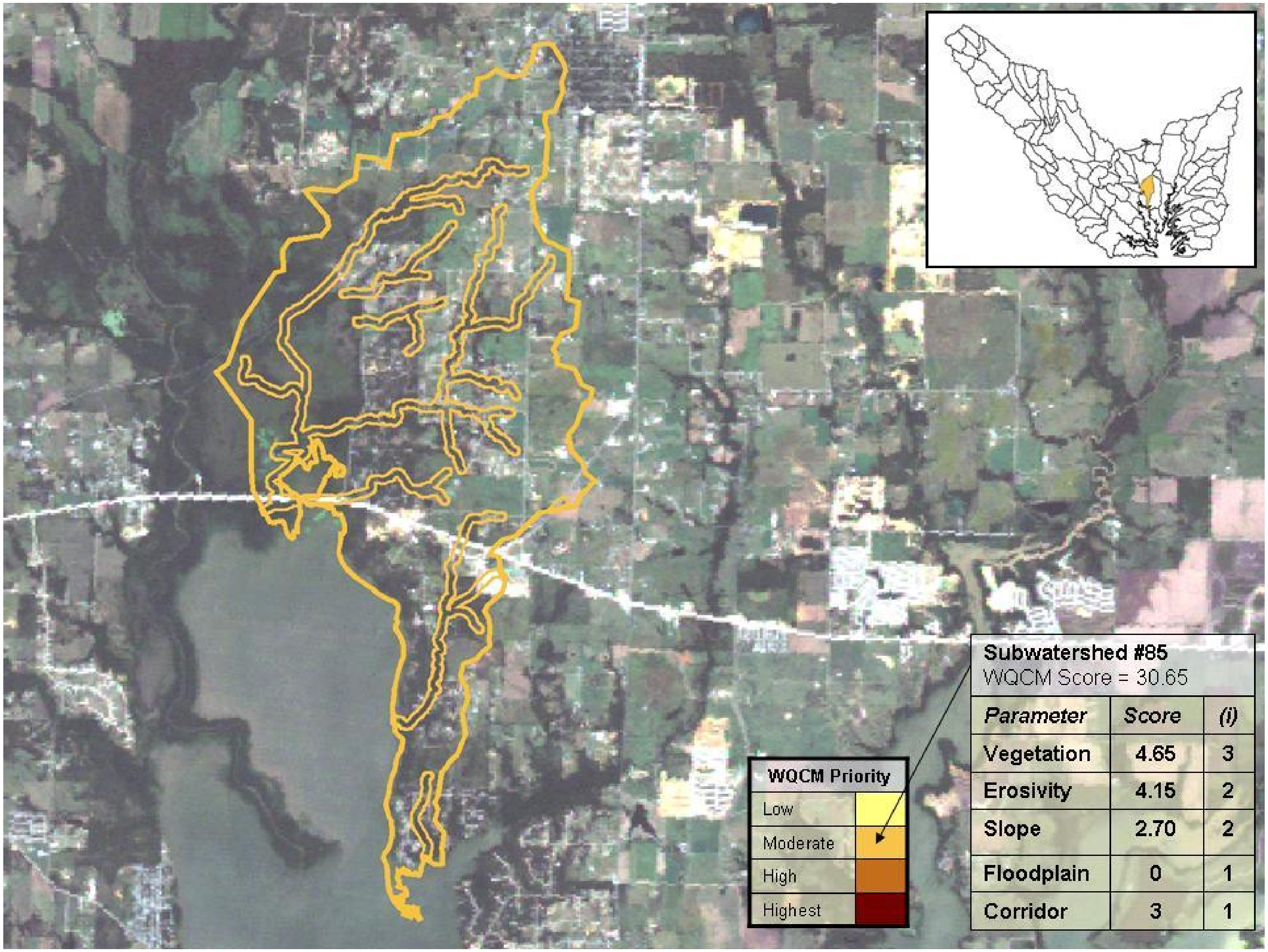
Subwatershed #83
WQCM Score = 29.20

Parameter	*Score*	*(i)*
Vegetation	4.71	3
Erosivity	3.85	2
Slope	3.18	2
Floodplain	0	1
Corridor	1	1



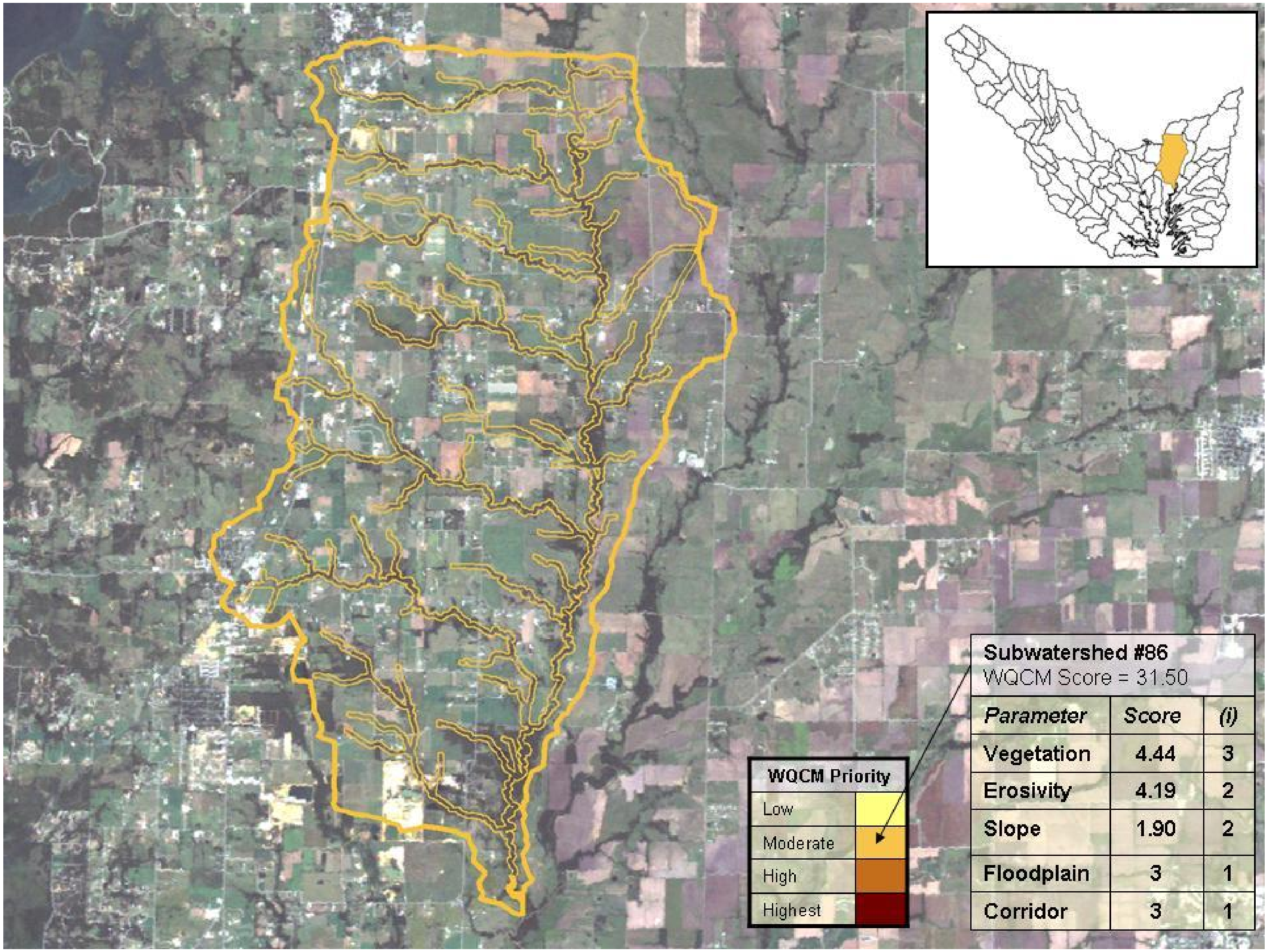
Subwatershed #84
WQCM Score = 25.96

Parameter	*Score*	*(i)*
Vegetation	4.40	3
Erosivity	3.39	2
Slope	2.50	2
Floodplain	0	1
Corridor	1	1



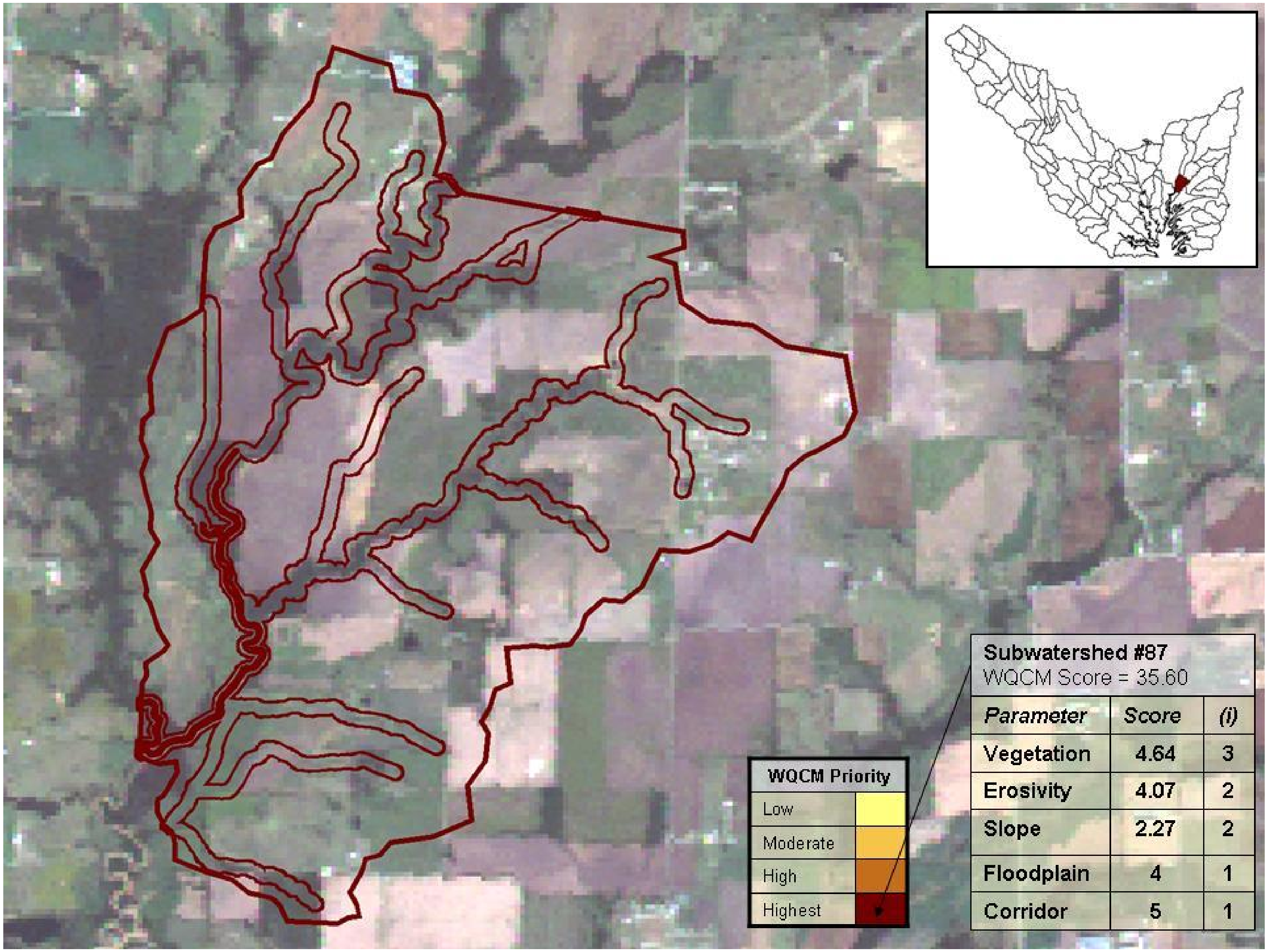
Subwatershed #85
WQCM Score = 30.65

Parameter	*Score*	*(i)*
Vegetation	**4.65**	**3**
Erosivity	**4.15**	**2**
Slope	**2.70**	**2**
Floodplain	**0**	**1**
Corridor	**3**	**1**



Subwatershed #86
WQCM Score = 31.50

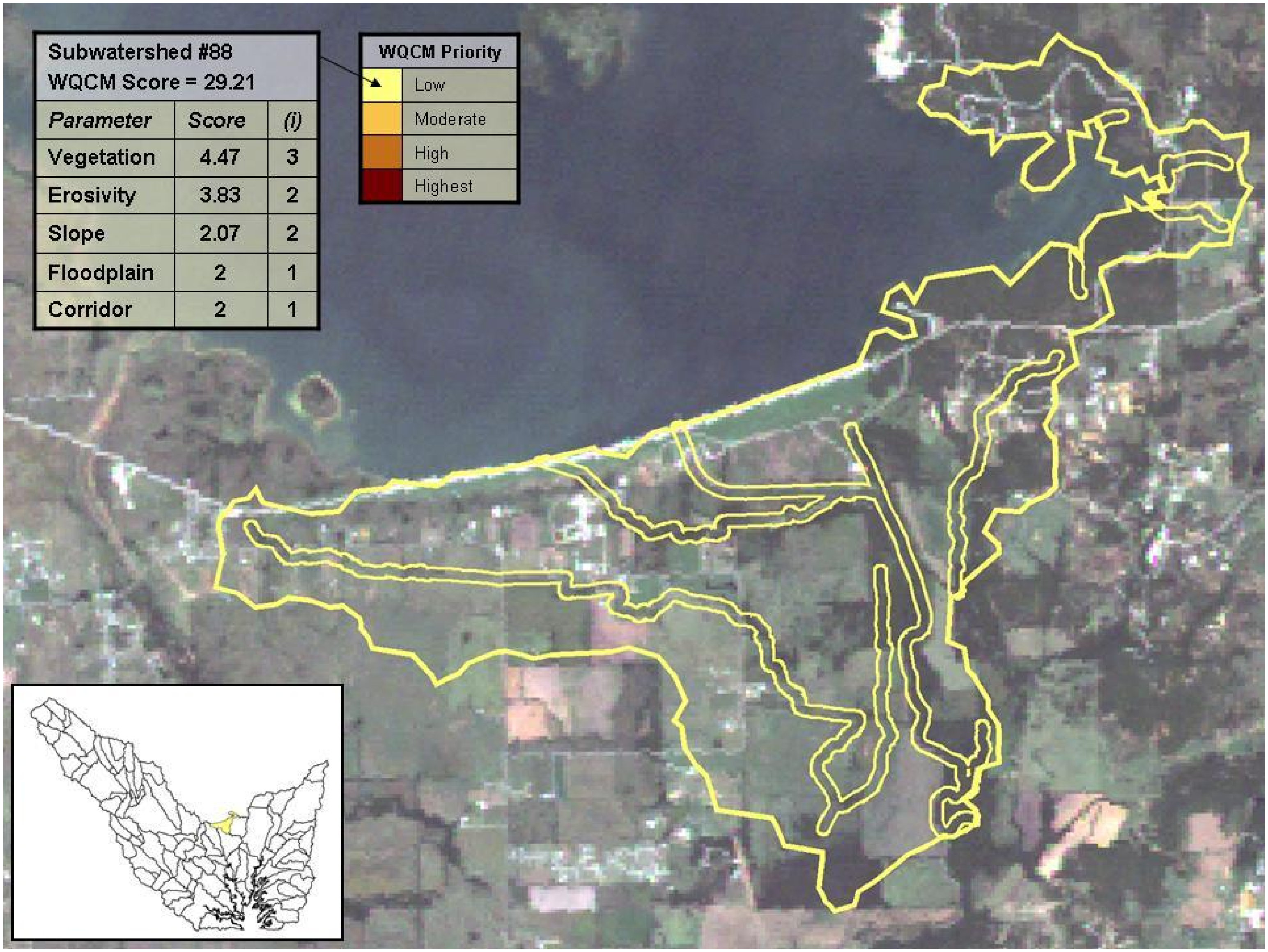
Parameter	*Score*	*(i)*
Vegetation	4.44	3
Erosivity	4.19	2
Slope	1.90	2
Floodplain	3	1
Corridor	3	1



Subwatershed #87

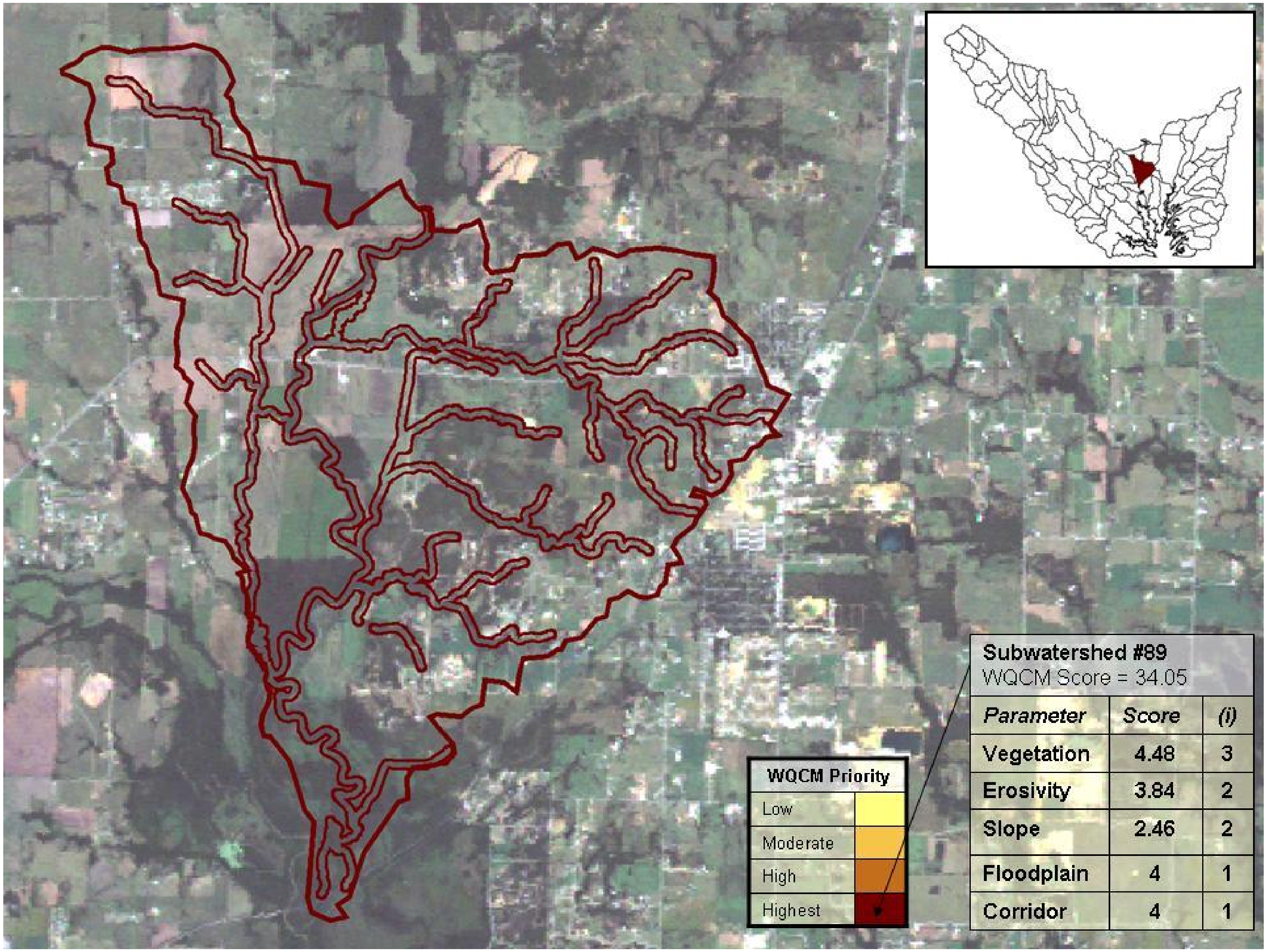
WQCM Score = 35.60

Parameter	*Score*	*(i)*
Vegetation	**4.64**	**3**
Erosivity	**4.07**	**2**
Slope	**2.27**	**2**
Floodplain	**4**	**1**
Corridor	**5**	**1**



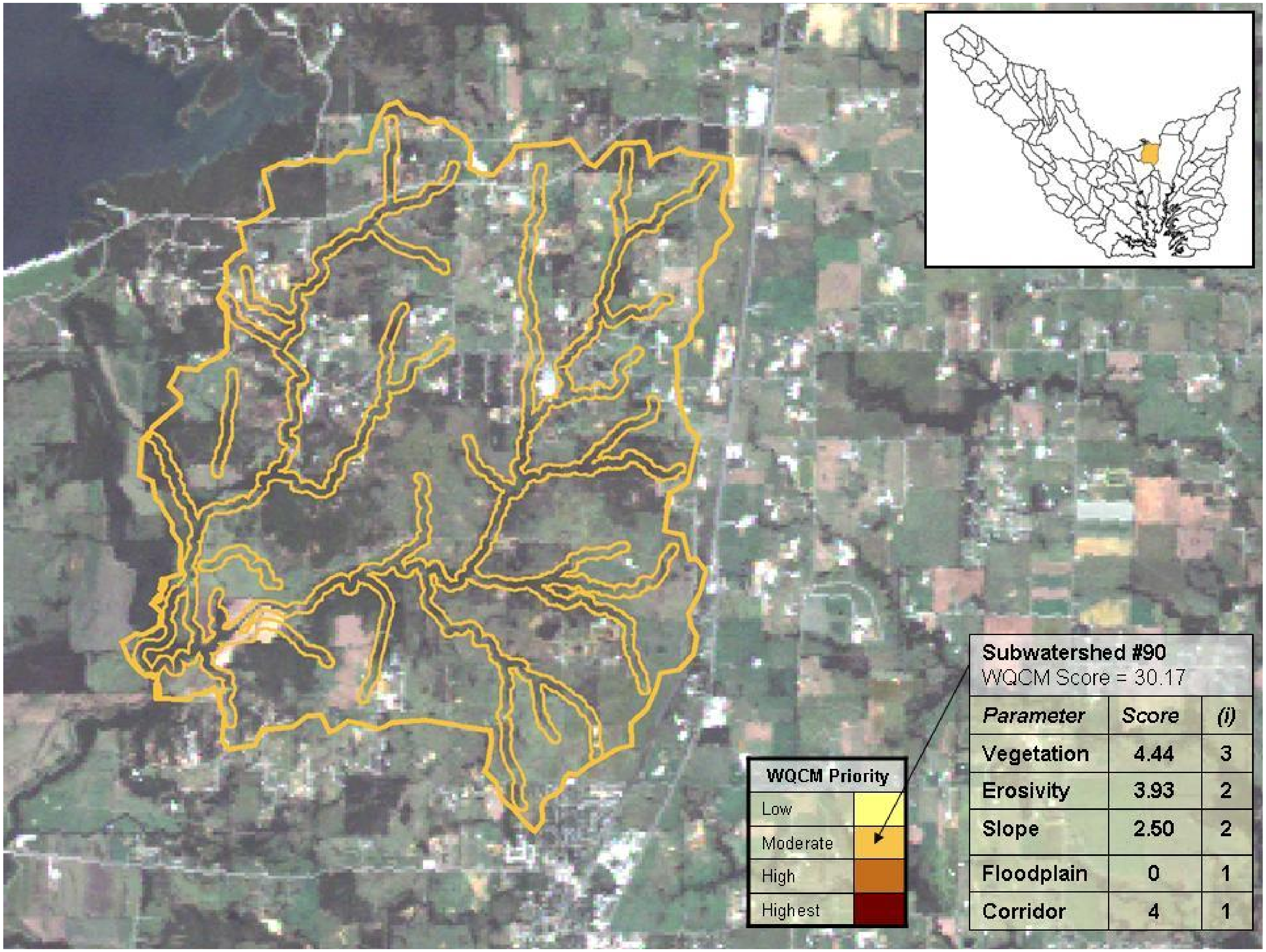
Subwatershed #88
WQCM Score = 29.21

Parameter	Score	(i)
Vegetation	4.47	3
Erosivity	3.83	2
Slope	2.07	2
Floodplain	2	1
Corridor	2	1



Subwatershed #89
WQCM Score = 34.05

Parameter	*Score*	*(i)*
Vegetation	4.48	3
Erosivity	3.84	2
Slope	2.46	2
Floodplain	4	1
Corridor	4	1



Subwatershed #90
WQCM Score = 30.17

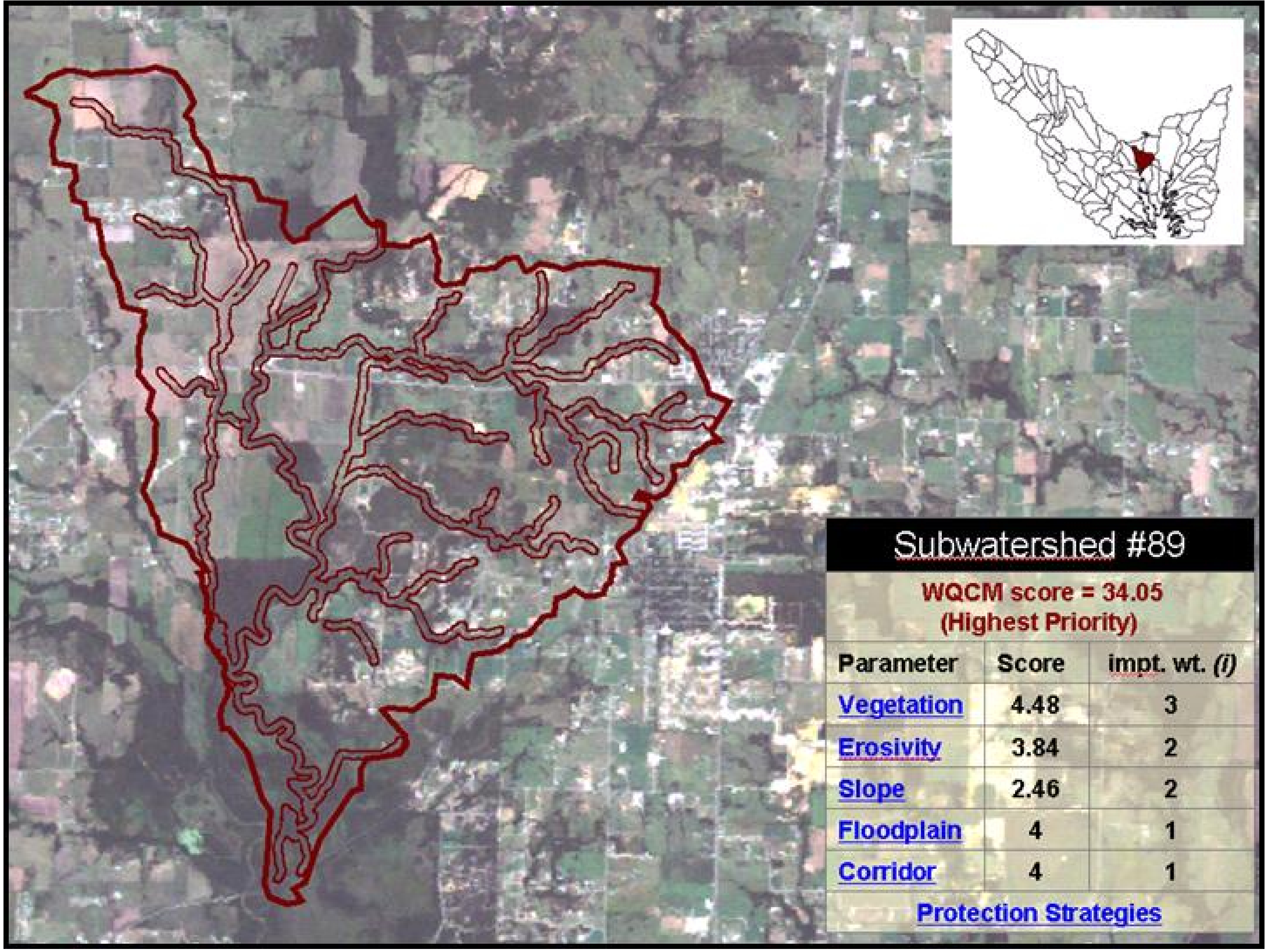
Parameter	*Score*	*(i)*
Vegetation	**4.44**	**3**
Erosivity	**3.93**	**2**
Slope	**2.50**	**2**
Floodplain	**0**	**1**
Corridor	**4**	**1**

APPENDIX B

PROSPECTIVE INTERACTIVE CD INTERFACES

Interactive CD interface example for subwatershed #89 of the Lake Lewisville watershed

Each subwatershed will have a similar interface, with the ability to click on any of the WQCM parameters for a GIS visualization of that parameter. The user will also have the ability to navigate to specific protection strategies associated with the different WQCM components.



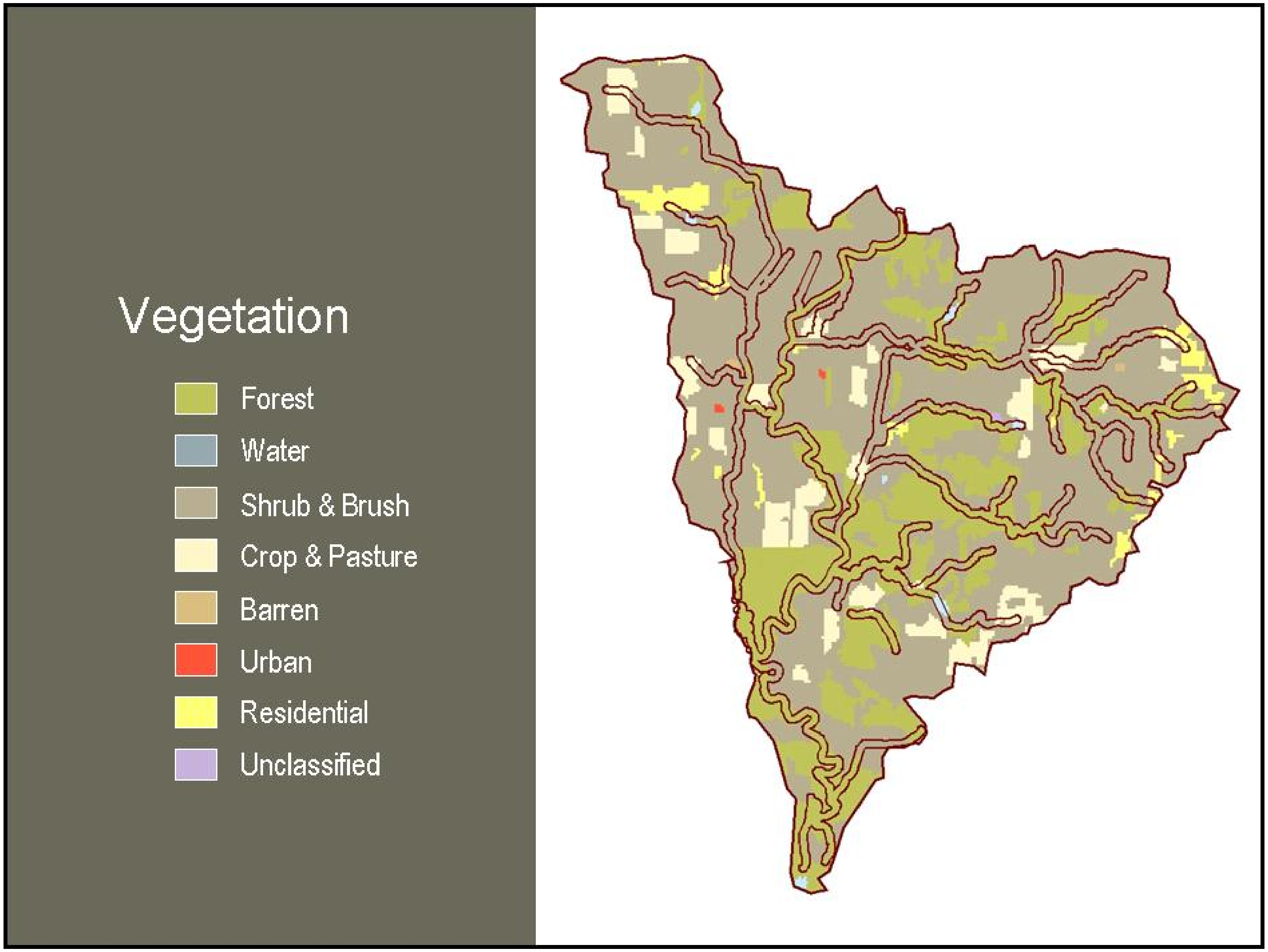
Subwatershed #89

WQCM score = 34.05
(Highest Priority)

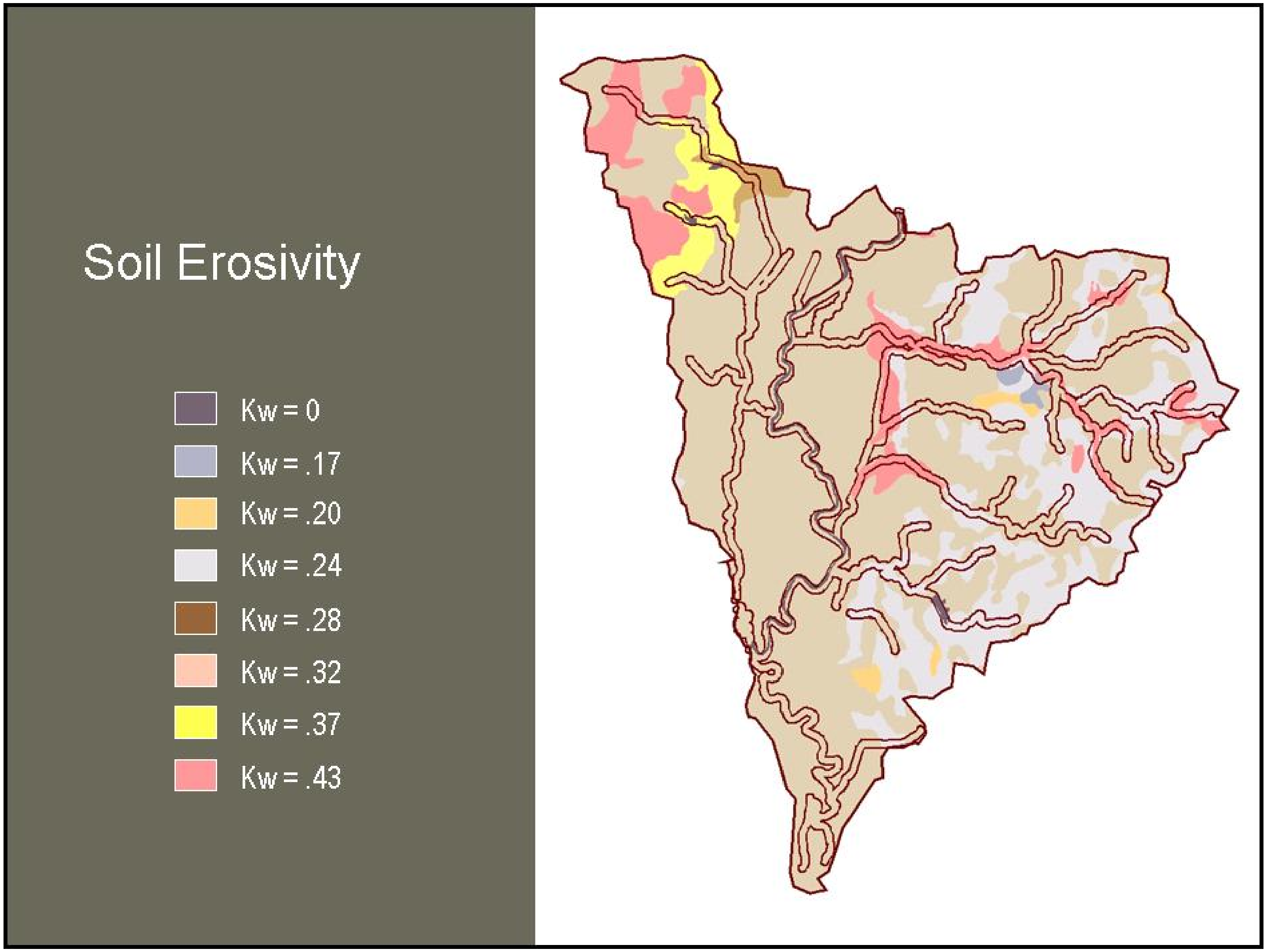
Parameter	Score	impt. wt. *(i)*
Vegetation	4.48	3
Erosivity	3.84	2
Slope	2.46	2
Floodplain	4	1
Corridor	4	1

Protection Strategies

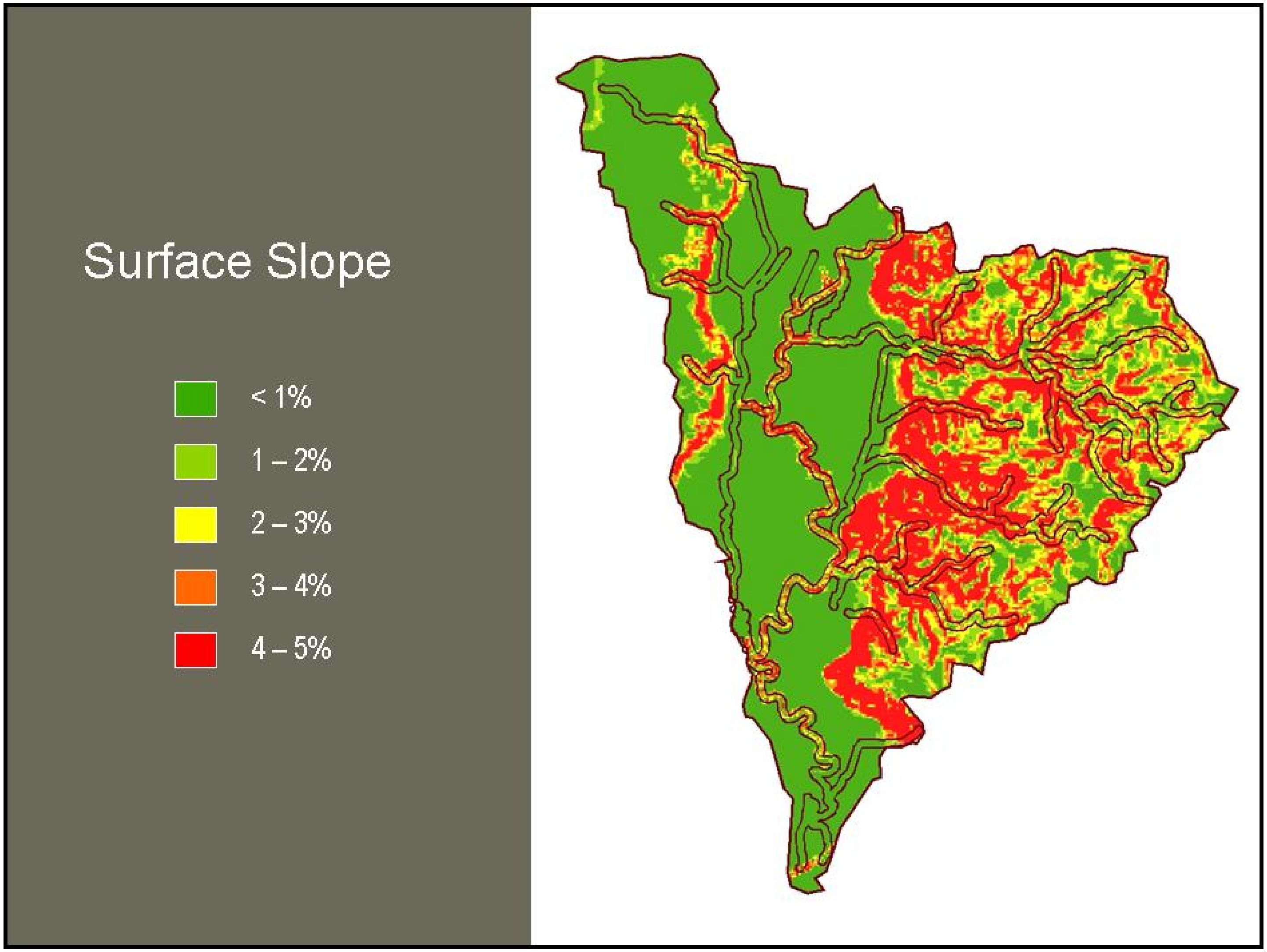
Interactive CD interface example for the vegetation classification associated with subwatershed #89 (pictured with stream corridors); what the user will see after clicking on the vegetation link from the main subwatershed #89 page.



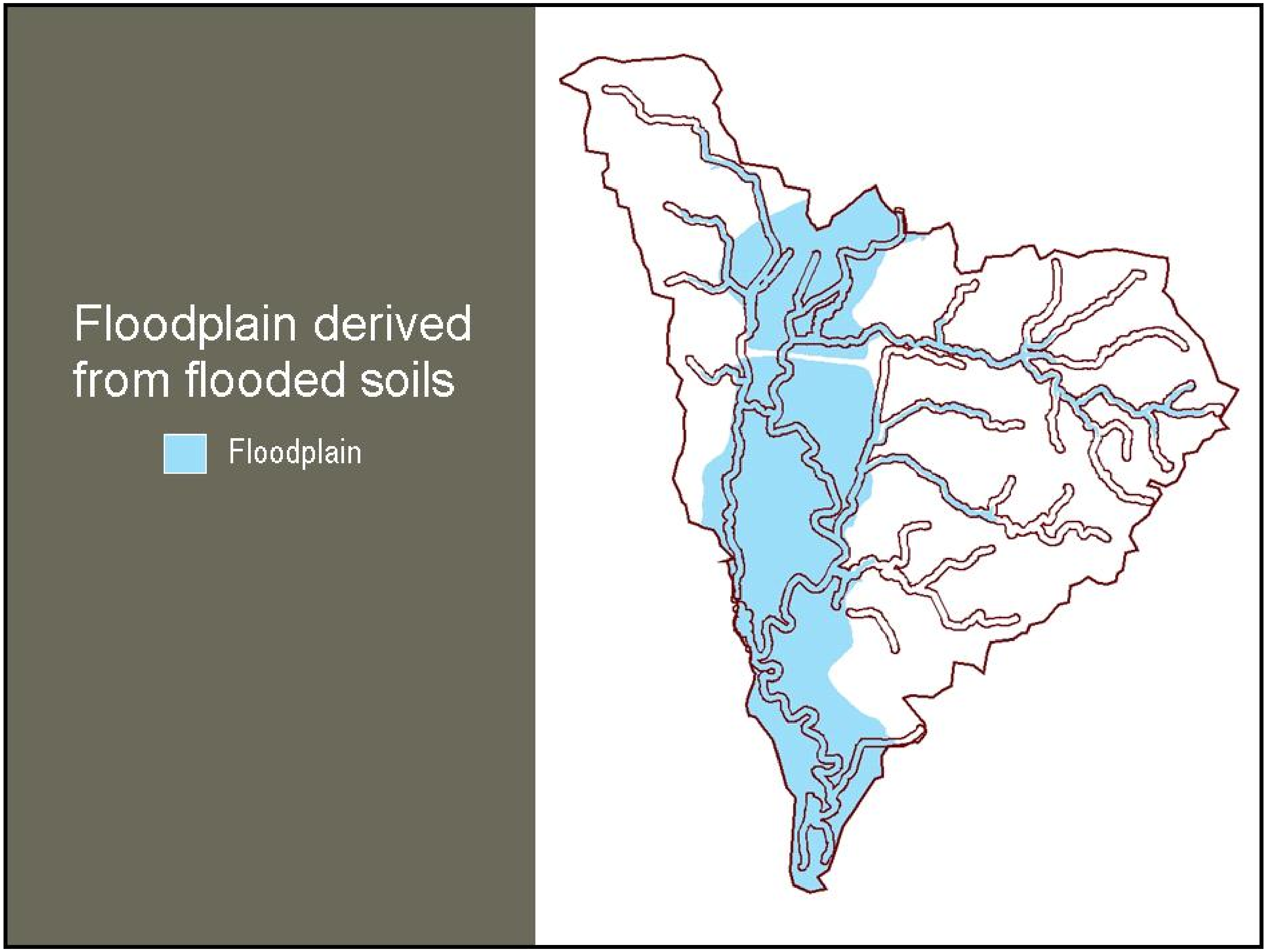
Interactive CD interface example for the soil erosivity categories associated with subwatershed #89 (pictured with stream corridors); what the user will see after clicking on the erosivity link from the main subwatershed #89 page.



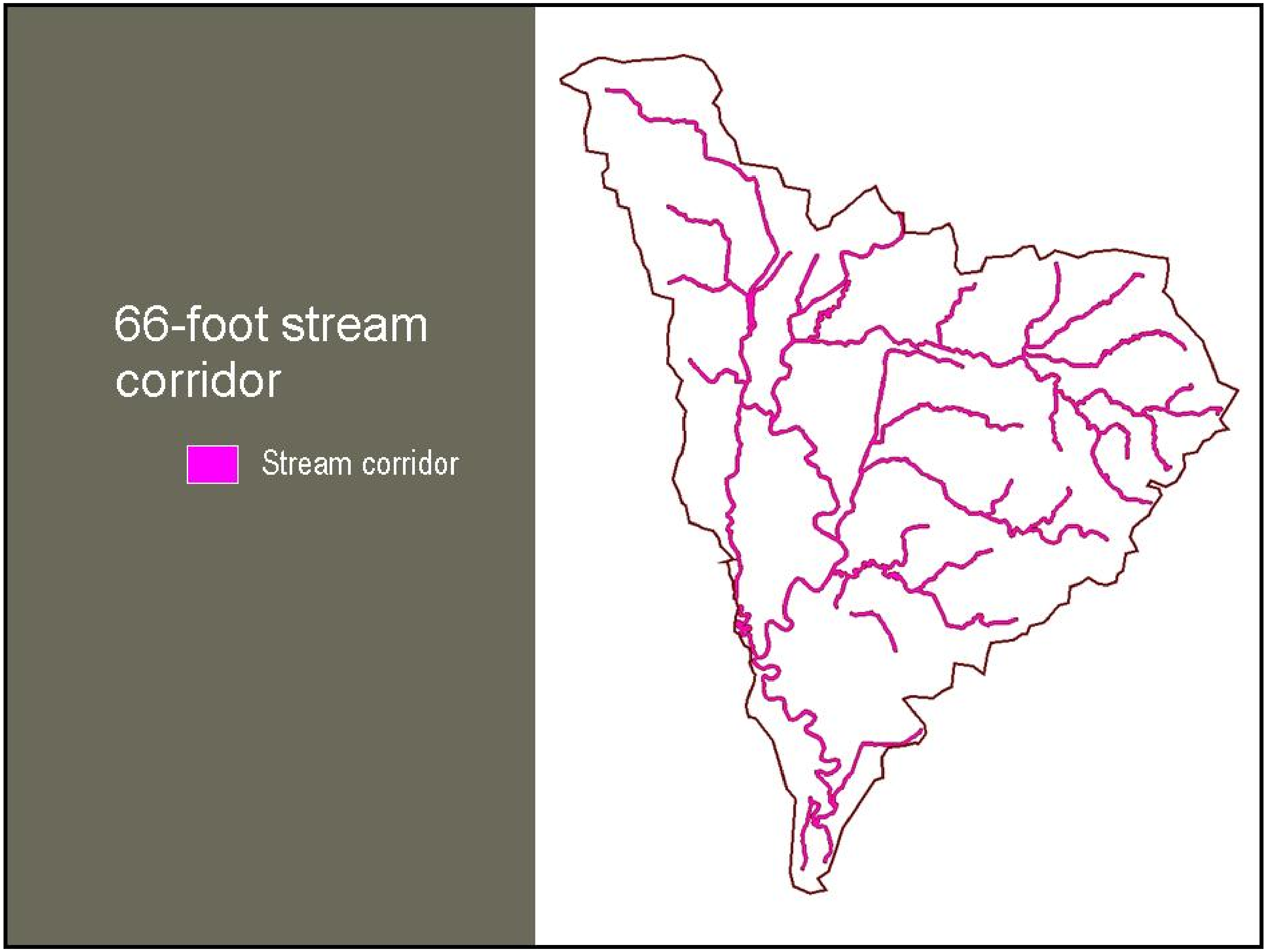
Interactive CD interface example for the slope categories associated with subwatershed #89 (pictured with stream corridors); what the user will see after clicking on the slope link from the main subwatershed #89 page.



Interactive CD interface example for the floodplain category associated with subwatershed #89 (pictured with stream corridors); what the user will see after clicking on the floodplain link from the main subwatershed #89 page.



Interactive CD interface example for the 66-foot stream corridors of subwatershed #8; what the user will see after clicking on the corridor link from the main subwatershed #89 page.



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