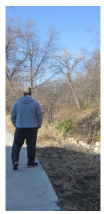
Watershed Assessment of River Stability and Sediment Supply | Wildcat Creek

Watershed Assessment of River Stability and Sediment Supply | Wildcat Creek

A study evaluating Wildcat Creek in Manhattan, Kansas to determine locations that contributed to severe flooding of the creek

Watershed Assessment for River Stability and Sediment Supply applied to Wildcat Creek Watershed in Riley County, Kansas

A Presentation of Rosgen's Watershed Assessment For Stream Stability and Sediment Supply (WARSSS) & Partial Design Solutions to Reduce flooding for the Wildcat Creek Watershed

LAR 705 Wildcat Creek Watershed Masters Reports |

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LAR 741 Wildcat Creek WARSSS Problems Course |

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THE COLLEGE of
ARCHITECTURE, PLANNING & DESIGN // K-STATE

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Abstract

Wildcat Creek Watershed (approx. 99 square miles) in Riley County, Kansas had significant flooding in recent years. A Watershed Assessment of River Stability and Sediment Supply (WARSSS, Rosgen, 2006) of Wildcat Creek was performed to determine locations that are contributing to the flooding. WARSSS is split into three levels: Reconnaissance Level Assessment (RLA), Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC), and Prediction Level Assessment (PLA). The assessment for Wildcat Creek completed to date focuses on the first two phases, RLA and RRISSC evaluations. The RLA level focuses on creating sections by similar land use and land cover to get an overall understanding of the watershed. The RRISSC level divides the watershed into nineteen sub-watersheds and takes a more detailed approach to the assessment. The WARSSS assessment is typically done on smaller watershed scale, but was adapted to encompass the entire Wildcat Creek Watershed.

The assessment provided the foundation for six masters reports. The reports focused on potential solutions to the flooding and improving Wildcat Creek Watershed.

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Abbreviations

Dr. Rosgen (2006), author and creator of the Watershed Assessment of River Stability and Sediment Supply uses four acronyms to refer to the process. These acronyms will commonly appear throughout the document and be explained as they are introduced. They are noted below for a point of reference.

WARSSS- Watershed Assessment of River Stability & Sediment Supply

RLA- Reconnaissance Level Assessment

RRISSC- Rapid Resource Inventory for Sediment and Stability Consequence

PLA- Prediction Level Assessment

Preface

On June 2, 2011 the City of Manhattan, Kansas experienced a downpour of nearly five inches of rain over a few short hours that caused Wildcat Creek to flood (Spicer, 2011). Two hundred residents were evacuated from their homes (Anderson, 2011). The June 2011 event was not the first time that Wildcat Creek has flooded. The extent of damage resulting from this particular flood and with the expectation that flooding events will become more frequent, community members were inspired to form the Wildcat Creek Working Group. The group, co-chaired by Riley County and the City of Manhattan, is exploring both a variety of both short and long term strategies to alleviate flooding.

During the 2011-2012 school year, Dr. Tim Keane, a professor at Kansas State University, lead nine graduate students in the department of Landscape Architecture and Regional and Community Planning and the department of Biological Systems Engineering in a comprehensive watershed assessment for the Wildcat Creek Watershed. Six students from the department of Landscape Architecture and Regional and Community Planning developed a variety of individual design strategies to reduce future flooding. The work presented in this document is intended to inform the Wildcat Creek Working Group and the community of the existing conditions in the Wildcat Creek watershed and facilitate ideas for the future.

WARSSS | Introduction

The watershed assessment of river stability and sediment supply method of analysis was applied to Wildcat Creek watershed in Riley County, Kansas as a strategy of understanding the causes of destructive flooding.

Background
Context

WARSSS

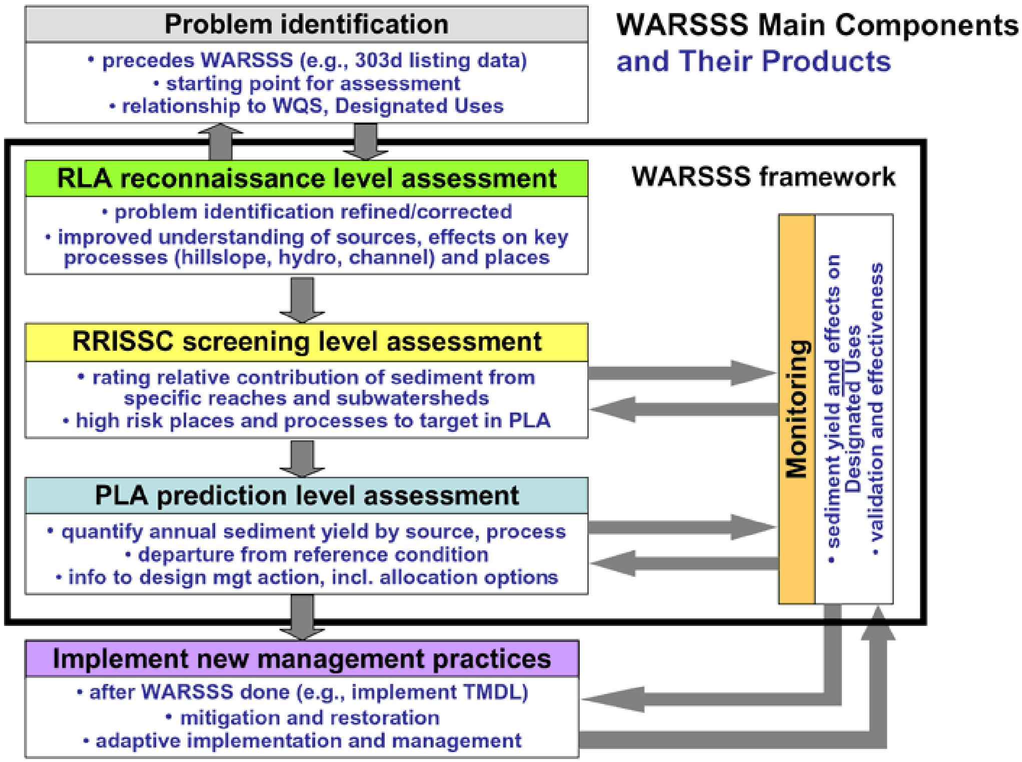
Water quality is a vital issue around the nation. Even with the knowledge that excess sediment is a large contributor to impaired water quality, there was no tool available to assess sediment excess (U.S. EPA, 2011). Dr. David L. Rosgen, with support from the United States Environmental Protection Agency (EPA), developed a technical tool to assess excess sediment in rivers and streams (U.S. EPA, 2011). Rosgen's Watershed Assessment of River Stability and Sediment Supply (WARSSS) is a three-phase tool for assessing river stability and sedimentation at a watershed scale developed for water quality scientists (U.S. EPA, 2011).

Excess sediment in rivers and streams is caused by high erosion and destabilized streambanks resulting in the decline of water quality in these water bodies (U.S. EPA, 2011). The U.S EPA (2011) states that the WARSSS process focuses on:

- "natural variability in sediment dynamics
- geologic versus anthropogenic sediment sources
- erosional and depositional processes
- prediction of sediment loads
- streamflow changes, and
- stream channel stability and departure from reference condition." (U.S. EPA, 2011)

As aforementioned WARSSS is characterized by three phases: (i) Reconnaissance Level Assessment (RLA), (ii) Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC), (iii) Prediction Level Assessment (PLA). The phases move from a general assessment during the RLA phase to a more specific and detailed assessment by the PLA phase (U.S. EPA, 2011). In brief, the RLA phase is a general, quick, qualitative assessment to delineate areas that are more likely to contribute to excess sediment and areas that are unlikely to contribute to excess sediment within the watershed in question (U.S. EPA, 2011).

The second phase, RRISSC, builds upon the RLA phase by conducting a more detailed analysis of problem areas (areas that are likely contributing to excess sediment) observed in the RLA phase (U.S. EPA, 2011). The RRISSC phase further narrows down the key areas from the RLA phase to be brought into the final most thorough phase, PLA. The PLA phase allows for an intensive evaluation of key problem areas (delineated by RRISSC phase) within the watershed (U.S. EPA, 2011). The results from this phase can then be used to inform mitigation and management options (U.S. EPA, 2011). Figure 1.01 is a flowchart summarizing the phases in WARSSS process.



Flowchart summarizing the three phases of the WARSSS approach.

Figure 1.01 | (U.S. EPA, 2011)

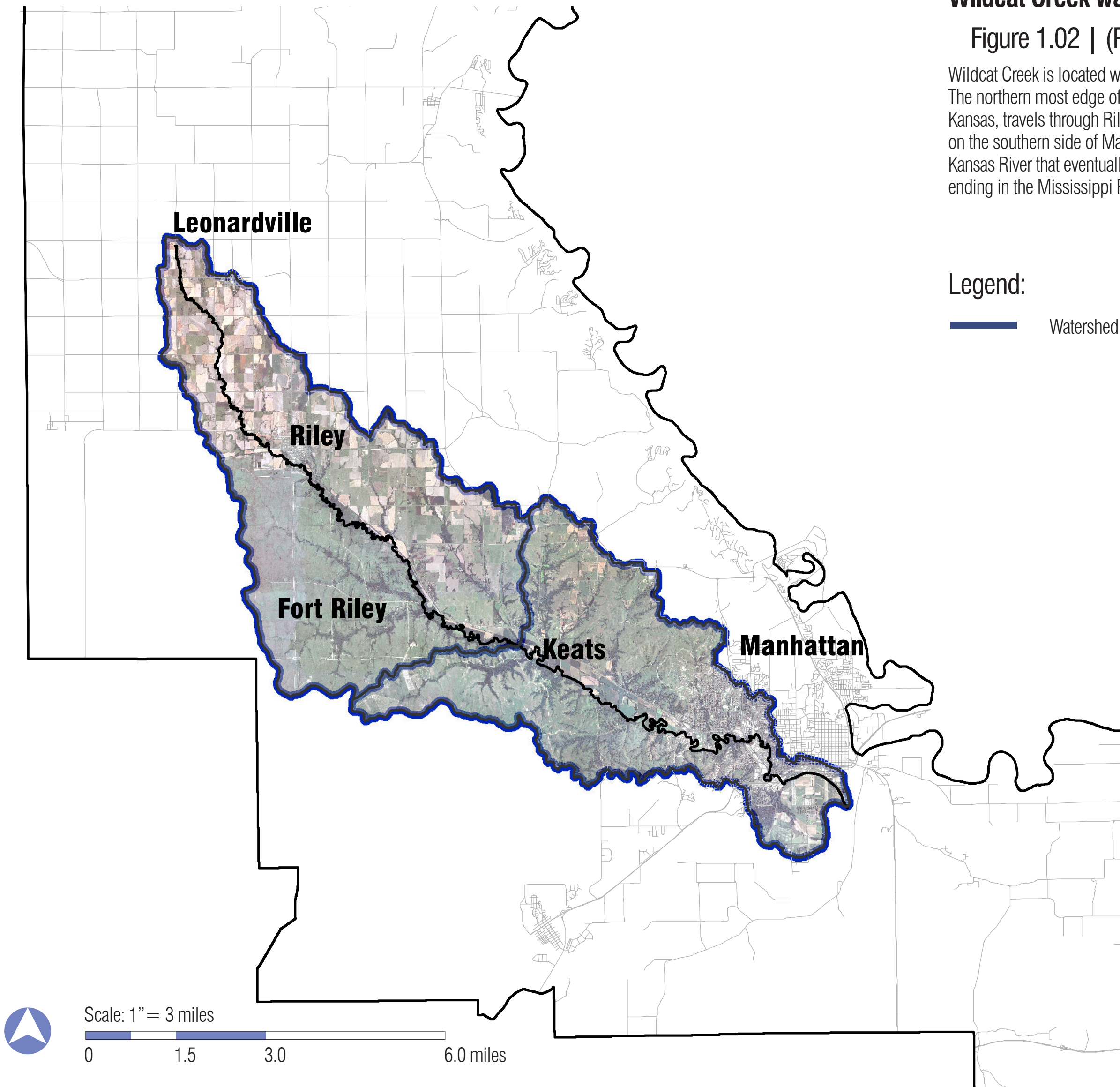
Context

The City of Manhattan, Kansas has been impacted by an increasing incidence of flooding events in the past years. The areas of the city that have been adversely impacted by the floods are within the Wildcat Creek Watershed (figure 1.02). The WARSSS approach helped the Wildcat Creek Master's Student Group delineate problem areas within the Wildcat Creek Watershed in Manhattan, Kansas. Using WARSSS, the group was able to understand which parts of the Wildcat Creek Watershed are being impacted by processes like erosion and bank destabilization. The results produced from the WARSSS assement allowed the group to further understand the flooding issues in the Wildcat Creek Watershed and which areas within the watershed are contributing to the flooding. Delineating the problem areas within the watershed allowed smaller sites to be chosen where their individual projects and design solutions could have a positive impact on the chosen site and the watershed as a whole.

Wildcat Creek watershed context

Figure 1.02 | (Produced by authors, 2012)

Wildcat Creek is located within the center of Riley County, Kansas. The northern most edge of the watershed begins near Leonardville, Kansas, travels through Riley, Keats, and Fort Riley, and finishes on the southern side of Manhattan. Wildcat Creek feeds into the Kansas River that eventually flows into the Missouri River and ending in the Mississippi River.



Legend:

Watershed Boundary

WARSSS | RLA

The chapter is dedicated to the Reconnaissance Level Assessment phase of the Watershed Assessment for River Stability and Stream Supply, in the Wildcat Creek Watershed.

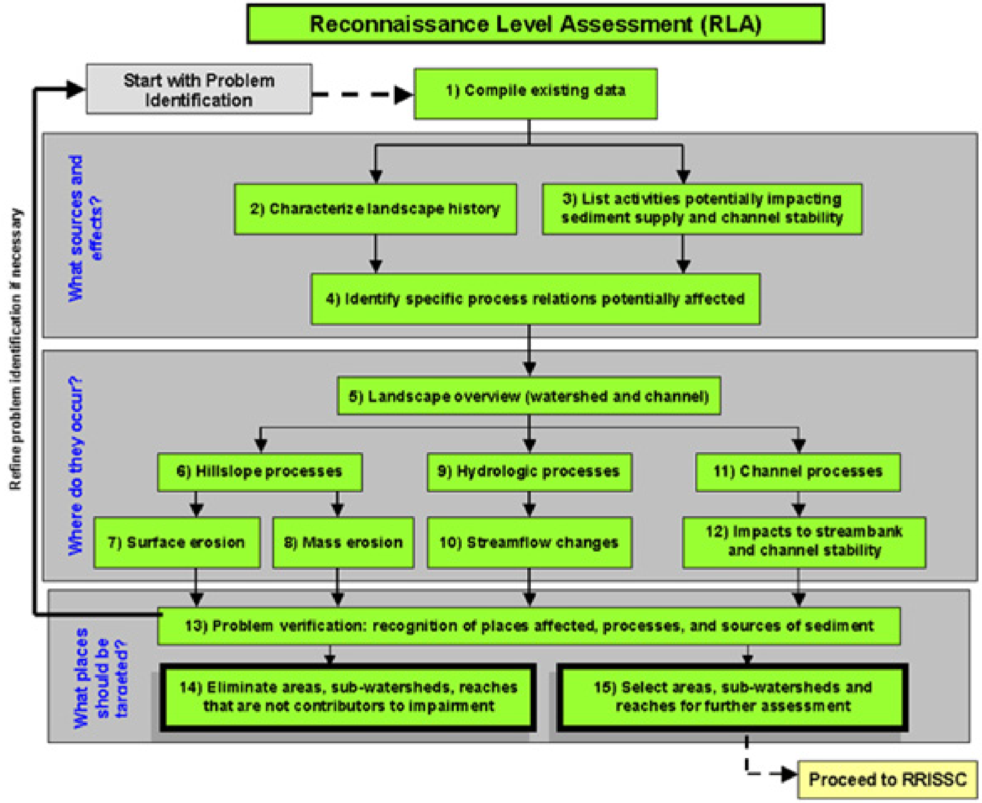
Process
Inventory
Analysis
Synthesis
Type Descriptions

Reconnaissance Level Assessment

Initial Phase of Rosgen's WARSSS

As mentioned previously, the Reconnaissance Level Assessment (figure 2.01) serves to explore the general landscape character of the area selected for the WARSSS assessment. The brief and rapid screening reduces the time and cost of the assessment, and provides base knowledge before in-depth analysis (U.S. EPA, 2011).

Conducting the RLA phase helps the user gather information about the watershed in question. The information includes but is not limited to land use/land cover maps, soil maps, topographic maps, aerial photographs and geologic maps (U.S. EPA, 2011). Aided by the collected information, the user can begin to identify problem areas and begin to eliminate sub-watersheds, reaches etc. that do not contribute to excess sediment. Alternatively, areas that contribute to excess sediment are brought into the second phase (RRISSC) of the WARSSS analysis (U.S. EPA, 2011).



WARSSS reconnaissance level assessment method

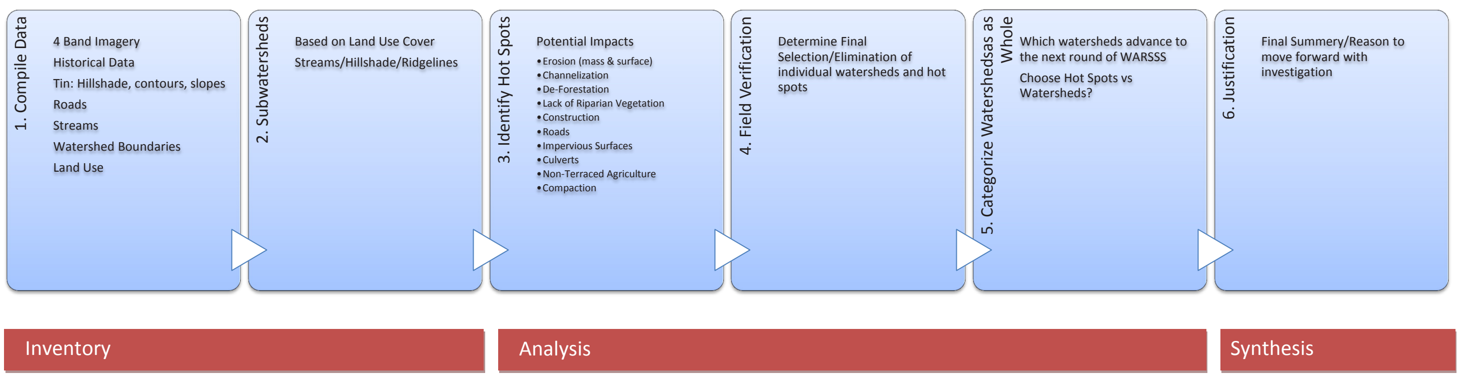
Figure 2.01 | (Rosgen, 2006)

The steps and process Rosgen uses to evaluate a watershed in the first look at the watershed. A quick evaluation of the watershed determines areas that move forward for more evaluation.

Process of Completion

Objectives

To complete the Reconnaissance Level Assessment of WARSSS, there were three objectives to achieve. The first objective was to find areas where land activities increase sediment yield and contribute to channel stability problems, the second objective was to bring clarity to identified problems, and the third objective was to determine which stream reaches to include for more thorough evaluation and which to exclude from further assessment. The process used to achieve these objectives is diagrammed in figure 2.02.



Team process diagram

Figure 2.02 | (Produced by authors, 2012)

Inventory

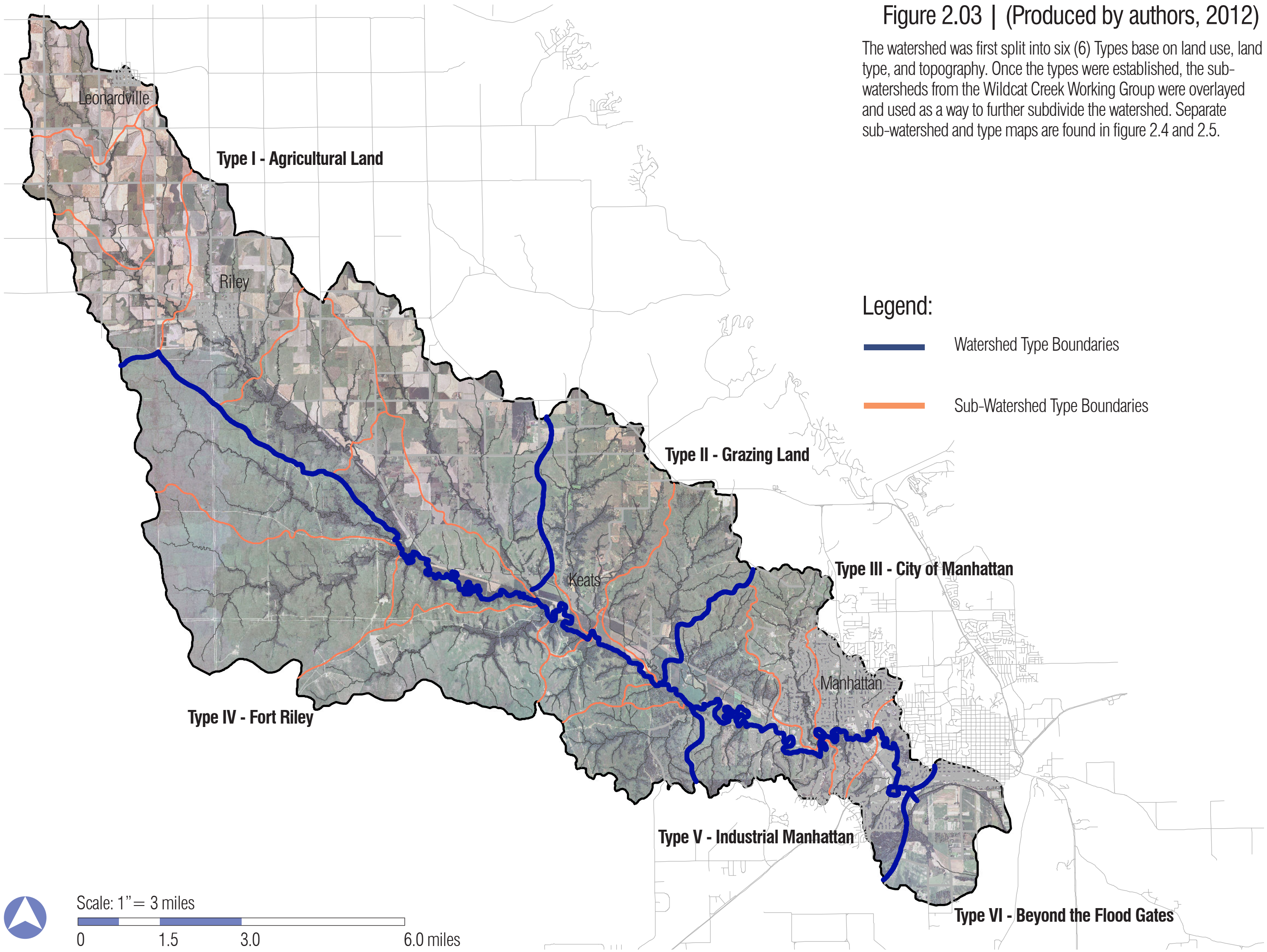
The initial step of the RLA phase consists of collecting and compiling existing data. Geographic Information Systems (GIS) data acquired from USDA: Natural Resources Conservation Service (NRCS) includes topographic maps, four band aerial photography from 2008, 2006 LiDAR imagery, and soil information. Historical aerial photographs were collected from the Kansas Aerial Photography Initiative of the Kansas State University Library. About one hundred aerial shots from the year 1950 were geo-referenced into a working GIS map file. The student group encountered some difficulties gathering data. Access to real-time stream flow information giving water heights, rate of speed of the water, and that location's weather information of Wildcat Creek is non-existent and information for other creeks in the area is limited.

After compiling the GIS data, the student group used a map released by the Wildcat Creek Working Group to divide the Wildcat Creek Watershed into sub-watersheds. The watershed was divided into nineteen sub-watersheds (figure 2.04). The student group then categorized the sub-watersheds by land activity. Type I is predominately agricultural tillage, Type II is an agricultural valley and grazing land with larger stream types, Type III is the city of Manhattan, Type IV is Fort Riley, Type V is the expansion of the city of Manhattan into grazing land, and Type VI is agricultural land below the flood wall heading toward the Kansas River (figure 2.05). The sub-watersheds and types are combined in figure 2.03.

Types and sub-watersheds

Figure 2.03 | (Produced by authors, 2012)

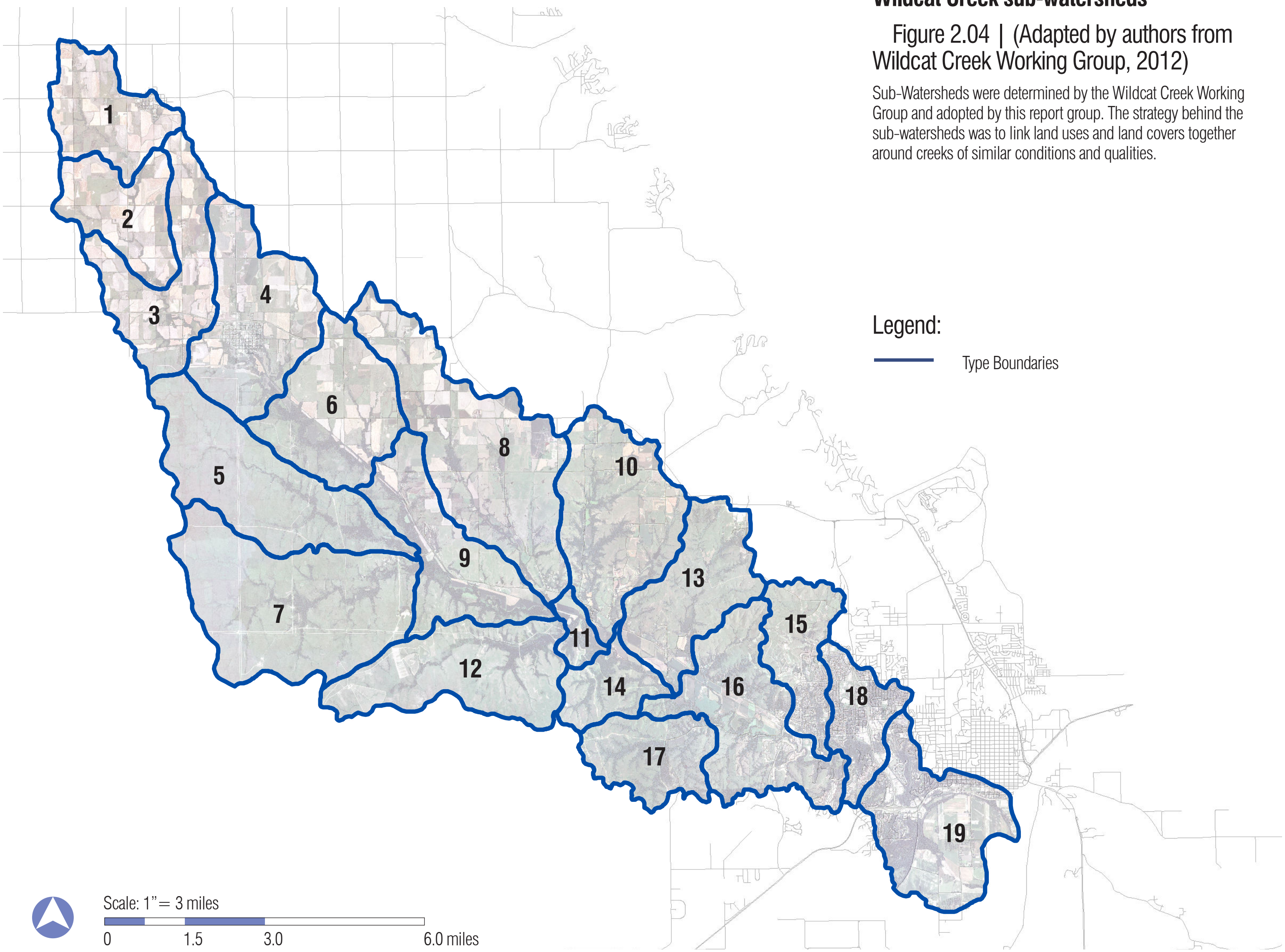
The watershed was first split into six (6) Types base on land use, land type, and topography. Once the types were established, the sub-watersheds from the Wildcat Creek Working Group were overlayed and used as a way to further subdivide the watershed. Separate sub-watershed and type maps are found in figure 2.4 and 2.5.



Wildcat Creek sub-watersheds

Figure 2.04 | (Adapted by authors from Wildcat Creek Working Group, 2012)

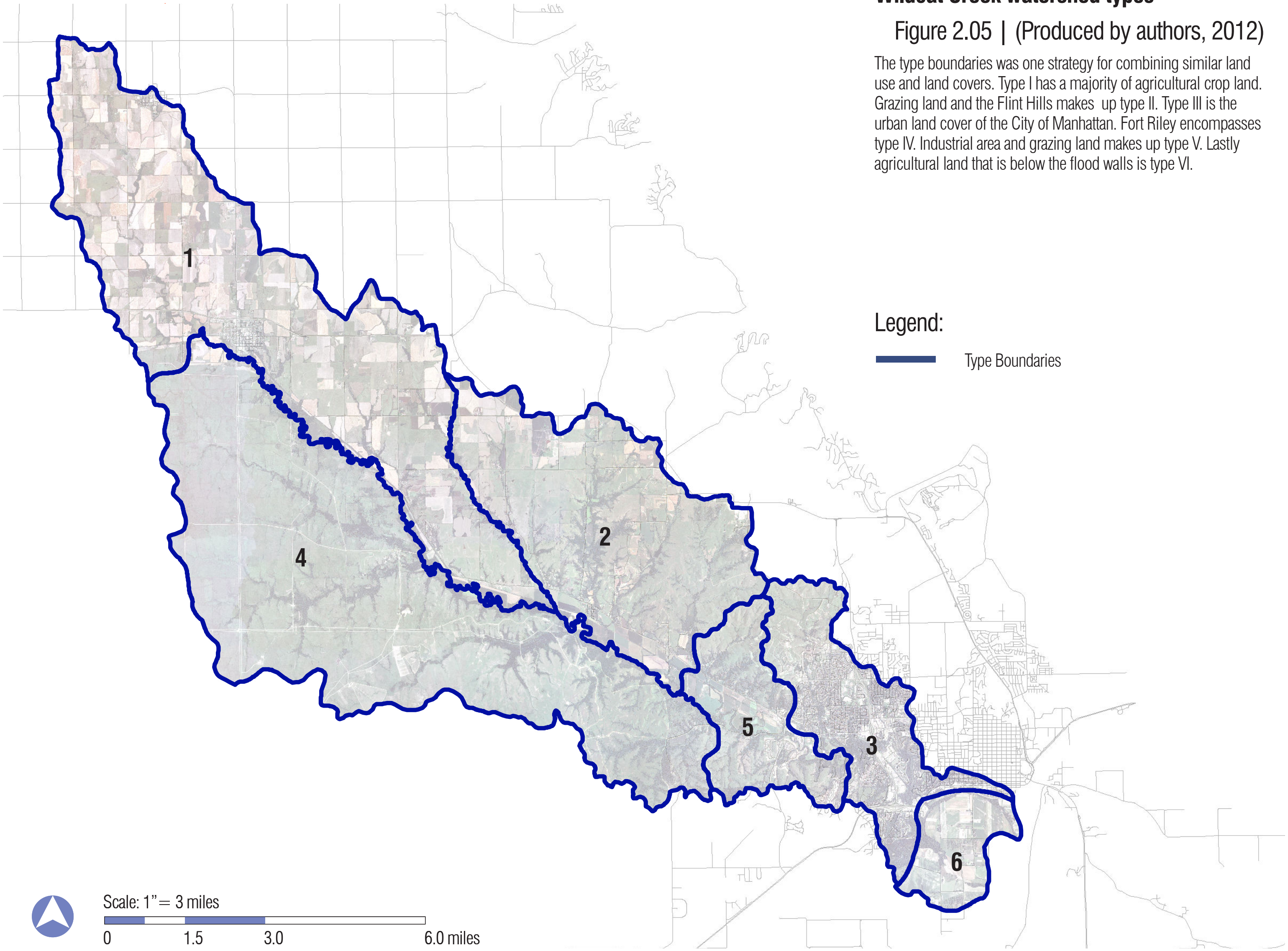
Sub-Watersheds were determined by the Wildcat Creek Working Group and adopted by this report group. The strategy behind the sub-watersheds was to link land uses and land covers together around creeks of similar conditions and qualities.



Wildcat Creek watershed types

Figure 2.05 | (Produced by authors, 2012)

The type boundaries was one strategy for combining similar land use and land covers. Type I has a majority of agricultural crop land. Grazing land and the Flint Hills makes up type II. Type III is the urban land cover of the City of Manhattan. Fort Riley encompasses type IV. Industrial area and grazing land makes up type V. Lastly agricultural land that is below the flood walls is type VI.



Legend:

Type Boundaries

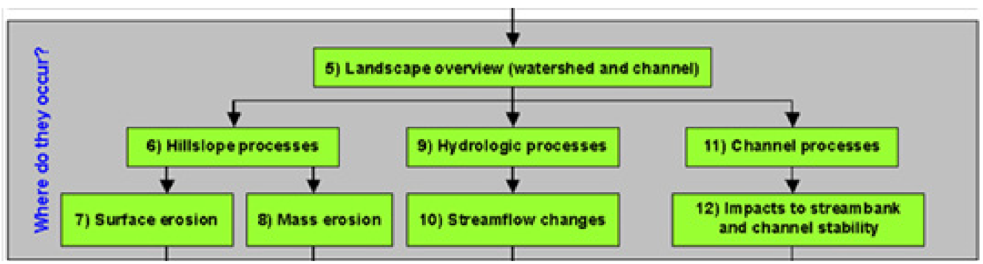
Analysis

Using the aerial photography, LiDAR data, hillslope, and historical data, sub-watersheds were individually screened to identify areas and processes that have a high risk of impact on sediment supply and channel stability. The group defined these areas of high risk as "hotspots" informed by Steps 5 through 12 of the RLA process (figure 2.06). Using the gathered data the group visually examined the topography, hillshade processes, and aerial photography from 1950 and 2008 to determine areas that appeared straighter or have been channelized. The group also pinpointed areas with limited wooded vegetation or a loss in vegetation, areas with urban development, and land use practices that would cause high levels of runoff (e.g. non-terraced agriculture and tank routes) within each sub-watershed.

Hotspots were discussed and revised on a case by case basis. After all the types were looked at together, some hotspots were added to make all the types consistent in the method in which they were selected. The hotspots were given a rating of one, two, or three according to the ambiguity of conditions observed in aerial photography and the need to make field observations during site visits. A rating of one identified hotspots that were imperative to visit, a rating of two identified those that were recommended to visit, and a rating of three was assigned to the hotspots that were undoubtedly contributing to sediment excess and channel instability. Hotspots and the site visit route is shown in figure 2.07.

Site Visit (figure 2.07)

The second objective of bringing clarity to potentially problematic areas was undertaken through ground truth and site visits. A route was established according to hotspots given a priority of one or two (figure 2.07), and a checklist was developed for field observation (Appendix B: table B.01-B.15). The checklist was formed to have a consistent list of criteria for choosing hotspots that were in question. The criteria were based on the land activities that impact sediment and channel stability and the factor of disturbance in the area. The checklist also allowed a way to track what was seen in the field, where problems occur, and what problems exist. Working from southeast to northwest, all sub-watershed types were visited with the exception of Fort Riley due to limited access. Eleven different hotspots were up for verification all but two were identified as finalists for the Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC) assessment level. The map in figure 8 serves as a contextual reference for the narrative summaries to follow. Each visited hotspot is labeled based on the type number first then the hotspot number.



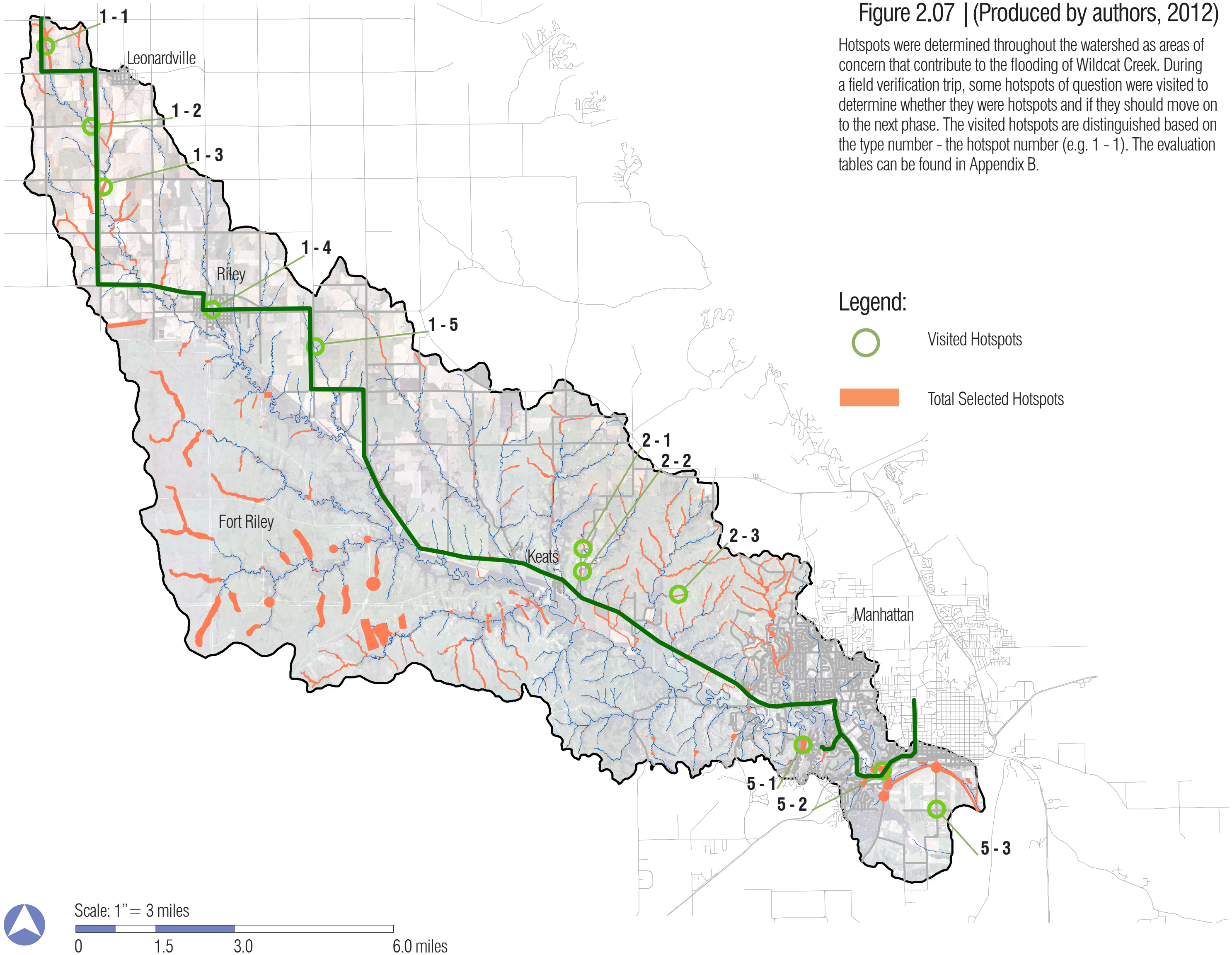
Steps 5 through 12 of RLA process

Figure 2.06 | (U.S. EPA, 2011)

Hotspots and visited locations

Figure 2.07 | (Produced by authors, 2012)

Hotspots were determined throughout the watershed as areas of concern that contribute to the flooding of Wildcat Creek. During a field verification trip, some hotspots of question were visited to determine whether they were hotspots and if they should move on to the next phase. The visited hotspots are distinguished based on the type number - the hotspot number (e.g. 1 - 1). The evaluation tables can be found in Appendix B.



Synthesis

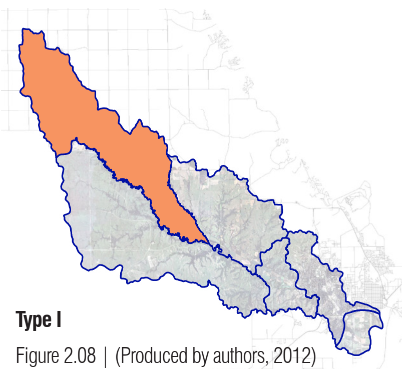
The final step in the RLA assessment was to determine which sub-waterheds areas are to be assessed more critically in the RRISSC phase. By combining the field verifications of the identified hot spots that were of questionable erosive potential with the aerial assessment of each sub watershed the group was able to determine which areas would move on to the RRISSC phase. It is important to note that while some hot spots will be moving to the next assessment level, it does not necessarily mean that the entire sub-watershed where the spot is located will be advancing as well. Hot spots are primarily an identification of areas that are major contributors to surface erosion, and not solely used to identify which sub-watersheds advance within the WARSSS assessment process. The identified hot spots within sub-watersheds that are not advancing to the next level of WARSSS will still move to the RRISSC level. This means that by analyzing each sub-watershed and the hot spots within them, an accurate distinction can be made as to which sub-watersheds as a whole will be more thoroughly assessed in the next phase, and which sub-watersheds include just hot spots that will need move on to the next phase.

Additionally, aerial photography, GIS, and site visits verified the land activity within each sub-watershed. These land activities gave insight as to its impact on sediment movement and channel stability and the disturbance factors contributing to those activities. This information was also utilized to determine the final areas to exclude from future analysis, and which areas to assess more critically in the RRISSC assessment level. The entire RLA process up to this point has contributed to the synthesis of the analysis for each sub-watershed and hot spot. As previously mentioned the sub-watersheds were grouped according to land use activity into types. Type I is predominately agricultural tillage, Type II is an agricultural valley with larger stream types and expanding development, Type III is the city of Manhattan, Type IV is Fort Riley, Type V is urban expansion and grazing land, and Type VI is agricultural land below the flood wall and heading toward the Kansas River. Due to similar land uses, the erosion and hillshade conditions were similar in sub-watersheds resulting in the same movement on to the next level (RRISSC) within the type. Types moving forward are shown in figure 2.14. The types are identified and summarized according to their status within the WARSSS assessment process.

Type I: Agricultural Land

Type I sub-watersheds are located on the northern edge of the watershed (as shown in figure 2.08). Between Keats and Riley up to Leonardville the land is a mixture of terraced and non-terraced agriculture land. Many farmers have chosen to use the terraced agriculture as visible through crop lines. Beyond Riley, there appears to be more non-terraced agriculture fields. The fields were based on the public land survey system that was used to divide Kansas when it was originally settled by Europeans. Type I is focused on agricultural land with one small town, Riley within its boundary. Type I is in the most upstream portion of the watershed. The likelihood of great runoff and a constant stream of water lessens resulting in a greater number of ephemeral streams, especially on the tributaries of Wildcat Creek.

The hotspot locations were determined mostly by de-vegetation and channelization and tend to be found upstream from the Wildcat Creek channel. The de-vegetation is most often found at the ends of streams that run through agricultural fields. The channelization is commonly found in agricultural fields that are in active use and places farmers wanted to get more farmable land both in the main stream and smaller tributaries of Wildcat Creek. The small tributaries that feed into the area run through agricultural fields and were originally altered to improve crop production. The fields have not had recent modification to their appearance beyond the turnover, tillage, and planting of crops each year. Non-terraced agricultural fields create greater surface erosion, resulting in hotspots in those areas along the creek. The de-vegetation occurs sporadically along the tributary channels. Finally, channelization is found in many of the agricultural fields to create larger parcels of land that are large enough to farm and fit within the public land survey system.



Type I

Figure 2.08 | (Produced by authors, 2012)

Type I has a significant amount of agricultural land which still allows the channels to have some sinuosity and freedom without having woody vegetation. Terraced agriculture helps reduce the surface erosion and shows positive use of land by the farmers. However, unstable, Class G stream types (Rosgen, 2006) are seen throughout the Type I area. The tall grass prairie was the native ecosystem of the area with woody vegetation around the creek channel, but not thick forested land.

As aforementioned, the town of Riley is also located within Type I. The town spans about half a square mile with a population of just under 1000 people. A small tributary of Wildcat Creek crosses through the entirety of the town from north to south. Even though Riley is considered a small town, its development has compromised the integrity of the tributary. Hotspots within the town of Riley were determined in areas where the tributary was disrupted by roads, loss of vegetative cover and the presence in impervious surfaces. From aerial photography and site verification, the entirety of the tributary through the town of Riley had been disrupted by a network of roads, crossing the tributary at several points. The loss of vegetation around the tributary to accommodate the development of structures and, consequently, the increased amount of impervious surfaces around the tributary have also compromised the tributary.

From this RLA level analysis, all the sub-watersheds in Type 1 can be carried forward to the RRISSC level. Even with the degree of terraced agriculture found within Type 1, many of the streams have been affected by various factors including the loss of vegetation, non-terraced agriculture and channelization. The presence of Riley further contributes to the degradation of Type 1. (For field verification charts see Appendix B)

Type II: Grazing Land

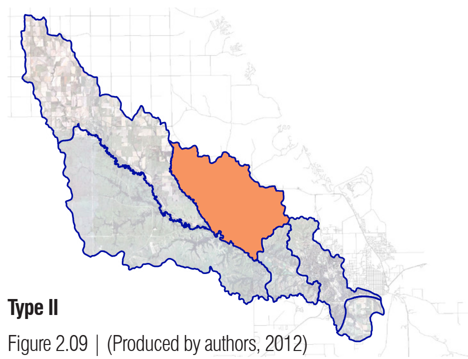
Type II begins at the Type I boundary between Riley and Keats and extends down to the edge of the City of Manhattan development, the Type III boundary (figure 2.09). The majority of the area is grazing land. At the northern edge, there is a small influence of terraced and non-terraced agricultural land is interspersed within the grazing land. The northern portion of Type II is relatively flat as compared to the southern half of the watershed that has more topographical changes. U.S. Highway 24 serves as a valley edge for the Wildcat Creek channel. Agricultural fields lie to the south of the highway.

Overgrazing can be a significant factor in determining whether an area is a hotspot or not. The impact of grazing on an area of land can be determined by the intensity and duration of grazing. Overgrazing increases the chances of soil erosion, as the soil is exposed to the elements (sun, wind, etc.) (WVU Extension Service, 2000). Overgrazed areas in the watershed would be considered as a hotspot due to the increased chance of possible soil erosion and possible sediment runoff. The sediment runoff and damage done to the land is greater and has a larger impact on nearby creeks and tributaries. The other determining factor in hotspots was the lack of woody vegetation around the creek channel. Some tributaries that have lost considerable woody vegetation and have high levels of surrounding sediment are designated as hotspots. Some areas have beneficial grazing land surrounding the creek and take the place of woody vegetation. Since there are not high levels of sediment in those areas, the area is not considered a hotspot.

Type II has a significant amount of grazing land. However, the majority of the grazing land does not seem to be overgrazed and thus does not contribute excess sediment to the creeks and the small amounts of agricultural fields in north part of Type II are terraced. The terraced fields produce less sediment than the non-terraced fields. The amount of sediment that enters the creek in Type II varies from each parcel of land, but not widely seen across the watershed. There are areas that lack woody vegetation around the creek channel, but there are also some areas that have very healthy woody vegetation that helps create stabilization and reduce sediment supply. Significant levels of channelization or channel changes are not present in Type II. Agricultural fields south of U.S. Highway 24 contribute some sediment to the creek, but the fields are in flat flood plain areas that do not produce the same amount of sediment that it would in an area with more topographical changes.

Type II, like Type I also has the presence of a populated area. Keats is an unincorporated town within Riley County. However, unlike Riley, Keats does not have a significant effect on the tributaries in the watershed. There are no significant tributaries crossing through Keats. The streams found in proximity to the town are protected by a significant presence of riparian vegetation. There is less development within the town of Keats as compared to Riley, thus less impervious surfaces are found within the town. Furthermore, a significant area of Keats is dedicated to a county park (Keats Park). Keats Park abuts a major stream protecting the stream from the development to the west. With these aspects in mind, Keats was not considered as a factor that added to the degradation to any of the streams.

As a result, Type II as a whole does not move forward to the RRISSC stage and possesses some very positive aspects and conditions within the watershed as a whole. There are hotspot locations within the Type II sub-watersheds that are moving forward to the RRISSC stage based on the considerations and factors listed above. (For field verification charts see Appendix B.)



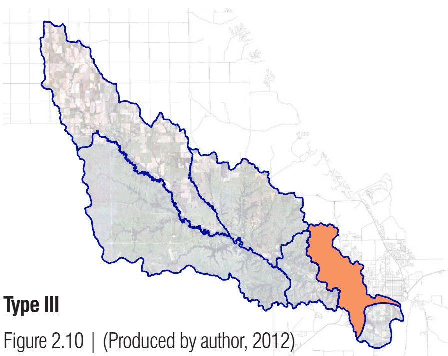
Type II

Figure 2.09 | (Produced by authors, 2012)

Type III: City of Manhattan

The sub-watersheds within Type III include the majority of the Manhattan urban context (figure 2.10). Type III is bordered by Wildcat Creek to the south, expanding northwest to the western ridgeline of Natalies Creek watershed, just north of Wildcat Park. From west to east, Type III transitions from primarily grazing land, to Colbert Hills golf course, into small rural neighborhoods, then into the city of Manhattan. Hotspots within Type III were determined mostly by urbanization, lack of woody riparian vegetation, and slope alteration.

Moving again from west to east, the lack of woody riparian vegetation within the grazing areas creates high potential for sediment displacement due to a low friction coefficient from a lack of root stability, increasing the possibility of runoff. These areas can still provide stable drainage ways depending on the type of grazing being conducted and to what extent. Much like in Type II, grazing plays a role in the increased possibility of surface erosion. The severity of erosion potential is mostly due to grazing intensity and duration. Hot spots in this type were identified because of their lack of woody riparian vegetation, attributed to clearing, and the adjacency to overgrazed areas.



Type III

Figure 2.10 | (Produced by author, 2012)

Continuing to move east, the Colbert Hills Golf Course was identified as a hot spot due to the lack of woody riparian vegetation, and slope alterations that are in place and that were conducted during its construction. While this area is very well kept, it is based on a system that displaces water at a fast pace, increasing the possibility for sediment displacement.

Moving further east into the neighborhoods on the east end of town there are large amounts of channelization, greater amounts of impervious surfaces, and less woody riparian vegetation. The combination of these three issues results in the entire urban area of Manhattan being identified as a hot spot. Having said this, there are some areas that can be directly identified as contributing larger amounts of sediment displacement than others. Two of these areas include Little Kitten Creek and CiCo Park and the tributary extending south from it into Wildcat Creek proper. Little Kitten Creek provides some woody riparian vegetation; however it winds through neighborhoods on the east end of town collecting street and roof top runoff, increasing the overall discharge of the tributary without allowing for any flood plain. The tributary flowing through CiCo Park has been severely channelized to the point where in the near future houses adjacent to the creek will need to either be moved or the creek will need it's bank structurally reinforced, only slowing down the erosion problem. The channelization process straightens the flow of water, increasing the overall discharge, in turn contributing to the erosion process. This narrowing of the creek eliminates the use of floodplains which decreases the streams ability to 'spread out' during times of excess flow in order to slow down the velocity and allow sediment to settle.

All the sub-watersheds delineated in Type III will move forward to the RRISSC stage due to these sediment contributing factors: urbanization, lack of woody riparian vegetation, and slope alteration and channelization. The urban portion of this sub-watershed will need to be addressed more closely on a site by site basis in order to understand where waterways are contributing to stormwater inlets, and where the water is then conveyed. (For field verification charts see Appendix B)

Type IV: Fort Riley

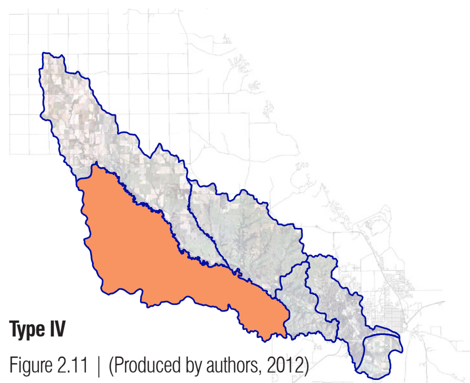
Type IV is located on the Northeastern portion of the Fort Riley military installation (figure 2.11). The area was historically agricultural lands reflecting those of Type I and II, but has since been acquired by the fort for military functions. Aerial imagery reveals evidence of terraced fields that have long since returned to grassy vegetation. While precise land use data was unavailable for type IV, the area is actively used for military training. Possibly the most important aspect of Type IV is the presence of tanks and other large military vehicles on a regular basis as Fort Riley is home to an armored detachment.

Type IV hotspots were determined in most instances due to a lack of woody riparian vegetation or stream disturbance due to vehicular crossings. The removal of woody riparian vegetation is detrimental to most streams from a stability standpoint. Loss of the structural support provided by the root systems of woody vegetation causes the stream bank to become less stable. Thus, areas lacking woody vegetation are susceptible to stream bank erosion and excess sedimentation. Lack of vegetation is the primary reasoning behind the identification of hotspots in the northern portion of Type IV.

However, as you move south, aerial imagery shows evidence of soil disturbance in several areas as well as near tributaries. This is cause for concern as tracked vehicles such as tanks can produce significant disturbance to the soil surface as well as compaction. By damaging plants and reducing the root structure present vehicles create soil stability issues. In contrast, the weight of the vehicle causes compaction in the sub soil reducing infiltration rates. In combination these factors can produce a large amount of surface erosion and excess sediment flow. Dirt roads found in many parts of rural America can be used as an example of this. While the surface degrades over time from tire tread disturbance and requires frequent grading, the base of the road continues to harden with use, creating a solid platform for vehicular traffic. The effects of this compaction in terms of infiltration are evident in the requisite drainage ditches found alongside these dirt roads. Vehicular soil compaction can contribute to vegetation issues as well. As the soil around trees is compacted the ability for roots to function properly in terms of water and nutrient uptake is reduced causing health problems or death. It is easy to see that an area used for tank warfare training is highly susceptible to these issues.

The southernmost sub-watershed of type V consists mainly of native grasslands, and canopy cover. The reason this sub-watershed was carried into the next level was because of the steep slopes and lack of riparian vegetation along many of the smaller streams that eventually flow into the main channel of Wildcat Creek. There is a corridor throughout the sub-watershed that contains bare earth that appears to be recently tilled ground. This corridor crosses many of the streams and has a potential to contribute to excess sediment.

As a result of issues associated with land use, vegetation scarcity, and road crossings, the type IV sub-watersheds must move forward into the RRISSC stage of the WARSSS process. Areas of the type IV sub-watersheds that were designated to be hotspots will need to be the focal points of the area in subsequent phases of WARSSS.



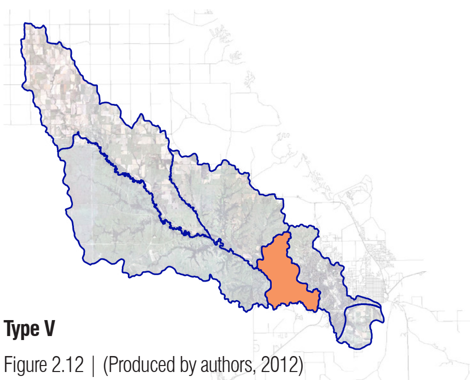
Type IV

Figure 2.11 | (Produced by authors, 2012)

Type V: Expanding Manhattan

Type V focuses on the southern and wester expansion of the City of Manhattan as well as grazing land that may some day become urban (figure 2.12). All sub-watersheds were advanced to the next phase, Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC). Type V borders the south side of Wildcat Creek. There is a gradual increase in land activities that impact the stream as you move closer to the city of Manhattan. The number of hotspots increases the closer you get to the city of Manhattan.

There were many factors taken into consideration when determining the location of hotspots and the identification of areas where land activities increase sediment and contribute to channel stability problems. The Reconnaissance Level Assessment (RLA) phase of the analysis looks at the character of the area from a general point of view. The main points evaluated were the stream channel stability, stream flow changes, sediment loads, potential for erosion, and lack of vegetation. The most important factor looked at when determining whether or not to include the area for advancement to the RRISSC level was whether or not there was good riparian vegetation. This is because lack of good riparian vegetation means there is a high likelihood for mass erosion . One example of mass erosion was a new neighborhood being built to the south of Wildcat Creek where a steep hillside has been cleared of vegetation for construction. There is a high likely hood of erosion from the hillside entering into Wildcat Creek.



Type V

Figure 2.12 | (Produced by authors, 2012)

The northern most area was the first sub-watershed studied. The area was carried on was due to of the new construction, proximity to the steam channel, and impervious surface, all of which occur directly south of the creek. Erosion due to steep slopes and bare earth create a potential for excess sediment to be carried into Wildcat Creek.

Wildcat Creek Golf Course and Frank Anneberg Park were marked as a hotspot, not because of excess sediment but because this area is now contributing more water from surface runoff and the development associated with the location than before this area was developed.

The main concerns in this area were stream bank erosion, road crossings, and bridges. Box culverts were marked as hotspots for degradation and excess sediment. The southernmost sub-watershed of Type V contains the most impervious surface, channelization, removal of riparian vegetation, road crossings, and changed stream flow. This sub-watershed was selected for the land activities that impact sediment and channel stability. Two hotspots were visited on-site one is located within a neighborhood development. Culverts, new construction, removal of riparian vegetation, road crossings, proximity to roads, and impervious surfaces occur where the stream flows through the neighborhood. The location where the stream flows through the neighborhood is flagged as a hotspot. Once it leaves the neighborhood the riparian edge has good vegetation, so this area was determined not to be a major factor contributing to excess sediment supply.

The other hotspot in this area was advanced to the RRISSC level because of the stream bank erosion. The water course is constricted in this area and does not have floodplain contact. The sheer stress and high velocity stays in the stream which leads to more erosive force that can be carried through the stream.

As a result of new development, proximity to the city of Manhattan, impervious surface, road crossings, stream channelization, de-vegetation and land use practices all sub-watersheds within Type V were advanced to the next phase for further assessment. (For field verification charts see Appendix B)

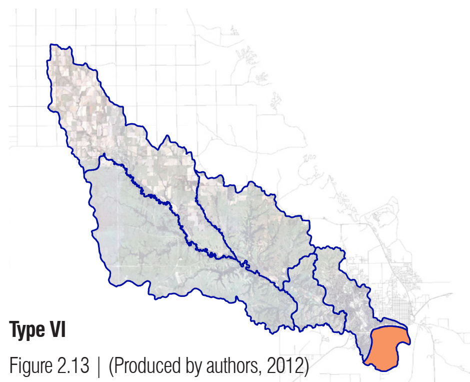
Type VI: Flood Wall

The final sub-watershed type, Flood Wall, is located at the far southeast of the Wildcat Creek watershed where the creek flows directly into the Kansas River (figure 2.13). This portion of the watershed is located below the flood wall, and generally consists of agricultural land. It consists of only one sub-watershed.

Upon initial observation of aerial photos, three areas were flagged as potential hotspots, and the absence of terraces in this predominantly agricultural area was noted as well. The first potential hotspot was marked where South Manhattan Avenue crosses Wildcat Creek. Two additional areas were flagged for minor riparian removal, and the entire northern edge of the sub-watershed was included for having noticeably thinner riparian vegetation than the northern bank where the historic rail line has been retrofitted to a paved and crushed limestone recreational trail.

After driving to see the site on the day of field verifications, it was determined that these hotspots and the sub-watershed as a whole can be eliminated from further assessment at the RISSCC level. While the fields are not terraced and therefore likely to contribute excess sediment, the general slope is not steep enough to contribute significant sediment. The critical areas contributing sediment are further up the creek, and this subwatershed is ultimately below the region of major concern.

Also, due to the immediate proximity to the Kansas River and the fact that the entire area will flood in a large rain event, it is not advisable to invest in wetland construction in this area. (For field verification charts see Appendix B)



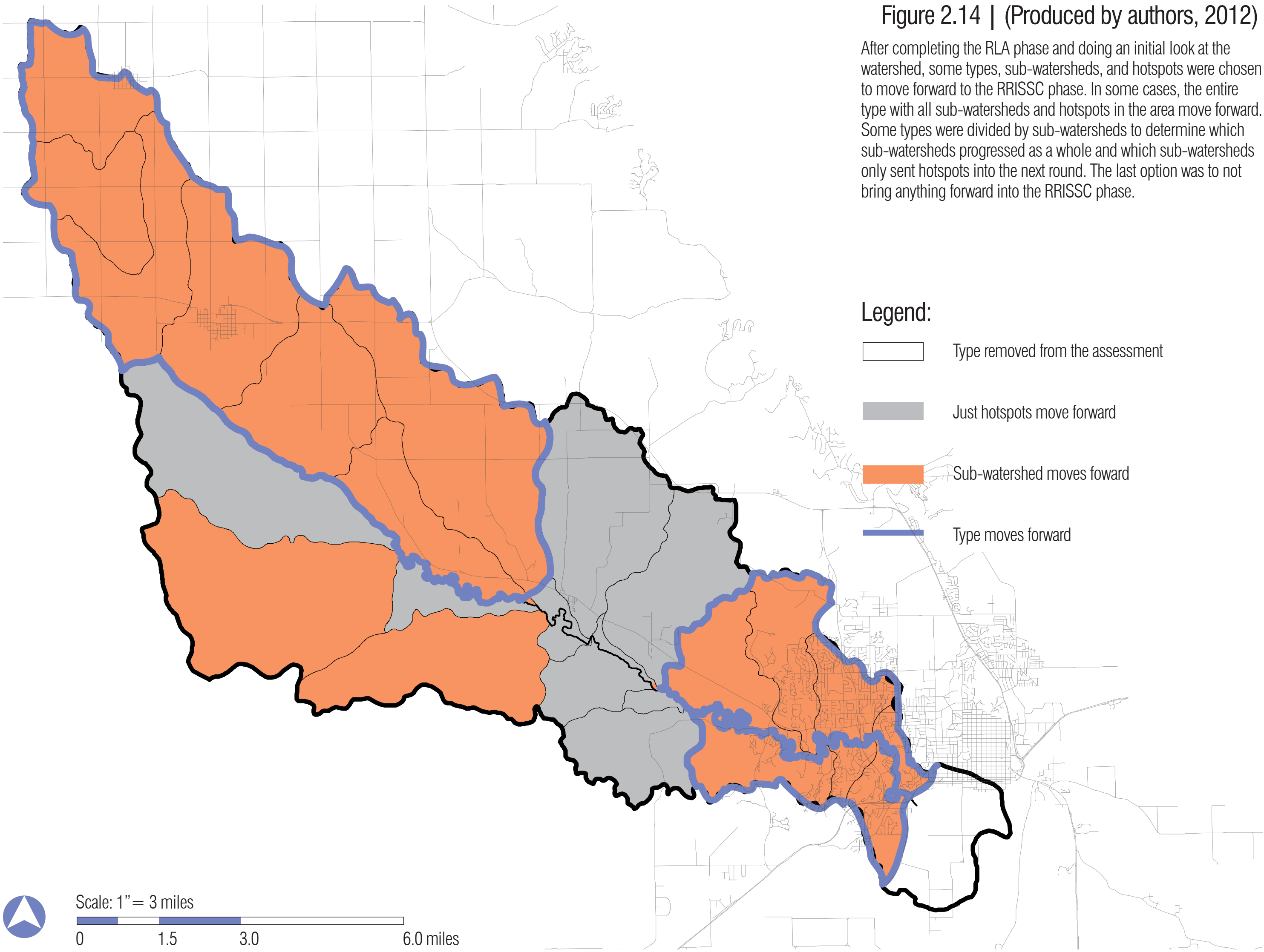
Type VI

Figure 2.13 | (Produced by authors, 2012)

Moving forward to the RRISSC phase

Figure 2.14 | (Produced by authors, 2012)

After completing the RLA phase and doing an initial look at the watershed, some types, sub-watersheds, and hotspots were chosen to move forward to the RRISSC phase. In some cases, the entire type with all sub-watersheds and hotspots in the area move forward. Some types were divided by sub-watersheds to determine which sub-watersheds progressed as a whole and which sub-watersheds only sent hotspots into the next round. The last option was to not bring anything forward into the RRISSC phase.



Conclusions

Out of the six different types, type I, III, IV, and Type V were selected to move on to the Rapid Resource Inventory for Sediment and Stability Consequence (RISSCC) level assessment. Two types, type II and type VI, were eliminated from further assessment. In type II the hotspots will still advance into the next round in order to be evaluated in a more detailed assessment for their impact on sediment supply and stream bank stability within the watershed. Type VI will be eliminated altogether from future stages of the WARSSS assessment due to the location within the watershed.

The completion of the RLA phase gave the group basic familiarity with the relative conditions of the Wildcat Creek Watershed and the land activities taking place throughout. The RLA phase of the assessment has identified a general understanding of the locations and processes within the watershed that are affecting channel stability and contributing to excess sediment supply.

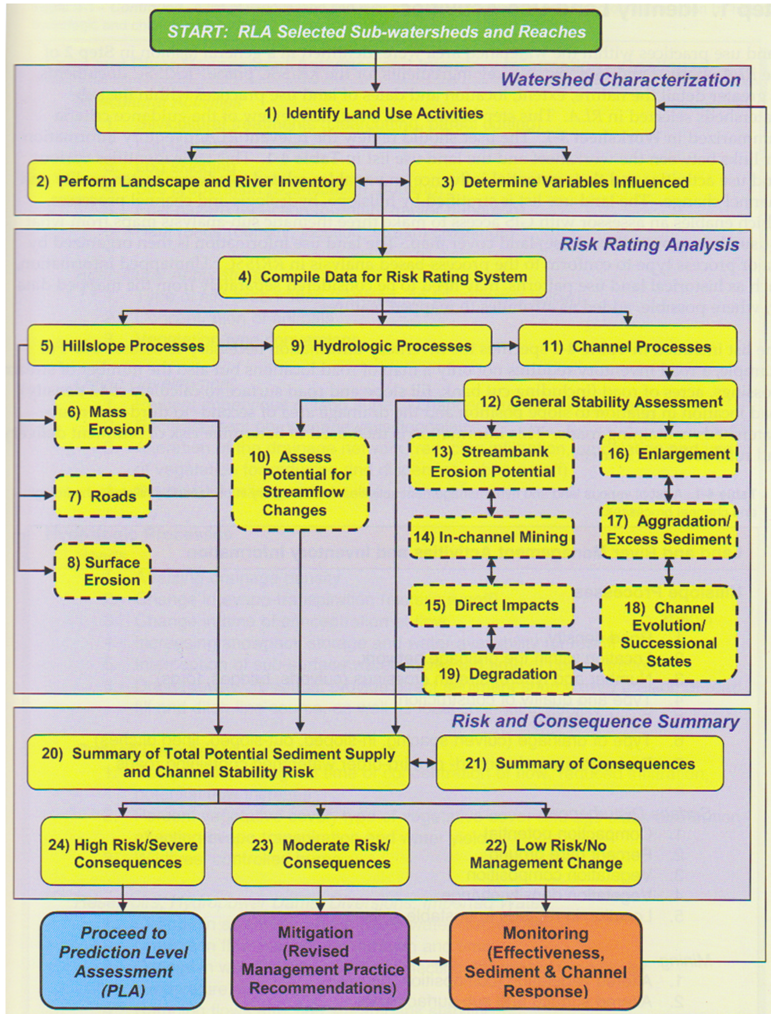
With this first phase complete, the group conducted the second phase of the WARSSS process. The second phase, Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC) was used to make a more detailed assessment of the problem areas within the Wildcat Creek Watershed.

WARSSS | RRISSC

The chapter is dedicated to the Rapid Resource Inventory for Sediment and Stability Consequence phase of the Watershed Assessment for River Stability and Stream Supply in the Wildcat Creek Watershed.

The risk analysis for sediment supply and stream channel stability (RRISSC) process is detailed in the following discussion and figure 3.01. The basis for the rating of risk in each of the following categories is a five level scale, five being the highest risk and one the lowest. Once all categories were assessed, the numerical totals for each were added and divided by the number of categories. The resultant number represents the risk assessment.

RRISSC evaluations were calculated for 19 sub-watersheds (shown in figure 3.22). Sub-watershed 19 was only evaluated northwest of the levee on the south of Fort Riley Boulevard in the City of Manhattan. Each sub-watershed was rated for mass erosion, roads, surface erosion, streamflow change, streambank erosion, direct channel impacts, channel enlargement, aggradation/ excess sediment, channel evolution/ succession states, degradation. Final results of subwatersheds moving forward to the PLA phase are found in table 3.13.

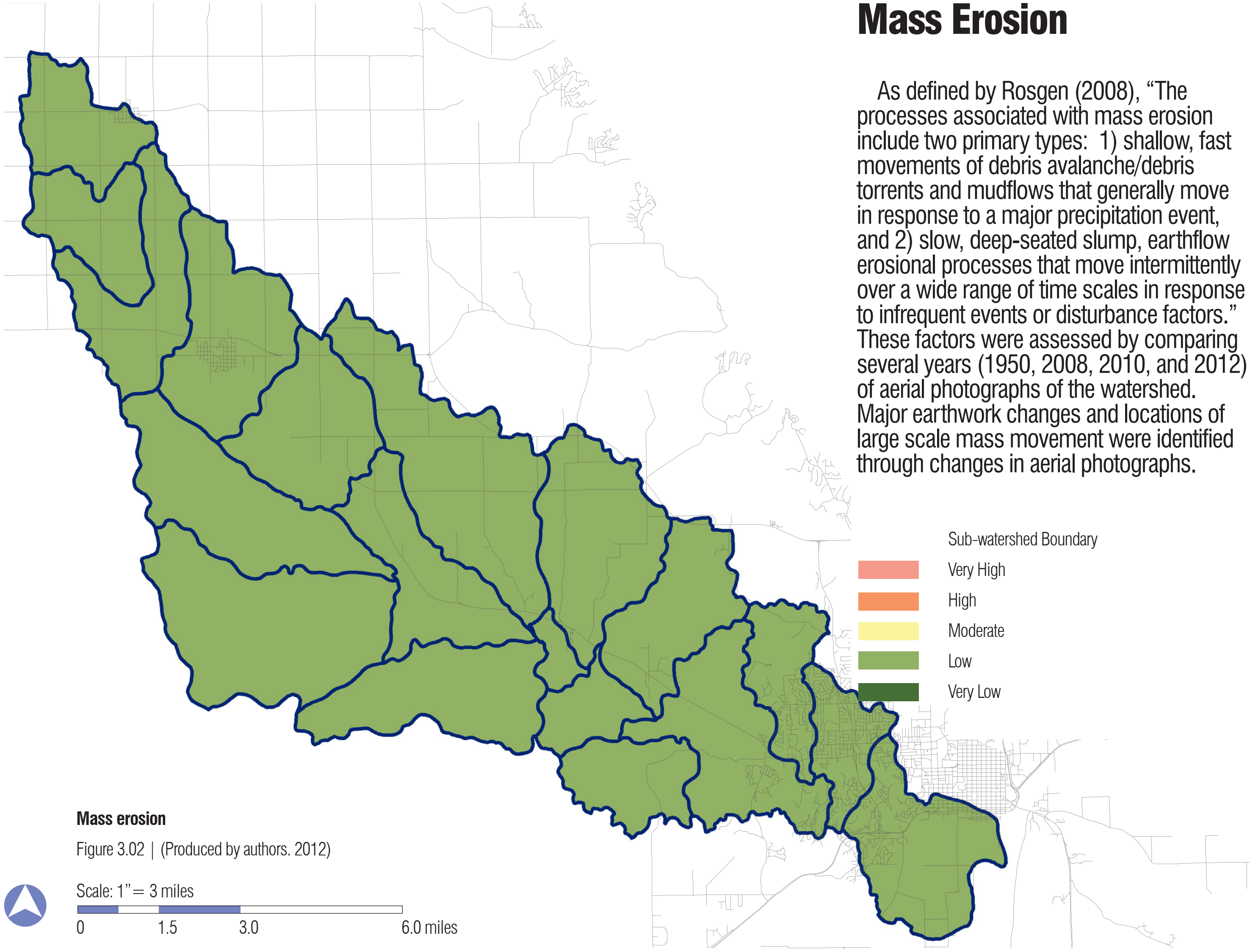


RRISSC process diagram

Figure 3.01 | (Rosgen, 2008)

Mass Erosion

As defined by Rosgen (2008), "The processes associated with mass erosion include two primary types: 1) shallow, fast movements of debris avalanche/debris torrents and mudflows that generally move in response to a major precipitation event, and 2) slow, deep-seated slump, earthflow erosional processes that move intermittently over a wide range of time scales in response to infrequent events or disturbance factors." These factors were assessed by comparing several years (1950, 2008, 2010, and 2012) of aerial photographs of the watershed. Major earthwork changes and locations of large scale mass movement were identified through changes in aerial photographs.

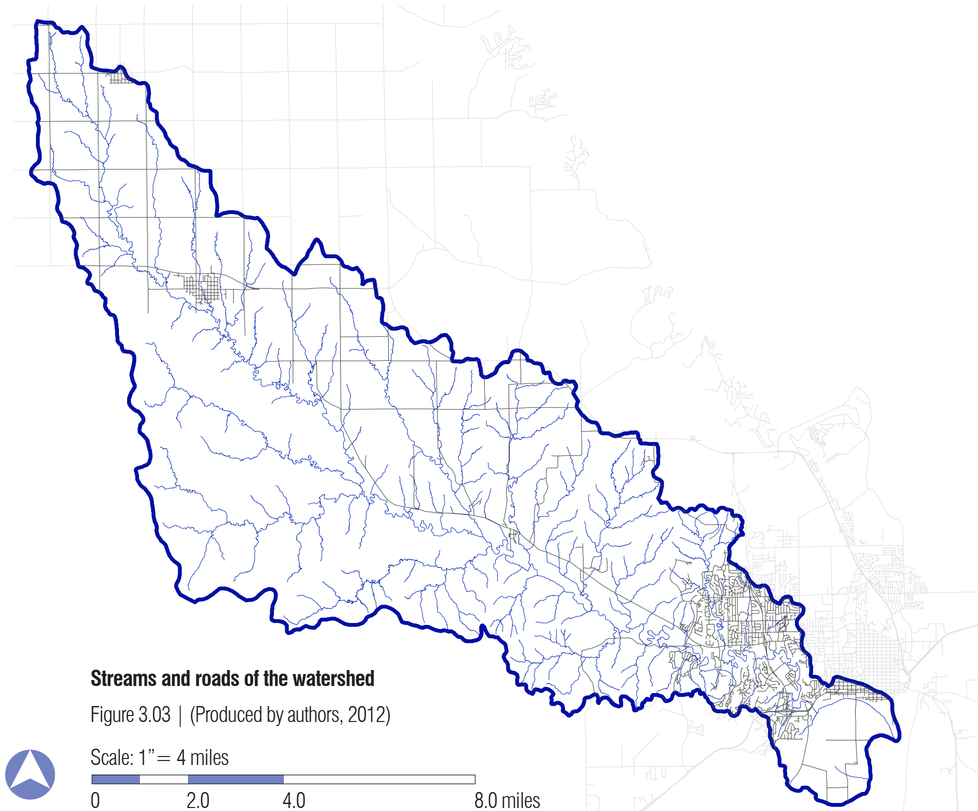


Mass erosion

Figure 3.02 | (Produced by authors. 2012)

Roads

The evaluation of road impacts are important due to the fact that they can produce increased sediment from a variety of sources such as cut banks, road fills, road surfaces and ditch-line erosion. The roads (shown in figure 3.03) can cause increased degradation or aggradation of stream channels and blockages at culverts that increased stream instability and decreased floodplain function. The data required for this analysis included acres of sub-watershed, acres of surface disturbance of roads including road surface, number of stream crossings, slope position, age of road, mitigation such as road surfacing, vegetative cover of cut banks and road fills, and presence of unstable, terrain associated with mass erosion processes. The road disturbance size included the road width plus the drainage way of the road. Stream crossings, locations where the stream may have an increase in sediment or shrinkage in streamflow, were counted by hand. The locations of the roads were isolated from the slope percentages and an average was calculated for each sub-watershed. The average elevation height of the roads and average length from the road to the stream channel were estimated based on aerial photographs. The slope percentages of the land were compiled for each sub-watershed. The adjacency of the road to the stream also considered the road crossings and conditions where the road runs parallel to the creek channel. Results are shown in figure 3.04 and table 3.01.

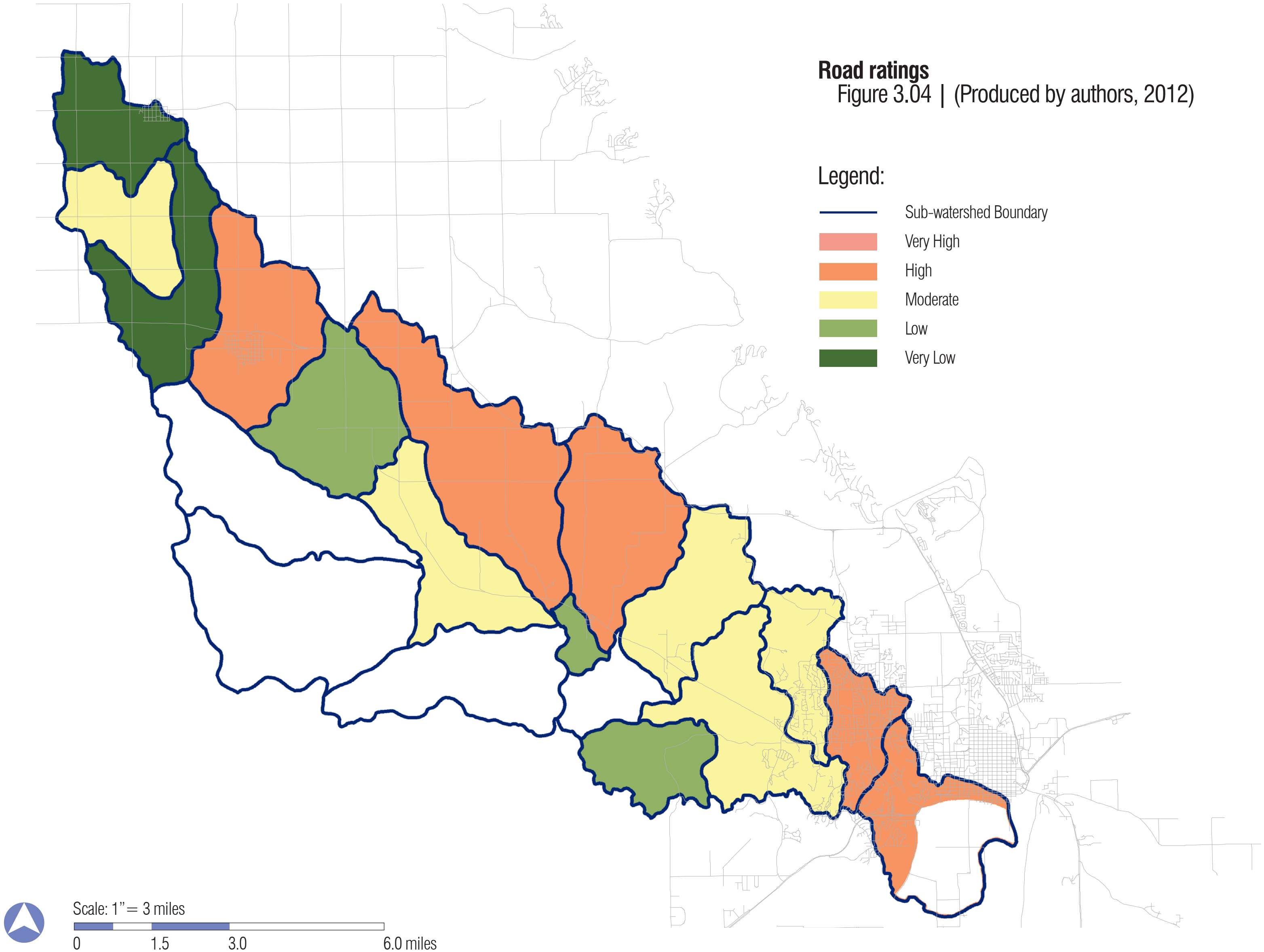


Streams and roads of the watershed

Figure 3.03 | (Produced by authors, 2012)

Scale: 1" = 4 miles

0 2.0 4.0 8.0 miles



Road ratings
Figure 3.04 | (Produced by authors, 2012)
Legend:
Sub-watershed Boundary
Very High
High
Moderate
Low
Very Low
Scale: 1"= 3 miles
0
1.5
3.0
6.0 miles

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Sub-watershed Location (I.D.)	Acres of Sub-watershed (200–5000 acres)	Acres of Disturbance of Road (Include Cut Bank, Fill Slope, Road Surface)	Number of Stream Crossings	Calculate Road Impact Index [(3)/(2)X(4)] *If Crossings = 0, Multiply by 1.	Slope Position (Lower or Mid-Upper)	Risk Rating: Road Impact Index (5) by Slope Position	Distance of Road Fill to Stream (ft)	Risk Rating: Distance of Road Fill to Stream (ft)	Slope of Road (%)	Risk Rating: Slope of Road (%)	Total Individual Risk Rating Points ∑[(7)+(9)+(11)]	Overall Risk Rating for Potential Sediment from Roads
1. sub-watershed one	2,394	89	7	0.026	Mid-Upper	2	200+	1	2.50%-3.50%	2	5	2
2. sub-watershed two	2,336	50	6	0.013	Lower	4	140-200	1	3.50%-5.0%	3	8	3
3. sub-watershed three	3,302	87	10	0.026	Mid-Upper	2	200+	1	2.50%-3.50%	2	5	2
4. sub-watershed four	4,119	201	17	0.083	Lower	5	70-140	2	3.50%-5.0%	3	10	4
5. sub-watershed five	4,659	x	x	x	x	x	x	x	x	x	0	x
6. sub-watershed six	3,674	56	6	0.009	Mid-Upper	0	200+	1	3.50%-5.0%	3	4	1
7. sub-watershed seven	6,362	x	x	x	x	x	x	x	x	x	0	x
8. sub-watershed eight	6,150	138	21	0.047	Lower	5	70-140	2	3.50%-5.0%	3	10	4
9. sub-watershed nine	3,441	65	8	0.015	Lower	4	140-200	1	2.50%-3.50%	2	7	3
10. sub-watershed ten	4,375	121	16	0.044	Lower	5	70-140	2	3.50%-5.0%	3	10	4
11. sub-watershed eleven	518	9	1	0.002	Lower	0	70-140	2	2.50%-3.50%	2	4	1
12. sub-watershed twelve	3,981	x	x	x	x	x	x	x	x	x	0	x
13. sub-watershed thirteen	3,212	57	7	0.012	Lower	4	140-200	1	3.50%-5.0%	3	8	3
14. sub-watershed fourteen	1,350	1	x	0.000	Lower	0	x	x	x	x	0	x
15. sub-watershed fifteen	2,016	19	16	0.015	Mid-Upper	2	70-140	2	5.0%-7.0%	4	8	3
16. sub-watershed sixteen	4,166	173	24	0.100	Lower	4	140-200	1	3.50%-5.0%	3	8	3
17. sub-watershed seventeen	2,118	18	4	0.003	Mid-Upper	0	140-200	1	3.50%-5.0%	3	4	1
18. sub-watershed eighteen	1,670	445	12	0.320	Mid-Upper	4	38-70	3	3.50%-5.0%	3	10	4
19. sub-watershed nineteen	3,795	449	13	0.154	Lower	4	70-140	2	3.50%-5.0%	3	9	4

Summary of risk ratings for roads

Table 3.01 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

(14)				(15)	(16)	(17)
Adjustments for Construction, Design and Age of Road				Risk Rating Adjustments for Mass Erosion Potential Slump/ Earthflow***	Debris Torrent/ Avalanche: If Erosion Risk and Sediment Delivery Potential is *High*, Raise Final Road Risk Rating to *Very High*	Final Risk Rating of Potential Sediment from Roads
Age of Road: If > 7 yrs and Sediment Delivery Potential = *Low*, Reduce One Risk Category*	Road Surfacing: If Gravel/ Asphalt, then Reduce One Risk Category**	Ditch Line: If Surfacing Out-sloped, Reduce One Risk Category	Vegetative Condition of Cut Banks, Road Fills: If > 50% Ground Cover, Reduce One Risk Category			
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x
x	x	x	x	x	x	x

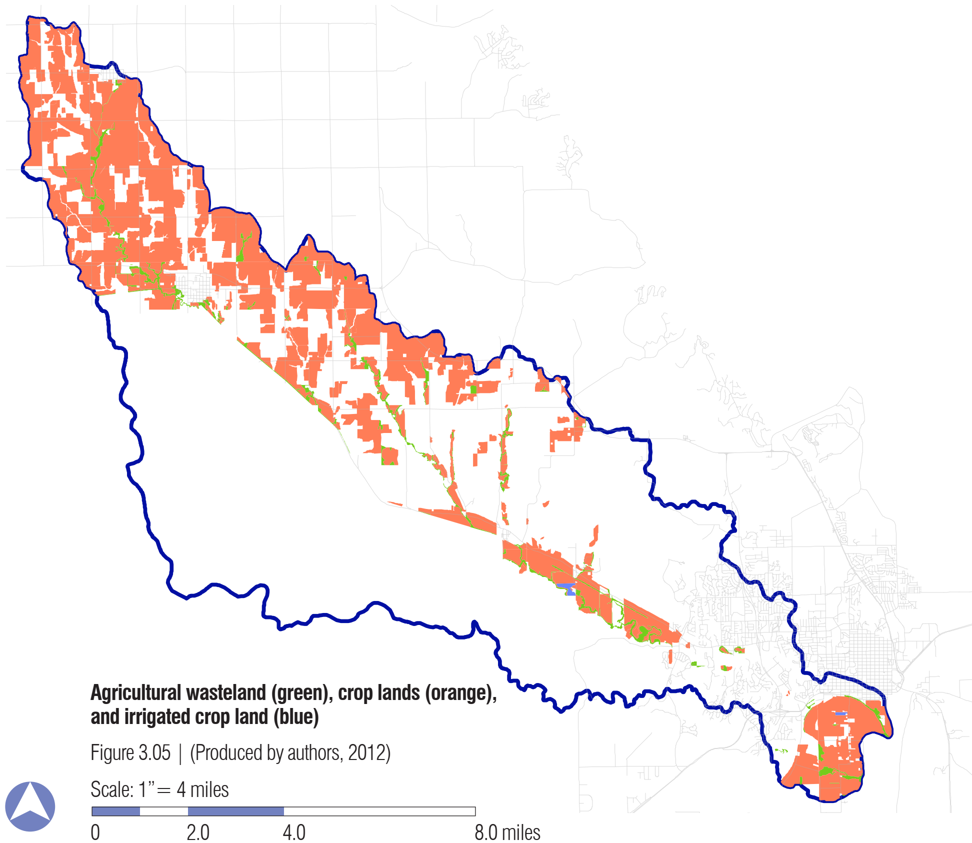
*Unless: Road has not recovered; poor maintenance; poor vegetative cover on cut bank and fill slopes - ditch line is still leading water into stream.

**Unless: Road cut bank, fills and ditch line continue to provide sediment source to stream

*** If risk is high or potential sediment delivery of mass erosion (Worksheet 4-3), then adjust overall risk up one category.

Surface Erosion | Sediment Delivery Potential

The major areas of concern in assessing an area's susceptibility for accelerated erosion were bare soils, compacted soils, and poor land use practices (i.e. agriculture, surface mining, land clearing and silviculture). Seven distinct data sets were analyzed to create the risk rating for this category. The seven data sets were total acres being evaluated for a sub-watershed and soil type erodibility potential, the acres impacted, percent bare ground of impacted acres, drainage density if impacted slope or width of interfluve spacing, slope position and gradient, distance of disturbance to nearest stream, and buffer width of riparian corridor. Areas that surface erosion impacted were calculated from the combination of agricultural wasteland, crop lands, and irrigated crop lands from Riley County land use maps (figure 3.06). The crop land areas were determined as the only areas with more than 50% bare ground. Drainage density was calculated for each sub-watershed by using stream length (length of flow lines) over basin area. A slope percentage of less than ten (10) was used for each sub-watershed. The slope position was determined by taking an average slope of the area impacted. The percent ground cover was the inverse of the percent acreage of the sub-watershed impacted by surface erosion (step 4). The distance of the disturbance to the stream was measured using aerial photography. The stream buffer risk rating was determined by the amount of riparian vegetation. Locations with healthy riparian vegetation were rated very low, while intermittent to no vegetation was rated as very high (figure 3.07 and table 3.02).

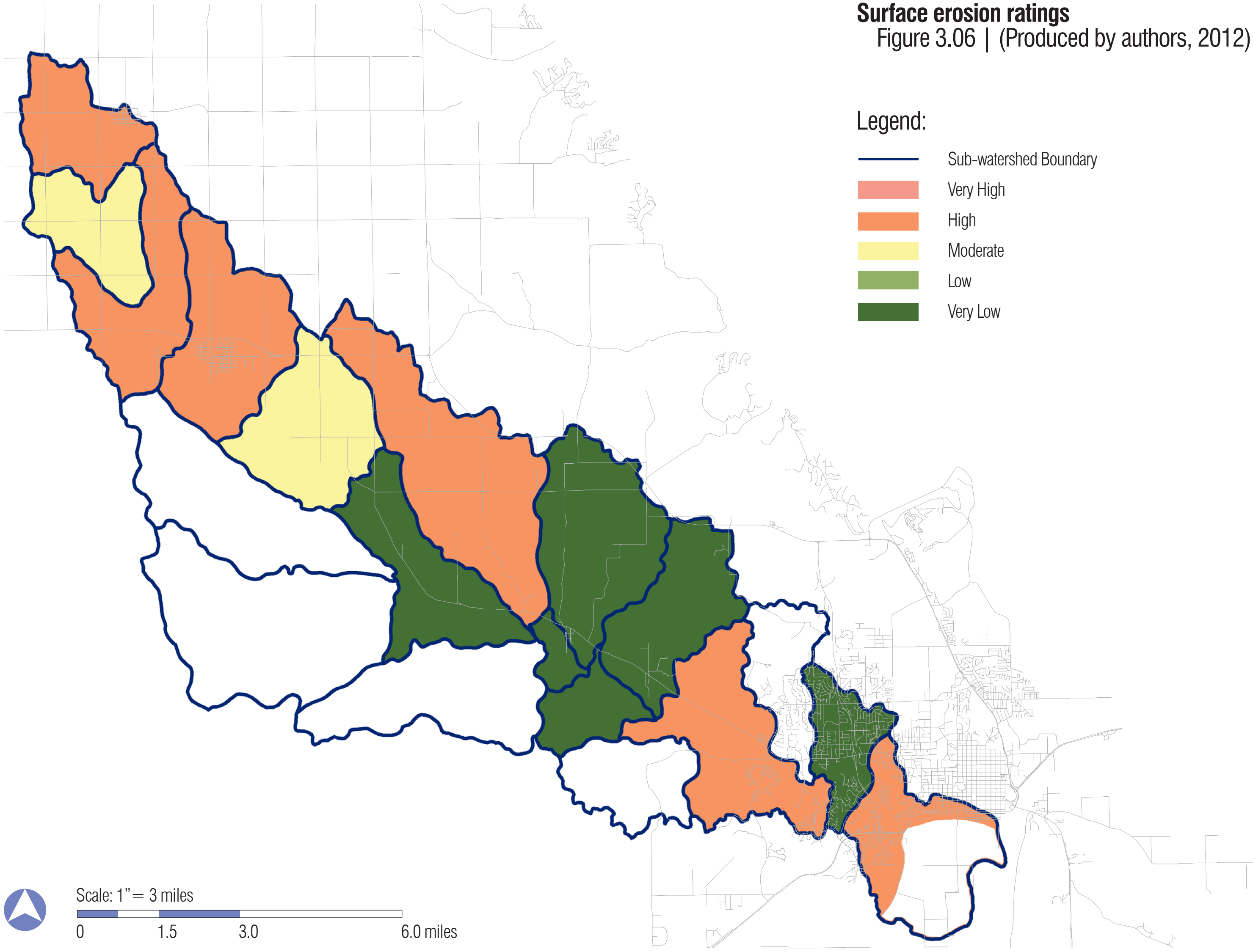


Agricultural wasteland (green), crop lands (orange), and irrigated crop land (blue)

Figure 3.05 | (Produced by authors, 2012)

Surface erosion ratings

Figure 3.06 | (Produced by authors, 2012)



	Surface Erosion Potential								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Sub-watershed Location (I.D.)	Total Acres of Sub-watershed	Acres Impacted (Road acres not included)	Percent of Acres Impacted [(3)/(2)X100]	Acres Impacted (3) with more than 50% Bare Ground	Percent of Acres Impacted with more than 50% Bare Ground [(5)/(3)X100]	Landscape Type (Stable or Unstable)	Overall Risk Rating: Surface Erosion	Converted Ratios or Risk Rating: Drainage Density by Slope Gradient (%)	Risk Rating: Slope Position
1. sub-watershed one	2,394	1,697	70.89%	1,682	99.11%	Unstable	VeryHigh	1.64% 1-VeryLow	3
2. sub-watershed two	2,336	1,734	74.23%	1,637	94.40%	Unstable	VeryHigh	2.21% 1-VeryLow	3
3. sub-watershed three	3,302	2,372	71.80%	2,296	96.80%	Unstable	VeryHigh	1.50% 1-VeryLow	3
4. sub-watershed four	4,119	2,004	48.70%	1,903	95.00%	Unstable	VeryHigh	12.74% 1-VeryLow	3
5. sub-watershed five	4,659	0	0.00%	0	0.00%	Unstable	VeryLow	x	x
6. sub-watershed six	3,674	1,187	32.30%	1,144	90.00%	Unstable	VeryHigh	12.87% 1-VeryLow	3
7. sub-watershed seven	6,362	0	0.00%	0	0.00%	Unstable	VeryLow	x	x
8. sub-watershed eight	6,150	2,954	48.00%	2,778	94.00%	Unstable	VeryHigh	19.95% 1-VeryLow	3
9. sub-watershed nine	3,441	461	13.40%	432	93.70%	Unstable	VeryHigh	14.49% 2-Low	3
10. sub-watershed ten	4,375	604	13.80%	541	89.60%	Unstable	VeryHigh	14.12% 1-VeryLow	3
11. sub-watershed eleven	518	136	26.00%	122	89.70%	Unstable	VeryHigh	3.50% 3-Moderate	3
12. sub-watershed twelve	3,981	0	0.00%	0	0.00%	Unstable	VeryLow	x	x
13. sub-watershed thirteen	3,212	463	14.40%	417	90.00%	Unstable	VeryHigh	17.30% 2-Low	3
14. sub-watershed fourteen	1,350	138	10.20%	114	83.00%	Unstable	VeryHigh	8.37% 3-Moderate	3
15. sub-watershed fifteen	2,016	0	0.00%	0	0.00%	Unstable	VeryLow	x	x
16. sub-watershed sixteen	4,166	697	16.50%	540	78.60%	Unstable	VeryHigh	25.29% 3-Moderate	3
17. sub-watershed seventeen	2,118	0.23	0.01%	0	0.00%	Unstable	VeryLow	x	x
18. sub-watershed eighteen	1,670	29	1.74%	14	48.30%	Unstable	VeryHigh	5.41% 1-VeryLow	3
19. sub-watershed nineteen	3,795	1,661	44.00%	1,530	92.00%	Unstable	VeryHigh	8.35% 1-VeryLow	3

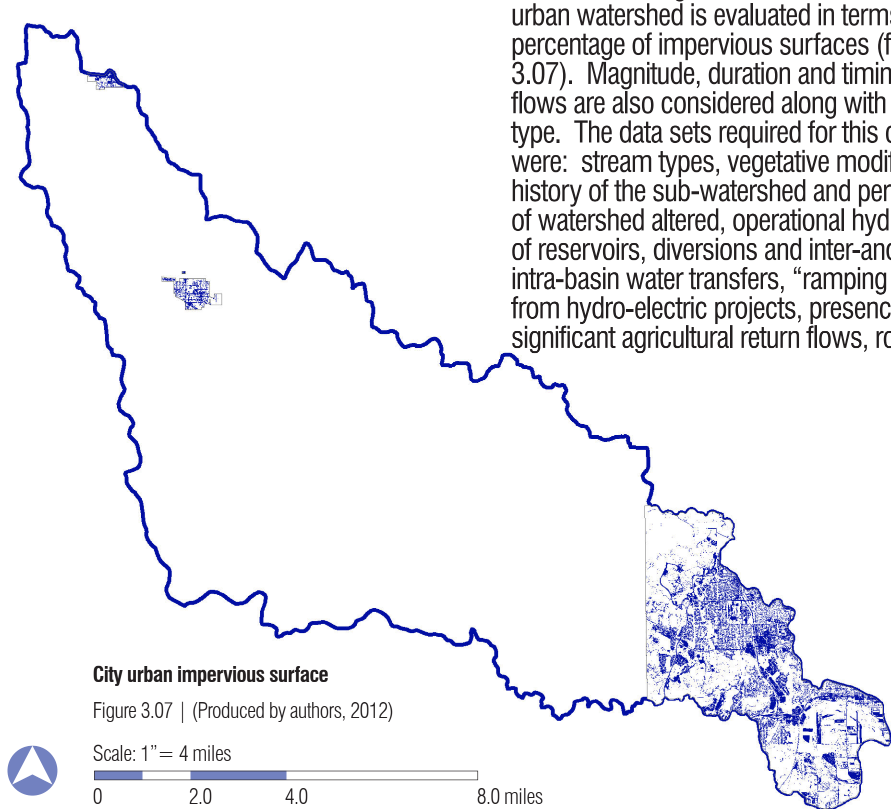
Sediment Delivery Potential					
(11)	(12)	(13)	(14)	(15)	(16)
Conditions for Numerical Risk Ratings of Sediment Delivery Potential				Overall Risk Rating: Sediment Delivery Potential; Use (14)	% of Sub-watershed with H or VH Erosion Potential, and with H or VH Sediment Delivery Potential
Risk Rating: Percent Ground Cover	Risk Rating: Distance of Disturbance to Stream (ft)	Risk Rating: Stream Buffer	Total Individual Risk Rating Points ∑[(9) through (13)]		
4-High	5-VeryHigh	5-VeryHigh	18	High	71.00%
4-High	5-VeryHigh	1-VeryLow	14	Moderate	x
4-High	5-VeryHigh	5-VeryHigh	18	High	72.00%
3-Moderate	5-VeryHigh	5-VeryHigh	17	High	49.00%
x	x	x	x	x	x
2-Low	5-VeryHigh	1-VeryLow	13	Moderate	x
x	x	x	x	x	x
3-Moderate	5-VeryHigh	5-VeryHigh	17	High	48.00%
1-VeryLow	1-VeryLow	1-VeryLow	8	Low	x
1-VeryLow	5-VeryHigh	1-VeryLow	11	Low	x
1-VeryLow	1-VeryLow	1-VeryLow	9	Low	x
x	x	x	x	x	x
1-VeryLow	1-VeryLow	5-VeryHigh	12	Low	x
1-VeryLow	1-VeryLow	1-VeryLow	9	Low	x
x	x	x	x	x	x
1-VeryLow	5-VeryHigh	5-VeryHigh	17	High	17.00%
x	x	x	x	x	x
1-VeryLow	1-VeryLow	1-VeryLow	7	Low	x
3-Moderate	5-VeryHigh	5-VeryHigh	17	High	44.00%

Summary of risk ratings for surface erosion

Table 3.02 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

Streamflow Change

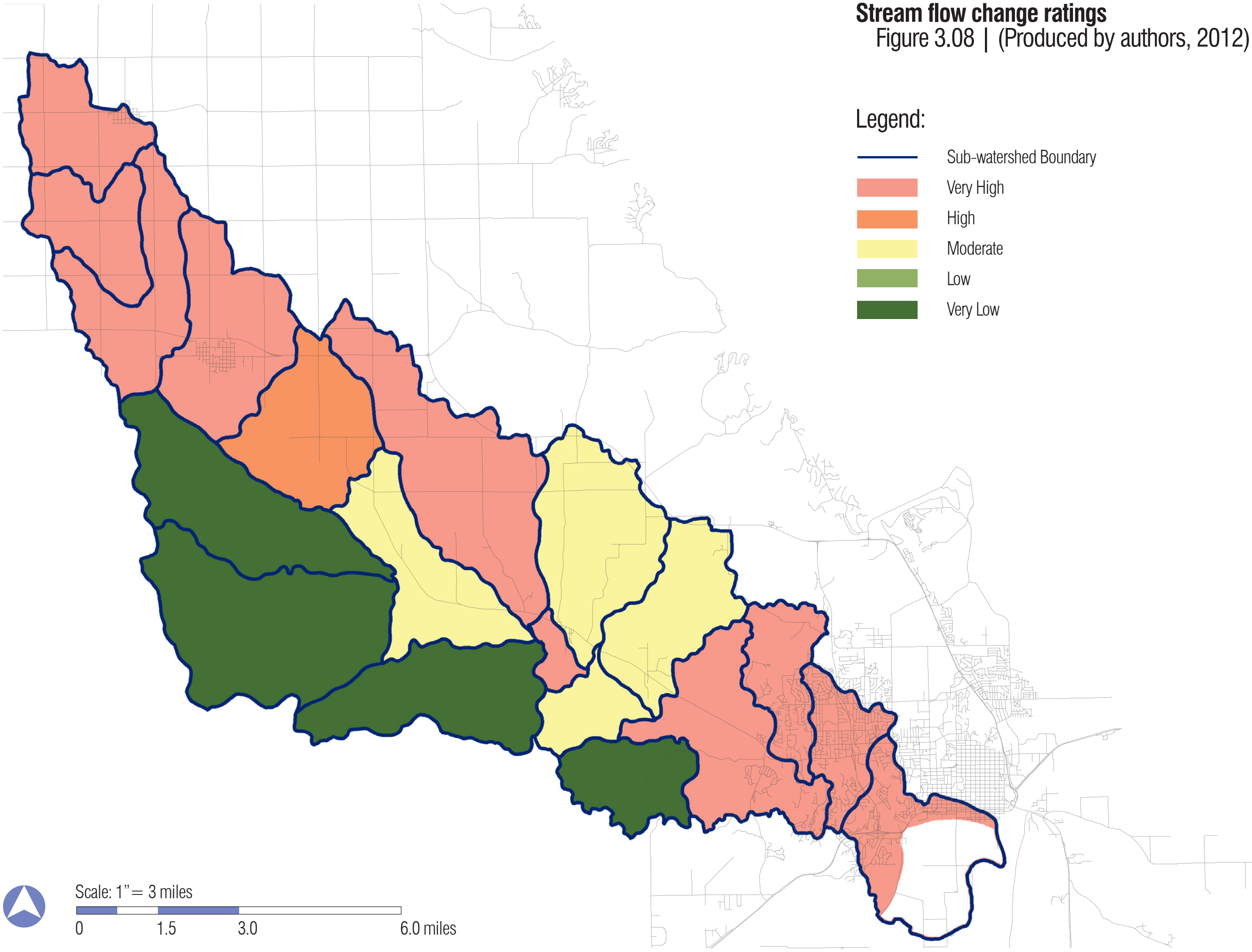
Streamflow changes are evaluated for the potential for increased water yield and associated flow-related sediment increases. The watersheds were assessed as rural or urban. The rural watersheds were evaluated in terms of the percentage in a modified vegetative condition while the urban watershed is evaluated in terms of the percentage of impervious surfaces (figure 3.07). Magnitude, duration and timing of flows are also considered along with stream type. The data sets required for this category were: stream types, vegetative modification history of the sub-watershed and percent of watershed altered, operational hydrology of reservoirs, diversions and inter-and intra-basin water transfers, "ramping flows" from hydro-electric projects, presence of significant agricultural return flows, road densities on steep/dissected slopes, wildfire locations and history, and percent of the urban watershed that is impervious. In rural locations, outside of city limits, vegetation of acres cleared and harvested were calculated based on land use types. Agriculture wasteland, cropland, and irrigated cropland land types were combined to get acreage of cleared and harvested land. All streams were classified based on Rosgen's (2007) method of stream classification with use of the aerial photographs and local knowledge. The classification is based on dominant bed material, entrenchment ratio, width/depth ratio, sinuosity, and slope. Typically, the tributaries all came out as stream type G4 or G6, while the main channel below Riley was most commonly classified as F4. The streams in the northern agricultural lands of the site consisted of silt-clay material, while the lower reaches of the watershed, the Flint Hills Region, had a gravel base. In urban areas, within incorporated city boundaries, impervious surfaces were calculated with an image classification to distinguish impervious from pervious surfaces. The percentage was then calculated from the attributes table. Keats, Kansas was not included in the impervious surface calculations since it is unincorporated. For each sub-watershed, a risk rating was calculated for rural and urban areas, then combined to create an overall risk rating (figure 3.08 and table 3.04).



City urban impervious surface

Figure 3.07 | (Produced by authors, 2012)

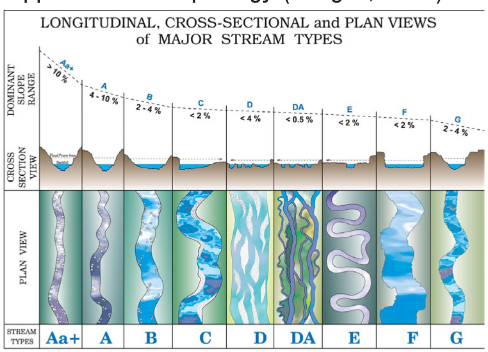
Stream flow change ratings
Figure 3.08 | (Produced by authors, 2012)



Stream Type Classification

Rosgen's Stream Classification System

Stream classification is an important part of the watershed assessment. Eight main stream channel shapes and six bed materials define type of stream (figure 3.09 and table 3.03). Stream channels can be stable or unstable. Unstable streams are typically incised in the channels with high sediment supply and constant changes. Stable channels are not static channels. They still move and change, but the bank height, bank width, and floodplain elevations stay consistent. Stream types D, F, and G are the most common unstable stream types, while type A,B,and C are commonly stable. There are always situations when the streams do not match the typical stream. In Wildcat Creek, the type F and G channels are generally unstable while the B and C streams in the watershed are generally stable (figure 3.10). Figures 3.9 and table 3.3 show the Rosgen's (2007) stream classification method. More information can be found in Applied River Morphology (Rosgen, 1996).



Stream type images

Figure 3.09 | (Rosgen and Silvey, 1996)

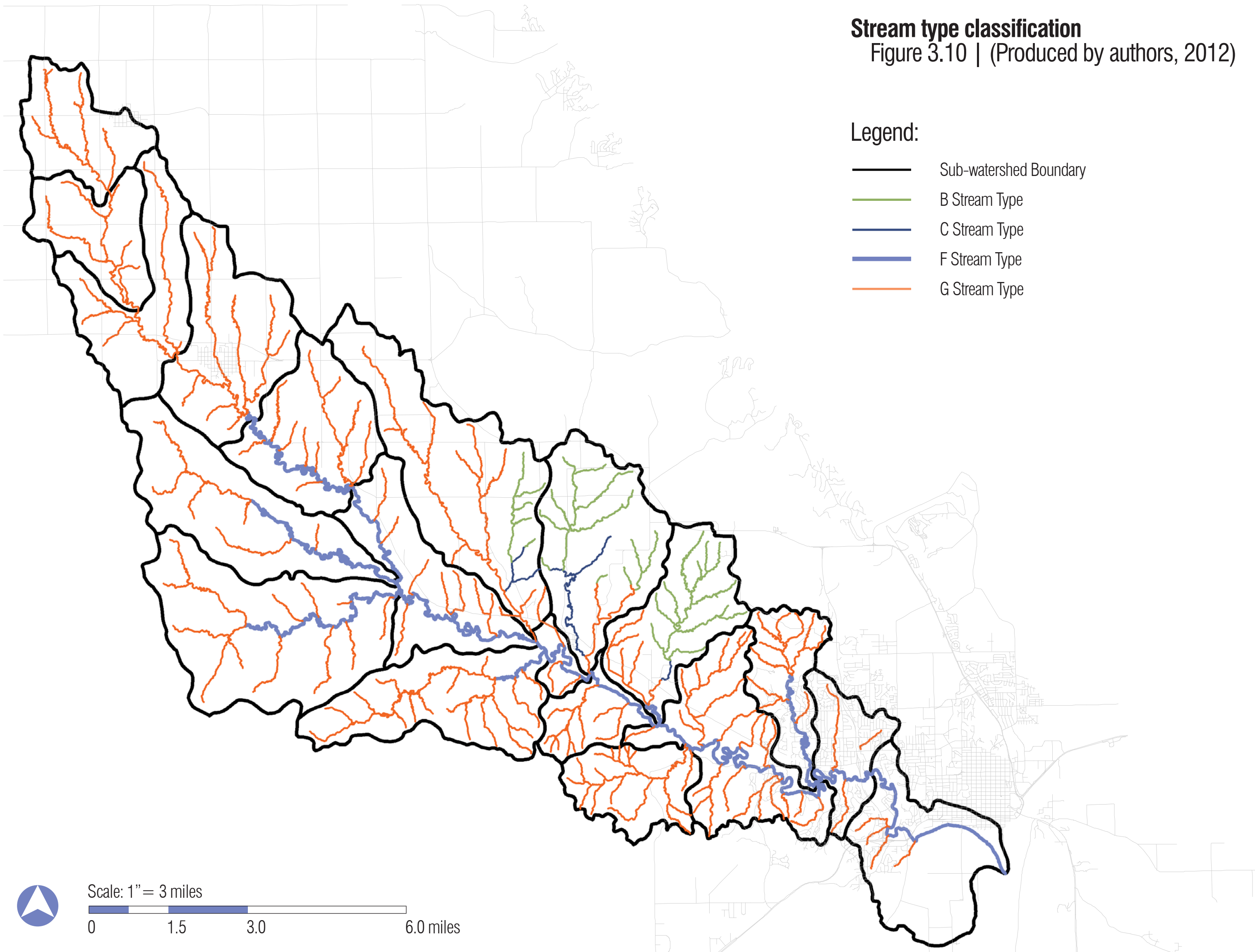
Stream Type	General Description	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Landform/ Soils/Features
Aa+	Very steep, deeply entrenched, debris transport, torrent streams.	<1.4	<12	1.0 to 1.1	>10	Very high relief. Erosional, bedrock or depositional features; debris flow potential. Deeply entrenched streams. Vertical steps with deep scour pools; waterfalls.
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder dominated channel.	<1.4	<12	1.0 to 1.2	.04 to .10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step/pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4 to 2.2	>12	>1.2	.02 to .039	Moderate relief, colluvial deposition, and/or structural. Moderate entrenchment and W/D ratio. Narrow, gently sloping valleys. Rapids predominate w/scour pools.
C	Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains.	>2.2	>12	>1.4	<.02	Broad valleys w/terraces, in association with floodplains, alluvial soils. Slightly entrenched with well-defined meandering channels. Riffle/pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	>40	n/a	<.04	Broad valleys with alluvium, steeper fans. Glacial debris and depositional features. Active lateral adjustment, w/abundance of sediment supply. Convergence/divergence bed features, aggradational processes, high bedload and bank erosion.
DA	Anastomosing (multiple channels) narrow and deep with extensive, well vegetated floodplains and associated wetlands. Very gentle relief with highly variable sinuosities and width/depth ratios. Very stable streambanks.	>2.2	Highly variable	Highly variable	<.005	Broad, low-gradient valleys with fine alluvium and/or lacustrine soils. Anastomosed (multiple channel) geologic control creating fine deposition w/well-vegetated bars that are laterally stable with broad wetland floodplains. Very low bedload, high wash load sediment.
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<.02	Broad valley/meadows. Alluvial materials with floodplains. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology with very low width/depth ratios.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.	<1.4	>12	>1.4	<.02	Entrenched in highly weathered material. Gentle gradients, with a high width/depth ratio. Meandering, laterally unstable with high bank erosion rates. Riffle/pool morphology.
G	Entrenched "gully" step/pool and low width/depth ratio on moderate gradients.	<1.4	<12	>1.2	.02 to .039	Gullies, step/pool morphology w/moderate slopes and low width/depth ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials, i.e., fans or deltas. Unstable, with grade control problems and high bank erosion rates.

Stream type descriptions

Table 3.03 | (Rosgen and Silvey, 1996)

Stream type classification

Figure 3.10 | (Produced by authors, 2012)



		Rural Sub-watershed Risk			
(1)	(2)	(3)	(4)	(5)	(6)
Sub-watershed Location/River Reach I.D. (Include Cumulative Total Watershed following Sub-watershed I.D.s)	Total Acres	Acres Cleared/ Harvested (Include Roads) [Roads + Clearcut = Total]	Percent Cleared/ Harvested of Total [(3)/(2)X100]	Stream Type Most Susceptible to Change or "Weak Link"	Risk Rating: Rural Sub-watershed Risk (Fig. 4-14) (4) by Stream Type (5)
1. sub-watershed one	2,394	1,682	70.30%	G6	5-VeryHigh
2. sub-watershed two	2,336	1,637	70.10%	G6	5-VeryHigh
3. sub-watershed three	3,302	2,296	69.50%	G6	5-VeryHigh
4. sub-watershed four	4,119	1,903	46.20%	G4	5-VeryHigh
5. sub-watershed five	4,659	0	0.00%	G4 (F4)	1-VeryLow
6. sub-watershed six	3,674	1,144	31.10%	G4 (F4)	4-High
7. sub-watershed seven	6,362	0	0.00%	G4 (F4)	1-VeryLow
8. sub-watershed eight	6,150	2,778	45.17%	G4	5-VeryHigh
9. sub-watershed nine	3,441	432	12.60%	G4	3-Moderate
10. sub-watershed ten	4,375	541	12.40%	G4	3-Moderate
11. sub-watershed eleven	518	122	23.60%	G4	5-VeryHigh
12. sub-watershed twelve	3,981	0	0.00%	G4	1-VeryLow
13. sub-watershed thirteen	3,212	417	13.00%	G4	3-Moderate
14. sub-watershed fourteen	1,350	114	8.44%	G4	3-Moderate
15. sub-watershed fifteen	2,016	0	0.00%	G4	1-VeryLow
16. sub-watershed sixteen	4,166	540	13.00%	G4	3-Moderate
17. sub-watershed seventeen	2,118	0	0.00%	G4	1-VeryLow
18. sub-watershed eighteen	1,670	14	0.80%	G4 (F4)	1-VeryLow
19. sub-watershed nineteen	3,795	1530	40.30%	G4 (F4)	5-VeryHigh

Urban Sub-watershed Risk				Adjustments		
(7)	(8)	(9)	(10)	(11)	(12)	(13)
Total Impervious Acres	Percent Impervious [(7)/(2)X100]	Stream Type Most Susceptible to Change or "Weak Link"	Risk Rating: Urban Sub-watershed Risk (8) by Stream Type (9)	Risk Rating: Percent Increase over Bankfull Discharge*	Risk Rating: Percent Reduction in Bankfull Discharge*	Overall Risk Rating: Streamflow Changes (Insert Adjective and Numeric Rating)
28.3	14.90%	G6	5-VeryHigh	x	x	5-VeryHigh
x	x	x	x	x	x	5-VeryHigh
1.6	37.80%	G6	5-VeryHigh	x	x	5-VeryHigh
98.5	32.40%	G6	5-VeryHigh	x	x	5-VeryHigh
x	x	x	x	x	x	1-VeryLow
x	x	x	x	x	x	4-High
x	x	x	x	x	x	1-VeryLow
x	x	x	x	x	x	5-VeryHigh
x	x	x	x	x	x	3-Moderate
x	x	x	x	x	x	3-Moderate
x	x	x	x	x	x	5-VeryHigh
x	x	x	x	x	x	1-VeryLow
1.5	1.60%	B6	1-VeryLow	x	x	3-Moderate
x	x	x	x	x	x	3-Moderate
368.2	18.30%	F4	5-VeryHigh	x	x	5-VeryHigh
364.6	17.50%	F4	5-VeryHigh	x	x	5-VeryHigh
x	x	x	x	x	x	1-VeryLow
630.7	37.80%	F4	5-VeryHigh	x	x	5-VeryHigh
922.3	24.30%	F4	5-VeryHigh	x	x	5-VeryHigh

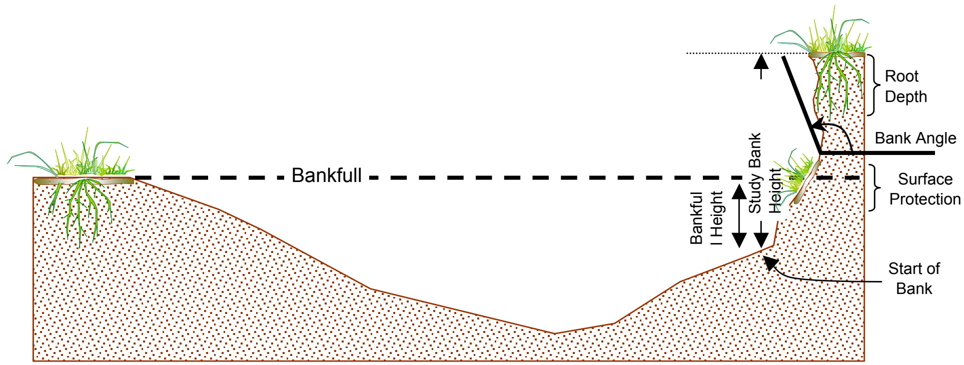
Summary of risk ratings for streamflow change

Table 3.04 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

* Describe source of increased or decreased bankfull discharge adjustment. (e.g., operational hydrology of reservoir.)

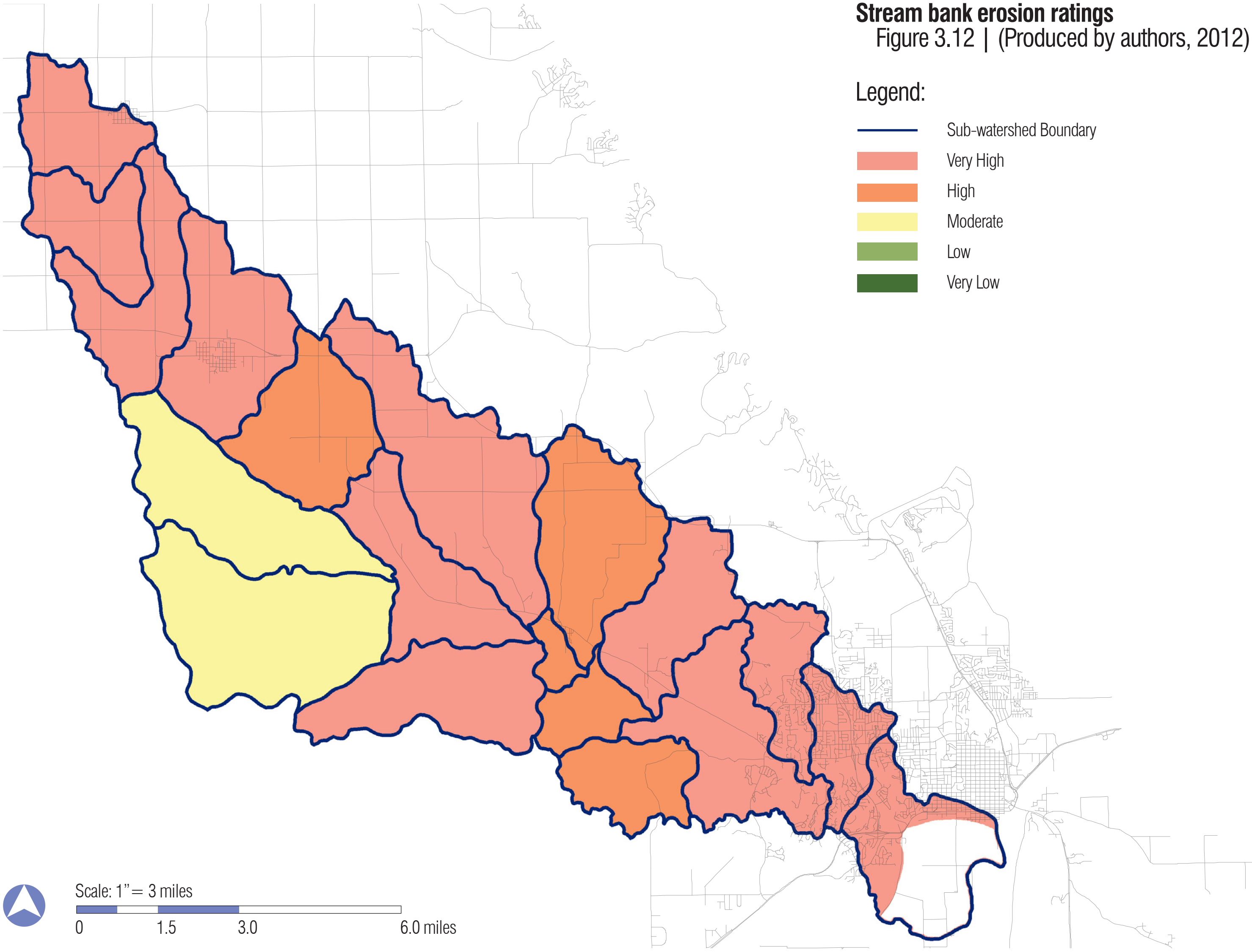
Streambank Erosion

Streambank erosion can be a major impact upon the stability of a fluvial system. The observed data used for this assessment includes: stream types, aerial photographs and drainage area maps, regional curves, bankfull width, radius of curvature, riparian species composition, bank height, and bankfull depth. The vegetation composition of each sub-watershed was determined by local knowledge and aerial photography. The amount of annual grass/forbs, perennial grass, and woody riparian vegetation was identified for each sub-watershed as well as if the sub-watershed has some land that is within city limits or shooting ranges. The bank height ratio (defined in figure 3.11) was determined for each order of streams, then averaged resulting in stream types G and F having a bank height ratio of 1.4-2 and stream types B and C having a bank height ration of 1.2-1.4. The radius of curvature was measured from the aerial photographs. The curvature and Flint Hills Regional Curves then determined the bankfull width. Results are shown in figure 3.12 and table 3.05.



Bank height and bank width depictions

Figure 3.11 | (Rosgen and Silvey, 1996)



Stream bank erosion ratings
Figure 3.12 | (Produced by authors, 2012)

(1)	(2)	(3)	(4)	(5)
Location Code/ River Reach I.D.	Vegetation Composition	Risk Rating: Vegetation Composition	Bank-Height Ratio (Average of first, second, and third order)	Risk Rating: Bank-Height Ratio
1. sub-watershed one	Annual Grasses & Forbs; Perennial Grasses	4-High	>2.0	5-VeryHigh
2. sub-watershed two	Annual Grasses & Forbs; Perennial Grasses	4-High	>2.0	5-VeryHigh
3. sub-watershed three	Annual Grasses & Forbs; Woody Riparian	3-Moderate	>2.0	5-VeryHigh
4. sub-watershed four	Annual Grasses & Forbs; Perennial Grasses	4-High	>2.0	5-VeryHigh
5. sub-watershed five	Good Forbs & Woody Riparian	2-Low	1.4	3-Moderate
6. sub-watershed six	Agricultural Land Annual Grasses; Good Woody Vegetation	3-Moderate	2.0	4-High
7. sub-watershed seven	Good Forbs & Woody Riparian	2-Low	1.4	3-Moderate
8. sub-watershed eight	Annual Grasses & Forbs; Perennial Grasses	4-High	>2.0	5-VeryHigh
9. sub-watershed nine	Good Woody Vegetation; some Annual Grasses & Forbs	3-Moderate	2.0	4-High
10. sub-watershed ten	Good Woody Vegetation; some Annual Grasses & Forbs	2-Low	1.4	3-Moderate
11. sub-watershed eleven	Good Woody Riparian	2-Low	2.0	4-High
12. sub-watershed twelve	Shooting grounds & Good Woody Riparian	3-Moderate	1.4	3-Moderate
13. sub-watershed thirteen	Some Annual Grasses & Perennial Grasses; Some Woody Riparian	4-High	1.4	3-Moderate
14. sub-watershed fourteen	Good Woody Riparian	2-Low	2.0	4-High
15. sub-watershed fifteen	City Limits; Some Woody Riparian	4-High	2.0	4-High
16. sub-watershed sixteen	Some Woody Riparian; Some Annual Grasses & Perennial Grasses	4-High	1.4	3-Moderate
17. sub-watershed seventeen	Some Woody Riparian; Spots of Annual Grasses & Forbs	2-Low	>2.0	5-VeryHigh
18. sub-watershed eighteen	City Limits; Some Woody Riparian	5-VeryHigh	2.0	4-High
19. sub-watershed nineteen	City Limits; Some Woody Riparian; Annual Grasses & Forbs	4-High	2.0	4-High

Summary of risk ratings for stream bank erosion

Table 3.05 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

(6)	(7)	(8)	(9)
Radius of Curvature Divided by Bankfull Width	Risk Rating: Radius of Curvature Divided by Bankfull Width	Total Individual Risk Rating Points by Reach $\sum[(3)+(5)+(7)]$	Overall Risk Rating by Stream Type
6.88	1-VeryLow	10	5-VeryHigh
3.94	1-VeryLow	10	5-VeryHigh
3.72	1-VeryLow	9	5-VeryHigh
4.49	1-VeryLow	10	5-VeryHigh
3.27	1-VeryLow	6	3-Medium
4.49	1-VeryLow	8	4-High
6.22	1-VeryLow	6	3-Moderate
2.37	3-Moderate	12	5-VeryHigh
1.22	4-High	11	5-VeryHigh
2.23	3-Moderate	8	4-High
3.02	1-VeryLow	7	4-High
2.16	4-High	10	5-VeryHigh
2.84	2-Low	9	5-VeryHigh
4.06	1-VeryLow	7	4-High
4.56	1-VeryLow	9	5-VeryHigh
2.44	3-Moderate	10	5-VeryHigh
4.08	1-VeryLow	8	4-High
9.99	1-VeryLow	10	5-VeryHigh
6.66	1-VeryLow	9	5-VeryHigh

Direct Channel Impacts

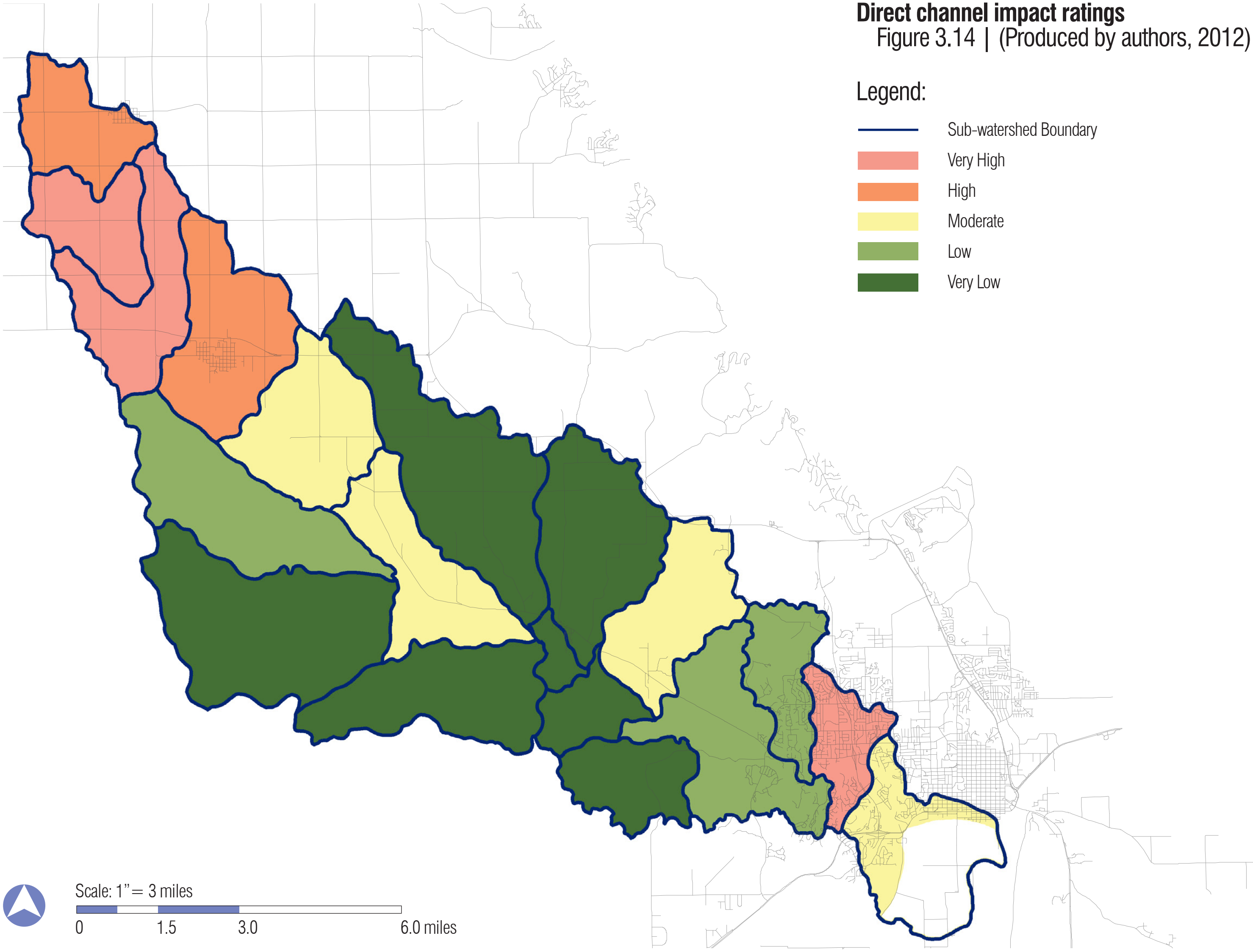
Direct channel impacts included flood control, land drainage, vegetative conversions, heavy grazing pressure, livestock concentrations, straightening, levees, dredging, clearing vegetation, and assorted “river engineering” projects (an example is shown in figure 3.13). The data required to determine risk for this category includes stream types, time-trend aerial photos, percent of riparian vegetation changed, length of channel with changed riparian vegetation with consideration to the nature of direct disturbance and percent of channel directly impacted, and percent of channel blockage, including woody debris. Riparian vegetation around the channels in 1992 and 2012 were compared to determine areas that had changed. In the areas that had changed, the stream length of the riparian vegetation change was calculated. Locations of channelization were identified and measured from aerial photographs. The channel was not significantly blocked by woody debris and was not factored into the risk rating. Sub-watersheds that were not indicated as critical in the RLA phase were only given risk ratings for their riparian vegetation change (shown in figure 3.14 and table 3.06).

One of many locations of channelization

Figure 3.13 | (Produced by authors, 2012)

Locations of channelization were identified throughout the watershed. Most of the locations are found in agricultural settings where more crop land or land to build homes were used and the channel was straightened around those areas.

Direct channel impact ratings
Figure 3.14 | (Produced by authors, 2012)



(1)	(2)	(3)	(4)	(5)	(6)	(7)
Location Code/ River Reach I.D.	Total Channel Length (ft)	Riparian Vegetation Change (ft)	Percent of Total Length Impacted [(3)/(2)X100]	Risk Rating: Percent of Riparian Vegetation Change (4) by Stream Type	Length Impacted by Direct Channel Disturbance (ft)	Percent of Total Length Impacted [(6)/(2)X100]
1. sub-watershed one	36,326 ft	0 ft	0.00%	1-VeryLow	8321 ft	22.90%
2. sub-watershed two	42,504 ft	7,545 ft	17.75%	2-Low	18170 ft	42.70%
3. sub-watershed three	41,659 ft	247 ft	0.60%	1-VeryLow	17139 ft	41.10%
4. sub-watershed four	67,267 ft	1,302 ft	2.00%	1-VeryLow	18079 ft	26.90%
5. sub-watershed five	61,550 ft	6,133 ft	10.00%	2-Low	x	x
6. sub-watershed six	67,954 ft	1,578 ft	2.32%	1-VeryLow	12,569 ft	18.50%
7. sub-watershed seven	85,822 ft	2,444 ft	2.85%	1-VeryLow	x	x
8. sub-watershed eight	105,336 ft	279 ft	0.26%	1-VeryLow	x	x
9. sub-watershed nine	76,507 ft	350 ft	0.46%	1-VeryLow	12,107 ft	15.80%
10. sub-watershed ten	78,507 ft	398 ft	0.51%	1-VeryLow	x	x
11. sub-watershed eleven	18,480 ft	408 ft	2.21%	1-VeryLow	x	x
12. sub-watershed twelve	88,130 ft	2,518 ft	2.85%	1-VeryLow	x	x
13. sub-watershed thirteen	91,816 ft	0 ft	0.00%	1-VeryLow	11,303 ft	12.30%
14. sub-watershed fourteen	44,194 ft	1,513 ft	3.42%	1-VeryLow	x	x
15. sub-watershed fifteen	63,513 ft	6,199 ft	9.76%	2-Low	6,400 ft	10.10%
16. sub-watershed sixteen	133,531 ft	3,919 ft	2.93%	1-VeryLow	8,850 ft	6.60%
17. sub-watershed seventeen	62,031 ft	1,472 ft	2.37%	1-VeryLow	200 ft	0.30%
18. sub-watershed eighteen	28,565 ft	1,813 ft	6.35%	1-VeryLow	14,046 ft	49.20%
19. sub-watershed nineteen	44,088 ft	4,133 ft	9.37%	2-Low	7,761 ft	17.60%

(8)	(9)	(10)	(11)	(12)
Risk Rating: Percent of Channel Length Impacted (7) by Stream Type	Length Impacted by Large Woody Debris	Percent of Length of Debris Blockage [(9)/(2)X100]	Risk Rating: Debris Blockage	Overall Risk Rating for Direct Channel Impacts (Insert Highest Risk Rating from Columns 5, 8 and 11)
4-High	x	x	x	4-High
5-VeryHigh	x	x	x	5-VeryHigh
5-VeryHigh	x	x	x	5-VeryHigh
4-High	x	x	x	4-High
x	x	x	x	2-Low
3-Moderate	x	x	x	3-Moderate
x	x	x	x	1-VeryLow
x	x	x	x	1-VeryLow
3-Moderate	x	x	x	3-Moderate
x	x	x	x	1-VeryLow
x	x	x	x	1-VeryLow
x	x	x	x	1-VeryLow
3-Moderate	x	x	x	3-Moderate
x	x	x	x	1-VeryLow
2-Low	x	x	x	2-Low
2-Low	x	x	x	2-Low
1-VeryLow	x	x	x	1-VeryLow
5-VeryHigh	x	x	x	5-VeryHigh
3-Moderate	x	x	x	3-Moderate

Summary of risk ratings for direct channel impacts

Table 3.06 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

Channel Enlargement

Channel enlargement was based on the “susceptibility of streams to incise and or widen at an accelerated rate due to changes in flow, clear water discharge, direct disturbance and streambank erosion” (Rosgen, 2008). An example of the erosion impacts is shown in figure 3.15. The data needed for review for this assessment includes stream types (figure 3.11), streamflow changes risk (table 3.4), streambank erosion risk (table 3.5, in-channel mining impact risk (not a risk in the Wildcat Creek watershed), and direct channel disturbance risk (table 3.6). All of the data used to determine the risk rating of channel enlargement comes from pervious calculations and ratings (shown in figure 3.16 and table 3.07).

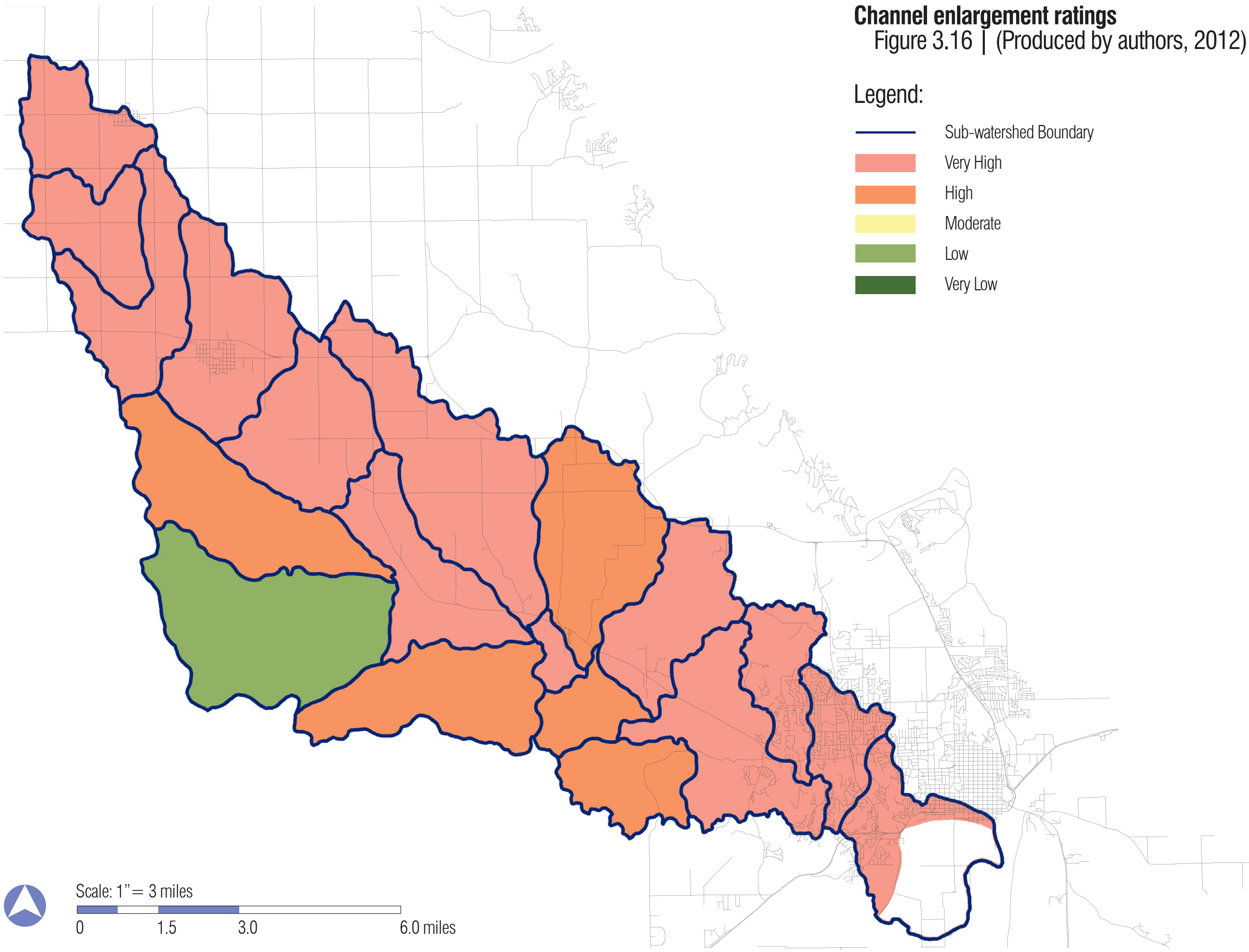
Channel erosion on Wildcat Creek

Figure 3.15 | (Denlinger, 2011)

Channel erosion and incised channels are one indication that the channel is unstable. Unstable channels are highly susceptibly to channel enlargement and rapid channel changes.

Channel enlargement ratings

Figure 3.16 | (Produced by authors, 2012)



(1)	(2)	(3)	(4)
Location Code/ River Reach I.D.	Overall Risk Rating: Streamflow Changes (Table 3.4)	Overall Risk Rating: Streambank Erosion (Table 3.5)	Overall Risk Rating: Direct Channel Impacts (Table 3.6)
1. sub-watershed one	5-VeryHigh	5-VeryHigh	4-High
2. sub-watershed two	5-VeryHigh	5-VeryHigh	5-VeryHigh
3. sub-watershed three	5-VeryHigh	5-VeryHigh	5-VeryHigh
4. sub-watershed four	5-VeryHigh	5-VeryHigh	4-High
5. sub-watershed five	1-VeryLow	3-Moderate	2-Low
6. sub-watershed six	4-High	4-High	3-Moderate
7. sub-watershed seven	1-VeryLow	3-Moderate	1-VeryLow
8. sub-watershed eight	5-VeryHigh	5-VeryHigh	1-VeryLow
9. sub-watershed nine	3-Moderate	5-VeryHigh	3-Moderate
10. sub-watershed ten	3-Moderate	4-High	1-VeryLow
11. sub-watershed eleven	5-VeryHigh	4-High	1-VeryLow
12. sub-watershed twelve	1-VeryLow	5-VeryHigh	1-VeryLow
13. sub-watershed thirteen	3-Moderate	5-VeryHigh	3-Moderate
14. sub-watershed fourteen	3-Moderate	4-High	1-VeryLow
15. sub-watershed fifteen	5-VeryHigh	5-VeryHigh	2-Low
16. sub-watershed sixteen	5-VeryHigh	5-VeryHigh	2-Low
17. sub-watershed seventeen	1-VeryLow	4-High	1-VeryLow
18. sub-watershed eighteen	5-VeryHigh	5-VeryHigh	5-VeryHigh
19. sub-watershed nineteen	5-VeryHigh	5-VeryHigh	3-Moderate

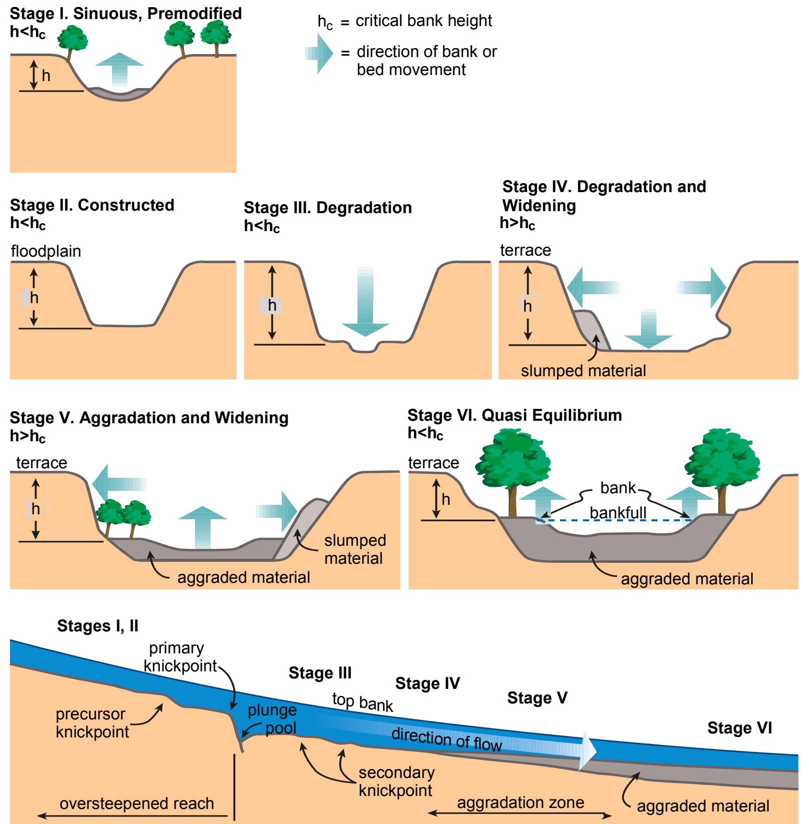
Summary of risk ratings for channel enlargement

Table 3.07 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

(5) Total Numeric Score ∑[(2)+(3)+(4)]	(6) Overall Risk Rating for Channel Enlargement by Stream Type	(7) Adjustment Due to In-Channel Mining
14	5-VeryHigh	x
15	5-VeryHigh	x
15	5-VeryHigh	x
14	5-VeryHigh	x
6	4-High	x
11	5-VeryHigh	x
5	2-Low	x
11	5-VeryHigh	x
11	5-VeryHigh	x
8	4-High	x
10	5-VeryHigh	x
7	4-High	x
11	5-VeryHigh	x
8	4-High	x
12	5-VeryHigh	x
12	5-VeryHigh	x
6	4-High	x
15	5-VeryHigh	x
13	5-VeryHigh	x

Aggradation | Excess Sediment Supply

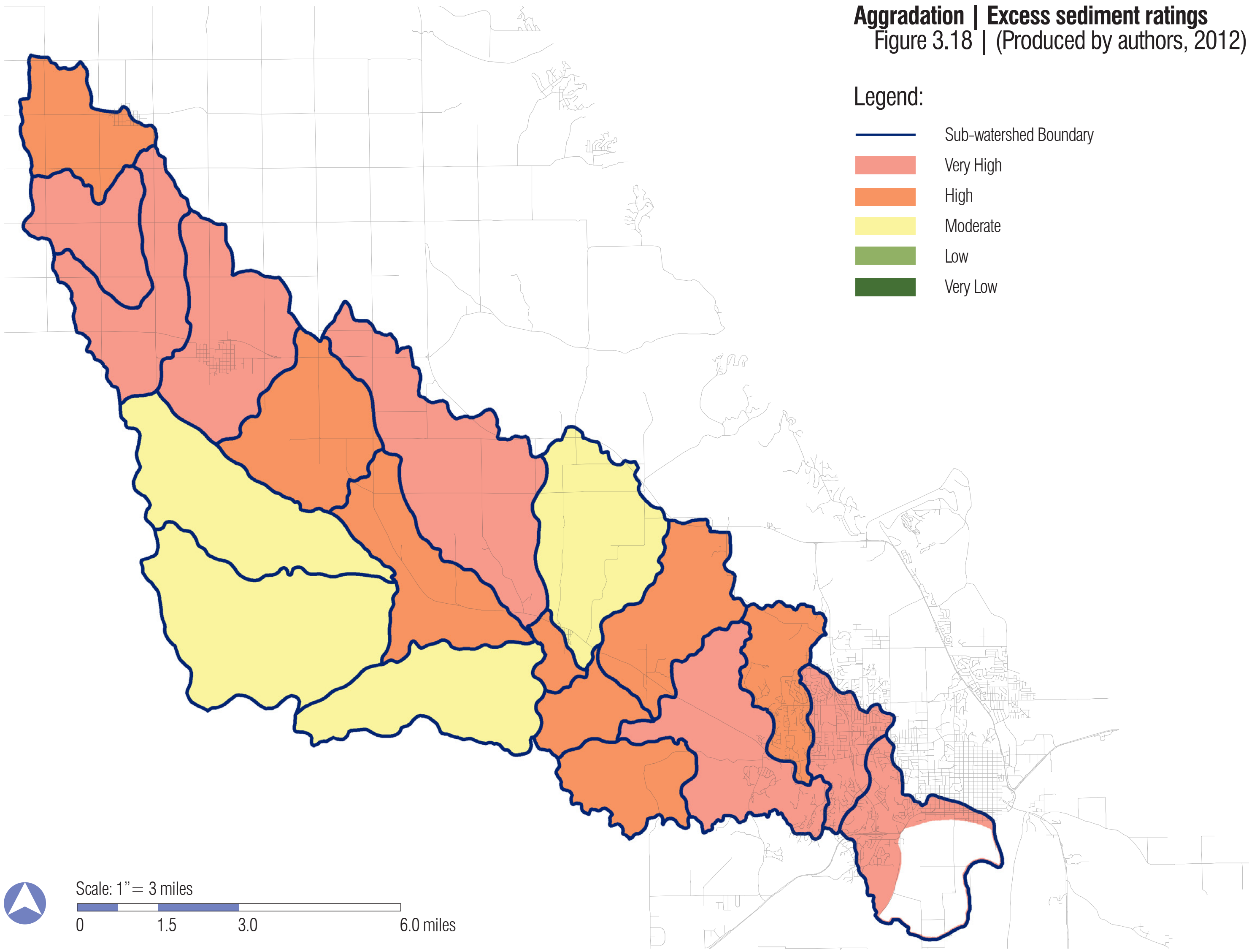
The risk assessment of aggradation/ excess sediment supply concerns increased in width/depth ratio or slope changes, as shown in figure 3.17. Examples of such impacts are over-widening due to bridge construction, channelization, riparian vegetation reduction, and poor grazing practices. The data required to assess the risk of aggradation/excess sediment supply was split into two broad categories: hillslope risk ratings (sediment supply) and channel process response to excess sediment. The hillslope assessment included mass erosion risk (low for entire watershed), roads risk (table 3.1), and surface erosion risk (table 3.2). Risk rates for the hillslope assessment were calculated in prior evaluations. Channel processes included bankfull width/depth ratio of existing and reference reaches, channel enlargement risk (table 3.7), streambank erosion risk (table 3.5), and depositional pattern evaluation. The bankfull widths and depths were determined using the Flint Hills Regional Curves of the associating drainage areas for the different stream order stream types. The channel enlargement and stream bank erosion risk ratings can be found in prior evaluations. Results are shown in figure 3.18 and table 3.08.



Examples of aggradation and degradation that cause changes in channel type evolution

Figure 3.17 | (Simon, 1989)

Changes in the stream channel occur from incising or widening of the stream channel. Different stages of aggradation and degradation are needed to move between channel stages.


Aggradation | Excess sediment ratings
Figure 3.18 | (Produced by authors, 2012)
Legend:
Sub-watershed Boundary
Very High
High
Moderate
Low
Very Low
Scale: 1"= 3 miles
0
1.5
3.0
6.0 miles

	Hillslope Risk Ratings (Sediment Supply)								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Location Code/ River Reach I.D.	Risk Rating: Mass Erosion	Risk Rating: Roads (Table 3.1)	Risk Rating: Surface Erosion Risk/ Delivered Sediment Risk	Point Subtotal ∑[(2)+(3)+(4)]	Hillslope Summary Overall Rating; Use Points from Column (5) VL(1) = 3 L(2) = 4–7 M(3) = 8–10 H(4) = 11–14 VH(5) = >14	Representative location & associated rating points from column (6)*	Risk Rating: Width/Depth Ratio Departure VL(1) = HS L(2) = S M(3) = MU H(4) = U VH(5) = HU	Risk Rating: Channel Enlargement (Table 4.7)	Risk Rating: Streambank Erosion (Table 4.5)
1. sub-watershed one	2-Low	2-Low	4-High	8	3-Moderate ; 8-10	3-Moderate ; G	3-Moderate ; 1.34 MU	5-VeryHigh	5-VeryHigh
2. sub-watershed two	2-Low	3-Moderate	3-Moderate	8	3-Moderate ; 8-10	3-Moderate ; G	4-High ; 1.49 U	5-VeryHigh	5-VeryHigh
3. sub-watershed three	2-Low	2-Low	4-High	8	3-Moderate ; 8-10	3-Moderate ; G	4-High ; 1.57 U	5-VeryHigh	5-VeryHigh
4. sub-watershed four	2-Low	4-High	4-High	10	3-Moderate ; 8-10	3-Moderate ; G	4-High ; 1.54 U	5-VeryHigh	5-VeryHigh
5. sub-watershed five	2-Low	x	x	2	1-VeryLow ; 3	1-VeryLow ; G	4-High ; 1.47 U	4-High	1-VeryLow
6. sub-watershed six	2-Low	1-VeryLow	3-Moderate	6	2-Low ; 4-7	2-Low ; G	4-High ; 1.46 U	5-VeryHigh	4-High
7. sub-watershed seven	2-Low	x	x	2	1-VeryLow ; 3	1-VeryLow ; G	5-VeryHigh ; 1.80 HU	2-Low	1-VeryLow
8. sub-watershed eight	2-Low	4-High	4-High	10	3-Moderate ; 8-10	3-Moderate ; G	5-VeryHigh ; 1.61 HU	5-VeryHigh	5-VeryHigh
9. sub-watershed nine	2-Low	3-Moderate	1-VeryLow	6	2-Low ; 4-7	2-Low ; F	5-VeryHigh ; 1.78 HU	5-VeryHigh	3-Moderate
10. sub-watershed ten	2-Low	4-High	1-VeryLow	7	2-Low ; 4-7	2-Low ; B	3-Moderate ; 1.29 MU	4-High	3-Moderate
11. sub-watershed eleven	2-Low	1-VeryLow	1-VeryLow	4	2-Low ; 4-7	2-Low ; F	4-High ; 1.55 U	5-VeryHigh	5-VeryHigh
12. sub-watershed twelve	2-Low	x	x	2	1-VeryLow ; 3	1-VeryLow ; G	4-High ; 1.52 U	4-High	1-VeryLow
13. sub-watershed thirteen	2-Low	3-Moderate	1-VeryLow	6	2-Low ; 4-7	2-Low ; B	3-Moderate ; 1.27 MU	5-VeryHigh	3-Moderate
14. sub-watershed fourteen	2-Low	x	1-VeryLow	3	1-VeryLow ; 3	1-VeryLow ; G	5-VeryHigh ; 1.71 HU	4-High	3-Moderate
15. sub-watershed fifteen	2-Low	3-Moderate	x	5	2-Low ; 4-7	2-Low ; G	4-High ; 1.54 U	5-VeryHigh	5-VeryHigh
16. sub-watershed sixteen	2-Low	3-Moderate	4-High	9	3-Moderate ; 8-10	3-Moderate ; G	5-VeryHigh ; 1.61 HU	5-VeryHigh	5-VeryHigh
17. sub-watershed seventeen	2-Low	1-VeryLow	x	3	1-VeryLow ; 3	1-VeryLow ; G	4-High ; 1.54 U	4-High	4-High
18. sub-watershed eighteen	2-Low	4-High	1-VeryLow	7	2-Low ; 4-7	2-Low ; G	5-VeryHigh ; 1.61 HU	5-VeryHigh	5-VeryHigh
19. sub-watershed nineteen	2-Low	4-High	4-High	10	3-Moderate ; 8-10	3-Moderate ; G	4-High ; 1.55 U	5-VeryHigh	5-VeryHigh

Summary of risk ratings for aggradation

Table 3.08 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

Channel Process Response to Excess Sediment				
(11)	(12)	(13)	(14)	(15)
Point Subtotal ∑[(7)+(8)+(9)+(10)]	Risk Rating: Use Points from Column (11) VL(1) < 5 L(2) = 5–8 M(3) = 9–12 H(4) = 13–16 VH(5) >16	Adjustments:Aggradation/Excess Sediment Indicators** a. Obvious excess deposition b. Filling of pools c. Deposition of sand or larger material on floodplain d. Bi-modal e. Depositional patterns	Adjustment: Reduction in Flow Due to Regulation**	Final Aggradation/ Excess Sediment Deposition Risk Rating
16	4-High	x	x	4-High
17	5-VeryHigh	x	x	5-VeryHigh
17	5-VeryHigh	x	x	5-VeryHigh
17	5-VeryHigh	x	x	5-VeryHigh
10	3-Moderate	x	x	3-Moderate
15	4-High	x	x	4-High
9	3-Medium	x	x	3-Moderate
18	5-VeryHigh	x	x	5-VeryHigh
15	4-High	x	x	4-High
12	3-Moderate	x	x	3-Moderate
16	4-High	x	x	4-High
10	3-Moderate	x	x	3-Moderate
13	4-High	x	x	4-High
13	4-High	x	x	4-High
16	4-High	x	x	4-High
18	5-VeryHigh	x	x	5-VeryHigh
13	4-High	x	x	4-High
17	5-VeryHigh	x	x	5-VeryHigh
17	5-VeryHigh	x	x	5-VeryHigh

* To appy risk rating from Hillslope Processes for aggradation risk, it is important to identify the location of the sediment supply in relation to the most representative stream type.

** Adjust a full risk category upward if streamflow decrease and/or indicators provide evidence appropriate to the observed condition such as the aggradation indicators listed above.

Channel Evolution

Successional States

The determination of channel evolution/ successional states dealt with the changes over time due to geologic influences and the tendency of rivers to seek their own stability within a specific climatic parameter (see figure 3.16). Reference reaches are considered stable and used as a baseline for assessments. The data required for this assessment included stream types (figure 3.11), reference condition, and scenarios of successional stages of stream channel evolution (table 3.09). The percentages of different types of stream classification were calculated for each sub-watershed (table 3.10). The risk ratings were then averaged from different stream type successional patterns. Results are in figure 3.19.

Channel Successional States of Stream Type Evolution	Risk Rating
E to C	3-Moderate
C to D	5-VeryHigh
B, C, E or D to G	5-VeryHigh
G to F	4-High
G to B	1-VeryLow
F to B	1-VeryLow
F to C	2-Low
F to D	3-Moderate
All others (e.g. C to E)	2-Low

Channel evolution rating system

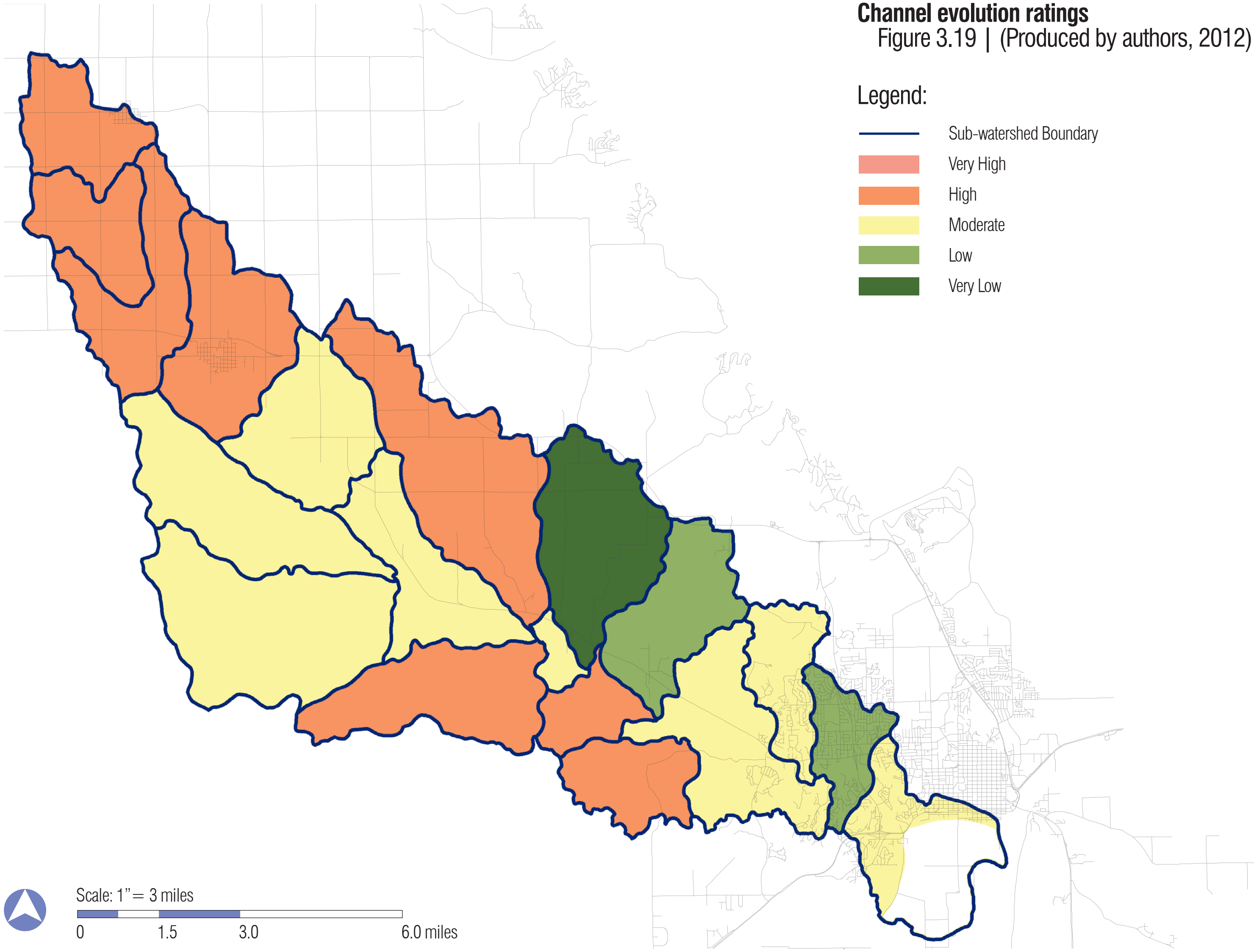
Table 3.09 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

(1)	(2)	(3)	(4)	(5)
Location Code/ River Reach I.D.	Stream Type Most Susceptible to Change or "Weak Link" (4) and (9) Table 3.4	Channel Successional States of Stream Type Evolution	Channel Successional States of Stream Type Evolution; Risk Rating	Channel Successional States of Stream Type Evolution; Risk Rating (average for sub-watershed)
1. sub-watershed one	G6	G to F	4-High	4-High
2. sub-watershed two	G6	G to F	4-High	4-High
3. sub-watershed three	G6	G to F	4-High	4-High
4. sub-watershed four	G6	G to F	4-High	4-High
5. sub-watershed five	G4 ; F4	G to F ; F to C	4-High ; 2-Low	3-Moderate
6. sub-watershed six	G4 ; F4	G to F ; F to C	4-High ; 2-Low	3-Moderate
7. sub-watershed seven	G4 ; F4	G to F ; F to C	4-High ; 2-Low	3-Moderate
8. sub-watershed eight	G4	G to F	4-High	4-High
9. sub-watershed nine	G4 ; F4	G to F ; F to C	4-High ; 2-Low	3-Moderate
10. sub-watershed ten	B	x	1-VeryLow	1-VeryLow
11. sub-watershed eleven	G4 ; F4	G to F ; F to C	4-High ; 2-Low	3-Moderate
12. sub-watershed twelve	G4	G to F	4-High	4-High
13. sub-watershed thirteen	F	F to C	2-Low	2-Low
14. sub-watershed fourteen	G4	G to F	4-High	4-High
15. sub-watershed fifteen	F ; G4	F to B ; G to F	1-VeryLow ; 4-High	3-Moderate
16. sub-watershed sixteen	F ; G4	F to B ; G to F	1-VeryLow ; 4-High	3-Moderate
17. sub-watershed seventeen	G4	G to F	4-High	4-High
18. sub-watershed eighteen	F4	F to C	2-Low	2-Low
19. sub-watershed nineteen	F ; G4	F to B ; G to F	1-VeryLow ; 4-High	3-Moderate

Summary of risk ratings for channel evolution

Table 3.10 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

Channel evolution ratings
Figure 3.19 | (Produced by authors, 2012)



Degradation

The risk of degradation is important in considering the stability of a stream (figure 3.20). By lowering the level of the channel bed, the ability for vegetation to stabilize erosion is decreased as the channel forces act below the root zone. Degradation advances head-ward in the stream and tributaries, increasing erosion and instability. The data required for a degradation assessment included stream types (figure 3.11), stream channel evolution risk (table 3.10), streamflow changes risk (table 3.4), roads (table 3.1), drainage way crossing designs (table 3.12), in-channel mining associated with base-level shifts (not found in Wildcat Creek watershed), and direct channel impact risk (table 3.6). All data was calculated in previous assessments. Results for degradation are shown in figure 3.21 and table 3.11. Drainage crossing results are found in table 3.12.

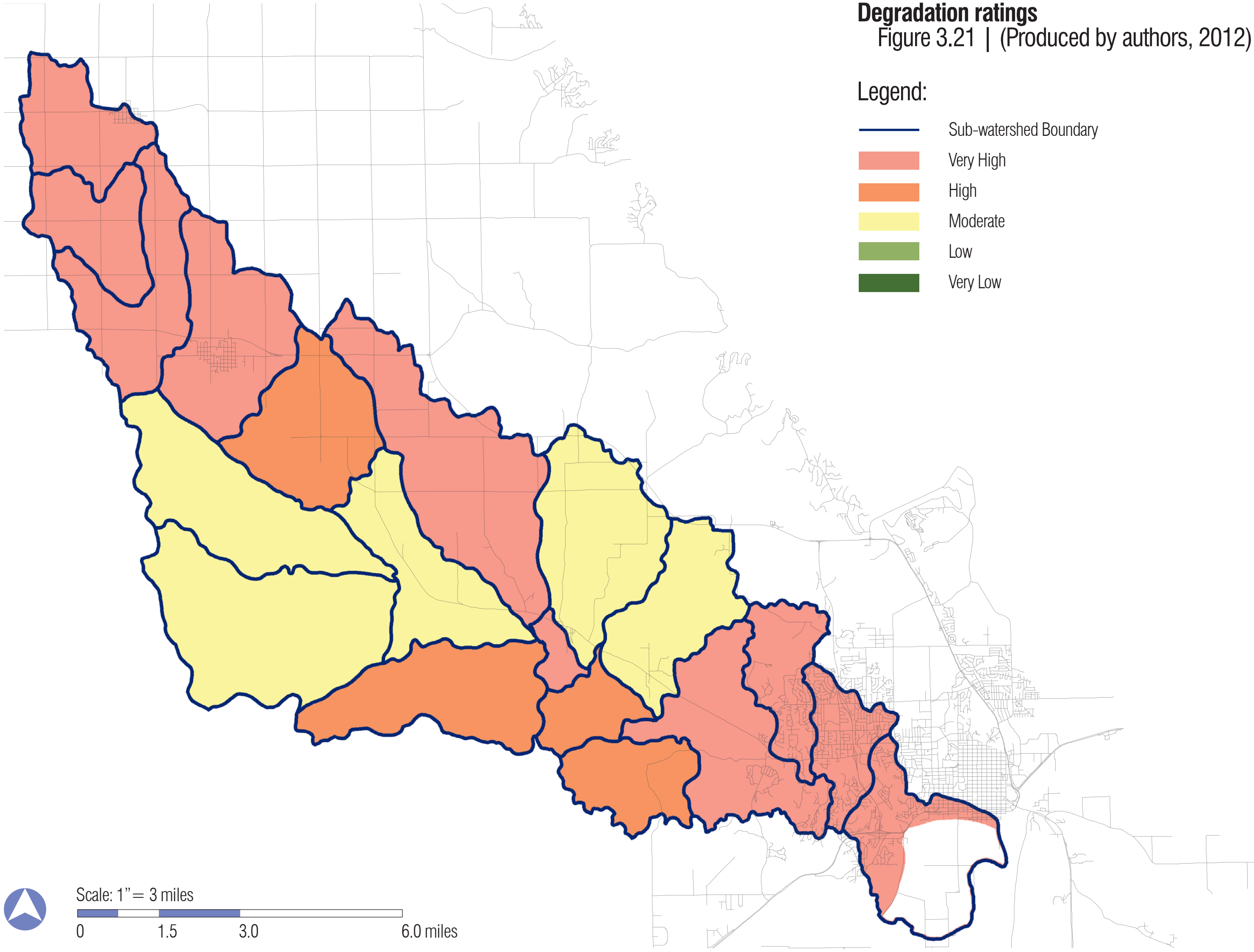
Increase in sediment supply and unstable stream conditions

Figure 3.20 | (Denlinger, 2012)

One of a multitude of locations throughout the watershed that have high levels of sediment supply and unstable streams that are going through degradation phases.

Degradation ratings

Figure 3.21 | (Produced by authors, 2012)



(1)	(2)	(3)	(4)
Location Code/ River Reach I.D.	Risk Rating: Streamflow Changes (Table 3.4)	Risk Rating: In-Channel Mining Associated with Base-Level Shifts (Not applicable for this watershed)	Risk Rating: Channel Evolution (Table 3.9)
1. sub-watershed one	5-VeryHigh	x	4-High
2. sub-watershed two	5-VeryHigh	x	4-High
3. sub-watershed three	5-VeryHigh	x	4-High
4. sub-watershed four	5-VeryHigh	x	4-High
5. sub-watershed five	1-VeryLow	x	3-Moderate
6. sub-watershed six	4-High	x	3-Moderate
7. sub-watershed seven	1-VeryLow	x	3-Moderate
8. sub-watershed eight	4-High	x	4-High
9. sub-watershed nine	1-VeryLow	x	3-Moderate
10. sub-watershed ten	4-High	x	1-VeryLow
11. sub-watershed eleven	1-VeryLow	x	3-Moderate
12. sub-watershed twelve	5-VeryHigh	x	4-High
13. sub-watershed thirteen	3-Moderate	x	2-Low
14. sub-watershed fourteen	3-Moderate	x	4-High
15. sub-watershed fifteen	5-VeryHigh	x	3-Moderate
16. sub-watershed sixteen	1-VeryLow	x	3-Moderate
17. sub-watershed seventeen	3-Moderate	x	4-High
18. sub-watershed eighteen	3-Moderate	x	2-Low
19. sub-watershed nineteen	5-VeryHigh	x	3-Moderate

Summary of risk ratings for degradation

Table 3.11 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

(5)	(6)	(7)
Risk Rating: Road Drainage Designs, "Shot Gun" Culverts (Base-Level Shifts) (Table 3.12)	Risk Rating: Direct Channel Impacts (Table 3.6)	Overall Risk Rating for Degradation (Insert highest adjective rating from Columns 2-6)
2-Low	4-High	5-VeryHigh
3-Moderate	5-VeryHigh	5-VeryHigh
2-Low	5-VeryHigh	5-VeryHigh
2-Low	4-High	5-VeryHigh
2-Low	2-Low	3-Moderate
3-Moderate	3-Moderate	4-High
2-Low	1-VeryLow	3-Moderate
2-Low	1-VeryLow	5-VeryHigh
2-Low	3-Moderate	3-Moderate
3-Moderate	1-VeryLow	3-Moderate
2-Low	1-VeryLow	5-VeryHigh
2-Low	1-VeryLow	4-High
3-Moderate	3-Moderate	3-Moderate
2-Low	1-VeryLow	4-High
2-Low	2-Low	5-VeryHigh
2-Low	2-Low	5-VeryHigh
3-Moderate	1-VeryLow	4-High
2-Low	5-VeryHigh	5-VeryHigh
2-Low	3-Moderate	5-VeryHigh

Summary of risk ratings for drainage way crossing designs

Table 3.12 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

(1)	(2)	(3)	(4)	(5)
Location Code/ River Reach I.D.	Percent Reduction of Sinuosity (Insert Numeric Rating) (1) = No change (2) = Sinuosity reduced up to 50% (3) = Sinuosity reduced 50–80% (4) = Sinuosity reduced more than 80%	Stream Crossing Structure (Insert Numeric Rating) (1) = Bridge (2) = Arch culvert (3) = Culvert (4) = Over-steepened culvert	Subtotal S[(2)+(3)]	Increase in Energy Slope (Use (4)) VL (1) = 2 L (2) = 3 M (3) = 4 H (4) = 5–6 VH (5) = 7–8
1. sub-watershed one	2	2	4	3
2. sub-watershed two	2	3	5	4
3. sub-watershed three	2	2	4	3
4. sub-watershed four	2	1	3	2
5. sub-watershed five	1	x	1	1
6. sub-watershed six	2	3	5	4
7. sub-watershed seven	1	x	1	2
8. sub-watershed eight	1	3	4	3
9. sub-watershed nine	2	1	3	2
10. sub-watershed ten	1	3	4	3
11. sub-watershed eleven	1	1	2	1
12. sub-watershed twelve	1	x	1	1
13. sub-watershed thirteen	2	2	4	3
14. sub-watershed fourteen	1	x	1	1
15. sub-watershed fifteen	2	1	3	2
16. sub-watershed sixteen	2	1	3	2
17. sub-watershed seventeen	2	3	5	4
18. sub-watershed eighteen	2	1	3	2
19. sub-watershed nineteen	2	1	3	2

(6)	(7)	(8)	(9)	(10)
Ratio of a Decrease in W/d Ratio to Existing Reference W/d Ratio VL (1) > 8.0 L (2) = 0.61–0.80 M (3) = 0.41–0.60 H (4) = 0.21–0.40 VH (5) ≤ 0.20	Backwater Potential above Structure (Insert Numeric Rating) VL (1) = None L (2) = Slight only for floods > 50 yr recurrence interval M (3) = Some for floods 11–50 yr recurrence interval H (4) = Evident for floods 2–10 yr recurrence interval VH (5) = Backwater at bankfull discharge	Presence of Floodplain Drains (Through Fills) (Insert Numeric Rating) VL (1) = All floods greater than bankfull drain through fill L (2) = Accomodates 90% of floods M (3) = Accomodates 50–89% of floods H (4) = Evident for floods 2–10 yr recurrence interval VH (5) = Backwater at bankfull discharge	Subtotal S[(5)+(6)+(7)+(8)]	Overall Risk Rating: Culverts or Bridges VL (1) = 4 L (2) = 5–8 M (3) = 9–12 H (4) = 13–16 VH (5) = 17–20
3-Moderate	1-VeryLow	1-VeryLow	8	2-Low
3-Moderate	1-VeryLow	1-VeryLow	9	3-Moderate
3-Moderate	1-VeryLow	1-VeryLow	8	2-Low
3-Moderate	1-VeryLow	1-VeryLow	7	2-Low
3-Moderate	1-VeryLow	1-VeryLow	6	2-Low
3-Moderate	1-VeryLow	1-VeryLow	9	3-Moderate
3-Moderate	1-VeryLow	1-VeryLow	7	2-Low
3-Moderate	1-VeryLow	1-VeryLow	8	2-Low
2-Low	1-VeryLow	1-VeryLow	6	2-Low
4-High	1-VeryLow	1-VeryLow	9	3-Moderate
2-Low	1-VeryLow	1-VeryLow	5	2-Low
3-Moderate	1-VeryLow	1-VeryLow	6	2-Low
4-High	1-VeryLow	1-VeryLow	9	3-Moderate
3-Moderate	1-VeryLow	1-VeryLow	6	2-Low
3-Moderate	1-VeryLow	1-VeryLow	7	2-Low
3-Moderate	1-VeryLow	1-VeryLow	7	2-Low
3-Moderate	1-VeryLow	1-VeryLow	9	3-Moderate
3-Moderate	1-VeryLow	1-VeryLow	7	2-Low
3-Moderate	1-VeryLow	1-VeryLow	7	2-Low

Watershed Name: Wildcat Creek Watershed **Date: Spring 2012**

	Geographic Location				Stream Type Location		
Location Code/ River Reach I.D.	Step 6: Mass Erosion	Step 7: Roads Table 3.1	Step 8: Surface Erosion Table 3.2	Step 10: Streamflow Change Table 3.4	Step 13: Streambank Erosion Table 3.5	Step 14: In-Channel Mining	Step 15: Direct Channel Impacts Table 3.6
1. sub-watershed one	2-Low	2-Low	4-High	5-VeryHigh	5-VeryHigh	x	4-High
2. sub-watershed two	2-Low	3-Moderate	3-Moderate	5-VeryHigh	5-VeryHigh	x	5-VeryHigh
3. sub-watershed three	2-Low	2-Low	4-High	5-VeryHigh	5-VeryHigh	x	5-VeryHigh
4. sub-watershed four	2-Low	4-High	4-High	5-VeryHigh	5-VeryHigh	x	4-High
5. sub-watershed five	2-Low	x	x	1-VeryLow	3-Moderate	x	2-Low
6. sub-watershed six	2-Low	1-Low	3-Moderate	4-High	4-High	x	3-Moderate
7. sub-watershed seven	2-Low	x	x	1-VeryLow	3-Moderate	x	1-VeryLow
8. sub-watershed eight	2-Low	4-High	4-High	5-VeryHigh	5-VeryHigh	x	1-VeryLow
9. sub-watershed nine	2-Low	3-Moderate	1-Low	3-Moderate	5-VeryHigh	x	3-Moderate
10. sub-watershed ten	2-Low	4-High	1-Low	3-Moderate	4-High	x	1-VeryLow
11. sub-watershed eleven	2-Low	1-VeryLow	1-Low	5-VeryHigh	4-High	x	1-VeryLow
12. sub-watershed twelve	2-Low	x	x	1-VeryLow	5-VeryHigh	x	1-VeryLow
13. sub-watershed thirteen	2-Low	3-Moderate	1-Low	3-Moderate	5-VeryHigh	x	3-Moderate
14. sub-watershed fourteen	2-Low	x	1-Low	3-Moderate	4-High	x	1-VeryLow
15. sub-watershed fifteen	2-Low	3-Moderate	x	5-VeryHigh	5-VeryHigh	x	2-Low
16. sub-watershed sixteen	2-Low	3-Moderate	4-High	5-VeryHigh	5-VeryHigh	x	2-Low
17. sub-watershed seventeen	2-Low	1-VeryLow	x	1-VeryLow	4-High	x	1-VeryLow
18. sub-watershed eighteen	2-Low	4-High	1-VeryLow	5-VeryHigh	5-VeryHigh	x	5-VeryHigh
19. sub-watershed nineteen	2-Low	4-High	4-High	5-VeryHigh	5-VeryHigh	x	3-Moderate

Summary of risk ratings for RRISSC in the Wildcat Creek watershed

Table 3.13 | (Adapted from Rosgen (2009) for Wildcat Creek watershed by authors, 2012)

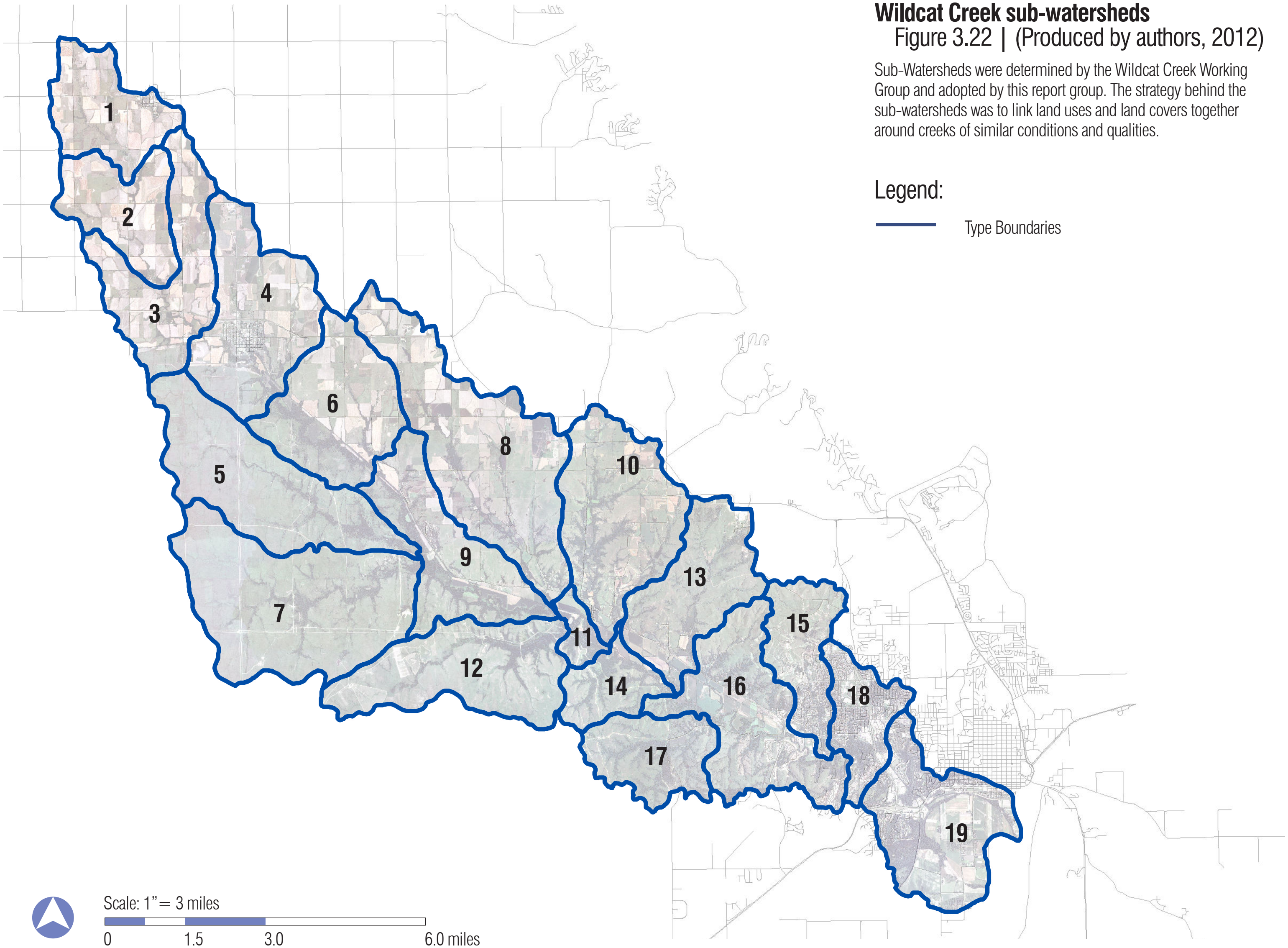
Observers: Wildcat Creek WARSSS Group

Step 16: Channel Enlargement Table 3.7	Step 17: Aggradation/ Excess Sediment Table 3.8	Step 18: Channel Evolution/ Succession States Table 3.10	Step 19: Degradation Table 3.11	Processes Identified by Step for Advancement to *PLA*	Check Location Selected for Advancement to *PLA*
5-VeryHigh	4-High	4-High	5-VeryHigh	5-VeryHigh	√
5-VeryHigh	5-VeryHigh	4-High	5-VeryHigh	5-VeryHigh	√
5-VeryHigh	5-VeryHigh	4-High	5-VeryHigh	5-VeryHigh	√
5-VeryHigh	5-VeryHigh	4-High	5-VeryHigh	5-VeryHigh	√
4-High	3-Moderate	3-Moderate	3-Moderate	4-High	√
5-VeryHigh	4-High	3-Moderate	4-High	5-VeryHigh	√
2-Low	3-Moderate	3-Moderate	3-Moderate	3-Moderate	
5-VeryHigh	5-VeryHigh	4-High	5-VeryHigh	5-VeryHigh	√
5-VeryHigh	4-High	3-Moderate	3-Moderate	5-VeryHigh	√
4-High	3-Moderate	1-VeryLow	3-Moderate	4-High	√
5-VeryHigh	4-High	3-Moderate	5-VeryHigh	5-VeryHigh	√
4-High	3-Moderate	4-High	4-High	4-High	√
5-VeryHigh	4-High	2-Low	3-Moderate	5-VeryHigh	√
4-High	4-High	4-High	4-High	4-High	√
5-VeryHigh	4-High	3-Moderate	5-VeryHigh	5-VeryHigh	√
5-VeryHigh	5-VeryHigh	3-Moderate	5-VeryHigh	5-VeryHigh	√
4-High	4-High	4-High	4-High	4-High	√
5-VeryHigh	4-High	2-Low	5-VeryHigh	5-VeryHigh	√
5-VeryHigh	5-VeryHigh	3-Moderate	5-VeryHigh	5-VeryHigh	√

Wildcat Creek sub-watersheds

Figure 3.22 | (Produced by authors, 2012)

Sub-Watersheds were determined by the Wildcat Creek Working Group and adopted by this report group. The strategy behind the sub-watersheds was to link land uses and land covers together around creeks of similar conditions and qualities.



Sub-Watershed 1

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Surface Erosion

Sub-watershed 1 contains large areas of conventional agricultural practices which expose over 50 percent of the bare earth making it vulnerable to surface erosion. Additionally, a lack of sufficient stream buffers and a small distance from disturbances to the streams are contributing factors. Sub-watershed 1 is given a rating of *Very High* for this vulnerability and thus is forwarded to the *PLA* level.

Streamflow Change

Sub-watershed 1 is designated as having *Very High* risk ratings and requires further assessment at the *PLA* level. The large area of conventional agriculture along with the town of Leonardville's impervious surfaces, create an environment susceptible to increased run-off due to land use practices especially for the "weak link" G6 streams.

Streambreak Erosion

All stream types within sub-watershed 1 are classified as G or F types. The streams within sub watershed 1 rated as *Very High* regarding streambank erosion risk as a result of the bank-height ratio evaluation as *Very High* risk. Further analysis at the *PLA* level is required for sub watershed 1.

Direct Channel Impacts

The F and G type streams within sub watershed 1 rated as *High* risk. The percentage of channel length impacted was evaluated as a *High* risk, resulting in the overall *High* rating. All streams within sub-watershed 1 require evaluation at the *PLA* level.

Channel Enlargment

The F and G type streams within sub-watershed 1 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes and streambank erosion within sub-watershed 1. Although a single *Very High* rating would have been required to classify channel enlargement as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of Channel Enlargement. All streams within sub-watershed 1 require evaluation at the *PLA* level.

Aggradation/Excess Sediment Supply

The F type streams within sub-watershed 1 rated as *High* risk. This is a result of the contribution from the risk ratings of channel enlargement and streambank erosion factors. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. Although a single elevated rating would have required the classification of aggradation or an excess sediment supply as a *High* risk, two elevated contributing factors reinforces the probability of an increase in aggradation or an excess sediment supply. All streams within sub-watershed 1 require evaluation at the *PLA* level.

Channel Evolution/ Successional States

Within sub-watershed 1 a stream received a *High* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further assessment at the *PLA* level.

Degradation

The G type streams within sub-watershed 1 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 1 is stream flow changes. All streams within sub watershed 1 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub watershed 1 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 2

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streamflow Change
Sub-watershed 2 is designated as having *Very High* risk ratings and requires further assessment at the *PLA* level. The large area of conventional agriculture creates an environment susceptible to increased run-off due to land use practices particularly for "weak link" G6 streams.

Streambank Erosion
All stream types within sub-watershed 2 are classified as G or F types. All of the streams within sub-watershed 2 rated as *Very High* regarding streambank erosion risk as a result of the bank-height ratio evaluation as *Very High* risk. Further analysis at the *PLA* level is required for sub-watershed 2.

Direct Channel Impacts
The F and G type streams within sub-watershed 2 rated as *Very High* risk. The percentage of channel length impacted was evaluated as a *Very High* risk, resulting in the overall *Very High* rating. All streams within sub-watershed 2 require evaluation at the *PLA* level.

Channel Enlargement
The F and G type streams within sub-watershed 2 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes, streambank erosion, and direct channel impacts within sub-watershed 2. Although a single *Very High* rating would have been required to classify channel enlargement as a *Very High* risk, three contributing factor's risk rating as *Very High* reinforces the probability of Channel Enlargement. All streams within sub-watershed 2 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply
The F type streams within sub-watershed 2 rated as *Very High* risk. This is a result of the *Very High* risk ratings of channel enlargement and streambank erosion factors. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. Although a single *Very High* rating would have been required to classify aggradation or an excess sediment supply as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of an increase in aggradation or an excess sediment supply. All streams within sub-watershed 2 require evaluation at the *PLA* level.

Channel Evolution | Successional States
Within sub-watershed 2, a stream received a *High* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further assessment at the *PLA* level.

Degradation
The G type streams within sub-watershed 2 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub watershed 2 is direct channel impacts. All streams within sub-watershed 2 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review
The overall RRISSC summary worksheet indicates that sub-watershed 2 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 3

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Surface Erosion

Sub-watershed 3 contains large areas of conventional agricultural practices which expose over 50 percent of the bare earth making it vulnerable to surface erosion. Additionally, a lack of sufficient stream buffers and a small distance from disturbances to the streams are contributing factors. Sub-watershed 3 is given a rating of *Very High* for this vulnerability and thus is forwarded to the *PLA* level.

Streamflow Change

Sub-watershed 3 is designated as having *Very High* risk ratings and requires further assessment at the *PLA* level. The large area of conventional agriculture along with the town of Riley's impervious surfaces, create an environment susceptible to increased run-off due to land use practices especially for the "weak link" G6 streams.

Streambank Erosion

All stream types within sub-watershed 3 are classified as G or F types. The streams within sub-watershed 3 rated as *Very High* regarding streambank erosion risk as a result of the bank-height ratio evaluation as *Very High* risk. Further analysis at the *PLA* level is required for sub watershed 3.

Direct Channel Impacts

The F and G type streams within sub-watershed 3 rated as *Very High* risk. The percentage of channel length impacted was evaluated as a *Very High* risk, resulting in the overall *High* rating. All streams within sub-watershed 3 require evaluation at the *PLA* level.

Channel Enlargement

The F and G type streams within sub-watershed 3 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes, streambank erosion, and direct channel impacts within sub-watershed 3. Although a single *Very High* rating would have been required to classify channel enlargement as a *Very High* risk, three contributing factor's risk rating as *Very High* reinforces the probability of Channel Enlargement. All streams within sub-watershed 3 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 3 rated as *Very High* risk. This is a result of the *Very High* risk ratings of channel enlargement and streambank erosion factors. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. Although a single *Very High* rating would have been required to classify aggradation or an excess sediment supply as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of an increase in aggradation or an excess sediment supply. All streams within sub-watershed 3 require evaluation at the *PLA* level.

Channel Evolution | Successional States

Within sub-watershed 3 streams received a *High* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further assessment at the *PLA* level.

Degradation

The G type streams within sub watershed 3 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. The new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 3 is direct channel impacts. All streams within sub-watershed 3 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 3 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 4

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Roads

Roads in sub-watershed 4 rated *High* risk to sediment contribution. The roads will be forwarded to the *PLA* phase for further assessment concerning specific annual sediment contributions and potential remediation.

Surface Erosion

Sub-watershed 4 contains large areas of conventional agricultural practices which expose over 50 percent of the bare earth making it vulnerable to surface erosion. Additionally, a lack of sufficient stream buffers and a small distance from disturbances to the streams are contributing factors. A rating of *Very High* was given for this vulnerability and thus is forwarded to the *PLA* level.

Streamflow Changes

Sub-watershed 4 is designated as a *Very High* risk rating and requires further assessment at the *PLA* level. The large area of conventional agriculture along with the town of Riley's impervious surfaces, create an environment susceptible to increased run-off due to land use practices especially for the "weak link" G4 streams.

Streambank Erosion

All stream types within sub-watershed 4 are classified as G or F types resulting in a *Very High* rating from the bank-height ratio evaluation as *Very High* risk. Further analysis at the *PLA* level is required for sub-watershed 4.

Direct Channel Impacts

The F and G type streams within sub-watershed 4 rated as *High* risk and the percentage of channel length impacted was evaluated as a *High* risk, resulting in the overall *High* rating. All streams within sub-watershed 4 require evaluation at the *PLA* level.

Channel Enlargement

The F and G type streams within sub-watershed 4 rated as *Very High* risk as a result of the combined effects of streamflow changes and streambank erosion within sub-watershed 4. Although a single *Very High* rating was required to classify channel enlargement as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of Channel Enlargement. All streams within sub-watershed 4 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 4 rated as *Very High* risk. A result of the *Very High* risk ratings of channel enlargement and streambank erosion factors. The increased erosion causes an excess in sediment supply which influence an increase in belt width and width/depth ratio. Although a single *Very High* rating would have been required to classify aggradation or an excess sediment supply as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of an increase in aggradation or excess sediment supply. All streams within sub-watershed 4 require evaluation at the *PLA* level.

Channel Evoluation | Successional States

Within sub-watershed 4 a stream received a *High* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further assessment at the *PLA* level.

Degradation

The G type streams within sub-watershed 4 rated as *Very High* risk. The down cutting common with G type streams results in a decrease in width/depth ratio causing a lowering of the base level and abandonment of the floodplain advancing on all connected reaches. The most likely factor to encourage degradation in sub-watershed 4 is direct channel impacts. All streams within sub-watershed 4 advanced to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub watershed 4 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 5 and 7

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streambank Erosion

All stream types within sub-watersheds 5 and 7 are located within Fort Riley and classified as G or F types. All of the streams within sub-watersheds 5 and 7 are rated as *Moderate* regarding streambank erosion risk. Vegetation along stream banks for most areas is consistent the likelihood that sub watersheds 5 and 7 will suffer from increased erosion rates is a moderate risk. Monitoring is required for sub-watersheds 5 and 7.

Channel Enlargement

The F and G type streams within sub-watershed 5 are rated as *High* risk. The *High* risk rating was a result of local knowledge of the northern Ft. Riley area which moved the risk from *Moderate* to *High*. All streams within sub-watershed 5 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watersheds 5 and 7 are rated as *Moderate* risk. This is a result of the adjustment of the *High* risk rating of channel enlargement for sub-watershed 5 to reflect the unadjusted risk. All streams within sub watershed 5 and 7 require monitoring.

Channel Evolution | Successional States

Within sub-watershed 5 and 7 streams received a *Moderate* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further monitoring.

Degradation

The G type streams within sub-watersheds 5 and 7 rated as *Moderate* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub watershed 3 is channel evolution. All streams within sub-watersheds 5 and 7 should be monitored for change.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 5 had at least **one** *High* risk rating. Sub-watershed 7 had at least **one** *Moderate* risk rating. Due to the adjacency of the watersheds and that they share the mitigating factor of military land use, it is suggested that both sub-watersheds advance to the *PLA* phase for further detailed evaluation.

Sub-Watershed 6

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streamflow Change

Sub-watershed 6 is designated as having *Very High* risk ratings and requires further assessment at the *PLA* level. The large area of conventional agriculture creates an environment susceptible to increased run-off due to land use practices particularly for "weak link" G4 and F4 streams.

Streambank Erosion

All stream types within sub-watershed 6 are classified as G or F types. All of the streams within sub watershed 6 rated as *High* regarding streambank erosion risk as a result of the bank-height ratio evaluation as *High* risk. Further analysis at the *PLA* level is required for sub watershed 6.

Channel Enlargement

The F type streams within sub-watershed 6 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes, streambank erosion, and an adjustment up one risk level due to local knowledge of the area. The local knowledge available concerning behavior of the stream in this reach reinforces the probability of Channel Enlargement. All streams within sub-watershed 6 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F and G type streams within sub-watershed 6 rated as *High* risk. This is a result of the adjustment of the *Very High* risk rating of channel enlargement for sub watershed 6 to reflect the unadjusted risk. All streams within sub watershed 6 require evaluation at the *PLA* level.

Degradation

The G type streams within sub-watershed 6 rated as *High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 6 is stream flow changes. All streams within sub-watershed 6 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 6 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 8

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Roads

The roads in sub-watershed 8 rated as a *High* risk to sediment contribution. The roads in sub-watershed 8 thus, will be forwarded to the *PLA* phase for further assessment concerning specific annual sediment contributions as well as potential remediation.

Surface Erosion

Sub-watershed 8 contains large areas of conventional agricultural practices which expose over 50 percent of the bare earth making it vulnerable to surface erosion. Additionally, a lack of sufficient stream buffers and a small distance from disturbances to the streams are contributing factors. Sub-watershed 8 is given a rating of *High* for this vulnerability and thus is forwarded to the *PLA* level.

Streamflow Change

Sub-watershed 1 is designated as having *Very High* risk ratings and requires further assessment at the *PLA* level. The large area of conventional agriculture creates an environment susceptible to increased run-off due to land use practices especially for the "weak link" G4 streams.

Streambank Erosion

All stream types within sub-watershed 8 are classified as G or F types. The streams within sub-watershed 8 rated as *Very High* regarding streambank erosion risk as a result of the bank-height ratio evaluation as *Very High* risk. Further analysis at the *PLA* level is required for sub-watershed 8.

Channel Enlargement

The F and G type streams within sub-watershed 8 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes and streambank erosion within sub-watershed 8. Although a single *Very High* rating would have been required to classify channel enlargement as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of Channel Enlargement. All streams within sub-watershed 8 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 8 rated as *Very High* risk. This is a result of the *Very High* risk ratings of channel enlargement and streambank erosion factors. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. Although a single *Very High* rating would have been required to classify aggradation or an excess sediment supply as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of an increase in aggradation or an excess sediment supply. All streams within sub-watershed 8 require evaluation at the *PLA* level.

Channel Evolution | Successional States

Within sub-watershed 8 streams received a *High* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further assessment at the *PLA* level.

Degradation

The G type streams within sub-watershed 8 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 8 is stream flow changes. All streams within sub-watershed 8 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 8 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 9

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streambank Erosion

All stream types within sub-watershed 9 are classified as G or F types. The streams within sub-watershed 9 rated as *Very High* regarding streambank erosion risk as adjustments up one risk level to the bank-height ratio evaluation and radius of curvature divided by bankfull width. Further analysis at the *PLA* level is required for sub-watershed 9.

Channel Enlargement

The F and G type streams within sub-watershed 9 rated as *Very High* risk. The *Very High* risk rating was a result of the effect of streambank erosion within sub-watershed 9. All streams within sub-watershed 9 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 9 rated as *High* risk. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. All streams within sub-watershed 9 require evaluation at the *PLA* level.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 9 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 10

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Roads

The roads in sub-watershed 10 rated as a *High* risk to sediment contribution. The roads in sub-watershed 10 thus, will be forwarded to the *PLA* phase for further assessment concerning specific annual sediment contributions as well as potential remediation.

Streambank Erosion

All stream types within sub-watershed 10 are classified as G or F types. The streams within sub-watershed 10 rated as *High* regarding streambank erosion risk as a result of an adjustment up one risk level due to local knowledge. Further analysis at the *PLA* level is required for sub watershed 10.

Channel Enlargement

The F and G type streams within sub-watershed 10 rated as *High* risk. The *High* risk rating was a result of the effect of the streambank erosion adjusted risk rating within sub-watershed 10. All streams within sub-watershed 10 require evaluation at the *PLA* level.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 4 had at least **one** *High* risk rating. The location of the sub-watershed within an area of grazed grassland, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 11

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streamflow Change

Sub-watershed 11 is designated as having *Very High* risk ratings and requires further assessment at the PLA level. The large area of conventional agriculture creates an environment susceptible to increased run-off due to land use practices especially for the "weak link" G4 streams.

Streambank Erosion

All stream types within sub-watershed 11 are classified as G or F types. The streams within sub-watershed 11 rated as High regarding streambank erosion risk as a result of the bank-height ratio evaluation as *High* risk. Further analysis at the PLA level is required for sub-watershed 11.

Channel Enlargement

The F and G type streams within sub-watershed 11 rated as *Very High* risk. The *Very High* risk rating was a result of the effect of streamflow changes within sub-watershed 11. All streams within sub-watershed 11 require evaluation at the PLA level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 11 rated as *High* risk. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. All streams within sub-watershed 11 require evaluation at the PLA level.

Degradation

The G type streams within sub-watershed 11 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 11 is stream flow changes. All streams within sub-watershed 11 should advance to the PLA level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 11 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the PLA phase for further detailed evaluation.

Sub-Watershed 12

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streambank Erosion

All stream types within sub-watershed 12 are classified as G or F types. The streams within sub-watershed 12 rated as *Very High* regarding streambank erosion risk as a result of the increase one level of the bank-height ratio evaluation from *High* risk. Further analysis at the PLA level is required for sub-watershed 12.

Channel Enlargement

The F and G type streams within sub-watershed 12 rated as *High* risk. The *High* risk rating was a result the reduction of the *Very High* risk rating of the effect of streambank erosion to the original level. All streams within sub-watershed 12 require evaluation at the PLA level.

Channel Evolution | Successional States

Within sub-watershed 12 streams received a *High* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further assessment at the PLA level.

Degradation

The G type streams within sub-watershed 12 rated as *High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. The new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 12 is direct channel impacts. All streams within sub-watershed 12 should advance to the PLA level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 12 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the PLA phase for further detailed evaluation.

Sub-Watershed 13

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streambank Erosion

All stream types within sub-watershed 13 are classified as G or F types. All of the streams within sub-watershed 13 rated as *Very High* due to the one level adjustment caused by the sporadic nature of the vegetative composition evaluated as *High* risk. Further analysis at the *PLA* level is required for sub-watershed 13.

Channel Enlargement

The F type streams within sub-watershed 13 rated as *Very High* risk. The *Very High* risk rating was a result of the effect of streambank erosion, and an adjustment up one risk level due to local knowledge of the area. The local knowledge available concerning behavior of the stream in this reach reinforces the probability of Channel Enlargement. All streams within sub-watershed 13 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F and G type streams within sub-watershed 13 rated as *High* risk. This is a result of the adjustment of the *Very High* risk rating of channel enlargement for sub-watershed 13 to reflect the unadjusted risk. All streams within sub-watershed 13 require evaluation at the *PLA* level.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 13 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 14

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streambank Erosion

All stream types within sub-watershed 14 are classified as G or F types. All of the streams within sub-watershed 14 rated as *High* regarding streambank erosion risk as a result of the bank-height ratio evaluation as *High* risk. Further analysis at the *PLA* level is required for sub-watershed 14.

Channel Enlargement

The F type streams within sub-watershed 14 rated as *High* risk. The *High* risk rating was a result of the effect of the *High* streambank erosion risk rating. All streams within sub-watershed 14 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F and G type streams within sub-watershed 14 rated as *High* risk. This is a result of the *High* risk rating of channel enlargement for sub-watershed 14. All streams within sub-watershed 14 require evaluation at the *PLA* level.

Channel Evolution | Successional States

Within sub-watershed 14 streams received a *High* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further assessment at the *PLA* level.

Degradation

The G type streams within sub-watershed 14 rated as *High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. The new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 14 is the effect of channel evolution. All streams within sub-watershed 14 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 14 had at least **one** *High* risk rating. The location of the sub-watershed within a grazed pasture area, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 15

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streamflow Change

Sub-watershed 15 is designated as having *Very High* risk ratings and requires further assessment at the *PLA* level. The large area of grazed pasture, along with the suburban areas of Manhattan's impervious surfaces, create an environment susceptible to increased run-off due to land use practices especially for the "weak link" G4 streams.

Streambank Erosion

All stream types within sub-watershed 15 are classified as G or F types. The streams within sub-watershed 15 rated as *Very High* regarding streambank erosion risk. The rating resulted from the upward adjustments of bank-height ratio and vegetative composition due to the proximity and influence of the urban elements of Manhattan, to *Very High* risk. Further analysis at the *PLA* level is required for sub-watershed 15.

Channel Enlargement

The F and G type streams within sub-watershed 15 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes and streambank erosion within sub-watershed 15. Although a single *Very High* rating would have been required to classify channel enlargement as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of channel enlargement. All streams within sub-watershed 15 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 15 rated as *High* risk. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. All streams within sub-watershed 4 require evaluation at the *PLA* level.

Degradation

The G type streams within sub-watershed 15 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 15 is streamflow changes. All streams within sub-watershed 15 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 15 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 16

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Surface Erosion

Sub-watershed 16 contains large areas of conventional agricultural practices, grazed pasture, and suburban sprawl which expose over 50 percent of the bare earth making it vulnerable to surface erosion. Additionally, a lack of sufficient stream buffers and a small distance from disturbances to the streams are contributing factors. Sub-watershed 16 is given a rating of *Very High* for this vulnerability and thus is forwarded to the *PLA* level.

Streamflow Change

Sub-watershed 16 is designated as having *Very High* risk ratings and requires further assessment at the *PLA* level. The large area of conventional agriculture and grazed pasture along with the impervious surfaces of suburban Manhattan, create an environment susceptible to increased run-off due to land use practices especially for the "weak link" G4 streams.

Streambank Erosion

All stream types within sub-watershed 16 are classified as G or F types. The streams within sub-watershed 16 rated as *Very High* regarding streambank erosion risk as a result of the vegetation composition evaluation as *Very High* risk. Further analysis at the *PLA* level is required for sub-watershed 16.

Channel Enlargement

The F and G type streams within sub-watershed 16 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes and streambank erosion within sub-watershed 16. Although a single *Very High* rating would have been required to classify channel enlargement as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of Channel Enlargement. All streams within sub-watershed 16 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 16 rated as *Very High* risk. This is a result of the *Very High* risk ratings of channel enlargement and streambank erosion factors. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. Although a single *Very High* rating would have been required to classify aggradation or an excess sediment supply as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of an increase in aggradation or an excess sediment supply. All streams within sub-watershed 16 require evaluation at the *PLA* level.

Degradation

The G type streams within sub-watershed 16 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 16 is streamflow changes. All streams within sub-watershed 16 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 16 had at least **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural, grazed pasture, and suburban zone, with the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 17

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Streambank Erosion

All stream types within sub-watershed 17 are classified as G or F types. The streams within sub-watershed 17 rated as *High* regarding streambank erosion risk as a result of the decrease of one level of the bank-height ratio evaluation from *Very High* risk. Further analysis at the *PLA* level is required for sub-watershed 17.

Channel Enlargement

The F and G type streams within sub-watershed 17 rated as *High* risk. The *High* risk rating was a result the reduction of the *Very High* risk rating of the effect of streambank erosion to the *High* level. All streams within sub-watershed 17 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 17 rated as *High* risk. This is a result of the *High* risk ratings of channel enlargement and streambank erosion factors. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. Although a single *Very High* rating would have been required to classify aggradation or an excess sediment supply as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of an increase in aggradation or an excess sediment supply. All streams within sub-watershed 17 require evaluation at the *PLA* level.

Channel Evolution | Successional States

Within sub-watershed 17 streams received a *High* risk rating for reaches which will have the probability to incur a time-trend shift from G to F. The targeted reaches will require further assessment at the *PLA* level.

Degradation

The G type streams within sub-watershed 17 rated as *High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. The new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 17 is channel evolution. All streams within sub-watershed 17 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 17 had at least **one** *High* risk rating. The location of the sub watershed within a grazed pasture area, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 18

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Roads

The roads in sub-watershed 18 rated as a *High* risk to sediment contribution. The roads in sub-watershed 18 thus, will be forwarded to the *PLA* phase for further assessment concerning specific annual sediment contributions as well as potential remediation.

Streamflow Change

Sub-watershed 18 is designated as having *Very High* risk ratings and requires further assessment at the *PLA* level. The large area of suburban sprawl creates an environment susceptible to increased run-off due to land use practices especially for the “weak link” G4 and F4 streams.

Streambank Erosion

All stream types within sub-watershed 18 are classified as G or F types. The streams within sub-watershed 18 rated as *Very High* regarding streambank erosion risk as a result of the vegetative composition evaluation as *Very High* risk. Further analysis at the *PLA* level is required for sub-watershed 18.

Direct Channel Impacts

The F and G type streams within sub-watershed 18 rated as *Very High* risk. The percentage of channel length impacted was evaluated as a *Very High* risk, resulting in the overall *Very High* rating. All streams within sub-watershed 18 require evaluation at the *PLA* level.

Channel Enlargement

The F and G type streams within sub-watershed 18 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes, streambank erosion, and direct channel impacts within sub watershed 18. Although a single *Very High* rating would have been required to classify channel enlargement as a *Very High* risk, three contributing factor’s risk rating as *Very High* reinforces the probability of Channel Enlargement. All streams within sub-watershed 18 require evaluation at the *PLA* level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 18 rated as *High* risk. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. All streams within sub-watershed 18 require evaluation at the *PLA* level.

Degradation

The G type streams within sub-watershed 18 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. The new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 18 is direct channel impacts. All streams within sub-watershed 18 should advance to the *PLA* level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 18 had at least **one** *High* risk rating and **one** *Very High* risk rating. The location of the sub-watershed within a conventional agricultural zone, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the *PLA* phase for further detailed evaluation.

Sub-Watershed 19

Table 3.13 is the summary of the process-based risk analysis for sediment supply and stream channel stability (RRISSC). The following recommendations are based upon the RRISSC analysis.

Roads

The roads in sub-watershed 19 rated as a *High* risk to sediment contribution. The roads in sub-watershed 19 thus, will be forwarded to the PLA phase for further assessment concerning specific annual sediment contributions as well as potential remediation.

Surface Erosion

Sub-watershed 19 contains large areas densely populated urban land practices which expose over 50 percent of the bare earth making it vulnerable to surface erosion. Additionally, a lack of sufficient stream buffers and a small distance from disturbances to the streams are contributing factors. Sub-watershed 19 is given a rating of *Very High* for this vulnerability and thus is forwarded to the PLA level.

Streamflow Change

Sub-watershed 19 is designated as having *Very High* risk ratings and requires further assessment at the PLA level. The large urban area of Manhattan creates an environment susceptible to increased run-off due to land use practices particularly for "weak link" G4 and F4 streams.

Streambank Erosion

All stream types within sub-watershed 19 are classified as G or F types. All of the streams within sub-watershed 19 rated as *Very High* regarding streambank erosion risk as a result of an increase of one risk level of the bank-height ratio and vegetative composition evaluations from *High* risk to *Very High* risk. Further analysis at the PLA level is required for sub-watershed 19.

Channel Enlargement

The F and G type streams within sub-watershed 19 rated as *Very High* risk. The *Very High* risk rating was a result of the combined effects of streamflow changes and streambank erosion within sub-watershed 19. Although a single Very High rating would have been required to classify channel enlargement as a *Very High* risk, three contributing factor's risk rating as *Very High* reinforces the probability of Channel Enlargement. All streams within sub-watershed 19 require evaluation at the PLA level.

Aggradation | Excess Sediment Supply

The F type streams within sub-watershed 19 rated as *Very High* risk. This is a result of the *Very High* risk ratings of channel enlargement and streambank erosion factors. The increased erosion causes an excess in sediment supply which influence an increase in both belt width and width/depth ratio. Although a single *Very High* rating would have been required to classify aggradation or an excess sediment supply as a *Very High* risk, two contributing factor's risk rating as *Very High* reinforces the probability of an increase in aggradation or an excess sediment supply. All streams within sub-watershed 19 require evaluation at the PLA level.

Degradation

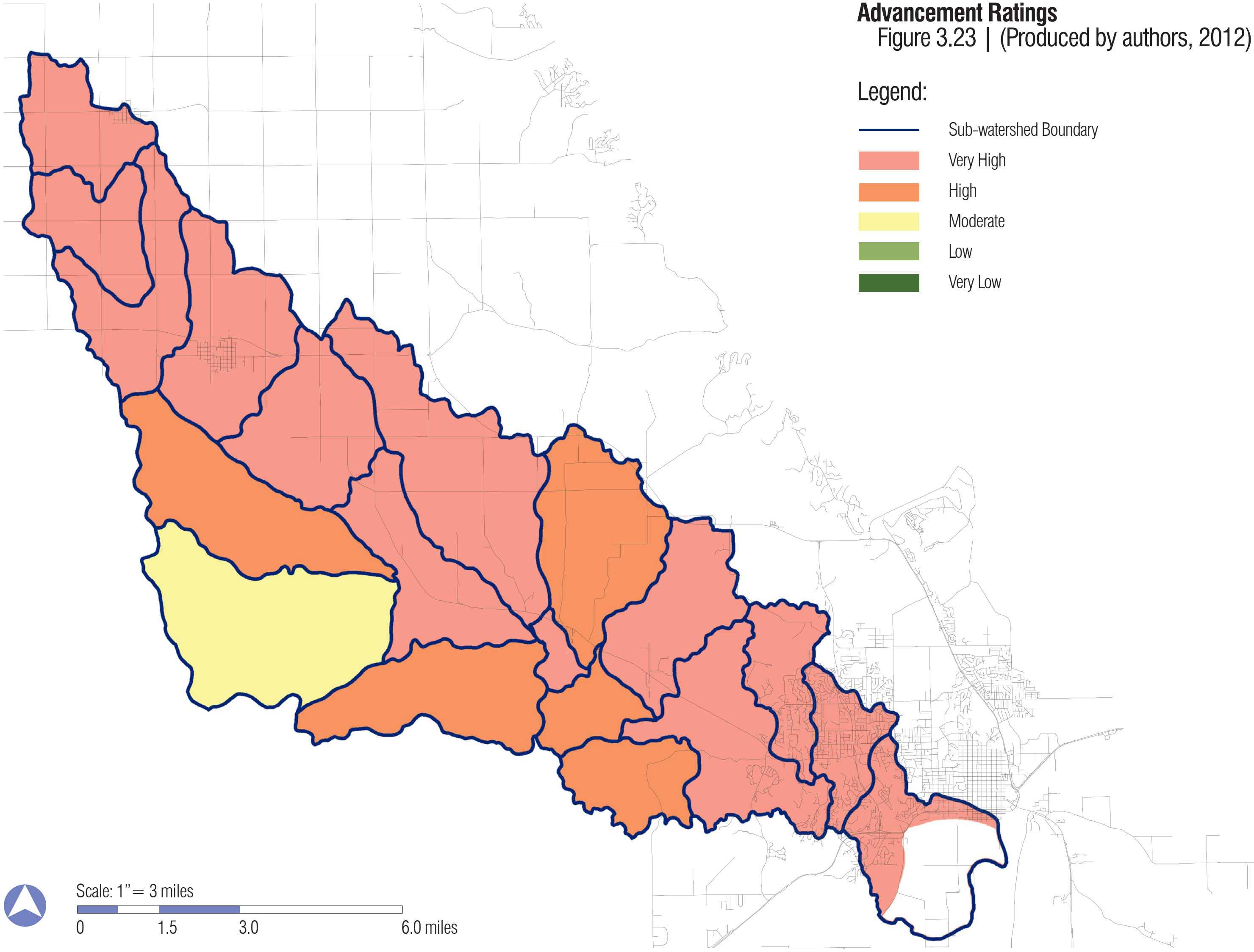
The G type streams within sub-watershed 19 rated as *Very High* risk. The down cutting common with G type streams will result in a decrease in width/depth ratio. This will cause a lowering of the base level and abandonment of the flood plain. This new base level will then advance on all connected reaches. The most likely factor to encourage degradation in sub-watershed 19 is stream flow changes. All streams within sub-watershed 19 should advance to the PLA level for detailed location analysis and evaluation.

Overall Review

The overall RRISSC summary worksheet indicates that sub-watershed 19 had at least **one** *High* risk rating and **one** *Very High* risk rating. The lower area of sub-watershed 19 below the locks were not considered in this assessment. The location of the sub-watershed within a densely populated urban area, and the associated land use practices are a driving force behind these elevated risk ratings. The areas rated as *High* and *Very High* will be forwarded to the PLA phase for further detailed evaluation.

Advancement Ratings

Figure 3.23 | (Produced by authors, 2012)



Masters Report Abstracts

Six group members have produced an individual Master's project that suggests possible solutions the City of Manhattan and Riley County can utilize in order to reduce the impact of the flooding events within the watershed. Full reports can be found here: **https://krex.k-state.edu/dspace/handle/2097/13605**

Jared Buffington | Evaluating the Aesthetic and Amenity Performance of Vegetated Stormwater Management Systems

Jeffrey Clark | A Hydrologic Approach to Environmental Golf and Hazard Design within the Wildcat Creek Watershed

Danielle Denlinger | Riparian Opportunities

Jennifer Engelke | Wetlands: A flooding Solution

Elizabeth Musoke | Implementation of a Rainwater Harvesting Network to manage Stormwater Runoff in Manhattan, Kansas

Christopher Sanders | Burning bridges | reinventing the American lawn: A strategic approach to residential stormwater management

Evaluating the Aesthetic and Amenity Performance of Vegetated Stormwater Management Systems

Jared Buffington

Stormwater management within the urban context has evolved over time. This evolution has been categorized by five paradigm shifts. (Novotny, Ahern, & Brown, 2010) The current paradigm of stormwater management utilizes hard conveyance and treatment infrastructure designed mainly to provide protection for people from typical 1-5 year frequency storms. Consequently, this infrastructure is sometimes unable to deal with larger sized, 50 to 100 year events which can have serious consequences.

Manhattan, Kansas has suffered multiple flooding episodes of severe proportion in the past decade. The dilemma of flooding within the Wildcat Creek watershed is a direct example of the current paradigm of stormwater management. This once ecologically healthy corridor is fed by conveyance systems that do not address the hydrologic needs of the watershed; decreasing the possibility for infiltration and groundwater recharge. Vegetated stormwater management systems must be implemented to help increase infiltration and address flooding problems within the Wildcat Creek watershed.

The aesthetic performance of designed landscapes has a tremendous effect on the appreciation and care given to them by the surrounding population. (Gobster, Nassauer, Daniel, and Fry, 2007) Landscape architecture has the ability to aid in the visual appeal and ecological design of vegetated stormwater management systems (SMS) by utilizing existing frameworks that address aesthetic reaction of the outdoor environment. (Kaplan, Kaplan, and Ryan, 1998) This document evaluates design alternatives of vegetated SMS in order to discern a set of variables that inform the relationship between each systems aesthetic and amenity performance and their ecosystem and hydrological performance.

Identified variables are combined into a set of guidelines for achieving different levels, or patterns of aesthetic performance found within the Understanding and Exploration Framework et al. (Kaplan, Kaplan, and Ryan, 1998) and amenity performance listed by Echols and Pennypacker's Amenity Goals et al. (2007) through vegetated SMS. These design guidelines illustrate how aesthetic theory can be applied through ecological systems in order to increase the coherence, legibility, complexity, and mystery (Kaplan & Kaplan, 1989) of existing sites. Creating spaces where ecological and socio-cultural activities can coexist addresses the local characteristics of aesthetics with the universal dilemma of stormwater management.

A Hydrologic Approach to Environmental Golf and Hazard Design within the Wildcat Creek Watershed

Jeffrey Clark

The City of Manhattan, Kansas is looking for possible solutions to mitigate flooding along Wildcat Creek within the Wildcat Creek Watershed. Recent flooding has caused substantial property damage. The project presented here brings recreation into the community by designing a golf course in a location along Wildcat Creek that addresses flooding issues, increases infiltration, and improves water quality. The golf industry has a long way to go to become more sustainable. The world is facing many challenges related to water and hydrology. Much of the opposition towards the golf industry is because critics see it as environmentally unfriendly. Golf has the potential to become a catalyst for change in the way we design and develop the landscape around us. The golf industry can become a leader in sustainable design while taking on hydrological concerns within the community.

This project demonstrates the application of a golf course to help mitigate flooding along Wildcat Creek with the use of vulnerability and suitability analysis as a guide to site selection. This method of analysis illustrates the process of identifying and protecting areas vulnerable to degradation by designing a golf course in a suitable location to utilize water hazards to store flood water, provide more floodplain access to effectively increase infiltration capacity, reduce runoff rates, and improve water quality. The report explains the relationship between golf course design and environmental practices as they relate to hydrology on a theoretical site in Manhattan, Kansas.

By integrating golf course design theory and environmentally sound stormwater management practices, water hazards on the golf course can become the fundamental elements used in strategizing the design of the golf course. A conceptual plan was created to maximize the infiltration capacity of the site as well as allow increased floodplain access, and provide a place to store flood water. A golf course can then be properly sited and designed hydrologically around the use of water hazards to help reduce flooding, and improve water quality within the watershed.

Riparian Opportunities

Danielle Denlinger

Since the flood event that occurred on June 2, 2011, the question lingers throughout the entire community. When will the next rainstorm cause major flooding in Manhattan, Kansas? The flooding, which seems to be increasing in frequency and intensity, will not be alleviated with any singular plan of action. It will only be alleviated through a major shift in management practices, and in the way we perceive floods. In order to create effective management strategies, we must first develop a deeper understanding of the natural systems with which our actions constantly intervene. Riparian re-creation projects that enhance open space networks, evince our impact on natural systems, and delineate stream stabilization strategies through time, will instill fundamental understanding of stream processes.

This proposal is for two riparian projects intended to exemplify a significant shift in riparian corridor management. Two site-scale designs demonstrate strategies for both the urban and the agricultural context of Wildcat Creek Watershed, and inspire strategic transformation of riparian corridors throughout the watershed. The designs display recreational trail planning, riparian vegetation management, compatibilities with open space planning and stream management, and designing inspirational, educational experiences in local riparian landscapes. These pilot projects will attract community interest, and when replicated across the entirety of the watershed, the introduction of best management practices will create healthier ecosystems, and alleviate future flooding.

Wetlands: A flooding solution

Jennifer Engelke

Wildcat Creek in Riley County, KS has repeatedly flooded in the past 5 years causing significant damage to the watershed, private property, and community livelihood. Strategically placing wetlands throughout the watershed can help reduce stormwater runoff, increase infiltration, and increase wildlife habitat. A watershed assessment was completed to determine the best location for wetlands in the Wildcat Creek basin. Two watershed-scale plans for wetlands were derived and evaluated based upon estimation of stormwater runoff and quality of wildlife habitat.

Wetlands were then examined and incorporated into existing land cover and land uses at the site-scale for an existing golf course. Three proposals for the nine hole course (for best golf experience, wildlife habitat, and wetland creation) were developed to reflect expansion options from a Par 30 to a Par 34 or 35 course. Each proposal was evaluated based on wetland capacity from estimated stormwater runoff, quality of wildlife habitat, playability of the golf course for all skill levels, and cost of implementation. After this evaluation, the wetland proposal was moved forward and further developed into a proposal that is best suited for the site. Following wetland implementation, stormwater runoff can be collected on-site to prevent runoff and flooding at the golf course and downstream.

In order to solve flooding problems in the Wildcat Creek watershed, a series of wetlands can be implemented at the smaller site scale, like the Wildcat Creek Golf Course site, throughout the watershed. Wetlands are one component of a larger stormwater management system that is needed to reduce flooding of the Wildcat Creek and the flood-prone area of Manhattan, KS.

Implementation of a Rainwater Harvesting Network to manage Stormwater Runoff in Manhattan, Kansas

Elizabeth Musoke

The City of Manhattan, Kansas has been subject to intense flooding in the last couple of years. Areas of the City, within the Wildcat Creek Watershed, have been adversely affected. The City of Manhattan and stakeholders from various walks of life are looking for solutions to alleviate flooding within the area. This Master's Project looks into rainwater harvesting as one of the solutions to help reduce stormwater runoff and contribute to the alleviation of flooding within the Watershed. Rainwater harvesting is increasingly being recognized as an effective way to reduce stormwater runoff. This Master's Project explores the potential benefit of using a network of rainwater harvesting elements, namely rain barrels and cisterns supplemented by rain gardens and other infiltration methods to reduce runoff in the City of Manhattan, Kansas.

To assess the benefit of using rainwater harvesting in the City, a neighborhood scale site was chosen and divided into land use types. Each land use type was analyzed using three phases. Phase I calculates the volume of runoff generated from each land use type and how much of that runoff can be harvested from the rooftops. Phase II looks at the configuration of a rainwater harvesting system for the structures in each land use type and rainwater reuse options. Finally, Phase III looks at policies, regulations and incentives that can be employed by the City of Manhattan to help encourage rainwater harvesting. This Master's project seeks to educate the City and its residents about the benefits of rainwater harvesting as a stormwater management tool and provide steps towards potentially using rainwater harvesting as a way to reduce runoff, and help alleviate flooding in the Wildcat Creek Watershed.

Burning bridges | reinventing the American lawn: A strategic approach to residential stormwater management

Christopher Sanders

Wildcat Creek watershed in Riley County, Kansas has been scene to increasingly severe and damaging flooding in recent years. Significant flood events in the summer of 2010 and 2011 have prompted the community to action. One of many areas of concern will be addressed by this project in order to facilitate community efforts to reduce future flooding.

Residential stormwater best management practices (BMPs) implemented by property owners to reduce the amount of stormwater runoff entering the Wildcat Creek watershed is the focus of this project. An analysis of the residential development typology in the City of Manhattan within the Wildcat Creek watershed will guide stormwater BMP implementation strategies.

GIS identifies residential development types based on land use, land cover, and parcel size. Single family residential and high density multi-family developments are the areas of focus. Rational method stormwater calculations were conducted on one sample site selected from of four areas identified as unique within the residential context. The four sample sites will include large lot single family, small lot single family, traditional single family, and high density multi-family. The current stormwater runoff situation was constructed for residential areas of Manhattan within the Wildcat Creek watershed using these samples.

Sample sites were evaluated four times. Existing stormwater runoff amounts for each site were determined. A minimal BMP treatment in the form of a rain garden was applied. Then a moderate BMP treatment including rain gardens, rain barrels, and native plantings was applied. The fourth evaluation was on a high level of rainwater BMP treatment including rain gardens, rain barrels, cisterns, native vegetation, bioretention, and permeable paving.

Post-BMP runoff calculations were performed. The resulting data was compared to the pre-BMP stormwater data to determine the impact of varying degrees BMP treatments.

This work produced a series of BMP strategies specifically suited to the Wildcat Creek watershed. These site specific strategies are a valuable resource for community members to help reduce flooding in the watershed. The resulting calculations are also valuable tools for community leaders determining the value of stormwater regulations that may require or promote stormwater BMPs in Manhattan.

Conclusion

The chapter focuses on what was produced in the RLA and RRISSC chapters and what is needed to complete the next step, Prediction Level Assessment phase. The data and time needs are estimated to complete the WARSSS assessment.

Prior to initiation of the RLA (Reconnaissance Level Assessment) Phase, the nature of the problem was identified and existing data reviewed. The RLA Phase, which is composed of 15 steps, is the initial and most general of the three phases in WARSSS. This assessment phase provides a broad overview of the landscape, focusing attention upon the processes that may affect sediment supply and channel stability, and identifying detrimental processes and their corresponding locations. The RLA Phase emphasizes three major goals: first, identification of sediment sources and channel stability problems linked directly to land and river management activities; second, refinement, clarification, or if necessary, redirection of problem identification; and finally, location of potential problem areas and reaches within a larger watershed requiring a more detailed assessment.

The RLA Phase assessment was initiated by dividing the watershed into six different land use types: agricultural land, grazing land, City of Manhattan, Fort Riley, expanding Manhattan, and flood wall. Of the six types, agricultural land, City of Manhattan, Fort Riley, and expanding Manhattan were judged as suited to move on to the next phase of the WARSSS assessment. The flood wall land use type was eliminated from further consideration due to its location within the watershed. The locations determined to contribute to sediment loading and increased amounts of runoff were advanced to the RRISSC phase of the assessment.

The RRISSC (Rapid Resource Inventory for Sediment and Stability Consequence), the second phase of the WARSSS process, was performed as part of the Wildcat Creek watershed analysis. The watershed was subdivided into 19 sub-watersheds to allow more detailed consideration. This phase was executed to provide a finer level of analysis and identification of areas that would likely contribute excess sediment and runoff. Each process assessment was used to create an overall summary risk rating by specific location, and then allowed determination as to whether a given sub-watershed or river reach merited further, more detailed assessment. The steps to determine the overall risk rating included: gathering information needed for the analysis, determining the risk ratings for three different erosional processes, and ultimately identifying areas in need of further quantified assessment.

Land uses activities evaluated, are considered for three different processes: hillslope, hydrologic, and channel. These processes were analyzed as to how different factors like roads, surface disturbance, agricultural application, and urban development may affect the watershed. Such consideration helps gather additional information needed to analyze the watershed for the RRISSC phase. The hillslope process analysis focused on the land uses that influence sediment supply by mass erosion, roads, and surface erosion. This included looking at the soil and hydrologic characteristics, vegetation coverage, slopes of roads, and many other factors to determine the risk rating for the hillslope process. The next process group analyzed was the hydrologic process. Here we assessed the potential for streamflow changes by looking at how both the rural and urban areas are contributing to additional sediment and runoff amounts. This assessment took into account the areas that were cleared or harvested and the amount of impervious land for all of the sub-watersheds, and resulted in a risk rating for hydrologic process. The risk rating analysis for channel process looks at how the channel system itself is contributing sediment. Assessed here are: broad-level channel stability, stream bank erosion risk, direct impacts, channel enlargement risk, aggradation and excess sediment, channel evolution potential, and degradation. Considered at this stage are many stream channel features such as bank heights, widths, the amount of riparian vegetation, among many other factors, and result in the risk rating for channel processes.

An overall risk rating was determined based upon individual hillslope, hydrologic, and channel risk ratings. Sub-watersheds that were likely to contribute excess sediment and runoff were identified. Sub-watersheds rated as high or very high risk ratings, were advanced for PLA assessment phase consideration. In the RRISSC assessment of Wildcat Creek watershed, eighteen of the nineteen sub-watersheds were rated high to very high risk. 64% of the total watershed was rated very high risk, 26 % was rated high, and only 10% was rated moderate. Sub-watersheds with high or very high risk rating (90% of the watershed) should advance to the PLA phase for further assessment. Only one sub-watershed was rated moderate risk (10% of the watershed), and would not automatically advance for more assessment in the PLA phase. It should be noted that PLA phase assessment would require further subdivision of the 19 sub-watersheds which would likely reduce the overall percentages of land falling into the high and very high risk ratings.

The Prediction Level Assessment (PLA) phase of the WARSSS methodology is the most detailed of all the levels. This level allows for the identification of problem zones that occur within the study area. The areas of focus at this level have all been identified as being at high risk for river stability and/or sediment issues in the previous RRISSC phase. Sediment is of concern because it has implications in areas such as floodplain management and river stability. The PLA phase is different from the previous phases of WARSSS in that it requires much more time and man-power. The PLA phase evaluates the direction, rate, nature and extent of departure of current sediment and channel stability to a reference reach condition that is typical of stable, natural land and stream systems.

The PLA will result in the identification and quantification of sediment sources and river stability issues. This identification is done through the use of monitoring and site evaluation so as to compare predicted values to actual values. The time requirement on average for the assessment of a single, third-order watershed is one month (Rosgen, 2006). Once sediment yield is identified, one can evaluate the effects of this sediment on river stability and how river instability in turn affects sediment yields. The information gained from evaluation of sediment supply and river stability allows for the design of site-specific and process specific management and mitigation techniques.

The RRISSC phase identified 18 of the 19 sub-watersheds in the Wildcat Creek Watershed to move forward to the PLA phase. During the PLA phase, various monitoring techniques such as suspended bedload sampling, suspended sediment sampling and velocity measurements will take place. These field measurements will compare and analyze both stable and impaired reaches within each sub-watershed to accurately predict and prioritize management and mitigation requirements.

Information on many different factors is needed to assess the amount of sediment and runoff supplied from the different sub-watersheds. Some of these factors address soil and landscape characteristics, and how those characteristics influence amounts of sediment and runoff supplied. These factors included determining the soil types, topographic maps, vegetation, aerial photographs, roads, valley types, geologic maps, and precipitation values. These factors play a significant role in determining if excess sediment and runoff will be produced from a certain areas, and will also help with some of the variables needed to do calculations and run the BANCS, FLOWSED, and POWERSED models.

Additional information needed to do calculations and run the models noted are the stream channel characteristics. This involves doing field survey measurements to determine the bankfull width, bankfull cross-sectional area, bankfull slope, and sampling the material that is located in the stream. Sampling of the bed material in the channel allows determination of the size and distribution of sediment, the friction in the channel, and the relative roughness of the channel. All these factors help calculate the mean bankfull velocity that occurs in the channel, determines the stream classification for the reach, and develops important stability indicators needed for model analysis.

The identification of stream stability indices determines many of the factors needed for the sediment transport capacity model (POWERSED). The stability indices include: riparian vegetation, flow regime, stream order and size, meander patterns, depositional patterns, channel blockages, degree of channel incision, width/depth ratio state, degree of channel confinement, stream succession stage shifts, and the Pfankuch channel stability rating. Sediment competence requirements also help determine the size and amount of sediment that could be carried by the stream. The sediment competence calculations include additional sediment sampling and determination of the average water surface slope and the mean bankfull depth.

To predict stream bank erosion, the BANCS model is employed. This model is separated into two different processes: Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS). The factors needed to determine the BEHI and NBS are observed in the field. The BEHI variables are examined by determining the study bank-height ratio, root depth ratio, weighted root density, bank angle, amount of surface protection, bank material, and stratification of bank material. The NBS (Near Bank Stress) is determined by selecting one or more of the following methods that helps determine the stress on the bank based on certain stream features: radius of curvature to bankfull width, depositional features, pool slope to average water surface slope, pool slope to riffle slope, near-bank max. depth to bankfull mean depth, near-bank shear stress to bankfull shear stress, or velocity gradients. The BEHI and NBS results are used to run the BANCS model to predict the sediment supplied from stream banks.

The FLOWSED model determines total annual sediment yield prediction. The model requires information needed for some of the previous calculations. It includes: stream classification, Pfankuch channel stability rating, bankfull discharge, and sediment. This model determines the total annual sediment yield prediction, and when combined with the streambank erosion amount and sediment delivery from hillslope processes results in the total annual sediment yield to be calculated.

Calculations and models help establish the amount of sediment that is being supplied to the stream and the stability of the stream. These are important in determining where the stream channel is heading and what kind damages might be incurred as a result of increasing sediment and runoff. The results of the calculations and models would also assist in the designs of structures to help reduce the amount of sediment and runoff. The type of detailed information provided by PLA level assessment is requisite to the prioritization of sub-watersheds for stabilization, restoration, or rehabilitation activities. Such prioritization is especially important in a watershed as large as that of Wildcat Creek where funding for improvements will be limited.

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Sources and literature used to complete the watershed assessment

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Appendix A | Glossary

Terms and definitions of fluvial vocabulary are defined to help understand the watershed assessment.

100 year Floodplain- Land that has a 1 to 100 probability of flooding each year.

Aggradation- "A raising of local base level due to sediment depositional processes over time" (Rosgen, 2006)

Bankflow depth (mean)- the distance between the creek surface and bankfull stage (Rosgen, 2006)

Bankflow width- Width of the stream at bankfull stage (Rosgen, 2006)

Base flow- "Stream flow coming from groundwater seepage into stream." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Bank-Height Ration

Basin – "A physiographic region bounded by a drainage divide; consists of a drainage system comprised of streams and often natural or man-made lakes." Another name for a watershed. (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Best Management Practice- Slowing and controlling stormwater runoff through systems that improve the quality of water in urban and rural environments. Typically used with areas that do not have high levels of infiltration and do collect stormwater runoff.

Biological Characteristics – "A characteristic of water defined by the levels of bacteria, viruses, and microscopic animals present." (Bell, Eccles, Garber, Kerby & Swaffar, 2004) Characteristics that are used to determine water quality.

Channel- An area intended for a concentrated flow of water that is designed and built to handle stream flow/water movement. Some areas may be ephemeral, but during rain events, water fills the otherwise dry creek bed.

Conservation – "Conservation is the wise use of natural resources (nutrients, minerals, water, plants, animals, etc.) Planned action or non-action to preserve or protect living and non-living resources." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Degradation - "A lowering of local base level over time due to channel incision processes" (Rosgen, 2006)

Discharge – "The outflow of water, originating from either a pipe or stream, into a larger body of water." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Domestic Water Use – Residents using water for everyday household activities "such as drinking, bathing, washing clothes, and watering lawns and gardens." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Ecosystem- "A group of plants or animals together with that part of the physical environment with which they interact." (Bell, Eccles, Garber, Kerby & Swaffar, 2004) Food, shelter, and water systems of an area working together to support each other.

Filtration – "A treatment technology used to remove inorganic compounds from water." (Bell, Eccles, Garber, Kerby & Swaffar, 2004) Gravel or vegetative sources can be used to clean water as it passes through.

Flooding Extent- Map of the major local flooding area in June 2011.

Flood Plain – A lowland area that has a high flooding risk. The official boundary is set by FEMA, causing higher insurance rates of developed land within this area.

Flow – "The rate of water discharged from a source expressed in volume with respect to time." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Ground Storage – "A below ground tank for storing water" also known as stormwater cisterns. (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Groundwater – "Water that flows or seeps downward and saturates soil or rock forming pockets of stored water." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Hydrologic Cycle- "Complete cycle through which water moves from the oceans, through the atmosphere, to the land and back to the oceans." (Bell, Eccles, Garber, Kerby & Swaffar, 2004) The cycle or evaporation, clouds forming, rain or snow falling, and runoff back into the water source.

Hydrology- "A study of water and its properties, circulation, principles and distribution." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Impermeable- "Geologic formations that resist water percolating through them." (Bell, Eccles, Garber, Kerby & Swaffar, 2004) Buildings, pavement (impermeable), infrastructure, and rock are some examples of impermeable surfaces that don't collect water and create higher levels of runoff.

Intermittent Stream- "A stream or reach of a stream that flows only at certain times of the year." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Infiltration- Water seeping into the ground and creating moist soil, feeding plants through the root system, and preventing water from leaving the site. This is encouraged through the use of permeable materials, sandy soils, and vegetation.

Leaching- "The separation of constituents from the soil by the movement of water through the ground. The soluble components are carried down by the moving water where they may enter ground water aquifers." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Mouth of Stream- "The point of discharge of a stream into another stream, lake or sea." (Bell, Eccles, Garber, Kerby & Swaffar, 2004) The point to were a tributary enters Wildcat Creek or were Wildcat Creek enters the Kansas River.

Municipal Water System- "A water system that serves at least 25 people, or has more than 15 service connections used by residents more than six months per year, governmental entity such as a city, county, town, village, sanitary district, state, or federal institution owned." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Natural Flow- "Rate that water moves past a specific point on a natural stream. The flow comes from a drainage area in which there has been no stream diversion caused by storage, import, export, return flow, or change in consumptive use; caused by land use modifications." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Paradigm- standards or model that guides design in a specific area (i.e.: water sensitive design paradigm)

Percolation- "The downward movement of water through the soil." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Permeable- "A characteristic of underground formations which have pores or openings that permit liquids to pass through." (Bell, Eccles, Garber, Kerby & Swaffar, 2004). Areas or materials with high levels of infiltration.

Perennial Stream- "A lasting or active stream that runs water throughout the year." (Bell, Eccles, Garber, Kerby & Swaffar, 2004). Wildcat creek is an perennial stream.

Persistent Pollutant- “A pollutant which degrades very slowly and remains in the environment for years.” (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Pollution of Water- “When the level of concentration is high enough to impair water quality to a degree that it has an adverse effect upon any beneficial use of the water.” (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Rip Rap- “Crushed and broken stone of varying sizes placed to cover soil. Used for landscaping and erosion control.” (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Riparian- Area that is adjacent to the creek and helps increase infiltration, commonly wooded. The riparian area often is a protector of the creek and a boundary between development or agricultural land and the creek.

Runoff- Stormwater that leaves the original point source and continues onto another property or location. Finding ways to reduce runoff will reduce flooding. Part of flooding is a result of too much runoff from other locations descending into a new location.

Sedimentation- “The deposition of silt, soil, clay or sand particles in locations where slow-moving water loses its ability to hold heavier particles in suspension.” (Bell, Eccles, Garber, Kerby & Swaffar, 2004) The changes in erosion processes will become critical in the RLA portion of the WARSSS analysis.

Static Water Level- “The water level in a well when the pump is not running.” (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Storm Water- “Rain water that is not treated and flows into a storm drain or storm ditch then into streams rivers and lakes.” (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Stormwater Management- “The collection, conveyance, storage, treatment and disposal of stormwater runoff to prevent accelerated channel erosion, increased flood damage, and degradation of water quality.” (Montgomery County Planning Department, 2009.)

Stream Bank Stabilization- “Attempts to retard the banks from eroding by use of vegetation, weirs, riprap, etc.” (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Surface Erosion- “The wearing away of the surface by water, wind, ice, or other erosional processes” (Rosgen, 2006)

Sustainability- A blend of social, economic, and environmental features in the landscape that allow the site to survive and hopefully thrive into the future. (Triple Bottom Line)

Sustainable Development- "Development that meets the needs of the present without sacrificing the ability to meet future needs." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Upland- Area within watershed that does not exist in the floodplain.

Vulnerability Assessments- "An assessment performed for all community and non-transient, non-community public water systems every three years. It consists of an inventory of potential contamination sources in a delineated area; includes: well construction and pesticide susceptibility and industrial chemical use evaluations; and vulnerability to volatile organic compounds (ethylene dibromide, asbestos and coal tar)." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Water Pressure- "The force of the water available in a water supply system." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Water source- "The origin of water in a water supply system, usually a well, reservoir, or river." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Water Table- "The upper portion of the part of the ground that is completely saturated with water. The water level in a well when the pump is not running." (Bell, Eccles, Garber, Kerby & Swaffar, 2004)

Watershed- Land that directs water into a concentrated water drainage way.

Watershed Planning- Process focusing on the means to "…resolve and prevent water quality problems that result from both point source and nonpoint source problems." Watershed planning process includes: Build partnerships, characterize watershed to identify problems, set goals and identify solutions, design an implementation program, implement the watershed plan and measure progress and make adjustments. (United States Environmental Protection Agency, 2008)

Appendix B | Field Check Lists

Field Check lists were developed for the RLA phase when hotspots and types were examined during a field visit. The criteria allowed all hotspots and types to be evaluated equally.

Type I: Agricultural Land

Field Checklist: Type I			
	Problematic	Not Applicaple	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization	High Channelization		Areas throughout the Tpye I subwatershed have been subject to channelization
Previously Channelized	Presence of Historically Channelized Areas		Tributaries in the northern part of Type I have experienced historical channelization. Remants of this previous channelization can still be seen even though the streams are reverting back to a more natural form.
Deforested		X	
Removal of Riparian Vegetation	Town of Riley		Removal of Riparian vegetation has occurred within the town of Riley to accommodate development.
Culverts and Road Crossings	Oversized culverts and numerous road crossings		Oversized culverts and road crossings affect many of the tributaries throughout type I.
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction			
New Construction			
Non-terraced agricultural fields	Grazing land		Although terraced agriculture is present in Type I a significant amount of non terraced argriculture compromises the integrity of the tributaries in this sub watershed.
Proximity to Impervious Surfaces	Town of Riley		Though small, the urbanized portion of Riley adds to the impervious surfaces in Type I. Some tributaries have been in impacted by the development.
Proximity to Roads	Roadnetwork in Riley and gravel roads.		Tributaries have been affected by the road network of Riley. A number of tributaries also lie in close proximity to gravel roads.
Significant Source of Sediment	Gravel roads		Proximity to gravel roads leave some of the streams suscpetible to high sediment flows
Lack of Riparian Vegetation	Grazing land and non-terraced ag		Land designated for grazing, and/or non-terraced agriculture has left the tributaries susceptible to erosion throughout Type 1.
Conclusion			Necessary to be taken to the RRISSC level assessment

Overall Type I Checklist

Table B.01 | (Produced by author, 2012)

Field Checklist: 1 - 1			
	Problematic	Not Applicable	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized	Parellel with road		The area was origninally channelized years ago. The creek is still close to the gravel road adding high levels of sediment.
Deforested		X	
Removal of Riparian Vegetation		X	
Culverts and Road Crossings	Oversized culverts		At road crossings two oversized culverts exist that were put in within the last ten years.
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields	Adjacent to stream channel		The area east of the hotspot has non-terraced agricultural fields with as small woody vegetation buffer between the field and the creek channel.
Proximity to Impervious Surfaces		X	
Proximity to Roads	Parellel with road		The area of concern begins at one of the road crossings, and runs parellel with another road. All raods are gravel wich prduces higher levels of
Significant Source of Sediment		X	
Lack of Riparian Vegetation	Grazing field with limited woody vegetation		There is spotty woody vegetation adjacent to the creek . The surrounding areas are pasture fields. That is etter than the crops, but not ideal for the creek.
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 1-1 Field Checklist

Table B.02 | (Produced by author, 2012)

Field Checklist: 1 - 2			
	Problematic	Not Applicaple	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized	Historically Channelized		The area appears to have historically been channelized, but it is now not needing to be kept up in the channelized form.
Deforested		X	
Removal of Riparian Vegetation		X	
Culverts and Road Crossings	culvert begins the hotspot area		Culvert don't appear to be new, but do restrict the flow of water
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields	Grazing land adjacency		There is not agricultural fields, but grazing land that is contributing sediment to the stream. The levels of sediment that could go into the stream are still
Proximity to Impervious Surfaces		X	
Proximity to Roads		X	
Significant Source of Sediment		X	
Lack of Riparian Vegetation	Grazing land with on Riparian		The grazing land does not have woody vegetation in that area. The grasses are the primary vegetation and food source.
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 1-2 Field Checklist

Table B.03 | (Produced by author, 2012)

Field Checklist: 1 - 3			
	Problematic	Not Applicable	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization	still highly channelized		The creek is still close to the gravel road adding high levels of sediment. Area around building is also been channelized to maximize crop growth and increase sediment.
Previously Channelized		X	
Deforested		X	
Removal of Riparian Vegetation		X	
Culverts and Road Crossings	Oversized culverts		At road crossings two oversized culverts exist that were put in within the last ten years.
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields	Adjacent to stream channel		The riparian corridor is surrounded by non-terraced agriculture, creating high levels of sediment. Some areas have direct adjacency to the creek, making it highly vulnerable.
Proximity to Impervious Surfaces		X	
Proximity to Roads	Parellel with road		The area of concern begins at one of the road crossings, and runs parellel with another road. All raods are gravel wich prduces higher levels of
Significant Source of Sediment	Gravel Roads		Some areas of have woody vegetation, but next to Alembic Road and and south, there is not woody vegetation to encourage unstablize creeks and high sediment flows.
Lack of Riparian Vegetation	Grazing field with limited woody vegetation		Some areas of have woody vegetation, but next to Alembic Road and and south, there is not woody vegetation to encourage unstablize creeks and high sediment flows.
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 1-3 Field Checklist

Table B.04 | (Produced by author, 2012)

Field Checklist: 1 - 4			
	Problematic	Not Applicaple	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization	Channelized segment		Part of the tirbutary to the north part of Riley has limited sinuousity implicating the presence of channelization.
Previously Channelized		X	
Deforested		X	
Removal of Riparian Vegetation	Development within Riley		The riparian buffer along the banks of the tributary been disturbed by the structural development in Riley.
Culverts and Road Crossings	Numerous road crossings		The tribuary is continually crossed by paved roads that form the roadway network for the town of Riley
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction			
New Construction		X	
Non-terraced agricultural fields		X	
Proximity to Impervious Surfaces	Residential area		The tributary is in close proximity to structures within Riley; mostly consisting of single family residences
Proximity to Roads	Paved Roads		Since the tributary flows through the town of Riley, it is in constant proximity to the town's road network
Significant Source of Sediment		X	
Lack of Riparian Vegetation	Areas of Open space		Areas around the tirbutary show no riparian vegtation or sparse riparian vegetation
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 1-4 Field Checklist

Table B.05 | (Produced by author, 2012)

Field Checklist: 1 - 5			
	Problematic	Not Applicaple	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization	Highly channelized		Tributary has been noticeable channelized. You can see the remants of its previous sinous form adjacent to the current channel.
Previously Channelized		X	
Deforested		X	
Removal of Riparian Vegetation			
Culverts and Road Crossings			Road crossings occur in two areas. Both a paved road and a gravel road coss the tributary.
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields	Tributary within the non-terraced ag		Part of the tributary passes through agricultural land that is non-terraced,
Proximity to Impervious Surfaces		X	
Proximity to Roads	Gravel Road		The tributary flows in close proximity to a gravel road, it also crosses the gravel road at a certain point
Significant Source of Sediment		X	
Lack of Riparian Vegetation	Agricultural field area		Areas around this particular tributary show a significant lack of riparian vegetation especicially where it has been channelized.
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 1-5 Field Checklist

Table B.06 | (Produced by author, 2012)

Type II: Grazing Land

Field Checklist: Type II			
	Problematic	Not Applicaple	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization			stream changes. The grazing land generally keeps the creek running through the land.
Previously Channelized		X	
Deforested		X	
Removal of Riparian Vegetation	Grazing Land		In order to create grazing land, it appears that the riparian vegetation that was adjacent to the creek was cleared creating more direct access for sediment to enter the creek.
Culverts and Road Crossings	Anderson Avenue		Tributaries transverse Anderson Avenue in numerous areas
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields	Small consideration		The agricultural land has a small portion of agricultural land that is not terraced, but a majority of it is flat and in the floodplain which doesn't produce as much sediment.
Proximity to Impervious Surfaces		X	
Proximity to Roads		X	
Significant Source of Sediment			The horse grazing land and pastures create more levels of sediment, but they are scattered throughout Type II.
Lack of Riparian Vegetation			Riparian vegetation for the most part is intact throughout Type II. Lack of riparian vegetation occurs in limited areas
Conclusion		X	Not to be taken to RRISSC level assessment

Overall Type II Checklist

Table B.07 | (Produced by author, 2012)

Field Checklist: 2 - 1			
	Problematic	Not Applicaple	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized		X	
Deforested		X	
Removal of Riparian Vegetation	structures		clearing for stable and surrounding buildings
Culverts and Road Crossings	multiple		gravel road crossings
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields		X	
Proximity to Impervious Surfaces		X	
Proximity to Roads		X	
Significant Source of Sediment	horse stables		over grazing causeing excess sediment displacement
Lack of Riparian Vegetation		X	
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 2-1 Field Checklist

Table B.08 | (Produced by author, 2012)

Field Checklist: 2 - 2			
	Problematic	Not Applicable	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized	straitened		gravel road adjacency
Deforested		X	
Removal of Riparian Vegetation	east side of stream		removed for gravel road access
Culverts and Road Crossings		X	
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields		X	
Proximity to Impervious Surfaces		X	
Proximity to Roads	adjacent to road		gravel road to east
Significant Source of Sediment		X	
Lack of Riparian Vegetation		X	
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 2-2 Field Checklist

Table B.09 | (Produced by author, 2012)

Field Checklist: 2 - 3			
	Problematic	Not Applicaple	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized		X	
Deforested		X	
Removal of Riparian Vegetation		X	
Culverts and Road Crossings	none	X	
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields		X	
Proximity to Impervious Surfaces		X	
Proximity to Roads		X	
Significant Source of Sediment		X	
Lack of Riparian Vegetation	not problematic	X	identified as well established drainage ways
Conclusion			Not to be taken to the RRISSC level assessment

Hotspot 2-3 Field Checklist

Table B.10 | (Produced by author, 2012)

Type III: City of Manhattan

Field Checklist: Type III			
	Problematic	Not Applicable	Explanation & Notes
Land Activities Impacting Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized	throughout		
Deforested	throughout		increased urbanization
Removal of Riparian Vegetation	frequent		due to new development
Culverts and Road Crossings	multiple		
Changed Stream Channel	throughout		daylit streams heavily channelized
Changed Stream Flow	throughout		most of drainage changed through piping
Disturbance Factors:			
Compaction	present		infill from new developments
New Construction	throughout		
Non-terraced agricultural fields		X	
Proximity to Impervious Surfaces	throughout		urban context of Manhattan
Proximity to Roads	throughout		
Significant Source of Sediment	infill		infill of surrounding floodplain contributes to channelization
Lack of Riparian Vegetation	throughout		
Conclusion			Subwatershed necessary to be taken to the RRISSC level assessment

Overall Type III Checklist

Table B.11 | (Produced by author, 2012)

Type V: South Manhattan and Industrial Area

Field Checklist: Type V			
	Problematic	Not Applicable	Explanation & Notes
Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized		X	
Deforested	X		Development
Removal of Riparian Vegetation	X		Only at road crossing
Culverts and Road Crossings	X		Crosses major Road
Changed Stream Channel	X		Stream Channel Straightened
Changed Stream Flow	X		water course is constricted and doesn't have floodplain contact. The channel velocity stays in the stream
Disturbance Factors:			
Compaction		X	
New Construction	X		
Non-terraced agricultural fields			The native grass fields are terraced
Proximity to Impervious Surface	X		Commercial devlelopement near stream channel
Proximity to Roads	X		Closer to the City of Manhattan
Significant Source of Sediment	X		Primarily Due to bank erosion
Lack of Riparian Vegetation	X		
Conclusion			Subwatershed to be taken to the RRISSC level assessment

Overall Type IV Checklist

Table B.12 | (Produced by author, 2012)

Field Checklist: 5 - 1			
	Problematic	Not Applicaple	Explanation & Notes
Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized		X	
Deforested	X		Development
Removal of Riparian Vegetation	X		Residential housing
Culverts and Road Crossings	X		
Changed Stream Channel	X		Stream Channel Straightened
Changed Stream Flow	X		water course is constricted and doesn't have floodplain contact. The channel velocity stays in the stream
Disturbance Factors:			
Compaction		X	
New Construction	X		Housing Under construction and Bare Ground
Non-terraced agricultural fields		X	
Proximity to Impervious Surface	X		
Proximity to Roads	X		
Significant Source of Sediment		X	
Lack of Riparian Vegetation	X		
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 5-1 Field Checklist

Table B.13 | (Produced by author, 2012)

Field Checklist: 5 - 2			
	Problematic	Not Applicable	Explanation & Notes
Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized		X	
Deforested	X		Development
Removal of Riparian Vegetation	X		Only at road crossing
Culverts and Road Crossings	X		Crosses major Road
Changed Stream Channel	X		Stream Channel Straightened
Changed Stream Flow	X		water course is constricted and doesn't have floodplain contact. The channel velocity stays in the stream
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields		X	
Proximity to Impervious Surface	X		Commercial devlelopement near stream channel
Proximity to Roads	X		
Significant Source of Sediment	X		Primarily Due to bank erosion
Lack of Riparian Vegetation	X		
Conclusion			Necessary to be taken to the RRISSC level assessment

Hotspot 5-2 Field Checklist

Table B.14 | (Produced by author, 2012)

Type VI: Flood Gates

Field Checklist: Type VI			
	Problematic	Not Applicaple	Explanation & Notes
Sediment and Channel Stability:			
Recent Channelization		X	
Previously Channelized		X	
Deforested		X	
Removal of Riparian Vegetation	Minimal		Riparian vegetation thinner than northern bank of creek
Culverts and Road Crossings	South Manhattan Ave		Not verified as hotspot during field visit
Changed Stream Channel		X	
Changed Stream Flow		X	
Disturbance Factors:			
Compaction		X	
New Construction		X	
Non-terraced agricultural fields	entire sub-watershed		Slope indicates fields won't contribute largely to sediment
Proximity to Impervious Surfaces		X	
Proximity to Roads		X	
Significant Source of Sediment		X	Not a significant source of sediment
Lack of Riparian Vegetation		X	
Conclusion		X	Not to be taken to RRISSC level assessment

Overall Type VI Checklist

Table B.15 | (Produced by author, 2012)

Appendix C | PLA Data Needs

Prediction Level Assessment is the final phase in the WARSSS assessment. Data elements are still needed in order to complete the assessment.

Data Needs
Information Needed for the Prediction Level Assessment PLA

Italics indicates what data still needs to be gathered

1. Soil Type Maps
2. Topographic Maps
3. Aerial Photography
    a. Current
    b. Historical
4. *Time-trend vegetation alteration maps*
    a. *Nature of change (Percent stand or area, composion change)*
    b. *Extent (acres)*
    c. *Location*
    d. *Dates of change*
5. Geologic maps for valley types and materials
6. Geologic hazard maps (Information not needed for assessment)
7. Precipitation isohyetal maps (Information not accessible)
8. Satellite imagery during run-off periods (color I-R) (Information not accessible)
9. Regional curves for appropriate hydrophysiographic province
    a. Bankfull discharge
    b. Bankfull dimensions

10. *Bankfull Velocity calculation: Data collected from field survey (Long and Cross-Sectional Profiles)*
    a. *Drainage Area*
    b. *Bankfull Width (Wbkf)*
    c. *Bankfull Cross-Sectional area (Abkf)*
    d. *Bankfull Slope (Sbkf)*
    e. *D84 riffle bed material*
    f. *Friction factor*
    g. *Relative roughness*
11. *Reach Morphology for stream classification and dimensionless ratios of dimension, pattern, and profile: Data from surveys will help determine the reach morphology*
12. *Stream stability indices inventory: Data collected from field survey (Long and Cross-Sectional Profiles)*
    a. *Riparian vegetation*
    b. *Flow regime type*
    c. Stream order and size
    d. Meander patterns
    e. *Depositional patterns*
    f. *Channel blockages*
    g. *Degree of channel incision*
    h. *Width/depth ratio state*
    i. *Degree of channel confinement*
    j. *Pfankuch stability ratings*
    k. Stream succession stage shifts

13. *Sediment competence calculations: Data collected from field survey (Long and Cross-Sectional Profiles)*

  a. *D50 riffle bed material*

  b. *Bar sample (Dmax and D50)*

  c. *Average water surface slope (S)*

  d. *Mean bankfull depth (dbkf)*

14. *BANCS model to predict streambank erosion*

  a. *BEHI (Bank Erosion Hazard Index) :Data collected during field survey*

    ii. *Study bank-height ration*

    iii. *Root depth ratio*

    iv. *Weighted root density*

    v. *Bank angle*

    vi. *Surface protection*

    vii. *Bank material*

    viii. *Stratification of bank material*

  b. *NBS (Near-Bank Stress): Data collected during field survey*

    i. *Depositional features*

    ii. *Radius of curvature to bankfull width*

    iii. *Pool Slope to average water surface slope*

    iv. *Pool slope to riffle slope*

    v. *Near-bank max depth to bankfull mean depth*

    vi. *Near-bank shear stress to bankfull shear stress*

    vii. Velocity gradient: (Information not needed for assessment)

15. *Sediment transport capacity calculations (FLOWSED and POWERSED models): Data from BEHI and NBS*
    a. *Dimensionless flow-duration curves*
    b. *Dimensionless sediment rating curves: One data point obtained at bankfull stage for bedload sediment, suspended sediment and streamflow*
    c. *Mean daily bankfull discharge*
    d. *Dimensional flow-duration curves for pre- and post- treatment change (from water yield model)*
    e. *Unit stream power*
    f. *Dimensionless hydraulic geometry*
16. Roads
    a. Number of stream crossings
    b. Acres of road
    c. Age of road
    d. Specific mitigation