AN ABSTRACT OF THE THESIS OF

Elizabeth Hagenmaier for the Master of Science

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Title:

An evaluation of the use of the Storm Water Management Model (SWMM) for predicting Storm Water Runoff of Remediated Areas in Newton County, Missouri of the Tri-State Mining District

Abstract approved: ____

Granby, Missouri is located in the Newton County Mine Tailings Superfund site (Site) within the larger Tri-State Mining District of Missouri, Kansas, and Oklahoma. Ongoing remediation efforts of large mine waste areas centered in and around the city of Granby in Newton County, Missouri have left large swaths of un-vegetated native soil areas. Remediation efforts began in 2015 and addressed over 100 acres of mine waste and contaminated soils. As part of the remedy, the five remediated areas were first cleared of all vegetation to facilitate access to the mine waste and underlying contaminated soils. Many of these areas were heavily vegetated with large trees and tremendous undergrowth. The removal of the mine waste, vegetation, and contaminated soils were hypothesized to contribute to a change in storm water runoff and surrounding surface water resources. This project will examine the effects of the remediation actions at one remediation area, selected as a study area. The United States Environmental Protection

Agency (USEPA) Storm Water Management Model (SWMM) was evaluated as a potential tool for modeling environmental impacts in response to excavation. Models were conducted using a range of input parameters, with a goal of identifying the most important parameters for future monitoring. The SWMM model compiled in this research is based on field- and geospatially derived values for study area width, surface area, pervious and impervious land surface, and slope. Where specific model input parameters have not been measured at a site, published values at similar sites were used. Model outcomes provided information on sediment volume, erosion potential, and contaminant concentrations in runoff, which would allow for recommendations regarding future site remediation action. A sensitivity analysis determined the most critical variables required for reliable modeling was the Washoff Coefficient. The outcome demonstrates the importance of site-specific measurements of these parameters, and the need to conduct periodic monitoring of surface water runoff volume and mass contaminant loading from remediated areas in the study area.

Keywords: USEPA, SWMM, runoff, model

AN EVALUATION OF THE USE OF THE STORM WATER MANAGEMENT MODEL (SWMM) FOR PREDICTING STORM WATER RUNOFF OF REMEDIATED AREAS IN NEWTON COUNTY, MISSOURI OF THE TRI-STATE MINING DISTRICT

A Thesis

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1.1 Introduction

Granby, Missouri is located in the Newton County Mine Tailings Superfund site (Site) within the larger Tri-State Mining District (District) of Missouri, Kansas, and Oklahoma (Figure 1). Ongoing remediation efforts of large mine waste areas centered in, and around, the city of Granby in Newton County, Missouri have left large steep swaths of un-vegetated native soil areas. Remediation efforts began in 2015, and addressed over 100 acres of mine waste and contaminated soils (USEPA, 2018a). As part of the remedy, the five remediated areas were first cleared of all vegetation to facilitate access to the mine waste and underlying contaminated soils (Figure 2, USACE, 2017). Many of these areas were heavily vegetated, with large trees and tremendous undergrowth prior to excavation. The removal of the mine waste, vegetation, and contaminated soils have been theorized to contribute to increased storm-water runoff volumes and the contamination of nearby surface water bodies; however no quantitative evaluation of this process has been conducted. This project examined the effects of the remediation actions on runoff and contaminant releases at one remediation area. The United States Environmental Protection Agency (USEPA) Storm Water Management Model (SWMM) was evaluated as a potential tool for modeling the environmental impacts in response to excavation (USEPA, 2015a and USEPA, 2015b).

The SWMM approach is typically used to evaluate storm-water runoff in urban settings. Although it holds promise for use at large-scale excavated mine tailings sites, few studies have tested the ability of the SWMM method to predict surface runoff and pollutant loading at these type of sites (Lee et al., 2010; Avellaneda et al., 2009; Jang et al., 2007). The hilly terrain, extensive excavation, and potential for significant overland flow at the Granby site make it an ideal site for examining usefulness of SWMM in excavated mine areas. Existing site-specific information, and values from nearby stream-gaging and weather station, provide detailed information that allowed for the design and validation of model predictions at the Granby site. SWMM models were therefore constructed using these data, along with geospatial analysis of land surface conditions and site boundaries. Where necessary, published values for un-measured parameters at similar sites were used as model input parameters. Three SWMM simulations were designed to demonstrate pre- and post-remediation conditions during high-precipitation periods. Pre- and post-remediation SWMM models were constructed in which the percentage of pervious and impervious land surfaces, amounts of precipitation, and surface roughness (Manning's roughness coefficient) were varied. The models provided estimates of volumes of surface water runoff and contaminant mass. The modeled post-remediation contaminant mass in runoff was compared to the cleanup levels established by USEPA. These assessments were used to test three hypotheses that will demonstrate the value of applying SWMM to excavated mine site investigations. The outcome of the work provides a new assessment tool that may enable recommendations regarding future site remediation action.

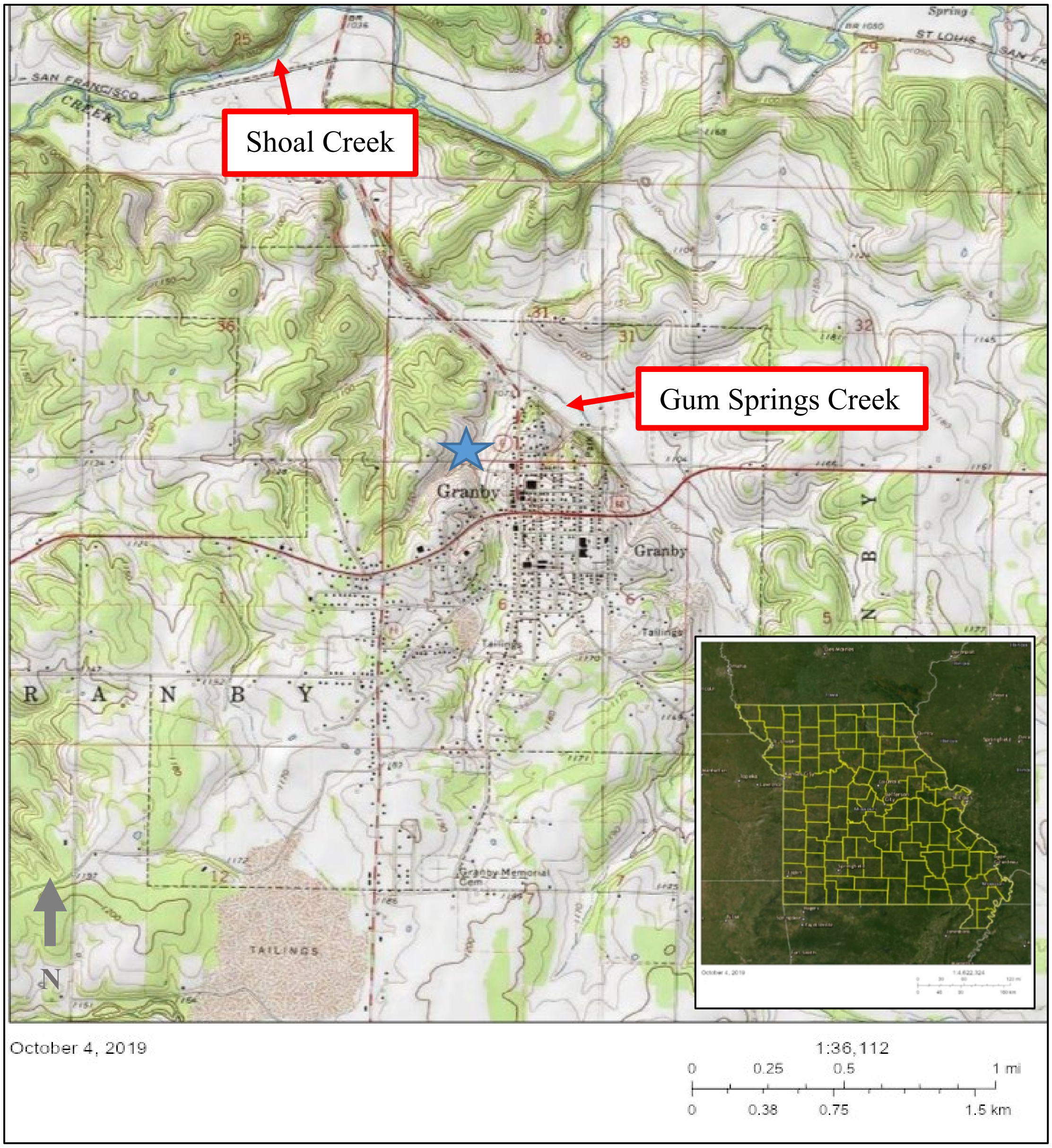
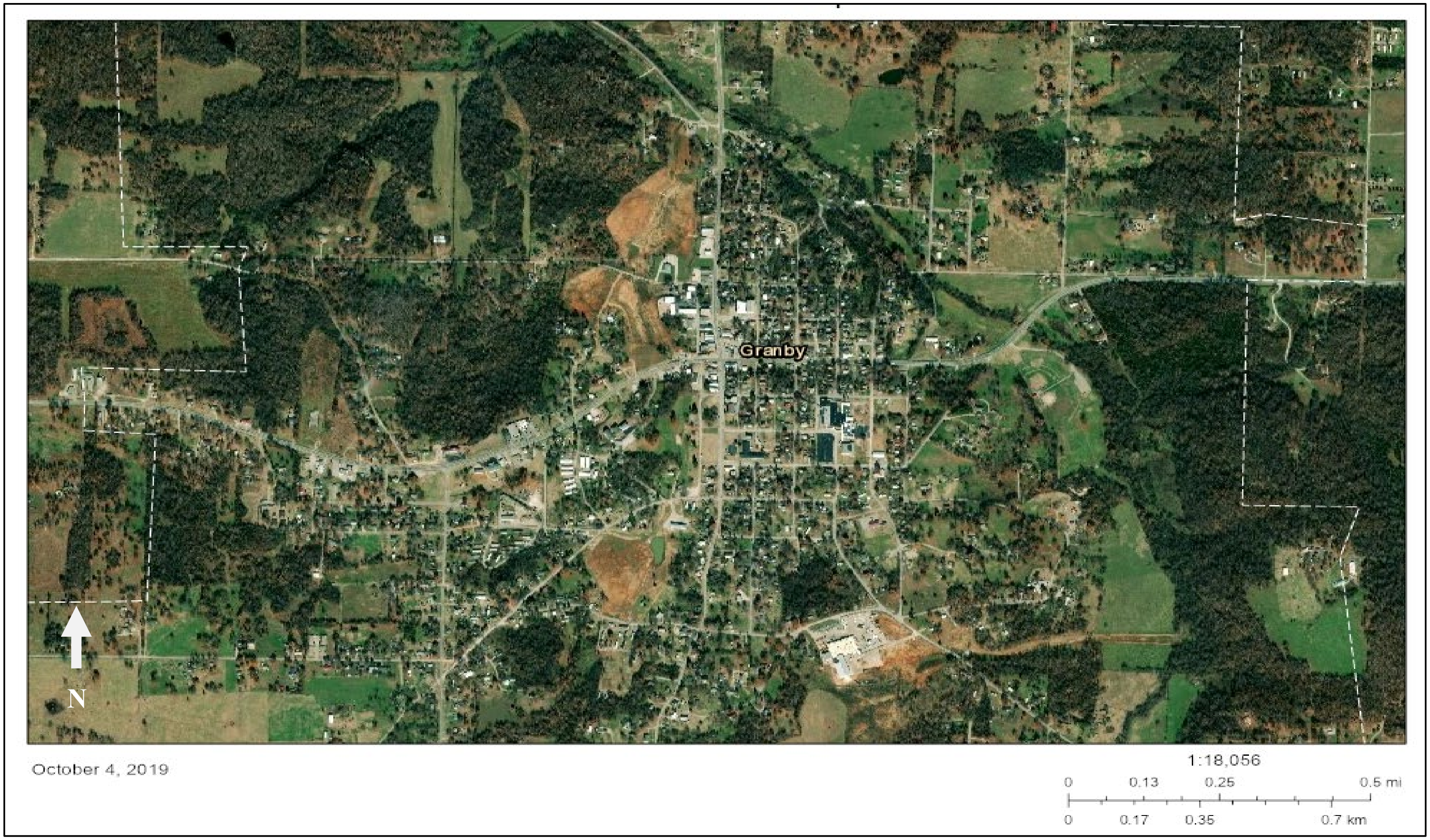


Figure. 1. The study site (blue star) is located on the west side of Granby in southwest Missouri. The site is south of Shoal Creek and west of Gum Springs Creek, in Newton County, Missouri. (MSDIS, 2019)



October 4, 2019

Figure 2. Remediated areas in the Granby Subdistrict are indicated by un-vegetated red clay surfaces (MSDIS, 2019).

1.2 Objectives

The primary objective of this research was to determine if SWMM modeling can reliably predict differences in storm-water runoff volumes and contaminant mass released after recent remediation activities were completed at an excavated mine tailings site. Predictions of the potential migration of metal contamination in runoff from residual surficial metals were made based on a comparison of initial and post-remediation metal concentration in runoff. To achieve these objectives, a three-step hypothesis was tested:

1. The volume of surface-water runoff was higher in post-remediation models than in pre-remediation models.

2. The volume of surface-water runoff increased after six months of above average precipitation.

3. The mass of lead and zinc in runoff in a post remediation landscape was higher after an above average six-month rainfall period than before it.

To test these hypotheses, SWMM models were constructed using information provided in previous site investigations and published monitoring data obtained by state and federal agencies.

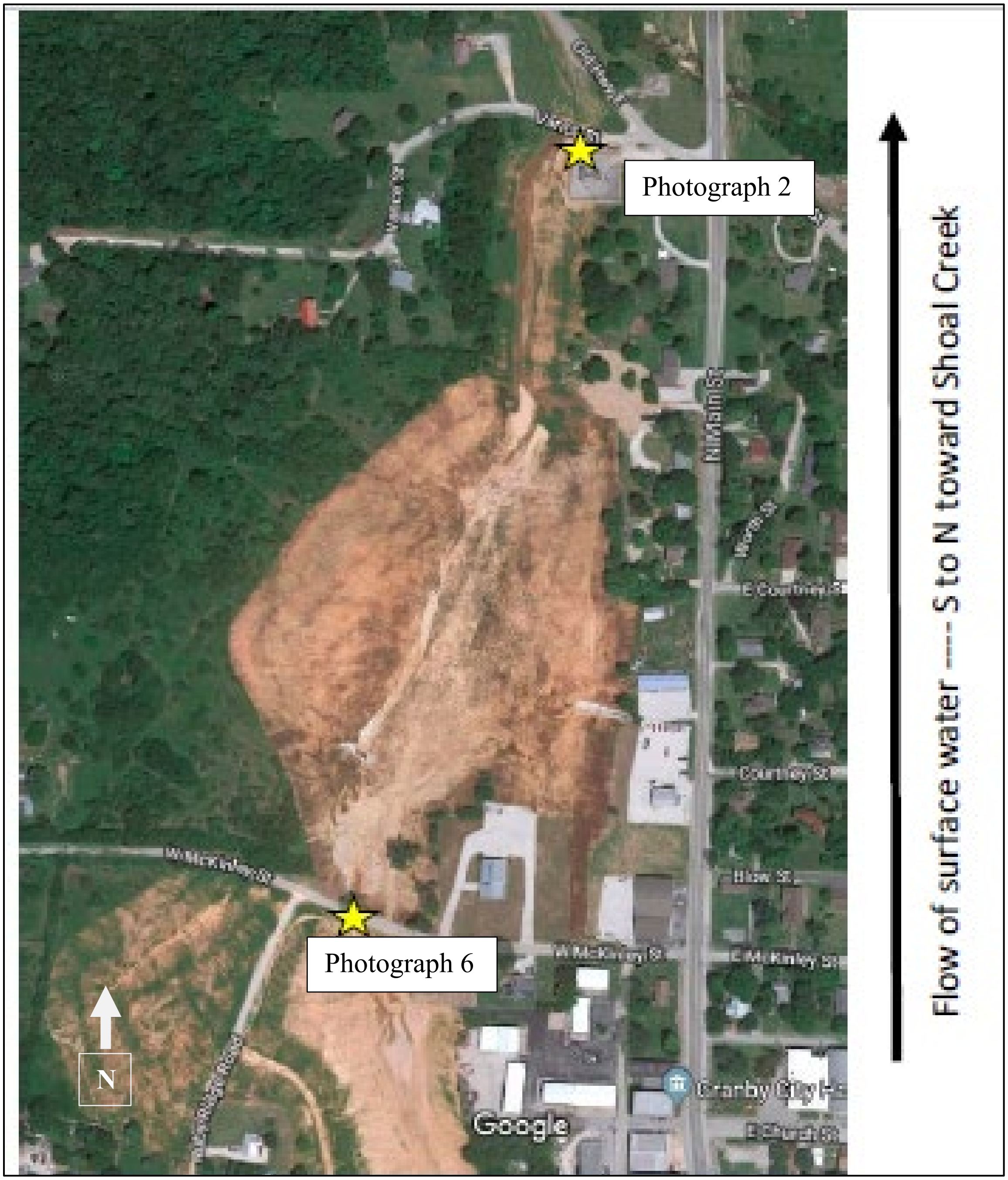


Figure 3. Study area in the Granby Subdistrict. The Granby Subdistrict is defined as the aerial extent of the mining impacts around the city of Granby, Missouri (USEPA, 2010). Gold stars represent the two road culverts that mark the north and south boundaries and locations of the culverts.

CHAPTER 2: BACKGROUND

2.1 Mining History in the Tri-State Mining District

Mining for lead and zinc in the Tri-State Mining District was conducted between 1850 and 1970 (Kansas Geological Survey, 2001). Majority of the mining was conducted using underground methods, where the mined ore was hoisted from the underground workings and treated at mills on the surface. At the mills, the crude ore was crushed and sized to less than 16 millimeters (mm) (5/8 inch). After 1920, the ore was concentrated using gravity-separation processes or froth-flotation. The wastes, produced from milling of the ore, primarily consisted of two types of material depending on the milling process used. Chat is sand- and gravel-sized particles that were produced by the gravity-separation processes. Tailings are sand- and silt-sized particles that were produced from the froth-flotation process and were slurried to impoundments with dikes (Dames & Moore, 1993).

After nearly 150 years of mining activities, the Newton County Superfund site is scattered with chat piles, tailings impoundments, and mine waste rock piles (Figure 2). Much of the total volume of surface mine wastes have been removed and reused. However, there are still hundreds of square kilometers (acres) of mining and milling wastes that remain at the Site (USEPA, 2018). These wastes are contaminated with residual heavy metals and have contaminated surface and subsurface soils, groundwater, surface water, and stream sediments. The primary contaminants of concern (COCs) are lead, cadmium, and zinc (USEPA 2010).

2.2 Demographics

The population of the Site area is approximately 58,000 with over 2,100 people residing in Granby (US Census Bureau, 2010). Much of the area is used for agriculture with rural residences. Woodlands, grasslands, pastures, oil fields, and mine-related areas exist throughout the landscape. Approximately 30 percent of the area is residential, urban, and commercial/industrial combined (USEPA, 2010). Many of the mine waste piles are in close proximity to residences, particularly in Granby on the west, south, and southeast areas of the city (Figure 1).

2.3 Previous USEPA Investigations

The USEPA placed the Site on the National Priorities List (NPL) in September 2003 (United States National Archives and Records Administration, 2003). The NPL is the list of priority sites across the nation that have known or threatened releases of hazardous substances, pollutants, or contaminants. The NPL was established under the National Contingency Plan (NCP). The NCP is formally known as the National Oil and Hazardous Substances Pollution Contingency Plan. It was first developed and published in 1968. The NCP provides a framework on how to respond to releases and spills (USEPA, 2019).

The Site includes wastes in, and around, 14 mining camps located within approximately 777 square kilometers (300 square miles) of Newton County. These locations were grouped into five Subdistricts: Spring City/Spurgeon, Granby, Diamond, Stark City, and Wentworth. The subject of the research is the Granby Subdistrict that is located in the east-central portion of Newton County, and includes the city of Granby, Missouri. (USEPA, 2018)

Under authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), investigations and studies conducted at the Site in the Granby area in 1986 began with a preliminary assessment that revealed elevated levels of lead, zinc and cadmium in soil and groundwater (USEPA, 2008). Removal actions at the Site addressed the contaminated wells and residential yard soils. With the remaining risks at the Site, a Record of Decision document was signed in 2010 to select a remedy for the mine and milling waste and contaminated soil and sediment (USEPA, 2010).

A main component of the selected remedy was the excavation of source materials. Specific actions to be implemented under the remedial action included excavation and removal of mine and milling wastes and contaminated soil and sediment. Areas identified for remediation were first cleared of large and underlying vegetation to facilitate access to the source materials. Erosion control features were installed around excavation areas to control storm water runoff during construction. Remedial action levels (also referred to as action levels) are developed with the use of site-specific data in a risk assessment to assess risks to human health and the environment. A Record of Decision describes the selected remedy with action levels for a specific portion of a site on the NPL. Excavation of the areas was achieved with heavy equipment and continued until levels of the Site COCs were below action levels selected in the Record of Decision (Table 1). The values listed in Table 1 were used as the initial concentration values for the land surface in this study. The excavated areas were regraded to promote proper drainage and then revegetated with native grasses (USEPA, 2010).

Table 1. Action levels established in the Site Record of Decision (USEPA, 2010)

Media	Lead (mg/kg)	Zinc (mg/kg)	Cadmium (mg/kg)
Soil	400	6,400	40
Sediment in intermittent tributaries	219	2,949	17

2.4 Applicable Laws and Regulations

Given the goals of the USEPA's selected remedy, the relative importance and application of federal and state laws, regulations, policies, and guidance of the CERCLA remedial action activities of the Site were assessed. CERCLA was enacted by Congress in 1980 and is commonly known as the Superfund law. Originally, the law created a tax that provided funding to respond directly to threats or potential threats to human health and the environment from hazardous substances. CERCLA authorized two kinds of response actions. The first is the short-term removal actions in a timely response. The second is a remedial response action that is generally a long-term action that provides permanent action to significantly reduce the risks to the release or threat of releases of hazardous substances. These actions can only be conducted on sites that are listed on the NPL (USEPA, 2018b).

2.4.1 Review of Site-Specific Federal and State Regulations

Under a CERCLA response action, the identification of the applicable federal and state regulations is conducted throughout the CERCLA process. After the Site was listed on the NPL in 2003 (United States National Archives and Records Administration, 2003), a remedial investigation was initiated along with a feasibility study. The applicable or relevant and appropriate requirements (ARARs) are first identified in the remedial investigation. These requirements are reviewed and analyzed in the feasibility study as they relate to the different remedy alternatives. The resulting analysis of the ARARs and selected remedy are documented in the Record of Decision. The Record of Decision for the Site identified both federal and state water regulations that relate to storm water as well as surface water quality (USEPA, 2008 and USEPA,2010).

For surface water quality, the chronic aquatic life criteria established under the Clean Water Act of 1972 § 33 U.S.C. §1251 et seq. (1972) were marked a standard to consider during the completion of the selected remedy (USEPA, 2010). The water-quality standards under Missouri Clean Water Law 10 CSR 20-7.031 were identified as potentially applicable in the future (USEPA, 2010). At the time of the Record of Decision, the federal standards were more stringent than the state's water quality standards. In the event the Missouri standards change, USEPA would consider the new information in determining the protectiveness of the remedy.

Additional citations under the Clean Water Act that were deemed applicable or relevant and appropriate include Section 404 requirements related to discharge of material to navigable waters (USEPA, 2010). Under the effluent discharge standards in the Clean Water Act, Best Management Practices (BMPs) and monitoring are required for discharges of pollutants directly into the environment. The only citation directly related to storm water is the discharge regulations for storm water under the National Pollutant Discharge Elimination System (NPDES). This regulation requires the management of storm water during construction activities. The State of Missouri has similar storm-water laws under their Clean Water Law. Missouri includes practices that may reduce metals loading from soils and sediments for transport to waters of the state (USEPA, 2010).

2.4.2 Storm-Water Management Regulations at the Site

Many of the cited laws and regulations within the Record of Decision normally require a permit. Under CERCLA, permits are not required for actions taken under CERCLA such as remedial actions. But the substantive provisions of the regulations would be required (USEPA, 2010). During the remedial action conducted at the Granby Site, erosion and sediment controls were installed and maintained prior to and during construction activities. Silt fencing, straw bales, construction entrances, check dams, filter rings, and erosion control matting were the noted technologies in the final report (USACE, 2017). A visual observation was conducted on September 27, 2018 and photographs were taken to document the current conditions (Photographs 1, 4, and 5). Although the control measures were to remain in place until vegetation was fully established, the field observations indicated bare areas and erosion rills in several areas. This observation was part of the motivation for this thesis.

2.5 Climate and Hydraulic Conditions

2.5.1 Precipitation

The annual precipitation in the Granby area is approximately 101.6 centimeters (40 inches) (USGS, 2019). Precipitation data are free to the public, and it may be downloaded from the National Oceanic and Atmospheric Administration's National Center for Environmental Information's (NCEI) online database website (NCEI, 2019). Daily summary precipitation data were used in the SWMM simulations (for both the time series and rain gage information). Local precipitation measurements obtained at the regional airport weather station (#USW00013987) in Joplin, Missouri (Figure 4) were used in this study (USGS, 2019). Reported precipitation includes both wet rain and melted snow. The downloaded data included precipitation total per day in each month. As discussed in the Methods chapter, to allow for the highest potential model result of surface runoff, the highest rainfall periods were selected for the SWMM simulations. The remediation of this area was completed by 2016. The pre-remediation timeframe was chosen as the highest rainfall month of 2015 since the remediation began in late 2015. The post-remediation timeframe was chosen as the first six months of 2017 to include the wettest months of the year. Rainfall data for May 1 to May 31, 2015 and January 1, 2017 to June 30, 2017 were used in pre- and post-remediation models (Appendix A and Table 2). Daily precipitation during the study period ranged from zero to 11.38 cm (4.52 inches). For the selected months, the lowest total precipitation in a month was February 2017 with 0.86 cm (0.34 inches). The highest total precipitation in a month was May 2015 with 10.41 cm (26.44 inches). May 2015 had 18 days of recorded precipitation, the highest number of days with precipitation in a month for the six months in the post-remediation study analysis (NCEI, 2019). SWMM program used Imperial instead of metric units, so English units were retained in this study to allow for comparison with similar SWMM studies.

Table 2. Rainfall amounts measured at weather station #USW00013987 for timeframes used in this study

Month Year	Range of precipitation totals	Days with recorded precipitation	Total daily precipitation for the month
May 2015	(0.00 – 2.48 inches)	18	26.44 inches
January 2017	(0.00 – 0.87 inches)	8	(3.65 inches)
February 2017	(0.00 – 0.13 inches)	4	(0.34 inches)
March 2017	(0.00 – 0.67 inches)	13	(2.70 inches)
April 2017	(0.00 – 4.52 inches)	16	(11.24 inches)
May 2017	(0.00 – 1.97 inches)	13	(8.00 inches)
June 2017	(0.00 – 0.97 inches)	10	(4.18 inches)

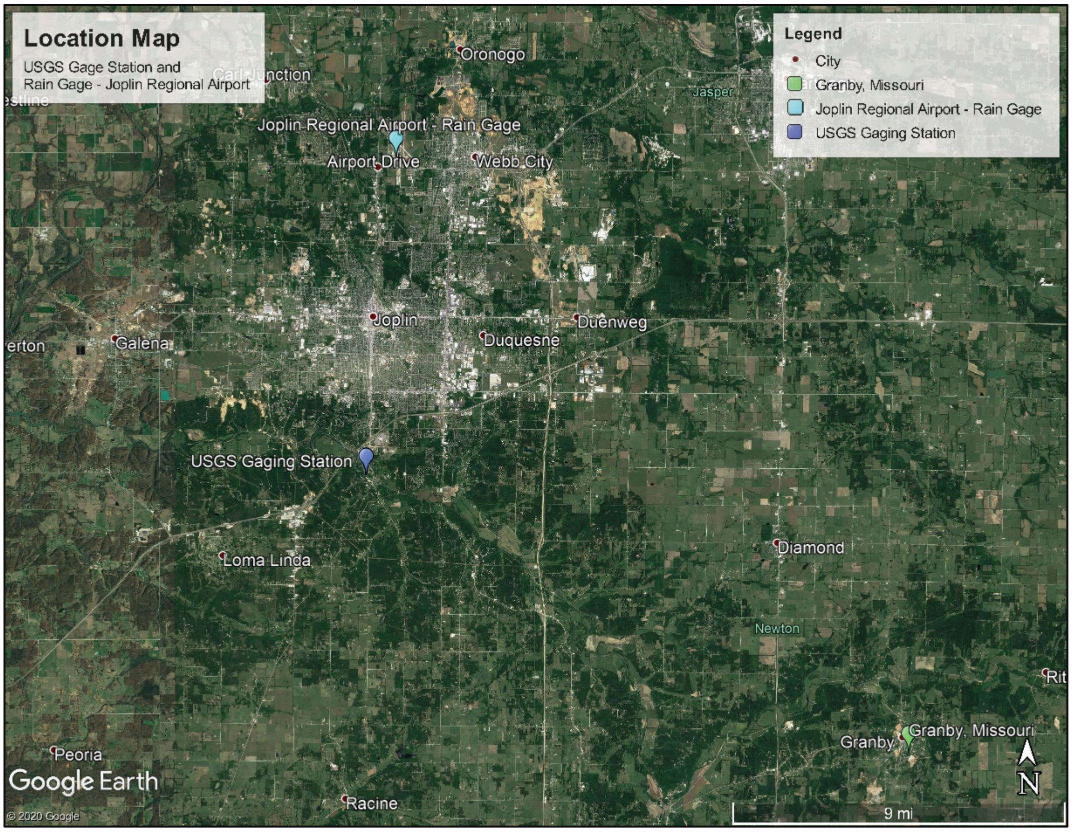


Figure 4. Location of the available rain gage is approximately 34 kilometers (21 miles) to the northwest and the USGS gage station found downstream of the study area in Granby, Missouri (Google Earth, 2019).

2.5.2 Streamflow Conditions

The Newton County Superfund site is located within the Spring River watershed, which spans 6,734 square kilometers (2,600 square miles) of southwest Missouri, southeast Kansas, and northeast Oklahoma. The Spring River flows into the Grand Lake of the Cherokees (Figure 5). The principal tributaries to the Spring River at the Site are Shoal Creek and Lost Creek. Base flows of these streams are sustained by springs from limestone in the headwater areas (EPA, 2008). Shoal Creek is located over 1.6 kilometers (1.0 miles) to the north of the study area. While Spring River is over 52 kilometers (32 miles) downstream from the study area following Shoal Creek. Shoal Creek flows from the west to the east toward Spring River in Kansas.

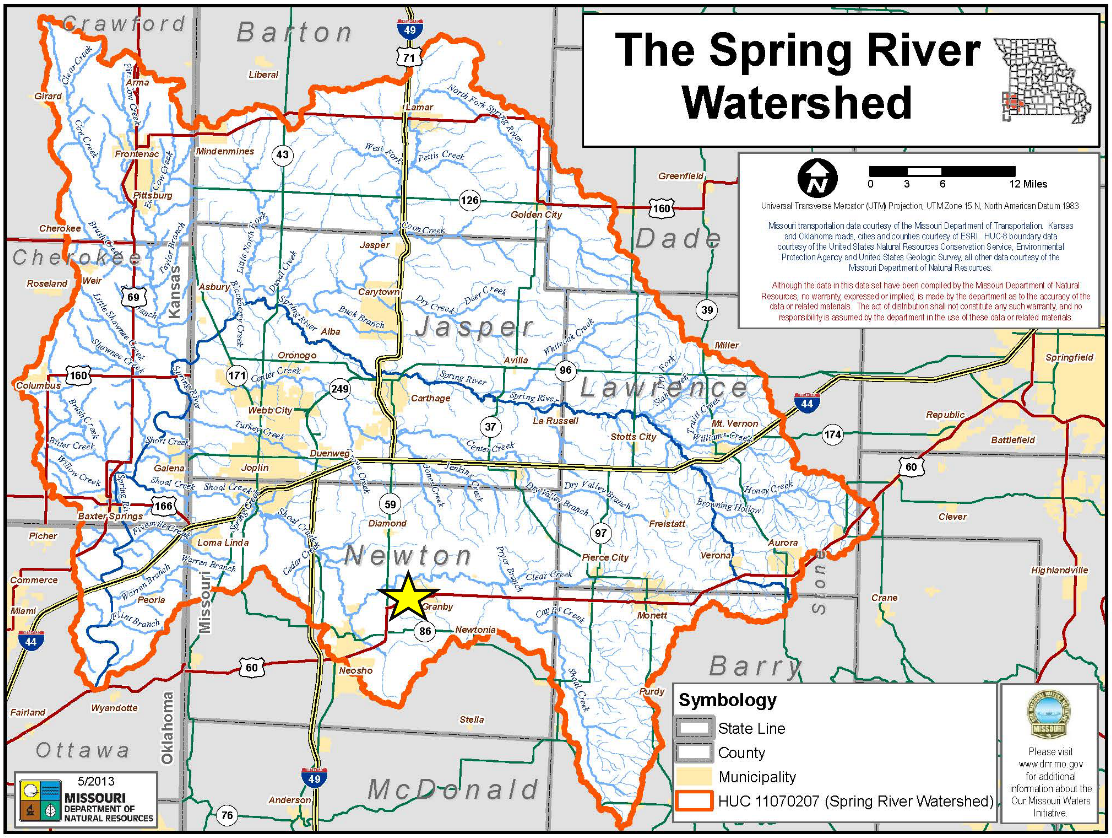


Figure 5. The Spring River watershed in southwestern Missouri. Yellow star indicates the location of Granby, Missouri (MDNR, 2013)

Daily discharge and gage height data from a nearby USGS gage station were used in this study for qualitative comparative analysis. Daily discharge is defined as the daily volume of water measured at the gaging station per day. Gage height is reported as the daily mean water height compared to a reference datum. The available downstream stream gage on Shoal Creek near Joplin, Missouri has a long record of streamflow data from 1924 to 2019. The gage station which is currently operating is located on Shoal Creek near Redings Mill, Missouri, approximately 26 kilometers (16 miles) downstream of the study area in Granby (Figure 4). Daily discharge and gage height data for the 2015 and 2017 study periods were used in this analysis (Figures 6a, 6b, 7a, and 7b). In 2015, the discharge ranged from 10 to 129 cubic meters per second (m^3/sec) and gage heights of 0.85 meters to 2.36 meters were observed. The highest daily discharge and gage height in the one-month pre-remediation study period was on May 5, 2015. In 2017, the discharge ranged from 2 to 733 m^3/sec and gage heights of 0.54 meters to 3.62 meters were observed. The highest daily discharge and gage height in the six-month post-remediation study period was on April 30, 2017.

Additionally, annual peak streamflow from 1924 to 2018 was evaluated to provide information on historic values that were used to compare with the study periods (Figure 8). Annual peak streamflow is the maximum streamflow, and gage height measured instantaneously, over a one-year period. The range of annual peak streamflow was 32 m^3/sec in 2014 to 1,758 m^3/sec in 1943. The range of gage height in the annual peak streamflow was 0.96 meters in 1934 to 8.53 meters in 1941. The highest annual peak streamflow was in 1943 and the highest gage height was in 1941 (USGS, 2019).

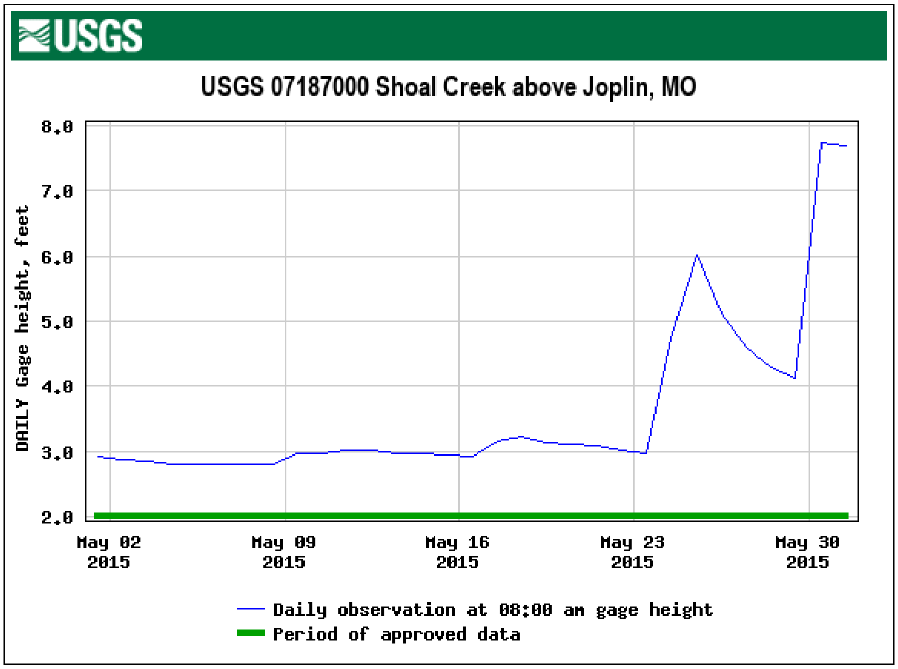


Figure 6a. Daily gage height for USGS station 07187000 Shoal Creek above Joplin, MO for May 1 to May 30, 2015 for the pre-remediation study period. (USGS, 2019)

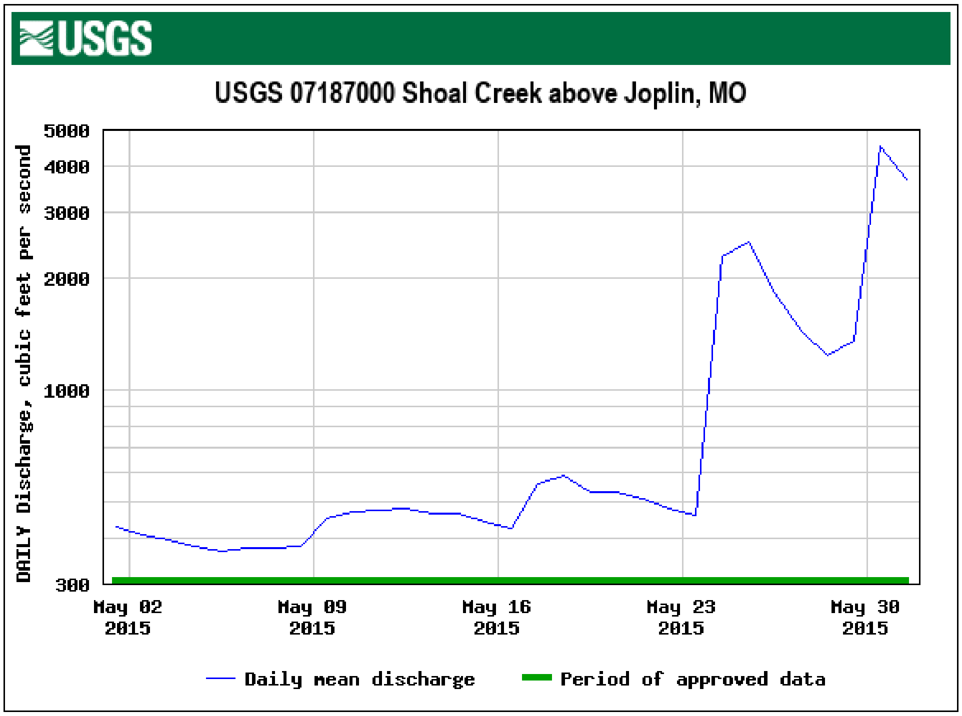


Figure 6b. Daily discharge for USGS station 07187000 Shoal Creek above Joplin, MO for May 1 to May 30, 2015 for the pre-remediation study period. (USGS, 2019)

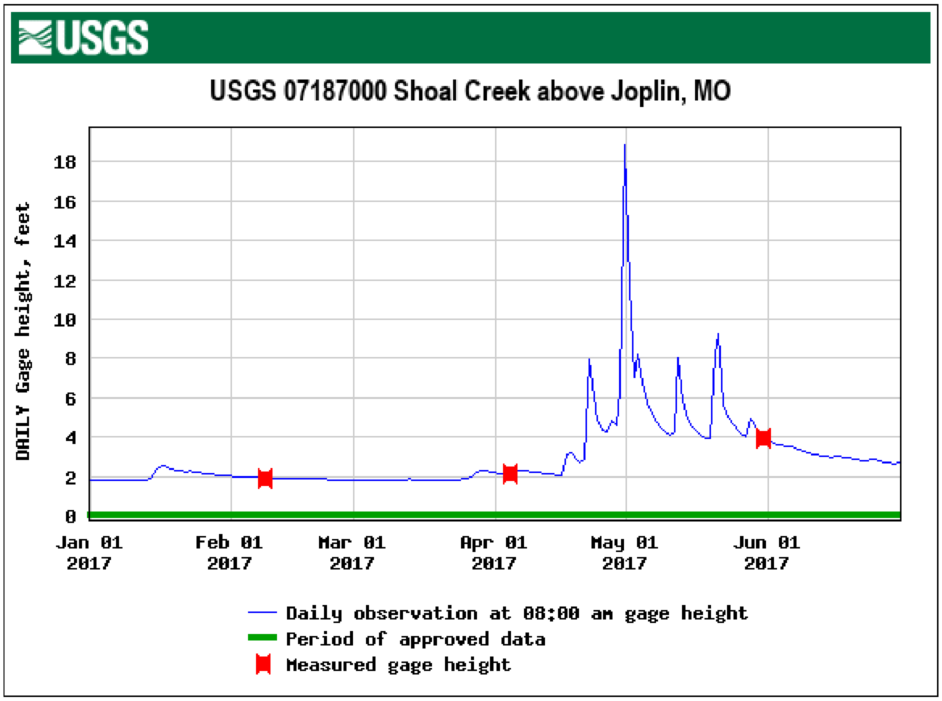


Figure 7a. Daily gage height for USGS station 07187000 Shoal Creek above Joplin, MO for January 1 to June 30, 2017 for the post-remediation study period. (USGS, 2019)

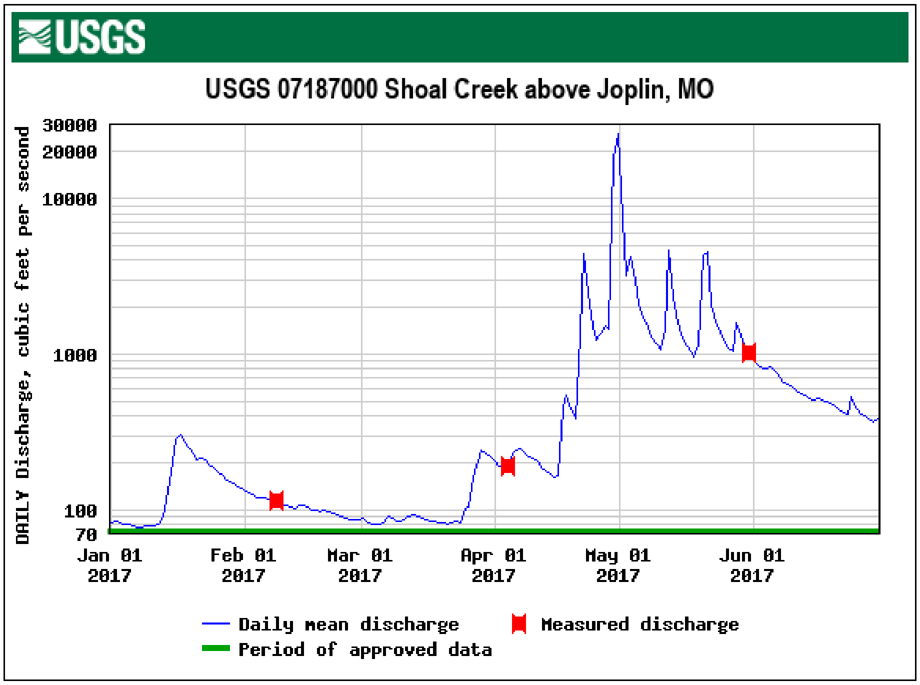


Figure 7b. Daily discharge for USGS station 07187000 Shoal Creek above Joplin, MO for January 1 to June 30, 2017 for the post-remediation study period. (USGS, 2019)

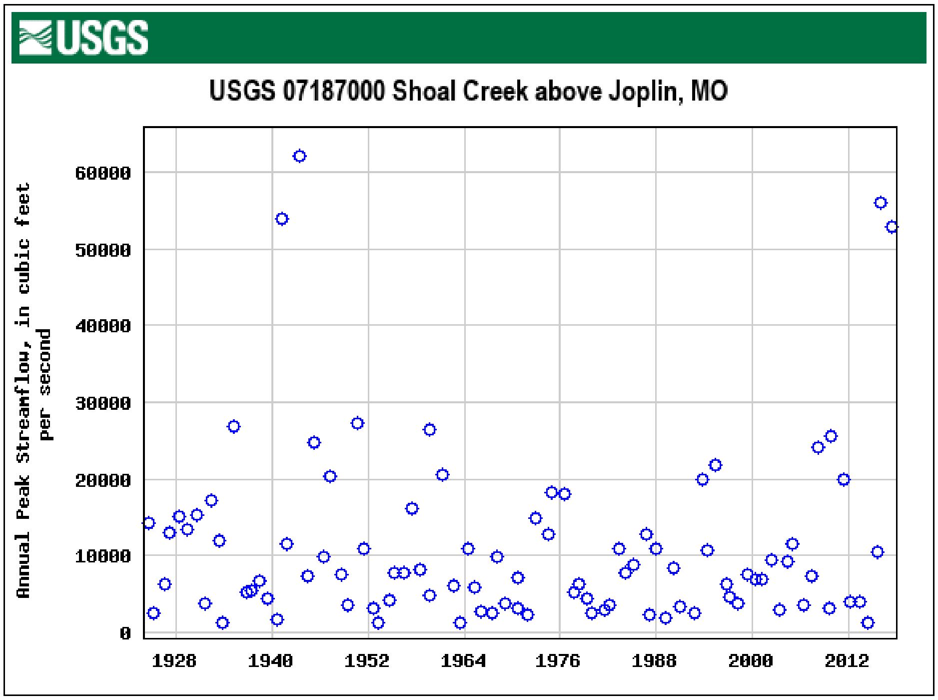


Figure 8. Annual peak streamflow for USGS station 07187000 Shoal Creek above Joplin, MO for 1924 to 2018. (USGS, 2019)

Periods of precipitation data were chosen in 2015 for pre-remediation and in 2017 for post-remediation study periods for the model. Peak streamflow in 2015 was 294 m^3/sec, with a maximum gage height of 3.77 meters (Figures 6a and 6b). In 2017, the peak streamflow was 1,498 m^3/sec and a maximum gage height of 7.00 meters (Figures 7a and 7b). 2016 had a higher streamflow of 1,589 m^3/sec and a gage height of 7.13 meters. The last record near study period's streamflow values was 1941 and 1943 with 1,529 and 1,758 m^3/sec, respectively (Figure 9). The intervening years' peak streamflow were half of those values (USGS, 2019).

2.5.3 Groundwater

Groundwater at the Site is provided by two aquifers, which are separated by a discontinuous aquitard. The shallow, Mississippian Springfield Plateau Aquifer hosts lead-zinc ores, and many shallow wells in this aquifer are contaminated with lead, zinc, and cadmium (USEPA, 2010). The deep, Ordovician and Cambrian-age Ozark Aquifer is generally used as a drinking water supply (USEPA, 2008). In some areas, these aquifers are connected by karst features (Miller and Appel, 1997). Such features have not been observed at the site, and surface contaminants are not likely to threaten the groundwater unless surface water bodies or open mine features such as mine shafts or subsidence pits directly overlie the aquifer. Groundwater is not considered in the SWMM model.

2.6 Sediment and Surface-water Contamination

Lead, zinc, and cadmium concentrations were evaluated in the initial 1986 site evaluation of the Granby site (USEPA, 1986) in mine waste, soil, sediment, surface water, and sediment pore water (USEPA, 2008). In soil and mine waste, lead concentrations ranged from below detection to 10,024 milligrams per kilogram (mg/kg) and zinc concentrations ranged from 48 to 133,498 mg/kg. Cadmium concentrations were below detection to 412 mg/kg. Metal concentrations in sediment ranged from 9 to 1,520 mg/kg for lead, 70 to 4,510 mg/kg for zinc, and below detection to 37 mg/kg for cadmium.

Water quality in the Spring River and its tributaries is impacted by runoff and seeps from the mine and milling wastes, sediment migration from source areas to streams, runoff from agricultural and urban areas, and wastewater discharge (USEPA, 2010). In 2008, metal concentrations in surface water ranged from below detection to 499 milligram per liter (mg/L) for lead, below detection to 30,900 mg/L for zinc, and below detection to 112 mg/L for cadmium (USEPA, 2008).

2.7 USEPA Stormwater Management Model

The USEPA's SWMM was developed to support local, state, and national storm-water management goals (Metcalf & Eddy, Inc. et al., 1971). First developed in 1971, several upgrades have followed. The current version (SWMM 5.1) was established in 2015 by the USEPA's National Risk Management Research Laboratory (USEPA, 2015a and USEPA, 2015b). Figure 9 is a screenshot of the SWMM opening window. Key model elements include climatology, hydrology, hydraulics, and quality, and allow individual parameters to be entered into an input screen. Every SWMM simulation begins with a conceptual model.

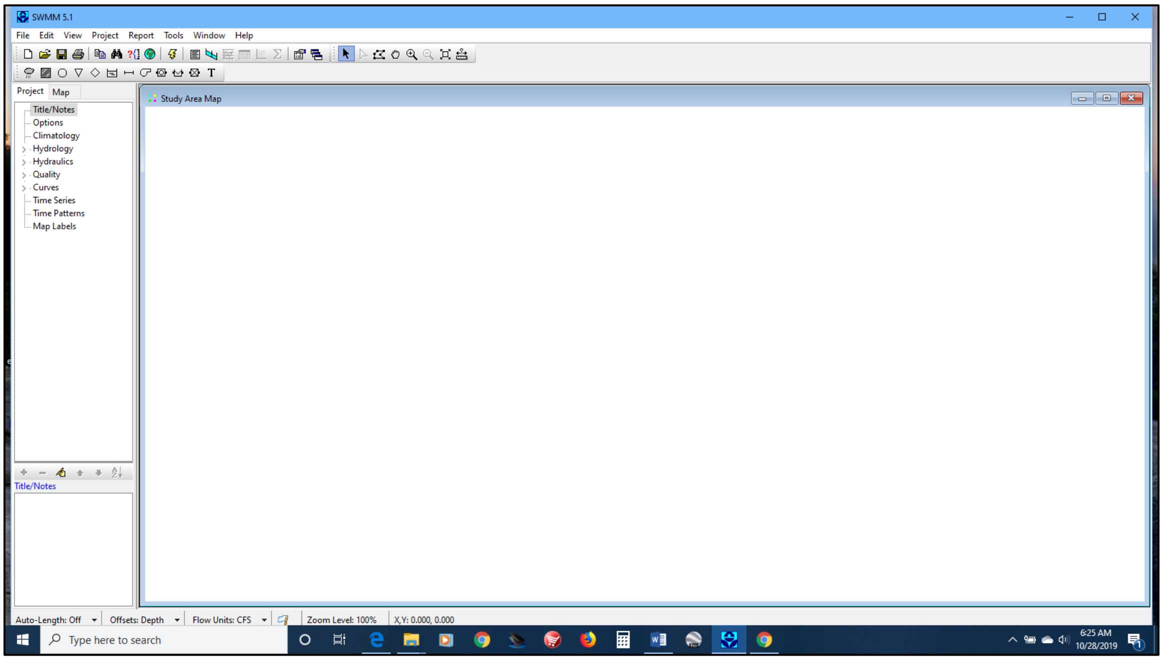


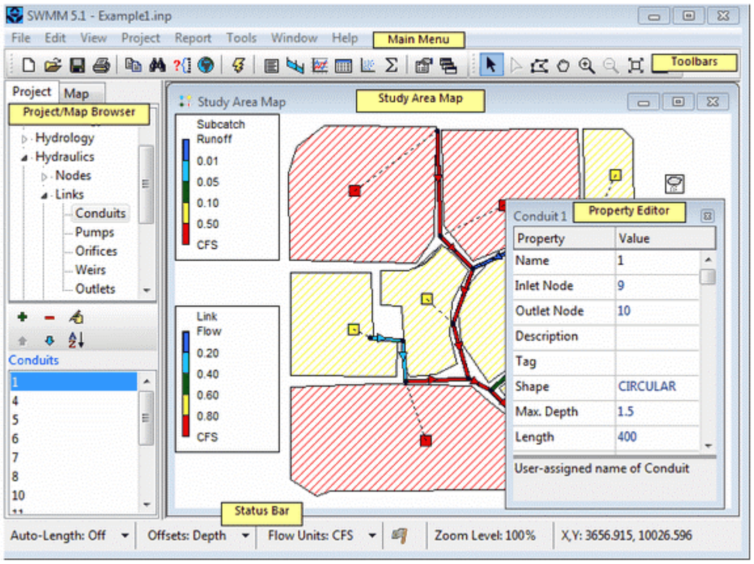
Figure 9. Screenshot of main SWMM menu window with input menus on the left-hand side of the screen. The top menu bar also provides options for setting up the model view (SWMM, 2015a)

2.7.1 SWMM Conceptual Model

The model parameters are highlighted in bold font throughout the thesis, to identify them as variables that may be modified during the analysis. Creating a conceptual drainage system is the first step to building a SWMM model. The flow of water and material between sections, or **compartments**, is assigned in this step. Four **compartments** exist conceptually in SWMM and are referred to as **Atmosphere**, **Land Surface**, **Groundwater**, and **Transport**. This work focused on an evaluation of inflows and outflows from the **Atmosphere**, **Land Surface**, and **Transport** compartments. The **Atmosphere** compartment creates the inflows into the **Land Surface** compartment, with "objects" that represent precipitation and pollutant mass. The **Land Surface** compartment include the inflows from the **Atmosphere** compartment and outflows from surface runoff and pollutant loadings to the **Transport** compartment. The **Transport** compartment focuses on the mechanisms of transport of the inflows to this compartment (USEPA, 2015b).

SWMM utilizes visual objects that are arranged in a network of basins and "conveyance elements". These objects are used to model the drainage system. A **rain gage** object supplies the precipitation input for surface runoff for a study area. A study area may include one or more subcatchments where surface runoff is discharged as a single point. A **subcatchment** is defined as the physical objects that create the system (USEPA, 2015b).

The input parameters that can be adjusted in the SWMM model include the sizes and locations of: **subcatchment**, **junctions**, **conduits**, **outlet**, **area**, **width**, **percent slope** and **impervious surface**, the **Manning's roughness coefficient** for impervious and pervious surfaces, **depression storage depth** for impervious and pervious surfaces, and the **percent of impervious area with no depression storag**e (Figure 10). These parameters are explained fully in Appendix B.



Property	Value
Name	1
Inlet Node	9
Outlet Node	10
Description	
Tag	
Shape	CIRCULAR
Max. Depth	1.5
Length	400

User-assigned name of Conduit

Auto-Length: Off
Offsets: Depth
Flow Units: CFS
Zoom Level: 100%
X,Y: 3656.915, 10026.596

Figure 10. Screenshot of example SWMM window with key windows and tools for use (Huber, et al., 2019)

2.7.2 Applications of SWMM

Typical applications of SWMM include management of drainage system components for flood control, flood plain mapping, and the design and evaluation of sanitary sewer systems (USEPA, 2015b). A user can run simulations of storm-water runoff that allow hydraulics, hydrology, and water quality variables to be modeled to allow their relative importance to be identified. Of specific interest for this research, SWMM also can estimate the production of pollutant loads associated with stormwater runoff and evaluate effectiveness of BMPs for reducing pollutant loading during rain events. (USEPA, 2015b) This research included the simulation of typical SWMM objectives of surface runoff and rainfall, with the addition of simulation of water quality of surface runoff from the study area.

SWMM is highly applicable to small- to medium-scale watersheds and has been used successfully in numerous studies. For example, in Jang et al. (2007), SWMM was tested as a tool for hydrologic impact assessment for urban development. Watershed modeling for runoff and nutrient loading was conducted by Rosa, et al. (2015) to test the use of low-impact development runoff controls. And Lee, et al. (2010) compared the use of SWMM and Hydrological Simulation Program in a small watershed that concluded that SWMM adequately simulated watershed characteristics but was more reliably applied to urban areas. Hydrological Simulation Program is a set of computer codes that can perform hydrologic simulations and water quality processes (Lee, et al., 2010).

The SWMM model compiled in this research is based on field- and geospatially derived values for study area width, surface area, pervious and impervious land surface, and slope. The use of the more generic values could result in unreliable extrapolation and analysis. Where specific model input parameters have not been measured at a site, published values at similar sites were used. SWMM is usually used as an analysis tool and thus may have limitations when used as a tool for design, as is the goal of this work. These strengths and limitations were examined, and an example model sensitivity analysis was conducted as a part of this research.

CHAPTER 3. METHODS AND PROCEDURES

The overall goal of the research was to demonstrate that SWMM could be used to model the environmental impacts in response to the excavation activities at a former mine waste site. Three hypotheses were tested to demonstrate an increase in surface-water runoff and the presence of mass contaminant in the runoff. The first hypothesis was selected to provide the foundation of the research. The second hypothesis was selected to intensify the results of the first hypothesis with an above average rainfall data set. The third hypothesis was selected to determine if that mass contaminant has migrated from the excavated areas. It was assumed that the first two hypotheses had to be fulfilled before the third hypothesis would be valid.

3.1 Hypotheses

Hypothesis no. 1: The volume of surface-water runoff was higher in post-remediation models than in pre-remediation models.

Hypothesis no. 1 will be satisfied if a higher runoff volume is determined in the post-remediation site conditions than in pre-remediation conditions.

Hypothesis no. 2: The volume of surface-water runoff increased after six months of above average precipitation.

Hypothesis no. 2 will be satisfied if the volume of surface-water runoff increases after six months of precipitation.

Hypothesis no. 3: The mass of lead and zinc in runoff in a post remediation landscape was higher after an above average six-month rainfall period than before it.

Hypothesis no. 3 will be satisfied if the following criteria are met:

1. Hypothesis no. 1 has been satisfied.

2. Hypothesis no. 2 has been satisfied.
3. SWMM post-remediation output values show the presence of lead and zinc at model outflow areas.

3.2 Study Design

To test the first hypothesis, two models were constructed and compared in which pre-remediation and post-remediation conditions were simulated. Land surfaces and precipitation data were varied in this analysis. Spatial parameters available from the Missouri Department of Natural Resources (MDNR) and coefficient values reported in USEPA and U.S. Geological Survey (USGS) reports were utilized for input parameters and in spatial assessments made to establish the different land surfaces (MSDIS, 2019; USEPA, 2015b; USGS, 1989; USGS, 2006). Site-specific, or area-specific, geology, climate, soil types, and vegetation types information was extracted from these reports. **Manning's roughness coefficients** were used to represent different vegetation types, soil types, and channel type. Several of the applicable Manning's roughness coefficients are presented as a range of values in the USEPA report (2015b) and in the USDA report (USDA, 2010); (Table 9 and 10). One value is selected from each range to represent each land surface within the study area, based on review of published information (Table 11).

A list of the input parameters and values used is presented in Table 7-11. Each parameter is discussed in more detail in later sections in this chapter. Geographic Information Systems (GIS) were utilized for digitizing the aerial extent of the study area (Google Earth, 2019). Polygon boundaries were drawn to quantify total area of pre-remediation and post-remediation vegetated area within the study area. In the thesis, remediation is defined as the completion of all clearing of trees and vegetation, removal of mine waste and soils, land surface regrading, and revegetation. Vegetated areas are defined by general categories of trees, grasses, and no vegetation. Each vegetated area category was assigned a selected Manning's **roughness coefficient** (Table 11). The selection of each coefficient is explained later in the chapter. The model produces output values for **runoff coefficients** which represent runoff from the study area. In the analysis of Hypothesis no. 1, the **runoff coefficient** output values in the pre-remediation and post-remediation model simulations are compared. To satisfy Hypothesis no.1, the **runoff coefficient** output value for the post-remediation model simulation must be higher than the **runoff coefficient** output value for the pre-remediation model simulation.

To test the hypothesis that above average rainfall will result in increased runoff volume, two model simulations were compared in which the post-remediation models were simulated for one month of precipitation data and six months of precipitation data. Spatial parameters available in MDNR's GIS database (MSDIS, 2019) and values from USGS and U.S. National Weather Service (NWS) were used to estimate topography, stream discharge, and local rainfall from the local airport rain gauge, and gauge station data for flow downstream in Shoal Creek (NEIC, 2019; USEPA, 2015b; USGS, 1989; USGS, 2006; USGS, 2019). **Manning's roughness coefficients** used in these models are the same as those used in Hypothesis no. 1. SWMM was used to model the precipitation data described in Chapter 2 and presented in Appendix A. Precipitation data from January 1, 2017 to June 30, 2017 was used in this analysis. Other model input parameters include: rainfall, slope, storage device area and volume, area of study area, and selected **Manning's roughness coefficients**. These are summarized in Tables 7-11 and discussed in more detail later in this chapter.

Model simulations were run using daily rainfall amounts during two time periods with all other input parameters remaining constant. Available climate data was reviewed to identify seasonal variations (Appendix A). To evaluate the most likely potential runoff, simulations were run for a high rainfall month in 2017 and for a six-month timeframe in 2017 with high rainfall events. The model produces output values for rainfall **volumes**. To satisfy Hypothesis no. 2, the rainfall **volume** in the six-month model simulation would be greater than the rainfall **volume** in the one-month model simulation.

To test the hypothesis that the mass of lead and zinc in runoff would be higher in a post remediation landscape, the results of two models of post-remediation simulated mass contaminant on the initial land surface pre-rainfall and post-rainfall models were compared. Simulations were conducted for the range of rainfall events and parameters utilized in the previous models, with the addition of lead and zinc contaminants. Manning's roughness coefficients utilized in these simulations were the same as in previous models (Table 6). The focus of Hypothesis no. 3 was on the mass contaminant of lead and zinc at the surface and its runoff potential from the study area. The initial concentration of a mass contaminant is assigned as the **Initial Buildup.** Modeled lead concentration of 400 mg/kg and zinc concentration of 6,400 mg/kg were used as the **Initial Buildup** concentration on the remediated surface assigned under **Land Use** in the subcatchments. These concentrations are the selected USEPA action levels identified in the study area's overall Site remedy decision (USEPA, 2010).

For Hypothesis no. 3 to be satisfied, both Hypothesis no. 1 and Hypothesis no. 2 must be satisfied. For surface concentrations of the Site COCs (lead and zinc) to migrate from the remediated areas, it is assumed that the runoff potential would increase due to the remediation and there is a causal relationship between storm water runoff and rainfall.

3.3 Sensitivity Analysis

To evaluate the model sensitivity, several test simulations were conducted to identify parameters with high potential to affect output values. Tested parameters included **%Imperv**, **N-Imperv**, **N-Perv**, and **Washoff Coefficient**. Model simulations were run with changes to each of the parameters. The output values were compared to change between model simulations. Based on this preliminary assessment, the **Washoff Coefficient** resulted in the highest change in the amount of lead and zinc in surface runoff. The **Washoff Coefficient** parameter was thus further evaluated in a more detailed model sensitivity analysis.

3.4 Assignment of Parameters in the SWMM Model

The assigned input values and model configuration parameters are summarized in Table 3a and b. Justification for the chosen values is discussed in detail in the following sections.

Table 3a. Runoff and precipitation values used in models

Property	**SWMM Parameter Term**	**Value or range of values**	
		West slope	**East Slope**
Pre-Remediation			
Impervious Surface (%)	% Imperv	0%	8%
Manning's roughness coefficient for impervious surfaces (n)	N-Imperv	0.03	0.05
Manning's roughness coefficient for impervious surfaces (n)	N-Perv	0.11	0.3
Depth of depression storage of impervious surfaces (inches)	Dstore-Imperv	0.05 inches	0.05 inches
Depth of depression storage of pervious surfaces (inches)	Dstore-Perv	0.3 inches	0.3 inches
Zero percentage of impervious surfaces (%)	%Zero-Imperv	100%	100%
Rainfall (inches)	Precipitation	30.11 inches	30.11 inches
Washoff Coefficient	Washoff Coefficient	10	10
Post-Remediation			
Impervious Surface (%)	% Imperv	0.62%	8.45%
Manning's roughness coefficient for impervious surfaces (n)	N-Imperv	0.012	0.012
Manning's roughness coefficient for impervious surfaces (n)	N-Perv	0.02	0.02
Depth of depression storage of impervious surfaces (inches)	Dstore-Imperv	0.05	0.05
Depth of depression storage of pervious surfaces (inches)	Dstore-Perv	0.2	0.2
Zero percentage of impervious surfaces (%)	%Zero-Imperv	0	0
Number of land uses	Land Uses	1	1
Initial concentrations of contaminant	Initial Buildup	YES	YES
Rainfall (inches)	Precipitation	26.44 inches	26.44 inches
Washoff Coefficient	Washoff Coefficient	10	10

Table 3b. Model configuration parameters

Feature Property	**Property**	**Subcatchment**	**Subcatchment**
Feature Name	Name	S1-WSlope	S2-ESlope
Outlet name	Outlet	J2	J2
Area (acres)	Area	6.49 acres	8.13 acres
Width (feet)	Width	220 feet	300 feet
Slope (%)	% Slope	11%	6.9%

Junctions:

		Junction 1 (J1)	***Junction 2 (J2)***
Inflow into junction (Yes/No)	Inflows	No	No
Treatment (Yes/No)	Treatment	No	No
Elevation of junction (feet)	Invert El.	1094	1077
Maximum depth of junction (feet)	Max. Depth	0	0
Initial depth of junction (feet)	Initial Depth	0	0
Depth of surcharge (inches)	Surcharge Depth	0	0
Ponded area (inches)	Ponded Area	0	0

Conduits:

		Conduit 1 (C1)	***Conduit 2 (C2)***
Inlet into conduit	Inlet Node	J1	J2
Outlet from conduit	Outlet Node	J2	Out1
Shape of conduit	Shape	Trapezoidal	Open Rectangle
Maximum depth of conduit (feet)	Max. Depth	1	2
Length of conduit (feet)	Length	1141	542
Manning's roughness coefficient of conduit (n)	Roughness	0.15	0.15

Outfall:

		Outfall 1 (Out1)
Inflow into junction (Yes/No)	Inflows	No
Treatment (Yes/No)	Treatment	No
Elevation of outfall (feet)	Invert El.	1069
Type of outfall	Type	FREE

3.4.1 Site Boundaries

The selected study area was divided into two subcatchments which are referred to as the west slope and the east slope (Figures 11 and 12). The approximate boundaries and discharge points for each subcatchment are labeled with white labels (Figures 11 and 12). The two subcatchments are the two polygons with diagonal lines. Within SWMM, the polygons for this study were not geographically referenced, and were drawn to match approximate boundaries of the study area in the post-excavation aerial imagery from Google Earth (Google Earth, 2014 and Google Earth, 2017).

3.4.2 Hydraulic Parameters

A rain gage must be included in the SWMM model. Because its location does not affect the model outcome, the rain gage, labeled as "Gage1" and represented as a cloud icon, is arbitrarily placed on the SWMM workspace for purposes of ease of access. As discussed in Chapter 2, the Joplin Regional Airport daily precipitation summary data was imported for model use (Figure 4). Within the dataset, the station ID was selected as the letter "J" for Joplin. Since daily rainfall data was used, the time interval selected in SWMM for Gage1 was 24 hours. Each subcatchment has a label of the letter "S" and a small black square. Junctions are marked with the letter "J" and black circles. The conduits are marked with the letter "C" and have a line with a black triangle showing flow direction. The outfall is labeled as "Out1" and is the terminus of water flow for the model.

3.4.3 Surface Parameters

The land coverage areas of the impervious and pervious zones for each pre-remediation and post-remediation subcatchment surface was determined using Google

Earth’s polygon tool (Google Earth, 2014 and Google Earth, 2017). The subcatchment boundary and the different land coverage polygons were drawn based on aerial imagery available in Google Earth. The subcatchment boundary polygon was generalized to recreate in SWMM. The subcatchment boundary was recreated as a polygon in SWMM based on the Google Earth subcatchment boundary. Based on these observations, eight different land coverages of the subcatchments were modeled (Table 4).

Figure 11. SWMM model area with labeled subcatchments (S1 – West Slope and S2 – East Slope), Junctions 1 and 2 (J), Conduits 1 and 2 (C), and the outfall point (Out1). (Google Earth, January 25, 2014).

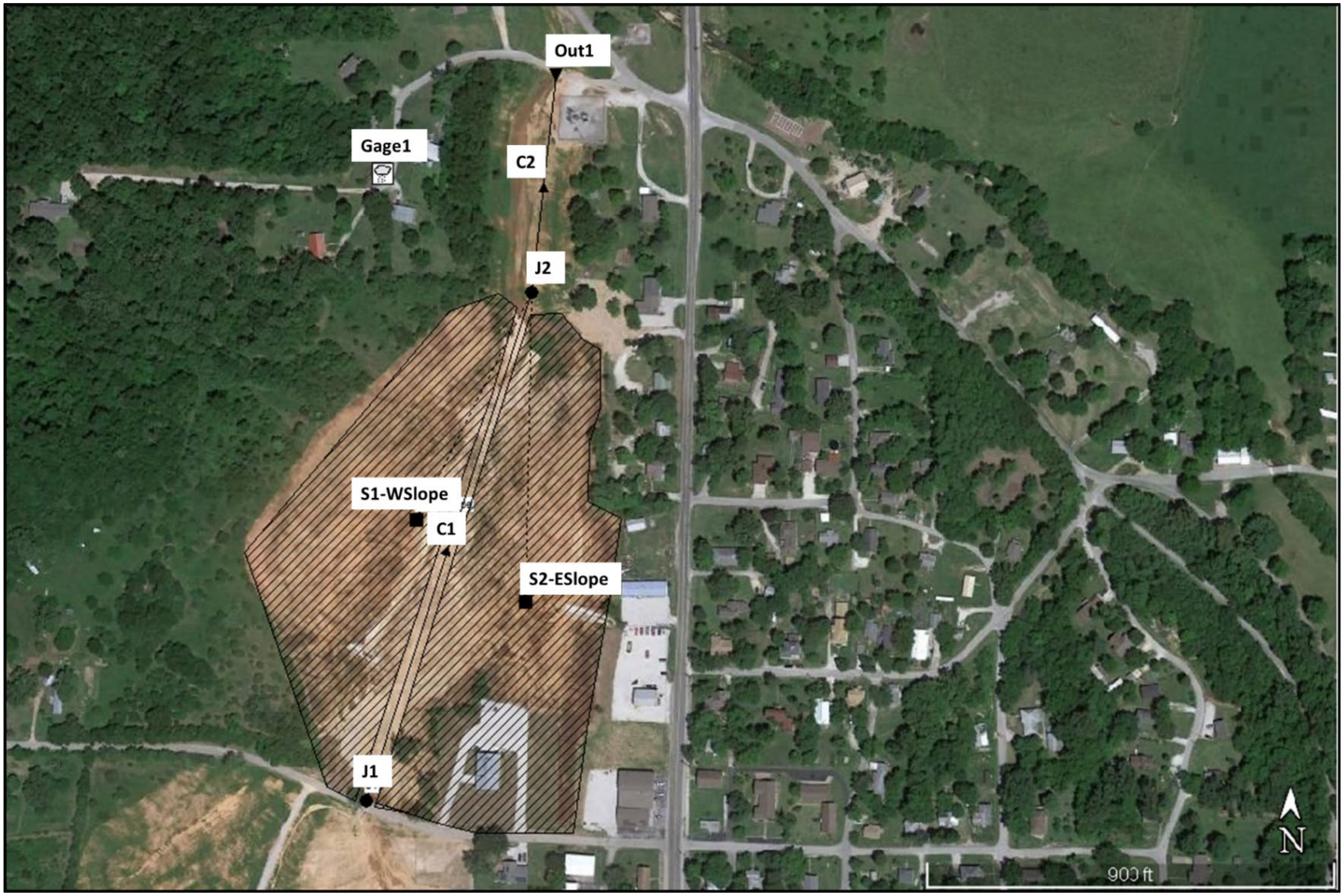


Figure 12. SWMM model area with subcatchments (S1 – West Slope and S2 – East Slope), Junctions 1 and 2 (J), Conduits 1 and 2 (C), and the outfall point (Out1). (Google Earth, May 24, 2017).

Pre-remediation conditions on the east side of the site included chat gravel, heavy forest with dense underbrush, native short grass, and a building with a parking area. Post-remediation conditions on the east side of the site included bare soil, rock diversion ditch, and a building with a parking area. The west side included native short grass and heavy forest with dense underbrush for pre-remediation conditions and a rock check dam and bare soil for the post-remediation conditions.

Table 4. Land coverages assigned in the model in pre- and post-remediation conditions

Pre-remediation	**Post-remediation**
Chat/gravel	Bare soil
Heavy forest with dense underbrush	Rock diversion ditch
Native, short grass	Building with a parking area
Building with a parking area	Rock check dam

A **subcatchment** surface is classified in SWMM with a percentage of pervious and impervious surface. Within the study area, it was assumed that the pre-remediation surface consisted of both pervious and impervious surfaces. Pervious and impervious surfaces have different **Manning's roughness coefficients**. The impervious pre-remediation surface included grass and mine waste overburden that consists of chat (Photograph 1). Pervious surfaces are composed of heavily-treed and heavy underbrush areas. Photographs 2 and 3 show the treed areas, grass coverage, and gravel-like chat material that was used in the pre-remediation parking area for the building. Conversely, in the post-remediation surface, the pervious surfaces consisted of grass, and impervious surfaces were rock structures such as a diversion ditch, rock check dam, and a building with a parking area (Photographs 4 and 5).

Photograph 1. Mining chat from a chat pile located on Kentucky Road, south of Granby, Missouri. Typical chat gravel ranges from sand and gravel-sized particles and contains residual lead, zinc and cadmium contaminants (USEPA, 2008). (Photograph by Marcia Schulmeister, September 2018).

Photograph 2. The building in the study area is in the middle of the image, while the pre-remediation tree and grass coverage is visible in the area surrounding the building. The parking area behind the building was gravel-sized chat material. Facing north, northwest. Photograph is a screen-shot of Google Maps street view dated June 2013.

Photograph 3. The northern boundary of the study area as viewed from Vance Street (lower right side and on Figure 2). The pre-remediation tree and grass coverage is visible in this image. The road culvert on Vance Street is also visible in the lower right corner. Facing south, southwest. Photograph is a screen-shot of Google Maps street view dated June 2013.

Photograph 4. Rock check dam in top left in the photograph, see the red arrow. Facing north, northwest. (Photograph by Marcia Schulmeister, September 2018).

Photograph 5. Diversion ditch on right side of the image, see red arrow. Image facing north. (Photograph by Marcia Schulmeister, September 2018.)

Polygon outlines were created for each surface modeled, using various colors to represent different surfaces. The subcatchment surface areas evaluated and estimated areas are presented in Figures 13 through 28 and summarized Tables 5 and 6 along with Manning's roughness coefficients chose for each surface.

Figure 13. Pre-remediation conditions, with pervious and impervious surface zones defined in this study (colored outlines). (Google Earth, January 25, 2014).

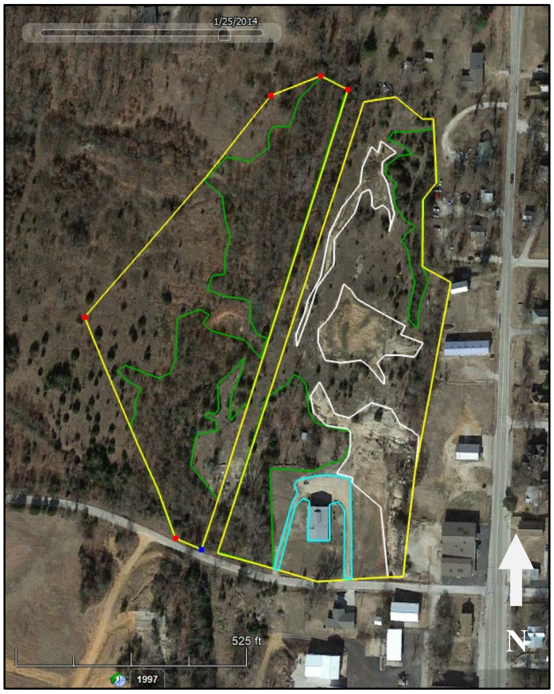


Figure 14. Pre-remediation conditions, with total surface area of the west slope measured as the first subcatchment, referenced as S1-WSlope. (Google Earth, January 25, 2014).

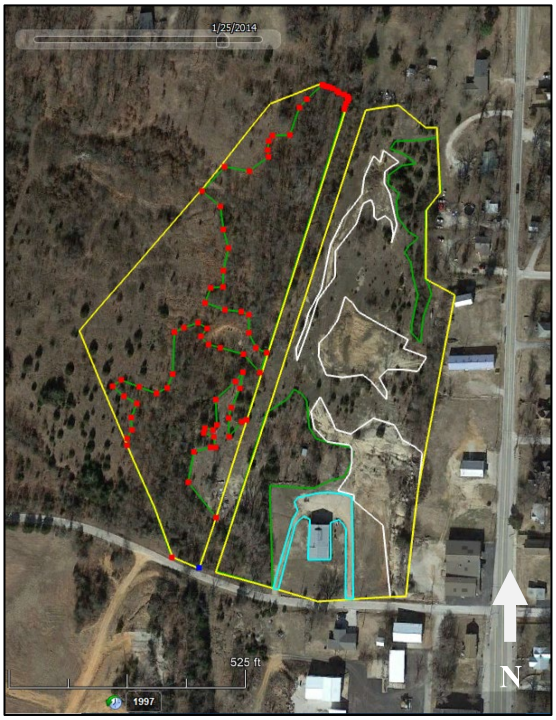


Figure 15. Pre-remediation conditions, with surface area of the pervious surface of dense forest and heavy underbrush in green outlines on the west slope. (Google Earth, January 25, 2014).

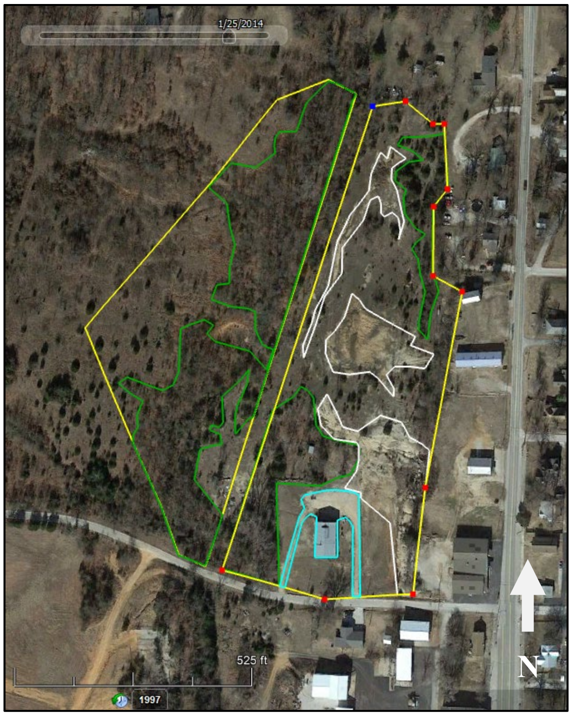


Figure 16. Pre-remediation conditions, with total surface area of the east slope as the second subcatchment, referenced as S2-ESlope. (Google Earth, January 25, 2014).

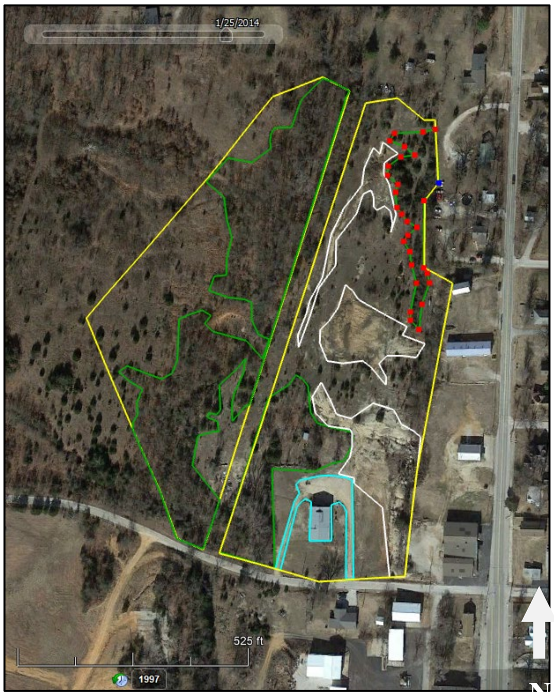


Figure 17. Pre-remediation conditions, with surface area of the northern pervious surface of dense forest and heavy underbrush in green outlines on the east slope. (Google Earth, January 25, 2014).

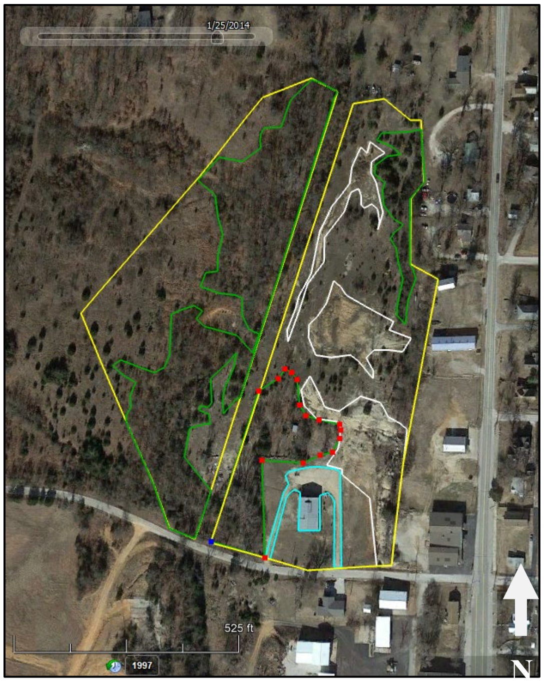


Figure 18. Pre-remediation conditions, with surface area of the southern pervious surface of dense forest and heavy underbrush in green outlines on the east slope. (Google Earth, January 25, 2014).

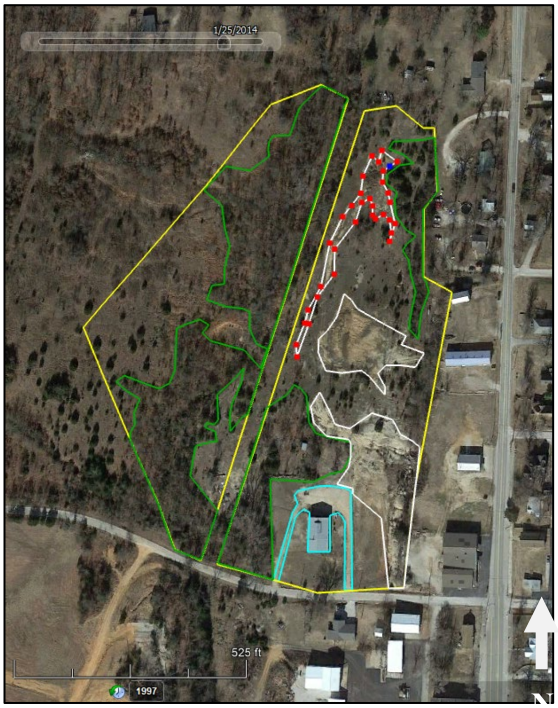


Figure 19. Pre-remediation conditions, with surface area of the northern impervious surface of chat gravel in white outlines on the east slope. (Google Earth, January 25, 2014).

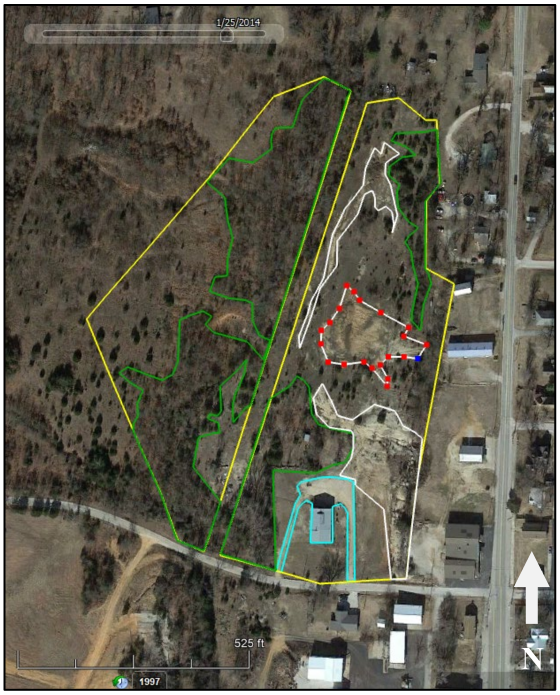


Figure 20. Pre-remediation conditions, with surface area of the impervious surface of chat gravel in white outlines in the middle of the east slope. (Google Earth, January 25, 2014).

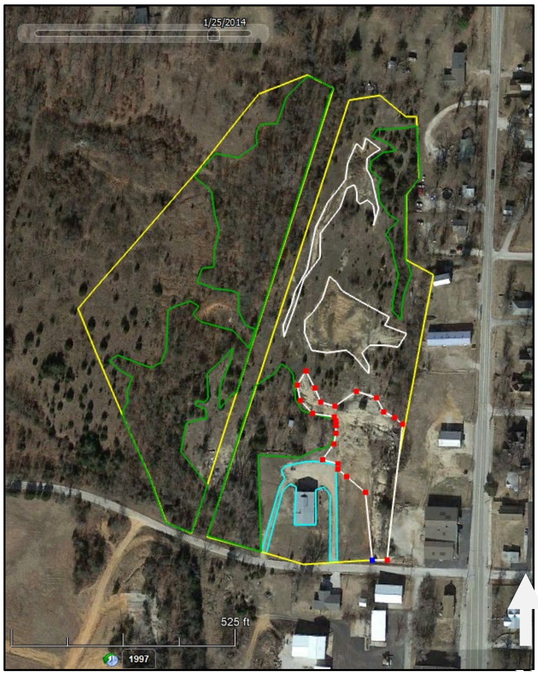


Figure 21. Pre-remediation conditions, with surface area of the southern impervious surface of chat gravel in white outlines on the east slope (Google Earth, January 25, 2014).

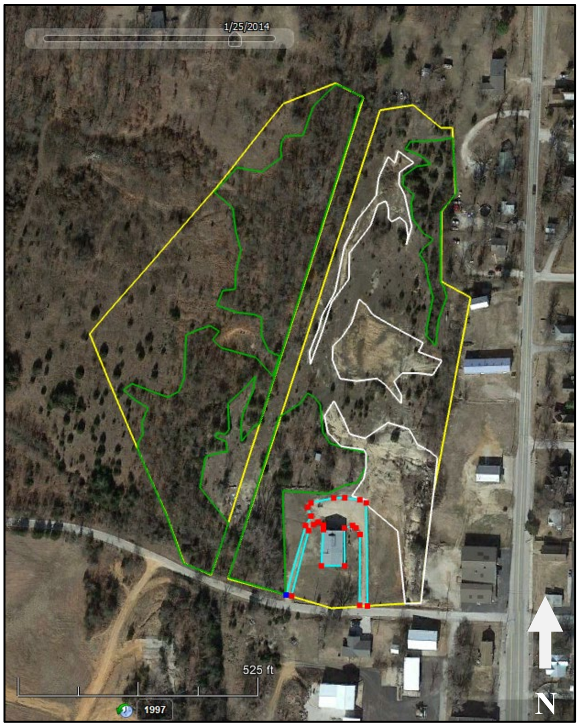


Figure 22. Pre-remediation conditions, with surface area of the impervious surface of a building and its parking area in blue outlines on the east slope. (Google Earth, January 25, 2014).

Table 5. Surface conditions, Manning's roughness coefficients (n) and coverage areas used in the nine polygons in the pre-remediation subcatchment surface modeled.

PRE-REMEDIATION			
Coverage Type	**Impervious or Pervious**	**Area km^2 (ft^2)**	**Figure**
East Subcatchment			
Dense forest with heavy underbrush (#1)	Pervious	2,311 (24,878)	19
Dense forest with heavy underbrush (#2)	Pervious	4,853 (52,239)	20
Short prairie grass	Impervious	16,377 (176,277)	18
Building with parking area	Impervious	1,533 (16,502)	24
Chat/gravel (#1)	Impervious	1,292 (13,908)	21
Chat/gravel (#2)	Impervious	2,395 (25,780)	22
Chat/gravel (#3)	Impervious	4,127 (44,427)	23
Total Surface Area for East Slope		32,889 (354,011)	18
West Subcatchment			
Dense forest with heavy underbrush	Pervious	15,055 (162,050)	16
Short prairie grass	Impervious	11,172 (120,250)	17
Total Surface Area for West Slope		26,252 (282,570)	17
Total Surface Area for Subcatchments		52,503 (565,140)	15

Figure 23. Post-remediation conditions, with pervious and impervious surface zones defined in this study (colored outlines). (Google Earth, May 24, 2017).

Figure 24. Post-remediation conditions, with total surface area of the west slope as the first subcatchment, referenced as S1-WSlope. (Google Earth, May 24, 2017).

Figure 25. Post-remediation conditions, with surface area of the impervious surface of rock check dam in blue outlines on the west slope. (Google Earth, May 24, 2017).

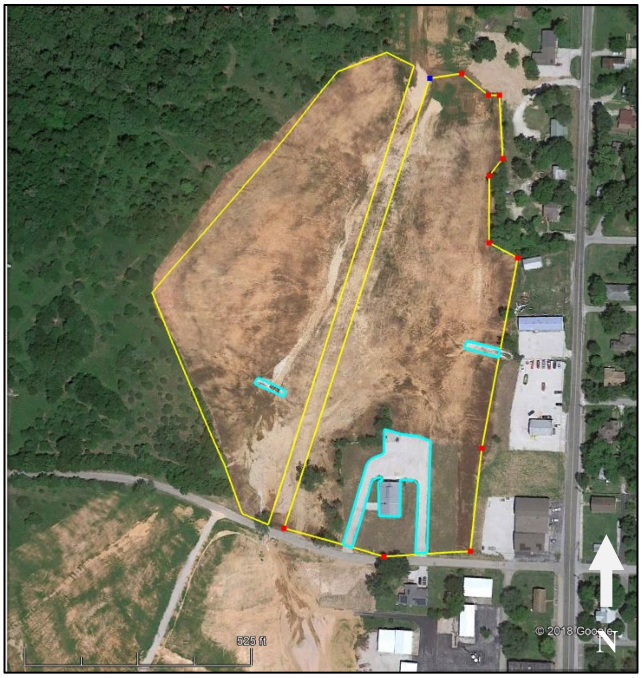


Figure 26. Post-remediation conditions, with total surface area of the west slope as the second subcatchment, referenced as S2-ESlope. (Google Earth, May 24, 2017).

Figure 27. Post-remediation conditions, with surface area of the impervious surface of a building with its parking area in blue outlines on the east slope. (Google Earth, May 24, 2017).

Figure 28. Post-remediation conditions, with surface area of the impervious surface of a rock diversion ditch in blue outlines on the east slope. (Google Earth, May 24, 2017).

In the post-remediation model, it was assumed that the area outside the building with its parking area, diversion ditch, and rock check dam were bare soil. It was noted that between 2014 and 2017, the surface area of the building and the parking area increased from 1,533 square kilometers (16,502 square feet) to 2,388 square kilometers (25,699 square feet). Google Earth imagery from 2014 to 2017 show earth-moving activities during the remediation period of the study area in 2016 (Google Earth, March 22, 2016).

Table 6. Surface conditions, Manning's roughness coefficients (n) and coverage areas used in the five polygons in the post-remediation subcatchment surface modeled.

POST-REMEDIATION			
Coverage Type	**Impervious or Pervious**	**Area km^2 (ft^2)**	**Figure**
East Subcatchment			
Bare soil	Pervious	30,360 (326,789)	28
Building with parking area	Impervious	2,388 (25,699)	29
Diversion ditch	Impervious	141 (1,523)	30
Total Surface Area for East Slope		32,889 (354,011)	28
West Subcatchment			
Bare soil	Pervious	26,147 (281,447)	26
Rock check dam	Impervious	104 (1,123)	27
Total Surface Area for West Slope		26,252 (282,570)	26
	Total Surface Area for Subcatchments	52,503 (565,140)	25

3.4.4 Selection of Manning's Roughness Coefficient Value from Ranges

A range of Manning's roughness coefficients (n) was reviewed based on literature review to identify the best-fit coefficient for the study area. A Manning's roughness coefficient can be calculated based on the radius of the hydraulic channel and diameter of bed material. Without site-specific channel and bed material values for the calculation, this study relied on similar type studies referenced in each subsection that range in specificity of material. Several materials have a range of coefficient values that were reported in the SWMM User's Guide (USEPA, 2015b) because the material may be heterogenous and have different coefficients for the same material. Ultimately, single values selected for this research were 0.80 for woods, heavy underbrush, 0.15 for short, prairie grass, 0.05 for bare soil, 0.035 for the rock check dam and diversion ditch, 0.011 for the building with parking area, and 0.011 for chat/gravel (Table 7).

Table 7. Summary of selected Manning's n coefficient values

Surface	**Range Manning's roughness coefficient(s) (n)**	**Selected Manning's roughness coefficient (n) used in models**	**Source**
Woods, heavy underbrush	0.80	0.80	USEPA, 2015b
Short prairie grass	0.15	0.15	
Bare soil	0.05-0.24	0.05	
Rock check dam and diversion ditch	0.020-0.035	0.035	
Building with parking area	0.011-0.024	0.011	USDA, 2010
Chat/gravel	0.011	0.011	

Woods, heavy underbrush

The review of the available pre-remediation Google Earth imagery (January 25, 2014) identified forested areas in both subcatchments (Figure 13). Limited field observations of the pre-remediation surfaces confirm the heavy underbrush within the stand of timber (Photographs 2 and 3). In the post-remediation surface, there were no trees indicated in the images. The remediation had included the clearing and grubbing of the land surface prior to excavation (USACE, 2017; Photograph 4). For purposes of this project, the n value for the dense woods with heavy underbrush was selected from a table in the SWMM User's Guide (2015b) as 0.80.

Short prairie grass

The review of the available pre- and post-remediation Google Earth imagery identified areas of grass coverage (January 25, 2014 and May 24, 2017; Figures 13 and 23). Field observations from pre- and post-remediation confirm the stand of grass. Photograph 4 documents the grass coverage in the post-remediation land surface. For purposes of this project, the value of short, prairie grass was selected from a table in the SWMM User's Guide (2015b) as 0.15.

Bare soil

The review of the available post-remediation Google Earth imagery identified the majority of the land surface as red soil with little to no vegetation. Photographs 4 and 5 confirm that additional vegetation has developed since the Google Earth imagery date of May 24, 2017. A range of values of 0.05 to 0.24 is available from a table in the SWMM User's Guide (2015b) for fallow soils, short prairie grass, and dense grass surface. Due to the lack of vegetation in the 2017 Google Earth imagery, the **fallow soil** coefficient was selected for the model. Therefore, the n value selected is 0.05.

Rock check dam and diversion ditch

The review of the available post-remediation Google Earth imagery identified the surface area of the rock check dam and diversion ditch. Photograph 4 documents the rock check dam, and Photograph 5 documents the diversion ditch in the post-remediation land surface. A range of values of 0.020 to 0.035 is available from a table in the SWMM

User's Guide Manning's n – Open Channels for rubble to riprap. The rock check dam and diversion ditch were constructed for surface water flow diversion (USACE, 2017). The use of the **riprap** value from the open channels coefficients was selected for this material in this model. The 2018 field observation confirms that riprap material was used for these features. Therefore, the n value selected is 0.035.

Building with parking area

The review of the available pre- and post-remediation Google Earth imagery identified the footprint of the building present in the study area and its surrounding parking area. Field observations from pre- and post-remediation confirm the existence and current status of the building and parking area. A range of values of 0.011 to 0.024 is reported in the SWMM User's Guide (2015b) for smooth asphalt, smooth concrete and a cement rubble surface. Based on the recommendation of the National Engineering Handbook (USDA, 2010), a single coefficient is used for all **smooth surfaces** that includes concrete, asphalt, and gravel. Therefore, the value selected is 0.011.

Chat/gravel

The review of the available pre-remediation Google Earth imagery identified the multiple areas of chat which is gravel-sized material. Photograph 3 provides a scale on size. Based on the recommendation of the National Engineering Handbook (USDA, 2010), a single coefficient for **smooth surfaces** includes concrete, asphalt, and gravel. Therefore, the value selected is 0.011.

3.4.5 Subcatchment Input Parameters

Subcatchments require several input parameters related to the surface and flow through the modeled system. The input parameters include user-defined names and outlets, measured area, width, slope, pervious and impervious surface areas, and coefficients for pervious and impervious surface areas. The input parameters are listed in Table 2. Rainfall is simulated by assigning a rain gage, Gage1, to each subcatchment**.** **Land use** is assigned an input parameter to each subcatchment that coincides to pollutant buildup and washoff. **Land use** for this study area was the remediated land surface because the model was for pollutants on the post-remediation land surface. Google Earth measurements were confirmed by limited field measurements to estimate the surface areas for pre-remediation and post-remediation models (Tables 5 and 6; Google Earth, 2014 and Google Earth, 2017). Tables 8 and 9 list the values and sources of the input parameters for each subcatchment.

Table 8. SWMM Parameters for Pre-remediation Subcatchments

PRE-REMEDIATION			
Property	*Subcatchment*	*Subcatchment*	*Source*
Name	S1-WSlope	S2-ESlope	User defined
Outlet	J2	J2	
Area	6.49 acres	8.13 acres	Google Earth, 2019
Width	220 feet	300 feet	
% Slope	11%	6.9%	
% Imperv	0%	8%	
N-Imperv	0.03	0.05	USEPA, 2015
N-Perv	0.11	0.3	
Dstore-Imperv	0.05 inches	0.05 inches	
Dstore-Perv	0.3 inches	0.3 inches	
%Zero-Imperv	100%	100%	

Table 9. SWMM Parameters for Post-remediation Subcatchments

POST-REMEDIATION			
Property	*Subcatchment*	*Subcatchment*	*Source*
Name	S1-WSlope	S2-ESlope	User defined
Outlet	J2	J2	
Area	6.49 acres	8.13 acres	Google Earth, 2019
Width	220 feet	300 feet	
% Slope	11%	6.9%	
% Imperv	0.62%	8.45%	
N-Imperv	0.012	0.012	USEPA, 2015
N-Perv	0.02	0.02	
Dstore-Imperv	0.05	0.05	
Dstore-Perv	0.2	0.2	
%Zero-Imperv	0	0	
Land Uses	1	1	User defined
Initial Buildup	YES	YES	

The selected width for each subcatchment was determined as the average width across the subcatchment as recommended in the SWMM Manual (2015b). The average width was calculated based on several Google Earth measurements across an entire subcatchment polygon. The percent slope was calculated using Google Earth by creating a path line and reviewing the elevation profile for the middle of each subcatchment polygon. Figures 29 and 30 show the elevation profiles along the middle of each subcatchment.

Figure 29. Print-screen image from Google Earth following study area measurement of the slope for the west slope subcatchment (S1-WSlope). (Google Earth, May 24, 2017)

Figure 30. Print-screen image from Google Earth following study area measurement of the slope for the east slope subcatchment (S1-ESlope). (Google Earth, May 24, 2017)

The percent impervious area was calculated by dividing the total of the Google Earth measurements for impervious surfaces by the total surface area of each subcatchment. Depression storage values for impervious and pervious surfaces were selected from a table of available values (SWMM Manual, Appendix A.5 Depression Storage). For impervious surfaces, the lowest value was selected for this project. For the pervious surfaces, the value for pasture at 0.2 inches was used for the post-remediation pervious surface because the surface is grass. In the pre-remediation pervious surface, the value for forest litter of 0.3 inches for depression storage was selected for this project based on the presence of a heavy forest. The selection of conservative values for this project was to allow for a greater effect of depression storage. Additionally, it was conservatively assumed that there was 100% of the impervious area with no depression storage.

For the pollutant component of the model, the **Land Use** of "Remediated" was applied to 100% of the subcatchments for the post-remediation model. The **Initial Buildup** was added for lead as a pollutant at a value of one. The remaining parameters were left as a default value in each subcatchment. Since site-specific data were not available for these parameters, they were not included in the model or left as a default value for this project. These values were either zero or left blank. Parameters that were not included in the model and not important for the current analysis include: **Subarea Routing**, **Percent Routed**, **Infiltration Data**, and **Groundwater**. The following parameters did not apply to this study because they did not exist in the model area: **Snow Pack**, **LID Controls**, **Curb Length**, **N-Perv Pattern**, **Dstore Pattern**, and **Infil. Pattern**.

3.4.6 Junction Input Parameters

Two junctions were assigned in the model. Figure 33 is an image from Google Earth with measurements of the road culvert on McKinley Street for model inputs for Junction 1, labeled as J1 in the SWMM project (Photograph 6). Figure 34 is an image from Google Earth, with measurements of the area within the study area with the channel area width between the two subcatchments. This area was assigned as Junction 2, labeled as J2 in the SWMM model. Assigned variables for defining a junction include **Invert El.**, **Max. Depth**, and **Initial Depth**. The junction values used in the model are listed in Table 14. It was assumed that no changes occurred at the junctions during the modeling period and that their elevations remained constant. The United States Army Corps of Engineers (USACE) indicated that the two road culverts used as model junctions were not altered between January 24, 2014 and May 25, 2017, and field observations support this assumption (USACE, 2017).

Table 10. SWMM Parameters selected for Junctions

Model Parameter Name	***Junction 1 (J1)***	***Junction 2 (J2)***
Inflows (Yes/No)	No	No
Treatment	No	No
Invert El. (feet)	1094	1077
Max. Depth (feet)	0	0
Initial Depth (feet)	0	0
Surcharge Depth	0	0
Ponded Area	0	0

Seven variables must be assigned at each junction (Table 10). It was assumed that there were no external surface water **Inflows** received at each junction, such as **Direct Inflow** and **Dry Weather Inflow**, because there is no measured value for this study. **Direct Inflow** to a junction is calculated by a baseline value multiplied by a baseline pattern. This is added to a time-series value multiplied by a scale factor that can be used to exaggerate the inflow**. Dry Weather Inflow** is calculated by multiplying an average value by different time patterns. Since no site-specific values were available for these calculations, **Direct Inflow** and **Dry Weather Inflow** for the junctions were not included in this project. Junction elevations were determined using Google Earth points using the available imagery. Since site-specific measurements for the land surface were not acquired before remediation in 2015, the measurements for the junctions on the land surface from Google Earth were used following completion of remediation in 2017. For both **Initial Depth** and **Max. Depth** values, the junctions did not have evidence of standing water in either Google Earth imagery or in 2018 field observations. Therefore, these properties were left at zero feet.

Photograph 6. Road culvert on McKinley Street, location marked on Figure 2. Image is facing north toward the study area. (Photograph taken by Marcia Schulmeister in September 2018).

Figure 31. Location of McKinley Street road culvert that is assigned as Junction 1 (J1) in the model. (Google Earth, May 24, 2017).

Figure 32. Location of the downstream Junction 2 (J2) as referenced in the model. (Google Earth, May 24, 2017).

3.4.7 Conduit Input Parameters

Low areas between the two subcatchments that act as drainage ditches flowing from south to north, and a channel to the north of the study area, were chosen as two conduits in the model (Figures 31 and 32). They are considered open conduits with identical roughness, based on review of the 2017 Google Earth imagery (Google Earth, 2017). Conduits are bounded by nodes such as junctions and outfalls. The upgradient junction (J1) was assigned as the road culvert under McKinley Street that forms the southern border of the study area (Photograph 6). A second junction (J2) represents the change from a larger surface area drainage to a channel area. The final stretch of Conduit 2 (C2) terminates at the outfall at a road culvert at Vance Street along the northern border of the study area (Figure 36). The outfall is the ultimate discharge point of the model area.

Table 11. SWMM Parameters selected for Conduits

Model Parameter Name	*Conduit 1 (C1)*	*Conduit 2 (C2)*
Inlet Node	J1	J2
Outlet Node	J2	Out1
Shape	Trapezoidal	Open Rectangle
Max. Depth (feet)	1	2
Length (feet)	1141	542
Roughness (Manning's n coefficient)	0.15	0.15

Values assigned to conduits are listed in Table 11. It was assumed that Conduit 1 (C1) connected J1 and J2 because it was spatially connected (Figure 33). The C2 connects J2 to the outfall in the study area as seen in Figure 34. Due to the gradual slopes along C1, a trapezoidal area was defined. An open rectangle shape was used to represent C2 because the side slopes were steeper than C1. The **Max. Depth** parameter is defined as the maximum depth of the cross section of the channel geometry. For C1, it was estimated by the slope cross-sections from Google Earth for change in elevation from base of the channel to the start of the subcatchment polygon. For C2, a similar approach of using Google Earth had estimated the maximum depth as two feet. Google Earth was also used for measurements of the two conduit lengths.

SWMM uses the Manning's roughness coefficient to relate flow rate, the cross-sectional area, hydraulic radius and slope of all conduits (USEPA, 2015). The Manning's roughness coefficients (n) were selected from a table of typical values listed in the SWMM Manual (Appendix A.6). The Manning's n value listed as **Overland Flow** for short, prairie grass was chosen. Based on the review of 2014 and 2017 Google Earth imagery, both pre- and post-remediation conduits were assumed to be grass covered (Google Earth, 2014 and Google Earth, 2017). The 2018 field observation confirmed the post-remediation land surface was grass covered. Since site-specific measurements for the pre-remediation land surface were not acquired, the measurements for the post-remediation land surface from Google Earth were used (Google Earth, 2017).

Several parameters were left as a default or zero value in each conduit because either site-specific data was not available, or it did not apply to non-sewer systems. Many of these parameters apply to urban sewer systems (USEPA, 2015b). Since site-specific data was not available for these parameters, they were omitted or left as a default value for this project. The following parameters were not adjusted from the default value of zero and their variation was not evaluated as part of this analysis: **Inlet Offset**, **Outlet Offset**, **Initial Flow**, **Maximum Flow**, **Entry Loss Coefficient**, **Exit Loss Coefficient**, **Average Loss Coefficient**, **Seepage Loss Rate, Flap Gate,** and **Culvert Code**.

Figure 33. Study area measurement of Conduit 1 (C1). Length of C1 was measured as 348 meters (1,141 feet) (Google Earth, May 24, 2017).

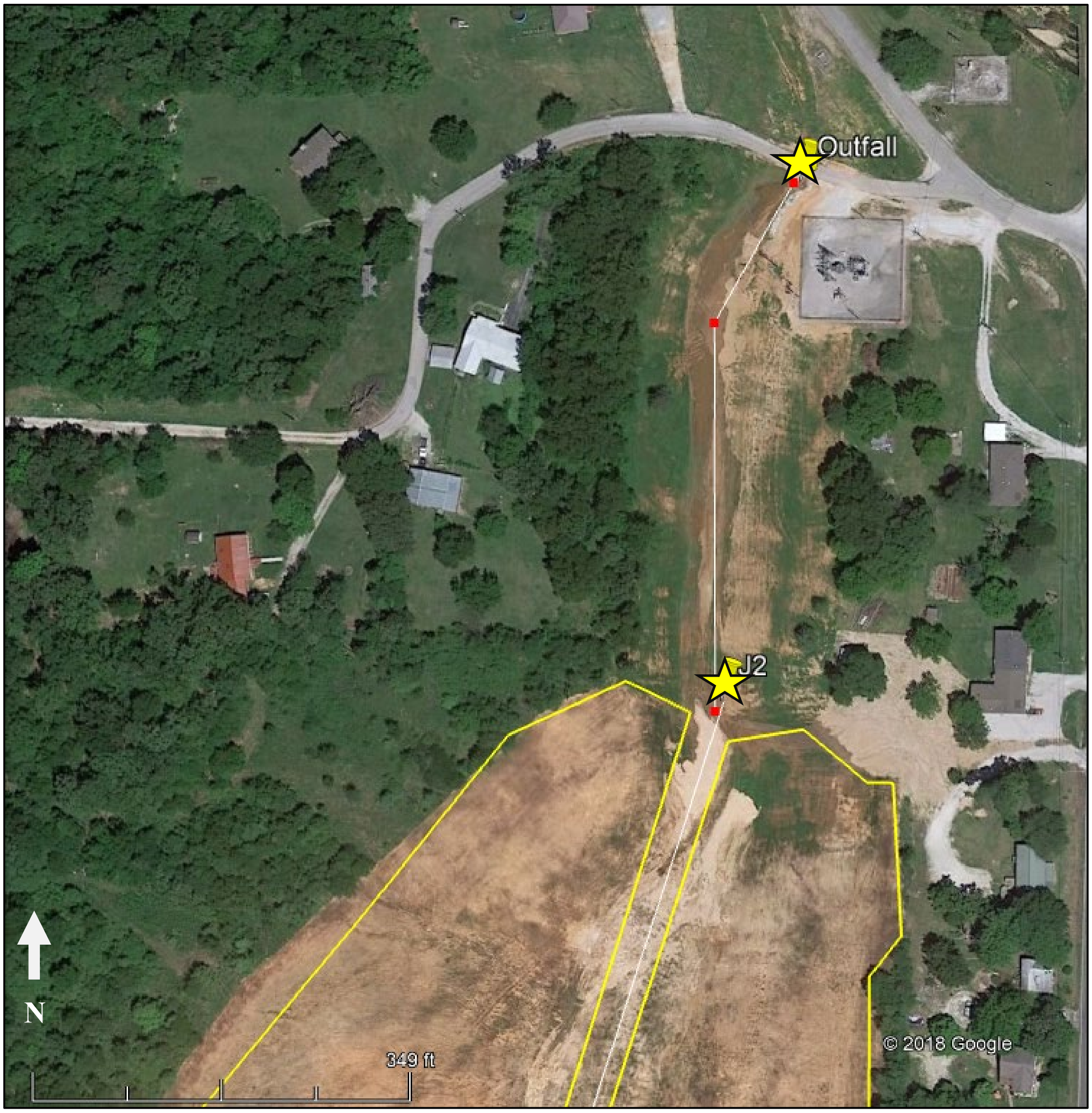


Figure 34. Study area measurement of Conduit 2 (C2). Length of C2 was measured as 165 meters (542 feet) (Google Earth, May 24, 2017).

3.4.8 Outfall Input Parameters

An outfall point is the point in a SWMM study area that receives the surface water runoff. The output values of SWMM are the conditions at the outfall point. The study area has one outfall point on the north side of the model area, labeled as Out1 in SWMM. In Figure 34, the outfall is located along Vance Street and acts as the end node for conduit C2. Outfalls require fewer inputs than subcatchments and conduits. Input parameters are inflows, elevation, and type (Table 12). The elevation of the outfall point is the **Invert El**. **Invert El** was the only measured input parameter, using Google Earth (Google Earth, 2017). Since site-specific measurements for the pre-remediation land surface were not acquired, the measurements for the post-remediation land surface from Google Earth were used in the models (Google Earth, 2017).

Table 12. SWMM parameters selected for the outfall

Model Parameter Name	***Outfall 1 (Out1)***
Inflows	No
Treatment	No
Invert El.	1069
Type	FREE

Several outfall parameters were left as a default values or assigned as zero. Since site-specific data were not available for these parameters, they were omitted or left as a default value of zero or left blank for this project. The following parameters were not adjusted and their variation was not evaluated as part of this analysis: **Inflows**, **Route To**, and **Type**. The parameters that did not apply to the model area because they do not exist in the model system are the following: **Treatment**, **Tide Gate**, **Fixed Outfall**, **Tidal Outfall** or **Time Series Outfall**.

3.5 Pollutant Model Inputs

Following the construction of the physical model domain in SWMM, several modeling approaches were used to test the three hypotheses presented in this research. One effort included the simulation of **Buildup** and **Washoff** of pollutants present at the surface. Lead and zinc washoff was selected to predict possible downstream occurrence of pollutants. In the Pollutant Editor, the pollutant values for the initial concentration, or **Initial Buildup**, were set at the maximum allowed level for the USEPA mining-related cleanup: lead as 400 parts per million (ppm) and zinc as 6,400 ppm. Those concentrations were assumed as the initial concentration throughout the system since the area was already remediated. This analysis does not account for any unremediated areas upstream of the study area. A time series element was utilized in SWMM to identify flow and buildup events that have occurred in the study area.

3.5.1 Land Use Editor

SWMM allowed for the simulation of the washoff and potential buildup of the pollutants by land use through the system and as it exits into the downstream aquatic system at the outfall point. Mechanisms for buildup involve factors such as wind, land surface activities, erosion, traffic, atmospheric fallout, and other physically-based processes. A constant concentration, referred to as an event mean concentration (EMC), was applied to quantity predictions. This process multiplies predicted volumes by an assumed concentration by storm events (USEPA, 2016). For this project, a user-defined land use was created for the remediated surface. Under the Land Use Editor, the buildup and washoff properties are based on land use, not by subcatchment. Both subcatchments had the same land use as a remediated surface.

Assignment of Values - Buildup

Buildup simulations allow for a model output of the maximum mass of pollutant that may be transported in a storm event. The default parameters of function (Power function), rate constant (value of 1), power buildup or saturation constant (value of 1), and normalizer (by area) remained unchanged for both Site COCs. The value of maximum possible buildup per unit of area was calculated by converting ppm to lbs. per acre. Using a USDA conversion, 1 ppm equals 2 lbs./acre of soil, 6 inches deep (USDA, 2019). Lead was 400 ppm multiplied by 2 to equal 800 pounds, then divided by 14.62 acres to equal 54.72 lbs./acre. Zinc was 6,400 ppm multiplied by 12,800 pounds, then divided by 14.62 to equal 875.51 lbs./acre.

Assignment of Values - Washoff

Washoff simulations model the process of erosion of pollutants from a subcatchment surface during a period of surface runoff. The default parameters of function (EMC function), exponent (value of 0), cleaning efficiency (value of 0), and BMP efficiency (value of 0) remained unchanged for both Site COCs. The value of washoff coefficient was selected as the maximum value of 10. The values of 1 through 10 are within a range of most observed values in urban runoff (USGS, 2016).

3.6 Additional Methods of Analysis

For all hypotheses, additional modeling and some prediction of outcomes were included and based on information sources to determine permissible range as part of a sensitivity analysis. Following the analysis of all hypotheses, there is a presentation of potential BMPs, seen as corrective measures of impacts of removal of mine waste, existing vegetation, and/or contaminated soil.

CHAPTER 4. RESULTS

Model input parameters described in Chapter 3 were incorporated in SWMM projects to create pre-remediation and post-remediation models. Model outcomes from SWMM are summarized in Tables 13-15 and discussed in the following sections. SWMM program used Imperial instead of metric units, so English units were retained in this study to allow for comparison with similar SWMM studies.

In this study, the three model runs were analyzed to evaluate three hypotheses. Model input parameters were consistent throughout except for additional precipitation data for the evaluation of Hypotheses no. 2 and 3.

4.1 Analysis of increase of surface-water runoff volume from pre-remediation to post-remediation (Hypothesis 1)

To evaluate the hypothesis that surface water runoff volume would increase in a post-remediation landscape, the surface water runoff volume in the post-remediation models needed to be greater than the pre-remediation models. The increase of depth of surface water runoff and the runoff coefficient indicates increased runoff. The values of **runoff coefficients** for the pre-remediation subcatchments are 0.00 for Subcatchment 1-WSlope and 0.08 for Subcatchment 2-ESlope. For the post-remediation subcatchments, the **runoff coefficient** for Subcatchment 1-WSlope are 0.006 and 0.085 for Subcatchment 2-ESlope. The **runoff coefficient** for both slopes was greater for the post-remediation land surface (Table 13).

Table 13. Pre and post-remediation runoff coefficients and surface runoff volumes

Pre-remediation runoff coefficient		Post-remediation runoff coefficient	
West Slope	0.000	West Slope	0.006
East Slope	0.080	East Slope	0.084
Pre-remediation total surface runoff (inches)		Post-remediation total surface runoff (inches)	
0.105		0.366	

The r**unoff coefficient** for the west slope (Subcatchment 1-WSlope) increased from 0.00 to 0.006 after remediation. The r**unoff coefficient** for the east slope (Subcatchment 1-ESlope) increased from 0.080 to 0.084, a five percent increase after remediation. **Total Runoff** is the depth of surface water runoff. The depth of surface water runoff from the pre-remediation study area was 0.105 inches and the depth of surface water runoff from the post-remediation study area was 0.366 inches. This is nearly a 250 percent increase. The models demonstrated that surface runoff volume and calculated **runoff coefficients** for the study area have increased after remediation.

4.2 Analysis of increase of surface-water runoff volume with increased precipitation data input (Hypothesis 2)

The second hypothesis was that a causal relationship existed between storm water runoff and rainfall. To test this hypothesis, the results for the post-excavation one-month rainfall model were compared to those of the post-excavation six-month period (Table 14). The volume of **Total Runoff** per subcatchment and the **Total Runoff** for the study area were noted for a one-month and six-month time series in the post-remediation landscape. In the one-month time series, the **Total Runoff** of Subcatchment 1-WSlope was 0.05 inches and 0.62 inches for Subcatchment 2-ESlope. The total study area runoff for one-month of precipitation data was 0.445 acre-feet. In the six-month time series, the **Total Runoff** of Subcatchment 1-WSlope was 0.07 inches and 0.98 inches for

Subcatchment 2-ESlope. The total study area runoff for six-month of precipitation data was 0.704 acre-feet.

Table 14. Comparison of model results to satisfy Hypothesis no. 2

Model period	**Total Input Precipitation (inches)**	**Modelled Runoff (inches)**
May 2017	7.350	0.366
January – June 2017	11.620	0.578
% difference	58%	58%

A total of 7.350 inches of precipitation fell over the one-month model period. In six months, there was a total of 11.620 inches of precipitation. The difference between these is 58%. **Surface Runoff**, of 0.366 inches was calculated over a one-month time period and 0.578 inches were calculated over a six-month period. The difference between these is also 58%. Both precipitation and **Surface Runoff** totals were 58 % higher in the six-month model. Based on these results, runoff and the amount of runoff appears directly related to the amount of rainfall in a given period and Hypothesis no. 2 has been satisfied.

4.3 Analysis of lead and zinc mass contaminant released from post-remediation surface during rainfall events (Hypothesis 3)

The criteria to satisfy Hypothesis no. 3 were first to satisfy the first and second hypotheses. The third hypothesis was that mass contaminant of lead and zinc, total amount in runoff, would be released from the excavated surface of the remediated areas during rainfall events. The initial mass of lead was 6.490 pounds and an initial mass of zinc was 0.000 pounds in Subcatchment 1-WSlope and Subcatchment 2-ESlope. The mass of lead and zinc accumulated from the post-remediation surface were 895.948 pounds on the Subcatchment 1-WSlope and 902.438 pounds on the Subcatchment 2-

ESlope. The mass in the surface runoff and washoff of each subcatchment, Subcatchment 1-WSlope and Subcatchment 2-ESlope, were identical for lead and zinc at 171.438 pounds. Similarly, the remaining mass was identical for lead and zinc at 731.000 pounds.

The results of the six-month models for post-remediation land surface that include model outputs for water quality are summarized in Table 15. Under the **Land Use** subcatchment parameter and defined as a **Remediated** use area, it was assumed that the subcatchment surface concentration of lead was 400 mg/kg and zinc was 6,400 mg/kg. The initial concentration, converted to mass in SWMM, for lead was in enough quantity to total nearly six and a half pounds while zinc did not have enough quantity.

Table 15. Comparison of model results to satisfy hypothesis no. 3

Model output	Lead (lbs.)	Zinc (lbs.)
Surface buildup	810	2,525
Subcatchment washoff	17	17

The mass accumulated from the land surface totaled over 810 pounds for lead and 2,525 pounds for zinc. Surface water runoff and washoff of each subcatchment at the designated outfall is the pollutant load that is transported during rain events. For the study area, these were 17 pounds of lead and zinc. The remaining buildup of 800 pounds of lead and 2,508 pounds of zinc is available on the subcatchment surface. Some fraction of that remaining material is modeled to wash off into the drainage system during storm events.

The increased surface runoff observed in the first model agrees with the interpretations of a causal relationship between surface runoff and rainfall that facilitates the transport of surface concentrations of the Site COCs. Site COCs of lead and zinc have been modeled to be at the outfall of the study area at a value of 17 pounds for each. The

SWMM simulations have shown that Site COCs have runoff from the post-excavation area of the study area. Therefore, hypothesis no. 3 has been satisfied.

4.4 Model Sensitivity Analysis

An analysis of the most sensitive model parameters focused on the input parameters used to test Hypothesis no. 3. Measured, site-specific data are incorporated in the model reliability and calibration. The SWMM Reference Manual for Water Quality emphasizes that without measured, site-specific data, limited reliability can be interpreted in the predicted magnitudes of quality parameters (USEPA, 2016). To test the range in magnitude of Site COCs, the inputs for the Land Use Editor under the Quality module in SWMM were altered based on recommendations in the SWMM Reference Manual for Water Quality. The manual recommends the data for calibration and verification of model results. Calibration and verification data were not available and not collected as part of this research. Since calibration and verification data are not available for the study area, the results of this analysis are hypothetical, but may provide a general understanding of the relative differences in output. The differences in output associated parameters that occur as key input parameters are varied. The key input parameter evaluated is **Washoff Coefficient**.

Values for the **Washoff Coefficient** for both Site COCs were selected as values of 1, 3, 5, and 9. **Washoff Coefficients** of 1 through 10 are within a range of most observed values in urban runoff (USGS, 2016). The **Washoff Coefficient** of 10 was used in the first model test. The range of outputs for **Surface Washoff** following the additional model runs was between 1.714 and 15.429 lbs. (Table 16).

Table 16. Water quality model outputs for range of washoff coefficient values

Washoff Coefficient Value (K_w)	Lead and Zinc in Surface Runoff (lbs.)	Percent Increase (%)
1	1.714	N/A
3	5.143	200%
5	8.572	67%
9	15.429	80%

The mass of lead and zinc in the surface water runoff increased as the **Washoff Coefficient** increased. A **Washoff Coefficient** ranged from 1 to 9 with the resulting mass ranging from 1.714 lbs. to 15.429 lbs. The percent increase from a **Washoff Coefficient** of 1 to 3 was 200%. The percent increase reduced to 67% and 80% from a **Washoff Coefficient** from 3 to 5 and 5 to 9, respectively.

Other studies have demonstrated the sensitivity of buildup inputs in response to changing the **Washoff Coefficient** (Avellaneda et al., 2009; Li, 2011). Li (2011) states that sensitivity of buildup values is higher for pollutants from impervious land surface that may occupy a larger percentage of an area than the pervious land surface (Li, 2011). Li's finding suggests that the percent of impervious surface in this study would also need to be revisited in model calibration for water quality.

CHAPTER 5: IMPLICATIONS OF THE MODEL RESULTS

5.1 Climate Change

Streamflow and gage height values during the model years were at near-record levels (Figure 8). Future years may continue to be near record or may return to more normal values. Therefore, it can be hypothesized that the surface runoff and pollutant loading would be highest during these near record streamflow events and could reduce in severity if streamflow returns to normal values. However, based on the Fourth National Climate Assessment (US Global Change Research Program, 2018), the Midwestern U.S.A. is vulnerable to climate change impacts. A localized increase in extreme precipitation and storm events can lead to an increase in flooding. Such events could increase the depth and volume of surface water runoff, based on this research.

5.2 Surface water runoff

The total **Surface Runoff** for both subcatchments is 0.704 acre-feet which is modeled from six months of rainfall events. In the runoff, there is a modeled 17.144 pounds of Site COCs. The concentration of 24.35 pounds per acre-foot is 8.95 mg/kg. The concentrations of contaminants in the subcatchment surface were assumed to be EPA's action levels at a concentration of 400 mg/kg for lead and 6,400 mg/kg for zinc. The model has predicted that surface concentrations of the Site COCs are migrating off the remediated area during rainfall events, if a poorly vegetated surface is modelled. Because a poorly vegetated surface followed EPA's remediation, EPA's remediation strategy for this Site should be revisited for effectiveness, as these results suggest. With each rainfall event, additional concentrations of Site COCs will be mobilized and may enter downstream surface-water bodies. USEPA selected Site action levels for sediment that were much lower for the Site COCs, assuming greater sensitivity and risk to the aquatic organisms. Therefore, the model area and other remediated areas that are left unvegetated may continue to release Site COCs in surface runoff. That surface runoff will flow to the surface-water bodies and may accumulate in sediments, with concentrations of Site COCs to exceed USEPA Site action levels for sediment.

As demonstrated in this research, the **Washoff Coefficien**t was one of the key input parameters that was sensitive. The increase in the **Washoff Coefficient** value increased the surface water runoff of the study area. Other key input parameters would require additional analysis.

CHAPTER 6. CONCLUSIONS

The results of this project imply that although the mine waste and contaminated soils were remediated in the study area, surface runoff and the transport of lead and zinc from the area may have increased. The subcatchment surface runoff coefficients, an index for the amount of runoff at a site, increased from the pre-remediation values of 0.00 and 0.006 to the post-remediation values of 0.080 and 0.084. Modeled runoff also increased from 0.105 inches in the pre-remediation surface, to 0.366 inches in the post-remediation surface. In a comparison of one-month and six-month model simulations of precipitation, total runoff volumes increased from 0.366 inches to 0.578 inches. The results confirm the expected increase in surface-water runoff volume as a result of increased precipitation.

The model results indicated 810 pounds of lead and 2,525 pounds of zinc were accumulated on the subcatchment surface based on the initial concentrations. Subcatchment washoff quantity was 17 pounds for each Site COC. The results confirm that Site COC's are present in the surface-water runoff from the study area. Both lead and zinc present risks to terrestrial and aquatic environments. The USEPA selected a remedy for the Site that was to protect both terrestrial and aquatic environments. In the selection of cleanup levels by USEPA, the levels for the remediation of surface soils was higher than the levels for the sediments. If some mass of Site COCs in the terrestrial environment is transported to the aquatic environment, the remediated areas may be creating unacceptable risks in the surface water and sediments in the tributaries and larger streams in the watershed. This finding could be tested by conducting continuous and heavy rainfall monitoring of Site COCs in surface water from the runoff and tributaries. Additionally, periodic monitoring of the sediments in the tributaries would provide data on the concentrations of Site COCs that may respond to changes in surface runoff following rain events.

6.1 Areas for Further Research

This project would have benefited from additional research. This project relied almost exclusively on publicly available software and information, and included limited field measurements and observations. Models outputs are generally reliant on measured, site-specific inputs. The measurement of site-specific input parameters would have allowed for more accurate models. Based on the current model outputs, it is assumed that water and pollutants are being transported more in the post-remediation study area than in the pre-remediation study area. Since the area has already been remediated and would likely not undergo additional excavation, the use of erosion control measures such as BMPs could reduce the surface runoff and the pollutant load transported from the study area. BMPs to consider include (1) modeling of revegetation as corrective measure to facilitate reduced runoff and (2) continuous or periodic modeling of the use of construction materials as engineering structures as corrective measure.

Low Impact Development Practices

SWMM has the functionality to model the use of BMPs using its default model input parameters. Additional modeling within the subcatchments could have included the use of low impact development (LID) controls or practices such as bio-retention cells, infiltration trenches, and vegetative swales. Bio-retention cells are designed drainage beds as a depression with gravel layered with soil and vegetation. Infiltration trenches are gravel-filled ditches that intercept runoff and provide storage volume. Vegetative swales are sloped channels or depressed areas with grass and other vegetation (USEPA, 2015).

These can all be modeled with the use of pre-designed LID controls available in SWMM. The LID Controls may lead to recommendations of how to manage both the stormwater and pollutant washoff within the study area. SWMM can only model the reduction in mass load resulting from the reduction in runoff flow volume; however, recommendations related to LID controls may include potential locations and types to include in the study area based on the modeled mass load reduction in several different modeled inputs.

6.2 Concluding Remarks

This project provides an example of the application of SWMM outside the typical use of storm water infrastructure. The use of free and publicly accessible data allows for available use. There are several similar-type mining sites in Missouri and surrounding states that may benefit from application of SWMM modeling. Many of these sites are similar in slope, excavation practices, and poor soil for revegetation.

In this study, more resources could have been focused on examining BMPs or refining site-specific inputs such as Manning's roughness coefficients. However, the input parameters used were adequate to show increased impacts of storm-water runoff and mass contaminant load to the post-remediation study area. SWMM was successfully used as a screening tool that could direct more focused site investigations.

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APPENDICES

Appendix A: Daily summary reports for precipitation at station #USW00013987

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Current Location: Elev: 972 ft. Lat: 37.1522° N Lon: -94.4953° W
Station: **JOPLIN REGIONAL AIRPORT, MO US USW00013987**

Record of Climatological Observations

These data are quality controlled and may not be identical to the original observations.

Generated on 02/09/2020

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Observation Time Temperature: Unknown Observation Time Precipitation: 2400

Year	Month	Day	Temperature (F)			Precipitation					Evaporation		Soil Temperature (F)					
			24 Hrs. Ending at Observation Time		At Observation	24 Hour Amounts Ending at Observation Time				At Obs. Time	24 Hour Wind Movement (mi)	Amount of Evap. (in)	4 in. Depth			8 in. Depth		
			Max.	Min.		Rain, Melted Snow, Etc. (in)	Flag	Snow, Ice Pellets, Hail (in)	Flag	Snow, Ice Pellets, Hail, Ice on Ground (in)			Ground Cover (see *)	Max.	Min.	Ground Cover (see *)	Max.	Min.
2015	05	01	75	42		0.00												
2015	05	02	79	50		T												
2015	05	03	81	59		T												
2015	05	04	82	64		T												
2015	05	05	81	61		T												
2015	05	06	81	61		0.28												
2015	05	07	81	65		0.03												
2015	05	08	78	64		0.96												
2015	05	09	76	61		0.56												
2015	05	10	74	61		0.59												
2015	05	11	65	47		T												
2015	05	12	70	43		0.00												
2015	05	13	68	43		0.02												
2015	05	14	78	57		1.43												
2015	05	15	80	65		T												
2015	05	16	83	64		0.13												
2015	05	17	79	62		1.30												
2015	05	18	81	59		0.00												
2015	05	19	68	51		0.07												
2015	05	20	65	51		0.52												
2015	05	21	66	45		0.00												
2015	05	22	66	44		T												
2015	05	23	75	56		0.46												
2015	05	24	68	61		2.48												
2015	05	25	82	61		0.12												
2015	05	26	78	62		0.03												
2015	05	27	85	65		T												
2015	05	28	77	64		0.24												
2015	05	29	73	63		1.13												
2015	05	30	66	59		0.00												
2015	05	31	68	58		0.06												
		Summary	75	57		10.41		0.0										

Empty, or blank, cells indicate that a data observation was not reported.

*Ground Cover: 1=Grass; 2=Fallow; 3=Bare Ground; 4=Brome grass; 5=Sod; 6=Straw mulch; 7=Grass muck; 8=Bare muck; 0=Unknown

"s" This data value failed one of NCDC's quality control tests.

"T" values in the Precipitation or Snow category above indicate a "trace" value was recorded.

"A" values in the Precipitation Flag or the Snow Flag column indicate a multiday total, accumulated since last measurement, is being used.

Data value inconsistency may be present due to rounding calculations during the conversion process from SI metric units to standard imperial units.

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Record of Climatological Observations

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Generated on 02/09/2020

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Current Location: Elev: 972 ft. Lat: 37.1522° N Lon: -94.4953° W
Station: **JOPLIN REGIONAL AIRPORT, MO US USW00013987**

Observation Time Temperature: Unknown Observation Time Precipitation: 2400

Year	Month	Day	Temperature (F)			Precipitation					Evaporation		Soil Temperature (F)					
			24 Hrs. Ending at Observation Time		At Observation	24 Hour Amounts Ending at Observation Time				At Obs. Time	24 Hour Wind Movement (mi)	Amount of Evap. (in)	4 in. Depth			8 in. Depth		
			Max.	Min.		Rain, Melted Snow, Etc. (in)	Flag	Snow, Ice Pellets, Hail (in)	Flag	Snow, Ice Pellets, Hail, Ice on Ground (in)			Ground Cover (see *)	Max.	Min.	Ground Cover (see *)	Max.	Min.
2017	01	01	58	26		0.00												
2017	01	02	60	46		0.02												
2017	01	03	51	21		0.00												
2017	01	04	31	12		0.00												
2017	01	05	25	12		0.02												
2017	01	06	18	5		0.00												
2017	01	07	34	4		0.00												
2017	01	08	41	13		0.00												
2017	01	09	53	30		0.00												
2017	01	10	67	42		0.00												
2017	01	11	74	43		0.00												
2017	01	12	48	26		0.00												
2017	01	13	32	28		0.64												
2017	01	14	32	29		0.79												
2017	01	15	47	32		0.74												
2017	01	16	63	41		0.26												
2017	01	17	41	37		0.00												
2017	01	18	54	34		T												
2017	01	19	55	45		0.00												
2017	01	20	66	49		T												
2017	01	21	62	37		0.31												
2017	01	22	51	35		0.87												
2017	01	23	52	35		0.00												
2017	01	24	70	39		0.00												
2017	01	25	45	29		0.00												
2017	01	26	36	27		0.00												
2017	01	27	46	24		0.00												
2017	01	28	49	27		0.00												
2017	01	29	53	31		0.00												
2017	01	30	65	28		0.00												
2017	01	31	61	29		0.00												
Summary			50	30		3.65		0.0										

Empty, or blank, cells indicate that a data observation was not reported.

*Ground Cover: 1=Grass; 2=Fallow; 3=Bare Ground; 4=Brome grass; 5=Sod; 6=Straw mulch; 7=Grass muck; 8=Bare muck; 0=Unknown

"s" This data value failed one of NCDC's quality control tests.

"T" values in the Precipitation or Snow category above indicate a "trace" value was recorded.

"A" values in the Precipitation Flag or the Snow Flag column indicate a multiday total, accumulated since last measurement, is being used.

Data value inconsistency may be present due to rounding calculations during the conversion process from SI metric units to standard imperial units.

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Record of Climatological Observations

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Generated on 02/09/2020

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Current Location: Elev: 972 ft. Lat: 37.1522° N Lon: -94.4953° W
Station: **JOPLIN REGIONAL AIRPORT, MO US USW00013987**

Observation Time Temperature: Unknown Observation Time Precipitation: 2400

Year	Month	Day	Temperature (F)			Precipitation					Evaporation		Soil Temperature (F)					
			24 Hrs. Ending at Observation Time		At Observation	24 Hour Amounts Ending at Observation Time				At Obs. Time	24 Hour Wind Movement (mi)	Amount of Evap. (in)	4 in. Depth			8 in. Depth		
			Max.	Min.		Rain, Melted Snow, Etc. (in)	Flag	Snow, Ice Pellets, Hail (in)	Flag	Snow, Ice Pellets, Hail, Ice on Ground (in)			Ground Cover (see *)	Max.	Min.	Ground Cover (see *)	Max.	Min.
2017	02	01	55	36		0.00												
2017	02	02	36	25		0.00												
2017	02	03	36	20		0.00												
2017	02	04	45	24		0.00												
2017	02	05	62	31		0.00												
2017	02	06	74	46		T												
2017	02	07	68	41		0.00												
2017	02	08	41	21		0.00												
2017	02	09	47	19		0.00												
2017	02	10	71	42		0.00												
2017	02	11	82	54		0.00												
2017	02	12	58	36		0.00												
2017	02	13	58	37		0.11												
2017	02	14	48	40		0.02												
2017	02	15	52	30		0.00												
2017	02	16	65	35		0.00												
2017	02	17	71	46		0.00												
2017	02	18	66	46		0.00												
2017	02	19	78	42		0.00												
2017	02	20	67	56		0.13												
2017	02	21	71	47		0.00												
2017	02	22	78	49		0.00												
2017	02	23	83	54		0.00												
2017	02	24	72	29		0.00												
2017	02	25	45	21		0.00												
2017	02	26	44	31		0.08												
2017	02	27	69	31		0.00												
2017	02	28	76	60		0.00												
Summary			61	37		0.34		0.0										

Empty, or blank, cells indicate that a data observation was not reported.

*Ground Cover: 1=Grass; 2=Fallow; 3=Bare Ground; 4=Brome grass; 5=Sod; 6=Straw mulch; 7=Grass muck; 8=Bare muck; 0=Unknown

"s" This data value failed one of NCDC's quality control tests.

"T" values in the Precipitation or Snow category above indicate a "trace" value was recorded.

"A" values in the Precipitation Flag or the Snow Flag column indicate a multiday total, accumulated since last measurement, is being used.

Data value inconsistency may be present due to rounding calculations during the conversion process from SI metric units to standard imperial units.

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Current Location: Elev: 972 ft. Lat: 37.1522° N Lon: -94.4953° W
Station: **JOPLIN REGIONAL AIRPORT, MO US USW00013987**

Record of Climatological Observations

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Generated on 02/09/2020

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Observation Time Temperature: Unknown Observation Time Precipitation: 2400

Year	Month	Day	Temperature (F)			Precipitation					Evaporation		Soil Temperature (F)					
			24 Hrs. Ending at Observation Time		At Observation	24 Hour Amounts Ending at Observation Time				At Obs. Time	24 Hour Wind Movement (mi)	Amount of Evap. (in)	4 in. Depth			8 in. Depth		
			Max.	Min.		Rain, Melted Snow, Etc. (in)	Flag	Snow, Ice Pellets, Hail (in)	Flag	Snow, Ice Pellets, Hail, Ice on Ground (in)			Ground Cover (see *)	Max.	Min.	Ground Cover (see *)	Max.	Min.
2017	03	01	62	33		0.01												
2017	03	02	60	26		0.00												
2017	03	03	65	30		0.00												
2017	03	04	69	49		0.00												
2017	03	05	60	53		0.00												
2017	03	06	76	45		0.40												
2017	03	07	61	36		0.00												
2017	03	08	71	34		0.00												
2017	03	09	81	47		0.67												
2017	03	10	51	34		0.00												
2017	03	11	43	30		0.01												
2017	03	12	49	30		0.15												
2017	03	13	42	29		0.01												
2017	03	14	33	24		T												
2017	03	15	42	21		0.00												
2017	03	16	68	37		0.00												
2017	03	17	75	54		0.00												
2017	03	18	69	45		0.00												
2017	03	19	85	56		0.00												
2017	03	20	85	66		0.00												
2017	03	21	68	54		0.00												
2017	03	22	57	47		0.00												
2017	03	23	79	51		0.00												
2017	03	24	71	56		0.29												
2017	03	25	59	47		0.11												
2017	03	26	68	43		0.15												
2017	03	27	61	51		0.42												
2017	03	28	68	50		0.01												
2017	03	29	77	51		0.28												
2017	03	30	51	46		0.19												
2017	03	31	58	45		0.00												
Summary			63	43		2.70		0.0										

Empty, or blank, cells indicate that a data observation was not reported.

*Ground Cover: 1=Grass; 2=Fallow; 3=Bare Ground; 4=Brome grass; 5=Sod; 6=Straw mulch; 7=Grass muck; 8=Bare muck; 0=Unknown

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U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Current Location: Elev: 972 ft. Lat: 37.1522° N Lon: -94.4953° W
Station: **JOPLIN REGIONAL AIRPORT, MO US USW00013987**

Record of Climatological Observations

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151 Patton Avenue
Asheville, North Carolina 28801

Observation Time Temperature: Unknown Observation Time Precipitation: 2400

Year	Month	Day	Temperature (F)			Precipitation					Evaporation		Soil Temperature (F)					
			24 Hrs. Ending at Observation Time		At Observation	24 Hour Amounts Ending at Observation Time				At Obs. Time	24 Hour Wind Movement (mi)	Amount of Evap. (in)	4 in. Depth			8 in. Depth		
			Max.	Min.		Rain, Melted Snow, Etc. (in)	Flag	Snow, Ice Pellets, Hail (in)	Flag	Snow, Ice Pellets, Hail, Ice on Ground (in)			Ground Cover (see *)	Max.	Min.	Ground Cover (see *)	Max.	Min.
2017	04	01	67	46		0.00												
2017	04	02	70	53		0.49												
2017	04	03	68	49		0.11												
2017	04	04	68	51		0.81												
2017	04	05	56	43		0.04												
2017	04	06	62	38		0.00												
2017	04	07	68	31		0.00												
2017	04	08	81	53		0.00												
2017	04	09	79	64		0.00												
2017	04	10	72	47		0.00												
2017	04	11	67	38		0.00												
2017	04	12	79	49		0.00												
2017	04	13	82	58		0.00												
2017	04	14	82	64		0.02												
2017	04	15	82	64		0.00												
2017	04	16	74	59		1.03												
2017	04	17	72	59		0.04												
2017	04	18	80	56		0.00												
2017	04	19	80	63		0.00												
2017	04	20	71	60		0.32												
2017	04	21	60	48		2.05												
2017	04	22	51	44		0.10												
2017	04	23	68	38		0.00												
2017	04	24	77	38		0.00												
2017	04	25	81	55		0.56												
2017	04	26	61	44		0.58												
2017	04	27	66	37		0.01												
2017	04	28	71	57		0.24												
2017	04	29	63	53		4.52												
2017	04	30	65	45		0.32												
Summary			71	50		11.24		0.0										

Empty, or blank, cells indicate that a data observation was not reported.

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U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Current Location: Elev: 972 ft. Lat: 37.1522° N Lon: -94.4953° W
Station: **JOPLIN REGIONAL AIRPORT, MO US USW00013987**

Record of Climatological Observations

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Generated on 02/09/2020

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Observation Time Temperature: Unknown Observation Time Precipitation: 2400

Year	Month	Day	Temperature (F)			Precipitation					Evaporation		Soil Temperature (F)					
			24 Hrs. Ending at Observation Time		At Observation	24 Hour Amounts Ending at Observation Time				At Obs. Time	24 Hour Wind Movement (mi)	Amount of Evap. (in)	4 in. Depth			8 in. Depth		
			Max.	Min.		Rain, Melted Snow, Etc. (in)	Flag	Snow, Ice Pellets, Hail (in)	Flag	Snow, Ice Pellets, Hail, Ice on Ground (in)			Ground Cover (see *)	Max.	Min.	Ground Cover (see *)	Max.	Min.
2017	05	01	66	42		0.01												
2017	05	02	74	47		0.07												
2017	05	03	56	48		1.77												
2017	05	04	68	41		T												
2017	05	05	72	46		0.00												
2017	05	06	82	51		0.00												
2017	05	07	84	56		0.00												
2017	05	08	83	60		0.00												
2017	05	09	83	59		0.00												
2017	05	10	84	67		0.65												
2017	05	11	75	60		0.96												
2017	05	12	75	56		0.11												
2017	05	13	80	51		0.00												
2017	05	14	81	57		0.00												
2017	05	15	86	62		0.00												
2017	05	16	84	65		0.00												
2017	05	17	83	65		0.02												
2017	05	18	87	64		0.41												
2017	05	19	78	63		1.97												
2017	05	20	71	51		0.62												
2017	05	21	73	47		0.00												
2017	05	22	78	52		0.00												
2017	05	23	71	55		T												
2017	05	24	68	50		0.00												
2017	05	25	81	47		0.00												
2017	05	26	86	65		0.00												
2017	05	27	86	66		0.73												
2017	05	28	81	61		0.00												
2017	05	29	86	60		0.00												
2017	05	30	81	56		0.03												
2017	05	31	84	61		0.65												
Summary			78	56		8.00		0.0										

Empty, or blank, cells indicate that a data observation was not reported.

*Ground Cover: 1=Grass; 2=Fallow; 3=Bare Ground; 4=Brome grass; 5=Sod; 6=Straw mulch; 7=Grass muck; 8=Bare muck; 0=Unknown

"s" This data value failed one of NCDC's quality control tests.

"T" values in the Precipitation or Snow category above indicate a "trace" value was recorded.

"A" values in the Precipitation Flag or the Snow Flag column indicate a multiday total, accumulated since last measurement, is being used.

Data value inconsistency may be present due to rounding calculations during the conversion process from SI metric units to standard imperial units.

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Record of Climatological Observations

These data are quality controlled and may not be identical to the original observations.

Generated on 02/09/2020

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Current Location: Elev: 972 ft. Lat: 37.1522° N Lon: -94.4953° W
Station: **JOPLIN REGIONAL AIRPORT, MO US USW00013987**

Observation Time Temperature: Unknown Observation Time Precipitation: 2400

Year	Month	Day	Temperature (F)			Precipitation					Evaporation		Soil Temperature (F)					
			24 Hrs. Ending at Observation Time		At Observation	24 Hour Amounts Ending at Observation Time				At Obs. Time	24 Hour Wind Movement (mi)	Amount of Evap. (in)	4 in. Depth			8 in. Depth		
			Max.	Min.		Rain, Melted Snow, Etc. (in)	Flag	Snow, Ice Pellets, Hail (in)	Flag	Snow, Ice Pellets, Hail, Ice on Ground (in)			Ground Cover (see *)	Max.	Min.	Ground Cover (see *)	Max.	Min.
2017	06	01	86	59		0.04												
2017	06	02	85	62		0.00												
2017	06	03	86	67		T												
2017	06	04	80	68		0.97												
2017	06	05	89	66		0.00												
2017	06	06	85	58		0.00												
2017	06	07	82	54		0.00												
2017	06	08	83	54		0.00												
2017	06	09	84	59		0.00												
2017	06	10	87	65		0.00												
2017	06	11	87	71		0.00												
2017	06	12	90	71		0.00												
2017	06	13	90	74		0.00												
2017	06	14	90	77		0.00												
2017	06	15	92	67		0.11												
2017	06	16	93	66		0.09												
2017	06	17	87	68		0.90												
2017	06	18	79	61		0.36												
2017	06	19	80	59		0.00												
2017	06	20	90	61		0.00												
2017	06	21	92	66		0.00												
2017	06	22	89	68		0.00												
2017	06	23	85	67		0.54												
2017	06	24	82	59		0.00												
2017	06	25	86	62		0.00												
2017	06	26	86	64		0.49												
2017	06	27	86	62		0.12												
2017	06	28	89	70		0.00												
2017	06	29	89	72		0.00												
2017	06	30	85	68		0.56												
		Summary	86	65		4.18		0.0										

Empty, or blank, cells indicate that a data observation was not reported.

*Ground Cover: 1=Grass; 2=Fallow; 3=Bare Ground; 4=Brome grass; 5=Sod; 6=Straw mulch; 7=Grass muck; 8=Bare muck; 0=Unknown

"s" This data value failed one of NCDC's quality control tests.

"T" values in the Precipitation or Snow category above indicate a "trace" value was recorded.

"A" values in the Precipitation Flag or the Snow Flag column indicate a multiday total, accumulated since last measurement, is being used.

Data value inconsistency may be present due to rounding calculations during the conversion process from SI metric units to standard imperial units.

Appendix B. Definitions of SWMM model input and output parameters

Subcatchment Parameters

There are 24 parameters that are used to model a subcatchment. The subcatchment **Name** is user-defined to identify the different subcatchments in the study area (Table 1). Rain gage data is entered into the model with a subcatchment with the parameter **Rain Gage**. The study area must have an O**utlet** node that receives the predicted runoff from the subcatchment. **Area** defines a subcatchment area units of acres. **Width** is the width of overland flow path on the subcatchment measured in feet. The **% Slope** is the average surface slope for the subcatchment area. The **% Imperv** is the percent of impervious surfaces that have been measured for the modelled subcatchment. The remaining percent is assumed to be a pervious surface. The Manning's roughness coefficient is a coefficient to represent the uniform flow in a channel over material that varies in roughness. A Manning's roughness coefficient may represent the surface resistance for flow in channels and flood plains (USGS, 1989). The **N-Imperv** and **N-Perv** are the assigned Manning's roughness coefficient (n) value for impervious and pervious surfaces in the subcatchment, respectively. **Dstore-Imperv** and **Dstore-Perv** are the measured depth of depression storage in the impervious and pervious surfaces, respectively. This value is measured in inches and represents the storage of runoff within the different surfaces on the subcatchment. **%Zero-Imperv** is the percent of impervious area with no depression storage. This allows for a percentage of impervious surfaces to have a measured depression storage depth. **Subarea Routing** is the assignment of internal routing as an outlet, pervious, or impervious surfaces in the subcatchment. **Percent Routed** is the percentage of subcatchment runoff routed between subareas. **Infiltration Data** assigns an infiltration method and its properties. Groundwater assigns parameters for groundwater flow. **Snow Pack** is the name of the imported snow pack data. **LID Controls** is the assignment of defined LID controls to the subcatchment. **Land Uses** is the assignment of defined land uses in the subcatchment. **Initial Buildup** is the initial pollutant amount on the subcatchment. If a curb exists and is necessary for a pollutant loading model, the length of the curb can be assigned as parameter, **Curb Length**. Three optional parameters, **N-Perv Pattern**, **Dstore Pattern**, and **Infil. Pattern**, adjust for monthly patterns of the Manning's roughness coefficient (n), depression storage, and infiltration rate, respectively (USEPA, 2015b).

Table 1. Subcatchment parameters that are assigned in the model and their SWMM property names

Property	***Model Parameter Name***
Subcatchment name	**Name**
Name of assigned rain gage	**Rain Gage**
Name of node that receives runoff	**Outlet**
Subcatchment area	**Area**
Width of overland flow path	**Width**
Average surface slope	**% Slope**
Percent of impervious area	**% Imperv**
Manning's roughness coefficient (n) value for impervious surface	**N-Imperv**
Manning's roughness coefficient (n) value for pervious surface	**N-Perv**
Depth of depression storage in impervious surface	**Dstore-Imperv**
Depth of depression storage in pervious surface	**Dstore-Perv**
Percent of impervious area with no depression storage	**%Zero-Imperv**
Choice of internal routing between outlet, pervious, and impervious surfaces	**Subarea Routing**
Percent of runoff routed between subareas	**Percent Routed**
Assign infiltration method and properties	**Infiltration Data**
Specify parameters for groundwater flow	**Groundwater**
Name of snow pack parameter set	**Snow Pack**
Specify defined LID controls to subcatchment	**LID Controls**
Specify defined land uses to subcatchment	**Land Uses**
Initial pollutant buildup on subcatchment	**Initial Buildup**
If curb exists, specify length of curb	**Curb Length**
Monthly pattern that adjusts pervious n value, optional	**N-Perv Pattern**
Monthly pattern that adjusts depression storage, optional	**Dstore Pattern**
Monthly pattern that adjusts infiltration rate, optional	**Infil. Pattern**

Junction Parameters

In an urban setting, junctions may be manholes (USEPA, 2015b). The junction **Name** is user-defined to identify the different junctions in the study area (Table 2). External inflows can be specified for a junction in **Inflows**. **Treatment** can define any pollutant removal at the junction. **Invert. El.** is the elevation of the bottom of the junction. **Max. Depth** is the maximum water depth in the junction, from the bottom to ground surface, if it is below ground. The **Initial Depth** is the initial water depth in the junction. **Surcharge Depth** is the excess of maximum depth before flooding occurs. **Ponded Area** is the square footage of ponded water when flooded in the junction.

Table 2. Junction parameters that are assigned in the model and their SWMM property names

Property	***Model Parameter Name***
Junction name	**Name**
Specify external inflows received at the junction	**Inflows**
Specify any pollutant removal at the junction	**Treatment**
Elevation of the junction invert	**Invert. El.**
Maximum water depth from invert to ground surface	**Max. Depth**
Initial water depth in junction	**Initial Depth**
Depth in excess of maximum depth before flooding occurs	**Surcharge Depth**
Area of ponded water when flooded	**Ponded Area**

Conduit Parameters

Conduits may have a closed or open shape such as pipes and channels (USEPA, 2015b). A conduit **Name** is user-defined to identify the different conduits in the model (Table 3). **Inlet Node** and **Outlet Node** are the name of the node on the inlet and outlet ends of the conduit, respectively. A conduit must have both an inlet and an outlet node. The conduit's **Shape** is specified by the cross-section geometry. The **Max. Depth** is the maximum depth of the conduit cross section. Length is the conduit length in feet. **Roughness** is an assigned Manning's roughness coefficient for the conduit. The **Inlet Offset** and **Outlet Offset** are the conduit invert depth above the node invert at the respective inlet and outlet ends of the conduit. The **Initial Flow** is the initial flow into the conduit. If the conduit had a maximum flow, the **Maximum**

Flow parameter would be assigned to the conduit. Coefficients for energy loss at the conduit entry, exit, and along the conduit length are the parameters **Entry Loss Coeff.**, **Exit Loss Coeff**., and **Avg. Loss Coeff**. The rate of seepage loss into the surrounding soil is parameter **Seepage Loss Rate**. If a flap gate existed on the conduit, the **Flap Gate** parameter would be assigned to the conduit. Similarly, if a culvert existed on the conduit, the **Culvert Code** would be assigned.

Table 3. Conduit parameters that are assigned in the model and their SWMM property names

Property	*Model Parameter Name*
Conduit name	**Name**
Name of the node on the inlet end of the conduit	**Inlet Node**
Name of the node on the outlet end of the conduit	**Outlet Node**
Specify the conduit's cross section geometry	**Shape**
Maximum depth of cross section	**Max. Depth**
Length of conduit	**Length**
Manning's roughness coefficient	**Roughness**
Conduit invert depth above node invert at inlet end	**Inlet Offset**
Conduit invert depth above node invert at outlet end	**Outlet Offset**
Initial flow in the conduit	**Initial Flow**
Maximum flow allowed, if applicable	**Maximum Flow**
Coefficient for energy loss at the conduit entry	**Entry Loss Coeff.**
Coefficient for energy loss at the conduit exit	**Exit Loss Coeff.**
Coefficient for energy loss along the conduit length	**Avg. Loss Coeff.**
Rate of seepage loss into surrounding soil in inches per hour	**Seepage Loss Rate**
Specify if a flap gate prevents reverse flow through conduit	**Flap Gate**
If a culvert exists, specify the conduit type code	**Culvert Code**

Outfall Parameters

The model area requires an outfall as the point of measurement for the output values. The outfall **Name** is the user-defined name for different outfalls in the model (Table 4). External inflows can be specified for an outfall in **Inflows**. **Treatment** can define any pollutant removal at the outfall. **Invert. El.** is the elevation of the bottom of the outfall. If an outfall contains a tidal gate that prevents backflow, then the parameter **Tidal Gate** would be assigned to the outfall. **Route To** is assigned if subcatchment outflow is routed onto the outfall. **Type** is the type of outfall boundary condition. For a **Fixed Outfall**, the **Fixed Stage** water level in feet would be assigned to the outfall. For a tidal outfall, the **Curve Name** would be assigned for tidal conditions at the outfall. And for time series outfall, the **Series Name** can be assigned to the outfall with an imported file (USEPA, 2015b).

Table 4. Outfall parameters that are assigned in the model and their SWMM property names

Property	***Model Parameter Name***
Outfall name	**Name**
Specify external inflows received at the outfall	**Inflows**
Specify any pollutant removal at the outfall	**Treatment**
Elevation of the outfall invert	**Invert El.**
Specify if tidal gate exists to prevent backflow at outfall	**Tide Gate**
Specify if subcatchment outflow is routed onto	**Route To**
Type of outfall boundary condition	**Type**
Water elevation at a fixed type of outfall boundary	**Fixed Outfall - Fixed Stage**
Name of tidal curve for a tidal type of outfall boundary	**Tidal Outfall - Curve Name**
Name of time series for a timeseries type of outfall boundary	**Time Series Outfall - Series Name**

Output values

The model may be used to predict output values for runoff quantity such as total precipitation, infiltration loss, and surface runoff. The output values for flow routing include wet weather inflow and external outflow. This is flow in and out of the model area. Output values are generally reported in volume units such as acre-feet and 10^6 gallons or depth in inches. Results are organized into runoff quantity, flow routing, runoff quality, and then summary results (Table 5).

In **Runoff Quantity**, **Total Precipitation** is the total volume and depth of precipitation during the model period. **Infiltration Loss** is the volume and depth of flow that is lost by infiltration in the subcatchment surface. **Surface Runoff** is the volume and depth of flow that runs off the subcatchment surface. **Final Storage** is the remaining volume and depth of flow that is stored in the subcatchment surface.

In flow routing, **Dry Weather Inflow** generally reflects the average flow into the system that is sustained between precipitation events. **Wet Weather Inflow** is the flow into the system during precipitation events. **External Outflow** is the flow that exits the system at an outfall node. In runoff quality,

In **Runoff Quality**, **Initial Buildup** is the existing amount of pollutants over the subcatchment surface. **Surface Buildup** is the amount of pollutants that build up from the subcatchment surface. **Surface Runoff** is the amount of pollutants that run off from the subcatchment surface. **Remaining Buildup** is the remaining amount of pollutants on the subcatchment surface. In summary results, the results are for each subcatchment.

For summary results, **Total Precipitation** is the depth of total precipitation in the model period. **Impervious Runoff** is the flow that runs off the impervious surfaces on the subcatchment. **Pervious Runoff** is the flow that runs off the pervious surfaces on the subcatchment. **Total Runoff** is the total flow that runs off all surfaces on the subcatchment. **Runoff Coefficient** is the calculated coefficient from the runoff. **Subcatchment Washoff** is the amount of pollutants in surface runoff from each subcatchment.

Table 5. Output parameters that are predicted in the SWMM model and their SWMM property names

Category	***Property***	***Model Parameter Name***
Runoff Quantity	Total precipitation in volume and depth	**Total Precipitation**
	Loss of precipitation by infiltration in volume and depth	**Infiltration Loss**
	Flow that runs off a surface	**Surface Runoff**
	Remaining flow that is stored in the surface	**Final Storage**
Flow Routing	Continuous inflow contribution from base flow	**Dry Weather Inflow**

	Inflow contribution from precipitation	**Wet Weather Inflow**
	Flow that leaves the system at the outfall node	**External Outflow**
Runoff Quality	Initial amount of pollutants on surface	**Initial Buildup**
	Amount of pollutants that build up from the surface	**Surface Buildup**
	Amount of pollutants that run off the surface	**Surface Runoff**
	Remaining amount of pollutants on the surface	**Remaining Buildup**
Summary Results (per subcatchment)	Total precipitation in inches	**Total Precipitation**
	Runoff from impervious surfaces in inches	**Impervious Runoff**
	Runoff from pervious surfaces in inches	**Pervious Runoff**
	Total runoff from all surfaces in inches	**Total Runoff**
	Calculated coefficient for runoff	**Runoff Coefficient**
	Amount of pollutants in surface runoff in pounds	**Subcatchment Washoff**

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Elizabeth M. Hagenmaier

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Date

An evaluation of the use of the Storm Water Management Model (SWMM) for predicting Storm Water Runoff of Remediated Areas in Newton County, Missouri of the Tri-State Mining District

Title of Thesis