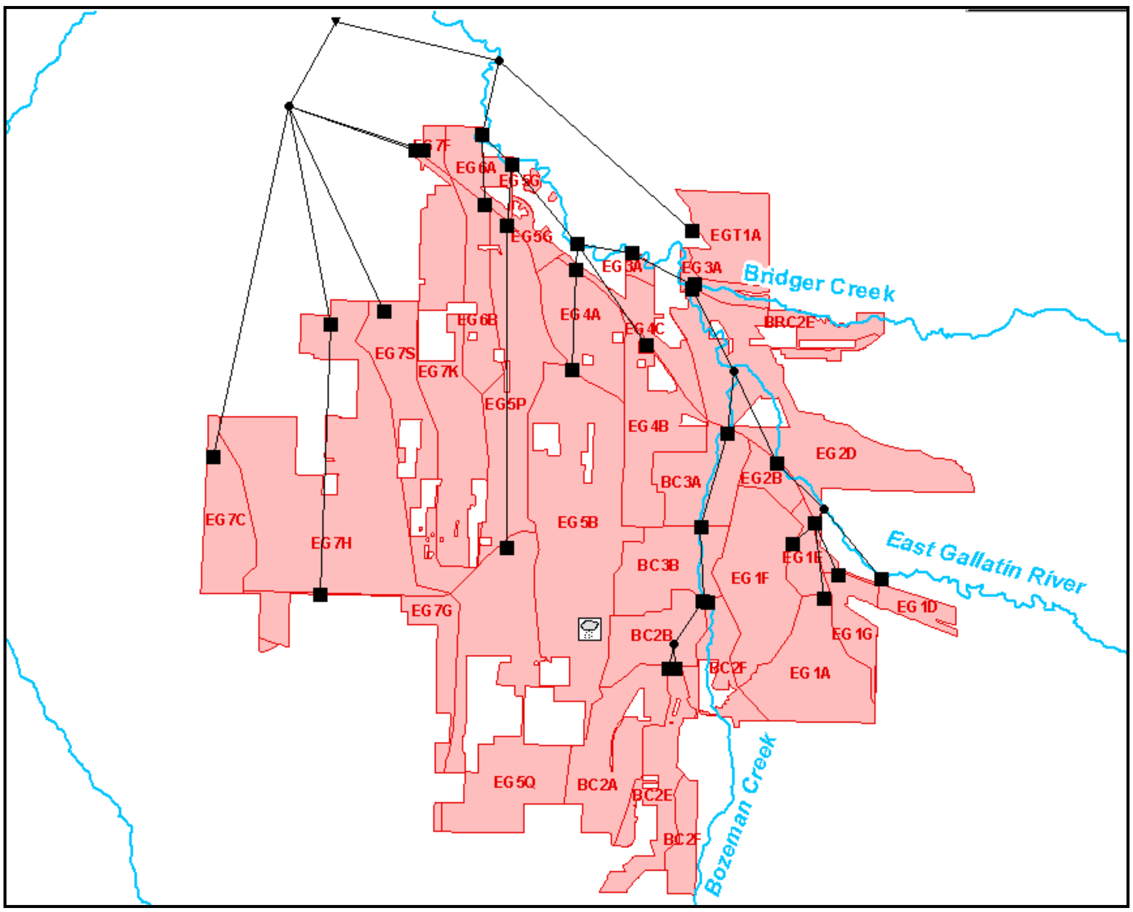
ATTACHMENT D - CITY OF BOZEMAN HYDROLOGIC MODEL REPORT

City of Bozeman Hydrologic Model Report



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BACKGROUND

The city of Bozeman (city) lies in the Bozeman Creek/East Fork Gallatin River drainage. This watershed is currently under TMDL development for sediment, nutrients, and pathogens. Therefore, it is of importance to identify the portion of this pollutant loading coming from urban runoff associated with the city. Additionally, an existing NPDES MS4 permit applies to this area, and developing a pollutant loading model may assist with refining the data in the MS4 permit.

In this study, a hydrologic stormwater model is used to estimate pollutant loadings due to city runoff for sediment and nutrients. This model is set up using a similar structure as a previous Bozeman-area model so as to be able to relate it to previous results. This pollutant loading model represents existing conditions in the project basin, and can be used to determine future loading totals from various future scenarios. This model can also be modified as more detailed information on existing BMPs, subsurface stormwater systems, and flow and water quality data from the stormwater systems becomes available, and can also be integrated with future improvements such as retention ponds, improved BMPs, LID, etc. This model was built using the Environmental Protection Agency's Storm Water Management Model (SWMM) Version 5.0 (Build 5.0.020)(Rossman, 2010).

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LIST OF ACRONYMS

Acronym	Definition
BMP	Best Management Practices
DEM	Digital Elevation Model
DEQ	Department of Environmental Quality (Montana)
EMC	Event Mean Concentration
EPA	Environmental Protection Agency (US)
GBA	Greater Bozeman Area
GIS	Geographic Information System
HDR	HDR, Inc.
JD	Julian Day
LID	Low Impact Development
MS4	Municipal Separate Storm Sewer System
MSU	Montana State University
NED	National Elevation Dataset
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
NSQD	National Storm Water Quality Database
NURP	Nationwide Urban Runoff Program
SCS	Soil Conservation Service (now the NRCS)
SSURGO	Soil Survey Geographic database
SWMM	Storm Water Management Model (EPA)
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
XP-SWMM	Storm Water and Wastewater Management Model (proprietary)

1.0 LOCATION AND SCOPE OF WORK

The city of Bozeman encompasses approximately 12,500 acres (as of September 2010) in Gallatin County, Montana, and is roughly bound by the East Gallatin River to the north and east, Stucky Road to the south, and Cottonwood Road to the west (**Figure 1-1**). Approximate central coordinates for the city are 45.68° north latitude and 111.05° west longitude. It includes multiple sections within township 1S and 2S, range 5E and 6E. Elevations within the city range from approximately 4,600 to 5,400 feet above sea level, referenced to the North American Vertical Datum of 1988 (NAVD88). All elevations in this report are referenced to NAVD88.

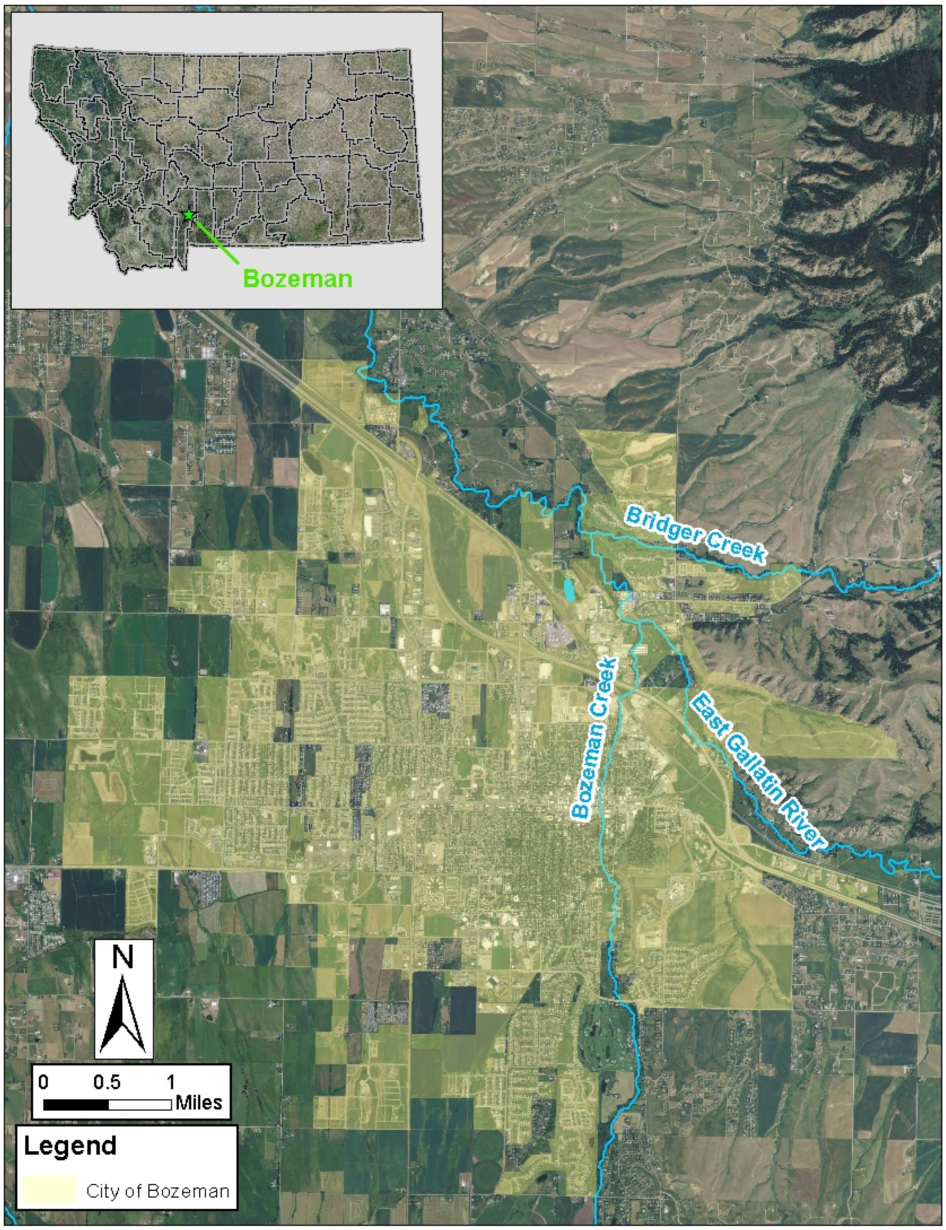


Figure 1-1. Project Location Map

1.1 SCOPE OF WORK

1.1.1 Objectives and Model Selection

The objective of the project is to build a pollutant loading model that represents existing and future conditions in the project basin, and that can be used to determine loading totals from the various catchments within the city. This model should provide a mechanism to model future improvements such as retention, improved BMPs, LID, etc. To meet these objectives, the stormwater modeling for the city performed by the Montana Department of Environmental Quality (DEQ) was done using the United States Environmental Protection Agency's (EPA's) Storm Water and Wastewater Management Model (SWMM) Version 5.0 (Build 5.0.020).

SWMM was chosen for several reasons:

- It can model stormwater runoff quality and quantity as a single event or on a continuous daily basis for multi-year period.
- It is intended primarily for use in urban areas.
- It is simple to use and widely accepted among the environmental community.
- It is produced and maintained by the Environmental Protection Agency and is publicly available.

After SWMM had been discussed as the appropriate software, it was found that the city had already modeled the study area through their consultant HDR, Inc. (HDR). HDR built the Greater Bozeman Area (GBA) stormwater model for the city using Storm Water and Wastewater Management Model (XP-SWMM) in 2008. This facilitated model development as the input structure for XP-SWMM and SWMM is similar. XP-SWMM is a proprietary hydrodynamic flow model that can simulate spatially distributed hydraulic conditions. It can also be linked to a digital elevation model of the ground surface to simulate overland flow. Traditional subsurface flow can be linked to the surface flow, creating a very detailed estimate of observed conditions. Although XP-SWMM could meet the bulleted criteria above, the software is proprietary and costs several thousand dollars to purchase. Also, the level of hydraulic detail achieved by XP-SWMM is higher than needed in this analysis. Therefore, DEQ chose to use the XP-SWMM input data to re-create the model within the SWMM platform. A final objective was to ensure the two models corroborated well, so that input and results from one could be used in the other to reproduce similar results.

Thus, the plan for this modeling effort was to first re-create the GBA model in SWMM, and have the results of that effort match well with the results from the original HDR/XP-SWMM version of the GBA model. Once this was achieved, the SWMM GBA model was pared down to the city of Bozeman, and run on a continuous time step for 30 years to estimate pollutant loading for the city only (the MS4 area). This two-phase modeling approach is broken down in **Sections 4** and **5** of this document.

1.1.2 Data Collection and Review

Data was acquired from the city of Bozeman and their consultant, HDR, Inc. Data received from the city includes a hard copy of the May 2008 *Bozeman Storm Water Facilities Plan* (with appendices)(HDR Engineering, Inc.,2008), a compact disc containing the basic inputs and outputs tables of the XP-SWMM model in spreadsheet format, and access to GIS data such as land use, zoning, and catchment delineations used in the XP-SWMM model. HDR provided some assistance in interpreting several of the XP-SWMM files.

1.1.3 Assumptions and Limitations

There were several assumptions and limitations associated with this modeling effort. SWMM uses a number of initial condition parameters. It was assumed that default values were adequate for this simulation. Since the main focus of this effort was a continuous runoff model that ran for approximately 30 years, this assumption should be valid. SWMM also does not simulate instream reactions, and delivers all loads through the routed system in a continuous stirred-tank reactor type method. This assumption should be valid for conveyance features with short travel times (as is the case in a small city setting such as Bozeman).

The data acquisition for this model is limited by the fact that almost all data was obtained from 3rd parties. The vast majority of the input data was obtained from the original HDR model. The assumption is that this data was correct. No surveys, ground-truthing, etc. was done to verify this data. There were several inconsistencies and/or data gaps within the reported HDR model data (explained further in the precipitation and infiltration sections), and when these were encountered, best professional judgment was used to determine the appropriate solution.

As is mentioned throughout this document, this model is severely limited by the lack of a mapped stormwater system, flow or water quality data, data on existing BMPs within the watershed, and/or ground-truthed watershed delineations. Without this data, it was unfeasible to calibrate this model in any meaningful way. While this limitation may change in the future as data becomes available and is added to the model, at this time the model should be used as a tool for determining relative load reductions between scenarios only. It should not be used for, or considered, a TMDL-level load allocation model.

2.0 Site Characterization

The site characterization will focus principally on the city of Bozeman, since the GBA has already been characterized by HDR and it was only used in this project to re-create the original model in SWMM.

2.1 Project Boundaries

The GBA stormwater model encompasses almost 50,000 acres within and around the city of Bozeman. The city of Bozeman stormwater model includes only the area within the Bozeman city limits (approximately 12,500 acres), as defined by the city GIS layer titled “Bozeman_City_Limits” available on their website (http://www.bozeman.net/Departments-(1)/Information-Technology/GIS) as of August 2010 (**Figure 2-1**). Throughout this report, these two models will be referred to as the GBA model and the City model.

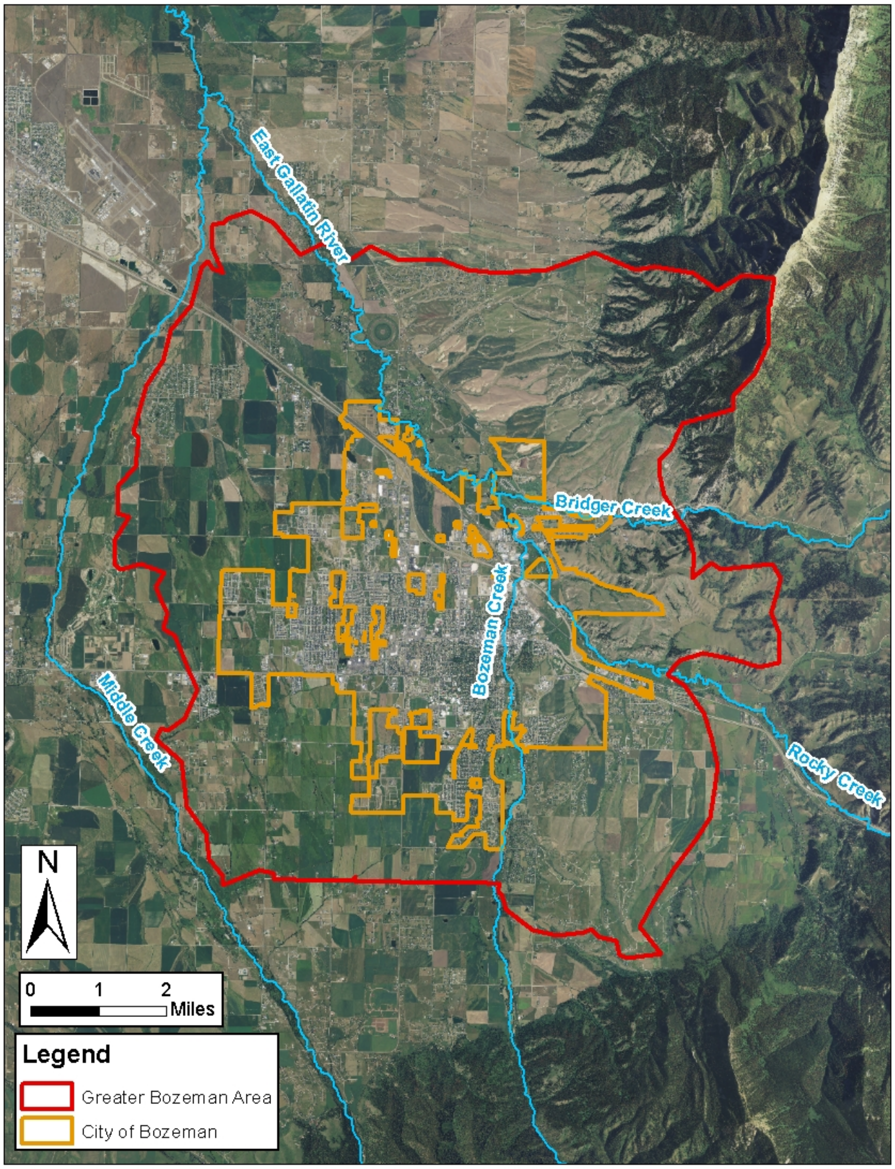


Figure 2-1. Greater Bozeman Area Location Map

2.2 Land Use

Land use data used in the GBA model was taken from the city's 2004 land use GIS data. However, this land use data only covers the area within the city limits, and it is unclear how land uses for areas outside the city (but inside the GBA) were determined. Regardless, the input data lists the land use, areas, and percent impervious area for each sub-catchment, and so the necessary data to re-create the model was available - even if it is unclear where it came from originally. For the City model, 2009 land use GIS data was used. The majority of the land use within the city is vacant (land that is currently unoccupied; no buildings) and right-of-way (roads and right-of-ways) (**Table 2-1**). Land uses were used in the City model to estimate the percent impervious area associated with each sub-catchment, a necessary modeling parameter.

Table 2-1. 2009 Land Use Within the City of Bozeman

Land Use	Area (acres)	Area (%)
Vacant	3,591.6	28.8%
Right of Way	2,269.1	18.2%
Public Facility/Park	1,657.6	13.3%
Single Home Residential	1,528.1	12.3%
School/Educational Facility	793.7	6.4%
Multiple Home Residential	512.8	4.1%
Commercial/Retail	442.7	3.6%
Mixed Use	252.4	2.0%
Duplex/Triplex Home Residential	235.4	1.9%
Admin/Professional	222.5	1.8%
Light Manufacturing	215.9	1.7%
Unknown	189.3	1.5%
Golf Course	178.6	1.4%
Commercial/Auto	112.4	0.9%
MHMP	104.9	0.8%
Hotel/Motel	68.2	0.5%
Church	52.2	0.4%
Restaurant/Bar	40.7	0.3%
Totals:	***12,468.0***	***100.0%***

2.3 TOPOGRAPHY AND DRAINAGE

The project area is moderately sloped from southeast to northwest, with surface elevations in the city ranging from approximately 4,600 ft. to 5,400 ft. (surface elevations within the GBA range from approximately 4,500 ft. to 8,700 ft.). The area drains generally to the north and west, towards the East Gallatin River (**Figure 2-2**). A digital elevation model with 10 meter resolution, obtained from the USGS National Elevation Dataset (NED), was used in the modeling process.

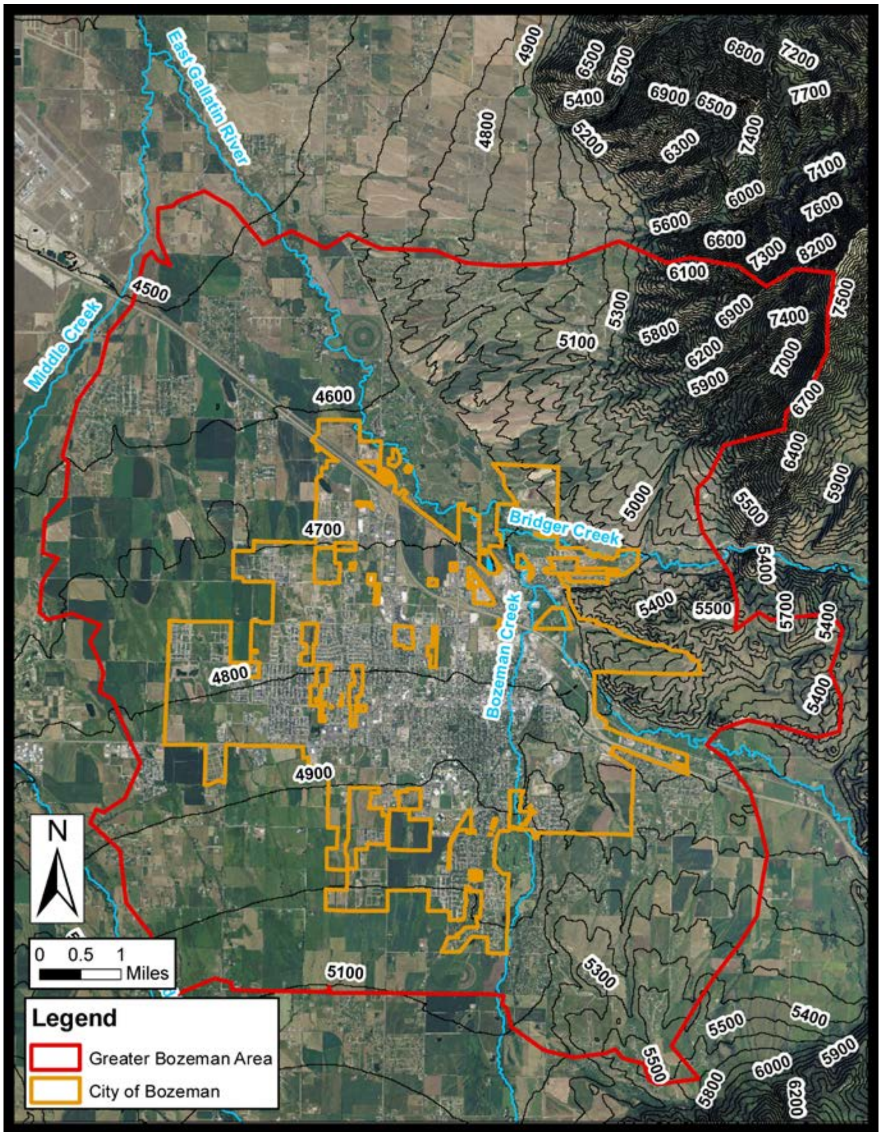


Figure 2-2. Drainage and Topography Map (elevation in feet)

2.4 SOILS AND INFILTRATION

Soil types for the project area were obtained from the State Soil Geographic (STATSGO) database. The project area consists of four soil types – MT587, MT535, MT544, and MT658. These soils typically consist of silts with 20-25% clay content and can be found on a multitude of slopes. Each of these soil types has a hydrologic soil group of either B or C (**Figure 2-3**).

Hydrologic soil types are used for determining infiltration rates in the model, as well as depths to groundwater for design purposes. Soils can be classified into one of four USDA Natural Resources Conservation Service (NRCS) hydrologic soil groups depending on their runoff potential (U.S. Department of Agriculture, NRCS, 1986). The four hydrologic soil groups are A through D, where Group A has the lowest runoff potential, and Group D has the highest runoff potential. A brief description of each is presented below:

Group A Soils having low runoff potential and high infiltration rates even when thoroughly saturated. They consist primarily of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

Group B Soils having moderate infiltration rates when thoroughly saturated and consist primarily of moderately deep-to-deep, moderately well-to-well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C Soils having low infiltration rates when thoroughly saturated and consist primarily of soils with a layer that impedes downward movement of water and soils with moderately fine-to-fine texture. These soils have a low rate of water transmission.

Group D Soils having high runoff potential. These soils have low infiltration rates when thoroughly saturated and consist primarily of clay soils with high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material. These soils have a very low rate of water transmission.

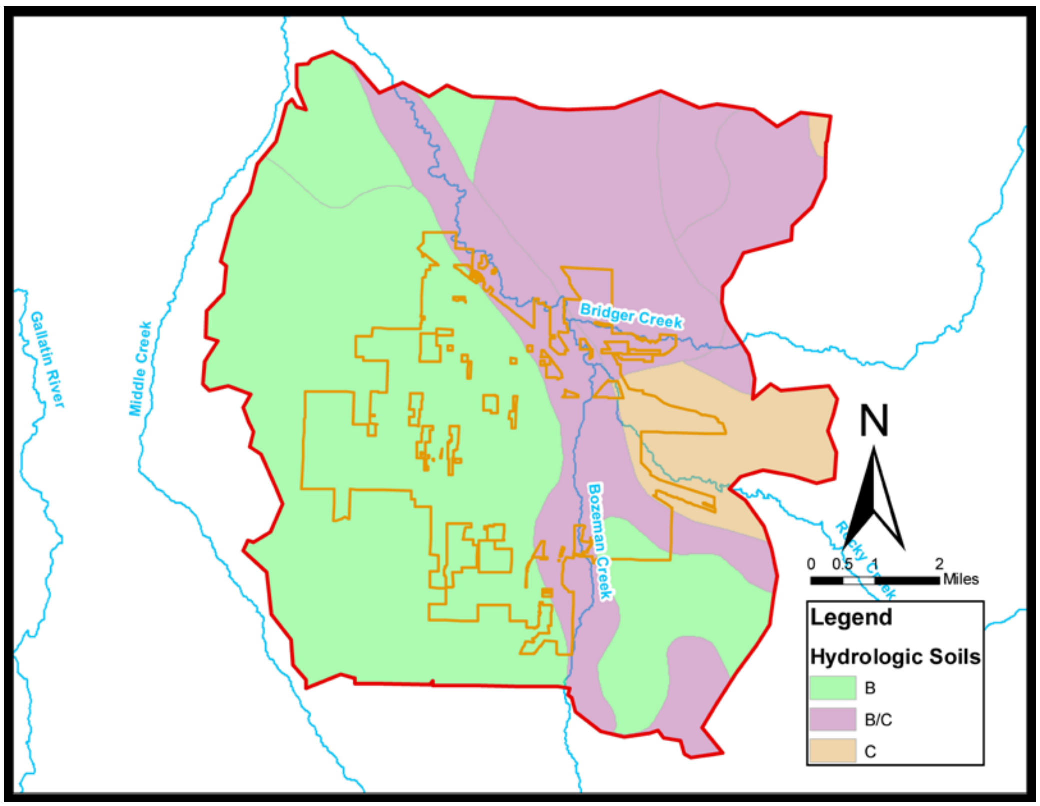


Figure 2-3. Soils Map

2.5 Hydrologic and Hydraulic Features

The major hydrologic and hydraulic features in the project area consist of a stormwater infrastructure network, multiple irrigation ditches, Bozeman Creek, Bridger Creek, and the East Gallatin River. Since the objectives of this project do not include detailed hydraulic analysis, the stormwater network of pipes and outlets was not modeled in detail, but rather on a sub-catchment basis only. There are no significant hydraulic storage features (ponds, lakes, etc.) within the basin.

3.0 GREATER BOZEMAN AREA: HYDROLOGIC ANALYSIS

The goal of the DEQ GBA model was to re-create the original HDR model (modeled in XP-SWMM) in SWMM. There were actually several model runs to re-create, as HDR ran several 24-hour storm events for their analysis. The goal was to match the hydrology as closely as possible for all scenarios, based on the limited amount of calibration data available.

Because SWMM and XPSWMM are similar, the input data was largely compatible between the two models. Compatible data included:

- geographic (x and y coordinates for each junction in the model);
- catchment (size, width, impervious percent, and slope);
- junction (invert elevations, ground elevations, and maximum depths);
- link (u/s and d/s elevations, slopes, conduit shapes, conduit lengths, Manning's roughness values, channel bottom widths/pipe diameters).

There were some parameters that had to be estimated (those that were not provided in the original HDR input data). These included parameters which are fairly standard, such as pervious and impervious manning's values for catchment areas, depressional area storage, etc. These values were input as standard values, and a later sensitivity analysis showed that the model was not sensitive to these parameters.

The infiltration values are more important. The infiltration used in the original HDR model is not stated, so DEQ had to use best professional judgment to determine infiltration rates and methods. Ultimately, the Horton's infiltration model was used, both because it separates out impervious area separate from the pervious infiltration areas (like HDR did), and it also tends to deal better with long term rainfall events (which is part of the goal of step 2). This is further described in **Section 4.4**.

See **Appendix A** for a list of all SWMM input data associated with the Greater Bozeman Area model.

3.1 RAINFALL

The rainfall events used by HDR for this study were the 2-yr 24-hr, 10-yr 24-hr, 25-yr 24-hr, and 100-yr 24-hr rainfall events as determined by HDR (**Table 3-1**). According to HDR, these are based on USGS Report 98-4100, *Characteristics of Extreme Storms in Montana and Methods for Constructing Synthetic Storm Hyetographs (Parrett, 1998)*, an assumed annual rainfall of 18.0 inches in Bozeman, MT, and the geographic position of Bozeman (45.68^{o} N, 111.05^{o} W). In the HDR modeling report, there is an inconsistency in the total rainfall reporting. Tables 2.2-2 and 2.4-1 from the *Bozeman Storm Water Facilities Plan* both give rainfall totals used in the model, but report different numbers (the difference is about 5-10%). The more conservative of these values (values from Table 2.4-1, also listed below in **Table 3-1**) were used in this modeling analysis.

The type of rainfall distribution used for the rainfall events in the model was determined by HDR from the USGS Report 98-4100. This report details how to determine region-specific design storm hyetographs. Two "unit" hyetographs for the 24-hr storm were used in the HDR model (Figures 2.2-2 and Figure 2.2-3 from the *Bozeman Storm Water Facilities Plan* report (HDR Engineering, Inc.,2008)). However, the two are not identical (temporally or spatially), and neither one sums to one (which is the definition of a "unit" hyetograph). Since there was no additional information in this report discussing the rainfall events used, these two graphs were both normalized to one inch of rainfall, and then an average of the two was taken and used in this analysis (**Figure 3-1**). This storm hyetograph is unlike the traditional SCS unit hyetograph. It has two smaller peaks, the large one very early in the storm event and a smaller one much later when the ground is theoretically saturated, as compared to the more traditional SCS hyetograph which has an intense peak in the middle of the storm event.

Table 3-1. Project Rain Events

Frequency (years)	Duration (hours)	Total Rainfall (inches)
2	24	1.18
10	24	1.96
25	24	2.10
100	24	2.81

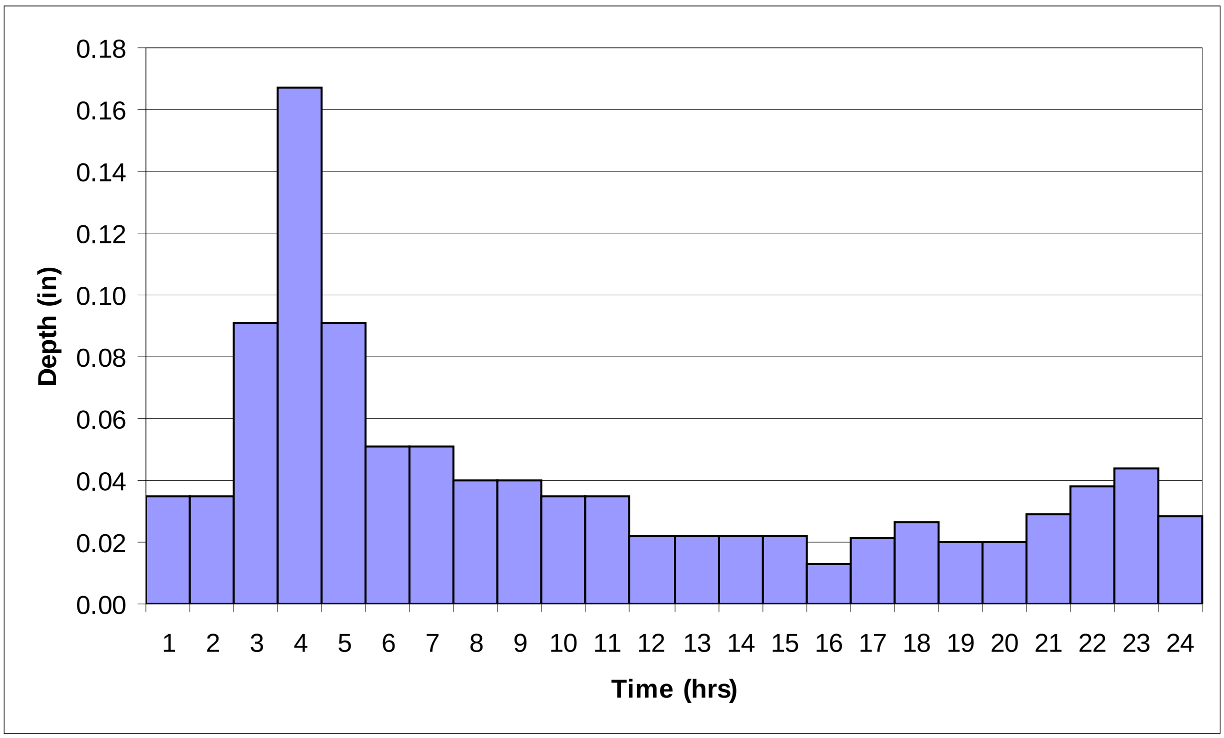


Figure 3-1. 24-hr Rain Hyetograph, Cumulative Depth = 1 inch.

3.2 Basin Area and Sub-catchments

The project basin was created by HDR using ArcHydro with a 5-foot contour topographic map from the city. This process resulted in 60 catchments within the GBA watershed. The desire was to maintain the same watersheds for continuity purposes; however, since the elevation data currently available is much more refined (10 meter DEM from the USGS National Elevation Dataset), the watershed delineation was redone using ArcSWAT, which uses a similar delineation process to ArcHydro. The updated delineation based on the 10-meter DEM was fairly similar to the original HDR delineation (**Figure 3-2**). The figure shows the three sub-catchments within the watershed (East Gallatin River, Bozeman Creek, and Bridger Creek) for both delineations. All three updated sub-catchments overlap significantly with the originals.

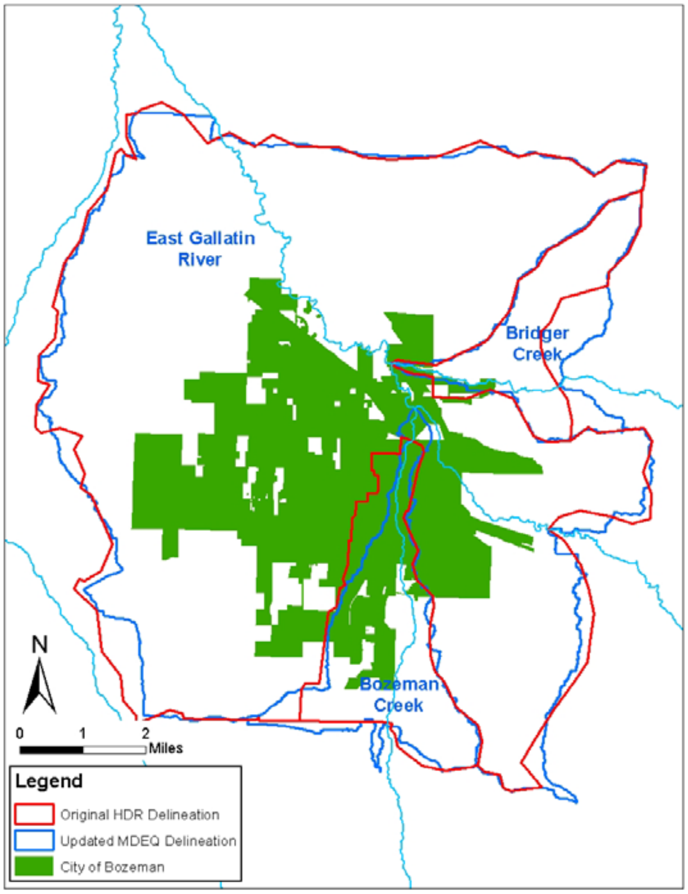


Figure 3-2. Comparison of Original HDR Delineation with Updated DEQ Delineation.

The original HDR basin is 49,063 acres and is broken up into 42 catchments (one of these catchments was later broken into several further sub-catchments). The catchments range in size from approximately 30 acres to over 6,000 acres (**Table 3-2**). DEQ forced the ArcSWAT program to divide the basin into approximately 42 catchments as well. When compared to the original delineations, these basins were found to be fairly similar in shape and location (**Figure 3-3**). Therefore, based on the similarity between the two delineations, the possibility that HDR had additional information (stormwater network information, irrigation ditches not in the DEM, etc.), and to preserve continuity between the two models, the original HDR basins were kept for further modeling efforts.

Table 3-2. Greater Bozeman Area Catchments

Basin Name	Area (acres)	Basin Name	Area (acres)	Basin Name	Area (acres)
BC1A	1,157.1	EG1G	175.6	EG5Q	1,811.4
BC2A	663.9	EG2A	1,525.6	EG6A	6,130.4
BC2B	230.7	EG2B	98.8	EG6B	266.8
BC2C	201.3	EG2C	703.9	EG7B	2,404.3
BC2E	667.4	EG2D	1,791.4	EG7C	4,261.1
BC2F	815.0	EG2E	513.9	EG7F	1,245.5
BC3A	306.8	EG3A	186.3	EG7G	2,372.7
BC3B	368.0	EG4A	358.2	EG7H	4,147.8
EG1A	484.7	EG4B	455.2	EG7K	973.3
EG1B	1,524.3	EG4C	273.4	EG7L	895.5

Table 3-2. Greater Bozeman Area Catchments

Basin Name	Area (acres)	Basin Name	Area (acres)	Basin Name	Area (acres)
EG1C	426.8	EG5B	1,352.2	EG7S	904.1
EG1D	4,399.5	EG5E	47.2	EGT1A	1,667.9
EG1E	111.4	EG5G	389.0	EGT1B	30.4
EG1F	537.3	EG5P	684.6	EGT2A	1,473.4
Total					49,034

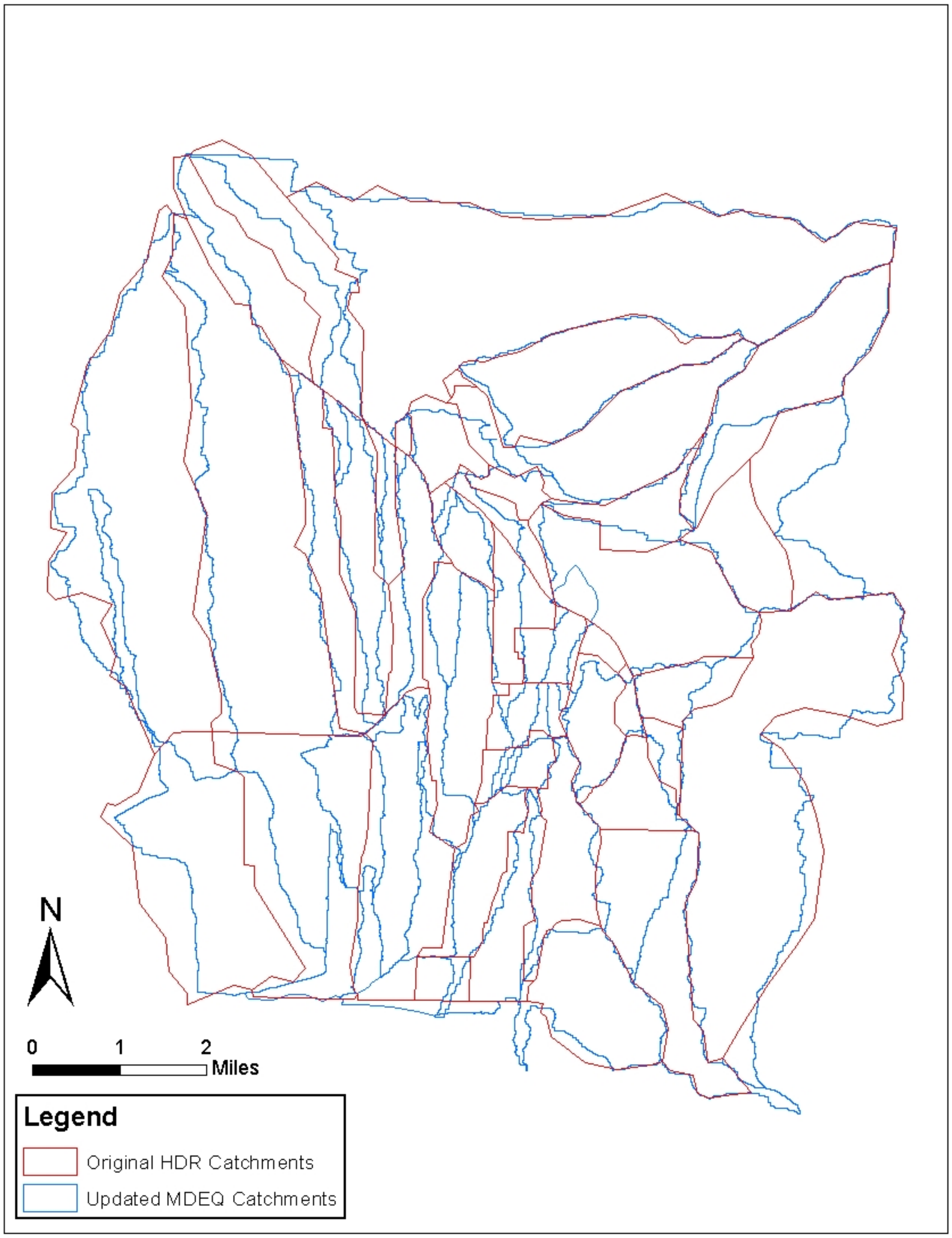


Figure 3-3. Comparison of Original HDR Catchments with Updated DEQ Catchments

3.3 PERCENT IMPERVIOUS AREA

HDR used land use as the major determination for percent impervious area within a catchment. To calculate percent impervious area by land use, HDR used 2004/5 land use data and assumed impervious percentages for each land use (**Table 3-3**; same as Table B.2-1 from the *Bozeman Storm Water Facilities Plan (HDR Engineering, Inc.,2008)*). Since the city land use data only covers the area within the city, it is not clear how HDR estimated percent impervious area for those areas outside the city. The report does not explain this.

Table 3-3. Percent Impervious Area Estimates

Description	LU CODE	% Impervious
Administrative/Professional	AP	90%
Commercial/Retail	C	70%
Commercial/Auto	CA	90%
Church	CHURCH	70%
Duplex/Triplex Household Residence	DTHR	50%
Golf Course	GOLF	5%
Hotel/Motel	HM	70%
Light Manufacturing	LM	70%
Mobile Home/Mobile Park	MHMP	45%
Multi-Family Household Residence	MHR	35%
Mixed Use	MIXED	65%
Public Facility/Park	PFP	10%
Restaurant/Bar	RB	70%
Rights-of-Way	ROW	100%
School/Educational Facility	SEF	65%
Single-Family Household Residence	SHR	45%
Vacant	VACANT	5%

Table taken from *Bozeman Storm Water Facilities Plan,* 2008 (HDR Engineering, Inc.,2008)

These values were used to re-create the original HDR model in EPA Storm Water Management Model (SWMM), although the values were tweaked for the second phase of the project (see **Section 4.5**).

3.4 HORTON INFILTRATION RATES

As mentioned above, the infiltration method used in the original HDR model is not stated. The input data lists an "infiltration reference" which identifies basins as sand, loam, clay, or mixes of these constituents. The *Bozeman Storm Water Facilities Plan* states that soil infiltration rates were developed from the SSURGO soil dataset, but there is no mention of either the infiltration rates used or the infiltration methodology used in the model. Therefore, for the DEQ modeling effort, an infiltration method was chosen based on available information. Horton's infiltration model was chosen, both because it separates out impervious area separately from the pervious infiltration areas (similar to what HDR did), and it also tends to deal better with long term rainfall events (which is part of the goal of step 2).

Horton's model is empirical and is a well known infiltration equation. It gives infiltration capacity as a function of time, with initial high rates of infiltration followed by an exponential decay rate during extended storms (**Figure 3-4**). Horton's equation is:

$$F_p(t) = F_c + (F_0 - F_c)e^{-kt}$$

Where (units are **L**ength, **T**ime):
F_p = overall infiltration rate as a function of time (L/T)
F_c = Minimum (final) infiltration rate (L/T)
F_0 = Maximum (initial) infiltration rate (L/T)
t = Time since beginning of storm (T)
k = Decay coefficient (T^{-1})

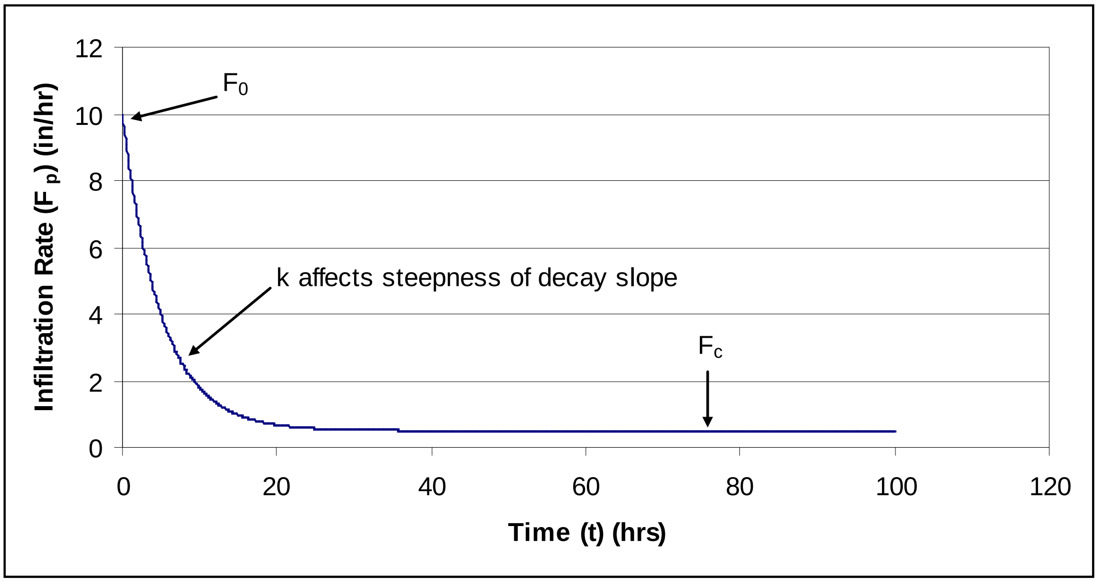


Figure 3-4. Example of Horton's Infiltration Model

Horton infiltration rates and parameters were estimated using a standard reference book (Mays, 1999), and the SWMM help section. Each soil type was given a set of Horton's parameter values, and then each catchment was prorated based on the soil make-up of the catchment. The soils in this area are hydrologic group 'B' and 'C', which means they have moderate initial infiltration rates. Horton infiltration rate parameter ranges used in the model are shown in **Table 3-4**.

Table 3-4. Horton Infiltration Rate Parameters

Parameter	Range	Unit
Max (Initial) Infiltration Rate	2.2 – 3.0	in/hr
Minimum (Final) Infiltration Rate	0.03 – 0.06	in/hr
Decay Rate of Infiltration	7.0	1/hr

3.5 Model Setup, Calibration, and Stability

3.5.1 Model Setup

The GBA model was set up without the use of any meteorological parameters besides the hyetograph and the rainfall totals for each storm event. Manning's n values and depressional storage values were assigned to pervious and impervious areas according to **Table 3-5**.

Table 3-5. Summary of Manning's n and Depressional Storage Values used in Model

Conveyance Type	Depressional Storage Value (in)	Manning's n Value
Pervious Areas	0.025	0.1
Impervious Areas	0.001	0.014

The outfall for the model is the East Gallatin River downstream of the city.

3.5.2 Model Calibration

Due to the lack of flow meters in the river, creeks, and storm water pipes, and the lack of historic data, calibration of this model was not possible. However, the goal for this modeling scenario was to re-create the results from the HDR model.

3.5.3 Model Stability and Error

All model runs were subjected to a detailed analysis for errors and discrepancies. This analysis included doing a mass balance check in SWMM to verify that there was no systemic net gain or loss of water volume (Total V_{in} – Total V_{out} = ΔV_{system}), and a check of the overall efficiency of the runoff and hydraulic blocks. If necessary, channels, pipes, and other conveyance/storage features were checked to make sure that SWMM did not have to extrapolate water elevations above defined input data. In all model runs, the overall runoff continuity error was less than 0.5 percent, and the overall routing continuity error was less than four percent. Finally, hydrographs were spot checked to insure that there was no major instability in the model. Modeling results can be found in **Appendix A**.

3.6 Model Results

3.6.1 GBA Runoff and Storm Events.

Runoff from the GBA catchments was generated in the runoff block of SWMM. Hydrographs based on the rain events described in **Table 3-1** were generated for each catchment, creating inflow hydrographs for each node.

The results of the DEQ GBA model show that infiltration plays a major role in the hydrology. Runoff percentages ranged from 7% to 93%, depending on the storm event and the sub-catchment (**Table 3-6**).

Table 3-6. Runoff Results

Catchment	2-year, 24-hour Event (1.18")		10-year, 24-hour Event (1.96")		25-year, 24-hour Event (2.10")		100-year, 24-hour Event (2.81")	
	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio
2769	0.87	80.8%	1.53	85.8%	1.66	85.6%	2.30	89.5%
2776	0.39	58.9%	0.77	69.2%	0.83	69.7%	1.20	77.1%
2780	0.79	58.9%	1.53	69.0%	1.66	69.6%	2.49	77.0%
2956	1.58	58.7%	3.04	68.4%	3.31	69.1%	4.91	76.6%
2958	0.86	58.8%	1.69	68.9%	1.81	69.4%	2.67	76.9%
2963	0.64	80.8%	1.14	85.9%	1.20	85.7%	1.69	89.5%
3054	0.62	58.9%	1.20	69.0%	1.29	69.5%	1.93	77.0%
3061	0.91	58.7%	1.75	68.2%	1.90	68.9%	2.82	76.3%
3068	1.37	65.7%	2.55	73.8%	2.76	74.3%	3.99	80.6%
3076	0.71	58.8%	1.38	68.6%	1.47	69.2%	2.18	76.7%
3105	0.69	58.8%	1.32	68.6%	1.44	69.3%	2.15	76.8%

Table 3-6. Runoff Results

Catchment	2-year, 24-hour Event (1.18")		10-year, 24-hour Event (1.96")		25-year, 24-hour Event (2.10")		100-year, 24-hour Event (2.81")	
	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio
3111	0.99	58.8%	1.93	68.9%	2.09	69.5%	3.07	77.0%
3115	1.30	80.7%	2.30	85.5%	2.46	85.4%	3.44	89.4%
3117	1.32	75.7%	2.36	81.6%	2.52	81.6%	3.59	86.4%
3119	1.50	58.7%	2.92	68.4%	3.13	69.1%	4.66	76.6%
3120	1.70	65.6%	3.16	73.5%	3.41	74.0%	4.97	80.3%
3290	1.61	75.6%	2.88	81.5%	3.07	81.6%	4.36	86.4%
3519	1.46	58.7%	2.82	68.3%	3.07	69.0%	4.54	76.5%
3526	0.48	48.8%	0.98	61.0%	1.07	62.0%	1.66	71.1%
BC1A	27.79	24.4%	73.01	38.6%	83.78	41.4%	143.84	53.1%
BC2A	36.98	56.6%	66.69	61.5%	72.76	62.6%	108.39	69.7%
BC2B	13.00	57.3%	26.12	69.3%	28.45	70.5%	41.80	77.4%
BC2C	6.97	35.2%	14.49	44.0%	16.17	45.9%	26.61	56.4%
BC2E	28.99	44.2%	58.28	53.5%	64.63	55.3%	100.05	64.0%
BC2F	33.61	41.9%	75.92	57.0%	84.03	58.9%	129.11	67.7%
BC3A	20.89	69.2%	39.28	78.4%	42.41	79.0%	60.64	84.4%
BC3B	3.03	56.8%	5.83	65.9%	6.35	67.1%	9.45	74.4%
EG1A	26.64	55.9%	51.71	65.3%	56.41	66.5%	84.18	74.2%
EG1B	40.45	27.0%	97.96	39.3%	112.05	42.0%	189.90	53.2%
EG1C	18.28	43.6%	44.53	63.9%	48.76	65.3%	73.90	73.9%
EG1D	85.43	19.7%	276.72	38.5%	318.12	41.3%	545.53	53.0%
EG1E	4.11	37.5%	10.96	60.2%	12.06	61.8%	18.60	71.2%
EG1F	23.43	44.3%	52.08	59.4%	57.45	61.1%	87.59	69.6%
EG1G	10.73	62.1%	21.76	75.9%	23.54	76.6%	33.97	82.6%
EG2A	11.48	7.7%	81.60	32.7%	96.21	36.0%	176.86	49.5%
EG2B	7.25	74.6%	13.60	84.3%	14.61	84.4%	20.56	88.8%
EG2C	17.13	24.7%	58.68	51.0%	65.70	53.4%	105.94	64.3%
EG2D	89.27	50.7%	197.27	67.4%	215.53	68.8%	319.29	76.1%
EG2E	21.19	41.9%	51.96	61.9%	57.14	63.5%	86.76	72.1%
EG3A	6.69	36.5%	15.77	51.9%	17.58	53.9%	27.59	63.3%
EG4A	30.81	87.5%	52.97	90.5%	56.62	90.3%	78.20	93.2%
EG4B	30.47	68.1%	55.55	74.7%	60.15	75.5%	86.36	81.0%
EG4C	12.50	46.5%	27.16	60.8%	29.89	62.4%	45.17	70.6%
EG5B	82.91	62.4%	146.26	66.2%	159.06	67.2%	232.62	73.5%
EG5E	3.36	72.4%	6.11	79.1%	6.54	79.2%	9.36	84.6%
EG5G	16.54	43.2%	37.16	58.5%	41.06	60.3%	62.79	68.9%
EG5P	42.07	62.5%	74.24	66.4%	80.71	67.4%	118.06	73.6%
EG5Q	85.77	48.2%	154.61	52.3%	170.20	53.7%	261.32	61.6%
EG6A	44.02	7.3%	262.82	26.2%	315.24	29.4%	608.50	42.4%
EG6B	18.02	68.7%	31.73	72.8%	34.31	73.5%	49.32	79.0%
EG7B	28.33	12.4%	70.68	18.0%	86.36	20.5%	184.62	32.8%
EG7C	43.30	10.3%	97.16	14.0%	117.91	15.8%	258.16	25.9%
EG7F	10.14	8.3%	33.82	16.6%	41.61	19.1%	88.60	30.4%
EG7G	66.91	28.7%	128.83	33.2%	146.02	35.2%	251.10	45.2%
EG7H	135.54	33.2%	249.04	36.8%	277.89	38.3%	454.99	46.8%
EG7K	50.51	52.8%	90.10	56.7%	98.73	58.0%	148.72	65.3%

Table 3-6. Runoff Results

Catchment	2-year, 24-hour Event (1.18")		10-year, 24-hour Event (1.96")		25-year, 24-hour Event (2.10")		100-year, 24-hour Event (2.81")	
	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio	Runoff (acre-feet)	Runoff Ratio
EG7L	7.35	8.3%	20.13	13.8%	25.32	16.2%	58.59	27.9%
EG7S	45.17	50.8%	80.56	54.6%	88.38	55.9%	133.87	63.2%
EGT1A	47.51	29.0%	137.92	50.6%	154.49	52.9%	246.28	63.1%
EGT1B	0.57	19.2%	2.42	48.6%	2.70	51.0%	4.48	62.9%
EGT2A	30.46	21.0%	110.63	46.0%	125.33	48.6%	206.23	59.8%
Totals	1,385.37	28.7%	3,241.36	40.5%	3652.41	42.6%	6036.48	52.6%

DEQ model results and HDR model results are compared in **Table 3-7**. The HDR results are those seen in Table 2.4-1 of the *Bozeman Storm Water Facilities Plan* (HDR Engineering, Inc.,2008) as 'existing' results (the East Gallatin/Bozeman Creek results from this table have been combined on an area-weighted average below, based on 9% of the total area in the Bozeman Creek watershed, and 91% of the area in the East Gallatin River watershed). Overall, the comparison is quite close. The large difference associated with the two-year storm event is likely explained by the lack of knowledge about the infiltration model used by HDR., or some other unknown in the HDR model (XP-SWMM may route runoff slightly different, for example). However, overall this comparison was considered adequate for the purpose of moving forward.

Beyond comparing results on a watershed basis, not much further comparison can be done. In Appendix C-2 of the *Bozeman Storm Water Facilities Plan (HDR Engineering, Inc.,2008)*, the individual output for each node/sub-catchment is listed. However, this appendix only contains runoff data for 22 of the 61 sub-catchments. Some are entirely omitted, while others are listed but not labeled with catchment info so a comparison cannot be made (see page 12 of 14 of Appendix C-2 of the *Bozeman Storm Water Facilities Plan* (HDR Engineering, Inc.,2008) for an example).

Table 3-7. DEQ and HDR model comparison

Event	Total Precip. (in)	Total Precip. (acre-feet)	DEQ Runoff	HDR Runoff	Difference
2-yr, 24-hr	1.18	4,820	28.8%	20.0%	-8.8%
10-yr, 24-hr	1.96	8,010	40.5%	40.4%	-0.1%
25-yr, 24-hr	2.10	8,580	42.6%	43.3%	0.7%
100-yr, 24-hr	2.81	11,480	52.6%	55.2%	2.6%

3.6.2 Conclusions

Based on the limited comparison with the original HDR model, the DEQ storm water model is roughly equivalent to the original. The DEQ model appears to slightly over predict runoff in urban areas, and slightly under predict runoff in rural areas as compared to the HDR model. However, since several parameters had to be estimated to re-create the original HDR model report, the comparison was considered adequate to move forward.

4.0 City of Bozeman: Hydrologic Analysis

Once the original HDR model of the GBA was re-created in SWMM, the next goal was to create a long term, continuous model of the city of Bozeman to help predict stormwater pollutant loading to the city.

Parameters were kept the same as in the previous model, except for a few updates. Since the original model was built in 2004, the model was updated for 2010. These changes included using an updated 2009 land use, and also re-evaluating the percent impervious areas that were used in the original HDR model (See **Section 4.5**).

The infiltration method used will be Horton's infiltration, which is described in detail in **Section 4.4**. Horton's infiltration model deals with impervious and pervious areas separately, and also handles long term rainfall better than the antecedent moisture condition method used by SCS.

4.1 RAINFALL

The rainfall methodology used in this model was a daily, continuous rainfall file for the period from 1980 through 2009 (30 years). There are several rain gages within a few miles of the project site. However, only one gage was located within the project site and had a multi-decade continuous rainfall record. The rain gage used was the Bozeman - Montana State University gage (Coop ID 241044). This gage has a continuous rainfall record from 1948 through 2010 and is located at 45.67^{o} N, 111.05^{o} W at an elevation of 4,913 feet above sea level. This location places it in the southern portion of the city of Bozeman. The data used in this analysis was from 1/1/1980 through 12/31/2009 – a period of 30 years. This was nearly a complete dataset, with only a few missing data points. There were five missing individual dates (11/18/1981, 11/28/2001, 2/1/2002, 11/2/2004, and 1/7/2006), along with the entire month of September 1995. These data gaps were filled by using a nearby National Weather Service/Federal Aviation Administration rain gage (Bozeman Gallatin Field [Coop ID 240622]) to replace the values for the month and individual days. The data was checked to make sure that actual rain events were transposed, rather than just the exact daily record. Averages and maxima for this period are shown in **Table 4-1**, and a histogram of the rainfall distribution is shown in **Figure 4-1**.

Table 4-1. Project Rainfall Summary

Parameter	Value
Period of Record	1980 - 2009
Average Annual Rainfall (in)	19.59
Maximum Daily Rainfall (in)	2.68
Average Annual "Rainy" Days (>0.01 in)	109

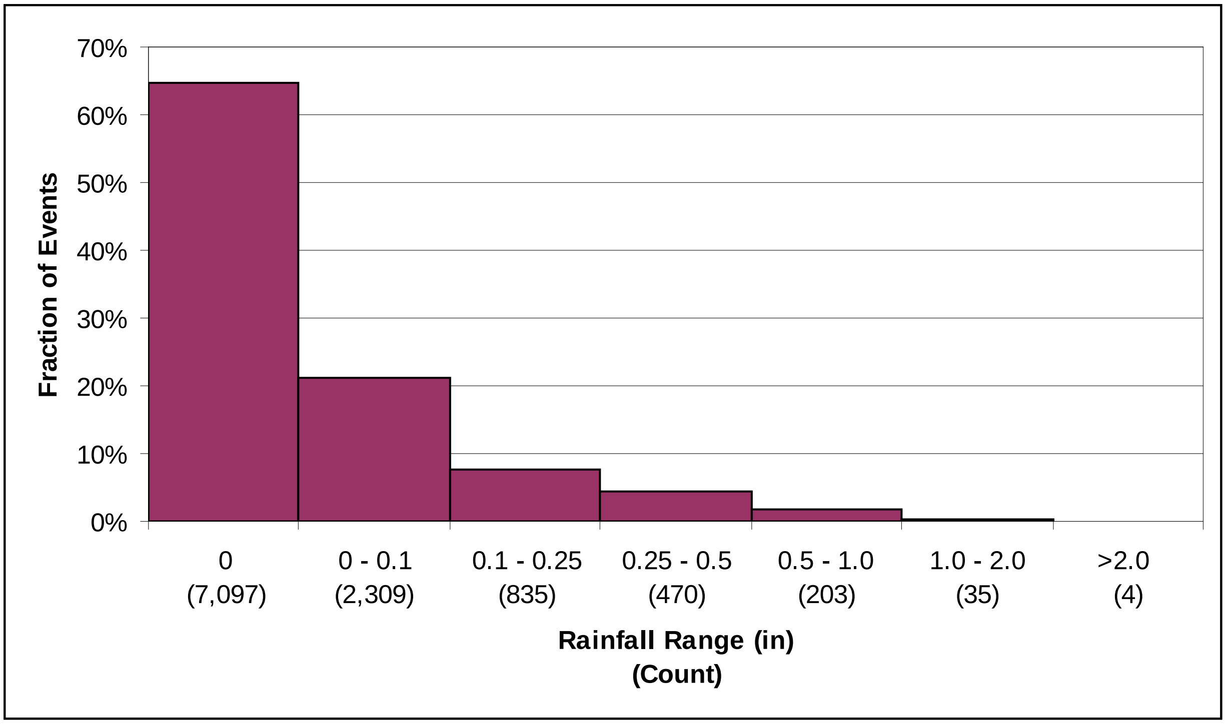


Figure 4-1. Daily Rainfall Distribution Histogram, MSU Station, 1980 – 2009 (approx. 11,000 records)

4.2 CLIMATOLOGY

The climatology portion of SWMM is used for long-term continuous simulations. This module describes climate related variables used for computing snowmelt and runoff. These variables include temperature, evaporation, wind speed, snowmelt, and areal depletion.

4.2.1 Temperature

Air temperature is used to calculate snowfall, snowmelt, and evaporation rates. For this simulation, data for both daily minimum and daily maximum temperatures were used. SWMM then fits a sinusoidal curve to this data to estimate temperatures at each time step. An external file containing 30 years worth of temperatures was used in this simulation. The temperature gage used was the Bozeman - Montana State University gage (Coop ID 241044 – see **Section 4.1** for location information). The data used in this analysis was from 1/1/1980 through 12/31/2009 – a period of 30 years. There were three missing periods, each about one month long. These data gaps were filled by using a nearby temperature gage (Bozeman Gallatin Field [Coop ID 240622]) to replace the values for the missing months.

4.2.2 Evaporation

Evaporation rates play a major role in the water budget. For this simulation, daily evaporation rates (in/day) were used. An external file containing 30 years worth of evaporation rates was used in this simulation. The gage used was the Bozeman - Montana State University gage (Coop ID 241044 – see **Section 4.1** for location information). The data used in this analysis was from 1/1/1980 through 12/31/2009 – a period of 30 years.

The evaporation rate data had numerous gaps. No evaporation data was collected for the winter months (November through April), and there were several years where there was no data collected for the entire year. It was not possible to fill this missing data with a nearby gage. Therefore, evaporation rates were averaged by Julian Day (JD), and a representative annual plot was created. To obtain values for the missing winter months, evaporation data from the Helena, MT area was analyzed (this data included winter averages), and a regression was done between the two datasets for the summer month data. This relationship was then applied to the Helena winter month evaporation rates to obtain values for Bozeman, MT. Once the entire year was estimated, a pan evaporation constant was used to convert the pan evaporation rates to actual field rates. Pan evaporation rates range from 0.35 to 1.1, depending on the location, distance from vegetation, wind speeds, temperatures, and other factors (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1982). The lack of knowledge about the types and location of the pan used at the weather station make it difficult to make an accurate estimate of the pan evaporation coefficient. However, the area in question is urban and therefore a higher than average pan evaporation constant of 0.95 was used in this study. This constant was estimated based on the factors mentioned, and best professional judgment. The evaporation curve used for the model is shown in **Figure 4-2**. The difference between the actual data and the regression data can be seen by the lack of variation in the regression data (November through April; JD 1 – 110, 300 - 365).

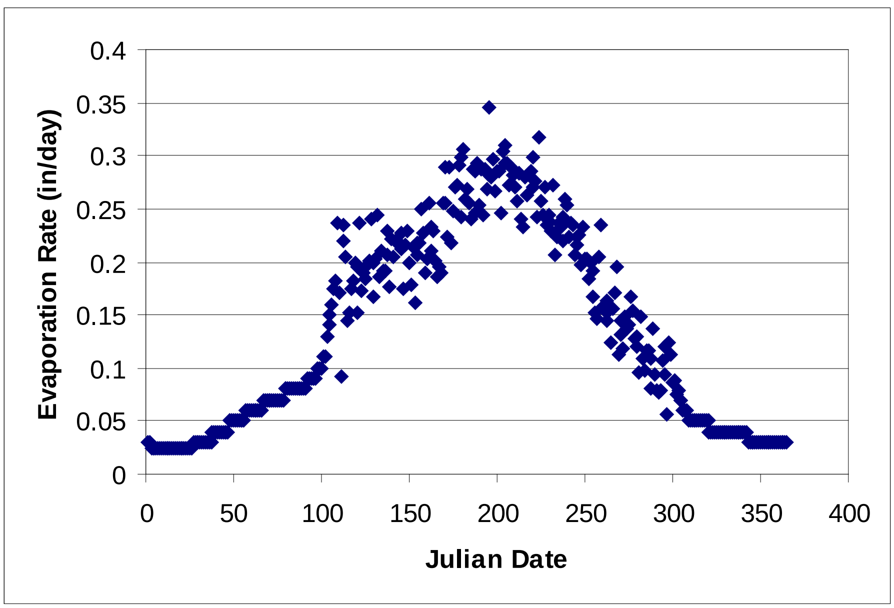


Figure 4-2. Evaporation Rate Data Used in Model

4.2.3 Wind Speed

Wind speed is used to calculate snowmelt rates. Higher wind speeds tend to increase the rate at which snow melts. An external file containing 30 years worth of wind speeds (in mph) was used in this simulation. The gage used was the Bozeman - Montana State University gage (Coop ID 241044 – see **Section 4.1** for location information). The data used in this analysis was from 1/1/1980 through 12/31/2009 – a period of 30 years. There was no missing data for this variable.

4.2.4 Snowmelt

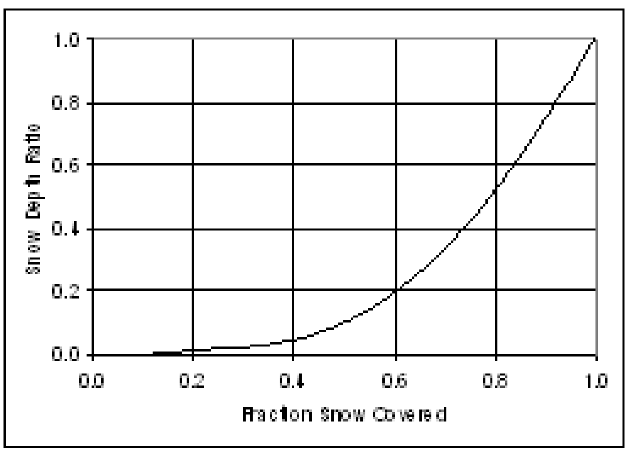
Snowmelt can affect runoff rates, volumes, and pollutant loads. Snowmelt is governed by several parameters, including the air temperature at which precipitation falls as snow, heat exchange at the snow surface, melt ratios, and the study area's elevation, latitude, and longitude. These parameters are all specified in the snowmelt editor within SWMM. Snowmelt parameters used in this study are listed in **Table 4-2**. Some of these were default values, and some were used as calibration parameters.

Table 4-2. Snowmelt Parameter Summary

Parameter	Value
Temperature Below Which Snow Falls/Melts (F)	33.5
Antecedent Temperature Index Weight (fraction)	0.5
Negative Melt Ratio	0.6
Elevation above Mean Sea Level (ft)	4,795
Latitude (degrees)	45.7
Longitude Correction (+/- minutes)	-24

4.2.5 Areal Depletion

Areal depletion is the tendency of accumulated snow to melt non-uniformly across the ground surface. Often, certain areas melt very quickly, whereas snow can remain in other locations for several weeks or more. An areal depletion curve shows the ratio of snow depth (as a fraction of the snow depth where there is 100% coverage) to fraction of snow coverage (**Figure 4-3**). SWMM provides the opportunity to use two areal depletion curves, one for pervious areas and one for impervious areas. The SWMM default values were used for both of these in this study – 'No areal depletion' for the impervious areas, and 'natural area depletion' for the pervious areas. 'No areal depletion' simply means that snow melts evenly across the entire snowpack at the same rate. This melts the snow at a faster rate than if areal depletion is used.



*Source: SWMM User's Manual Version 5.0, Figure 3-2, page 44

Figure 4-3. Areal Depletion Curve

4.3 Basin Area and Sub-catchments

The project basin includes only the area within the Bozeman city limits (approximately 12,500 acres), as defined by the city GIS layer titled "Bozeman_City_Limits" available on their website (http://www.bozeman.net/Departments-(1)/Information-Technology/GIS) as of August 2010. To maintain continuity between the two models, the original HDR catchment delineation was clipped to the city of Bozeman layer. This process resulted in 38 catchments within the Bozeman-area watershed (the original breakdown of sub-catchment BC3B was not used). Although the goal was to maintain the same watersheds for continuity purposes, after the clip there were several catchments that were tiny, isolated slivers, some less than one acre (**Figure 4-4**). Therefore, all catchment slivers less than 35 acres were merged with the next downstream one. This value (35 acres) was based on both the fact that the smallest catchment in the HDR model was around 35 acres, and that this was a point in which the data split conveniently – catchments larger than this appeared to have their own characteristics/drainage method. This did not have an effect on routing to the major rivers – no land area was re-routed to a new river – just a new catchment within the same stream watershed. A total of seven catchments were merged with their larger neighbors to create 31 catchments in the City model (**Table 4-3**). Of these seven, five were merged with the downstream catchment according to the HDR model, whereas two were merged with a different downstream catchment based on aerial interpretation. These slight modifications do not affect model integrity, but do help to simplify the model.

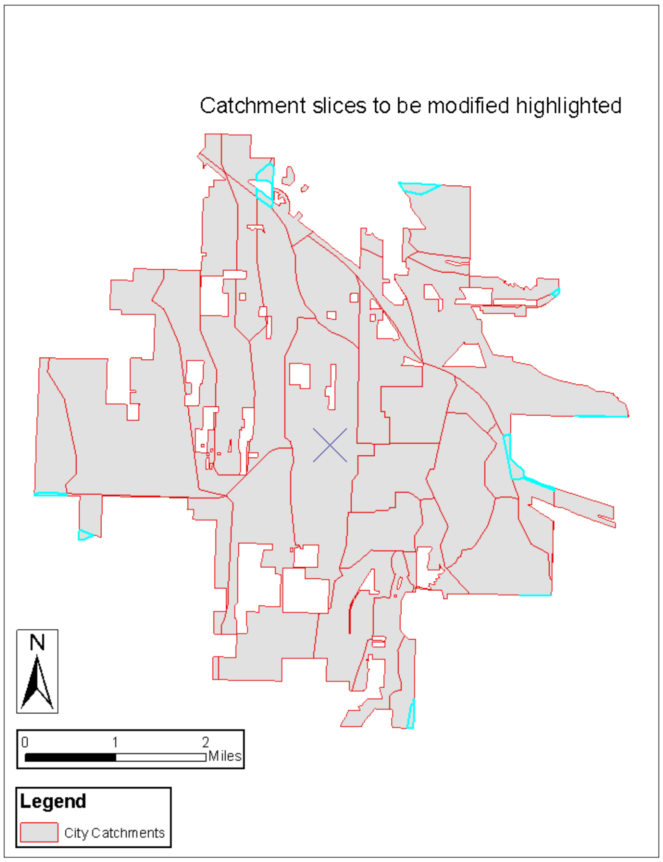


Figure 4-4. Catchments to be Incorporated into Larger Downstream Basins

Table 4-3. Catchment Redistribution for City Model

Catchment	Area (ac.)	Merged?	Catchment Merged With/Updated Area (ac.)	Catchment	Area (ac.)	Merged?	Catchment Merged With/Updated Area (ac.)
EG1B	0.21	Y	EG1A	BC2B	280.53	N	
EG2C	2.16	Y	EG2E	EGT1A	296.88	Y	EGT2A / 319.45
BC1A	8.59	Y	BC2F*	EG7C	305.15	Y	EG7B / 317.96
EG7B	12.81	Y	EG7C	BC2F	306.72	Y	BC1A / 315.30
EGT2A	22.57	Y	EGT1A*	BC2E	310.70	N	
EG5E	31.79	Y	EG6A	BC3A	318.70	N	

Table 4-3. Catchment Redistribution for City Model

Catchment	Area (ac.)	Merged?	Catchment Merged With/Updated Area (ac.)	Catchment	Area (ac.)	Merged?	Catchment Merged With/Updated Area (ac.)
EG1C	32.99	Y	EG2D	EG4A	348.13	N	
EG7F	40.93	N		BC3B	354.53	N	
EG3A	53.66	N		EG4B	407.65	N	
EG5G	82.55	N		EG7S	440.16	N	
EG1D	90.58	N		BC2A	454.98	N	
EG2B	98.85	N		EG1A	474.53	Y	EG1B / 474.74
EG1E	111.38	N		EG1F	523.86	N	
EG6A	132.09	Y	EG5E / 163.88	EG5P	666.73	N	
EG1G	153.06	N		EG7K	699.54	N	
EG2E	173.40	Y	EG2C / 175.56	EG5Q	910.50	N	
EG4C	181.25	N		EG2D	973.64	Y	EG1C / 1006.63
EG6B	250.79	N		EG5B	1165.68	N	
EG7G	262.36	N		EG7H	1472.15	N	
Total Area (acres):					12,452.8		

* These combinations differ from the HDR model routing; this divergence was based on aerial and DEM interpretation.

This updated network was input into the SWMM interface and a new link-node network was created (**Figure 4-5**).

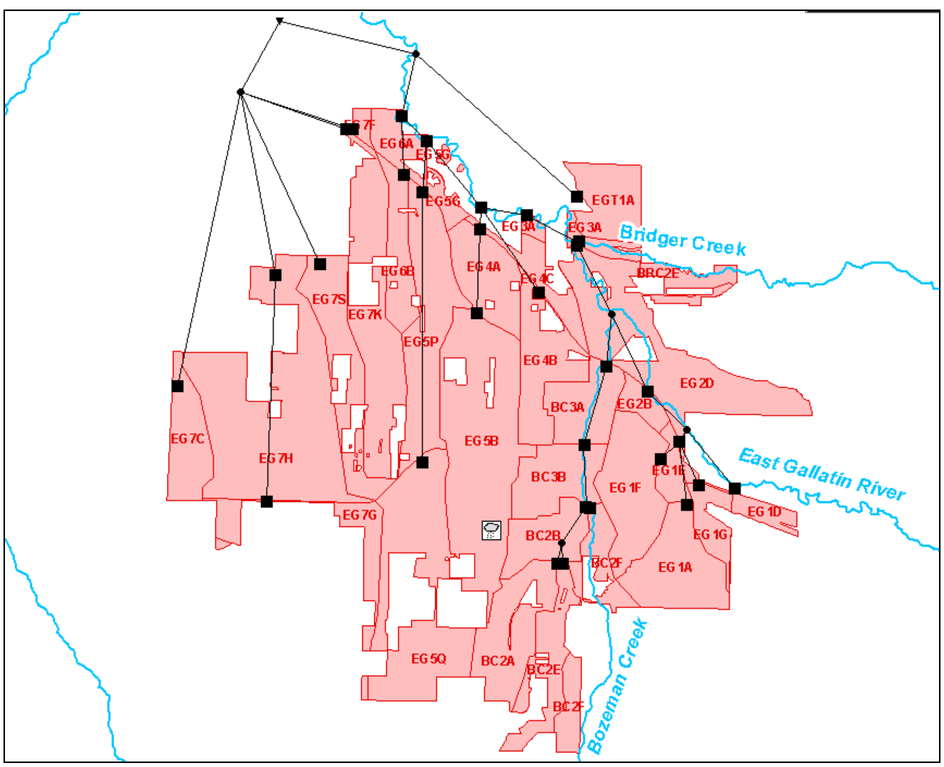


Figure 4-5. Link-Node Network for City of Bozeman Model

4.4 Land Use

The 2009 land use was obtained from the city. This was the most recent land use available. Land uses within the city are shown in **Table 4-4**.

Table 4-4. City of Bozeman 2009 Land Use

Land Use	Description	Area (acres)	Area (%)
AP	Administrative/Professional	222.3	1.8%
C	Commercial/Retail	442.1	3.6%
CA	Commercial/Auto	112.3	0.9%
CHURCH	Church	52.1	0.4%
DTHR	Duplex/Triplex Household Residence	235.1	1.9%
GOLF	Golf Course	178.3	1.4%
HM	Hotel/Motel	68.1	0.5%
LM	Light Manufacturing	215.6	1.7%
MHMP	Mobile Home/Mobile Park	104.8	0.8%
MHR	Multi-Family Household Residence	512.1	4.1%
MIXED	Mixed Use	252.1	2.0%
PFP	Public Facility/Park	1,655.5	13.3%
RB	Restaurant/Bar	40.6	0.3%
ROW	Rights-of-Way	2,266.3	18.2%
SEF	School/Educational Facility	792.8	6.4%
SHR	Single-Family Household Residence	1,526.2	12.3%
	Unknown	189.1	1.5%
VACANT	Vacant	3,587.2	28.8%
Total		12,452.8	100.0%

Most (but not all) of the descriptions are self-explanatory. From aerial interpretation, the ‘Mixed Use’ land use appears to be a hodge-podge of malls, apartments, parking lots, and a few homes. Based on this aerial interpretation, mixed use is most closely related to Commercial/Retail type of land use. The ‘Unknown’ land use consists of empty or partially empty lots and parcels that have been disturbed, and are in the process of being developed. However, most are not developed yet and are still open areas. The ‘Vacant’ land use is the largest single land use, composing over 25% of the city. This land use exists mainly along the periphery of the city, and is composed of areas recently acquired by the city but still under production for crops, areas that have been sub-divided into parcels, areas in the process of being developed, and areas that have recently been developed but not yet re-categorized under the proper land use. A general breakdown of the city of Bozeman land use is shown in **Figure 4-6**.

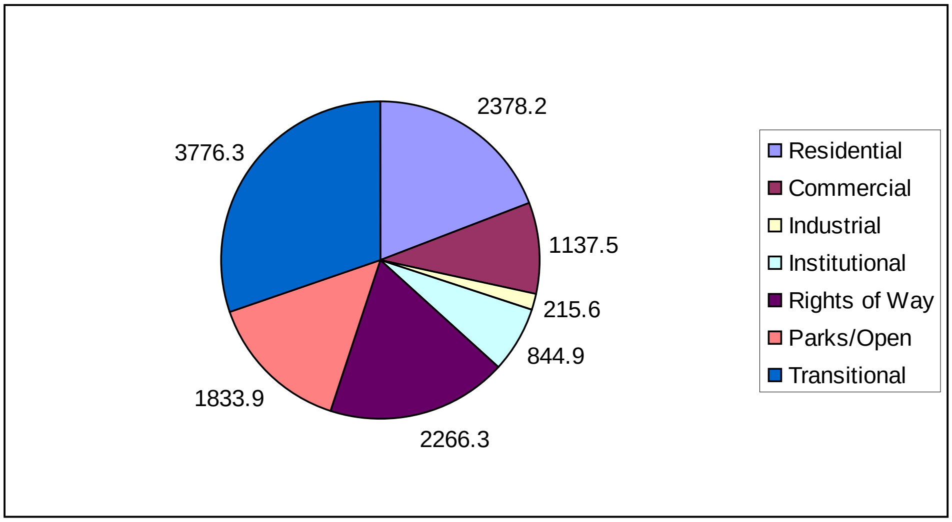


Figure 4-6. City of Bozeman Major Land Use Categories (in acres)

4.5 Percent Impervious Area

The percent impervious areas used by HDR are listed in **Section 4.3**. Although they seem reasonable, some random checks of catchments indicate that some percent impervious areas were estimated too high. An example is shown in **Figure 4-7**. Catchment BC2C (shown in the figure) is listed as having 35% impervious area. Based on the 2009 aerial photograph, this seems unlikely.

Figure 4-7. Percent Impervious Discrepancies

For this analysis, five parcels from each land use were analyzed to determine the percent impervious. The top two parcels in size of that particular land use were chosen, plus three additional random parcels. The percent impervious area was interpreted for each based on the aerial photographs. An average percent impervious area was obtained for each land use, and these are reported (rounded to the nearest 5%) in **Table 4-5** along with the HDR values used in the original model.

Table 4-5. Percent Impervious Area Estimates

Description	LU CODE	HDR Estimate: % Impervious	DEQ Estimate: % Impervious
Administrative/Professional	AP	90%	70%
Commercial/Retail	C	70%	90%
Commercial/Auto	CA	90%	90%
Church	CHURCH	70%	40%
Duplex/Triplex Household Residence	DTHR	50%	60%
Golf Course	GOLF	5%	5%
Hotel/Motel	HM	70%	90%
Light Manufacturing	LM	70%	55%
Mobile Home/Mobile Park	MHMP	45%	40%
Multi-Family Household Residence	MHR	35%	45%
Mixed Use	MIXED	65%	70%
Public Facility/Park	PFP	10%	15%
Restaurant/Bar	RB	70%	70%
Rights-of-Way	ROW	100%	90%
School/Educational Facility	SEF	65%	20%
Single-Family Household Residence	SHR	45%	30%
Unknown	-	-	16%
Vacant	VACANT	5%	5%

There were only a few major differences between the two methods. The School/Educational Facility land use is composed mainly of the Montana State University campus. This campus includes a large amount of open lands, and even the developed land has large open spaces between buildings. This is the reason for the low value obtained from this analysis. Other land uses that dropped significantly include Church, Administrative/Professional, Light Manufacturing, and Single Family Residential. The Hotel/Motel and Commercial/Retail land use impervious areas increased significantly. Since the *Bozeman Storm Water Facilities Plan* (HDR Engineering, Inc.,2008)does not discuss how they came up with their impervious percentage values, no further comparison can be made, but updated percent impervious areas were used in the City model.

4.6 Horton Infiltration Rates

The infiltration methodology chosen for this model was Horton's infiltration method (see **Section 4.4** for further description). The rates and parameters were estimated using standard reference books and the SWMM help section. Each soil type was given a set of Horton's parameter values, and then each catchment was prorated based on the soil make-up of the catchment. The soils in this area are hydrologic group 'B' and 'C', which means they have moderate initial infiltration rates. Horton infiltration rate parameter ranges are shown in **Table 4-6**.

Table 4-6. Horton Infiltration Rate Parameters

Parameter	Range	Unit
Max (Initial) Infiltration Rate	2.2 – 3.0	in/hr
Minimum (Final) Infiltration Rate	0.03 – 0.06	in/hr
Decay Rate of Infiltration	7.0	1/hr

4.7 EVENT MEAN CONCENTRATIONS AND STORMWATER LOADING

Event mean concentration (EMC) is a physically-based parameter used in stormwater modeling. It is defined as the mean pollutant concentration found in stormwater runoff. The annual EMC is the mean pollutant concentration of all runoff events throughout the year. It can be used, along with volumetric runoff estimates, to predict stormwater loading to downstream waterbodies. Typical units for EMC are either mg/L (volumetric) or kg/ha/year (areal). Volumetric loading rates (mg/L) will be used for this study.

Event mean concentrations are region specific. Differences in precipitation type, frequency, quantity, and other patterns all play a significant role in determining EMCs. EMCs can easily range over an order of magnitude based on regional differences. Therefore, it is imperative to get as region specific data as possible. In the early 1980s, EPA did a national study, called the Nationwide Urban Runoff Program (NURP)(U.S. Environmental Protection Agency, 1983), which categorized urban runoff for different pollutants and urban land uses throughout the U.S. The study was aimed at all major cities & towns (at least 100,000 population), which means that Montana urban areas was not large enough to be featured in this study. However, the NURP project included data from Denver, CO; Boise, ID; and Rapid City, SD. These cities, although outside of Montana and several hundred miles from Bozeman, MT, are all categorized as either arid or semi-arid mountain west or high plains cities, and therefore have some similarities to the study area. There have been many studies since then that further the values for various regions around the country; however, the general problem is best stated by the National Storm Water Quality Database (Pitt et al., 2004): *Excellent national coverage is anticipated, although there will be few municipalities from the northern, west-central states of Montana, Wyoming, and North and South Dakota (where cities are generally small, and few were included in the Phase 1 NPDES program).*

This problem was further observed during the literature search. No literature was found on Montana EMC runoff values, so other regional sources were used. One important study was Caraco (2000), which analyzed runoff in Boise, Denver, and Phoenix, AZ for total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), and others. The results of this study compared to national studies indicate that runoff concentrations in arid/semi-arid areas are much higher. They also came up with a general urban land use value of EMCs for each of the parameters listed above. The National Storm Water Quality Database (NSQD) did not obtain values from our region, although their results compare similarly to the NURP values.

The Denver Urban Drainage District discusses EMCs, and based on EMCs in the Denver Metropolitan Area, come up with EMCs for different land uses (industrial, commercial, residential, and undeveloped) in the Denver area (Denver Urban Drainage and Flood Control District, 1999). These values are relatively high compared to nationwide EMC values.

The Salt Lake Countywide Watershed – Water Quality Stewardship Plan (2009) attempts to provide a master stormwater plan for the Salt Lake City region. This region is characterized as semi-arid and, although slightly warmer than Bozeman, is similar in elevation, rainfall and temperature patterns. The study summarizes several earlier studies done within the County and reports regional EMCs for both TSS and TP, as well as bacteria counts for city runoff (unfortunately, nitrogen was not analyzed in this study). All reported values are for typical urban runoff; however, the study also analyzed different contributing land uses and, although there was not enough data to propose land use specific EMCs, they did conclude that land use does make a difference, and presented the available data. The study used five land uses – commercial, industrial, residential, mixed (general urban), and transportation. It found that, in general, residential and transportation land uses had TSS and TP EMCs about twice as high as commercial and industrial land uses. Mixed land use fell somewhere in the middle of this range.

The information on bacteria counts is even sparser than that on sediment and nutrients, and a determination of EMC values for bacteria counts could not even be attempted with the available data. Therefore, bacterial loading was not included in this model. Note that the SWMM platform does support simple bacteria loading, and if additional information should become available, it would be very easy to incorporate bacteria loading into the modeling effort.

Taking these three to four studies into account, the following values were taken as averages EMCs for the land uses necessary to this study (**Table 4-7**).

Table 4-7. Event Mean Concentrations Used in Study

Land Use	TSS (mg/L)				
	Salt Lake City Study	Denver	Caraco	NURP	DEQ
General Urban	154	-	242	141 - 224	
Commercial*	60	225	242		176
Industrial	45	399	242		
Mixed	100	-			
Residential*	115	240	242		199
Transportation*	160	-	242		201
Open/Undeveloped	-	400			
Open – Vacant*	154	400	242		332
Open – Maintained*	154	400	242		212
Land Use	**TP (mg/L)**				
	Salt Lake City Study	**Denver**	**Caraco**	**NURP**	**DEQ**
General Urban	0.68	-	0.65	0.37 - 0.47	
Commercial*	0.22	0.42	0.65		0.43
Industrial	0.18	0.43			
Mixed	0.34	-			
Residential*	0.50	0.65	0.65		0.60
Transportation*	0.48	-	0.65		0.57
Open/Undeveloped	-	0.40			
Open – Vacant*	0.68	0.40	0.65		0.46
Open – Maintained*	0.68	0.40	0.65		0.72
Land Use	**TN (mg/L)**				
	Salt Lake City Study	**Denver**	**Caraco**	**NURP**	**DEQ**
General Urban		-	4.06	2.44 - 3.08	
Commercial*		3.3	4.06		3.68
Industrial		2.7			
Mixed		-			
Residential*		3.4	4.06		3.73
Transportation*		-	4.06		4.06
Open/Undeveloped		3.4			
Open – Vacant*		3.4	4.06		2.98
Open – Maintained*		3.4	4.06		4.66

*Land uses used in this study

4.8 Model Setup, Calibration, and Stability

4.8.1 Model Setup

The City model was set up with 30 years of continuous weather data. Manning's n values and depressional storage values were assigned to pervious and impervious areas according to **Table 4-8**. The outfall for the model is the East Gallatin River downstream of Bozeman.

Table 4-8. Summary of Manning's n and Depressional Storage Values used in Model

Conveyance Type	Depressional Storage Value (in)	Manning's n Value
Pervious Areas	0.1	0.1
Impervious Areas	0.01	0.014

4.8.2 Model Calibration

Due to the lack of flow meters in the river, creeks, and stormwater pipes, and the lack of historic data, calibration of this model was not possible. However, the objective is to create a tool that can be used to estimate loading to Bozeman Creek and the East Gallatin River. As new data is gathered on flow rates, etc, this model can be modified accordingly.

4.8.3 Model Stability and Error

All model runs were subjected to a detailed analysis for errors and discrepancies. This analysis included doing a mass balance check in SWMM to verify that there was no systemic net gain or loss of water volume (Total V_{in} – Total V_{out} = ΔV_{system}), and a check of the overall efficiency of the runoff and hydraulic blocks. If necessary, channels, pipes, and other conveyance/storage features were checked to make sure that SWMM did not have to extrapolate water elevations above defined input data. In all model runs, the overall runoff continuity error was less than 0.5 percent, and the overall routing continuity error was less than one percent. Finally, hydrographs were spot checked to insure that there was no major instability in the model. Modeling results can be found in **Appendix B**.

4.9 Existing Model

4.9.1 Project Basin Runoff

Runoff from the city of Bozeman catchments was generated in the runoff block of SWMM. Continuous hydrographs based on the rainfall amounts were generated for each catchment, creating inflow to each node. For runoff block input and output, please see Appendix B.

4.9.2 Existing Modeling Results

General watershed runoff values for the model are shown in **Table 4-9**. As can be seen, the mass balance for the precipitation is about 49% evaporation, 32% infiltration, and 20% surface runoff. Both the rainfall totals and the breakdown of the rainfall into evaporation, infiltration, and runoff are reasonable values for urban areas within the region, and these ranges have been observed in other regional modeling efforts.

Table 4-9. Runoff Quantity Mass Balance

Parameter	Volume (acre-feet)	Depth (inches)	Mass Balance
Initial Snow Cover	269.8	0.26	-
Total Precipitation	568,443	547.8	-
Evaporation Loss	277,434	267.3	48.8%

Table 4-9. Runoff Quantity Mass Balance

Parameter	Volume (acre-feet)	Depth (inches)	Mass Balance
Infiltration Loss	180,635	174.1	31.8%
Surface Runoff	112,862	108.8	19.8%
Final Snow Cover	131.9	0.13	0.02%
Final Surface Storage	0	0	0.00%
Continuity Error (%)	*-0.41*		*100.41%*

Breakdowns for each catchment, with total volume of runoff, peak outflow, and the runoff fraction listed for each are shown in **Table 4-10**. Runoff fractions varied greatly within the city, ranging from 5.1% (EG3A) up to 40.1% (EG1D). This reflects the large variation within the city as far as land use, impervious area, and other runoff parameters are concerned.

Table 4-10. Water Balance by Catchment

Catchment	Percent Impervious Area	Total Precipitation (in)	Total Evaporation (in)	Total Infiltration (in)	Total Runoff (in)	Total Runoff (acre-feet)	Runoff Fraction
BC2A	35.1%	547.8	266.9	180.4	102.5	3885	18.7%
BC2B	45.5%	547.8	268.4	149.5	133.5	3121	24.4%
BC2E	36.9%	547.8	267.3	174.1	108.8	2816	19.9%
BC2F	32.9%	547.8	267.0	183.3	99.5	2613	18.2%
BC3A	57.1%	547.8	269.8	117.0	166.1	4412	30.3%
BC3B	57.3%	547.8	269.4	118.1	165.1	4876	30.1%
BRC2E	16.4%	547.8	266.4	223.8	59.2	866	10.8%
EG1A	15.6%	547.8	265.0	233.6	49.0	1938	8.9%
EG1D	75.7%	547.8	271.8	64.0	219.5	1657	40.1%
EG1E	36.7%	547.8	267.9	169.4	113.7	1055	20.8%
EG1F	34.2%	547.8	267.3	178.8	104.3	4554	19.0%
EG1G	34.7%	547.8	267.6	175.3	107.9	1376	19.7%
EG2B	39.1%	547.8	268.0	164.4	118.8	979	21.7%
EG2D	31.8%	547.8	267.6	181.8	101.1	8479	18.5%
EG3A	5.5%	547.8	265.2	255.3	27.9	125	5.1%
EG4A	22.7%	547.8	265.6	215.1	67.7	1963	12.4%
EG4B	61.3%	547.8	269.8	107.0	176.2	5984	32.2%
EG4C	55.4%	547.8	269.5	120.7	162.6	2456	29.7%
EG5B	47.8%	547.8	268.3	145.8	137.1	13314	25.0%
EG5G	70.0%	547.8	271.0	82.7	200.5	1379	36.6%
EG5P	54.4%	547.8	269.1	127.4	155.6	8645	28.4%
EG5Q	31.9%	547.8	266.5	190.2	92.4	7011	16.9%
EG6A	33.3%	547.8	266.8	184.9	98.0	1339	17.9%
EG6B	34.9%	547.8	266.9	181.8	100.8	2107	18.4%
EG7C	13.3%	547.8	264.7	242.2	40.2	1064	7.3%
EG7F	39.5%	547.8	267.4	169.0	113.8	388	20.8%
EG7G	29.7%	547.8	266.3	196.4	86.2	1885	15.7%
EG7H	31.5%	547.8	266.5	191.3	91.3	11198	16.7%
EG7K	37.1%	547.8	267.1	175.7	107.0	6238	19.5%
EG7S	33.0%	547.8	266.7	187.1	95.5	3503	17.4%
EGT1A	17.2%	547.8	266.3	221.5	61.3	1633	11.2%

4.9.3 Water Quality Loading

The water quality method in this simulation is quite simple. The runoff volume times the event mean concentration gives the pollutant loading. Pollutant loads by catchment are shown in **Table 4-11**, and a summary of pollutant loading is shown in **Table 4-12**.

Table 4-11. Pollutant Loading by Catchment

Catchment	TSS (lbs)	TN (lbs)	TP (lbs)
BC2A	2,303,744	39,286	5,981
BC2B	1,687,905	33,431	5,084
BC2E	1,571,241	29,118	4,487
BC2F	1,513,339	27,267	4,168
BC3A	2,368,588	45,944	6,691
BC3B	2,584,869	51,058	7,537
BRC2E	529,809	8,411	1,288
EG1A	1,329,467	15,204	2,345
EG1D	876,218	16,989	2,249
EG1E	719,490	9,938	1,448
EG1F	2,853,479	45,897	6,779
EG1G	992,240	12,085	1,776
EG2B	693,427	8,855	1,289
EG2D	5,547,172	80,573	11,837
EG3A	65,166	837	129
EG4A	1,481,024	15,641	2,325
EG4B	3,354,609	61,306	8,433
EG4C	1,554,760	23,934	3,328
EG5B	7,486,903	139,705	20,492
EG5G	799,500	14,254	2,047
EG5P	4,968,004	86,968	12,286
EG5Q	4,589,258	67,513	10,049
EG6A	731,012	15,745	2,384
EG6B	1,467,187	18,723	2,746
EG7C	742,513	7,558	1,164
EG7F	212,832	4,559	685
EG7G	1,196,176	19,311	2,905
EG7H	7,367,450	106,004	16,032
EG7K	3,896,948	60,712	9,306
EG7S	2,307,528	32,824	4,895
EGT1A	859,928	17,960	2,774

Table 4-12. Pollutant Loading Basin Summary

	Total Loading (lbs)			Annual Loading (lbs/year)		
Pollutant	Bozeman Creek	Bridger Creek	East Gallatin River	Bozeman Creek	Bridger Creek	East Gallatin River
TSS	12,029,686	529,809	56,092,290	400,990	17,660	1,869,743
TN	226,104	8,411	883,095	7,537	280	29,436
TP	33,948	1,288	129,702	1,132	43	4,323

5.0 SUMMARY

The Lower Gallatin watershed is currently under TMDL development for sediment, nutrients, and pathogens. In an effort to determine the portion of sediment and nutrient pollutant loading coming from urban runoff associated with the city, a SWMM model was built using a previous Bozeman-area model as a guideline.

The SWMM model was shown to re-create the original model reasonably well, and was then used to create a smaller, city-specific model that used a 30 year daily simulation to determine average existing loading rates for sediment and nutrients. This model represents existing conditions in the project basin, and can be used to determine relative reductions between management scenarios. It could also be used to determine loading totals from future scenarios. This model can be modified as more detailed information on existing BMPs, subsurface stormwater systems, and flow and water quality data from the stormwater system becomes available, and can also be integrated with future improvements such as retention ponds, improved BMPs, low impact development (LID), etc.

There were several assumptions and limitations associated with this modeling effort, including the use of initial condition parameters, SWMM built in limitations, and some inconsistencies and minor data gaps within the HDR model data (which was assumed to be accurate; no ground-truthing or field data collection was performed by DEQ). However, the DEQ model was able to re-create the results from the original GBA model with some consistency (+/-10% for all scenarios). This re-created base model was then applied to the city for a continuous time period of 30 years.

Due to a lack of complete calibration data (flows, sediment and nutrient samples), this model was not calibrated, but several checks show it appears mechanistically stable and the results are reasonable. While the lack of calibration limitation may change in the future as data becomes available and is added to the model, at this time the model should be used as a tool for determining relative load reductions between scenarios only. It should not be used for, or considered, a TMDL-level load allocation model.

6.0 REFERENCES

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APPENDIX A – GREATER BOZEMAN AREA MODEL INPUT AND OUTPUT

(Provided electronically upon request)

APPENDIX B – CITY OF BOZEMAN MODEL - INPUT AND OUTPUT

(Provided electronically upon request)