APPENDIX A – MODEL DEVELOPMENT DOCUMENTATION

This appendix presents details about the SWATSalt Code, errors fixed during modeling development, and QA/QC of boundary conditions.

TABLE OF CONTENTS

A.1 PRACTICAL IMPLEMENTATION OF SWATSALT

This section provides a summary of steps to develop the SWATSalt used in the Tongue River model project, in consultation with Texas A & M University. The content was based on a memo received from Katrin Bieger on 3/23/2017 and modified to fit the formatting of the model report. Contact Montana DEQ Watershed Planning Bureau for more information.

Reference: Texas A & M University. 2017. Content taken from memo received 3/23/2017 from Katrin Bieger.

A.1.1 BACKGROUND

All code development was done in Revision 663 of the Soil and Water Assessment Tool (http://swat.tamu.edu/docs).

A.1.2 SALT SOURCES

Salt can be added in SWATSalt from two different sources, point sources/inlets and HRUs.
For the point sources/inlets, the concentrations of up to ten salt cations can be read in on a daily basis using the recday command in the watershed configuration file. The daily salt concentrations have to be specified in the last 10 columns (Salt1 to Salt 10) in the point source/inlet files.

Table A- 1: Description of salt variables in the recday.dat input file

Variable Name	Definition
SALT1	Concentration of salt cation #1 in flow to reach for the day (mg/l)
SALT2	Concentration of salt cation #2 in flow to reach for the day (mg/l)
SALT3	Concentration of salt cation #3 in flow to reach for the day (mg/l)
SALT4	Concentration of salt cation #4 in flow to reach for the day (mg/l)
SALT5	Concentration of salt cation #5 in flow to reach for the day (mg/l)
SALT6	Concentration of salt cation #6 in flow to reach for the day (mg/l)
SALT7	Concentration of salt cation #7 in flow to reach for the day (mg/l)
SALT8	Concentration of salt cation #8 in flow to reach for the day (mg/l)
SALT9	Concentration of salt cation #9 in flow to reach for the day (mg/l)
SALT10	Concentration of salt cation #10 in flow to reach for the day (mg/l)

Salt1	Salt2	Salt3	Salt4	Salt5	Salt6	Salt7	Salt8	Salt9	Salt10
7.50E+01	8.70E+01	2.19E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.20E+01	8.20E+01	2.06E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.50E+01	8.70E+01	2.19E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.50E+01	8.70E+01	2.19E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.50E+01	8.70E+01	2.19E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.50E+01	8.70E+01	2.19E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.50E+01	8.70E+01	2.19E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.50E+01	8.70E+01	2.19E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.90E+01	9.30E+01	2.37E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.10E+01	9.70E+01	2.49E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.40E+01	1.02E+02	2.63E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.40E+01	1.02E+02	2.63E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Figure A-1: Example for salt concentration inputs in the recday.dat input file

Salt inputs from the HRUs can be specified in the HRU operations files (*.ops) as concentrations in surface runoff, lateral flow, groundwater flow, and tile flow. Again, concentrations of up to ten different salt cations can be added and read in to the model. Defining the salt concentrations at HRU level allows the user to vary them by land use, soil type, and slope. The MGT_OP code for salt is 11.
When two or more salt cations are read in, the user should make sure that they are in the same order in both the point source/inlet and the HRU operations file.

Table A-2: Description of salt operation variables in the *.ops input files

Variable Name	Definition
MONTH	Month operation takes place
DAY	Day operation takes place
IYEAR	Year operation takes place
MGT_OP	Management operation code, MGT_OP = 11 for salt
SALT_NUM	Number of salt cation
SALT_SURQ	Salt concentration in surface runoff
SALT_LATQ	Salt concentration in lateral flow
SALT_GWQ	Salt concentration in groundwater flow
SALT_TILEQ	Salt concentration in tile flow

```
.ops file Watershed HRU:140 Subbasin:4 HRU:24 Luse:AGRR Soil: 343485 Slope 2-5
 1  1     2002 11    3   0    0.3         0.06   0.06
 1  1     2002 11    3   0   40.0         60.0  152.0
 1  1     2002 11    3   0   40.0         60.0  152.0
 1  1     2002 11    0
```

Figure A-2: Example for an HRU operations file with concentrations of three different salt cations in the last three columns. The first row is for surface runoff, the second for lateral flow, the third for groundwater flow, and the last one for tile flow. The number 11 in the fourth column denotes the operation used for adding salt concentrations.

A.1.3 SALT ROUTING IN THE CHANNEL

The salt cations are assumed to be conservative in the water. However, the user can define a delivery ratio to account for settling and temporary storage within the stream. Also, a monthly adjustment factor can be applied to the HRU loadings to vary them by month. The delivery ratio and the monthly factors are specified in the channel routing files (*.rte).

Table A-3: Description of salt variables in the *.rte files

Variable Name	Definition
HRU_SALT(mon)	Monthly adjustment factor for HRU salt loadings (Range: 0-10, Default = 1)
SALT_DEL	Salt delivery ratio in reach (Range: 0-10, Default = 1)

```
.rte file Subbasin: 54 12/15/2015 12:00:00 AM ArcSWAT 2012.10_2.15
      35.846    | CHW2 : Main channel width [m]
       1.428    | CHD : Main channel depth [m]
     0.00087    | CH_S2 : Main channel slope [m/m]
      11.091    | CH_L2 : Main channel length [km]
       0.025    | CH_N2 : Manning's nvalue for main channel
       4.000    | CH_K2 : Effective hydraulic conductivity [mm/hr]
       0.000    | CH_COV1: Channel erodibility factor
       1.000    | CH_COV2 : Channel cover factor
      25.107    | CH_WDR : Channel width:depth ratio [m/m]
       0.000    | ALPHA_BNK : Baseflow alpha factor for bank storage [days]
        0.00    | ICANAL : Code for irrigation canal
        0.00    | CH_ONCO : Organic nitrogen concentration in the channel [ppm]
        0.00    | CH_OPCO : Organic phosphorus concentration in the channel [ppm]
        0.00    | CH_SIDE : Change in horizontal distance per unit vertical distance
        0.00    | CH_BNK_BD : Bulk density of channel bank sediment (g/cc)
        0.00    | CH_BED_BD : Bulk density of channel bed sediment (g/cc)
        0.00    | CH_BNK_KD : Erodibility of channel bank sediment by jet test (cm3/N-s)
        0.00    | CH_BED_KD : Erodibility of channel bed sediment by jet test (cm3/N-s)
        0.00    | CH_BNK_D50 : D50 Median particle size diameter of channel bank sediment (µm)
        0.00    | CH_BED_D50 : D50 Median particle size diameter of channel bed sediment (µm)
        0.00    | CH_BNK_TC : Critical shear stress of channel bank (N/m2)
        0.00    | CH_BED_TC : Critical shear stress of channel bed (N/m2)
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
           0    | CH_EQN : Sediment routing methods
           0    |prf
           0    |spcon
           0    |spexp
 1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00    |salt concentration by month
        1.00    | saltdr (salt delivery ratio)
```

Figure A-3: Example for a channel routing file with the monthly salt adjustment factor and the salt delivery ratio in the last two rows.

A.1.4. Calculation of Electrical Conductivity

SWATSalt has the capability to calculate the Electrical Conductivity [mS/cm] using a simple regression equation with salt cation concentrations as the independent variable. For this, three variables were added to the basin file (basins.bsn), EC_INT, EC_SLP, and SALT_NUM.

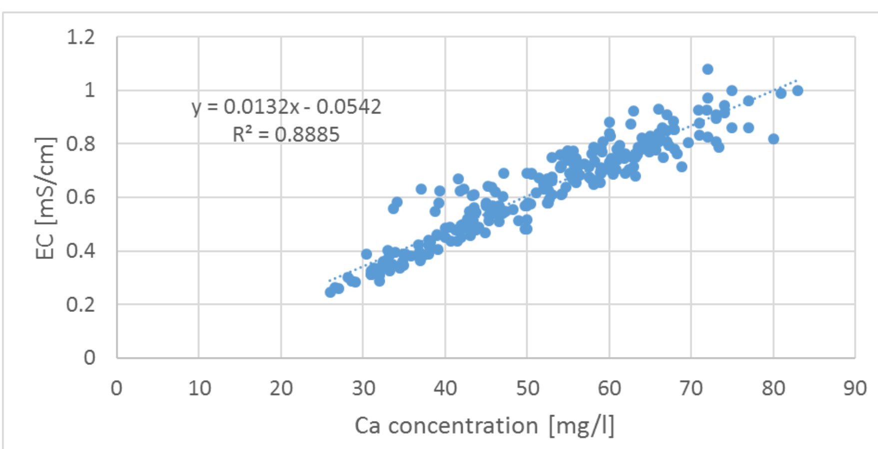


Figure A-4: Example for scatter plot and regression equation to calculate EC from Ca concentrations at Tongue River near Birney

Table A-4: Description of salt variables in the basins.bsn file

Variable Name	Definition
EC_INT	Intercept of regression line
EC_SLP	Slope of regression line
SALT_NUM	Number of salt cation to be used in the regression equation (1 – 10 for Salt1 – Salt10)

```
        0.05    | EC_INT
        0.01    | EC_SLP
           1    | SALT_NUM
```

Figure A-5: Salt input variables at the bottom of the basins.bsn file

A.1.5 WRITING OUTPUT

Up to ten salt constituents can be written to the reach output file (output.rch). Depending on the print code specified by the user in the file.cio file, salt loads will be written on a daily, monthly, or yearly time step. Regardless of the time step selected, average annual salt loads will be included in the reach output file. Additionally, SWATSalt also includes the Sodium Adsorption Ratio, which is calculated based on Calcium, Magnesium, and Sodium concentrations, and the Electrical Conductivity in the reach output file. The Sodium Adsorption Ratio is calculated according to the following equation:

$$\text{S.A.R.} = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

For the Sodium Adsorption Ratio, the user has to make sure that Salt1, Salt2 and Salt3 in the point source/inlet and the HRU operations files are Calcium, Magnesium, and Sodium, respectively.

Table A-5: Description of salt variables in the output.rch file

Variable Name	Definition
SALT1	Load of salt cation #1 transported out of reach (kg/day)
SALT2	Load of salt cation #2 transported out of reach (kg/day)
SALT3	Load of salt cation #3 transported out of reach (kg/day)
SALT4	Load of salt cation #4 transported out of reach (kg/day)
SALT5	Load of salt cation #5 transported out of reach (kg/day)
SALT6	Load of salt cation #6 transported out of reach (kg/day)
SALT7	Load of salt cation #7 transported out of reach (kg/day)
SALT8	Load of salt cation #8 transported out of reach (kg/day)
SALT9	Load of salt cation #9 transported out of reach (kg/day)
SALT10	Load of salt cation #10 transported out of reach (kg/day)
SAR	Sodium adsorption ratio in flow out of reach
EC	Electrical conductivity in flow out of reach (mS/cm)

A.1.6 COMMENTS-SALT DELIVERY RATIO

The salt delivery ratio in the channel routing file needs to be used with caution. For example, if the user specifies a delivery ratio of 0.5 for all reaches, the salt loads will be reduced by half in every reach and there will only be very low concentrations left at the watershed outlet. To achieve a 50% reduction of salt loads at a specific subbasin outlet, it is probably best to apply the desired delivery ratio to the corresponding reach only.

A.2 Code Development-Corrections Made by DEQ and Tetratech

It should be noted that DEQ and Tetra Tech discovered and fixed several errors in the SWATSalt code resulting in differences between the initial DEQ calibration and the final calibration. These corrected errors were:

1. To estimate loads, SWATSalt was incorrectly multiplying the concentrations of salts by the depth of runoff, interflow, and groundwater flow rather than multiplying by volume, resulting in an under prediction of salt loads.
2. SWATSalt was not removing salts from a reach when water is withdrawn for irrigation. This modification was necessary to reduce artificially high salt concentrations during low flow periods.
3. SWATSalt was not appropriately simulating salts as water enters bank storage. This error was found because pulses of flow from the Tongue River Reservoir were creating high concentrations of salt in the downstream channel because salts were not being retained in bank storage along with flow. The old model assumed that all salt mass entering a reach exits the reach without any impact from transmission losses or bank releases. The concentration in the old model changed based on volume that changed based on the difference between bank release gain and channel transmission loss, plus evaporative losses. The new model (with the revised code) assumes that concentration, rather than load, is not affected by bank release and channel transmission loss (but is affected by volume reduction due to evaporation). Only on days where bank release minus transmission loss is significantly different from zero will this make much of a difference – such as at the start of dam release periods.

A.3 Streamflow and Water Quality Data QA/QC

The streamflow and water quality data used to establish boundary conditions and to calibrate the model underwent quality assurance checks and were screened via the following methods:

1. All data obtained from the USGS were confirmed to be "Approved". This means that USGS confirms that the data were collected with no instrument malfunctions or changes to the measurement site and were determined to be accurate (USGS Provisional Data Statement; https://waterdata.usgs.gov/provisional-data-statement/).
2. The USGS data used for the LOADEST analysis at the four inlet files to the model (Tongue River Dam, Hanging Woman Ck., Otter Ck. and Pumpkin Ck.) were checked for outliers and unrealistic values, but none were found.
3. The flow, water quality, and precipitation data used during calibration were visually inspected for outliers and screened accordingly.
4. Datasets that were used for the final calibration were checked against their original sources to ensure there were no errors in transferring the data between files or during pre- or post-processing.
5. Streamflow and water quality Discharge Monitoring Report (DMR) data from the Wyoming and Montana CBM and coal mines were checked for outliers and unrealistic values. Commonly, such errors are due to the use of

incorrect units in the DMR forms submitted to the state. Where possible, these values were corrected to the correct units. Where the correct value was not obvious the value was removed from the input data or was replaced using interpolated or average data from the acceptable DMR data.

APPENDIX B – CHARACTERISTICS OF SWATSALT MODELED SUBBASINS

This appendix presents the basin characteristics for the subbasins in the SWATSalt modeled portion of the study area.

TABLE OF CONTENTS

B.1 Characteristics of SWATSalt Modeled Subbasins

Table B-1. Sub-basin summary, Tongue River watershed

Sub-Basin	Area (hectares)	Area (acres)	Watershed Area (%)	Median Elevation (ft)
1	1,964	4,854	0.44	2,428
2	12,753	31,514	2.83	2,571
3	9,232	22,813	2.05	2,868
4	1,188	2,937	0.26	2,520
5	13,126	32,434	2.91	2,820
6	3,196	7,897	0.71	2,597
7	6,126	15,137	1.36	2,628
8	743	1,835	0.16	2,560
9	4,335	10,711	0.96	2,786
10	11,123	27,485	2.47	2,690
11	11,759	29,056	2.61	2,750
12	3,774	9,326	0.84	2,771
13	5,179	12,797	1.15	2,891
14	5,055	12,492	1.12	2,828
15	9,759	24,116	2.16	2,809
16	6,520	16,112	1.45	2,913
17	3,751	9,269	0.83	2,779
18	3,184	7,868	0.71	2,825
19	4,175	10,316	0.93	2,941
20	9,342	23,084	2.07	3,055
21	1,826	4,512	0.4	2,724
22	7,120	17,594	1.58	2,865
23	15,294	37,792	3.39	2,946
24	8,375	20,695	1.86	2,995
25	6,269	15,492	1.39	2,897
26	5,600	13,838	1.24	3,095
27	10,383	25,658	2.3	3,052
28	8,126	20,081	1.8	3,109
29	12,580	31,085	2.79	2,958
30	5,478	13,535	1.21	2,990
31	12,522	30,943	2.78	3,259
32	3,688	9,113	0.82	3,045
33	6,352	15,697	1.41	3,241
34	4,358	10,769	0.97	3,555

Table B-1. Sub-basin summary, Tongue River watershed

Sub-Basin	Area (hectares)	Area (acres)	Watershed Area (%)	Median Elevation (ft)
35	3,745	9,255	0.83	3,485
36	13,291	32,844	2.95	3,114
37	5,809	14,353	1.29	3,611
38	4,888	12,078	1.08	3,345
39	8,696	21,488	1.93	3,186
40	1,994	4,927	0.44	3,052
41	5,173	12,783	1.15	3,484
42	6,158	15,217	1.36	3,259
43	9,338	23,076	2.07	3,810
44	7,146	17,659	1.58	3,167
45	16,134	39,869	3.58	3,382
46	6,850	16,927	1.52	3,427
47	8,916	22,033	1.98	3,877
48	1,790	4,424	0.4	3,489
49	1,677	4,145	0.37	3,414
50	5,176	12,790	1.15	3,704
51	4,375	10,811	0.97	3,863
52	11,036	27,272	2.45	3,919
53	12,147	30,015	2.69	3,741
54	3,038	7,506	0.67	3,254
55	834	2,061	0.18	3,322
56	6,005	14,838	1.33	3,455
57	11,768	29,080	2.61	3,927
58	7,314	18,074	1.62	3,568
59	6,238	15,415	1.38	3,895
60	1,009	2,494	0.22	3,315
61	6,934	17,133	1.54	3,576
62	13,050	32,246	2.89	3,990
63	1,635	4,041	0.36	3,473
64	351	868	0.08	3,380
65	5,840	14,431	1.29	3,997
66	4,578	11,311	1.01	3,803
67	13,974	34,530	3.1	3,793
Modeling Basin Totals	**451,166**	**1,114,853**	**100%**	**3,242**

APPENDIX C. ROUTING COEFFICIENTS FOR MODELED SUBBASINS

TABLE OF CONTENTS

C.0 Introduction

In order to simulate the physical processes affecting the flow of water and transport of sediment in the channel network, SWAT requires information on the physical characteristics of the main channel within each subbasin. The main channel input file (.rte) summarizes the physical characteristics of the channel which affects water flow and transport. The coefficients used for each subbasin are presented in this appendix.

C.1 Routing Coefficients for Each Modeled Subbasin

The routing coefficient values are provided in Table C-1.

Table C-1. Routing Coefficients

SUBBASIN	CH_W2	CH_D	CH_S2	CH_L2	CH_N2	CH_K2	CH_COV1	CH_COV2	CH_WDR	ALPHA_BNK
1	65.07	2.21	0.00	4.17	0.025	30	0	1	29.44	0.7
2	65.02	2.21	0.00	22.65	0.025	30	0	1	29.43	0.7
3	12.53	0.90	0.00	30.63	0.035	30	0	1	13.90	0.7
4	64.52	2.20	0.00	3.98	0.025	30	0	1	29.33	0.7
5	14.18	0.96	0.00	49.31	0.035	30	0	1	14.70	0.7
6	64.19	2.19	0.00	7.28	0.025	30	0	1	29.26	0.7
7	59.60	2.11	0.00	10.50	0.025	30	0	1	28.29	0.7
8	59.32	2.10	0.00	3.79	0.025	30	0	1	28.23	0.7
9	9.61	0.78	0.00	3.79	0.035	30	0	1	12.31	0.7
10	59.30	2.10	0.00	17.55	0.025	30	0	1	28.22	0.7
11	58.47	2.09	0.00	19.27	0.025	30	0	1	28.04	0.7
12	58.15	2.08	0.00	9.24	0.025	30	0	1	27.97	0.7
13	10.23	0.81	0.00	9.17	0.035	30	0	1	12.67	0.7
14	57.89	2.07	0.00	7.38	0.025	30	0	1	27.92	0.7
15	16.18	1.04	0.00	35.03	0.035	30	0	1	15.61	0.7
16	11.09	0.84	0.00	10.32	0.035	30	0	1	13.14	0.7
17	56.89	2.05	0.00	7.25	0.025	30	0	1	27.69	0.7
18	56.59	2.05	0.00	5.18	0.025	30	0	1	27.63	0.7

Table C-1. Routing Coefficients

SUBBASIN	CH_W2	CH_D	CH_S2	CH_L2	CH_N2	CH_K2	CH_COV1	CH_COV2	CH_WDR	ALPHA_BNK
19	9.49	0.78	0.01	3.16	0.035	30	0	1	12.24	0.7
20	12.59	0.90	0.00	11.46	0.035	30	0	1	13.92	0.7
21	19.00	1.13	0.00	14.59	0.03	30	0	1	16.80	0.7
22	56.37	2.04	0.00	12.73	0.025	30	0	1	27.58	0.7
23	55.85	2.03	0.00	14.87	0.025	30	0	1	27.46	0.7
24	12.11	0.89	0.00	22.52	0.035	30	0	1	13.68	0.7
25	16.44	1.05	0.00	32.54	0.035	30	0	1	15.73	0.7
26	10.52	0.82	0.00	1.46	0.035	30	0	1	12.83	0.7
27	13.06	0.92	0.00	24.94	0.035	30	0	1	14.16	0.7
28	11.98	0.88	0.00	17.56	0.035	30	0	1	13.62	0.7
29	55.00	2.02	0.00	23.23	0.025	30	0	1	27.27	0.7
30	54.61	2.01	0.00	12.15	0.025	30	0	1	27.18	0.7
31	13.95	0.96	0.00	37.42	0.035	30	0	1	14.59	0.7
32	17.51	1.08	0.00	19.08	0.03	30	0	1	16.19	0.7
33	16.52	1.05	0.00	16.35	0.03	30	0	1	15.76	0.7
34	9.63	0.78	0.00	2.51	0.035	30	0	1	12.32	0.7
35	12.68	0.91	0.00	7.48	0.035	30	0	1	13.97	0.7
36	53.67	1.99	0.00	21.69	0.025	30	0	1	26.97	0.7
37	10.65	0.83	0.01	3.98	0.035	30	0	1	12.90	0.7
38	10.03	0.80	0.01	5.22	0.035	30	0	1	12.55	0.7
39	53.24	1.98	0.00	9.24	0.025	30	0	1	26.87	0.7
40	52.79	1.97	0.00	7.04	0.025	30	0	1	26.76	0.7
41	10.23	0.81	0.01	5.60	0.035	30	0	1	12.67	0.7
42	52.55	1.97	0.00	14.60	0.025	30	0	1	26.71	0.7
43	12.58	0.90	0.01	20.68	0.035	30	0	1	13.92	0.7
44	45.24	1.81	0.00	17.51	0.025	30	0	1	24.95	0.7
45	44.50	1.80	0.00	27.11	0.025	30	0	1	24.76	0.7
46	43.17	1.77	0.00	19.23	0.025	30	0	1	24.42	0.7
47	12.38	0.90	0.01	17.48	0.035	30	0	1	13.82	0.7

Table C-1. Routing Coefficients

SUBBASIN	CH_W2	CH_D	CH_S2	CH_L2	CH_N2	CH_K2	CH_COV1	CH_COV2	CH_WDR	ALPHA_BNK
48	42.39	1.75	0.00	3.49	0.025	30	0	1	24.22	0.7
49	42.04	1.74	0.00	4.60	0.025	30	0	1	24.13	0.7
50	10.23	0.81	0.01	8.08	0.035	30	0	1	12.67	0.7
51	9.64	0.78	0.01	3.98	0.035	15	0	1	12.33	0.35
52	13.34	0.93	0.01	16.02	0.035	15	0	1	14.30	0.35
53	13.80	0.95	0.01	27.53	0.035	30	0	1	14.52	0.7
54	41.95	1.74	0.00	11.09	0.025	15	0	1	24.10	0.35
55	15.28	1.00	0.00	7.56	0.03	15	0	1	15.21	0.35
56	40.95	1.72	0.00	15.76	0.025	15	0	1	23.84	0.35
57	13.65	0.94	0.01	26.30	0.035	15	0	1	14.45	0.35
58	32.63	1.52	0.00	16.91	0.025	15	0	1	21.50	0.35
59	10.92	0.84	0.01	11.28	0.035	15	0	1	13.05	0.35
60	31.01	1.48	0.00	6.75	0.025	15	0	1	21.00	0.35
61	30.35	1.46	0.00	8.26	0.025	15	0	1	20.80	0.35
62	14.15	0.96	0.01	4.64	0.035	15	0	1	14.69	0.35
63	28.38	1.41	0.00	6.51	0.025	15	0	1	20.17	0.35
64	27.71	1.39	0.00	3.43	0.025	15	0	1	19.95	0.35
65	10.67	0.83	0.01	8.05	0.035	15	0	1	12.91	0.35
66	9.80	0.79	0.01	5.04	0.035	15	0	1	12.42	0.35
67	27.01	1.37	0.00	23.18	0.025	15	0	1	19.72	0.35

C.2 ROUTING COEFFICIENTS DESCRIPTIONS

This table gives a definition of the abbreviations in Table C-1.

Table C-2. Routing coefficients

CH_W2	average width of main channel at top of bank (m)
CH_D	depth of main channel from top of bank to bottom (m)
CH_S2	average slope of main channel along the channel length (m/m)
CH_L2	length of main channel (km)
CH_N2	Manning's "n" value for main channel
CH_K2	effective conductivity in main channel alluvium
CH_COV1	channel erodibility factor
CH_COV2	channel cover factor
CH_WDR	channel width to depth ratio
ALPHA_BNK	baseflow alpha factor for bank storage (days)

Appendix D. Relevant Studies Used in Model Development

The following appendix describes studies in the Tongue River watershed from which data was taken, or assumptions were based, in the development of the Tongue River Watershed Salinity Modeling Report.

Table of Contents

D.1 Tongue River Assessment

United States Protection Agency and Tetratech. 2007a. Water Quality Assessment for the Tongue River Watershed, Montana. Project Manager, Ron Steg.
The primary purpose of this assessment was to compare the available water quality data to the applicable Montana water quality standards and, in cases where exceedances occurred, to provide insight as to the cause based on the results of modeling and analyses. Data is presented for Specific Conductance and SAR, as well as metals and total suspended solids. The entire period of record until 2006 was evaluated, with some SC samples collected as early as 1966. For the mainstem, only one exceedance of the instantaneous SC standard occurred, which was in October 2001. One month (out of 22 months of data) exceeded the irrigation season SC standard at the Birney gauge. Ten months(out of 22 months of data) exceeded the irrigation season SC standard at the Miles City gauge. No samples exceeded the instantaneous or monthly SAR standard. However, data was limited to the last 5 years.

D.2 Loading Simulation Program C++ Modeling Study

United States Protection Agency and Tetratech. 2007b. Modeling the Tongue River Watershed with LSPC and CE-Qual-W2. Project Manager, Ron Steg.
A model was used to simulate watershed processes in the Tongue River watershed, and fate and transport of select chemicals including EC, SAR, total nitrogen, and total phosphorous using the Loading Simulation Program C++ (LSPC). The calibration encompassed the period between 1991 and 2006. The model effort was later transferred to a SWAT platform because it was found that SWAT gave more options related to detailed management conditions for simulating agriculture and livestock management.

D.3 Otter Creek Study

Montana Department of Environmental Quality. 2015. Otter Creek Watershed Salinity Assessment – Modeling Report. Helena, MT: Montana Dept. of Environmental Quality.
To help evaluate salinity loads in the watershed, DEQ applied the Loading Simulation Program in C++ (LSPC) water quality model, in conjunction with field assessments, to Otter Creek and its tributaries. DEQ compiled data from several sources including climate data from four nearby weather stations, land use, soils, and elevation data, and both stream flow and water quality data. This field data was used to populate the model. The model was based on the LSPC model that EPA built in the mid-2000s for the entire Tongue River watershed. DEQ updated, refined, and re-calibrated this model to focus specifically on Otter Creek. In particular, the hydrology and water quality were updated to reflect more local, sites pecific conditions. Other updates included new weather stations located in the watershed, customized irrigation, channel hydraulics, land use, and updates to the number and size of stock ponds and check dams throughout the watershed based on aerial photo interpretation. Water quality refinements included additional water quality data used for calibration. This includes data collected by USGS and DEQ, and hundreds of measurements from Hydrometrics on groundwater quality in the lower portion of the watershed. Once a calibrated existing conditions model was completed, the model was modified to reproduce historical conditions by removing human influences including stock and check dams, urban settlements, and irrigated plant. These modifications show that salinity concentrations in the watershed are not significantly affected by anthropogenic activities. While there is estimated to be less water exiting the watershed than would occur naturally due to irrigation, the water quality associated with

Otter Creek is very similar (< 1% difference in SC and SAR) in both existing and historical scenarios. Over 100 years of agricultural practices in the watershed have resulted in very little practical change in the Otter Creek specific conductivity and sodium adsorption ratio values.

D.4 Trend Analysis

HydroSolutions completed the Tongue River Trend Analysis project in 2022 to support the Montana Department of Environmental Quality (DEQ) in potential development of a salinity Total Maximum Daily Load (TMDL) for the Tongue River downstream of the Tongue River Dam in southeastern Montana. The focus of this study was data from three USGS gages. Specifically, this included specific conductance (SC) and sodium adsorption ratio (SAR) data from these gages:—State Line (06306300), Tongue River Dam (06307500), and Birney School (06307616)— which were evaluated for trends over the period of 2000 to 2020.

Preferred TSM models for SAR at Birney School and Tongue River Dam both identified increasing trends from the early 2000s to 2010-2012, followed by a decreasing trend from the 2010s to 2020. This pattern is generally consistent with increasing SAR during the period of active CBM development and decreasing SAR during the post-peak CBM development period. In contrast, the preferred SAR trend for the State Line site consists of a single decreasing trend from 2000 to 2020, showing no apparent correlation with changes in CBM activity.

The preferred TSM SC trends in general do not directly correspond to the timing of the area’s peak or post CBM development periods. There is no SC trend identified at the Tongue River Dam site and the only SC trend identified at the State Line site is an increasing trend from 2016–2020. Birney School exhibits a slight decreasing SC trend from 2000 to 2006 when CBM activity was high but began to increase in 2006 and continued doing so throughout the period of record even after the end of peak-CBM. Overall, TSM SC trends do not appear to correspond directly with changes in CBM activity.

APPENDIX E. COAL BED METHANE SOURCE DATA SUMMARY

TABLE OF CONTENTS

E.0 INTRODUCTION

Salinity loads from CBM development were primarily based on data from the Montana Pollutant Discharge Elimination System (MPDES) and the Wyoming Pollutant Discharge Elimination System (WYPDES) programs. Water produced and discharged for CBM production is monitored as part of the MPDES and WYPDES permits and reported to each agency via discharge monitoring reports (DMRs). Where data was not available or sporadic, averages of existing data or extrapolation of data was used as described in this section. Off-channel ponds in Montana were not required to obtain an MPDES permit, for those sources produced water data from the Montana Bureau of Oil and Gas Conservation was used. The source of data used to calculate and estimate salinity loading from all the CBM sources in the watershed in summarized in **Table E-1.**

E.1 SUMMARY OF CBM DATA

This table provides a summary of CBM data used in model development.

Table E-1. Summary of data used in SWATSalt Model for flow and concentration from CBM outfalls in Montana and Wyoming

SOURCE DESCRIPTION	TYPE OF DISCHARGE	TIME PERIOD OF DISCHARGE	DISCHARGE RATE MEASUREMENT FREQUENCY AND DATES	CALCIUM, MAGNESIUM AND SODIUM MEASUREMENT FREQUENCY AND DATES	SPECIFIC CONDUCTANCE MEASUREMENT FREQUENCY AND DATES	DATA SOURCE	NOTES
MPDES MT0030457	direct discharge to Tongue River	6/2000 - 10/2010	Monthly. 4/2006 - 10/2010	Monthly. 4/2006 - 10/2010	Monthly. 6/2000 - 10/2010	MPDES DMR	From 6/2000-3/2006 Calcium (Ca), Magnesium (Mg) and Sodium (Na) were not measured. To estimate salinity loads for this period the average Ca, Mg and Na concentrations measured from 4/2006-10/2010 were used with the measured discharge rates.
MPDES MT0030724	direct discharge to Tongue River	6/2006 - 6/2013	Monthly. 6/2006 - 6/2013	Monthly. 6/2006 - 6/2013	Monthly. 6/2006 - 6/2013	MPDES DMR	
MPDES MT0030660	direct discharge to Tongue River	4/2005 - 3/2007	Monthly. 4/2005 - 3/2007	Monthly. 4/2005 - 3/2007	Monthly. 4/2005 - 3/2007	MPDES DMR	

Table E-1. Summary of data used in SWATSalt Model for flow and concentration from CBM outfalls in Montana and Wyoming

SOURCE DESCRIPTION	TYPE OF DISCHARGE	TIME PERIOD OF DISCHARGE	DISCHARGE RATE MEASUREMENT FREQUENCY AND DATES	CALCIUM, MAGNESIUM AND SODIUM MEASUREMENT FREQUENCY AND DATES	SPECIFIC CONDUCTANCE MEASUREMENT FREQUENCY AND DATES	DATA SOURCE	NOTES
Montana Ponds	Off-channnel ponds	8/2006 - 12/2013	Monthly. 8/2006 - 12/2013	None	none	MBOGC	Water quality data was not collected for these outfalls. To estimate salinity loads the average Ca, Mg and Na concentrations measured from MPDES Permit MT0030457 (4/2006 - 10/2010) were used with the measured discharge rates.
Wyoming Discharges	On-channel, off-channel and direct discharge to Tongue River or tributary	1/2000 - 12/2013	Monthly. 1/2000 - 12/2013	Intermittent. 4/2004 - 12/2013	Intermittent. 4/2004 - 12/2013	WYPDES DMR	During the model period there were 228 CBM outfalls in the Wyoming portion of the watershed that received produced water for at least one month. From 4/2004 - 12/2013 49 of those outfalls had one or more date when Ca, Mg and Na concentrations were meaured in the produced water; the total number of measurements was over 1,000. To estimate the salinity load the median of those Ca, Mg and Na measurements were used with the measured discharge rates. The median concentrations were used instead of the average to avoid bias towards outfalls that had more than one date of measurement.

APPENDIX F. LOADEST MODEL RESULTS AT CALIBRATION STATIONS

TABLE OF CONTENTS

F.0. Introduction

Discrete data was also used to estimate Ca, Mg, and Na at calibration stations using LOADEST. LOAD Estimator (LOADEST) is a FORTRAN program for estimating loads in streams and river. Given a time series of streamflow, additional data variables, and concentrations, LOADEST can be used to develop a regression equation to estimate loads.

F.1. LOADEST Regression Models and Performance at Calibration Stations

Table F-1 describes the LOADEST regression equations and model performance for Cations at Birney, T & Y, and Miles City USGS gauges.

Table F-1. LOADEST Regression Models and Performance

Load	Cation	Estimation Method	Model #	Model	Statistic	Load	Concentration
Birney	Ca	AMLE	8	Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)	Bias (%)	-1.558	0.163
					PLR	0.984	1.002
					NSE	0.931	0.734
	Mg	AMLE	7	Ln(Load) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime) + a4 dtime	Bias (%)	-3.356	0.753
					PLR	0.966	1.008
					NSE	0.847	0.689
	Na	AMLE	7	Ln(Load) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime) + a4 dtime	Bias (%)	-5.241	1.538
					PLR	0.948	1.015
					NSE	0.729	0.609
T&Y	Ca	AMLE	9	Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)	Bias (%)	-1.941	0.208
					PLR	0.981	1.002
					NSE	0.871	0.562
	Mg	AMLE	9	Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)	Bias (%)	-4.495	0.81
					PLR	0.955	1.008
					NSE	0.754	0.622
	Na	AMLE	9	Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)	Bias (%)	-6.22	1.459
					PLR	0.938	1.015
					NSE	0.731	0.697

Table F-1. LOADEST Regression Models and Performance

Load	Cation	Estimation Method	Model #	Model	Statistic	Load	Concentration
Miles City	Ca	AMLE	8	Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)	Bias (%)	-1.267	0.545
					PLR	0.987	1.005
					NSE	0.916	0.432
	Mg	AMLE	7	Ln(Load) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime) + a4 dtime	Bias (%)	-2.432	1.532
					PLR	0.976	1.015
					NSE	0.871	0.556
	Na	AMLE	7	Ln(Load) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime) + a4 dtime	Bias (%)	-5.139	1.458
					PLR	0.949	1.015
					NSE	0.744	0.546

Note - PLR = Partial Load Ratio, NSE = Nash-Sutcliffe Efficiency

APPENDIX G. STREAMFLOW CALIBRATION RESULTS FOR BIRNEY AND MILES CITY

TABLE OF CONTENTS

G.0. INTRODUCTION

Total streamflow simulated by the SWAT model at Birney, the T&Y Diversion Dam, and Miles City, MT were compared against USGS timeseries data from 2005 to 2013 for calibration. Streamflow calibration generally focused on comparing incremental and total simulated streamflow against observed streamflow at the USGS gages. The model statistics for Birney, T & Y Diversion, and Miles City gages are presented in Section 6.5.2. The resulting graphs illustrating this calibration for the gage above T & Y diversion are presented in Figures 6-9 & 6-10 within the model report. The same calibration graphs for Birney and Miles City are presented in this appendix.

G.1. SIMULATED VERSUS OBSERVED MONTHLY INCREMENTAL AND TOTAL STREAMFLOW FOR BIRNEY AND MILES CITY GAGES

Figures G-1 and **G-2** illustrate the total and incremental streamflow for the USGS gage at Birney, and Figures **G-3** and **G-4** illustrate the total and incremental streamflow for the UGSG gage at Miles City.

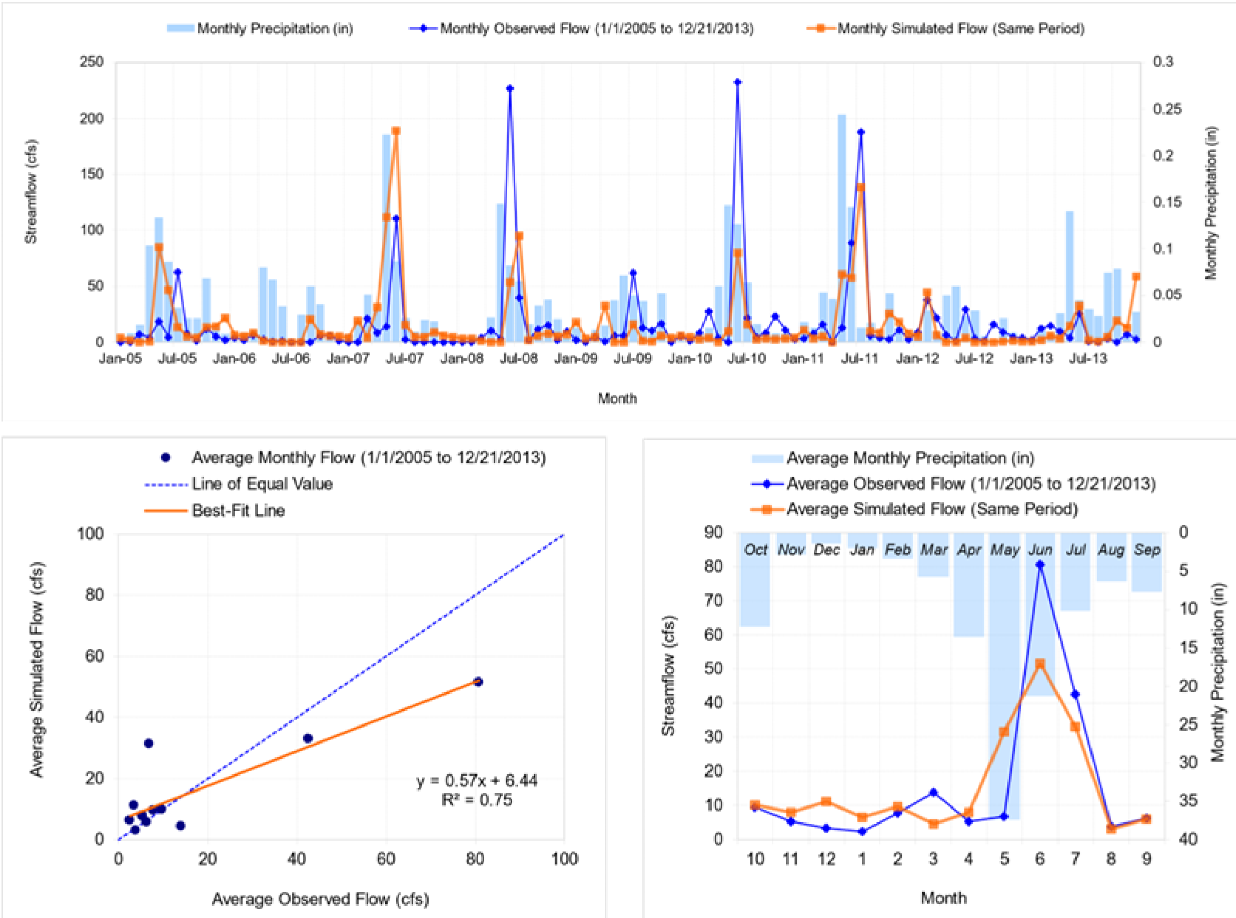


Figure G-1. Simulated and observed monthly incremental streamflow for USGS gage at Birney

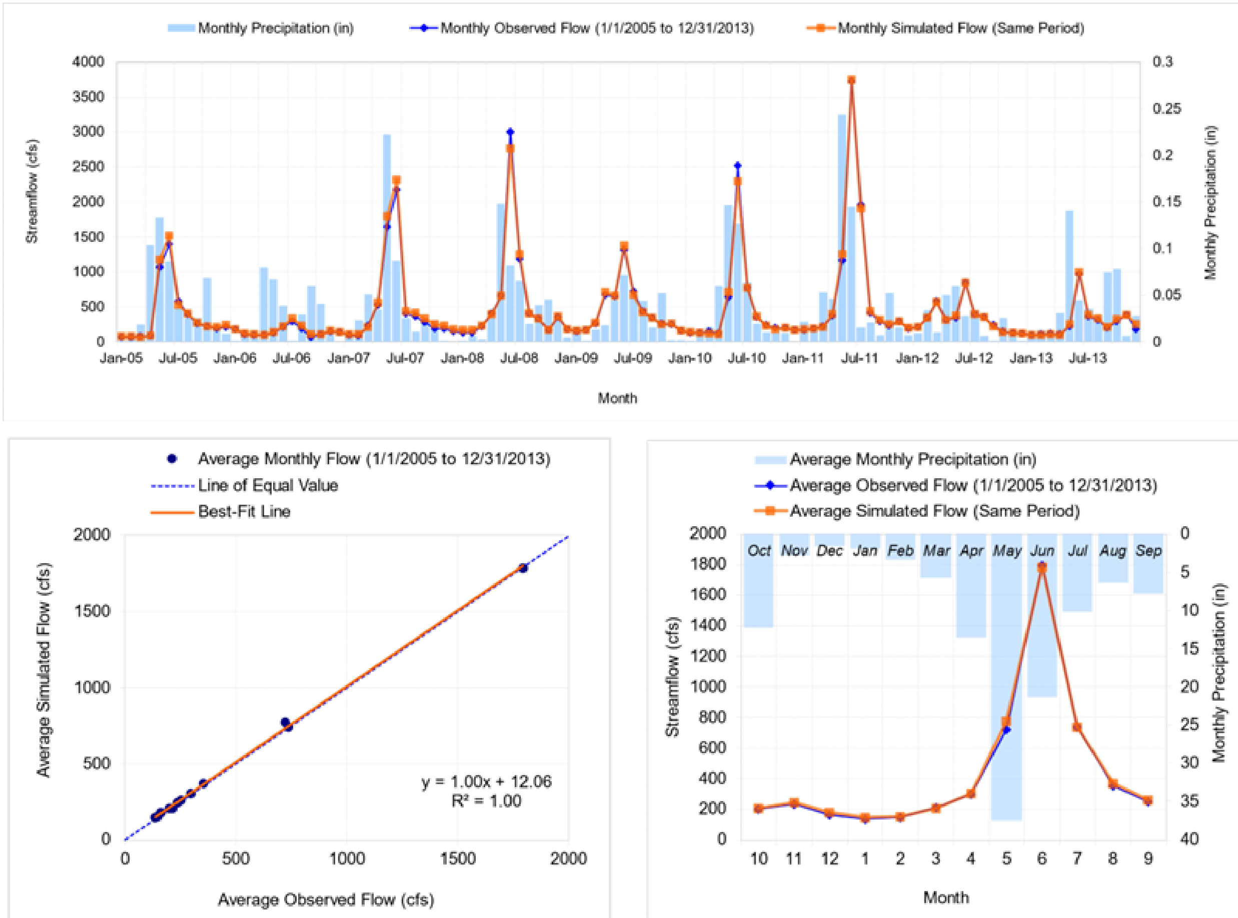


Figure G-2. Simulated and observed monthly total streamflow for USGS gage at Birney

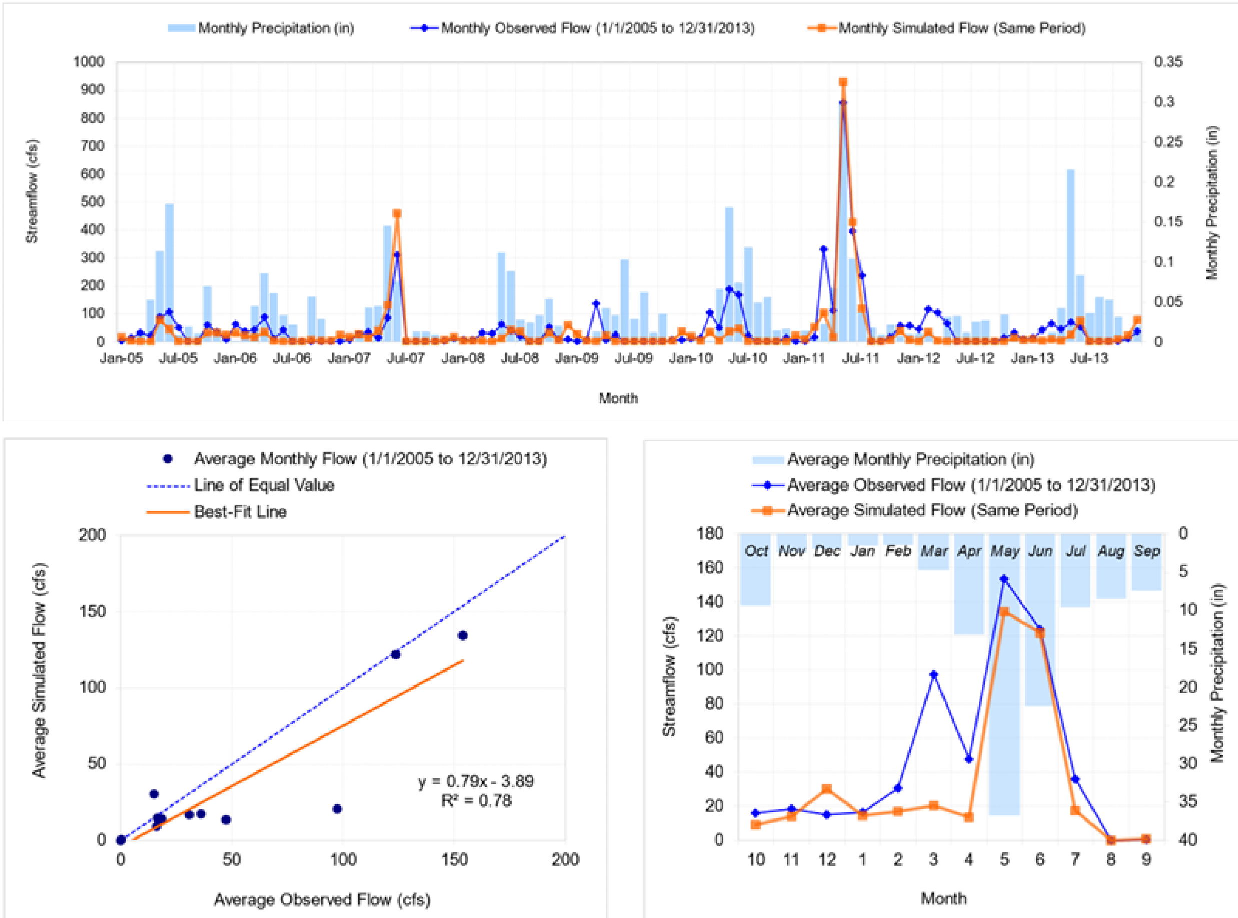


Figure G-3. Simulated and observed monthly incremental streamflow for USGS gage at Miles City

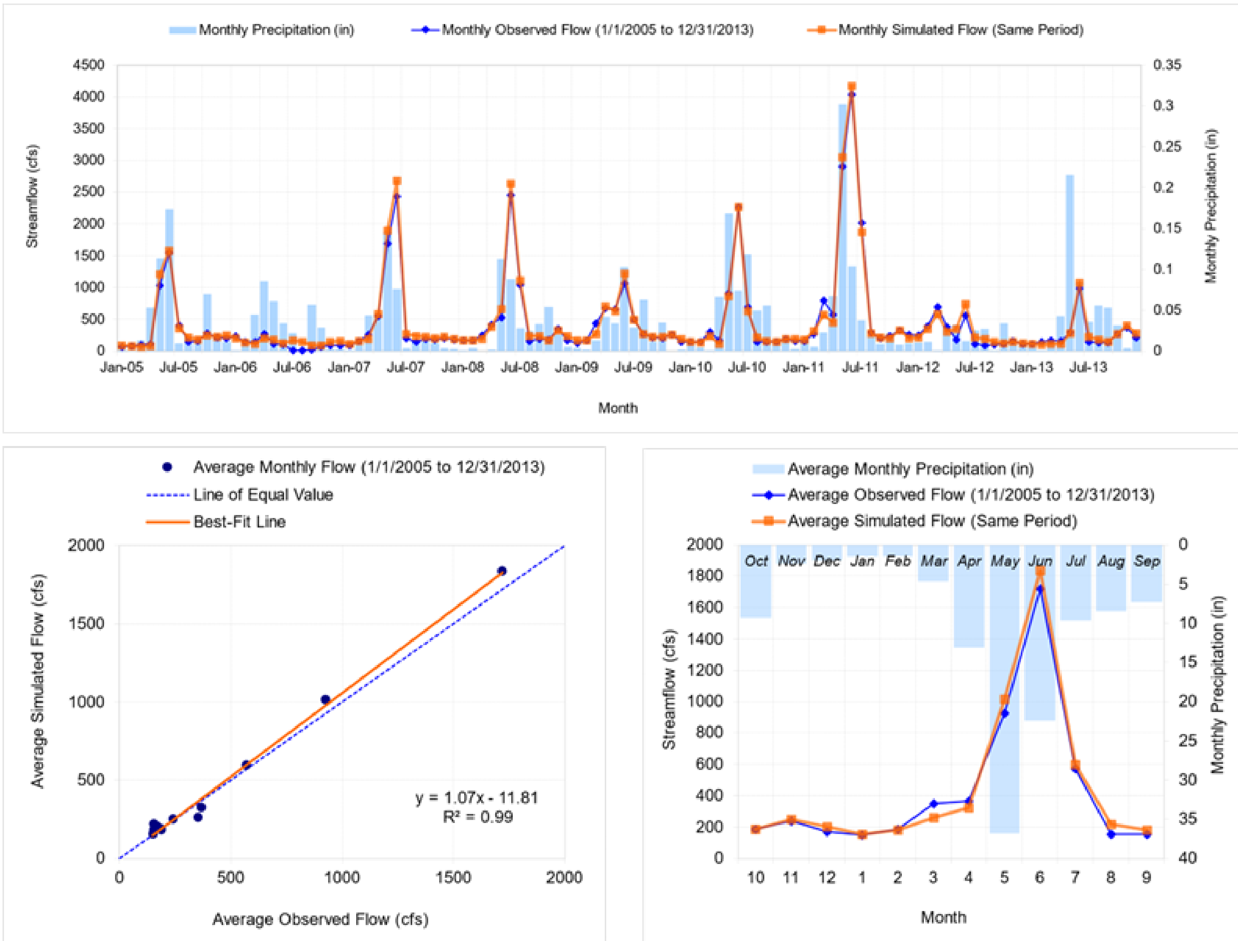


Figure G-4. Simulated and observed monthly total streamflow for USGS gage at Miles City

APPENDIX H. SIMULATED AND OBSERVED CONCENTRATIONS AND LOADS FOR BIRNEY AND MILES CITY CALIBRATION STATIONS

TABLE OF CONTENTS

H.0. Introduction

Salt concentrations and loads simulated in the model are determined by a combination of tributary boundary conditions and user-specified salt concentrations in local surface and subsurface flow pathways (**Section 6.5.3**). A regression relationship was used to estimate SC from the salt concentrations (**Section 6.5.4**) and equation 1 in **Section 3.2** was used to calculate SAR from cation concentrations (**Section 6.5.5**). Results for Birney and miles City calibration gage are provided here and results for the calibration gage at T & Y Dam are provided in **Section 6.5.**

H.1 Simulated Versus Observed Cation Concentration Results-Birney and Miles City

Simulated versus observed cation concentrations for Birney and Miles City are provided in **Figures H-1** to **H-6**.

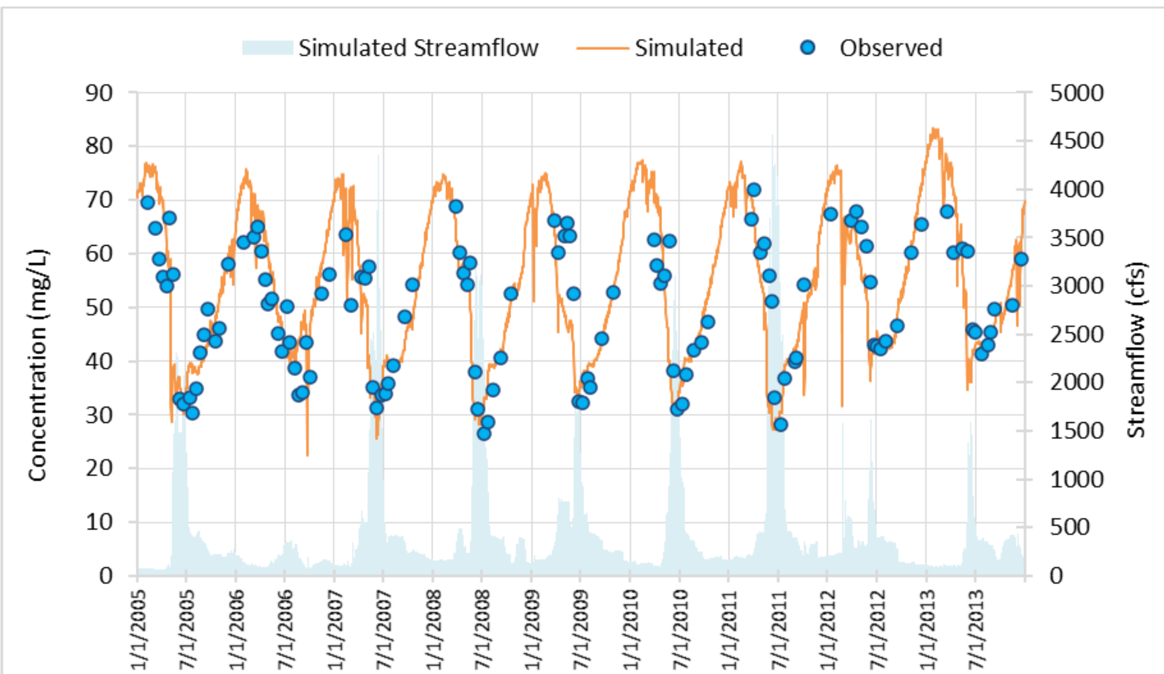


Figure H-1. Daily simulated and discrete observed Ca concentrations at Birney

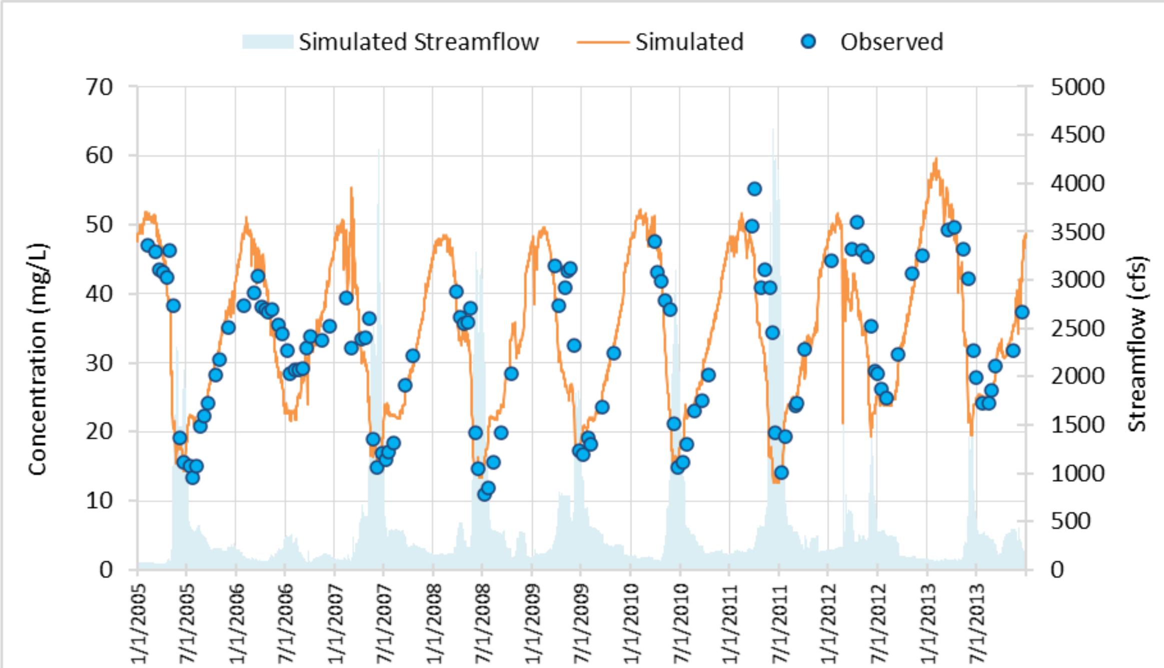


Figure H-2. Daily simulated and discrete observed Mg concentrations at Birney

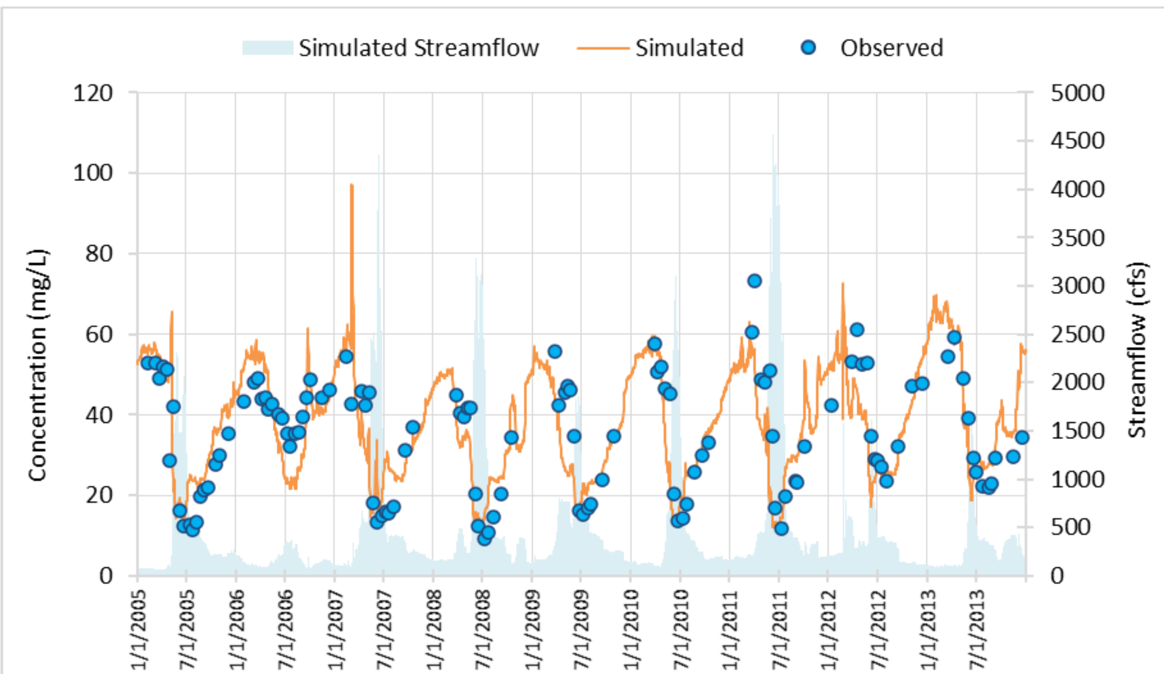


Figure H-3. Daily simulated and discrete observed Na concentrations at Birney

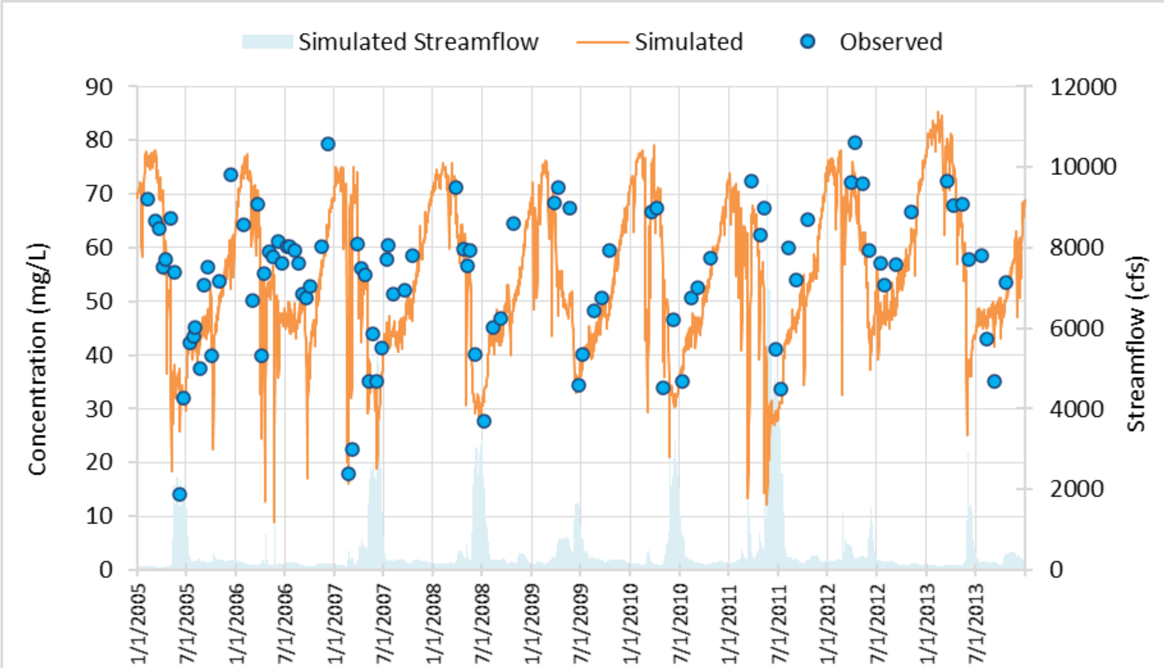


Figure H-4. Daily simulated and discrete observed Ca concentrations at Miles City

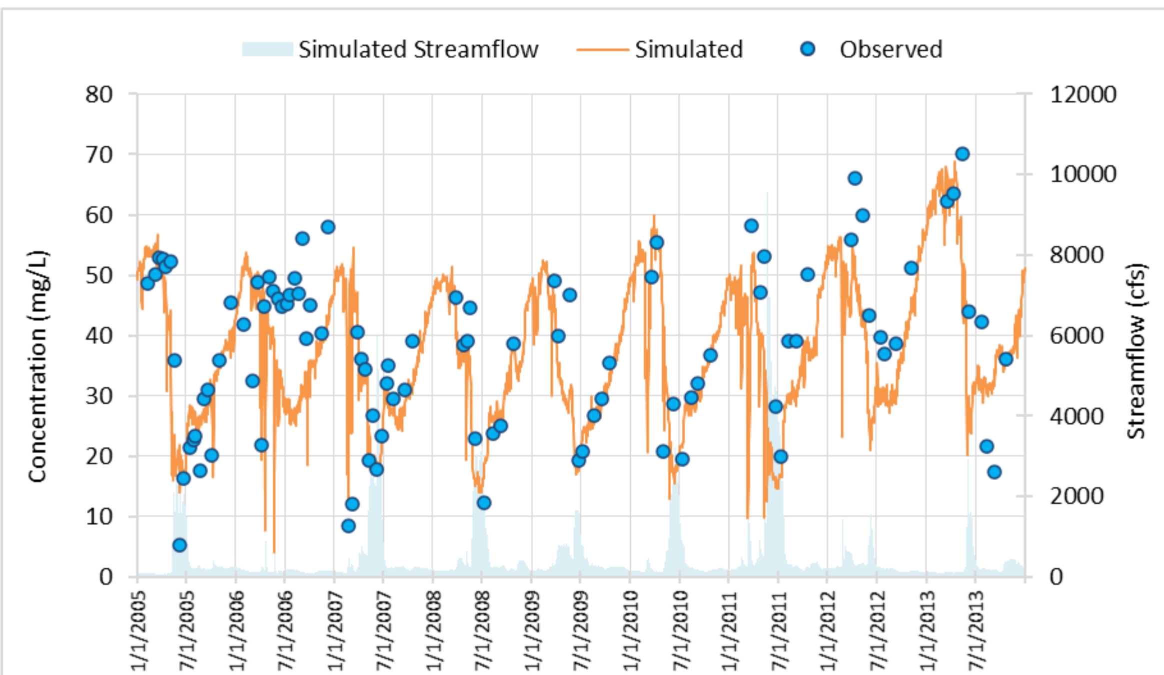


Figure H-5. Daily simulated and discrete observed Mg concentrations at Miles City

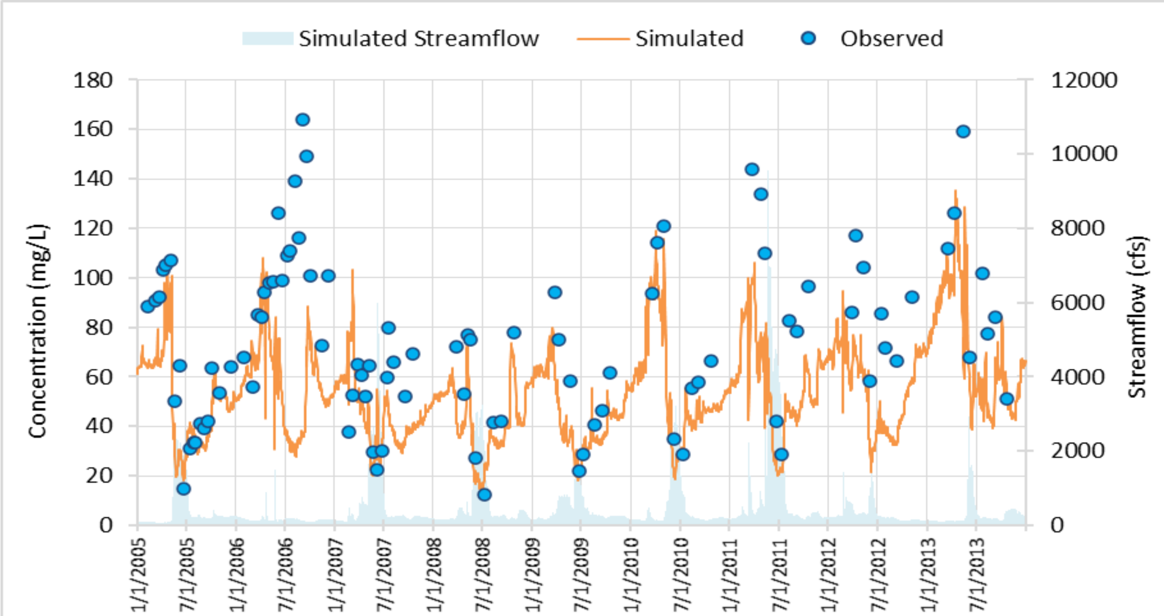


Figure H-6. Daily simulated and discrete observed Na concentrations at Miles City

H.2 Simulated Versus Observed Cation Load Results-Birney and Miles City

Simulated versus observed cation loads for Birney and Miles City are provided in **Figures H-7** to **H-12**.

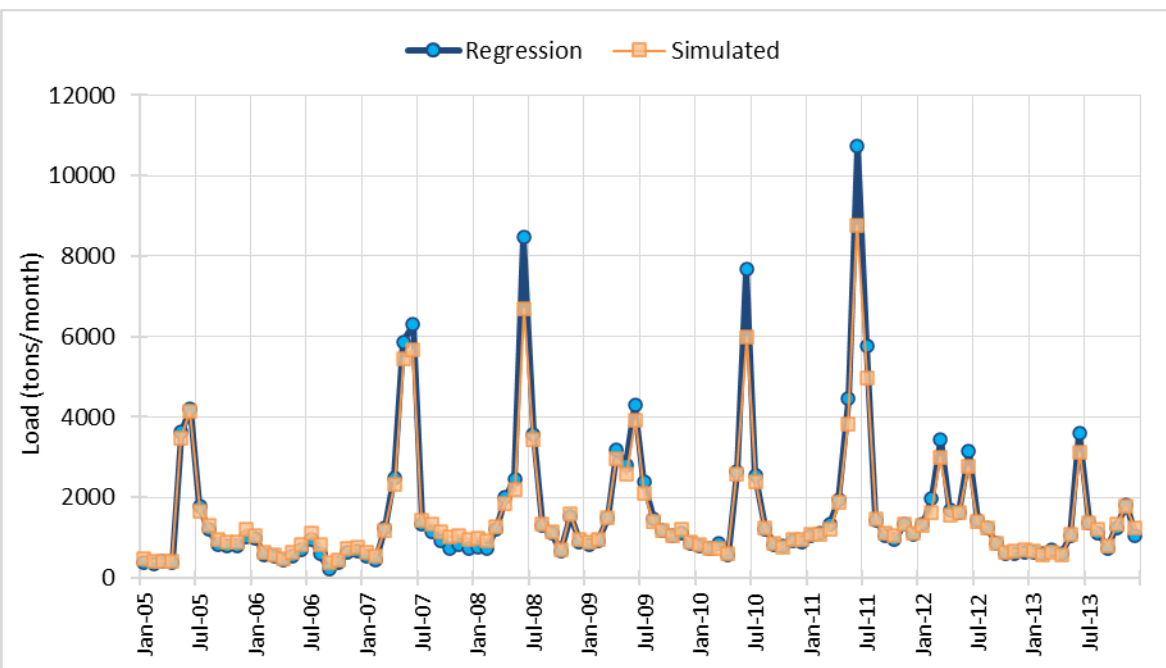


Figure H-7. Monthly simulated and regression loads for Ca at Birney

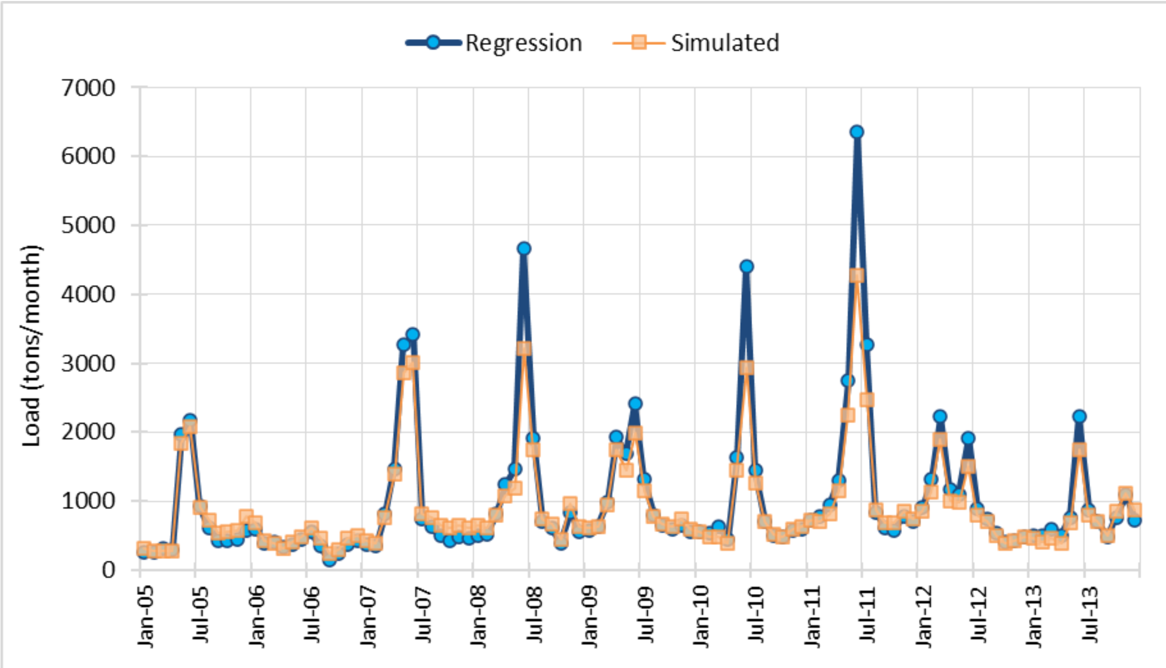


Figure H-8. Monthly simulated and regression loads for Mg at Birney

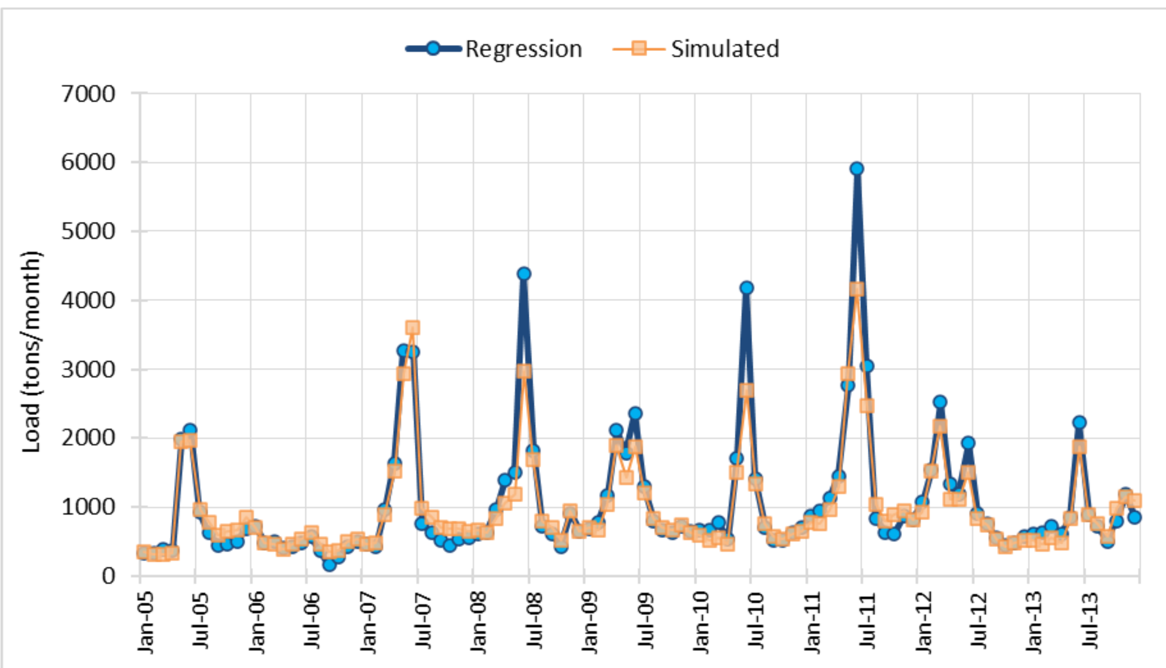


Figure H-9. Monthly simulated and regression loads for Na at Birney

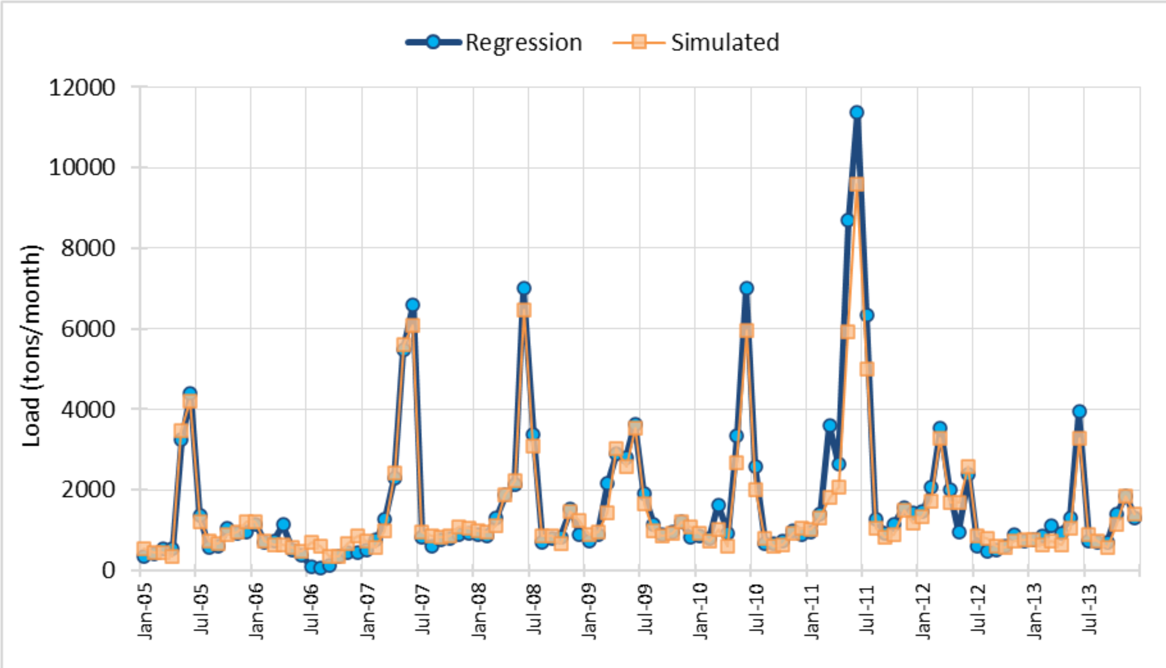
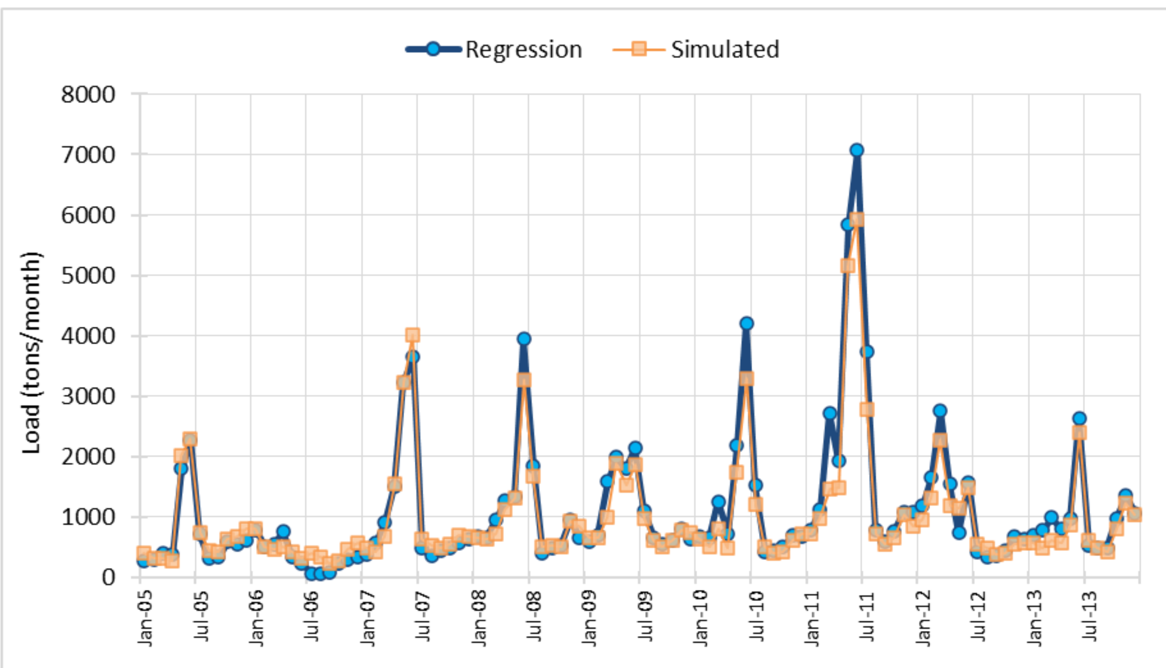


Figure H-10. Monthly simulated and regression loads for Ca at Miles City



H-11. Monthly simulated and regression loads for Mg at Miles City

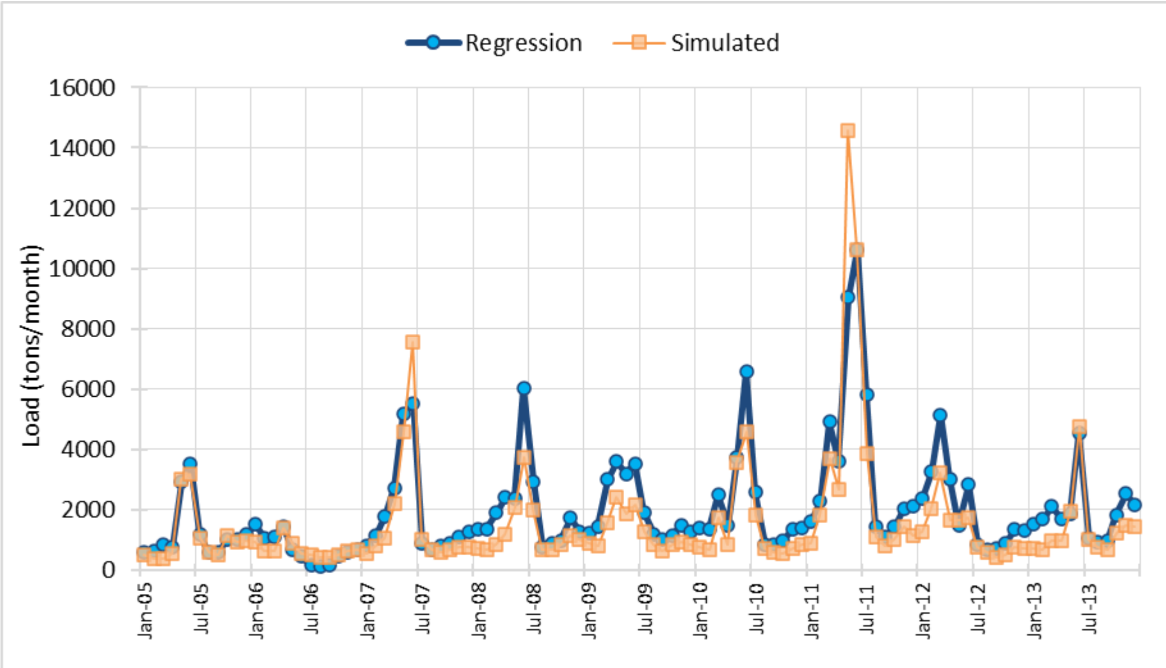


Figure H-12. Monthly simulated and regression loads for Na at Miles City

H.3 Simulated Versus Observed Daily and Monthly SC Results for Birney and Miles City

Simulated versus observed daily (top) and monthly SC (bottom) values are graphed for Birney (**Figure H-13**) and Miles City (**Figure H-14**).

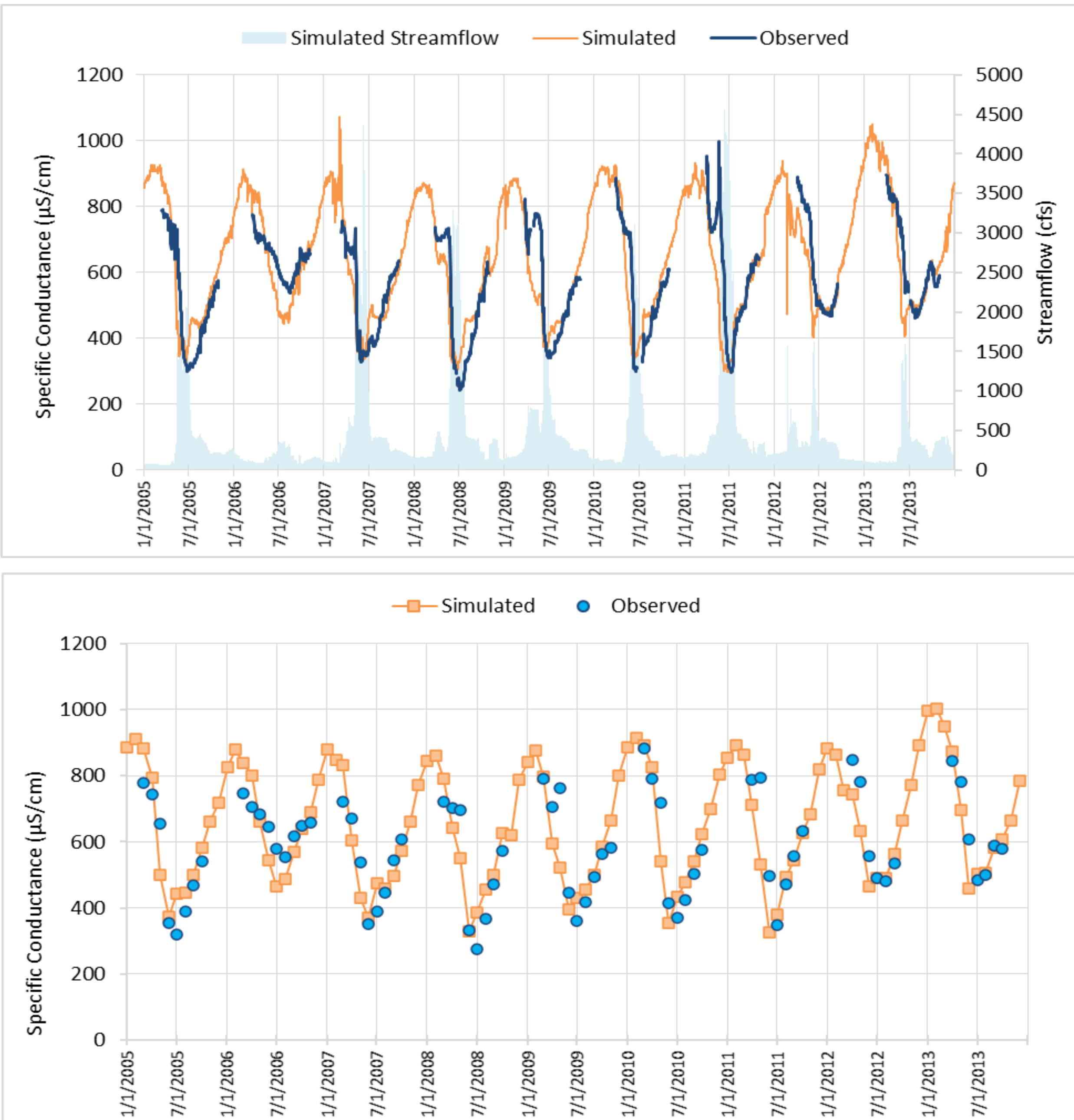


Figure H-13. Average daily (top) and monthly (bottom) simulated and continuous observed SC at Birney

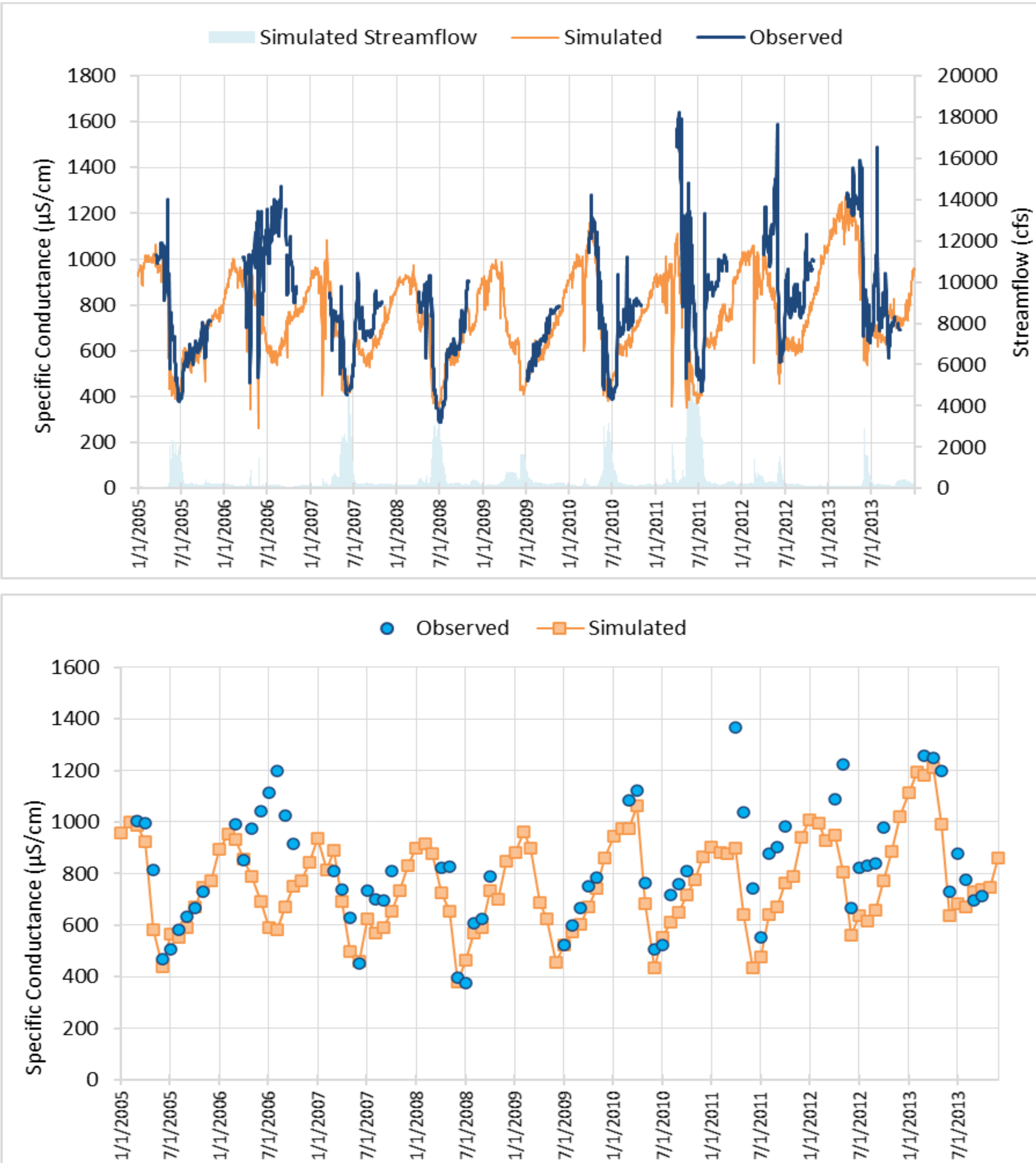


Figure H-14. Average daily (top) and monthly (bottom) simulated and discrete observed SC at Miles City

H.4 Simulated Versus Observed Daily and Monthly SAR Results for Birney and Miles City

Simulated versus observed daily (top) and monthly SAR (bottom) values are graphed for Birney (**Figure H-15**) and Miles City (**Figure H-16**).

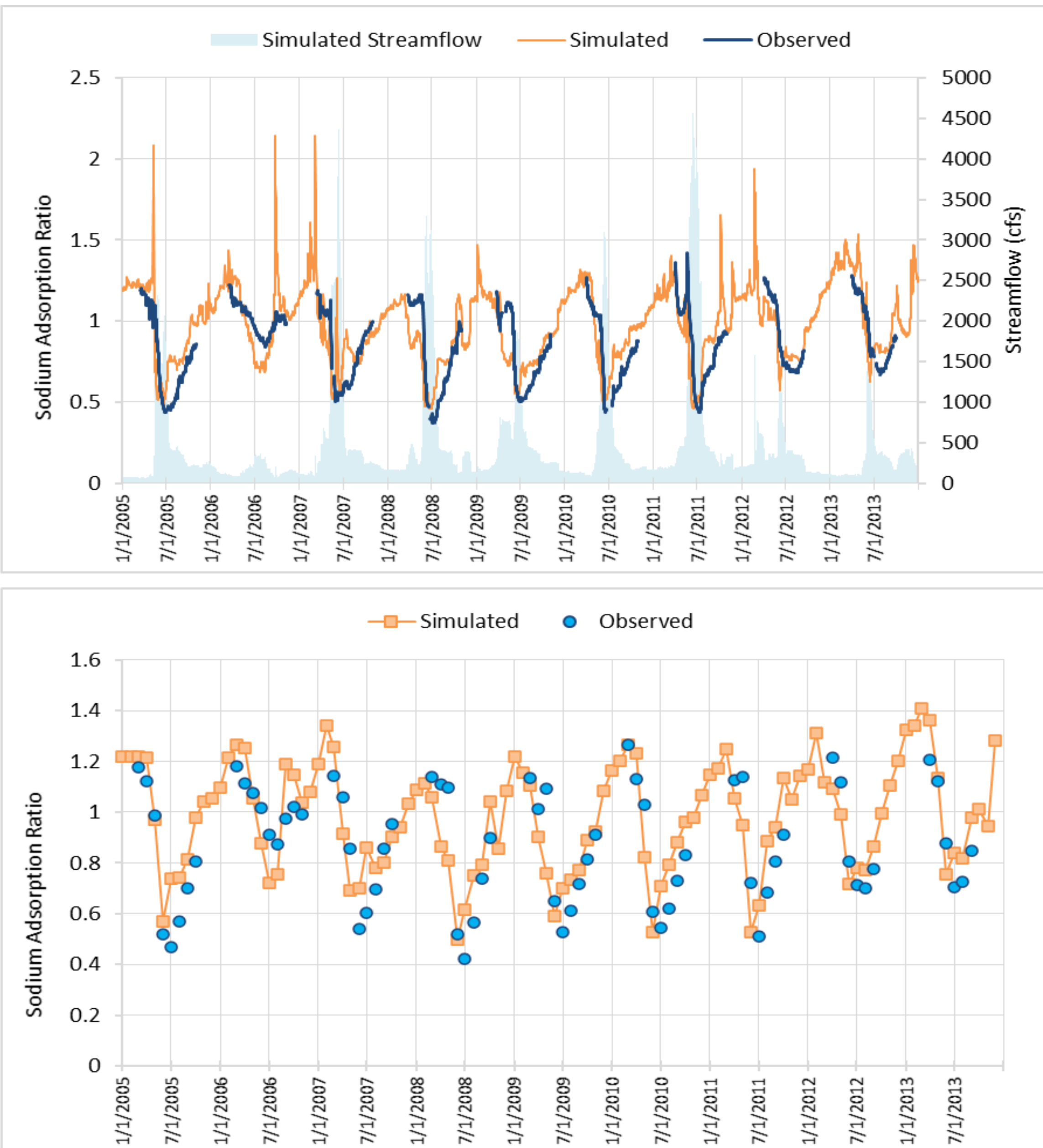
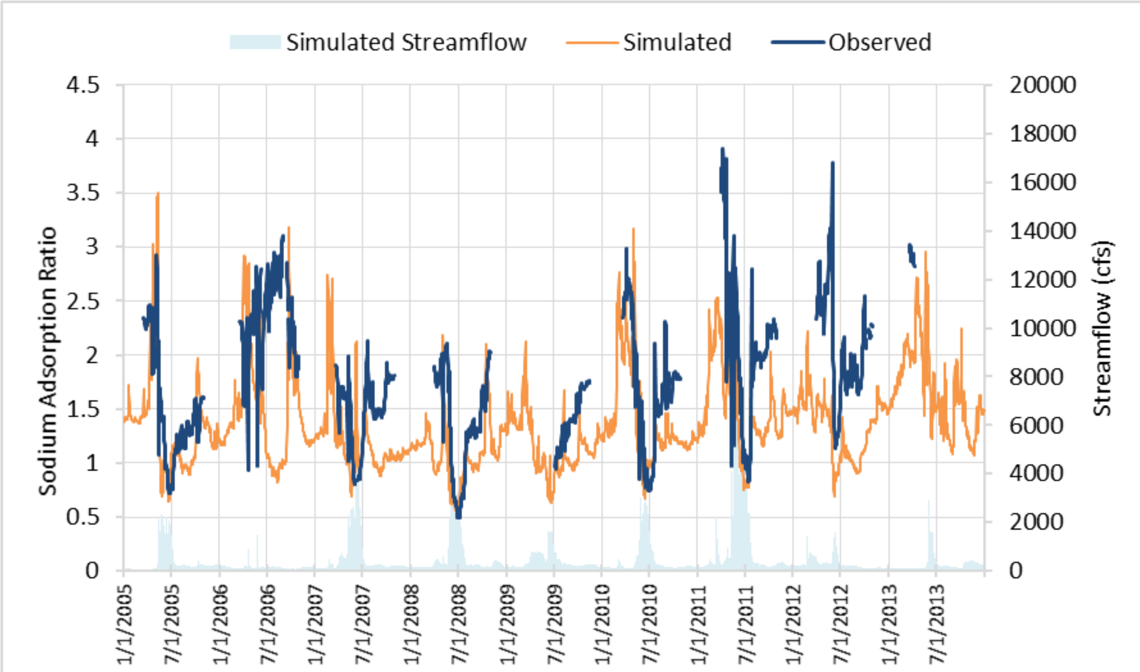


Figure H-15. Average daily (top) and monthly (bottom) simulated and continuous observed SAR at Birney



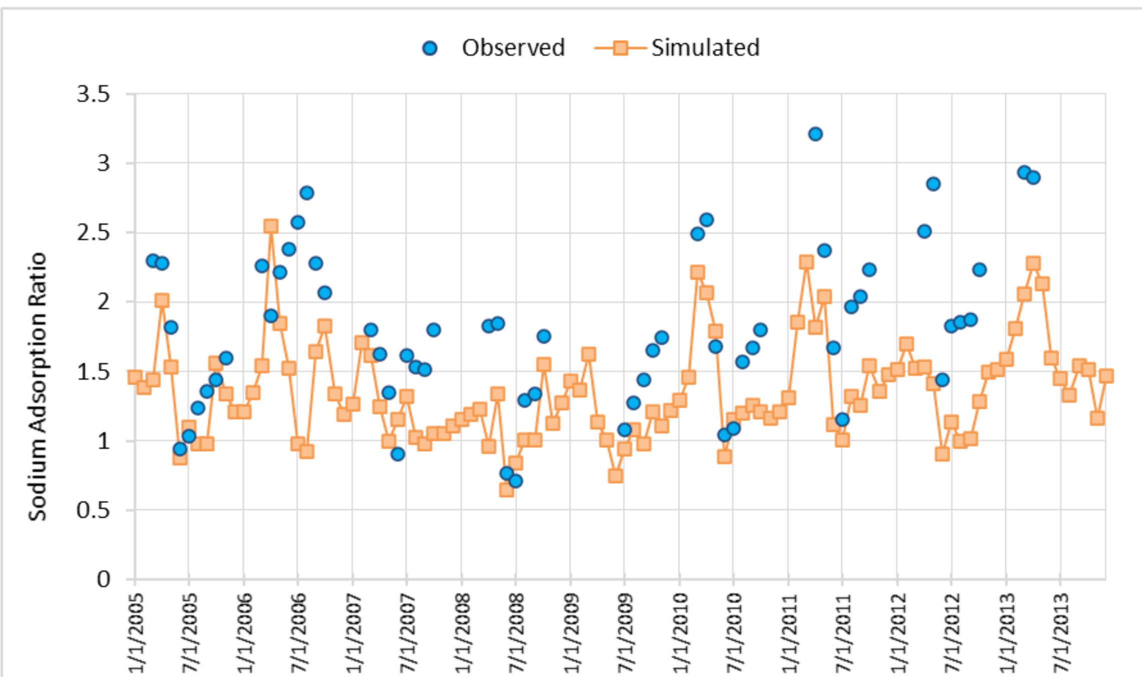


Figure H-16. Average daily (top) and monthly (bottom) simulated and continuous observed SAR at Miles City

Appendix I. Seasonal and Annual Flow Volumes for Non-Alfalfa Land Uses

Table of Contents

APPENDIX I. FLOW VOLUMES FOR NON-ALFALFA LAND USES

I.0 INTRODUCTION

It should be noted that geology and existing soil characteristics have a large influence on salt loading. As such, some of the patterns in the unit area loading rates are due to these natural conditions rather than the type of anthropogenic land use/activity (i.e., alfalfa/hay) occurring there. The graph showing loading by flow path type for alfalfa is **Figure 6-24** in the model report. The loading by flow path type for the other land uses is found in this appendix. For alfalfa, rangeland, and hay land uses (**Figure 6-24**,**Figure I-1**,**Figure I-3**, and **Figure I-4**) both lateral flow and surface flow are dominant. For forest, the bulk of the load is in lateral flow (**Figure I-2**). For wetlands, the bulk of the load is in groundwater flow (**Figure I-5).** For urban land use, the bulk of the load is in surface flow.

I.1. SIMULATED SALT LOADS AND FLOW VOLUMES

Appendix I-1 to I-6 contains simulated seasonal and annual average surface runoff, lateral flow and groundwater flow volumes and salt loads for the non-alfalfa simulated land uses.

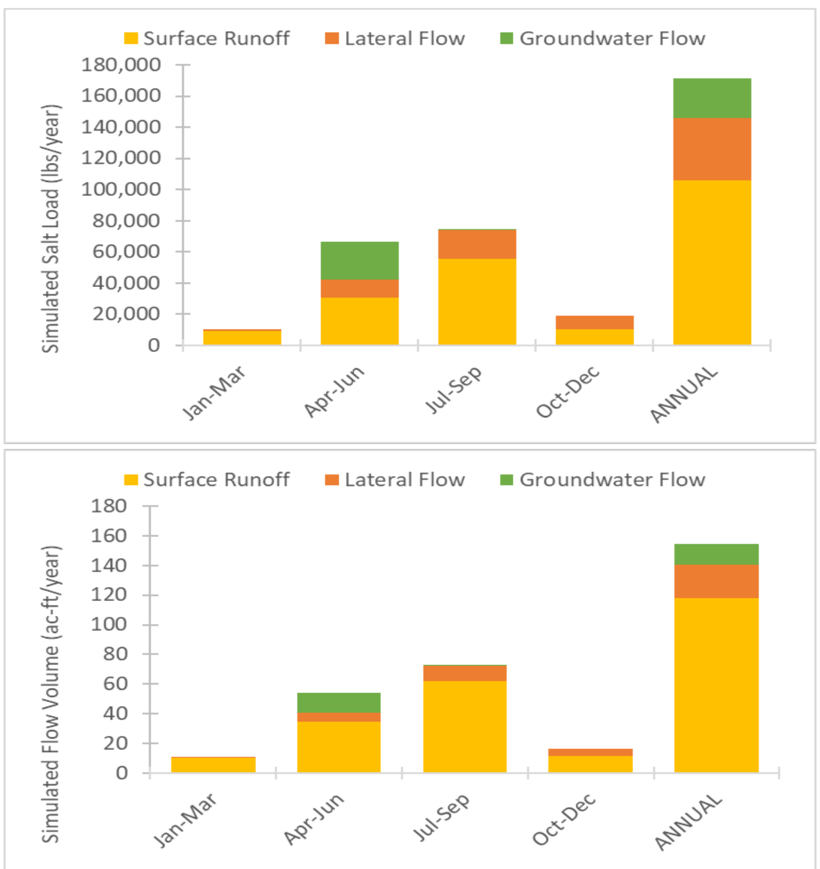


Figure I-1. Simulated seasonal salt load and flow volume for hay by type.

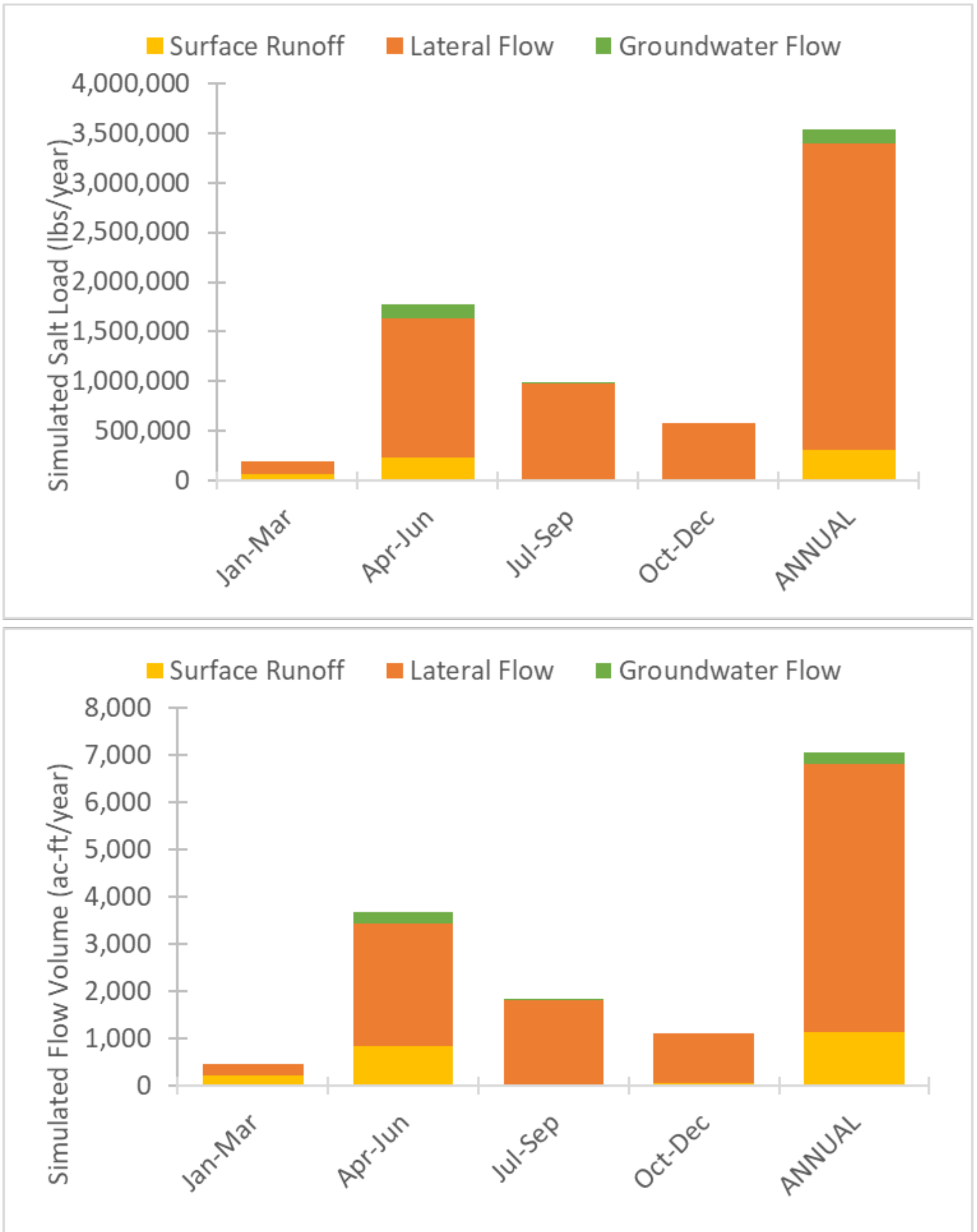
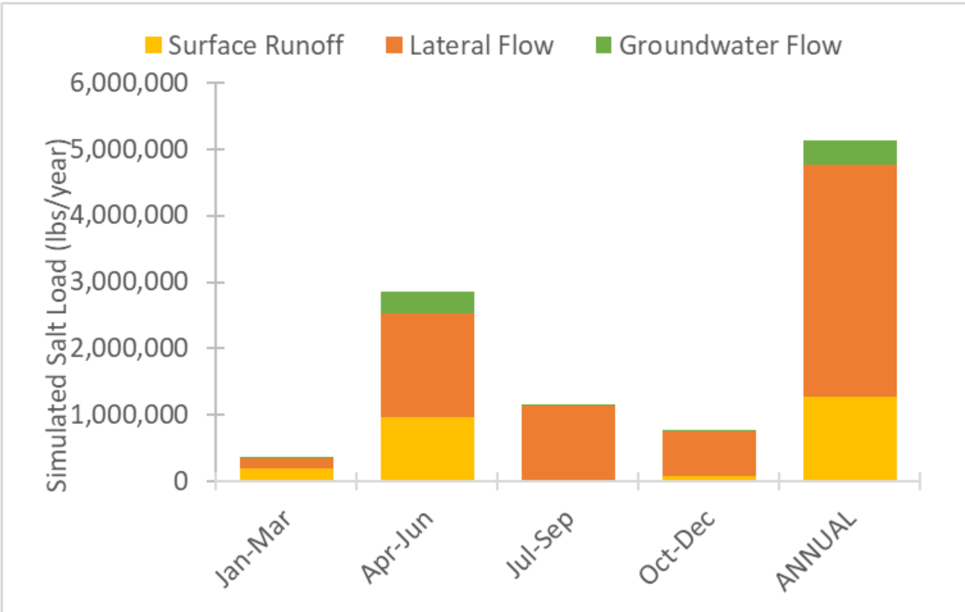


Figure I-2. Simulated seasonal salt load and flow volume for forest by type.



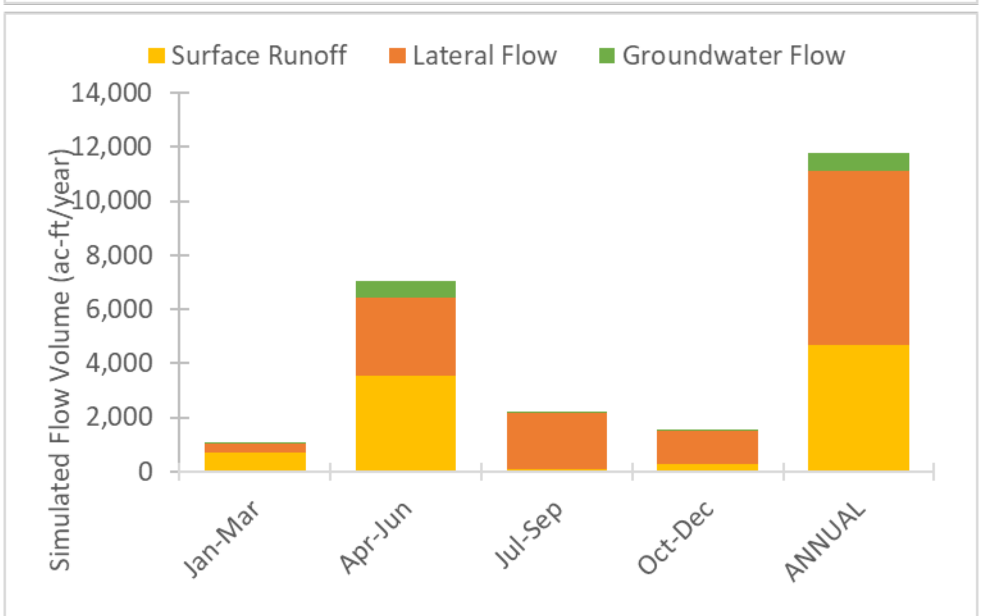


Figure I-3. Simulated seasonal salt load and flow volume for rangebrush by type.

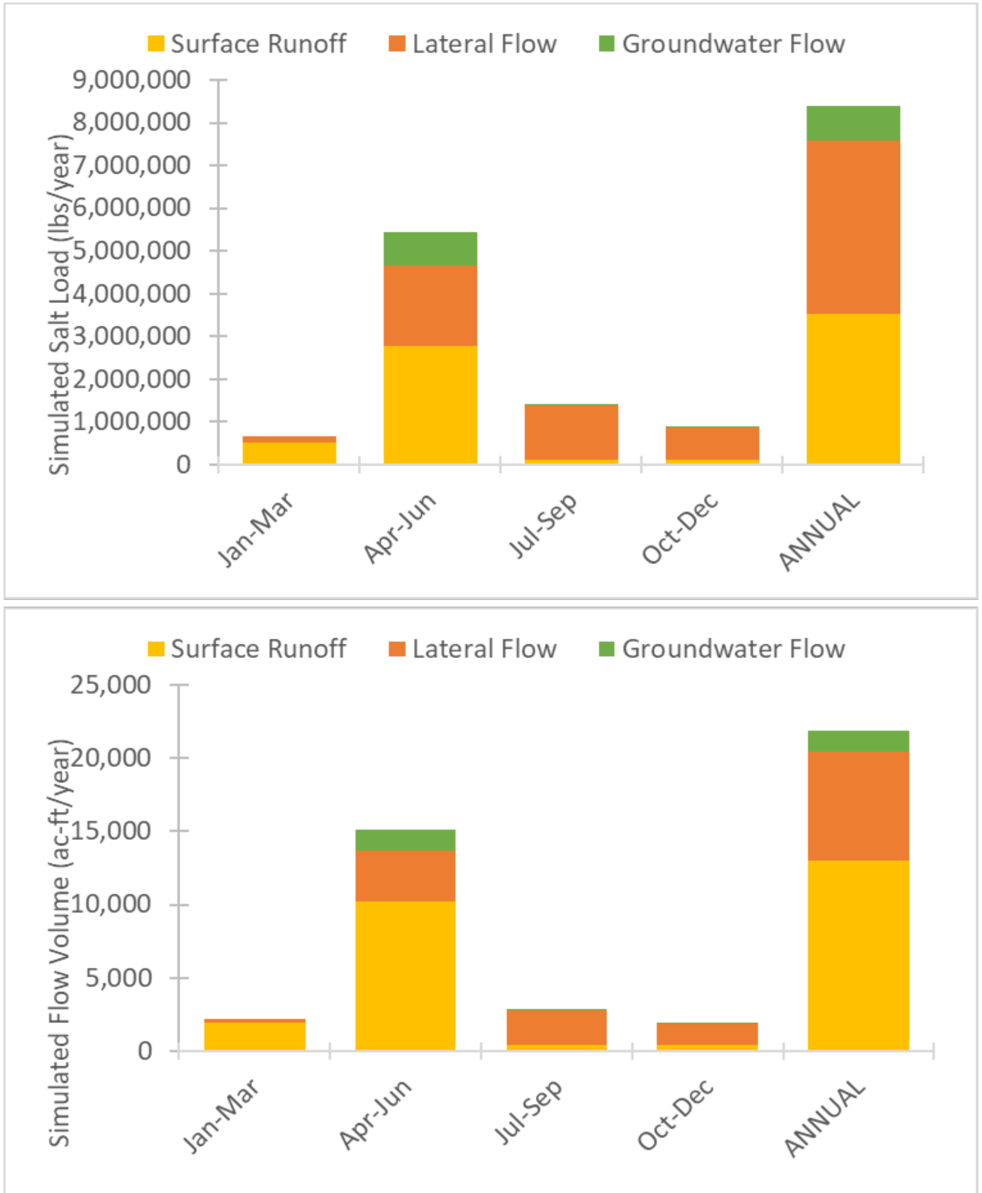
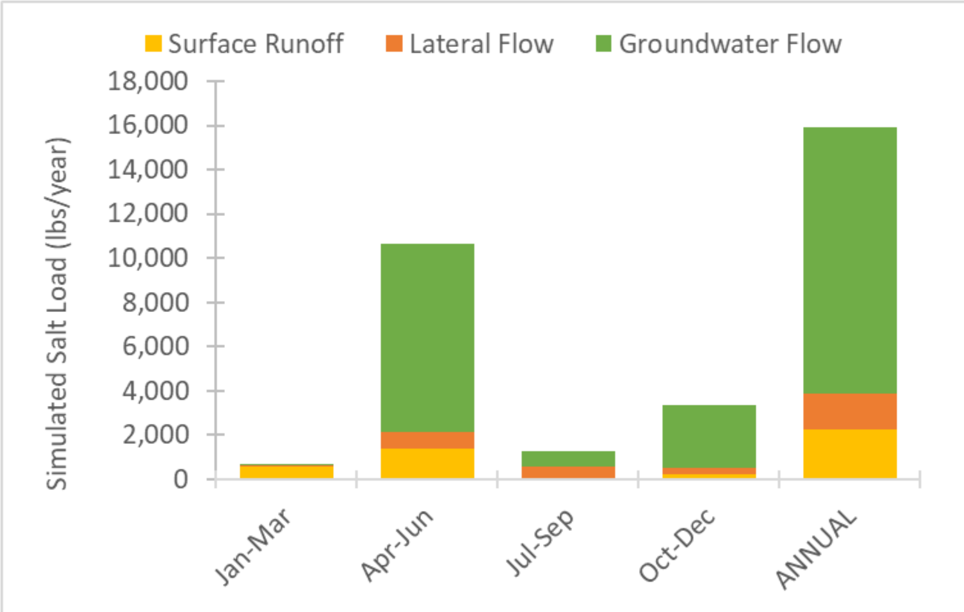


Figure I-4. Simulated seasonal salt load and flow volume for rangegrass by type.



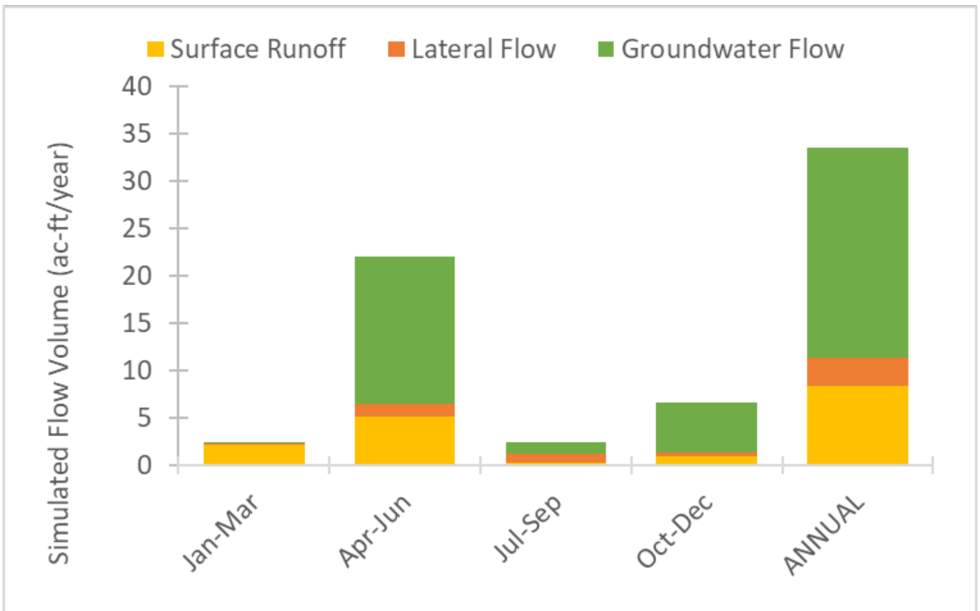


Figure I-5. Simulated seasonal salt load and flow volume for wetlands by type.

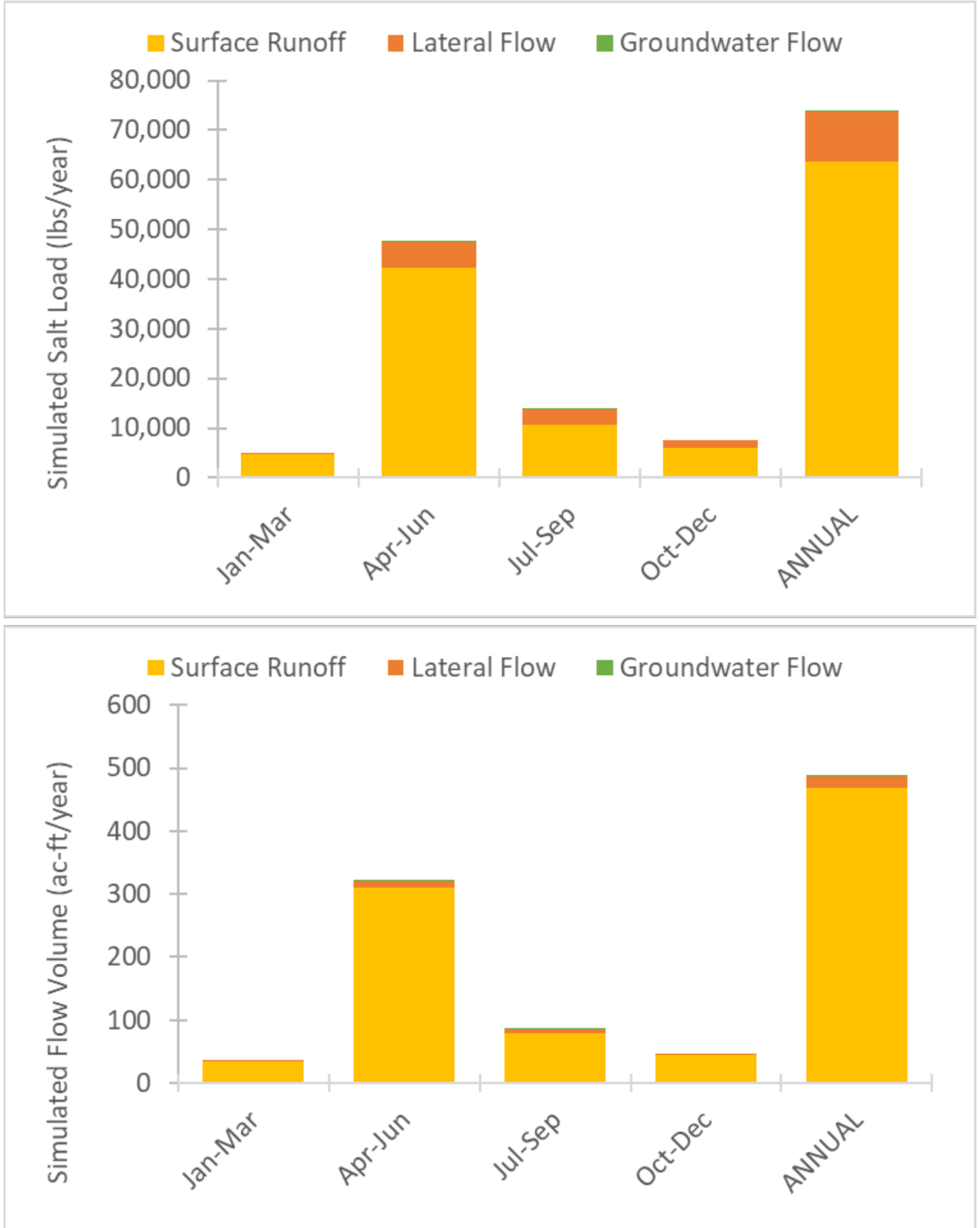


Figure I-6. Simulated seasonal salt load and flow volume for urban land use by type.