THESIS

SALT TRANSPORT IN THE SOUTH PLATTE RIVER SYSTEM: MODELING, CONTROLLING FACTORS, AND MANAGEMENT STRATEGIES

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2021

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ABSTRACT

SALT TRANSPORT IN THE SOUTH PLATTE RIVER SYSTEM: MODELING, CONTROLLING FACTORS, AND MANAGEMENT STRATEGIES

Increasing salinity poses a severe threat to urban and agricultural areas. Excess salt can accumulate in soils and groundwater, thereby impacting crop growth and productivity. This thesis aims to quantify the influence of the driving forces behind salt transport in Colorado's agro-urban South Platte River network, which has an approximate drainage area of 24,300 mi^2 (62,937 km^2), and investigates possible mitigation strategies to reduce salinity levels in both urban and agricultural river reaches. For this study, a one-dimensional in-river salt transport model was developed for the South Platte River system utilizing StateMod (Colorado's Division of Water Resources water allocation model) to simulate streamflow. The model accounts for multiple inputs and outputs of salt within the river network, including tributaries, wastewater treatment plants, road salt, runoff return flows from irrigation, and groundwater discharge, the latter from interpolated groundwater concentration maps generated from sampling data provided by the Agricultural Water Quality database. These concentration data are combined with the StateMod-simulated streamflow to simulate salt flow through the river network. The flow and salt models were run on a monthly basis over five years between 2002 and 2006. Based on Nash-Sutcliffe Coefficient of Efficiency (NSCE) statistics for the flow and salt models, 85% of the flow model's monthly NSCE values and approximately 68% of the salt model's monthly NSCE values fell within the acceptable range of zero to one.

A global sensitivity analysis was implemented to determine the controlling factors behind salt transport in the river system. Two different scenarios were run: a reach-to-reach sensitivity study where the South Platte River was divided into five different reaches, and a seasonal sensitivity study performed over the entire South Platte River for spring (March to May), summer (June to August), fall (September to November), and winter (December to February). For urban areas located in the upstream region of the basin, controlling factors include wastewater treatment plant (WWTP) effluent concentration, salt in urban return flows, the initial concentration of salinity in upstream river water, and road salt loading. For agriculture areas located in the downstream region of the basin, controlling factors include the WWTP effluent concentration, salt in urban return flows, salt in agricultural return flows, and road salt loading, indicating the influence of upstream salinity loadings on downstream river water.

Based on the sensitivity studies results, an assessment of potential management practices (MPs) was carried out for both urban and agricultural reaches. A total of 256 different MP trials were run each month. The final MP results were then calculated as the averages of the individual monthly results. A point system was assigned to help rank the trials by how efficient they were at reducing salinity levels. For the urban region, the most efficient MP during the spring and summer months is to reduce WWTP effluent concentration by 35%, resulting in a salinity concentration of 340 mg/L, a decrease of 17% from the baseline value. During the fall and winter months, the most efficient MP is to reduce road salt by 35%, resulting in a salinity concentration of 730 mg/L, a decrease of 19% from the baseline value. For agricultural areas, very few MP combinations achieve an in-river salinity concentration less than 1000 mg/L, which is approximately the level in irrigation water at which crop yield decreases. The most effective MP to accomplish this consists of a 35% reduction in WWTP effluent concentration, salt in urban return flows, salt in agricultural return flows, and road salt loading. These results point to the extreme challenge of managing salinity in the South Platte River Basin and the aggressive approaches that must be implemented to sustain irrigation practices in the basin's downstream regions. In general, this thesis provides a framework for assessing salinity movement and mitigation in a large-scale urban-agricultural river basin.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Ryan Bailey, for his support during this project. His guidance and knowledge were invaluable. This research was funded by a grant from the National Science Foundation, Award No. 1845605.

I would also like to thank the following people for helping with this research project:
Fatima Aliyari for the help she provided me after I first joined Dr. Bailey's research group.
Grady O'Brien at NEIRBO for taking the time to answer my questions and providing insight.
Kelley Thompson at Colorado's DWR for his patience and willingness to help.

I would also like to acknowledge Michael Ronayne and Jeffery Niemann for participating in my master's committee and providing valuable advice.

Finally, I'm grateful to Caislin Wheeler for supporting me during this time, as well as my parents for their never-ending encouragement.

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Q_{Node}	[m^3/s]	StateMod Output Flowrate
Q_i	[m^3/s]	Adjusted StateMod Flowrate at the Current Step
Q_{gw}	[m^3/s]	Total Groundwater Flow between StateMod Nodes
Q_{ret}	[m^3/s]	Total Return Flow between StateMod Nodes
Q_{trib}	[m^3/s]	Tributary Flowrate
Q_{wwtp}	[m^3/s]	Wastewater Treatment Plant Effluent Flowrate
C_i	[mg/L]	Concentration at the Current Step
C_{node}	[mg/L]	Concentration at the StateMod Node
C_{gw}	[mg/L]	Concentration of the Groundwater Flow between StateMod Nodes
C_{ret}	[mg/L]	Concentration of the Return Flow between StateMod Nodes
C_{trib}	[mg/L]	Concentration of a Tributary
C_{wwtp}	[mg/L]	Concentration of a Wastewater Treatment Plant Effluent
$\dot{M}_{\mathrm{road}}$	[mg/s]	Mass Loading Rate of Road Salt
n	-	Number of Cells between StateMod Nodes
N	-	Number of Data Points
M_{i}	-	Modeled Value
O_i	-	Observed Value
$\overline{O}$	-	Mean of the Observed Values
EE_k	-	Elementary Effect of Parameter k
n_k	-	Number of Elementary Effects
SEE_k	-	Standardized Elementary Effect
σ_k^*	-	Mean of the Standardized Elementary Effects
μ_{k}^*	-	Standard Deviation of the Standardized Elementary Effects

1. Introduction

Soil salinity is a worldwide threat to global agricultural and food industries. Saline soil can interfere with a crop's nitrogen and water uptake, growth, and reproduction leading to severe crop losses (Queensland Government, 2013). Elevated levels of salt can turn previously rich land non-arable. According to a report by the U.S. Department of Agriculture (USDA), only 15% of the earth's cultivated land is irrigated. Yet, this small percentage of land accounts for approximately 35 to 40% of global food production (USDA, 2019). As the world's population continues to grow, it is paramount that our arable lands are protected to meet global food demands. In their report, the USDA estimates that 10 million hectares of land are lost every year due to salinization. The more land lost, the greater the threat to global food supplies, making it vital to study salinization and how best to prevent it.

The South Platte River Basin in the western United States spans three different states: Colorado (79%), Nebraska (15%), and Wyoming (6%) and has an approximate drainage area of 24,300 mi^2 (62,937 km^2) (Dennehy, 1998). The primary river, the South Platte River, begins in central Colorado and flows northeast to Nebraska. Water development in the South Platte River Basin began in the 1870s and expanded rapidly with the construction of diversions, reservoirs, and wells. A report by the United States Geological Survey (USGS) estimated that irrigated agriculture only accounts for 8% of land use in the South Platte River Basin, but as much as 71% of the basin’s water use (Dennehy, 1998). In a South Platte Basin Implementation Plan published by the Metro and South Platte Basin Roundtable, agricultural production in 2007 over the South Platte River Basin accounted for 73% of Colorado's agrarian products produced that year while generating $4.4 billion in revenue (Cook, 2015).

Salinity levels in the surface water, soil, and groundwater throughout the South Platte River Basin have been increasing over the past decades, drastically increasing the risk to crop growth and productivity (NERIBO, 2020). A salinity study on the South Platte River Basin recently published by NEIRBO found that salinity levels, measured as total dissolved solids (TDS), in the upper part of the basin have increased from approximately 400 mg/L in 1995 to close to 700 mg/L in 2018 (NEIRBO, 2020). The study showed that the South Platte River's salinity level in the lower part of the basin could be as low as 200 mg/L. This value increases to an average of 569 mg/L near the Denver Metro area, up to 700 mg/L around Kersey, and continues to rise towards 1,165 mg/L near the Nebraska border.

In a report published as part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program, researchers estimated that the annual precipitation in the South Platte River Basin was only 12-16 inches, resulting in the need for additional irrigation to meet crop water demands (Dennehy et al., 1993). The report estimated that electrical conductivity (EC) values in the South Platte River increased from 0.06 dS/m in the mountainous region to approximately 2.0 dS/m towards the end of the river. This increase is particularly concerning as values above 1-2 dS/m, approximately 640-1,280 mg/L TDS, can cause crop yield reductions in the range of 10-25% in saline sensitive crops such as alfalfa and corn (Maas, 1990; "Northern Water," 2009). Groundwater studies conducted by Northern Colorado Water Conservatory District also found that at 42 different observation sites throughout the South Platte River Basin, groundwater salinity values were higher than surface water, with an average EC of 2.32 dS/m (1485 mg/L TDS) ("Northern Water," 2005). The study sampled soil salinities at 13 different sites, finding that 6 of the 13 had soil salinity levels high enough to be classified as saline. It is clear that salinity levels have been rising in the South Platte River Basin, and unless a mitigation strategy is employed, the threat to the basin's economic and environmental health will continue to grow.

The objectives of this thesis are to:

- Develop a model to simulate salt transport throughout the South Platte River system.
- Implement a global sensitivity analysis to quantify the influence of the driving forces behind salt transport.
- Identify potential management practices (MPs) to reduce salinity levels in the South Platte River below 1000 mg/L TDS.
- Provide additional recommendations and suggestions on how best to implement the various MPs which showed promising results towards decreasing salinity levels.

These objectives were accomplished using a one-dimensional (1D) steady-state in-river salt transport model, with in-stream flowrates provided by a water allocation model (StateMod) developed by the Colorado Division of Water Resources. The numerical method used in the salinity model is a control volume scheme with the backward difference method and ignores diffusion and reaction terms. The salinity model accounts for inputs of salt from tributaries, wastewater treatment plants, road salt, returns flows from rainfall and irrigation, and groundwater discharge. The model is tested against in-stream flowrates and salinity concentrations.

1.1. Literature Review

Salinity transport in river basins has been studied for decades. In recent years, models have been constructed to simulate the movement and accumulation of salt in landscapes and stream networks of large river basins. This section provides a review of previous studies and available models.

A hydrologic-salinity flow system model was developed by researchers at Utah State University to study the transport of dissolved salts in the Upper Colorado River Basin (Hyatt et al., 1970). The basin was experiencing a deterioration in water quality due to the prominence of water reuse practices for irrigation and industry uses. The model was run on an analog computer using a mathematical approach that accounted for inflows of salts from tributaries, rainfall, snowmelt, groundwater, and natural sources such as mineral springs and chemical weathering of shale deposits. The Upper Colorado River Basin was divided into 40 different subbasins. Water and salt flows were simulated monthly for two years from 1964 to 1965 resulting in suitable matches between modeled and observed outflows for most of the subbasins.

A hybrid computer model was developed at Utah State University to study the quantity and chemical quality of return flows in a portion of the Little Bear River Basin in northern Utah (Thomas et al., 1971). The hybrid computer model utilized an analog hydrologic model similar to the one developed by Hyatt, Riley, and Mckee (Hyatt et al., 1970) in conjunction with a digital computer model to simulate salinity transport. The model simulated total dissolved solids (TDS) as the sum of six different ions (Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}). Water and salt flows were simulated monthly for two years from 1967 to 1968 resulting in a good agreement between modeled and observed outflows for all the salt ions except Na^{+}.

The accelerated salt transport (Astran) method was utilized to identify salinity management techniques to decrease groundwater salinity in the Bonsall Subbasin in the San Luis Rey River Basin (Helweg, Labadie, 1977). When water is pumped out of a well for irrigation purposes and then drains back into the aquifer close to its origin, a cyclical cycle can form where irrigation water is re-used and, with each pass, picks up more salt. In the Astran method, irrigated water is transported farther downstream away from its origin to break this cycle. The Bonsall Subbasin was broken up and modeled as finite difference cells used to calculate head values and water quality TDS concentrations. The model was calibrated, optimized, and run over a historical period spanning from 1958 to 1969. The results show that applying the Astran model helps prevent groundwater salinization and could be used as an effective and low-cost salt management strategy.

A simple mass balance analysis was conducted to analyze and characterize salinity throughout the South Platte River (Haby et al., 2000). The study focused on the middle portion of the South Platte River basin with the goal of understanding the spatial and temporal characteristics of the river's water salinity and identify the primary sources of dissolved solids. Available data were collected from various sources including water quality data from the USGS Quality of Water – West 1 dataset, flow data from the USGS NWIS-W web server, and EC measurements from various stations located throughout the basin, which were converted to monthly TDS values using a linear regression relationship. Total dissolved solid loads were calculated by establishing a relationship between monthly TDS values and daily flow values at each monitoring station. The study found that the mean EC of the South Platte River increased from approximately 800 µs/cm at Henderson up to 1300 µs/cm at Kersey, before dipping slightly until Weldona, and then increasing again until the end of the river. The study also found that the flow and dissolved solids load reached their highest point at Kersey, as farther downstream, water was diverted for irrigation purposes, thus decreasing flow and dissolved solids loads. A mass balance analysis was performed on the dissolved solids load at Kersey to determine the sources of the dissolved solids. It was found that approximately 25% of the dissolved solids at Kersey were already in the river when it exited the Denver metro area. An additional 50% of the dissolved solids were attributed to the three tributaries, the St. Vrain River, the Big Thompson River, and the Cache La Poudre River. The remaining proportion of dissolved solids were assumed to be from unmeasured sources. It was believed that urban areas along the South Platte and its tributaries were potentially significant source of dissolved solids and that municipal treatment plants may be the most prominent contributor.

A hydrosalinity balance was implemented in the Monegros II irrigation district in the Ebro River Basin in Aragón, Spain, to study irrigation and drainage management and their effects on the salt loading (Tedeschi et al., 2001). The hydrosalinity balance included inflows of salt from irrigation, precipitation, and canal seepage, as well as outflows of salt from evapotranspiration and drainage. Researchers found that between June 1997 to September 1998, there was a net loss of 108 mm of irrigation water and a total exported mass of 13.5 mg ha^{-1} of salt, approximately seven times greater than what was imported. It was concluded that the current irrigation management strategies being implemented were sufficient enough to control the build-up of salt in the area.

The Integrated Quantity Quality Model (IQQM), used to primarily evaluate instream water quantity issues in the Muray Darling Basin located in southeastern Australia, was modified to include a new salt routing technique (Davidson et al., 2003). Because a large proportion of Australia's agriculture is grown in the Muray Darling Basin, and the basin had been experiencing a massive increase in salt mobilization due to land-use changes that raised water tables, the New South Wales Department of Sustainable Natural Resources decided to upgrade the IQQM model's salinity routing scheme. Two new modifications to the IQQM's original code, which originally modeled salt routing as a continuously stirred tank reactor, were developed. The continuously stirred tank reactor model was changed to a lagrangian transport model to allow plug-flow. A dispersion component was added to enable modeling salt transport in streams where dispersion was deemed significant.

An integrated spatial-agro-hydro-salinity model (SAHYSMOD) was developed to analyze water and salt balances in an irrigated semiarid area located in the Haryana State of India (Singh et al., 2012). The Haryana State of India had been experiencing rising groundwater levels, waterlogging, and salinization. The SHAHYMOD model combined the salinity model SaltMod with the groundwater model Standard Groundwater Model Package (SGMP). The model inputs consisted of seasonal water and salt balance components related to surface and groundwater hydrology. The model used a nodal network composed of 44 square nodes where the external nodes acted as head-controlled boundaries and could simulate flow controlled and no-flow conditions. The model was calibrated between October 2000 and June 2004 and validated between October 2004 and June 2008. After calibration, a sensitivity analysis found that the hydraulic conductivity had a significant effect on groundwater levels and salinity, the effective porosity had a moderate impact on groundwater levels and salinity, and the leaching efficiency had a noticeable impact on solely salinity levels. Results from the model showed a good agreement between simulated and observed groundwater levels and salinities for most nodes.

With these various modeling examples to draw inspiration from, a one-dimensional steady-state in-river flow and salt model was constructed to identify the driving forces behind salt transport in Colorado's South Platte River network.

2 Methods

2.1 Model Basis

A one-dimensional steady-state flow and salt model were built to simulate salt transport in the South Platte River network. The flow model utilized monthly averaged values to model the flowrate over the South Platte River's distance and includes inflows from groundwater, return flows, tributaries, and wastewater treatment plants located along the South Platte River. After constructing the flow model, a salt model was built to simulate the total dissolved solids (TDS) concentration over the South Platte River's distance. The salt model includes salt sources from groundwater, return flows, tributaries, road salt, and wastewater treatment plants located along the South Platte River.

2.2 Flow Model

2.2.1 StateMod

The flow model utilized Colorado's Division of Water Resources (DWR) StateMod model as a basis. StateMod is a surface water allocation and accounting model used to simulate in-stream flows and can account for features such as stream diversions, in-stream demands, water rights, well pumping, and recharge. Colorado's DWR has used StateMod to model the South Platte River Basin and has provided the model for use. The StateMod model consists of 1444 different connected nodes located in the South Platte River Basin and are listed below in Table 1.

Table 1. StateMod Node Types

Node Type	**Count**
Diversion and Well	123
Diversion	452
Stream Gages	49
In-stream Flow	31
Other	71
Plan Structures	458
Reservoirs	143
Wells	117

The StateMod model uses Colorado’s DWR's South Platte River historical dataset, which spans between 1950 to 2012, to calculate the flows in and out of each node using monthly time steps. These results serve as a baseline. The user can then add or modify existing nodes, re-run the model, and compare the outputs to determine the effects of any proposed changes. The entirety of the South Platte River StateMod node network is shown in Figure 1.

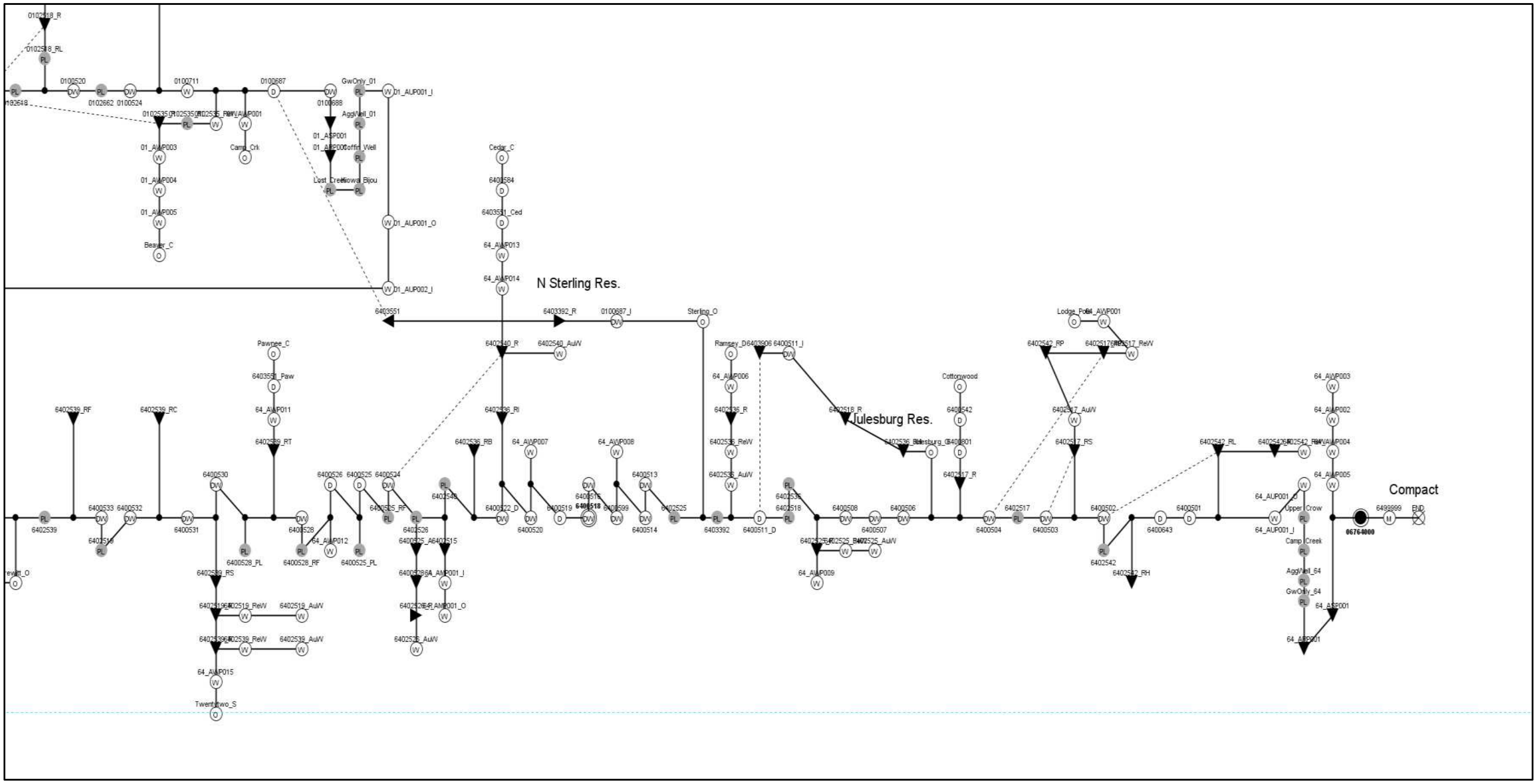

Figure 1. Example Portion of the StateMod Node Network Made up of 1,444 Different Nodes

2.2.2 StateMod Node Flowrates

The StateMod model calculates monthly streamflows at each node. The flow model then uses these monthly streamflows as a starting point. Each StateMod node has a unique WDID identifier. These identifiers were compared to a South Platte Ditches and Canal GIS dataset provided by Colorado's Decision Support System (CDSS) through the official state web portal ("Colorado Division of Water Resources," 2019). Out of the 1444 nodes in the StateMod model, 280 were successfully matched to the GIS dataset. Using ArcMap, an 8-digit HUC South Platte River Basin shapefile along with river and stream data was imported ("South Platte River," 2019). The 280 matched nodes, shown in Figure 2, were added to ArcMap and filtered down to 66 StateMod nodes by performing a query search for nodes located along the South Platte River.

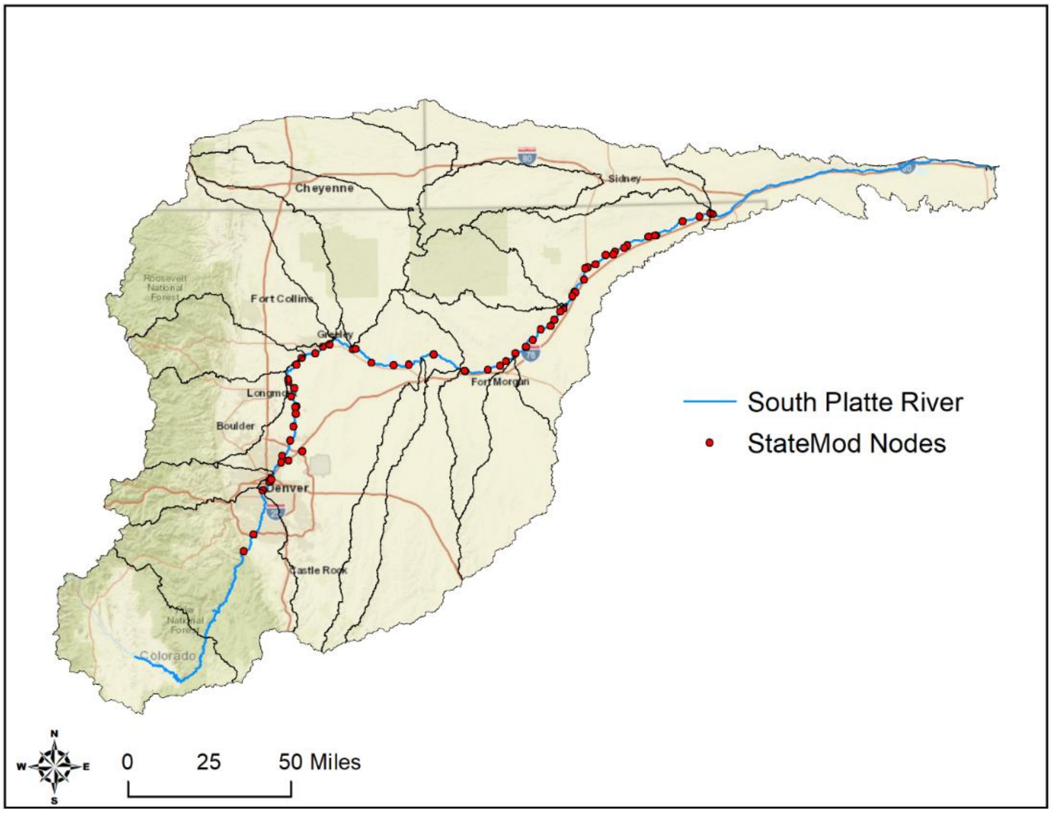

Figure 2. Location of the 66 matched StateMod nodes located along the South Platte River

2.2.3 Adjusted StateMod Node Flowrates

Monthly averaged flowrates at each of the 66 StateMod nodes along the South Platte River were obtained from the StateMod output file SP2016_H.b43 during the 1950 to 2012 model period. The flow model initially assumes that the South Platte River's flowrate is constant and equal to the previous node's flowrate. The flowrate between nodes is then adjusted to include groundwater flows and runoff return flows from irrigation, which are obtained from StateMod's model output.

The StateMod SP2016_H.xnm output file contains detailed node-to-node flow accounting, which includes flows due "To/From GW Storage" as well as flows due to "Return Flow." The amount of groundwater flow and runoff return flow entering between StateMod nodes was calculated. The node network file was analyzed to determine all the intermediate nodes located in between the 66 StateMod nodes that were not matched to the Canals and Ditches GIS dataset. The total groundwater flow entering or leaving between a pair of StateMod nodes was calculated as the sum of the groundwater flows at each intermediate node between the pair. Similarly, the total return flow between a pair of StateMod nodes was calculated as the sum of the return flows at each intermediate node between the pair.

2.2.4 Tributary Flowrates

The flow model includes three main tributaries of the South Platte River. These are the St. Vrain, Big Thompson, and the Cache La Poudre tributaries. Each of these tributaries has a stream gage, maintained by Colorado's DWR, located near their confluence with the South Platte River. Average streamflow values between 1999 and 2020 at these gages were obtained from Colorado's DWR Surface Water Conditions ("Colorado Surface Water Conditions," n.d.). The coordinate data for each tributary gage was added into ArcMap shown in Figure 3.

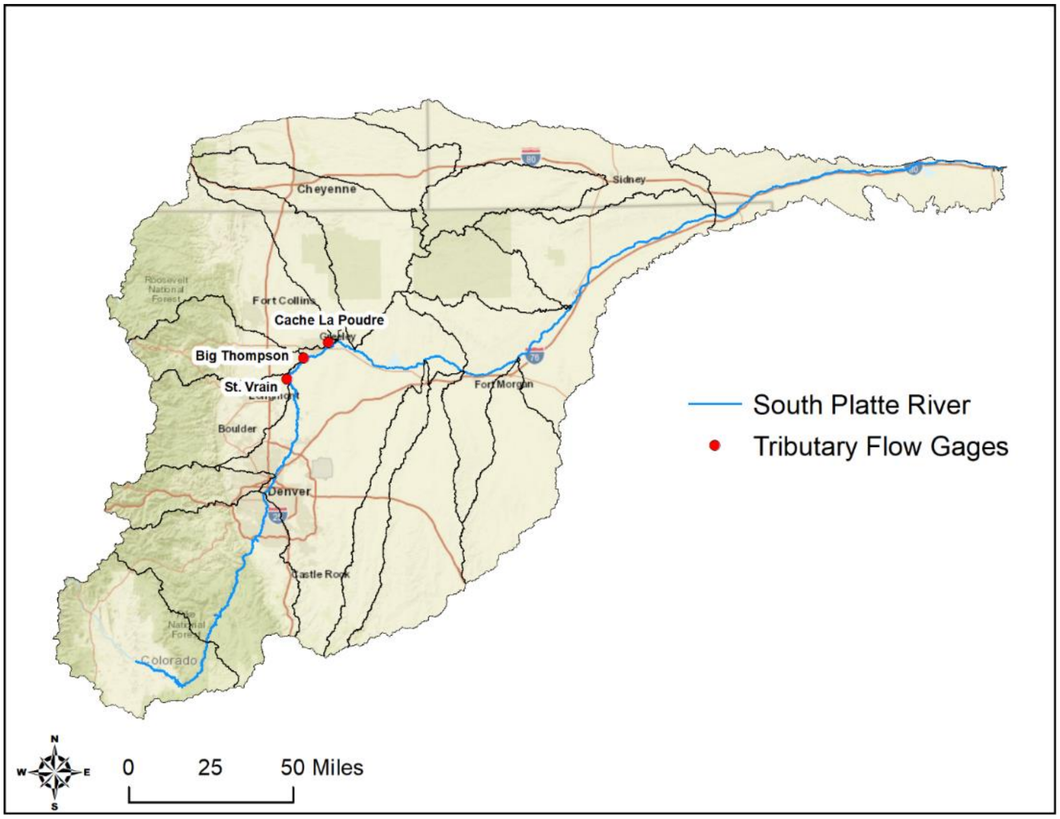

Figure 3. Location of the St. Vrain, Big Thompson, and Cache La Poudre streamflow gages

The location of each gage was determined by referencing the gage IDs with coordinate data from the Water Quality Portal Database ("Water Quality Data Home," n.d.). The ArcMap Measure tool was used to determine the distance of each gage along the South Platte River. The three tributary gages are summarized in Table 2.

Table 2. Tributary Streamflow Gages

Station ID	Abbreviation	Station Name	Distance along South Platte River (m)
6731000	SVCPLACO	Saint Vrain Creek at Mouth near Platteville	278,781
6744000	BIGLASCO	Big Thompson River at mouth near La Salle	294,380
6752500	CLAGRECO	Cache La Poudre near Greeley	312,497

2.2.5 Wastewater Treatment Plant Flowrates

Using the Environmental Protection Agency's (EPA) Facility Registry Service Dataset, coordinate data detailing the location of major pollution point sources in the South Platte River Basin was added to ArcMap (“EPA Facility Registry,” 2020). The data was filtered down through a query search, resulting in 16 different sites which discharged directly into the South Platte River or one of the three tributaries.

The location of these sites along the South Platte River was determined using the Measure tool in ArcMap. All 16 of these sites are included in the flow model, but only the Robert W. Hite Wastewater Treatment Plant (W. Hite WWTP) has nonzero values due to a lack of available data. The W. Hite WWTP, shown in Figure 4, is located in Denver. If additional data at the other 15 sites become available, the model can be easily modified to include these sources.

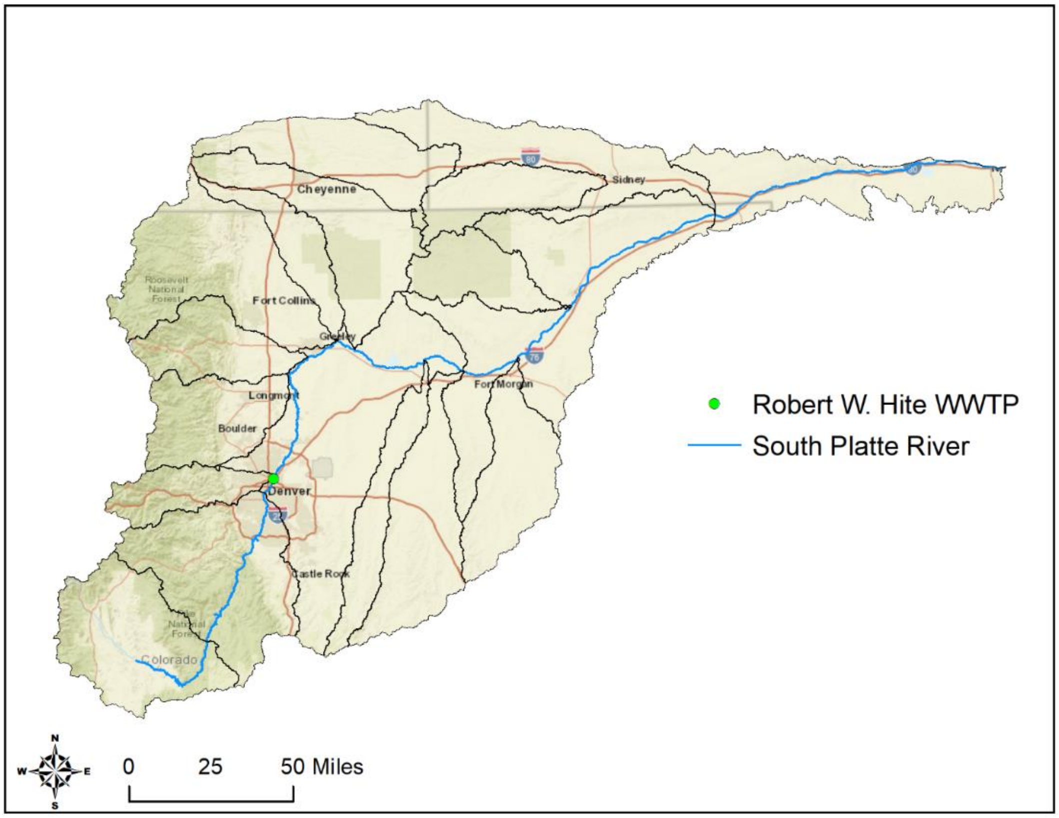

Figure 4. Location of the Robert W. Hite Wastewater Treatment Plant

The W. Hite WWTP effluent flowrate was estimated using a South Platte River Salinity Study conducted by NEIRBO, a consulting company located in Fort Collins, Colorado (NEIRBO, 2020). In their report, NEIRBO displayed the total W. Hite WWTP effluent discharge and TDS concentration between 2013 and 2018, shown in Figure 5. Based on this figure, the W. Hite WWTP effluent flowrate was estimated to be 200 cubic feet per second (cfs).

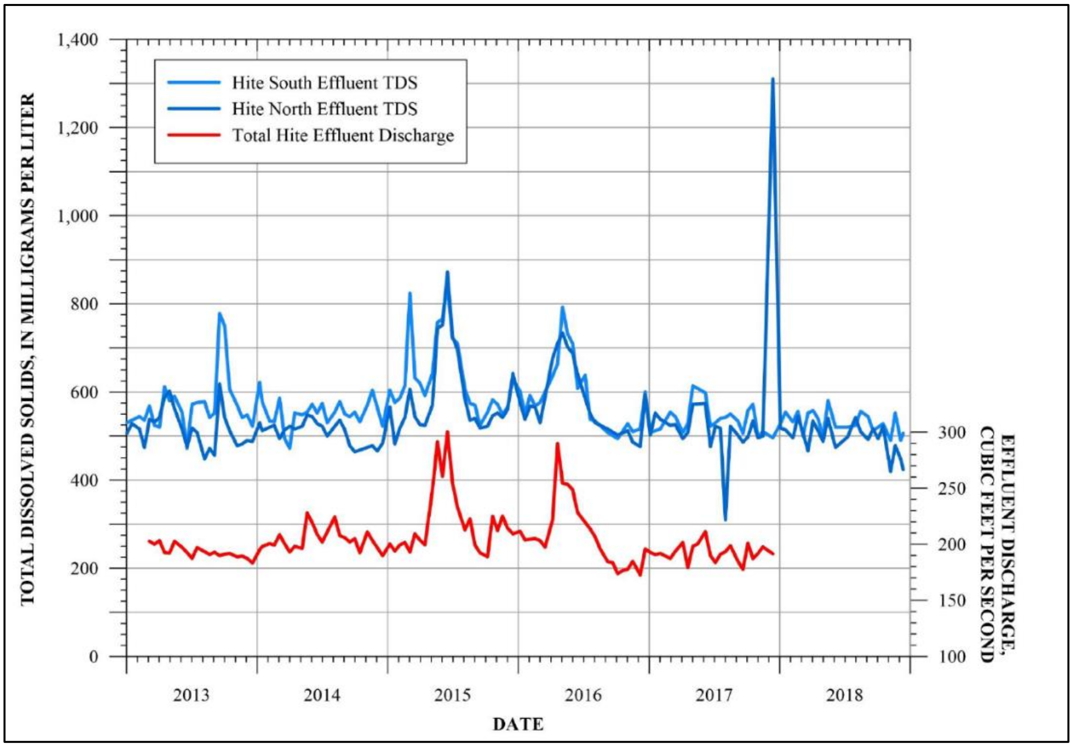

Figure 5. Robert W. Hite Wastewater Treatment Plant Effluent concentration and flowrate. Figure provided by NEIRBO (NEIRBO, 2020)

2.2.6 Model Flowrate Calculations

The one-dimensional steady-state flow model was constructed in Microsoft Excel. Using the South Platte River GIS stream and river data in ArcMap, the South Platte River's length was calculated to be 723 km or 449 miles. The ArcMap features representing the 66 StateMod nodes' location had South Platte River stream mile locations listed in their attribute table. These stream miles locations were initially set-up so that mile zero was located at the end of the river instead of the beginning. The stream mile locations of each of the 66 StateMod nodes were recalculated by subtracting each node's original mile location from the South Platte River's length so that mile zero was located at the river's start.

The Measure tool in ArcMap was used to determine the locations of each of the 66 StateMod nodes along the South Platte River. The length of the South Platte River was divided into 100-meter steps. The location of each of the 66 StateMod nodes, the three tributaries, and the W. Hite WWTP were added to the model.

With the StateMod model output, monthly flowrates at the 66 StateMod nodes were obtained during the 1950 to 2012 StateMod model simulation period. The flowrate between each pair of StateMod nodes was adjusted to account for the total amount of groundwater and return flows entering between the pair. These flows were divided by the number of cells n between the two nodes. The flowrate at the first step following a StateMod node is calculated as:

$$Q_i = Q_{Node} + (Q_{gw} + Q_{ret})/n$$

Where Q_i is the flowrate at the current step i, Q_{Node} is the flowrate at the upstream StateMod node in the pair, Q_{gw} is the flowrate of the entering or exiting groundwater, Q_{ret} is the flowrate of the entering or exiting return flow, and n is the number of 100-meter steps between the two nodes. And the flowrate at all subsequent steps after the initial StateMod node until the next StateMod node is calculated as:

$$Q_i = Q_{i-1} + (Q_{gw} + Q_{ret})/n$$

For the three tributaries and the W. Hite WWTP, their inflows were added to the South Platte River as a point source at their location along the South Platte River. For example, in the case of a tributary located at the current step, an additional inflow term is added to the flow equation:

$$Q_i = Q_{trib} + Q_{i-1} + (Q_{gw} + Q_{ret})/n$$

2.3 Simulating Salt Transport in the South Platte River System

2.3.1 Salt Transport Model

The salt transport model estimates in-stream salinity concentration (g/m^3 = mg/L) throughout the length of the South Platte River considering salt loading from upstream reaches, groundwater discharge, rainfall and irrigation return flow, wastewater treatment plant effluent, tributary inflow, and applied road salt. Salinity concentration is computed at individual reaches (i.e. cells) along the South Platte River using a steady-state mass balance approach. Figure 6 shows a schematic of the computational system:

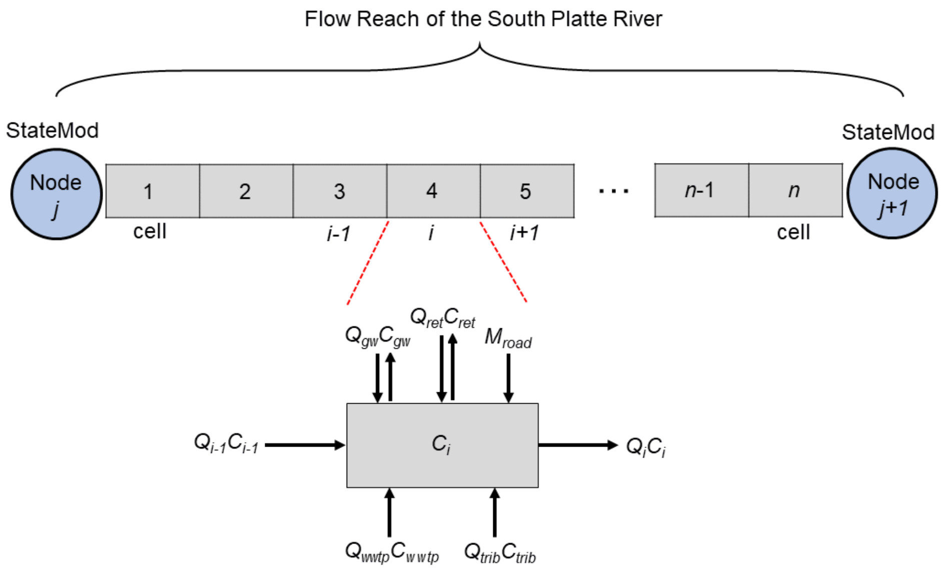

Figure 6. Schematic for salt transport computational cells within the StateMod flow reaches of the South Platte River. An example salt mass balance is shown for one of the grid cells. Salinity concentration C_i is calculated using Equation 4.

For a given grid cell i, the change of salt mass M (g) in the river water per time step Δt is the difference between the salt mass entering and leaving the cell during Δt:

$$\frac{\Delta M_i}{\Delta t} = \dot{M}_{in,i} - \dot{M}_{out,i} \qquad (1)$$

For this study, the change of salt mass in the grid cell over Δt is not considered, i.e. salinity concentration depends only on flowrates and salt mass inputs for the current time step. Hence, Equation 1 simplifies to:

$$\dot{M}_{out,i} = \dot{M}_{in,i} \quad (2)$$

which can be expanded to the following equation using the salt mass inputs shown in Figure 6:

$$Q_i C_i = Q_{i-1} C_{i-1} + Q_{gw,i} C_{gw,i} + Q_{ret,i} C_{ret,i} + Q_{wwtp,i} C_{wwtp,i} + Q_{trib,i} C_{trib,i} + \dot{M}_{road,i} \quad (3)$$

The concentration of salt in grid cell i is then calculated by dividing through Equation 3 by Q_i:

$$C_i = \left(Q_{i-1} C_{i-1} + Q_{gw,i} C_{gw,i} + Q_{ret,i} C_{ret,i} + Q_{wwtp,i} C_{wwtp,i} + Q_{trib,i} C_{trib,i} + \dot{M}_{road,i}\right) / Q_i \quad (4)$$

For this study each cell is specified to be 100 m in length, resulting in 5,633 intermediate cells for the South Platte River. The model is run for each month between 2002 and 2006 using monthly flowrates (m^3/month) of river water and sources (groundwater discharge, rainfall and irrigation return flow, tributary inflow, wastewater treatment plant inflow) from the StateMod simulation (see Section 2.2) and from Colorado's Division of Water Resources Surface Water data, and estimated salt concentration g/m^3 for each of the salt sources, to yield a salinity concentration of g/m^3 for each cell. Road salt loading $M_{road,i}$ is provided in g/month. For the case of using StateMod flowrates in Equations 3 and 4, Q_{gw} and Q_{ret} are simulated between two nodes (see Figure 6), and hence the contribution to each individual cell must be divided by the number of cells n between the two nodes. All salt inputs vary spatially throughout the river basin. Sections 2.3.2 through 2.3.7 describe the methods for estimating the concentration values of salt sources in Equation 4. Section 2.3.8 describes the Excel VBA code used to run the model.

2.3.2 South Platte River Upstream Concentration

The first StateMod node is the Highline Canal, located 160,274 meters downstream of the South Platte River's start. Because the flow model depends on the StateMod model output, the portion of the South Platte River before the Highline Canal node is not modeled. As shown in Figure 7, NEIRBO estimated that the 2018 average annual TDS concentration at the South Platte River's start was between 100 – 500 mg/L (NEIRBO, 2020). Based on this figure, an intermediate value of 300 mg/L was picked to serve as the initial TDS concentration at the Highline Canal.

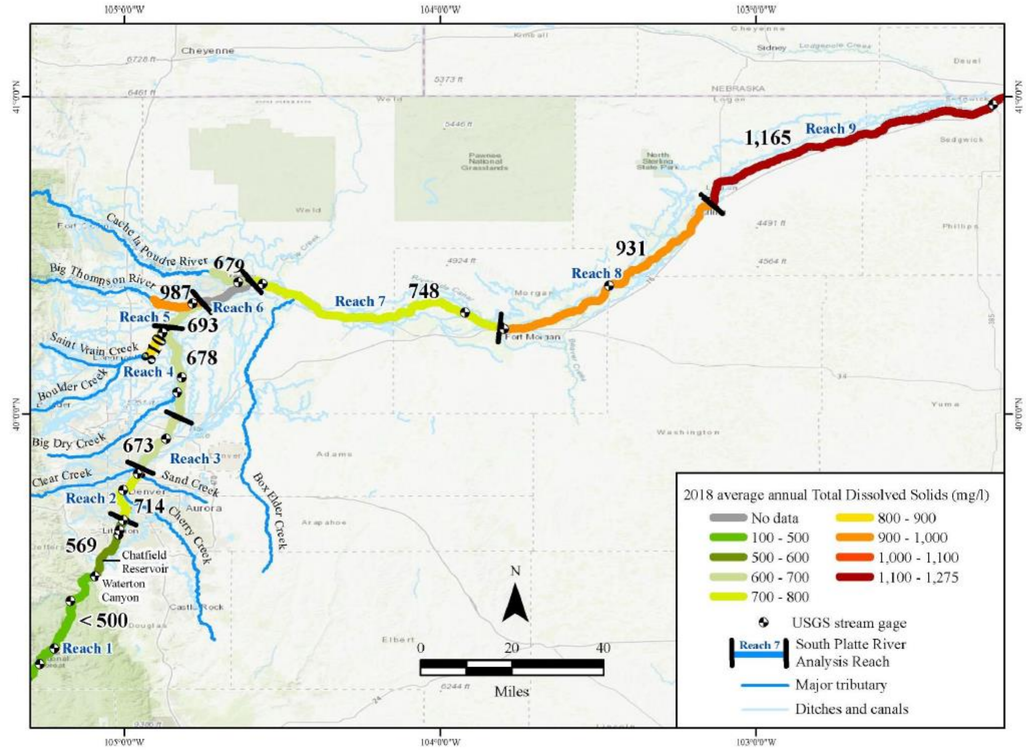

Figure 7. South Platte River 2018 Average Reach-to-Reach TDS Concentrations. Figure Provided by NEIRBO (NEIRBO, 2020)

2.3.3 Groundwater Concentration

The loading of salt from groundwater discharge is calculated as the product of Q_{gw} and C_{gw} (see Equation 4). Groundwater concentration values C_{gw} were calculated from generating an interpolated groundwater concentration map of the South Platte River Basin. Groundwater concentration data were obtained from the Agricultural Chemicals Groundwater Protection Water Quality Database using the following search parameters: Statewide CO, All Well Types, Inorganic, Detected, All Years (1989-2018), Species: TDS (mg/L) ("ERAMS" Environmental Resources," 2020). The output JSON data file was converted to a .csv file and imported into ArcMap as coordinate data. The location of each well data point and measured TDS (mg/L) concentration are shown below in Figure 8.

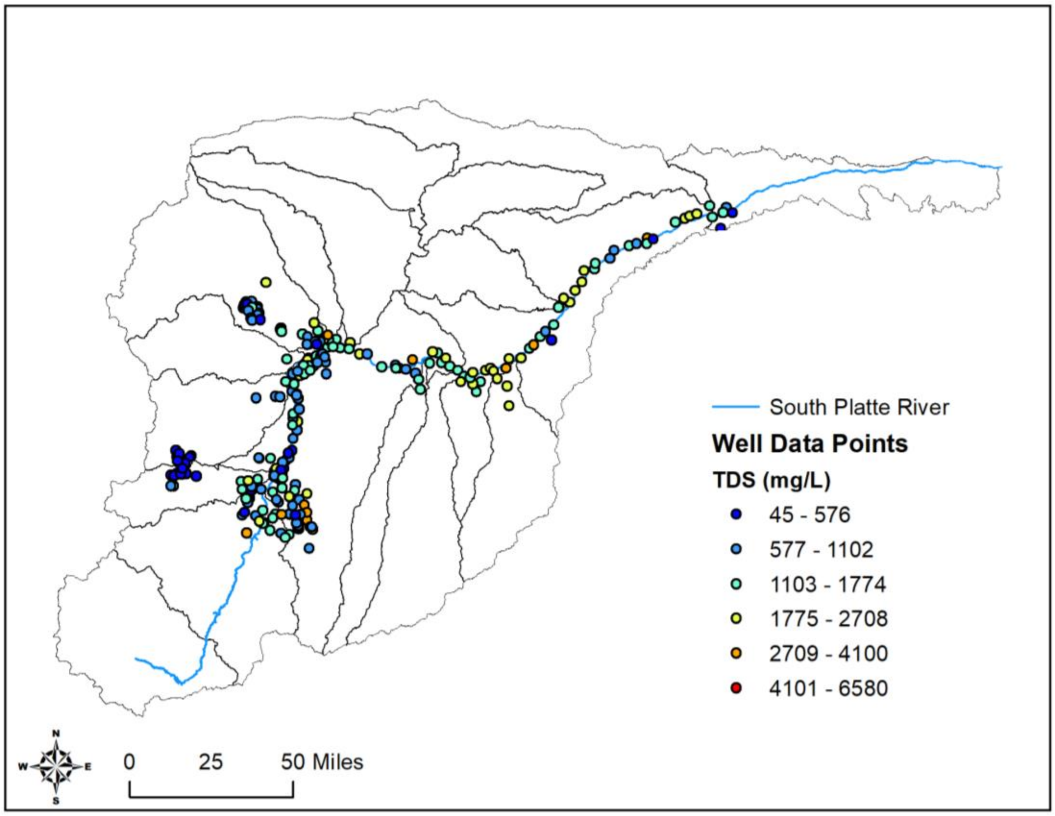

Figure 8. Groundwater TDS concentration data points from the Agricultural Chemicals Groundwater Protection Water Quality Database

Using the well data points, a groundwater concentration map was generated by performing an Ordinary Kriging interpolation operation with a spherical variogram. As shown in Figure 9, the top portion of the South Platte River Basin was not mapped due to a lack of data points, but this was determined to be acceptable as all the StateMod nodes fell within the interpolated areas.

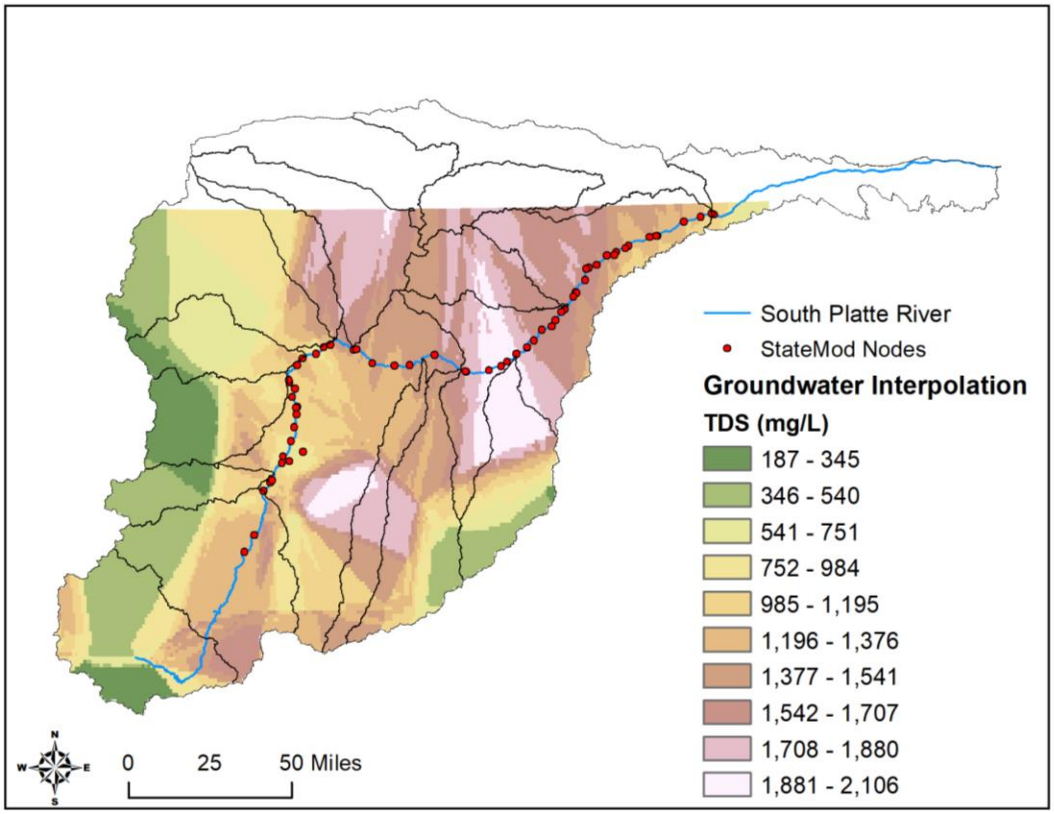

Figure 9. Groundwater interpolated map showing TDS concentration (mg/L)

Groundwater concentration values from the interpolated map of Figure 9 were mapped to delineated subbasins within the basin, and then to the river reach between two StateMod nodes, where they were then assigned to the salt transport cells (see Section 2.3.1). The subbasin delineation was provided by a watershed model constructed in a companion project (Aliyari et al., 2019). A query search was made to determine the subbasins that intersected the South Platte River between the first and last StateMod nodes, with resulting subbasins shown in Figure 10.

The average groundwater TDS concentration (mg/L) was calculated for each of these subbasins using ArcMap's Zonal Statistics tool in conjunction with the interpolated groundwater map. Because the groundwater flow in the flow model is calculated as the sum of all intermediate StateMod node groundwater flows, the groundwater concentration is calculated in a similar fashion. The groundwater concentration between a pair of StateMod nodes is calculated as the average value of all the pair's subbasin concentration values.

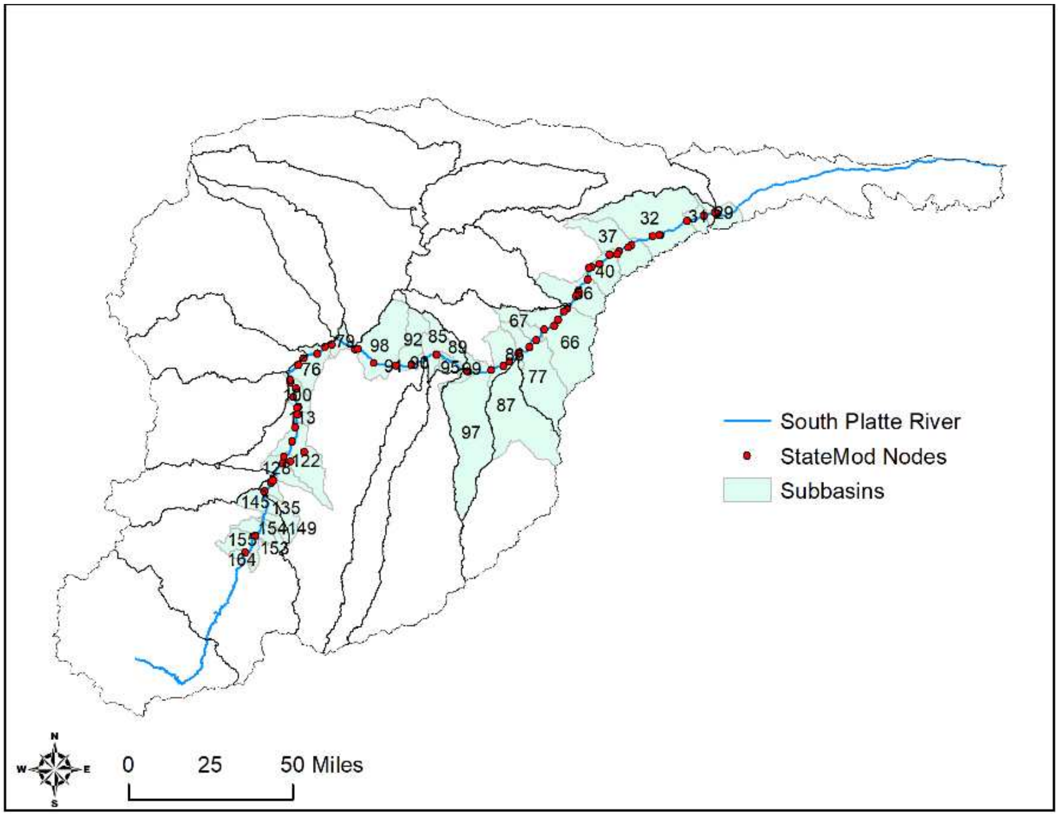

Figure 10. South Platte River subbasins (from Aliyari et al., 2019) that intersect the South Platte River.

2.3.4 Soil and Return Flow Concentrations

The loading of salt to the South Platte River via surface runoff requires estimates of runoff return flowrate Q_{ret} and the associated concentration of salinity C_{ret} (see Equation 4). Q_{ret} is provided by StateMod. C_{ret} is estimated using a combination of river water salinity concentration and soil salinity, as the salt mass in irrigation water runoff is a combination of the salt mass in the diverted irrigation water (i.e. from the river) and the salt mass in the soil that is picked up by irrigation water as it runs across fields and into nearby ditches. Soil concentration values were calculated using STATSGO2 soil data from the US Department of Agriculture for Colorado, Wyoming, and Nebraska ("Description of STATSGO2," n.d.). As shown in Figure 11, an electrical conductivity (dS/m) soil map for the South Platte River Basin was generated using the ArcMap GIS add-on NRCS Soil Data Viewer 6.2.

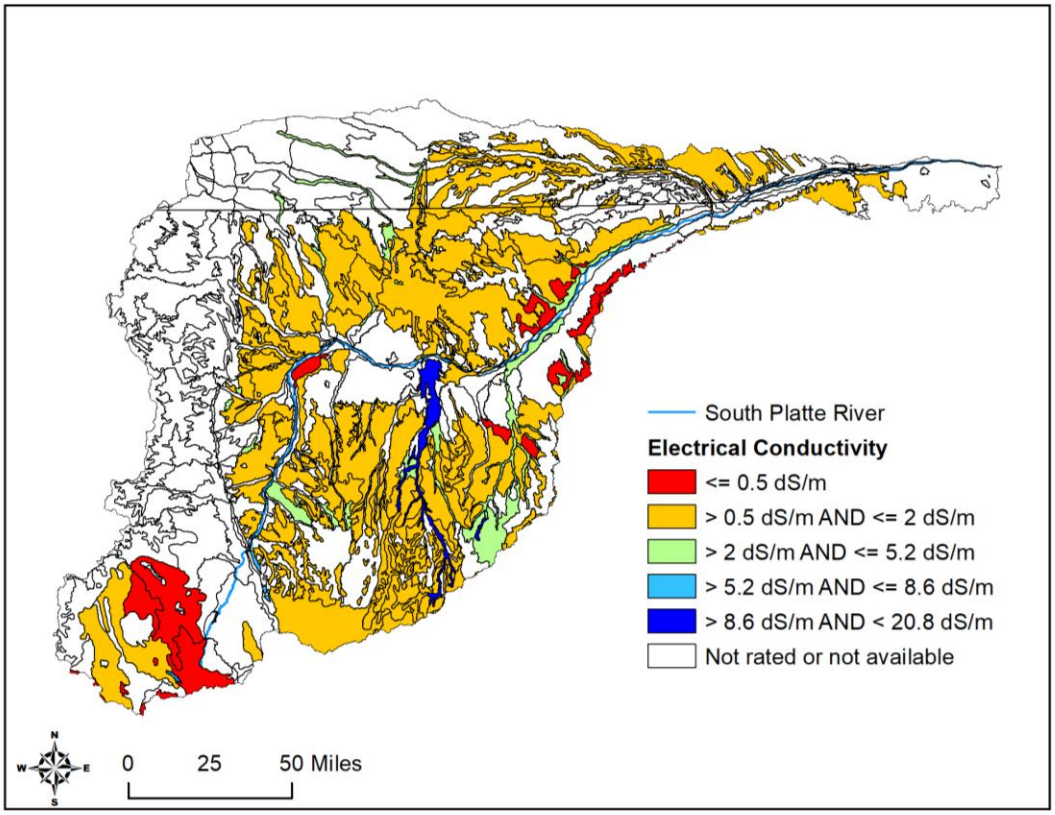

Figure 11. NRCS Soil Data Viewer Electrical Conductivity (dS/m) map generated using STATSGO2 Data

Using the South Platte River subbasin shapefile shown in Figure 10 of Section 2.3.3, the average soil electrical conductivity (dS/m) was calculated for each subbasin using ArcMap's Zonal Statistics tool in conjunction with the electrical conductivity soil map. Because the flow model's return flows are calculated as the sum of all intermediate StateMod node return flows, the soil concentration is calculated in a similar fashion. The soil electrical conductivity between a pair of StateMod nodes was calculated as the average value of all the pair's subbasin electrical conductivity values. The average soil electrical conductivity (dS/m) value of each subbasin was then converted to TDS concentration (mg/L) values using a 640 conversion factor referenced in a 5-Year South Platte River Salinity Study published by Northern Water, a Northern Colorado utility company ("Northern Water," 2009).

The TDS concentration for return flows between a pair of StateMod nodes was calculated as the river's concentration at the initial StateMod node plus a percentage of the averaged soil concentration value between the pair. This percentage is referred to as the Return Flow % in the model. It is split into two different parameters: Return Flow % before Union Ditch, which covers the more urban areas in the South Platte River basin, and Return Flow % after Union Ditch, which covers the more agricultural areas in the South Platte River basin. The location of Union Ditch is shown in Figure 12. This split was made to allow for more flexibility when conducting the sensitivity analysis and potential management practices study discussed later in Sections 2.5 and 2.6. Both Return Flow % before Union Ditch and Return Flow % after Union Ditch are set to 9%. These values were chosen through manual calibration.

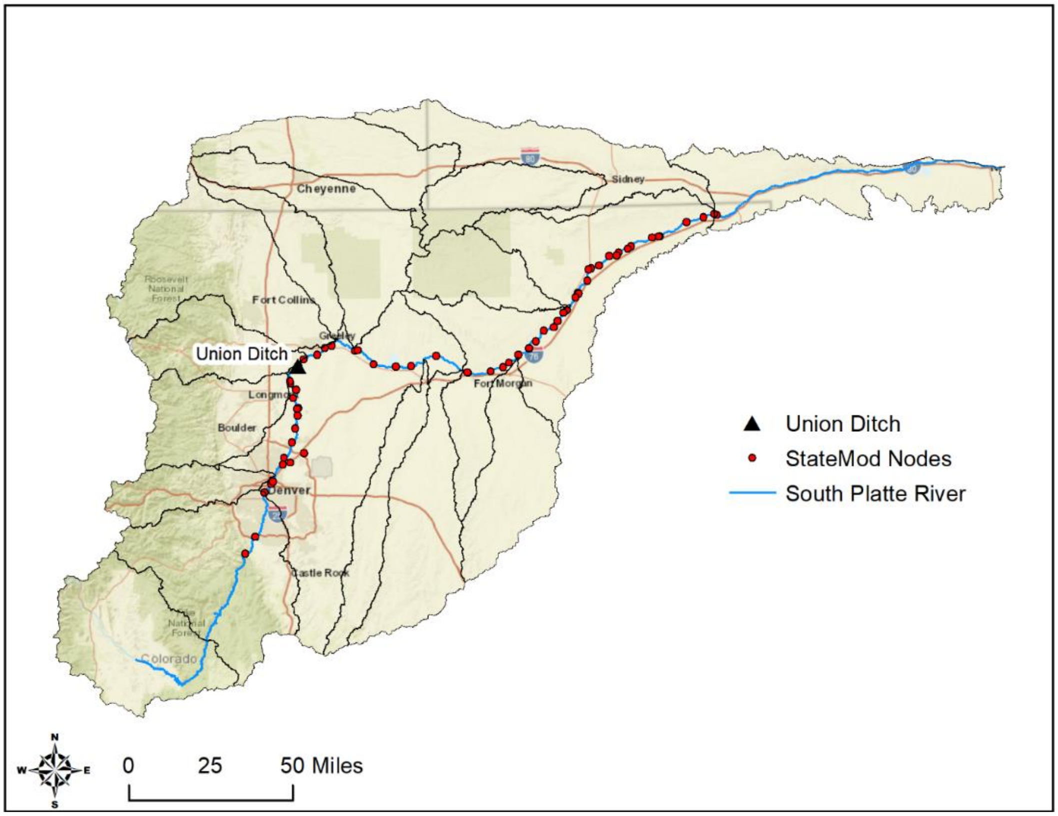

Figure 12. Location of the Union Ditch StateMod node which divides the Return Flow %'s before and after Union Ditch

2.3.5 Wastewater Treatment Plant Concentrations

Salt loading from wastewater treatment plants (WWTPs) is calculated as the product Q_{wwtp} and C_{wwtp} (see Equation 4). As discussed in Section 2.2.5, 16 different major pollution point sources were included in the model, but only one site had non-zero data. This site is the Robert W. Hite Wastewater Treatment Plant (W. Hite WWTP) located in Denver, Colorado, as seen in Figure 4 in Section 2.2.5.

The W. Hite WWTP effluent TDS concentration was estimated using the South Platte River Salinity Study conducted by NEIRBO (NEIRBO, 2020). As seen in Figure 5 in Section 2.2.5, NEIRBO provided a figure detailing the total W. Hite WWTP effluent discharge and TDS concentration between 2013 and 2018. A conservative TDS concentration of 500 mg/L was picked to serve as the W. Hite WWTP Effluent concentration for the salt model.

2.3.6 Tributary Concentrations

Salt loading from tributaries is calculated as the product Q_{trib} and C_{trib} (see Equation 4). The salt model includes three main tributaries of the South Platte River: the St. Vrain River, the Big Thompson River, and the Cache La Poudre River. Each of these tributaries has a stream gage near their confluence with the South Platte River. Northern Water has collected daily electrical conductivity (EC) values at each of these gages. These EC values were included in their 5-Year South Platte River Salinity Study, which spanned between 2002 to 2006 (“Northern Water,” 2009). The raw EC data (dS/m) was unavailable, but in their report, Northern Water displayed figures of these measurements. Using a program called Graph Grabber, the average monthly electrical conductivity values at each gage were estimated then converted to TDS concentration (mg/L) values using a 640 conversion factor that Northern Water suggests (“Northern Water,” 2009). An example of the Northern Water graph for the Cache La Poudre gage is shown in Figure 13.

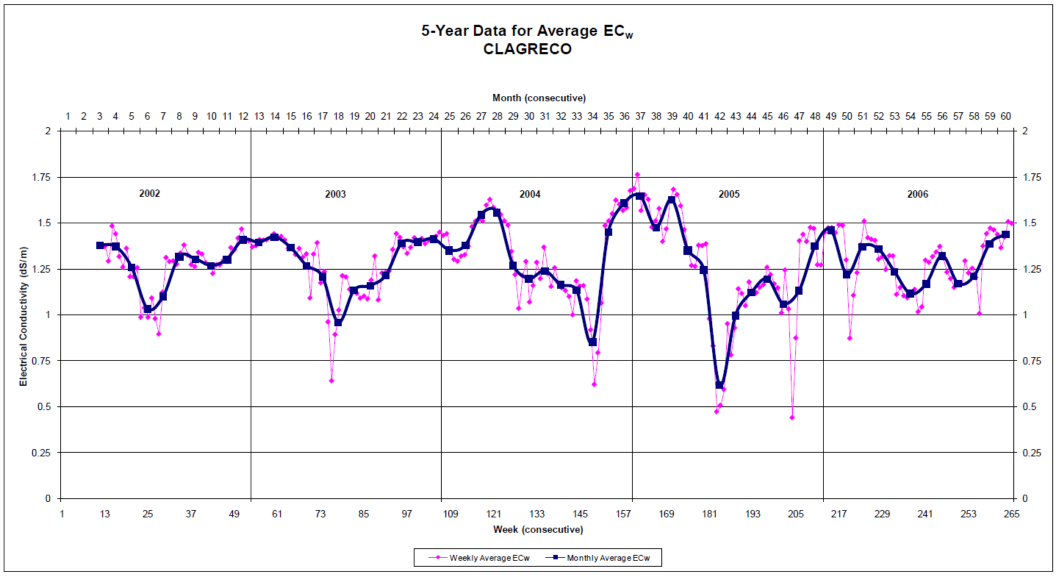

Figure 13. Example graph of EC data at the CLAGRECO gage, located at the confluence of the South Platte River and the Cache La Poudre tributary. Figured Provided by Northern Water (“Northern Water,” 2009)

2.3.7 Road Salt Concentration

Salt loading from road salt is calculated as the road salt mass loading term M_{road} (see Equation 4). A Colorado Open Records Act (CORA) request was submitted to obtain the amount of road salt applied over the different Colorado's Department of Transportation regions shown in Figure 14.

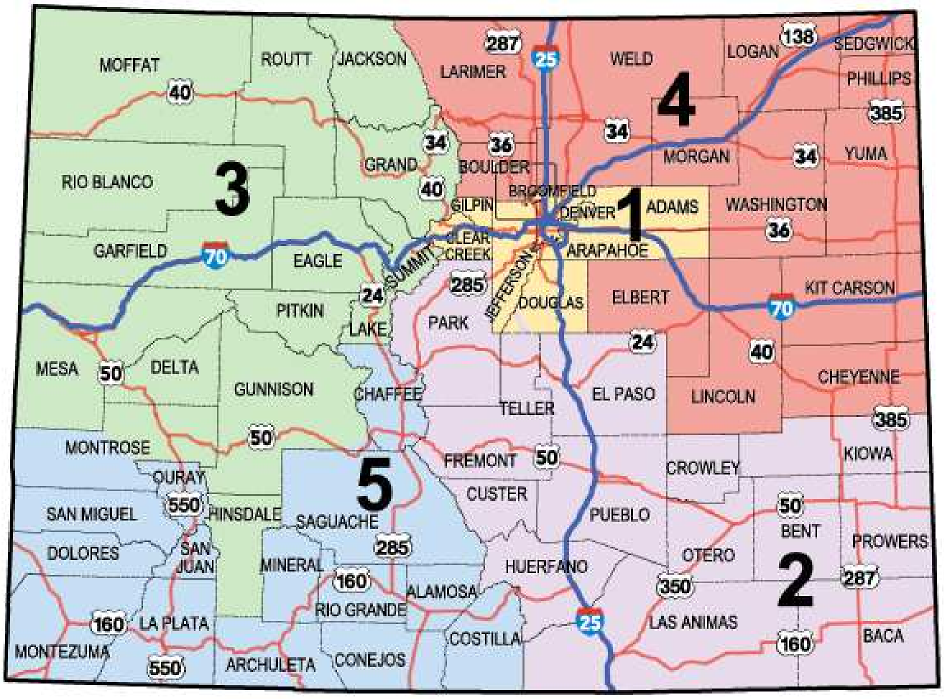

Figure 14. Colorado Department of Transportation Region Map provided by CDOT ("Questions / Comments," n.d.)

The CORA request response included a list of Snow and Ice Material Usage over various Colorado Department of Transportation Regions between July 1, 2018 to June 20, 2019. The snow and ice material usage over Region 1 (Denver Area) was included in the salt model and is listed in Table 3.

Table 3. CDOT Region 1 Snow and Ice Material Usage

Section	Component	Description	Quantity	UoM
Region 1 Section 5	10001786	CALCIUM CHLORIDE, 50# BAG, 55/PALLET	2.4	TON
Region 1 Section 9	10001786	CALCIUM CHLORIDE, 50# BAG, 55/PALLET	5.2	TON
Region 1 Section 9	10005151	SALT, ROAD 50 LB BAG	37.525	TON
Region 1 Section 9	10200005	SALT-SAND MIX	54	TON
Region 1 Section 5	10200008	Liquid Deicer	6,400.00	GLL
Region 1 Section 5	10200009	ICE SLICER RS	37,374.00	TON
Region 1 Section 9	10200009	ICE SLICER RS	20,330.00	TON
Region 1 Section 5	11000070	APEX, LIQUID DEICER	1,588,353.00	GLL
Region 1 Section 9	11000070	APEX, LIQUID DEICER	2,755,603.40	GLL
Region 1 Section 5	11000835	SAND SLICER	163	TON
Region 1 Section 9	11000835	SAND SLICER	6,524.00	TON
Region 1 Section 5	11000880	ICE SLICER SB	15	TON
Region 1 Section 5	11001719	SALT, BRINE, GALLON	346,730.00	GLL
Region 1 Section 9	11001719	SALT, BRINE, GALLON	15,600.00	GLL
Region 1 Section 5	11002895	ICE-MELT, SNOW, ICE, SIDEWALK, 50#, -25F	3.5	TON
Region 1 Section 9	11002895	ICE-MELT, SNOW, ICE, SIDEWALK, 50#, -25F	0.05	TON
Region 1 Section 9	11007643	NexGen Torch	3,700.00	GLL

Chemical compositions of each listed product were estimated in order to calculate the total amount of salt applied over Region 1. The Calcium Chloride and Road Salt bags were assumed to be solid deicer with 95% salt composition. The Salt-Sand mix was assumed to have a composition of 11.5% salt (Pulley, Baird, Felsburg, 2010). The Liquid Deicer was assumed to have a composition of 28.5% salt and a density of 1.29 g/cm^3 ("Colorado Department of Transportation," n.d.). The Ice Slicer RS was assumed to have a composition of 95% salt ("REDMON Minerals," n.d. a). The Apex Liquid Deicer was assumed to have a composition of 30% salt and a density of 1.29 g/cm^3 ("MeltDown® Apex," 2017). The Sand Slicer was assumed to be the same composition as the Salt-Sand mix at 11.5% salt. The Ice Slicer SB was assumed to have a composition of 95% salt ("REDMON Minerals," n.d. b). The Salt Brine was assumed to have a composition of 23.3% salt and a density of 1.20 g/cm^3 ("Engineering Toolbox," 2017). The Ice Melt bags were assumed to have a composition of 95% salt. The NexGen Torch was assumed to have a composition of 30% salt and a density of 1.29 g/cm^3 ("Pre-Approved Product Evaluation," n.d.).

Using the above chemical compositions, the total amount of salt applied over Region 1 between July 1, 2018 and June 20, 2019 was calculated to be 63,100 tons. This value was set as a yearly constant in the salt model. It was assumed that 99% of the road salt would be applied equally over the four coldest months in Denver: January, February, November, and December ("Climate and Average Monthly Weather," n.d.). The remaining 1% was applied equally over the remaining eight months. The total road salt applied each month was converted to a mass rate (mg/s) and distributed in the urban Denver area downstream of Last Chance Ditch 2 to just past Brighton Ditch which are shown in Figure 15. Through manual calibration, it was assumed that

60% of the total salt applied in any given month would runoff into the South Platte River during that month.

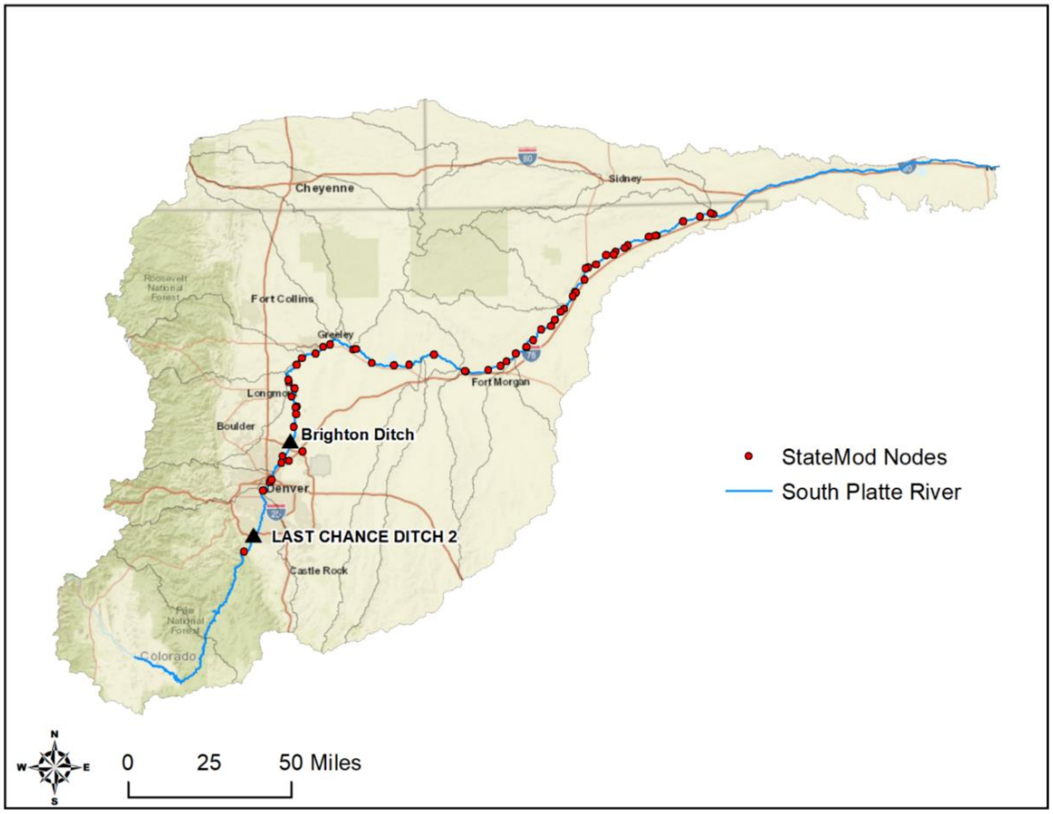

Figure 15. Location of Road Salt Distribution downstream of Last Chance Ditch 2 to just past Brighton Ditch

2.3.8 Model Concentration Calculations

The salt transport model is run in Excel using a variety of different Visual Basic for Applications (VBA) scripts. After the user enters the month and year they wish to model, the model can be run. Once complete, four different plots are generated for the specified month (see Figure 16 for an example of September 2005): 1) distance-flow plot for observed (gage) and simulated streamflow; 2) 1:1 plot of observed vs. simulated streamflow; 3) distance-concentration plot for observed (gage) and simulated TDS concentration; and 4) 1:1 plot of observed vs. simulated TDS concentration.

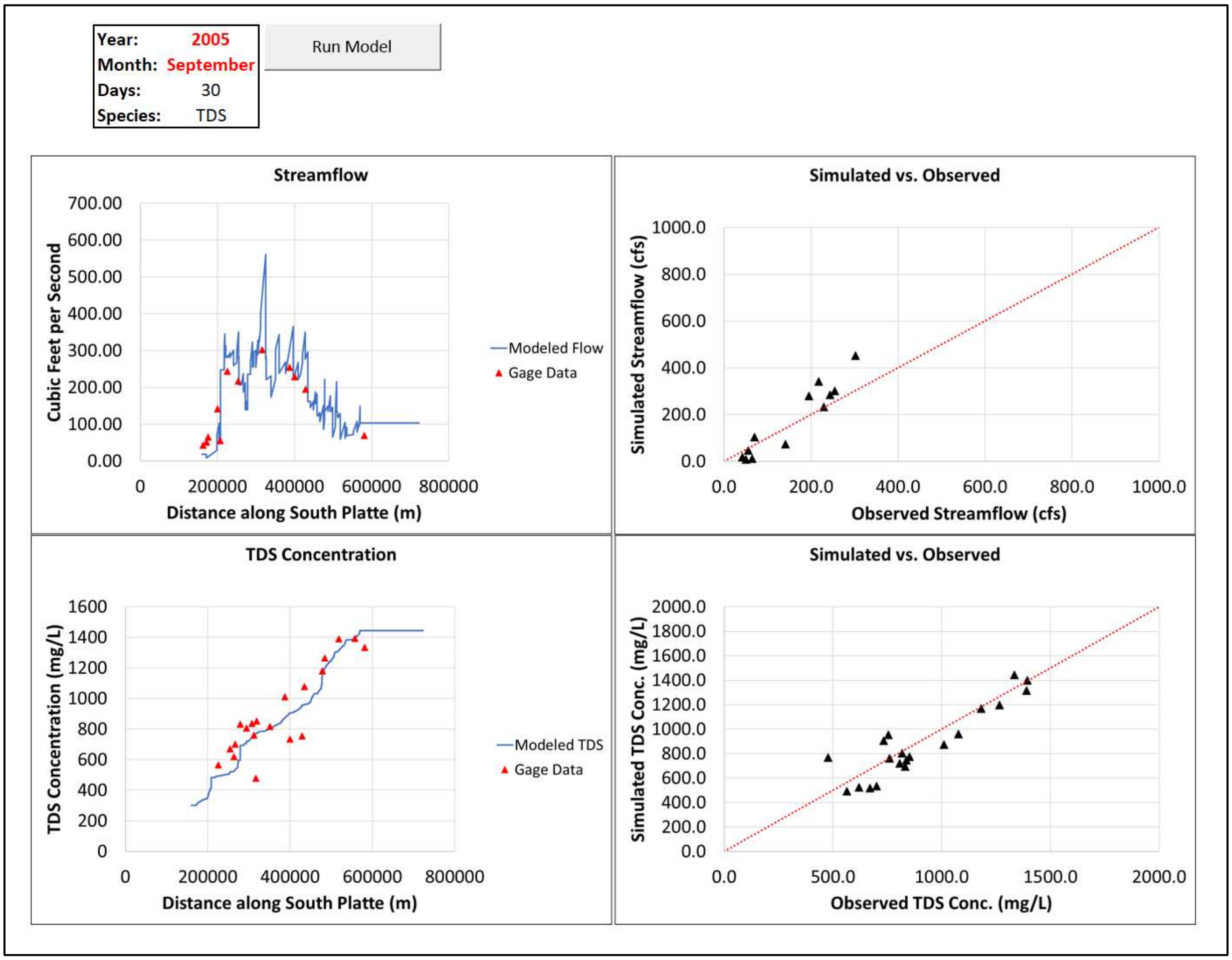
Year: 2005
Month: September
Days: 30
Species: TDS

Figure 16. Salt transport model user interface and generated plots

When running the salt transport model, based on the user input month and year, the nine VBA scripts listed in Table 4 are run to simulate the flowrate and concentration over the South Platte River. The model must be updated each run to account for groundwater flows and concentrations, return flows and concentrations, wastewater treatment plant flows and concentration, tributary flows and concentrations, and road salt mass loading for the month specified.

Table 4. List of salt transport model VBA scripts

VBA Script	Purpose
NodeDataPull	Pulls and updates StateMod output streamflow data for all 1444 StateMod nodes.
GWFlow	Pulls and updates groundwater flow data for all intermediate StateMod nodes from StateMod output files. Converts the flows from acre-ft/month to cubic feet per second (cfs) and calculates the total groundwater flow entering or leaving between the matched 66 StateMod nodes along the South Platte River.
RunoffFlow	Pulls and updates return flow data for all intermediate StateMod nodes from StateMod output files. Converts the flows from acre-ft/month to cubic feet per second (cfs) and calculates the total groundwater flow entering or leaving between the matched 66 StateMod nodes along the South Platte River.
WWTP	Updates wastewater treatment plant effluent flowrates and concentrations with available data.
Trib_Data	Updates streamflow data at each of the three tributary flow gages. Calculates monthly average flowrates at the St. Vrain, Big Thompson, and Cache La Poudre tributaries.
SP_GageData	Updates streamflow data at each of the 14 stream gages along the South Platte River. Calculates monthly average flowrates at each gage.
EC_Data	Updates EC data at each of the three tributary flow gages and 17 stream gages along the South Platte River. Converts EC values (dS/m) to TDS (mg/L).
Salt_Load	Updates applied road salt data. Calculates a mass loading rate.
StreamFlowRun	Updates the flowrate at each of the 66 StateMod nodes along the South Platte River.

2.4 Model Simulation

2.4.1 Observed Streamflow and River Salinity Concentration

Stream gage data were obtained from 14 streamflow gages along the South Platte River and the three tributary streamflow gages for the St. Vrain River, Big Thompson River, and Cache La Poudre River. Daily averaged streamflow values at these gages were obtained from DWR's Colorado Surface Water Conditions (“Colorado Surface Water Conditions,” n.d.) and used to calculated monthly averaged streamflow values. Coordinate data for each streamflow gage was obtained from the Water Quality Portal (“Water Quality Data Home,” n.d.) and added into ArcMap, as shown in Figure 17.

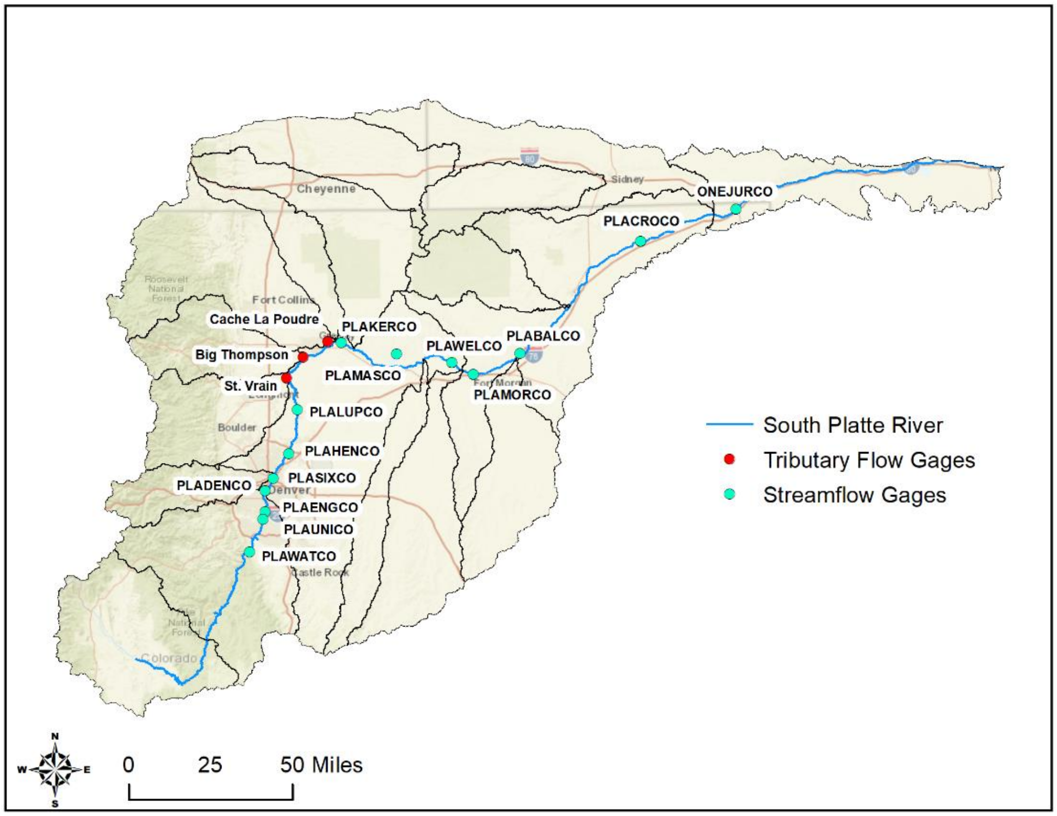

Figure 17. Location of the Streamflow Gages along the South Platte River

The location of each gage located along the South Platte River was measured in ArcMap using the Measure tool and is listed in Table 5.

Table 5. South Platte River Streamflow Gages

Station ID	Abbreviation	Station Name	Distance along South Platte River (m)
6708000	PLAWATCO	South Platte River at Waterton	163,051
6710247	PLAUNICO	South Platte River below Union Ave	171,942
6711565	PLAENGCO	South Platte River and Englewood	176,330
6714000	PLADENCO	South Platte River at Denver	200,055
6714215	PLASIXCO	South Platte River at 64th Ave Commerce	207,837
6720500	PLAHENCO	South Platte River at Henderson	225,994
6721000	PLALUPCO	South Platte River at Fort Lupton	254,496
6754000	PLAKERCO	South Platte River near Kersey	316,588
6756995	PLAMASCO	South Platte River at Masters	351,174
6758500	PLAWELCO	South Platte River near Weldona	387,009
6759500	PLAMORCO	South Platte River at Fort Morgan	400,127
6759910	PLABALCO	South Platte River at Cooper Bridge	429,123
6760500	PLACROCO	South Platte River near Crook	525,216
N/A	ONEJURCO	South Platte River at Julesburg	581,283

EC gage data was available in Northern Water's 5-Year South Platte River Salinity Study (“Northern Water,” 2009). The report included EC data taken at the three tributary gages and 17 different EC gages along the South Platte River and are listed in Table. Coordinate data for all but eight EC gages were obtained from the Water Quality Portal (“Water Quality Data Home,” n.d.) and added into ArcMap. The locations of the remaining eight EC gages were estimated using Google Maps.

Table 6. Northern Water EC Gages

Station ID	Abbreviation	Distance along South Platte River (m)
6720500	PLAHENCO	225,994
6721000	PLALUPCO	254,496
N/A	PLAPLACO*	263,521
N/A	PLAACRH60*	266,957
6731000	SVCPLACO	278,781
6744000	BIGLASCO	294,380
N/A	PLAEVACO*	307,210
6752500	CLAGRECO	312,497
6754000	PLAKERCO	316,588
N/A	PLAKUNCO*	319,293
6756995	PLAMASCO	351,174
6758500	PLAWELCO	387,009
N/A	PLAMORCO*	400,127
6759910	PLABALCO	429,123
N/A	PLAMERCO*	434,645
N/A	PLASTLCO	478,300
N/A	PLALIFCO*	484,526
N/A	PLAJUMCO	518,791
N/A	PLASEDCO*	557,930
N/A	ONEJURCO	581,283

* Location Estimated by Google Maps

Northern Water has collected daily EC (dS/m) values at each of these gages between 2002 to 2006. The raw data was unavailable, but in their report, Northern Water displayed figures of these measurements. Using a program called Graph Grabber, the average monthly EC value at each gage was estimated and converted to TDS concentration (mg/L) values using the 640 conversion factor Northern Water suggests in their report (Northern Water," 2009). See Figure 13 in Section 2.3.6 for an example of Northern Water's EC data graphs.

2.4.2 Simulation Period

The flow model was built around the South Platte River Basin StateMod model, which runs from 1950 and 2012. Due to a lack of comprehensive observed salinity data along the South Platte River, the flow and salt models were only analyzed between 2002 to 2006 to compare the modeled results with the available salinity data in Northern Water's 5-Year Salinity Study.

2.4.3 Model Output and Analysis

Three different statistics are used to quantify the goodness-of-fit between observed and simulated streamflow and TDS concentration.

Mean Absolute Error (MAE): The arithmetic average of the absolute error between predicted and observed data points. A MAE value of 0 means there is a perfect match between predicted and observed data points.

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|M_i - O_i|$$

Root Mean Squared Error (RMSE): The residuals' standard deviation between predicted and observed data points. A RMSE value of 0 means there is a perfect match between predicted and observed data points.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)^2}$$

Nash-Sutcliffe Coefficient of Efficiency (NSCE): A normalized statistic calculated as one minus the ratio of the modeled series' error variance divided by the observed series variance. A NSCE value of 1 means there is a perfect match between predicted and observed data points. A NSCE value between 0 and 1 is often assumed to imply reasonable model performance.

$$NSCE = 1 - \frac{\sum_{i=1}^{N}(M_i - O_i)^2}{\sum_{i=1}^{N}(O_i - \bar{O})^2}$$

2.5 Sensitivity Analysis

In order to quantify the influence of the driving forces behind salt transport in the South Platte River network, a local sensitivity analysis was implemented using a modified version of the Morris method (Wicaksono, 2016). The sensitivity study's goal was to determine which parameters have the most significant impact on salt transport. For each month over the study period, each parameter had its nominal value adjusted in 1% increments over a ±10% range. For every 1% increment, an elementary effect (EE) was calculated by taking the ratio of the change in the model output to the change in the parameter. A set of n_k number of EE's were calculated for each parameter. For a model with K parameters, the EE for parameter k with a deviation of delta was calculated as (Wicaksono, 2016):

$$EE_k = \frac{f\left(x_{1,}x_2x_3, \ldots, x_{k+\Delta}, x_K\right) - f\left(x_{1,}x_2x_3, \ldots x_K\right)}{\Delta}$$

The EE's were standardized by multiplying each EE by the parameter value and dividing by the model output to calculate the standardized EE (SEE). For a model with K parameters, the SEE for parameter k with a deviation of delta was calculated as (Wicaksono, 2016):

$$SEE_k = \frac{EE_k * x_{k+\Delta}}{f\left(x_{1,}x_2x_3, \ldots, x_{k+\Delta}, x_K\right)}$$

The mean of the absolute value of the SEEs was calculated as μ^*, where μ^* represents the current parameter's overall sensitivity. For parameter k with n_k number of elementary effects, μ^* was calculated as (Wicaksono, 2016):

$$\mu_k^* = \frac{1}{n_k}\sum_{r=1}^{n_R}\left|SEE_k^R\right|$$

The standard deviation of the SEE's absolute values was calculated as σ^*, where σ^* represents possible interaction effects between the current parameter and other parameters and/or a non-linear effect on the model output. For parameter k with n_k number of elementary effects, the σ^* was calculated as (Wicaksono, 2016):

$$\sigma_k^* = \sqrt{\frac{1}{n_k}\sum_{r=1}^{n_R}\left(\left|SEE_k^R\right| - \mu_k\right)^2}$$

Two different sensitivity scenarios were studied. The first scenario was a spatial sensitivity study where the South Platte River was split into five different reaches. The second scenario was a temporal sensitivity study performed over the entire South Platte River during the four seasons: spring, summer, fall, and winter. In both scenarios, the following 77 parameters listed in Table 7 were studied.

Table 7. Sensitivity Analysis Model Parameters

Initial Concentration Model Parameters	
Initial Concentration	
Groundwater Model Parameters	
Nevada Ditch GW conc.	Deuel Synder Ditch GW conc.
Last Chance Ditch 2 GW conc.	Upper Platte Beaver Canal GW conc.
Farmers Gardeners Ditch GW conc.	Lower Platte Beaver Ditch GW conc.
Burlington Canal GW conc.	Tremont System GW conc.
Gardeners Ditch GW conc.	Gill Stevens Ditch GW conc.
Fulton Ditch GW conc.	Trowell Ditch GW conc.
Little Burlington GW conc.	N Sterling System GW conc.
Brantner Ditch GW conc.	Union Ditch 2 GW conc.
Denver Hudson Canal GW conc.	Tetsel Ditch GW conc.
Brighton Ditch GW conc.	Johnson Edwards Ditch GW conc.
Lupton Bottom Ditch GW conc.	Prewitt Res Inlet GW conc.
Platteville Ditch GW conc.	South Platte Ditch GW conc.
Meadow Island 1 Ditch GW conc.	Pawnee Ditch GW conc.
Evans No 2 Ditch GW conc.	Davis Bros Ditch GW conc.
Meadow Island Ditch GW conc.	Schneider Ditch GW conc.
Farmers Indep Ditch GW conc.	Springdale Ditch GW conc.
Hewes Cook Ditch GW conc.	Sterling IRR CO Ditch 1 GW conc.
Jay Thomas GW conc.	Sterling IRR CO Ditch 2 GW conc.
Union Ditch GW conc.	Henderson Smith Ditch GW conc.
Section No 3 Ditch GW conc.	Lowline Ditch GW conc.
Lower Latham Ditch GW conc.	Bravo Div System GW conc.
Patterson Ditch GW conc.	Iliff Platte Valley Ditch GW conc.
Highland Ditch GW conc.	Jud Brush Ditch GW conc.
Empire Canal GW conc.	Long Tree Ditch GW conc.
Riverside System GW conc.	Powell Blair Ditch GW conc.
Bijou System GW conc.	Rice Ditch GW conc.
Jackson Lake Inlet GW conc.	Ramsey Ditch GW conc.
Weldon Valley Ditch GW conc.	Chambers Ditch GW conc.
Ft Morgan Canal GW conc.	Harmony Div System GW conc.
Settlers Ditch GW conc.	Long Island Ditch GW conc.
Red Supply Lion Ditch GW conc.	Peterson Ditch GW conc.
South Reservation Ditch GW conc.	Liddle Ditch GW conc.
Carlson Ditch GW conc.	

Return Flow Model Parameters	
Return Flow % before Union Ditch	Return Flow % after Union Ditch
Wastewater Treatment Plant Model Parameters	
Robert W. Hite WWTP Flowrate	Robert W. Hite WWTP Concentration
Tributary Model Parameters	
St. Vrain River Flowrate	St. Vrain River Concentration
Big Thompson River Flowrate	Big Thompson River Concentration
Cache La Poudre River Flowrate	Cache La Poudre River Concentration
Road Salt Model Parameters	
Road Salt Mass Loading	

In the first scenario, the South Platte River was broken into five different reaches, as shown in Figure 18.

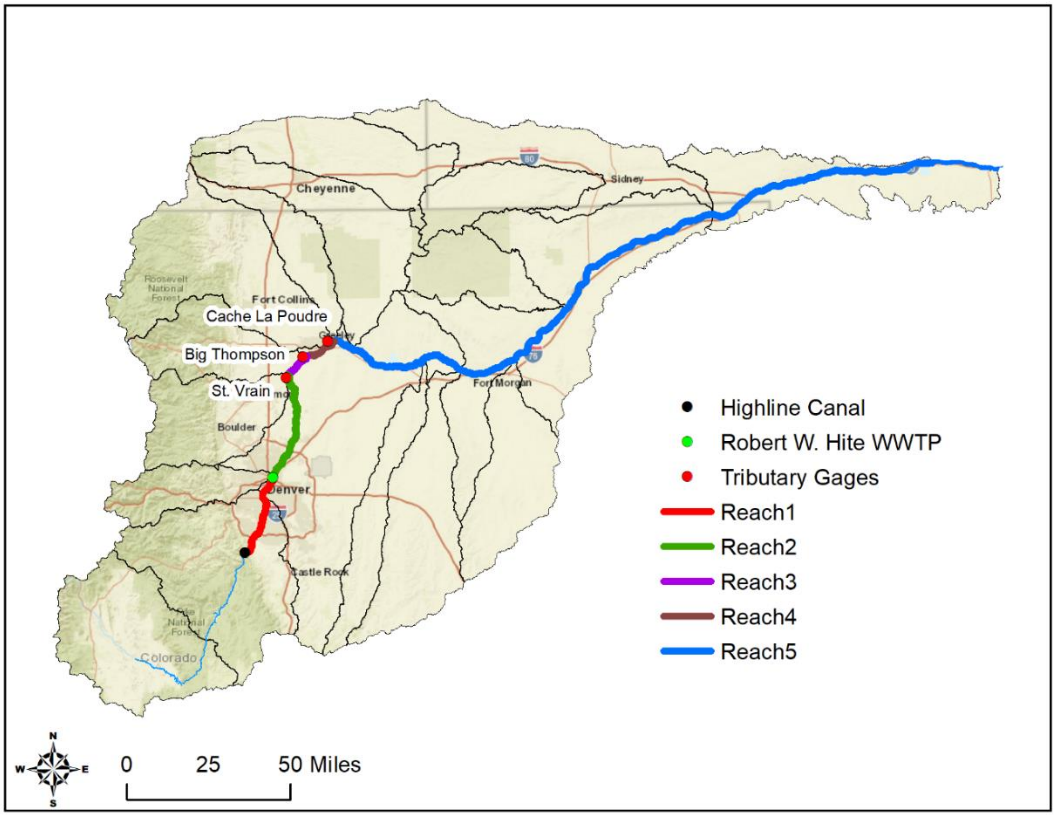

Figure 18. The South Platte River divided up into five different reaches. The portion of the river upstream of the Highline Canal is not included in the model due to a lack of data

Reach one spanned between the Highline Canal and the W. Hite WWTP. Reach two spanned between W. Hite WWTP and the South Platte River's confluence with the St. Vrain tributary. Reach three spanned between the confluence with the St. Vrain tributary to the confluence with the Big Thompson tributary. Reach four spanned between the confluence with Big Thompson tributary to the confluence with the Cache La Poudre tributary. Reach five spanned between the confluence with the Cache La Poudre tributary to the end of the South Platte River. For each reach, the sensitivity analysis assessed each parameter one at a time. For each parameter, the flow and salt models were run for every month during the 2002 to 2006 study period. For each month, a set of EE's was calculated where the model output was taken as the average TDS (mg/L) concentration over the reach being studied. Each parameter's monthly μ^* and σ^* were calculated, and the parameter’s final μ^* and σ^* values were the averages of the monthly μ^* and σ^* values.

In the second scenario, the 2002 to 2006 study period was split up by seasons: spring (March to May), summer (June to August), fall (September to November), and winter (December to February). For each season, the sensitivity study looked at all 77 parameters one at a time. For each parameter, the flow and salt models were run for every month during that season during the 2002 to 2006 study period. For each month, a set of EEs was calculated where the model output was taken as the average TDS (mg/L) concentration over the entire South Platte River. Each parameter's monthly μ^* and σ^* were calculated on a seasonal basis, and the parameter’s final μ^* and σ^* values were the averages of the monthly μ^* and σ^* values.

2.6 Potential Management Practices (MPs)

The sensitivity analysis results were used to identify the controlling factors behind salt transport in the South Platte River basin. A study was designed around these controlling factors to determine the best combination of actions to reduce salinity levels. Two different scenarios were developed. The first scenario was a MP analysis over an urban reach of the South Platte

River basin. The second scenario was a MP analysis over an agricultural reach of the South Platte River.

In the first scenario, the MP analysis was conducted over reaches one and two (see Figure 18 in Section 2.5), which represent an urban area along the South Platte River and includes the city of Denver. In this scenario, four parameters were picked based on their high μ* values in the reach-to-reach sensitivity analysis results for reaches one and two (see Section 3.2.1). These four parameters are the Road Salt Mass Loading, the Initial Concentration, the Return Flow % before Union Ditch, and the W. Hite WWTP Effluent concentration.

In the second scenario, the MP analysis was conducted over reach five (see Figure 18 in Section 2.5), representing an agricultural area of the South Platte River Basin and includes the end of the South Platte River. In this scenario, four parameters were picked based on their high μ* values in the reach-to-reach sensitivity analysis results over reach five (see Section 3.2.1). These parameters are the Road Salt Mass Loading, the Return Flow % before Union Ditch, the Return Flow % after Union Ditch, and the W. Hite WWTP Effluent concentration. The Return Flow % after Union Ditch and the W. Hite WWTP Effluent concentration parameters had the first and second highest μ* values in reach five, respectively. The remaining two parameters, Road Salt Mass Loading and Return Flow % before Union Ditch, while not having the third and fourth highest μ* values, were included to maintain some consistency across both the urban and agricultural MP analysis, as well as due to their real-world ability to be more easily modified. For example, decreasing the amount of road salt applied during the winter would be easier to accomplish than lowering the groundwater concentration at Jud Brush Ditch, even though the groundwater concentration at Jud Brush Ditch has a higher μ* value compared to the Road Salt Mass Loading.

In both scenarios, each parameter was assigned one of four different value options. The first option is Baseline, which means the parameter retains its monthly nominal value. The second option is Low, which means the parameter undergoes a 5% reduction to its monthly nominal value. The third option is Medium, which means the parameter undergoes a 20% reduction to its monthly nominal value. The fourth option is High, which means the parameter undergoes a 35% reduction to its monthly nominal value. A total of 256 trials, which encompass all the different possible combinations of the four parameters and their four value options, were run for every month in each scenario.

In the urban MP analysis, the model output was the average river TDS concentration (mg/L) over reaches one and two. In the agricultural MP analysis, the model output was the average TDS concentration (mg/L) over reach five. In both scenarios, the 60-months between 2002 and 2006 was split into two time periods. The first time period included all months from April to October (corresponding with the growing season in the agricultural reach), and the second time period included all months from November to March (corresponding with the non-growing season in the agricultural reach). A trial's final model output was calculated by averaging that trial's individual monthly model outputs across each time period. For example, in the urban MP analysis, the final value of trial 5 during the April to October time period would be calculated as the average of all trial 5 model outputs between April and October during the 2002 to 2006 period:

$$Trial\ 5_{April-October} = \frac{1}{35}\sum_{i=2}^{6}\left(Trial\ 5_{April\ 2000+i} + Trial\ 5_{May\ 2000+i} + Trial\ 5_{June\ 2000+i} + Trial\ 5_{July\ 2000+i} + Trial\ 5_{August\ 2000+i} + Trial\ 5_{September\ 2000+i} + Trial\ 5_{October\ 2000+i}\right)$$

The final MP trials in each scenario are compared to each other to determine which combination of parameter changes have the largest impact on the South Platte River's salinity. A point system was setup to rate the MP trials. For every total 5% reduction in a trial’s parameter values, one point would be assigned. For example, a trial with the following combination: Baseline (no reduction), Low (5% reduction), Baseline (no reduction), Baseline (no reduction) would have a total % reduction of 5%, and a value of one point. A trial with the following combination: Low (5% reduction), Medium (20% reduction), Baseline (no reduction), Low (5% reduction) would have a total % reduction of 30%, and a value of six points.

For each trial, the TDS % Reduction was calculated by comparing the trial's average TDS (mg/L) value to the average TDS (mg/L) value of the all Baseline trial. The TDS % Reduction was then divided by the trial's total number of assigned points to calculate the TDS % Reduction per Point value. Trials with a higher TDS % Reduction per Point value are considered a more efficient MP towards reducing salinity values in the South Platte River.

3 Results

3.1 Model Results

3.1.1 Flow Model Graphs

The flow model was run over the 60-month period between 2002 to 2006. The model output includes a streamflow graph comparing the modeled adjusted streamflow over the South Platte River's distance and a graph comparing simulated and observed streamflow data. In general, the modeled adjusted streamflow follows the gage data regardless of year or month. Comparing a month modeled towards the beginning of the study period, March 2003 as seen in Figure 19, to the same month modeled at the end of the study period, March 2006 as seen in Figure 20, the results of the flow model match the gage data well in both cases regardless of the year.

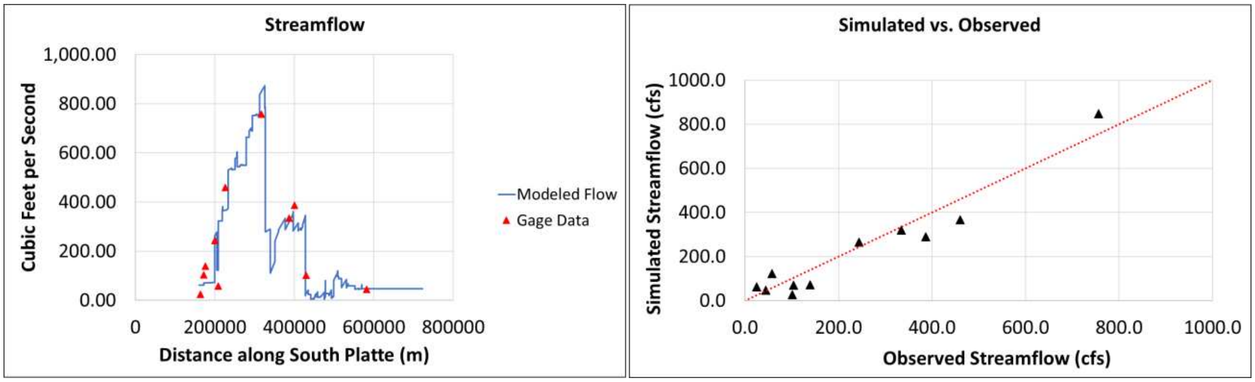

Figure 19. Flow Model Results for March 2003

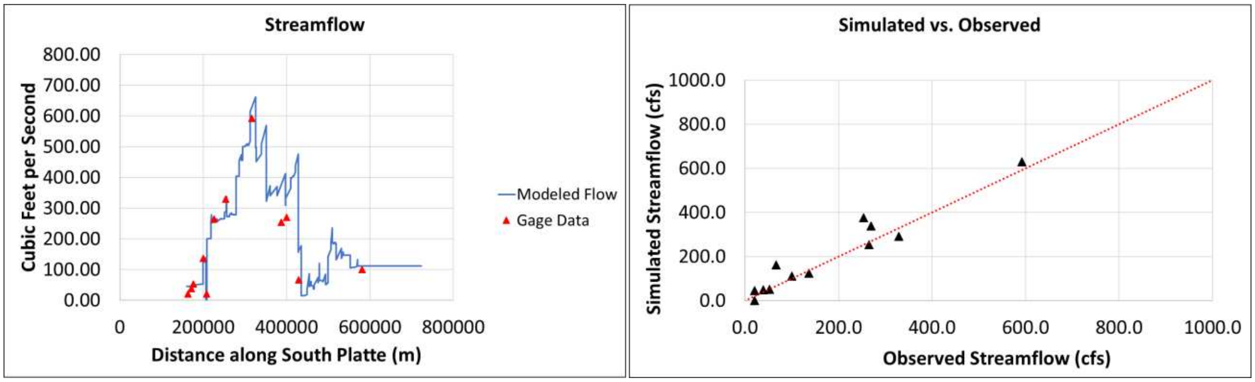

Figure 20. Flow Model Results for March 2006

During the spring and summer months, high streamflow values would be expected due to annual snowmelt reaching the South Platte River. As seen in the flow model results for May 2003 and June 2003, shown below in Figures 21 and 22, the flow model is capable of simulating these high flowrates.

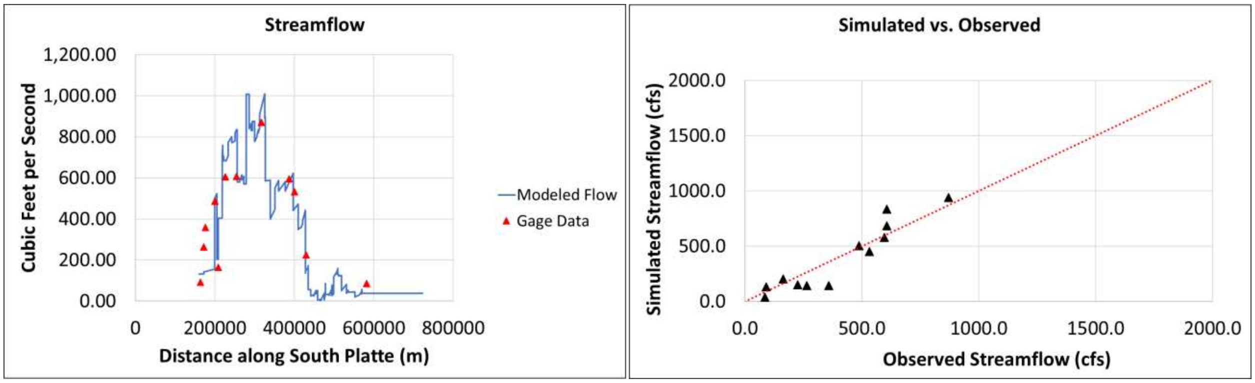

Figure 21. Flow Model Results for May 2003

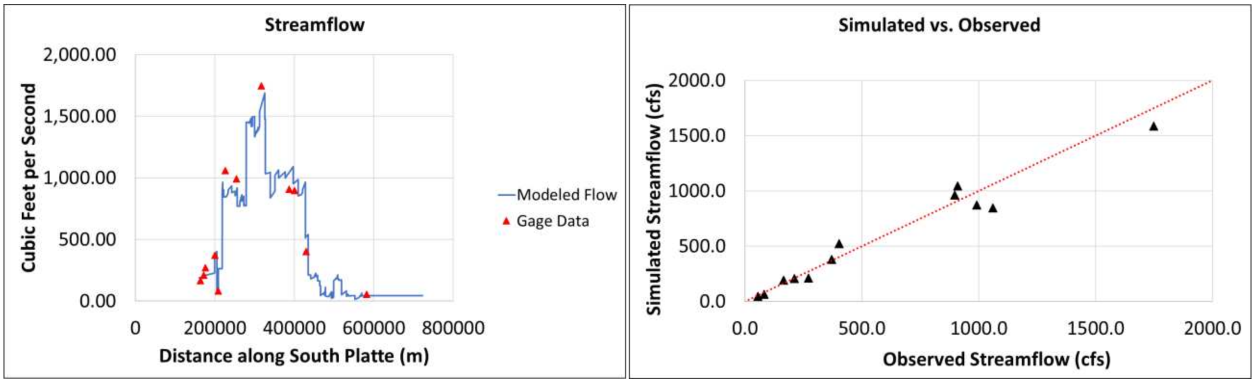

Figure 22. Flow Model Results for June 2003

After the peak annual snowfall runoff occurs, lower streamflow values would be expected over the South Platte River during the fall and winter. As seen in the flow model results for December 2004 and August 2006, shown below in Figures 23 and 24, the flow model is capable or simulating these low flowrates.

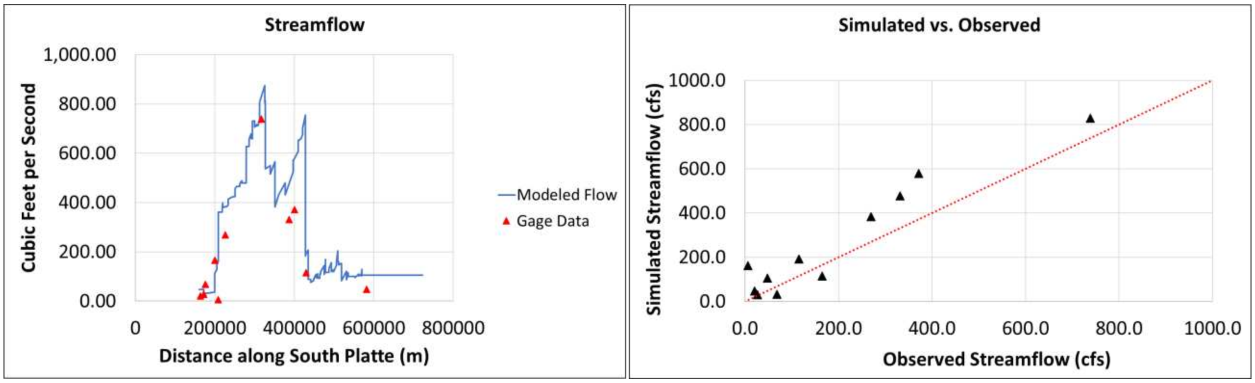

Figure 23. Flow Model Results for December 2004

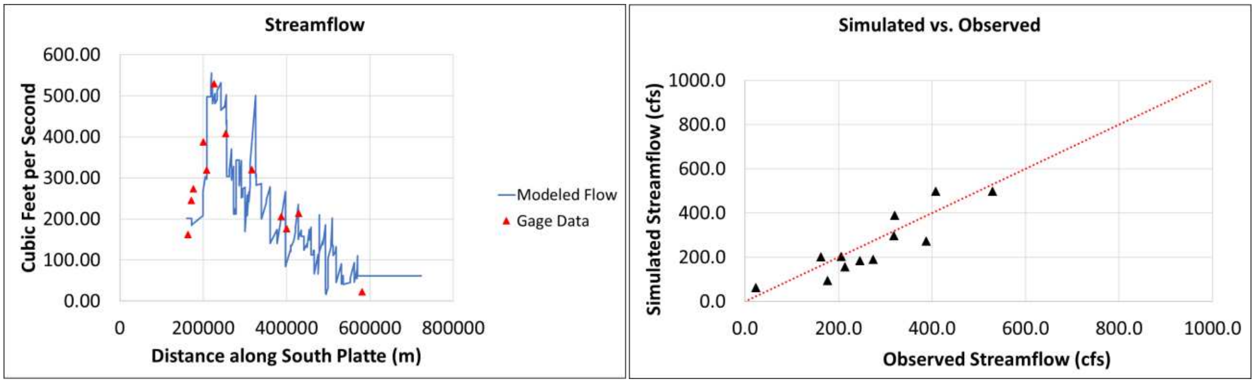

Figure 24. Flow Model Results for August 2006

While many months display modeled results that closely match the gage data, some months overestimate or underestimate the flowrate. The flow model results for October 2004, shown below in Figure 25, underestimate the flowrate while the flow model results for May 2006, shown below in Figure 26, overestimate the flowrate as seen in their respective Simulated vs. Observed graphs.

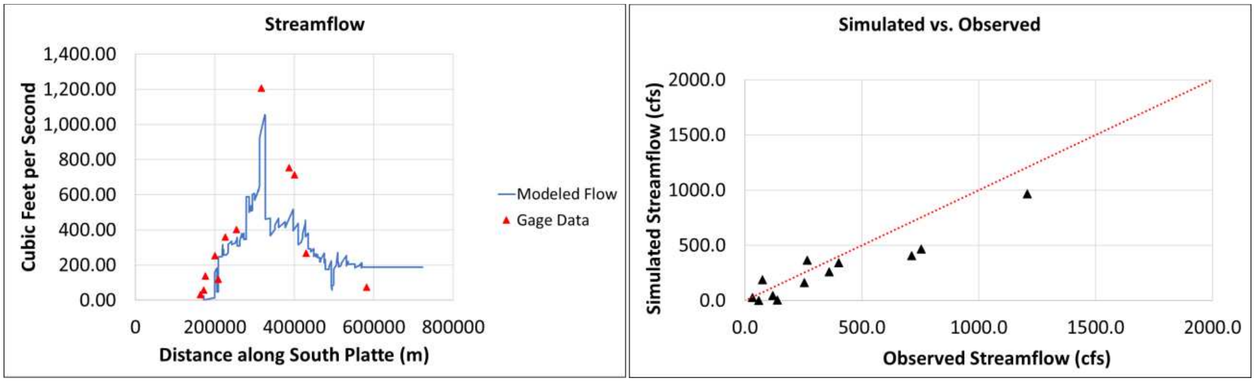

Figure 25. Underestimated Flow Model Results for October 2004

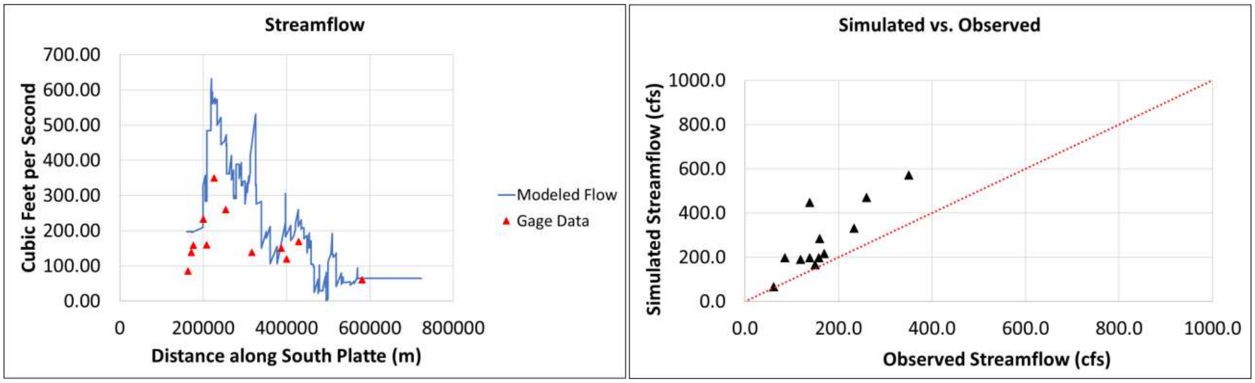

Figure 26. Overestimated Flow Model Results for May 2006

To view a complete list of flow model output graphs between the 2002 to 2006 study period, refer to Appendix A.

3.1.2 Salt Model Graphs

The salt model was run over the 60-month period between 2002 to 2006. The model output includes a TDS concentration graph comparing the modeled concentration over the South Platte River's distance and a graph comparing simulated and observed concentration data. The modeled concentration data shows the general trends expected over the South Platte River, but does not perform as well statistically as the flow model. The flow model is based on the established Colorado's DWR StateMod model, while the salt model was built from scratch. Due to the complexity of trying to account for all inputs and outputs of salt, it is not surprising that the flow model would outperform the salt model.

Northern Water's salinity report, which was used to estimate the EC gage measurements, had limited data during the first year of their study. No EC data was available for January and February 2002; however, these months were still included in the overall model analysis. Because of the lack of early EC data, it is difficult to compare the model's performance over 2002. Even so, the salt model's results during this year still display the expected increasing salinity trend over the South Platte River. This can be seen in the salt model's result for June 2002 and July 2002, shown below in Figures 27 and 28.

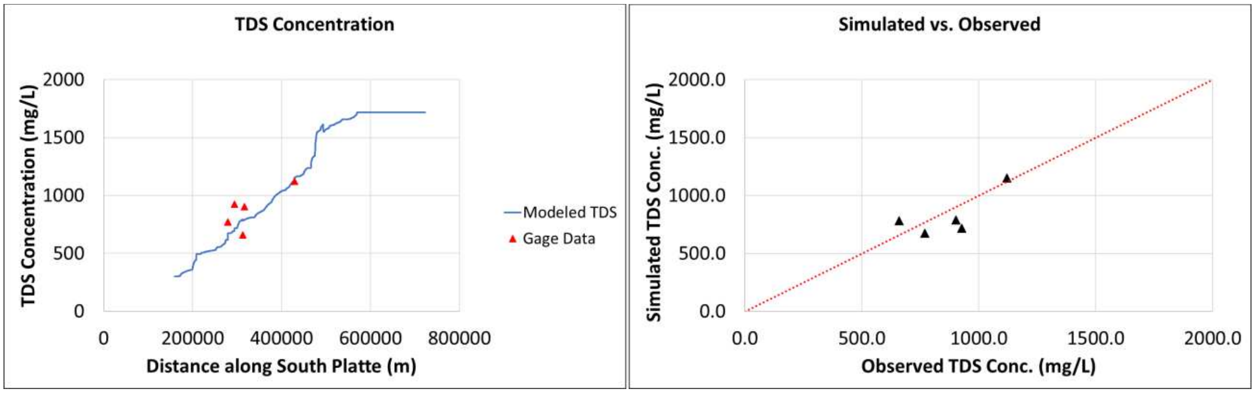

Figure 27. Salt Model Results for June 2002

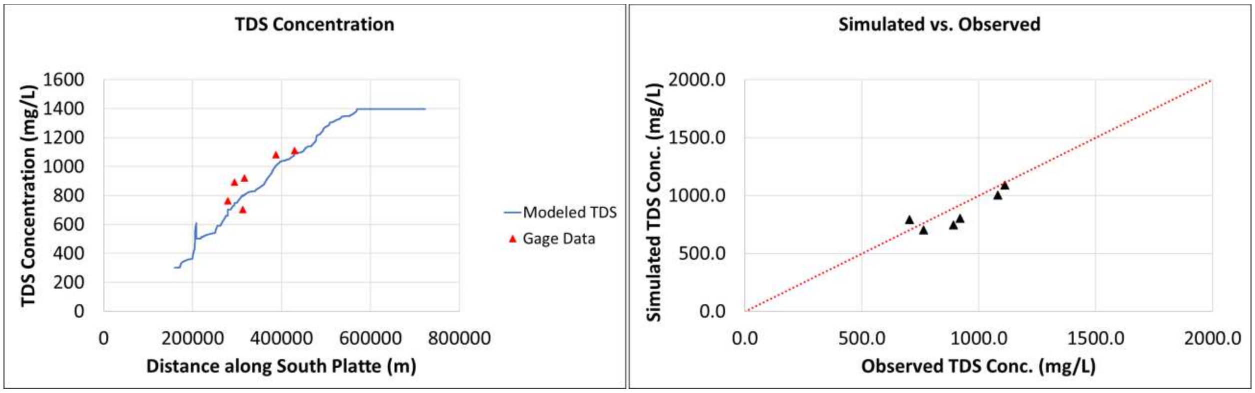

Figure 28. Salt Model Results for July 2002

Between 2003 and 2006, additional gage data was available in Northern Water's report. This additional data allows for a better comparison between modeled and observed concentration values over the South Platte River as seen in the salt model's results for September 2005 and November 2006, shown below in Figures 29 and 30.

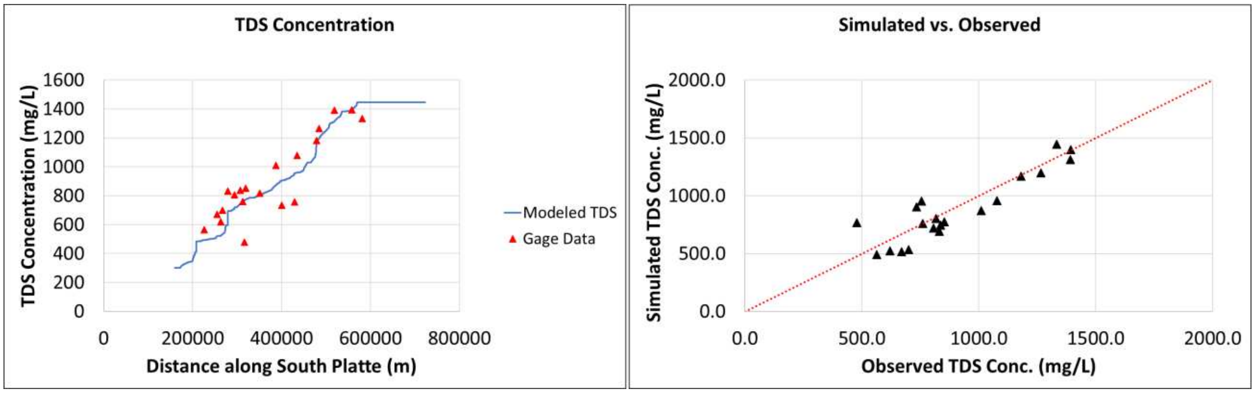

Figure 29. Salt Model Results for September 2005

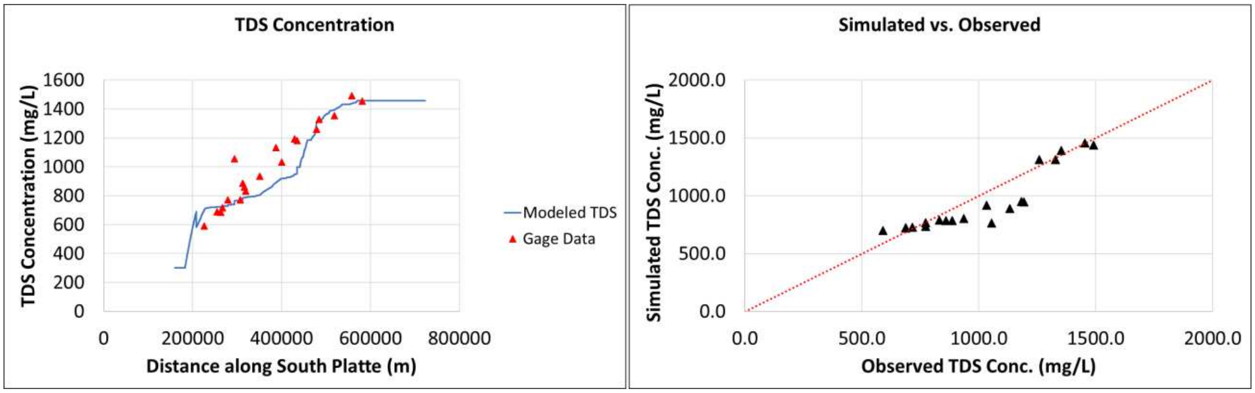

Figure 30. Salt Model Results for November 2006

During the spring and summer months, the salt model is capable of simulate the high salinity values expected near the end of the South Platte River. This can be seen in the salt model's results for March 2005 and August 2006, shown below in Figures 31 and 32.

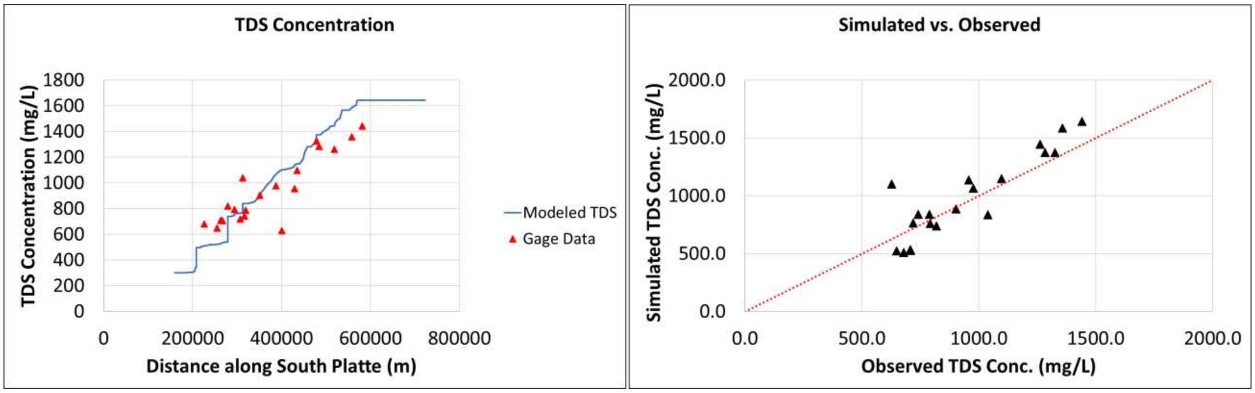

Figure 31. Salt Model Results for March 2005

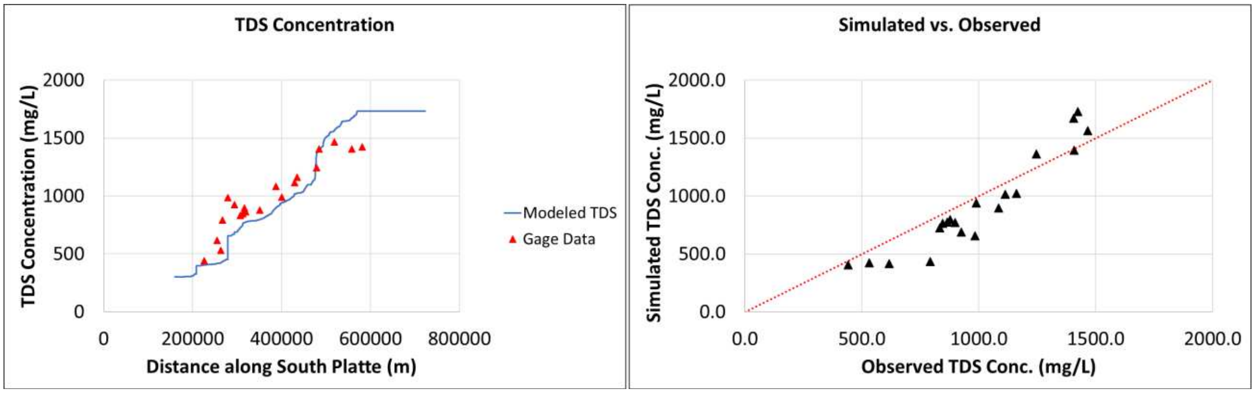

Figure 32. Salt Model Results for August 2006

Over the winter months, when most road salt is applied (November to February), the salt model often displays a sharp concentration spike in the Denver area. This spike is due to the low StateMod flowrates at Burlington Canal and Gardeners Ditch. Because there are not EC gages located in this area, it is hard to determine the legitimacy of this spike. Additional data would be useful to compare the model's performance over this area. Examples of this concentration spike can be seen in the salt model's results for February 2005 and January 2006, shown below in Figures 33 and 34.

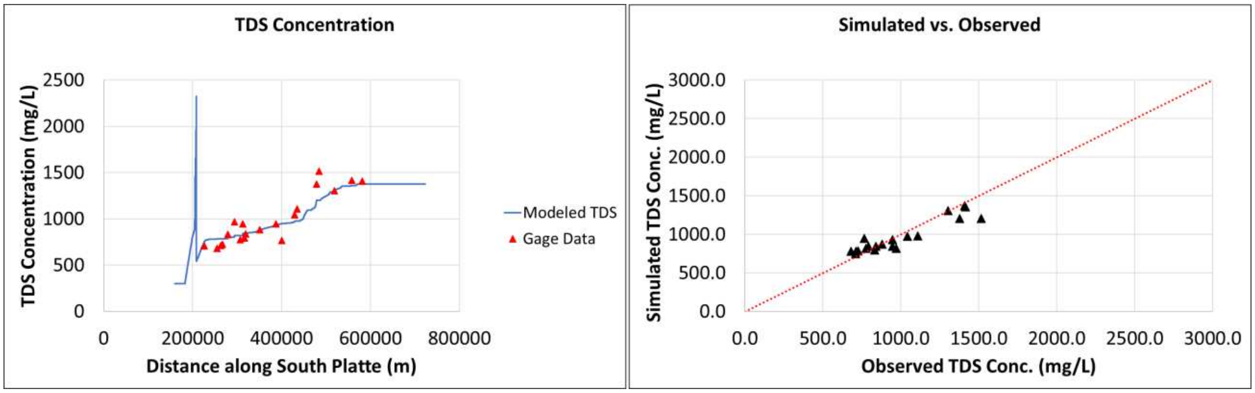

Figure 33. Salt Model Results for February 2005

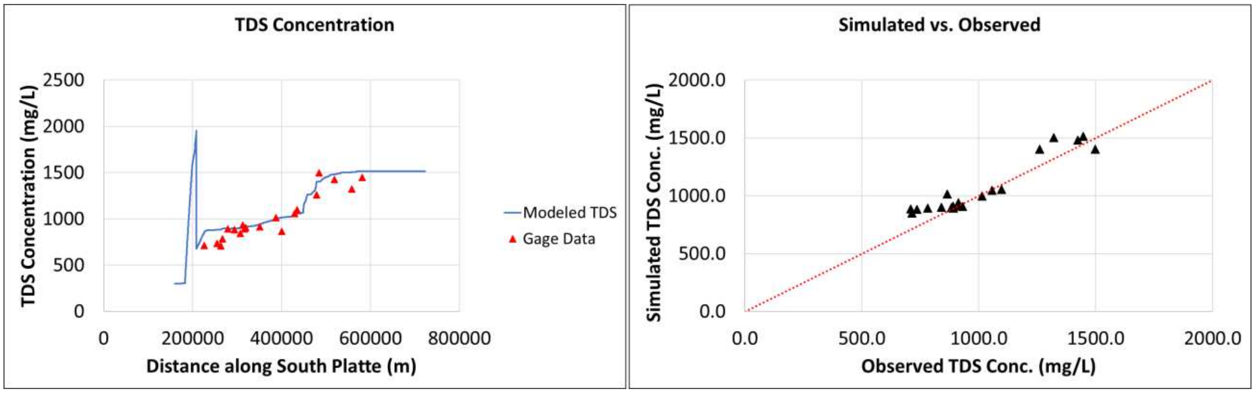

Figure 34. Salt Model Results for January 2006

While the salt model's result match the observed EC data in most cases, some months display modeled concentrations that overestimate or underestimate the observed EC data. The salt model results for July 2005, shown below in Figure 35, overestimate the concentration and the salt model results for September 2006, shown below in Figure 36, underestimate the concentration as seen in their respective Simulated vs. Observed graphs.

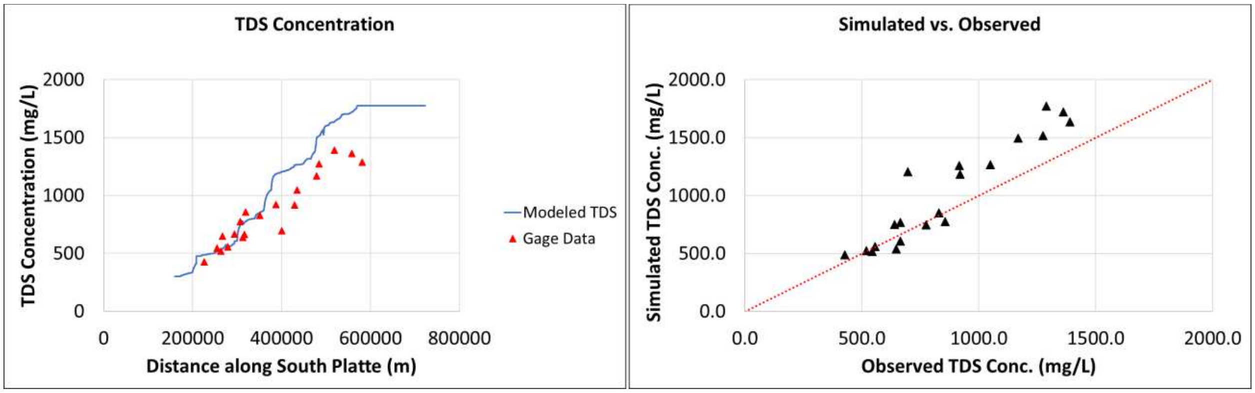

Figure 35. Overestimated Salt Model Results for July 2005

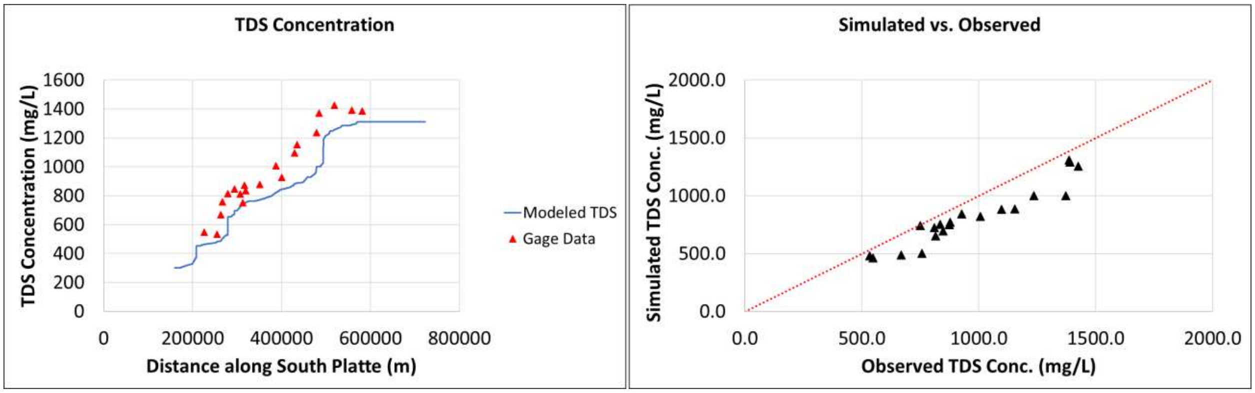

Figure 36. Underestimated Salt Model Results for September 2006

For a complete list of the salt model output graphs between the 2002 to 2006 study period, refer to Appendix A.

3.1.3 Statistics

Three statistical measurements, MAE, RMSE, and NSCE, are calculated each run by comparing the model's output to observed gage data. A full summary of these statistics during the 2002 to 2006 study period is available for view in Appendix B. While the MAE and RMSE can provide useful information on model performance, this section will focus on the NSCE results for the flow and salt model.

The NSCE is often used to evaluate hydrological model outputs and is calculated as one minus the ratio of the modeled series' error variance divided by the observed series' variance (see Section 2.4.3). NSCE values can range from negative infinity to one. An NSCE value of one means the model perfectly match the observed data. An NSCE value of zero means the model is as efficient of a predictor as the mean of the observed data. An NSCE value between zero and one is often considered as an indicator of acceptable model performance.

Figure 37 shows the flow model's results during the 2002 to 2006 study period. 51 out of 60 months (85%) have NSCE values that fall within the acceptable range of zero to one.

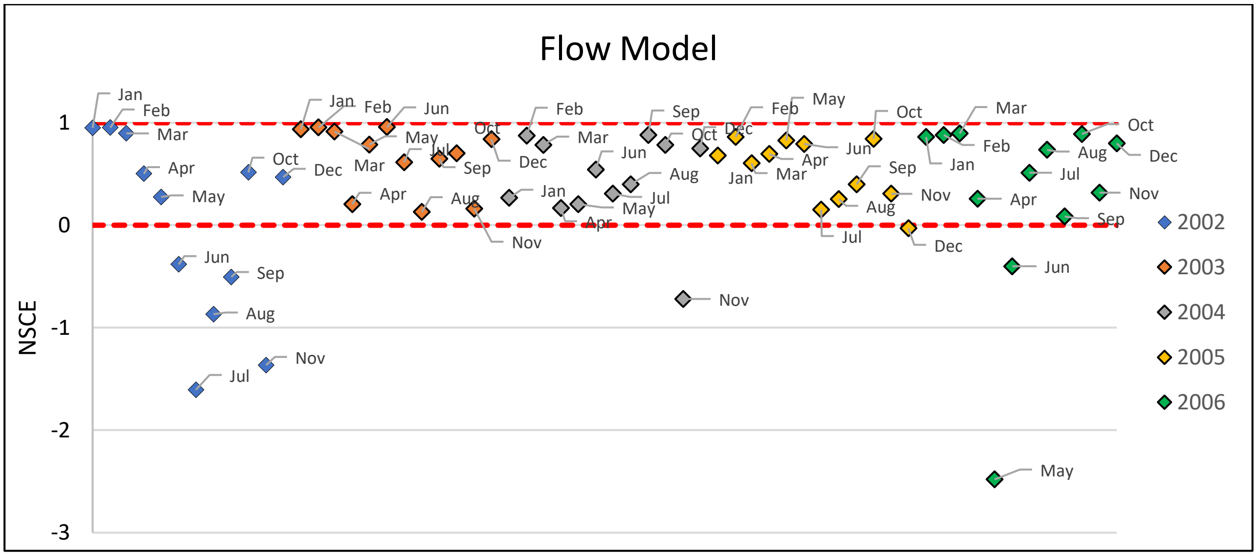

Figure 37. Flow Model NSCE Values

Figure 38 shows the salt model's results during the 2002 to 2006 study period. 39 out of 57 months (68.4%) have NSCE values that fall within the acceptable range of zero to one. NSCE values for January, February, and March 2002 could not be calculated due to the lack of observed EC gage data.

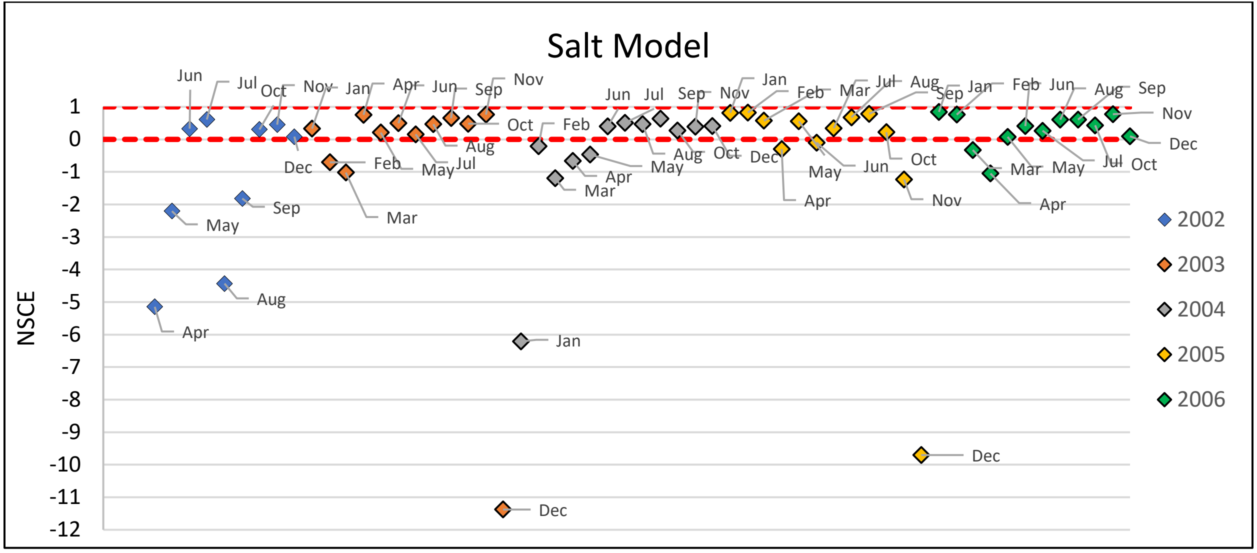

Figure 38. Salt Model NSCE Values

The flow model performs better compared to the salt model. The flow model is based on Colorado's DWR's StateMod model, while the salt model was built from scratch. Because the salt model also relies on the results of the flow model to calculate concentration, any errors in the flow model will carry over to the salt model. One interesting note is that both models perform relatively poorly over 2002 compared to the other four years.

While the salt model does not perform as well as initially hoped, it does appear to more often or not display the general trends seen in the observed EC data. Due to the complexity of accounting for all salt inflows and outflows in the South Platte River, we were satisfied with the model results.

3.2 Sensitivity Analysis

3.2.1 Reach-to-Reach Sensitivity

The reach-to-reach sensitivity analysis results were used to plot σ^* vs. μ^* over each reach for the 77 different parameters included in the study. The larger a parameter's μ^* value, the larger its influence on the model output. The larger a parameter's σ^* value, the larger its influence on other parameters and/or a non-linear effect on the model output. Only parameters with μ^* values greater than 0.02 were considered influential and displayed graphically. A complete list of the reach-to-reach sensitivity analysis results can be found in Appendix C.

Reach one was designated as the portion of the South Platte River between the Highline Canal StateMod node and the W. Hite WWTP (see Figure 18 in Section 2.5). In this reach, the South Platte River's salinity is most sensitive to the Initial Concentration, as seen in Figure 39. The Initial Concentration parameter has the largest μ^* and σ^* values compared to any other parameter over this reach. The only other two sensitive parameters are the Return Flow % before Union Ditch and the Road Salt Mass Loading. Reach one is relatively short, and most of the parameters considered are located downstream of its end, and therefore do not have an impact on reach one's salinity.

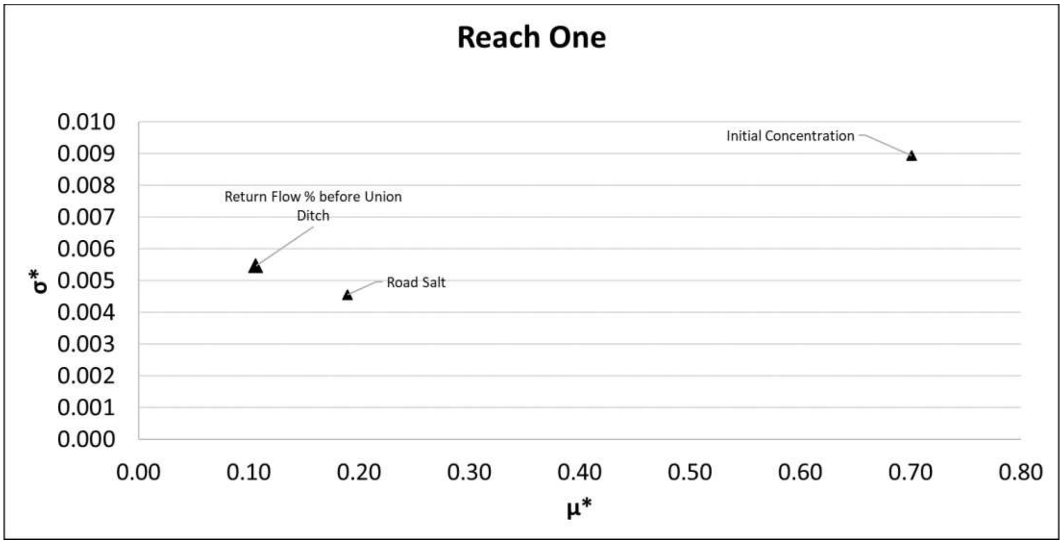

Figure 39. Reach One Sensitivity Results

Reach two was designated as the portion of the South Platte River between the W. Hite WWTP and the South Platte River's confluence with the St. Vrain tributary (see Figure 18 in Section 2.5). In this reach, the South Platte River's salinity is most sensitive to the W. Hite WWTP Effluent concentration, as seen in Figure 40. The remaining sensitive parameters include the Return Flow % before Union Ditch, Initial Concentration, Road Salt Mass Loading, and the W. Hite WWTP Effluent Flowrate.

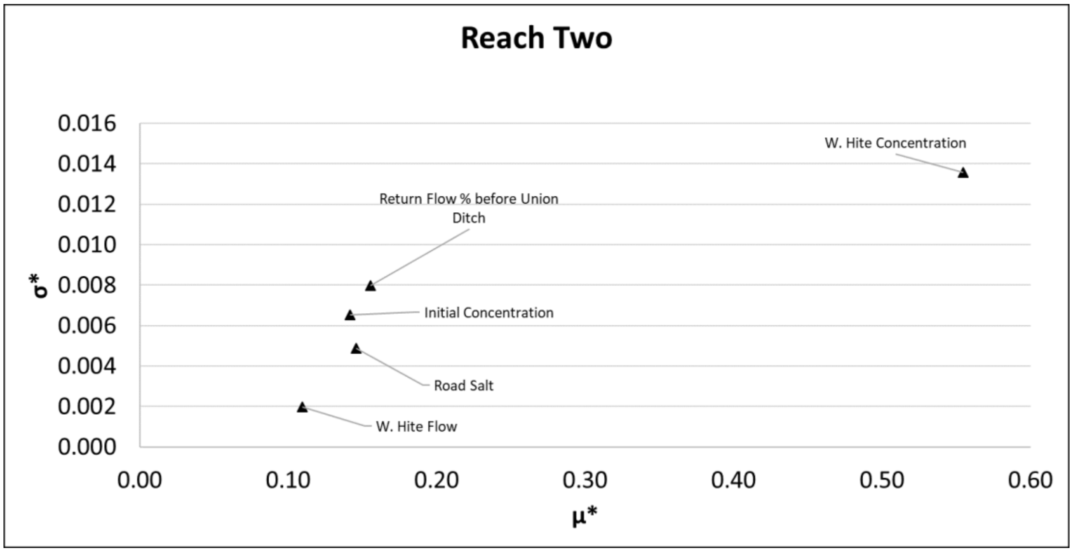

Figure 40. Reach Two Sensitivity Results

Reach three was designated as the portion of the South Platte River between the confluence with the St. Vrain tributary and the confluence with the Big Thompson tributary (see Figure 18 in Section 2.5). In this reach, the South Platte River's salinity is most sensitive to the St. Vrain Tributary Concentration, followed closely by the W. Hite WWTP Effluent concentration, as seen in Figure 41. The other sensitive parameters include the Return Flow % before Union Ditch, Road Salt Mass Loading, Initial Concentration, and the St. Vrain Tributary and W. Hite WWTP flowrates.

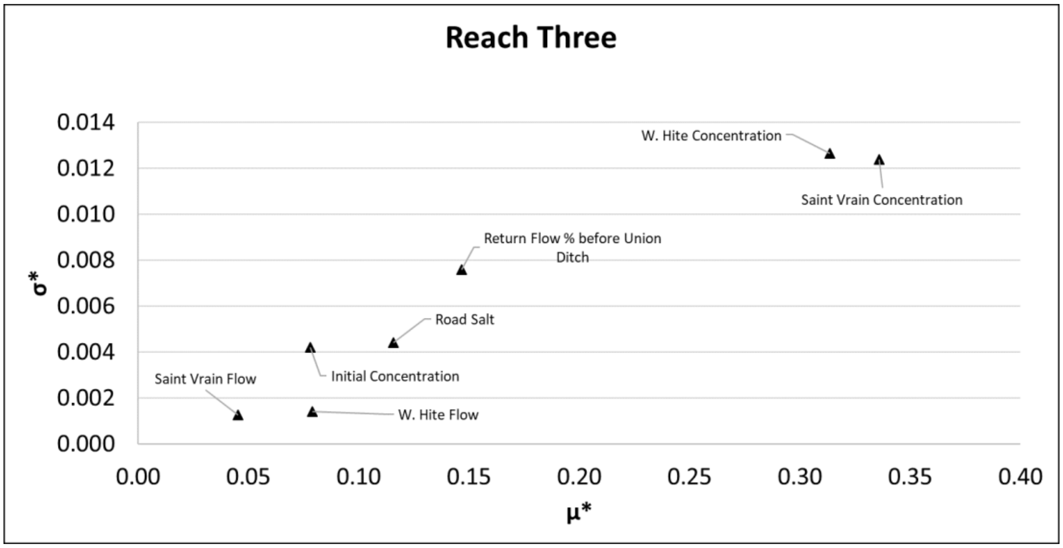

Figure 41. Reach Three Sensitivity Results

Reach four was designated as the potion of the South Platte River between the confluence with the Big Thompson tributary and the confluence with the Cache La Poudre tributary (see Figure 18 in Section 2.5). In this reach, the South Platte River's salinity is most sensitive to the St. Vrain Tributary Concentration, followed closely by the W. Hite WWTP Effluent concentration, as seen in Figure 42. Other sensitive parameters include the Return Flow % before and after the Union Ditch, Big Thompson Tributary Concentration, Road Salt Mass Loading, Initial Concentration, and the St. Vrain Tributary and W. Hite WWTP flowrates.

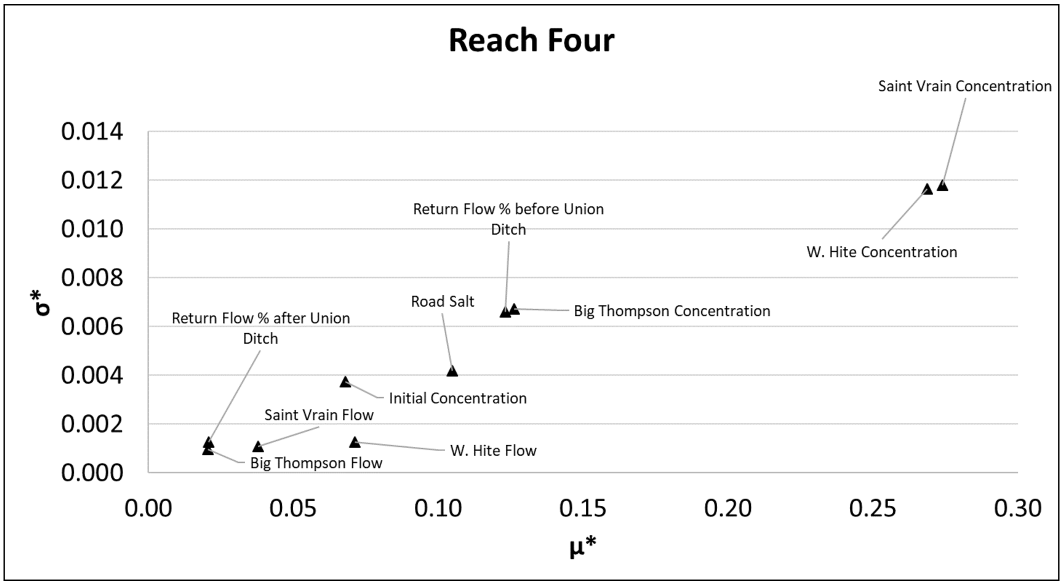

Figure 42. Reach Four Sensitivity Results

Reach five was designated as the portion of the South Platte River between the confluence with the Cache La Poudre tributary and the end of the river (see Figure 18 in Section 2.5). In this reach, the South Platte River's salinity is most sensitive to the Return Flow % after Union Ditch, as seen in Figure 43. Other sensitive parameters include the W. Hite WWTP Effluent concentration, the three Tributary Concentrations, the Return Flow % before Union Ditch, Initial Concentration, Road Salt Mass Loading, and the Groundwater Concentration at Jud Brush Ditch.

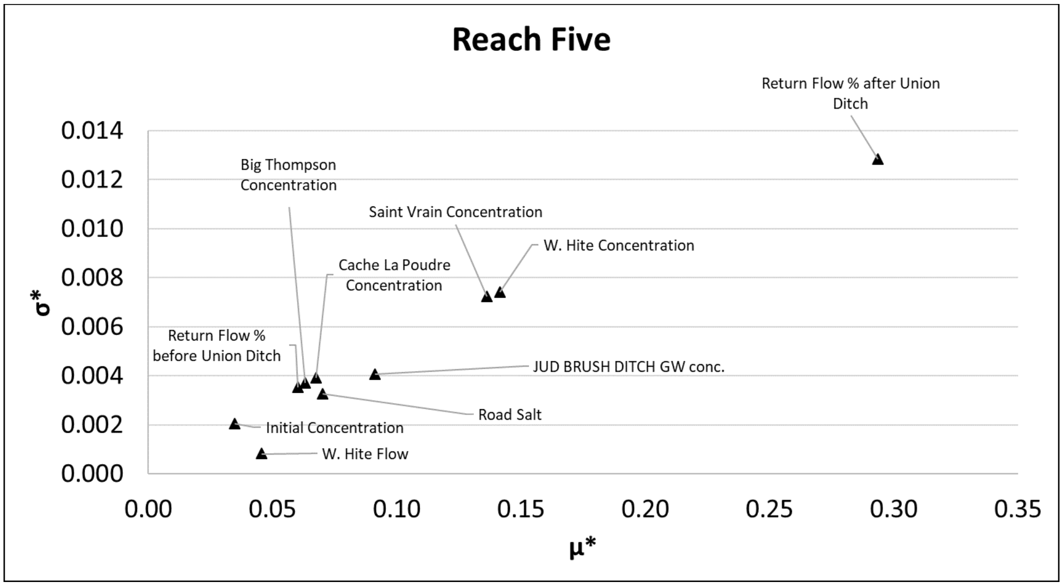

Figure 43. Reach Five Sensitivity Results

3.2.2 Seasonal Sensitivity

The seasonal sensitivity analysis results were used to plot σ^* vs. μ^* over each season for the 77 different parameters included in the study. The larger a parameter's μ^* value, the larger its influence on the model output. The larger a parameter's σ^* value, the larger its influence on other parameters and/or a non-linear effect on the model output. Only parameters with μ^* values greater than 0.02 were considered influential and displayed graphically. A complete list of the seasonal sensitivity analysis results can be found in Appendix C.

The spring season was designated as March to May. In this season, the South Platte River's salinity is most sensitive to the Return Flow % after Union Ditch, as seen in Figure 44. Other sensitive parameters include the W. Hite WWTP Effluent concentration, the three Tributary Concentrations, Initial Concentration, Return Flow % before Union Ditch, and the Groundwater Concentration at Jud Brush Ditch.

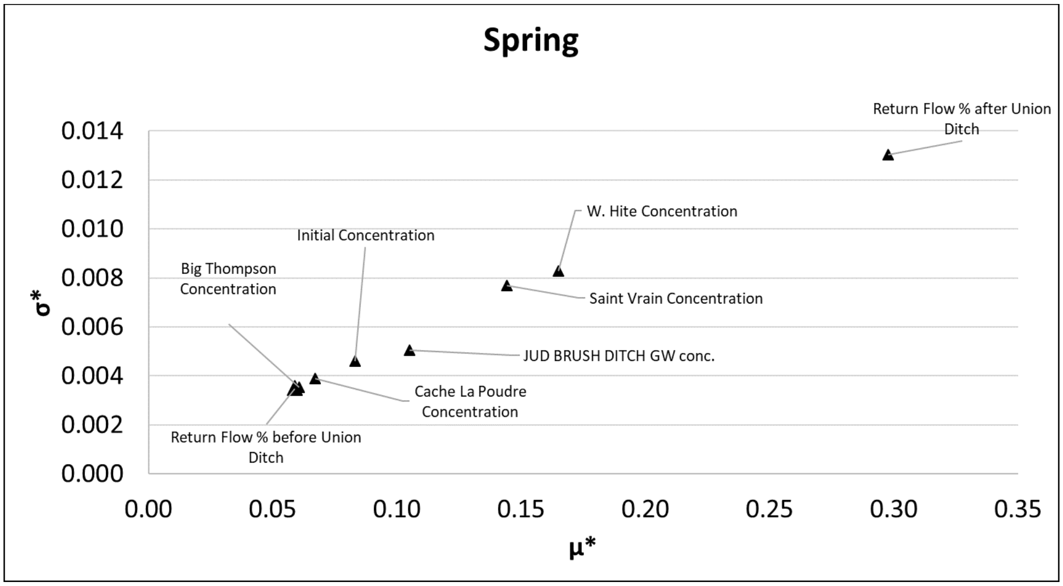

Figure 44. Spring Sensitivity Results

The summer season was designated as June to August. In this season, the South Platte River's salinity is most sensitive to the Return Flow % after Union Ditch, as seen in Figure 45. Other sensitive parameters include the W. Hite WWTP Effluent concentration, the three Tributary Concentrations, Return Flow % before Union Ditch, and the Groundwater Concentration at Jud Brush Ditch and the Bravo Ditch System.

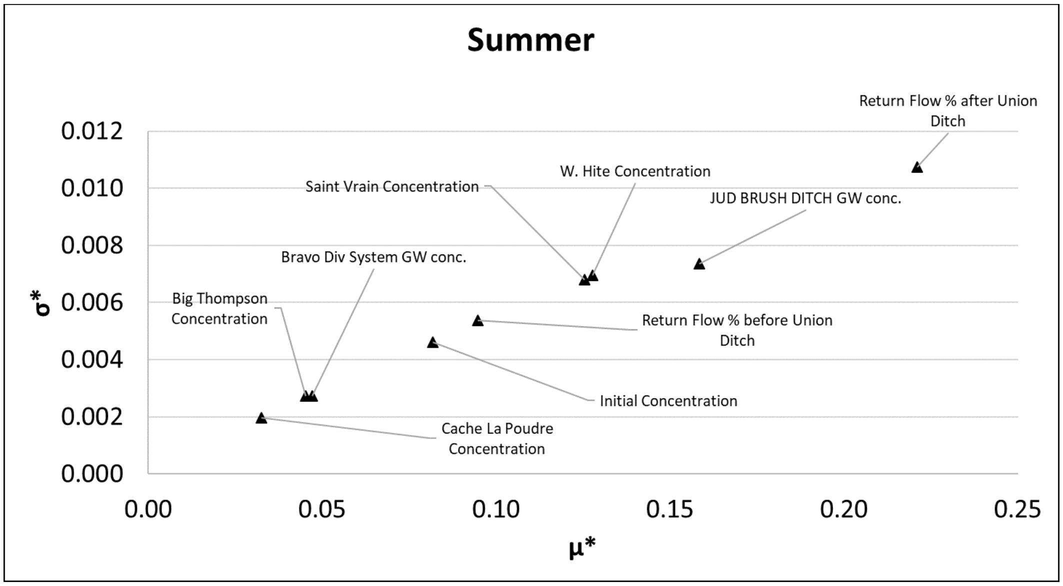

Figure 45. Summer Sensitivity Results

The fall season was designated as September to November. In this season, the South Platte River's salinity is most sensitive to the Return Flow % after Union Ditch followed closely by the W. Hite WWTP Effluent concentration, as seen in Figure 46. Other sensitive parameters include the three Tributary Concentrations, Return Flow % before Union Ditch, Road Salt Mass Loading, W. Hite WWTP Flowrate, and the Groundwater Concentration at Jud Brush Ditch.

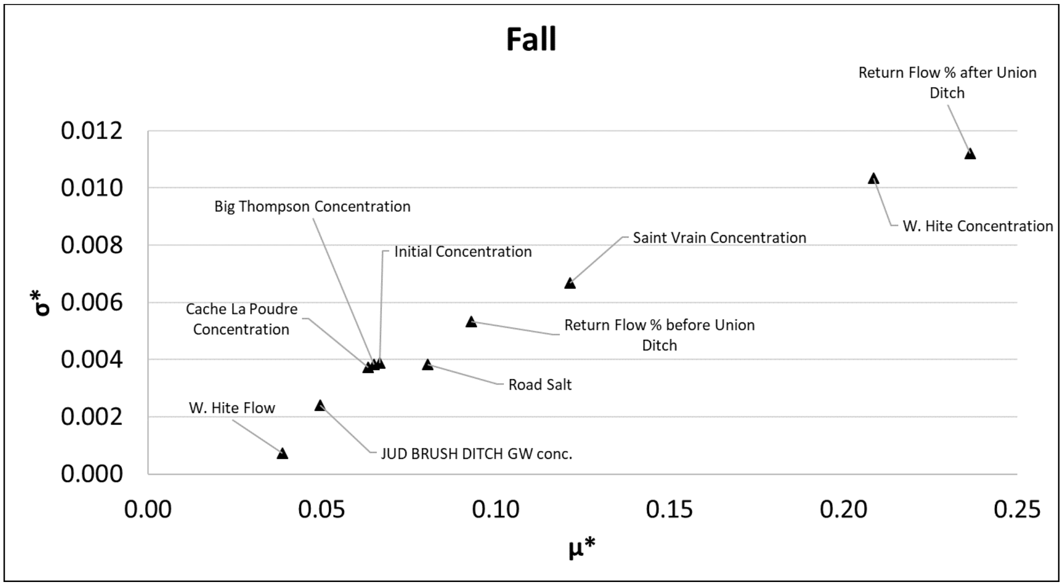

Figure 46. Fall Sensitivity Results

The winter season was designated as December to February. In this season, the South Platte River's salinity is most sensitive to the Road Salt Mass Loading, followed by the Return Flow % after Union Ditch and the W. Hite WWTP Effluent concentration, as seen in Figure 47. Other sensitive parameters include the three Tributary Concentrations, Return Flow % before Union Ditch, W. Hite WWTP Flowrate, and the Initial Concentration.

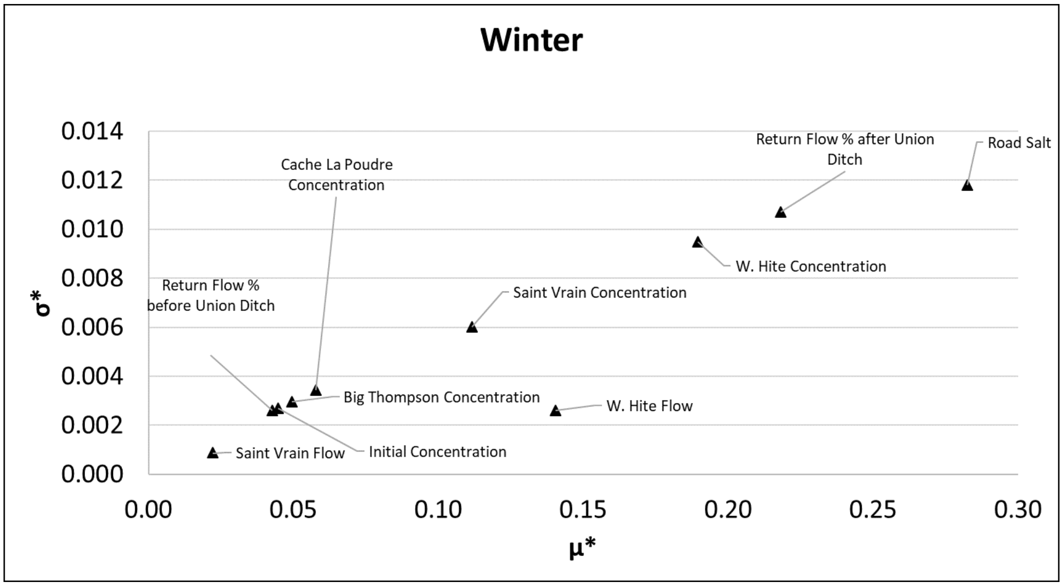

Figure 47. Winter Sensitivity Results

3.3 Assessment of Potential Management Practices (MPs)

3.3.1 Urban Reaches

The urban MP analysis was conducted over reaches one and two (see Figure 18 in Section 2.5). The analysis was split into two periods of time, April to October (corresponding with the growing season in the agricultural reach), and November to March (corresponding with the non-growing season in the agricultural reach). Based on the sensitivity results for reaches one and two, four parameters were picked to be included in the MP (see Section 2.6). These parameters were the W. Hite WWTP Effluent concentration, the Return Flow % before Union Ditch, the Initial Concentration, and the Road Salt Mass Loading.

The final values of each MP trial were compared to one another by looking at each trial's TDS % Reduction per Point value. This value was found by first calculating each trial's TDS % Reduction by comparing the trial's average TDS (mg/L) concentration output to the average TDS (mg/L) concentration output of the all Baseline trial. After calculating each trial's TDS % Reduction, the next step was to determine the total amount of points assigned to each trial. For every total 5% reduction in parameter values, one point is assigned. A trial's TDS % Reduction per Point value is then calculated by dividing the trial's TDS % Reduction by the total number of points assigned. Trials with a higher TDS % Reduction per Point are considered a more efficient MP, but do not necessarily result in the greatest decrease in salinity.

In Table 8, the MP trials between April and October are sorted by the highest TDS % Reduction per Point. The top three MP trials are comprised of reductions to the W. Hite WWTP Effluent concentration. All three options, Low, Medium, and High, result in the same TDS % Reduction per Point value of 2.41. The next seven MP trials are combinations of reducing the W. Hite WWTP Effluent concentration and the Initial Concentration. The full urban MP analysis between April and October can be viewed in Appendix D.

Table 8. Top 10 Efficient Urban MP Trials between April and October

	Baseline	Low	Med	High
Parameter Reduction	0%	5%	20%	35%

Trial	W. Hite Conc.	Return % Before Union	Initial Conc.	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction per Point
1	Base	Base	Base	Base	0	411.55	NA
193	High	Base	Base	Base	7	342.18	2.41
129	Med	Base	Base	Base	4	371.91	2.41
65	Low	Base	Base	Base	1	401.64	2.41
197	High	Base	Low	Base	8	333.16	2.38
133	Med	Base	Low	Base	5	362.89	2.36
201	High	Base	Med	Base	11	306.10	2.33
69	Low	Base	Low	Base	2	392.62	2.30
137	Med	Base	Med	Base	8	335.83	2.30
205	High	Base	High	Base	14	279.04	2.30
141	Med	Base	High	Base	11	308.77	2.27

In Table 9, the MP trials between November and March are sorted by the highest TDS % Reduction per Point. The top three MP trials are comprised of reductions to the Road Salt Mass Loading. All three options, Low, Medium, and High, result in the same TDS % Reduction per Point value of 2.72. The next seven MP trials are combinations of reducing the Road Salt Mass Loading with various combinations of the other three parameters. The full urban MP analysis between November and March can be viewed in Appendix D.

Table 9. Top 10 Efficient Urban MP Trials between November and March

	Baseline	Low	Med	High
Parameter Reduction	0%	5%	20%	35%

Trial	W. Hite Conc.	Return % Before Union	Initial Conc.	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction per Point
1	Base	Base	Base	Base	0	904.04	NA
4	Base	Base	Base	High	7	732.21	2.72
3	Base	Base	Base	Med	4	805.85	2.72
2	Base	Base	Base	Low	1	879.49	2.72
68	Low	Base	Base	High	8	720.26	2.54
8	Base	Base	Low	High	8	724.38	2.48
67	Low	Base	Base	Med	5	793.91	2.44
20	Base	Low	Base	High	8	731.34	2.39
72	Low	Base	Low	High	9	712.43	2.35
7	Base	Base	Low	Med	5	798.02	2.35
84	Low	Low	Base	High	9	719.39	2.27

3.3.2 Agricultural Reaches

The agricultural MP analysis was conducted over reach five (See Figure 18 in Section 2.5) for both the growing season (April to October) and the non-growing season (November to March). Based on the seasonal sensitivity analysis results, four parameters were picked to be included in the MP (see Section 2.6). These parameters were the W. Hite WWTP Effluent concentration, Return Flow % before Union Ditch, Return Flow % after Union Ditch, and Road Salt Mass Loading. In Table 10, the MP trials during the growing season are sorted by the highest TDS % Reduction per Point. The top three MP trials are comprised of reductions to the Return Flow % after Union Ditch. All three options, Low, Medium, and High, result in the same TDS % Reduction per Point value of 1.57. The next seven MP trials are combinations of reducing the Return Flow % after Union Ditch with various combinations of the other three parameters. The full agricultural MP analysis over the growing season can be viewed in Appendix D.

Table 10. Top 10 Efficient Agricultural MP Trials between April and October (Growing Season)

	Baseline	Low	Med	High
Parameter Reduction	0%	5%	20%	35%

Trial	W. Hite Conc.	Return % Before Union	Return % After Union	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction per Point
1	Base	Base	Base	Base	0	1145.78	NA
13	Base	Base	High	Base	7	1019.91	1.57
9	Base	Base	Med	Base	4	1073.85	1.57
5	Base	Base	Low	Base	1	1127.80	1.57
77	Low	Base	High	Base	8	1013.40	1.44
29	Base	Low	High	Base	8	1018.61	1.39
14	Base	Base	High	Low	8	1019.87	1.37
73	Low	Base	Med	Base	5	1067.35	1.37
93	Low	Low	High	Base	9	1012.10	1.30
78	Low	Base	High	Low	9	1013.37	1.28
25	Base	Low	Med	Base	5	1072.55	1.28

In Table 11, the MP trials during the non-growing season are sorted by the highest TDS % Reduction per Point. The top three MP trials are comprised of reductions to the Return Flow % after Union Ditch. All three options, Low, Medium, and High, result in the same TDS % Reduction per Point value of 1.56. The next seven MP trials are combinations of reducing the Return Flow % after Union Ditch with various combinations of the other three parameters. The full agricultural MP analysis over the non-growing season can be viewed in Appendix D.

Table 11. Top 10 Efficient Agricultural MP Trials between November and March (Non-Growing Season)

	Baseline	Low	Med	High
Parameter Reduction	0%	5%	20%	35%

Trial	W. Hite Conc.	Return % Before Union	Return % After Union	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction per Point
1	Base	Base	Base	Base	0	1313.63	NA
13	Base	Base	High	Base	7	1169.85	1.56
9	Base	Base	Med	Base	4	1231.47	1.56
5	Base	Base	Low	Base	1	1293.09	1.56
14	Base	Base	High	Low	8	1157.22	1.49
77	Low	Base	High	Base	8	1158.38	1.48
10	Base	Base	Med	Low	5	1218.84	1.44
73	Low	Base	Med	Base	5	1220.00	1.43
78	Low	Base	High	Low	9	1145.75	1.42
29	Base	Low	High	Base	8	1169.03	1.38
74	Low	Base	Med	Low	6	1207.37	1.35

3.3.3 MP Summary

Looking at the results of the urban MP analysis for April to October, the most efficient MP was to reduce the W. Hite WWTP Effluent concentration. For every 5% reduction in Effluent concentration, the average TDS (mg/L) over reaches one and two was reduced by 2.41%. By reducing the W. Hite WWTP effluent by 35% (High), the average TDS over reaches one and two decreases from 411.55 mg/L to 342.18 mg/L, a reduction of 16.87%. Looking at the results for November to March, the most efficient MP was to reduce the Road Salt Mass Loading. For every 5% reduction in the mass of road salt applied, the average TDS (mg/L) over reaches one and two was reduced by 2.72%. By reducing the Road Salt Mass Loading by 35% (High), the average TDS over reaches one and two decreases from 904.04 mg/L to 732.31 mg/L, a reduction of 19.04%.

According to the South Platte River Salinity study conducted by NEIRBO, a TDS range of 0 to 500 mg/L is deemed acceptable for most crops, 500 to 1000 mg/L results in crop yield reductions for sensitive crops, 1000 to 2000 mg/L results in crop yield reductions for most crops, and above 2000 mg/L is only suitable for salt tolerant plants (NEIRBO, 2020).

In the urban MP analysis, the Baseline average TDS (mg/L) values during both time periods, April to October and November to March, already fall below the 1000 mg/L cutoff for crop yield reductions for most crops. Between April and October, the average Baseline TDS value of 411.55 mg/L is securely inside to 0 to 500 mg/L range deemed acceptable for most crops, whereas the average TDS value of 904.04 mg/L between November and March is right at the upper edge of the 500 to 1000 mg/L range (NEIRBO, 2020). It may not be necessary to implement a MP between April and October, but implementing a MP to reduce the mass of road salt applied between November and March would be useful in lowering the average TDS (mg/L) away from the 1000 mg/L cutoff.

Looking at the results of the agricultural MP analysis the most efficient MP during the growing season (April to October) and the non-growing season (November to March), was to reduce the Return Flow % after Union Ditch. For every 5% reduction in Return Flow % after Union Ditch, the average TDS (mg/L) over reach five was reduced by 1.57% and 1.56% respectively. By reducing the Return Flow % after Union Ditch by 35% (High) during the growing season, the average TDS over reach five decreases from 1145.78 mg/L to 1019.91 mg/L, a reduction of 10.99%. By reducing the Return Flow % after Union Ditch by 35% (High) during the non-growing season, the average TDS over reach five decreases from 1313.63 mg/L to 1169.85 mg/L, a reduction of 10.92%. Even with a 35% reduction to the Return Flow % after Union Ditch, both average TDS values during the growing and non-growing season are above the 1000 mg/L cutoff into the 1000 to 2000 mg/L range where crop yield reductions occur for most crops (NEIRBO, 2020). To achieve average TDS values below 1000 mg/L during the growing and non-growing seasons, the agricultural MP trials must be ranked by effectiveness rather than efficiency. In Table 12, the MP trials during the growing season are sorted by the highest TDS % Reduction instead of TDS % Reduction per Point.

Table 12. Top 10 Effective Agricultural MP Trials between April and October (Growing Season)

	Baseline	Low	Med	High
Parameter Reduction	0%	5%	20%	35%

Trial	W. Hite Conc.	Return % Before Union	Return % After Union	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction
1	Base	Base	Base	Base	0	1145.78	NA
256	High	High	High	High	28	965.04	15.77
255	High	High	High	Medium	25	965.14	15.77
254	High	High	High	Low	22	965.25	15.76
253	High	High	High	Base	21	965.28	15.75
240	High	Medium	High	High	25	968.94	15.43
239	High	Medium	High	Medium	22	969.04	15.43
238	High	Medium	High	Low	19	969.14	15.42
237	High	Medium	High	Base	18	969.18	15.41
224	High	Low	High	High	22	972.83	15.09
223	High	Low	High	Medium	19	972.94	15.09

When ranking effectiveness rather than efficiency, MP trial number 256 is the most effective at reducing salinity levels. Consisting of a 35% reduction (High) to all four parameters, trial 256 would lower the average TDS in reach five from 1145.78 mg/L to 965.04 mg/L, a reduction of 15.77%. When sorted by the highest TDS % Reduction, the top 32 trials are capable of reducing salinity levels below 1000 mg/L.

In Table 13, the MP trials during the non-growing season are sorted by the highest TDS % Reduction instead of TDS % Reduction per Point.

Table 13. Top 10 Effective Agricultural MP Trials between November and March (Non-Growing Season)

	Baseline	Low	Med	High
Parameter Reduction	0%	5%	20%	35%

Trial	W. Hite Conc.	Return % Before Union	Return % After Union	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction
1	Base	Base	Base	Base	0	1313.63	NA
256	High	High	High	High	28	995.43	24.22
240	High	Medium	High	High	25	997.89	24.04
224	High	Low	High	High	22	1000.36	23.85
208	High	Base	High	High	21	1001.18	23.79
192	Medium	High	High	High	25	1029.84	21.60
255	High	High	High	Medium	25	1033.30	21.34
160	Medium	Low	High	High	19	1034.77	21.23
144	Medium	Base	High	High	18	1035.59	21.17
239	High	Medium	High	Medium	22	1035.77	21.15
223	High	Low	High	Medium	19	1038.24	20.96

When ranking effectiveness rather than efficiency, MP trial number 256 is the most effective at reducing salinity levels. Consisting of a 35% reduction (High) to all four parameters, trial 256 would lower the average TDS in reach five from 1313.63 mg/L to 995.43 mg/L, a reduction of 24.22%. When sorted by the highest TDS % Reduction, only the top two trials are capable of reducing salinity levels below 1000 mg/L.

Based on these results, if a series of aggressive MPs were implemented targeting the W. Hite WWTP, return flows, and road salt, it appears it could be possible to reduce the average salinity levels in the South Platte River to below 1000 mg/, lowering the of crop losses as well helping slow the rate at which salinity levels have been rising throughout the South Platte River basin.

4 Summary and Conclusions

This thesis aimed to model salt transport in the South Platte River network, determine the critical controlling factors via sensitivity analysis, and then use these identified factors to determine potential strategies for mitigating rising salinity levels. For this purpose, a one-dimensional steady-state flow and salt model was constructed. While the flow model outperformed the salt model (85% of the flow model's NSCE values fell within the acceptable range of zero to one compared to the 68.42% of the salt model's NSCE values), both models were able to, in general, capture the overall trends shown in the observed flow and concentration data. A local sensitivity analysis based on a modified version of the Morris method was implemented to determine the controlling factors of salt transport in the river system. The top controlling factors identified in the sensitivity analysis were used to design a MP analysis over an urban and agricultural reach in the South Platte River basin. This thesis found that:

- Over the urban reach, the four most influential parameters on salt transport were identified as the W. Hite WWTP Effluent concentration, the Return Flow % before Union Ditch, the Initial Concentration, and the Road Salt Mass Loading.
- Over the agricultural reach, four influential parameters on salt transport were identified as the W. Hite WWTP Effluent concentration, the Return Flow % before Union Ditch, the Return Flow % after Union Ditch, and the Road Salt Mass Loading.
- The most efficient MP strategy to lower the salinity in the urban reach between April and October was to reduce the W. Hite WWTP's Effluent concentration. A 5% reduction in the W. Hite WWTP's Effluent concertation resulted in a 2.41% reduction in the average TDS (mg/L).

- The most efficient MP strategy to lower the salinity in the urban reach between November and March was to reduce the Road Salt Mass Loading. A 5% reduction in the Road Salt Mass Loading resulted in a 2.72% reduction in the average TDS (mg/L). This MP was considered a possible solution as it decreased the average TDS from 904.04 mg/L to 732.21 mg/L.
- The most efficient MP strategy to lower the salinity in the agricultural reach during the growing season (April to October) and the non-growing season (November to March) was to reduce the Return Flow % after Union Ditch. A 5% reduction in the Return Flow % after Union Ditch resulted in a 2.57% and 2.56% reduction in the average TDS (mg/L), respectively. In both cases, this MP alone was unable to reduce the average TDS values below 1000 mg/L.
- The most effective MP strategy to lower the salinity in the agricultural reach during the growing season (April to October) and the non-growing season (November to March) was trial 256, which consisted of reducing all four parameters by 35% (High). During the growing season, trial 256 lowered the TDS in reach five from 1145.78 mg/L to 965.04 mg/L. During the non-growing season, trial 256 lowered the TDS in reach five from 1313.63 mg/L to 995.43 mg/L
- With a series of aggressive MP's, it appears possible to reduce the salinity levels in the South Platte River to below 1000 mg/L. This reduction would help reduce the risk of crop losses and help slow the rate at which salinity levels have been rising in the South Platte River basin.

In order to reduce the salinity levels in the South Platte River, changes have to be made to reduce the impact of the W. Hite WWTP, the Return Flow % before Union Ditch, the Return Flow % after Union Ditch, and the Road Salt Mass Loading.

To reduce the impact of the W. Hite WWTP, steps would need to be taken to reduce the salt concentration in the plant's effluent. A report published by the Minnesota Pollution Control Agency addresses multiple alternatives for reducing chloride in wastewater treatment plant effluent (Kyser, Doucette, 2018). The report states that the most viable approach to reducing a treatment plant's effluent salinity is to minimize the amount of salt in the water entering the plant in the first place. The Minnesota Pollution Control Agency determined that the most feasible option would be to promote local residences and businesses to switch to a high-efficiency point-of-entry softener system when treating their water. These high-efficiency softener systems help reduce the amount of salt brine by-product produced during the water softening process, which gets discharged to a local wastewater plant. Other potential options include adding a centralized lime or reverse-osmosis softening system for residential and commercial buildings to replace individual point-of-entry softening systems.

Techniques to reduce the contribution of salinity from groundwater and agricultural return flows could be explored and implemented. A case study by Dr. Labadie and Dr. Khan on river basin salinity management in the lower San Luis Rey River basin in California (Khan, Labadie, 1979) discusses several of these salinity management techniques. One of these techniques is the application of demineralization of groundwater, which is the process where salts are separated from the water they reside in, resulting in a salty brine by-product that can be later disposed of. An example of this process is the Zone 7 Mocho Groundwater Demineralization plant, located in the Alameda Creek Watershed in Northern California, which removes up to 6000 lbs of salt each year from the surrounding groundwater (“Moco Groundwater,” n.d.). Another example of a demineralization plant is the Colorado River Basin PVU unit in Paradox Valley, which removes salt from the surrounding groundwater and injects the concentrated brine by-product into nearby deep geological formations for disposal (“Paradox Valley Unit,” 2020).

Improved irrigation techniques could also be implemented to reduce the amount of salt contributed by return flows. A study on best management practices for irrigation management by Dr. Waskom at Colorado State University discusses several methods that could be used to, directly and indirectly, reduce the contribution of salt from return flows (Waskom, 1994). Improved irrigation scheduling in agricultural areas could help optimize the amount of water applied to crops by using soil moisture measurements taken with hand probes, tensiometers, or neutron probes. Improved irrigation methods such as low-pressure center pivots, micro-irrigation, or surge techniques could be installed to increase water usage efficiency. Lining water delivery ditches with concrete or plastic can also help reduce the seepage of irrigation water and decrease return flows. Tailwater Recovery systems can be built to capture rainwater and irrigation runoff from making its way back into the surface or groundwater. Implementing one or more of these techniques could help reduce rainfall and irrigation runoff, which would in turn help reduce the volume of return flows and the amount of salt reentering the South Platte River.

To reduce the amount of road salt applied during the winter, different pre-treatment techniques and road salt alternatives could be considered. The Cary Institute of Ecosystem Studies in New York published a report on road salt usage and its associated problems and their potential solutions (Kelley et al., 2019). The report found that the amount of road salt applied could be reduced by following certain pre-treatment practices such as anti-icing streets with a brine solution before using road salt and pre-wetting salt before application to reduce salt kick-up. Agro-based road salt alternatives such as corn steepwater, cheese and pickle brine, fermentation byproducts, and de-sugared molasses have also shown promising results in lowering the freezing points of traditional chloride-based products, increasing the time road salt can remain on the applied surface, and helping reduce the overall amount of road salt applied.

The flow and salt models constructed in this thesis were built to model all the various ways water and salt were entered and left the South Platte River network. While we acknowledge the salt model does not perform as well as we would have liked, we are happy with the model's results. We hope these results can be expanded on in future studies to further expand our knowledge on salt transport in agro-urban basins.

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Appendix A

This appendix contains a complete list of flow and salt model results for each month between the 2002 to 2006 study period.

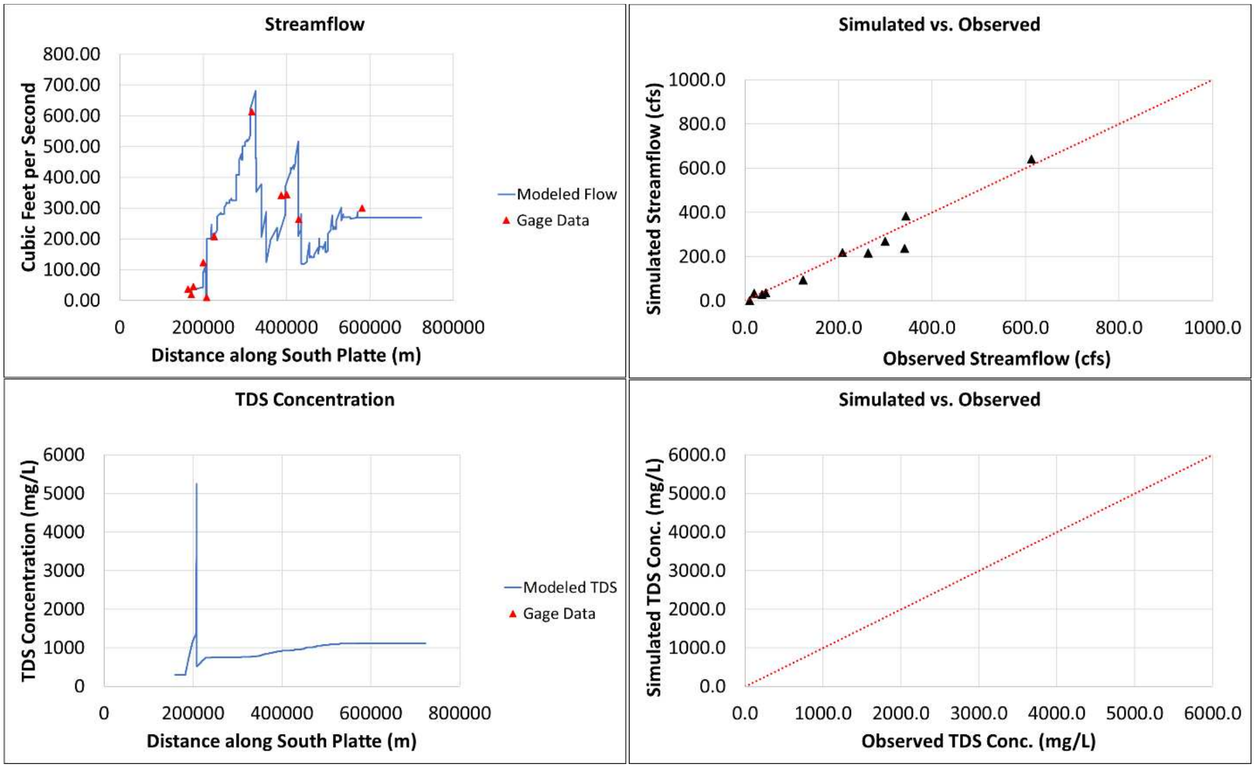


Figure A1. Flow and Salt Model Results for January 2002

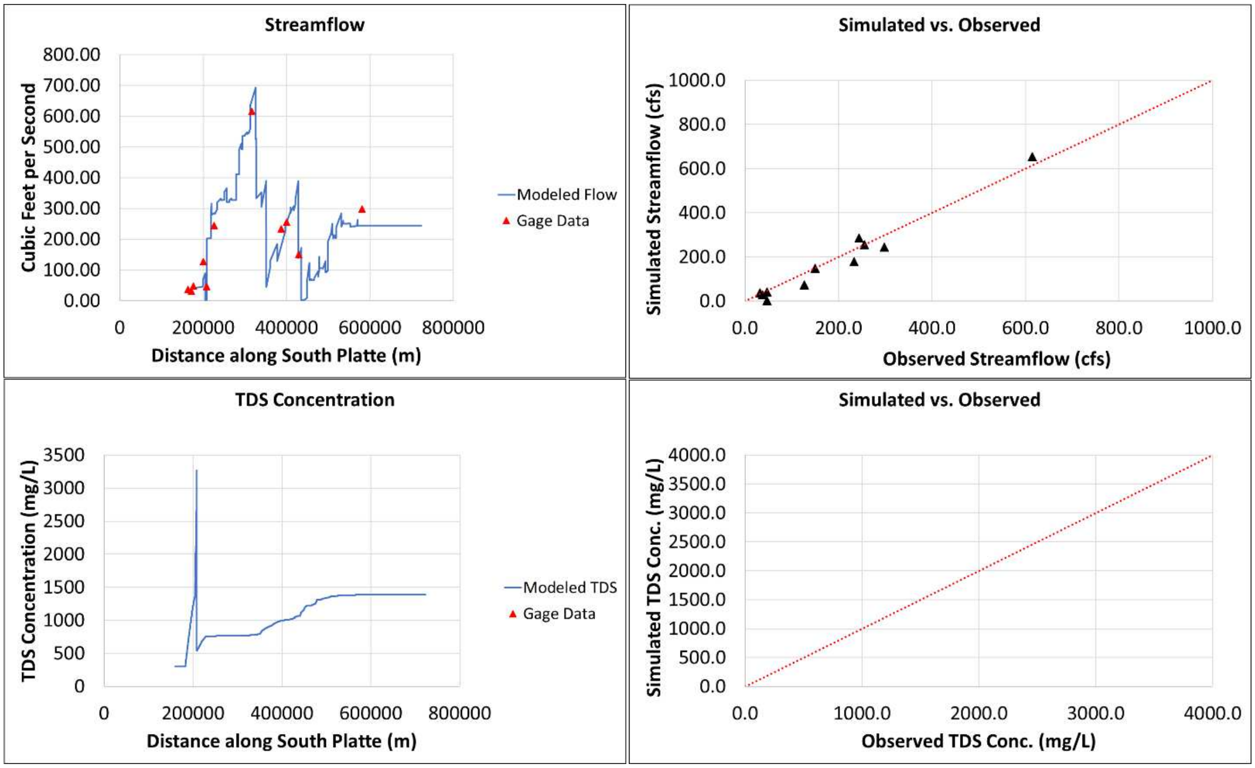


Figure A2. Flow and Salt Model Results for February 2002

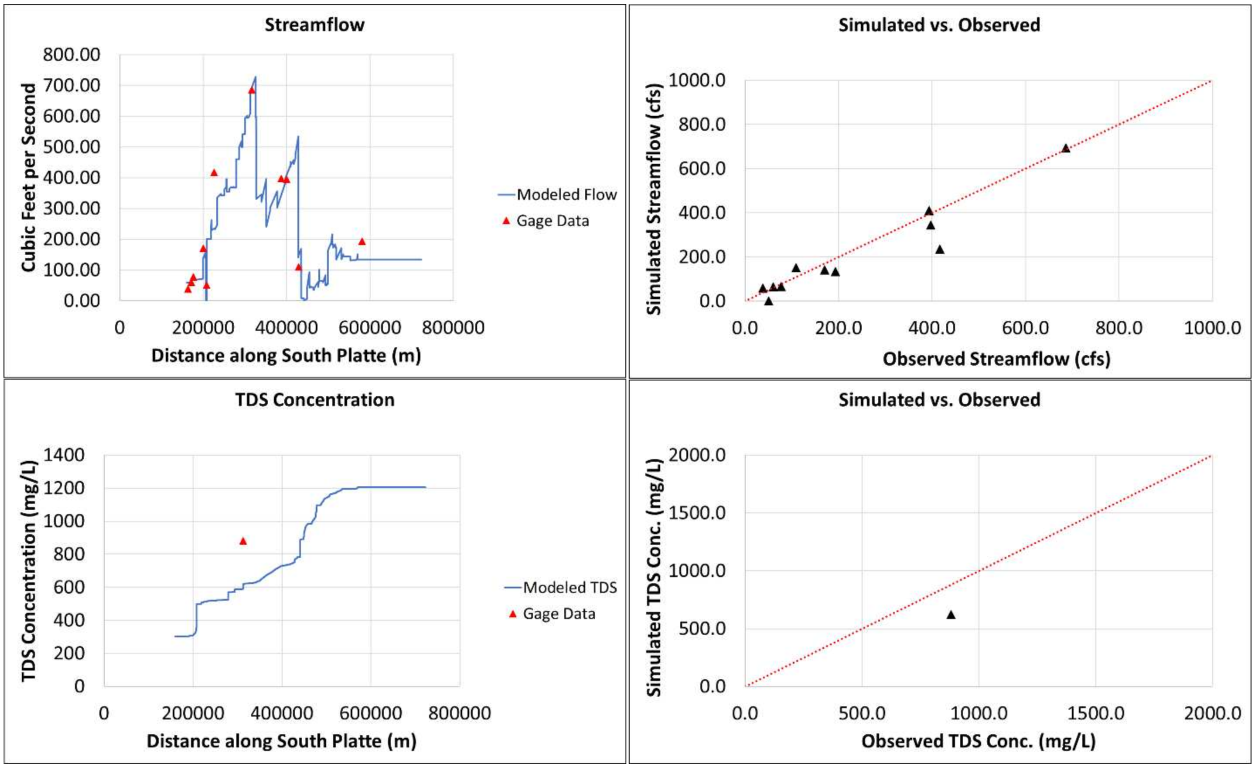


Figure A3. Flow and Salt Model Results for March 2002

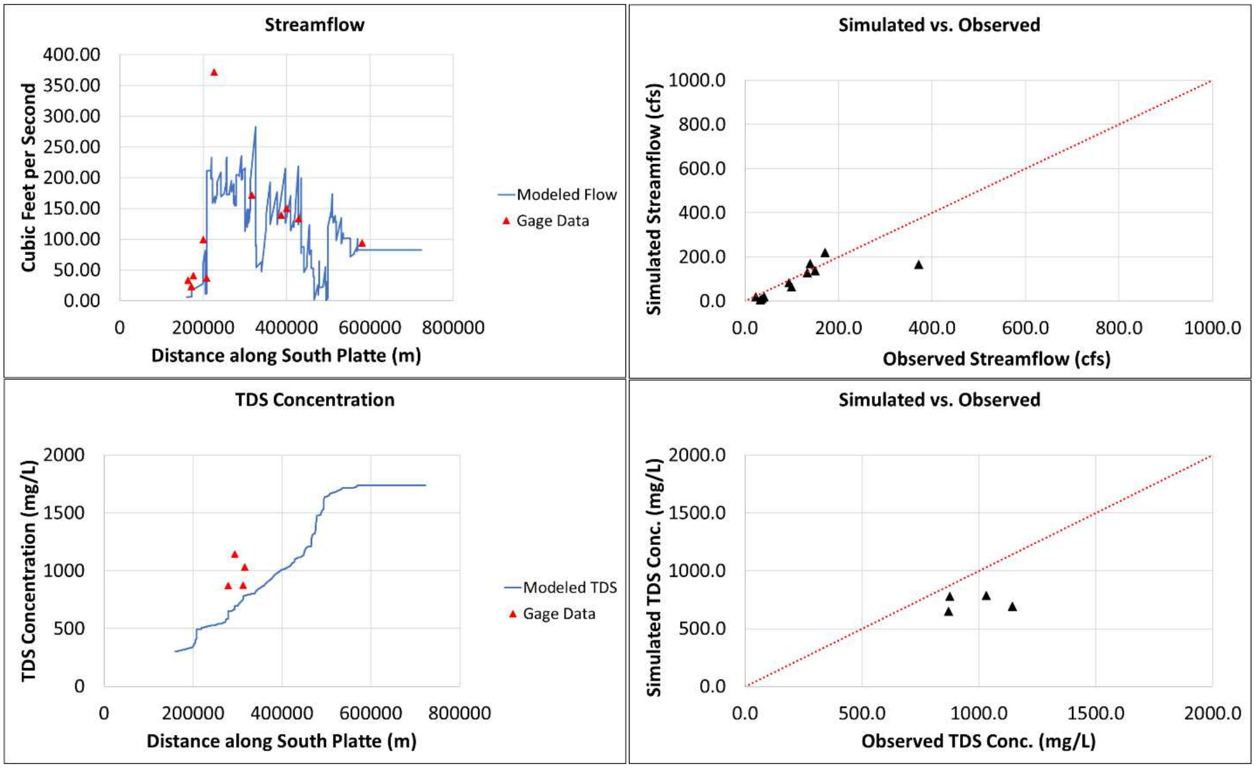


Figure A4. Flow and Salt Model Results for April 2002

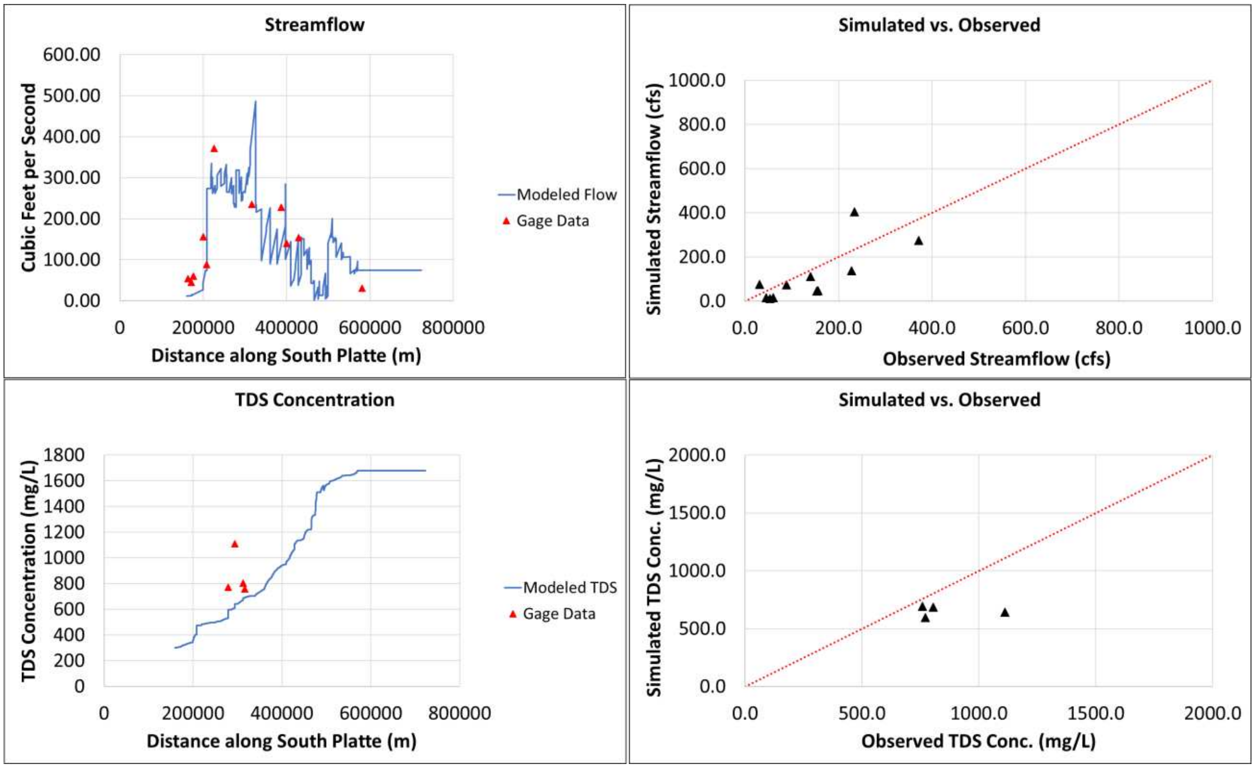


Figure A5. Flow and Salt Model Results for May 2002

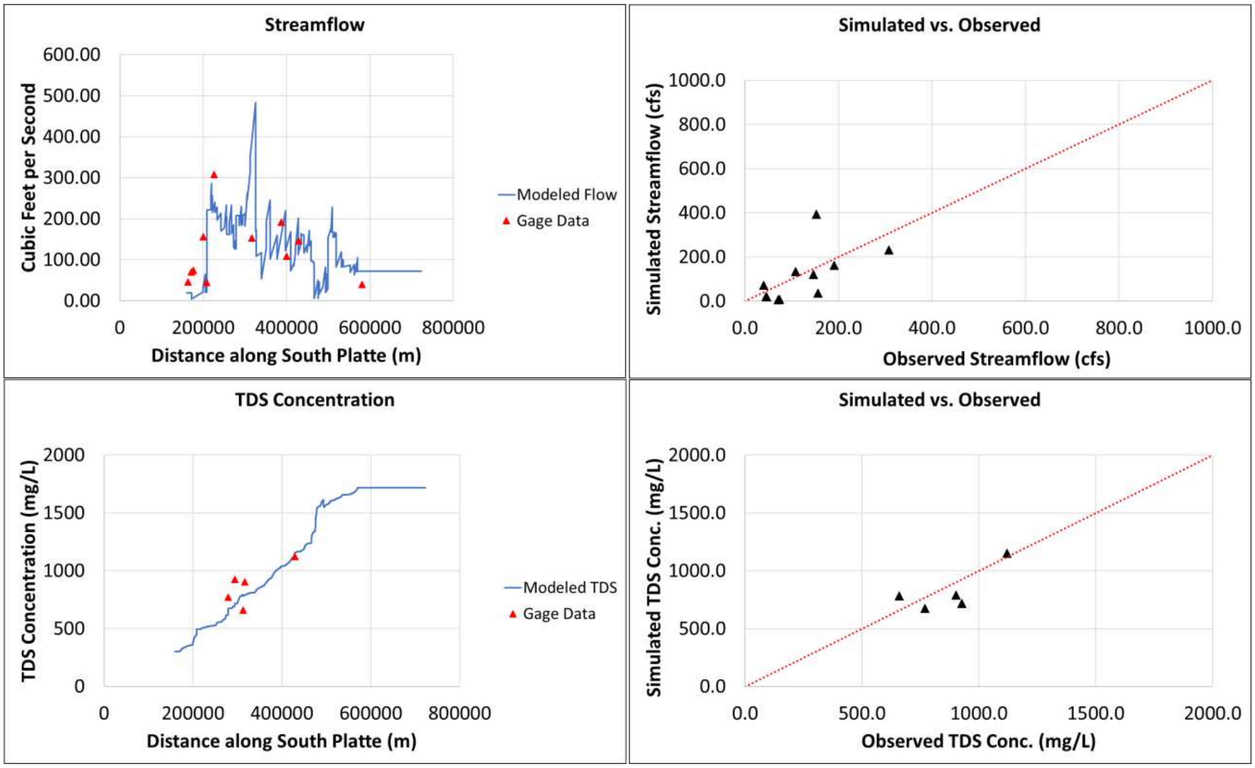


Figure A6. Flow and Salt Model Results for June 2002

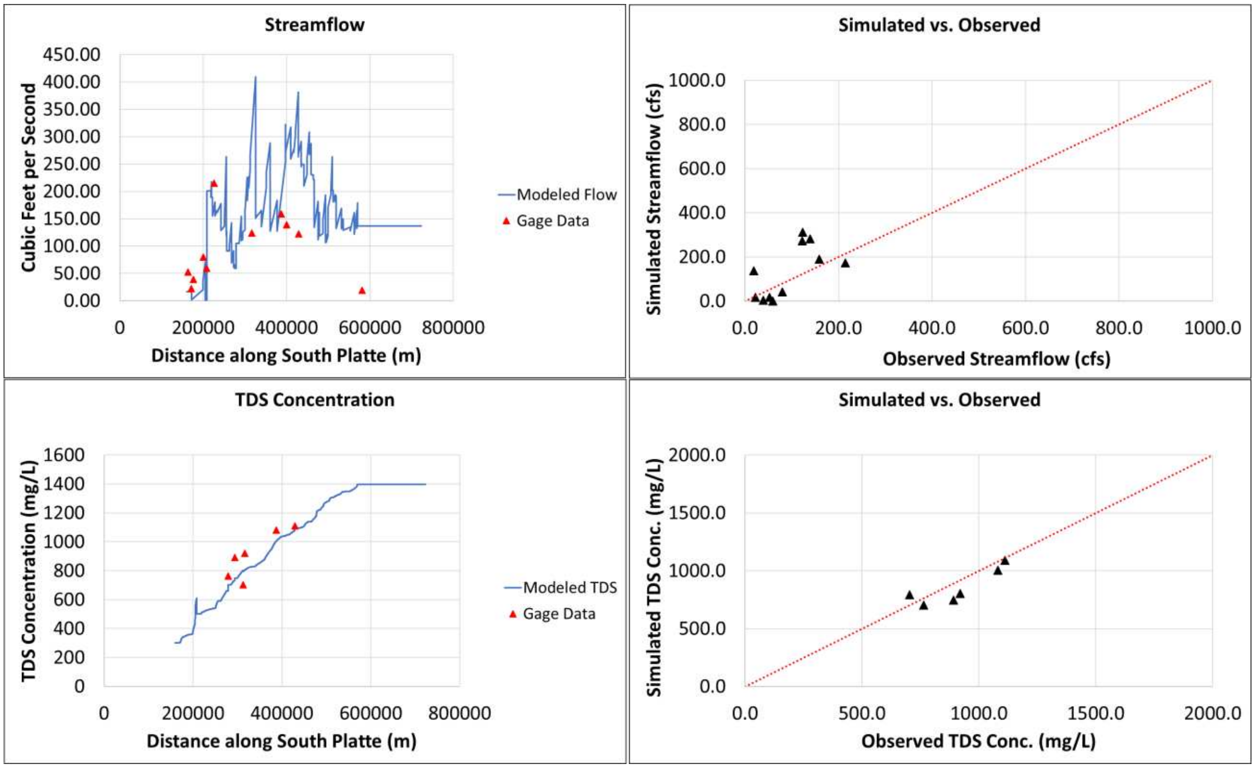


Figure A7. Flow and Salt Model Results for July 2002

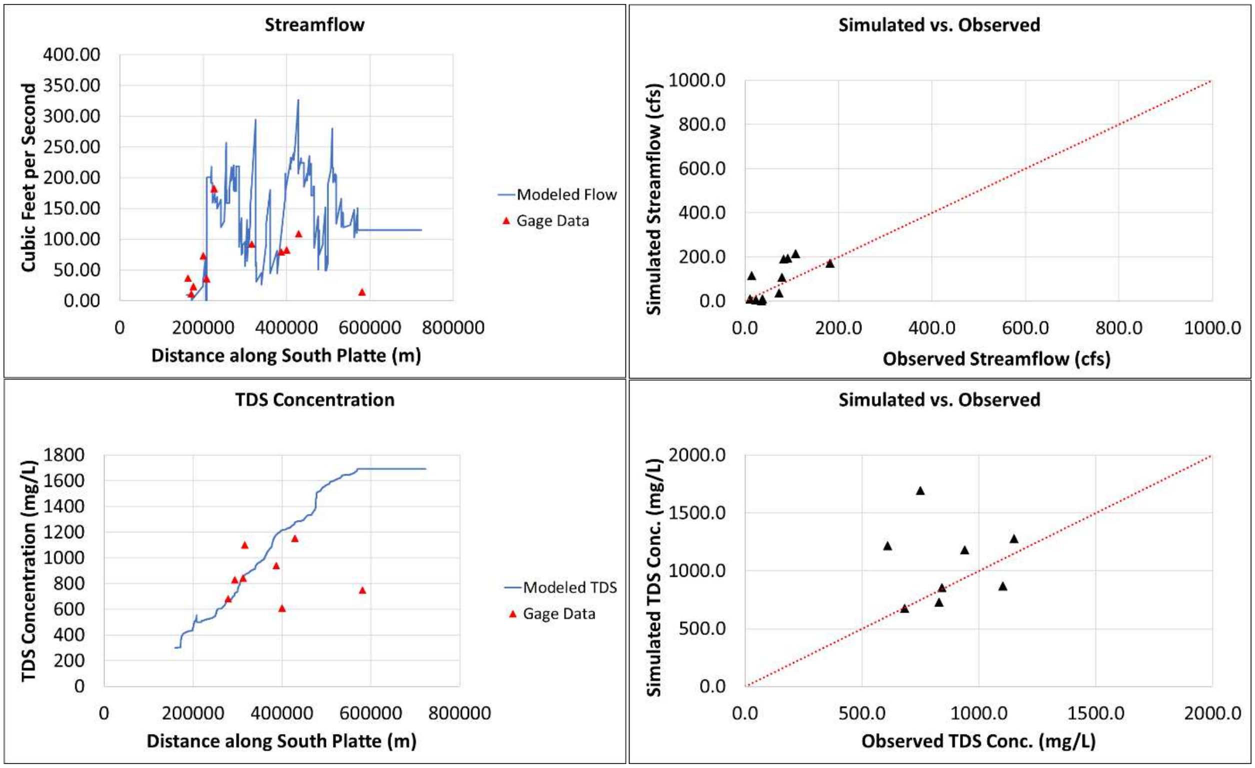


Figure A8. Flow and Salt Model Results for August 2002

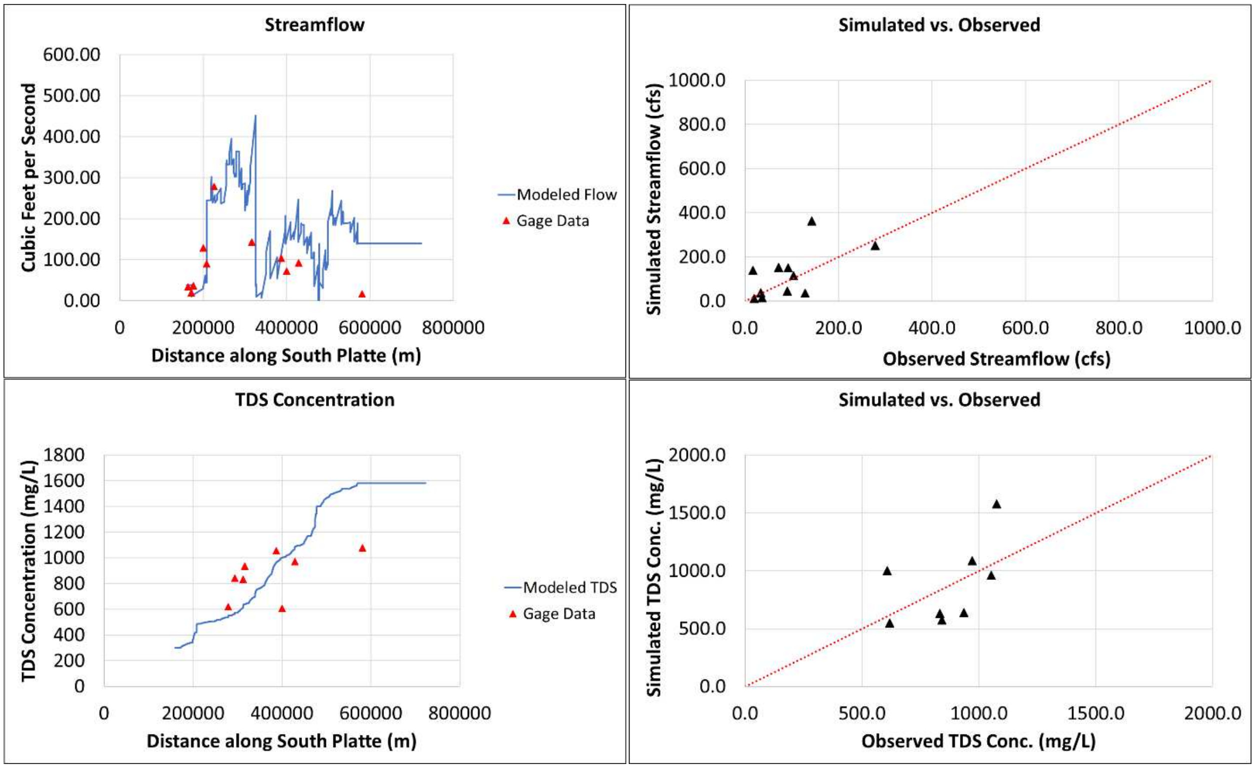


Figure A9. Flow and Salt Model Results for September 2002

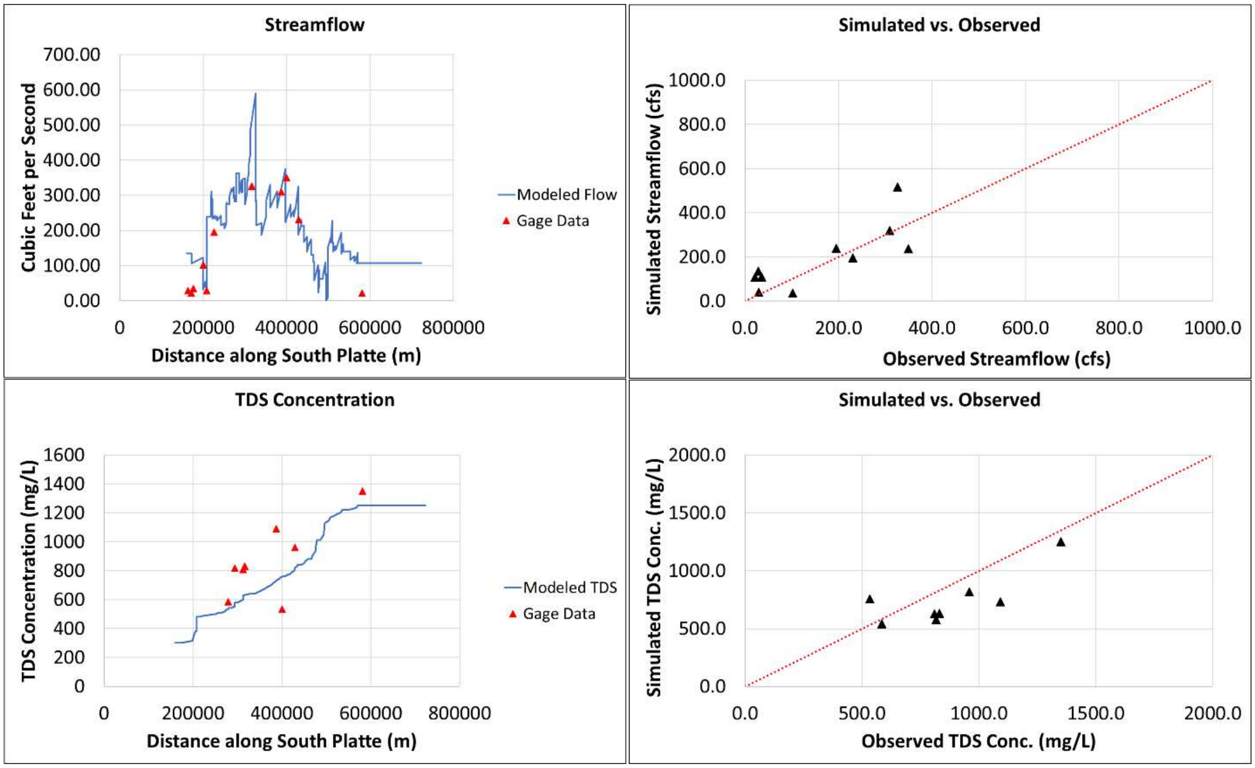


Figure A10. Flow and Salt Model Results for October 2002

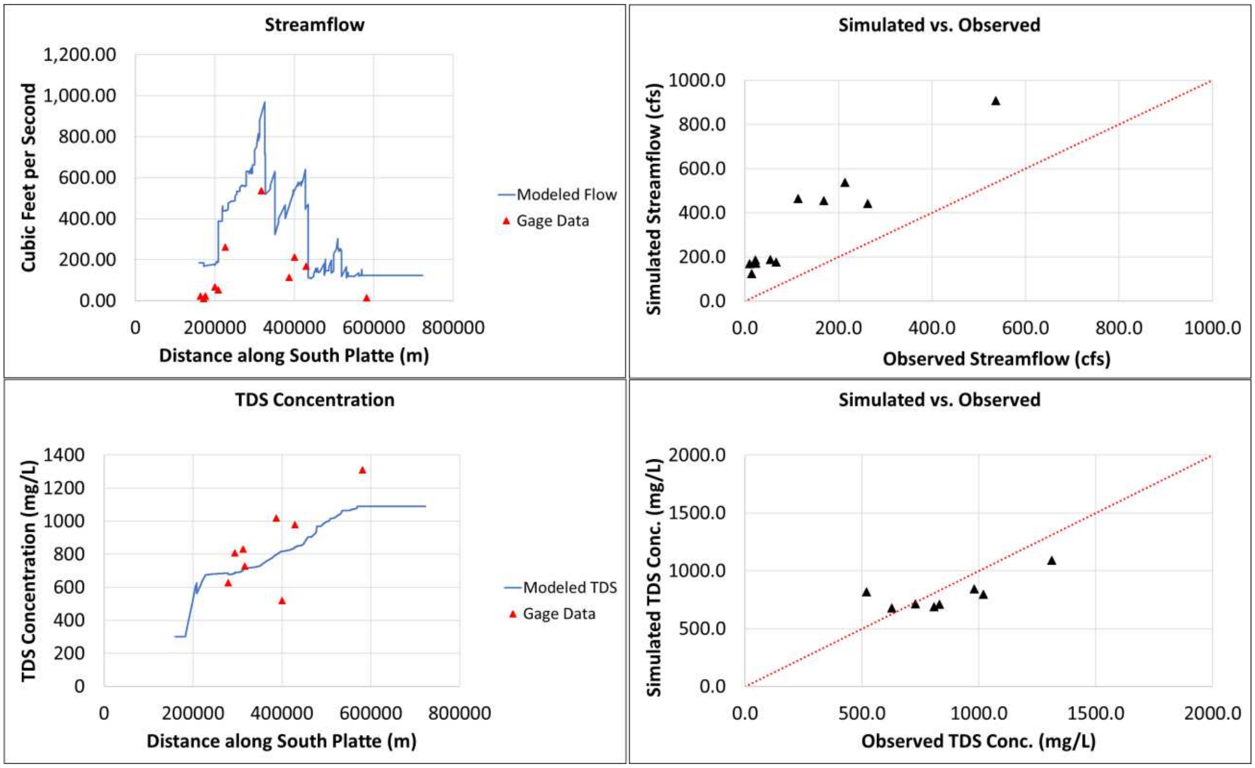


Figure A11. Flow and Salt Model Results for November 2002

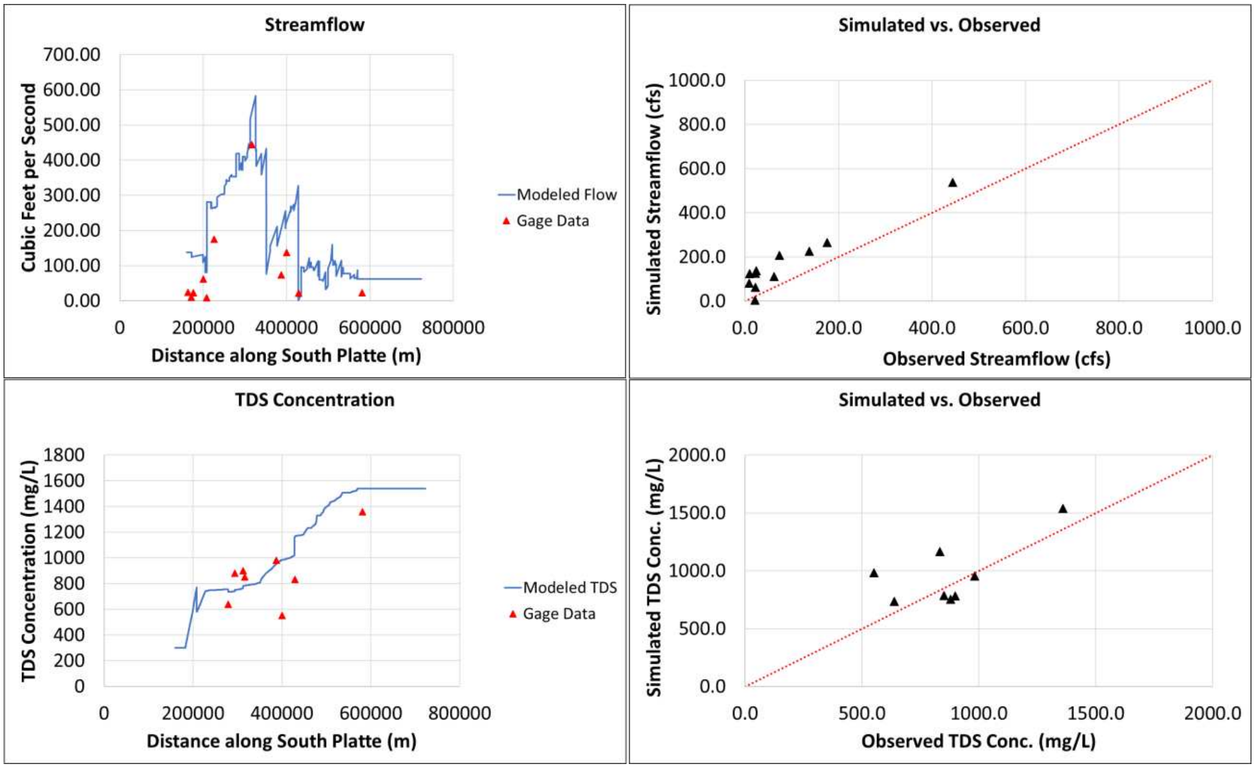


Figure A12. Flow and Salt Model Results for December 2002

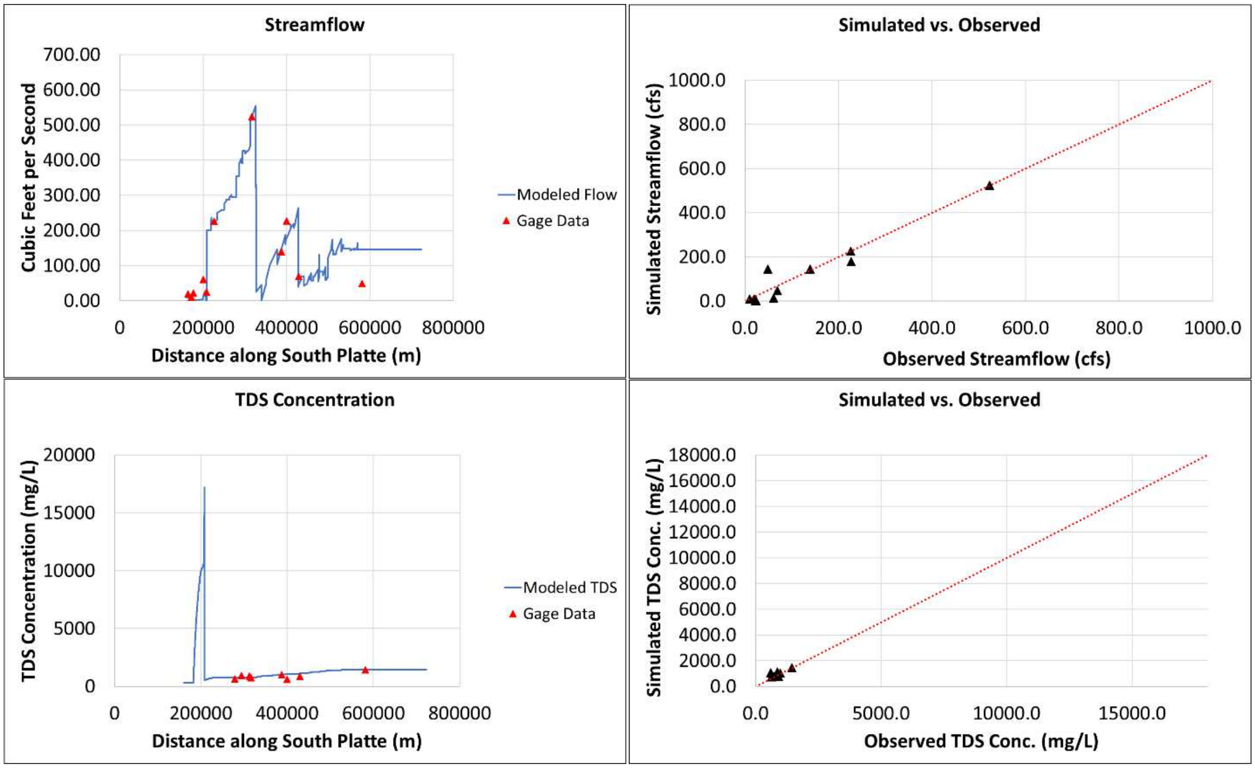
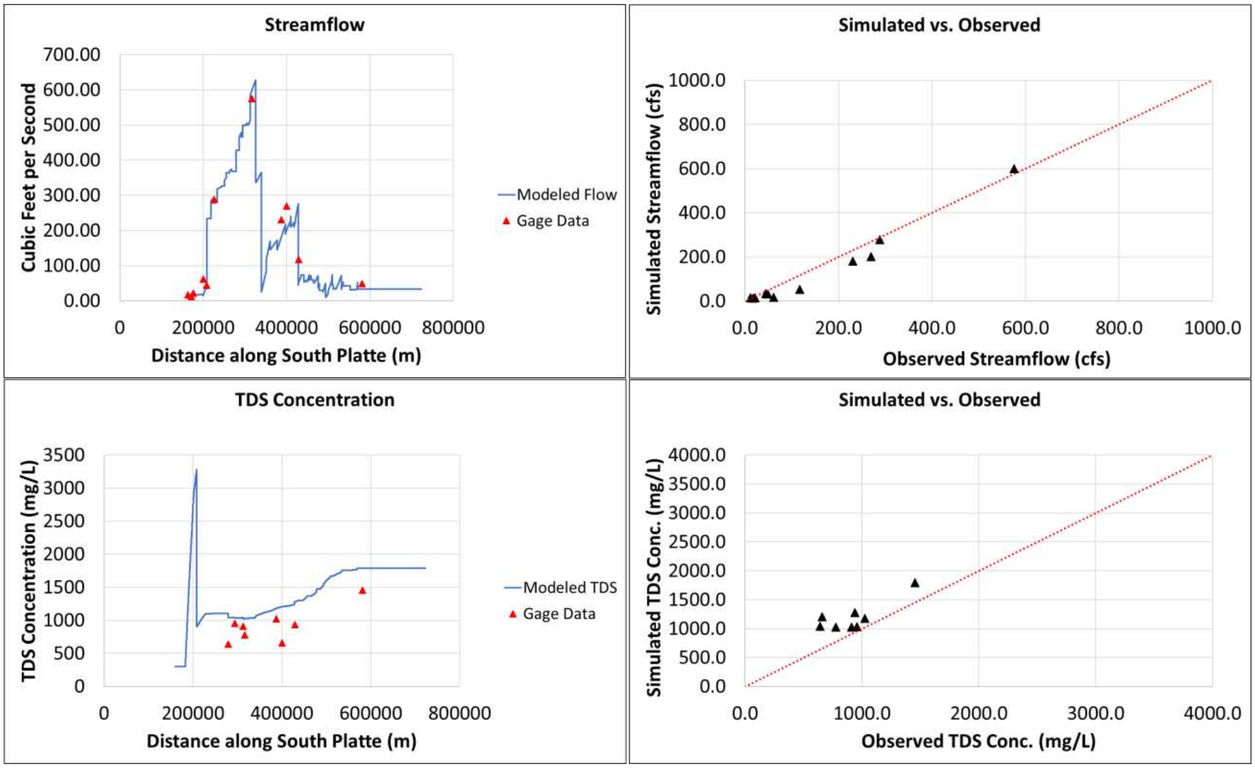


Figure A13. Flow and Salt Model Results for January 2003



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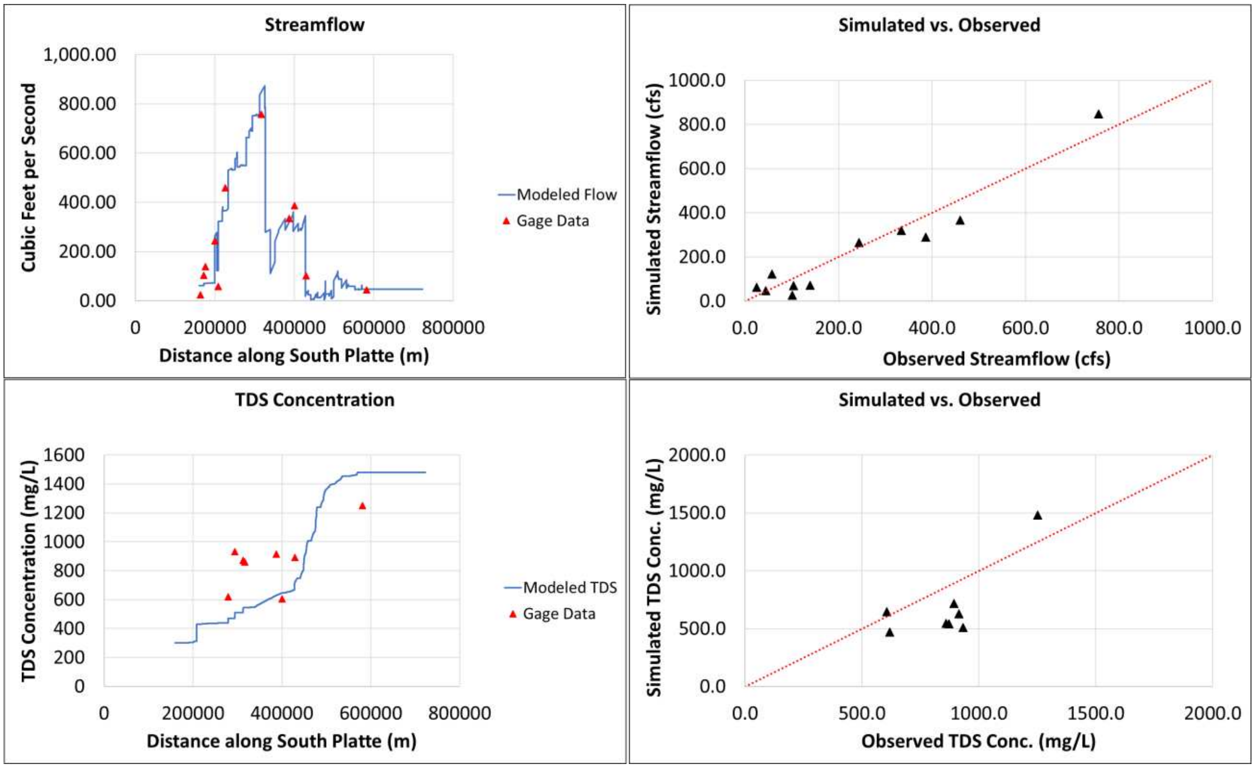


Figure A15. Flow and Salt Model Results for March 2003

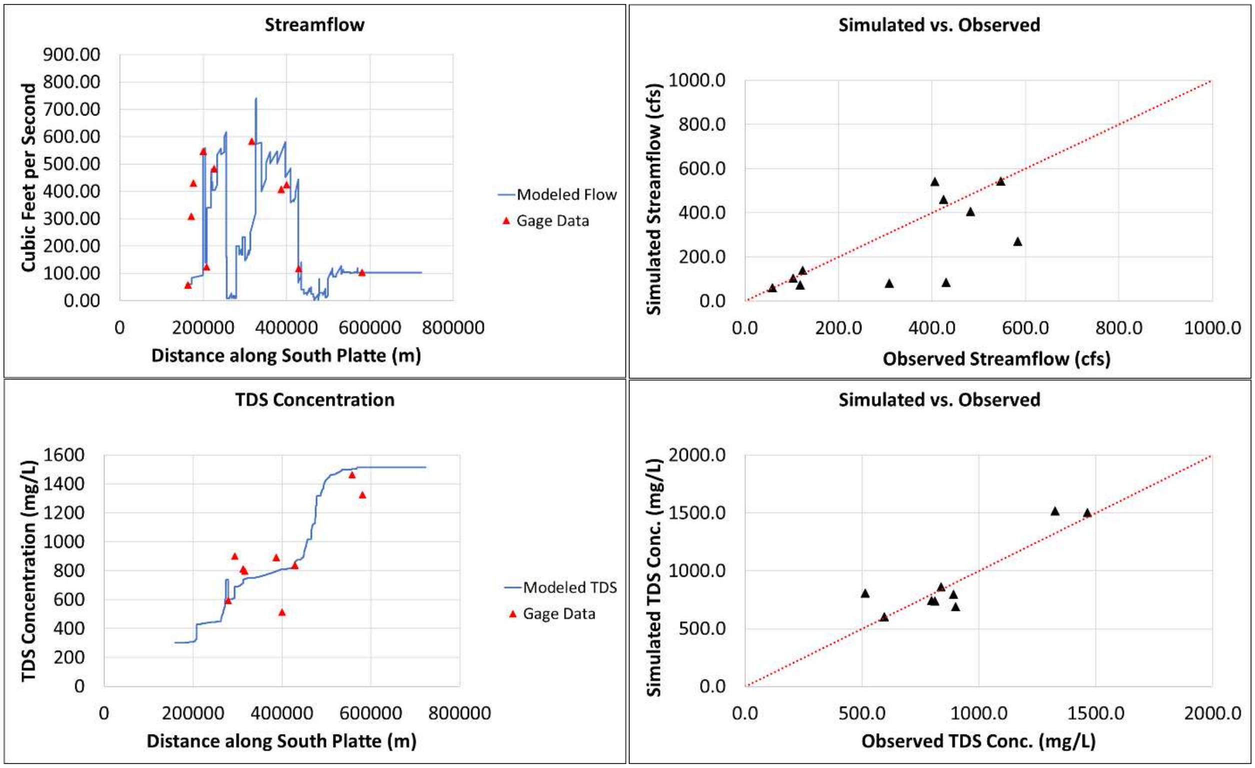


Figure A16. Flow and Salt Model Results for April 2003

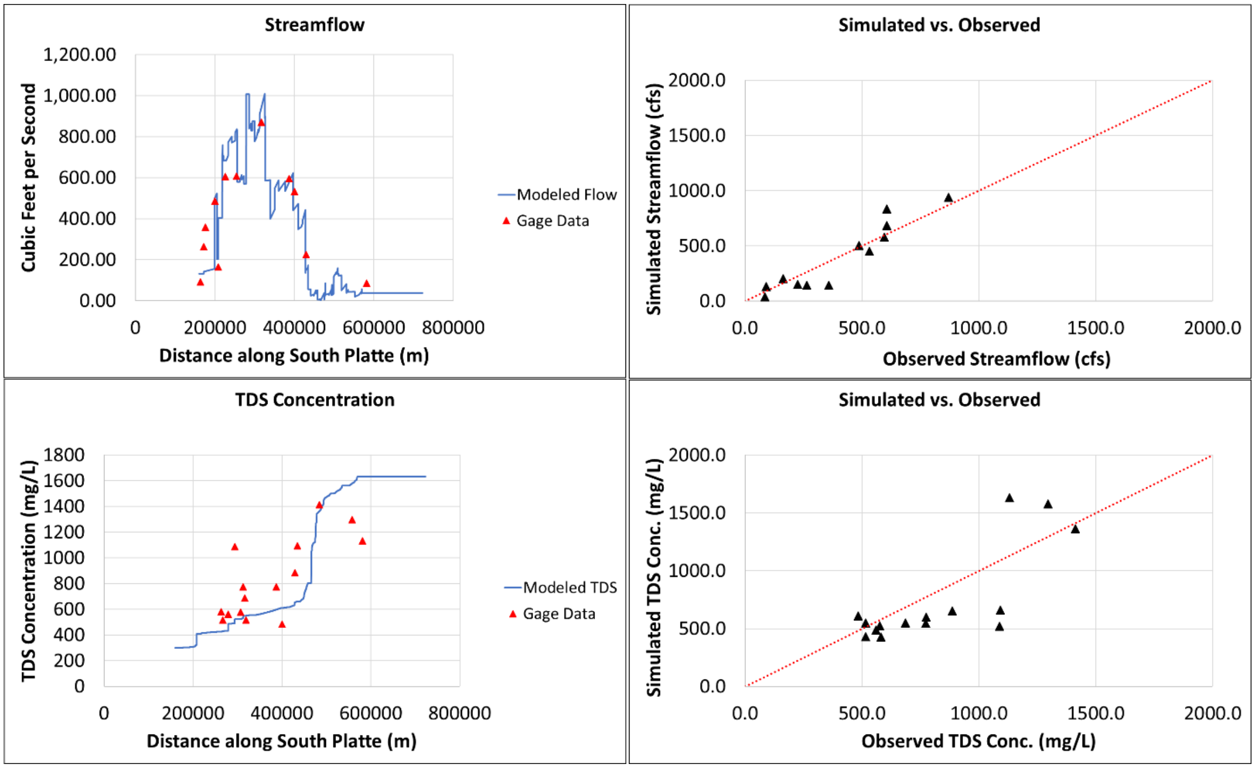


Figure A17. Flow and Salt Model Results for May 2003

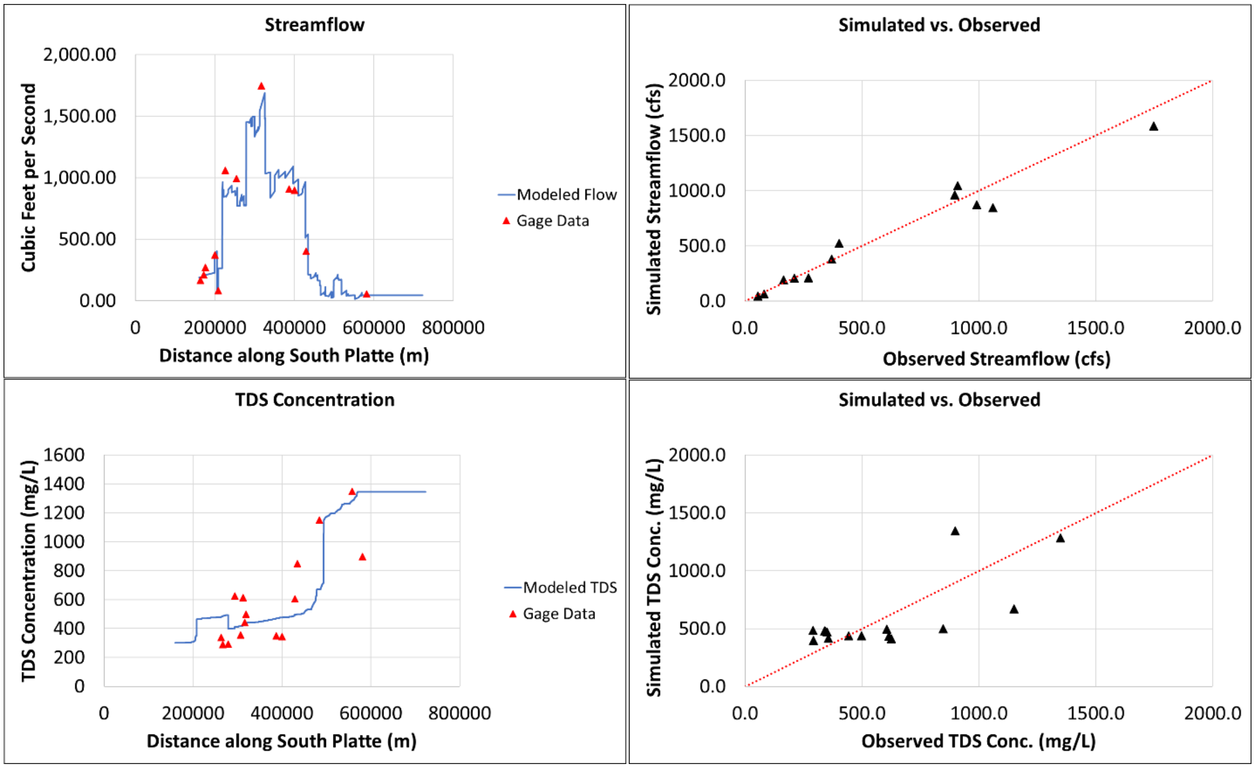
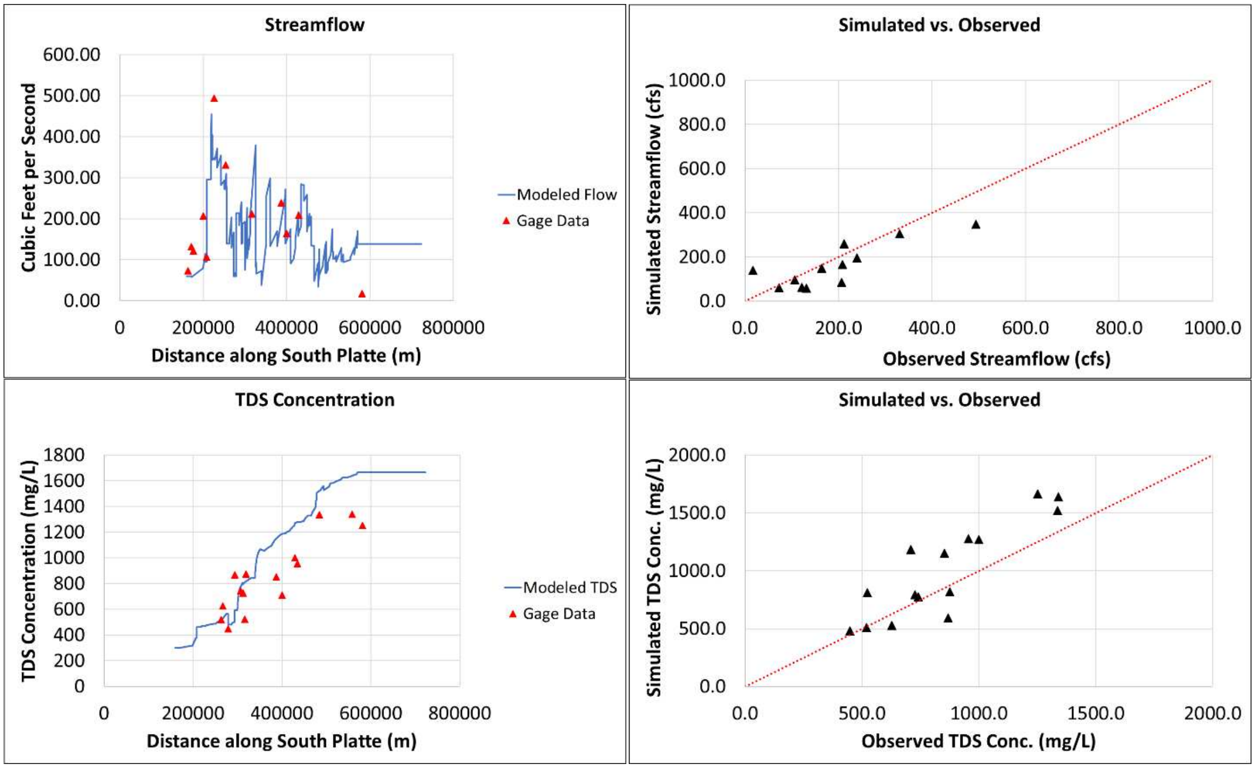


Figure A18. Flow and Salt Model Results for June 2003



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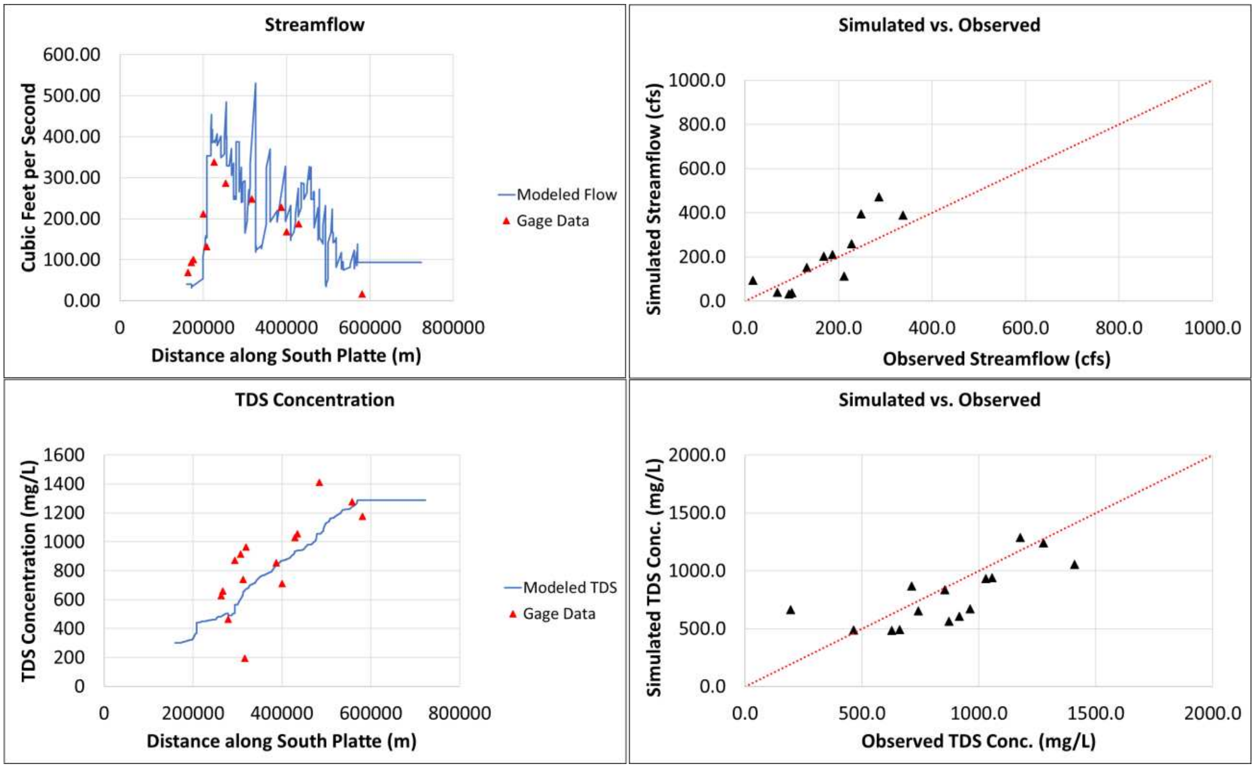
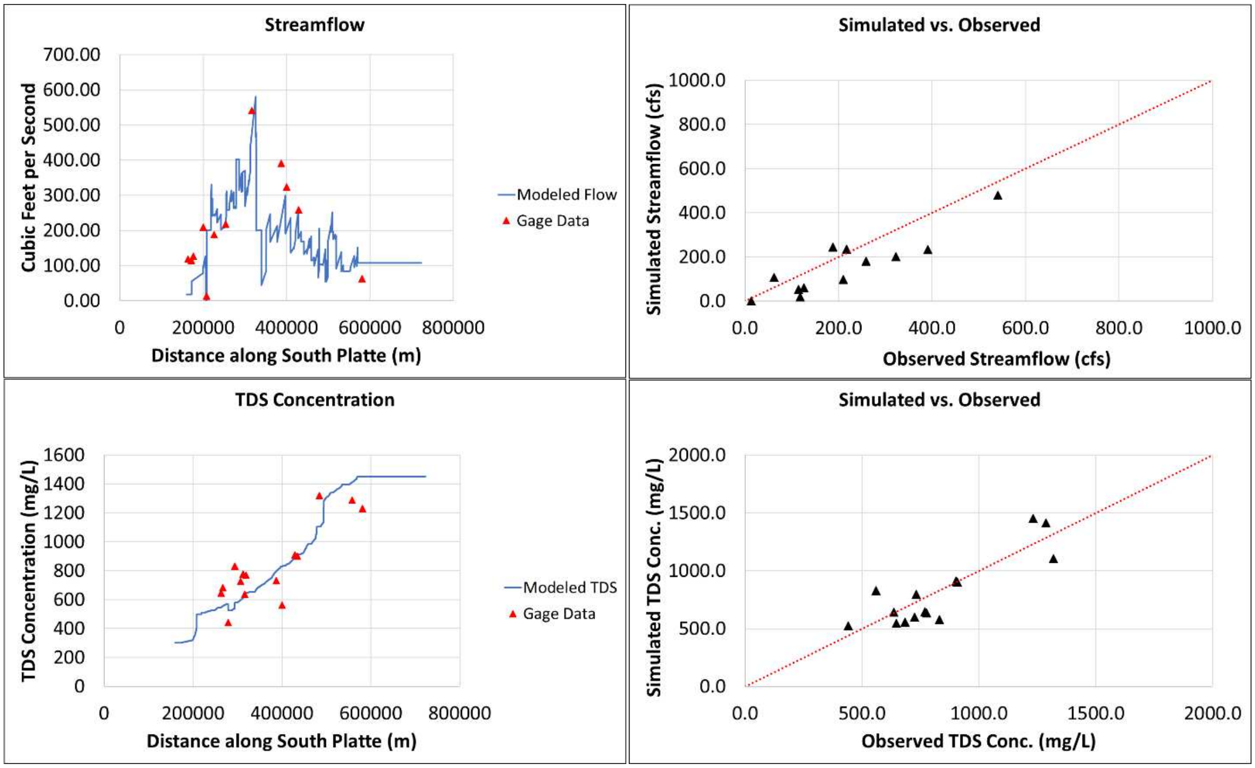


Figure A20. Flow and Salt Model Results for August 2003



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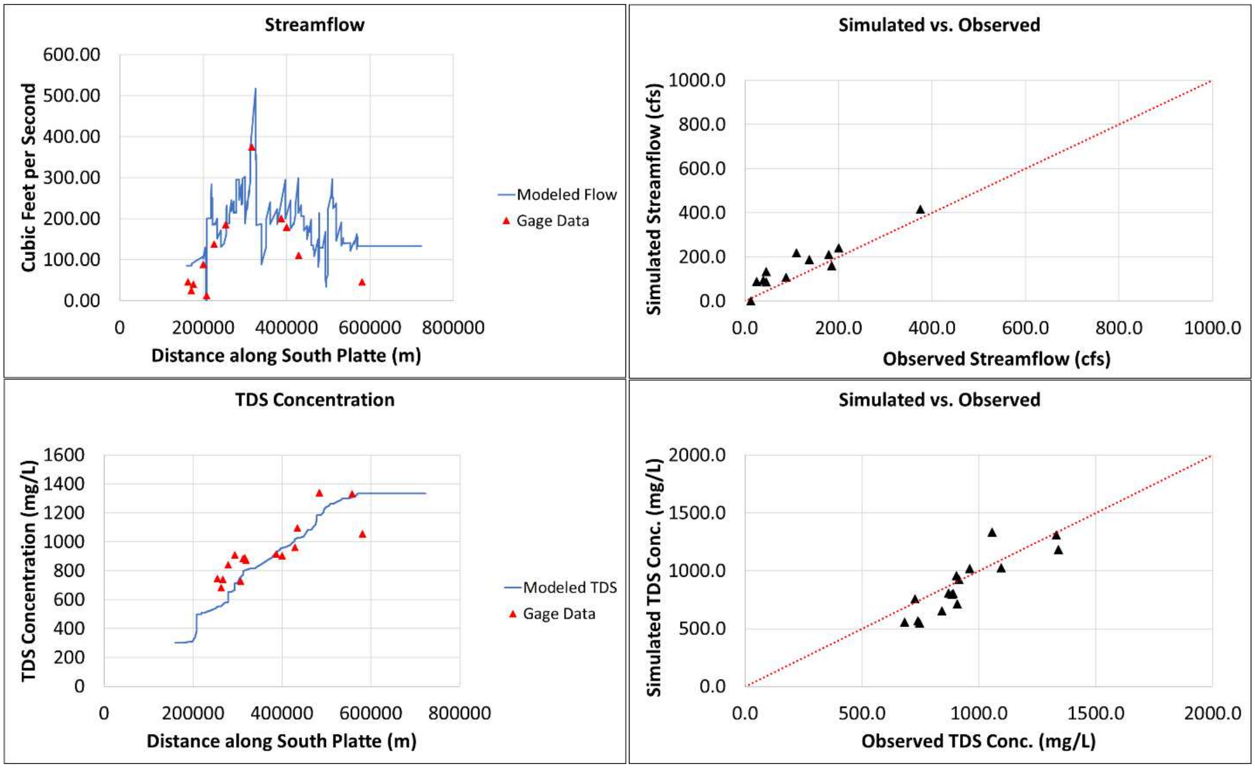


Figure A22. Flow and Salt Model Results for October 2003

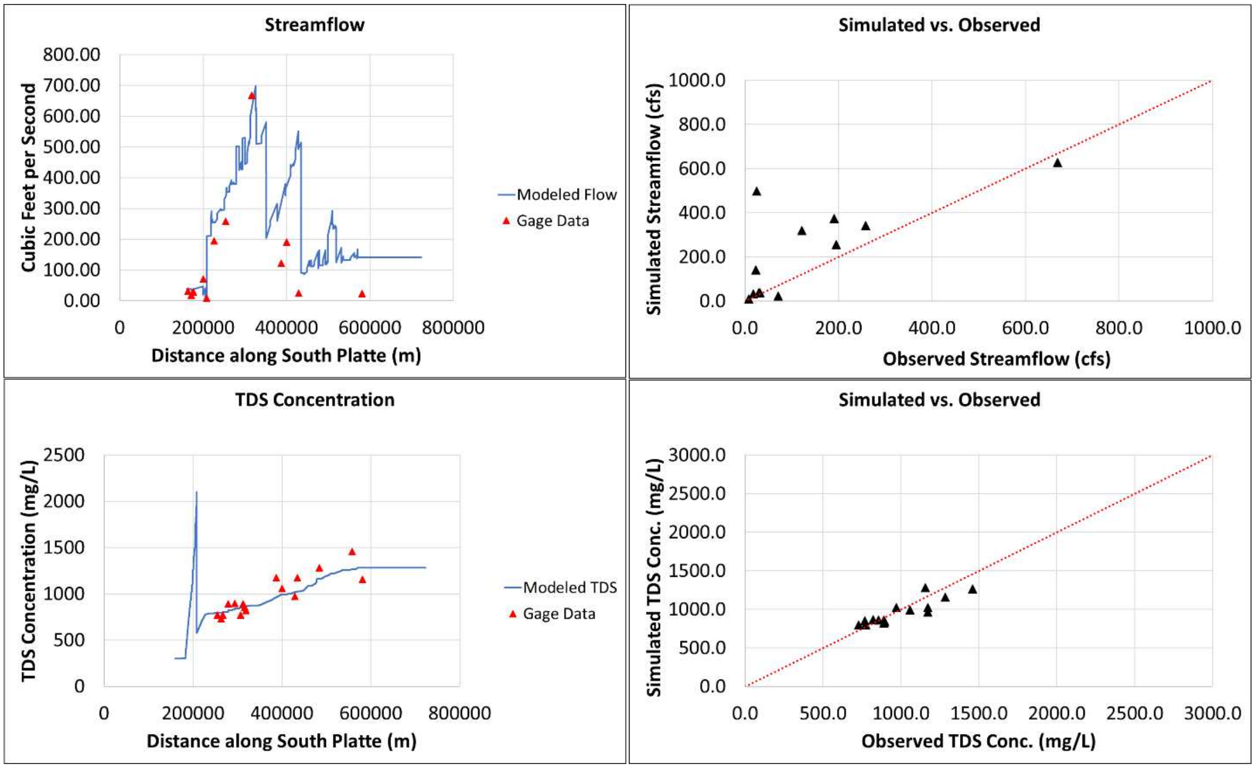
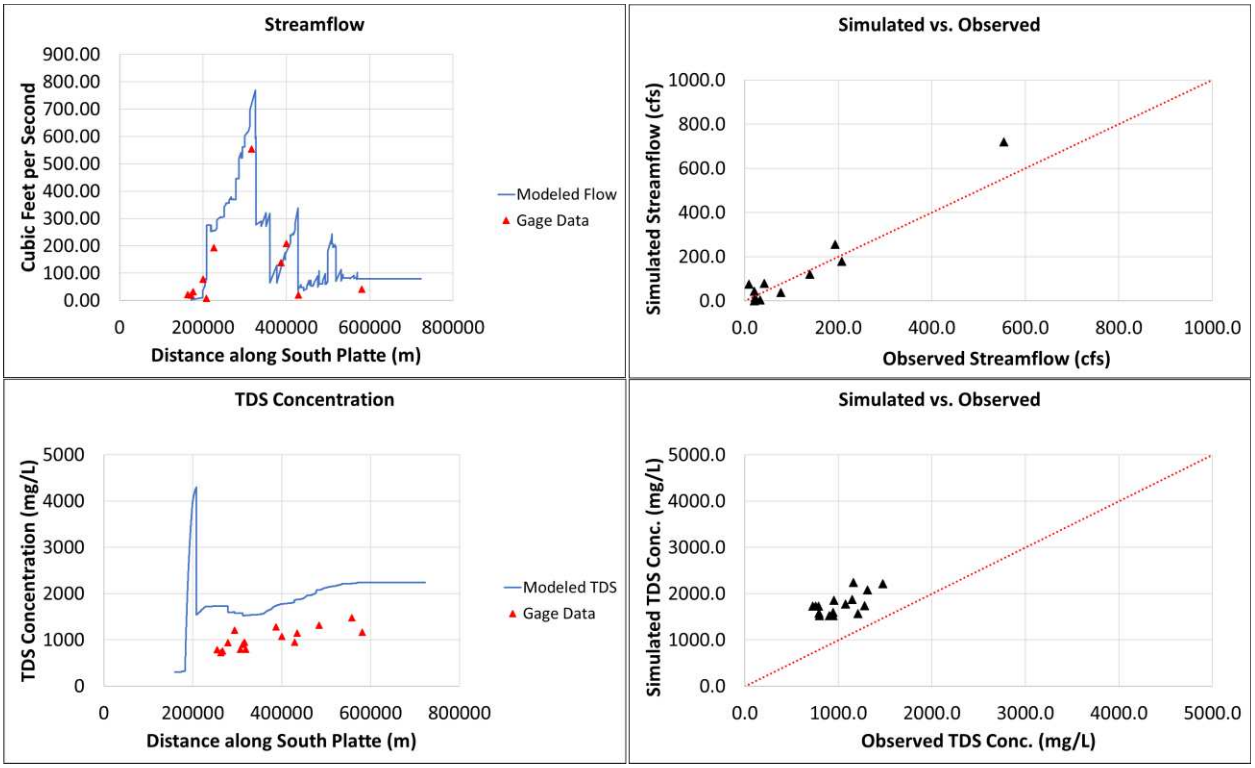


Figure A23. Flow and Salt Model Results for November 2003



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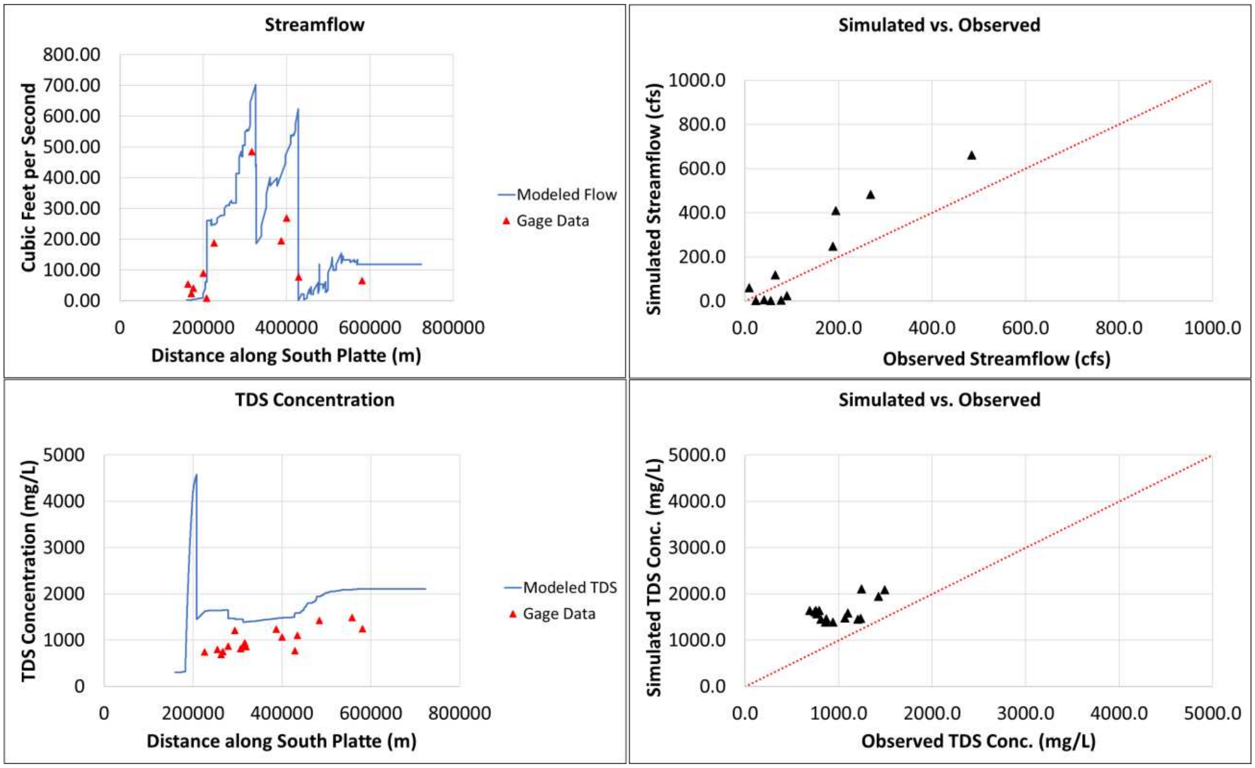

Figure A25. Flow and Salt Model Results for January 2004

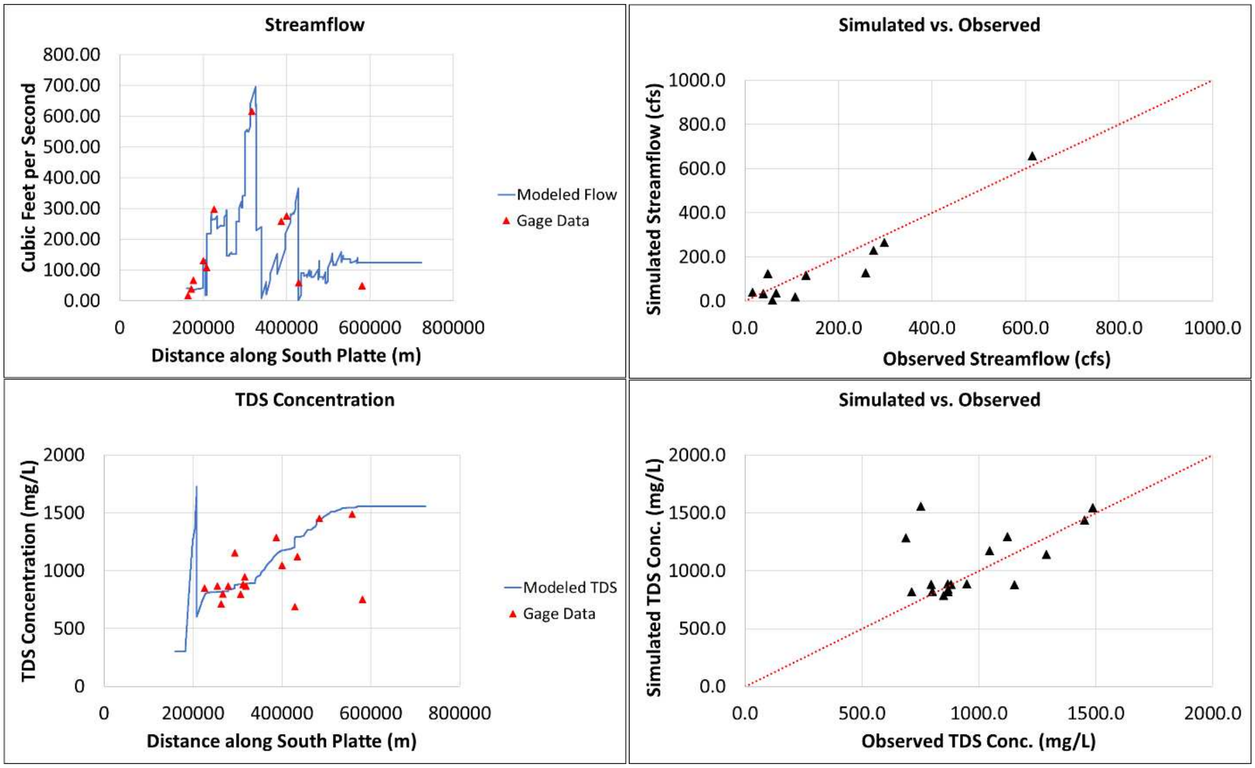

Figure A26. Flow and Salt Model Results for February 2004

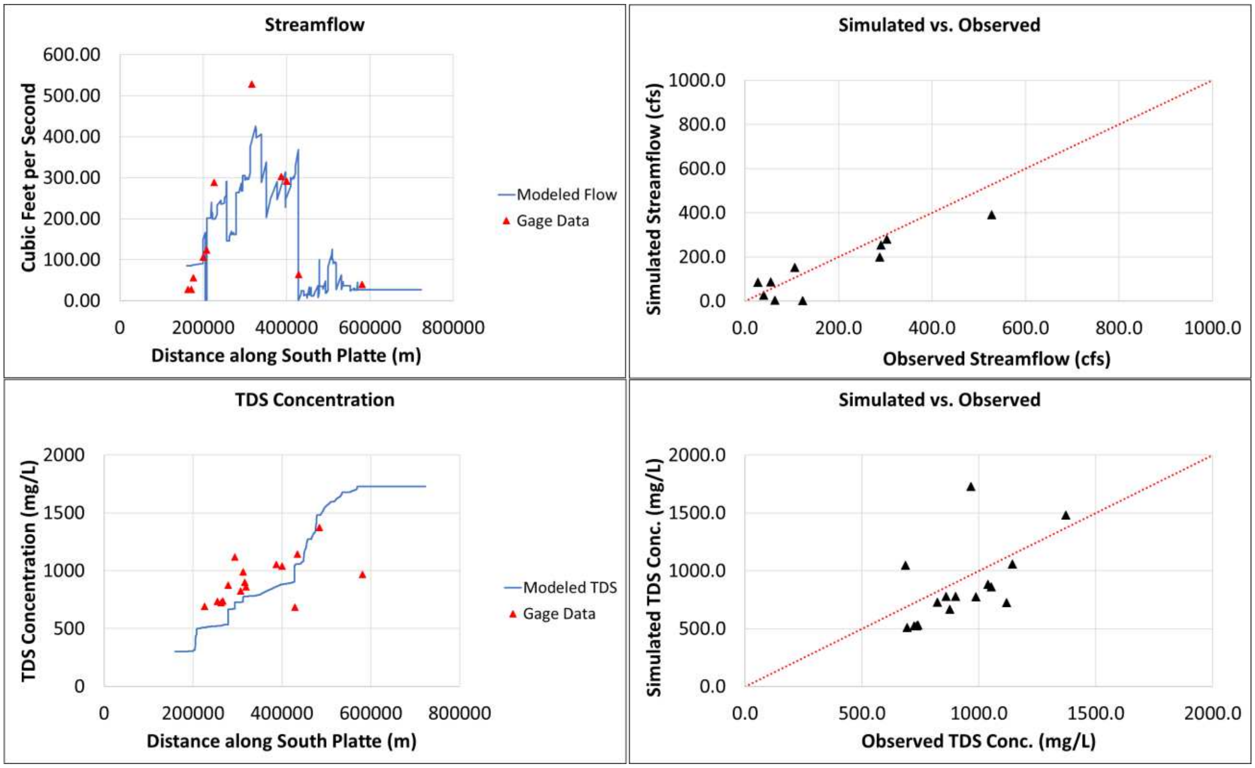

Figure A27. Flow and Salt Model Results for March 2004

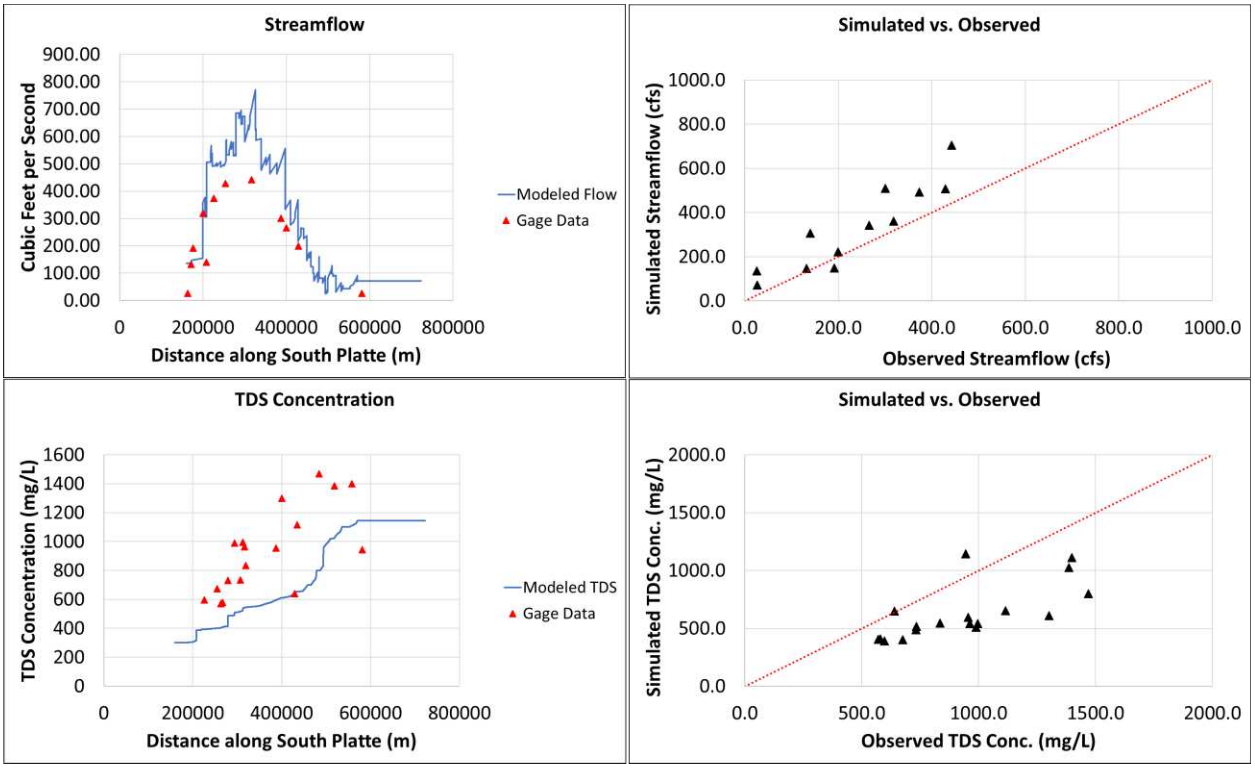

Figure A28. Flow and Salt Model Results for April 2004

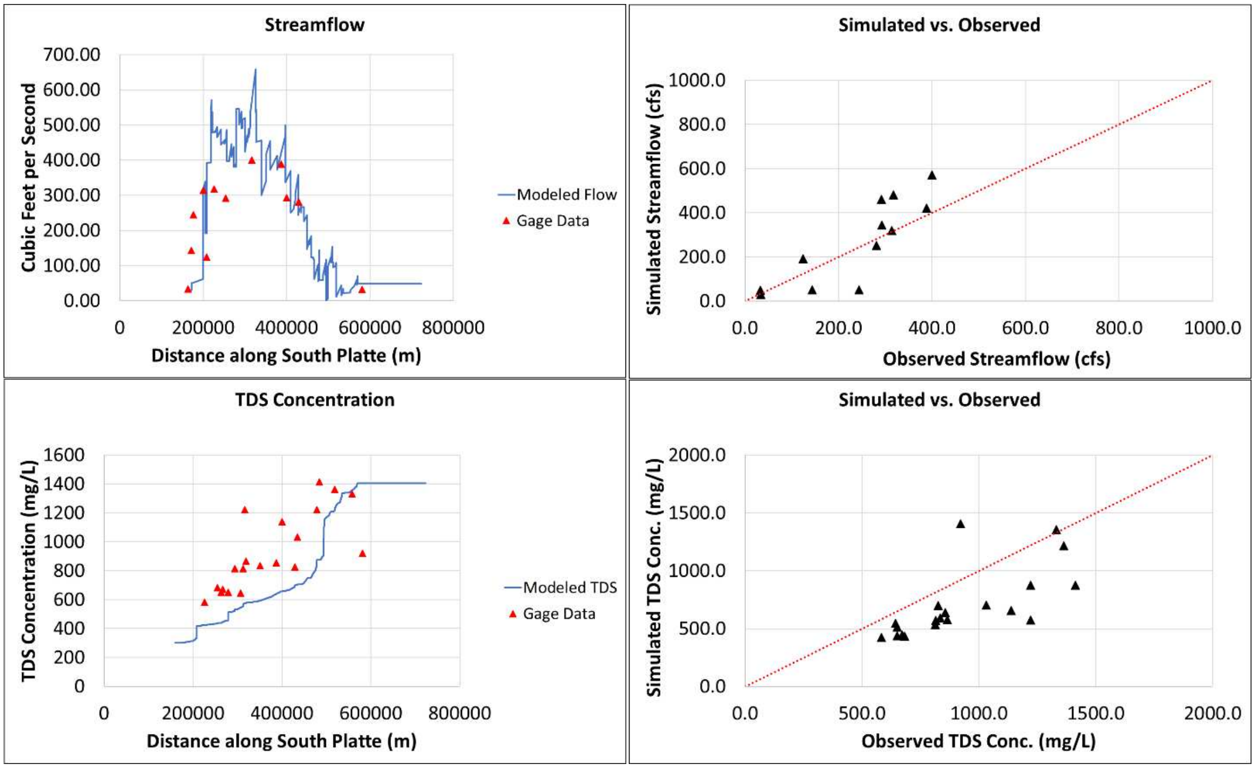

Figure A29. Flow and Salt Model Results for May 2004

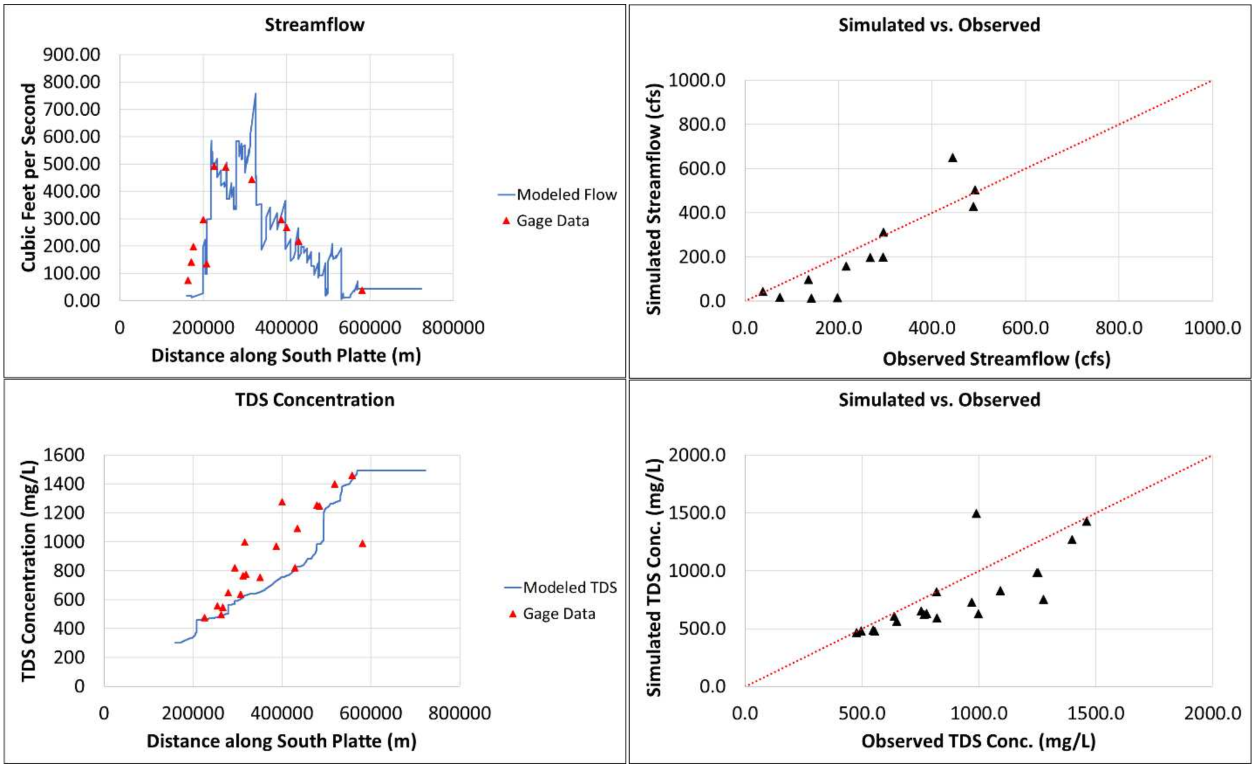

Figure A30. Flow and Salt Model Results for June 2004

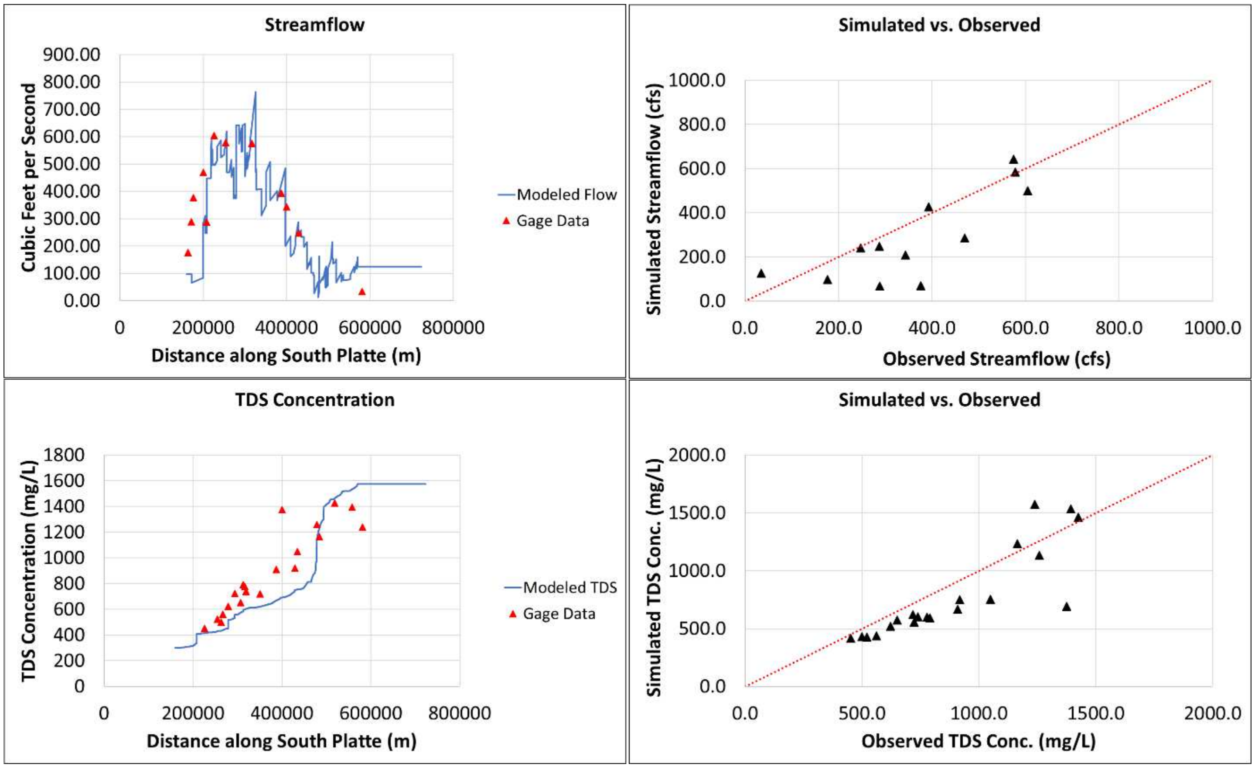

Figure A31. Flow and Salt Model Results for July 2004

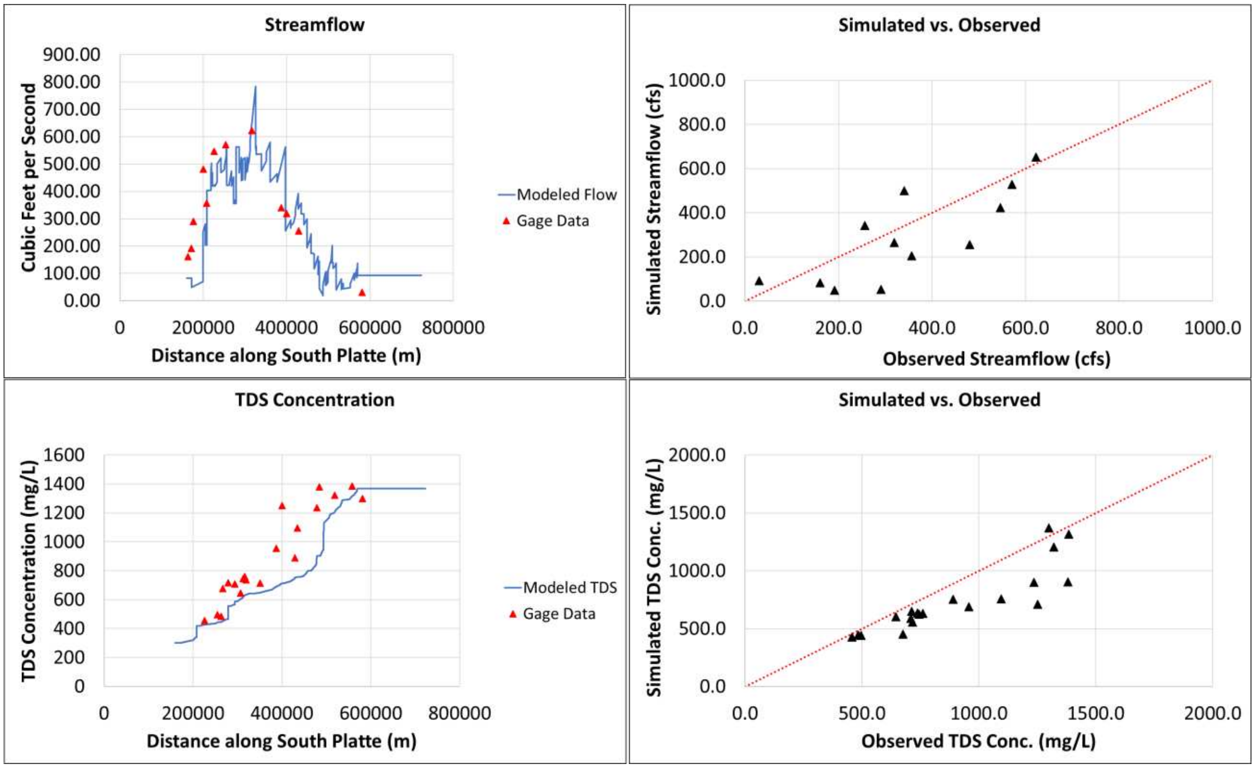

Figure A32. Flow and Salt Model Results for August 2004

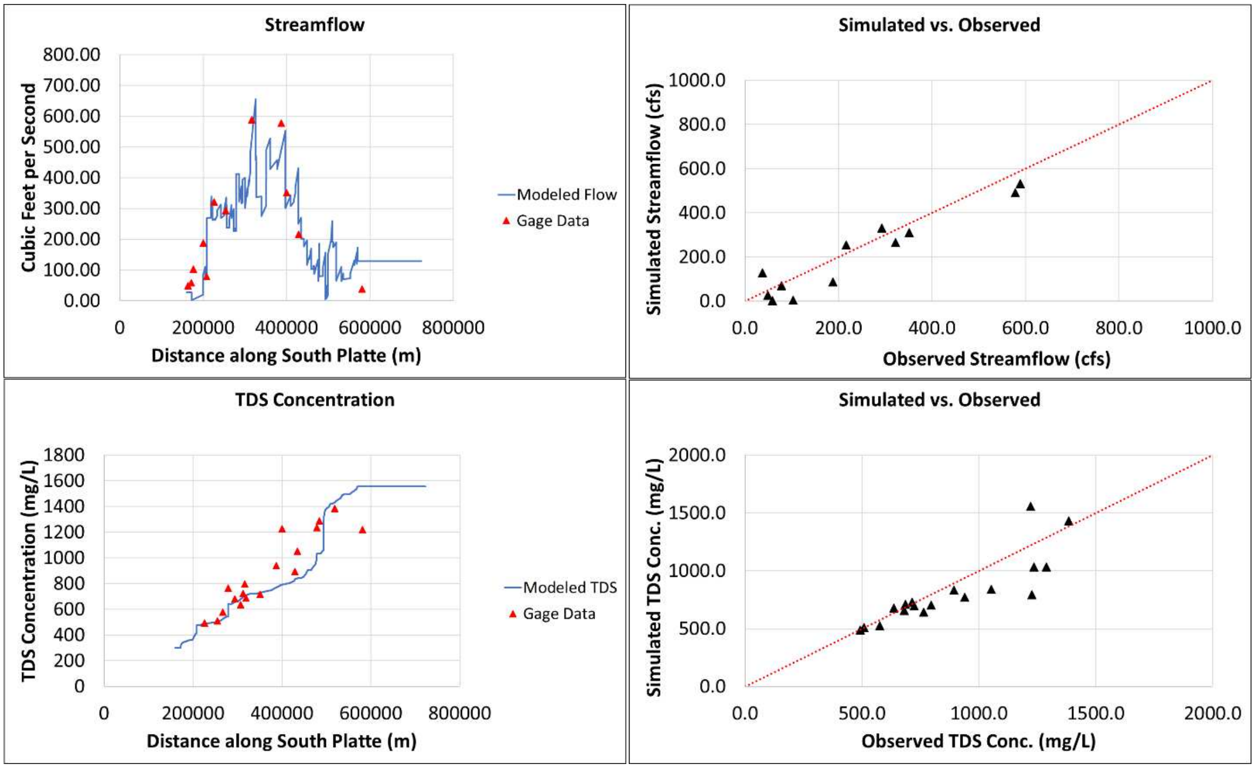

Figure A33. Flow and Salt Model Results for September 2004

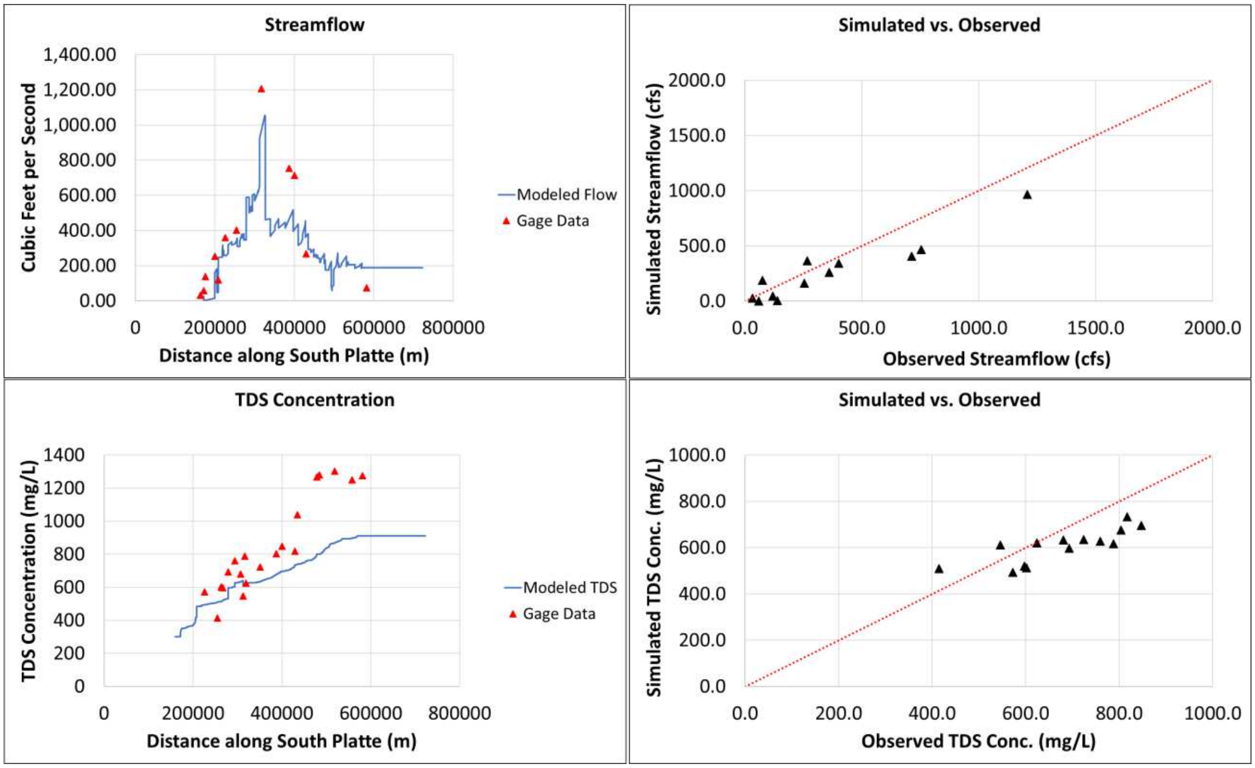

Figure A34. Flow and Salt Model Results for October 2004

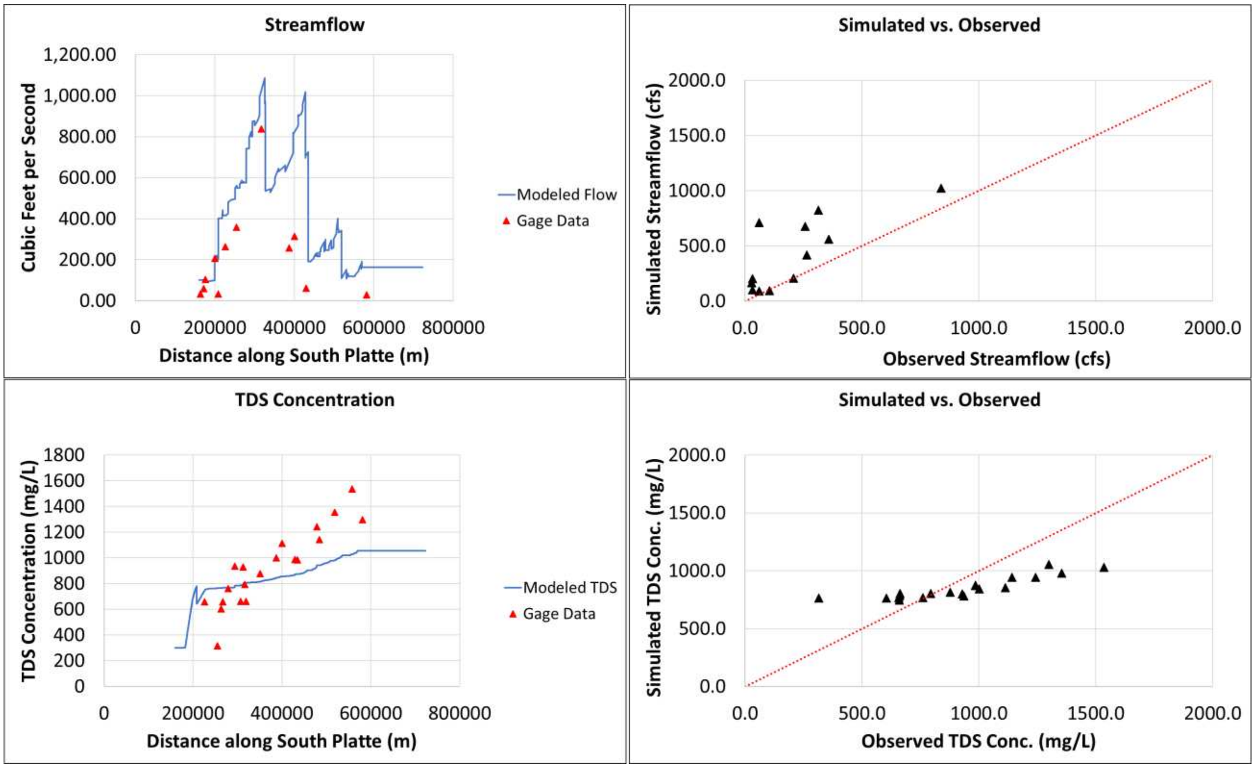

Figure A35. Flow and Salt Model Results for November 2004

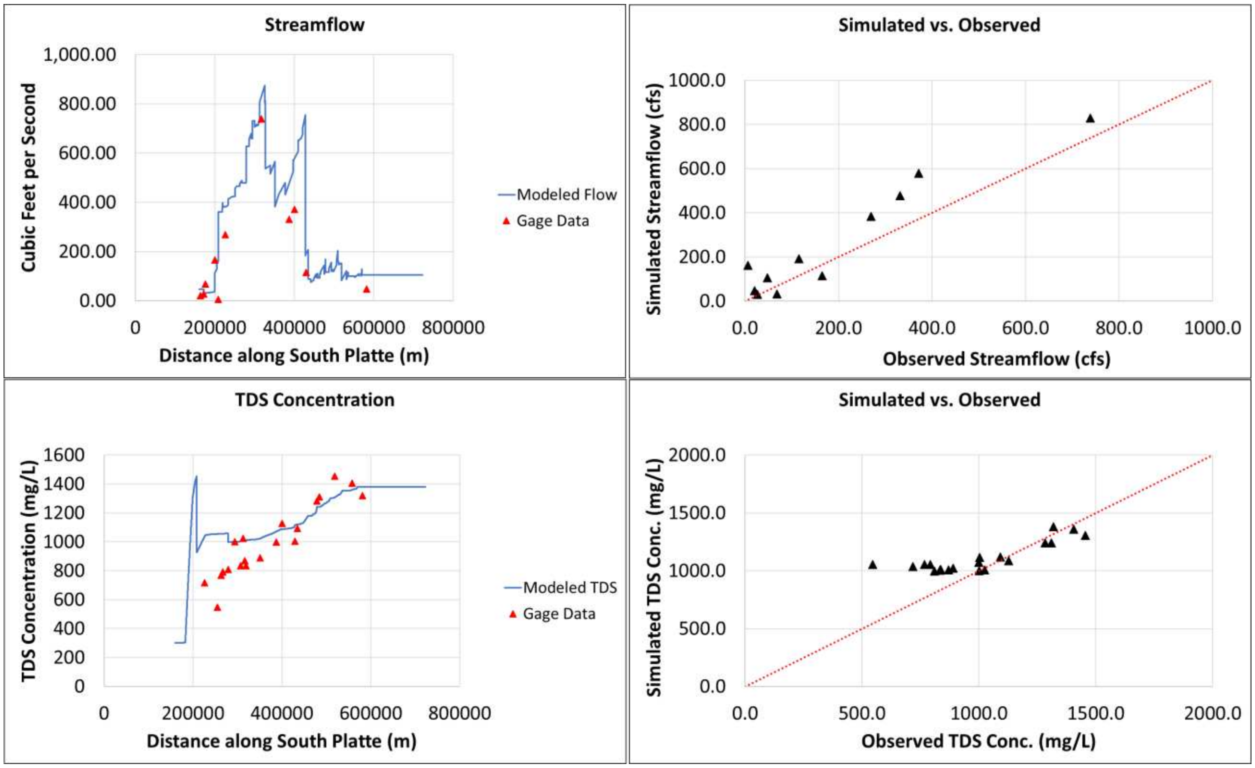

Figure A36. Flow and Salt Model Results for December 2004

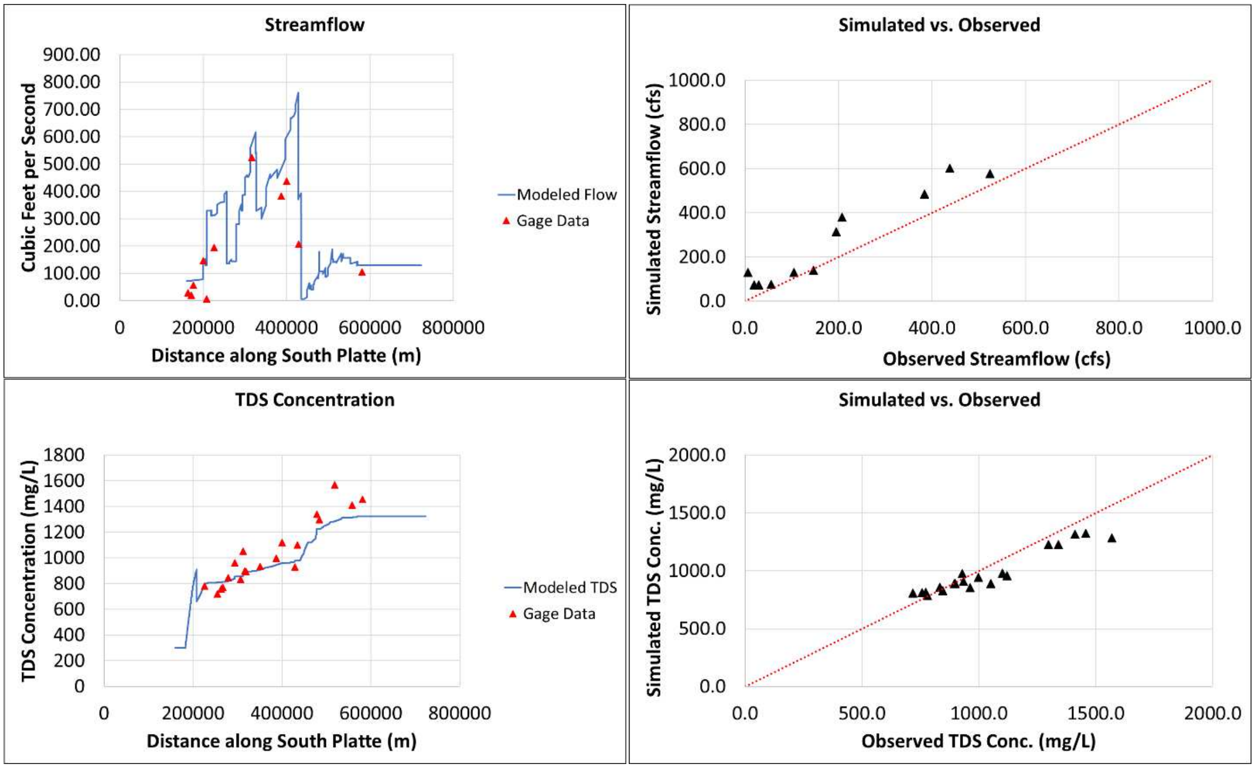

Figure A37. Flow and Salt Model Results for January 2005

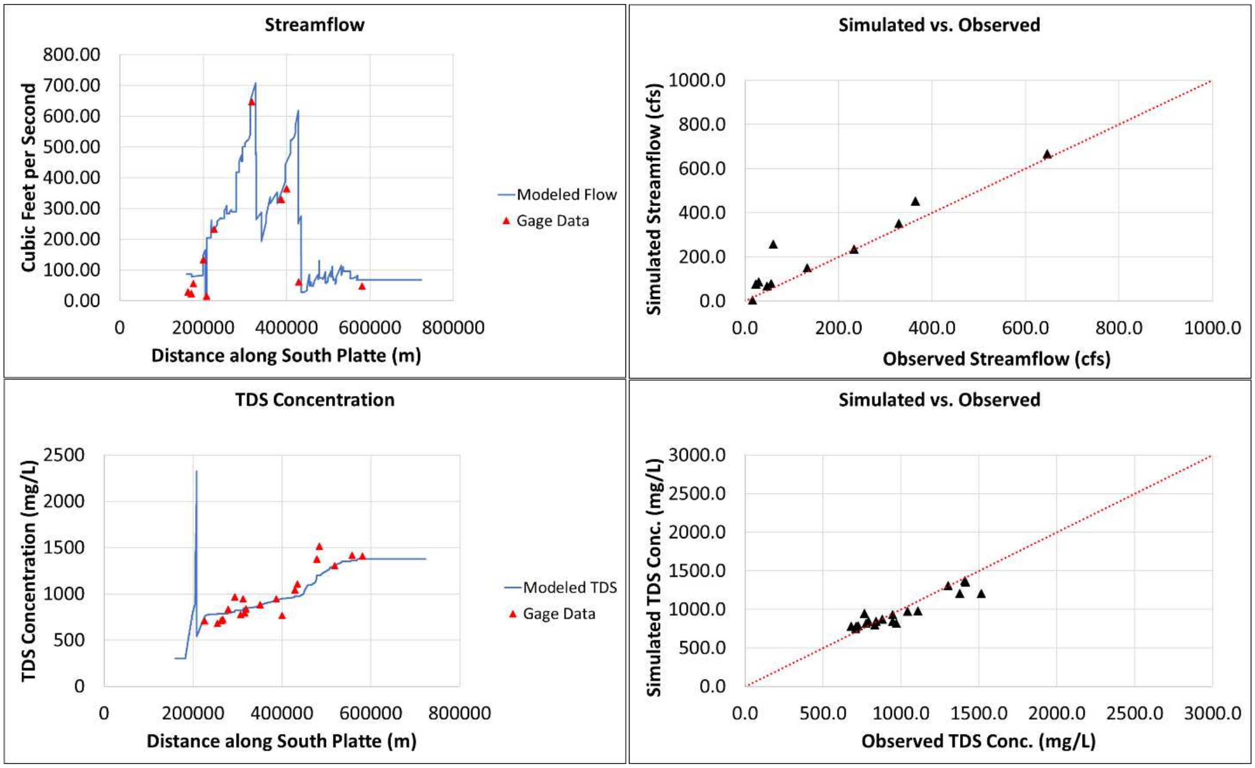

Figure A38. Flow and Salt Model Results for February 2005

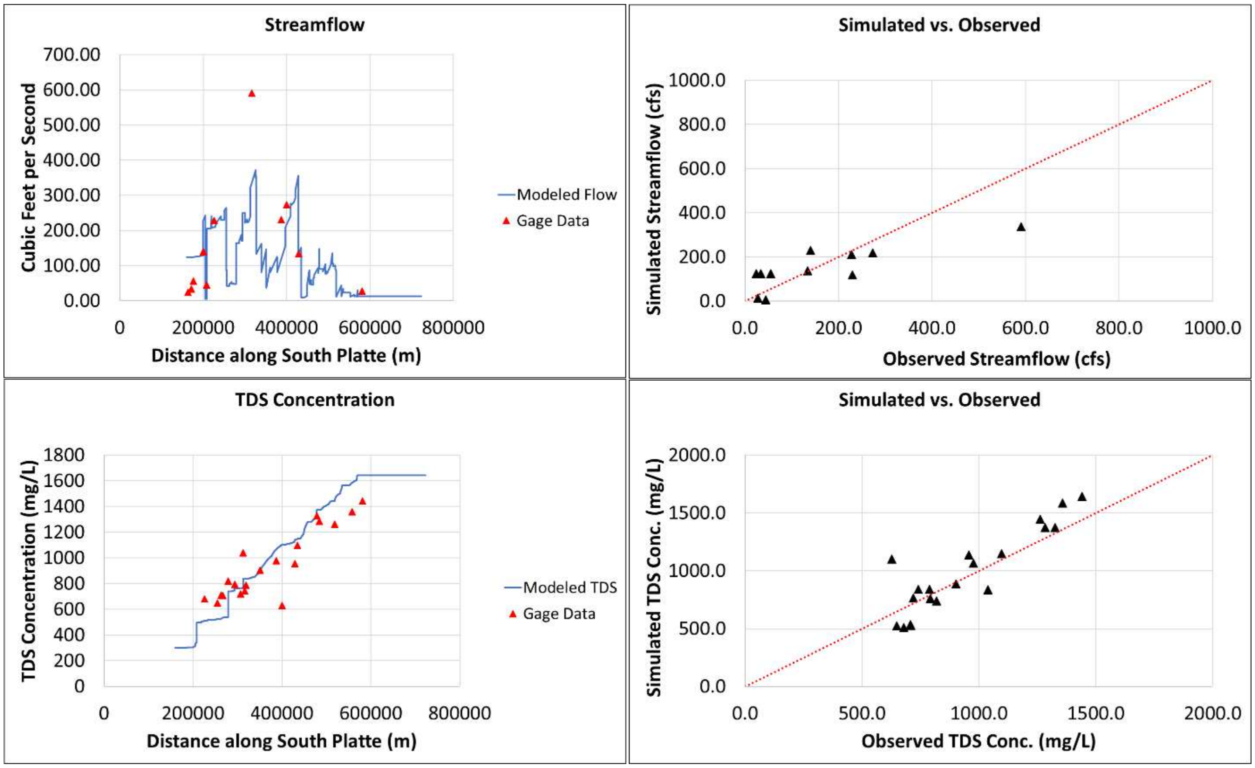

Figure A39. Flow and Salt Model Results for March 2005

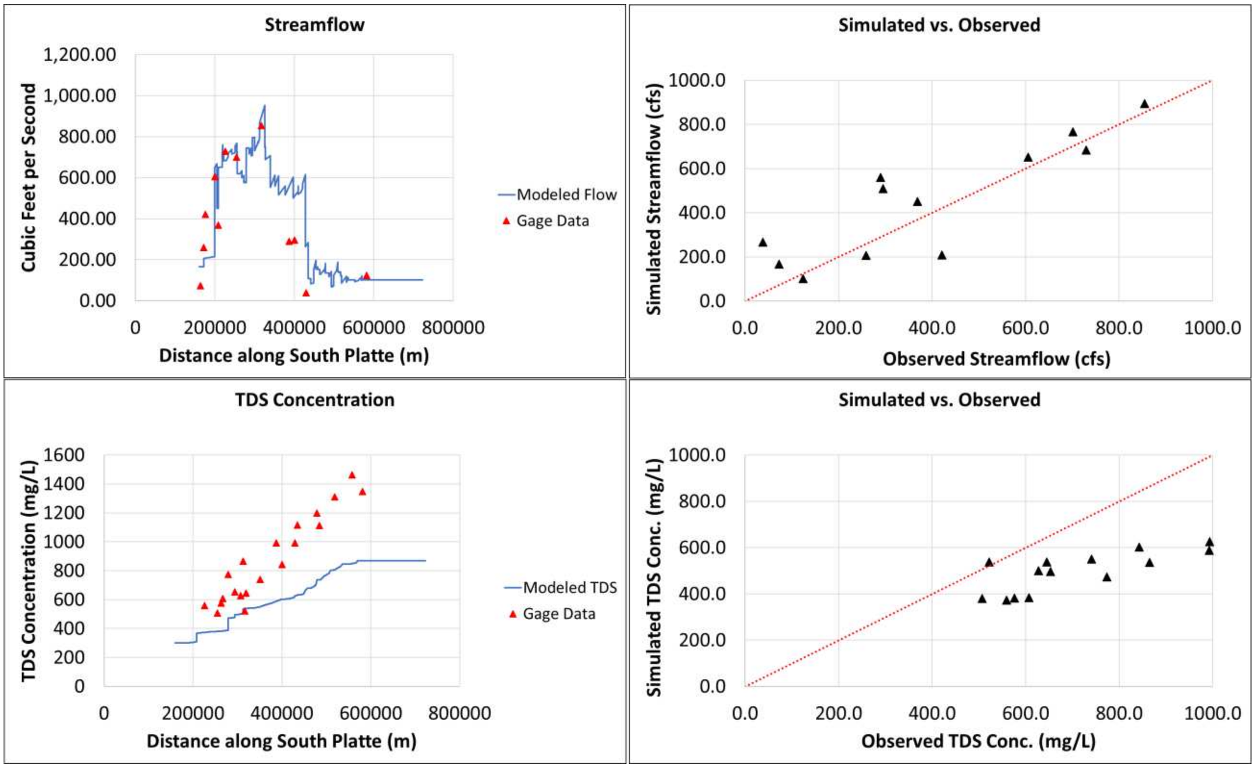

Figure A40. Flow and Salt Model Results for April 2005

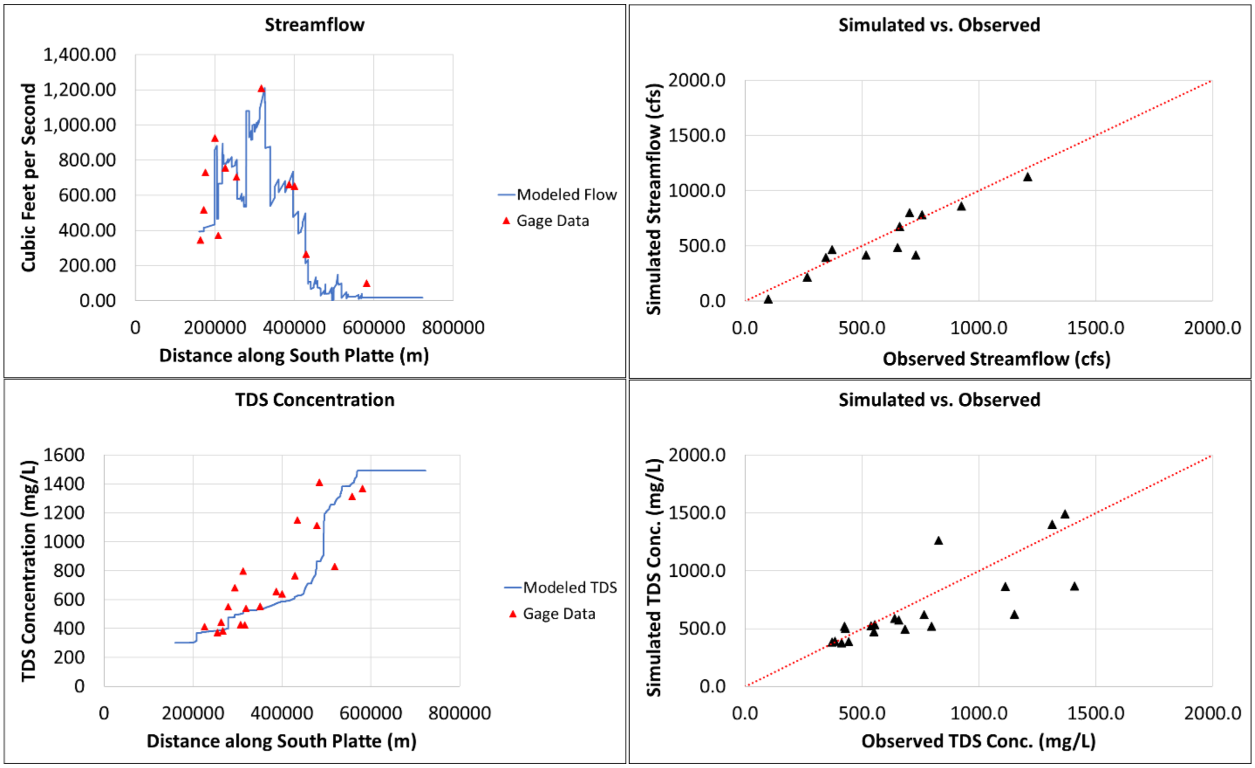

Figure A41. Flow and Salt Model Results for May 2005

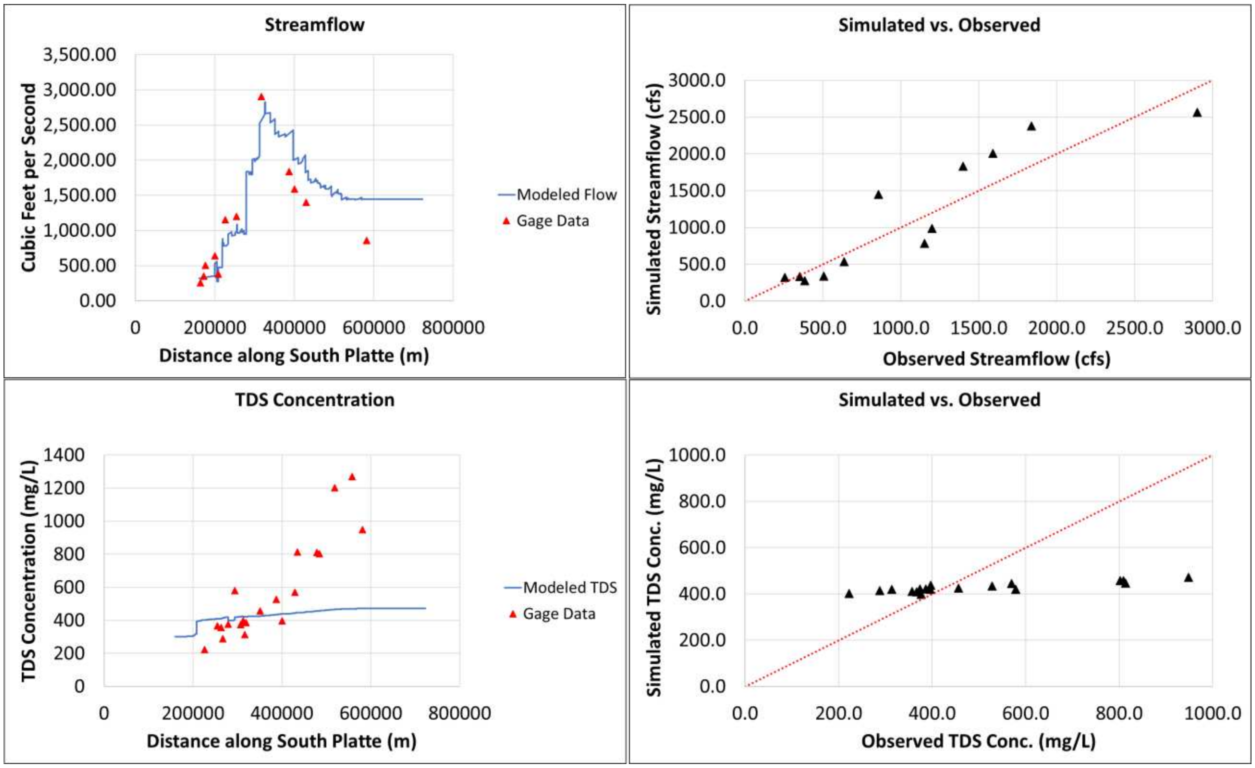

Figure A42. Flow and Salt Model Results for June 2005

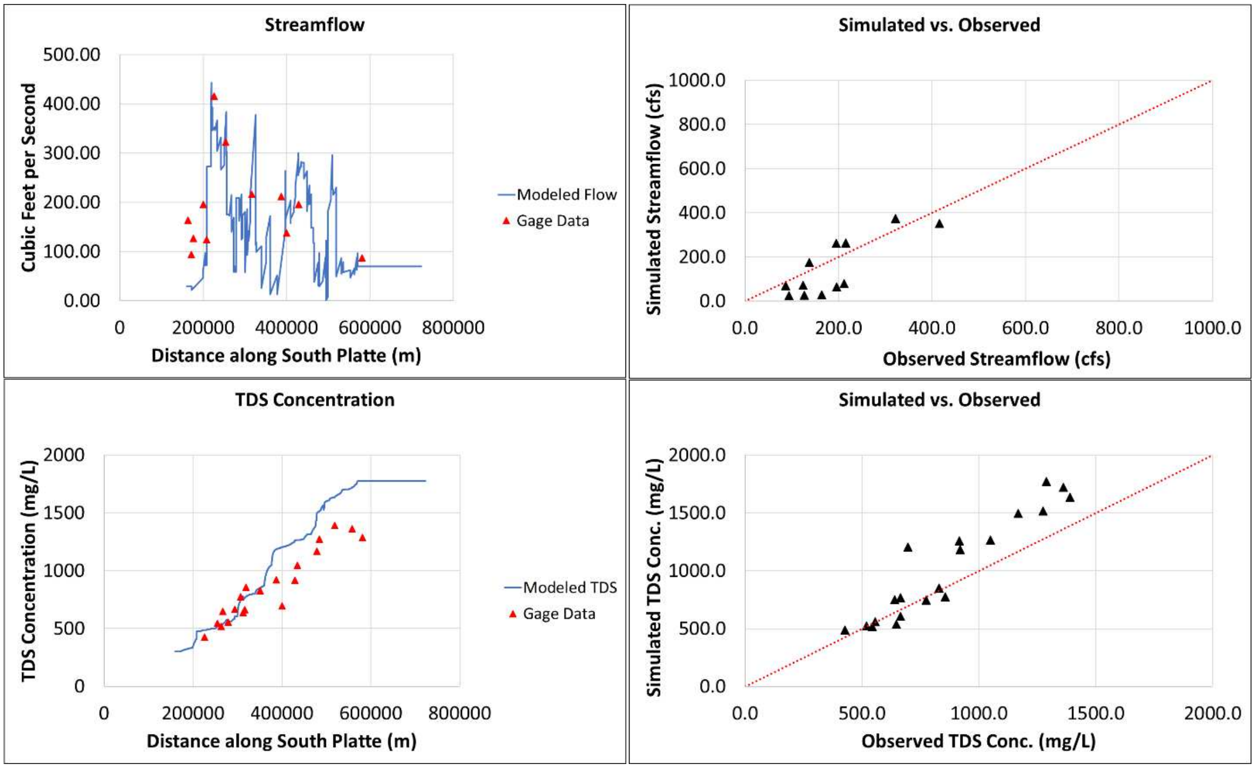

Figure A43. Flow and Salt Model Results for July 2005

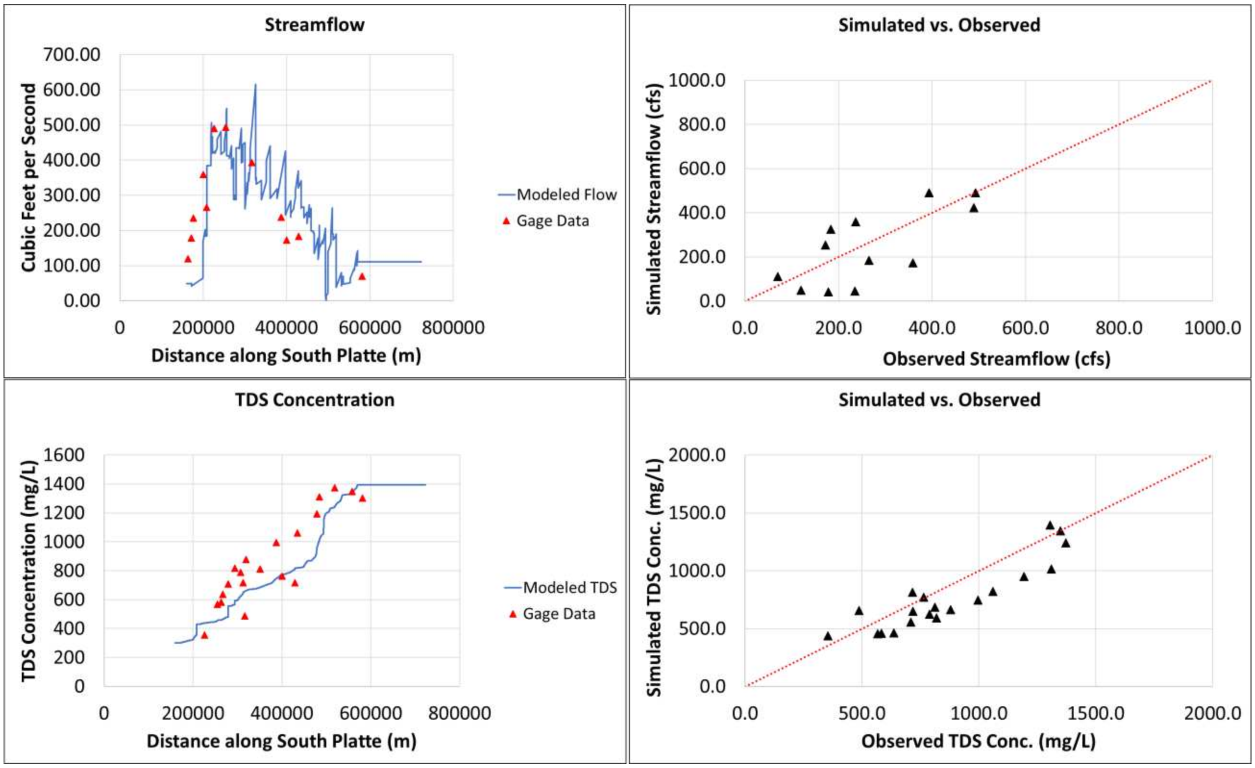

Figure A44. Flow and Salt Model Results for August 2005

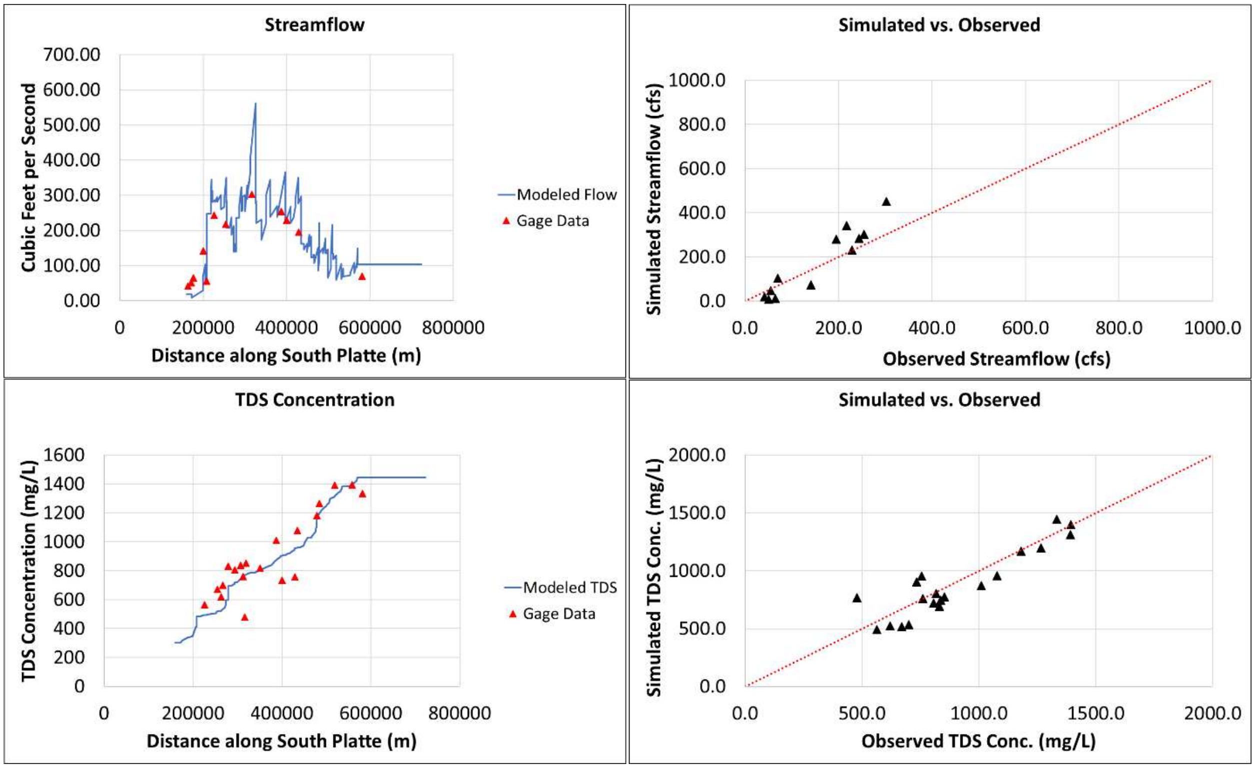

Figure A45. Flow and Salt Model Results for September 2005

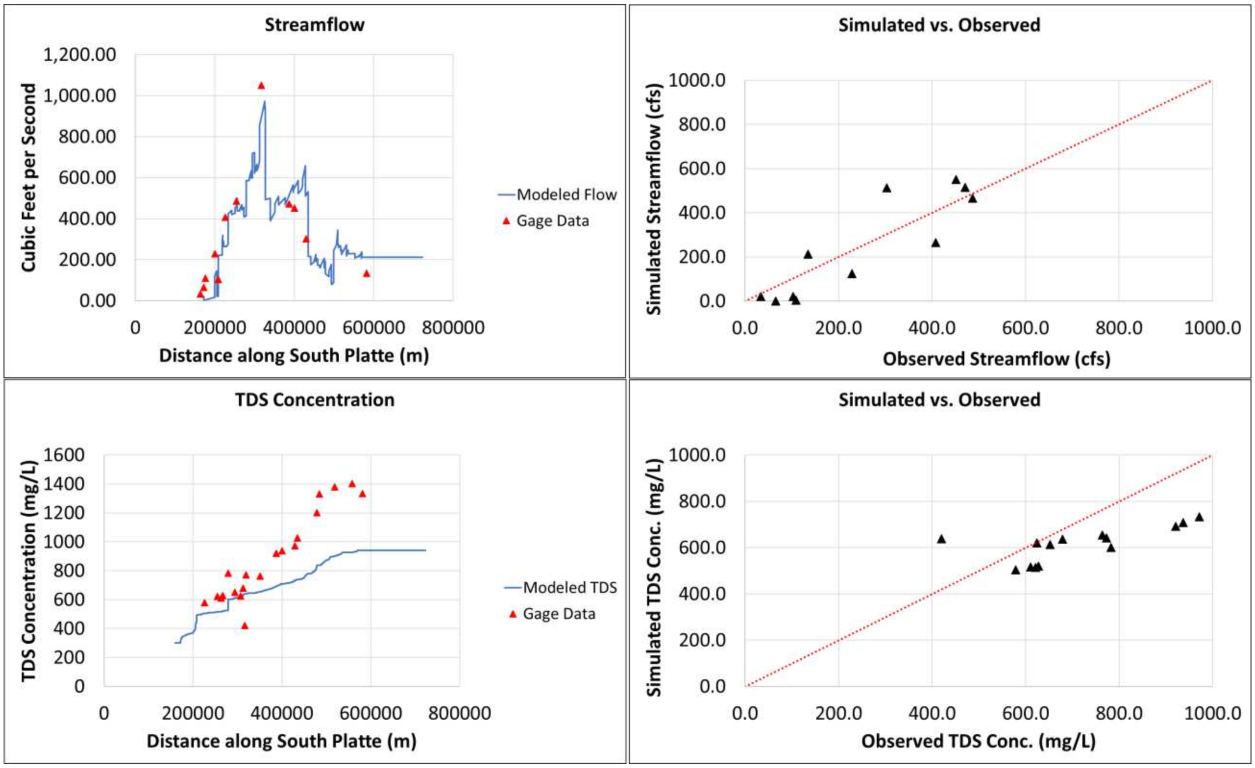

Figure A46. Flow and Salt Model Results for October 2005

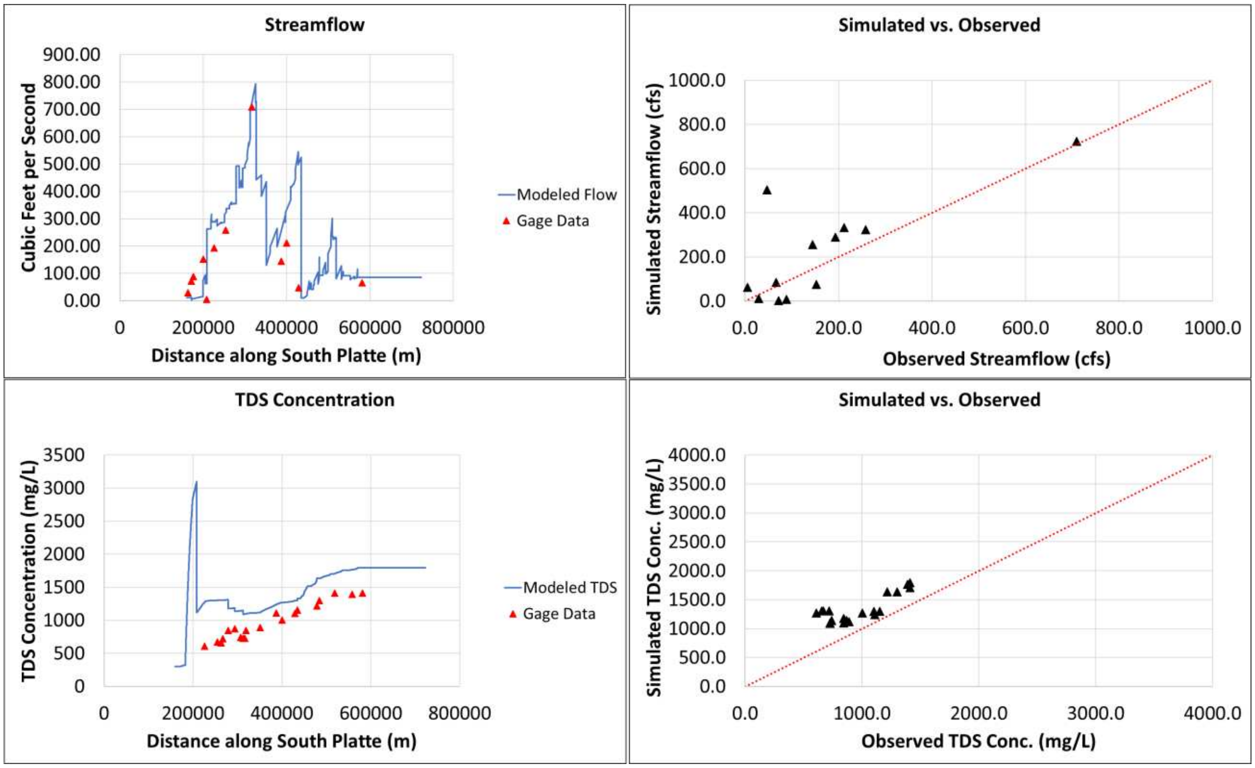

Figure A47. Flow and Salt Model Results for November 2005

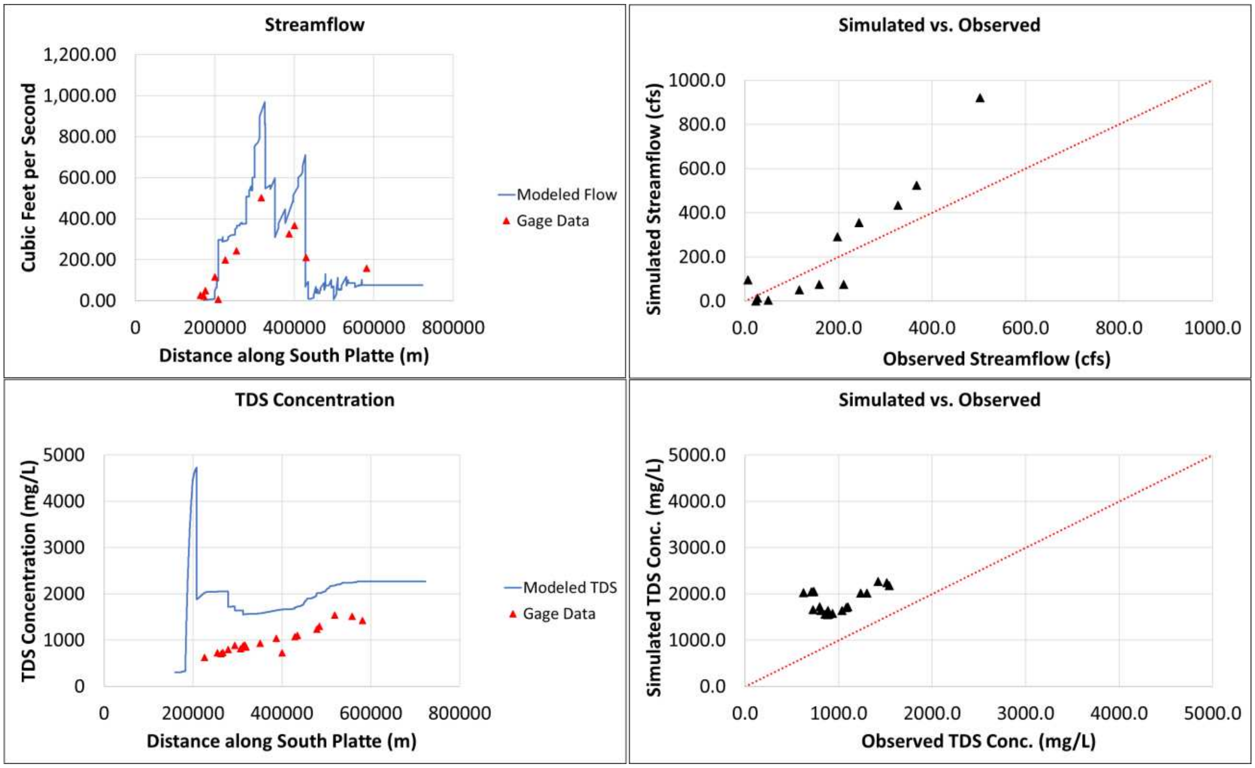

Figure A48. Flow and Salt Model Results for December 2005

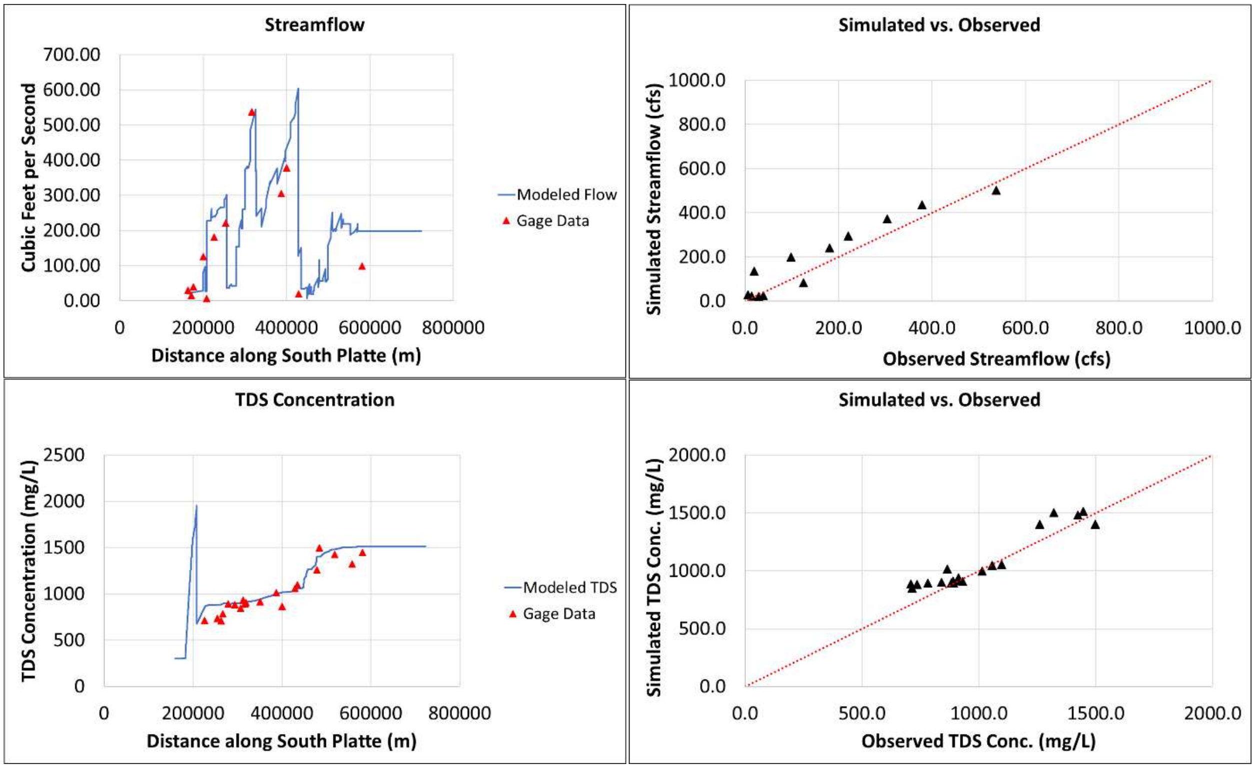

Figure A49. Flow and Salt Model Results for January 2006

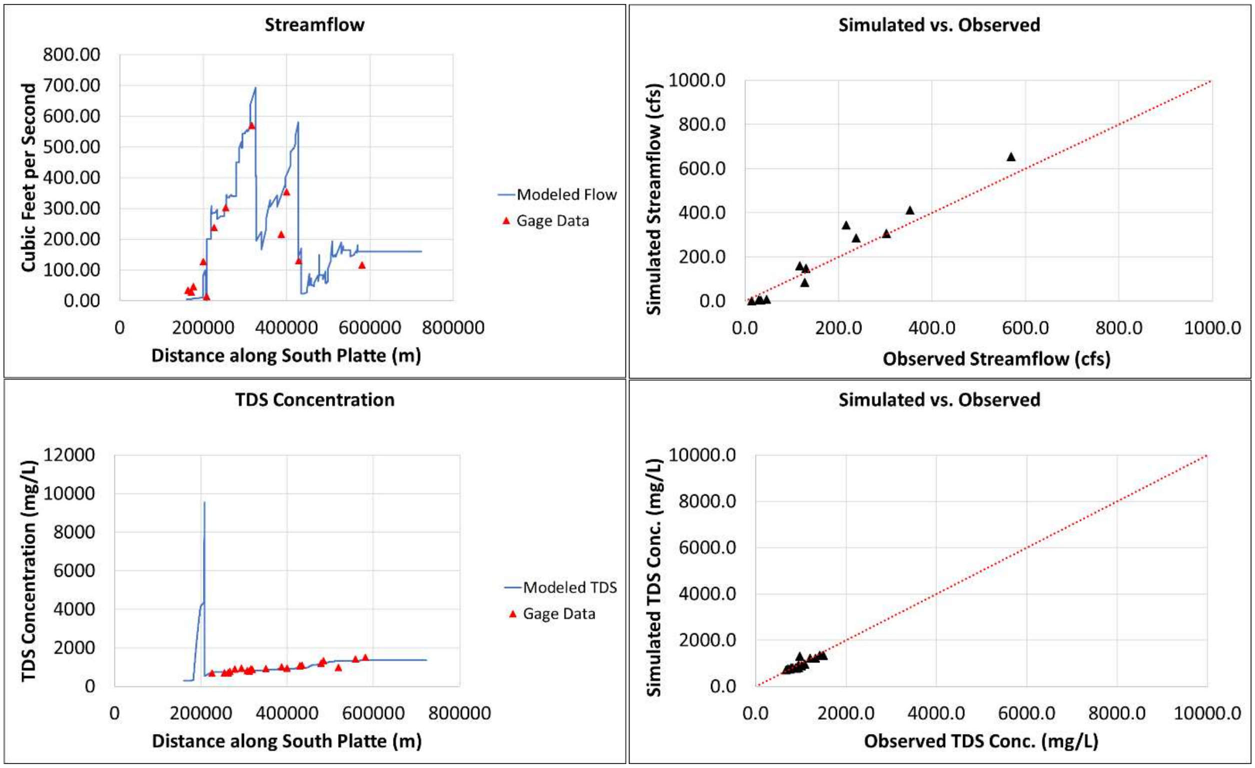

Figure A50. Flow and Salt Model Results for February 2006

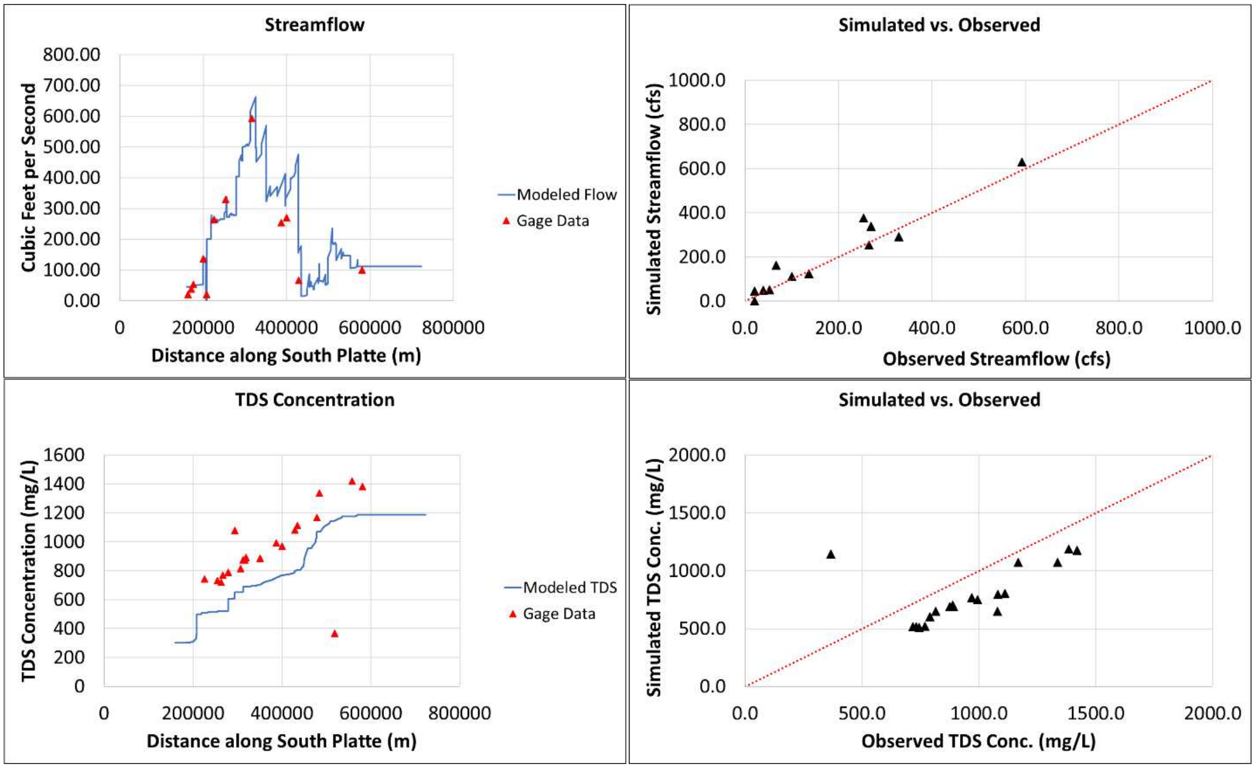

Figure A51. Flow and Salt Model Results for March 2006

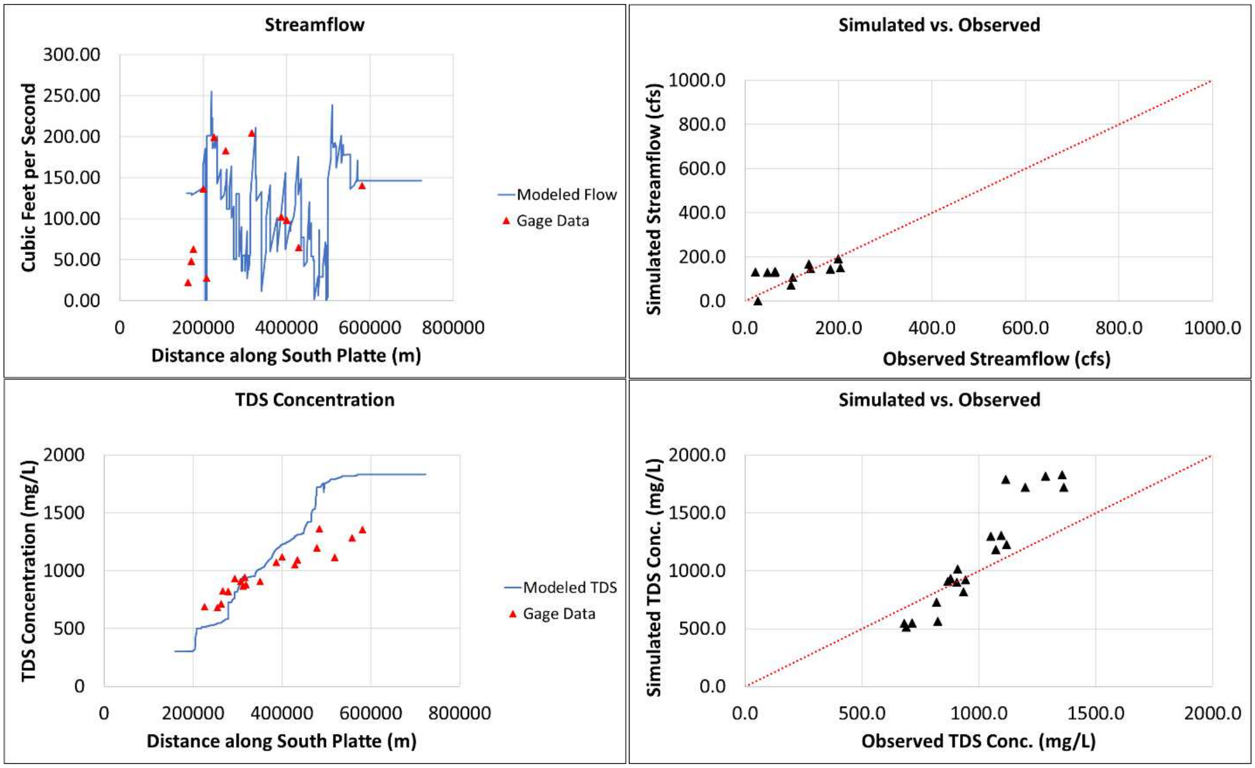

Figure A52. Flow and Salt Model Results for April 2006

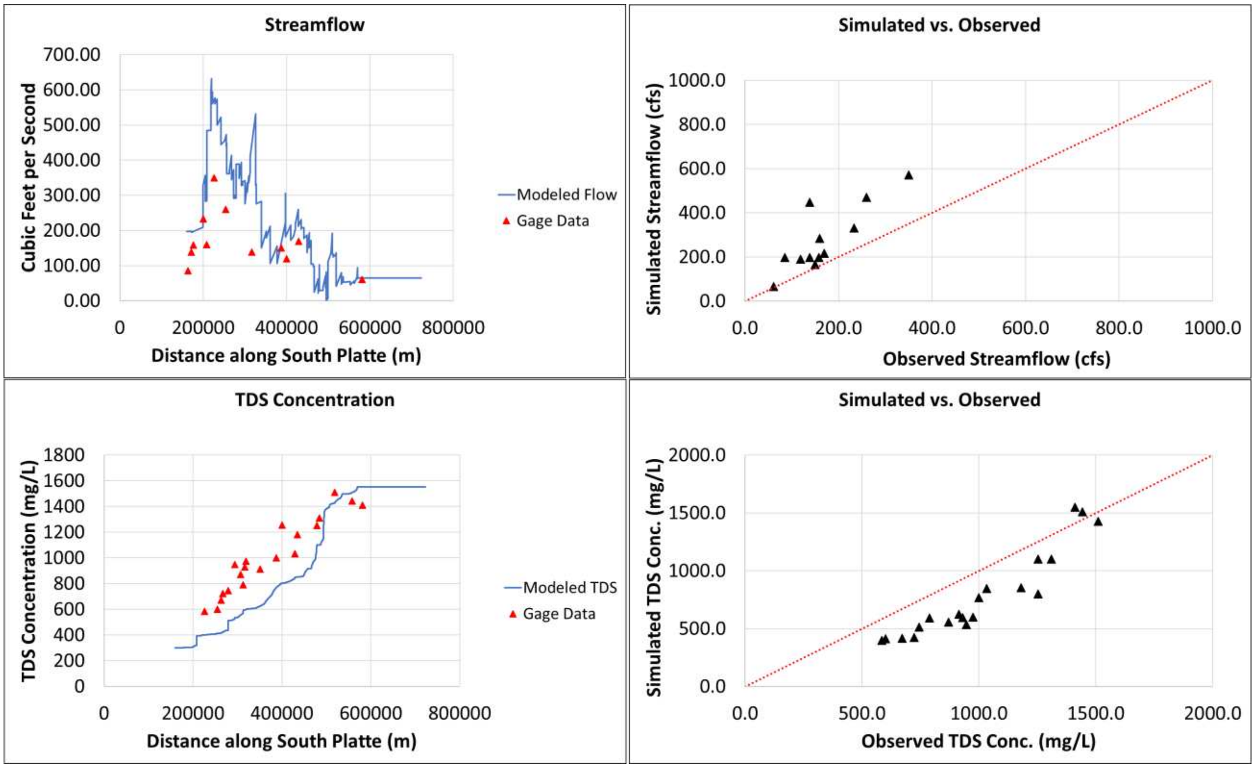

Figure A53. Flow and Salt Model Results for May 2006

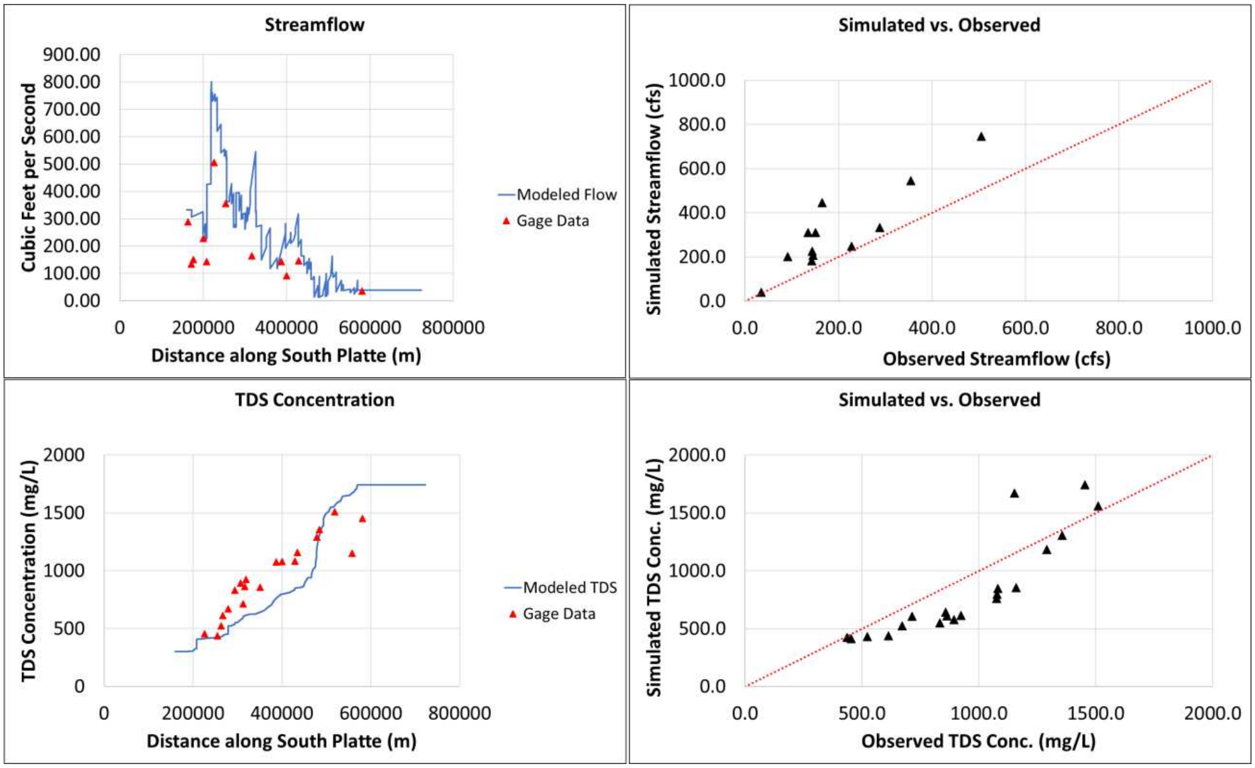

Figure A54. Flow and Salt Model Results for June 2006

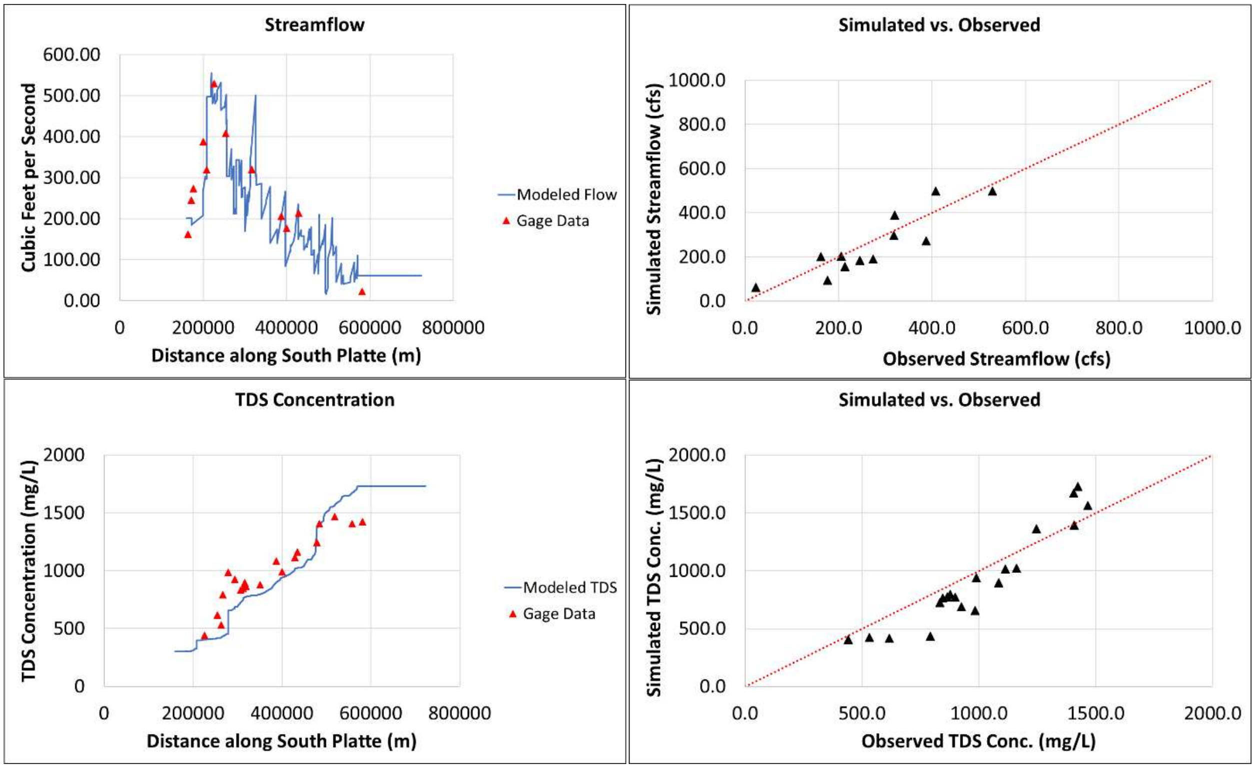

Figure A55. Flow and Salt Model Results for July 2006

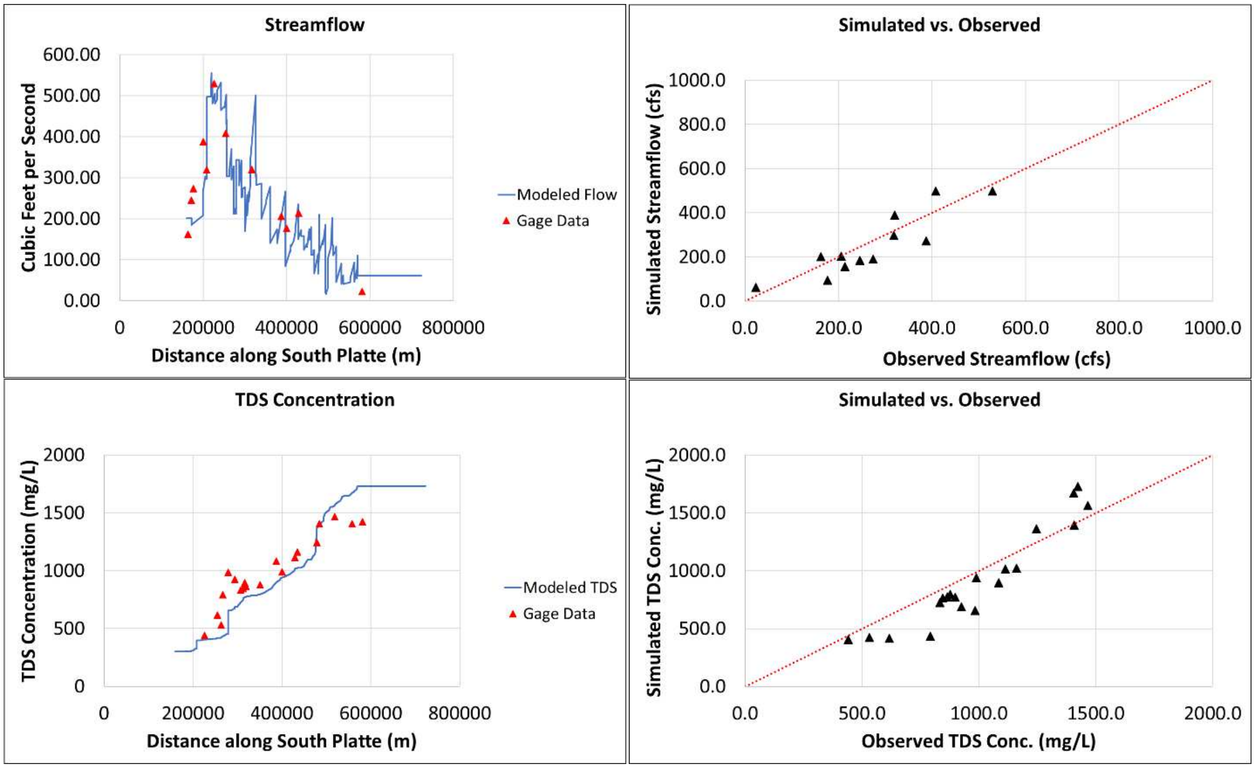

Figure A56. Flow and Salt Model Results for August 2006

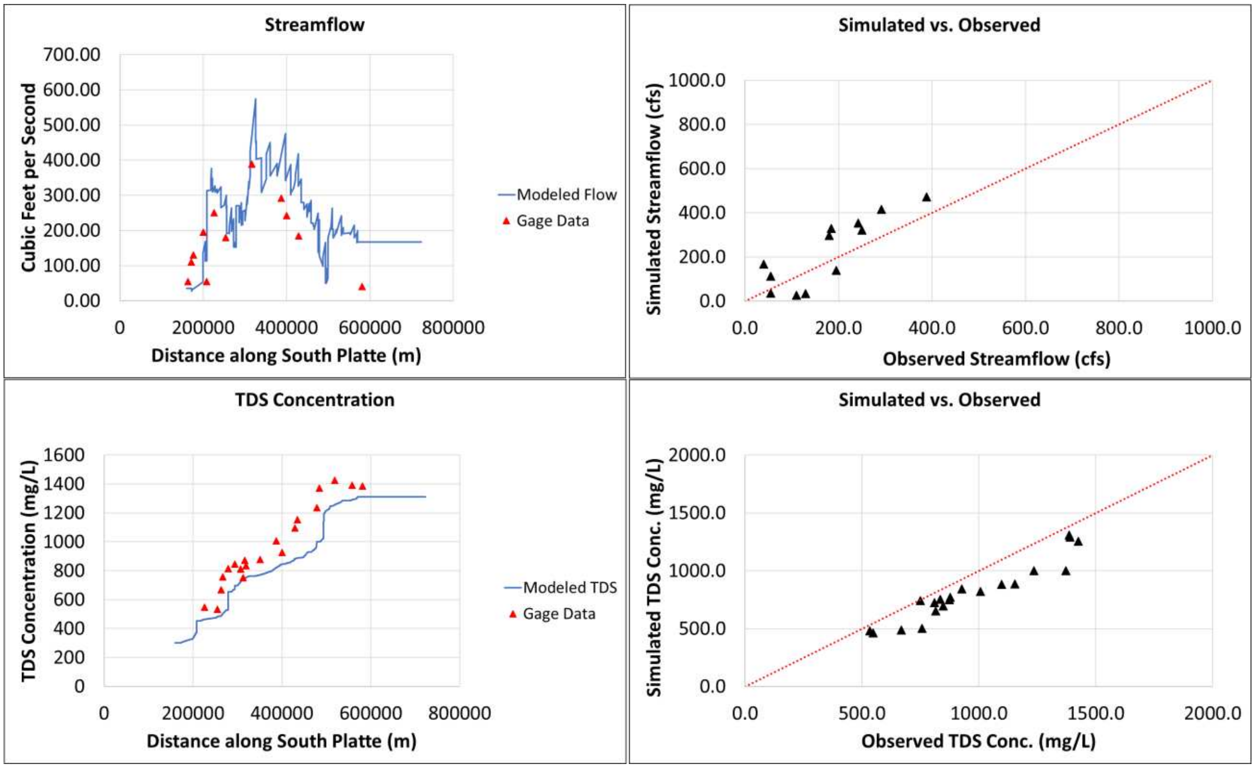

Figure A57. Flow and Salt Model Results for September 2006

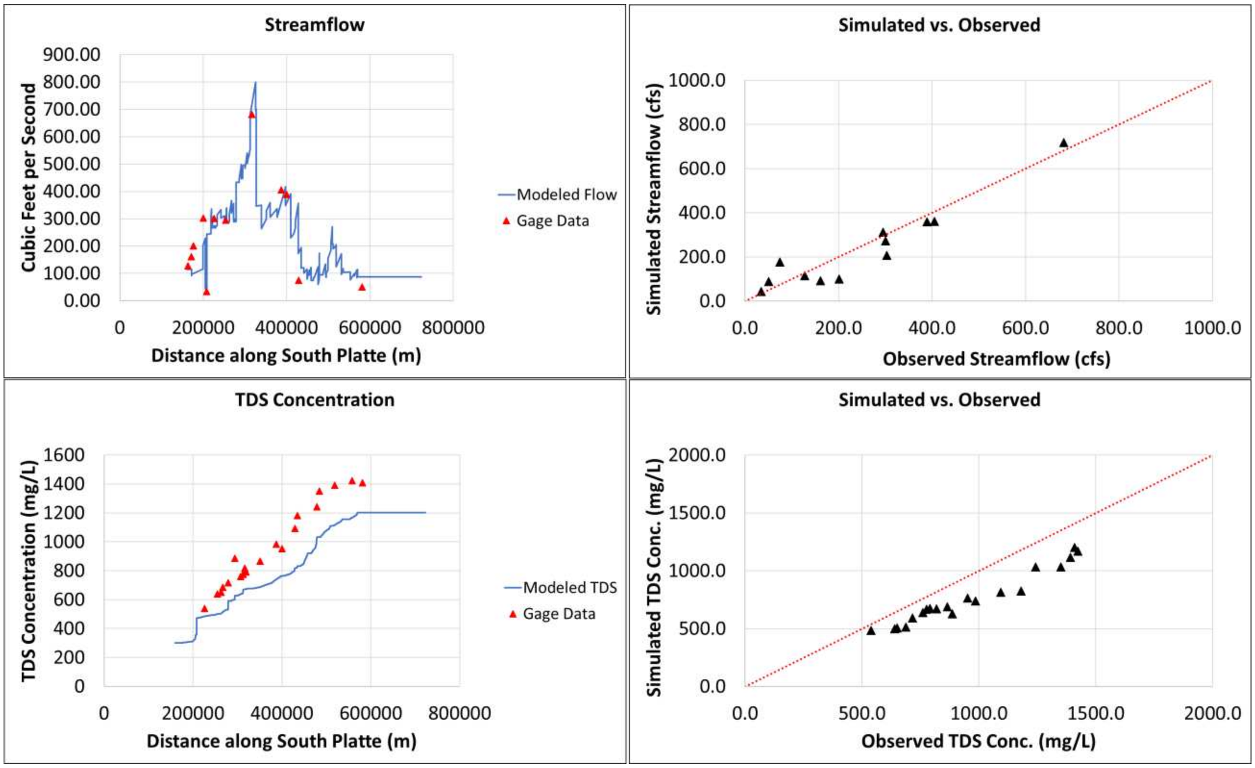

Figure A58. Flow and Salt Model Results for October 2006

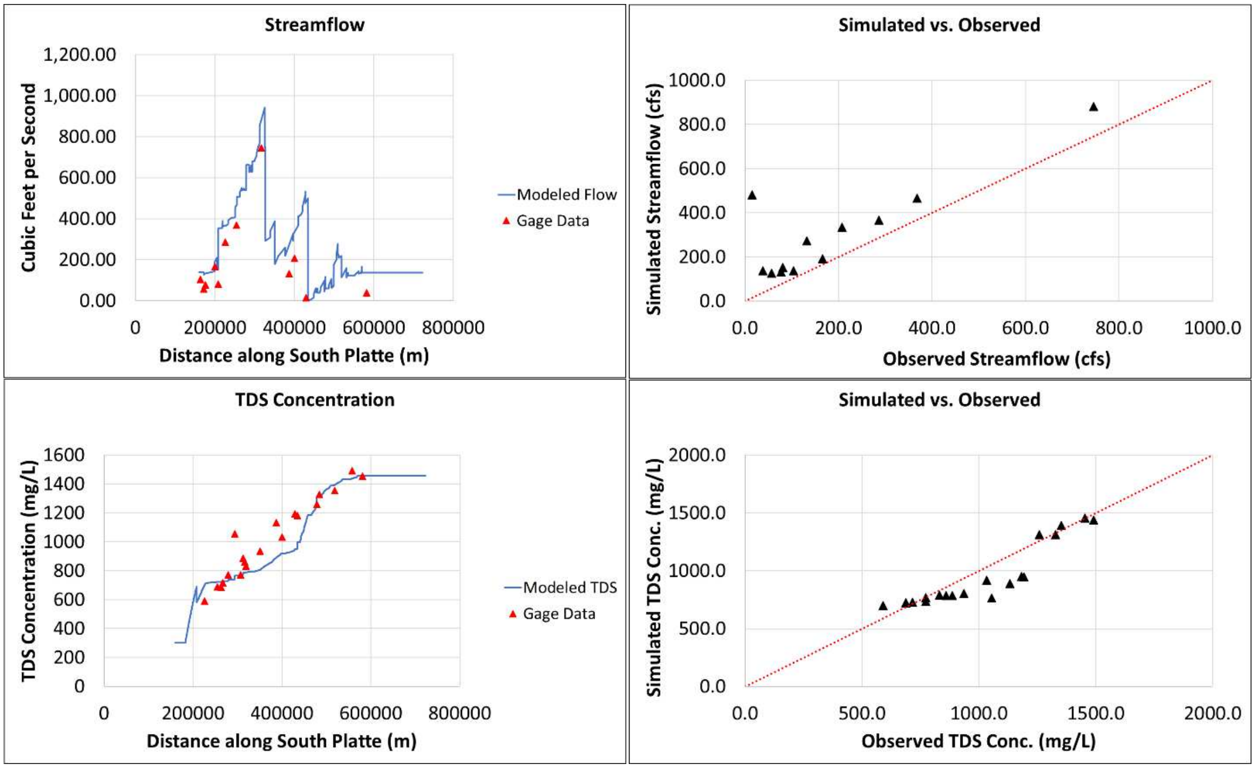

Figure A59. Flow and Salt Model Results for November 2006

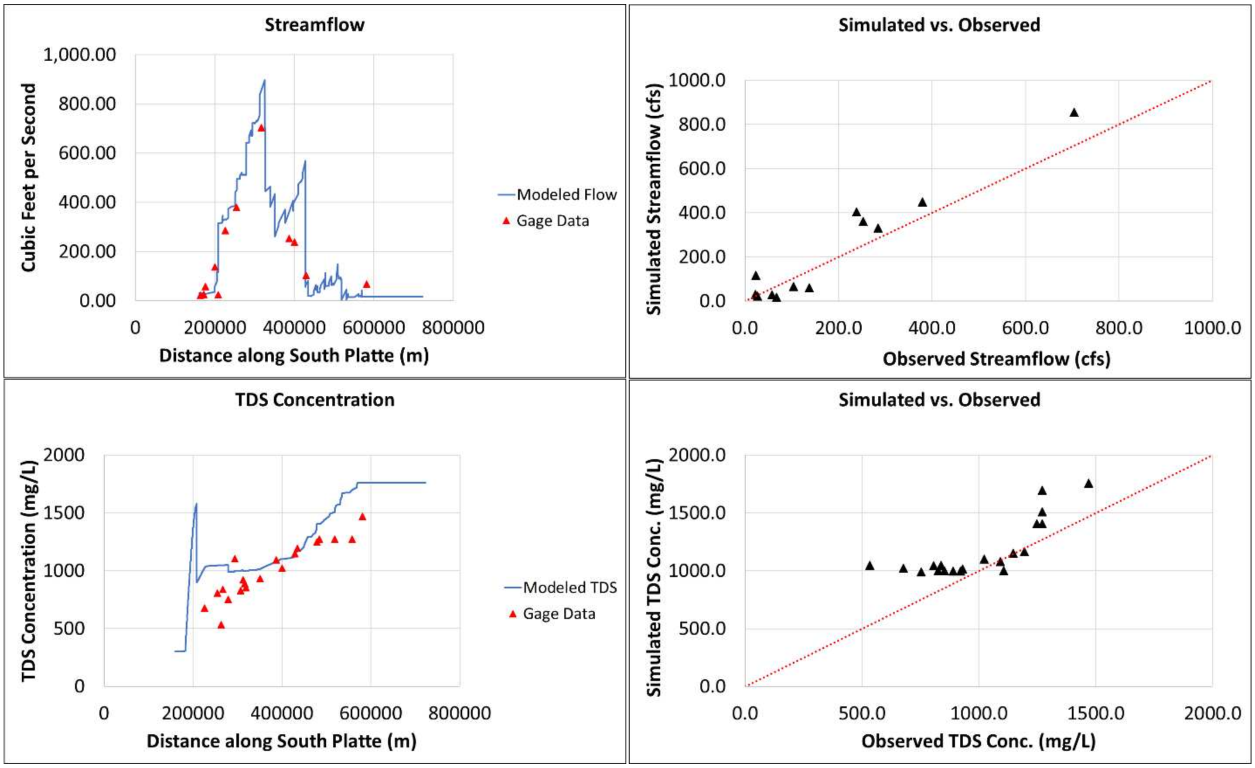

Figure A60. Flow and Salt Model Results for December 2006

Appendix B

This appendix contains a complete list of MAE, RMSE, and NSCE statistics for the flow and salt model over the

Table B1. Flow and Salt Model Statistics

		Flow Model			Salt Model		
Month	**Year**	**MAE (cfs)**	**RMSE (cfs)**	**NSCE**	**MAE (mg/L)**	**RMSE (mg/L)**	**NSCE**
January	2002	29.98	40.20	0.95	#N/A	#N/A	#N/A
February	2002	28.23	35.80	0.95	#N/A	#N/A	#N/A
March	2002	43.26	64.43	0.90	260.78	260.78	#N/A
April	2002	39.01	66.82	0.50	253.19	282.88	-5.15
May	2002	71.01	84.32	0.28	207.82	259.90	-2.21
June	2002	66.38	90.77	-0.38	113.91	127.37	0.33
July	2002	76.95	96.53	-1.61	84.75	93.37	0.61
August	2002	52.40	66.15	-0.87	283.53	417.34	-4.43
September	2002	62.94	87.95	-0.50	241.88	281.39	-1.82
October	2002	75.00	89.83	0.51	186.13	206.67	0.30
November	2002	212.18	232.52	-1.37	148.03	172.33	0.45
December	2002	83.33	89.84	0.47	172.85	216.48	0.08
January	2003	25.22	37.60	0.93	146.44	201.83	0.33
February	2003	27.15	36.10	0.95	277.28	314.50	-0.70
March	2003	54.28	63.25	0.91	243.33	268.22	-1.02
April	2003	109.15	164.28	0.20	109.50	143.99	0.76
May	2003	86.12	109.05	0.79	208.68	264.91	0.21
June	2003	78.23	103.04	0.96	177.65	224.21	0.50
July	2003	60.39	74.99	0.61	208.84	253.88	0.16
August	2003	68.72	84.67	0.13	179.65	222.34	0.47
September	2003	74.07	84.51	0.65	124.42	149.56	0.65
October	2003	47.51	54.41	0.70	112.30	135.00	0.48
November	2003	102.74	164.55	0.16	82.60	101.50	0.76
December	2003	45.23	61.63	0.84	750.89	774.45	-11.38
January	2004	92.83	115.67	0.27	615.77	652.65	-6.21
February	2004	49.31	60.46	0.87	154.40	263.20	-0.21
March	2004	61.11	71.81	0.78	224.13	277.10	-1.19
April	2004	98.85	123.98	0.17	331.19	372.56	-0.67
May	2004	82.61	107.55	0.21	273.64	314.31	-0.47
June	2004	77.73	99.73	0.54	174.54	231.69	0.40
July	2004	106.23	137.93	0.31	168.58	219.95	0.50
August	2004	115.99	133.53	0.40	171.98	223.97	0.47
September	2004	57.95	65.00	0.88	117.88	169.84	0.63
October	2004	130.90	159.96	0.78	185.53	237.86	0.27
November	2004	211.33	289.62	-0.72	184.70	226.70	0.39

December	2004	87.74	106.02	0.75	140.80	186.68	0.41
January	2005	80.12	97.59	0.68	81.04	106.06	0.82
February	2005	47.02	71.03	0.86	82.25	111.32	0.83
March	2005	76.60	101.21	0.60	135.78	169.27	0.57
April	2005	114.76	143.19	0.69	294.45	334.17	-0.30
May	2005	95.15	121.85	0.83	155.71	225.56	0.55
June	2005	280.12	336.09	0.79	208.17	309.09	-0.10
July	2005	75.48	84.56	0.15	179.97	237.87	0.34
August	2005	101.22	114.61	0.25	148.92	167.93	0.68
September	2005	56.53	70.64	0.40	104.25	125.67	0.79
October	2005	93.72	108.50	0.84	214.71	262.56	0.22
November	2005	98.72	150.24	0.31	364.94	396.59	-1.23
December	2005	112.15	151.03	-0.03	852.89	892.42	-9.70
January	2006	50.42	60.67	0.86	74.45	96.13	0.85
February	2006	44.44	54.93	0.88	86.27	111.28	0.76
March	2006	38.03	52.89	0.90	252.85	287.55	-0.33
April	2006	43.34	53.59	0.26	220.58	289.96	-1.05
May	2006	109.22	141.15	-2.48	246.81	266.84	0.08
June	2006	117.19	145.92	-0.40	205.29	240.45	0.41
July	2006	102.40	110.94	0.51	244.46	274.45	0.27
August	2006	57.59	65.50	0.73	151.54	180.31	0.61
September	2006	90.63	96.95	0.08	149.39	171.81	0.61
October	2006	48.90	59.10	0.89	194.99	209.54	0.43
November	2006	116.72	161.32	0.32	93.47	128.14	0.77
December	2006	70.16	85.94	0.80	180.22	223.51	0.09

Appendix C

This appendix contains a complete list of reach-to-reach and seasonal sensitivity study results.

Table C1. Reach One Sensitivity Results

Model Factors	**Units**	**μ* Morris**	**μ* Stnd. Morris**	**σ^{*} stnd. Morris**
St. Vrain Concentration	mg/L	#N/A	#N/A	#N/A
Big Thompson Concentration	mg/L	#N/A	#N/A	#N/A
Cache La Poudre Concentration	mg/L	#N/A	#N/A	#N/A
St. Vrain Flow	cfs	#N/A	#N/A	#N/A
Big Thompson Flow	cfs	#N/A	#N/A	#N/A
Cache La Poudre Flow	cfs	#N/A	#N/A	#N/A
W. Hite Concentration	mg/L	#N/A	#N/A	#N/A
W. Hite Flow	cfs	#N/A	#N/A	#N/A
Initial Concentration	mg/L	0.998880	0.700959	0.008939
Return Flow % before Union Ditch	%	177.329964	0.106475	0.005466
Return Flow % after Union Ditch	%	#N/A	#N/A	#N/A
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	0.001033	0.002479	0.000139
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	0.000087	0.000222	0.000014
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jay Thomas GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Lower Latham Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Patterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Riverside System GW conc.	mg/L	#N/A	#N/A	#N/A
Bijou System GW conc.	mg/L	#N/A	#N/A	#N/A
Jackson Lake Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
Weldon Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ft Morgan Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Deuel Synder Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	#N/A	#N/A	#N/A
Henderson Smith Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lowline Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Bravo Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lone Tree Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Settlers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Long Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
South Reservation Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Liddle Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Carlson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Road Salt	mg/s	0.000149	0.189327	0.004562

Table C2. Reach Two Sensitivity Results

Model Factors	**Units**	**μ* Morris**	**μ* Stnd. Morris**	**σ^* stnd. Morris**
St. Vrain Concentration	mg/L	#N/A	#N/A	#N/A
Big Thompson Concentration	mg/L	#N/A	#N/A	#N/A
Cache La Poudre Concentration	mg/L	#N/A	#N/A	#N/A
St. Vrain Flow	cfs	#N/A	#N/A	#N/A
Big Thompson Flow	cfs	#N/A	#N/A	#N/A
Cache La Poudre Flow	cfs	#N/A	#N/A	#N/A
W. Hite Concentration	mg/L	0.724963	0.554609	0.013575
W. Hite Flow	cfs	0.580966	0.109582	0.001972
Initial Concentration	mg/L	0.273857	0.141394	0.006522
Return Flow % before Union Ditch	%	328.998115	0.155495	0.007979
Return Flow % after Union Ditch	%	#N/A	#N/A	#N/A
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	0.000033	0.000067	0.000004
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	0.000110	0.000217	0.000014
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	0.000265	0.000464	0.000029
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	0.000009	0.000017	0.000001
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	0.000070	0.000120	0.000008
Jay Thomas GW conc.	mg/L	0.000693	0.001268	0.000078
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Latham Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Patterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Riverside System GW conc.	mg/L	#N/A	#N/A	#N/A
Bijou System GW conc.	mg/L	#N/A	#N/A	#N/A
Jackson Lake Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
Weldon Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ft Morgan Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Deuel Synder Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	#N/A	#N/A	#N/A
Henderson Smith Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lowline Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Bravo Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lone Tree Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Settlers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Long Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
South Reservation Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Liddle Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Carlson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Road Salt	mg/s	0.000116	0.145593	0.004892

Table C3. Reach Three Sensitivity Results

Model Factors	**Units**	**μ* Morris**	**μ* Stnd. Morris**	**σ^* stnd. Morris**
St. Vrain Concentration	mg/L	0.346145	0.335913	0.012386
Big Thompson Concentration	mg/L	#N/A	#N/A	#N/A
Cache La Poudre Concentration	mg/L	#N/A	#N/A	#N/A
St. Vrain Flow	cfs	0.337636	0.045064	0.001249
Big Thompson Flow	cfs	#N/A	#N/A	#N/A
Cache La Poudre Flow	cfs	#N/A	#N/A	#N/A
W. Hite Concentration	mg/L	0.472857	0.313564	0.012656
W. Hite Flow	cfs	0.432759	0.078811	0.001407
Initial Concentration	mg/L	0.176848	0.077885	0.004203
Return Flow % before Union Ditch	%	360.216656	0.146586	0.007585
Return Flow % after Union Ditch	%	33.703691	0.004148	0.000262
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	0.000024	0.000041	0.000003
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	0.000075	0.000127	0.000008
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	0.000427	0.000573	0.000036
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	0.000009	0.000013	0.000001
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	0.000391	0.000516	0.000032
Jay Thomas GW conc.	mg/L	0.003208	0.004369	0.000263
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Latham Ditch GW conc.	mg/L	0.000017	0.000021	0.000001
Patterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Riverside System GW conc.	mg/L	#N/A	#N/A	#N/A
Bijou System GW conc.	mg/L	#N/A	#N/A	#N/A
Jackson Lake Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
Weldon Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ft Morgan Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Deuel Synder Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	#N/A	#N/A	#N/A
Henderson Smith Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lowline Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Bravo Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lone Tree Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Settlers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Long Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
South Reservation Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Liddle Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Carlson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Road Salt	mg/s	0.000082	0.115495	0.004398

Table C4. Reach Four Sensitivity Results

Model Factors	**Units**	**μ* Morris**	**μ* Stnd. Morris**	**σ^{*} stnd. Morris**
St. Vrain Concentration	mg/L	0.295266	0.273971	0.011811
Big Thompson Concentration	mg/L	0.114308	0.126082	0.006736
Cache La Poudre Concentration	mg/L	#N/A	#N/A	#N/A
St. Vrain Flow	cfs	0.298332	0.037776	0.001081
Big Thompson Flow	cfs	0.421444	0.020412	0.000969
Cache La Poudre Flow	cfs	#N/A	#N/A	#N/A
W. Hite Concentration	mg/L	0.419562	0.268622	0.011648
W. Hite Flow	cfs	0.391913	0.071204	0.001265
Initial Concentration	mg/L	0.160478	0.067990	0.003742

Return Flow % before Union Ditch	%	316.386631	0.122995	0.006606
Return Flow % after Union Ditch	%	177.156541	0.020718	0.001270
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	0.000021	0.000035	0.000002
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	0.000064	0.000106	0.000007
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	0.000346	0.000435	0.000027
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	0.000006	0.000009	0.000001
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	0.000319	0.000397	0.000025
Jay Thomas GW conc.	mg/L	0.002731	0.003501	0.000213
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Latham Ditch GW conc.	mg/L	0.000359	0.000423	0.000026
Patterson Ditch GW conc.	mg/L	0.006523	0.009143	0.000500
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	0.000016	0.000031	0.000002
Riverside System GW conc.	mg/L	#N/A	#N/A	#N/A
Bijou System GW conc.	mg/L	#N/A	#N/A	#N/A
Jackson Lake Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
Weldon Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ft Morgan Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Deuel Synder Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	#N/A	#N/A	#N/A
Henderson Smith Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lowline Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Bravo Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lone Tree Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Settlers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Long Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
South Reservation Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Liddle Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Carlson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Road Salt	mg/s	0.000073	0.104868	0.004179

Table C5. Reach Five Sensitivity Results

Model Factors	**Units**	**μ* Morris**	**μ* Stnd. Morris**	**σ^{*} stnd. Morris**
St. Vrain Concentration	mg/L	0.227483	0.136050	0.007242

Big Thompson Concentration	mg/L	0.088611	0.063160	0.003702
Cache La Poudre Concentration	mg/L	0.099349	0.067429	0.003907
St. Vrain Flow	cfs	0.246770	0.019745	0.000599
Big Thompson Flow	cfs	0.326196	0.010090	0.000495
Cache La Poudre Flow	cfs	0.198523	0.010042	0.000492
W. Hite Concentration	mg/L	0.344134	0.141339	0.007402
W. Hite Flow	cfs	0.347857	0.045532	0.000843
Initial Concentration	mg/L	0.128953	0.034638	0.002039
Return Flow % before Union Ditch	%	245.992126	0.060173	0.003541
Return Flow % after Union Ditch	%	4127.978141	0.293394	0.012828
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	0.000017	0.000017	0.000001
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	0.000052	0.000064	0.000004
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	0.000247	0.000201	0.000013
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	0.000005	0.000004	0.000000
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	0.000227	0.000179	0.000011
Jay Thomas GW conc.	mg/L	0.002005	0.001588	0.000099
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Latham Ditch GW conc.	mg/L	0.000260	0.000188	0.000012
Patterson Ditch GW conc.	mg/L	0.006075	0.004700	0.000283
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	0.000440	0.000509	0.000031
Riverside System GW conc.	mg/L	0.000122	0.000151	0.000010
Bijou System GW conc.	mg/L	0.000270	0.000334	0.000021
Jackson Lake Inlet GW conc.	mg/L	0.003613	0.003566	0.000192

Weldon Valley Ditch GW conc.	mg/L	0.000020	0.000021	0.000001
Ft Morgan Canal GW conc.	mg/L	0.001284	0.001383	0.000085
Deuel Synder Canal GW conc.	mg/L	0.000082	0.000093	0.000006
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	0.000023	0.000026	0.000002
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	0.000104	0.000175	0.000011
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	0.000126	0.000203	0.000013
Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	0.001440	0.001845	0.000106
Henderson Smith Ditch GW conc.	mg/L	0.004524	0.005036	0.000291
Lowline Ditch GW conc.	mg/L	0.001811	0.002231	0.000136
Bravo Div System GW conc.	mg/L	0.013266	0.015448	0.000888
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	0.076607	0.091154	0.004069
Lone Tree Ditch GW conc.	mg/L	0.001583	0.001777	0.000112
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	0.000748	0.000881	0.000053
Settlers Ditch GW conc.	mg/L	0.000402	0.000424	0.000027
Long Island Ditch GW conc.	mg/L	0.000063	0.000062	0.000004
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	0.000160	0.000179	0.000011
South Reservation Ditch GW conc.	mg/L	0.000380	0.000482	0.000030

Liddle Ditch GW conc.	mg/L	0.000323	0.000282	0.000018
Carlson Ditch GW conc.	mg/L	0.000097	0.000072	0.000005
Road Salt	mg/s	0.000061	0.069961	0.003268

Table C6. Spring Sensitivity Results

Model Factors	Units	μ* Morris	μ* Stnd. Morris	σ^* stnd. Morris
St. Vrain Concentration	mg/L	0.200316	0.144347	0.007699
Big Thompson Concentration	mg/L	0.069048	0.060664	0.003527
Cache La Poudre Concentration	mg/L	0.077751	0.066949	0.003877
St. Vrain Flow	cfs	0.147863	0.018778	0.000550
Big Thompson Flow	cfs	0.404940	0.013600	0.000649
Cache La Poudre Flow	cfs	0.182981	0.011885	0.000558
W. Hite Concentration	mg/L	0.324373	0.164984	0.008286
W. Hite Flow	cfs	0.052091	0.011642	0.000205
Initial Concentration	mg/L	0.249530	0.083047	0.004596
Return Flow % before Union Ditch	%	196.179146	0.058960	0.003488
Return Flow % after Union Ditch	%	3359.308397	0.297701	0.013029
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	0.000005	0.000006	0.000000
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	0.000021	0.000020	0.000001
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	0.000053	0.000045	0.000003
Jay Thomas GW conc.	mg/L	0.001932	0.001829	0.000115
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Lower Latham Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Patterson Ditch GW conc.	mg/L	0.002366	0.002085	0.000131
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Riverside System GW conc.	mg/L	#N/A	#N/A	#N/A
Bijou System GW conc.	mg/L	#N/A	#N/A	#N/A
Jackson Lake Inlet GW conc.	mg/L	0.000115	0.000124	0.000008
Weldon Valley Ditch GW conc.	mg/L	0.000058	0.000073	0.000005
Ft Morgan Canal GW conc.	mg/L	0.000393	0.000586	0.000037
Deuel Synder Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	0.000065	0.000090	0.000006
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	0.000360	0.000681	0.000043
Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	0.004123	0.006442	0.000377
Henderson Smith Ditch GW conc.	mg/L	0.001334	0.002145	0.000132
Lowline Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Bravo Div System GW conc.	mg/L	0.001462	0.002351	0.000144
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	0.072437	0.105038	0.005048
Lone Tree Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Settlers Ditch GW conc.	mg/L	0.000166	0.000200	0.000013
Long Island Ditch GW conc.	mg/L	0.000182	0.000216	0.000014
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
South Reservation Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Liddle Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Carlson Ditch GW conc.	mg/L	0.000029	0.000025	0.000002
Road Salt	mg/s	0.000049	0.000811	0.000052

Table C7. Summer Sensitivity Results

Model Factors	**Units**	**μ* Morris**	**μ* Stnd. Morris**	**σ^* stnd. Morris**
St. Vrain Concentration	mg/L	0.197801	0.125463	0.006808
Big Thompson Concentration	mg/L	0.056770	0.045217	0.002722
Cache La Poudre Concentration	mg/L	0.044721	0.032483	0.001970
St. Vrain Flow	cfs	0.167186	0.019286	0.000334
Big Thompson Flow	cfs	0.185736	0.006862	0.000332
Cache La Poudre Flow	cfs	0.116155	0.004509	0.000235
W. Hite Concentration	mg/L	0.253365	0.127607	0.006952
W. Hite Flow	cfs	0.033459	0.007644	0.000123
Initial Concentration	mg/L	0.247689	0.081811	0.004617
Return Flow % before Union Ditch	%	323.646963	0.094648	0.005371
Return Flow % after Union Ditch	%	2591.529949	0.221083	0.010737
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	0.000355	0.000330	0.000021
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	0.000576	0.000504	0.000032
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	0.000433	0.000363	0.000023
Jay Thomas GW conc.	mg/L	0.002601	0.002214	0.000138
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Latham Ditch GW conc.	mg/L	0.000794	0.000684	0.000043
Patterson Ditch GW conc.	mg/L	0.013816	0.012681	0.000760
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	0.001261	0.001726	0.000107
Riverside System GW conc.	mg/L	0.000350	0.000512	0.000032
Bijou System GW conc.	mg/L	0.000774	0.001132	0.000071
Jackson Lake Inlet GW conc.	mg/L	0.010227	0.012214	0.000672
Weldon Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ft Morgan Canal GW conc.	mg/L	0.003283	0.004139	0.000255
Deuel Synder Canal GW conc.	mg/L	0.000235	0.000323	0.000020
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	#N/A	#N/A	#N/A
Henderson Smith Ditch GW conc.	mg/L	0.011262	0.014747	0.000853
Lowline Ditch GW conc.	mg/L	0.003690	0.005486	0.000335

Bravo Div System GW conc.	mg/L	0.033965	0.047093	0.002735
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	0.112142	0.158449	0.007354
Lone Tree Ditch GW conc.	mg/L	0.002554	0.003261	0.000206
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Settlers Ditch GW conc.	mg/L	0.000985	0.001264	0.000080
Long Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	0.000459	0.000603	0.000038
South Reservation Ditch GW conc.	mg/L	0.001088	0.001625	0.000101
Liddle Ditch GW conc.	mg/L	0.000925	0.000966	0.000061
Carlson Ditch GW conc.	mg/L	0.000078	0.000068	0.000004
Road Salt	mg/s	0.000050	0.000807	0.000051

Table C8. Fall Sensitivity Results

Model Factors	**Units**	**μ* Morris**	**μ* Stnd. Morris**	**σ^* stnd. Morris**
St. Vrain Concentration	mg/L	0.162862	0.121393	0.006672
Big Thompson Concentration	mg/L	0.077971	0.064837	0.003828
Cache La Poudre Concentration	mg/L	0.080635	0.063308	0.003722
St. Vrain Flow	cfs	0.099342	0.010883	0.000330
Big Thompson Flow	cfs	0.159758	0.007378	0.000358
Cache La Poudre Flow	cfs	0.083631	0.007107	0.000329
W. Hite Concentration	mg/L	0.415188	0.208477	0.010348
W. Hite Flow	cfs	0.230363	0.038681	0.000726
Initial Concentration	mg/L	0.218850	0.066579	0.003875
Return Flow % before Union Ditch	%	310.469817	0.092866	0.005322
Return Flow % after Union Ditch	%	2704.649612	0.236371	0.011207
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	0.000087	0.000110	0.000007
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	0.000238	0.000335	0.000021
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	0.000367	0.000403	0.000026
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	0.000290	0.000316	0.000020
Jay Thomas GW conc.	mg/L	0.002314	0.002420	0.000150
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Latham Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Patterson Ditch GW conc.	mg/L	0.002097	0.002250	0.000138
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Riverside System GW conc.	mg/L	#N/A	#N/A	#N/A
Bijou System GW conc.	mg/L	#N/A	#N/A	#N/A
Jackson Lake Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
Weldon Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ft Morgan Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Deuel Synder Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	0.000298	0.000590	0.000037
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	#N/A	#N/A	#N/A
Henderson Smith Ditch GW conc.	mg/L	0.000352	0.000520	0.000033
Lowline Ditch GW conc.	mg/L	0.001492	0.002205	0.000136
Bravo Div System GW conc.	mg/L	0.002543	0.003757	0.000226
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	0.034690	0.049471	0.002402
Lone Tree Ditch GW conc.	mg/L	0.001978	0.002784	0.000176
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Settlers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Long Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
South Reservation Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Liddle Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Carlson Ditch GW conc.	mg/L	0.000138	0.000135	0.000009
Road Salt	mg/s	0.000078	0.080334	0.003819

Table C9. Winter Sensitivity Results

Model Factors	**Units**	**μ* Morris**	**μ* Stnd. Morris**	**σ^* stnd. Morris**
St. Vrain Concentration	mg/L	0.170493	0.111545	0.006003
Big Thompson Concentration	mg/L	0.065417	0.049446	0.002966
Cache La Poudre Concentration	mg/L	0.081253	0.057837	0.003441
St. Vrain Flow	cfs	0.371716	0.022055	0.000887
Big Thompson Flow	cfs	0.240662	0.007264	0.000380
Cache La Poudre Flow	cfs	0.185453	0.008936	0.000462
W. Hite Concentration	mg/L	0.485030	0.189573	0.009490
W. Hite Flow	cfs	1.088610	0.140422	0.002611
Initial Concentration	mg/L	0.198962	0.044818	0.002694

Return Flow % before Union Ditch	%	195.402667	0.042598	0.002589
Return Flow % after Union Ditch	%	3187.848282	0.218161	0.010708
Nevada Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Last Chance Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Gardeners Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Burlington Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Gardeners Ditch GW conc.	mg/L	0.000012	0.000013	0.000001
Fulton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Little Burlington GW conc.	mg/L	#N/A	#N/A	#N/A
Brantner Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Denver Hudson Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Brighton Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lupton Bottom Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Platteville Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island 1 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Evans No 2 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Meadow Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Farmers Indep Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Hewes Cook Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jay Thomas GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Section No 3 Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Latham Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Patterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Highland Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Empire Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Riverside System GW conc.	mg/L	#N/A	#N/A	#N/A
Bijou System GW conc.	mg/L	#N/A	#N/A	#N/A
Jackson Lake Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
Weldon Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ft Morgan Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Deuel Synder Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Upper Platte Beaver Canal GW conc.	mg/L	#N/A	#N/A	#N/A
Lower Platte Beaver Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Tremont System GW conc.	mg/L	#N/A	#N/A	#N/A
Gill Stevens Ditch GW conc.	mg/L	#N/A	#N/A	#N/A

Trowell Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
N Sterling System GW conc.	mg/L	#N/A	#N/A	#N/A
Union Ditch 2 GW conc.	mg/L	#N/A	#N/A	#N/A
Tetsel Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Johnson Edwards Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Prewitt Res Inlet GW conc.	mg/L	#N/A	#N/A	#N/A
South Platte Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Pawnee Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Davis Bros Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Schneider Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Springdale Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 1 GW conc.	mg/L	#N/A	#N/A	#N/A
Sterling Irr Co Ditch 2 GW GW conc.	mg/L	#N/A	#N/A	#N/A
Henderson Smith Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lowline Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Bravo Div System GW conc.	mg/L	#N/A	#N/A	#N/A
Iliff Platte Valley Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Jud Brush Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Lone Tree Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Powell Blair Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Rice Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Ramsey Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Chambers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Harmony Div System GW conc.	mg/L	0.002140	0.002839	0.000173
Settlers Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Long Island Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Red Lion Supply Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Peterson Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
South Reservation Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Liddle Ditch GW conc.	mg/L	#N/A	#N/A	#N/A
Carlson Ditch GW conc.	mg/L	0.000033	0.000016	0.000001
Road Salt	mg/s	0.000130	0.282567	0.011793

Appendix D

This appendix contains a complete list of Urban and Agricultural MP analysis.

	Baseline	Low	Med	High
Parameter Reduction	0%	5%	20%	35%

Table D1. Urban MP Trial Results between April and October

Trial	W. Hite Conc.	Return % Before Union	Initial Conc.	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction per Point
1	Base	Base	Base	Base	0	411.55	NA
193	High	Base	Base	Base	7	342.18	2.41
129	Med	Base	Base	Base	4	371.91	2.41
65	Low	Base	Base	Base	1	401.64	2.41
197	High	Base	Low	Base	8	333.16	2.38
133	Med	Base	Low	Base	5	362.89	2.36
201	High	Base	Med	Base	11	306.10	2.33
69	Low	Base	Low	Base	2	392.62	2.30
137	Med	Base	Med	Base	8	335.83	2.30
205	High	Base	High	Base	14	279.04	2.30
141	Med	Base	High	Base	11	308.77	2.27
73	Low	Base	Med	Base	5	365.55	2.24
77	Low	Base	High	Base	8	338.49	2.22
13	Base	Base	High	Base	7	348.40	2.19
9	Base	Base	Med	Base	4	375.46	2.19
5	Base	Base	Low	Base	1	402.53	2.19
221	High	Low	High	Base	15	277.60	2.17
217	High	Low	Med	Base	12	304.66	2.16
213	High	Low	Low	Base	9	331.72	2.16
209	High	Low	Base	Base	8	340.74	2.15
206	High	Base	High	Low	15	278.95	2.15
202	High	Base	Med	Low	12	306.02	2.14
198	High	Base	Low	Low	9	333.08	2.12
157	Med	Low	High	Base	12	307.32	2.11
194	High	Base	Base	Low	8	342.10	2.11
153	Med	Low	Med	Base	9	334.39	2.08
142	Med	Base	High	Low	12	308.68	2.08
138	Med	Base	Med	Low	9	335.74	2.05
222	High	Low	High	Low	16	277.51	2.04
149	Med	Low	Low	Base	6	361.45	2.03
93	Low	Low	High	Base	9	337.05	2.01
218	High	Low	Med	Low	13	304.66	2.00

145	Med	Low	Base	Base	5	370.47	2.00
78	Low	Base	High	Low	9	338.41	1.97
134	Med	Base	Low	Low	6	362.80	1.97
29	Base	Low	High	Base	8	346.96	1.96
158	Med	Low	High	Low	13	307.24	1.95
214	High	Low	Low	Low	10	331.64	1.94
130	Med	Base	Base	Low	5	371.82	1.93
89	Low	Low	Med	Base	6	364.11	1.92
14	Base	Base	High	Low	8	348.32	1.92
210	High	Low	Base	Low	9	340.66	1.91
154	Med	Low	Med	Low	10	334.30	1.88
237	High	Med	High	Base	18	273.27	1.87
74	Low	Base	Med	Low	6	365.47	1.87
25	Base	Low	Med	Base	5	374.02	1.82
94	Low	Low	High	Low	10	336.97	1.81
233	High	Med	Med	Base	15	300.33	1.80
207	High	Base	High	Med	18	278.70	1.79
238	High	Med	High	Low	19	273.19	1.77
173	Med	Med	High	Base	15	303.00	1.76
10	Base	Base	Med	Low	5	375.38	1.76
30	Base	Low	High	Low	9	346.88	1.75
150	Med	Low	Low	Low	7	361.36	1.74
223	High	Low	High	Med	19	277.26	1.72
203	High	Base	Med	Med	15	305.76	1.71
229	High	Med	Low	Base	12	327.40	1.70
234	High	Med	Med	Low	16	300.25	1.69
143	Med	Base	High	Med	15	308.43	1.67
146	Med	Low	Base	Low	6	370.38	1.67
225	High	Med	Base	Base	11	336.42	1.66
85	Low	Low	Low	Base	3	391.17	1.65
169	Med	Med	Med	Base	12	330.06	1.65
253	High	High	High	Base	21	268.95	1.65
174	Med	Med	High	Low	16	302.92	1.65
90	Low	Low	Med	Low	7	364.11	1.65
219	High	Low	Med	Med	16	304.57	1.62
109	Low	Med	High	Base	12	332.73	1.60
199	High	Base	Low	Med	12	332.82	1.59
159	Med	Low	High	Med	16	306.99	1.59
254	High	High	High	Low	22	268.86	1.58
230	High	Med	Low	Low	13	327.31	1.57
249	High	High	Med	Base	18	296.01	1.56
139	Med	Base	Med	Med	12	335.49	1.54
208	High	Base	High	High	21	278.45	1.54

70	Low	Base	Low	Low	3	392.53	1.54
195	High	Base	Base	Med	11	341.84	1.54
239	High	Med	High	Med	22	272.94	1.53
170	Med	Med	Med	Low	13	329.98	1.52
189	Med	High	High	Base	18	298.68	1.52
26	Base	Low	Med	Low	6	373.94	1.52
226	High	Med	Base	Low	12	336.33	1.52
45	Base	Med	High	Base	11	342.64	1.52
215	High	Low	Low	Med	13	331.38	1.50
79	Low	Base	High	Med	12	338.16	1.49
224	High	Low	High	High	22	277.01	1.49
250	High	High	Med	Low	19	295.93	1.48
110	Low	Med	High	Low	13	332.64	1.47
165	Med	Med	Low	Base	9	357.12	1.47
155	Med	Low	Med	Med	13	334.05	1.45
190	Med	High	High	Low	19	298.59	1.44
211	High	Low	Base	Med	12	340.40	1.44
245	High	High	Low	Base	15	323.07	1.43
204	High	Base	Med	High	18	305.51	1.43
235	High	Med	Med	Med	19	300.00	1.43
15	Base	Base	High	Med	11	348.07	1.40
95	Low	Low	High	Med	13	336.72	1.40
105	Low	Med	Med	Base	9	359.79	1.40
46	Base	Med	High	Low	12	342.55	1.40
144	Med	Base	High	High	18	308.18	1.40
175	Med	Med	High	Med	19	302.66	1.39
185	Med	High	Med	Base	15	325.74	1.39
255	High	High	High	Med	25	268.61	1.39
81	Low	Low	Base	Base	2	400.19	1.38
161	Med	Med	Base	Base	8	366.14	1.38
241	High	High	Base	Base	14	332.09	1.38
220	High	Low	Med	High	19	304.07	1.37
240	High	Med	High	High	25	272.68	1.35
125	Low	High	High	Base	15	328.40	1.35
246	High	High	Low	Low	16	322.99	1.34
160	Med	Low	High	High	19	306.74	1.34
166	Med	Med	Low	Low	10	357.04	1.32
135	Med	Base	Low	Med	9	362.55	1.32
31	Base	Low	High	Med	12	346.62	1.31
186	Med	High	Med	Low	16	325.65	1.30
242	High	High	Base	Low	15	332.01	1.29
231	High	Med	Low	Med	16	327.06	1.28
251	High	High	Med	Med	22	295.67	1.28

200	High	Base	Low	High	15	332.57	1.28
21	Base	Low	Low	Base	2	401.08	1.27
41	Base	Med	Med	Base	8	369.70	1.27
61	Base	High	High	Base	14	338.31	1.27
126	Low	High	High	Low	16	328.32	1.26
106	Low	Med	Med	Low	10	359.70	1.26
75	Low	Base	Med	Med	9	365.22	1.25
191	Med	High	High	Med	22	298.34	1.25
86	Low	Low	Low	Low	4	391.09	1.24
171	Med	Med	Med	Med	16	329.72	1.24
256	High	High	High	High	28	268.36	1.24
140	Med	Base	Med	High	15	335.24	1.24
236	High	Med	Med	High	22	299.74	1.23
162	Med	Med	Base	Low	9	366.06	1.23
151	Med	Low	Low	Med	10	361.11	1.23
227	High	Med	Base	Med	15	336.08	1.22
216	High	Low	Low	High	16	331.13	1.22
66	Low	Base	Base	Low	2	401.55	1.21
131	Med	Base	Base	Med	8	371.57	1.21
196	High	Base	Base	High	14	341.59	1.21
111	Low	Med	High	Med	16	332.39	1.20
176	Med	Med	High	High	22	302.92	1.20
80	Low	Base	High	High	15	337.90	1.19
181	Med	High	Low	Base	12	352.80	1.19
62	Base	High	High	Low	15	338.23	1.19
156	Med	Low	Med	High	16	333.80	1.18
212	High	Low	Base	High	15	340.15	1.16
91	Low	Low	Med	Med	10	364.03	1.15
96	Low	Low	High	High	16	336.46	1.14
247	High	High	Low	Med	19	322.73	1.14
121	Low	High	Med	Base	12	355.46	1.14
42	Base	Med	Med	Low	9	369.61	1.13
252	High	High	Med	High	25	295.42	1.13
47	Base	Med	High	Med	15	342.30	1.12
147	Med	Low	Base	Med	9	370.13	1.12
6	Base	Base	Low	Low	2	402.44	1.11
11	Base	Base	Med	Med	8	375.13	1.11
16	Base	Base	High	High	14	347.81	1.11
192	Med	High	High	High	25	298.09	1.10
187	Med	High	Med	Med	19	325.40	1.10
182	Med	High	Low	Low	13	352.71	1.10
177	Med	High	Base	Base	11	361.82	1.10
232	High	Med	Low	High	19	326.81	1.08

243	High	High	Base	Med	18	331.75	1.08
127	Low	High	High	Med	19	328.07	1.07
32	Base	Low	High	High	15	346.37	1.06
122	Low	High	Med	Low	13	355.38	1.05
172	Med	Med	Med	High	19	329.47	1.05
167	Med	Med	Low	Med	13	356.79	1.02
27	Base	Low	Med	Med	9	373.69	1.02
228	High	Med	Base	High	18	335.83	1.02
57	Base	High	Med	Base	11	365.37	1.02
112	Low	Med	High	High	19	332.14	1.02
178	Med	High	Base	Low	12	361.73	1.01
101	Low	Med	Low	Base	6	386.85	1.00
136	Med	Base	Low	High	12	362.30	1.00
63	Base	High	High	Med	18	337.98	0.99
248	High	High	Low	High	22	322.48	0.98
107	Low	Med	Med	Med	13	359.45	0.97
188	Med	High	Med	High	22	325.15	0.95
152	Med	Low	Low	High	13	360.86	0.95
76	Low	Base	Med	High	12	364.97	0.94
58	Base	High	Med	Low	12	365.29	0.94
48	Base	Med	High	High	18	342.55	0.93
163	Med	Med	Base	Med	12	365.81	0.93
82	Low	Low	Base	Low	3	400.11	0.93
244	High	High	Base	High	21	331.50	0.93
128	Low	High	High	High	22	327.81	0.92
92	Low	Low	Med	High	13	363.52	0.90
183	Med	High	Low	Med	16	352.46	0.90
132	Med	Base	Base	High	11	371.32	0.89
102	Low	Med	Low	Low	7	386.77	0.86
123	Low	High	Med	Med	16	355.13	0.86
22	Base	Low	Low	Low	3	401.00	0.85
43	Base	Med	Med	Med	12	369.36	0.85
64	Base	High	High	High	21	337.72	0.85
148	Med	Low	Base	High	12	369.88	0.84
168	Med	Med	Low	High	16	356.53	0.84
179	Med	High	Base	Med	15	361.48	0.81
12	Base	Base	Med	High	11	374.87	0.81
108	Low	Med	Med	High	16	359.20	0.79
117	Low	High	Low	Base	9	382.53	0.78
71	Low	Base	Low	Med	6	392.28	0.78
28	Base	Low	Med	High	12	373.43	0.77
97	Low	Med	Base	Base	5	395.87	0.76
184	Med	High	Low	High	19	352.21	0.76

59	Base	High	Med	Med	15	365.04	0.75
164	Med	Med	Base	High	15	365.55	0.75
124	Low	High	Med	High	19	354.88	0.72
87	Low	Low	Low	Med	7	390.84	0.72
37	Base	Med	Low	Base	5	396.76	0.72
118	Low	High	Low	Low	10	382.44	0.71
44	Base	Med	Med	High	15	369.11	0.69
180	Med	High	Base	High	18	361.23	0.68
98	Low	Med	Base	Low	6	395.79	0.64
60	Base	High	Med	High	18	364.78	0.63
103	Low	Med	Low	Med	10	386.51	0.61
113	Low	High	Base	Base	8	391.55	0.61
38	Base	Med	Low	Low	6	396.68	0.60
53	Base	High	Low	Base	8	392.43	0.58
119	Low	High	Low	Med	13	382.19	0.55
114	Low	High	Base	Low	9	391.46	0.54
72	Low	Base	Low	High	9	392.03	0.53
54	Base	High	Low	Low	9	392.35	0.52
88	Low	Low	Low	High	10	390.59	0.51
67	Low	Base	Base	Med	5	401.30	0.50
83	Low	Low	Base	Med	6	399.86	0.47
104	Low	Med	Low	High	13	386.26	0.47
7	Base	Base	Low	Med	5	402.19	0.45
120	Low	High	Low	High	16	381.94	0.45
23	Base	Low	Low	Med	6	400.75	0.44
99	Low	Med	Base	Med	9	395.53	0.43
115	Low	High	Base	Med	12	391.21	0.41
39	Base	Med	Low	Med	9	396.42	0.41
55	Base	High	Low	Med	12	392.10	0.39
17	Base	Low	Base	Base	1	410.10	0.35
49	Base	High	Base	Base	7	401.46	0.35
33	Base	Med	Base	Base	4	405.78	0.35
116	Low	High	Base	High	15	390.96	0.33
100	Low	Med	Base	High	12	395.28	0.33
84	Low	Low	Base	High	9	399.61	0.32
56	Base	High	Low	High	15	391.85	0.32
68	Low	Base	Base	High	8	401.05	0.32
40	Base	Med	Low	High	12	396.17	0.31
50	Base	High	Base	Low	8	401.37	0.31
24	Base	Low	Low	High	9	400.49	0.30
8	Base	Base	Low	High	8	401.94	0.29
34	Base	Med	Base	Low	5	405.70	0.28
51	Base	High	Base	Med	11	401.12	0.23

18	Base	Low	Base	Low	2	410.02	0.19
52	Base	High	Base	High	14	400.87	0.19
35	Base	Med	Base	Med	8	405.44	0.19
36	Base	Med	Base	High	11	405.19	0.14
19	Base	Low	Base	Med	5	409.77	0.09
20	Base	Low	Base	High	8	409.51	0.06
2	Base	Base	Base	Low	1	411.46	0.02
3	Base	Base	Base	Med	4	411.21	0.02
4	Base	Base	Base	High	7	410.96	0.02

Table D2. Urban MP Trial Results between November and March

Trial	W. Hite Conc.	Return % Before Union	Initial Conc.	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction per Point
1	Base	Base	Base	Base	0	904.04	NA
4	Base	Base	Base	High	7	732.21	2.72
3	Base	Base	Base	Med	4	805.85	2.72
2	Base	Base	Base	Low	1	879.49	2.72
68	Low	Base	Base	High	8	720.26	2.54
8	Base	Base	Low	High	8	724.38	2.48
67	Low	Base	Base	Med	5	793.91	2.44
20	Base	Low	Base	High	8	731.34	2.39
72	Low	Base	Low	High	9	712.43	2.35
7	Base	Base	Low	Med	5	798.02	2.35
84	Low	Low	Base	High	9	719.39	2.27
24	Base	Low	Low	High	9	723.51	2.22
132	Med	Base	Base	High	11	684.44	2.21
19	Base	Low	Base	Med	5	804.98	2.19
71	Low	Base	Low	Med	6	786.08	2.17
88	Low	Low	Low	High	10	711.56	2.13
136	Med	Base	Low	High	12	676.61	2.10
83	Low	Low	Base	Med	6	793.04	2.05
12	Base	Base	Med	High	11	700.88	2.04
148	Med	Low	Base	High	12	683.57	2.03
196	High	Base	Base	High	14	648.62	2.02
131	Med	Base	Base	Med	8	758.08	2.02
66	Low	Base	Base	Low	2	867.55	2.02
76	Low	Base	Med	High	12	688.94	1.98
23	Base	Low	Low	Med	6	797.15	1.97
152	Med	Low	Low	High	13	675.74	1.94
200	High	Base	Low	High	15	640.78	1.94
135	Med	Base	Low	Med	9	750.25	1.89
212	High	Low	Base	High	15	647.75	1.89

28	Base	Low	Med	High	12	700.01	1.88
87	Low	Low	Low	Med	7	785.21	1.88
140	Med	Base	Med	High	15	653.12	1.85
92	Low	Low	Med	High	13	688.07	1.84
195	High	Base	Base	Med	11	722.26	1.83
216	High	Low	Low	High	16	639.91	1.83
147	Med	Low	Base	Med	9	757.21	1.80
11	Base	Base	Med	Med	8	774.53	1.79
16	Base	Base	High	High	14	677.39	1.79
6	Base	Base	Low	Low	2	871.66	1.79
36	Base	Med	Base	High	11	728.73	1.76
204	High	Base	Med	High	18	617.29	1.76
80	Low	Base	High	High	15	665.45	1.76
199	High	Base	Low	Med	12	714.43	1.75
156	Med	Low	Med	High	16	652.25	1.74
75	Low	Base	Med	Med	9	762.58	1.74
100	Low	Med	Base	High	12	716.78	1.73
151	Med	Low	Low	Med	10	749.38	1.71
40	Base	Med	Low	High	12	720.90	1.69
144	Med	Base	High	High	18	629.62	1.69
211	High	Low	Base	Med	12	721.39	1.68
32	Base	Low	High	High	15	676.52	1.68
220	High	Low	Med	High	19	616.42	1.67
104	Low	Med	Low	High	13	708.95	1.66
96	Low	Low	High	High	16	664.58	1.66
164	Med	Med	Base	High	15	680.96	1.65
139	Med	Base	Med	Med	12	726.76	1.63
208	High	Base	High	High	21	593.80	1.63
70	Low	Base	Low	Low	3	859.72	1.63
215	High	Low	Low	Med	13	713.56	1.62
160	Med	Low	High	High	19	628.75	1.60
27	Base	Low	Med	Med	9	773.66	1.60
130	Med	Base	Base	Low	5	831.73	1.60
168	Med	Med	Low	High	16	673.13	1.60
228	High	Med	Base	High	18	645.14	1.59
203	High	Base	Med	Med	15	690.93	1.57
224	High	Low	High	High	22	592.93	1.56
232	High	Med	Low	High	19	637.30	1.55
15	Base	Base	High	Med	11	751.03	1.54
44	Base	Med	Med	High	15	697.40	1.52
79	Low	Base	High	Med	12	739.09	1.52
155	Med	Low	Med	Med	13	725.89	1.52
108	Low	Med	Med	High	16	685.46	1.51

194	High	Base	Base	Low	8	795.90	1.50
172	Med	Med	Med	High	19	649.64	1.48
143	Med	Base	High	Med	15	703.27	1.48
134	Med	Base	Low	Low	6	823.89	1.48
236	High	Med	Med	High	22	613.81	1.46
207	High	Base	High	Med	18	667.44	1.45
198	High	Base	Low	Low	9	788.07	1.43
31	Base	Low	High	Med	12	750.16	1.42
95	Low	Low	High	Med	13	738.22	1.41
112	Low	Med	High	High	19	661.97	1.41
52	Base	High	Base	High	14	726.12	1.41
18	Base	Low	Base	Low	2	878.62	1.41
35	Base	Med	Base	Med	8	802.37	1.41
116	Low	High	Base	High	15	714.17	1.40
99	Low	Med	Base	Med	9	790.43	1.40
159	Med	Low	High	Med	16	702.40	1.39
240	High	Med	High	High	25	590.32	1.39
180	Med	High	Base	High	18	678.35	1.39
223	High	Low	High	Med	19	666.57	1.38
244	High	High	Base	High	21	642.53	1.38
163	Med	Med	Base	Med	12	754.60	1.38
82	Low	Low	Base	Low	3	866.68	1.38
56	Base	High	Low	High	15	718.29	1.37
120	Low	High	Low	High	16	706.34	1.37
227	High	Med	Base	Med	15	718.78	1.37
184	Med	High	Low	High	19	670.52	1.36
248	High	High	Low	High	22	634.69	1.35
146	Med	Low	Base	Low	6	830.86	1.35
39	Base	Med	Low	Med	9	794.54	1.35
103	Low	Med	Low	Med	10	782.60	1.34
210	High	Low	Base	Low	9	795.03	1.34
167	Med	Med	Low	Med	13	746.77	1.34
231	High	Med	Low	Med	16	710.95	1.33
65	Low	Base	Base	Base	1	892.10	1.32
129	Med	Base	Base	Base	4	856.27	1.32
193	High	Base	Base	Base	7	820.45	1.32
252	High	High	Med	High	25	611.20	1.30
214	High	Low	Low	Low	10	787.20	1.29
188	Med	High	Med	High	22	647.03	1.29
124	Low	High	Med	High	19	682.85	1.29
60	Base	High	Med	High	18	694.79	1.29
202	High	Base	Med	Low	12	764.58	1.29
150	Med	Low	Low	Low	7	823.02	1.28

138	Med	Base	Med	Low	9	800.40	1.27
197	High	Base	Low	Base	8	812.62	1.26
235	High	Med	Med	Med	19	687.45	1.26
74	Low	Base	Med	Low	6	836.23	1.25
86	Low	Low	Low	Low	4	858.85	1.25
171	Med	Med	Med	Med	16	723.28	1.25
256	High	High	High	High	28	587.71	1.25
192	Med	High	High	High	25	623.53	1.24
10	Base	Base	Med	Low	5	848.17	1.24
107	Low	Med	Med	Med	13	759.10	1.23
128	Low	High	High	High	22	659.36	1.23
133	Med	Base	Low	Base	5	848.44	1.23
43	Base	Med	Med	Med	12	771.05	1.23
64	Base	High	High	High	21	671.30	1.23
22	Base	Low	Low	Low	3	870.79	1.23
239	High	Med	High	Med	22	663.96	1.21
206	High	Base	High	Low	15	741.08	1.20
175	Med	Med	High	Med	19	699.79	1.19
142	Med	Base	High	Low	12	776.91	1.17
209	High	Low	Base	Base	8	819.58	1.17
111	Low	Med	High	Med	16	735.61	1.16
154	Med	Low	Med	Low	10	799.53	1.16
201	High	Base	Med	Base	11	789.12	1.16
243	High	High	Base	Med	18	716.17	1.15
47	Base	Med	High	Med	15	747.55	1.15
247	High	High	Low	Med	19	708.34	1.14
213	High	Low	Low	Base	9	811.75	1.13
222	High	Low	High	Low	16	740.21	1.13
78	Low	Base	High	Low	9	812.73	1.12
179	Med	High	Base	Med	15	751.99	1.12
183	Med	High	Low	Med	16	744.16	1.11
251	High	High	Med	Med	22	684.84	1.10
14	Base	Base	High	Low	8	824.68	1.10
205	High	Base	High	Base	14	765.63	1.09
137	Med	Base	Med	Base	8	824.95	1.09
69	Low	Base	Low	Base	2	884.27	1.09
158	Med	Low	High	Low	13	776.04	1.09
145	Med	Low	Base	Base	5	855.40	1.08
255	High	High	High	Med	25	661.35	1.07
115	Low	High	Base	Med	12	787.82	1.07
187	Med	High	Med	Med	19	720.67	1.07
217	High	Low	Med	Base	12	788.25	1.07
119	Low	High	Low	Med	13	779.99	1.06

51	Base	High	Base	Med	11	799.76	1.05
26	Base	Low	Med	Low	6	847.30	1.05
149	Med	Low	Low	Base	6	847.57	1.04
191	Med	High	High	Med	22	697.18	1.04
55	Base	High	Low	Med	12	791.93	1.03
141	Med	Base	High	Base	11	801.46	1.03
226	High	Med	Base	Low	12	792.42	1.03
221	High	Low	High	Base	15	764.76	1.03
123	Low	High	Med	Med	16	756.49	1.02
94	Low	Low	High	Low	10	811.86	1.02
230	High	Med	Low	Low	13	784.59	1.02
59	Base	High	Med	Med	15	768.44	1.00
127	Low	High	High	Med	19	733.00	1.00
234	High	Med	Med	Low	16	761.10	0.99
30	Base	Low	High	Low	9	823.81	0.99
218	High	Low	Med	Low	13	788.25	0.99
153	Med	Low	Med	Base	9	824.08	0.98
63	Base	High	High	Med	18	744.94	0.98
219	High	Low	Med	Med	16	763.71	0.97
238	High	Med	High	Low	19	737.60	0.97
73	Low	Base	Med	Base	5	860.77	0.96
157	Med	Low	High	Base	12	800.59	0.95
162	Med	Med	Base	Low	9	828.25	0.93
166	Med	Med	Low	Low	10	820.41	0.93
77	Low	Base	High	Base	8	837.28	0.92
170	Med	Med	Med	Low	13	796.92	0.91
174	Med	Med	High	Low	16	773.43	0.90
225	High	Med	Base	Base	11	816.97	0.88
229	High	Med	Low	Base	12	809.14	0.87
233	High	Med	Med	Base	15	785.64	0.87
237	High	Med	High	Base	18	762.15	0.87
9	Base	Base	Med	Base	4	872.72	0.87
13	Base	Base	High	Base	7	849.22	0.87
5	Base	Base	Low	Base	1	896.21	0.87
254	High	High	High	Low	22	734.99	0.85
250	High	High	Med	Low	19	758.49	0.85
246	High	High	Low	Low	16	781.98	0.84
242	High	High	Base	Low	15	789.81	0.84
93	Low	Low	High	Base	9	836.41	0.83
89	Low	Low	Med	Base	6	859.90	0.81
110	Low	Med	High	Low	13	809.25	0.81
106	Low	Med	Med	Low	10	832.75	0.79
173	Med	Med	High	Base	15	797.98	0.78

190	Med	High	High	Low	19	770.82	0.78
29	Base	Low	High	Base	8	848.35	0.77
46	Base	Med	High	Low	12	821.20	0.76
169	Med	Med	Med	Base	12	821.47	0.76
253	High	High	High	Base	21	759.54	0.76
85	Low	Low	Low	Base	3	883.40	0.76
91	Low	Low	Med	Med	10	835.36	0.76
186	Med	High	Med	Low	16	794.31	0.76
102	Low	Med	Low	Low	7	856.24	0.76
249	High	High	Med	Base	18	783.03	0.74
98	Low	Med	Base	Low	6	864.07	0.74
182	Med	High	Low	Low	13	817.80	0.73
42	Base	Med	Med	Low	9	844.69	0.73
165	Med	Med	Low	Base	9	844.96	0.73
178	Med	High	Base	Low	12	825.64	0.72
245	High	High	Low	Base	15	806.53	0.72
25	Base	Low	Med	Base	5	871.85	0.71
241	High	High	Base	Base	14	814.36	0.71
161	Med	Med	Base	Base	8	852.79	0.71
81	Low	Low	Base	Base	2	891.23	0.71
90	Low	Low	Med	Low	7	859.90	0.70
126	Low	High	High	Low	16	806.64	0.67
189	Med	High	High	Base	18	795.37	0.67
38	Base	Med	Low	Low	6	868.18	0.66
176	Med	Med	High	High	22	773.43	0.66
109	Low	Med	High	Base	12	833.80	0.65
62	Base	High	High	Low	15	818.59	0.63
122	Low	High	Med	Low	13	830.14	0.63
185	Med	High	Med	Base	15	818.86	0.63
34	Base	Med	Base	Low	5	876.01	0.62
45	Base	Med	High	Base	11	845.74	0.59
105	Low	Med	Med	Base	9	857.29	0.57
58	Base	High	Med	Low	12	842.08	0.57
181	Med	High	Low	Base	12	842.35	0.57
118	Low	High	Low	Low	10	853.63	0.56
177	Med	High	Base	Base	11	850.18	0.54
125	Low	High	High	Base	15	831.19	0.54
114	Low	High	Base	Low	9	861.46	0.52
48	Base	Med	High	High	18	821.20	0.51
61	Base	High	High	Base	14	843.13	0.48
41	Base	Med	Med	Base	8	869.24	0.48
21	Base	Low	Low	Base	2	895.34	0.48
54	Base	High	Low	Low	9	865.57	0.47

121	Low	High	Med	Base	12	854.68	0.45
101	Low	Med	Low	Base	6	880.79	0.43
50	Base	High	Base	Low	8	873.40	0.42
57	Base	High	Med	Base	11	866.63	0.38
97	Low	Med	Base	Base	5	888.62	0.34
117	Low	High	Low	Base	9	878.18	0.32
37	Base	Med	Low	Base	5	892.73	0.25
113	Low	High	Base	Base	8	886.01	0.25
53	Base	High	Low	Base	8	890.12	0.19
49	Base	High	Base	Base	7	897.95	0.10
33	Base	Med	Base	Base	4	900.56	0.10
17	Base	Low	Base	Base	1	903.17	0.10

Table D3. Agricultural MP Trial Results between April and October (Growing Season)

Trial	W. Hite Conc.	Return % Before Union	Return % After Union	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction per Point
1	Base	Base	Base	Base	0	1145.78	NA
13	Base	Base	High	Base	7	1019.91	1.57
9	Base	Base	Med	Base	4	1073.85	1.57
5	Base	Base	Low	Base	1	1127.80	1.57
77	Low	Base	High	Base	8	1013.40	1.44
29	Base	Low	High	Base	8	1018.61	1.39
14	Base	Base	High	Low	8	1019.87	1.37
73	Low	Base	Med	Base	5	1067.35	1.37
93	Low	Low	High	Base	9	1012.10	1.30
78	Low	Base	High	Low	9	1013.37	1.28
25	Base	Low	Med	Base	5	1072.55	1.28
10	Base	Base	Med	Low	5	1073.82	1.26
30	Base	Low	High	Low	9	1018.57	1.23
141	Med	Base	High	Base	11	993.89	1.21
94	Low	Low	High	Low	10	1012.07	1.17
89	Low	Low	Med	Base	6	1066.05	1.16
74	Low	Base	Med	Low	6	1067.31	1.14
157	Med	Low	High	Base	12	992.59	1.11
142	Med	Base	High	Low	12	993.85	1.10
137	Med	Base	Med	Base	8	1047.83	1.07
205	High	Base	High	Base	14	974.37	1.07
69	Low	Base	Low	Base	2	1121.29	1.07
26	Base	Low	Med	Low	6	1072.52	1.07
45	Base	Med	High	Base	11	1014.71	1.04
158	Med	Low	High	Low	13	992.55	1.03
221	High	Low	High	Base	15	973.07	1.00

109	Low	Med	High	Base	12	1008.21	1.00
15	Base	Base	High	Med	11	1019.77	1.00
206	High	Base	High	Low	15	974.34	1.00
90	Low	Low	Med	Low	7	1066.05	0.99
79	Low	Base	High	Med	12	1013.27	0.96
153	Med	Low	Med	Base	9	1046.53	0.96
46	Base	Med	High	Low	12	1014.68	0.95
138	Med	Base	Med	Low	9	1047.80	0.95
222	High	Low	High	Low	16	973.04	0.94
201	High	Base	Med	Base	11	1028.32	0.93
31	Base	Low	High	Med	12	1018.47	0.93
110	Low	Med	High	Low	13	1008.17	0.92
173	Med	Med	High	Base	15	988.69	0.91
95	Low	Low	High	Med	13	1011.97	0.90
143	Med	Base	High	Med	15	993.75	0.88
154	Med	Low	Med	Low	10	1046.50	0.87
217	High	Low	Med	Base	12	1027.02	0.86
174	Med	Med	High	Low	16	988.66	0.86
237	High	Med	High	Base	18	969.18	0.86
202	High	Base	Med	Low	12	1028.28	0.85
21	Base	Low	Low	Base	2	1126.50	0.84
61	Base	High	High	Base	14	1010.82	0.84
41	Base	Med	Med	Base	8	1068.66	0.84
159	Med	Low	High	Med	16	992.45	0.84
207	High	Base	High	Med	18	974.23	0.83
125	Low	High	High	Base	15	1004.31	0.82
238	High	Med	High	Low	19	969.14	0.81
105	Low	Med	Med	Base	9	1062.15	0.81
218	High	Low	Med	Low	13	1027.02	0.80
223	High	Low	High	Med	19	972.94	0.79
16	Base	Base	High	High	14	1019.67	0.79
11	Base	Base	Med	Med	8	1073.72	0.79
6	Base	Base	Low	Low	2	1127.76	0.79
62	Base	High	High	Low	15	1010.78	0.79
189	Med	High	High	Base	18	984.80	0.78
126	Low	High	High	Low	16	1004.28	0.77
80	Low	Base	High	High	15	1013.16	0.77
133	Med	Base	Low	Base	5	1101.78	0.77
47	Base	Med	High	Med	15	1014.58	0.76
75	Low	Base	Med	Med	9	1067.21	0.76
111	Low	Med	High	Med	16	1008.07	0.75
253	High	High	High	Base	21	965.28	0.75
169	Med	Med	Med	Base	12	1042.64	0.75

85	Low	Low	Low	Base	3	1119.99	0.75
42	Base	Med	Med	Low	9	1068.62	0.75
32	Base	Low	High	High	15	1018.37	0.74
190	Med	High	High	Low	19	984.76	0.74
144	Med	Base	High	High	18	993.65	0.74
96	Low	Low	High	High	16	1011.86	0.73
106	Low	Med	Med	Low	10	1062.12	0.73
175	Med	Med	High	Med	19	988.56	0.72
254	High	High	High	Low	22	965.25	0.72
233	High	Med	Med	Base	15	1023.12	0.71
70	Low	Base	Low	Low	3	1121.26	0.71
139	Med	Base	Med	Med	12	1047.69	0.71
208	High	Base	High	High	21	974.13	0.71
27	Base	Low	Med	Med	9	1072.42	0.71
160	Med	Low	High	High	19	992.35	0.70
239	High	Med	High	Med	22	969.04	0.70
91	Low	Low	Med	Med	10	1066.01	0.70
197	High	Base	Low	Base	8	1082.26	0.69
170	Med	Med	Med	Low	13	1042.60	0.69
224	High	Low	High	High	22	972.83	0.69
203	High	Base	Med	Med	15	1028.18	0.68
234	High	Med	Med	Low	16	1023.09	0.67
155	Med	Low	Med	Med	13	1046.40	0.67
149	Med	Low	Low	Base	6	1100.48	0.66
63	Base	High	High	Med	18	1010.68	0.66
127	Low	High	High	Med	19	1004.18	0.65
219	High	Low	Med	Med	16	1026.98	0.65
57	Base	High	Med	Base	11	1064.76	0.64
134	Med	Base	Low	Low	6	1101.74	0.64
191	Med	High	High	Med	22	984.66	0.64
121	Low	High	Med	Base	12	1058.26	0.64
48	Base	Med	High	High	18	1014.68	0.64
112	Low	Med	High	High	19	1007.97	0.63
255	High	High	High	Med	25	965.14	0.63
213	High	Low	Low	Base	9	1080.96	0.63
176	Med	Med	High	High	22	988.66	0.62
185	Med	High	Med	Base	15	1038.74	0.62
240	High	Med	High	High	25	968.94	0.62
198	High	Base	Low	Low	9	1082.23	0.62
249	High	High	Med	Base	18	1019.23	0.61
58	Base	High	Med	Low	12	1064.73	0.59
122	Low	High	Med	Low	13	1058.22	0.59
186	Med	High	Med	Low	16	1038.71	0.58

250	High	High	Med	Low	19	1019.19	0.58
12	Base	Base	Med	High	11	1073.61	0.57
76	Low	Base	Med	High	12	1067.11	0.57
140	Med	Base	Med	High	15	1047.59	0.57
204	High	Base	Med	High	18	1028.08	0.57
193	High	Base	Base	Base	7	1100.24	0.57
65	Low	Base	Base	Base	1	1139.27	0.57
129	Med	Base	Base	Base	4	1119.76	0.57
214	High	Low	Low	Low	10	1080.93	0.57
150	Med	Low	Low	Low	7	1100.44	0.57
235	High	Med	Med	Med	19	1022.99	0.56
86	Low	Low	Low	Low	4	1119.96	0.56
256	High	High	High	High	28	965.04	0.56
171	Med	Med	Med	Med	16	1042.50	0.56
192	Med	High	High	High	25	984.56	0.56
107	Low	Med	Med	Med	13	1062.02	0.56
128	Low	High	High	High	22	1004.07	0.56
43	Base	Med	Med	Med	12	1068.52	0.56
64	Base	High	High	High	21	1010.58	0.56
22	Base	Low	Low	Low	3	1126.47	0.56
220	High	Low	Med	High	19	1026.78	0.55
156	Med	Low	Med	High	16	1046.29	0.54
92	Low	Low	Med	High	13	1065.81	0.54
28	Base	Low	Med	High	12	1072.31	0.53
209	High	Low	Base	Base	8	1098.95	0.51
251	High	High	Med	Med	22	1019.09	0.50
229	High	Med	Low	Base	12	1077.07	0.50
194	High	Base	Base	Low	8	1100.21	0.50
187	Med	High	Med	Med	19	1038.61	0.49
236	High	Med	Med	High	22	1022.88	0.49
123	Low	High	Med	Med	16	1058.12	0.48
165	Med	Med	Low	Base	9	1096.58	0.48
145	Med	Low	Base	Base	5	1118.46	0.48
172	Med	Med	Med	High	19	1042.40	0.47
59	Base	High	Med	Med	15	1064.63	0.47
199	High	Base	Low	Med	12	1082.12	0.46
230	High	Med	Low	Low	13	1077.03	0.46
108	Low	Med	Med	High	16	1061.91	0.46
130	Med	Base	Base	Low	5	1119.72	0.45
210	High	Low	Base	Low	9	1098.91	0.45
44	Base	Med	Med	High	15	1068.42	0.45
252	High	High	Med	High	25	1018.99	0.44
215	High	Low	Low	Med	13	1080.83	0.44

101	Low	Med	Low	Base	6	1116.10	0.43
166	Med	Med	Low	Low	10	1096.55	0.43
135	Med	Base	Low	Med	9	1101.64	0.43
188	Med	High	Med	High	22	1038.50	0.43
245	High	High	Low	Base	15	1073.17	0.42
37	Base	Med	Low	Base	5	1122.60	0.40
124	Low	High	Med	High	19	1058.02	0.40
225	High	Med	Base	Base	11	1095.05	0.40
146	Med	Low	Base	Low	6	1118.43	0.40
151	Med	Low	Low	Med	10	1100.34	0.40
246	High	High	Low	Low	16	1073.14	0.40
60	Base	High	Med	High	18	1064.52	0.39
181	Med	High	Low	Base	12	1092.69	0.39
231	High	Med	Low	Med	16	1076.93	0.38
200	High	Base	Low	High	15	1082.02	0.37
102	Low	Med	Low	Low	7	1116.07	0.37
226	High	Med	Base	Low	12	1095.02	0.37
195	High	Base	Base	Med	11	1100.11	0.36
71	Low	Base	Low	Med	6	1121.16	0.36
182	Med	High	Low	Low	13	1092.65	0.36
216	High	Low	Low	High	16	1080.72	0.35
211	High	Low	Base	Med	12	1098.81	0.34
161	Med	Med	Base	Base	8	1114.57	0.34
241	High	High	Base	Base	14	1091.15	0.34
81	Low	Low	Base	Base	2	1137.98	0.34
38	Base	Med	Low	Low	6	1122.57	0.34
247	High	High	Low	Med	19	1073.04	0.33
167	Med	Med	Low	Med	13	1096.45	0.33
117	Low	High	Low	Base	9	1112.20	0.33
87	Low	Low	Low	Med	7	1119.86	0.32
136	Med	Base	Low	High	12	1101.54	0.32
242	High	High	Base	Low	15	1091.12	0.32
232	High	Med	Low	High	19	1076.83	0.32
7	Base	Base	Low	Med	5	1127.66	0.32
152	Med	Low	Low	High	13	1100.24	0.31
162	Med	Med	Base	Low	9	1114.53	0.30
227	High	Med	Base	Med	15	1094.91	0.30
53	Base	High	Low	Base	8	1118.71	0.30
118	Low	High	Low	Low	10	1112.17	0.29
183	Med	High	Low	Med	16	1092.55	0.29
248	High	High	Low	High	22	1072.93	0.29
196	High	Base	Base	High	14	1100.00	0.29
131	Med	Base	Base	Med	8	1119.62	0.29

66	Low	Base	Base	Low	2	1139.24	0.29
23	Base	Low	Low	Med	6	1126.36	0.28
177	Med	High	Base	Base	11	1110.67	0.28
212	High	Low	Base	High	15	1098.71	0.27
168	Med	Med	Low	High	16	1096.34	0.27
147	Med	Low	Base	Med	9	1118.32	0.27
243	High	High	Base	Med	18	1091.02	0.27
54	Base	High	Low	Low	9	1118.68	0.26
103	Low	Med	Low	Med	10	1115.96	0.26
178	Med	High	Base	Low	12	1110.64	0.26
228	High	Med	Base	High	18	1094.81	0.25
184	Med	High	Low	High	19	1092.45	0.24
72	Low	Base	Low	High	9	1121.05	0.24
163	Med	Med	Base	Med	12	1114.43	0.23
244	High	High	Base	High	21	1090.92	0.23
82	Low	Low	Base	Low	3	1137.94	0.23
88	Low	Low	Low	High	10	1119.76	0.23
119	Low	High	Low	Med	13	1112.07	0.23
39	Base	Med	Low	Med	9	1122.47	0.23
132	Med	Base	Base	High	11	1119.52	0.21
179	Med	High	Base	Med	15	1110.53	0.21
97	Low	Med	Base	Base	5	1134.08	0.20
104	Low	Med	Low	High	13	1115.86	0.20
148	Med	Low	Base	High	12	1118.22	0.20
8	Base	Base	Low	High	8	1127.56	0.20
55	Base	High	Low	Med	12	1118.57	0.20
24	Base	Low	Low	High	9	1126.26	0.19
120	Low	High	Low	High	16	1111.96	0.18
164	Med	Med	Base	High	15	1114.33	0.18
180	Med	High	Base	High	18	1110.43	0.17
98	Low	Med	Base	Low	6	1134.05	0.17
40	Base	Med	Low	High	12	1122.37	0.17
113	Low	High	Base	Base	8	1130.19	0.17
56	Base	High	Low	High	15	1118.47	0.16
114	Low	High	Base	Low	9	1130.15	0.15
67	Low	Base	Base	Med	5	1139.14	0.12
83	Low	Low	Base	Med	6	1137.84	0.12
99	Low	Med	Base	Med	9	1133.94	0.11
115	Low	High	Base	Med	12	1130.05	0.11
17	Base	Low	Base	Base	1	1144.48	0.11
33	Base	Med	Base	Base	4	1140.59	0.11
49	Base	High	Base	Base	7	1136.69	0.11
50	Base	High	Base	Low	8	1136.66	0.10

116	Low	High	Base	High	15	1129.95	0.09
34	Base	Med	Base	Low	5	1140.55	0.09
100	Low	Med	Base	High	12	1133.84	0.09
84	Low	Low	Base	High	9	1137.74	0.08
68	Low	Base	Base	High	8	1139.04	0.07
51	Base	High	Base	Med	11	1136.55	0.07
52	Base	High	Base	High	14	1136.45	0.06
35	Base	Med	Base	Med	8	1140.45	0.06
18	Base	Low	Base	Low	2	1144.45	0.06
36	Base	Med	Base	High	11	1140.35	0.04
19	Base	Low	Base	Med	5	1144.34	0.03
20	Base	Low	Base	High	8	1144.24	0.02
2	Base	Base	Base	Low	1	1145.75	0.00
3	Base	Base	Base	Med	4	1145.64	0.00
4	Base	Base	Base	High	7	1145.54	0.00

Table D4. Agricultural MP Trial Results between November and March (Non-Growing Season)

Trial	W. Hite Conc.	Return % Before Union	Return % After Union	Road Salt	Points	Average TDS (mg/L)	TDS % Reduction per Point
1	Base	Base	Base	Base	0	1313.63	NA
13	Base	Base	High	Base	7	1169.85	1.56
9	Base	Base	Med	Base	4	1231.47	1.56
5	Base	Base	Low	Base	1	1293.09	1.56
14	Base	Base	High	Low	8	1157.22	1.49
77	Low	Base	High	Base	8	1158.38	1.48
10	Base	Base	Med	Low	5	1218.84	1.44
73	Low	Base	Med	Base	5	1220.00	1.43
78	Low	Base	High	Low	9	1145.75	1.42
29	Base	Low	High	Base	8	1169.03	1.38
74	Low	Base	Med	Low	6	1207.37	1.35
15	Base	Base	High	Med	11	1119.35	1.34
30	Base	Low	High	Low	9	1156.40	1.33
93	Low	Low	High	Base	9	1157.56	1.32
141	Med	Base	High	Base	11	1123.97	1.31
79	Low	Base	High	Med	12	1107.88	1.31
94	Low	Low	High	Low	10	1144.93	1.28
142	Med	Base	High	Low	12	1111.34	1.28
25	Base	Low	Med	Base	5	1230.65	1.26
16	Base	Base	High	High	14	1081.47	1.26
6	Base	Base	Low	Low	2	1280.47	1.26
11	Base	Base	Med	Med	8	1180.97	1.26
31	Base	Low	High	Med	12	1118.52	1.24

80	Low	Base	High	High	15	1070.00	1.24
75	Low	Base	Med	Med	9	1169.50	1.22
143	Med	Base	High	Med	15	1073.47	1.22
69	Low	Base	Low	Base	2	1281.62	1.22
205	High	Base	High	Base	14	1089.56	1.22
137	Med	Base	Med	Base	8	1185.59	1.22
26	Base	Low	Med	Low	6	1218.02	1.21
95	Low	Low	High	Med	13	1107.05	1.21
157	Med	Low	High	Base	12	1123.15	1.21
206	High	Base	High	Low	15	1076.94	1.20
89	Low	Low	Med	Base	6	1219.18	1.20
138	Med	Base	Med	Low	9	1172.97	1.19
158	Med	Low	High	Low	13	1110.52	1.19
32	Base	Low	High	High	15	1080.65	1.18
12	Base	Base	Med	High	11	1143.09	1.18
144	Med	Base	High	High	18	1035.59	1.18
96	Low	Low	High	High	16	1069.18	1.16
207	High	Base	High	Med	18	1039.06	1.16
76	Low	Base	Med	High	12	1131.62	1.15
159	Med	Low	High	Med	16	1072.65	1.15
221	High	Low	High	Base	15	1088.74	1.14
208	High	Base	High	High	21	1001.18	1.13
70	Low	Base	Low	Low	3	1269.00	1.13
139	Med	Base	Med	Med	12	1135.09	1.13
222	High	Low	High	Low	16	1076.11	1.13
27	Base	Low	Med	Med	9	1180.15	1.13
201	High	Base	Med	Base	11	1151.18	1.12
160	Med	Low	High	High	19	1034.77	1.12
202	High	Base	Med	Low	12	1138.56	1.11
223	High	Low	High	Med	19	1038.24	1.10
140	Med	Base	Med	High	15	1097.21	1.10
153	Med	Low	Med	Base	9	1184.77	1.09
28	Base	Low	Med	High	12	1142.27	1.09
224	High	Low	High	High	22	1000.36	1.08
7	Base	Base	Low	Med	5	1242.59	1.08
203	High	Base	Med	Med	15	1100.68	1.08
154	Med	Low	Med	Low	10	1172.14	1.08
92	Low	Low	Med	High	13	1130.80	1.07
204	High	Base	Med	High	18	1062.81	1.06
155	Med	Low	Med	Med	13	1134.27	1.05
71	Low	Base	Low	Med	6	1231.12	1.05
8	Base	Base	Low	High	8	1204.71	1.04
217	High	Low	Med	Base	12	1150.36	1.04

156	Med	Low	Med	High	16	1096.39	1.03
90	Low	Low	Med	Low	7	1219.18	1.03
72	Low	Base	Low	High	9	1193.24	1.02
45	Base	Med	High	Base	11	1166.56	1.02
46	Base	Med	High	Low	12	1153.93	1.01
133	Med	Base	Low	Base	5	1247.21	1.01
220	High	Low	Med	High	19	1061.98	1.01
109	Low	Med	High	Base	12	1155.09	1.01
134	Med	Base	Low	Low	6	1234.59	1.00
47	Base	Med	High	Med	15	1116.06	1.00
110	Low	Med	High	Low	13	1142.46	1.00
111	Low	Med	High	Med	16	1104.59	0.99
112	Low	Med	High	High	19	1066.71	0.99
135	Med	Base	Low	Med	9	1196.71	0.99
136	Med	Base	Low	High	12	1158.84	0.98
173	Med	Med	High	Base	15	1120.68	0.98
174	Med	Med	High	Low	16	1108.06	0.98
175	Med	Med	High	Med	19	1070.18	0.98
237	High	Med	High	Base	18	1086.27	0.96
238	High	Med	High	Low	19	1073.65	0.96
239	High	Med	High	Med	22	1035.77	0.96
240	High	Med	High	High	25	997.89	0.96
3	Base	Base	Base	Med	4	1263.13	0.96
4	Base	Base	Base	High	7	1225.25	0.96
2	Base	Base	Base	Low	1	1301.01	0.96
200	High	Base	Low	High	15	1124.43	0.96
199	High	Base	Low	Med	12	1162.30	0.96
198	High	Base	Low	Low	9	1200.18	0.96
197	High	Base	Low	Base	8	1212.81	0.96
218	High	Low	Med	Low	13	1150.36	0.96
68	Low	Base	Base	High	8	1213.78	0.95
67	Low	Base	Base	Med	5	1251.66	0.94
132	Med	Base	Base	High	11	1179.38	0.93
24	Base	Low	Low	High	9	1203.89	0.93
88	Low	Low	Low	High	10	1192.42	0.92
196	High	Base	Base	High	14	1144.97	0.92
131	Med	Base	Base	Med	8	1217.25	0.92
66	Low	Base	Base	Low	2	1289.54	0.92
23	Base	Low	Low	Med	6	1241.77	0.91
152	Med	Low	Low	High	13	1158.01	0.91
87	Low	Low	Low	Med	7	1230.30	0.91
195	High	Base	Base	Med	11	1182.84	0.91
216	High	Low	Low	High	16	1123.61	0.90

151	Med	Low	Low	Med	10	1195.89	0.90
215	High	Low	Low	Med	13	1161.48	0.89
130	Med	Base	Base	Low	5	1255.13	0.89
194	High	Base	Base	Low	8	1220.72	0.88
44	Base	Med	Med	High	15	1139.80	0.88
108	Low	Med	Med	High	16	1128.33	0.88
172	Med	Med	Med	High	19	1093.92	0.88
236	High	Med	Med	High	22	1059.52	0.88
193	High	Base	Base	Base	7	1233.35	0.87
129	Med	Base	Base	Base	4	1267.75	0.87
65	Low	Base	Base	Base	1	1302.16	0.87
214	High	Low	Low	Low	10	1199.36	0.87
150	Med	Low	Low	Low	7	1233.77	0.87
235	High	Med	Med	Med	19	1097.39	0.87
86	Low	Low	Low	Low	4	1268.17	0.87
171	Med	Med	Med	Med	16	1131.80	0.87
256	High	High	High	High	28	995.43	0.87
192	Med	High	High	High	25	1029.84	0.86
107	Low	Med	Med	Med	13	1166.21	0.86
128	Low	High	High	High	22	1064.24	0.86
64	Base	High	High	High	21	1075.71	0.86
43	Base	Med	Med	Med	12	1177.68	0.86
22	Base	Low	Low	Low	3	1279.64	0.86
212	High	Low	Base	High	15	1144.15	0.86
213	High	Low	Low	Base	9	1211.98	0.86
148	Med	Low	Base	High	12	1178.55	0.86
255	High	High	High	Med	25	1033.30	0.85
149	Med	Low	Low	Base	6	1246.39	0.85
84	Low	Low	Base	High	9	1212.96	0.85
191	Med	High	High	Med	22	1067.71	0.85
20	Base	Low	Base	High	8	1224.43	0.85
234	High	Med	Med	Low	16	1135.27	0.85
127	Low	High	High	Med	19	1102.12	0.85
63	Base	High	High	Med	18	1113.59	0.85
170	Med	Med	Med	Low	13	1169.68	0.84
233	High	Med	Med	Base	15	1147.89	0.84
254	High	High	High	Low	22	1071.18	0.84
219	High	Low	Med	Med	16	1137.74	0.84
211	High	Low	Base	Med	12	1182.02	0.83
106	Low	Med	Med	Low	10	1204.08	0.83
190	Med	High	High	Low	19	1105.59	0.83
85	Low	Low	Low	Base	3	1280.80	0.83
169	Med	Med	Med	Base	12	1182.30	0.83

253	High	High	High	Base	21	1083.81	0.83
42	Base	Med	Med	Low	9	1215.55	0.83
189	Med	High	High	Base	18	1118.21	0.83
126	Low	High	High	Low	16	1140.00	0.83
62	Base	High	High	Low	15	1151.47	0.82
147	Med	Low	Base	Med	9	1216.43	0.82
105	Low	Med	Med	Base	9	1216.71	0.82
125	Low	High	High	Base	15	1152.62	0.82
91	Low	Low	Med	Med	10	1206.55	0.82
61	Base	High	High	Base	14	1164.09	0.81
41	Base	Med	Med	Base	8	1228.18	0.81
21	Base	Low	Low	Base	2	1292.27	0.81
83	Low	Low	Base	Med	6	1250.84	0.80
210	High	Low	Base	Low	9	1219.90	0.79
19	Base	Low	Base	Med	5	1262.31	0.78
252	High	High	Med	High	25	1057.05	0.78
209	High	Low	Base	Base	8	1232.52	0.77
232	High	Med	Low	High	19	1121.14	0.77
188	Med	High	Med	High	22	1091.46	0.77
251	High	High	Med	Med	22	1094.93	0.76
146	Med	Low	Base	Low	6	1254.31	0.75
124	Low	High	Med	High	19	1125.87	0.75
168	Med	Med	Low	High	16	1155.55	0.75
60	Base	High	Med	High	18	1137.33	0.75
187	Med	High	Med	Med	19	1129.33	0.74
231	High	Med	Low	Med	16	1159.01	0.74
228	High	Med	Base	High	18	1141.68	0.73
250	High	High	Med	Low	19	1132.80	0.72
104	Low	Med	Low	High	13	1189.95	0.72
123	Low	High	Med	Med	16	1163.74	0.71
40	Base	Med	Low	High	12	1201.42	0.71
249	High	High	Med	Base	18	1145.43	0.71
176	Med	Med	High	High	22	1108.06	0.71
145	Med	Low	Base	Base	5	1266.93	0.71
167	Med	Med	Low	Med	13	1193.42	0.70
59	Base	High	Med	Med	15	1175.21	0.70
164	Med	Med	Base	High	15	1176.09	0.70
186	Med	High	Med	Low	16	1167.21	0.70
230	High	Med	Low	Low	13	1196.89	0.68
227	High	Med	Base	Med	15	1179.56	0.68
185	Med	High	Med	Base	15	1179.84	0.68
48	Base	Med	High	High	18	1153.93	0.68
248	High	High	Low	High	22	1118.67	0.67

229	High	Med	Low	Base	12	1209.52	0.66
122	Low	High	Med	Low	13	1201.62	0.66
100	Low	Med	Base	High	12	1210.49	0.65
103	Low	Med	Low	Med	10	1227.83	0.65
184	Med	High	Low	High	19	1153.08	0.64
58	Base	High	Med	Low	12	1213.09	0.64
36	Base	Med	Base	High	11	1221.96	0.63
82	Low	Low	Base	Low	3	1288.71	0.63
163	Med	Med	Base	Med	12	1213.96	0.63
244	High	High	Base	High	21	1139.21	0.63
121	Low	High	Med	Base	12	1214.24	0.63
247	High	High	Low	Med	19	1156.55	0.63
39	Base	Med	Low	Med	9	1239.30	0.63
166	Med	Med	Low	Low	10	1231.30	0.63
226	High	Med	Base	Low	12	1217.43	0.61
57	Base	High	Med	Base	11	1225.71	0.61
120	Low	High	Low	High	16	1187.49	0.60
180	Med	High	Base	High	18	1173.62	0.59
165	Med	Med	Low	Base	9	1243.92	0.59
183	Med	High	Low	Med	16	1190.96	0.58
56	Base	High	Low	High	15	1198.96	0.58
225	High	Med	Base	Base	11	1230.06	0.58
243	High	High	Base	Med	18	1177.09	0.58
246	High	High	Low	Low	16	1194.42	0.57
99	Low	Med	Base	Med	9	1248.37	0.55
245	High	High	Low	Base	15	1207.05	0.54
116	Low	High	Base	High	15	1208.03	0.54
162	Med	Med	Base	Low	9	1251.84	0.52
102	Low	Med	Low	Low	7	1265.71	0.52
179	Med	High	Base	Med	15	1211.50	0.52
119	Low	High	Low	Med	13	1225.36	0.52
18	Base	Low	Base	Low	2	1300.18	0.51
52	Base	High	Base	High	14	1219.50	0.51
35	Base	Med	Base	Med	8	1259.84	0.51
242	High	High	Base	Low	15	1214.96	0.50
182	Med	High	Low	Low	13	1228.83	0.50
55	Base	High	Low	Med	12	1236.83	0.49
241	High	High	Base	Base	14	1227.59	0.47
161	Med	Med	Base	Base	8	1264.46	0.47
81	Low	Low	Base	Base	2	1301.34	0.47
38	Base	Med	Low	Low	6	1277.18	0.46
181	Med	High	Low	Base	12	1241.46	0.46
101	Low	Med	Low	Base	6	1278.33	0.45

115	Low	High	Base	Med	12	1245.90	0.43
178	Med	High	Base	Low	12	1249.37	0.41
51	Base	High	Base	Med	11	1257.37	0.39
118	Low	High	Low	Low	10	1263.24	0.38
37	Base	Med	Low	Base	5	1289.80	0.36
177	Med	High	Base	Base	11	1262.00	0.36
98	Low	Med	Base	Low	6	1286.25	0.35
54	Base	High	Low	Low	9	1274.71	0.33
117	Low	High	Low	Base	9	1275.87	0.32
114	Low	High	Base	Low	9	1283.78	0.25
53	Base	High	Low	Base	8	1287.33	0.25
34	Base	Med	Base	Low	5	1297.72	0.24
97	Low	Med	Base	Base	5	1298.87	0.22
50	Base	High	Base	Low	8	1295.25	0.17
113	Low	High	Base	Base	8	1296.41	0.16
33	Base	Med	Base	Base	4	1310.34	0.06
49	Base	High	Base	Base	7	1307.88	0.06
17	Base	Low	Base	Base	1	1312.81	0.06