Trevor Grout

CEES 5020 019 Independent Study Course

Dr. Vieux

Final Report

Summary

A Vflo™ model was set up and run for multiple continuous simulations from 1999-2003. The study area was the Fort Cobb Reservoir watershed with an area of 307mi^2. Daily baseflow, derived from daily Corps of Engineer lake level data using PART, was added to Vflo™ model output to produce streamflow estimates. These streamflow estimates were accumulated and compared to accumulated Corps of Engineer inflow estimates for the Fort Cobb Reservoir. Model performance was assessed using accumulated flow volumes beginning on Oct. 1, 1999 and ending on Sept. 30, 2003. Multiple simulations, each with different initial conditions, demonstrated:

1) That once the model was warmed-up, initial saturation differences made no difference in long term flow volumes,
2) Increased soil depths decreased accumulated volumes ,
3) Decreased hydraulic conductivities increased accumulated volumes,
4) Baseflow + Vflo™ runoff resulted in much better agreement to observed Corps estimates.

Additionally, the Vflo™ model was calibrated using instantaneous data from a USGS gage on Cobb Creek at Eakley, OK (Gage 07325800). This gage was located within the broader Fort Cobb Reservoir watershed and had a drainage area of 132mi^2. Hydrologic responses were not simultaneous between modeled and observed data and this could be caused by regulation upstream of the gage. There was one event which did show a simultaneous hydrologic response in both observed and modeled data and this event (March 20, 2000) was used for calibration. A simple calibration procedure was conducted based on sensitivity to Nash-Sutcliffe values and peak flow values. Calibration was achieved by adjusting one variable (Ksat = 0.23) and resulted in a Nash-Coefficient of 0.82 and a nearly perfect agreement in peak flow values (2,498CFS vs 2,500 CFS).

Calibration parameters, from the single March, 2000 event, were then applied to the larger Fort Cobb Reservoir basin and Vflo™ runoff combined with baseflow, resulted in nearly perfect model performance (Model Accumulated Flow = 1.002*Observed Accumulated Flow) from Oct. 1, 1999 – Sept 30, 2002.

Results

Notes about Data Massaging

The XMRG time stamp is in UTC format. All other observed data was in CST/CDT format. To correct for this, the output from the continuous simulations was converted from UTC to CST/CDT. All calculations, such as adding baseflow to Vflo™ output were performed after this transformation.

When calibrating, the observed data from the Cobb Creek Gage at Eakley (Gage ID 07325800) was converted to UST. This was done to ensure that the XMRG and observed data were in the same time format.   All volumes are reported in acre-ft.

Initial Saturation

The effects of differing initial saturation values (0.0 and 0.50) were evaluated from Oct 1, 1999 – Sept 30, 2003. One simulation had a soil depth of 34” and initial saturation saturation of 0, and another with soil depth of 34” and Initial saturation of 0.50. Figure 1 and Figure 2 show that initial saturation did not make a difference in total volume for both direct runoff (Vflo only) and total streamflow (Vflo + baseflow). Figure 3 shows that after the first three months of 1999, the two simulations were nearly identical except when saturation was very low. It does appear that there is a floor of ~4% soil moisture for the simulation with initial saturation of 0.50.

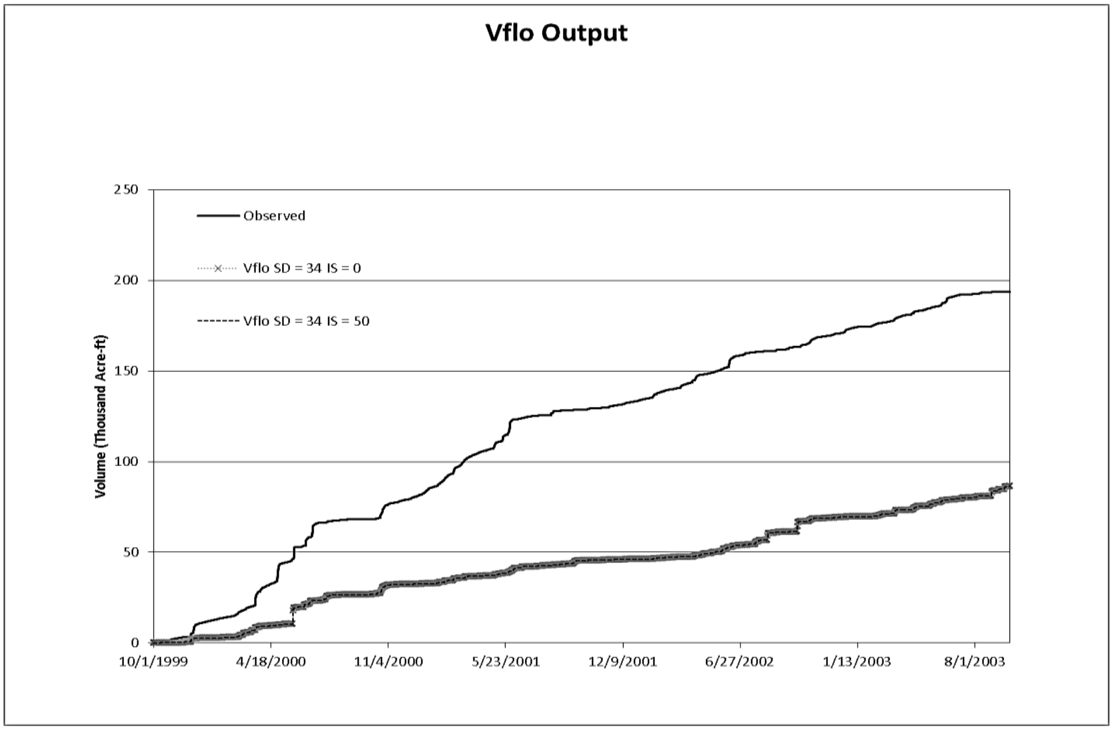


Figure 1: Cumulative output for two different initial saturation values (0.0 and 0.5) direct runoff only (Vflo™).

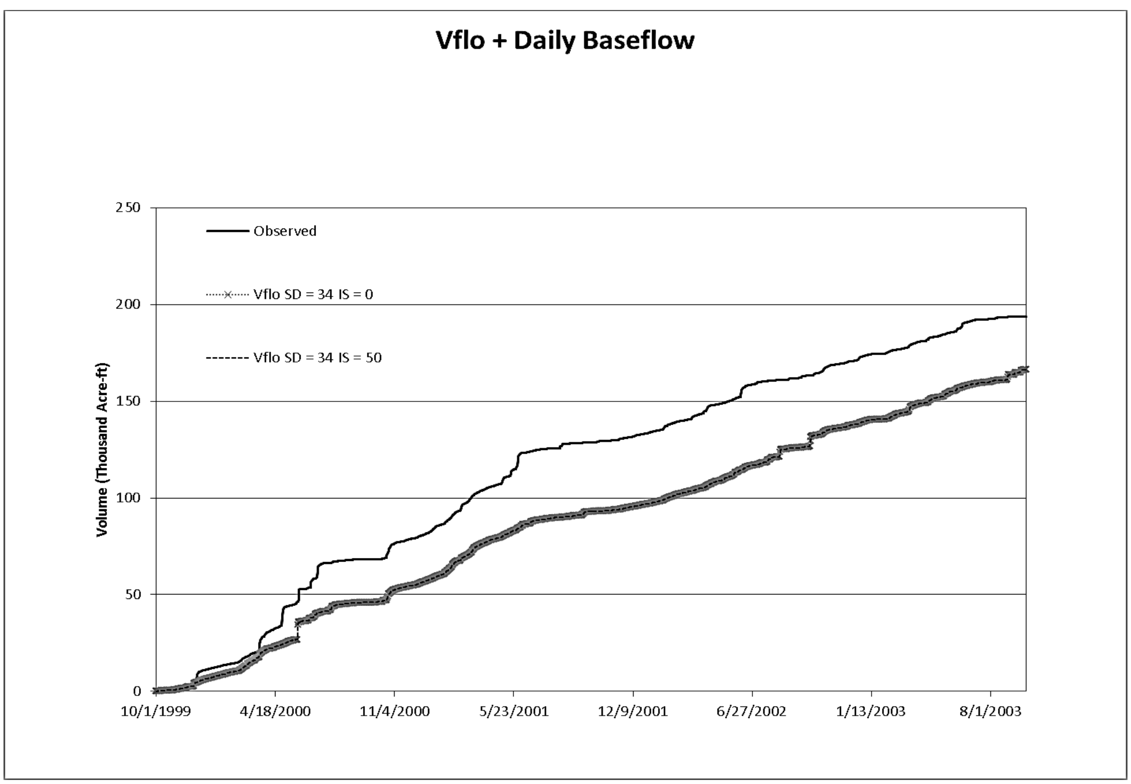


Figure 2: Cumulative output for two different initial saturation values (0.0 and 0.5) total streamflow (Vflo™+ baseflow).

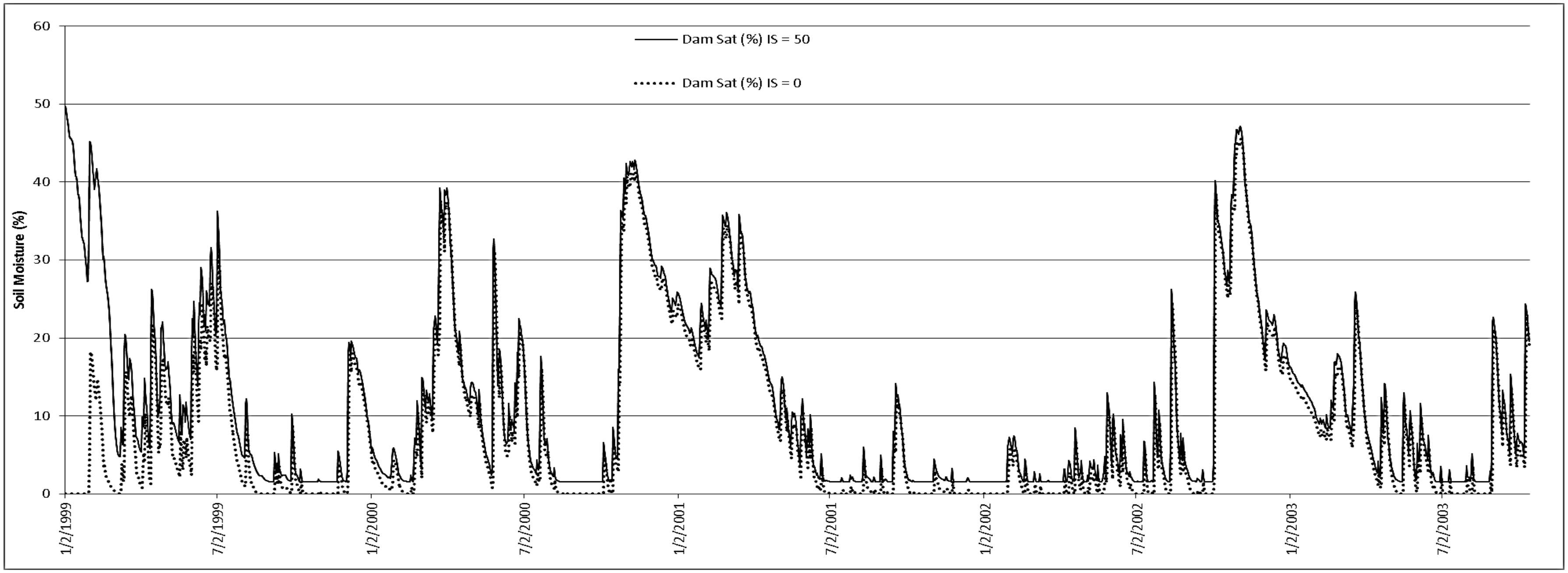


Figure 3: Soil moisture (%) for long term simulation with initial saturation of 0.0 (dotted) and initial saturation of 0.50 (solid) at the Fort Cobb Dam. Soil depth was 34".

Soil Depth

Simulations were run with soil depths of 0 and 34 inches. Increased soil depths caused flow volumes to decrease. Figure 4 and Figure 5 show runoff and streamflow volumes compared to observed data.

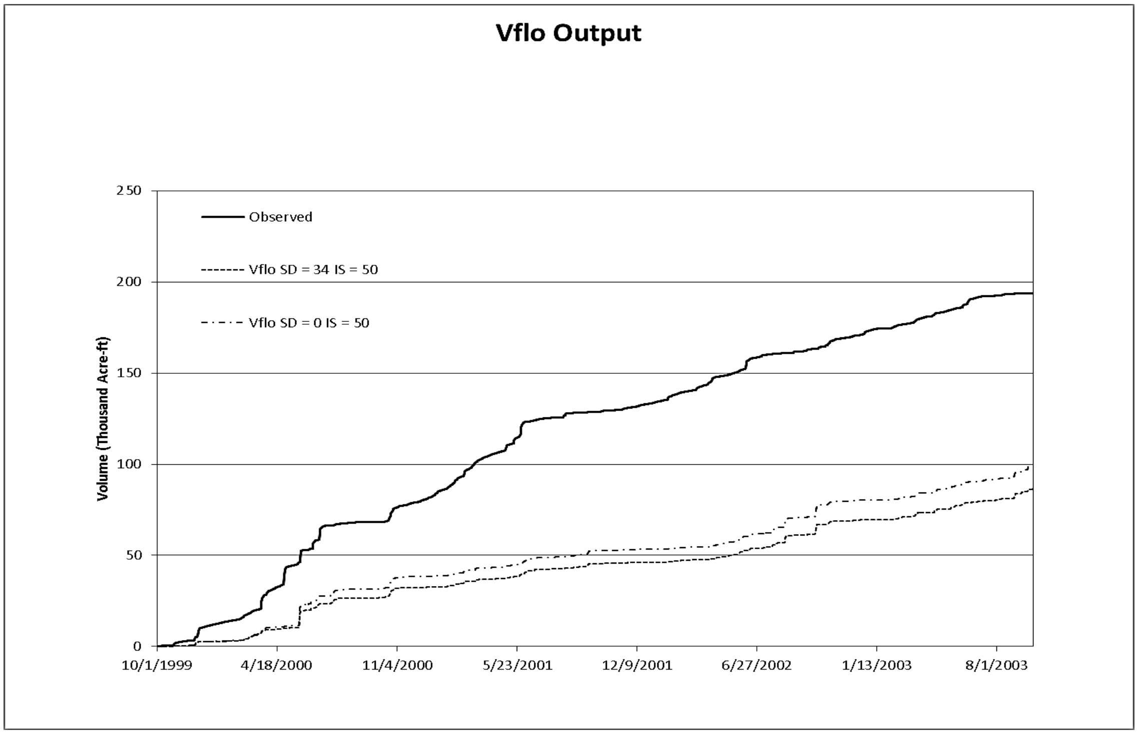


Figure 4: accumulated runoff (Vflo) for soil depths of 34" and 0" .

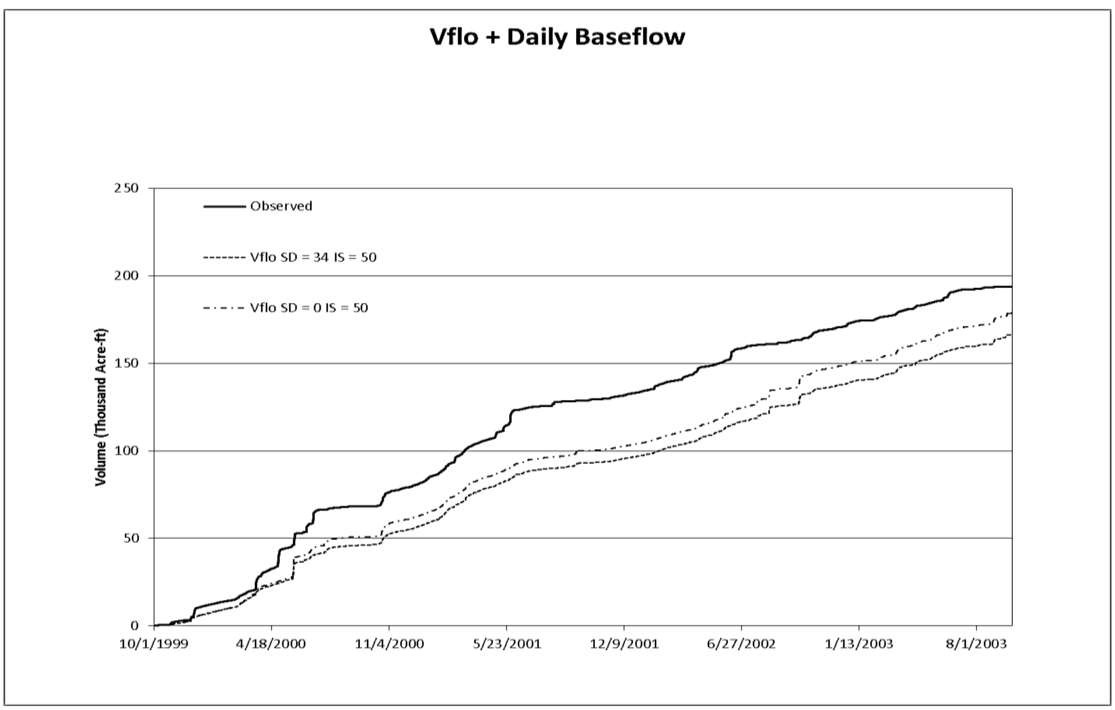


Figure 5: accumulated streamflow (Vflo + baseflow) for soil depths of 34" and 0".

Hydraulic Conductivity

Simulations with hydraulic conductivity multipliers of 1.0 and 0.50 were run. Decreased hydraulic conductivity caused increased flow volume. Figures 6 & 7 show runoff and streamflow volumes compared to observed Corps data.

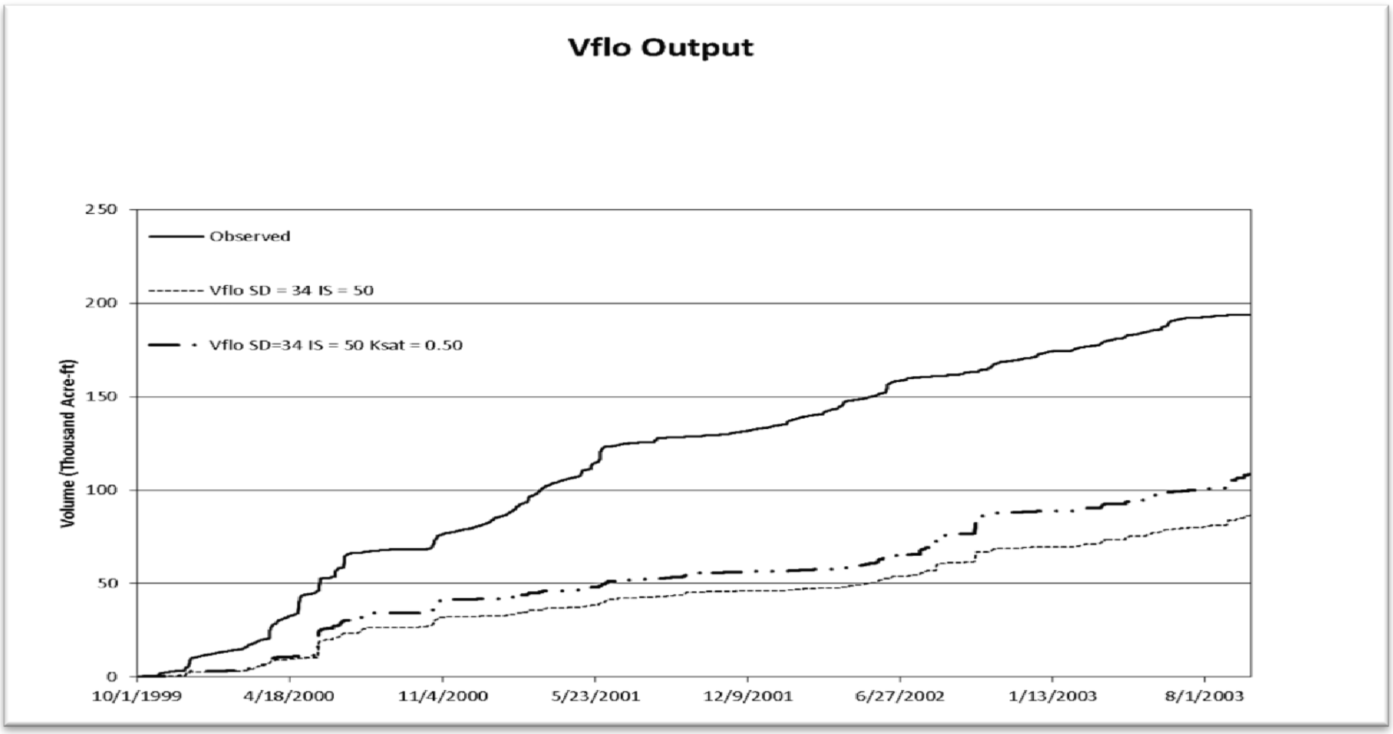


Figure 6: accumulated runoff (Vflo) for Ksat of 1 and 0.50.

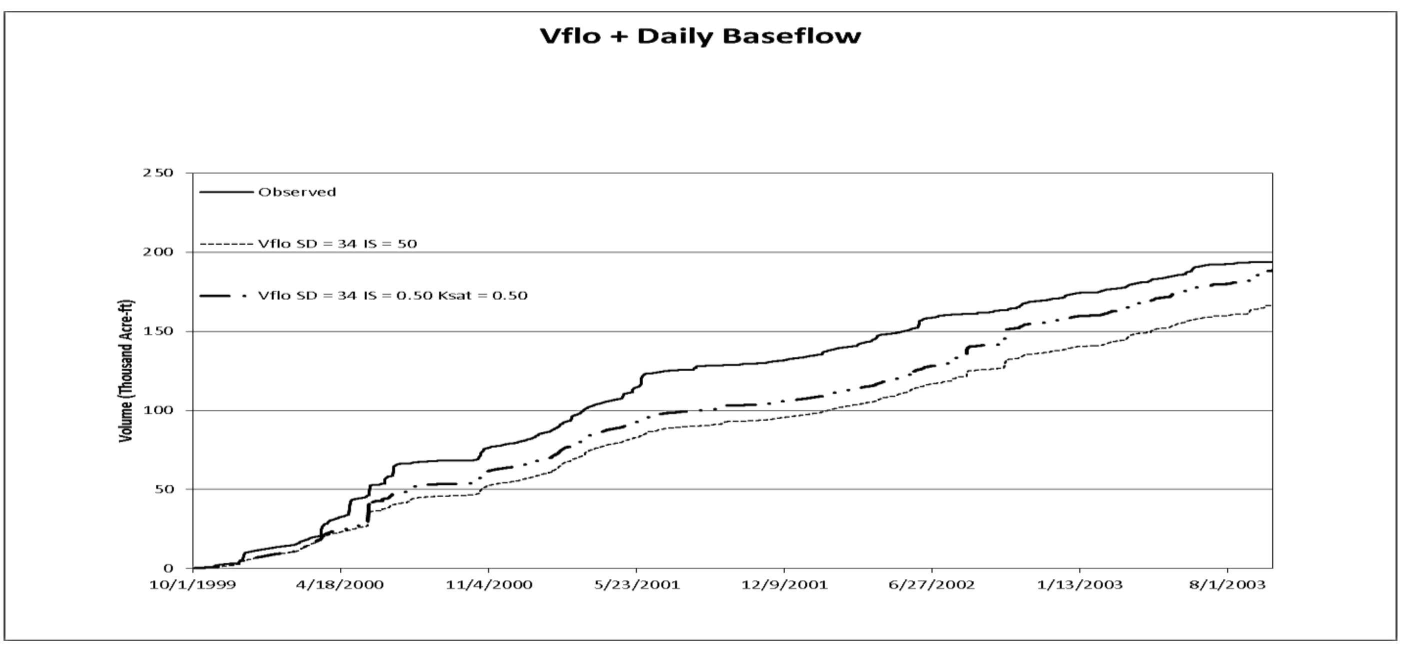


Figure 7: Accumulated streamflow (Vflo + baseflow) for Ksat of 1 and 0.50.

Calibration

Event Identification

Calibration was performed on an interior point within the Fort Cobb Reservoir basin. The interior point corresponded with the USGS gage located on the Cobb Creek at Eakley, OK (USGS Gage 07325800). This location was used because there was hourly gage data from the USGS available for calibration. To identify potential calibration events, the continuous Vflo simulation (soil depth 34" and initial saturation of 0.50) output was upscaled to daily average flows and compared to observed daily average flow (Figure 8). In general, there was little agreement between the data on a daily basis with Nash Coefficient of -0.45. Upon close inspection of individual events, it was evident that there was a considerable lag between predicted and observed hydrograph responses (Figure 9). This lag could be due to substantial regulation upstream of our data point or faulty radar data. Fortunately, there was one event where modeled and observed streamflow experienced simultaneous hydrograph responses (Figure 10). Initial saturation values for individual events were assigned the value given in the continuous simulation output (see Figure 3). The initial saturation for the calibration event (March, 2000) was 0.38.

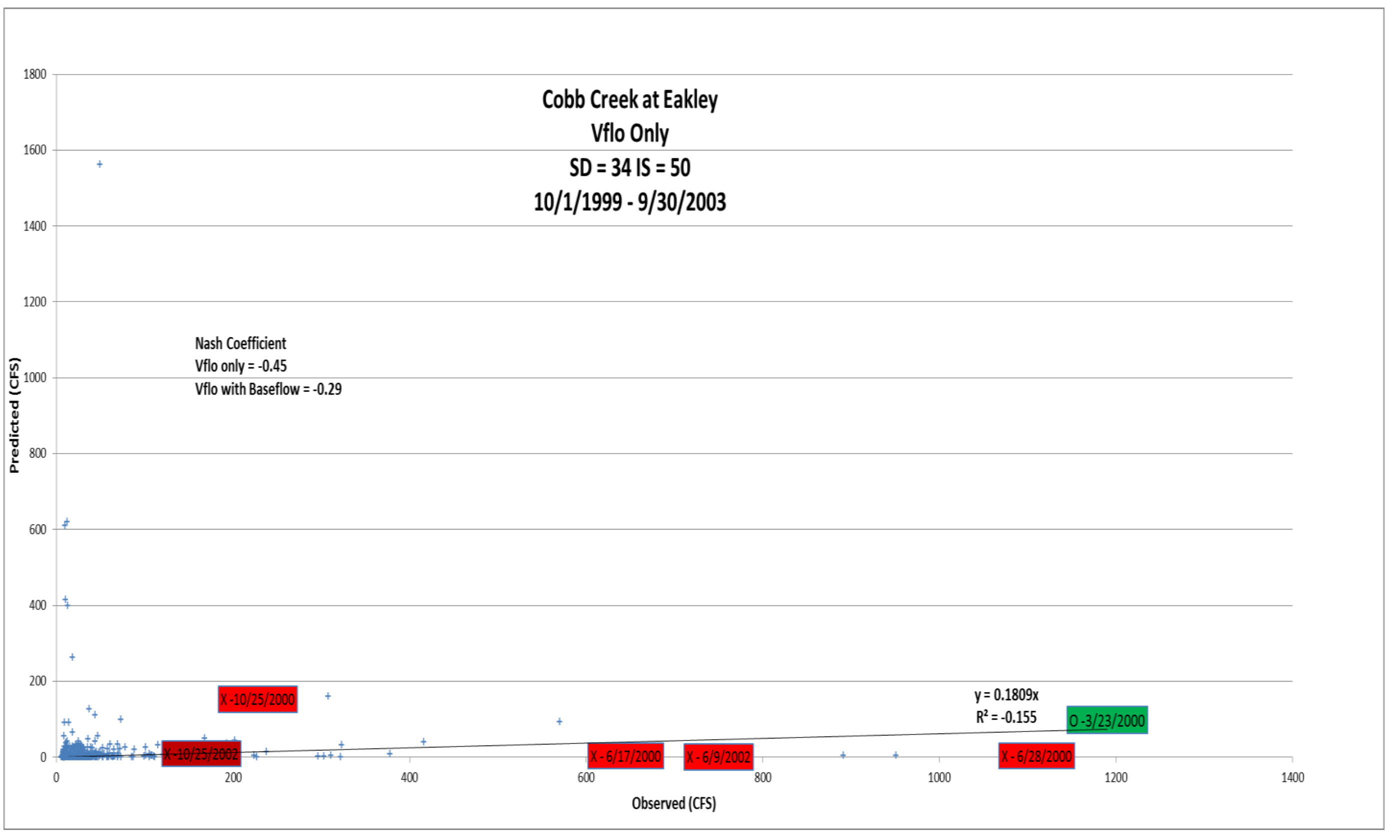


Figure 8: Vflo vs observed on a daily basis. Red labels indicate no calibration attempted, green label indicates successful calibration.

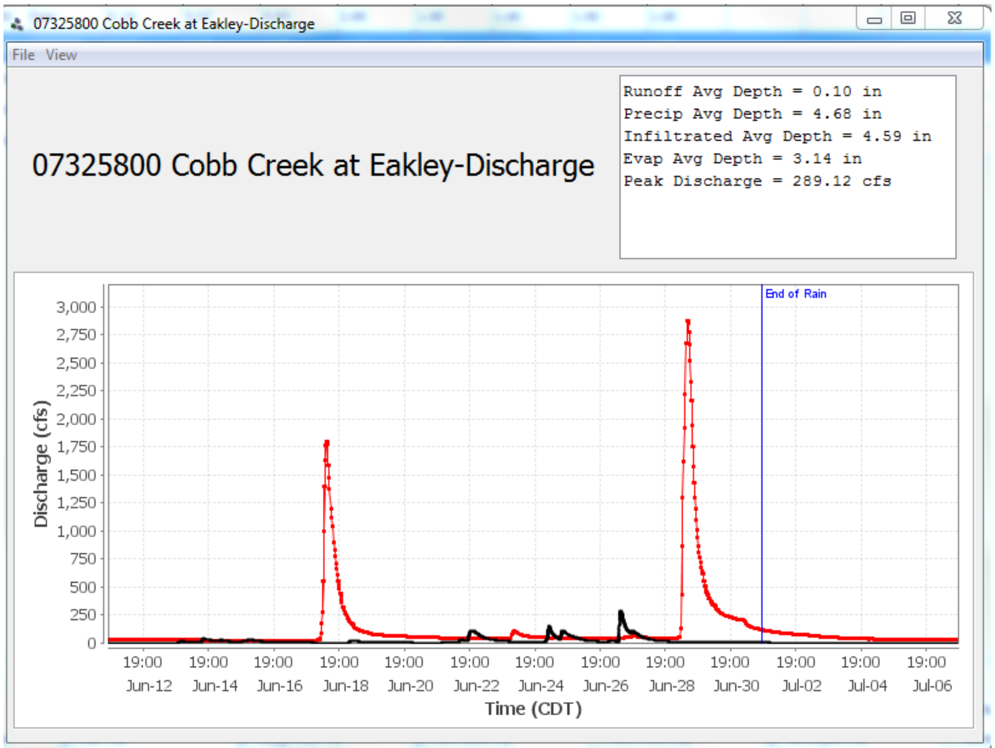


Figure 9: Sample of lag time between observed and predicted in June, 2000. All multipliers were 1.0.

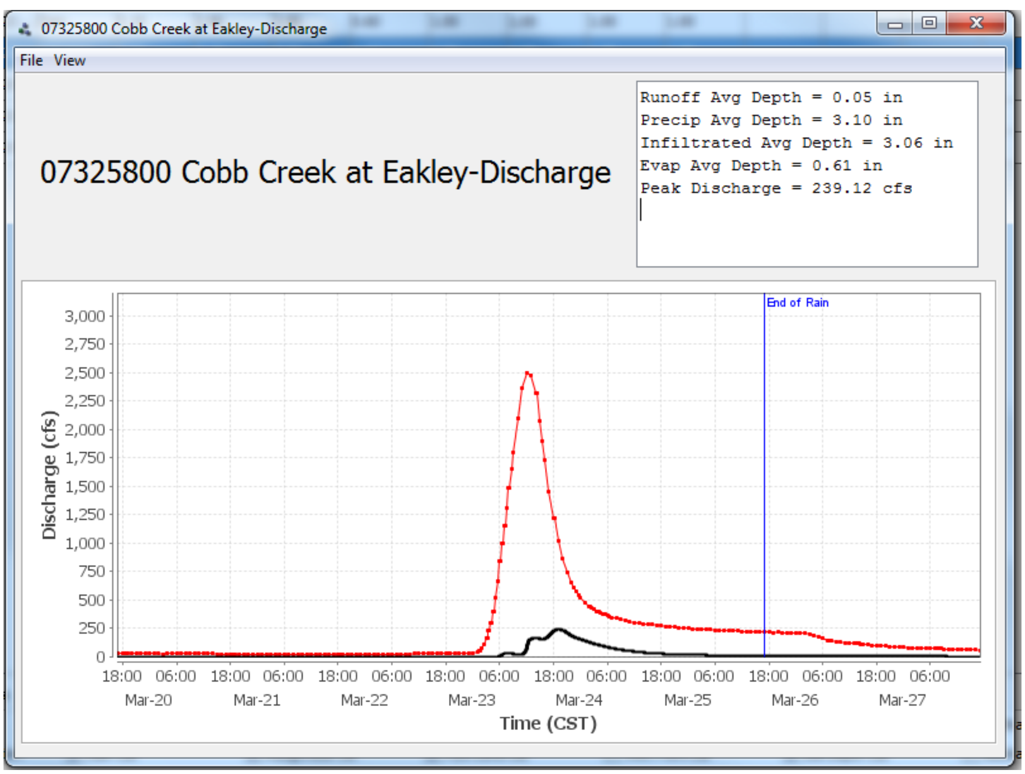


Figure 10: March, 2000 - Vflo output with SD = 34 and IS = 0.38 (IS value from long term simulation).

Calibration Sensitivity Analysis

Sensitivity Analysis -- Nash Coefficient

A sensitivity analysis between hydraulic conductivity (ksat) and soil depth was performed. Initial saturation was set to 0.38 and was based on output from the long term continuous simulation. Ksat and soil depths were varied 0.25 multiplier steps from 0.01 to 1 (Table 1). Nash coefficients were highest when the Ksat multiplier was approximately 0.25 and when the soil depth multiplier ranged from 0.5 – 1.0. Sensitivity plots (Figures 11 & 12) show that the Nash coefficient was more sensitive to hydraulic conductivity than soil depth. The highest Nash coefficient (0.82) occurred when the Ksat multiplier was 0.23 and soil depth was unchanged (multiplier of 1).

Table 1: Sensitivity analysis for March 2000 event.

Nash-Sutcliffe Perfect Value = 1		Soil Depth (Multiplier) SD_0 = 34"				
		0.01	0.25	0.5	0.75	1
Ksat (Multiplier) Ksat mean = 2.35 in/hr	0.01	-51.49	-14.81	-15.24	-15.49	-15.62
	0.25	-51.04	-0.59	**0.77**	**0.78**	**0.78**
	0.5	-51.04	-0.3	0.17	0.17	0.18
	0.75	-51.04	-0.49	-0.05	-0.05	-0.04
	1	-51.04	-0.57	-0.14	-0.14	-0.14

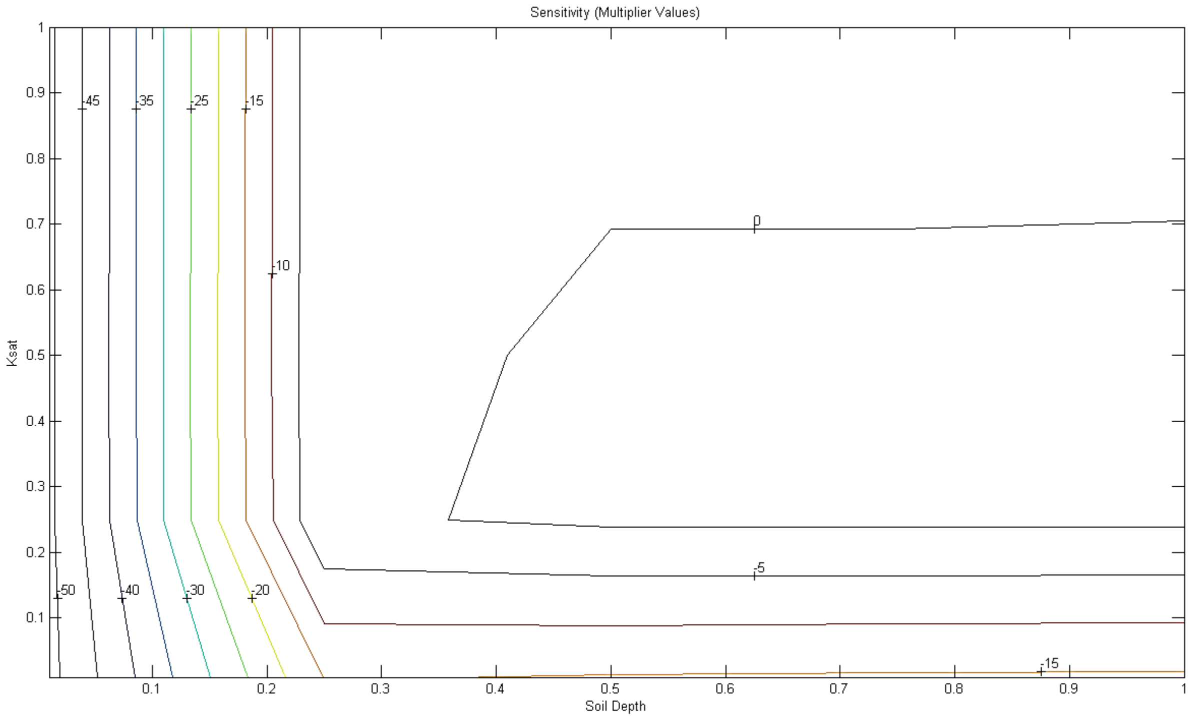


Figure 11: Sensitivity plot for March, 2000 event. Nash coefficients are contoured.

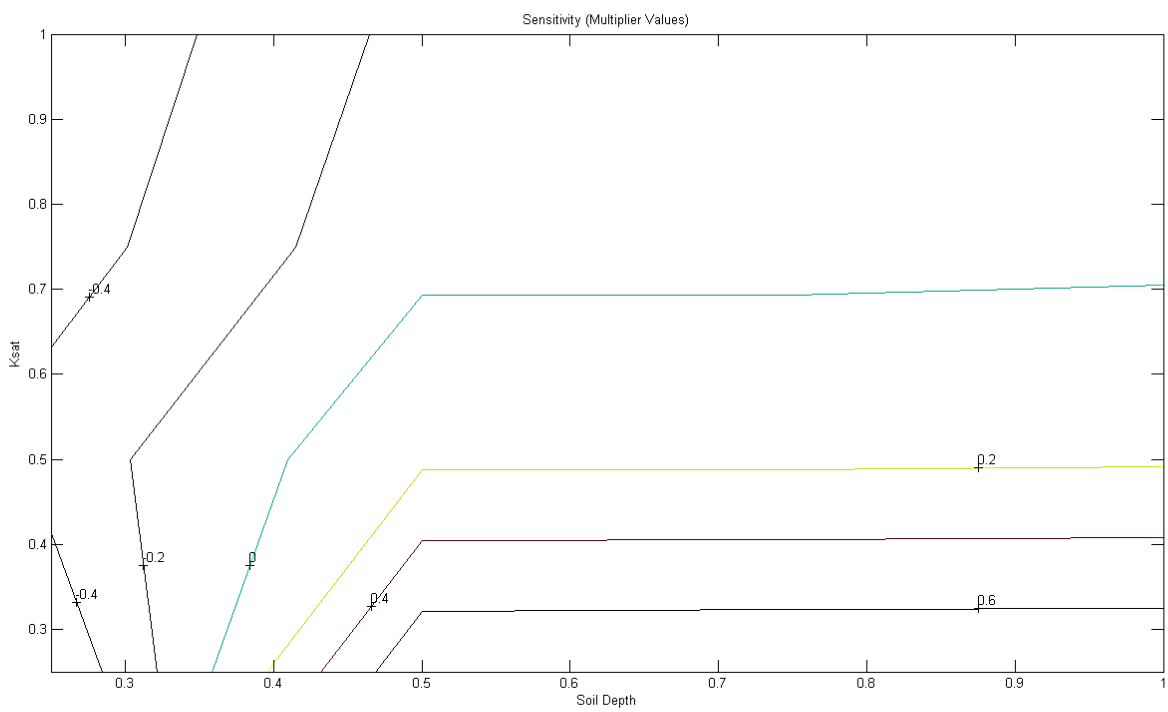


Figure 12: Sensitivity plot (multipliers >= 0.25) for March 2000 event. Nash Coefficients are contoured.

Sensitivity Analysis -- Peak Flow

Sensitivity analysis was also based on peak flow values (Table 2). The best model agreement occurred when the Ksat multiplier was 0.25 and when the soil depth multiplier was between 0.5 -1.0.

Table 2: Sensitivity analysis based on predicted flow value/ observed peak flow value.

Modeled Peak/Observed Peak Perfect Value = 1 Observed Peak (2,500 CFS)		**Soil Depth (Multiplier)** **SD_0 = 34"**				
		0.01	0.25	0.5	0.75	1
Ksat (Multiplier) **$Ksat_0$ mean = 2.35 in/hr**	0.01	6.63	4.30	4.33	4.35	4.36
	0.25	6.63	2.23	**0.87**	**0.88**	**0.88**
	0.5	6.63	1.78	0.27	0.27	0.27
	0.75	6.63	1.88	0.14	0.14	0.14
	1	6.63	1.95	0.09	0.09	0.09

Using the sensitivity analysis, a best parameter combination was determined to be ksat multiplier of 0.23 and soil depth multiplier of 1. This combination yielded a Nash coefficient of 0.82 and the modeled peak was 2498 CFS or 99% of the observed peak (Figure 13).

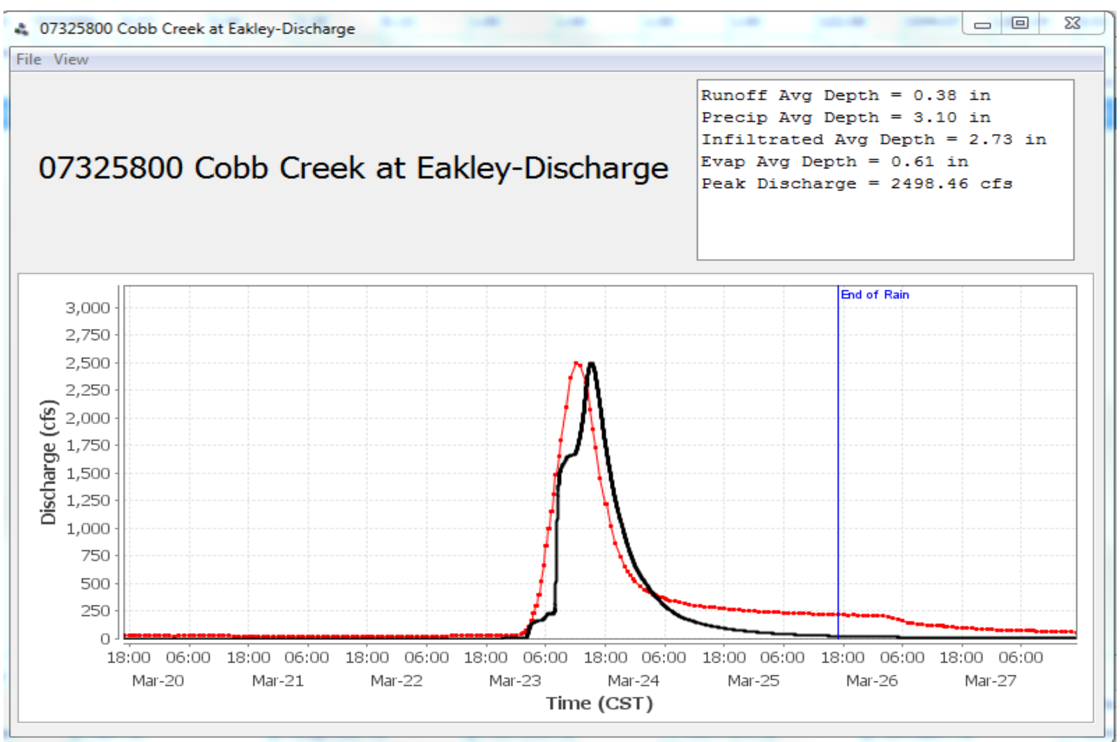


Figure 13: Calibrated model (Ksat 0.23, SD 1.0) for March, 2000 event. Nash Coefficient 0.82 and modeled peak flow was 99% of observed peak flow.

Calibrated Long Term Simulation

When calibration parameters (Ksat 0.23, SD 1.0) from the March, 2000 event were applied to continuous Vflo^{TM} simulation (1999-2003) they resulted in much better model performance, especially for the first three years and particularly when baseflow was incorporated (Figures 14 & 15).

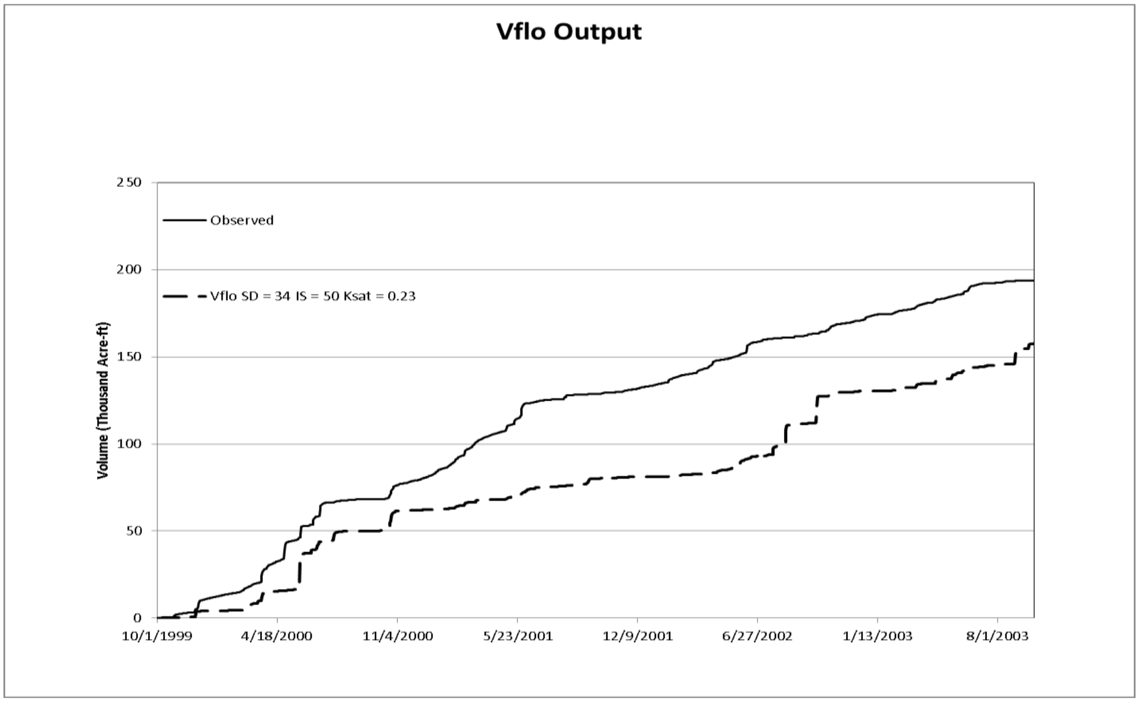


Figure 14: Accumulated runoff (Vflo) at Fort Cobb Dam from calibrated long term simulation.

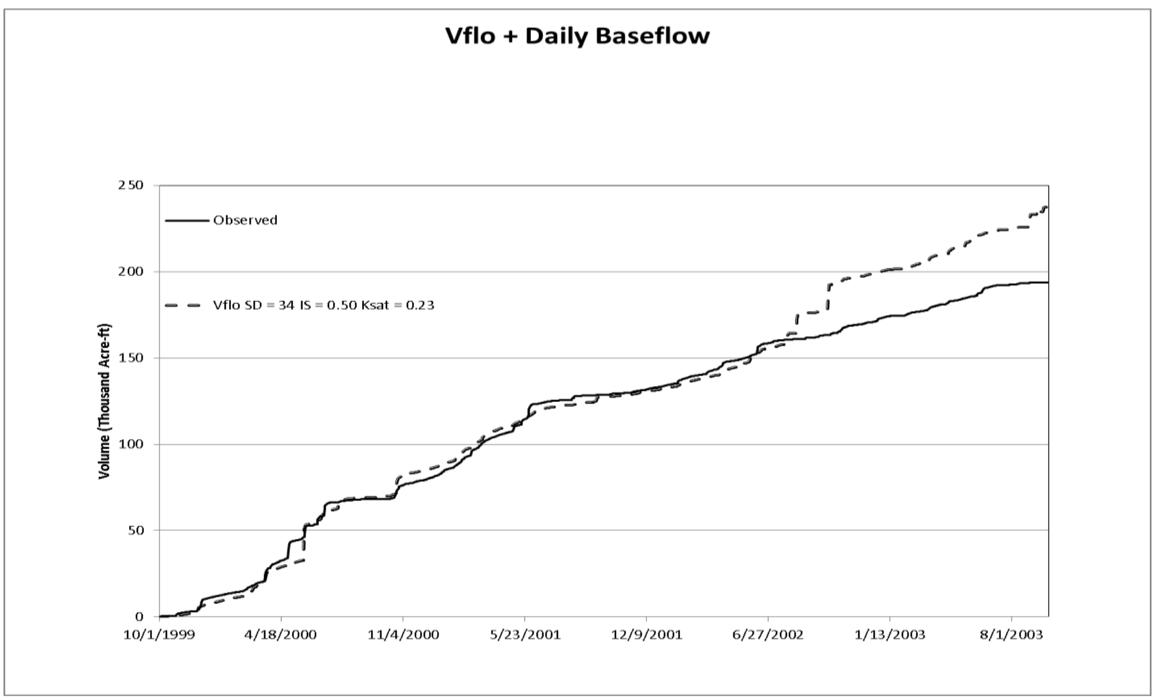


Figure 15: Accumulated streamflow (Vflo + baseflow) at Fort Cobb Dam from calibrated continuous simulation.

Model performance can be quantified by using a scatter plot (Figures 16 & 17). Direct runoff results in a nearly 30% underprediction of accumulated flow volumes. When baseflow is incorporated the total flow volumes show slight overprediction of 8% for the period Oct 1,1999 – Sept. 30, 2003. It appears that most of the model disagreement occurs after Sept 30, 2002 as there is nearly perfect model performance up until that date (Figure 18).

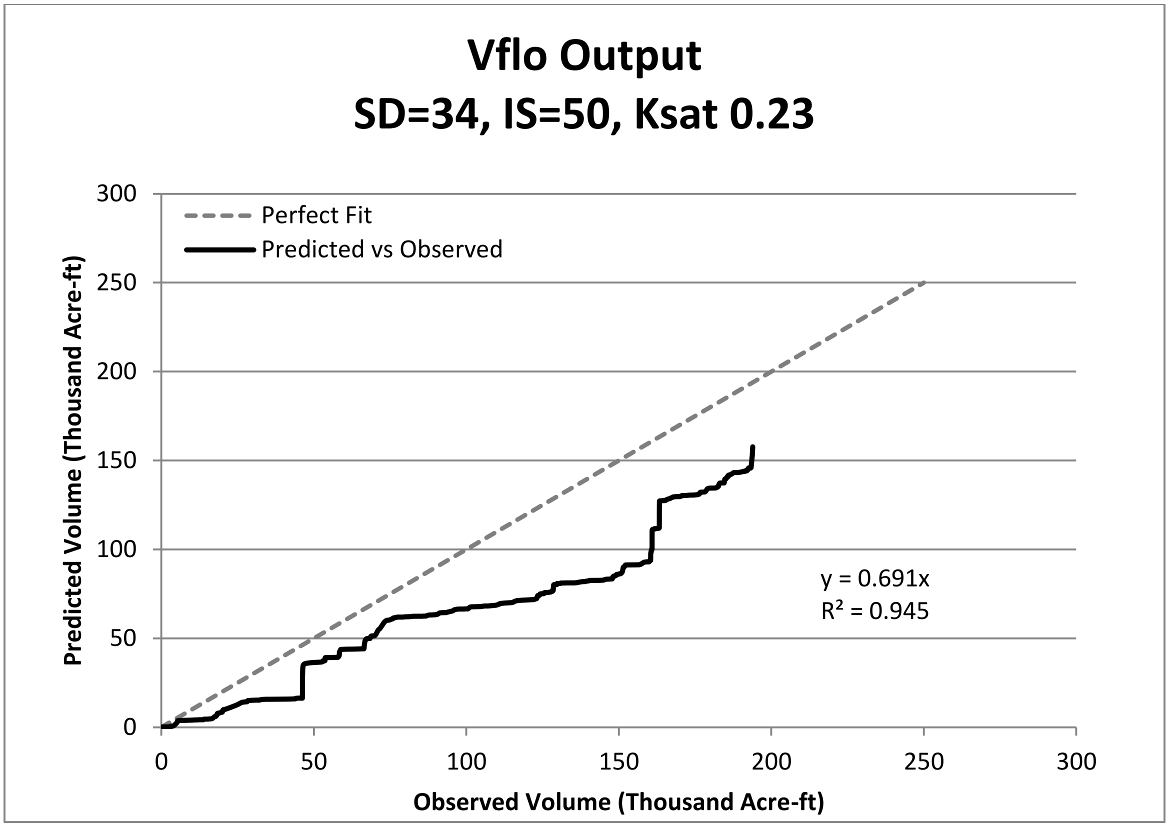


Figure 16: Scatter plot of Vflo vs Observed at Fort Cobb Dam (Oct 1, 1999 - Sept 30, 2003)

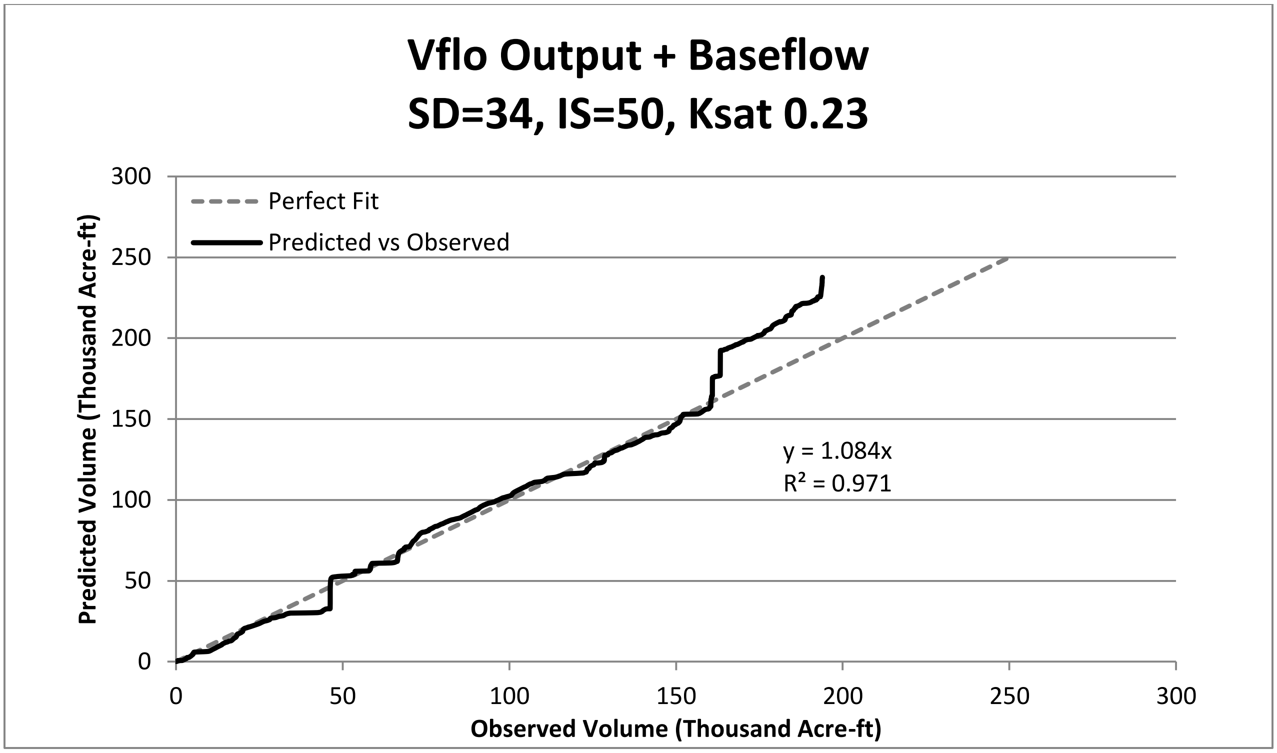


Figure 17: Predicted vs observed (Vflo + baseflow) at Fort Cobb Dam (Oct 1, 1999 – Sept 30, 2003).

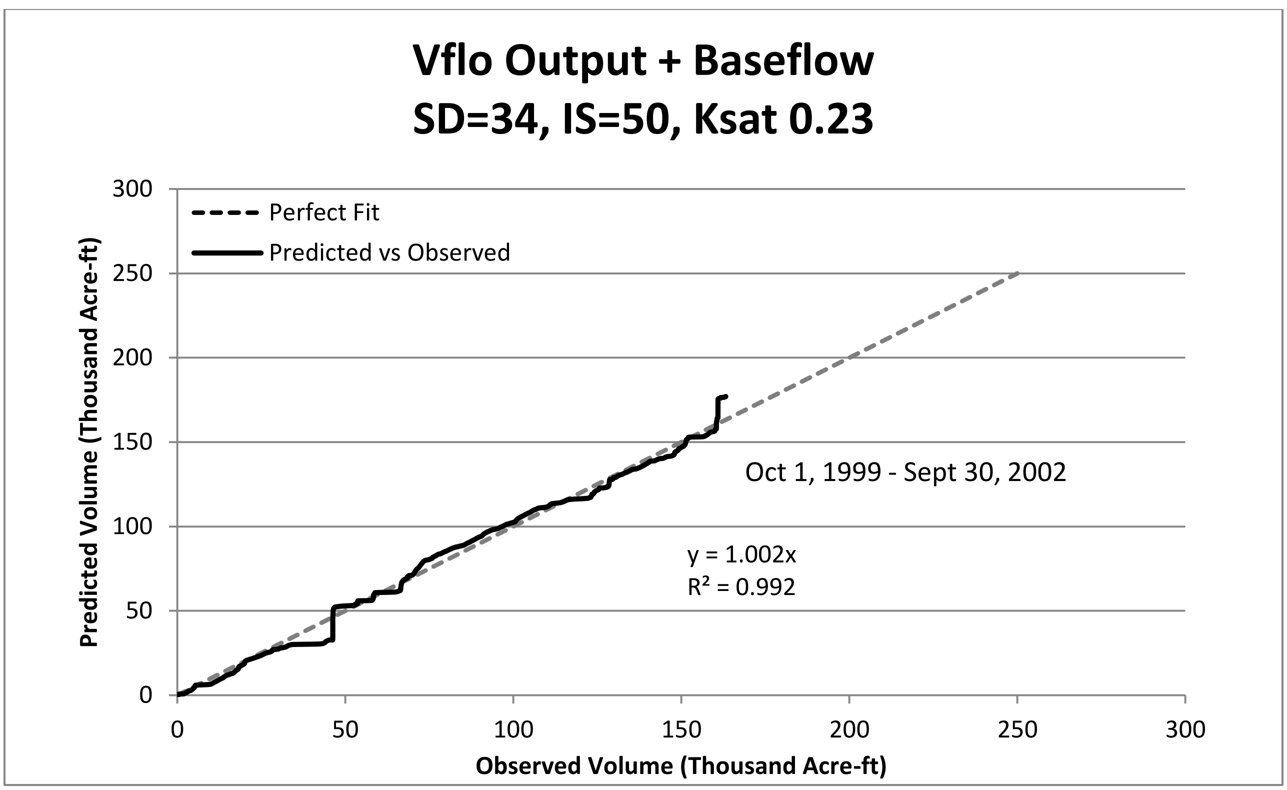


Figure 18: Predicted vs Observed (Vflo + baseflow).

Discussion

Continuous Vflo™ simulations demonstrated very little sensitivity to initial saturation and this is verified by viewing the plot of soil moisture over the entire simulation period (Jan 1, 1999 – Oct 14, 2003). In fact, it took a relatively short time (~3 months) for the two simulations to match % soil moisture at the Fort Cobb Dam watchpoint. One interesting note is the apparent floor that the 50% initial saturation simulation exhibited throughout the entire simulation period. This was in contrast to the 0% initial saturation simulation which frequently returned to 0% soil moisture. The cause of this phenomenon is unknown and should be explored further.

When hydraulic conductivity was decreased (Table 3: 1&4) it increased Vflo™predicted accumulated flow volumes by 25% (86,547 Acre-ft to 108, 541 Acre-ft)and the ratio of predicted volume to observed volume increased from 45% to 56%. Decreasing soil depth (Table 3: 1 & 3) yielded a 14% increase in Vflo™predicted accumulated volumes (86,547 Acre-ft to 98,912 Acre-ft) and the ratio of predicted volume to observed volume increased from 0.45 to 0.51. Adjusting initial saturation caused no difference in volumes (Table 3: 1&2). Baseflow adjustment proved to be very effective in increasing the predicted volumes to levels more consistent with observed. When baseflow was added to Vflo™ it increased the ratio between predicted and observed volumes by 41% (e.g. Case 1: 45% to 86%).

Table 3: Long term flow accumulations at Fort Cobb Dam for different long term simulations (listed by multiplier values)

	Total Observed Volume Oct 1, 1999 – Sept 30, 2003	**193,902**	**Acre-ft**		
Number	**Total Predicted Volume (Ac-Ft) Oct 1, 1999 – Sept 30, 2003**	Vflo™	Predicted/Observed	Vflo™ + Baseflow	Predicted/Observed
1	Ksat 1, SD 1 (34”), IS 0.50	86,547	0.45	166,462	0.86
2	Ksat 1, SD 1 (34”), IS 0.0	86,547	0.45	166,462	0.86
3	Ksat 1, SD 0(0”),IS 0.50	98,912	0.51	178,828	0.92
4	Ksat 0.50,SD 1 (34”),IS 0.50	108,541	0.56	188,456	0.97
5	Ksat 0.23,SD 1 (34”),IS 0.50	157,714	0.81	237,629	1.23

Due to substantial lag periods between observed and simulated, only one event (March,2000) was calibrated. A simple sensitivity analysis resulted in good calibration between predicted and observed. Sensitivity plots to Nash coefficients showed that there was little sensitivity to soil depth above a multiplier value of 0.50 with Nash values ranging from -0.14 to 0.17. Sensitivity plots did show that the model was very sensitivity to hydraulic conductivity with Nash coefficients peaking at 0.78 when the ksat multiplier was 0.25 and quickly dropping to 0.17 at a ksat multiplier of 0.50. Further fine tuning allowed the Nash coefficient to peak at 0.82 when the ksat multiplier was 0.23 and soil depth multiplier was 1.

The ksat multiplier value of 0.23 resulted in actual hydraulic conductivity values to range from 0 in/hr to 0.54 in/hr with an average 0.36 in/hr (Table 4). The Fort Cobb basin is mostly underlain by deep silty soils (Oklahoma Soil Map available at http://www.ogs.ou.edu/pubsscanned/EP9p16_19soil_veg_cl.pdf).

Silty soil types have a saturated hydraulic conductivity ranging from 0.5 in/hr to 2.01 in/hr (USDA, available at http://www.mo10.nrcs.usda.gov/references/guides/properties/sathydcond.html). The spatial distribution of hydraulic conductivity (Appendix, Figure 25) shows that most of the Fort Cobb Reservoir basin had hydraulic conductivity values closer to 2.35 in/hr. Therefore, even with hydraulic conductivity reduced in the calibrated model, the calibrated hydraulic conductivity values are still within an acceptable range for silty soils (~0.5 in/hr).

Table 4: Calibrated hydraulic conductivity values (original * 0.23 multiplier) comparisons.

	Minimum	Mean	Maximum
Hydraulic Conductivity from Lab 4	0.0 in/hr	1.56 in/hr	2.35 in/hr
Calibrated Hydraulic Conductivity	0.0 in/hr	0.36 in/hr	0.54 in/hr
Acceptable Range for Silty Soils	0.5 in/hr		2.01 in/hr

The calibration parameter (ksat of 0.23), when applied to a continuous simulation resulted in much better agreement with the observed accumulated flow volumes from the Corps of Engineers. A linear regression indicates a slight tendency for overprediction (y = 1.08x, R^2 of 0.97). When only considering the first three years of the simulation (Oct 1, 1999 – Sept 30, 2002) there was nearly perfect model agreement (Y = 1.002x, R^2 of 0.99) when adjusted with baseflow.

Conclusion

This study found that continuous Vflo^{TM} simulations with varying initial saturation conditions quickly converge (~3 months) and after the initial warm-up the differences in accumulated flows between the two simulations are negligible. Additionally, incorporating baseflow is essential in improving the accuracy of the model as baseflow increased the ratio of predicted volume to observed volume by 40% (from 0.50 to 0.90).

Calibration to observed USGS data (USGS Gage 07325800) was achieved by performing a sensitivity analysis which yielded high sensitivity to hydraulic conductivity and somewhat lower sensitivity to soil depth. Successful calibration was achieved by adjusting ksat (0.23) and resulted in a Nash coefficient of 0.82 with the modeled nearly matching the observed peak (2,498 CFS vs 2,500 CFS). Even after calibration, adjusted ksat values were reasonable (~0.5 in/hr) and within the range associated with the silty soil type (0.5 - 2.0 in/hr) found across the Fort Cobb basin.

This study successfully calibrated a single event (March,2000) using USGS gage data at an interior location within the Fort Cobb basin by adjusting one parameter (ksat = 0.23). This calibration parameter was applied to a continuous simulation (Oct 1, 1999 – Sept 30, 2002) of the larger Fort Cobb Reservoir watershed. This calibrated simulation, combined with daily baseflow, resulted in nearly perfect model performance (model accumulated flow =1.002 * observed accumulated flow) when compared to the Corps of Engineer lake inflow estimates. This suggests that Corps of Engineer lake inflow estimates may be a reasonably reliable dataset, as far as accumulated volumes are concerned, in the absence of more accurate and conventional datasets (e.g. USGS streamgage data). The transferability of calibration parameters (from interior gage to larger watershed) determined from a limited number of events (one) demonstrates one of the primary advantages to using a distributed, physics-based hydrologic model such as Vflo^{TM}.

Appendix

Setting up Vflo

Watershed Delineation

Vflo has a new feature called AutoBOP which automatically generates a stream network based on DEM data and Stream shapefiles. DEM data was supplied from internal USGS dataset and was at 30m resolution. To minimize computing power, the Vflo basin was resampled to 250 meter resolution. The Vflo generated elevation map (from DEM data) as well as the Stream network. AutoBop default values were used when defining channel cells. The existing river shapefile, from NHD dataset, was used as forcing data when creating drainage network from DEM data.

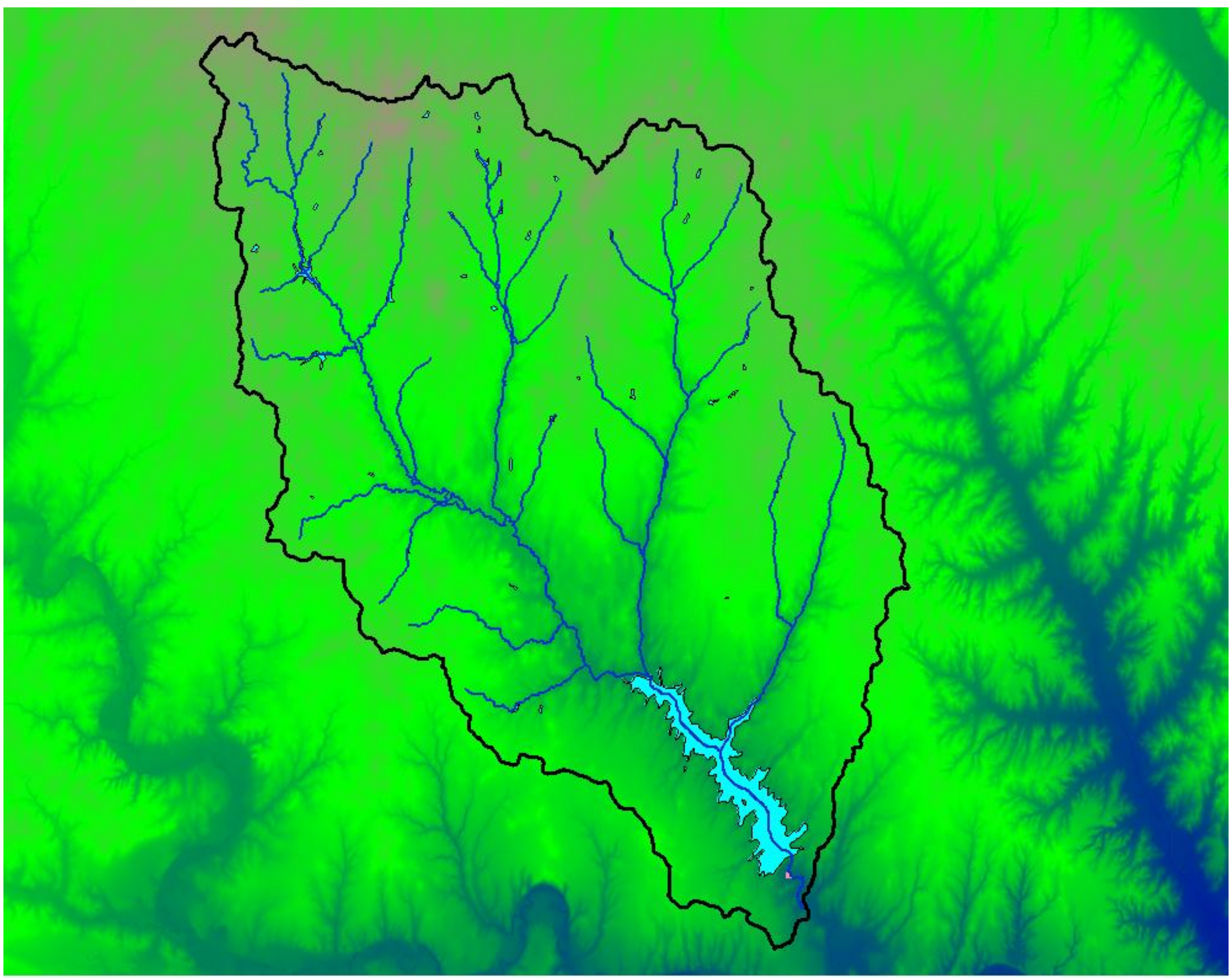


Figure 19: Vflo generated elevation map from DEM data. Rivers are in blue and basin boundary is in black and waterbodies are filled in light blue.

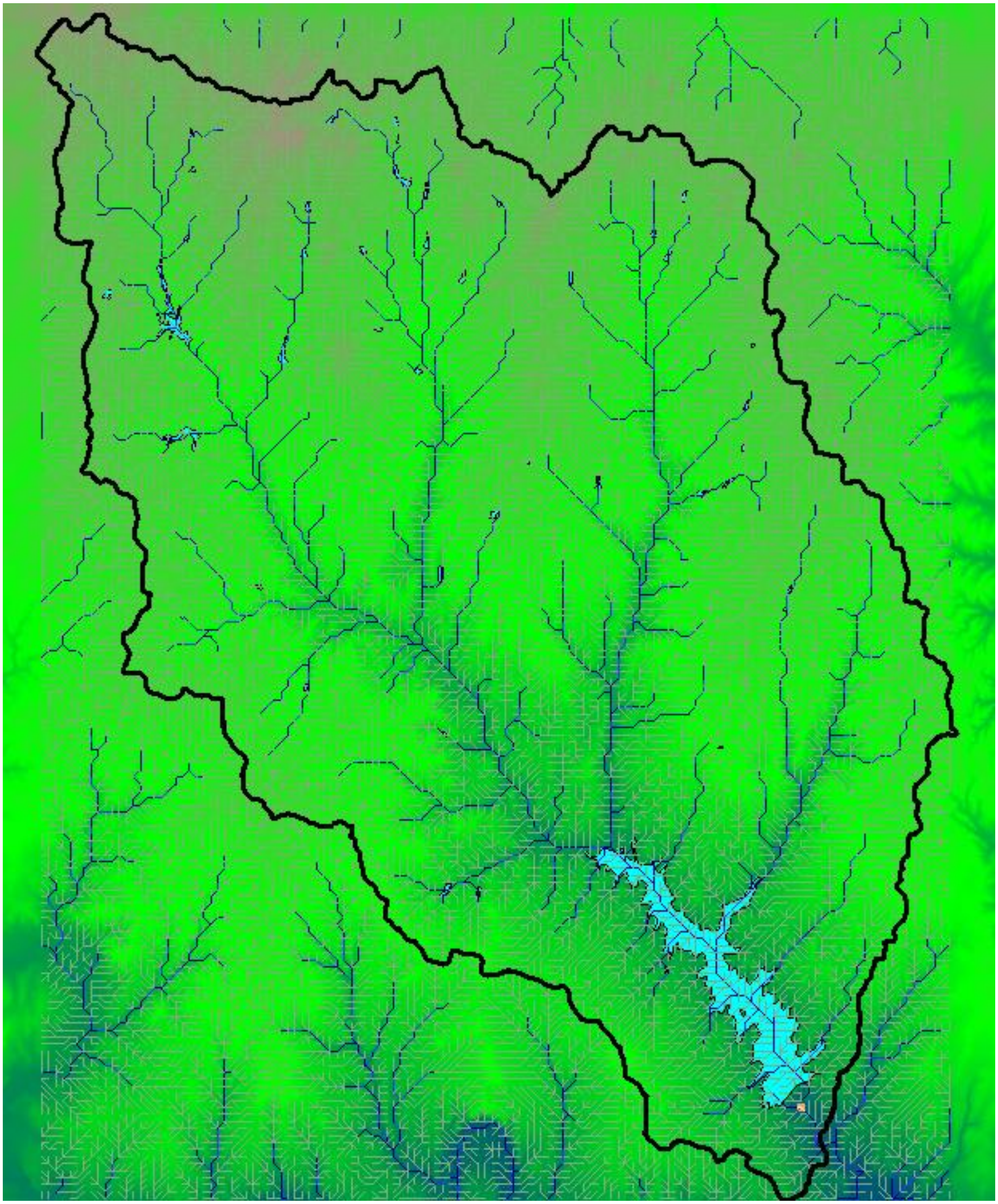


Figure 20: Vflo generated drainage network derived from DEM data.

Channel Width and Channel Cross Sections

To incorporate more realistic predictions, actual channel widths were measured using Google Earth. Roughly 10 locations (Figure 21) were chosen across the basin on various tributaries and on Cobb Creek. These 10 width measurements were imported into Vflo and using the Vflo basin calculator upstream areas were determined. Although some of the widths appear to be on the Fort Cobb Reservoir, they are in reality measured on the main river channel prior to entering the lake. Some of the river widths may have been affected by backwater, locations were chosen using satellite data from Google Earth and every effort was made to minimalize bias from backwater. Additionally, some river widths are shown to be beyond the Fort Cobb Dam. These measurements were not used to establish a width/basin area relationship which was input into Vflo (Figure 22).

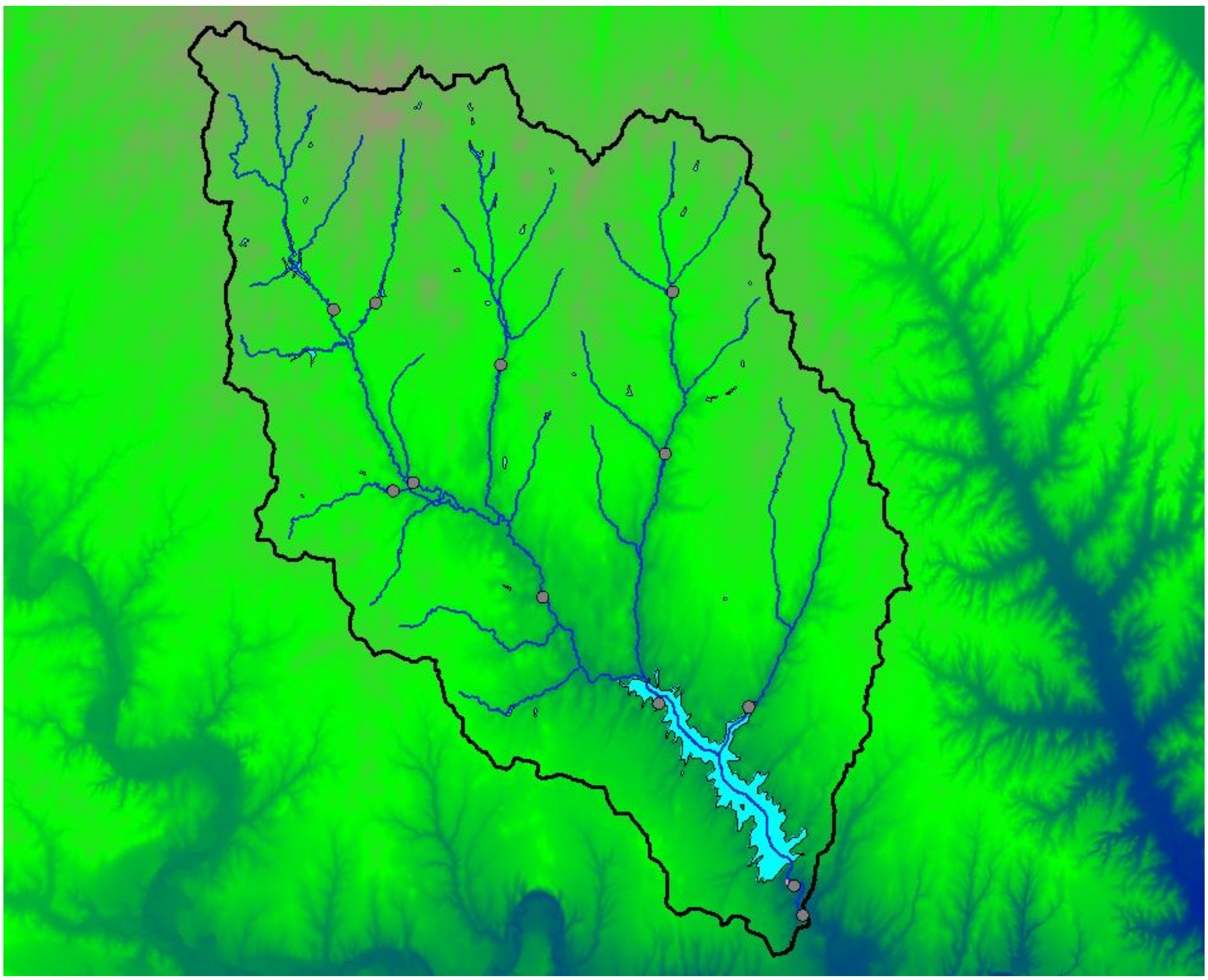


Figure 21: Locations of channel width measurements made with Google Earth. Locations downstream of the Fort Cobb Reservoir were omitted when establishing a channel width/basin area relationship.

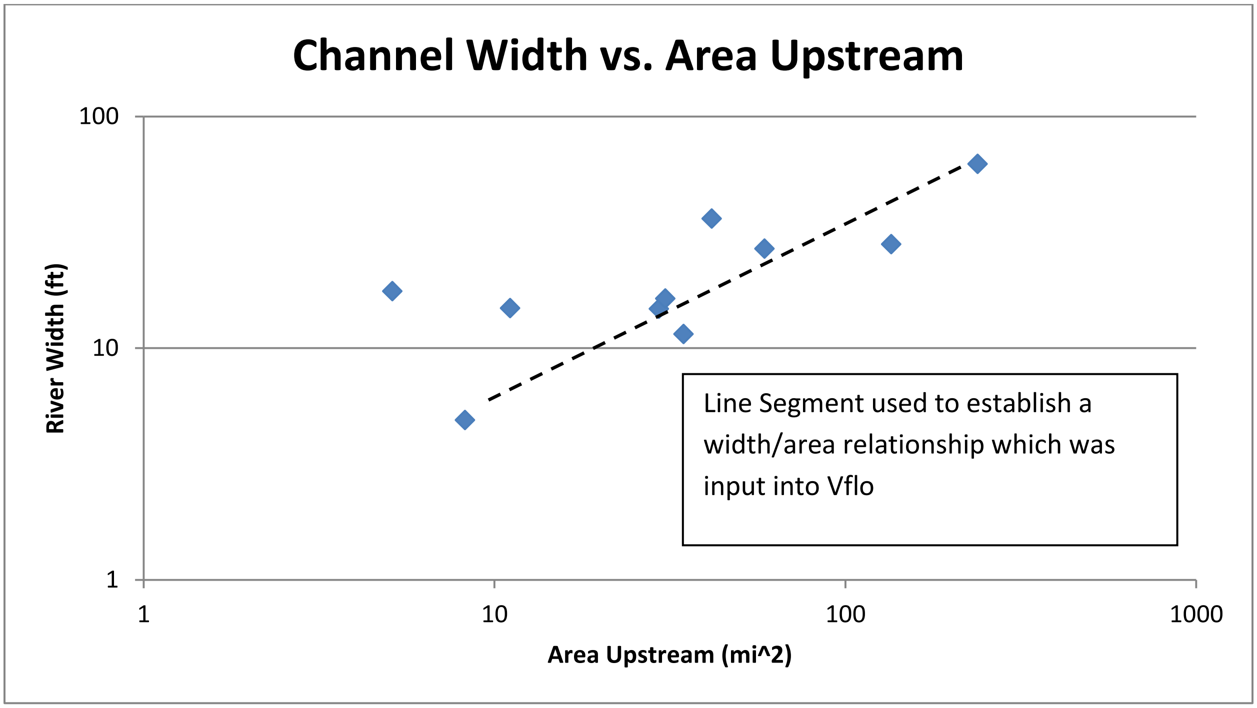


Figure 22: Plot of River Widths vs Upstream Area for 10 selected points in the Fort Cobb Reservoir basin.

Channel Cross Sections were determined from DEM data to better model realistic conditions (Figures 23 & 24).

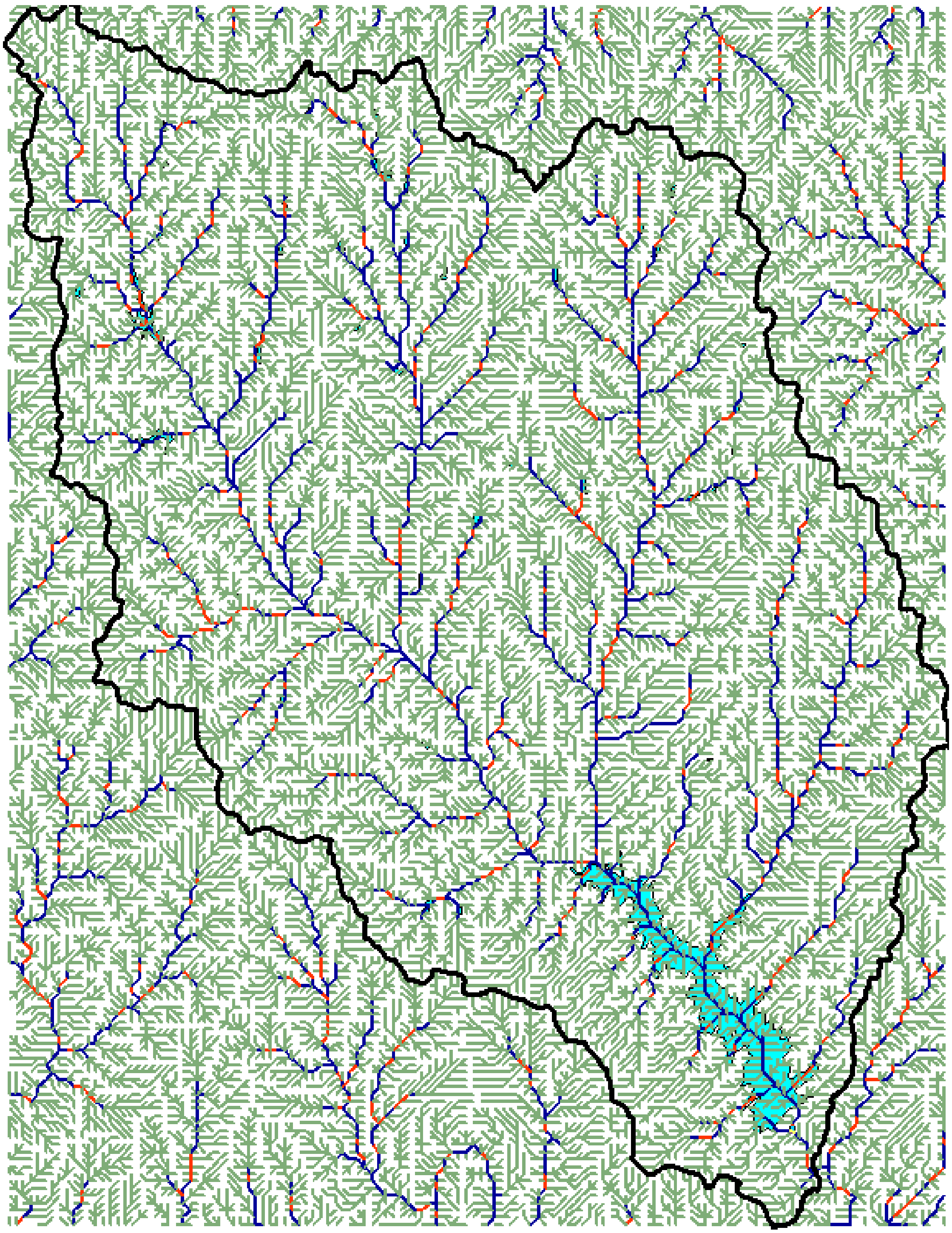


Figure 23: Channel Cross Sections are in Red, Overland Cells are in Green, and Channel Cells are in Blue.

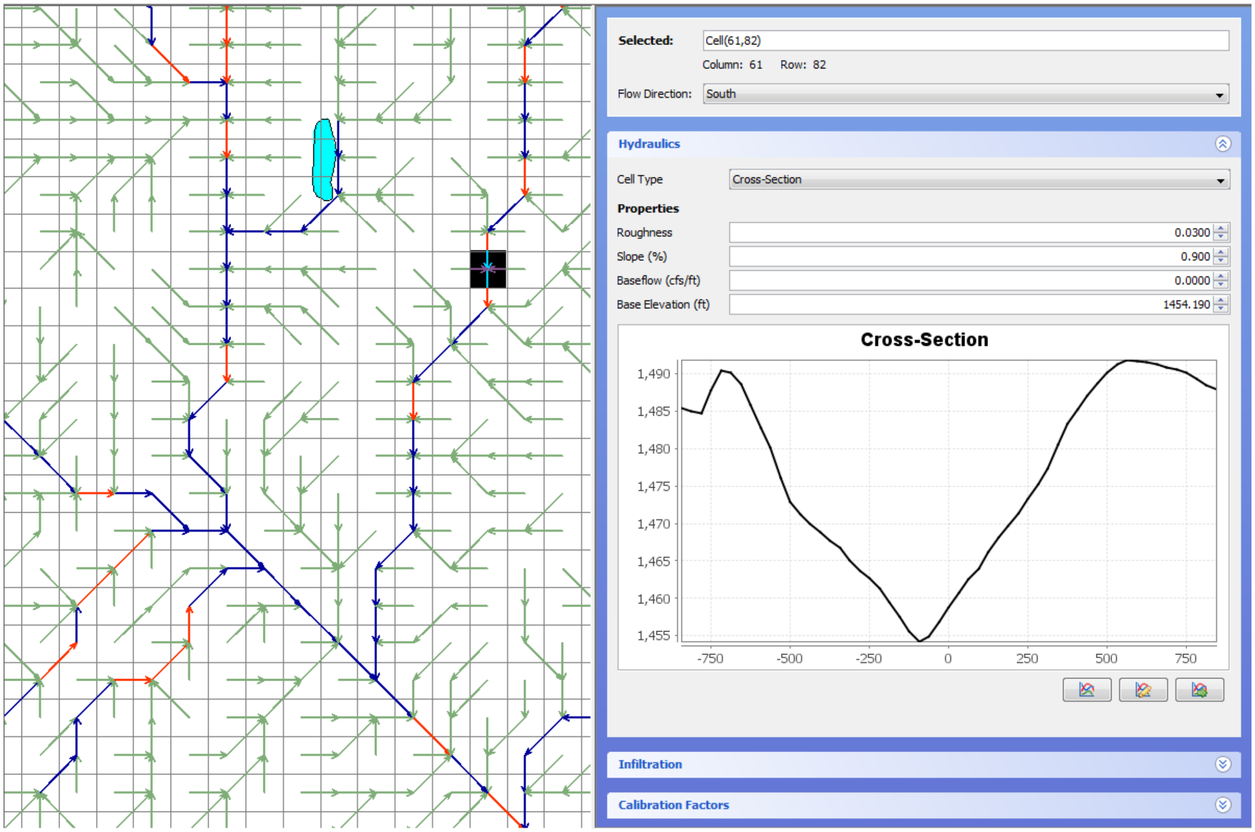


Figure 24: Example cross section from a channel cell.

Green and Ampt parameters

The Green and Ampt equation estimates infiltration into the soil and is a critical component to predicting the rainfall-runoff relationship. To estimate infiltration Vflo needs three parameters to calculate the Green and Ampt equation : Hydraulic Conductivity, Porosity, and Wetting Front. These parameters were supplied by Dr. Vieux in a Lab exercise for the GIS Applications in Hydrologic Modeling course. Below are Maps and statistics from the Vflo BOP file for each of the parameters.

Saturated Hydraulic Conductivity (Ksat) – This is a measure of how fast moisture can move through the soil. Higher Ksat values mean higher infiltration rates. Soils which are sandy and gravelly typically have higher Ksat values. For the modeled basin, Ksat values were generally high which is consistent with the silty soil type which underlies the Fort Cobb Reservoir Basin (Figure 25).

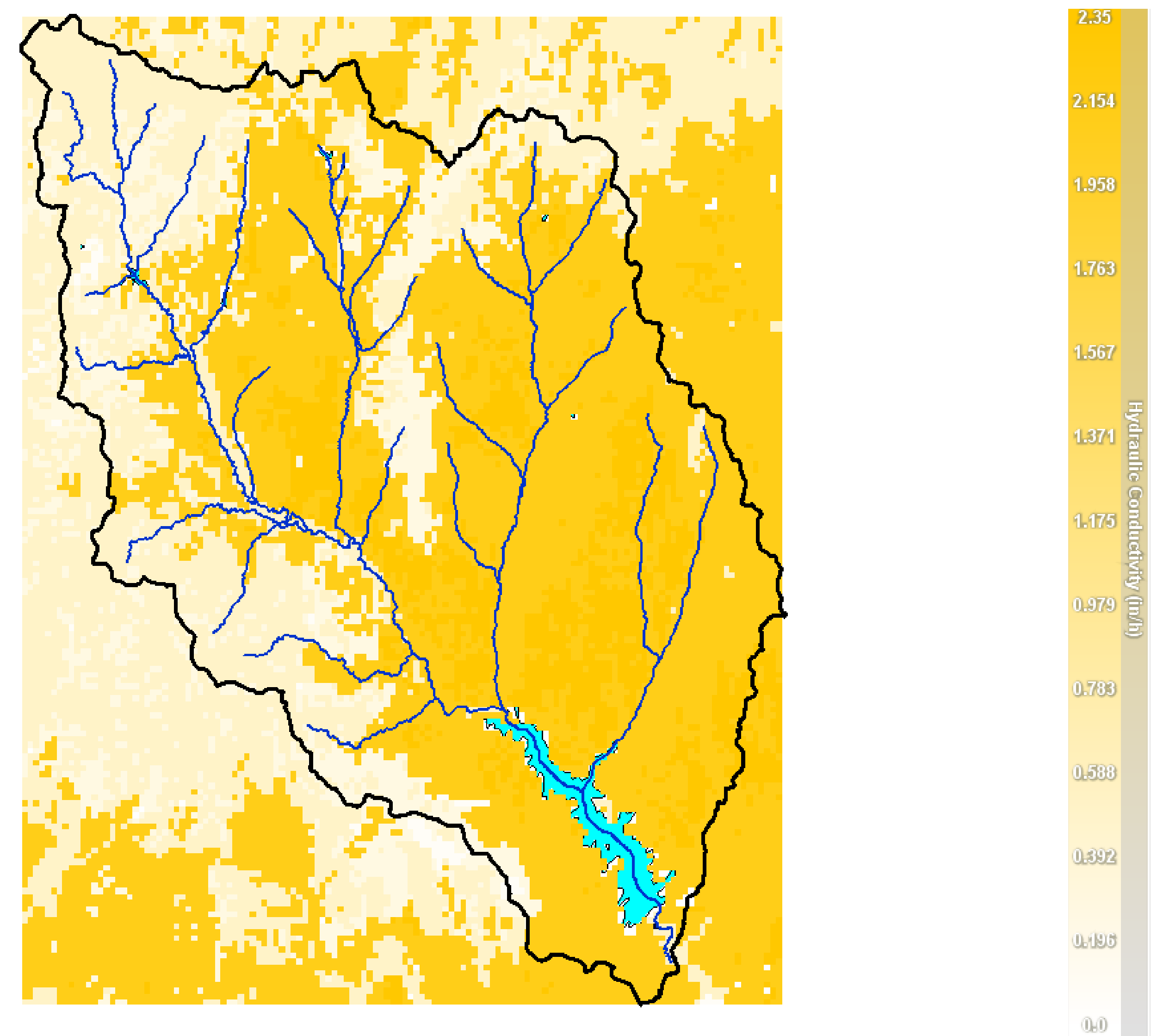


Figure 25: Saturated Hydraulic Conductivity for Fort Cobb Basin.

Porosity – This is a measure of how much water a rock can hold. It is the fraction of rock which is filled with voids which could be filled with water. Sandstone is somewhat porous material (Figure 26).

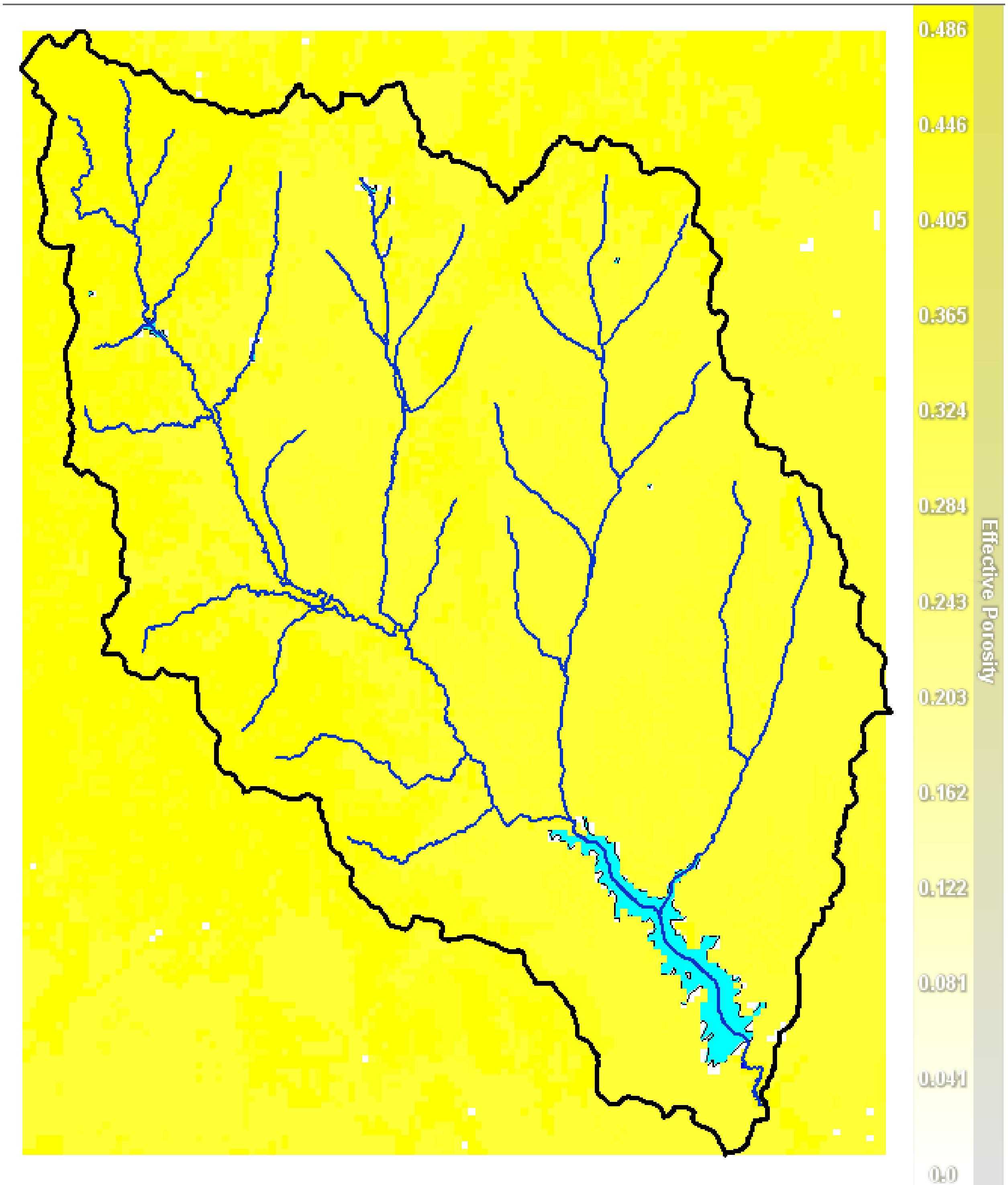


Figure 26: Effective Porosity of Fort Cobb Reservoir Basin.

Wetting Front – The wetting front describes the depth which marks the saturated soil from dry soil as rain infiltrates from above (Figure 27).

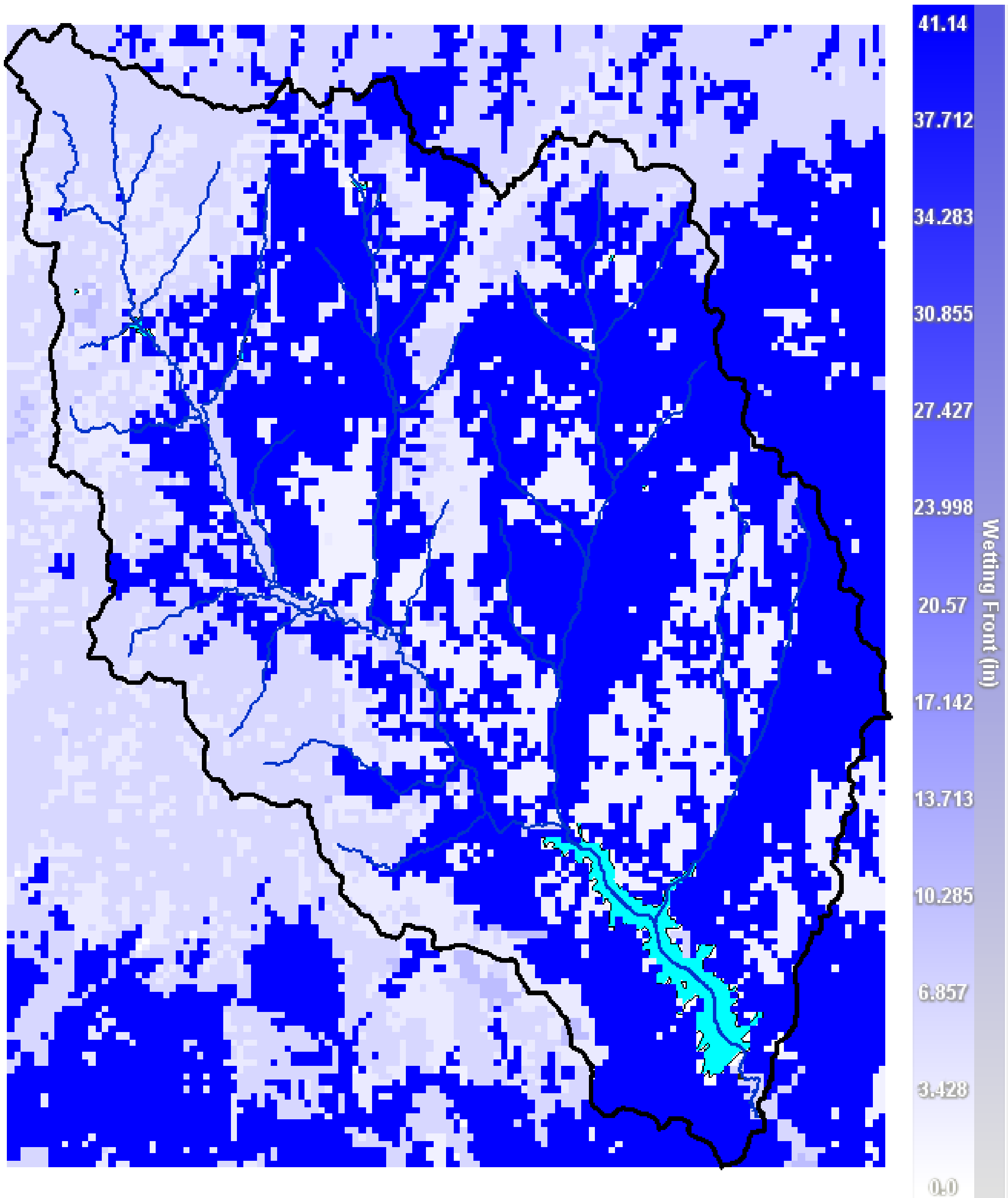


Figure 27: Wetting Front depth for Fort Cobb Reservoir Basin.

Roughness

Roughness is derived from Land Cover datasets. For each land cover there is an associated manning's roughness (n) which describes the difficulty for a water droplet to move across that surface. These empirically derived values are required to calculate manning's equation. Generally the lower the roughness the easier it is for water to move across the surface. There are numerous sources which cite roughness values for various land cover datasets, however, for this study we used roughness values derived from a study over the southeast U.S. The 2006 NLCD Land Use/Land Cover dataset was used for this project (Figures 28 & 29). One deviation from the supplied roughness values was assigning channel cells a roughness of 0.035 per Dr. Vieux's suggestion.

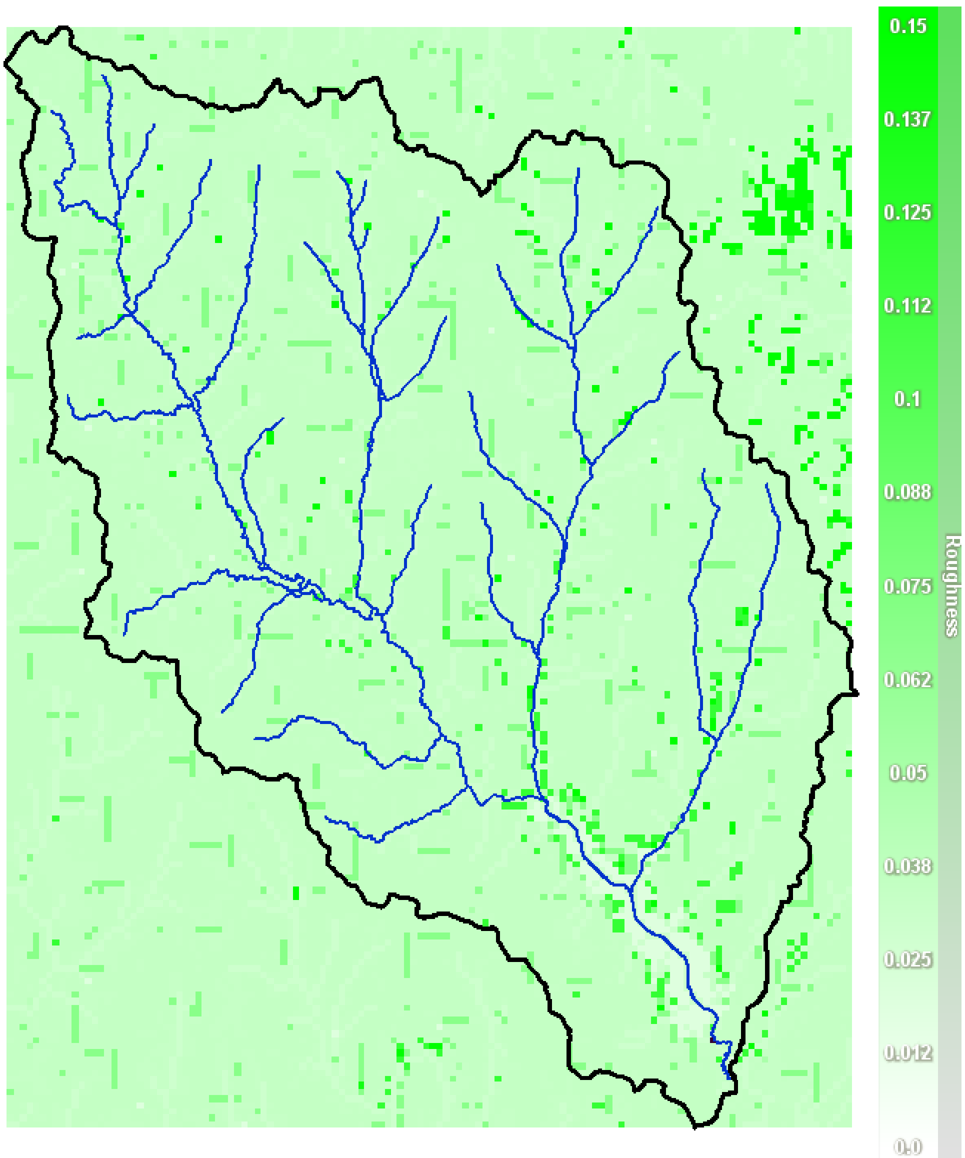


Figure 28: Roughness values derived from 2006 NLCD dataset.

	Description	$z_{0_{land}}$	Manning n
11	Open water	0.001	0.020
21	Low residential	0.330	0.070
22	High residential	0.500	0.140
23	Commercial	0.390	0.050
31	Bare rock/sand	0.090	0.040
41	Deciduous forest	0.650	0.120
42	Evergreen forest	0.720	0.150
43	Mixed forest	0.710	0.120
51	Shrub land	0.120	0.050
61	Orchard/vineyard	0.270	0.100
71	Grassland	0.040	0.034
81	Pasture	0.060	0.030
82	Row crops	0.060	0.035
83	Small grains	0.050	0.035
84	Fallow	0.050	0.030
85	Recreational grass	0.050	0.025
91	Woody wetland	0.550	0.100
92	Herbaceous wetland	0.110	0.040
95	Cypress forest	0.550	0.100

Figure 29: Roughness Values used for Fort Cobb Basin. Courtesy of Wamsley Ty.V.,Cialone,Mary A.,Smith,Smith, Jane M., Ebersole, Bruce A., Grzegorzewski, Alison S., 2009, Influence of Landscape Restoration and Degradation on Storm Surge and Waves in Souther Louisiana, Journal of Natural Hazards, 51: pp 207-224, Table 2

Imperviousness and Soil Depth

Additional parameters such as percent imperviousness and Soil Depth were input. The % impervious was downloaded from the online website seamless.usgs.gov and the Soil Depth was determined from SSURGO data. Incidentally, this watershed is in a very rural area and the % imperviousness was zero. An average soil depth was calculated over the entire basin and was input as lumped parameter (34”).

Evapotranspiration

Dr. Jeff Basara of the Oklahoma Climatological Survey supplied Mesonet calculated evapotranspiration for the entire period of record (1994-2010). The evapotranspiration was extracted from these data files for the Fort Cobb Mesonet station. This was on a daily basis and was input into Vflo as an average hourly amount per day (Figure 30).

Time	PET
01/01/1999	0.000869423
01/02/1999	0.002312992
01/03/1999	0.002575459
01/04/1999	0.001476378
01/05/1999	0.002591864
01/06/1999	0.00277231
01/07/1999	0.001000656
01/08/1999	0.000557743
01/09/1999	0.001755249
01/10/1999	0.002050525
01/11/1999	0.003822178
01/12/1999	0.004839239
01/13/1999	0.00277231
01/14/1999	0.001935696
01/15/1999	0.003543307
01/16/1999	0.004166667
01/17/1999	0.002936352
01/18/1999	0.004133858
01/19/1999	0.00593832
01/20/1999	0.003887795
01/21/1999	0.004248688
01/22/1999	0.002116142
01/23/1999	0.00296916
01/24/1999	0.004265092
01/25/1999	0.002280184
01/26/1999	0.003395669
01/27/1999	0.004888451
01/28/1999	0.002378609
01/29/1999	0.001230315
01/30/1999	0.000557743
01/31/1999	0.001312336

Figure 30: PET data from Fort Cobb Mesonet Station (in/hr).

Running Vflo (Continuous Mode)

Location of Watch Points

There were two main watchpoints used in this study. There was observed data available for both of these points. The first was at the Fort Cobb Reservoir Dam. Figure 31 shows the drainage area of the Fort Cobb Reservoir Dam watchpoint.

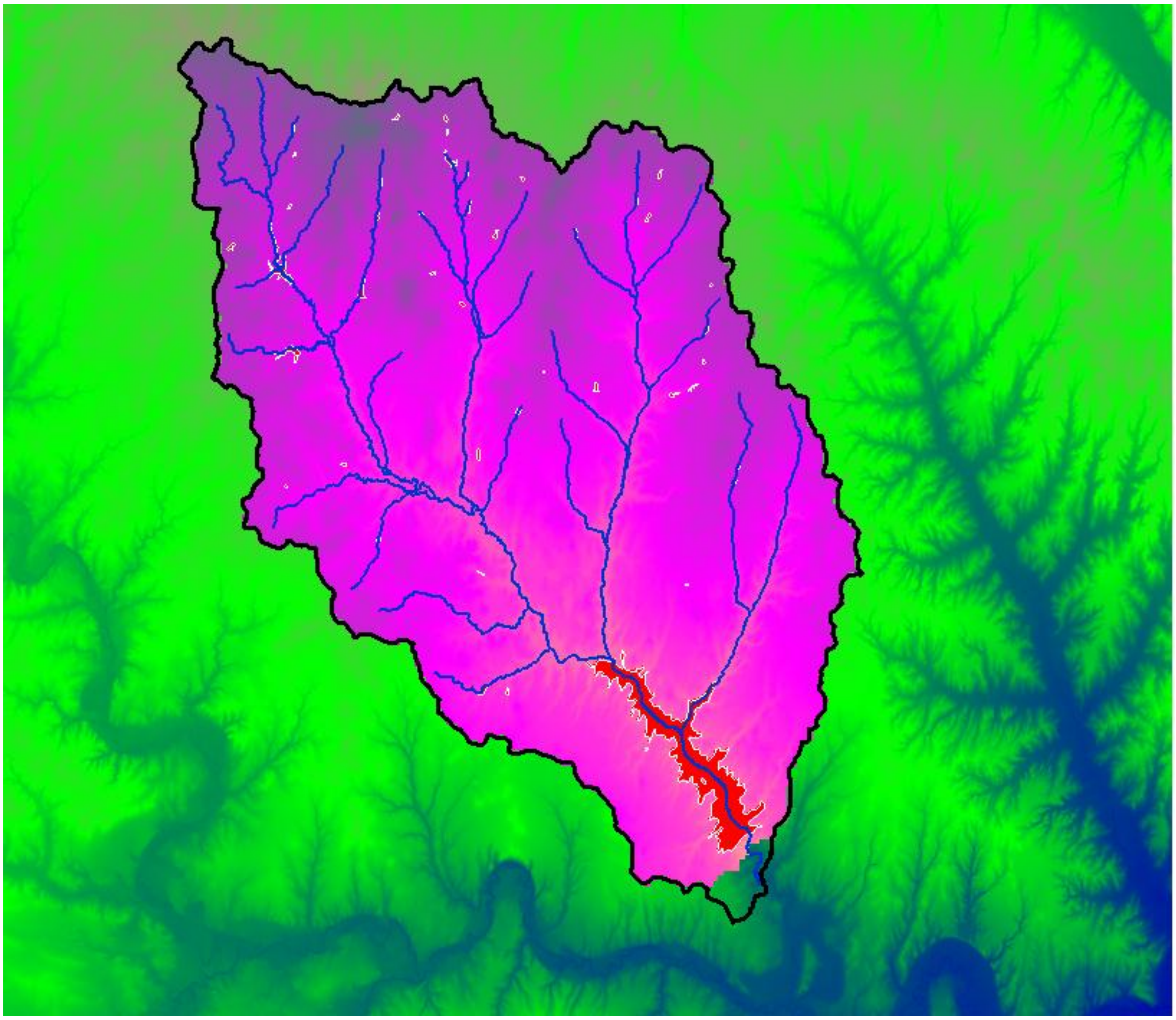


Figure 31: Fort Cobb Reservoir Dam Watchpoint Watershed.

The watchpoint is placed downstream of the dam to allow for some tributaries, which contribute to the reservoir, to be included (Figure 32). This is a reasonable location for the watchpoint as drainage area is 307 mi^2. The Corps of Engineers estimates the drainage area at the Fort Cobb dam to be 314 mi^2 (http://www.swt-wc.usace.army.mil/FCOB.lakepage.html). Basin statistics were generated from Vflo™ and are found in Figure 33.

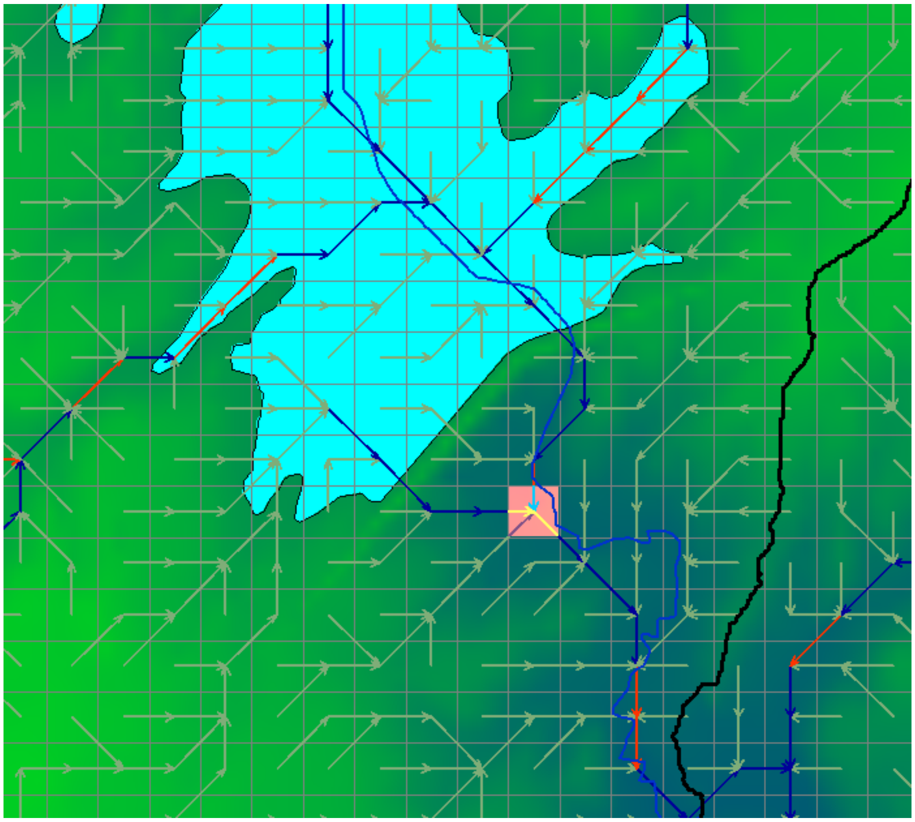


Figure 32: Fort Cobb Reservoir Watch Point which is intentionally placed downstream of dam to include tributaries which contribute to lake levels.

Network Statistics

Cell Information:

Name:	Multiple Cells
Coordinates:	Multiple Cells
Connected Cells:	12763
Drainage Area:	307.99 sq. mi.

Cell Types/Quantity:

Number of BaseCells:	0
Number of Overland Cells:	11379
Number of Channel Cells:	1384
Total Baseflow:	0.0 cfs

Name:	Minimum	Average:	Maximum:
Roughness	0.02	0.037	0.15
Slope	0.0010 %	3.335 %	49.799 %
Hyd. Conductivity	0.0 in/h	1.56 in/h	2.35 in/h
Wetting Front	0.0 in	23.59 in	41.14 in
Effective Porosity	0.0	0.402	0.486
Soil Depth	34.0 in	34.0 in	34.0 in
Initial Saturation	0.5	0.5	0.5
Impervious	0.0	0.0	0.0
Abstraction	0.0 in	0.0 in	0.0 in
Channel Width	1.23 ft	8.651 ft	74.2 ft
Side Slope	1.0	1.0	1.0

Figure 33: Basin statistics for the Fort Cobb Dam watershed.

Another watch point was installed which corresponded to the USGS Cobb Creek at Eakley gage (USGS Gage 07325800). This gage data was used for calibration purposes. The drainage area above this watch point is 132mi^2 which is exactly the drainage area of the USGS gage (http://waterdata.usgs.gov/nwis/nwisman/?site_no=07325800&agency_cd=USGS). Figure 34 shows the drainage area above this watchpoint. Basin statistics were also calculated for this basin (Figure 35).

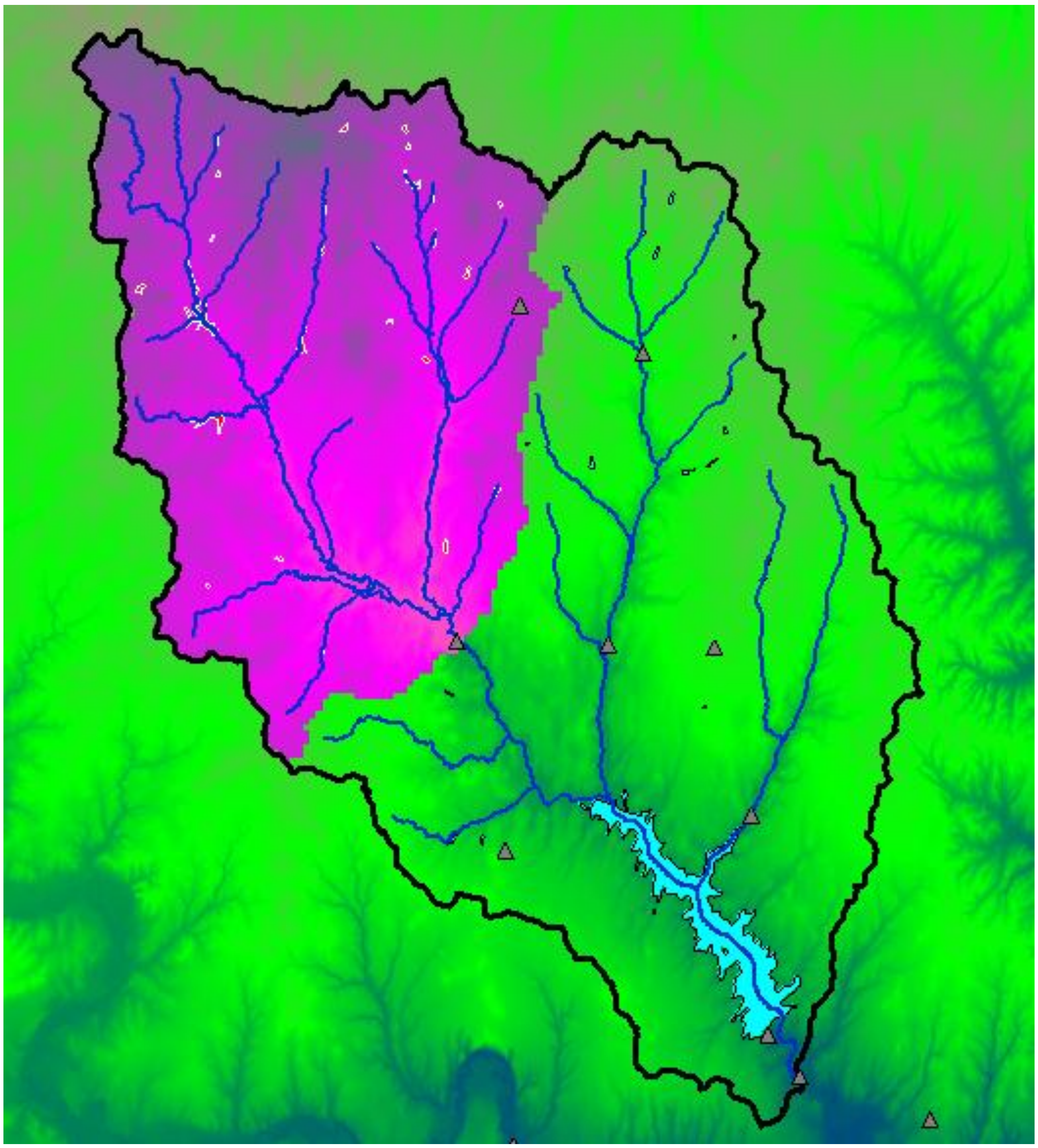
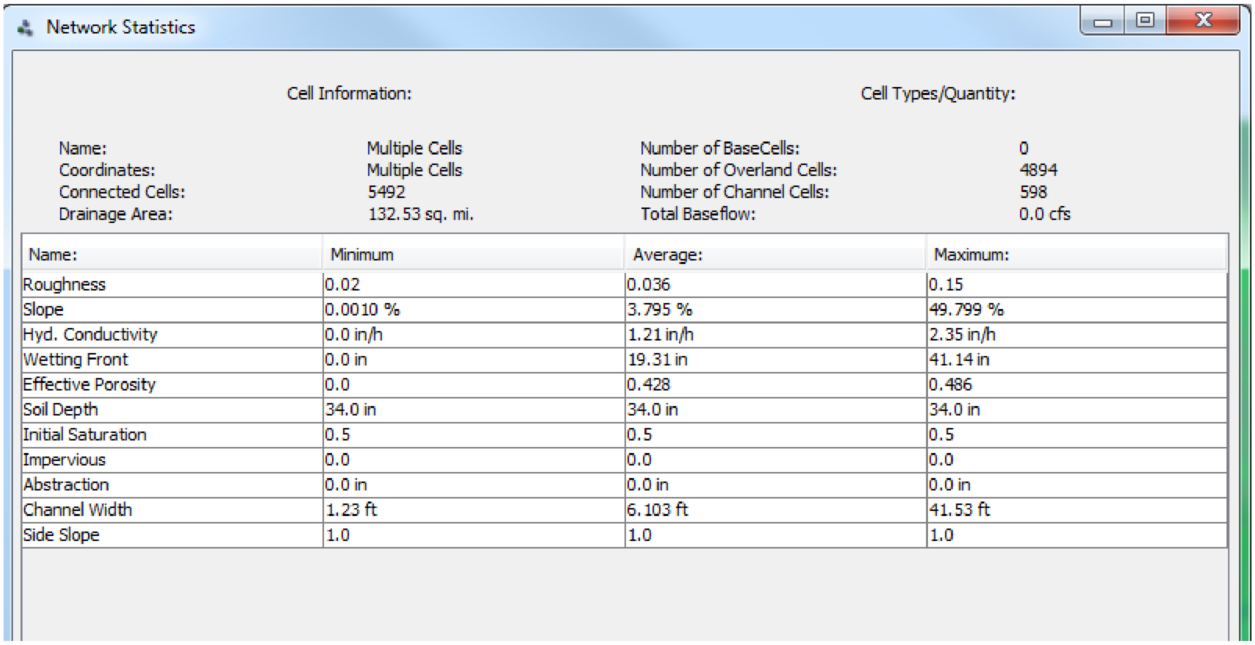


Figure 34: Cobb Creek at Eakley Watchpoint. Corresponds to USGS Gage 07325800 (Triangle).



Network Statistics

Cell Information:

Name: Multiple Cells
Coordinates: Multiple Cells
Connected Cells: 5492
Drainage Area: 132.53 sq. mi.

Cell Types/Quantity:

Number of BaseCells: 0
Number of Overland Cells: 4894
Number of Channel Cells: 598
Total Baseflow: 0.0 cfs

Name:	Minimum	Average:	Maximum:
Roughness	0.02	0.036	0.15
Slope	0.0010 %	3.795 %	49.799 %
Hyd. Conductivity	0.0 in/h	1.21 in/h	2.35 in/h
Wetting Front	0.0 in	19.31 in	41.14 in
Effective Porosity	0.0	0.428	0.486
Soil Depth	34.0 in	34.0 in	34.0 in
Initial Saturation	0.5	0.5	0.5
Impervious	0.0	0.0	0.0
Abstraction	0.0 in	0.0 in	0.0 in
Channel Width	1.23 ft	6.103 ft	41.53 ft
Side Slope	1.0	1.0	1.0

Figure 35: Cobb Creek at Eakley Basin Statistics.

Rainfall Data

XMRG data was used for these simulations. This data was supplied by Dr. Vieux. It consisted of hourly rainfall rates from 1/1/1999 – 12/31/2010. Unfortunately, a large number of these files were corrupted and as such only data from 1/1/1999 – 10/14/2003 was useable. And within the useable dates, there were likely many others which were also bad. Figure 36 shows the total rainfall distribution from the March, 2000 rainfall event.

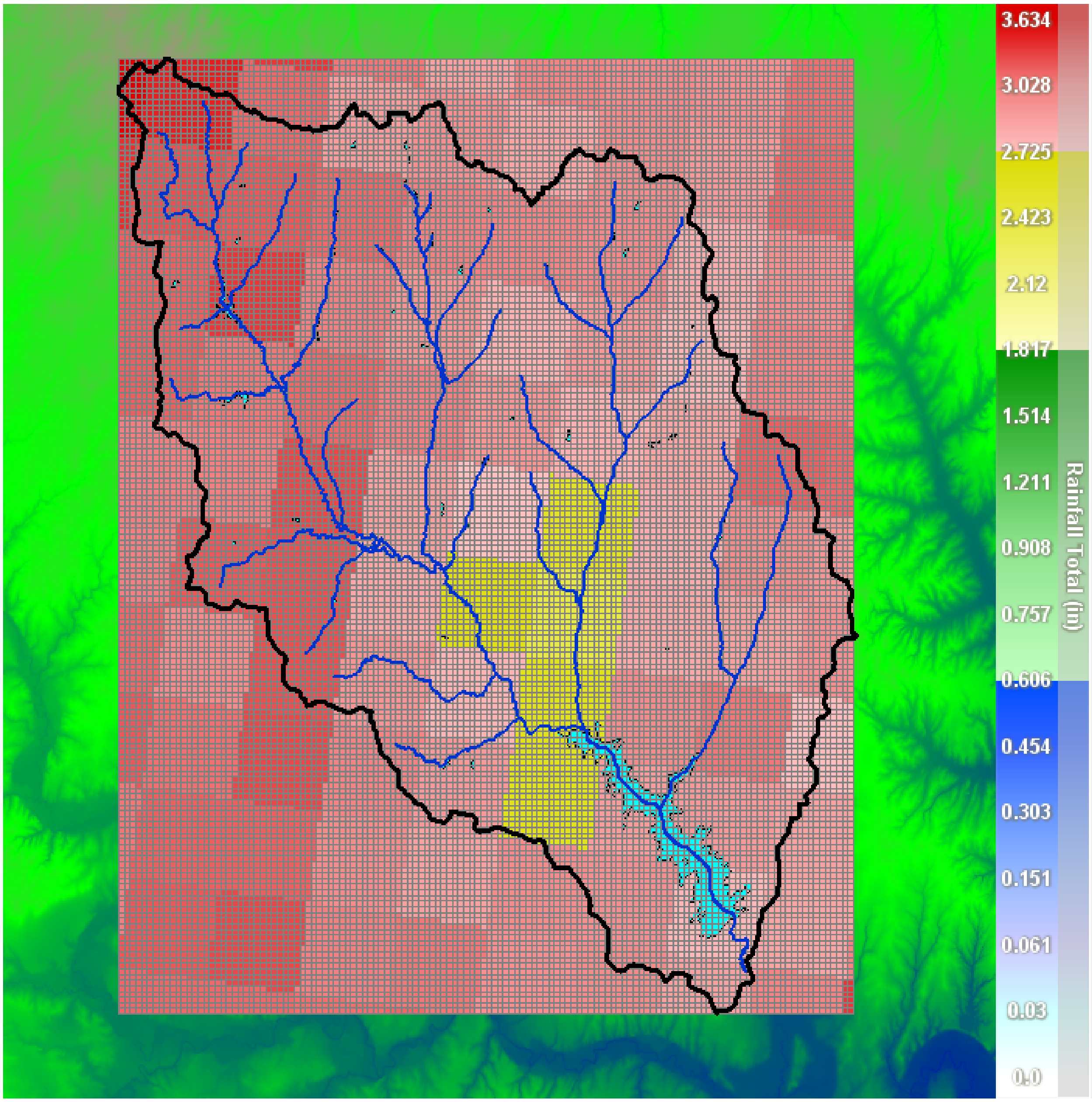


Figure 36: XMRG Data from March, 2000 rainfall event.

Observed Data

Corps of Engineer Data

The Corps of Engineers are currently responsible for releases from the Fort Cobb Reservoir. Daily data, as far back as 1995, is available at http://www.swt-wc.usace.army.mil/FCOBcharts.html. Daily inflow was then extracted from this data and was used as our observed streamflow in the results section. This data is actually reported as Day-Second Foot (DSF) and is equivalent to using the mean daily flow (CFS). There are a couple of uncertainties associated with this data source. It is unknown if this data is routinely quality checked. It is also unknown what time increment the inflow is measured from (midnight - midnight, 7am-7am, or 8am-8am). For purposes of this study it was assumed that the time period was from midnight to midnight.

Baseflow

Baseflow is not estimated by Vflo. To obtain total streamflow, it is necessary to add baseflow to the direct runoff and this is shown in the results section. To estimate the baseflow component to the dam data, a custom file had to be made for input into the USGS PART program (available at: http://water.usgs.gov/ogw/part/). USGS PART program calculated baseflow on a daily basis. These daily estimates were used in conjunction with Vflo output.

USGS GAGE Data

For calibration purposes, the USGS Gage on Cobb Creek at Eakley, OK (Gage ID 07325800) was used. Daily data was used to identify events which could potentially be calibrated and instantaneous data was used to actually calibrate those events.