Hydrologic Model of the Silver River Watershed
Baraga County, Michigan

Surface Water Modeling with HEC-HMS and HEC-RAS

AquaTerraTech

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Introduction

The Surface Water Modeling Group (SWMG) of the Aqua Terra Tech (ATT) enterprise won a Haestad Methods, Inc. competition for the use of HEC-Pack services. The company provided software to model the surface water of the project area in addition to unlimited technical support. This surface hydrology model will be compared to the outputs of a Groundwater Modeling System (GMS) model as a full area calibration for the groundwater model.

SWMG will utilize the software and services from Haestad Methods to:

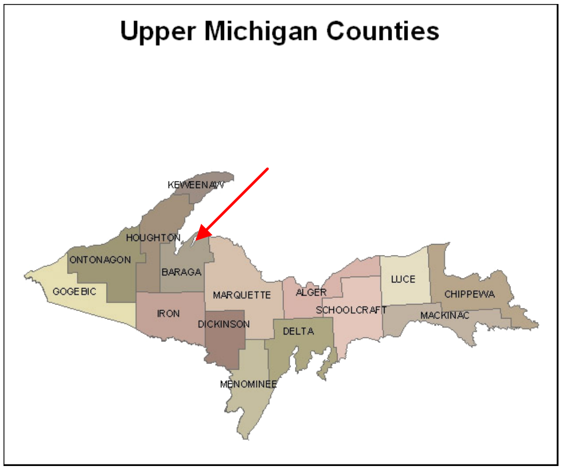
1. build and test a surface hydrology model (SHM) of the watershed
2. estimate river stages for the source/sink conditions in the existing GMS model
3. compare SHM results in ungaged streams to the estimated groundwater discharges to calibrate both models simultaneously

Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) will be used to estimate flows in each subbasins, which contain ungaged tributaries of the Silver River. The HMS calculated discharges will be entered into the Hydrologic Engineering Center River Analysis System (HEC-RAS). This program will predict the river stage along main channels and aids in floodplain delineation. The results from the SHM will be compared to the estimated flows from the groundwater model to calibrate both models. These two models will provide tools for the Keweenaw Bay Indian Community (KBIC) to analyze the effects of future developments.

Background

ATT, a student group at Michigan Technological University (MTU), was started as an engineering consulting enterprise. It currently consists of undergraduate students studying civil, environmental, and geological engineering. MTU created the Enterprise Program to allow students a curriculum path for developing technical skills and business practices in a multidisciplinary project setting. Enterprise teams are managed by the student members, with a faculty member serving as the advisor.

The KBIC is located in Baraga County in Michigan's Upper Peninsula (Figures 1 and 2). The reservation was established by the Treaty of 1854 and encloses 70,327 acres (284600000 m^2) of land, including: 17 miles (27.36 km) of shoreline on Lake Superior , 80 miles (128.75 km) of streams and rivers, 15,000 acres (6070000 m^2) of lakes, and 3,000 acres (12140000 m^2) or wetlands. The KBIC is a sovereign nation established by the US Government in 1936. Having lived on the land for over 150 years, the members of the tribe are striving to better themselves and their standards of living through many means, including education, child care, universal health care for tribe members, care for the elderly, and employment opportunities.



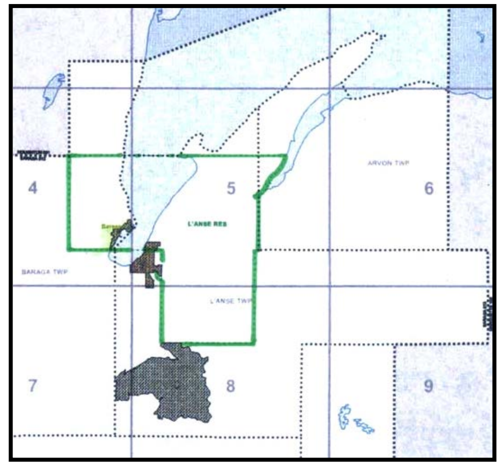


Figure 1: *The Silver River Watershed is located in Baraga, County Michigan. (left)*
Figure 2: *The majority of the basin lies in land owned by the Keweenaw Bay Indian Community. (right)*

The KBIC is rapidly developing and a growing percentage of its land is being used for construction of facilities. The KBIC has an interest in protecting the water resources on its land. Community planners must decide which land should be available for construction and what impacts the development could have on the hydrology of the watershed. A grant from the Environmental Protection Agency (EPA) was awarded to the KBIC and Dr. John Gierke to fund the project in 2000. The objectives of the project were:

1. to assess the hydrogeology within the Herman, Silver, and Zeba watersheds
2. to develop a water budget for the proposed study areas
3. to identify areas of groundwater recharge and discharge

To create an accurate groundwater model, members of ATT collected field-data from the Silver River watershed area using water level meters, seismographs, and Global Positioning System (GPS) Trimble units. These instruments were used to determine the depth to bedrock and groundwater table at various well locations. This data, along with river and stream locations and topographical data, were entered into the GMS groundwater model.

Dr. Gierke led the creation of the ATT enterprise as a means to achieve the objectives of the grant while involving undergraduate students in a professional experience. ATT has been working for 6 years to gather data from the watershed and construct a groundwater model using GMS and Geographic Information Systems (GIS) software programs. With the model nearing completion, it became necessary to calibrate the model, insuring a larger degree of accuracy was achieved.

Objectives and Scope

Objectives

The specific goal of creating the surface water model of the Silver River watershed was dual fold: to check the accuracy of the developing subsurface model of the region, and to provide a tool to the KBIC to assess the impacts of possible development on the watershed.

Scope

This model is a simplified representation of the actual watershed. Minimal field work was conducted to gather the information used in the simulation because the time frame of the project was during the winter, with snow and ice preventing data acquisition. Instead data were collected from established sources which can lead to generalized information. For example, there is no established precipitation gage within the boundaries of the watershed, and nearby sources were substituted. In addition, several components such as watershed slope and Soil Conservation Service (SCS) curve numbers were assumed to be uniform over the area of each sub-basin.

HEC-HMS and HEC-RAS are powerful tools that can design both relatively simple and complex models. The more simple methods chosen for use in these models tend to be more applicable for event based simulation rather than longer term modeling, where greater accuracy requires more complex methods.

Some characteristics of the watershed were estimated or neglected for the simulation. Baseflow to the stream was estimated from past information, and evapotranspiration and soil moisture accounting were neglected for the purposes of the model. Due to the low level of development on the watershed it was assumed that impermeable surfaces could be neglected, when in fact some do exist (roads, bedrock outcroppings, etc.).

Methods & Procedures

HEC-HMS Model

Basin Model

Topographic maps of the entire watershed were obtained from the Michigan DNR website, and the topographic divides were used to estimate seven sub-basins (Figure 3). GMS software's GIS capabilities allowed for accurate estimations of each respective sub-basin's area. Down stream connections and junctions were constructed, and reaches were placed where necessary to separate the sub-basins. USGS stream gage data was collected for the Silver River to serve as a check of total outflow from the watershed.

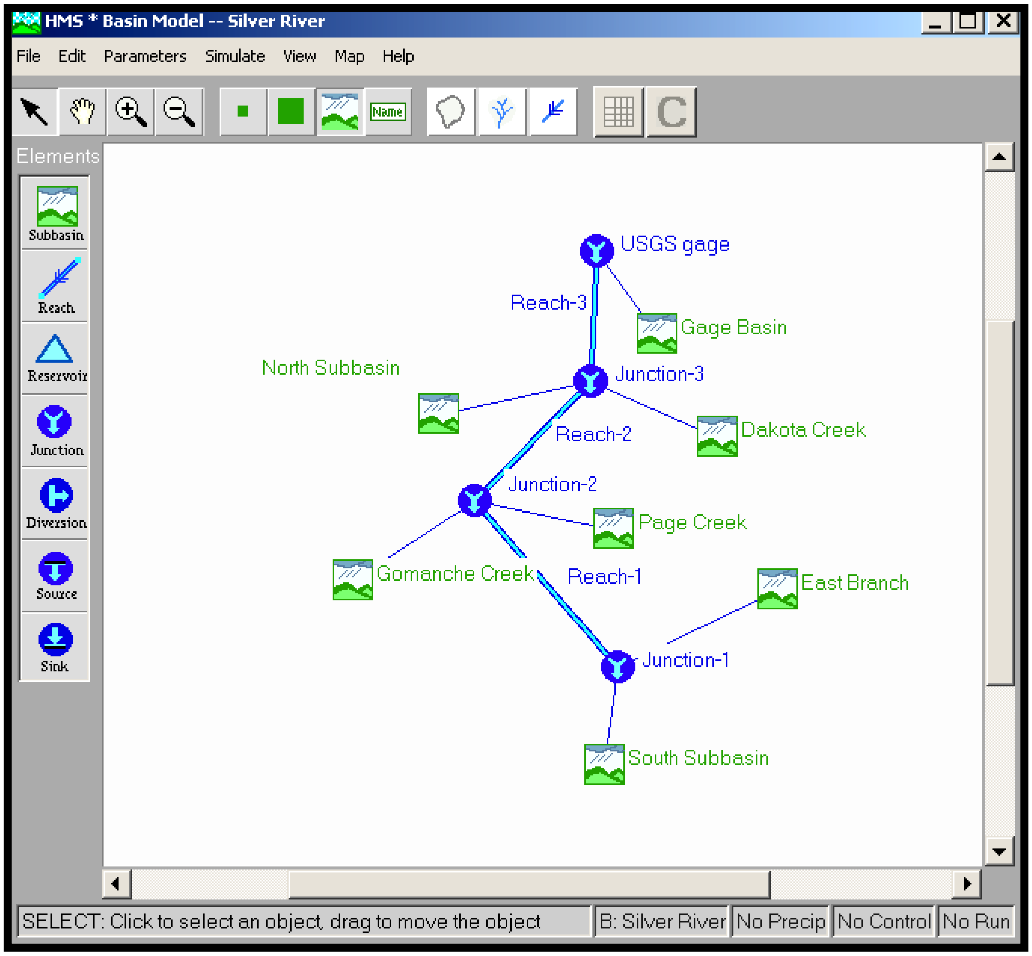


Figure 3: *HEC HMS basin model of the Silver River watershed depicting the seven subbasins and three reaches.*

The next step in the preparing the model was to decide which parameters would be used to simulate the sub-basin. Methods developed by the SCS were chosen to represent this model in the majority of cases. The components imported into the basin model are as follows:

a) Loss Model / Infiltration:

The SCS Curve Method was chosen to determine loss rate. The vast majority of the watershed is wooded, with some variability of cover due to occasional logging or clearing, etc. and a curve number of 58 was chosen to represent the watershed. This value was based not only on the land use, but also the soil type. Based upon a soil report of the area and field experiences, the group chose a type “B” Hydrologic Soil Group (approximately Sandy Loam).

b) Transform:

A simple SCS lag time was utilized to determine a synthetic unit hydrograph for the model’s transform demands. The lag time is the basis for finding the time of concentration, and is dependant upon the length to the divide, average watershed slope, and SCS curve number. The length of stream and the average slope were found using the digital representation of the watershed from GMS, as previously stated.

$$t_p = \frac{l^{.8} \cdot \left(\frac{1000}{Cn} - 10 + 1 \right)^{.7}}{1900 \cdot y^{.5}}$$

c) *Baseflow:*

The baseflow contribution to the watershed was represented using the constant monthly option. Discharge data from two years of the USGS gauging station on the Silver River were analyzed on a monthly basis to estimate total baseflow at the final discharge point. The contributing component from each subbasin was determined using the total length of perennial stream in the respective subbasins, and each subbasin's land area. Both the fractional area and fractional stream lengths were averaged to determine what percentage each sub-basin contributed to total baseflow.

d) *Reaches*:

The Muskingum Cunge Standard method was used to simulate the reaches in the model. Archived data from several river walk observations were used in determining general characteristics of the channel. The channel was modeled as a prism. The reach length and energy slope were found using topographic maps. The bottom diameter and side slope of the steam were determined from the field walks. Manning n values were determined with standard tables, with the model representing a typical upper Great Lakes region river.

Meteorological Model

Precipitation data was obtained from Herman Weather Station in Herman, MI approximately 1.5 miles (2.41 km) southwest of the watershed. Precipitation was considered constant over the entire watershed. Due to the lack of other stations, relative closeness of Herman, and lack of weather affecting topography, no attempts were made to distribute rainfall. Daily incremental data were entered into a simulated rain gage, which was applied to each sub-basin. Precipitation data for the entire time period were entered for modeling.

Control Specifications

Control specifications for the model were designed to encompass the full time period for which discharge data were available from the USGS gauging station. This provided ease in comparison, and allowed easy determination if the model were accurate over a long period. The dates for the control specification were set from 10/01/99 to 9/30/2003, with a time interval of twenty four hours.

HEC-RAS Model

The HEC-RAS model was constructed to determine surface water elevations, floodplains, and to calibrate the GMS model. Cross-sections of the rivers were estimated to be trapezoidal, with information on width and depth from data collected during past river observation walks for approximately 10% of the river length modeled. River characteristics were estimated in areas for which no information was available. Over-bank topography was constructed based quadrangle maps at the river cross-section locations. Additional cross sections were created using an interpolation feature of the software.

Manning's n values were chosen from a table of standard values for natural channels. Information on the composition of the banks and river channel was collected from river observation walks and reasonable estimates were made where no data was available. Testing revealed that the value chosen did not have a significant impact on the model.

Flow data collected from the HEC-HMS model was utilized to provide control points in the model. Flow was assumed to be uniform and steady. The HEC-HMS model output was only for the discharge from each subbasin, meaning that flows needed to be estimated in the upper portions of each reach. Baseflow at the head of each river was assumed to be 5cfs (.142 m^3/s), a conservative estimate. This estimate means that the model will show slightly higher volumes of water in each reach, resulting in a degree of safety in floodplain estimation. Calculated monthly baseflow data is shown in Appendix A. Flows at intermediate locations were determined by linear interpolation of the discharge and estimated base flows.

Known water depths at the gauging station were used as a limit for the model. Other specified flow points were limited by normal depth, with slope being calculated as the change in river height divided by the length of river in the subbasin.

Results and Discussion

HEC-HMS Model

The HMS model was run for the time period per the control specifications. An output hydrograph of the model was produced at the simulated gauging station (Figure 4). The results from the two year simulation can be compared to the actual measured flow rate at the USGS gauging station on the Silver River (Figure 5).

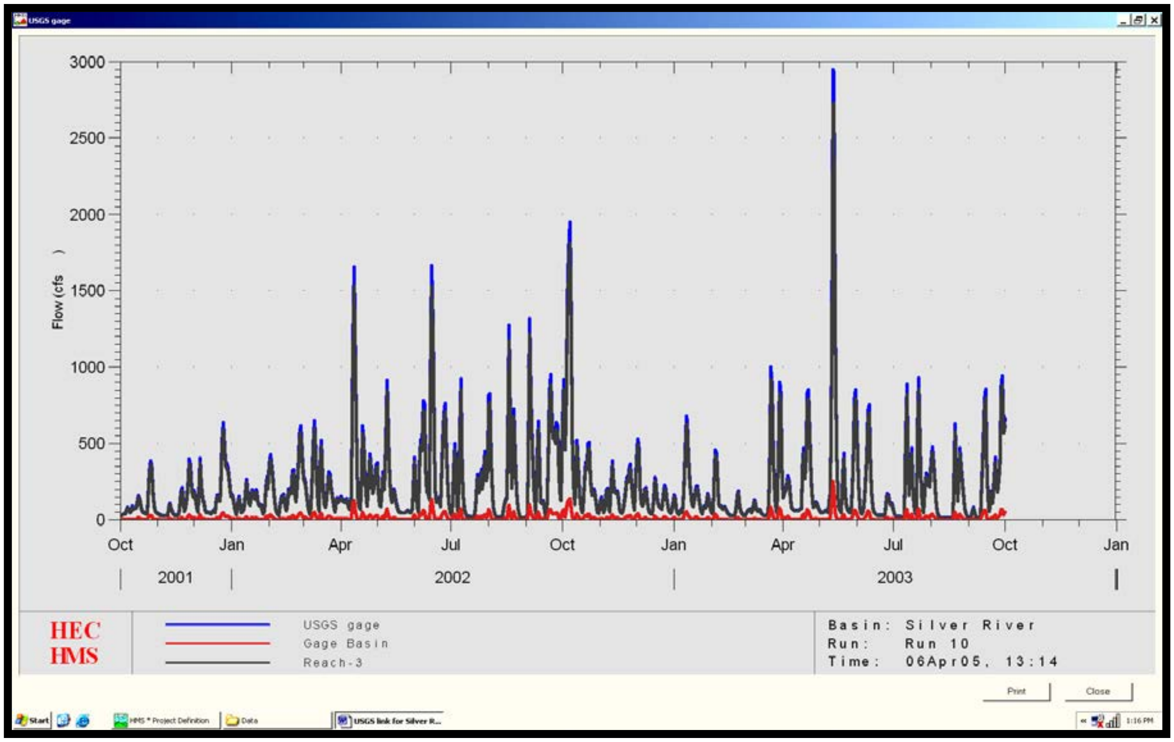


***Figure 4**: Outflow hydrograph generated from HMS model at the simulated USGS gauging station.*

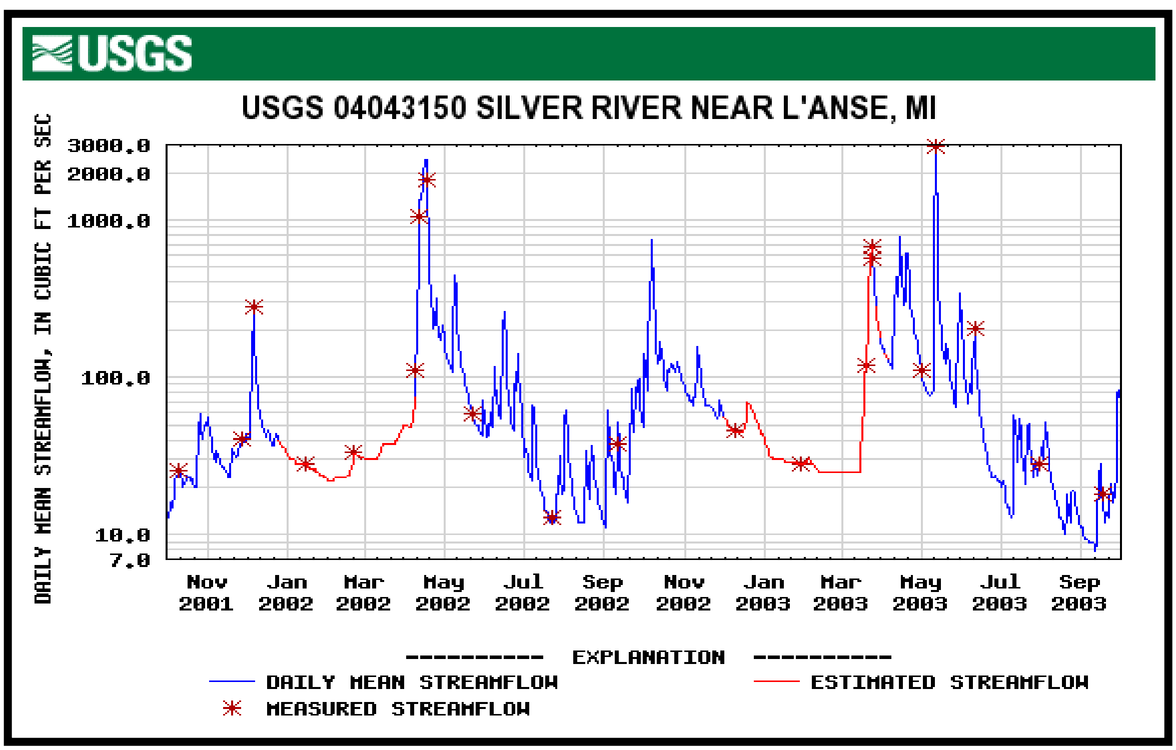


***Figure 5:** Recorded data from the USGS gauging station on the Silver River.*

The outflow hydrographs indicate that the HMS model has a clear correlation with the measured data. The model shows a great variety of flow peaks, which are often between 500 cfs (14.16 m^3/s), and 1000 cfs (28.32 m^3/s),. These peaks do not commonly occur in the actual data. This is possibly due to the model being more sensitive to small precipitation events than the actual watershed due to neglecting evapotranspiration and soil moisture properties. The model seems to produce acceptable results of predicting when the peak discharges will occur, and the peak flowrates at those maximums are close to known values.

Table 1: *Comparison of recorded discharge and model predictions of annual peak flow rate.*

	Date of Peak		Peak Discharge (cfs)	
	USGS Measured	Model Predictions	USGS Measured	Model Predictions
2002	17-Apr-02	12-Apr-02	2,650	1655
2003	12-May-03	12-May-03	3,180	2951

The HMS model yields reasonable results. The observed tendency is for the model to over predict the impacts of small precipitation events, and underestimate the magnitude when flowrates are large (Figure 6). For nearly the entire duration of the control specifications, the model predicts greater discharge results than are actually encountered, except during the spring melt season peak.

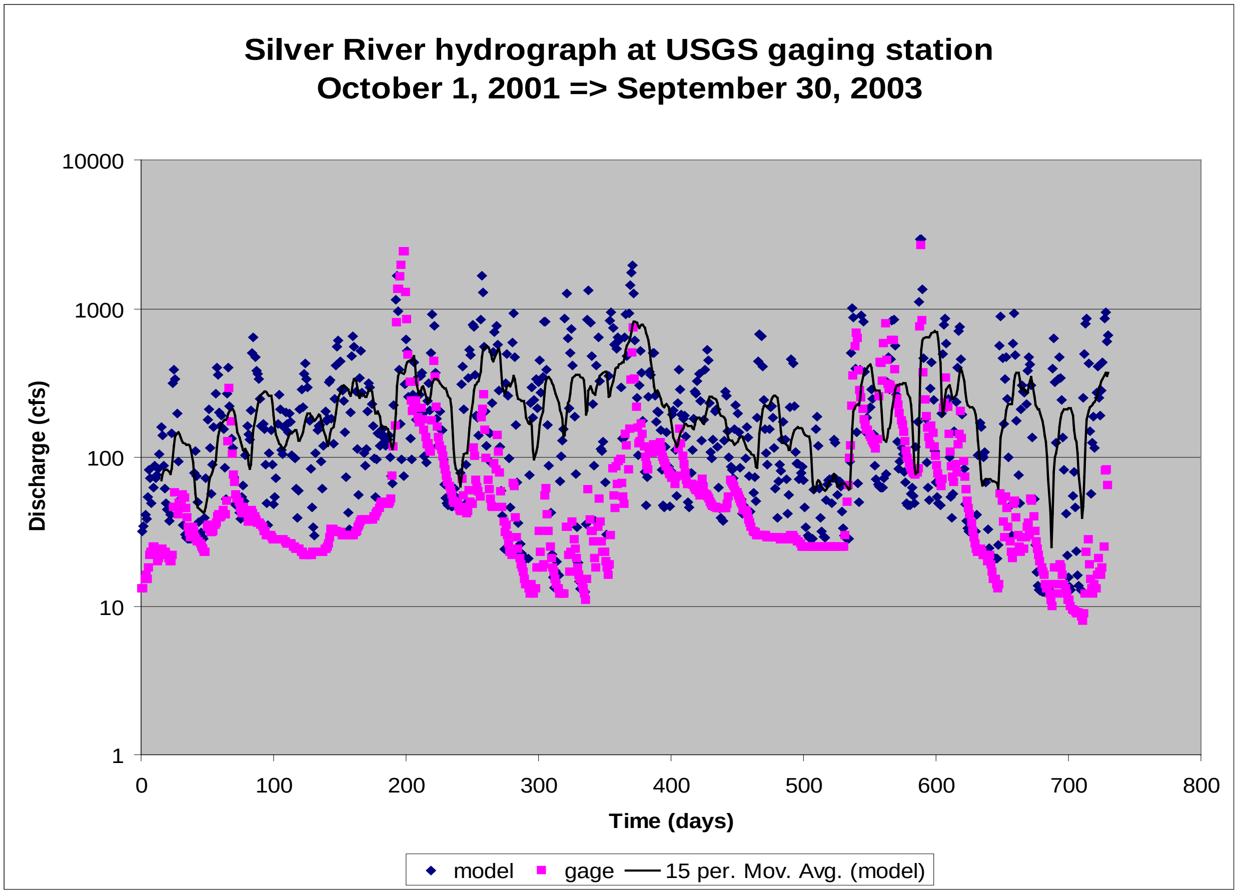


Figure 6*: Scatter plot of the daily average discharge data from both the actual USGS gauging station and the HMS simulated gauging station, along with the 15 day moving average of the model data.*

There are several possible explanations for this seasonal phenomenon. The comparison to the actual data is likely related to the climate of the region. The beginning of April is when the heavy snowfalls from the previous winter most commonly melt. Although this hydrological component is reflected in the increased baseflow for the month, a sudden increase in temperature combined with rain on frozen ground (which is not accounted for in determining the SCS curve number) can produce high flowrates quickly with little actual precipitation perceptible to the HMS model.

The model's increased reaction to common small precipitation events may be due to the simplicity inherent in the simulation. Although infiltration, lag time, etc. are accounted for in small ways, a more complex system exists in nature, with varied slopes and terrain, fast and slow water flow areas, evapotranspiration, vegetation interception, etc. Many natural forces in this relatively undeveloped watershed keep the system much more stable than what this simple model tends to predict.

HEC-RAS Model

The HEC-RAS model for the Silver River (Figure 7) was run with the peak flows predicted by the HMS model for 2002 and 2003 from delineated sub-basins. The program outputs predicted flow at points in the rivers sections including critical or subcritical flow and energy grade line. Data can be viewed as water surface profiles (Appendix B) or as an isometric view of rivers and water levels (Figure 8).

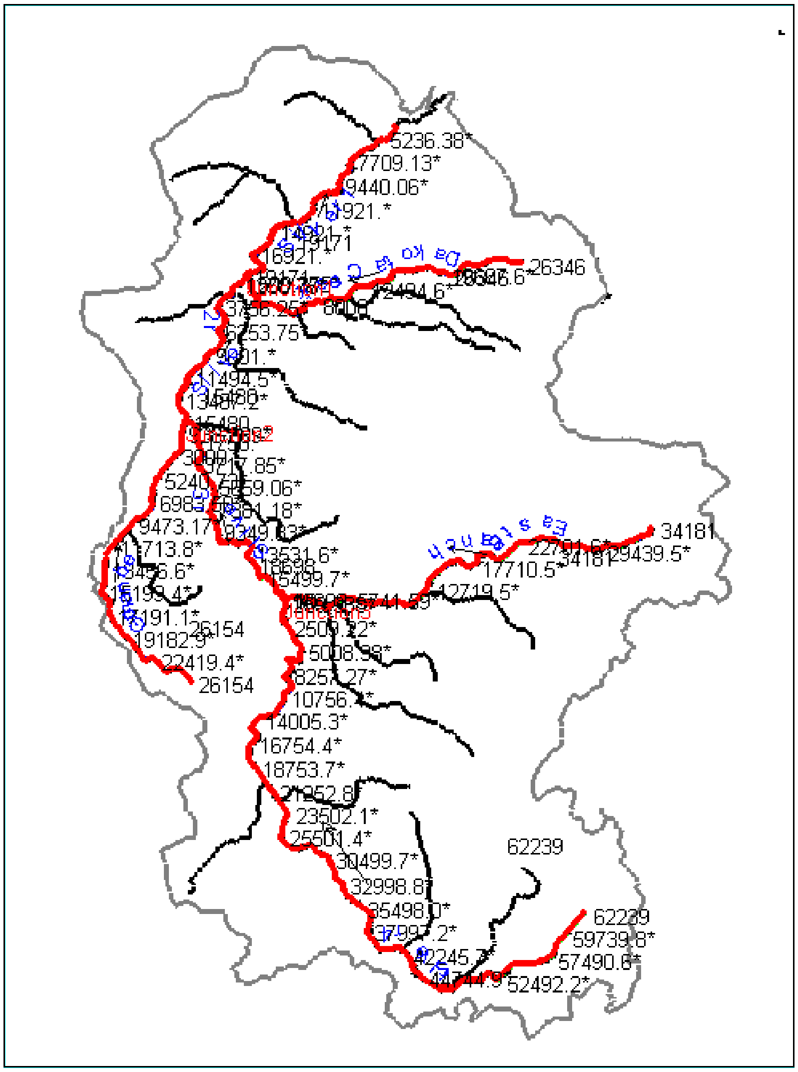


***Figure 7:** The HEC-RAS Model Geometry (plan view)*

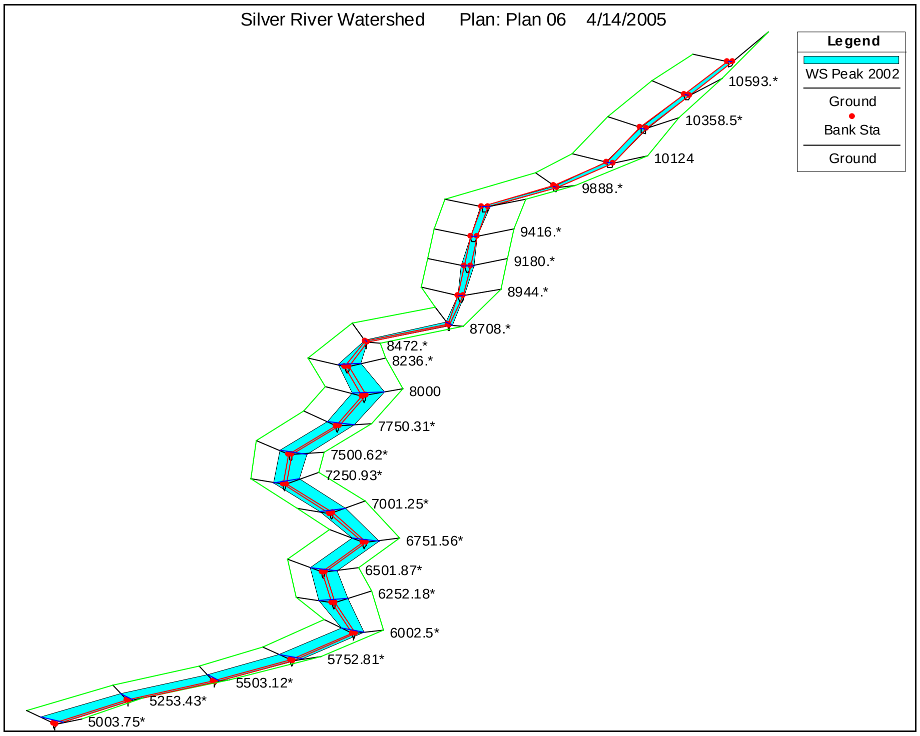


Figure 8: *Isometric view of the lower Dakota Creek during predicted flooding in 2002.*

Cross sections along the river can be viewed to show elevations at points along the river (Figure 9). The results of the analysis show that there was flooding during the peak flows of both 2002 and 2003. Floodplains were generally within 100 feet (30.48 m) of the river with the exception of a few points.

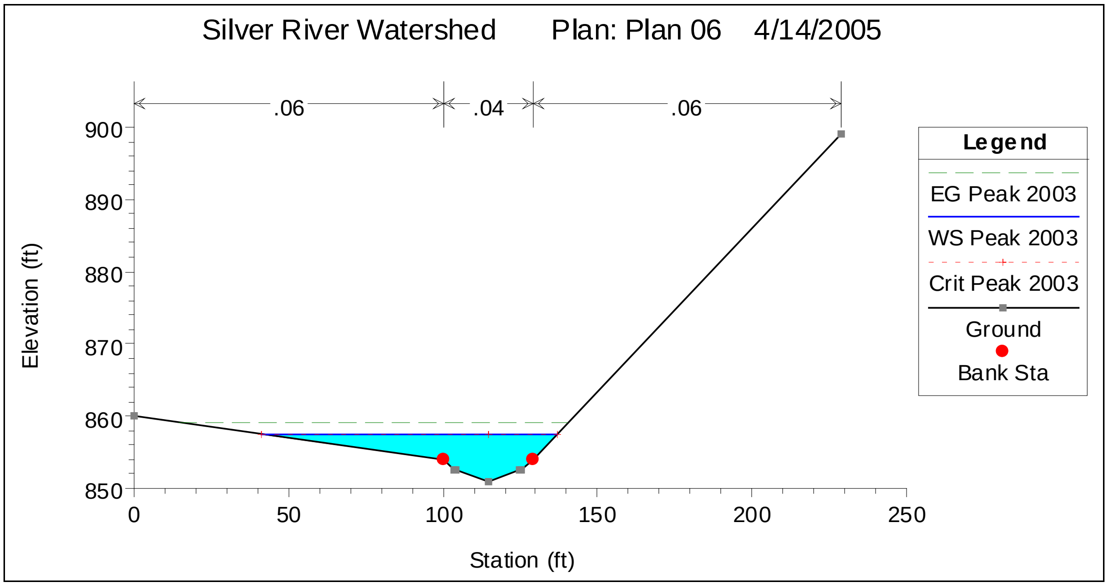


Figure 9: *Cross section showing flooding in the Silver River near Arvon road.*

There are several potential sources of error in the HEC-RAS model. Some flow data was obtained from the HMS model, which has its own sources of error. The remaining flow values were estimated using the team's engineering judgment. River-walk profiles from 2002 and 2003 were completed for only a small portion of the rivers modeled. The remaining cross sections were estimated from topographic maps and previous modeling experience. Manning's n values were assumed from a table of known values, but not checked in the field. Also, one value was applied to the entire channel which discounts the effect of changing channel conditions.

Comparison to Groundwater Model

The final flow results from the HMS model were compared to ATT's groundwater flow model for the Silver River region. The average flowrates for the duration of the control specifications were tabulated for (Table 2).

Table 2: *Comparison of flow results between the HMS and GMS models, as well as adjusted HMS results.*

Location	HEC Flow (cfd)	HEC adjusted (cfd)	GMS Flow (cfd)	Ratio	Ratio adjusted	% Difference between models
USGS Gage	20206995	7216784	8965381	2.25	80.5%	19.5%
Gomanche Creek	1376441	491586	658000	2.09	74.7%	25.3%
East Branch	4779341	1706908	1820106	2.63	93.8%	6.2%
South Subbasin	5777218	2063292	1040511	5.55	198.3%	98.3%
Junction 1	10556636	3770227	2860617	3.69	131.8%	31.8%
Junction 2	13865602	4952001	4394466	3.16	112.7%	12.7%
Junction 3	18800841	6714586	7963961	2.36	84.3%	15.7%

The output results from the HMS model are substantially higher than those derived from the groundwater flow water. The basis for comparison was the *average flows* for the two year period for each of the subbasins used in the study. As previously noted, the HMS model yielded consistently higher outputs than the stream gage for all but the peak conditions. The comparison to GMS reaffirms this observation, and was cause for further evaluation of the HMS model.

One of the major components of the hydrologic cycle that was neglected during the construction of the HMS model was evapotranspiration. In a heavily forested region, such as the Silver River watershed, this factor is significant.

A water budget of the region has been prepared (Appendix C). The evapotranspiration calculated from the water budget was subtracted from the flow results of the HMS model to obtain HEC adjusted flows. When the adjusted flow outputs of the HMS model were compared to the GMS model, the results become much closer to one another. When all subbasins and junctions are compared, the models average within thirty percent of one another. If the largest anomaly, the South Subbasin and its effects on Junction 1, are not included the models are within fifteen percent of one another.

This analysis illustrates the importance of all components of the model when constructing longer time scale simulations. Ignoring evapotranspiration had a dramatic impact on the results, which became exposed when the models were compared to both a known gauging station and an independent GMS model.

Conclusions

The HEC models have been completed to sufficiently meet the objective of calibration for the GMS model. Computed flows were within a reasonable range between the two models. The RAS model is working and can be utilized to roughly determine floodplains within the Silver River watershed.

Future Recommendations

Based on the performance of the model some recommendations for future exploration have been developed:

1. Modify the HMS model to include evapotranspiration. The GMS model can already utilize this data and provide a calibration tool.
2. Explore the flow irregularity in the South sub-basin. The area delineated is large and perhaps further dividing could help to minimize the inconsistency between the models.
3. Collect field data when weather is favorable. Field observations and data collection could be used to more accurately determine SCS curve numbers, Manning's n values, and evapotranspiration data. Measuring river cross sections would improve the accuracy of the RAS model.
4. Place a rain gage within the watershed to gather more accurate precipitation data.
5. Modify the models to account for the accumulation and melt of snowfall.
6. Develop a spreadsheet application to help KBIC planners more easily modify the models to test future scenarios.

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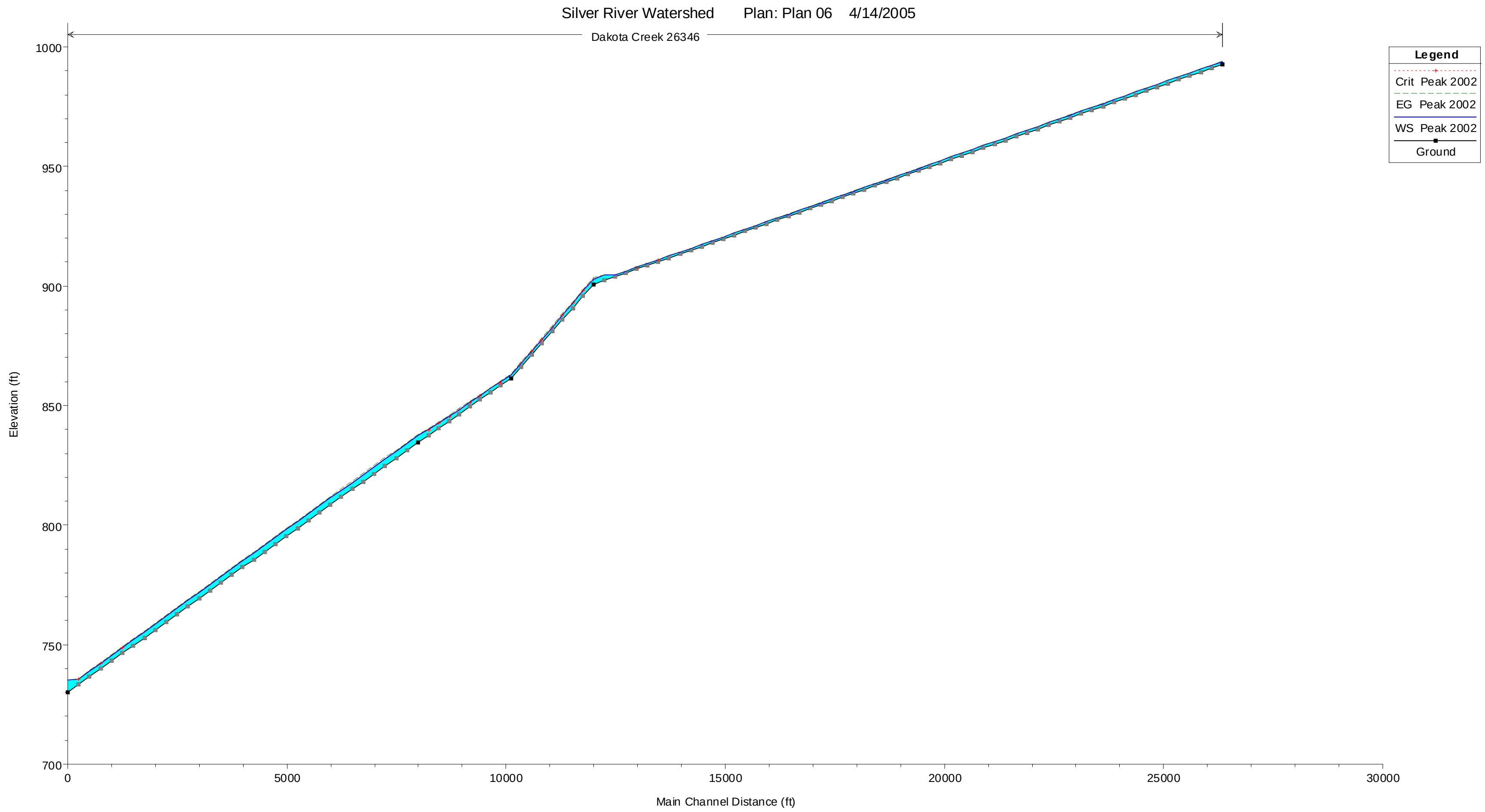
APPENDIX A – Baseflow Calculations

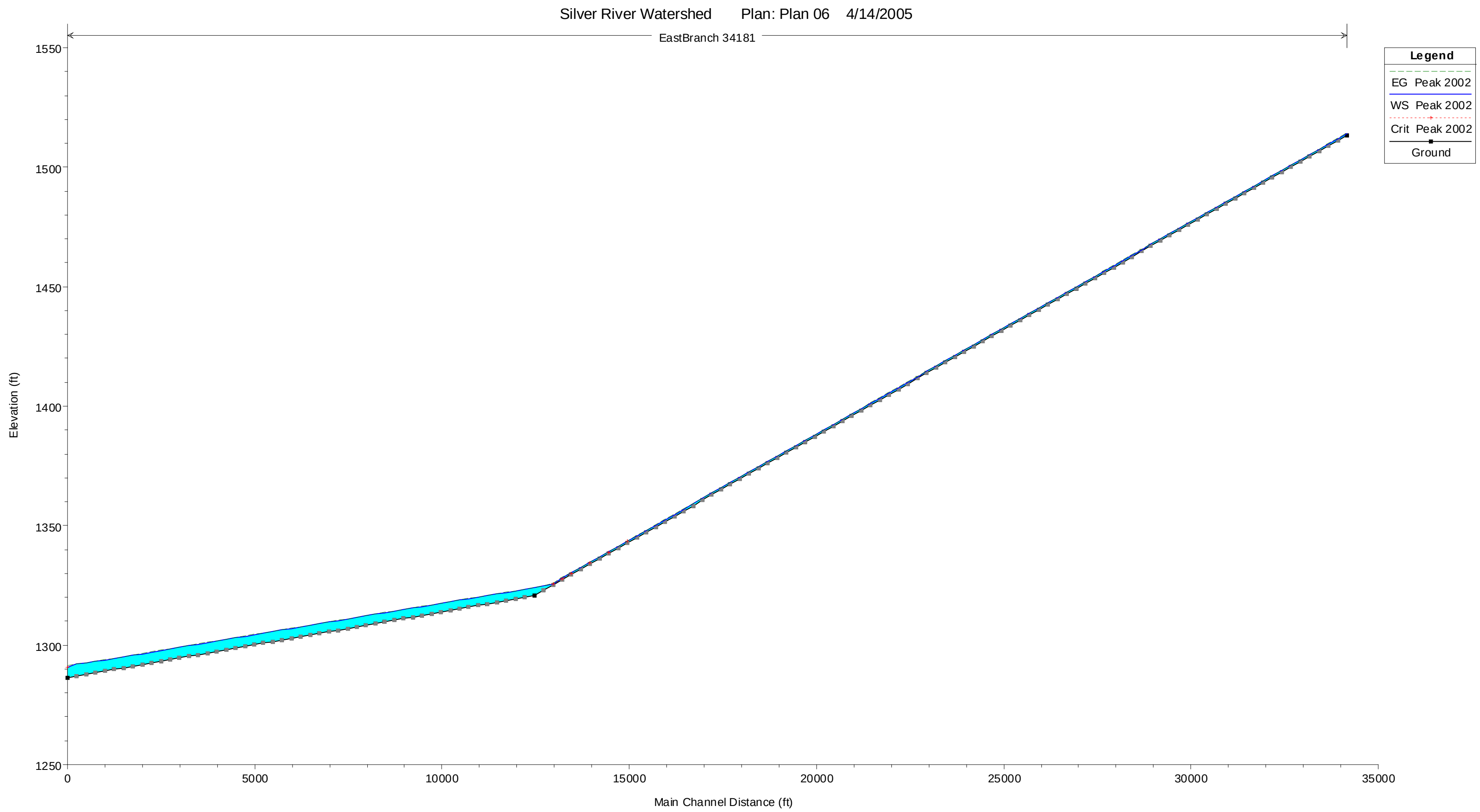
	Areas		Total lineal footage of stream	percentage	estimated baseflow ft^3/d)	estimated baseflow (cfs)	
	feet squared	square miles					
Gage	126866989.1	4.55	NA	NA	649374	7.52	
Dakota	278115098.4	9.98	63071	17.40	1423545	16.48	
North	17072792.35	0.61	40066	11.05	87388	1.01	
Page	176588600	6.33	37736	10.41	903877	10.46	
East Branon	443235078.2	15.90	74404	20.52	2268719	26.26	
Grum	122707637	4.40	36579	10.09	628085	7.27	
South	530205627.3	19.02	110708	30.53	2713881	31.41	
		sum	362564		total	100.4035703	percent
Recharge (USGS) (ft/d):	0.005118545	ave. for WY2002, based on area					

APPENDIX B – Water Surface Profiles (2002 Peak flow)

Dakota Creek

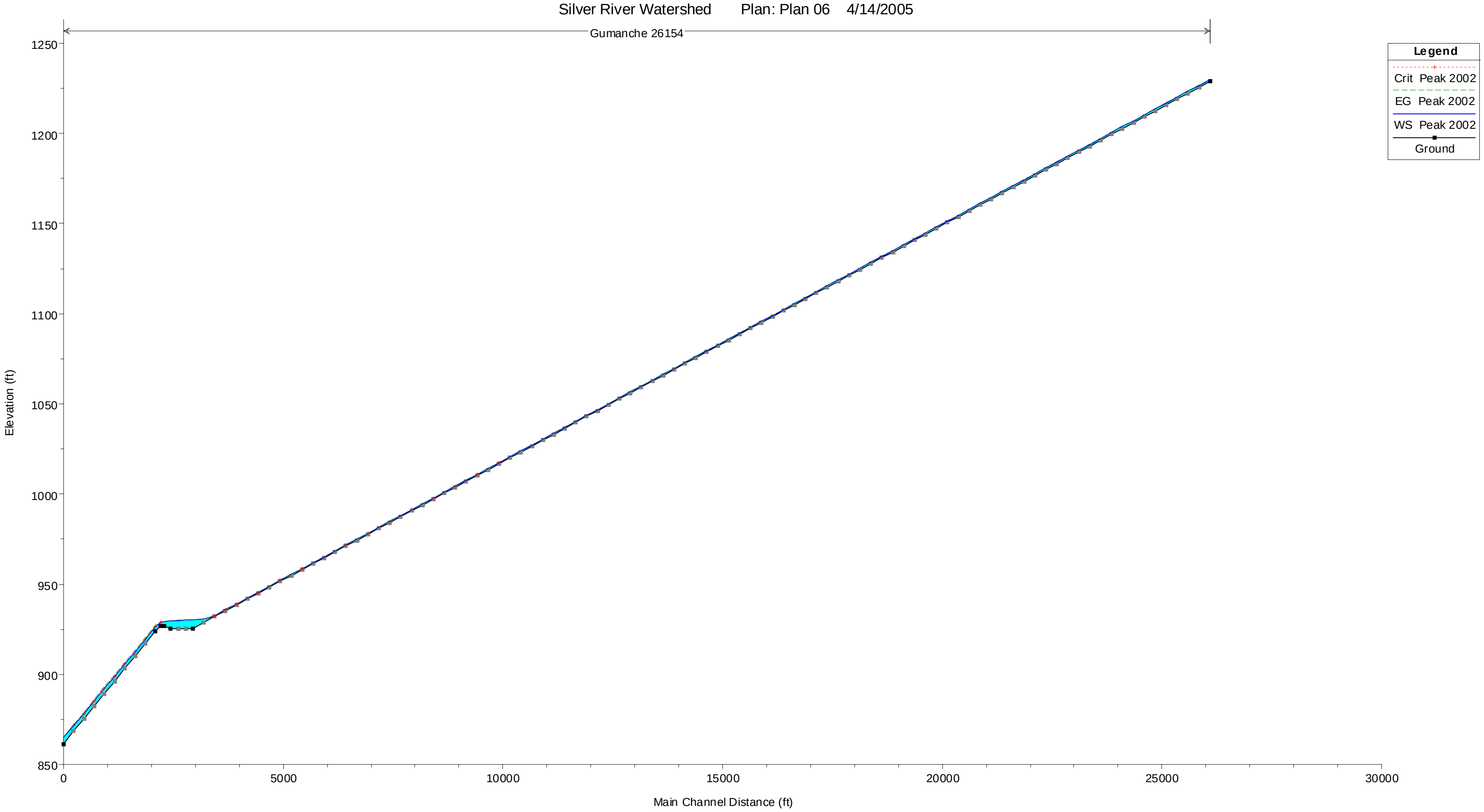


East Branch



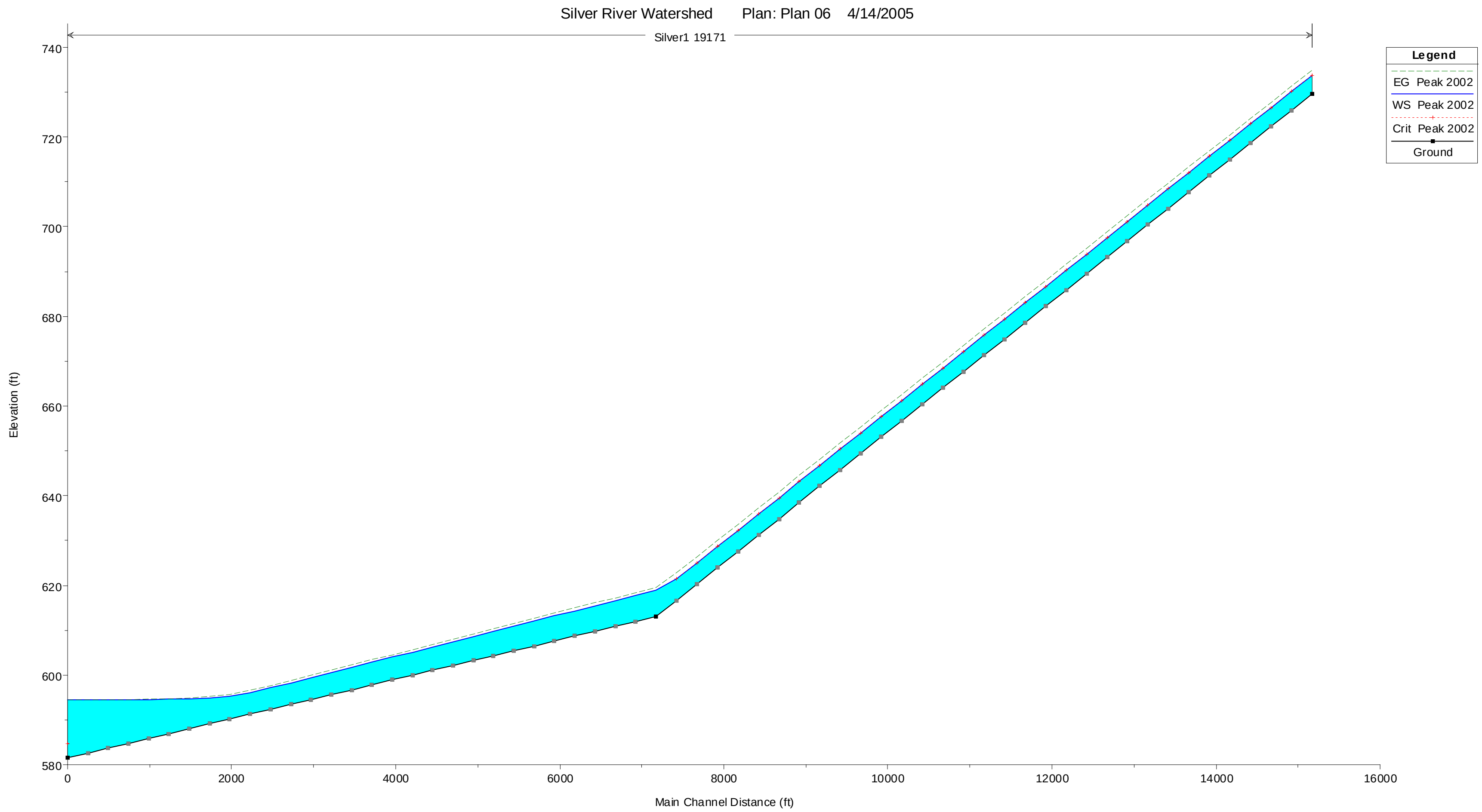
Silver River Watershed Plan: Plan 06 4/14/2005
EastBranch 34181
Legend
EG Peak 2002
WS Peak 2002
Crit Peak 2002
Ground
Elevation (ft)
1550
1500
1450
1400
1350
1300
1250
0
5000
10000
15000
20000
25000
30000
35000
Main Channel Distance (ft)

Gumanche

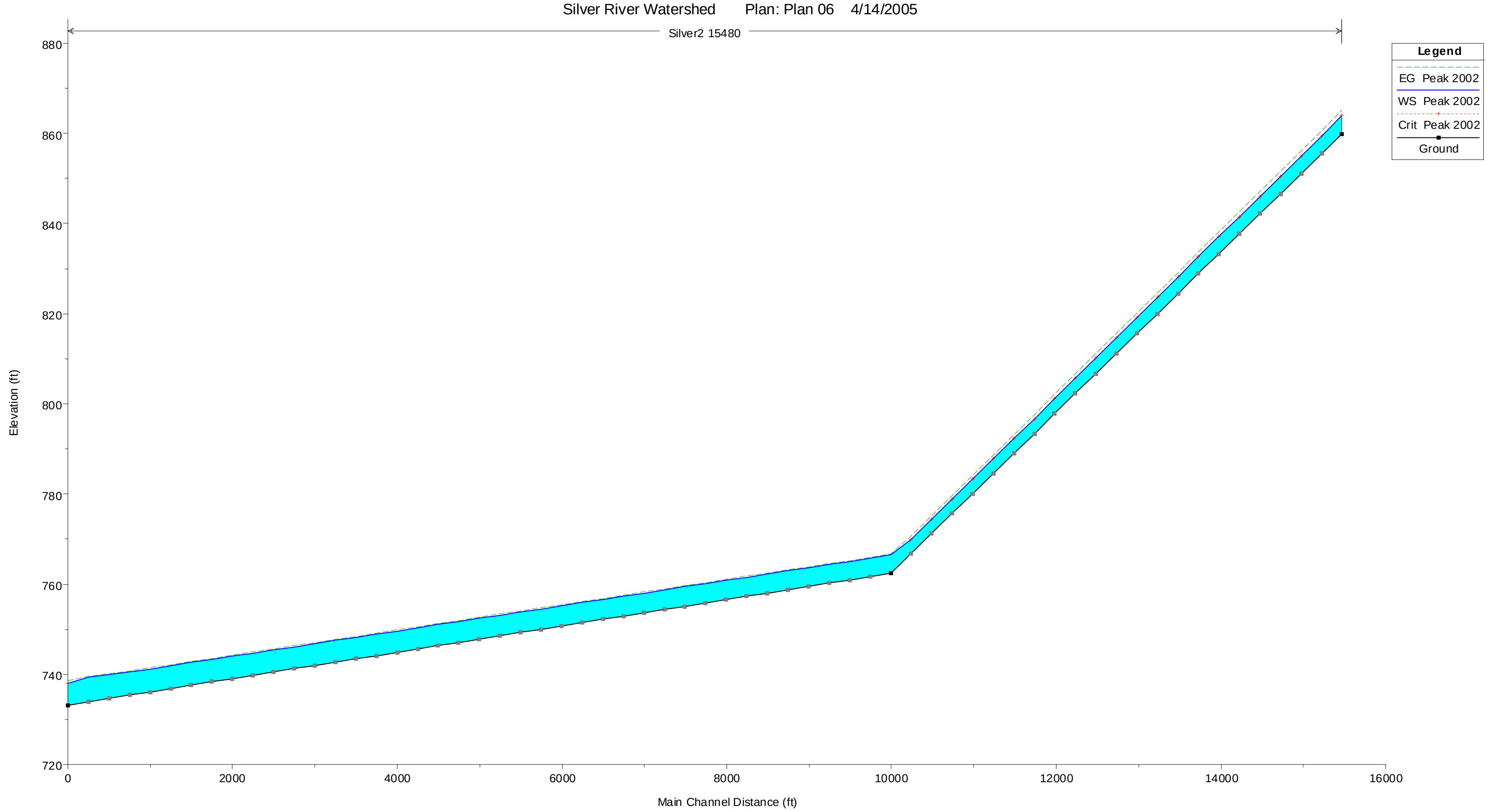


Silver River Watershed Plan: Plan 06 4/14/2005
Gumanche 26154
Legend
Crit Peak 2002
EG Peak 2002
WS Peak 2002
Ground
Elevation (ft)
1250
1200
1150
1100
1050
1000
950
900
850
0
5000
10000
15000
20000
25000
30000
Main Channel Distance (ft)

Silver 1 (most downstream reach)

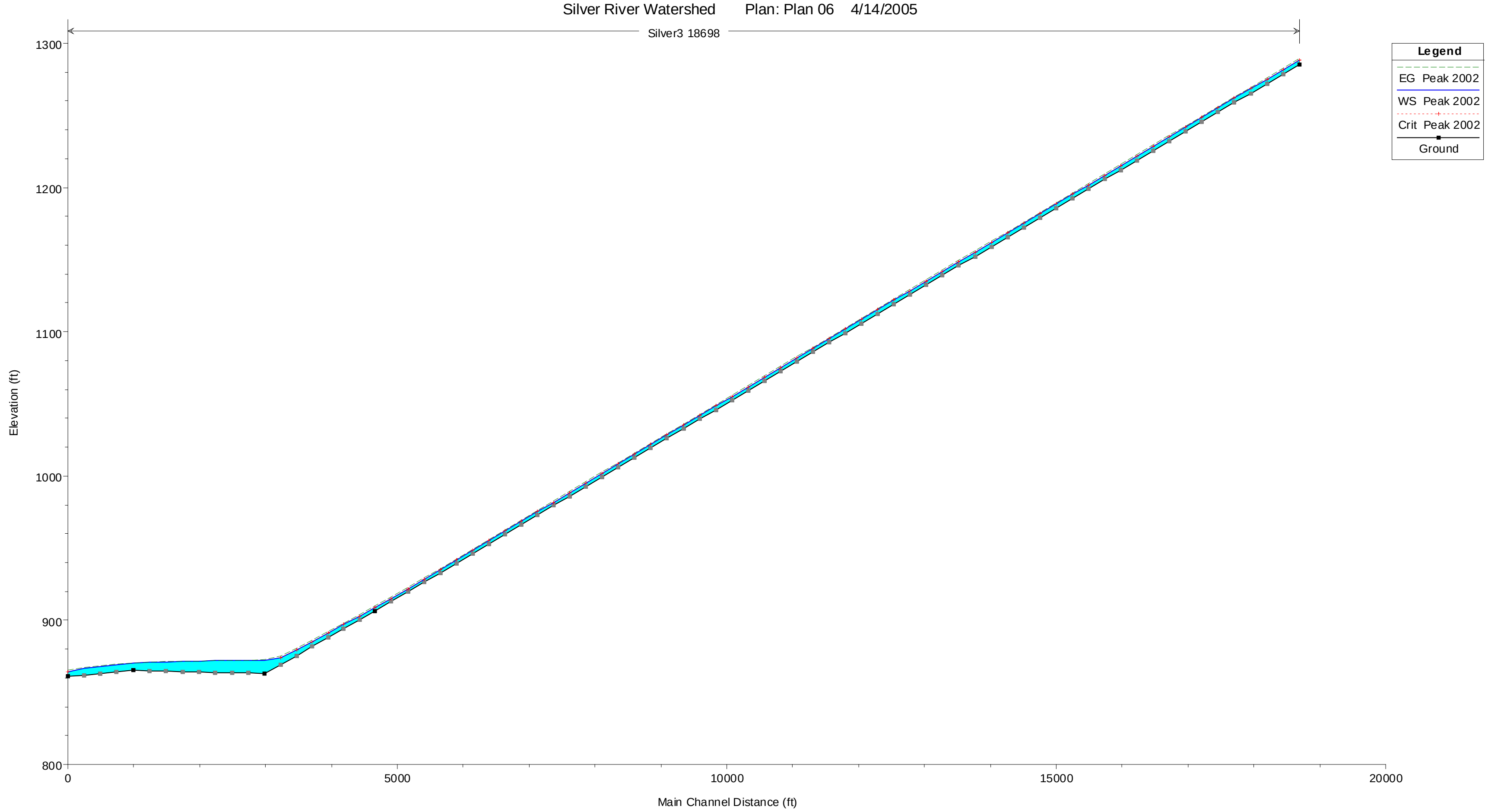


Silver 2

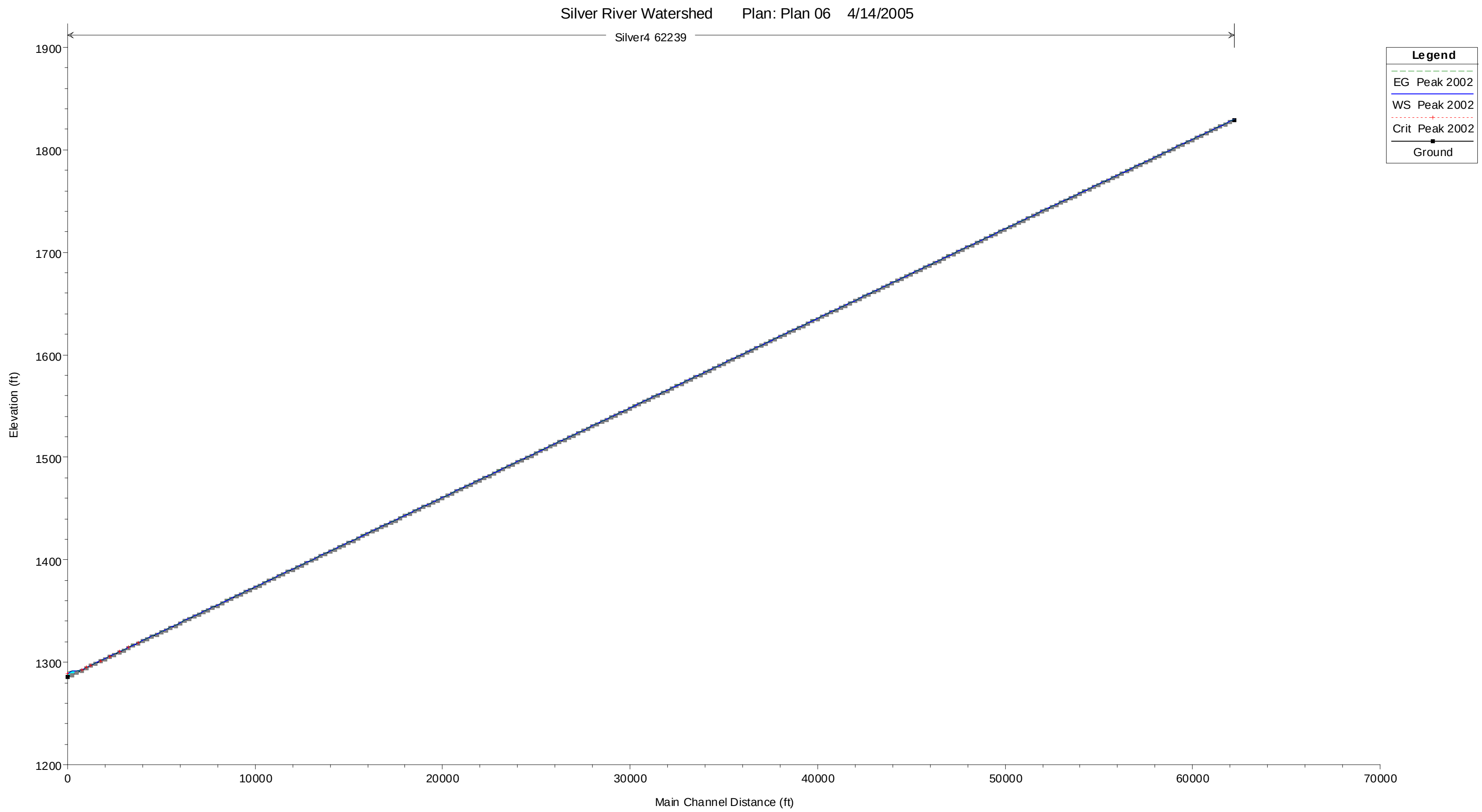


Silver River Watershed Plan: Plan 06 4/14/2005
Silver2 15480
Legend
EG Peak 2002
WS Peak 2002
Crit Peak 2002
Ground
Elevation (ft)
880
860
840
820
800
780
760
740
720
0
2000
4000
6000
8000
10000
12000
14000
16000
Main Channel Distance (ft)

Silver 3


Silver River Watershed Plan: Plan 06 4/14/2005
Silver3 18698
Legend
EG Peak 2002
WS Peak 2002
Crit Peak 2002
Ground
Elevation (ft)
1300
1200
1100
1000
900
800
0
5000
10000
15000
20000
Main Channel Distance (ft)

Silver 4 (most upstream reach)



APPENDIX C – Silver River Region Water Budget

Watershed Calculations	***Area:***	**64**	**sq. miles**	
Month	***P* (inches)**	***ET* (inches)**	***RO+RCHG* (inches)**	***RO+RCHG* (cfs)**
J	**2.2**	**0.0**	**0.0**	**0**
F	**3.7**	**0.0**	**0.0**	**0**
M	**3.6**	**0.0**	**0.0**	**0**
A	**4.9**	**1.3**	**33.1**	**1901**
M	**2.7**	**2.0**	**43.2**	**2476**
J	**6.6**	**3.8**	**2.8**	**159**
J	**3.9**	**4.6**	**0.0**	**0**
A	**3.9**	**3.6**	**0.0**	**0**
S	**6.8**	**2.7**	**3.7**	**212**
O	**7.9**	**1.1**	**4.8**	**275**
N	**2.6**	**0.0**	**0.0**	**0**
D	**2.0**	**0.0**	**0.0**	**0**
Annual Average:	**50.7**	**19.1**	**87.6**	
Monthly Average:	**4.23**	**1.59**	**7.30**	
Daily Average:	**0.14**	**0.05**	**0.24**	**413**

Month	**Precipitation**	**Snow Pack**	**Snow Melt**	**Soil Moisture**	**Evapotranspiration**	**Runoff & Recharge**
J	57	1645	0	100	0	0
F	93	1738	0	100	0	0
M	91	1828	0	100	0	0
A	125	1079	821	100	33	842
M	69	0	1079	100	52	1096
J	166	0	0	100	96	70
J	98	0	0	81	117	0
A	99	0	0	89	91	0
S	173	0	0	100	68	94
O	202	53	50	100	27	122
N	66	119	0	100	0	0
D	50	169	0	100	0	0