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Betsie River Hydrologic and Hydraulic Study

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Background

The Michigan Department of Environmental Quality (MDEQ) Hydrologic Studies and Dam Safety Unit (HSDSU) supports the Nonpoint Source (NPS) Program by providing hydrologic analysis critical to understanding the impacts of stormwater runoff on stream dynamics. Watershed studies have been conducted by the HSDSU for a number of Michigan river basins for the purpose of long-range planning efforts, community stormwater ordinances, and Best management Practices (BMP) selection, design, and evaluation. The Betsie River Watershed hydrologic and hydraulic (H&H) study similarly characterizes the flow response of the Betsie River system, in order to support the development of the Betsie River Watershed Plan.

Sources of information for spatial watershed data are presented first in this report. These include landcover (and its variation with time), soils and topography; these properties were determined for individual watershed subbasins. The specification of the design storm used for hydrologic and hydraulic analysis is presented next, followed by sections presenting the key aspects of the hydrologic analysis: runoff Curve Numbers, times of concentration, and ponding adjustment. The final sections of the report present results in terms of runoff volume, peak flow yield, and stream flow; and, discussion of the results.

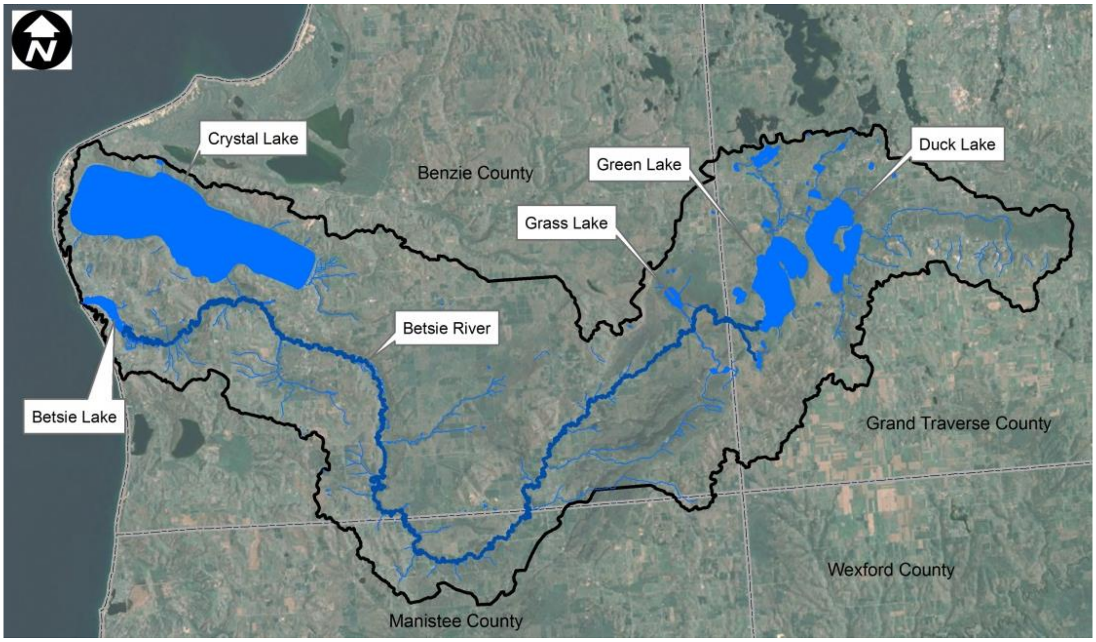
Watershed Description and Data Processing

Overview

The Betsie River Watershed is located in northwestern Lower Michigan in the counties of Benzie, Manistee, and Grand Traverse. The watershed is approximately 242 square miles, and it consists predominantly of forest and rangeland. The Betsie River originates at Green Lake and meanders for approximately 52 miles before discharging into Lake Michigan. The Betsie River also includes approximately 41 miles of tributary streams[1]. Figure 1 shows a map of the Betsie River Watershed.

[1] Michigan Department of Natural Resources. July 1973. Betsie River Natural River Plan.

Figure 1: Betsie River Watershed



Landcover

For the purpose of this project, three different years representing landcover at different stages of watershed development were analyzed. These include the 1800, 1978, and 2006 landcover conditions. The 1800 and 1978 landcover map data were obtained from the Michigan Center for Geographic Information (CGI) Geographic Data Library. The 1978 land cover map was published in 1978 and was created from aerial photo interpretation and county data using the Michigan Resource Inventory System (MIRIS) mapping framework at 1:24,000 scale. The 1978 land cover map utilizes the Anderson/Hardy Land Cover Classification System[2]. Land cover code descriptions are provided for each map polygon and are assigned descriptions and codes for Levels 1-3 of the classification system. The land cover classes used for the 1978 MIRIS land cover maps are the same as those utilized in the runoff curve number lookup tables found in the MDEQ method *Calculating Runoff Curve Numbers with GIS*[3] used for this study.

The 1800 land cover map was also published in 1978. Land cover polygons were created based on original surveyor's tree data and descriptions of the vegetation and land between 1816 and 1856. The land cover classification system for the 1800 land cover map is similar to the 1978 map system with some differences in level of detail and descriptions (e.g. 423 Mixed Conifer Swamp vs. 423 Lowland Conifer). For the purposes of this study, the 1800 land use classification scheme was easily interpreted as needed to match the 1978 MIRIS land cover and the MDEQ curve number lookup table scheme. Current-day (e.g., 2014) landcover is not available for the entire Betsie River Watershed in a form that follows the same map structure, level of detail (resolution), and classification schemes as the 1800 and 1978 land cover maps. As an alternative, the most recent National Land Cover Dataset (NLCD), which represents 2006 conditions, was used as the best available data to represent current landcover

[2] Anderson, Hardy, Roach, and Witmer, 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. U.S. Department of the Interior Geological Survey.
[3] https://www.michigan.gov/deq/0,4561,7-135-3313_3684_3724-112833--,00.html

conditions. The NLCD data was downloaded from the NLCD website[4]. The 2006 NLCD was created by updating a prior (2001) NLCD map using LANDSAT spectral imagery. The NLCD is provided in a raster format (pixels) vs. the vector format (polygons) used to create the 1978 MIRIS and 1800 land cover maps. The NLCD landcover data uses a different 16-class classification scheme at a spatial resolution of 30 meters. In order to provide a meaningful comparison of the 2006 NLCD map to the 1978 and 1800 maps and utilize the runoff curve number lookup table, the NLCD land cover data was reclassified. This process is explained further in the section "Runoff Curve Numbers".

The major landcover classes for the three time periods (1800, 1978 and 2006) are shown in Table 1 (more detailed landcover classes were used for the hydrologic and hydraulic analysis). This table shows that over time, agricultural and urban land areas increase while forested land areas decrease. Rangeland increases from 1800 to 1978, but then decreases from 1978 to 2006. Wetland areas decrease from 1800 to 1978 and then increase from 1978 to 2006 based on the comparison between the 1978 MIRIS and 2006 NLCD maps. The area covered by water remains the same over time.

Table 1: Percent Area of Major Landcover Classes

Major Landcover Classes	1800 Conditions Percent of Total Area	1978 Conditions Percent of Total Area	2006 Conditions Percent of Total Area
Agricultural Land	0%	6%	8%
Forest Land	76%	51%	46%
Rangeland	0%	19%	13%
Urban and Built Up	0%	5%	8%
Water	10%	10%	10%
Wetlands	14%	9%	15%

Watershed imperviousness is a common indicator of the general water quality of a stream. The higher the imperviousness, the more likely that the stream water quality will be poor[5]. The impervious cover model, developed by Schueler[6], shows that when the imperviousness starts exceeding 5-10%, the water quality of the stream begins to significantly degrade. The imperviousness in the Betsie River Watershed increased from 0% (pre-development) to about 3% (current conditions), with individual subbasins displaying percent imperviousness ranging from 0% to 6%. While the percent imperviousness is still relatively low, the trend over time shows steady increases in imperviousness that, if left unmitigated, may significantly impact the water quality of the Betsie River and its tributaries in the future.

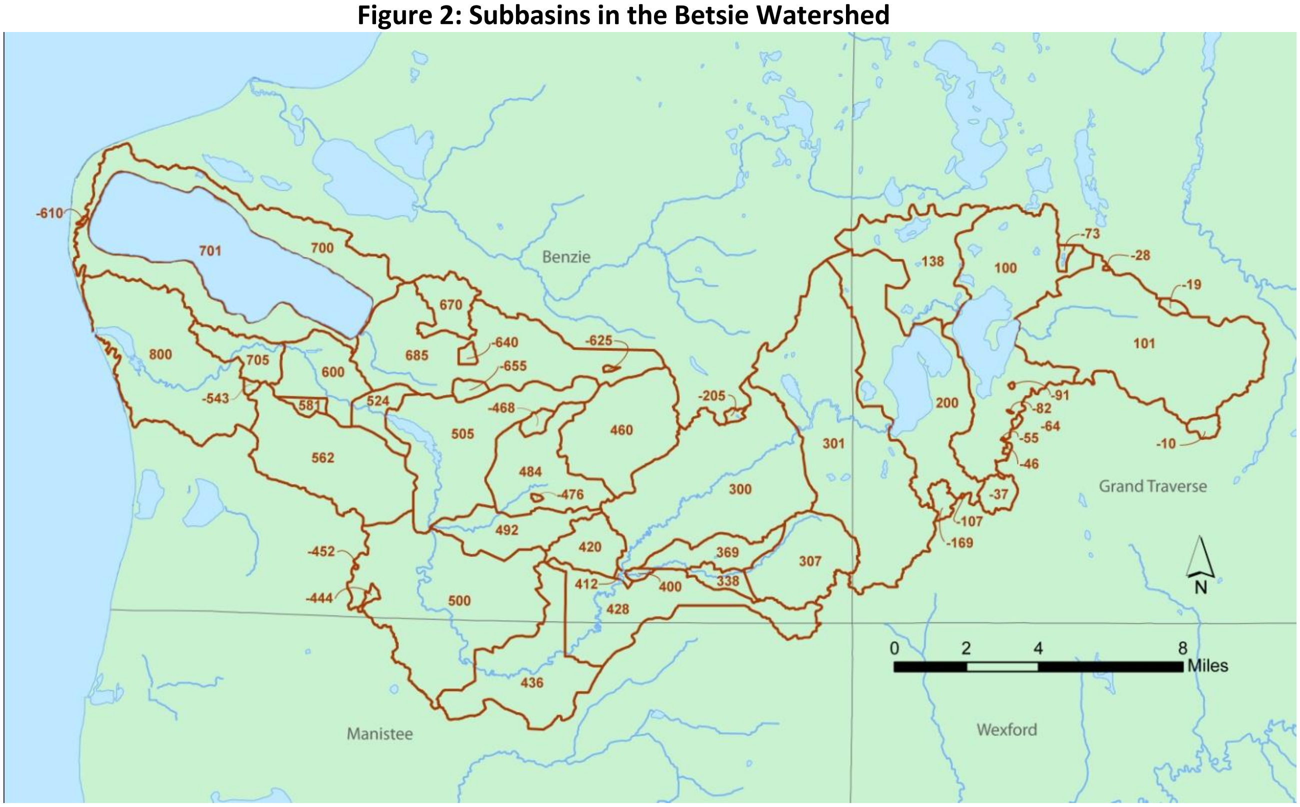
Subbasins

The Betsie River Watershed is divided into seven major subbasins according the USGS Hydrologic Unit classification system. These seven subbasins have been further divided into 48 subbasins by the MDEQ and provided as GIS polygons for this study[7]. Nineteen of the 48 subbasins are identified by MDEQ as "non-contributing" because they do not have a surface water outlet for stormwater runoff, and do not contribute surface runoff during precipitation. These areas are typically deep depressions in the landscape, and their subbasin numbers are preceded by a minus sign in the subbasin map (Figure 2).

[4] (http://www.mrlc.gov/nlcd2006.php
[5] Schueler and Holland, 2000. The Importance of Imperviousness, The Practice of Watershed Protection, published by the Center for Watershed Protection, Ellicott City, MD
[6] http://chesapeakestormwater.net/2009/11/the-reformulated-impervious-cover-model/
[7] BetsieWorking.shp transmitted by MDEQ to GLEC 6/10/2013

The subbasin areas that contribute to surface runoff range in size from about 78 acres to more than 23,300 acres. To properly calculate the runoff from the subbasins using the MDEQ methodology, the maximum subbasin area should not exceed 12,800 acres. Three subbasins (subbasin 100, 300, and 700) were larger than this limit and were therefore subdivided into two smaller areas each in order to comply with the runoff methodology (100/101, 300/301, and 700/701). Subbasin 100 was subdivided into two areas by delineating the drainage area of Mason Creek (subshed 101). This subdelineation was achieved based solely on the topographic divide between the Mason Creek drainage area and the rest of the watershed, using the digital elevation model (DEM). To subdivide subbasin 300, a location slightly downstream of the Grass Lake dam was chosen as a break point since it is an important hydrologic feature in this watershed and in the analysis. This subdelineation was achieved based solely on topography using the DEM. To subdivide subbasin 700, the entire footprint of Crystal Lake was considered its own subbasin and was therefore cut out of the overall watershed. After this subdivision, the maximum area of the subbasins is 12,842 acres, as shown in Table 2. A map of the subbasins is provided below in Figure 2.

Figure 2: Subbasins in the Betsie Watershed



Some landcover areas in the Betsie Watershed are "open pits" or excavation areas that do not contribute to the surface runoff volume. These excavation areas change between the three time periods. In 1800, there are no areas labeled as open pits. In 1978, approximately 208 acres of land cover are labeled as open pits. The 2006 NLCD dataset does not provide this level of detail, so no areas are labeled as open pits. Because of the differences in the classification method, the total area of analysis for 1978 and some of the individual subbasin areas are slightly smaller (by less than 0.5%) than the areas used for the 1800 and 2006 conditions, as shown in Table 2. This has a minor effect on the amount of total runoff generated in each subbasin, as explained in more detail in the Hydrologic Analysis Parameters section.

Table 2: Area in Acres per Subbasin

Subbasin Number	1800 Area (acres)	1978 Area (acres)	2006 Area (acres)
100	9,840	9,819	9,840
101	11,103	11,053	11,103
138	4,585	4,578	4,585
200	8,761	8,753	8,761
300	10,539	10,529	10,539
301	12,842	12,834	12,842
307	3,480	3,467	3,480
338	606	606	606
369	1,638	1,638	1,638
400	125	125	125
412	79	79	79
420	1,550	1,550	1,550
428	5,441	5,436	5,441
436	5,235	5,232	5,235
460	4,938	4,935	4,938
484	3,778	3,773	3,778
492	2,450	2,450	2,450
500	10,729	10,723	10,729
505	6,811	6,811	6,811
524	1,052	1,052	1,052
562	6,322	6,316	6,322
581	290	290	290
600	2,630	2,630	2,630
670	1,380	1,380	1,380
685	8,544	8,519	8,544
700	8,022	7,996	8,022
701	9,865	9,865	9,865
705	1,459	1,457	1,459
800	8,174	8,167	8,174
Total:	**152,270**	**152,062**	**152,270**

Soils

Soil map data for the hydrologic analysis were obtained from the Michigan CGI Geographic Data Library. The source of the soils data was the U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Geographic (SSURGO) data, published in 2000 for each county in Michigan. Data were prepared by interpreting 1:12,000 scale aerial photography and generally represents the most detailed maps of soil type polygons for any given area in Michigan. SSURGO soil maps for Grand Traverse and Benzie-Manistee counties were downloaded from the CGI library and geoprocessed in ArcGIS by merging the base soil maps, clipping the maps to the Benzie watershed boundary, and then joining the soil data to the overlying subbasin data to derive detailed soil maps for each subbasin in the analysis.

Topography

The topography of the Betsie River Watershed consists of gentle hills in the western part of the watershed, and steeper hills and ridges in the northeastern part of the watershed. The elevation at the headwaters of the Betsie River, Green Lake, is 825 feet above sea level while the elevation at the river's mouth at Lake Michigan is 580 feet. The highest elevation in the watershed is approximately 1,175 feet above sea level, while the lowest elevation, 576 feet, occurs in a few depressed areas. A DEM was prepared for the Betsie River Watershed by merging 10 meter USGS National Elevation Dataset DEMs obtained from the National Map Viewer and Download Platform[8] and clipping the surface to the general watershed boundary. The DEM was then processed in ArcGIS to generate contours at 1 foot intervals, and all slope calculations and point elevations were obtained using these contours.

Modeling Approach

The hydrologic and hydraulic study of the Betsie River Watershed follows the methodology outlined by MDEQ in the report *Computing Flood Discharges for Small Ungaged Watersheds (Sorrell, 2010)*[9]. The report describes the methodology for calculating the runoff curve number, determining the design storm depth, and calculating the runoff volume and peak discharge for each subbasin. The curve number and runoff volume calculations are based on procedures similar to those developed by the Natural Resource Conservation Service (NRCS) and commonly referred to as the "SCS method"[10]. The peak discharge calculations are computed using the unit hydrograph (UH) technique, a procedure that is also described in the SCS method. The main difference between the SCS method and the method described in Sorrell (2010) is that the latter uses a Michigan-specific unit hydrograph rather than a generic SCS unit hydrograph. The two methods produce identical runoff volumes, but differ in their characterizations of peak flow rates. The Michigan-specific unit hydrograph produces slightly smaller peak discharges, and more volume is placed under the falling limb of the hydrograph.

The MDEQ methodology allows the user to calculate runoff volumes and peak flow rates from each watershed of concern, but it is not a model that can route flow through streams and lakes. In order to accomplish that task, the United States Army Corps of Engineers HEC-HMS reservoir routing model[11] was applied to estimate peak flows at key locations in the Betsie River. The HEC-HMS (version 3.4) model

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[8] http://nationalmap.gov/viewer.html

[9] Sorrell, R.C. 2010. Computing Flood Discharges for Small Ungaged Watersheds. Michigan Department of Natural Resources and Environment, Land and Water Management Division. June 22, 2010. (http://www.michigan.gov/documents/deq/lwm-scs_198408_7.pdf).

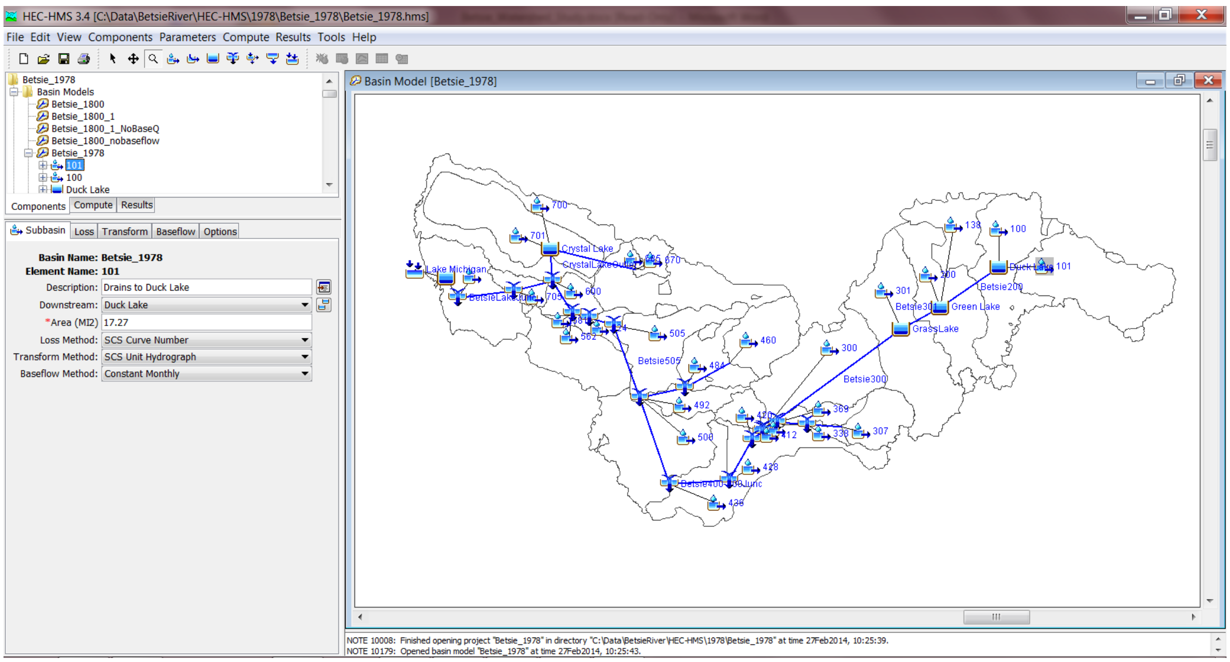
[10] USDA NRCS National Engineering Handbook (NEH), Part 630: Hydrology (2004). Downloaded from http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1043063 in Fall of 2013

[11] http://www.hec.usace.army.mil/software/hec-hms/

created for the Betsie Watershed also uses the SCS method to determine runoff volumes and peak discharges, and it uses the Muskingum attention method to route flows through the Betsie River. Flows through lakes and impoundments are calculated by specifying an elevation-storage curve and by characterizing the outflow weir/dam structure. Figure 3 illustrates how the Betsie River Watershed is represented in HEC-HMS as a network of hydrologic elements, including subbasins, reaches, junctions and reservoirs.

The hydrologic parameters that are used in the MDEQ method and in the HEC-HMS model are further described in the next section.

Figure 3: HEC-HMS representation of the Betsie Watershed



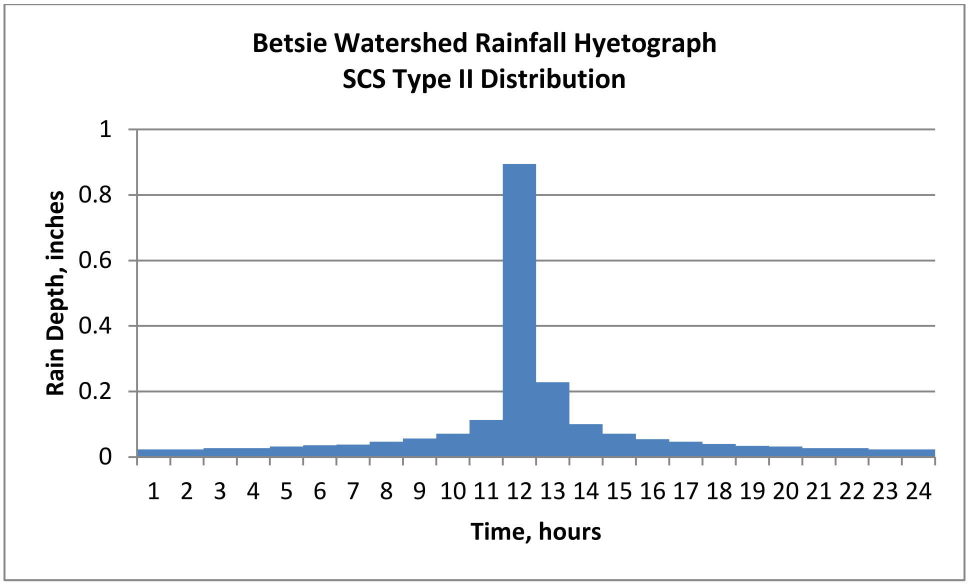
Hydrologic Analysis Parameters

Parameters that are used to calculate the watershed response to rainfall include precipitation, the curve number, the time of concentration, and ponding adjustments.

Rainfall

This hydrologic study uses the 2-year 24-hour design storm. According to Sorrell (2010), the Betsie River Watershed is located in Michigan Climatic Zone 3 (northwestern Lower Michigan), and the 50% annual probability (i.e., 1 in 2 year) rainfall depth for this zone is 2.09 inches. The rainfall distribution follows the SCS Type II distribution, as shown in Figure 4.

Figure 4: 2-year, 24-hour Rainfall Distribution for the Betsie Watershed



Runoff Curve Numbers

The curve number (CN) is a numeric value assigned to a subbasin based on its landcover and underlying soils. The higher the curve number, the more runoff is produced. For example, pavement has a curve number of 99, and virtually all rainfall that falls on pavement becomes runoff. The lower the curve number, the less runoff is produced. For example, grassland growing in Hydrologic Soil Group (HSG) Type A soils can have a curve number as low as 30. Rainfall falling on such an area is predominantly infiltrated into the soil, and only a small fraction of the rainfall is typically transformed into runoff.

The curve numbers for each subbasin in the Betsie watershed were calculated using the MDEQ method "Calculating Runoff Curve Numbers with GIS"[12]. This method uses lookup tables to assign a curve number based on the landcover and soils. As previously mentioned, areas that were listed as open pits were not included in the hydrologic analysis per the MDEQ methodology, and therefore those areas did not receive a curve number. As explained previously, the MDEQ curve number lookup tables use landcover classifications which are similar to or the same as the 1800 and 1978 landcover maps. The 2006 NLCD landcover data, however, uses a classification system different than from the 1978 MIRIS classification system. In order to use the MDEQ curve number look-up tables, the NLCD classes were reclassified to better match with the classes used in the curve number look-up tables. This reclassification is shown in Table 3. The NLCD categories for "developed" landcover were reclassified such that the curve number for high intensity development was higher than the curve number for medium intensity, which in turn was higher than the curve number for low intensity.

[12] http://michigan.gov/documents/deq/lwm-cn-calc-using-gis_202628_7.pdf

Table 3: 2006 Landcover Reclassification

Original 2006 NLCD Landcover Categories	Reclassified 2006 NLCD Landcover Categories
Barren Land	Barren
Cultivated Crops	Cropland
Deciduous Forest	Deciduous
Developed, High Intensity	Commercial
Developed, Low Intensity	Single Family
Developed, Medium Intensity	Industrial Park
Developed, Open Space	Open Land
Emergent Herbaceous Wetlands	Emergent Wetland
Evergreen Forest	Pine
Hay/Pasture	Permanent Pasture
Herbaceous	Herbaceous
Mixed Forest	Woodland
Open Water	Water
Shrub/Scrub	Shrub
Woody Wetlands	Wooded Wetland

Individual subbasins in the Betsie River Watershed are composed of a variety of soil types and landcovers; therefore an area-weighted or composite runoff curve number was calculated for each subbasin as follows:

$$CN_{avg} = \frac{CN_1 * Area_1 + CN_2 * Area_2 + \cdots + CN_n * Area_n}{Area_{tot}}$$

The composite curve numbers for the subbasins range from 42 to 100 (water), as shown in Table 4 below. Changes in landcover within the Betsie River Watershed have occurred over time and these changes are reflected in adjustments to the curve numbers. In most subbasins, the curve number increases slightly over time due to development. This trend is not observed in a few subbasins and is the result of converting areas with higher curve numbers, like wetland areas (CN ~ 75), to areas with lower curve numbers, like dense herbaceous areas (CN = 30).

Table 4: Curve Number per Subbasin

Subbasin Number	1800 CN	1978 CN	2006 CN
100	64	66	67
101	58	58	61
138	56	58	56
200	61	61	60
300	54	52	54
301	59	58	57
307	55	52	54
338	54	60	56

Subbasin Number	1800 CN	1978 CN	2006 CN
369	61	63	67
400	51	46	50
412	54	43	45
420	54	52	55
428	50	49	48
436	52	51	51
460	50	47	50
484	47	45	45
492	49	46	47
500	48	46	47
505	47	47	48
524	50	47	49
562	47	48	52
581	48	48	59
600	54	56	61
670	45	42	47
685	48	48	47
700	49	52	51
701	100	100	100
705	50	51	54
800	53	55	57

Time of Concentration

The time of concentration is the time it takes for a drop of water to travel from the hydraulically most distant point in the watershed (or subbasin) to the outlet point of the watershed/subbasin. The hydraulically most distant point in the watershed is typically governed by not only the longest distance a drop of water has to travel, but also involves consideration of the steepness (slope) of its flow path as well as the local landcover. The time of concentration affects the intensity of the peak flow rates: the longer the time of concentration, the lower the peak flow rate, and the shorter the time of concentration, the higher the peak flow rate (assuming all other variables remain the same). The time of concentration for each subbasin in the Betsie watershed was calculated using the approach outlined in the MDEQ guidance document. The slopes used to determine the time of concentration were calculated using the Michigan DEM, available online from the Michigan Department of Technology, Management & Budget[13], and converting the DEM into 1-ft contour lines. The time of concentration for the Betsie subbasins are the same across the three time periods and are shown in Table 5 below.

[13] http://www.mcgi.state.mi.us/mgdl/?rel=ext&action=sext

Table 5: Time of Concentration per Subbasin

Subbasin Number	Time of Concentration (hours)
100	2.75
101	19.32
138	17.34
200	9.02
300	7.51
301	11.48
307	10.68
338	3.89
369	9.86
400	1.20
412	0.39
420	2.86
428	8.05
436	3.71
460	9.42
484	3.42
492	5.44
500	9.14
505	5.33
524	2.00
562	4.38
581	1.45
600	3.11
670	2.81
685	16.68
700	1.51
701	8.89
705	1.33
800	3.06

Ponding Adjustments

Ponding represents temporary storage in the landscape provided by swampy areas, small depressions, and small ponds. Based on site-specific data including aerial photography and land cover maps of the Betsie River Watershed, it is clear that there are many small ponds and swampy areas scattered throughout the watershed. These landscape features retain and retard the runoff and cause peak flow rates to be reduced. Table 10.1 in Sorrell (2010) provides adjustment factors to determine this reduction based on the ratio of ponding area to the total drainage area. The ponding adjustment factor was selected based on a percentage of ponded area of 0.5% and an annual storm probability of 50%, resulting in a ponding factor of 0.88 for the entire Betsie River Watershed. This ponding factor is used to adjust peak flow rates, reflecting the attenuation that is provided by the small ponds and swampy areas. Ponding adjustments are replaced by reservoir routing for the larger lakes in the Betsie Watershed. All large lakes, including Duck Lake, Grass Lake, Green Lake, Crystal Lake, and Betsie Lake are explicitly modeled using HEC-HMS to estimate peak outflows from these waterbodies. Ponding factors were not used in HEC-HMS to calculate flow rates routed through the lakes and reservoirs.

Results

Runoff Volume Analysis

Runoff volumes were calculated for the 1800, 1978, and 2006 conditions for the 2-year, 24 hour (50% annual probability) design storm. Table 6 shows the runoff volume results for each of the subbasins. Note that subbasins with a curve number of less than or equal to 49 do not produce any runoff under the 2-year, 24 hour storm event, since the initial abstraction[14] in these subbasins is calculated to be equal to the precipitation depth. The total runoff volume increases approximately by 5% from predevelopment (1800) conditions to current conditions.

Table 6: Runoff Volume in Acre-Feet

Subbasin Number	1800 Runoff Volume (acre-ft)	1978 Runoff Volume (acre-ft)	2006 Runoff Volume (acre-ft)
100	120.61	141.44	160.52
101	47.23	52.28	86.29
138	11.31	20.93	12.19
200	61.73	66.69	58.22
300	16.39	6.66	13.65
301	68.25	50.94	43.79
307	7.35	2.26	5.38
338	0.93	3.84	1.50
369	12.40	16.12	27.84
400	0.04	0.00	0.01
412	0.11	0.00	0.00
420	2.32	0.93	2.61
428	0.13	0.09	0.00
436	2.69	0.98	1.31
460	0.16	0.00	0.11
484	0.00	0.00	0.00
492	0.03	0.00	0.00
500	0.00	0.00	0.00
505	0.00	0.00	0.00
524	0.02	0.00	0.00
562	0.00	0.00	2.79

[14] Initial abstraction refers to all water losses before runoff begins, including water retained in surface depressions, taken up by vegetation, evaporation and infiltration.

Subbasin Number	1800 Runoff Volume (acre-ft)	1978 Runoff Volume (acre-ft)	2006 Runoff Volume (acre-ft)
581	0.00	0.00	1.48
600	3.64	7.95	21.13
670	0.00	0.00	0.00
685	0.00	0.00	0.00
700	0.10	4.44	2.67
701	1622.34	1622.34	1622.34
705	0.12	0.33	1.70
800	7.71	17.43	26.87
TOTAL	**1,986**	**2,016**	**2,092**

In most subbasins, the runoff volume increases with time due to the effects of increased development. This is evident, for example, in subbasins 100, 369, and 600. In a few subbasins, this trend of runoff consistently increasing over time is not observed. A closer look at these subbasins shows that runoff decreases because areas with higher curve numbers (forest, wetland) were converted to areas with a lower curve number (rangeland, agriculture). This is evident, for example, in subbasin 420. The area and curve number breakdown for subbasin 420 is shown in Table 7 (the curve numbers were taken directly from the MDEQ lookup tables). The curve number decreases from the 1800 to the 1978 conditions because a large portion of wetlands were converted to forested and range land. This results in a decrease in the runoff volumes between these two time periods. The curve number then increased from the 1978 to the 2006 conditions because: (1) significant areas classified as forest and rangelands in the 1978 MIRIS map were classified as wetlands in the 2006 NLCD map, and (2) urban areas increased from 1978 to 2006.

Table 7: Detailed Runoff Analysis of Subbasin 420

Subbasin 420 Characteristics	Typical CN* (HSG A)	1800	1978	2006
Landcover breakdown				
Agricultural Land	45-65	0	112	11
Forest Land	45	1,144	1,008	876
Rangeland	30	0	311	174
Urban and Built Up	61-89	0	10	76
Wetlands	78-85	406	109	412
TOTAL		1,550	1,550	1,550
Composite Curve Number	-	54	52	55
Runoff Volume (acre-ft/acre)		2.32	0.93	2.61

*Note: The curve numbers (CNs) shown here are taken directly from the MDEQ lookup tables.

To provide a comparison of runoff volume generated from each subbasin, the runoff volumes were normalized by area. This creates a runoff depth per watershed, in inches, and provides an indication of which areas produce the most runoff due to their hydrologic characterization. Table 8 shows the area-normalized runoff volumes for all watersheds. The largest area-normalized contributors are subbasin 100, which is located in the eastern part of the Betsie watershed; subbasin 369, which drains to the Little Betsie River; and subbasin 701, which represents Crystal Lake proper. Subbasin 100 has a relatively high curve number, steep slopes, and short time of concentration, all of which contribute to a higher area-normalized runoff volume. Subbasin 369 also has a relatively high curve number because of the large amounts water relative to its total area (water has a curve number of 98), which drives the higher area-normalized runoff volume. Any precipitation that falls onto Crystal Lake (subbasin 701) is converted to "runoff" and should not be used as a point of comparison with the other subbasins because it represents water storage in a lake system rather than surface runoff from the landscape.

Table 8: Area-Normalized Runoff Volume in inches

Subbasin Number	1800 Runoff Volume (inches)	1978 Runoff Volume (inches)	2006 Runoff Volume (inches)
100	0.15	0.17	0.20
101	0.05	0.06	0.09
138	0.03	0.05	0.03
200	0.08	0.09	0.08
300	0.02	0.01	0.02
301	0.06	0.05	0.04
307	0.03	0.01	0.02
338	0.02	0.08	0.03
369	0.09	0.12	0.20
400	0.00	0.00	0.00
412	0.02	0.00	0.00
420	0.02	0.01	0.02
428	0.00	0.00	0.00
436	0.01	0.00	0.00
460	0.00	0.00	0.00
484	0.00	0.00	0.00
492	0.00	0.00	0.00
500	0.00	0.00	0.00
505	0.00	0.00	0.00
524	0.00	0.00	0.00
562	0.00	0.00	0.01
581	0.00	0.00	0.06
600	0.02	0.04	0.10
670	0.00	0.00	0.00
685	0.00	0.00	0.00
700	0.00	0.01	0.00
701	1.97	1.97	1.97

Subbasin Number	1800 Runoff Volume (inches)	1978 Runoff Volume (inches)	2006 Runoff Volume (inches)
705	0.00	0.00	0.01
800	0.01	0.03	0.04

Peak Flow Yield Analysis

The peak flows from each subbasins were also calculated following the MDEQ methodology outlined in Sorrell (2010). The peak flow analysis takes into account the ponding and the time it takes for runoff to flow through each subbasin. The peak flow rate, along with the runoff volume, provides a complete measure of the hydrologic responsiveness of each subbasin. The peak flow yield is the peak flow divided by the drainage area, and this metric allows for a direct comparison of the hydrologic responsiveness of differently sized subbasins.

Table 9 shows the peak flow rates from each subbasin for the three different time periods. In most cases, the peak flow rate from a subbasin increases over time due to increased development. In a few subbasins, this trend of increased peak flow rate over time is not observed. The reasons for this were described in the previous section.

Table 9: Peak flow rate in cubic feet per second

Subbasin Number	1800 Peak Flow Rate (cfs)	1978 Peak Flow Rate (cfs)	2006 Peak Flow Rate (cfs)
100	207	243	276
101	16	18	30
138	4	8	5
200	40	43	38
300	12	5	10
301	36	27	23
307	4	1	3
338	1	5	2
369	7	10	17
400	0	0	0
412	1	0	0
420	4	2	4
428	0	0	0
436	4	1	2
460	0	0	0
484	0	0	0
492	0	0	0
500	0	0	0
505	0	0	0
524	0	0	0
562	0	0	3

Subbasin Number	1800 Peak Flow Rate (cfs)	1978 Peak Flow Rate (cfs)	2006 Peak Flow Rate (cfs)
581	0	0	4
600	6	12	33
670	0	0	0
685	0	0	0
700	0	12	8
701	1,065	1,065	1,065
705	0	1	5
800	12	27	42

Table 10 shows the peak flow yield per subbasin. The subbasin that has the highest peak flow yield is subbasin 701, which represents Crystal Lake. Precipitation that falls on this subbasin is directly added to the existing water in the lake, and this subbasin was included in the hydrologic and hydraulic analysis in order to represent the precipitation falling onto this lake directly. It does not make for a good point of comparison for analyzing the peak flow yield of other subbasins, since it is so unique in its characterization. Subbasin 100 and 412 have the highest peak flow yields after Crystal Lake. All other subbasins have a peak flow yield that is a magnitude of order smaller than these two. Subbasin 100 has a relatively high curve number, a relatively steep slope, and a short time of concentration, all of which contribute to a higher peak flow yield. Subbasin 412 is one of the smallest subbasins in the Betsie watershed (79 acres), and while the peak flow for the 1800 conditions is fairly high, its contributing area is so small that the peak flow rates from this area are very small compared to the rest of the neighboring area, and should not be considered a hydrological area of concern.

Table 10: Peak flow yield in cubic feet per second per acre

Subbasin	1800 Peak Flow Yield (cfs/acre)	1978 Peak Flow Yield (cfs/acre)	2006 Peak Flow Yield (cfs/acre)
100	0.021	0.025	0.028
101	0.001	0.002	0.003
138	0.001	0.002	0.001
200	0.005	0.005	0.004
300	0.001	0.000	0.001
301	0.003	0.002	0.002
307	0.001	0.000	0.001
338	0.002	0.008	0.003
369	0.005	0.006	0.010
400	0.001	0.000	0.000
412	0.012	0.000	0.000
420	0.002	0.001	0.003
428	0.000	0.000	0.000
436	0.001	0.000	0.000
460	0.000	0.000	0.000
484	0.000	0.000	0.000

Subbasin	1800 Peak Flow Yield (cfs/acre)	1978 Peak Flow Yield (cfs/acre)	2006 Peak Flow Yield (cfs/acre)
492	0.000	0.000	0.000
500	0.000	0.000	0.000
505	0.000	0.000	0.000
524	0.000	0.000	0.000
562	0.000	0.000	0.001
581	0.000	0.000	0.015
600	0.002	0.005	0.012
670	0.000	0.000	0.000
685	0.000	0.000	0.000
700	0.000	0.002	0.001
701	0.108	0.108	0.108
705	0.000	0.001	0.004
800	0.001	0.003	0.005

Stream Flow Analysis

Flow from each subbasin was routed through the Betsie River and its lakes using the HEC-HMS model. The Muskingum-Cunge routing method was used to simulate the attenuation of flow through the Betsie River. This routing method requires information on the stream length and slope; Manning's roughness coefficient; and channel shape, bottom width, and side slope. The stream length and gradient were estimated in GIS using the NHDPlus dataset, which was developed under USEPA funding[15]. The shape of each river section was assumed to be trapezoidal. The bottom width, side slope, and Manning's roughness coefficient were estimated based on field surveys of similar streams in the Platte River Watersheds. The Platte River Watershed is located north of the Betsie River Watershed and both share features such as consisting largely of undeveloped areas, having many small lakes and tributaries, and being roughly of similar size. Figure 5 shows an aerial of the two watersheds. Reports on the Platte River Watershed study can be accessed at www.platte-lake.org[16].

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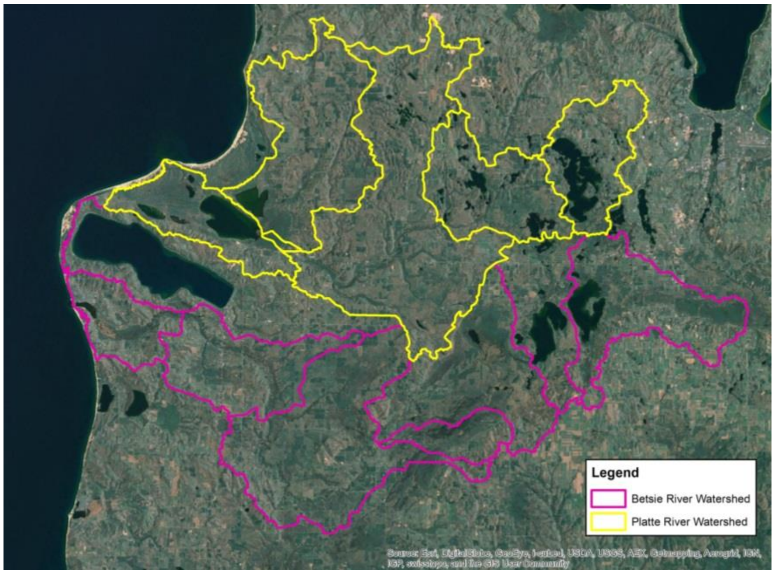
[15] http://www.horizon-systems.com/nhdplus/

[16] http://www.platte-lake.org/October_2010_ASCE_Paper.pdf , http://www.platte-lake.org/BASINSReportPlatteRiverWatershed.pdf, http://www.platte-lake.org/BASINSAppendixG.pdf

Figure 5: Location of the Betsie River and Platte River Watershed



Flow through the lakes was simulated using an area-elevation rating curve for the lakes (Table 11) coupled to characterization of the outflow weirs (Table 12). The area-elevation rating curve was obtained by calculating the surface areas of topographic contours around the lake. These topographic contours were extrapolated from the Michigan DEM.

Table 11: Elevation-Area Rating Curves

Duck Lake Elevation (ft)	Duck Lake Area (acres)	Green Lake Elevation (ft)	Green Lake Area (acres)	Grass Lake Elevation (ft)	Grass Lake Area (acres)	Crystal Lake Elevation (ft)	Crystal Lake Area (acres)
840.00	1896.87	823.00	1951.75	824.0	721.76	600.0	9758.55
841.00	2528.07	826.00	1997.92	825.0	1153.86	601.0	9794.35
842.00	2602.52	827.00	4566.13	826.0	1634.44	602.0	9821.63
				827.0	4566.12	603.0	9850.56
						604.0	9909.03

Table 12: Spillway Characteristics

	Duck Lake	Grass Lake	Crystal Lake
Spillway Type	Broad-Crested	Broad-Crested	Broad-Crested
Spillway Elevation, ft	837.3	824.05	600.25
Spillway Length, ft	23	61	50
Spillway Coefficient	3.2	3.2	3.2

Green Lake has no outflow structure, so an elevation-discharge rating curve (Table 13) was used to describe the flow leaving Green Lake. This elevation discharge rating curve was obtained by applying the Manning Equation for open channel flow to the Betsie stream segment below Green Lake and calculating the flow at various elevations (water depths). A few basic assumptions had to be made to characterize this section of the river, including its shape (trapezoidal), manning's n (0.05), bottom width (14m, measured using GIS), side slope (45 degrees), and stream slope (0.0001).

Table 13: Green Lake Elevation-Discharge Rating Curve

Elevation (ft)	Discharge (cfs)	Elevation (ft)	Discharge (cfs)
823.00	0.0	831.20	477.0
823.82	10.0	832.02	560.0
824.64	31.0	832.84	648.0
825.00	43.0	833.66	742.0
826.28	101.0	834.48	840.0
827.10	148.0	835.30	943.0
827.92	201.0	836.12	1051.0
828.74	261.0	836.94	1163.0
829.56	328.0	837.76	1280.0
830.38	400.0		

To characterize total streamflow through the Betsie River, baseflow was added to all stream segments. In lieu of site-specific baseflow information for the Betsie Watershed, the baseflow was estimated based on a study[17] that characterized the baseflow of streams in the Platte River Watershed. Since the Platte River Watershed is hydrologically similar in size and characteristics to the Betsie Watershed, it was considered reasonable to extrapolate the results from the Platte River Watershed and applied them to the Betsie River Watershed. The Platte River average baseflow was normalized by the contributing drainage area, and then applied to all the subbasin reaches in the Betsie River Watershed.
Once the stream and subbasin characteristics were defined in HEC-HMS, the model was run for the three time periods (1800, 1978, 2006) for the 2-year, 24-hour design storm. Table 14 below shows the base flow rate as well as the peak flow rate at several key hydraulic points within the Betsie River system, starting from the most upstream location and moving downstream. Reported results include the peak flow rates of major tributaries like the Little Betsie River, Dair Creek, Rice Creek, and the Crystal Lake Outlet. These key hydraulic points are also shown in Figure 6. Note that the flow rates in Table 14 are estimates based on the best available data and best professional judgment. No gaged flow data currently exist for the Betsie Watershed; therefore, it was not possible to calibrate the HEC-HMS model under this effort.

The results of the HEC-HMS modeling show that peak flow rates are significantly attenuated by the reservoirs and lakes in the Betsie River Watershed. Figure 7 shows that the peak inflow into Duck Lake is in excess of 300 cfs, but the corresponding outflow is only about 35 cfs. Similar predictions are made at the outflow of each of the lakes. These results are as expected, and they illustrate the importance of explicitly modeling lake storage and routing characteristics in the Betsie River Watershed and other

17 Limno-Tech, Inc. Platte River Watershed Baseline Calibration Report. May 2004 (http://www.platte-lake.org/BASINSAppendixG.pdf).

similar watersheds that include significant lake systems. The predicted hydrographs at other key hydraulic points within the mainstem Betsie River are included as Figures 8 through 14 in an appendix to this report.

Table 14 shows that computed peak flow rates typically increase slightly over time, but exceptions are seen at several key locations. For example, peak flow rates below Grass Lake actually decrease over time. This is because the landscape of the drainage areas changes from being one that contributes more runoff (because of more open water, wetlands and forests) and has more contributing area to one that contributes less runoff (because some open water became wetlands, some wetlands became forests, and some forests became dense grasslands). Also note that the contributing area is slightly less in 1978 than in 1800, which also contributes, in a minor way, to the smaller runoff volumes observed in 1978. This follows the same explanation given in previous sections to describe the increasing curve numbers and runoff volumes for some of these watersheds.

Table 14: Peak flow rates at key hydraulic points in the Betsie River System

Location	Baseflow (CFS)	1800 Peak Flow (CFS)	1978 Peak Flow (CFS)	2006 Peak Flow (cfs)
1. Mainstem below Duck Lake	26	32	33	35
2. Mainstem below Green Lake	44	45	46	46
3. Mainstem below Grass Lake	58	71	68	67
4. Little Betsie River before confluence with Betsie River	7	19	22	29
5. Mainstem below Little Betsie River	79	109	103	116
6. Dair Creek before confluence with Betsie River	10	10	10	10
7. Mainstem below Dair Creek	119	151	143	159
8. Rice Creek before confluence with Betsie River	7	7	7	12
9. Crystal Lake outlet before confluence with Betsie River	34	60	60	60
10. Betsie River mainstem below connection to Crystal Lake	171	229	222	237
11. Mouth of Betsie River at Betsie Lake	183	232	227	239

Figure 6: Location of Key Hydraulic Points in the Betsie Watershed

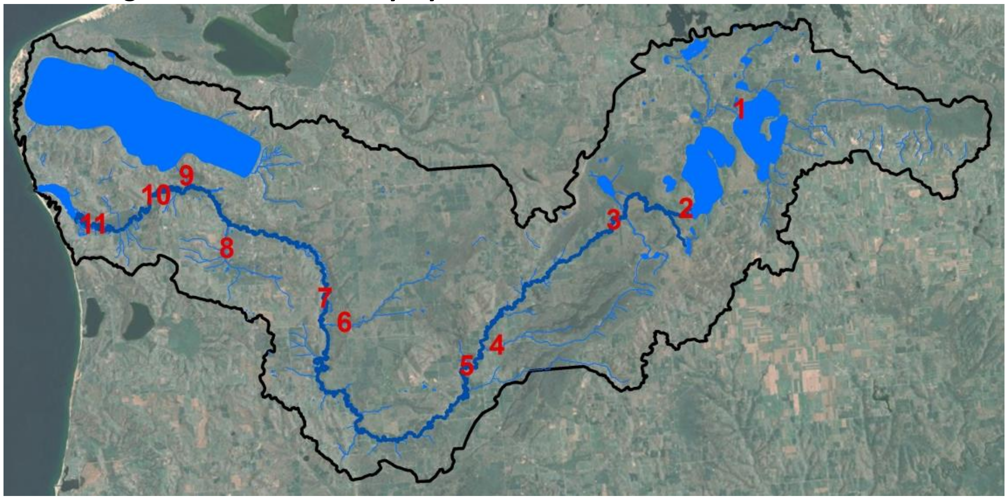
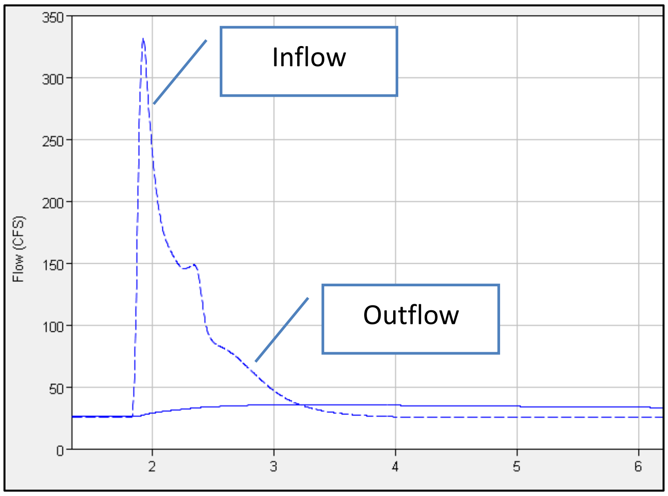


Figure 7: Inflow and Outflow hydrograph at Duck Lake



Discussion on the Limitations of the Study

The following limitations of runoff and peak flow analysis were identified during the course of the study:

- The 2006 NLCD landcover data has a different resolution and classification system than the 1978 and 1800 landcover data. The NLCD classifications were renamed to closely match the classifications used in the runoff curve number lookup tables (Table 3, pg. 10). However, differences in the NLCD land cover data resolution and production methods result in some inconsistent comparisons to the 1978 map data (e.g. large increase in wetlands). These inconsistencies affect the hydrologic parameters and the runoff calculations to a certain extent, but not enough to invalidate the study conclusions

- The 1978 data includes excavation pits which, according to the MDEQ methodology, should not be included in the computational analysis of direct contributing flows. However, by removing these areas, the effect of development on increases in runoff and peak flow rates is masked.
- The MDEQ methodology for determining peak flow rates is based on the Michigan-specific unit hydrograph. The HEC-HMS methodology for determining peak flow rates is based on the SCS unit hydrograph. The SCS unit hydrograph generally produces higher peak flow rates than the Michigan unit hydrograph, so the in-stream peak flow results are more conservative (higher) than if the Michigan unit hydrograph were used. At the time of the study, HEC-HMS did not provide the capability to change the unit hydrograph specifications. Runoff volumes calculated by the two methodologies are the same since they are not affected by the unit hydrograph.
- The Betsie River Watershed is ungaged, so it was not possible to calibrate the HEC-HMS model to any flow data. The runoff volumes and peak flow rates are based on the best available data that characterizes the watershed and best professional judgment. The confirmation of these predictions using observed flows is an important step in assuring the reliability of the results. Accordingly, it is recommended that MDEQ or its partner organizations involved in the Watershed Management Plan collect wet weather flow data at one or more of the key hydraulic points in the Betsie River system.
- The history of the dams that have been constructed along the Betsie River, and the differences that took place between 1800, 1978 and 2006 are factors that were not considered in this analysis. For example, the dam on Crystal Lake was built in 1911, the dam on Grass Lake was built in 1951, and dam on Duck Lake was built in 1959. There was also a dam built at Thompsonville in 1901 that failed in 1989 and was removed in 1998, and another, the Homestead Dam (construction date unknown) that was converted to a lamprey weir in 1974. These changing hydraulic controls on this river, due to the addition and removal of dams, likely affected peak flow rates. Although these factors were not analyzed, it should be recognized that these changes, in addition to changes in landcover, may have also affected the flood hydrographs.

Appendix: Predicted hydrographs at other key hydraulic points within the Betsie River Mainstem (Figures 8 through 14)

Note: In the following figures for each of the key hydraulic points, 3 inflow/outflow hydrographs are presented. These correspond to landcover conditions in 1800, 1978 and 2006, as discussed in the text.

Figure 8a: Betsie River Mainstem Below Duck Lake

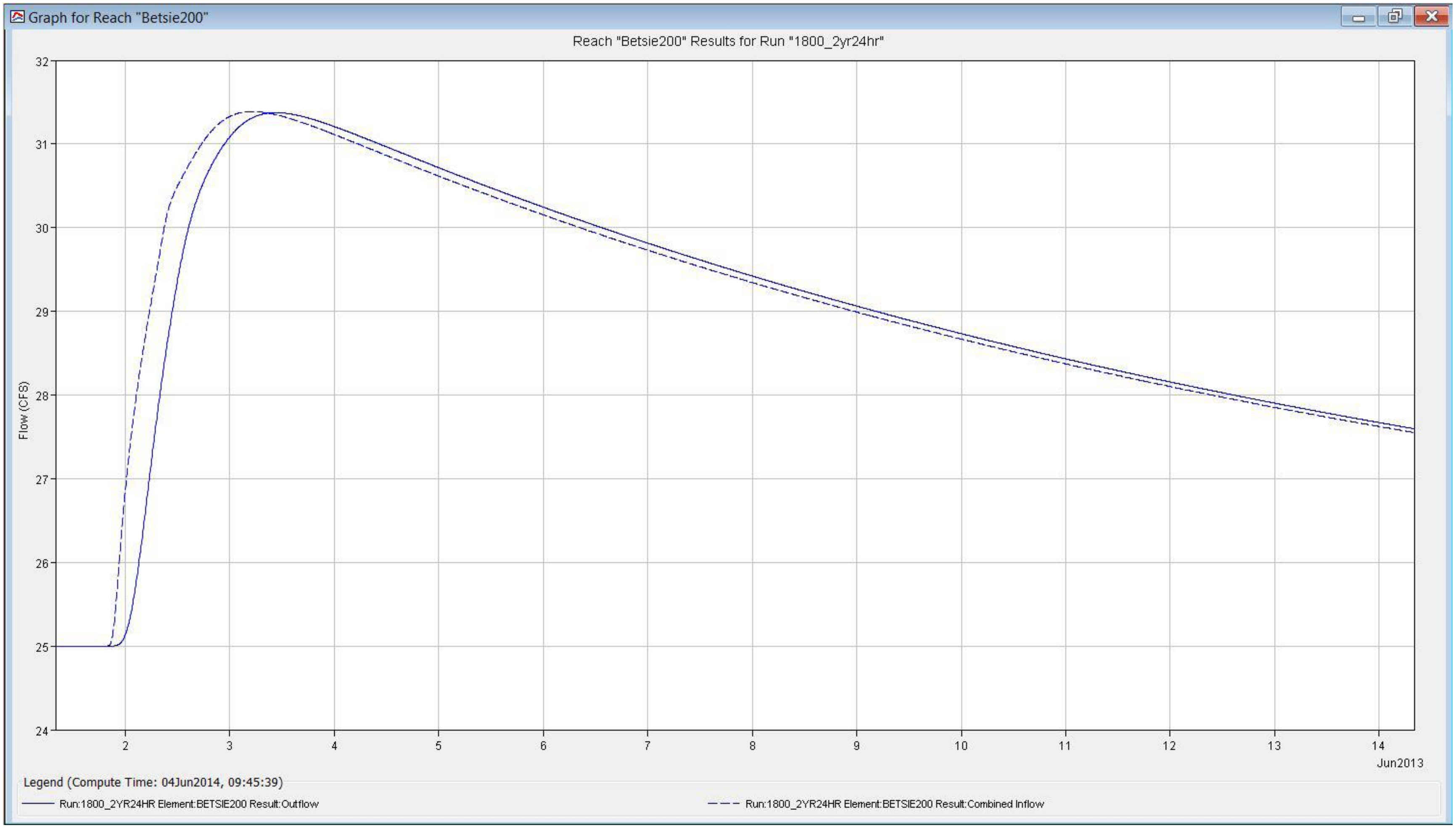


Figure 8b: Betsie River Mainstem Below Duck Lake

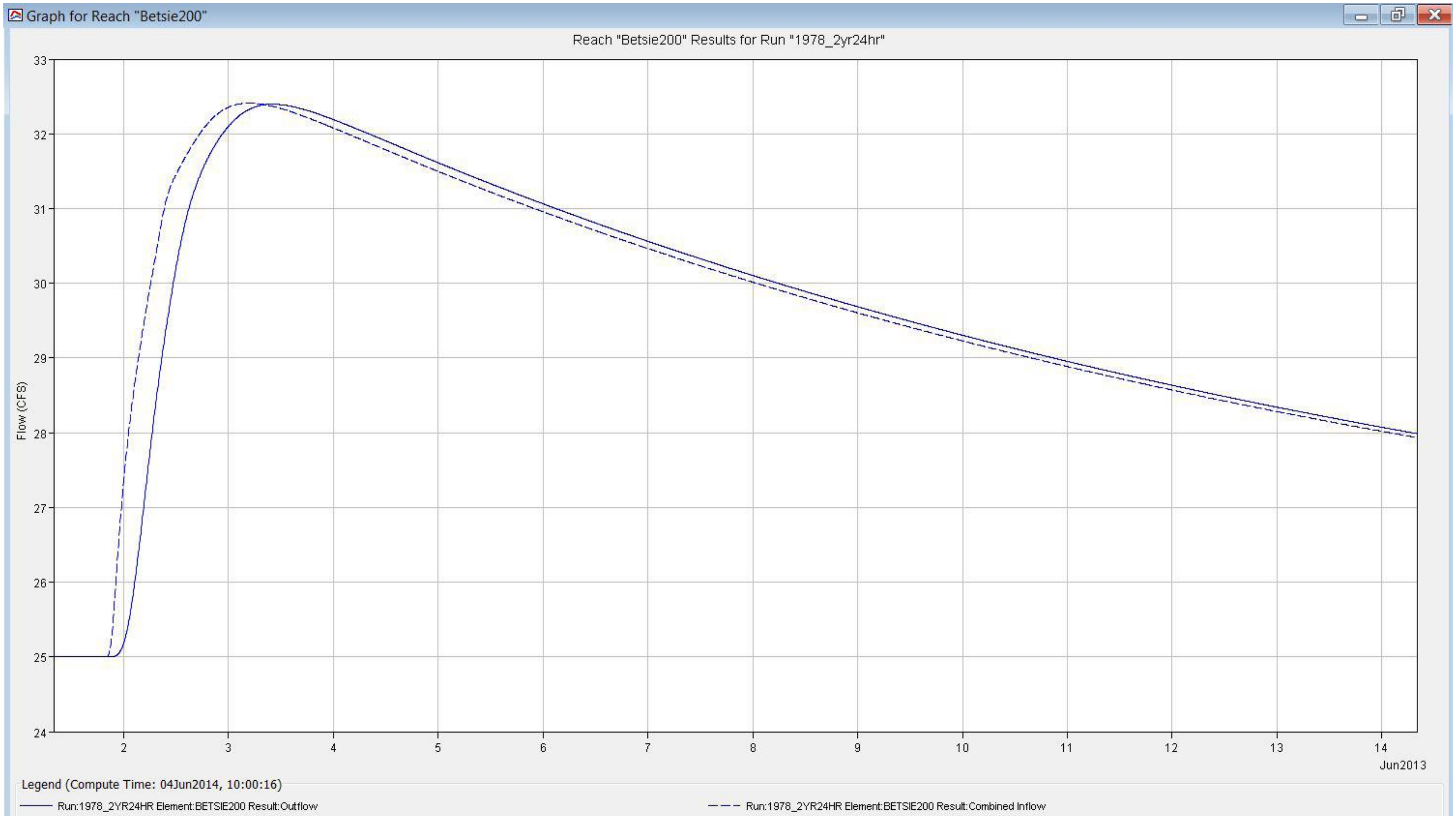


Figure 8c: Betsie River Mainstem Below Duck Lake

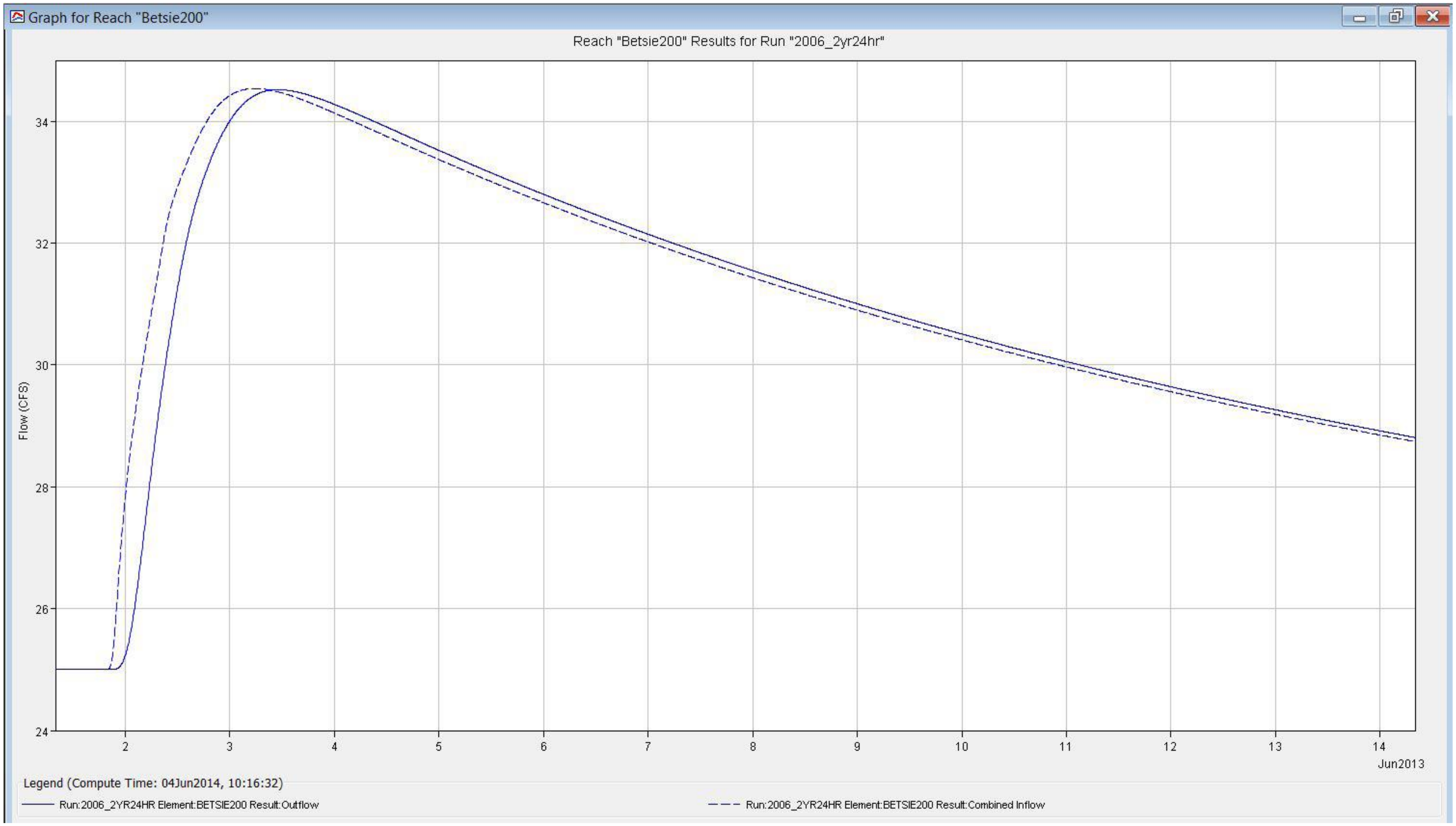


Figure 9a: Betsie River Mainstem Below Green Lake

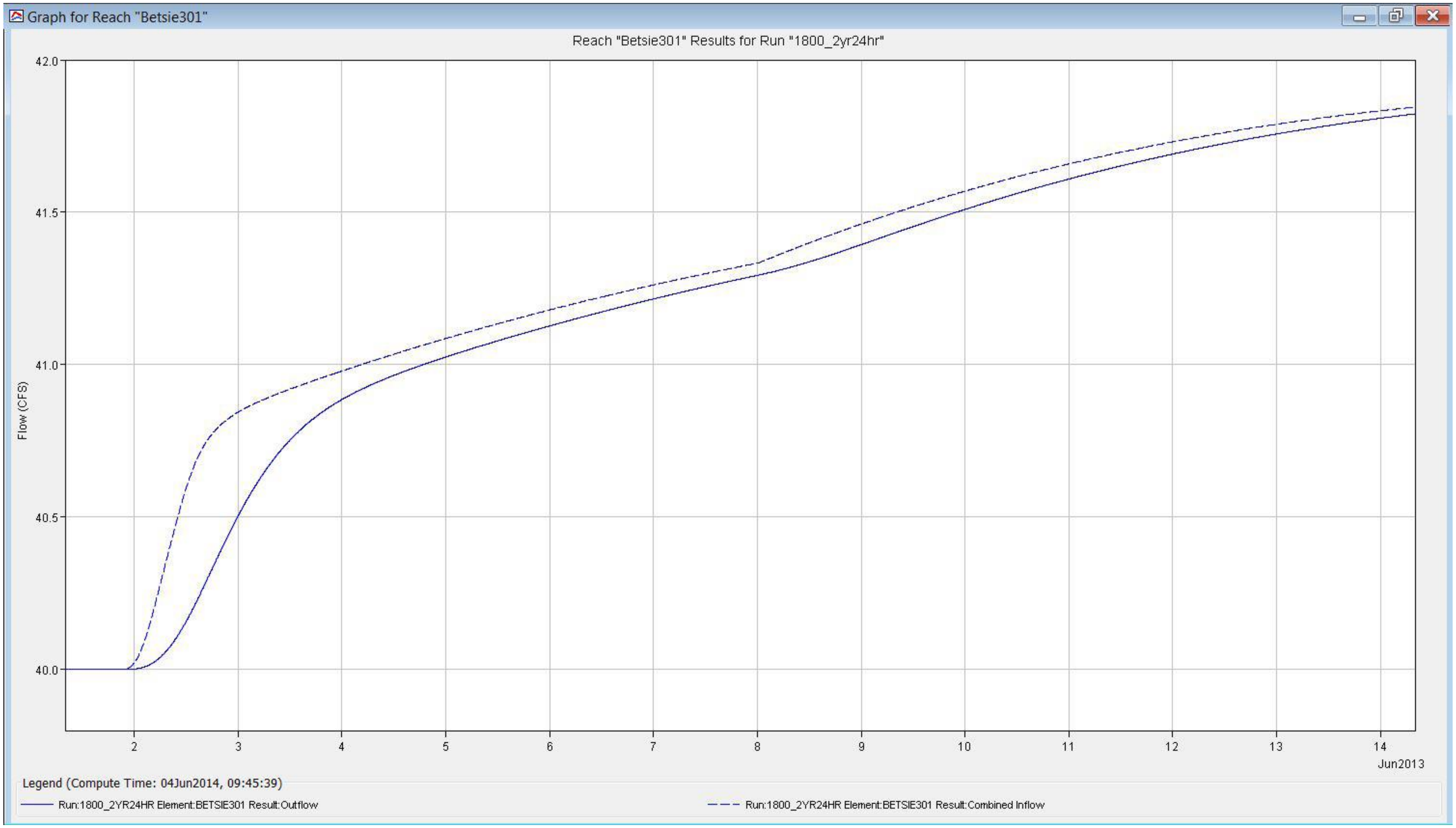


Figure 9b: Betsie River Mainstem Below Green Lake

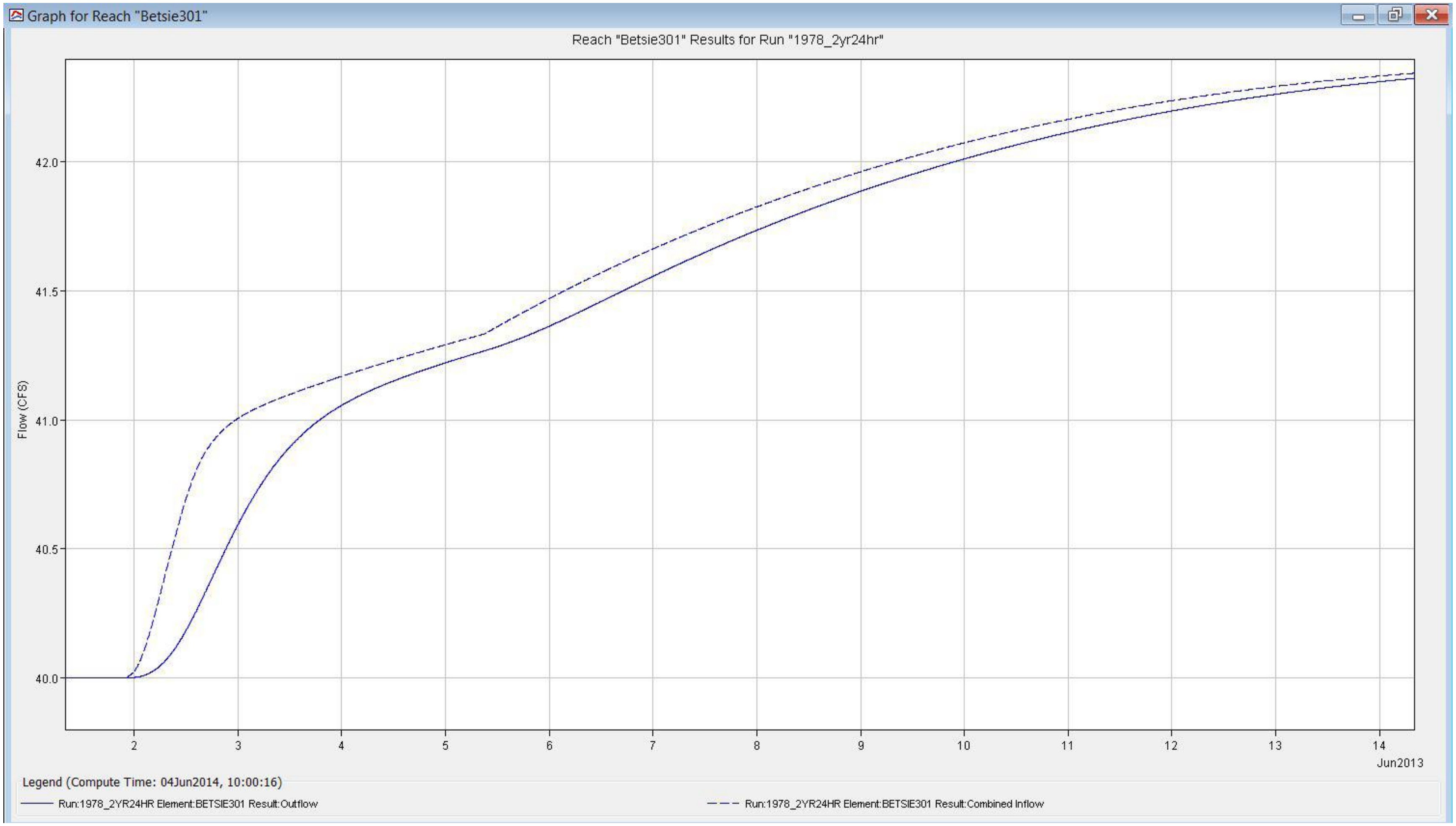


Figure 9c: Betsie River Mainstem Below Green Lake

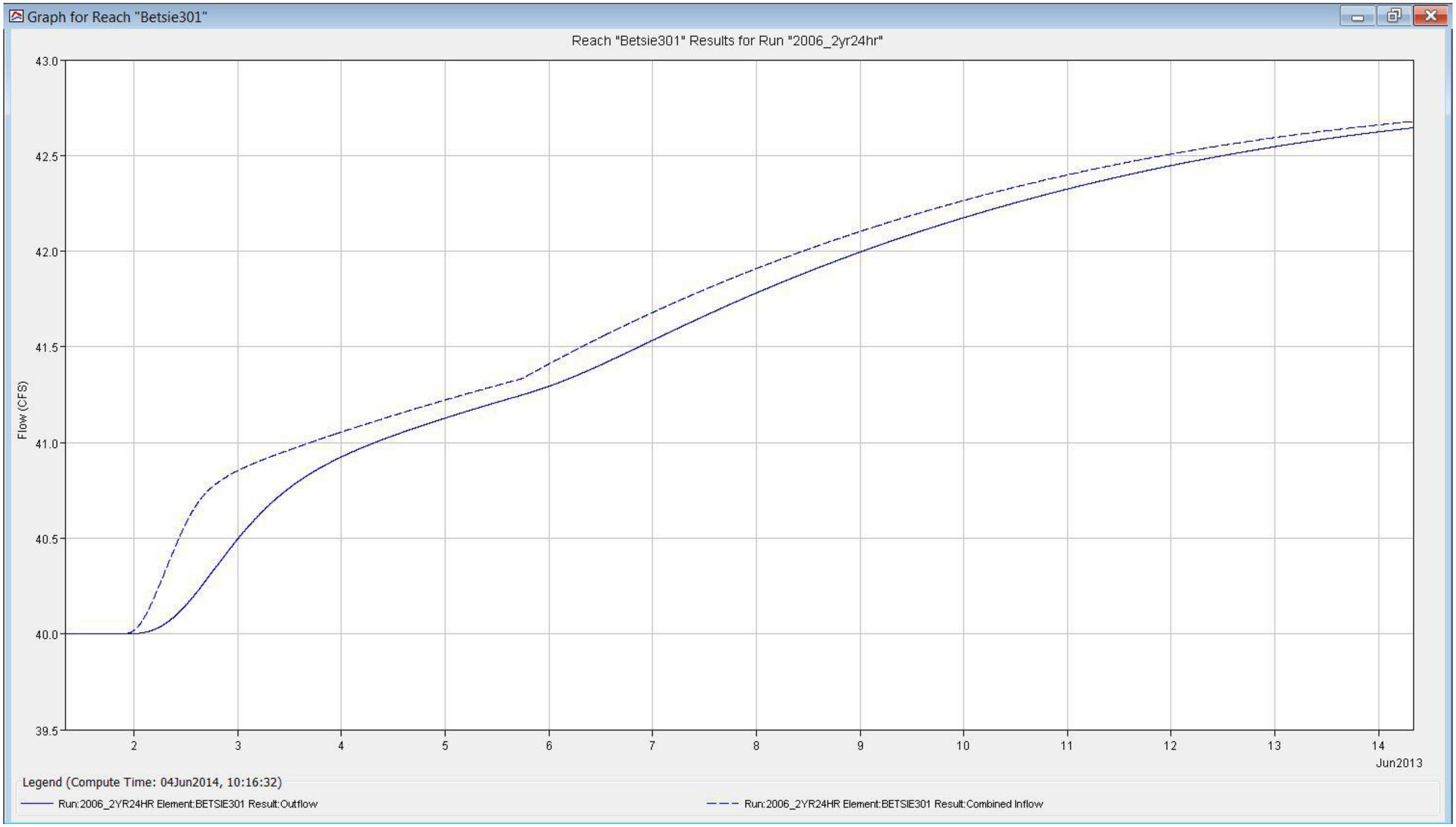


Figure 10a: Betsie River Mainstem Below Grass Lake

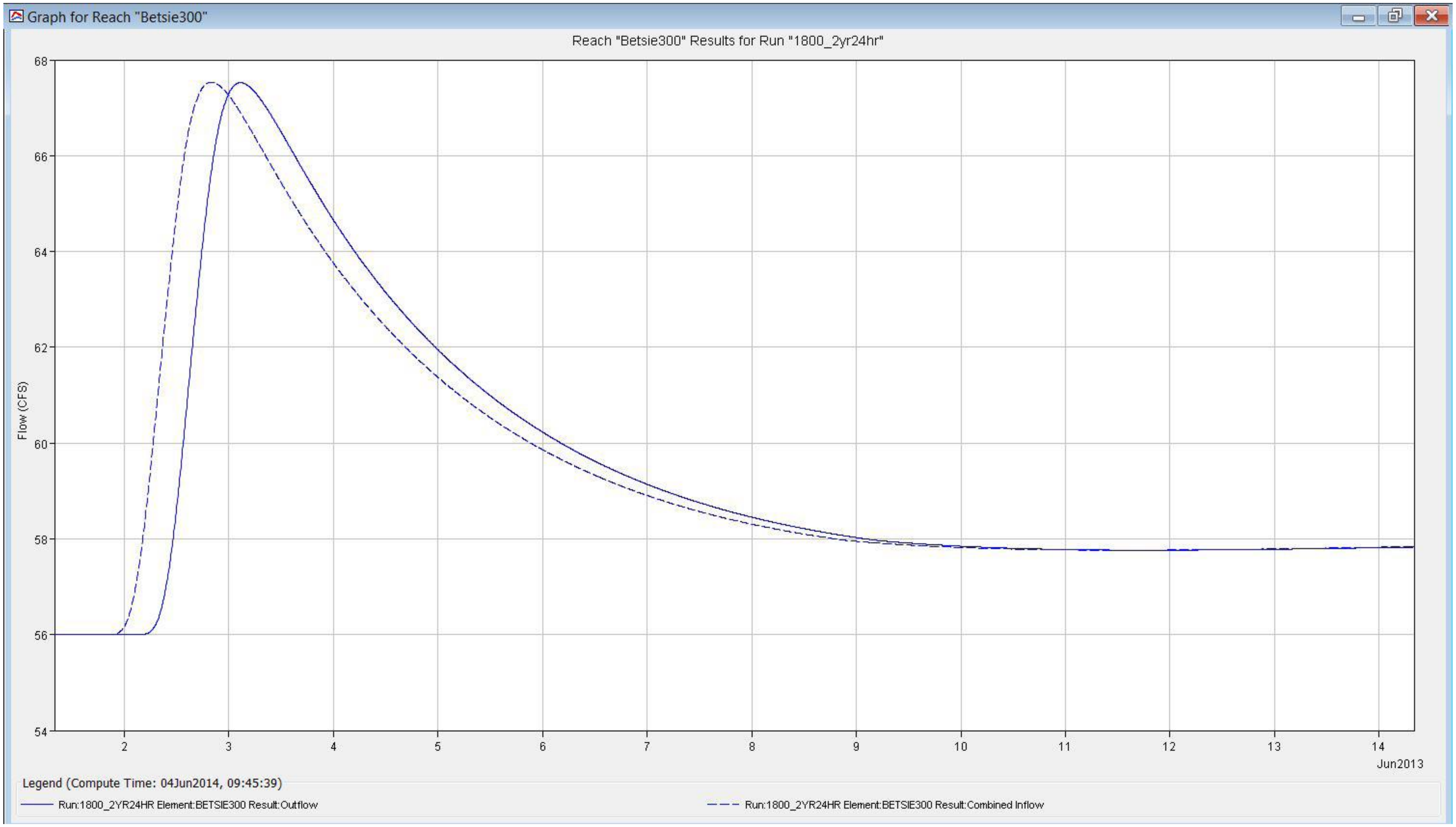


Figure 10b: Betsie River Mainstem Below Grass Lake

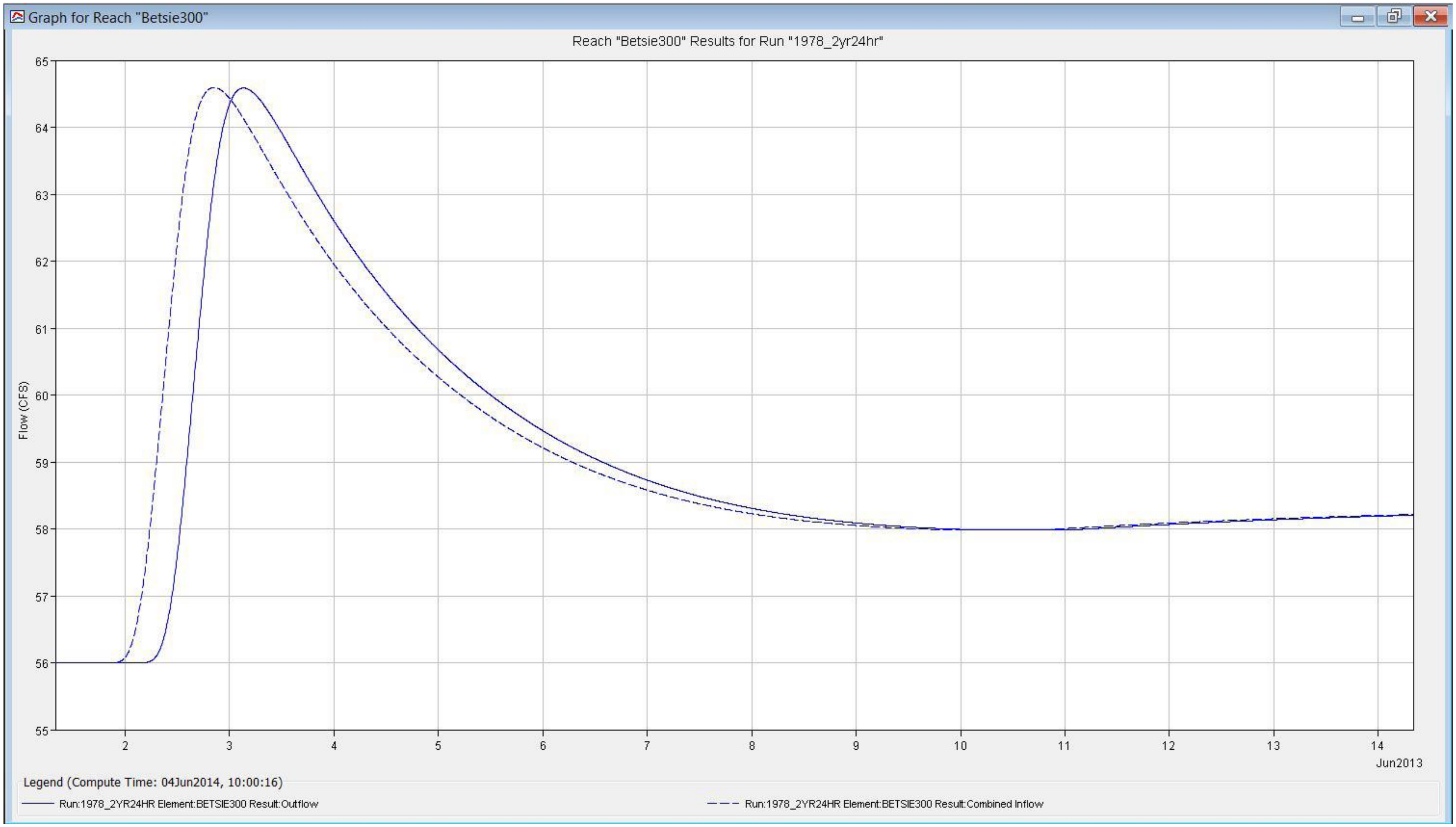


Figure 10c: Betsie River Mainstem Below Grass Lake

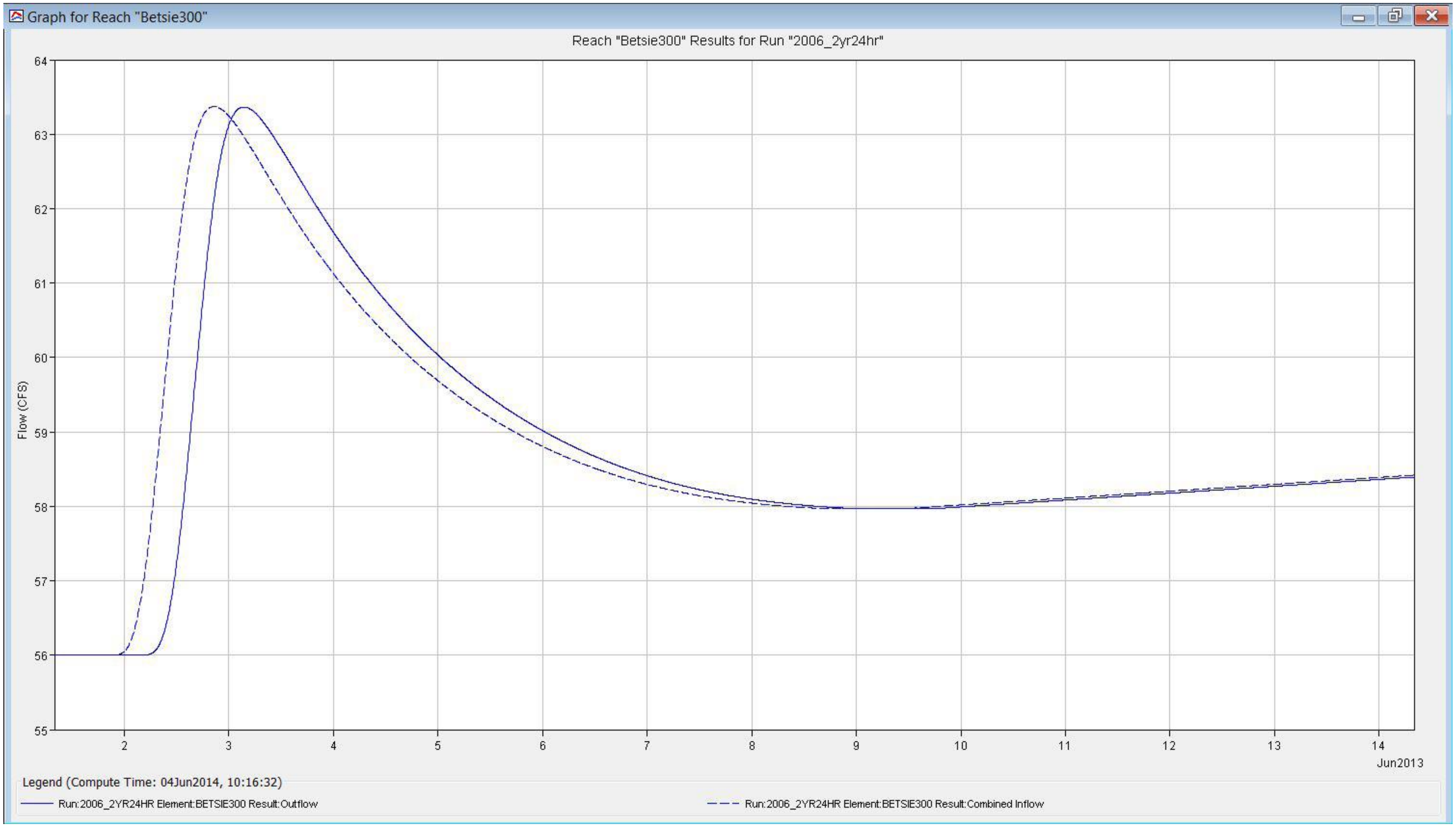


Figure 11a: Betsie River Mainstem Below Little Betsie River Junction

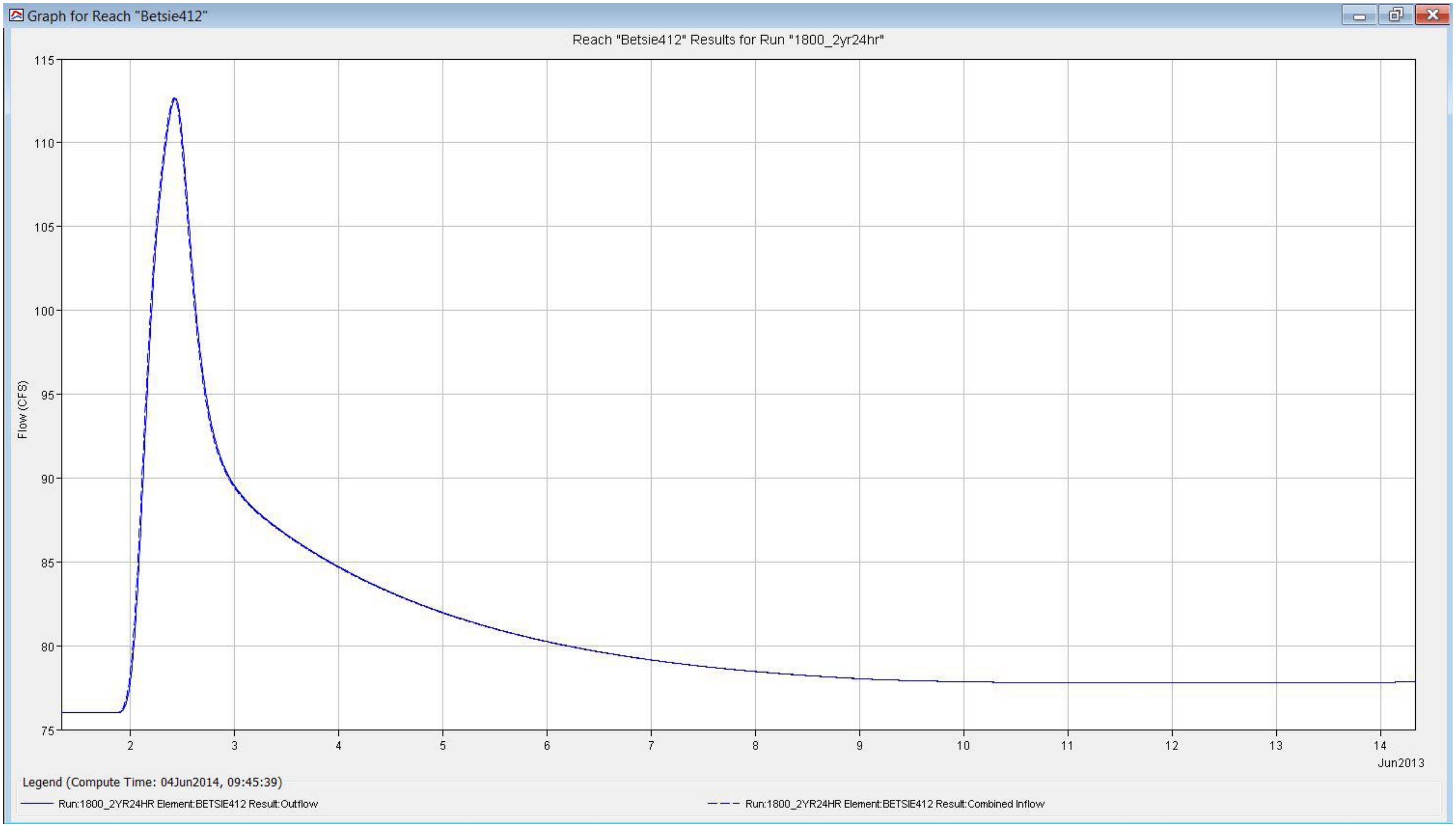


Figure 11b: Betsie River Mainstem Below Little Betsie River Junction

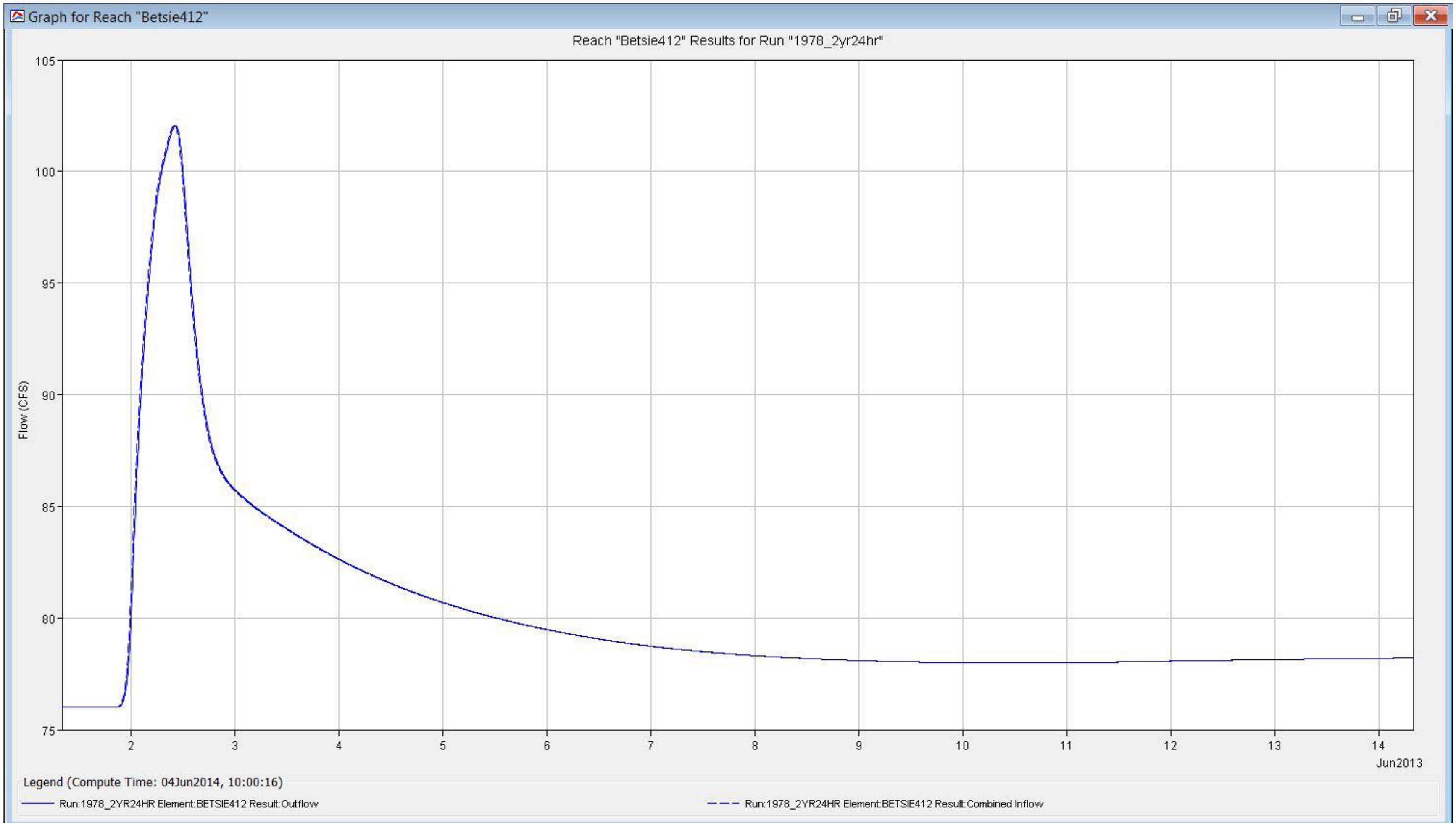


Figure 11c: Betsie River Mainstem Below Little Betsie River Junction

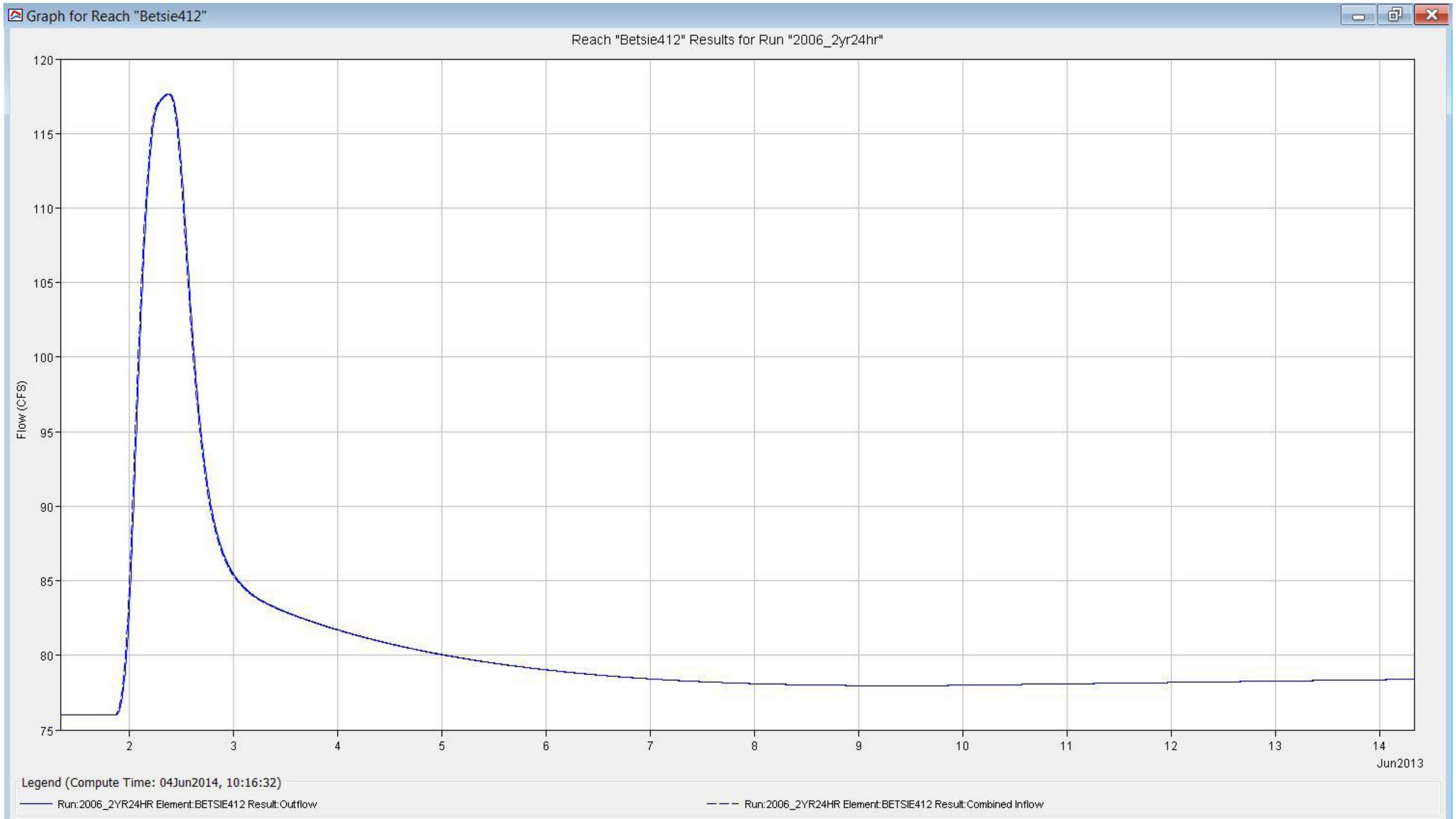


Figure 12a: Betsie River Mainstem Below Dair Creek Junction

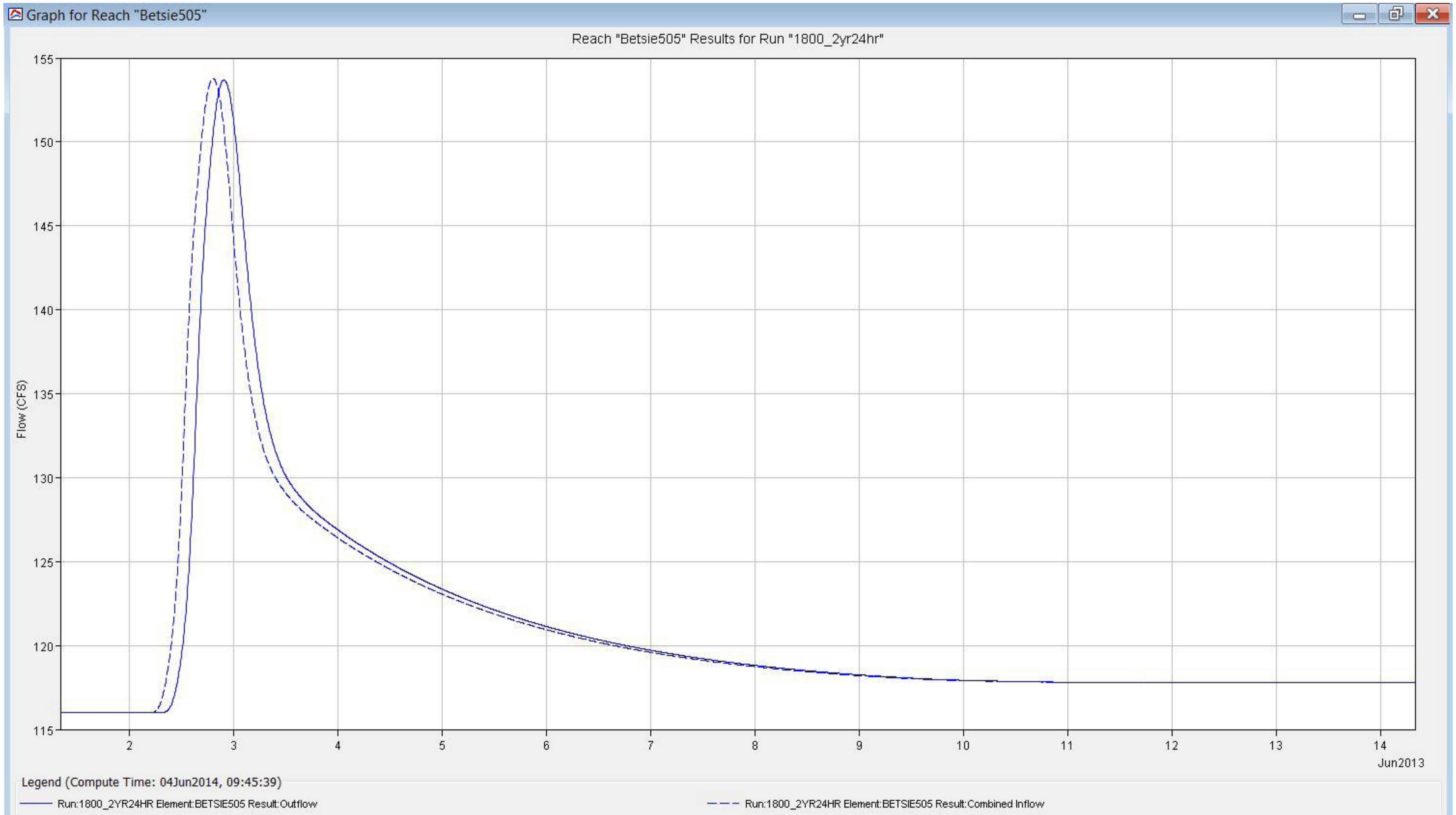


Figure 12b: Betsie River Mainstem Below Dair Creek Junction

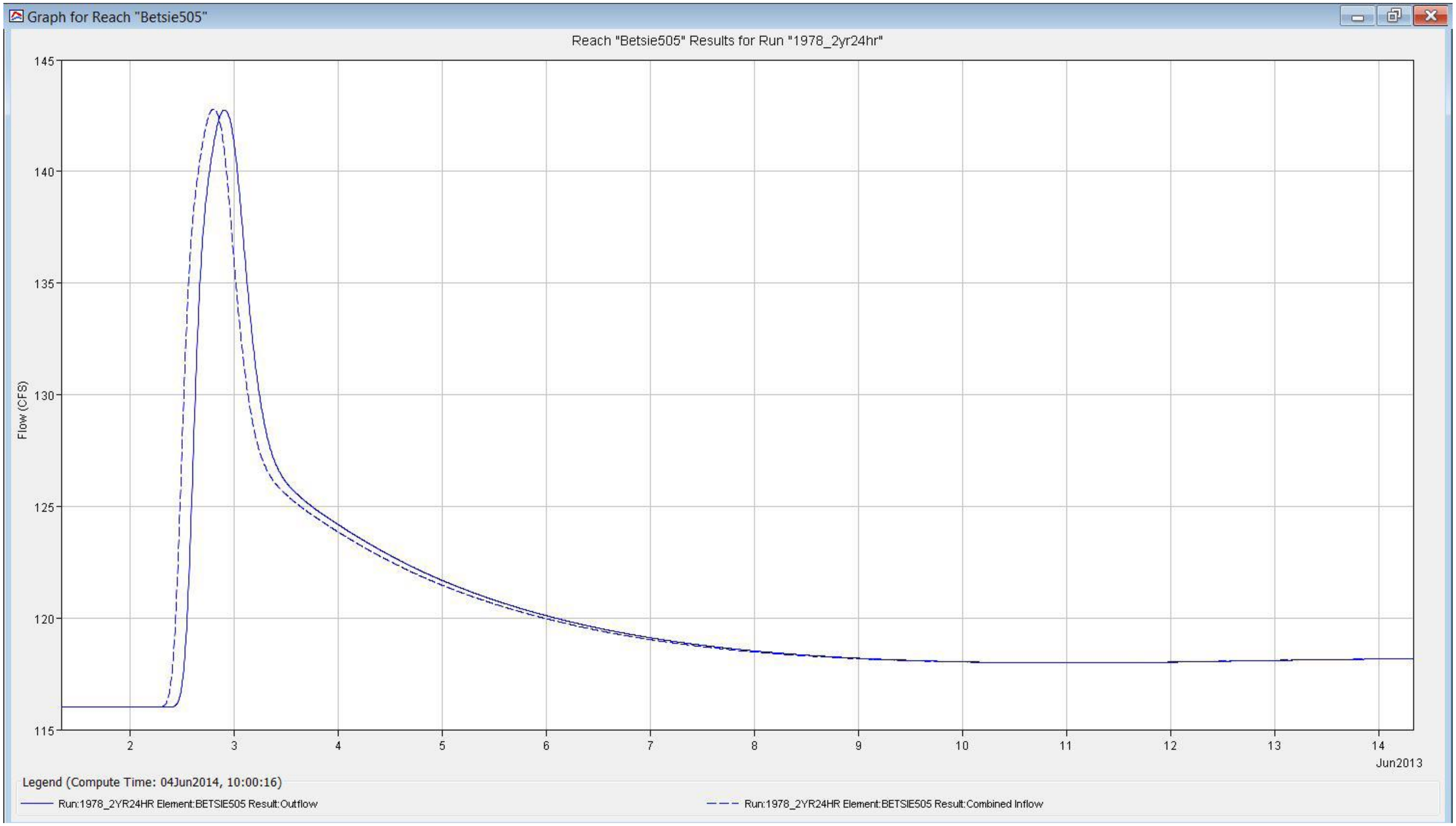


Figure 12c: Betsie River Mainstem Below Dair Creek Junction

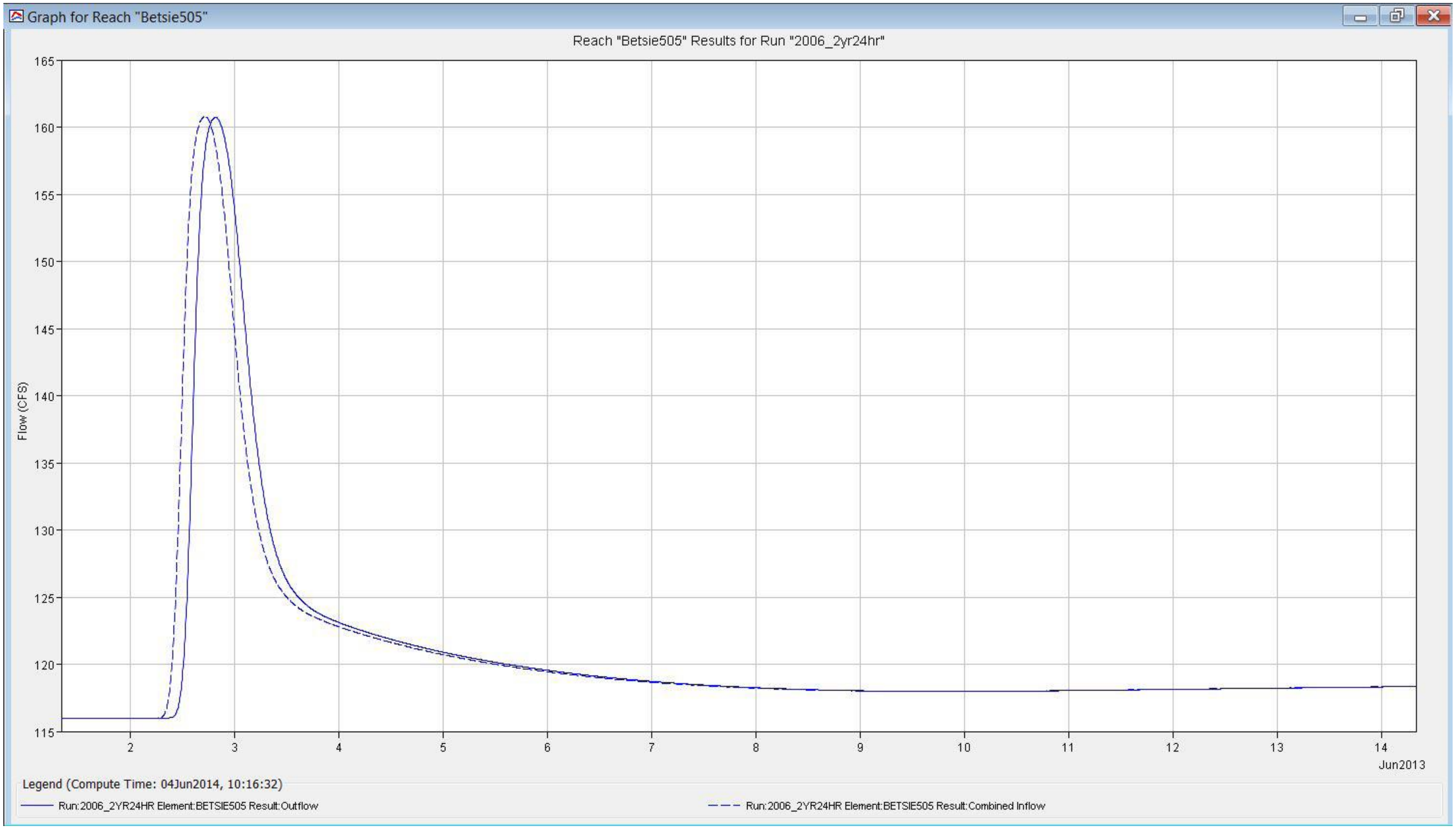


Figure 13a: Betsie River Mainstem Below Connection to Crystal Lake

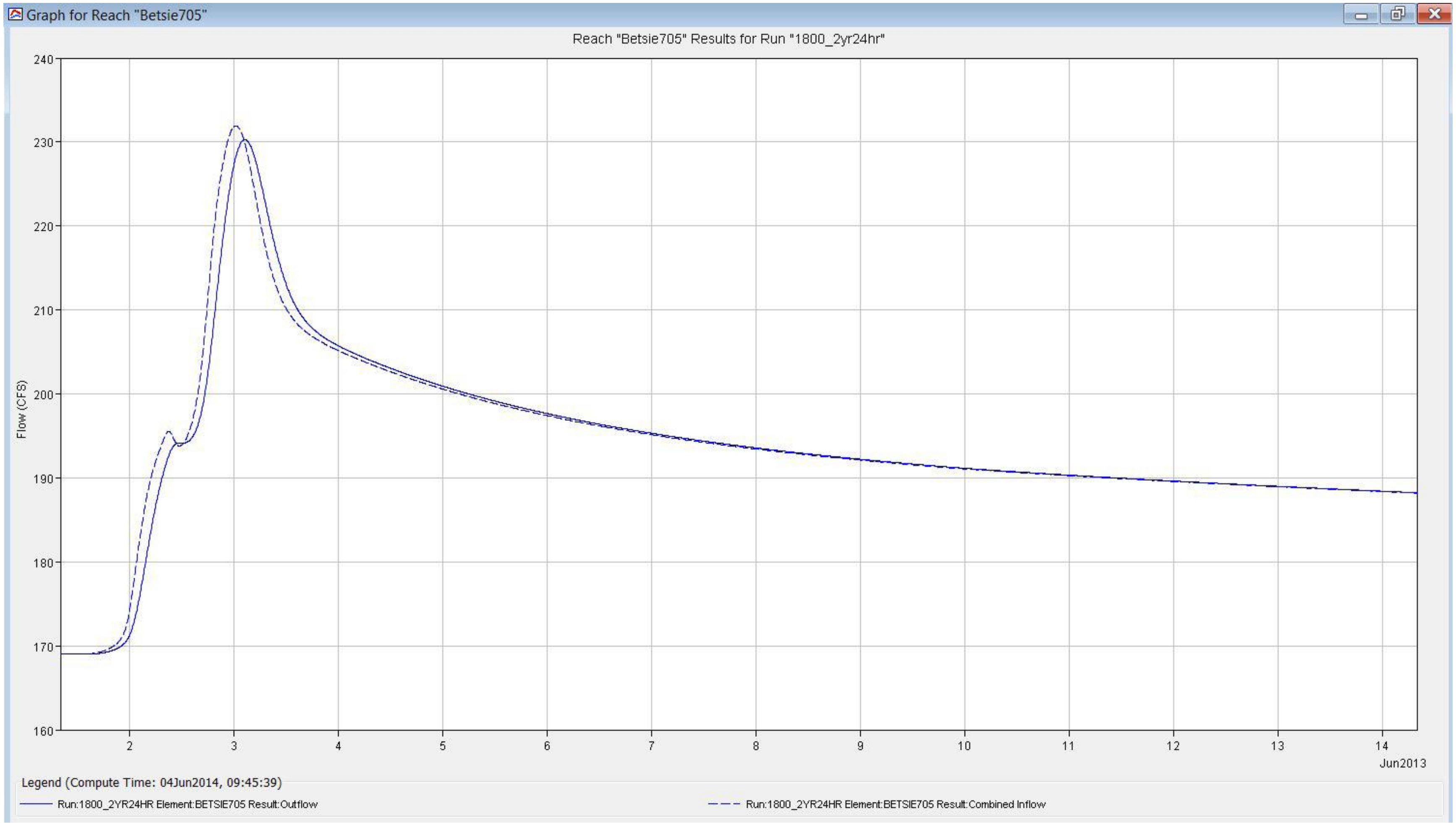


Figure 13b: Betsie River Mainstem Below Connection to Crystal Lake

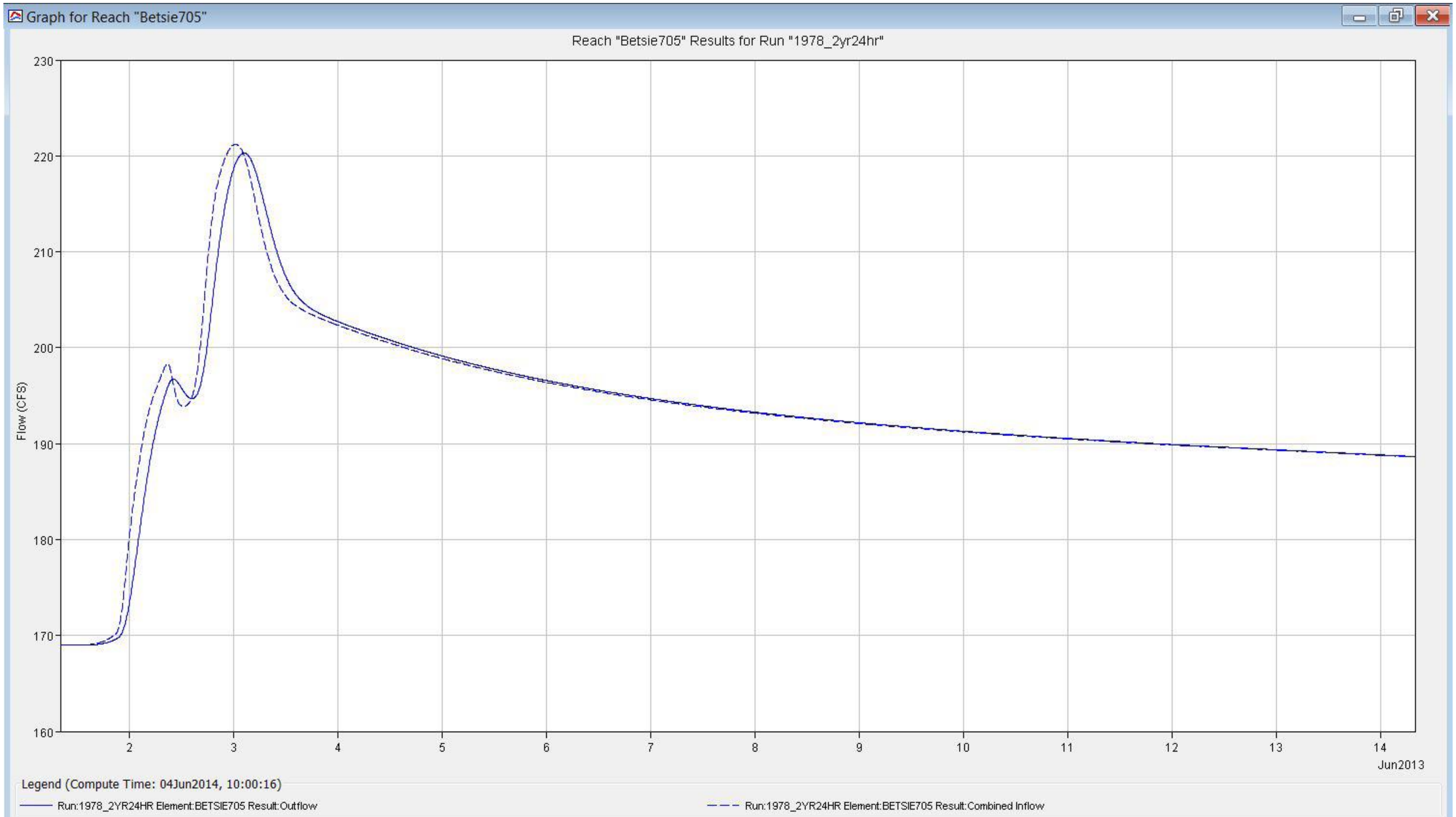


Figure 13c: Betsie River Mainstem Below Connection to Crystal Lake

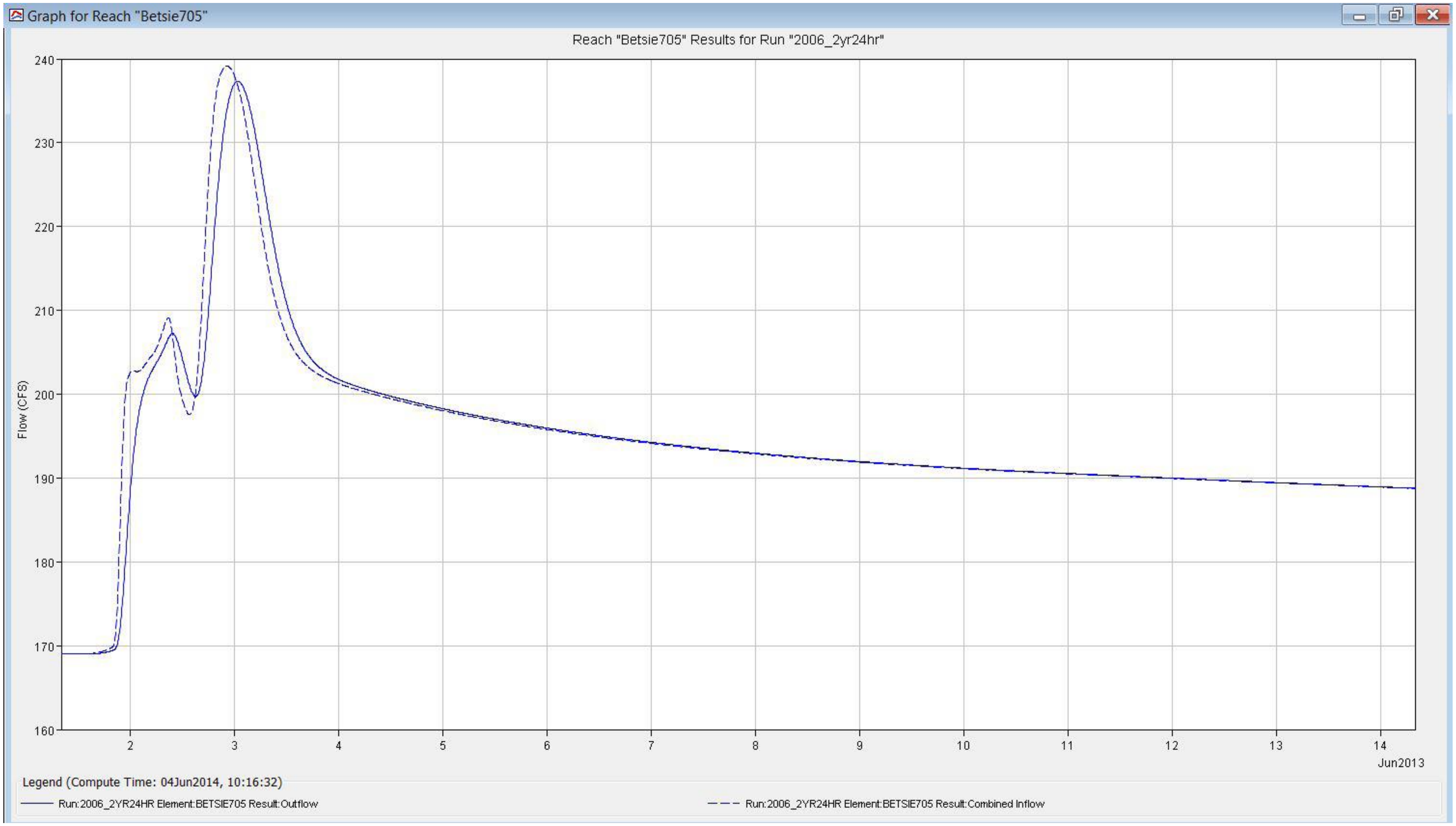


Figure 14a: Mouth of Betsie River at Betsie Lake

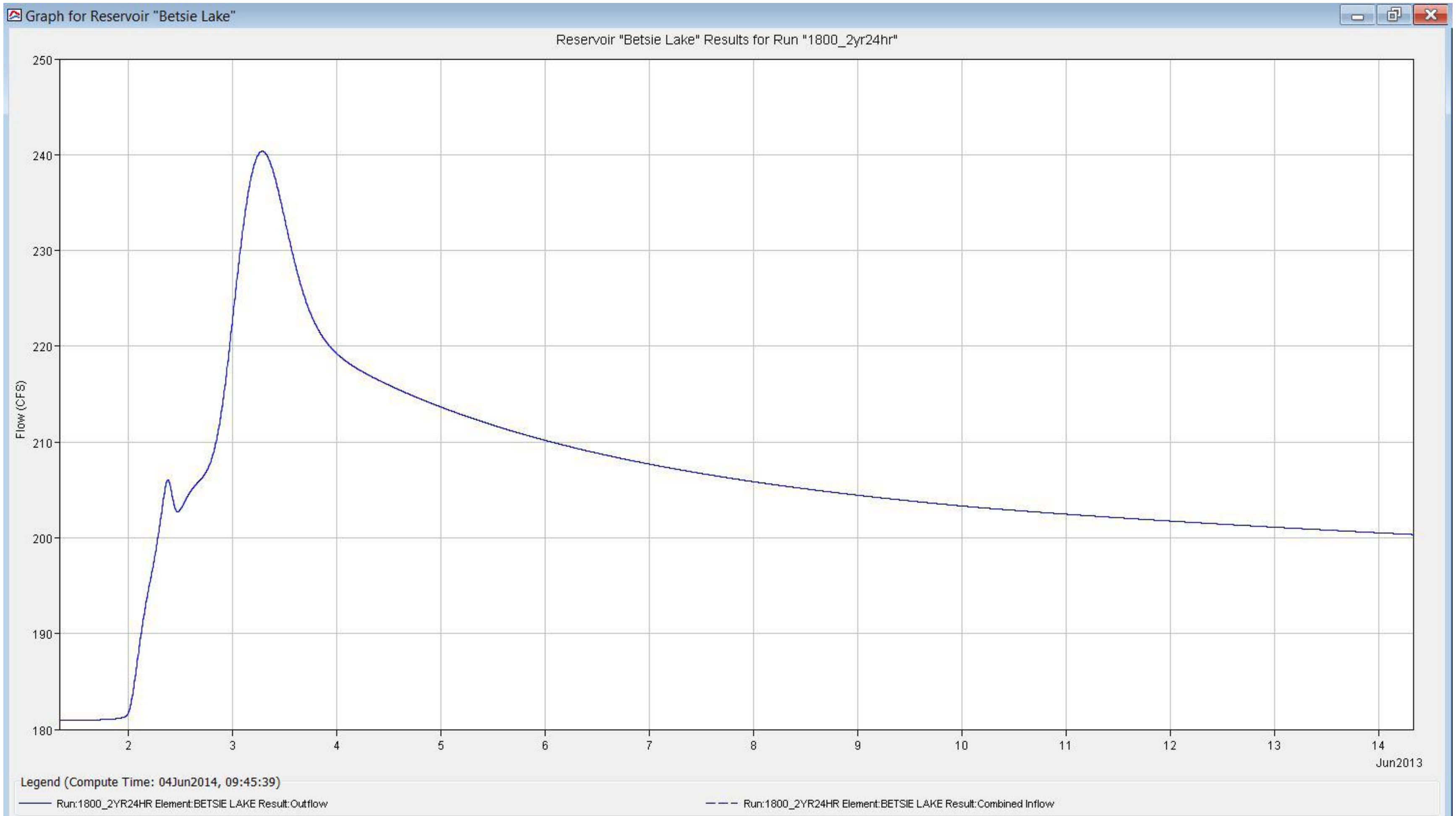


Figure 14b: Mouth of Betsie River at Betsie Lake

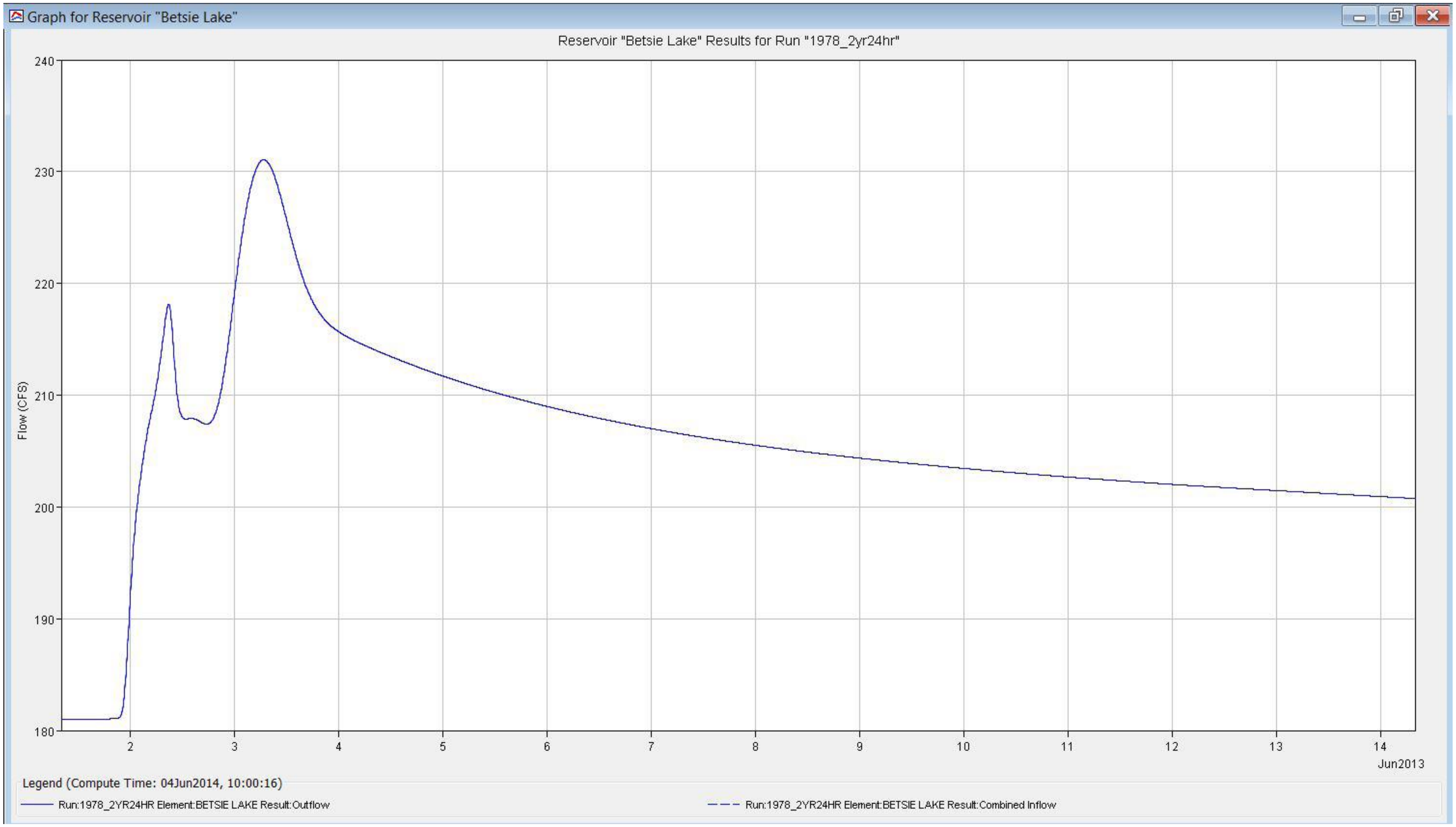


Figure 14c: Mouth of Betsie River at Betsie Lake