Data Evaluation

During CY 2011, predischarge samples were collected during at Ponds A-4, B-5, and C-2 prior to opening the outlet valve to initiate discharge. All predischarge sample results indicated that water quality was acceptable for discharge. Subsequent POC sampling during discharge also indicated acceptable water quality for the discharged water.

3.1.3 Rocky Flats Hydrology

The following section provides information for all automated surface-water monitoring and precipitation gage locations at the Site that operated during CY 2011. For locations with continuous flow measurement, graphical discharge summaries are provided. Graphical summaries are also provided for all precipitation gage locations. Numerical discharge and precipitation values are included in the tables in Appendix A.

Groundwater hydrology is also addressed. This includes a discussion of groundwater levels in various areas of interest via the preparation of hydrographs and potentiometric surface maps. Flow velocities are also calculated. Hydrographs for monitoring wells are included in Appendix A.

3.1.3.1 General Hydrologic Setting

Streams and seeps at the Site are largely ephemeral, with stream reaches gaining or losing flow, depending on the season and precipitation amounts. Section 3.1.3.6 discusses the 2011 efforts to document observed seeps at the site. Surface-water flow across the Site is primarily from west to east, with three major drainages traversing the Site. In 2011, five ponds within the COU collected and managed surface-water runoff.[7] The Site drainages and ponds, including their respective pertinence to this report, are described below and shown on Figure 85.

The major stream drainages leading out of the Refuge, from north to south, are Rock Creek, Walnut Creek, and Woman Creek. North Walnut Creek flows through the A-3 and A-4 Ponds, and South Walnut Creek flows through the B-5 Pond; both are tributaries to Walnut Creek. The hydrologic routing diagram (as of December 31, 2011) for the locations included in this report is shown on Figure 86.

The groundwater hydrology is generally characterized by relatively thin, shallow, saturated materials (in the COU, typically on the order of a few dozen feet thick or less, and less than 50 feet deep). This shallow saturated interval occurs within the unconsolidated Rocky Flats Alluvium, hillslope colluvium, valley-fill alluvium, artificial fill, and the weathered portion of the underlying bedrock. Collectively, these materials are referred to as the upper hydrostratigraphic unit (UHSU). Regionally, groundwater flows from west to east within the UHSU of the pediment surfaces, except where locally diverted toward the generally east-west trending drainages that bisect these pediments. Groundwater typically discharges at seeps and

[7] Former Dams A-1, A-2, B-1, B-2, B-3, and B-4 were breached during 2008−2009.

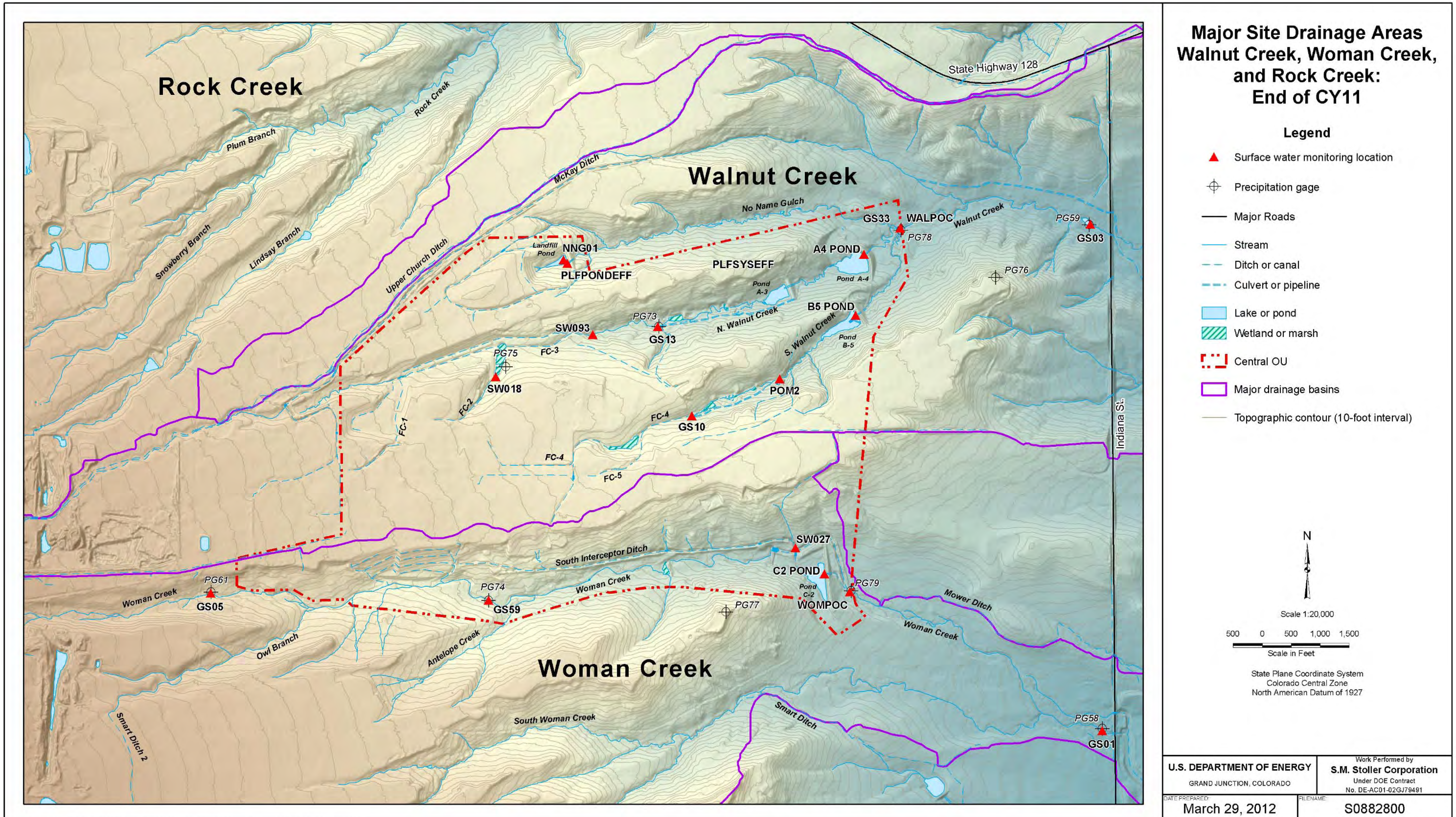

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Figure 85. Major Site Drainage Areas—Walnut Creek, Woman Creek, and Rock Creek: End of CY 2011

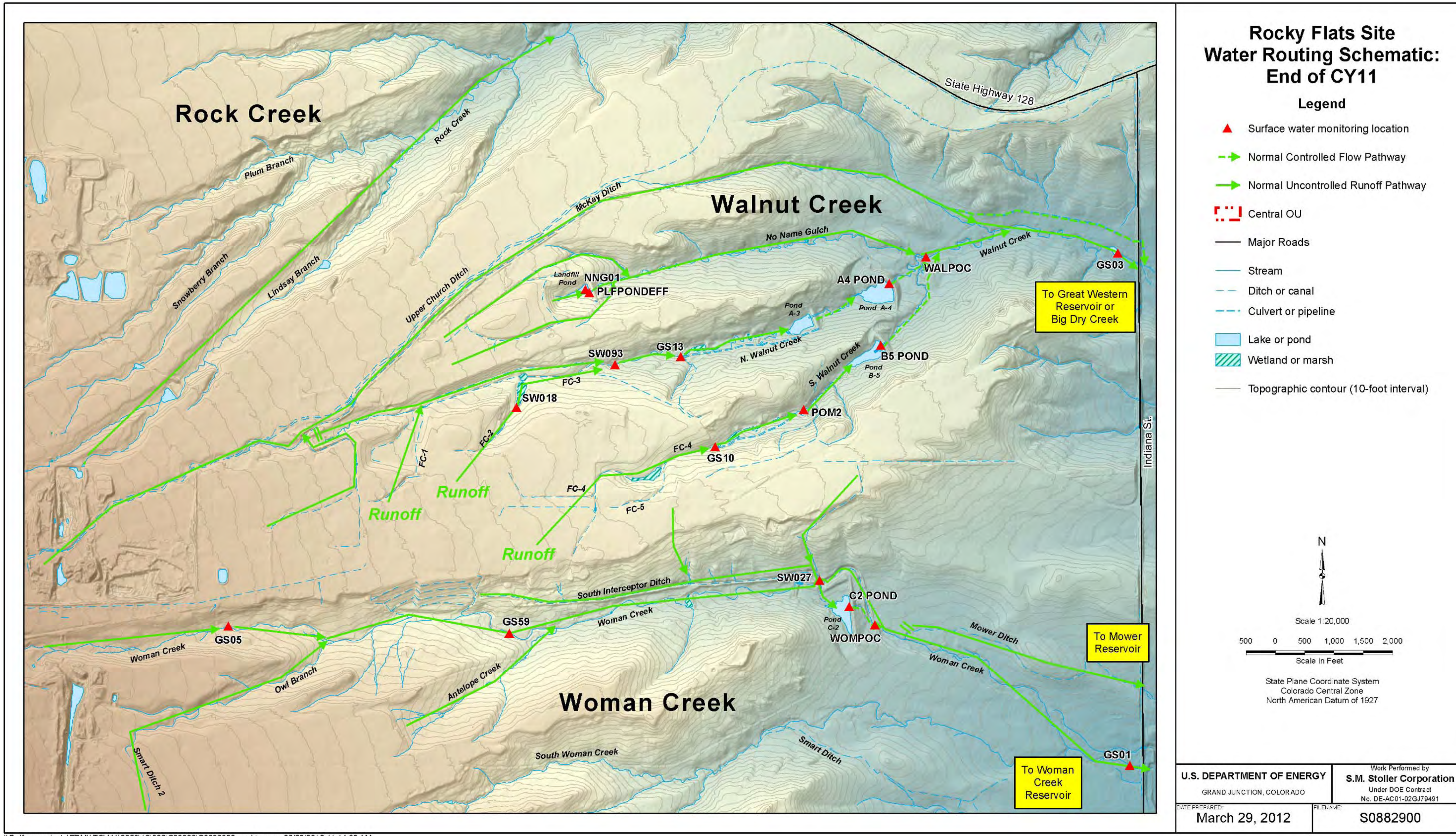

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Figure 86. Rocky Flats Site Water Routing Schematic: End of CY 2010

springs along pediment edges, or as baseflow to surface water. Vertical flow is sharply limited by the low-permeability claystones underlying the unconsolidated surficial materials. This underlying low-permeability bedrock surface comprises the Arapahoe and Laramie Formations, which are typically undifferentiated; the gentle eastward dip of the unconformity marking the contact between this bedrock and the overlying unconsolidated surficial materials acts to direct the groundwater flow. Locally, this bedrock may include sandstone lenses that subcrop or are sufficiently shallow to be included in the UHSU. For a more thorough description of the hydrogeology at Rocky Flats, refer to the EG&G hydrogeologic report (EG&G 1995a).

Surface Water

Walnut Creek

Walnut Creek receives surface-water flow from the central third of the Refuge, including the majority of the COU. It consists of several tributaries: McKay Ditch, No Name Gulch, North Walnut Creek, and South Walnut Creek. These tributaries join Walnut Creek upstream of the Refuge's eastern boundary (Indiana Street). East of Indiana Street, Walnut Creek flows through a diversion structure normally configured to divert flow to the Broomfield Diversion Ditch around Great Western Reservoir and into Big Dry Creek. The Walnut Creek tributaries, from north to south, are described below.

McKay Ditch

The McKay Ditch was formerly a tributary to Walnut Creek within the Refuge boundary but was modified in July 1999 to allow for diversion into a new pipeline to keep McKay Ditch water from commingling with water in Walnut Creek upstream of Indiana Street. Although periodically not a contributor to Walnut Creek (depending on headgate configuration), the McKay Ditch drainage is described here to clarify water routing. The new configuration allows the City and County of Broomfield to direct water from the South Boulder Diversion Canal, across the northern portion of the Refuge, through the McKay Bypass Pipeline, and directly into Great Western Reservoir, without entering Walnut Creek. This configuration prevents the commingling of McKay Ditch water with water originating in the COU. McKay Ditch (as well as both the McKay Bypass Canal and McKay Bypass Pipeline) are outside the COU; these features are not maintained by LM.

No Name Gulch

This drainage is located downstream of the Present Landfill Pond. A surface-water diversion ditch is constructed around the perimeter of the PLF to divert surface-water runoff around the landfill area to No Name Gulch. Effluent from the PLFTS and runoff from the area immediately surrounding the Landfill Pond are the sole surface-water sources to the Landfill Pond. The Landfill Pond is normally operated in a flow-through configuration, although the pool level periodically drops below the outlet works.

North Walnut Creek

Runoff from the northern portion of the COU flows into this drainage, which has two ponds (Ponds A-3 and A-4). Dams A-1 and A-2 were breached in 2008−2009. The combined capacity of the remaining A-Series Ponds is approximately 170,000 cubic meters (m^3) (45 million gallons, or 137 acre-feet). In the normal operational configuration, the A-1 and A-2 wetland areas receive flow to sustain habitat, with water subsequently flowing to Pond A-3. Pond A-3 is normally operated in flow-through mode allowing water to flow directly to the A-series “terminal pond” Pond A-4. As of September 12, 2011, Pond A-4 is also operated in a flow-through mode. If a valve closure at Pond A-4 causes water to temporarily be retained, a predischarge sample is collected prior to resuming discharge. Criteria for emergency discharge, regardless of predischarge pond sampling results, are detailed in the *Emergency Response Plan for Rocky Flats Site Dams* (ERP) (DOE 2010f).

South Walnut Creek

Runoff from the central portion of the COU flows into this drainage, which has one pond, Pond B-5. Dams B-1, B-2, B-3, and B-4 were breached in 2008−2009. The capacity of Pond B-5 is approximately 87,000 m^3 (23 million gallons or 71 acre-feet). In the normal operational configuration, the B-1, B-2, B-3, and B-4 wetland areas receive flow to sustain habitat, with water subsequently flowing to “terminal pond” Pond B-5. As of September 12, 2011, Pond B-5 is also operated in a flow-through mode. If a valve closure at Pond B-5 causes water to temporarily be retained, a predischarge sample is collected prior to resuming discharge. Criteria for emergency discharge, regardless of predischarge pond sampling results, are detailed in the ERP.

Woman Creek

South of the COU is Woman Creek, which flows through the C-1 wetland (Dam C-1 was breached in 2004) and offsite onto Refuge lands toward Indiana Street. The Woman Creek drainage basin extends eastward from the base of the foothills, near Coal Creek Canyon, to Standley Lake. In the current configuration, Woman Creek flows into the Standley Lake Protection Project, also known as the Woman Creek Reservoir, located east of Indiana Street and upstream of Standley Lake, where the water is held until it is pump-transferred to Big Dry Creek by the Woman Creek Reservoir Authority.

South Interceptor Ditch

In the southern portion of the COU, and a tributary to Woman Creek, is the SID drainage. Surface-water runoff from the southern portion of the COU is intercepted by the SID, which flows from west to east into Pond C-2. Woman Creek water does not enter Pond C-2, but is diverted around Pond C-2 through the Woman Creek Diversion Canal. As of November 7, 2011, Pond C-2 is also operated in a flow-through mode. If a valve closure at Pond C-2 causes water to temporarily be retained, a predischarge sample is collected prior to resuming discharge. Criteria for emergency discharge, regardless of predischarge pond sampling results, are detailed in the ERP.

Other Drainages

The third major drainage, other than Walnut and Woman Creeks, is Rock Creek. The Rock Creek drainage covers the northwestern portion of the Refuge. East-sloping alluvial plains to the west, several small stock ponds within the creek bed, and multiple steep gullies and stream channels to the east characterize the drainage channel. This entire basin is outside the COU.

Smart Ditch/South Woman Creek, located south of Woman Creek, is also completely outside the COU. The D-Series Ponds (D-1 and D-2) are located on Smart Ditch. This drainage and these ponds are not maintained by LM.

3.1.3.2 Surface-Water Hydrologic Data Presentation

Flow Data Collection and Computation

Data obtained at a continuous surface-water gaging station on a stream or conveyance, such as an irrigation ditch, consist of a continuous record of stage,[8] individual measurements of flow throughout a range of stages, and notations regarding factors that might affect the relation of stage to flow rate. These data, together with supplemental information such as climatological records, are used to compute daily mean discharges.

Continuous records of stage are obtained with electronic recorders that store stage values at selected time intervals or secondarily with radio-telemetry data-collection platforms that transmit near real-time data at selected time intervals to a central database for subsequent processing. Direct field measurements of flow are made with current meters, using methods adapted by the U.S. Geological Survey, or with flumes or weirs that are calibrated to provide a relation of observed stage to flow rate. These methods are described by Carter and Davidian (1968) and by Rantz (1982a, 1982b).

In computing flow records for nonstandard flow-control devices, results of individual measurements are plotted against the corresponding stage, and stage-flow rate relation curves are constructed. From these curves, rating tables indicating the computed flow rate for any stage within the range of the measurements are prepared. For standard devices (e.g., flumes and weirs), rating tables indicating the flow rate for any stage within the range of the device are prepared based on the geometry of the device. If it is necessary to define extremes of flow outside the range of the device, the curves can be extended using (1) logarithmic plotting, (2) velocity-area studies, (3) results of indirect measurements of peak flow rate, such as slope-area or contracted-opening measurements, and computation of flow over dams or weirs, or (4) step-back-water techniques.

Daily mean discharges are computed by averaging the individual flow measurements using the stage-flow rate curves or tables. If the stage-flow rate relation is subject to change because of frequent or continual change in the physical features that form the control, the daily mean discharge is determined by the shifting-control method, in which correction factors based on the individual flow rate measurements and notes by the personnel making the measurements are applied to the gage heights before the flow rates are determined from the curves or tables. This shifting-control method also is used if the stage-flow rate relation is changed temporarily because of aquatic vegetation growth or debris on the control. For some gaging stations, formation of ice in the winter can obscure the stage-flow rate relations so that daily mean discharges need to be estimated from other information, such as temperature and precipitation

[8] Stage is the water level (in units such as feet or meters) in a conveyance structure.

records, notes of observations, and records for other gaging stations in the same or nearby basins for comparable periods.

For most gaging stations, there may be periods when no gage-height record is obtained or the recorded gage height is faulty so that it cannot be used to compute daily mean discharge. This record loss occurs when recording instruments malfunction or otherwise fail to operate properly, intakes are plugged, the stilling well is frozen, or for various other reasons. For such periods, the daily discharges are estimated from the recorded range in stage, previous or following record, field discharge measurements, climatological records, and comparison with other gaging-station records from the same or nearby basins. Information explaining how estimated daily discharge values are identified in gaging-station records is provided in the "Identifying Estimated Daily Discharge" section.

Data Presentation

The information published for each continuous-record surface-water gaging station consists of six parts: the station description, a map showing the drainage area for the station, a plot of the daily mean discharge for the CY(s), a table of daily mean discharge values for the CY with summary data, a tabular statistical summary of monthly mean discharge data for the CY, and a summary statistics table that includes statistical data of annual discharge and runoff. The tables are included in Appendix A, and the other information is presented below.

Station Description

The station description provides, under various headings, descriptive information including gaging-station location, drainage area, period of record, and gage information. The following information is provided:

- Location—This entry provides the gaging station state plane coordinates and geographic location. Gaging station state plane coordinates were obtained by geographic positioning system or digitized from Site geographic information system (GIS) coverages.
- Drainage Area—This entry provides the drainage area (in acres) of the gaged basin. If, because of unusual natural conditions or artificial controls, some part of the basin does not contribute flow to the total flow measured at the gage, the noncontributing drainage area also is identified. Drainage area is usually measured using digital techniques and the most accurate maps available. Because the type of map available might vary from one drainage basin to another, the accuracy of digitized drainage areas also can vary. Drainage areas are updated as better maps become available. Some of the gaging stations included in this report measure stage and flow rate in channels that convey water to or from reservoirs or other features; these channels might have little or no contributing drainage area. Drainage areas in this report were provided by Site GIS coverages.[9]

[9] Drainage area maps show Site configuration at the end of CY 2010.

- Period of Record—This entry provides the period for which the Site has been collecting records at the gage. This entry includes the month and year of the start of collection of hydrologic records by the Site and the words “to current year” if the records are to be continued into the following year.
- Gage—This entry provides the type of gage currently in use and a condensed history of the types and locations of previous gages.

Daily Mean Discharge Values

The daily mean discharge values computed for each gaging station during a CY are listed in the body of the data tables in Appendix A. In the monthly “Flow Rate” summary part of the table, the line headed “Average” lists the average flow rate in cubic feet per second during the month, and the lines headed “Maximum” and “Minimum” list the maximum and minimum daily mean discharges for each month. Total discharge for the month also is expressed in cubic feet, gallons, and acre-feet. The term “Partial Data” denotes a month with incomplete data.

Summary Statistics

A section of the table titled “Annual Summaries for CY 2011” follows the monthly mean data section. This section provides a statistical summary of annual flow rates and discharge for the labeled CY. The applicable units are to the left of the table value. The term “Partial Data” denotes a year with incomplete data.

Identifying Estimated Daily Discharge

Estimated daily discharges published in water-discharge tables and figures of this annual report are identified by *italicizing* individual daily values or through color coding in hydrographs. For periods of no data, a gap is shown on the hydrographs.

Other Records Available

Information used in the preparation of the records in this report, such as discharge-measurement notes, gage-height records, and rating tables, are on file. Information on the availability of the unpublished information or on the published statistical analyses is available from personnel involved with data collection at the Site.

3.1.3.3 Surface-Water Discharge Data Summaries

Sitewide Discharge Summary

Discharge summaries for the two major drainages receiving flow from the COU (Walnut and Woman Creeks) are given on Figure 87 and Figure 88.[10] Walnut Creek flows are measured at GS03 and Woman Creek flows are measured at GS01. Figure 89 shows the relative total CY 1997−2011 discharge volumes from the major Site drainages as measured at Site POEs and POCs. Through CY 2004, Walnut Creek discharged larger volumes than Woman Creek due to

[10] The pre-closure period is for the dates January 1, 1997–October 1, 2004; the post-closure period is for the dates October 1, 2005–December 31, 2011.

the contribution of imported water and runoff from impervious surfaces. After physical completion in CY 2005, the reduction of discharge in Walnut Creek and the corresponding change in relative volumes is clearly observed.

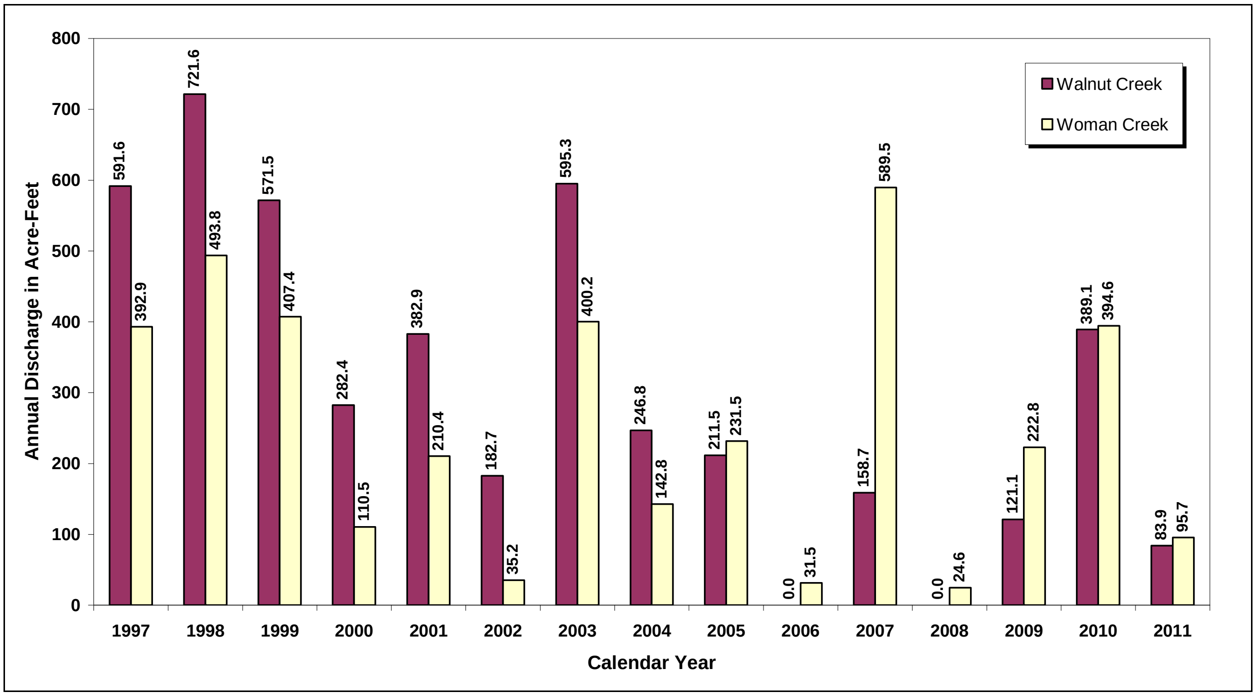


Figure 87. Annual Discharge Summary from Major Site Drainages: CY 1997−2011

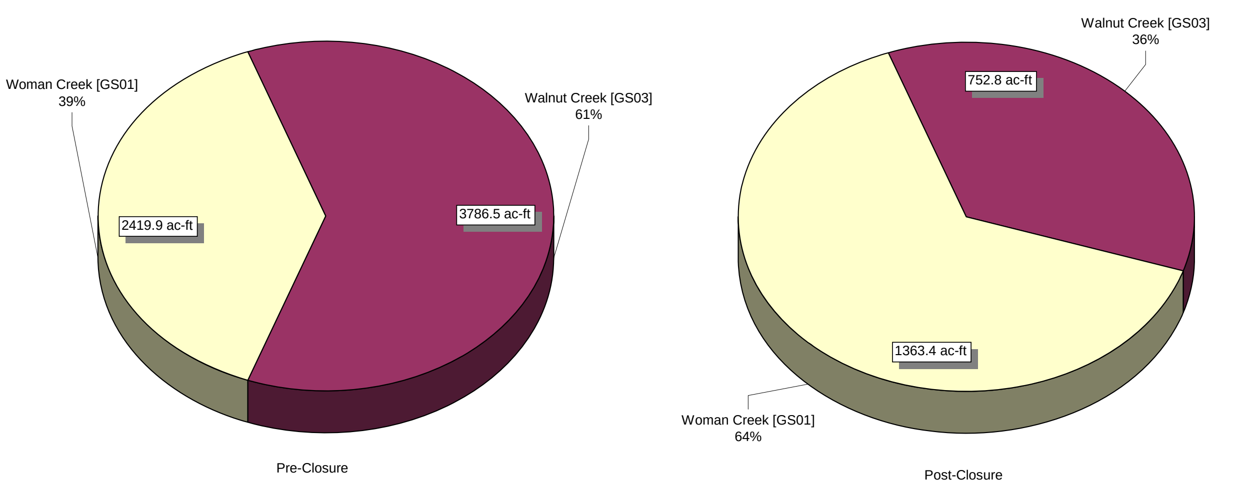


Figure 88. Relative Total Discharge Summary from Major Site Drainages: Pre- and Post-Closure Periods

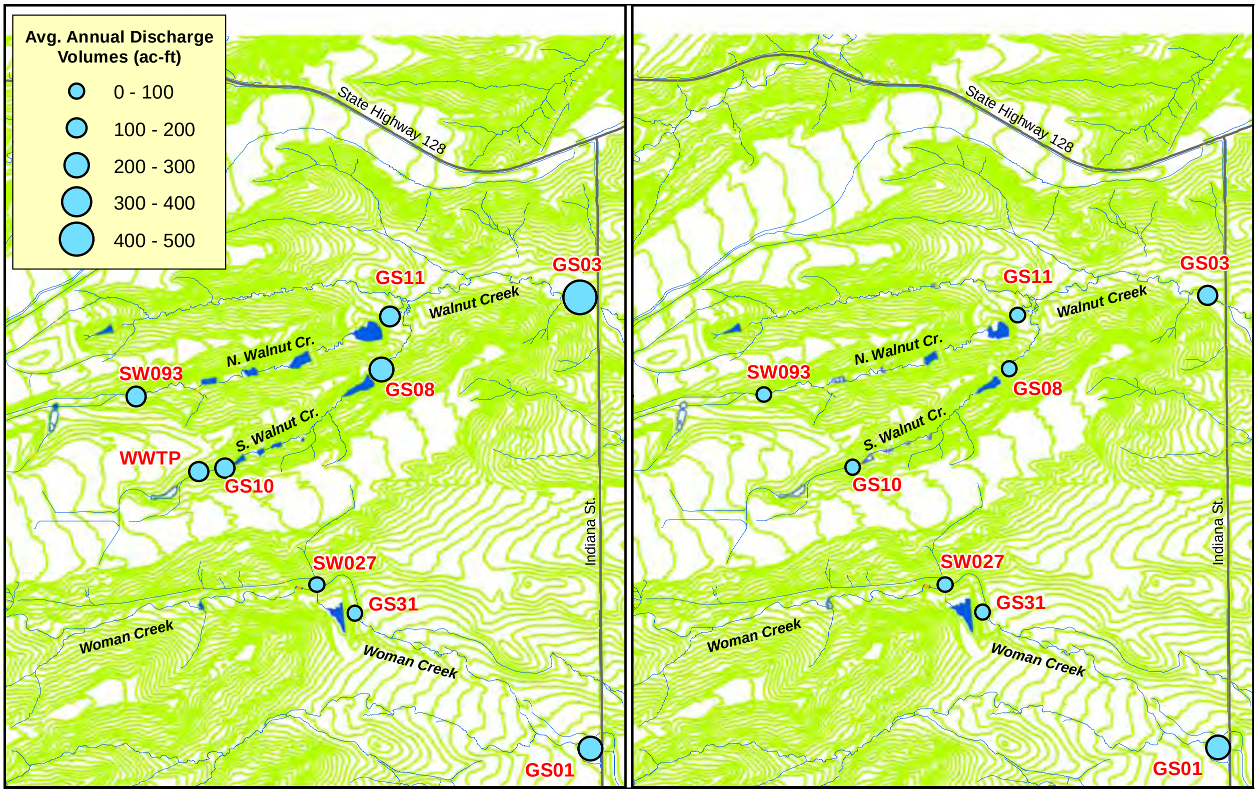
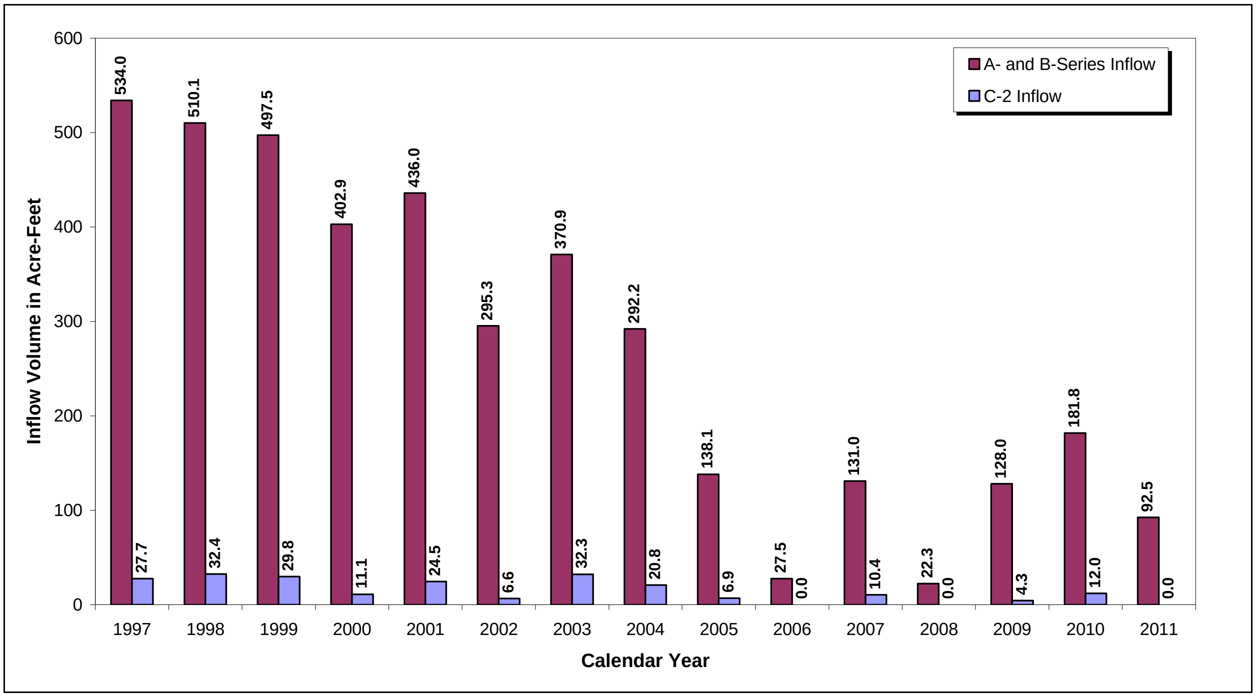


Figure 89. Map Showing Relative CY 1997−2011 Average Annual Discharge Volumes for POEs and POCs: Pre- and Post-Closure Periods

Pond Discharge Summary

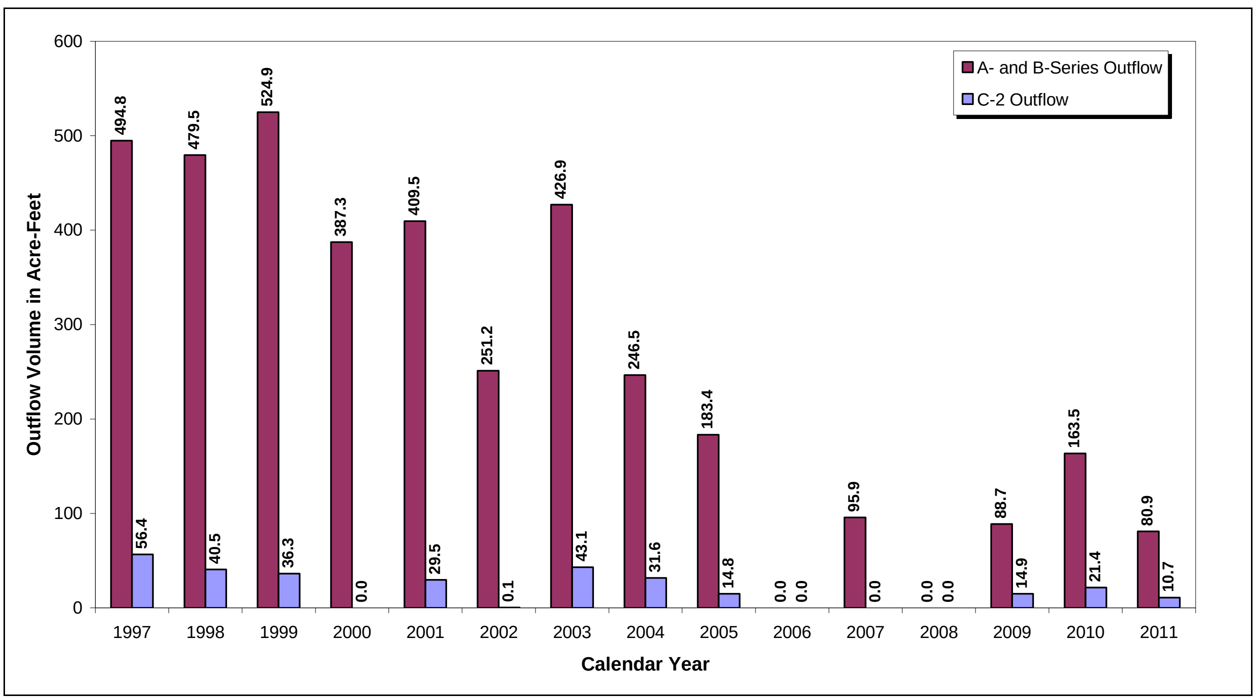
Figure 90 and Figure 91 show the annual ponds inflows and outflows, respectively. Due to the intermittent pump transfers of Pond B-5 water to Pond A-4, the volumes for the A- and B-Series Ponds are combined. The reduction in pond water volumes as the Site progressed toward closure is clearly observed. Figure 92 and Figure 93 show the relative total CY 1997−2011 discharge volumes from the ponds (as measured at GS08, GS11, and GS31) and from the major drainages tributary to the ponds (as measured at GS10, SW027, SW091, SW093, and the former WWTP [995POE]).[11, 12] Pond inflows do not necessarily equal outflows for any given year due to the storage of water in the ponds across water years, evaporative/seepage losses/gains, and local runoff to the ponds.

[11] The WWTP was removed from service on November 4, 2004.
[12] The pre-closure period is for the dates January 1, 1997–October 1, 2004; the post-closure period is for the dates October 1, 2005–December 31, 2011.



Notes: A- and B-Series Inflow is the sum of GS10, the former WWTP, and SW093. The C-2 Inflow is the volume measured at SW027.

Figure 90. Pond Inflows: CY 1997−2011



Notes: A- and B-Series Outflow is the sum of GS11 and GS08. The C-2 Outflow is the volume measured at GS31.

Figure 91. Pond Outflows: CY 1997−2011

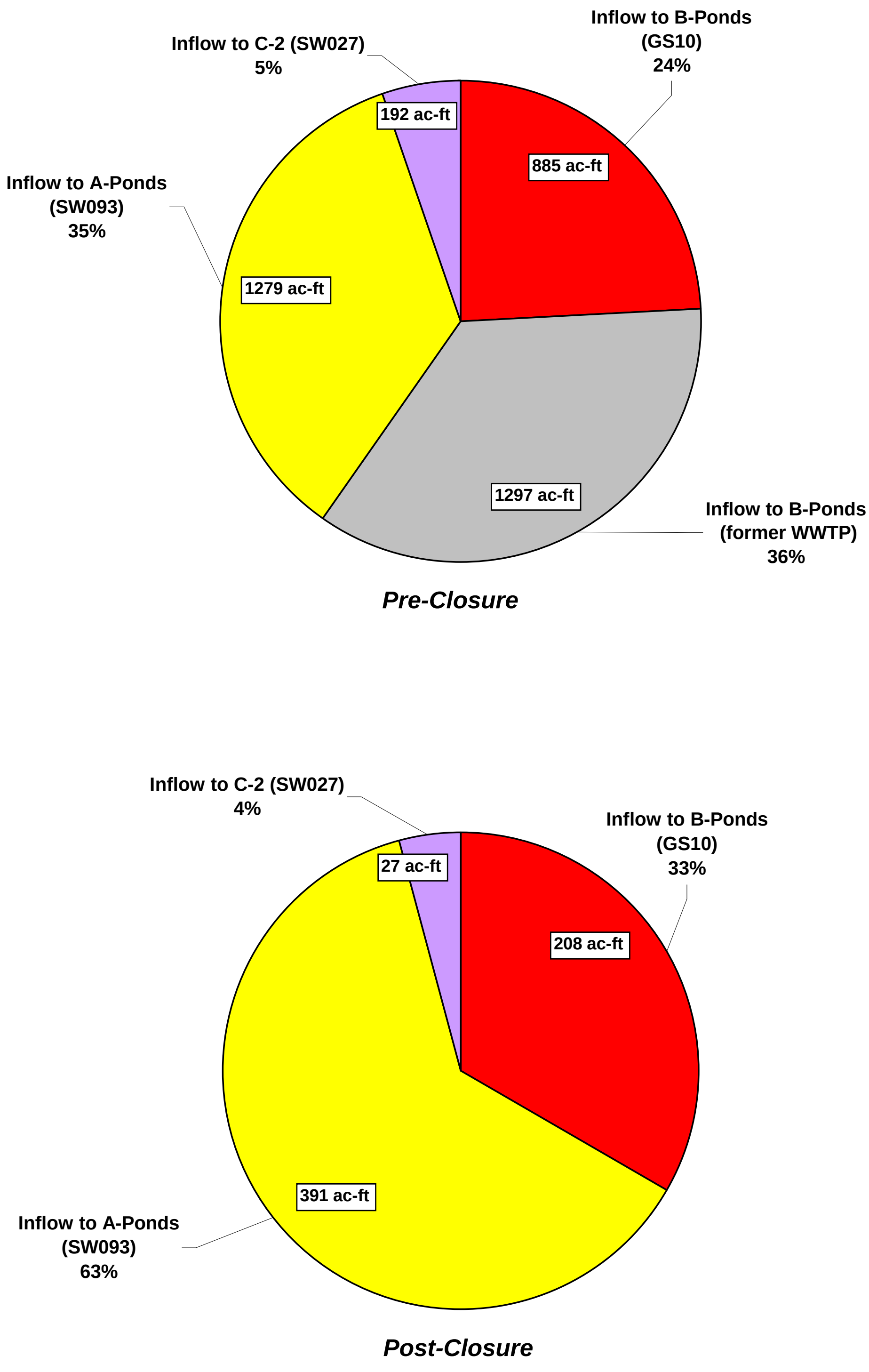
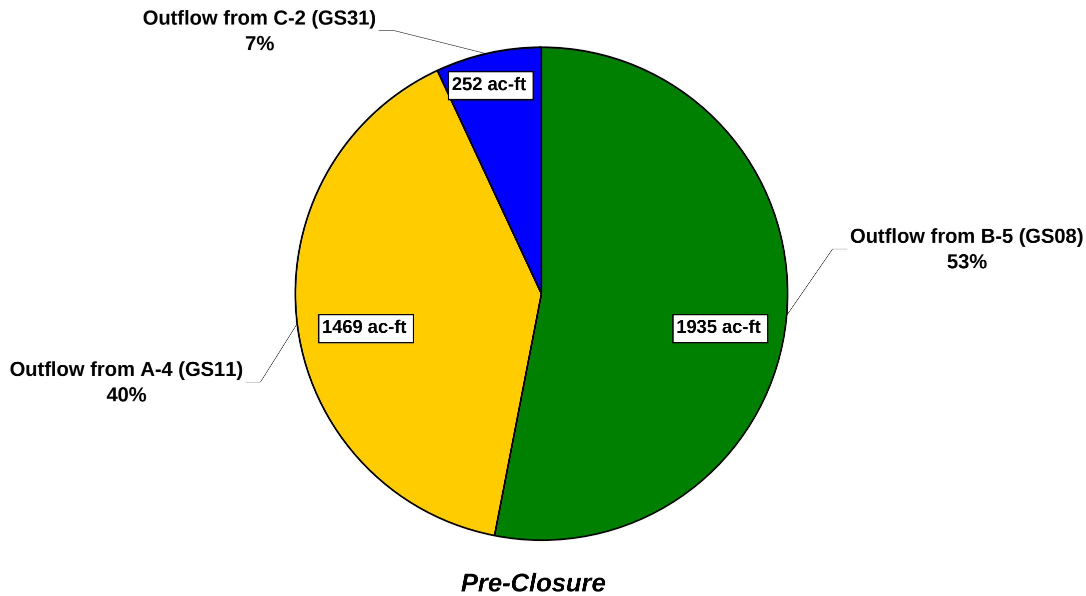


Figure 92. Relative Total Inflow Volumes for Site Ponds: Pre- and Post-Closure Periods



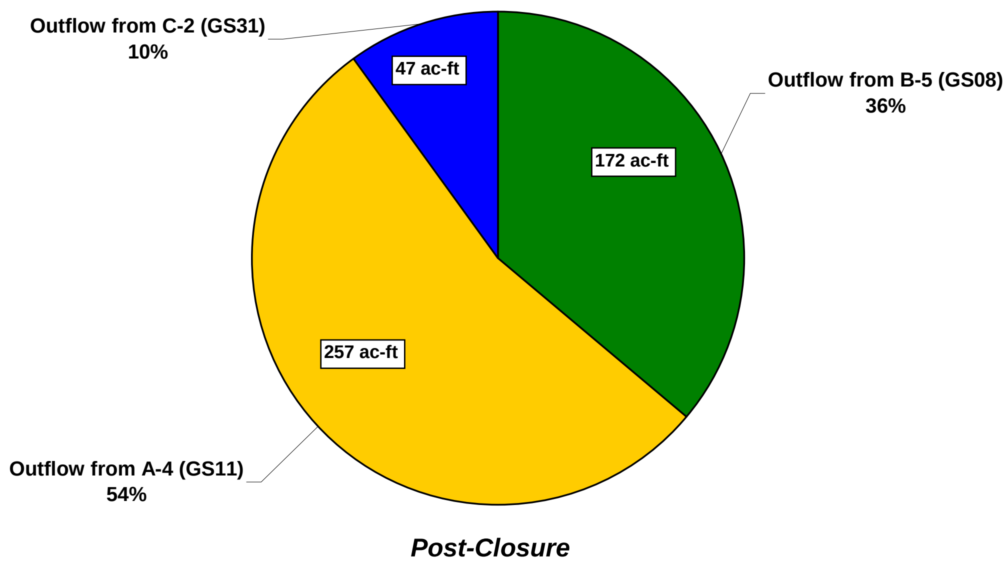


Figure 93. Relative Total Outflow Volumes for Site Ponds: Pre- and Post-Closure Periods

GS01: Woman Creek at Indiana Street

Location—Woman Creek 200 feet upstream of Indiana Street; State Plane: E2093824, N744889.

Drainage Area—The basin includes the Woman Creek drainage and southern portions of the COU; areas west of Highway 93 also contribute runoff (total drainage acreage undetermined).

Period of Record—September 16, 1991, to current year.

Gage—Water-stage recorder and 18-inch Parshall flume (flume is located just east of Indiana Street, sampling conducted on Refuge property); prior to March 24, 1998, flow measurement was at the onsite sampling location using a 9-inch Parshall flume.

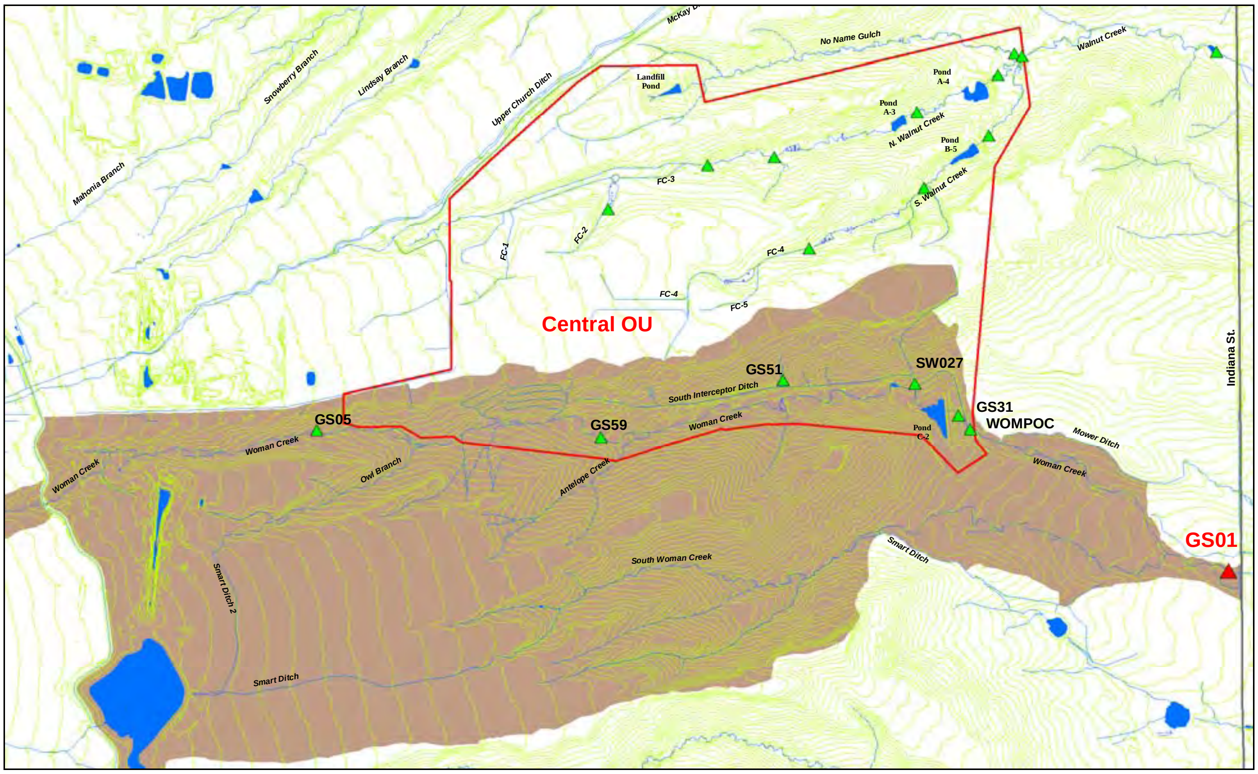


Figure 94. GS01 Drainage Area

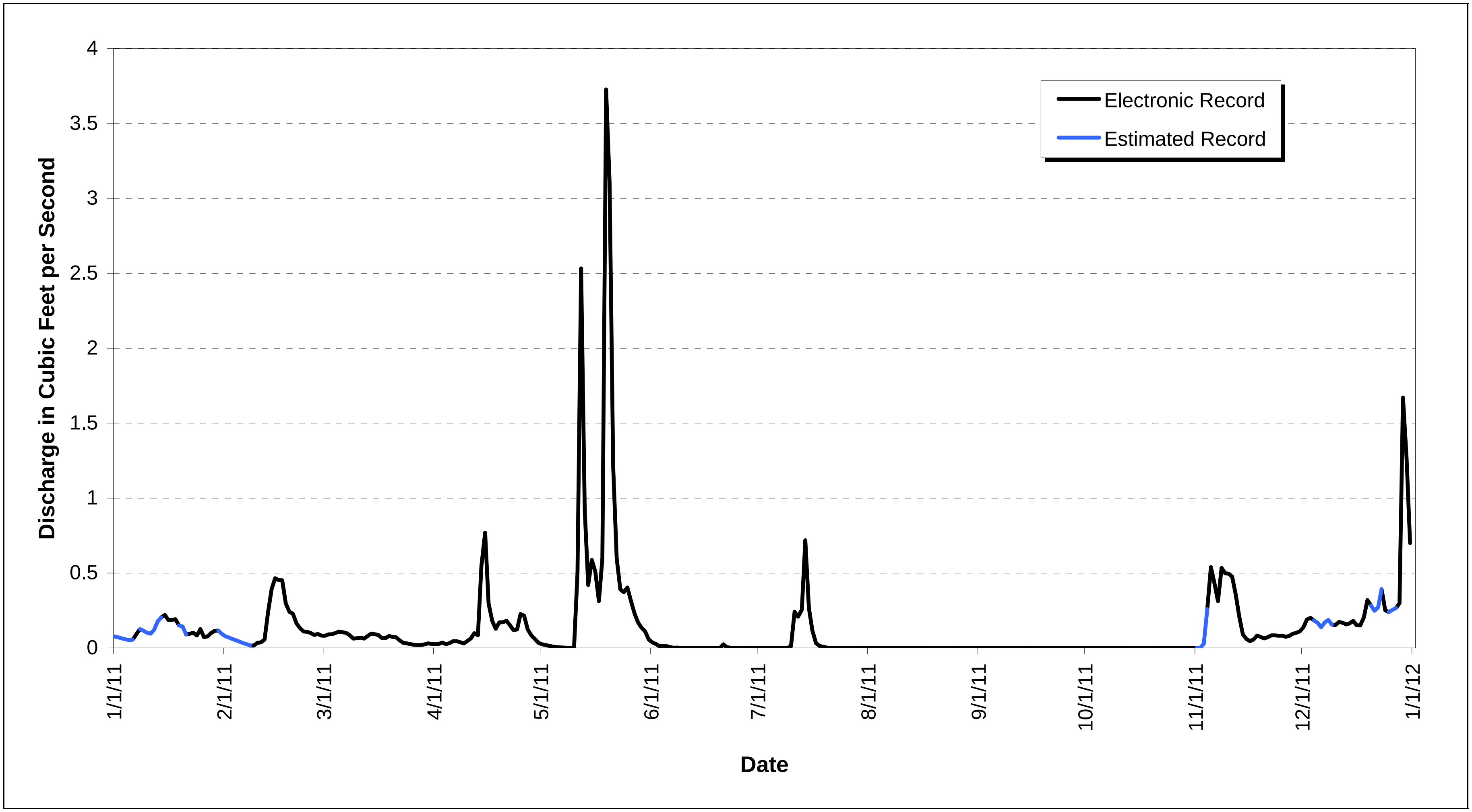


Figure 95. CY 2011 Mean Daily Hydrograph at GS01: Woman Creek at Indiana Street

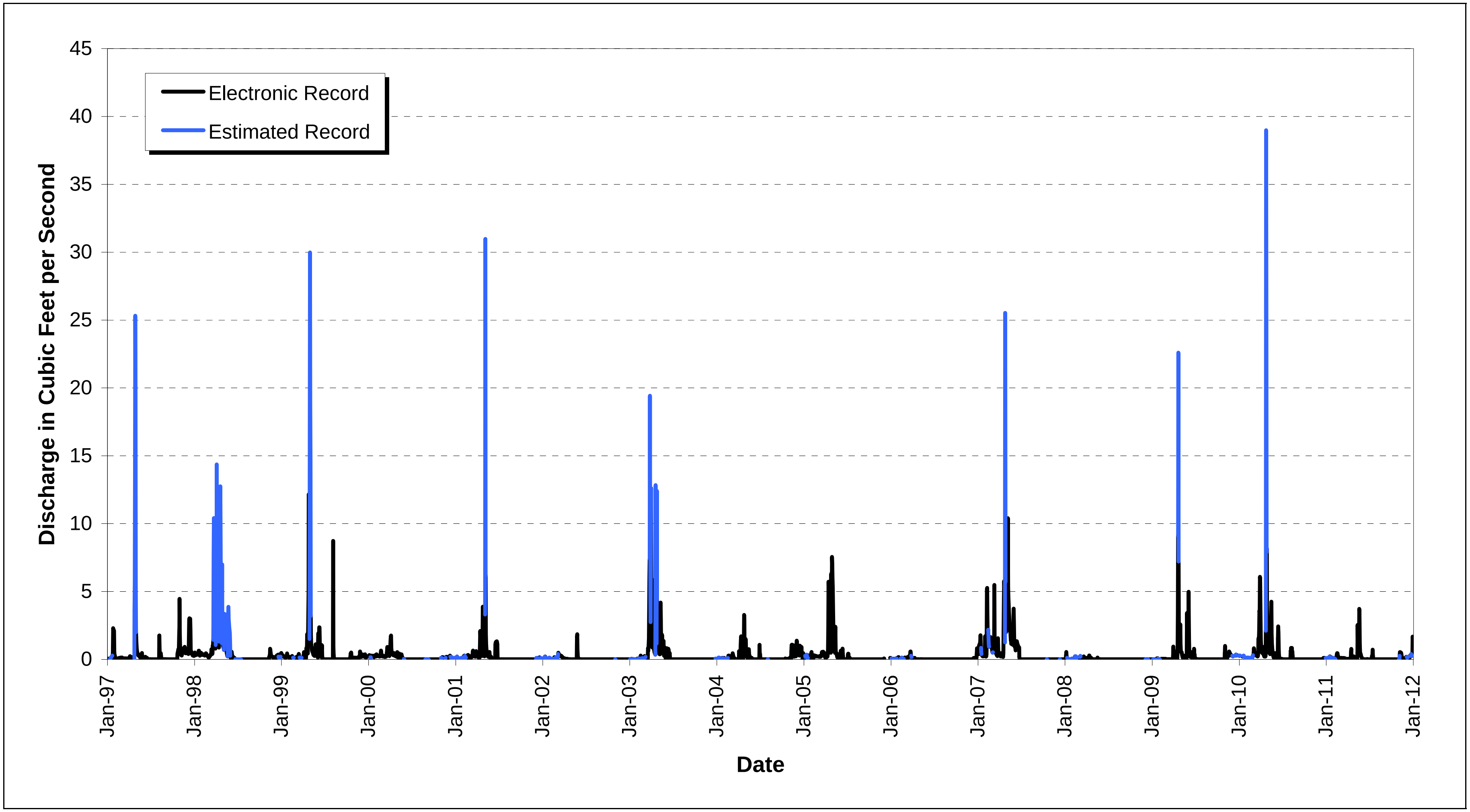


Figure 96. CY 1997−2011 Mean Daily Hydrograph at GS01: Woman Creek at Indiana Street

GS03: Walnut Creek at Indiana Street

Location—Walnut Creek at Flume Pond outlet upstream of Indiana Street; State Plane: E2093618, N753646.

Drainage Area—The basin includes the Walnut Creek drainage and the majority of the COU; areas west of Highway 93 also contribute runoff (total drainage acreage undetermined).

Period of Record—September 2, 1991, to current year.

Gage—Water-stage recorder and parallel 6-inch and 36-inch Parshall flumes prior to November 5, 2002. Rated stream section during flume construction (GS03T; November 5, 2002−February 12, 2003). Three-foot HL flume starting February 12, 2003.

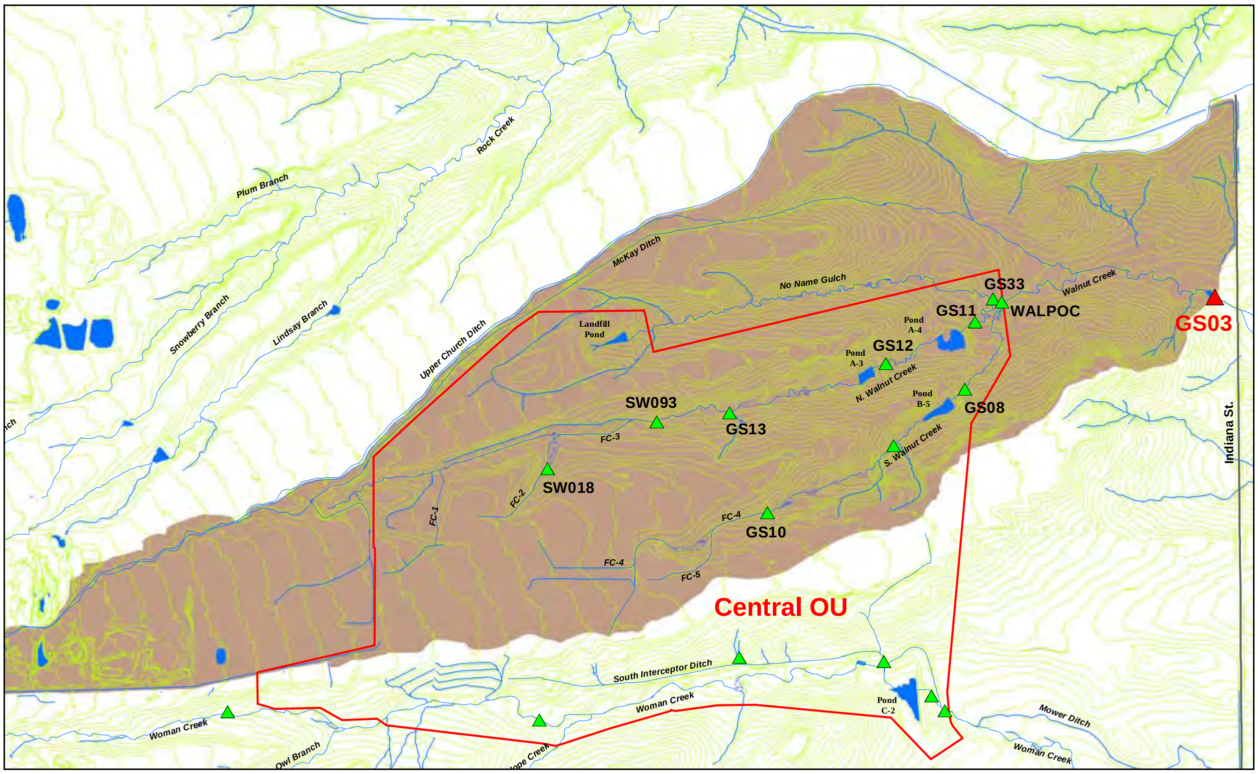


Figure 97. GS03 Drainage Area

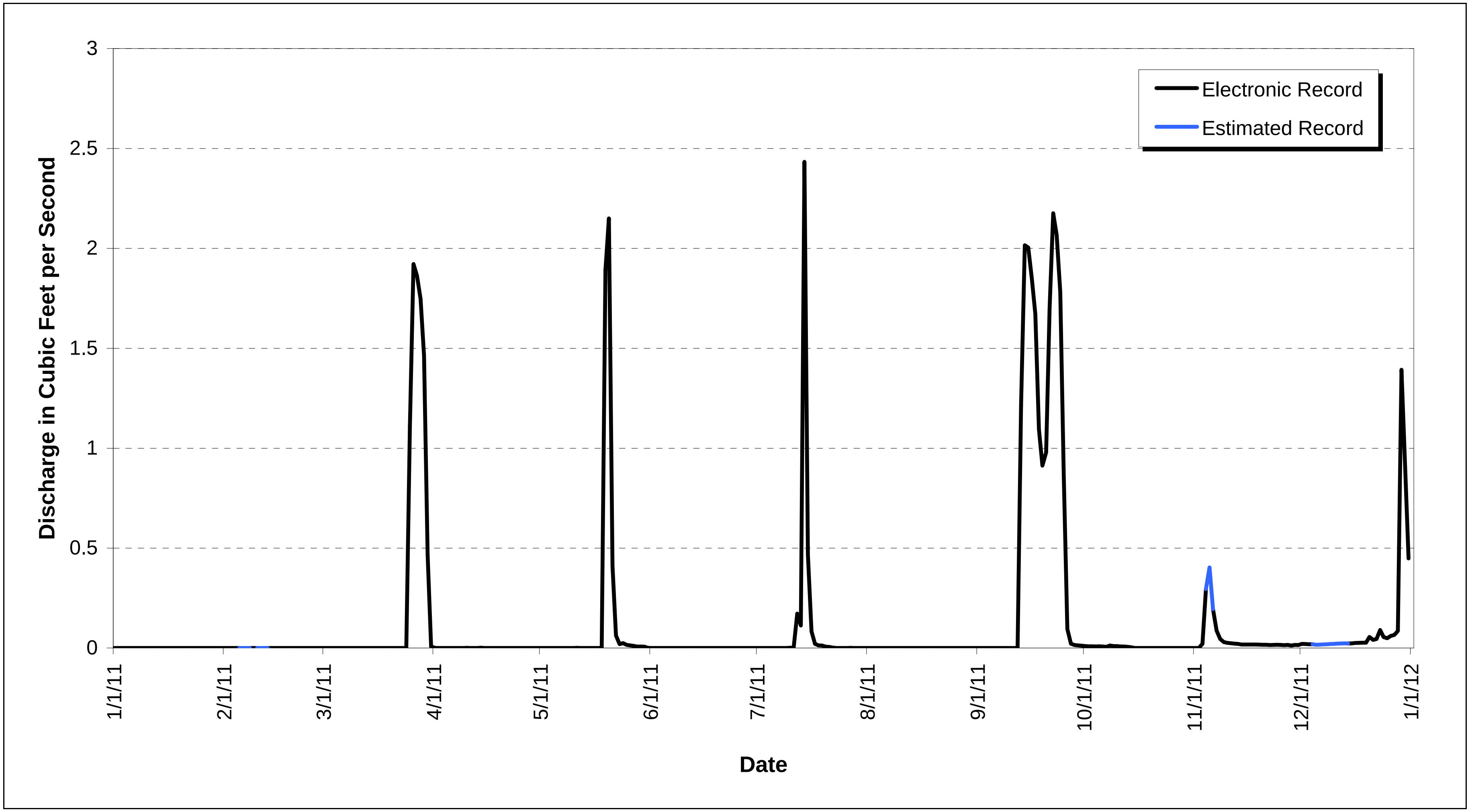


Figure 98. CY 2011 Mean Daily Hydrograph at GS03: Walnut Creek at Indiana Street

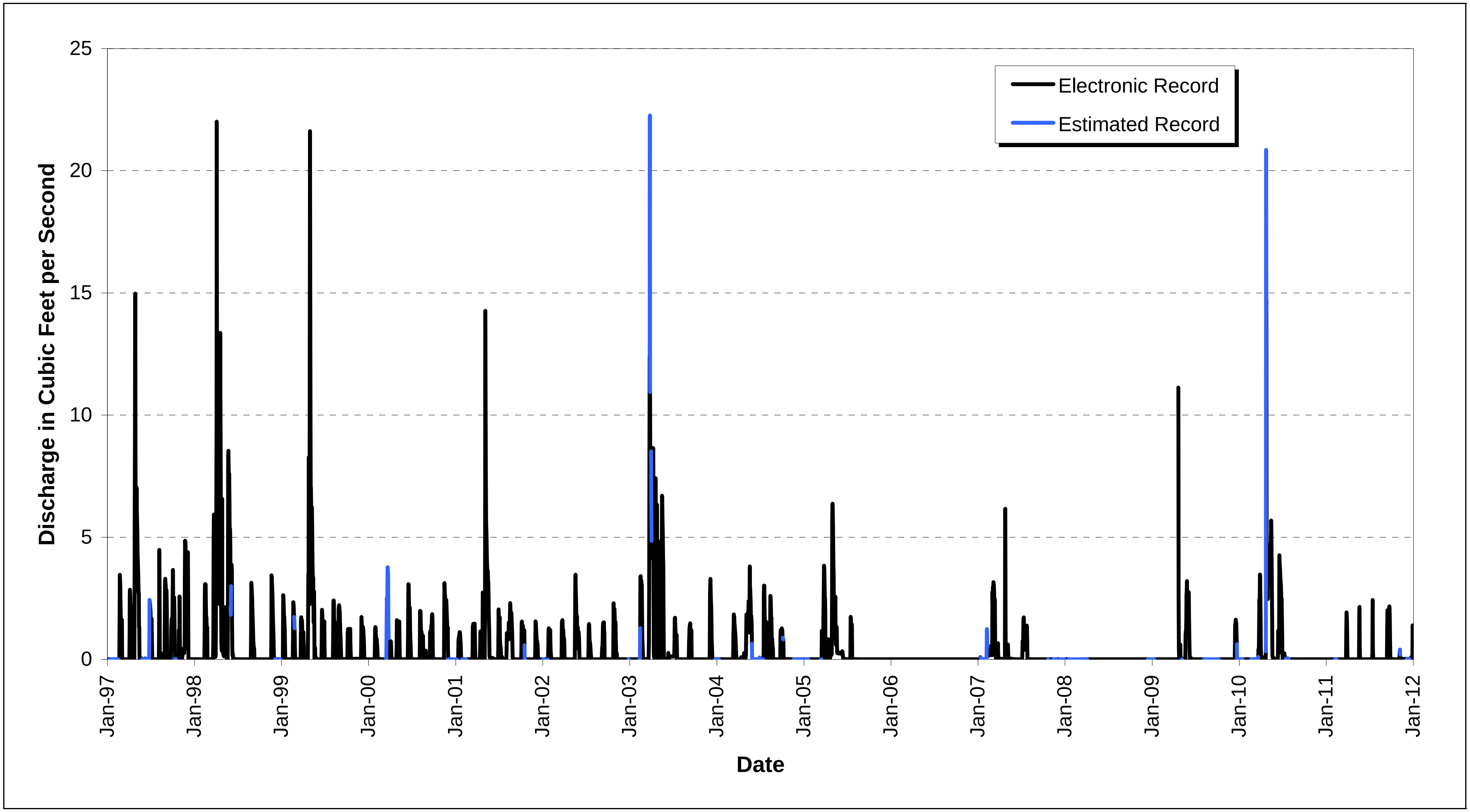


Figure 99. CY 1997−2011 Mean Daily Hydrograph at GS03: Walnut Creek at Indiana Street

WOMPOC: Woman Creek at Eastern COU Boundary

Location—Woman Creek 60 feet upstream of eastern COU boundary; State Plane: E2089468, N747282.

Drainage Area—The basin includes the Woman Creek drainage and southern portions of the COU; areas west of Highway 93 also contribute runoff (total drainage acreage undetermined).

Period of Record—September 28, 2011, to current year.

Gage—Water-stage recorder and 3-foot HL flume.

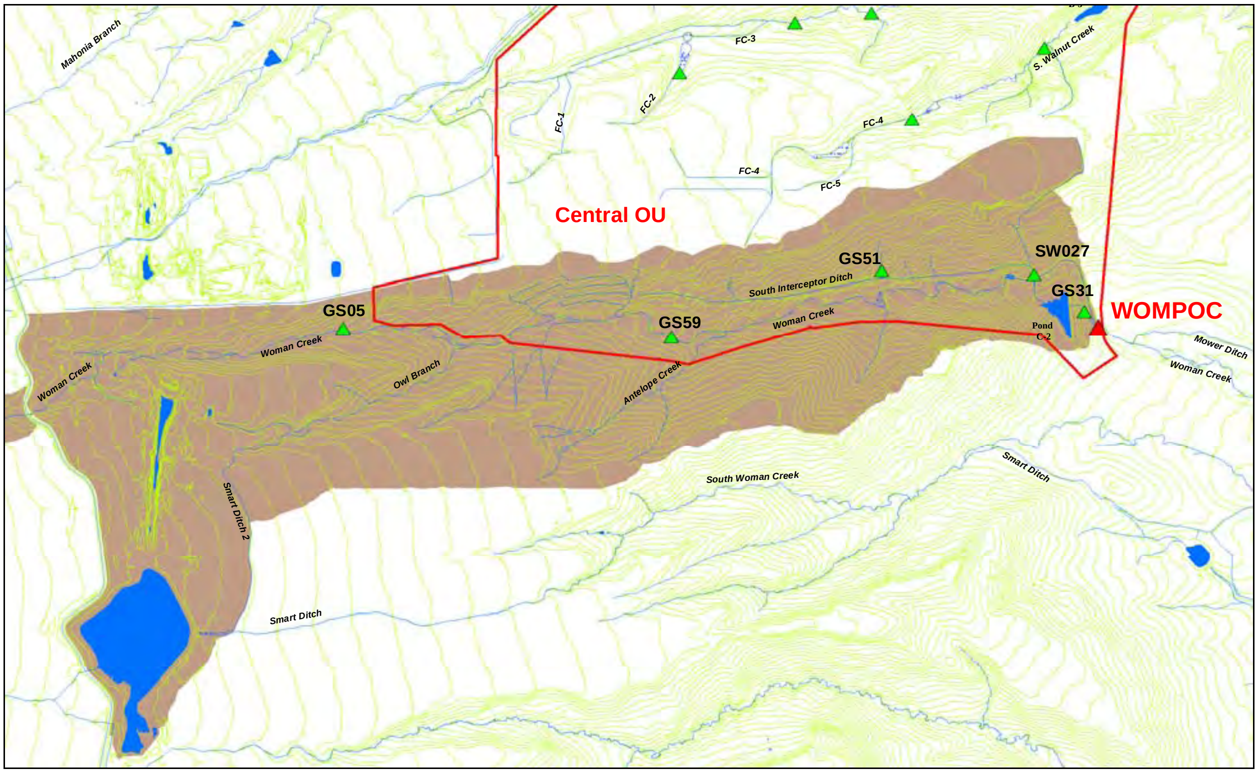


Figure 100. WOMPOC Drainage Area

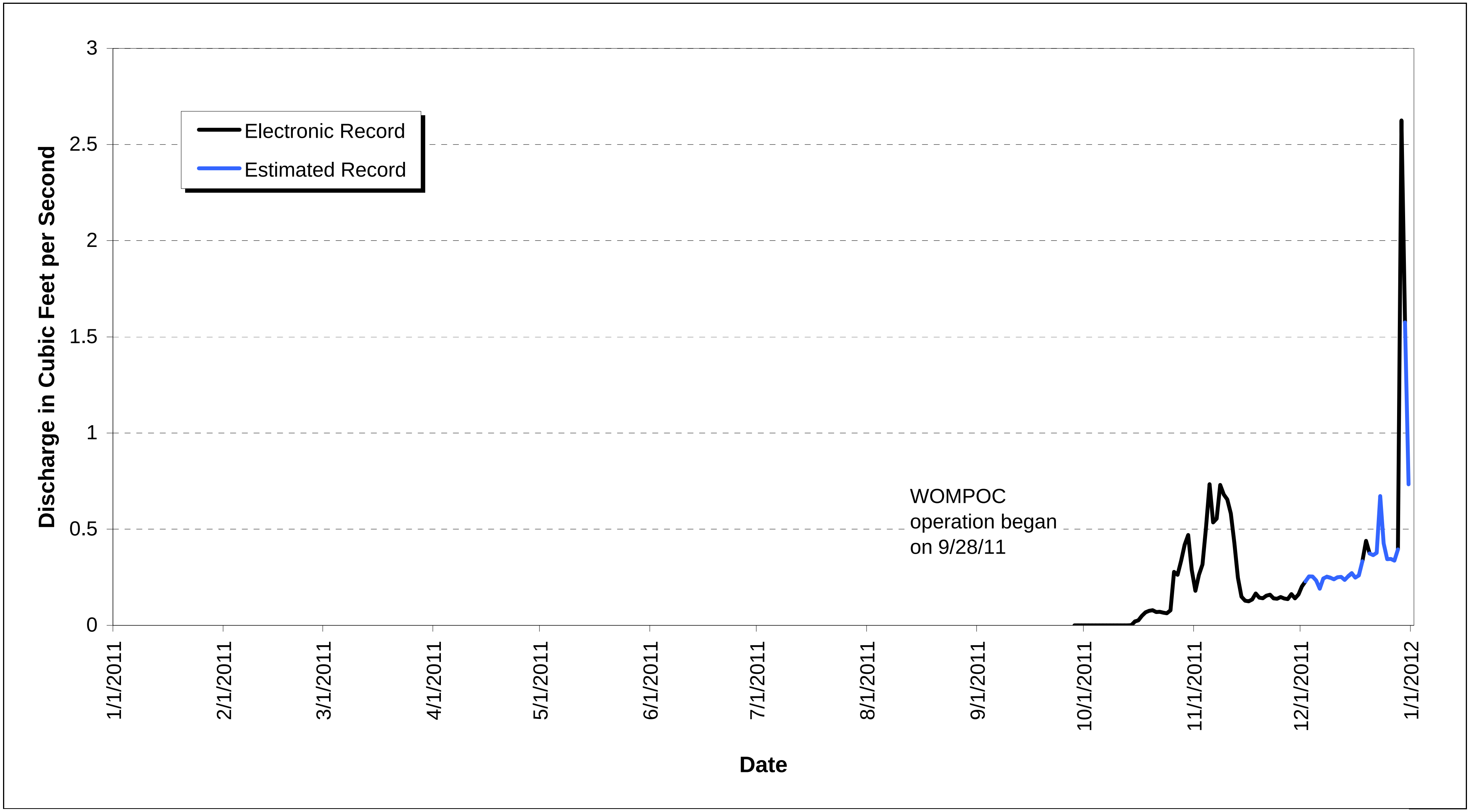


Figure 101. CY 2011 Mean Daily Hydrograph at WOMPOC: Woman Creek at Eastern COU Boundary

WALPOC: Walnut Creek at Eastern COU Boundary

Location—Walnut Creek 15 feet upstream of eastern COU boundary; State Plane: E2090341, N753574.

Drainage Area—The basin includes the No Name Gulch, NorthWalnut Creek, and South Walnut Creek drainages, including a majority of the COU (total of 1051.6 acres).

Period of Record—September 9, 2011, to current year.

Gage—Water-stage recorder and 3-foot HL flume.

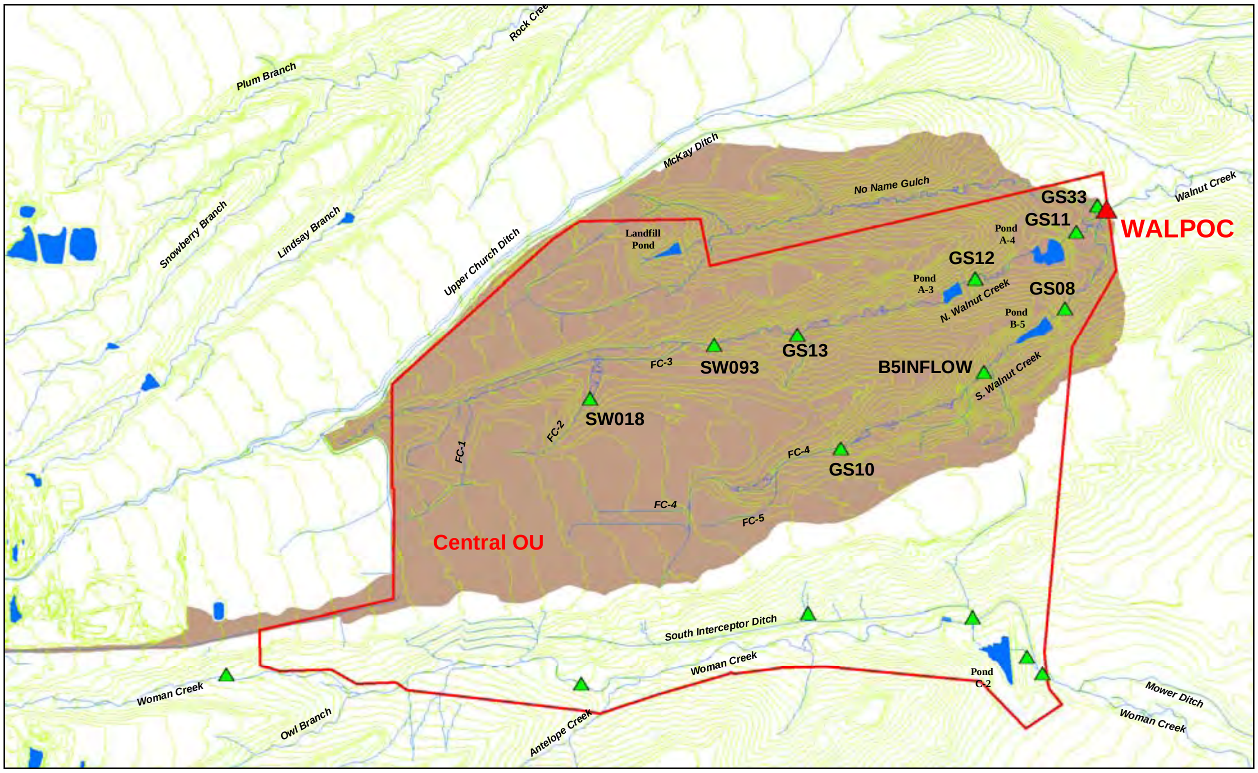


Figure 102. WALPOC Drainage Area

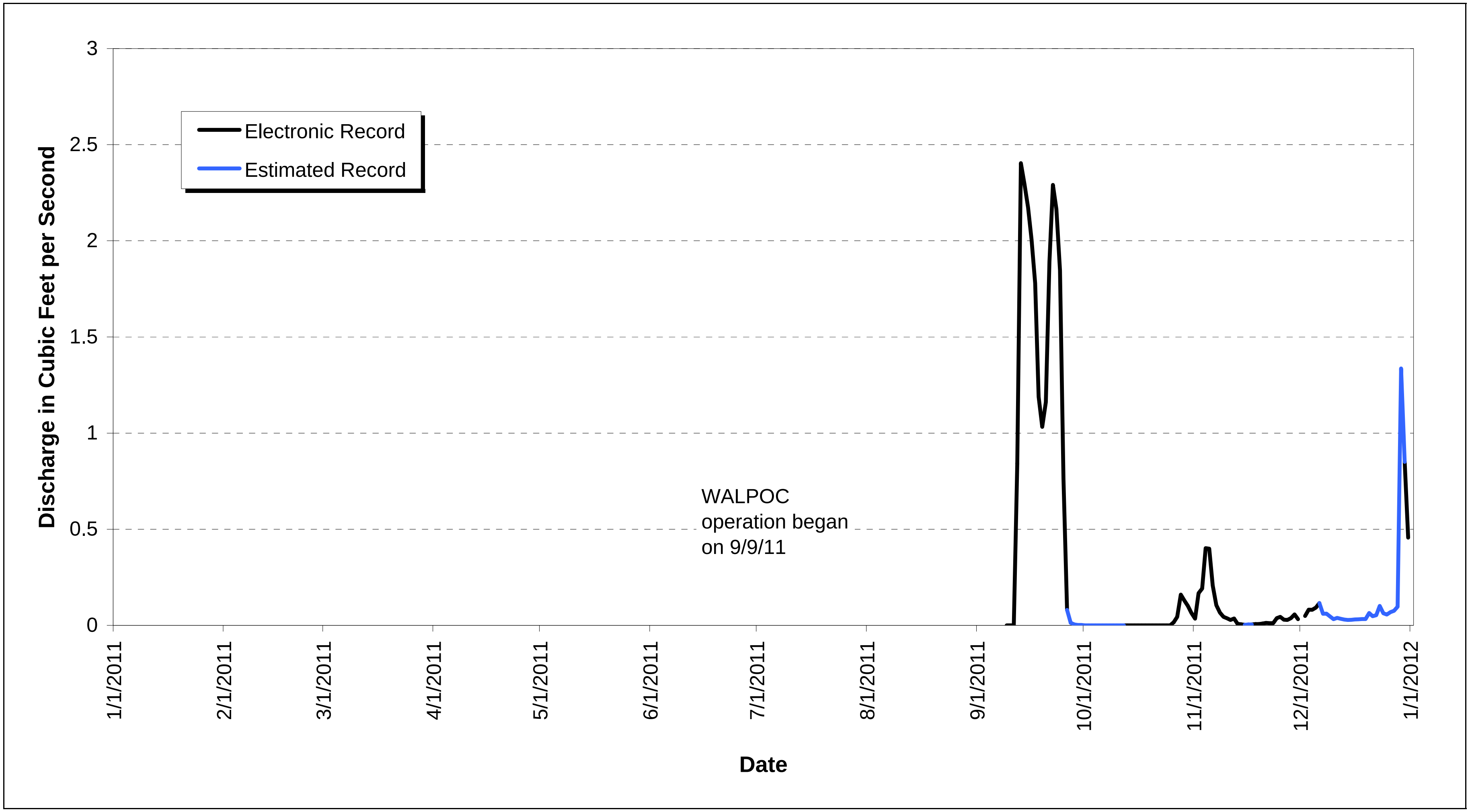


Figure 103. CY 2011 Mean Daily Hydrograph at WALPOC: Walnut Creek at Eastern COU Boundary

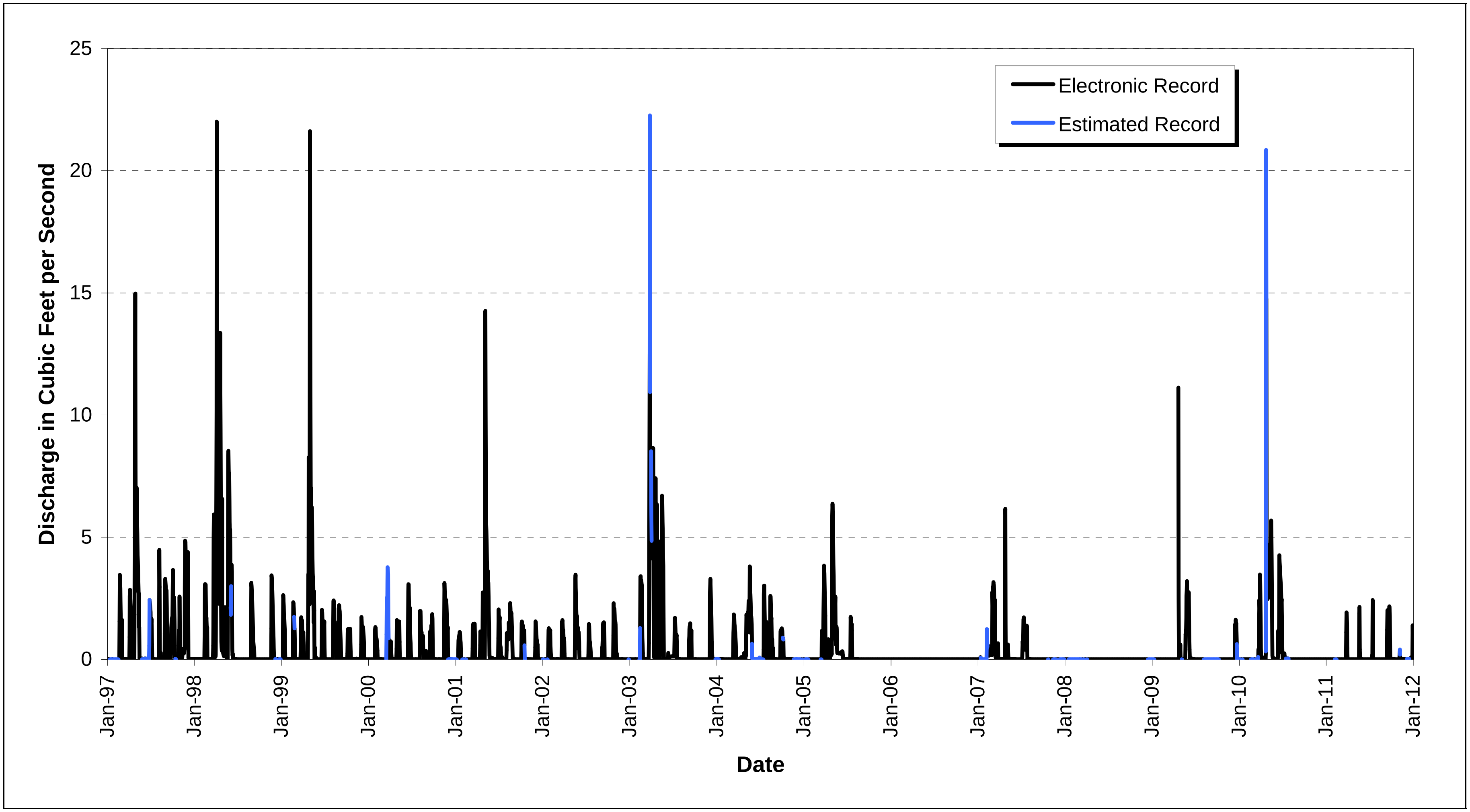


Figure 104. CY 1997−2011 Mean Daily Hydrograph at GS03: Walnut Creek at Indiana Street

GS05: North Woman Creek at West Fenceline

Location—Woman Creek east of western Site boundary; State Plane: E2078429, N747264.

Drainage Area—The basin includes a portion of the Woman Creek drainage; areas west of Highway 93 also contribute runoff (total drainage acreage undetermined).

Period of Record—September 23, 1991, to current year.

Gage—Water-stage recorder and 9-inch Parshall flume with weir insert.

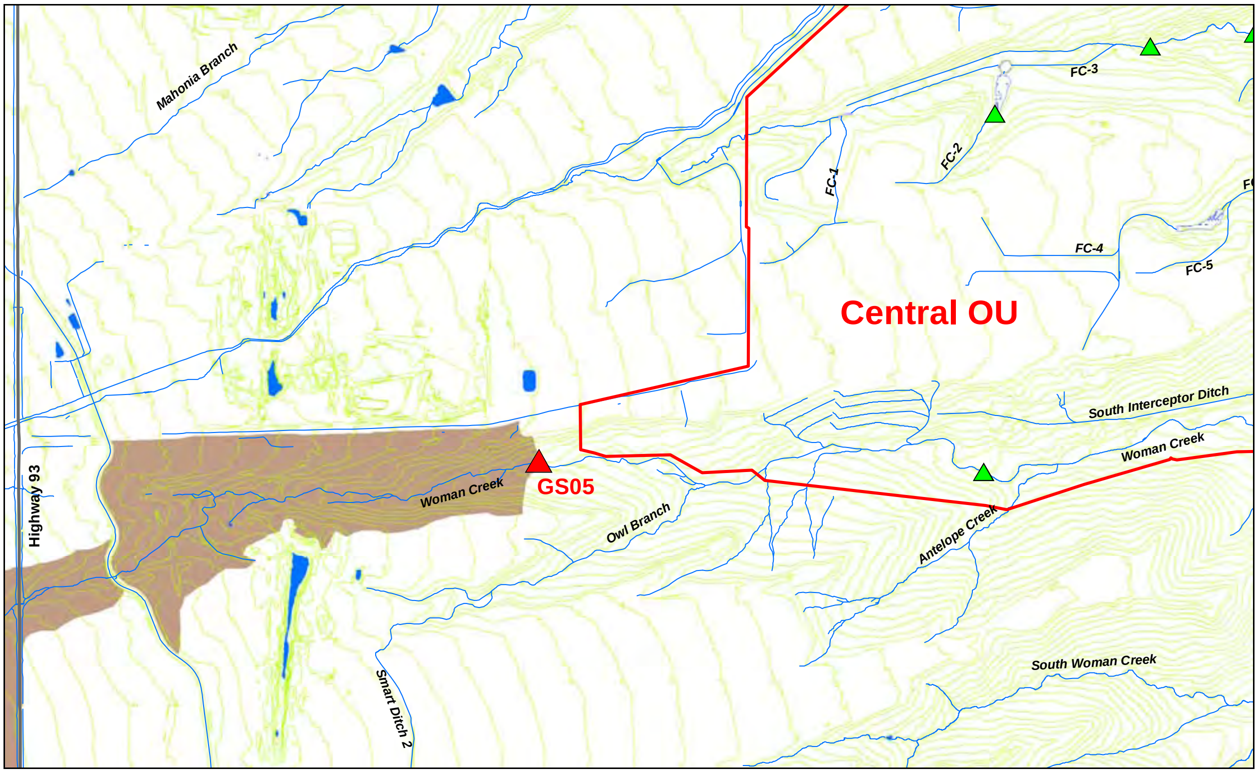


Figure 105. GS05 Drainage Area

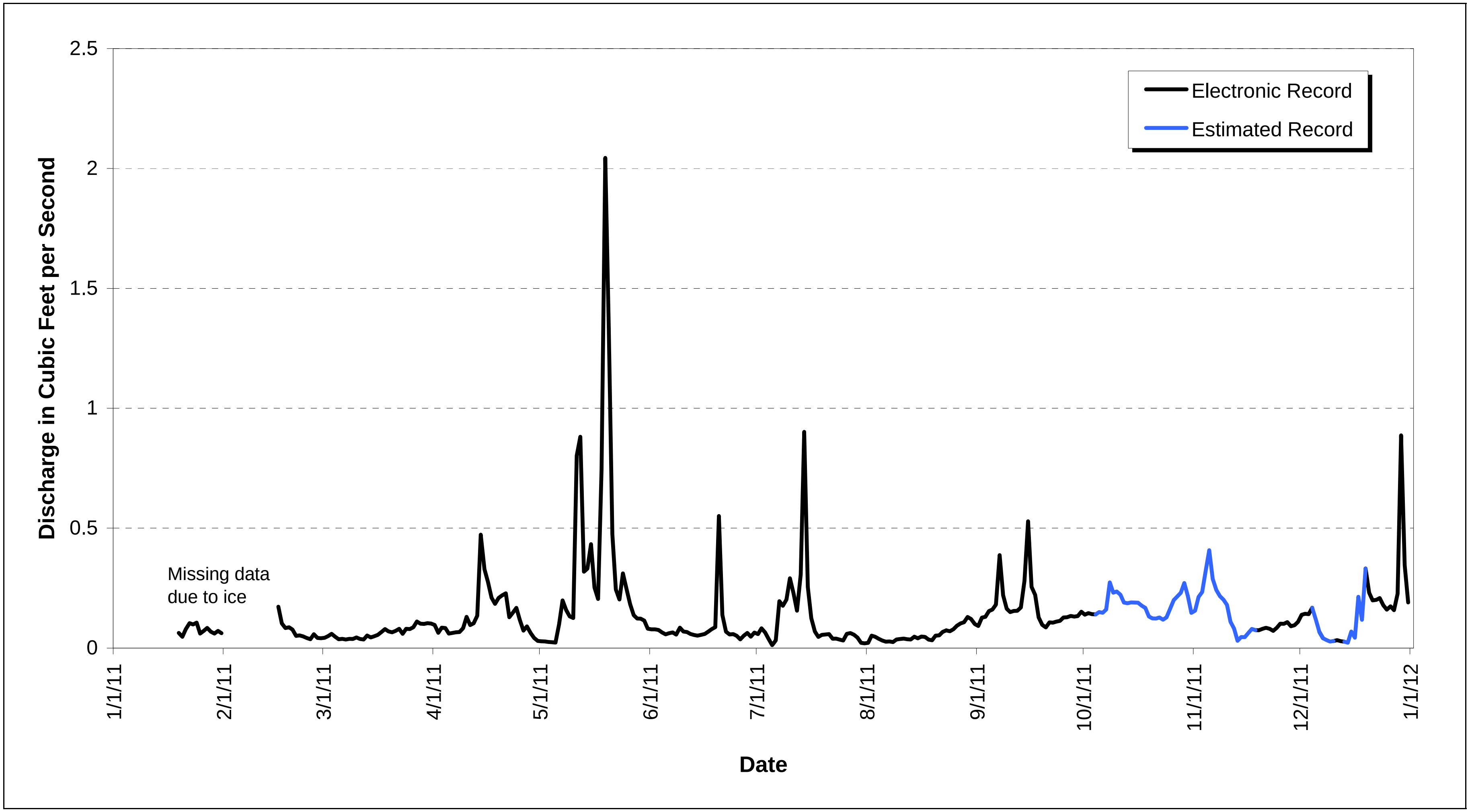


Figure 106. CY 2011 Mean Daily Hydrograph at GS05: North Woman Creek at West Fence Line

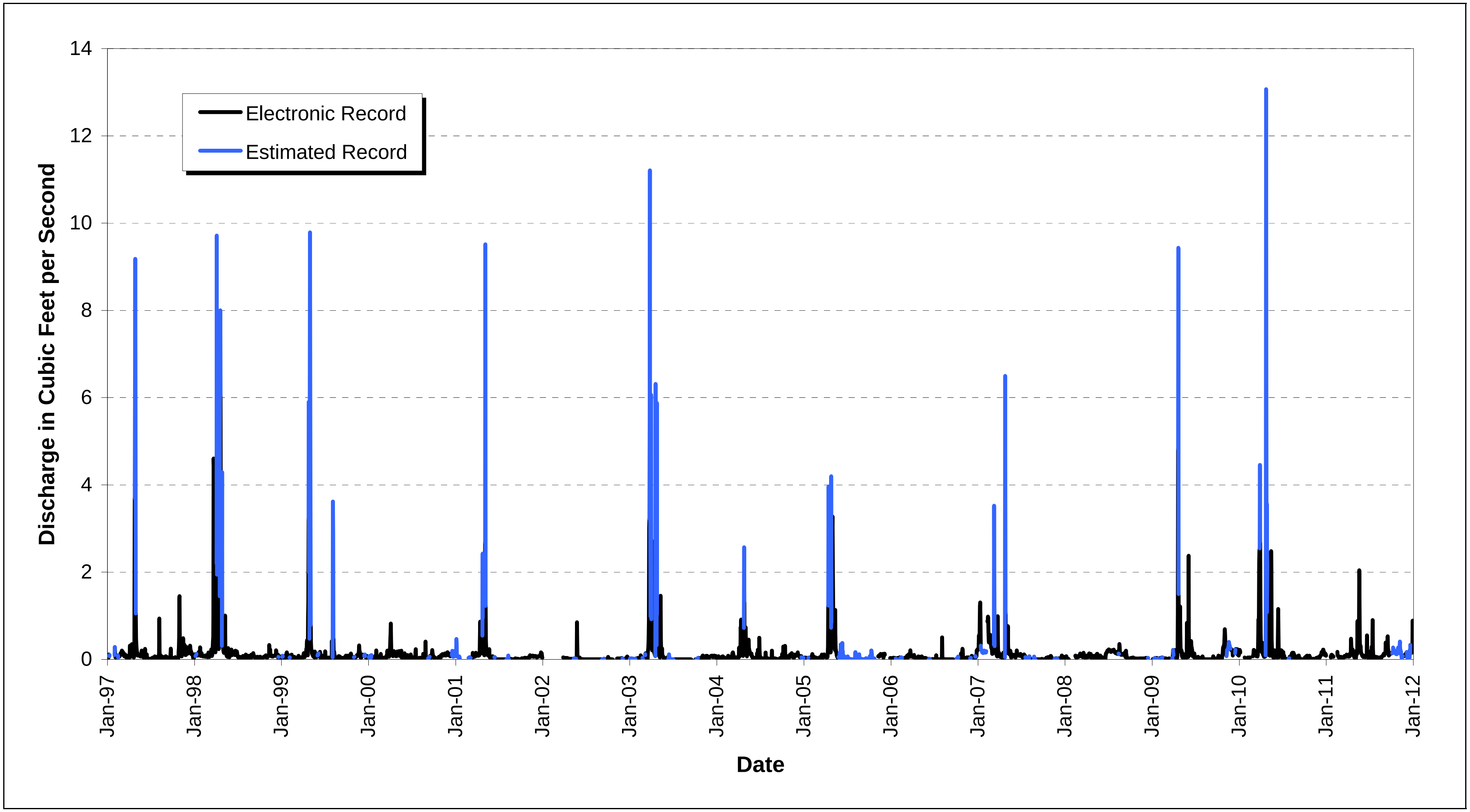


Figure 107. CY 1997−2011 Mean Daily Hydrograph at GS05: North Woman Creek at West Fence Line

GS08: South Walnut Creek at Pond B-5 Outlet

Location—South Walnut Creek at Pond B-5 outlet; State Plane: E2089778, N752231.

Drainage Area—The basin includes the South Walnut Creek drainage and central portions of the COU (total of 311.0 acres).

Period of Record—March 23, 1994, to current year.

Gage—Water-stage recorder and 24-inch Parshall flume.

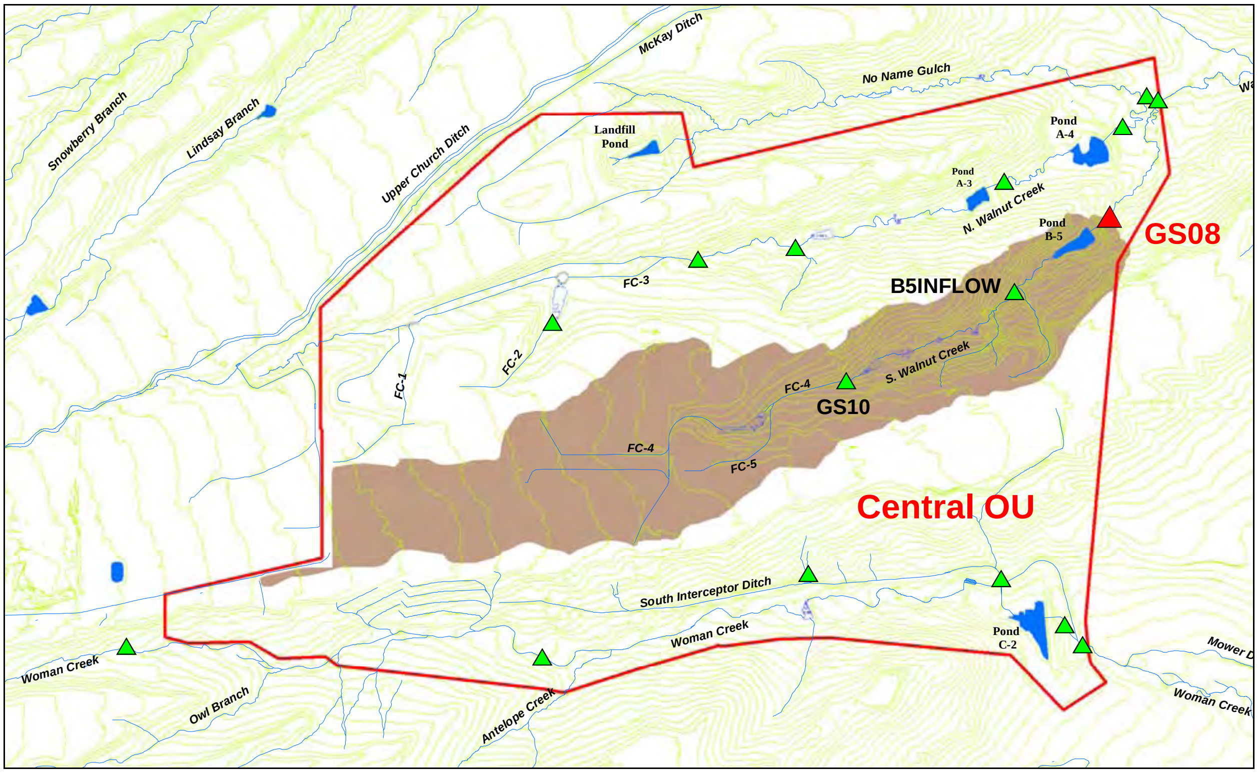


Figure 108. GS08 Drainage Area

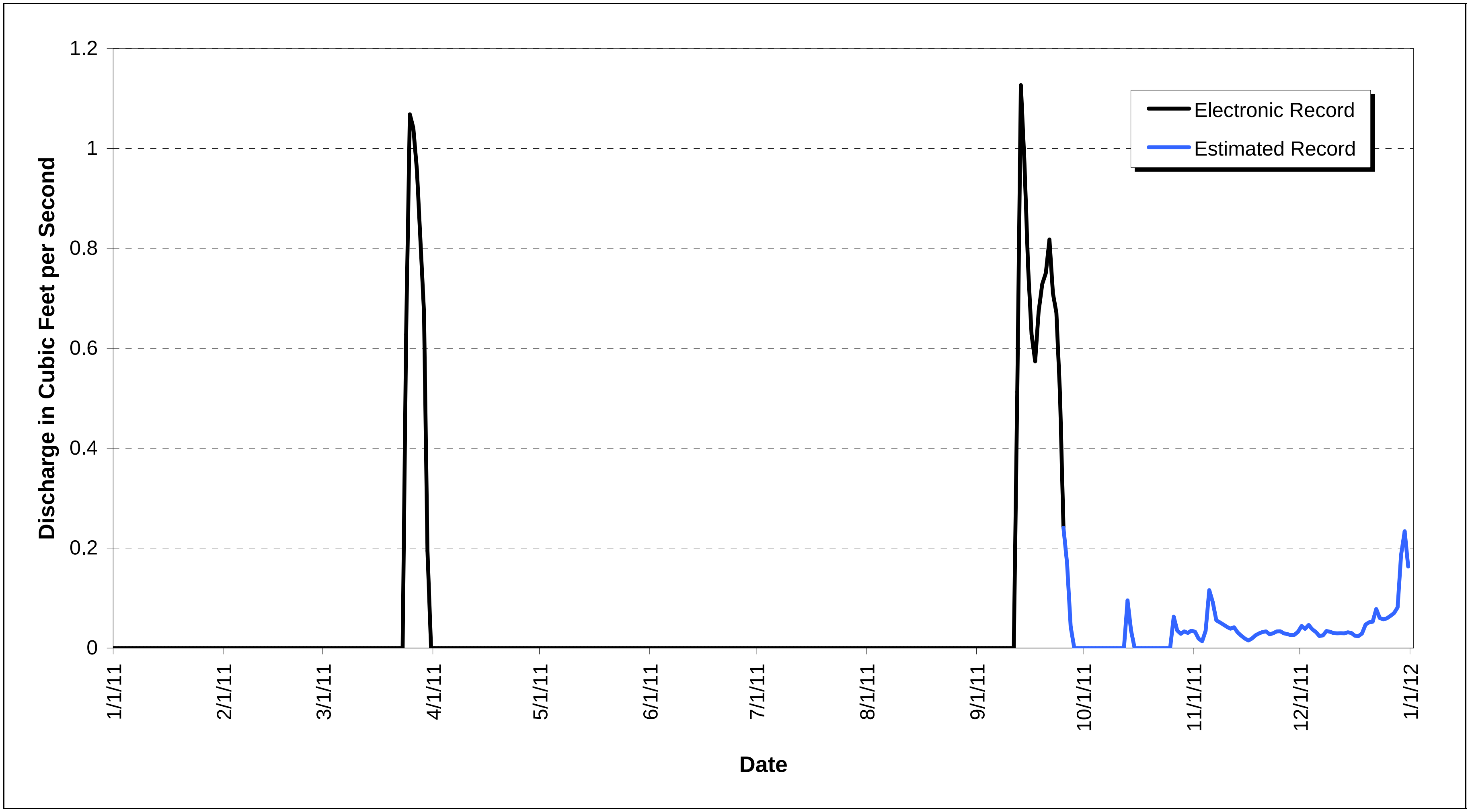


Figure 109. CY 2011 Mean Daily Hydrograph at GS08: South Walnut Creek at Pond B-5 Outlet

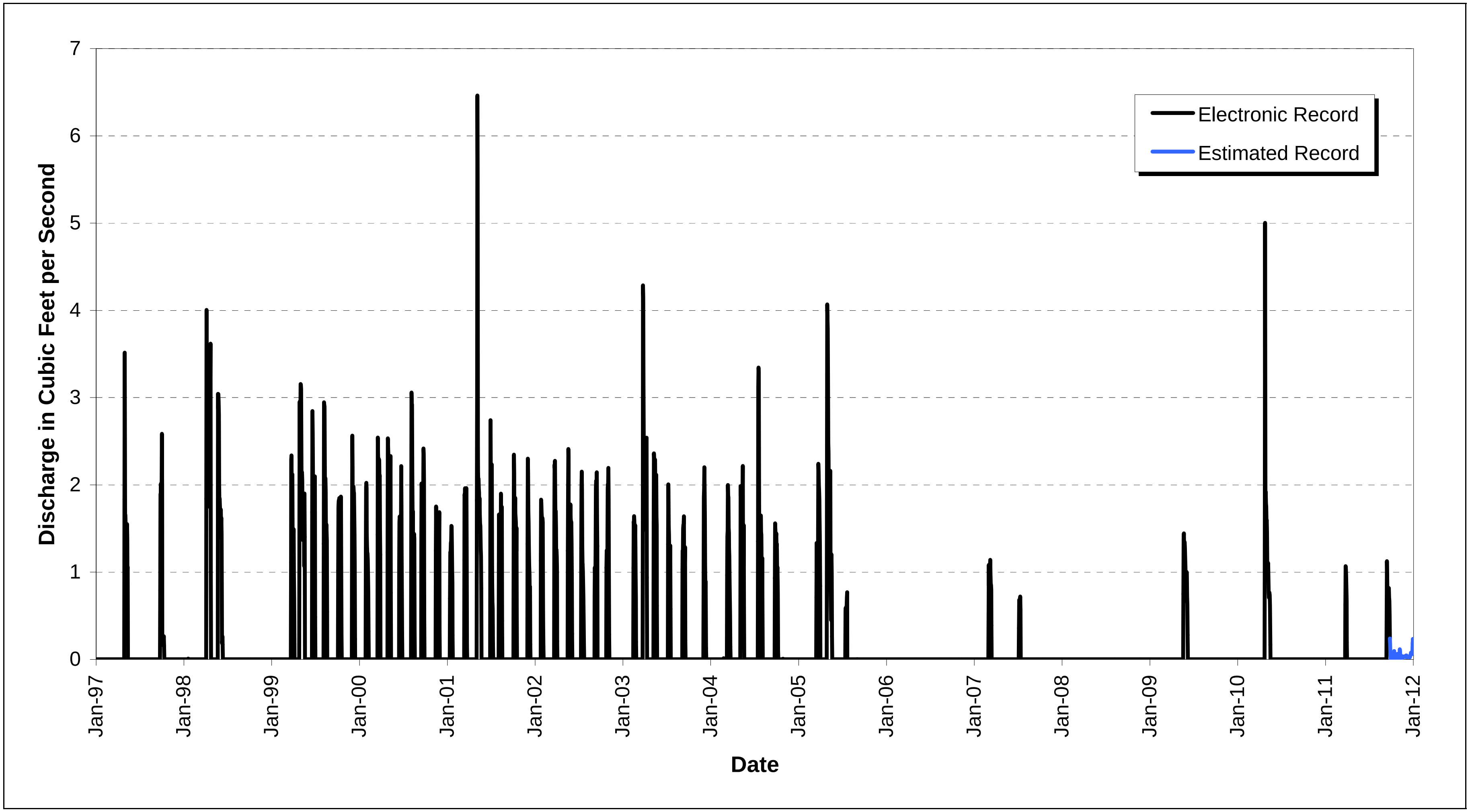


Figure 110. CY 1997−2011 Mean Daily Hydrograph at GS08: South Walnut Creek at Pond B-5 Outlet

GS10: South Walnut Creek at Pond B-1

Location—South Walnut Creek above Pond B-1; State Plane: E2086741, N750329.

Drainage Area—The basin includes the central portion of the COU (total of 206.0 acres).

Period of Record—April 1, 1993, to current year.

Gage—Water-stage recorder and 9-inch Parshall flume with weir insert.

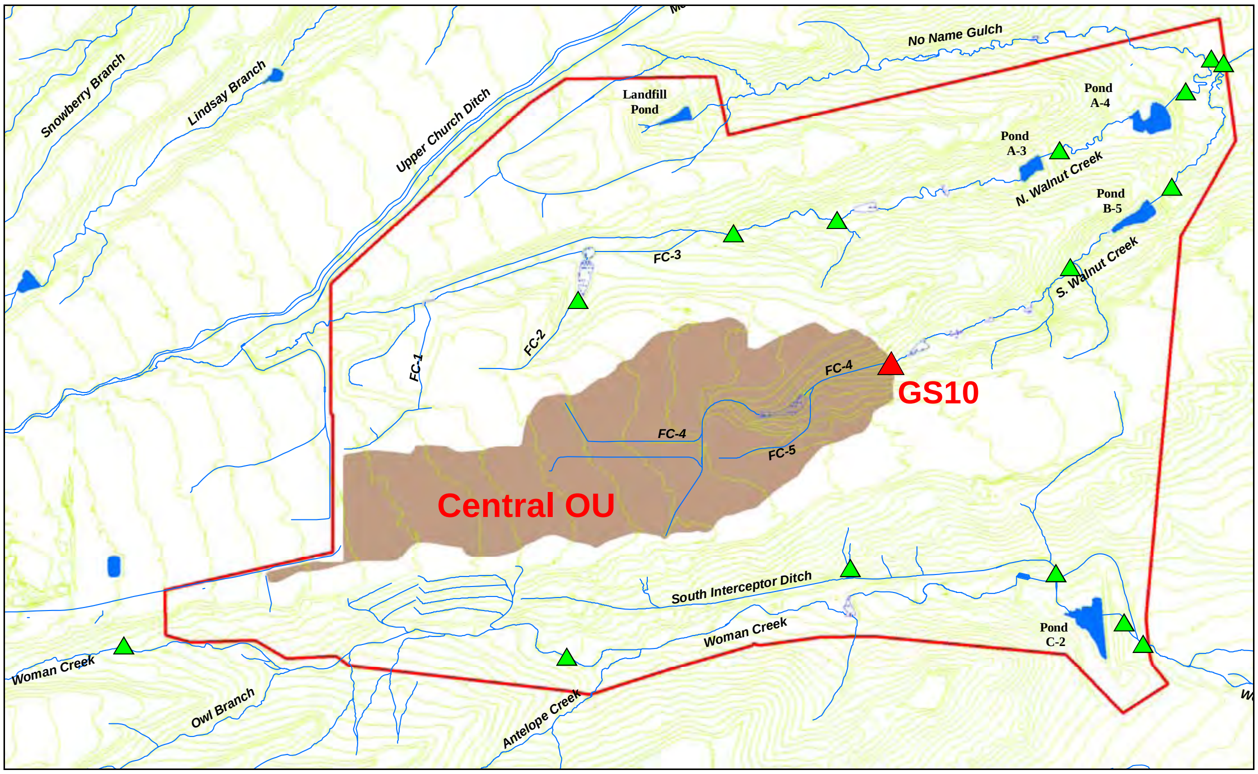


Figure 111. GS10 Drainage Area

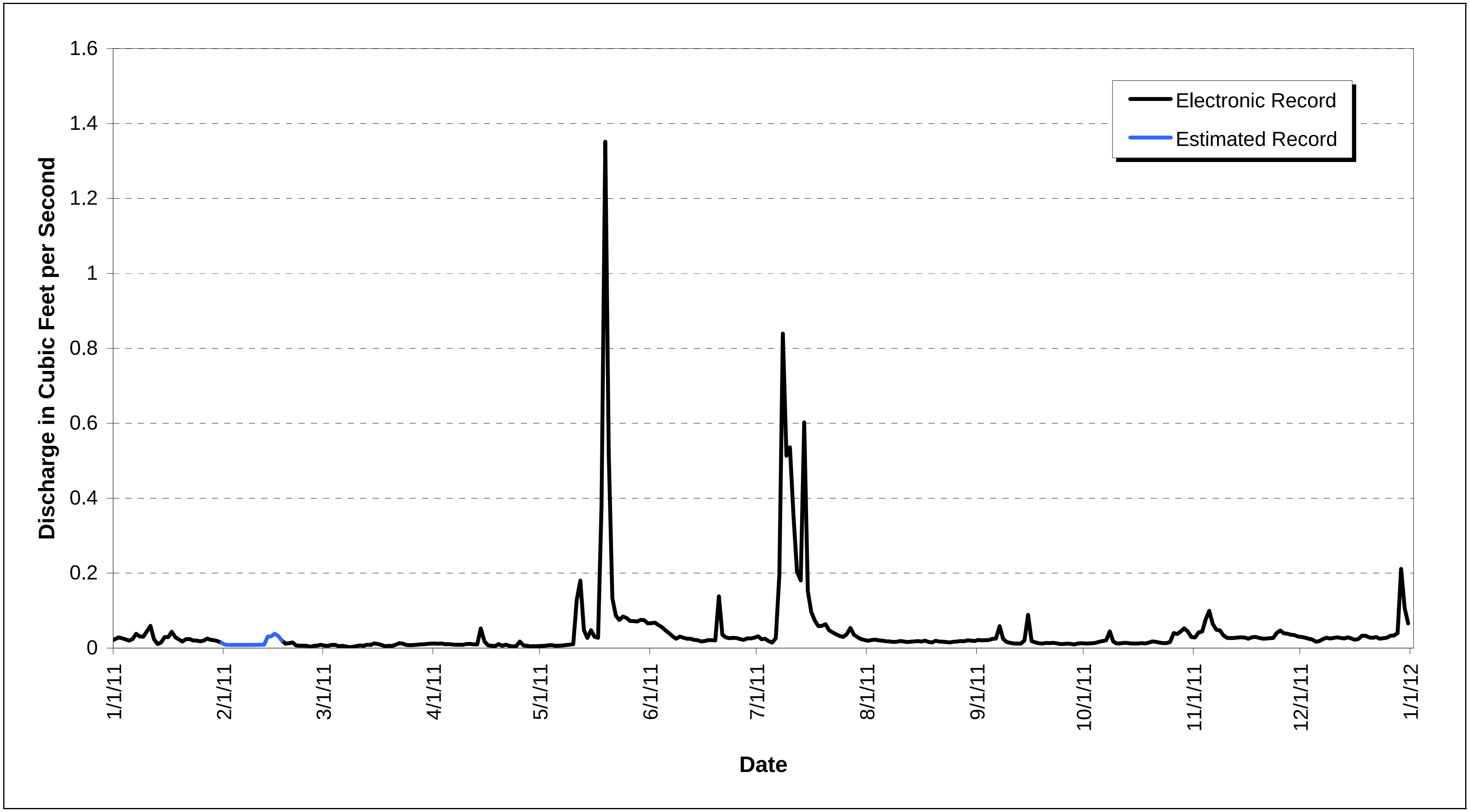


Figure 112. CY 2011 Mean Daily Hydrograph at GS10: South Walnut Creek at Pond B-1

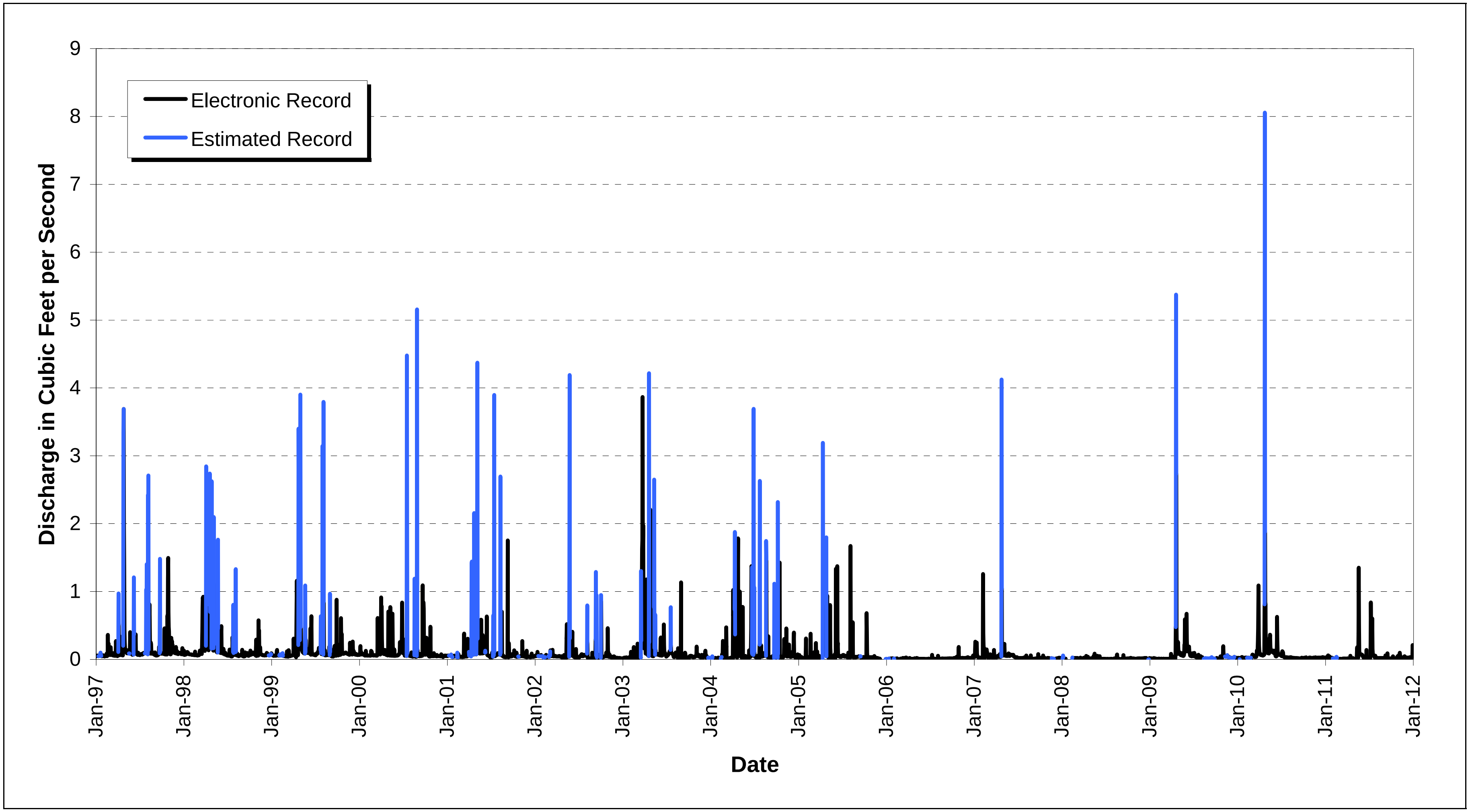


Figure 113. CY 1997–2011 Mean Daily Hydrograph at GS10: South Walnut Creek at Pond B-1

GS11: North Walnut Creek at Pond A-4 Outlet

Location—North Walnut Creek at Pond A-4 outlet; State Plane: E2089930, N753265.

Drainage Area—The basin includes the North Walnut Creek drainage and northern portions of the COU (total of 395.0 acres).

Period of Record—May 12, 1992, to current year.

Gage—Water-stage recorder and 24-inch Parshall flume.

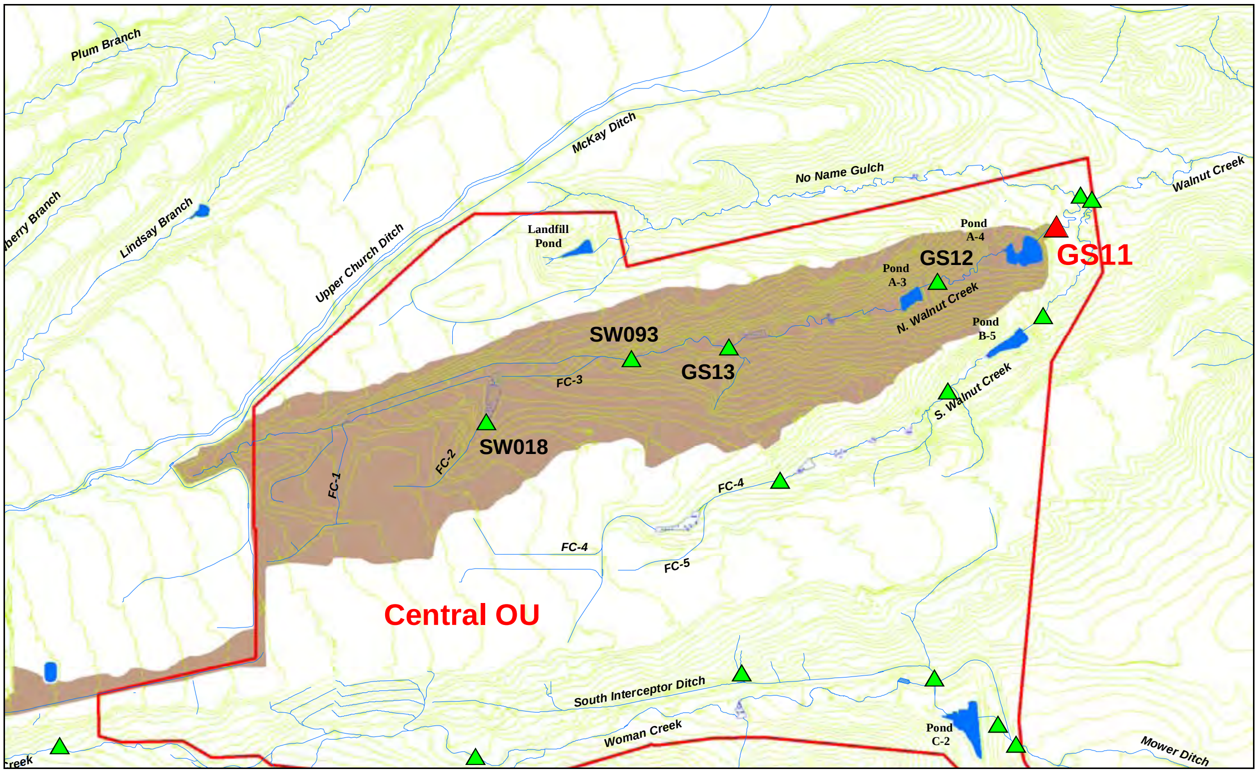


Figure 114. GS11 Drainage Area

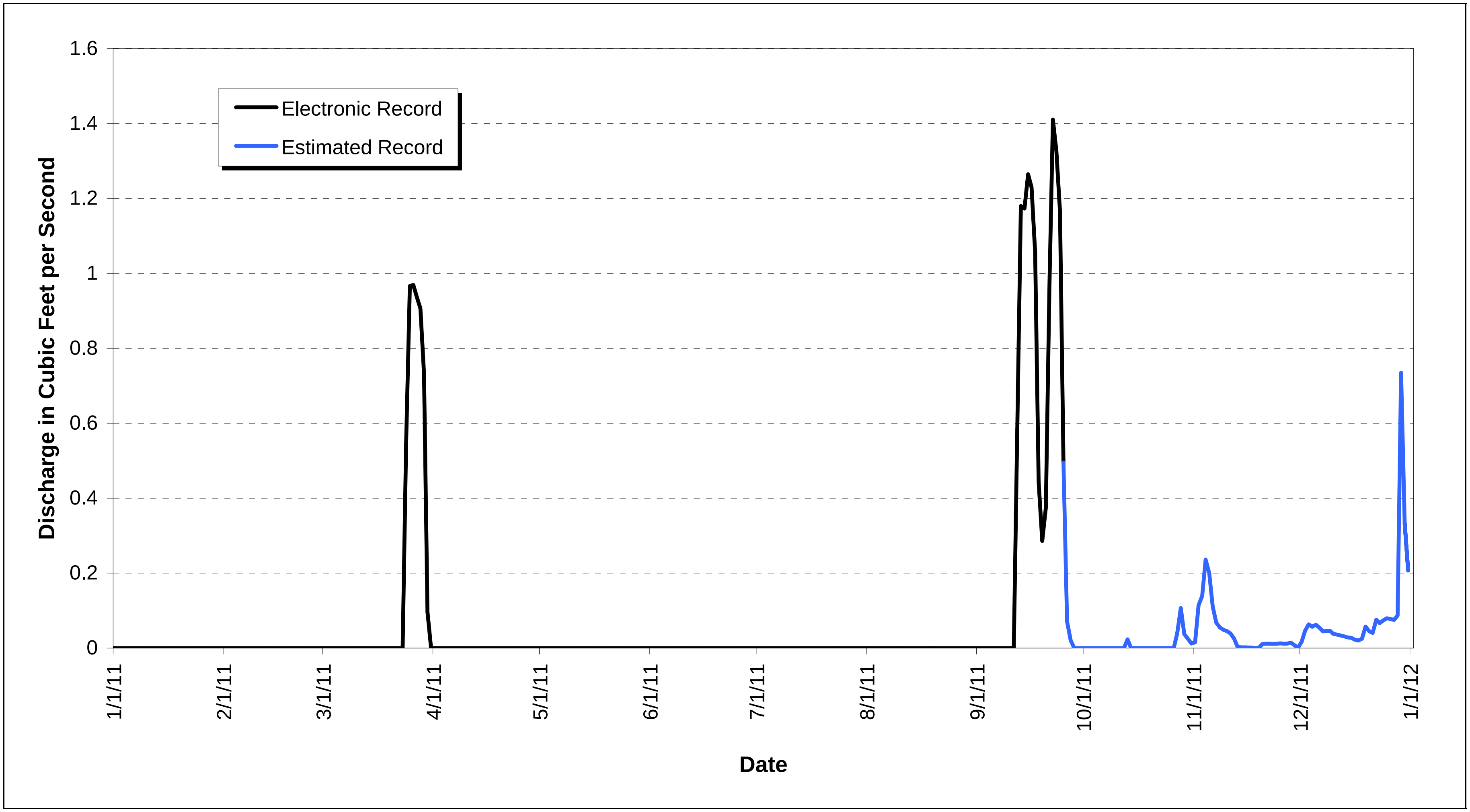


Figure 115. CY 2011 Mean Daily Hydrograph at GS11: North Walnut Creek at Pond A-4 Outlet

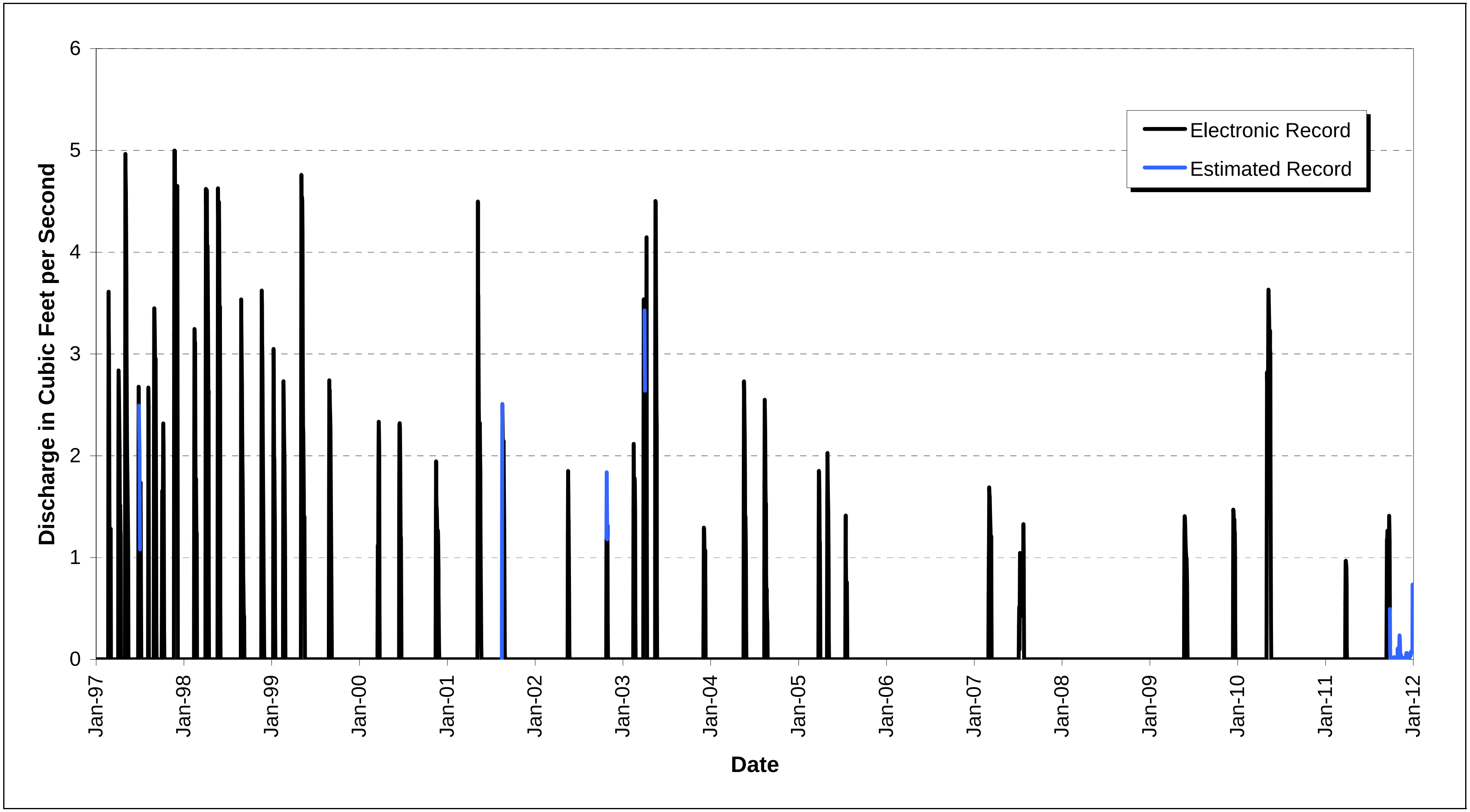


Figure 116. CY 1997−2011 Mean Daily Hydrograph at GS11: North Walnut Creek at Pond A-4 Outlet

GS12: North Walnut Creek at Pond A-3 Outlet

Location—North Walnut Creek at Pond A-3 outlet; State Plane: E2088564, N752629.

Drainage Area—The basin includes the North Walnut Creek drainage and northern portions of the COU (total of 361.7 acres).

Period of Record—May 13, 1992, to current year.

Gage—Water-stage recorder and 30-inch Parshall flume.

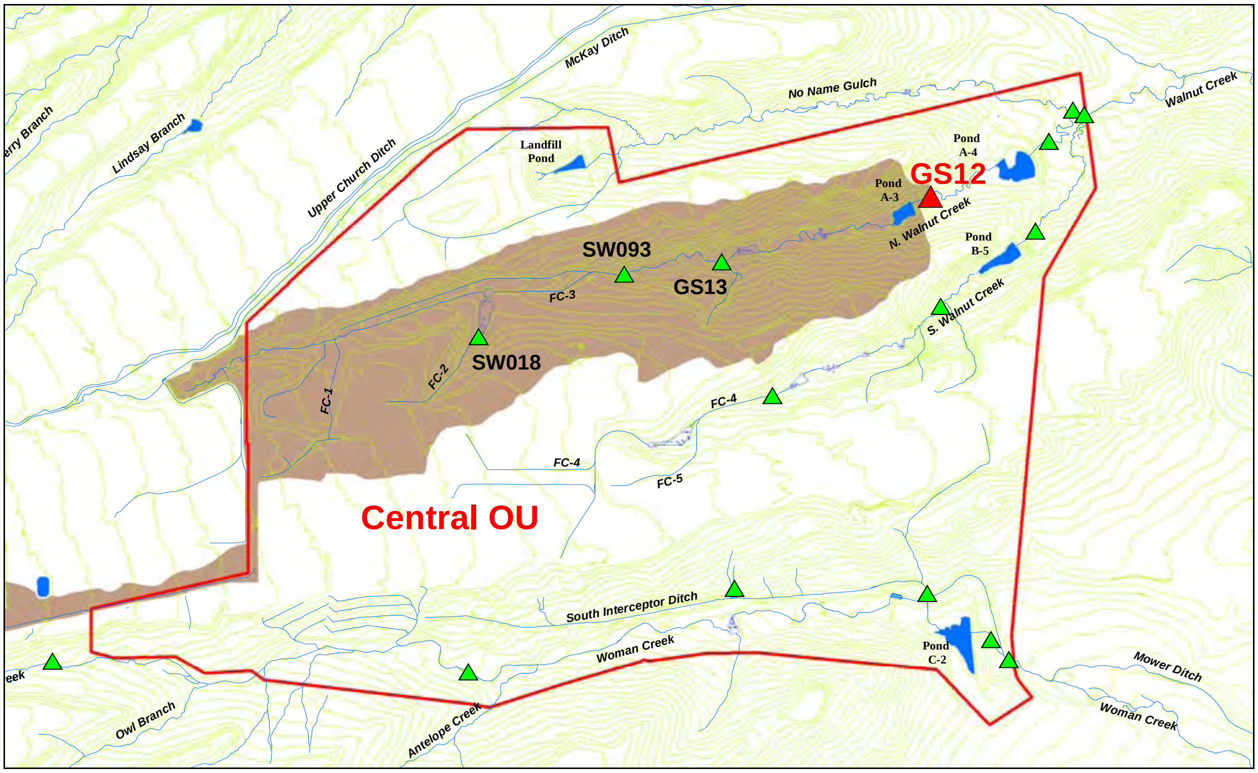


Figure 117. GS12 Drainage Area

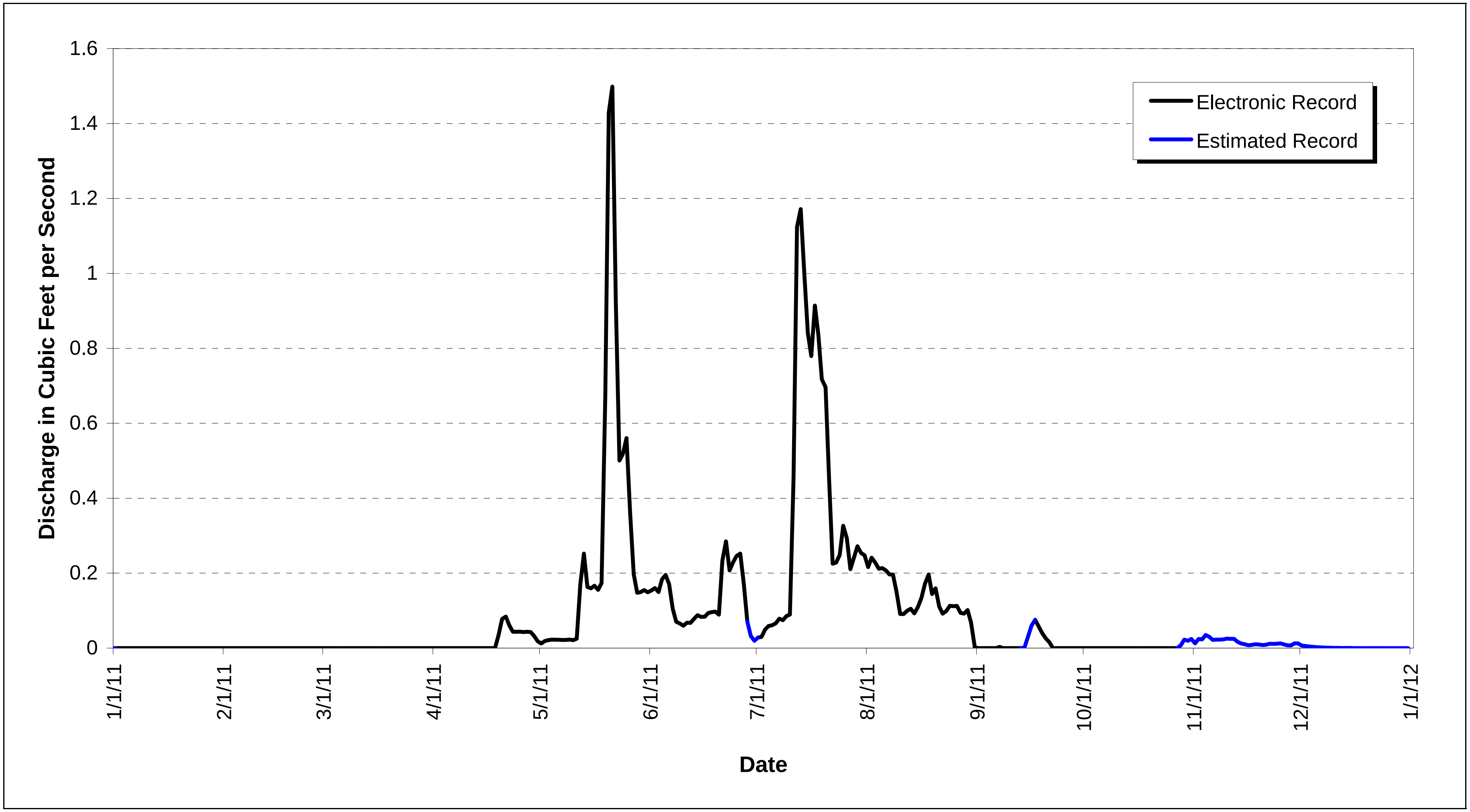


Figure 118. CY 2011 Mean Daily Hydrograph at GS12: North Walnut Creek at Pond A-3 Outlet

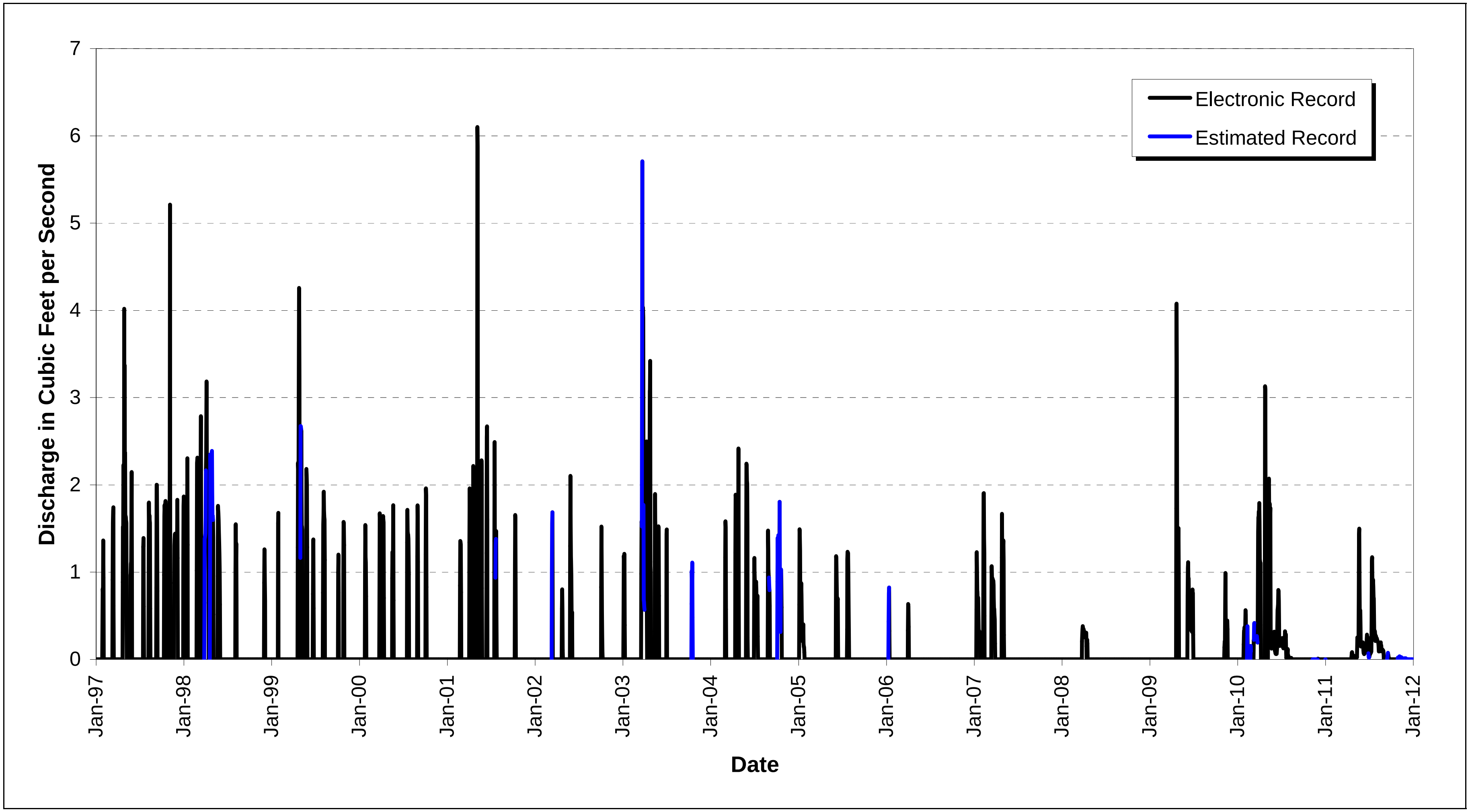


Figure 119. CY 1997−2011 Mean Daily Hydrograph at GS12: North Walnut Creek at Pond A-3 Outlet

GS13: North Walnut Creek at Pond A-1

Location—North Walnut Creek at Pond A-1; State Plane: E2086153, N751870.

Drainage Area—The basin includes the North Walnut Creek drainage and northwestern portions of the COU (total of 260.8 acres).

Period of Record—October 1, 2005, to current year.

Gage—Water-stage recorder and 6-inch Parshall flume.

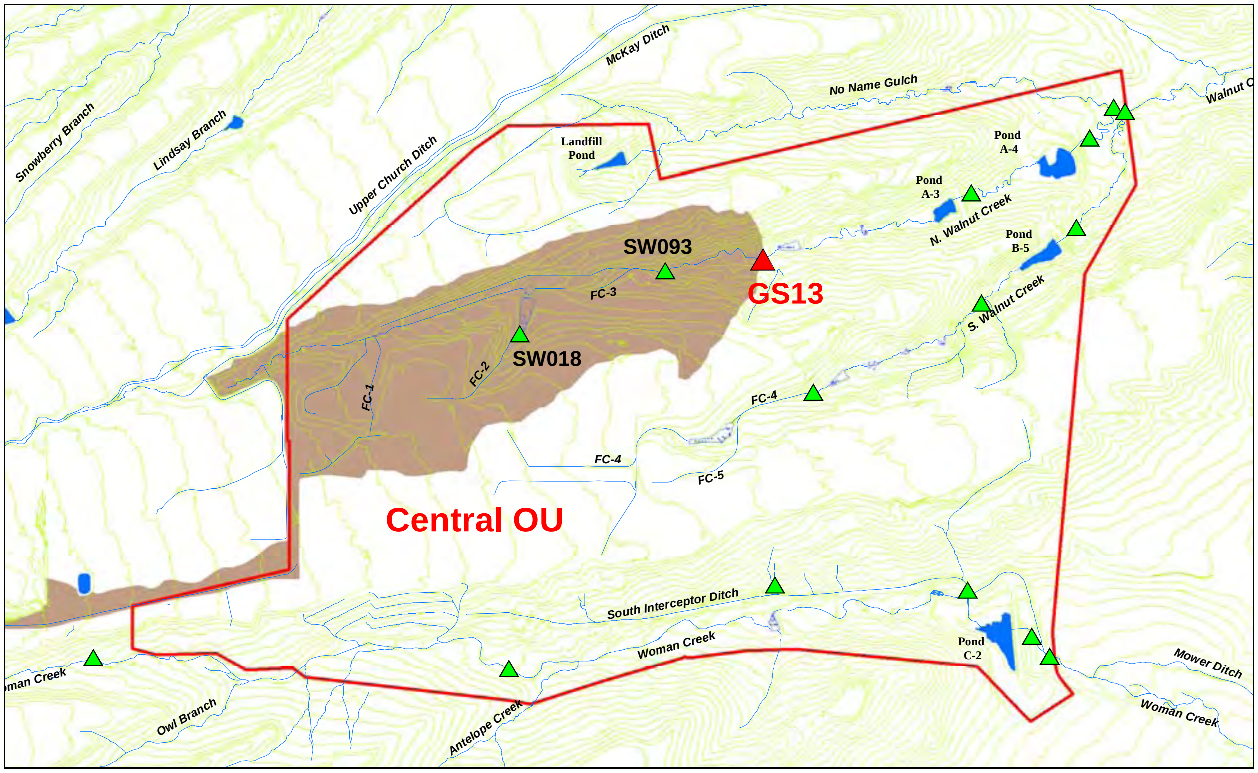


Figure 120. GS13 Drainage Area

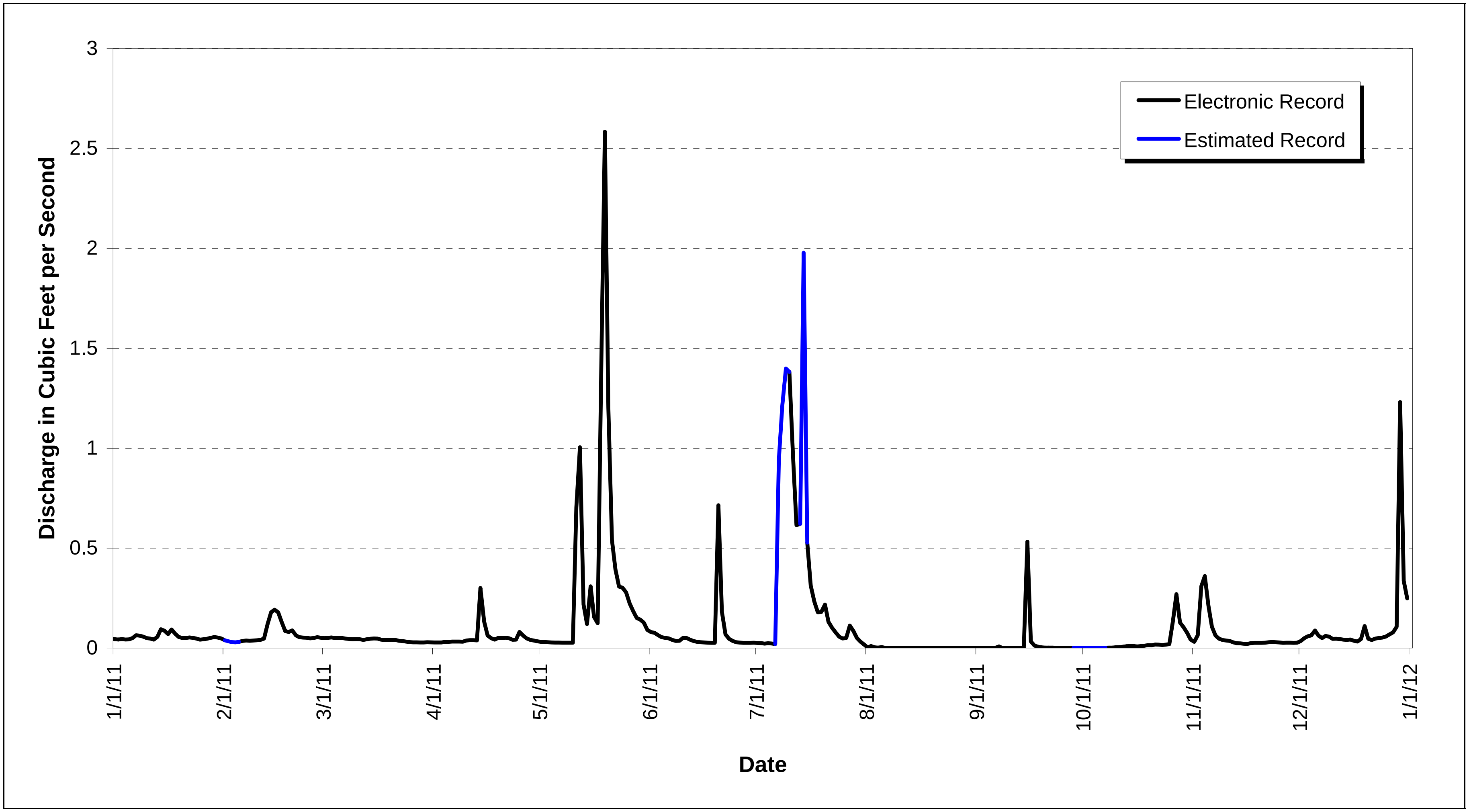


Figure 121. CY 2011 Mean Daily Hydrograph at GS13: North Walnut Creek at Pond A-1 Bypass

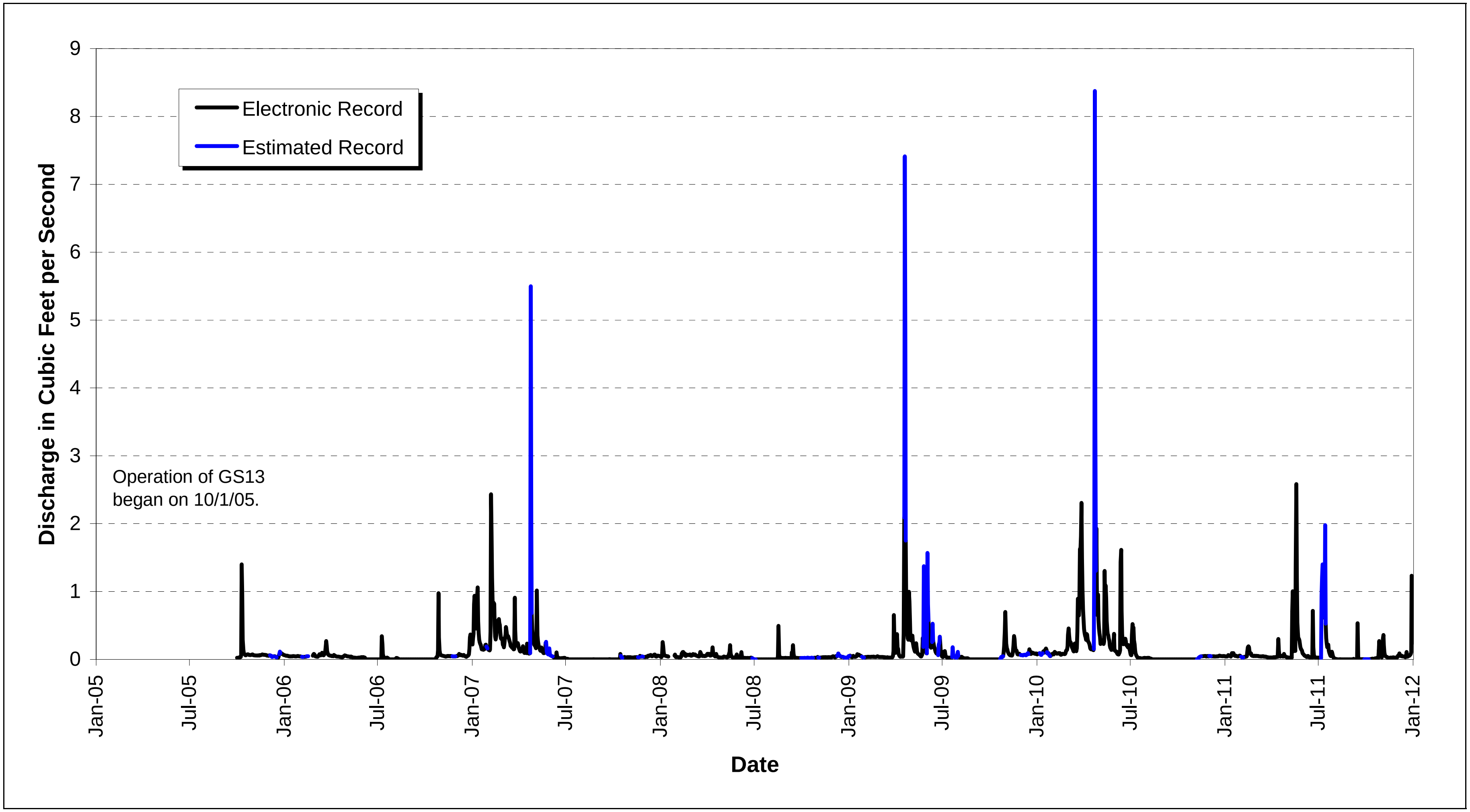


Figure 122. CY 2005−2011 Mean Daily Hydrograph at GS13: North Walnut Creek at Pond A-1 Bypass

GS31: Woman Creek at Pond C-2 Outlet

Location—Pond C-2 outlet; State Plane: E2089261, N747512.

Drainage Area—The basin includes a portion of the southern COU draining to the SID and the area surrounding Pond C-2 (total of 204.1 acres).

Period of Record—October 1, 1996, to current year.

Gage—Water-stage recorder and 24-inch Parshall flume.

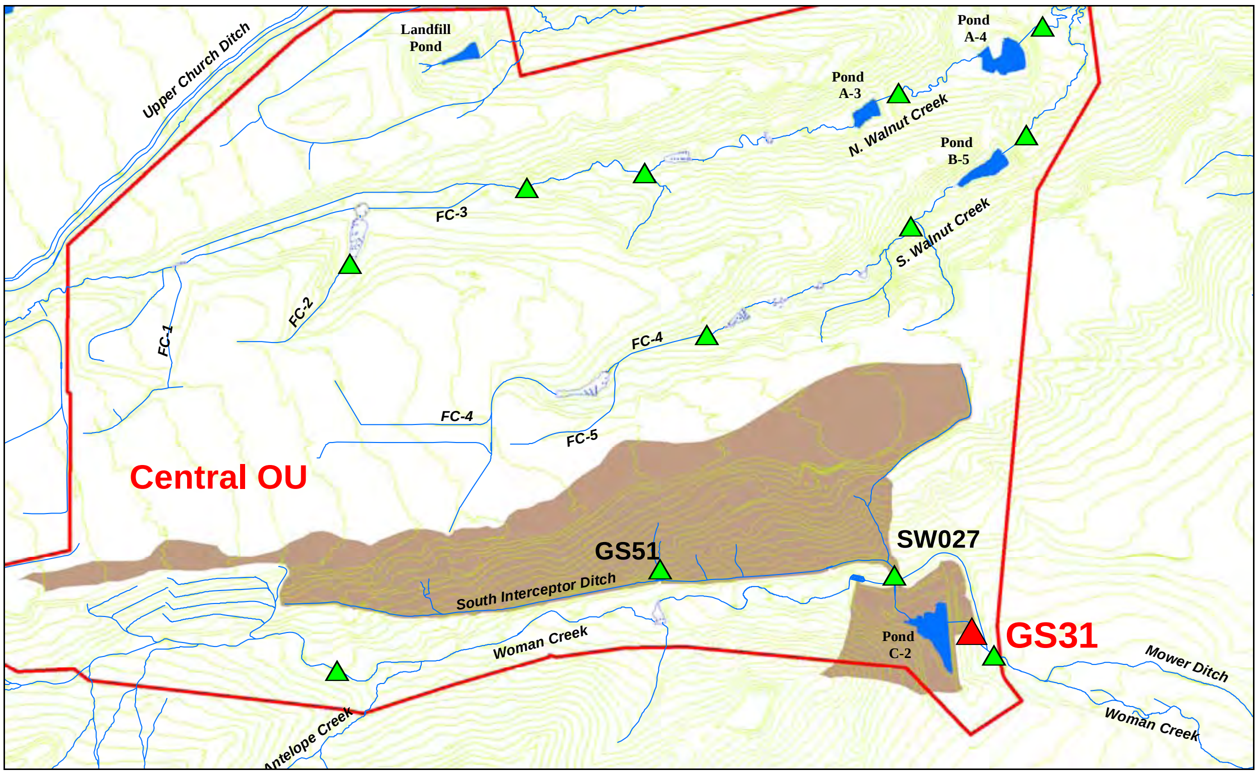


Figure 123. GS31 Drainage Area

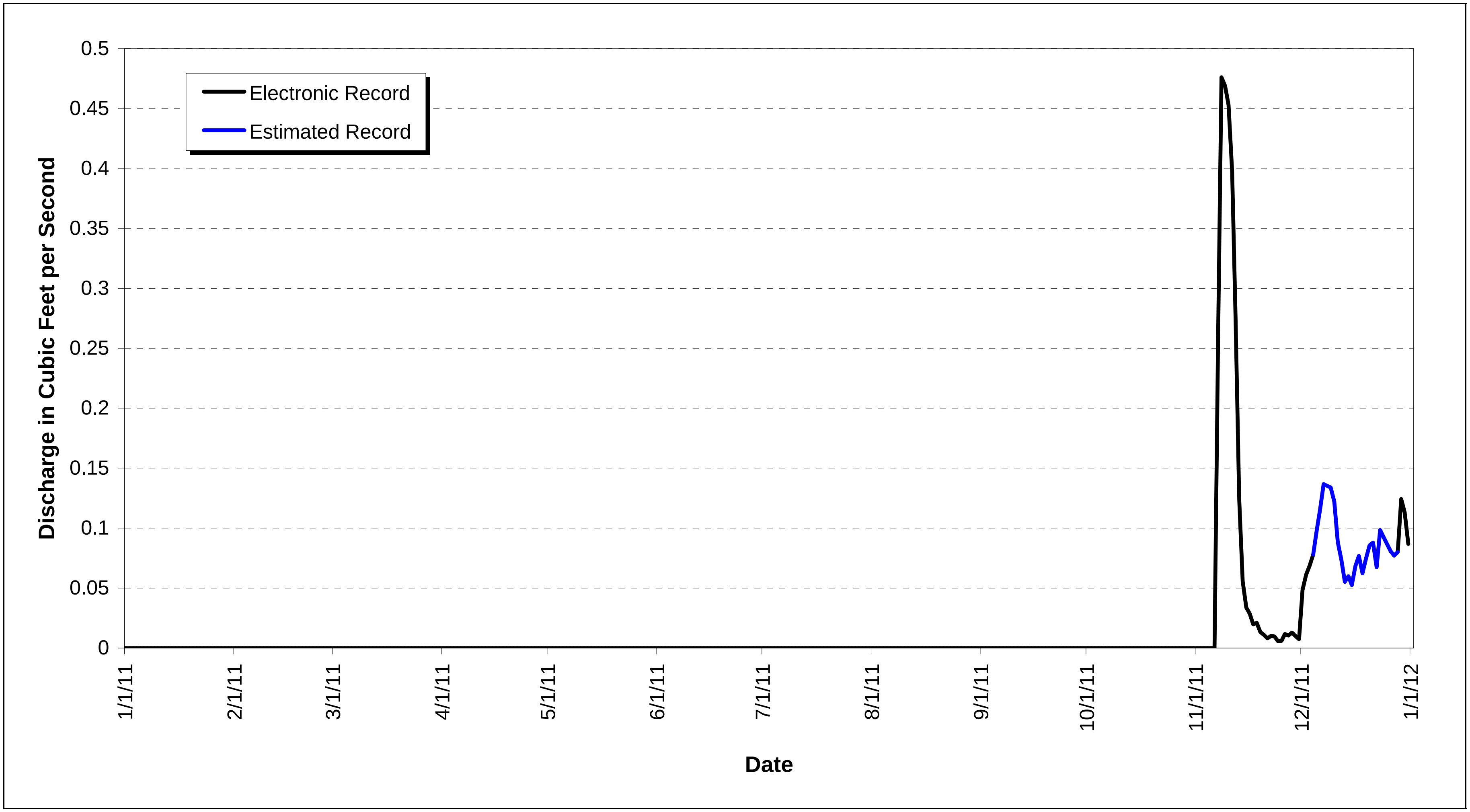


Figure 124. CY 2011 Mean Daily Hydrograph at GS31: Woman Creek at Pond C-2 Outlet

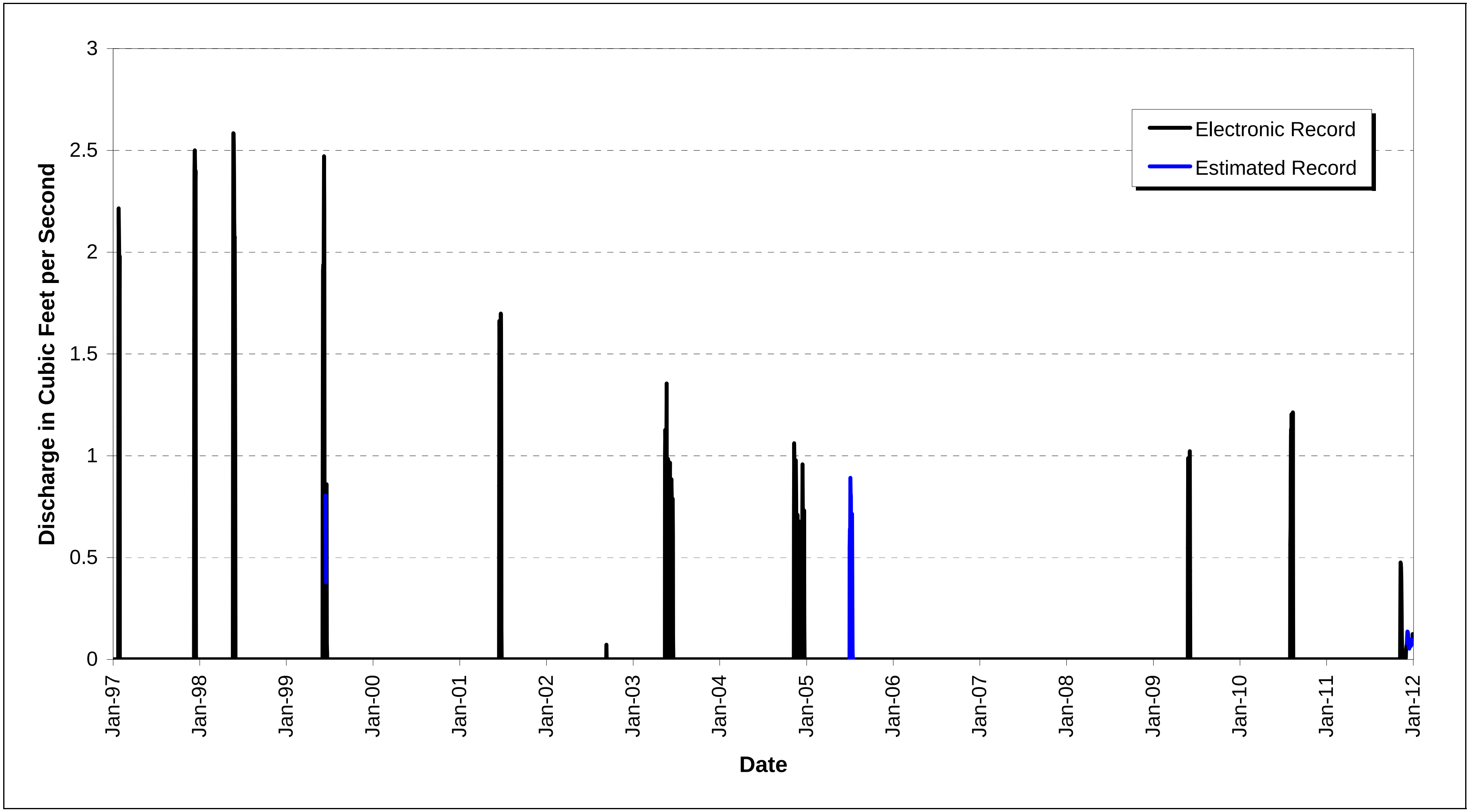


Figure 125. CY 1997−2011 Mean Daily Hydrograph at GS31: Woman Creek at Pond C-2 Outlet

GS33: No Name Gulch at Walnut Creek

Location—No Name Gulch at Walnut Creek; State Plane: E2090210, N753623.

Drainage Area—The basin is the No Name Gulch drainage (total of 295.3 acres).

Period of Record—September 16, 1997, to current year.

Gage—Water-stage recorder and 9.5-inch Parshall flume.

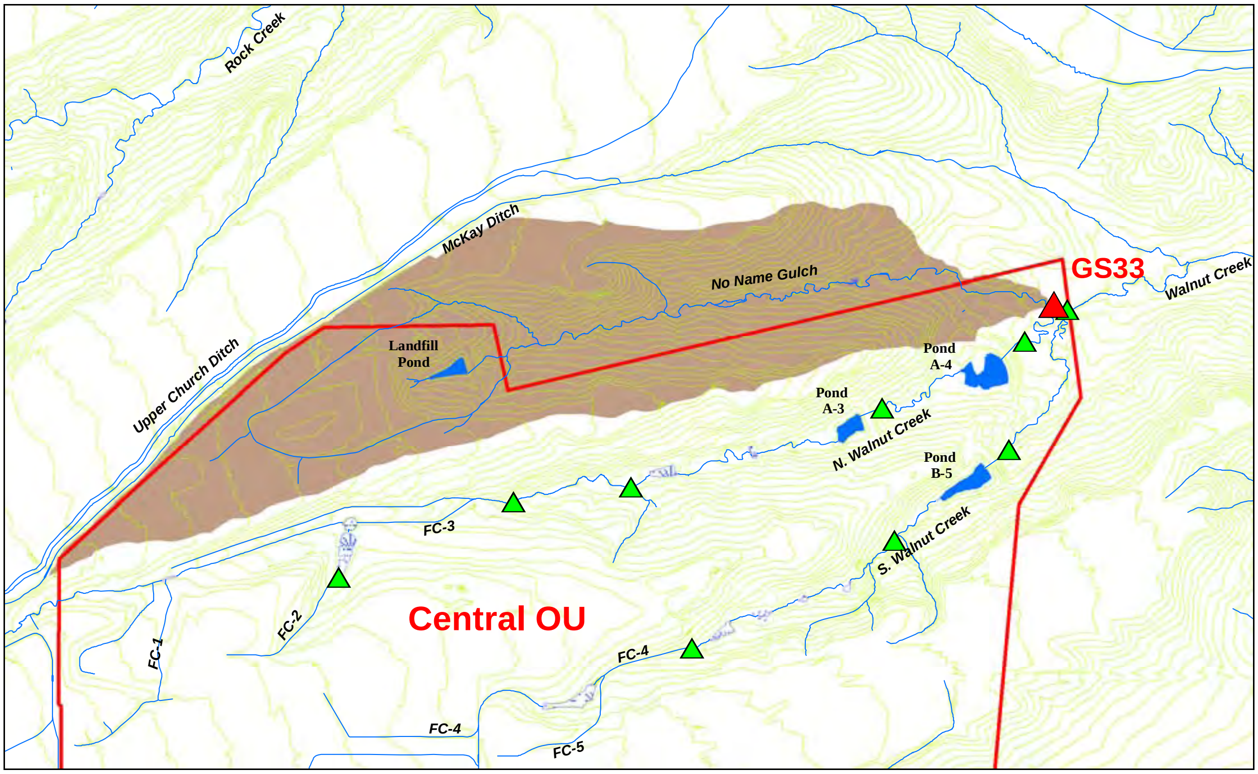


Figure 126. GS33 Drainage Area

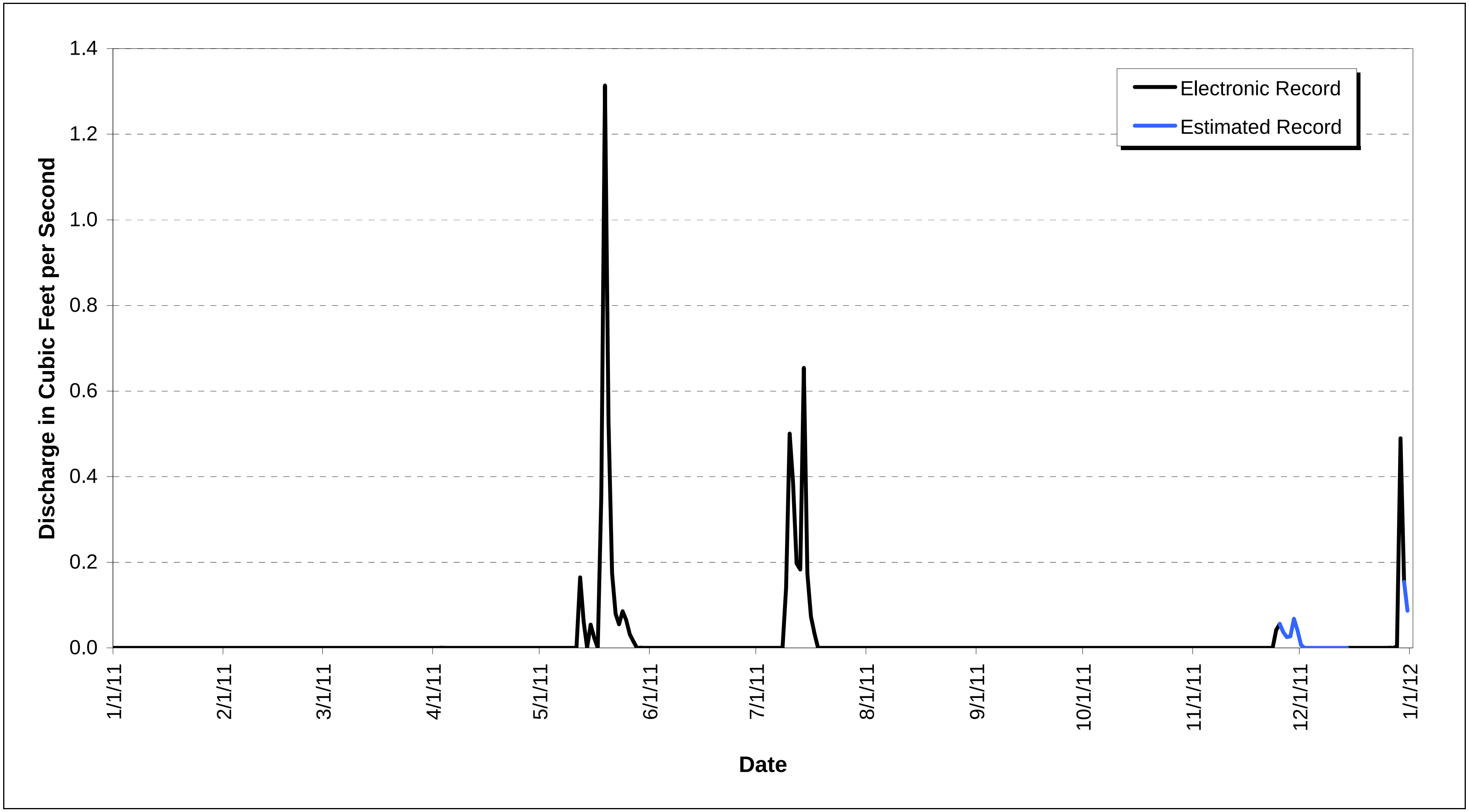


Figure 127. CY 2011 Mean Daily Hydrograph at GS33: No Name Gulch at Walnut Creek

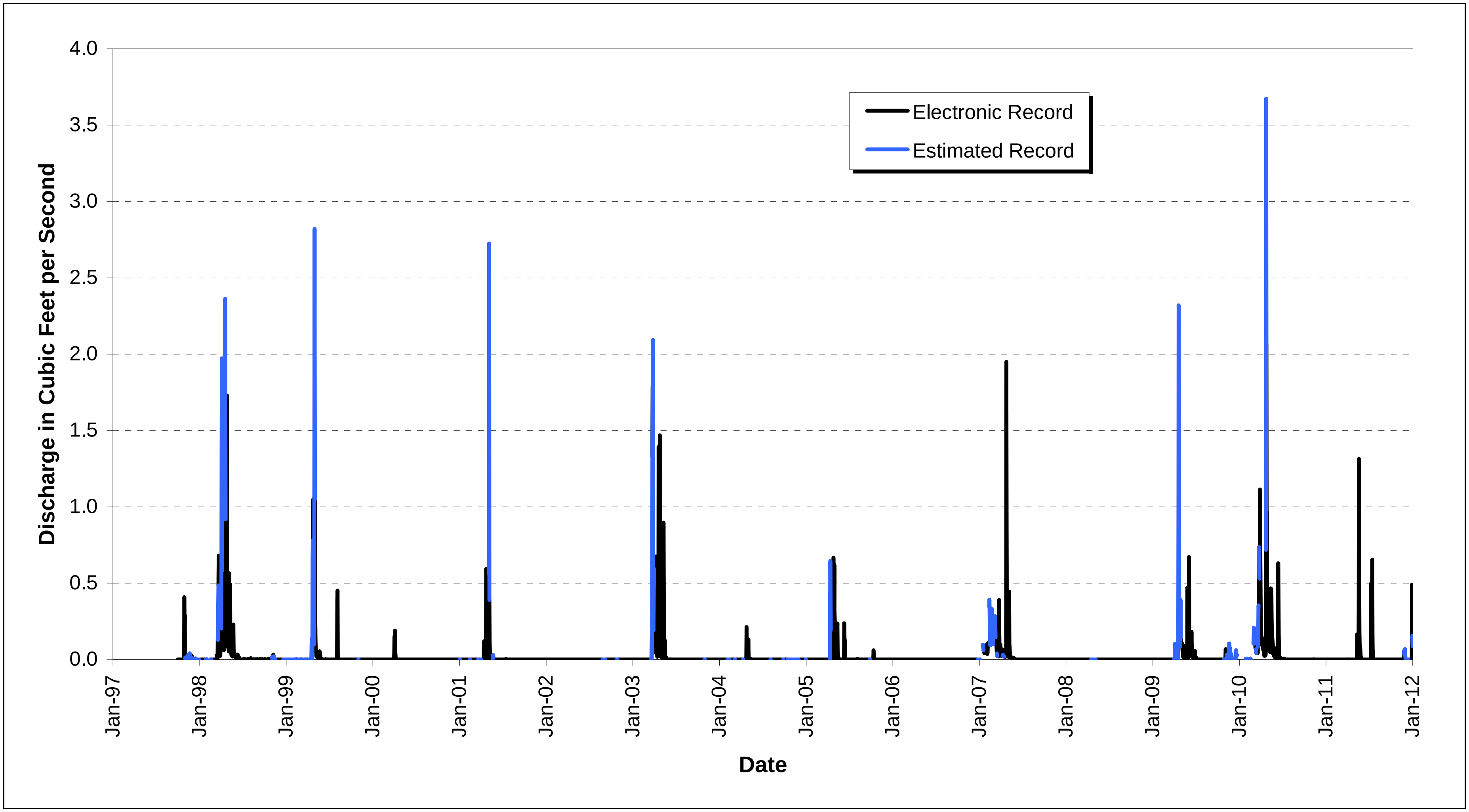


Figure 128. CY 1997−2011 Mean Daily Hydrograph at GS33: No Name Gulch at Walnut Creek

GS51: Ditch South of Former 903 Pad

Location—Ditch south of former 903 Pad; State Plane: E2086300, N748102.

Drainage Area—The basin includes an area south and west of the former 903 Pad (total of 16.0 acres).

Period of Record—August 13, 2001, to current year.

Gage—Water-stage recorder and 0.75-foot H-flume.

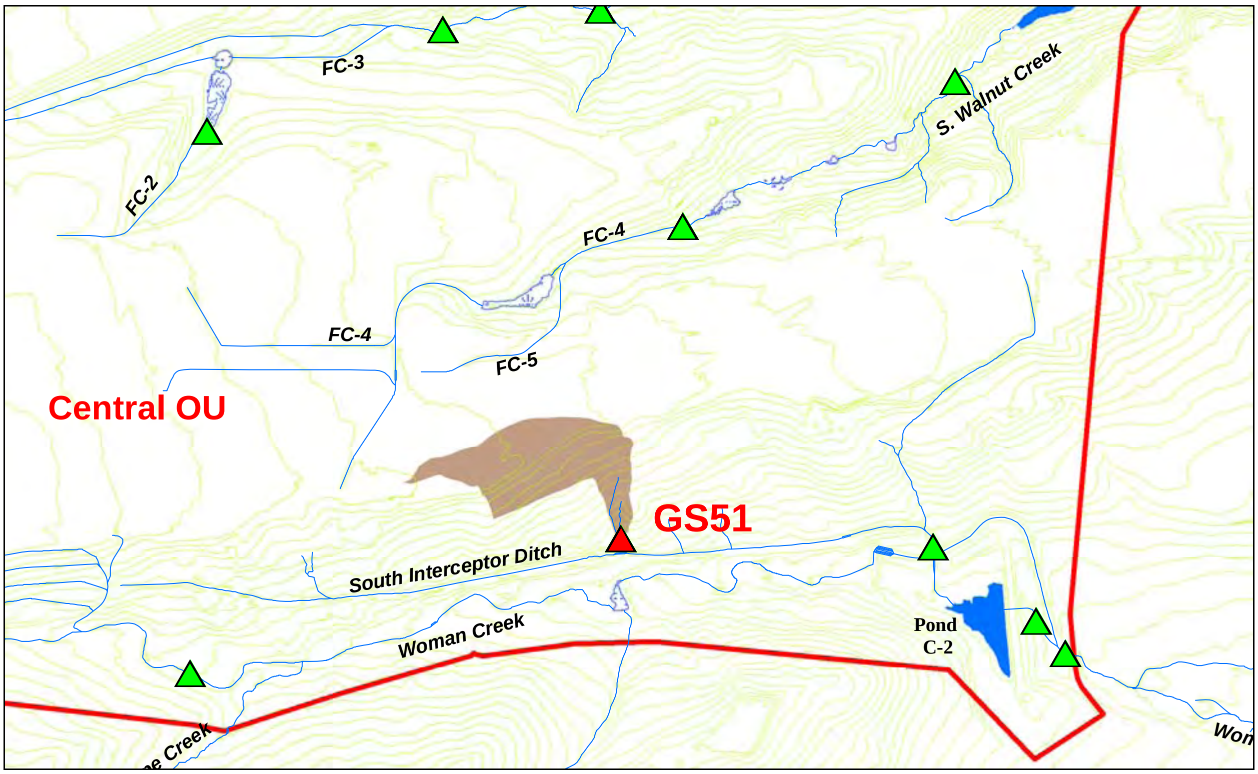


Figure 129. GS51 Drainage Area

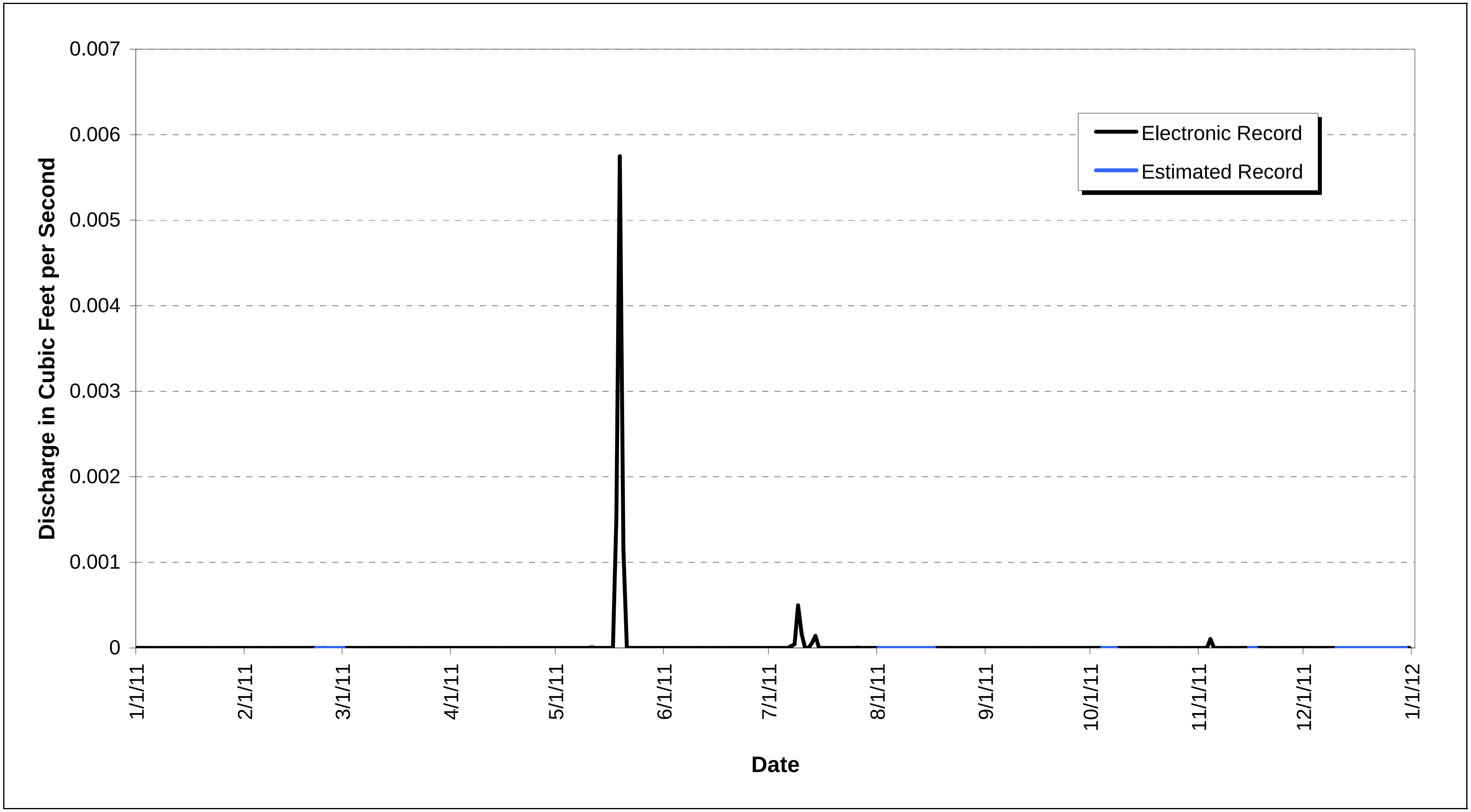


Figure 130. CY 2011 Mean Daily Hydrograph at GS51: Ditch South of 903 Pad

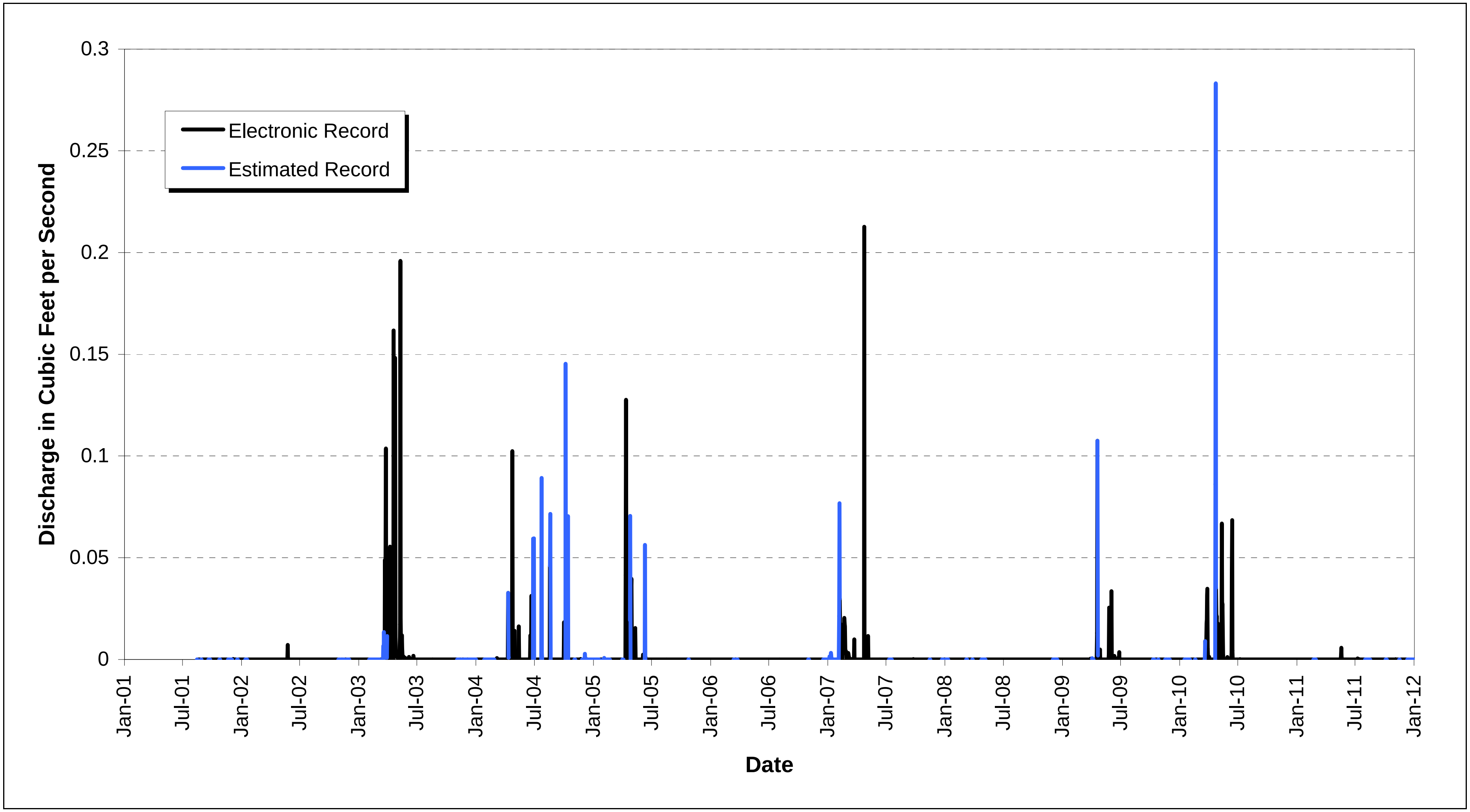


Figure 131. CY 2001−2011 Mean Daily Hydrograph at GS51: Ditch South of 903 Pad

GS59: Woman Creek Upstream of Antelope Springs Confluence

Location—Woman Creek 900 feet upstream of Antelope Springs confluence; State Plane: E2083228, N747139.

Drainage Area—The basin includes upstream reaches of Woman Creek; areas west of Highway 93 also contribute runoff (total drainage acreage undetermined).

Period of Record—November 20, 2002, to current year.

Gage—Water-stage recorder and 1.5-foot Parshall flume.

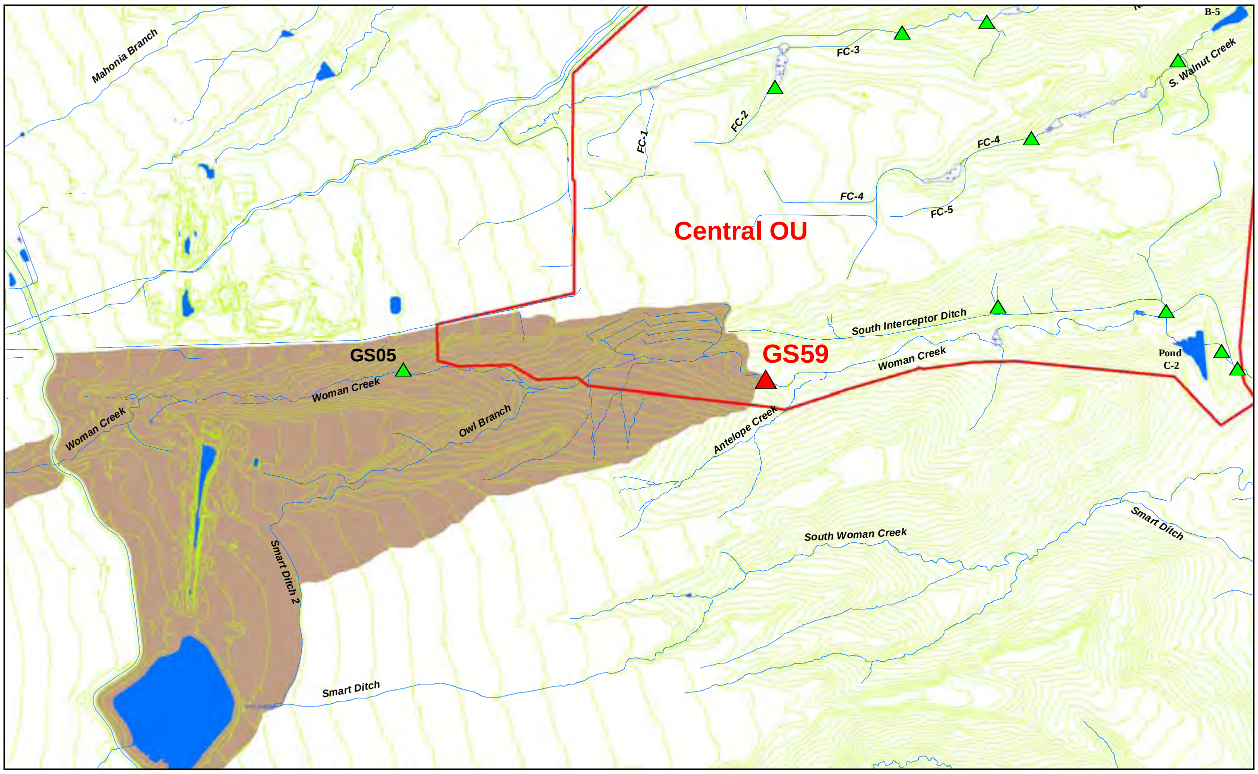


Figure 132. GS59 Drainage Area

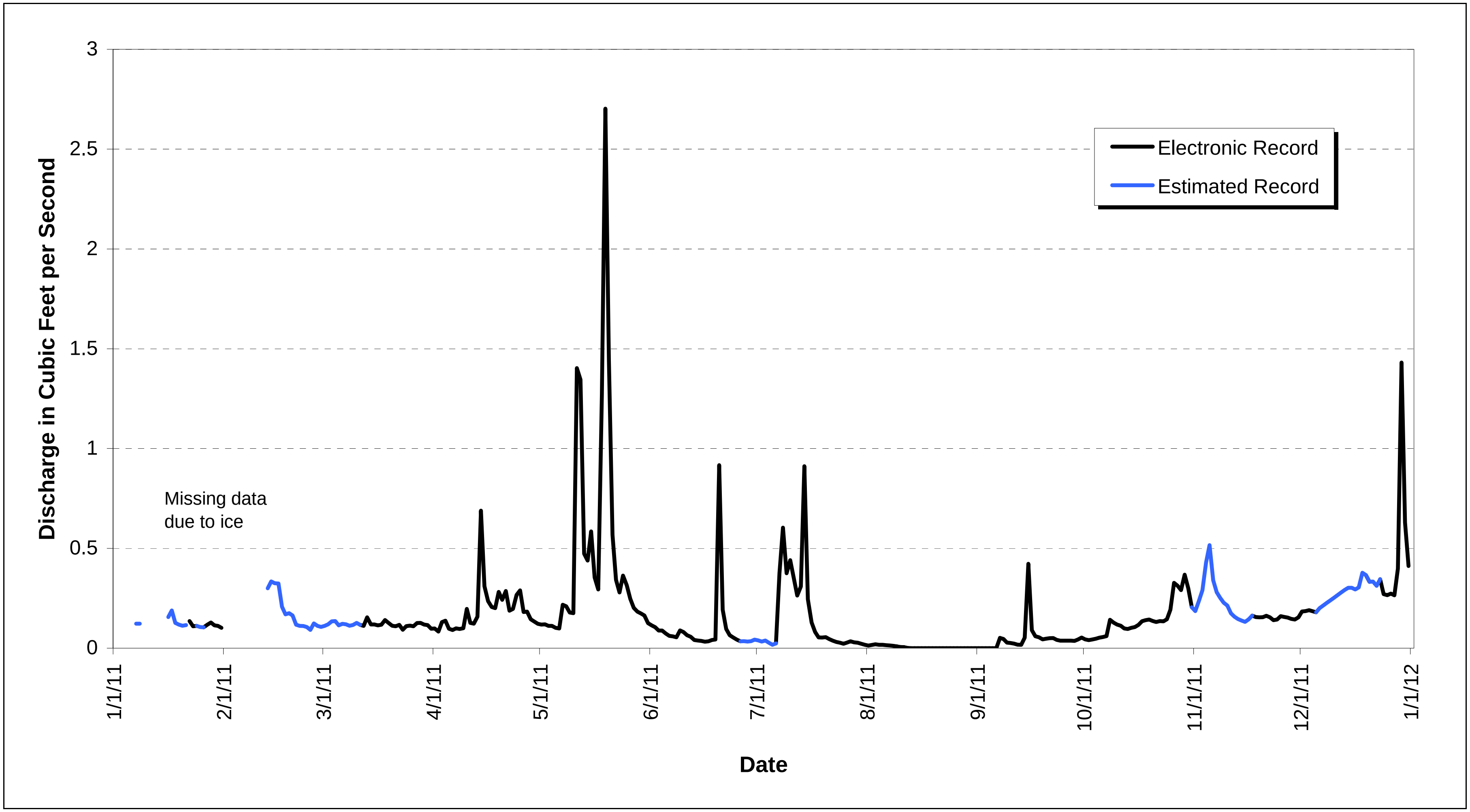


Figure 133. CY 2011 Mean Daily Hydrograph at GS59: Woman Creek Upstream of Antelope Springs Confluence

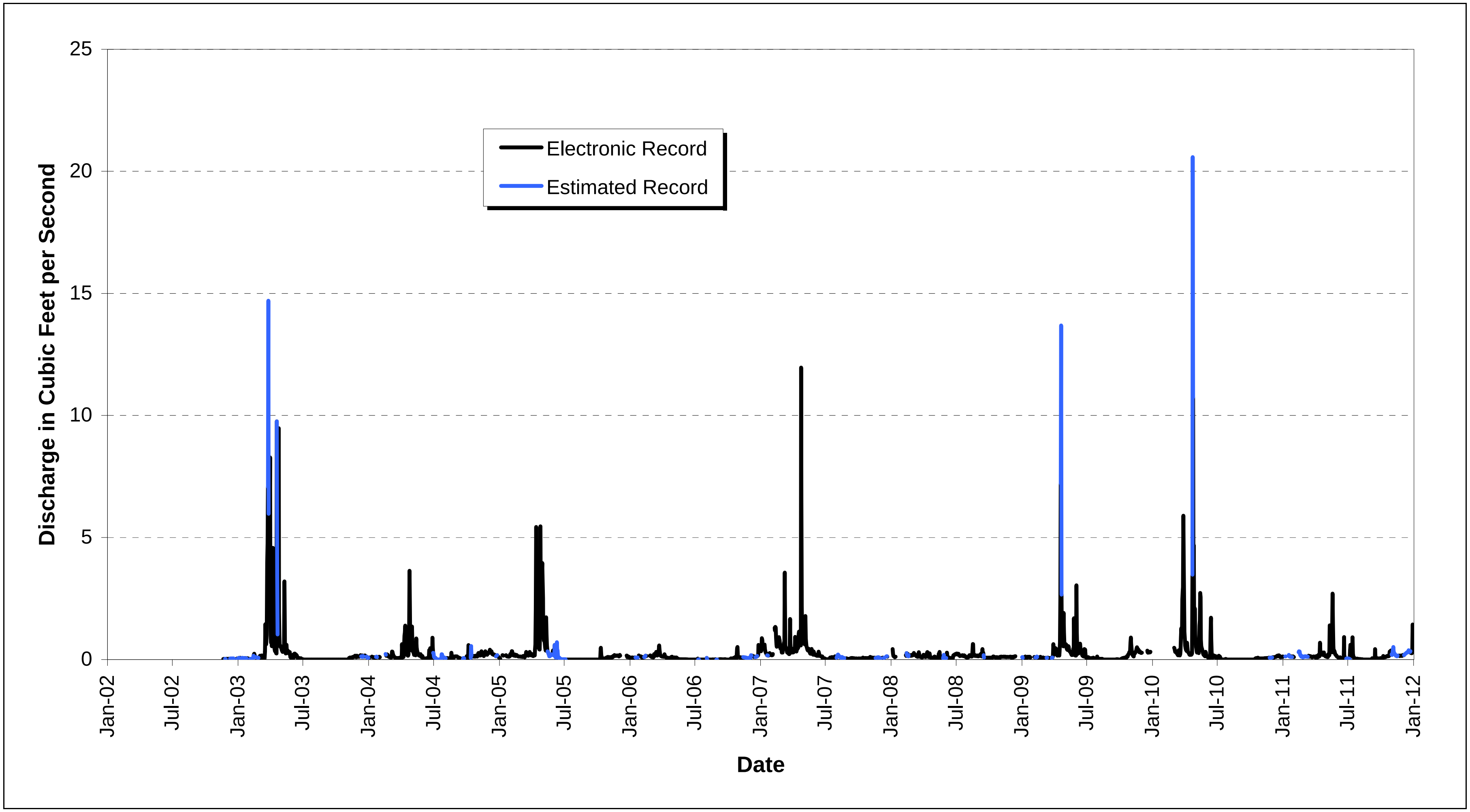


Figure 134. CY 2002−2011 Mean Daily Hydrograph at GS59: Woman Creek Upstream of Antelope Springs Confluence

B5INFLOW: South Walnut Creek Above Pond B-5

Location—South Walnut Creek 500 feet upstream of Pond B-5; State Plane: E2088676, N751358.

Drainage Area— The basin includes the central portion of the COU and the former B-Series Ponds (total of 260.3 acres).

Period of Record—June 17, 2010, to current year.

Gage—Water-stage recorder and 9-inch Parshall flume.

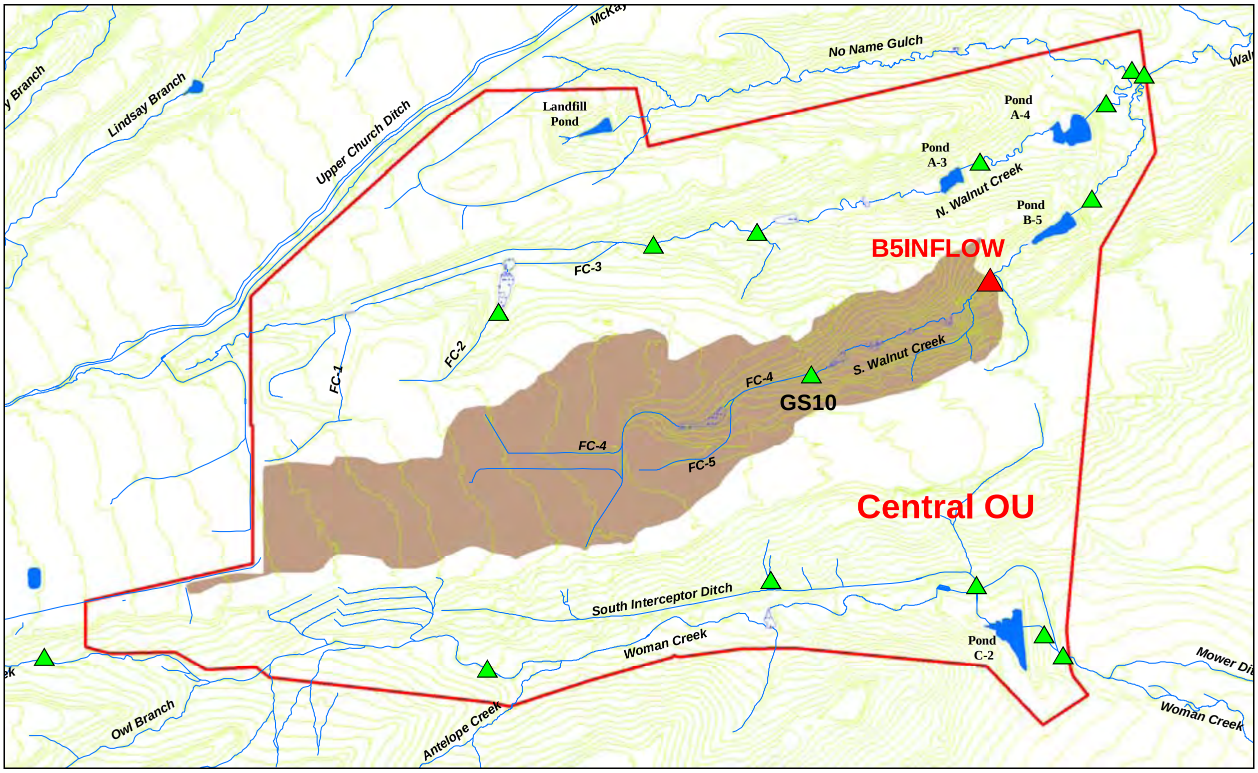


Figure 135. B5INFLOW Drainage Area

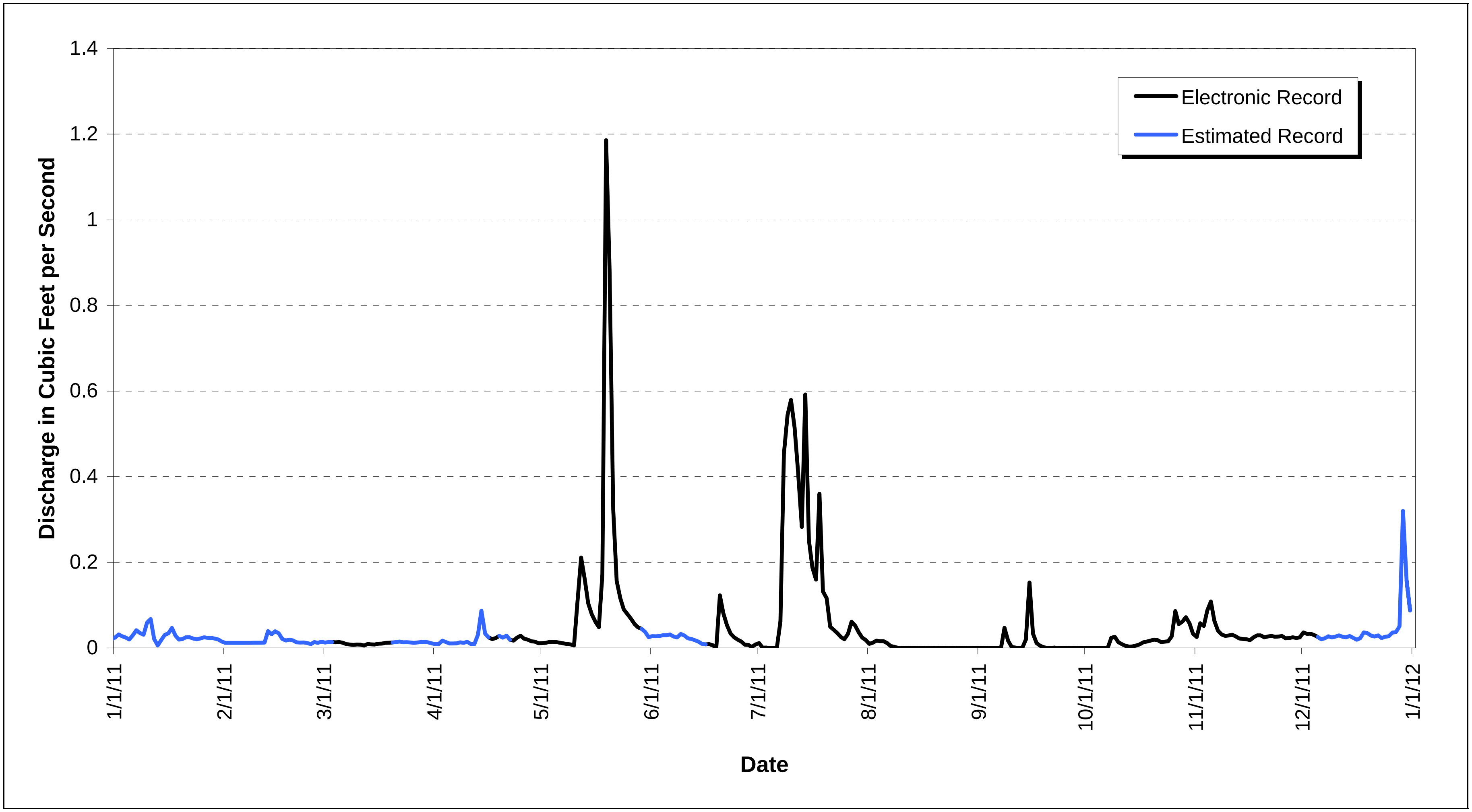


Figure 136. CY 2011 Mean Daily Hydrograph at B5INFLOW: South Walnut Creek Above Pond B-5

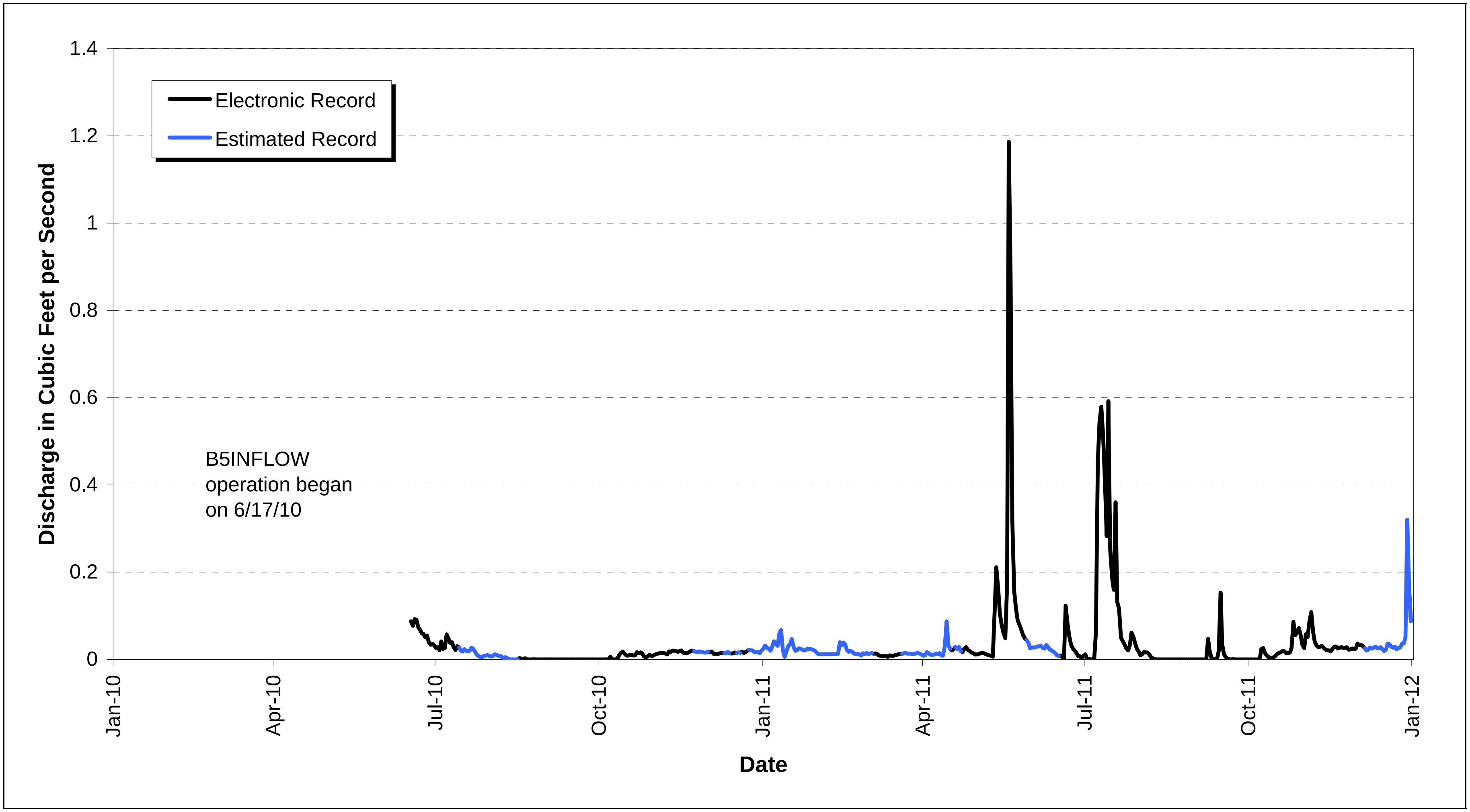


Figure 137. CY 2010−2011 Mean Daily Hydrograph at B5INFLOW: South Walnut Creek Above Pond B-5

SW018: FC-2 at FC-2 Wetland

Location—FC-2 drainage just upstream of FC-2 wetland; State Plane: E2083351, N751006.

Drainage Area—The basin includes FC-2 areas tributary to North Walnut Creek (total of 42.4 acres).

Period of Record—October 10, 2003, to current year.

Gage—Water-stage recorder and 1-foot Parshall flume through September 12, 2006. One-foot H flume installed on September 13, 2006.

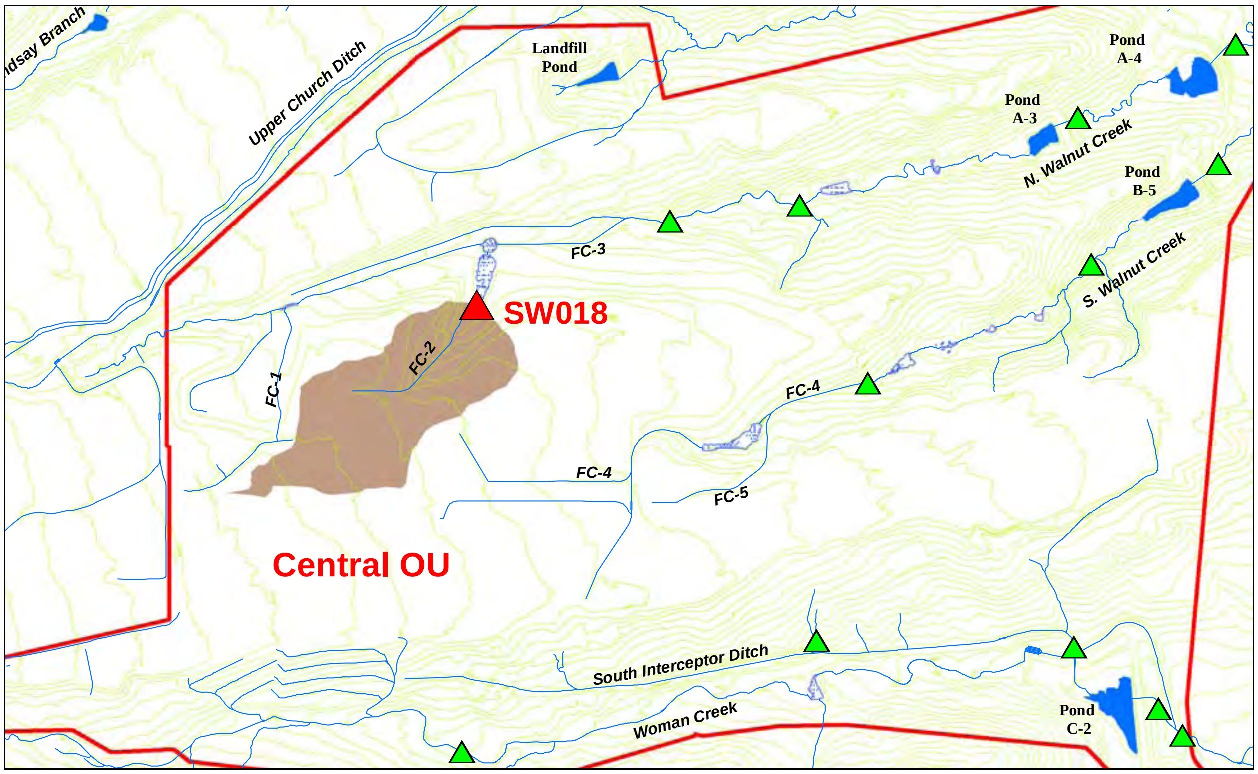


Figure 138. SW018 Drainage Area

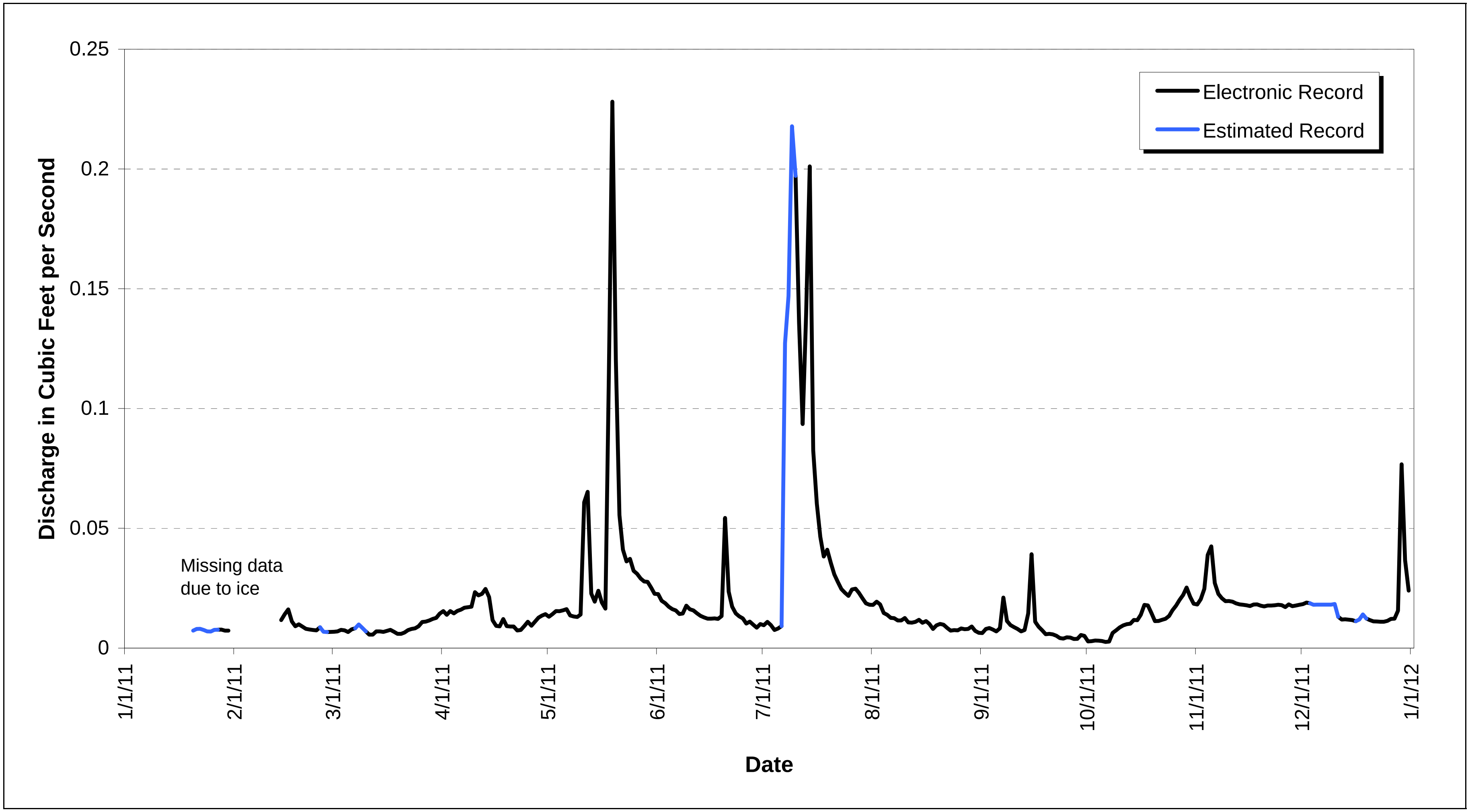


Figure 139. CY 2011 Mean Daily Hydrograph at SW018: FC-2 at FC-2 Wetland

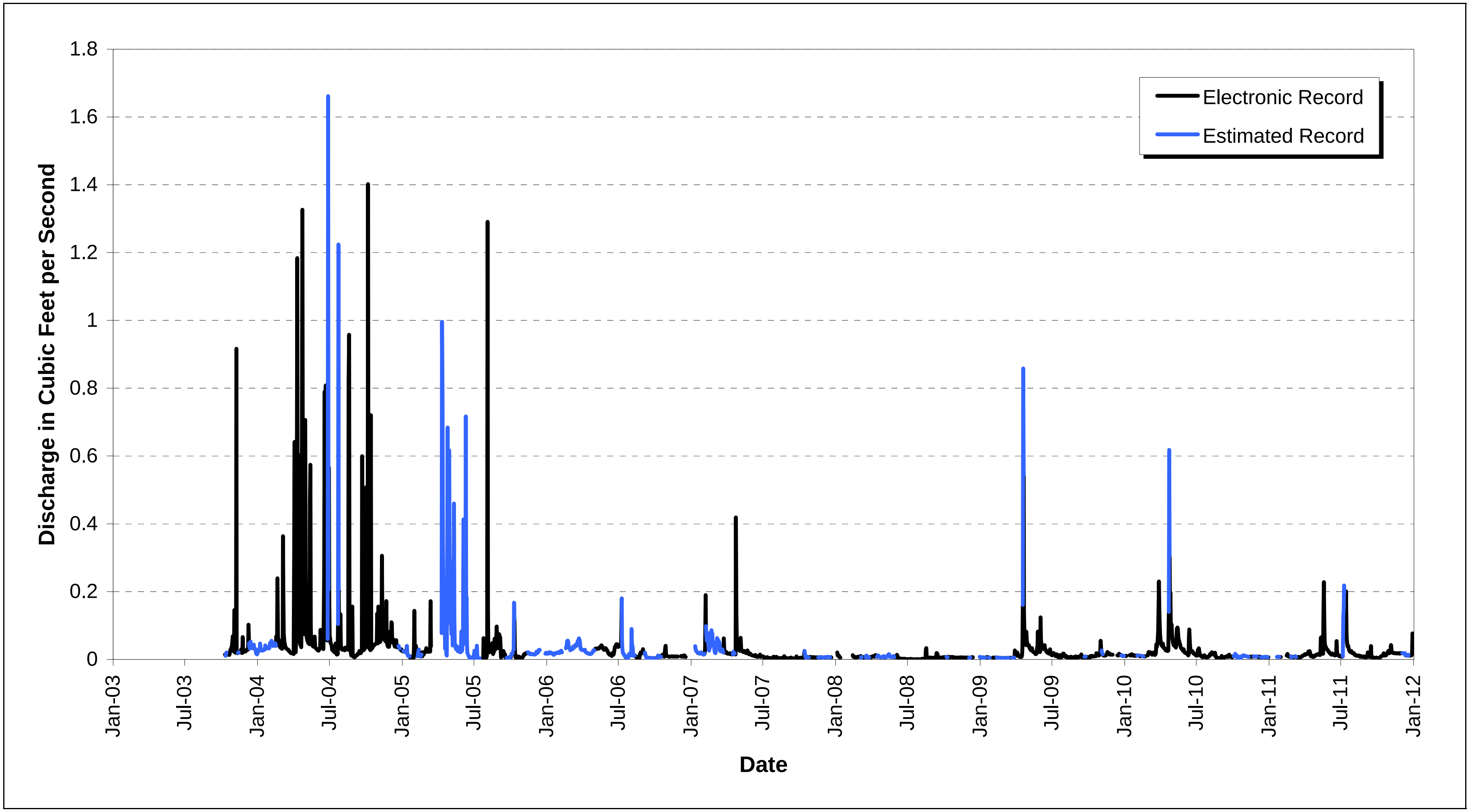


Figure 140. CY 2003−2011 Mean Daily Hydrograph at SW018: FC-2 at FC-2 Wetland

SW027: SID at Pond C-2

Location—East end of SID at Pond C-2; State Plane: E2088527, N748044.

Drainage Area—The basin includes a portion of the southern COU drained by the SID (total of 177.6 acres).

Period of Record—September 11, 1991, to current year.

Gage—Water-stage recorder and dual parallel 120° V-notch weirs.

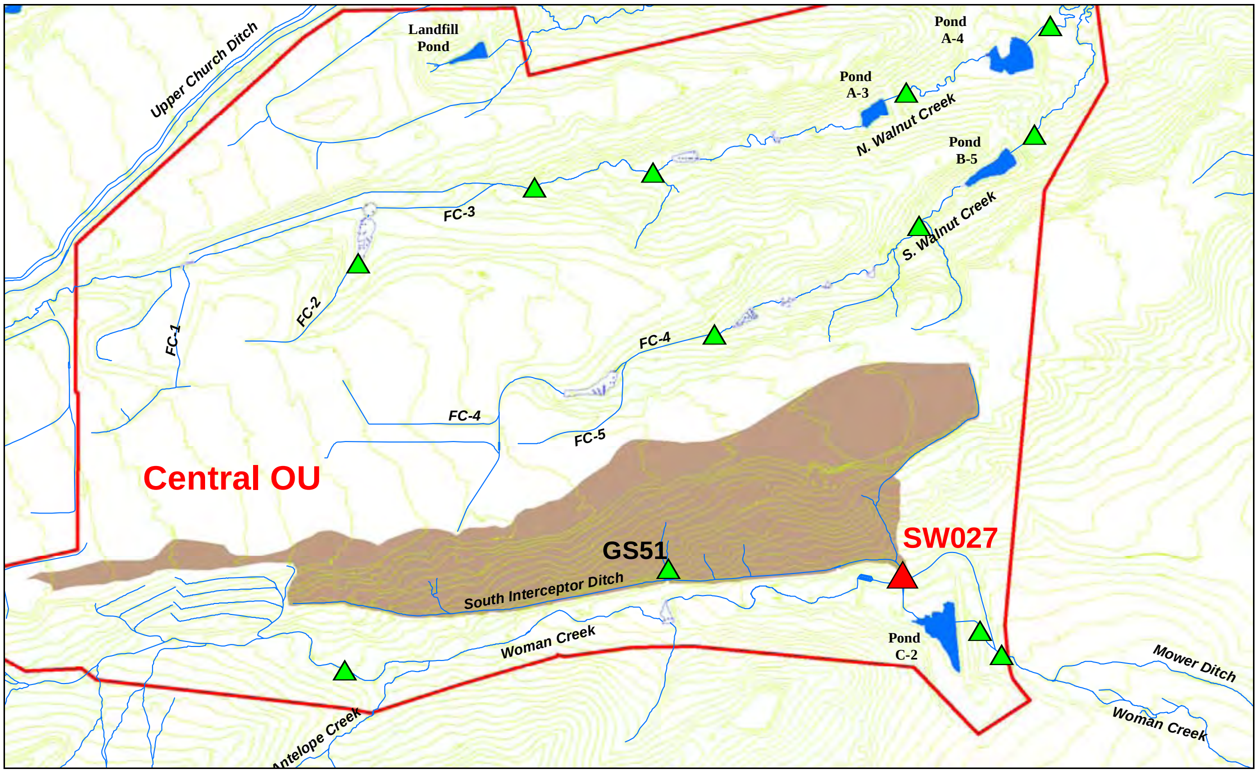


Figure 141. SW027 Drainage Area

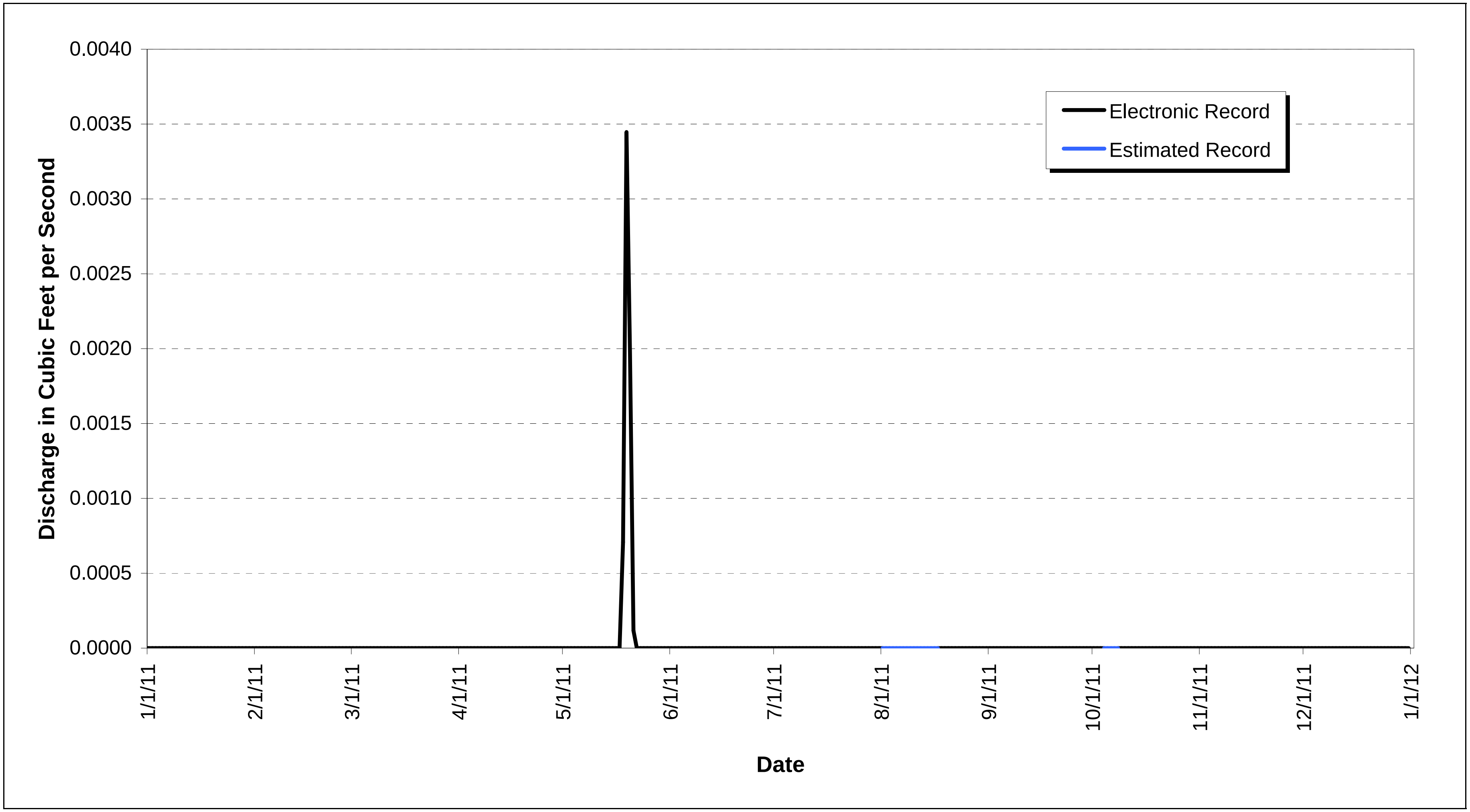


Figure 142. CY 2011 Mean Daily Hydrograph at SW027: SID at Pond C-2

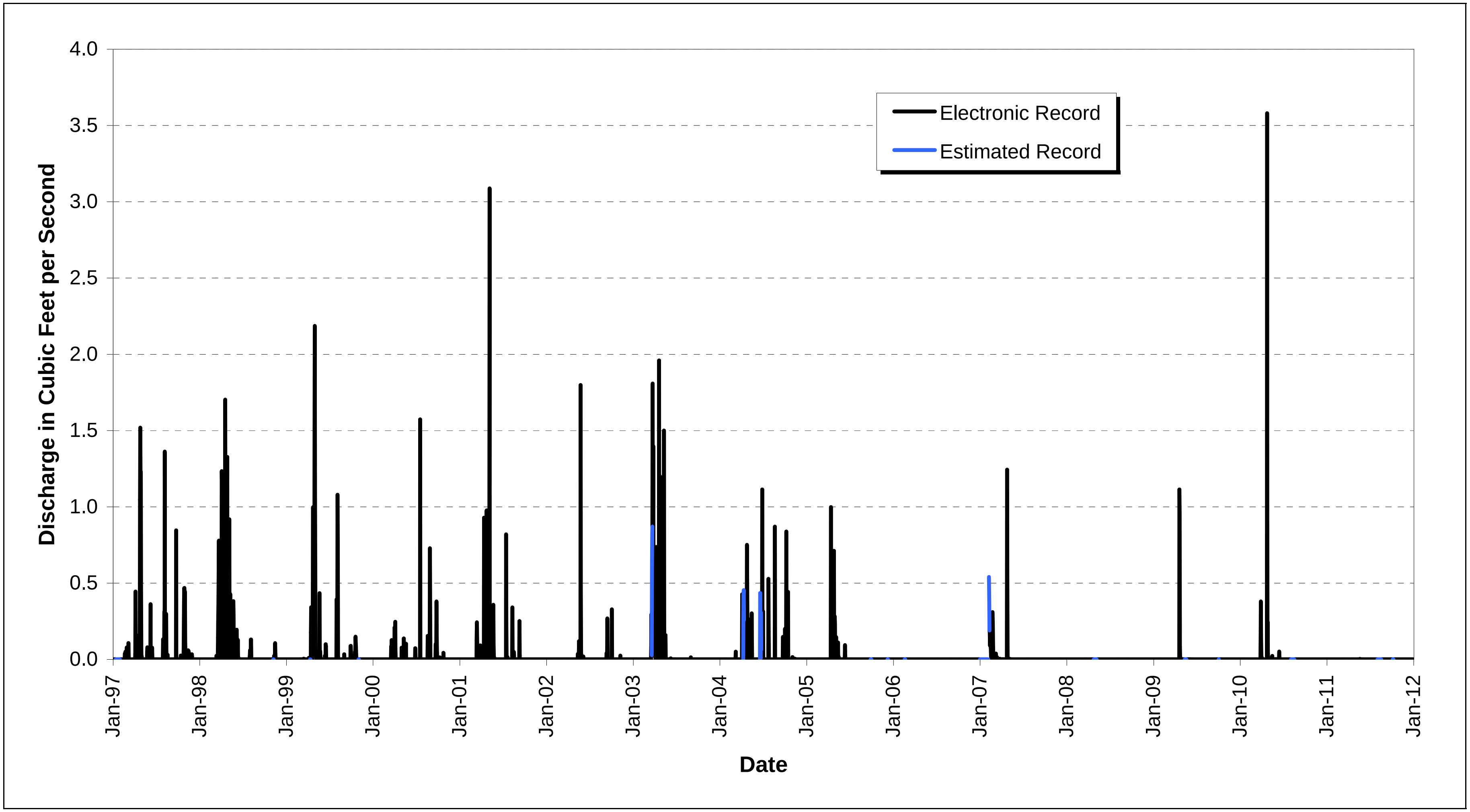


Figure 143. CY 1997−2011 Mean Daily Hydrograph at SW027: SID at Pond C-2

SW093: North Walnut Creek Upstream of Pond A-1

Location—North Walnut Creek 1,300 feet above Pond A-1; State Plane: E2085030, N751730.

Drainage Area—The basin includes the northwestern portion of the COU drained by FC-3 (total of 220.0 acres).

Period of Record—September 11, 1991, to current year.

Gage—Water-stage recorder and 36-inch suppressed, rectangular, sharp-crested weir to January 27, 2003; rated stream section during new flume construction (SW093T; January 27, 2003−May 29, 2003). Three-foot H flume starting May 29, 2003.

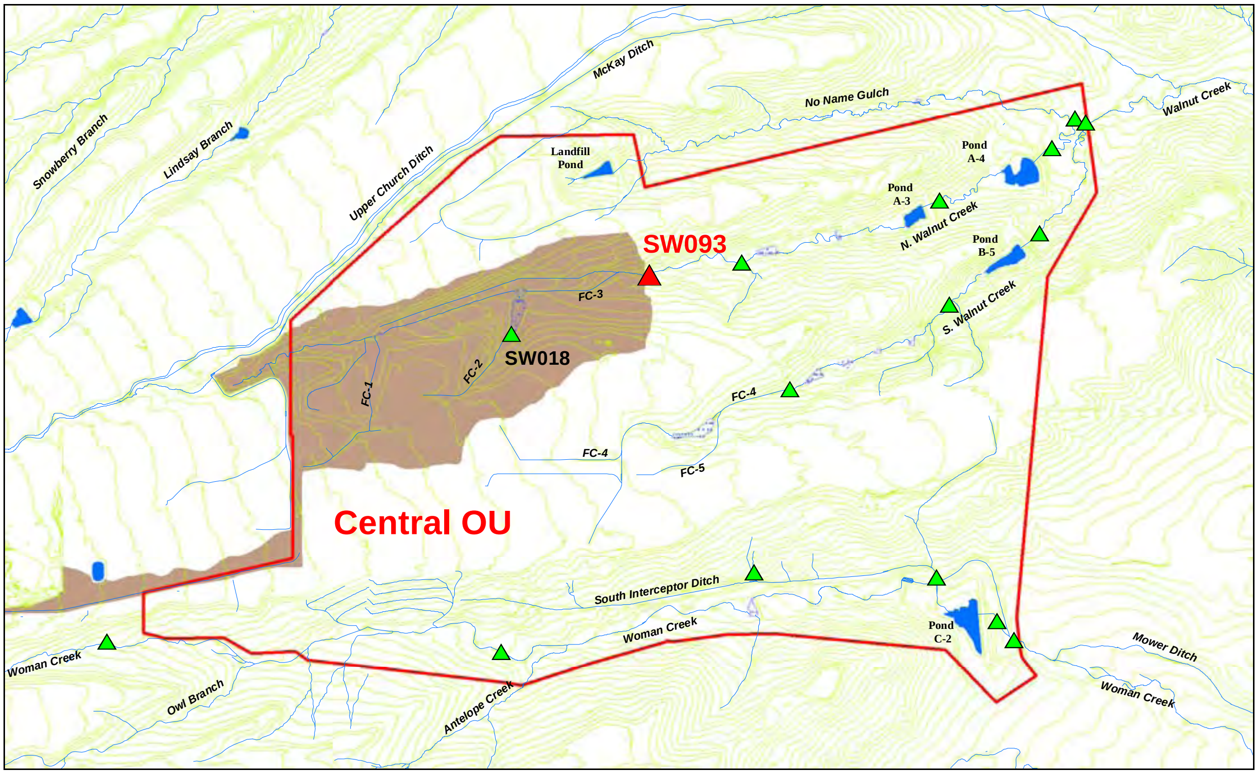


Figure 144. SW093 Drainage Area

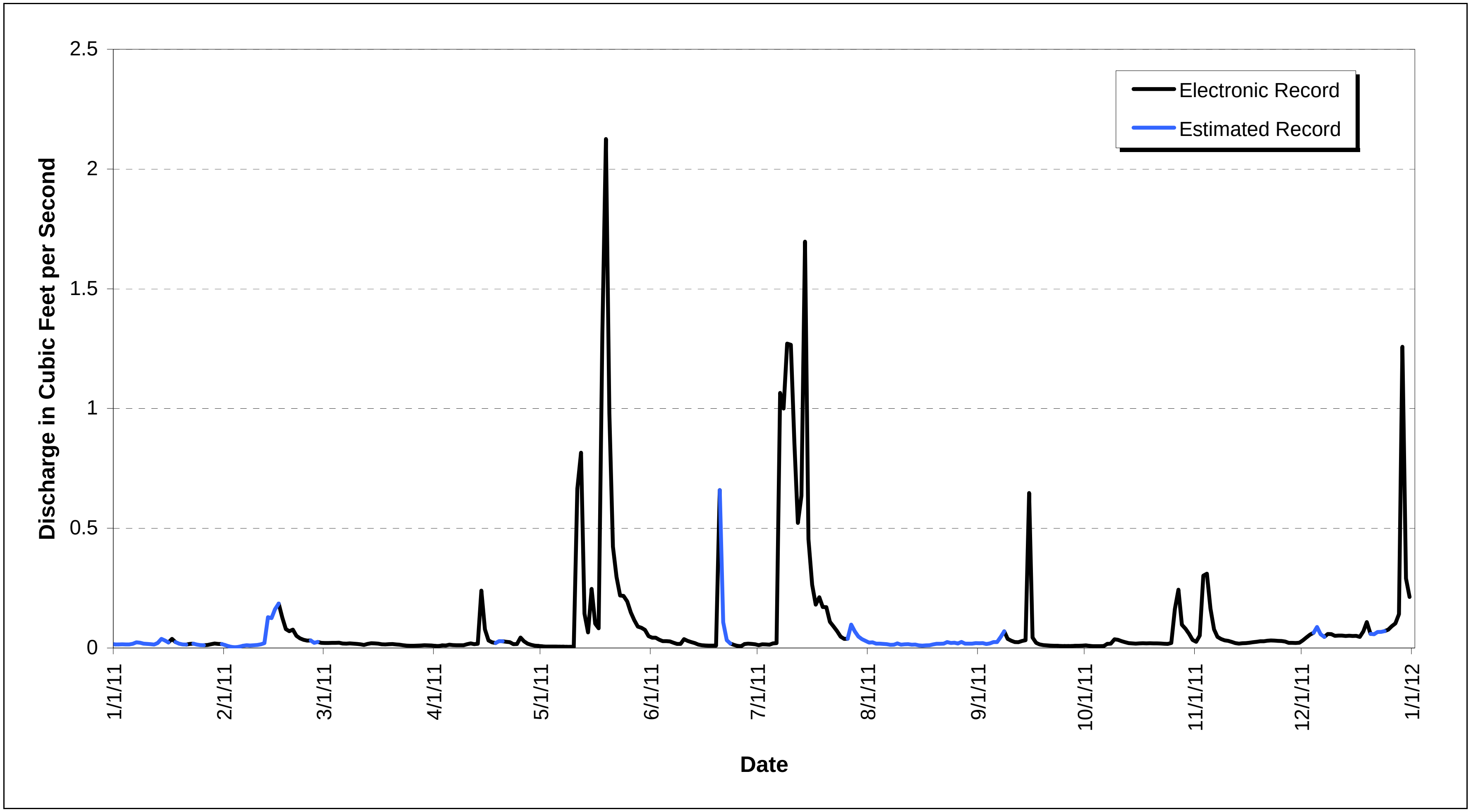


Figure 145. CY 2011 Mean Daily Hydrograph at SW093: North Walnut Creek Upstream of Pond A-1 Bypass

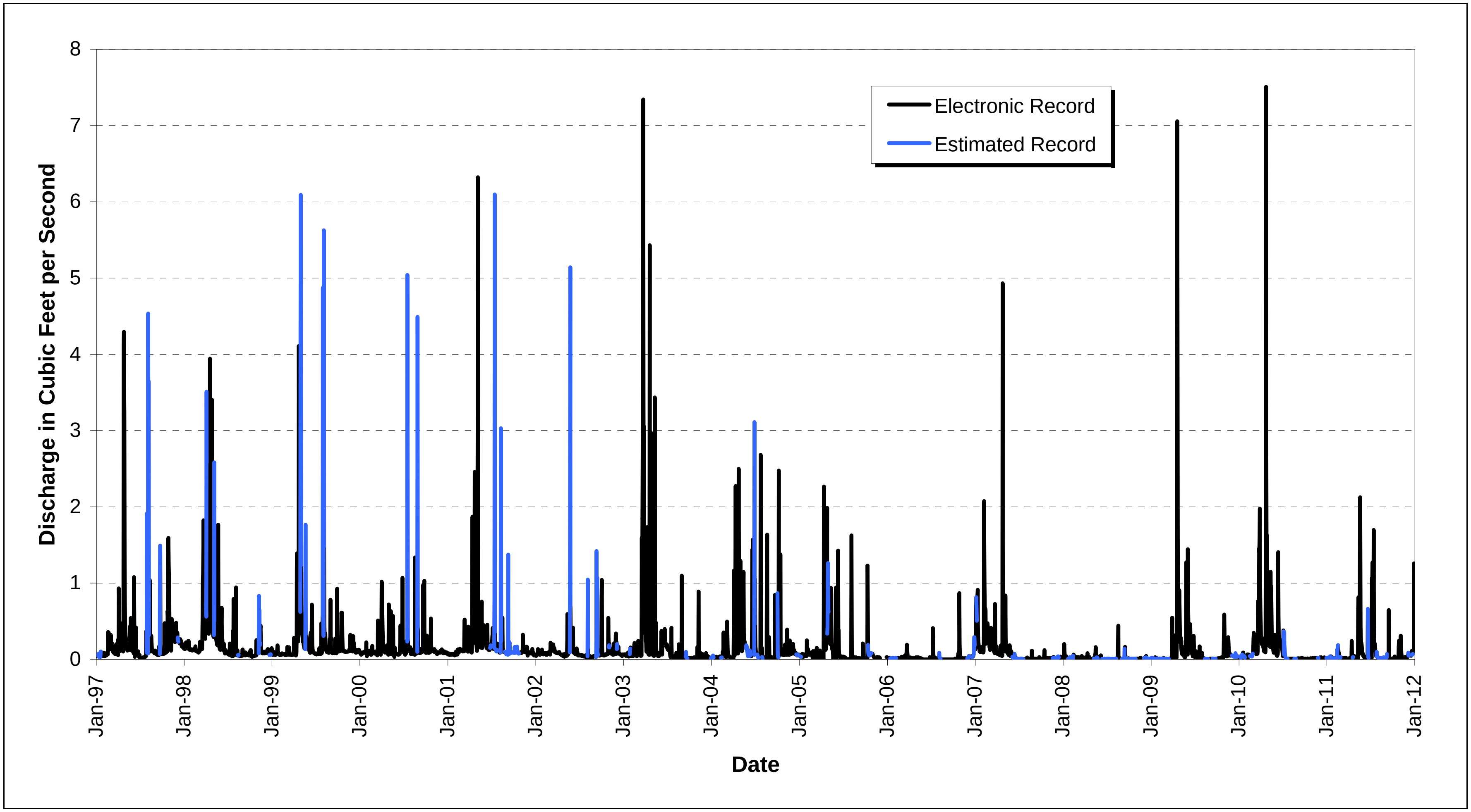


Figure 146. CY 1997−2011 Mean Daily Hydrograph at SW093: North Walnut Creek Upstream of Pond A-1 Bypass

3.1.3.4 *Precipitation Data*

During CY 2011, ten precipitation gages were operated as part of the automated surface-water monitoring network (Table 49 and Figure 147). The locations employ tipping-bucket rain gages generally mounted at ground level. Precipitation totals are logged on 5-minute intervals, 15-minute intervals, or both. The gages are not heated and will not accurately record equivalent precipitation for all snowfall events. The following sections present several figures (Figure 148, Figure 149, Figure 150, Figure 151, Figure 152, and Figure 153) summarizing the precipitation data collected for CY 1997−2011.

Table 49. Monitoring Network Precipitation Gage Information

Location Code (Surface-Water Gage)	Easting (State Plane)	Northing (State Plane)	Period of Operation
PG58 [GS01]	2093835.22	744921.16	10/11/96−current year
PG59 [GS03]	2093598.99	753629.51	4/1/96−current year
PG61 [GS05]	2078432.10	747285.45	4/1/96−current year
PG73 [GS13]	2086169.70	751862.47	9/27/05−current year
PG74 [GS59]	2083245.00	747172.00	9/5/06−current year
PG75 [SW018]	2083522.00	751181.00	3/27/08–current year
PG76 [NA]	2091963.00	752705.00	3/28/07−current year
PG77 [NA]	2087329.00	746937.00	8/23/07−current year
PG78 [WALPOC]	2090350.00	753546.00	9/9/11−current year
PG77 [WOMPOC]	2089488.00	747308.00	9/27/11−current year

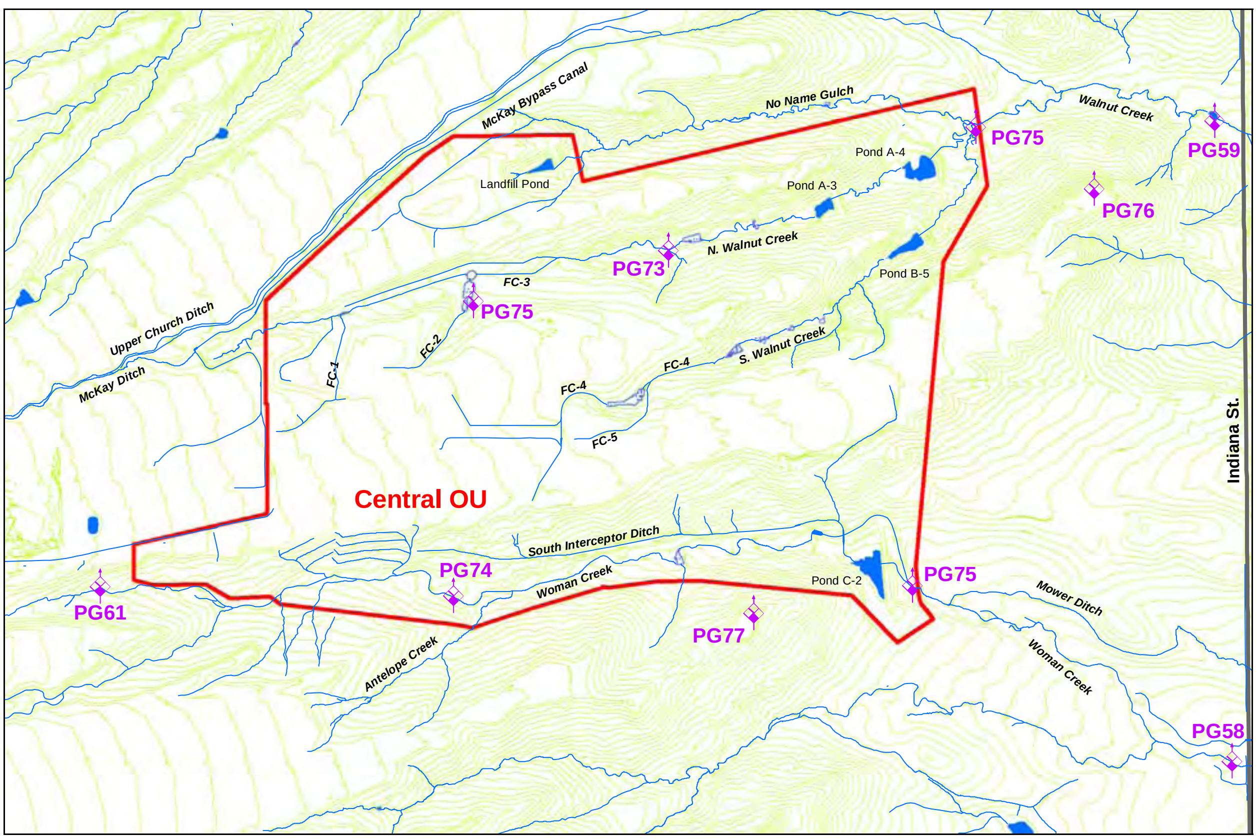
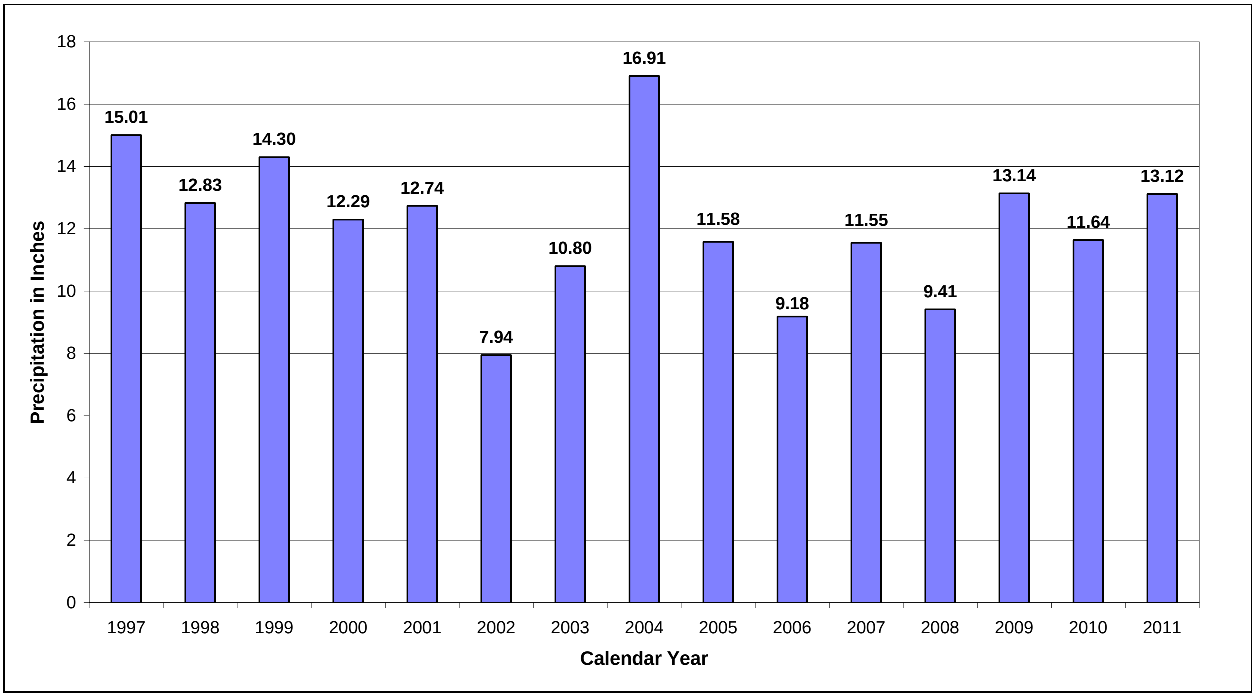


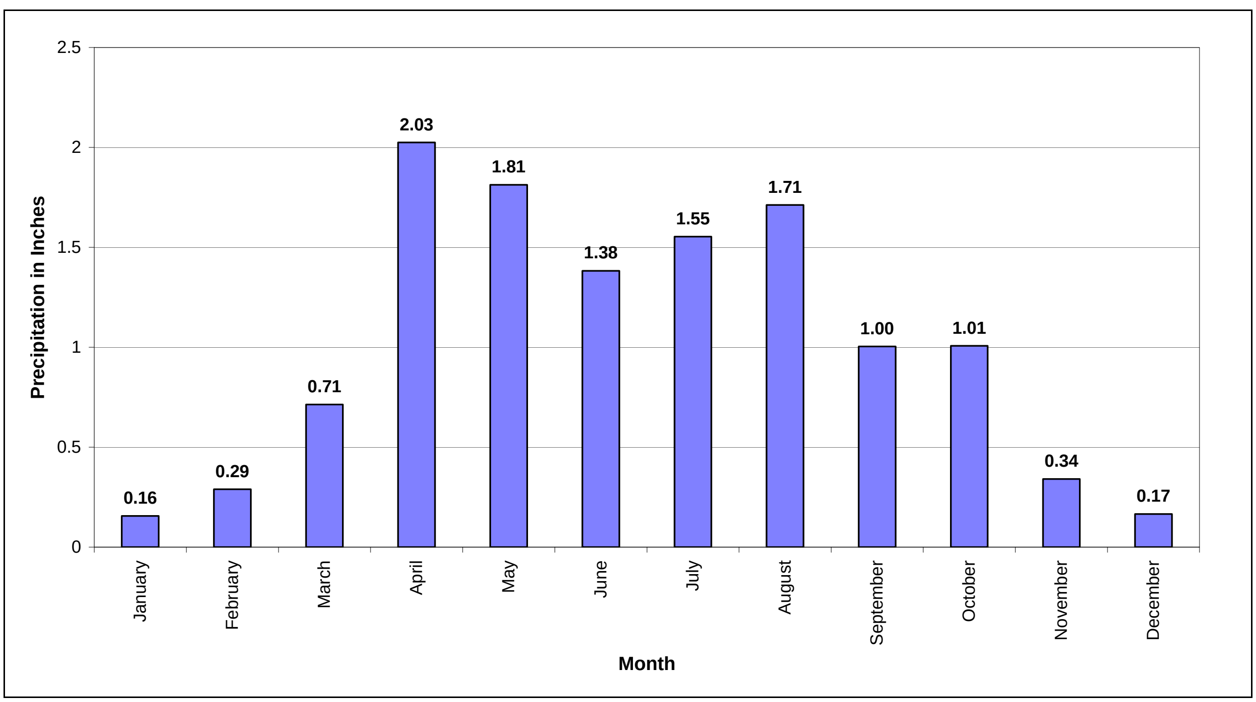
Figure 147. Site Precipitation Gages: CY 2011

CY 1997–2011 Summary



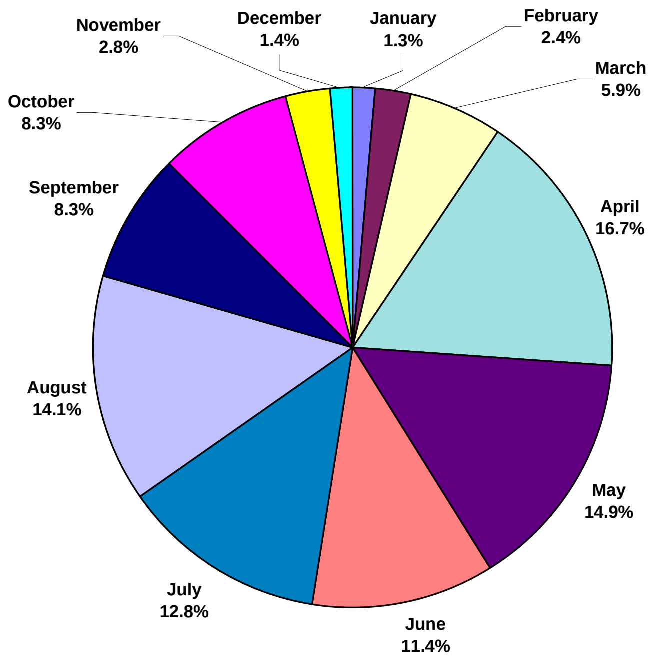
Note: Arithmetic average of gages in operation.

Figure 148. Annual Total Precipitation for CY 1997–2011



Note: Arithmetic average of gages in operation.

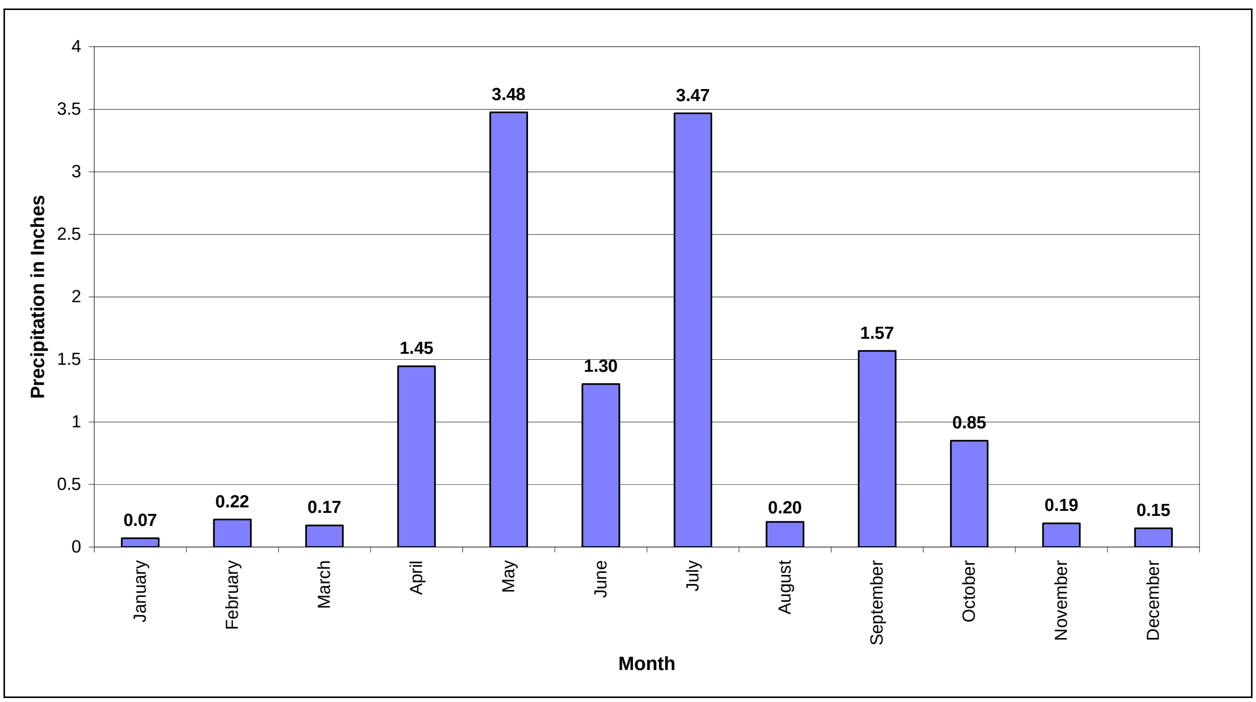
Figure 149. Average Monthly Precipitation for CY 1997–2011



Note: Arithmetic average of gages in operation.

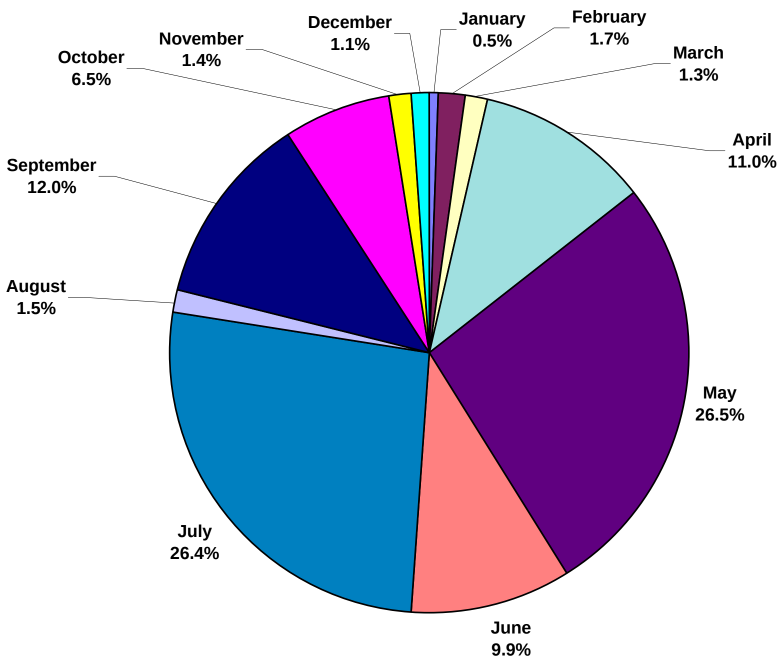
Figure 150. Relative Monthly Precipitation Totals for CY 1997–2011

CY 2011 Summary



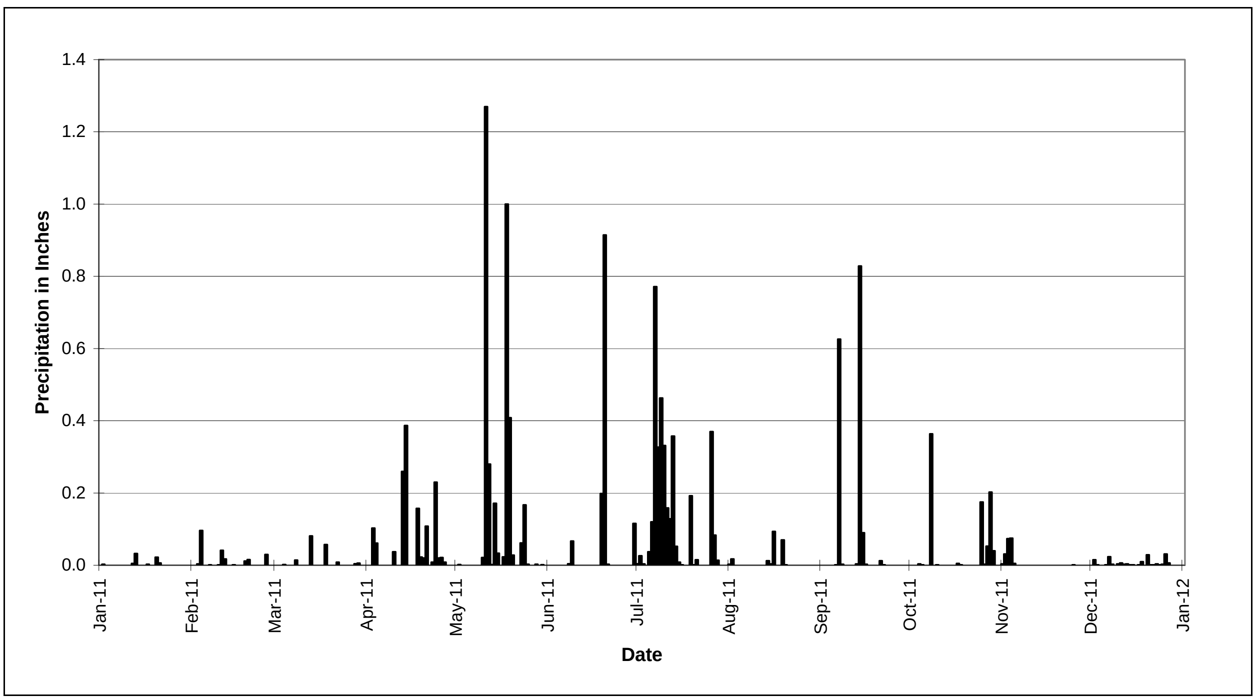
Note: Arithmetic average of gages in operation.

Figure 151. Monthly Precipitation for CY 2011



Note: Arithmetic average of gages in operation.

Figure 152. Relative Monthly Precipitation Volumes for CY 2011



Note: Arithmetic average of gages in operation.

Figure 153. Daily Precipitation Totals for CY 2011

3.1.3.5 Groundwater Flow

This section summarizes groundwater elevations and flow characteristics. Groundwater elevation data are discussed through the construction and interpretation of potentiometric surface maps and hydrographs. Groundwater flow characteristics are then assessed.

Groundwater Elevations

Groundwater elevation data were manually collected at the start of the second and fourth quarters in 2011; these data are included in Appendix A. In previous years water levels were also measured at selected wells using dedicated instrumentation. This system was retired in 2011, and this topic is summarized in Appendix A.

The second and fourth quarter groundwater elevation data were plotted and hand-contoured to create potentiometric surface maps. The potentiometric surface map for second quarter CY 2011 is included as Figure 155. The map for the fourth quarter of CY 2011 is included as Figure 156. These maps are derived from manual water level measurements.

Monitoring wells at Rocky Flats are screened within the UHSU. The UHSU encompasses unconsolidated surface materials such as Rocky Flats Alluvium, hillslope colluvium, valley-fill alluvium, and artificial fill (all of which are often referred to as "alluvium"), and underlying weathered bedrock (the Cretaceous-age Laramie Formation or the Cretaceous-age Arapahoe Formation). A well screened entirely within the weathered bedrock may yield different water levels than an adjacent well screened entirely within the alluvium.

Potentiometric surface maps for 2011 are based on many fewer locations than maps from pre-closure years and are, therefore, less detailed in comparison. Due to the distribution of groundwater contamination, the areas of interest in post-closure years are the former IA and adjacent areas; groundwater monitoring data from the unimpacted former Buffer Zone provide no meaningful data. Boundary wells 10394 and 41691 have been marked for abandonment and were removed from the network in early 2011 (see Section 1.4.2). For this reason, they are omitted from the fourth quarter potentiometric surface maps.

Wells are labeled as dry if there is no water measured or if the water level measured is below the bottom of the screened interval (water below the screen is stagnant and may not reflect the actual groundwater level). The locations labeled as dry may indicate areas where the UHSU is unsaturated. These areas are a result of limited groundwater, caused by a reduction in recharge from precipitation (e.g., droughts, such as that in 2002), the reduction in contributions from artificial sources (e.g., removal of water lines, foundation drains, and dust suppression water), or local conditions that may result from an engineered structure (such as the groundwater intercept trenches that collect groundwater and route it to the associated treatment systems). However, some wells in the monitoring network do not fully penetrate the UHSU; therefore, a location that is depicted as dry does not necessarily indicate that it is in an area of unsaturated UHSU, as the UHSU may be saturated at depths greater than that of the dry well.

Unsaturated areas were generally unchanged from those observed in 2010. For example, well 95299, which is located adjacent to and downgradient of the ETPTS groundwater intercept trench, was dry. This well has been observed to contain water only once since 2000 (in late 2006). This area is typically dry due to the dewatering effects of that trench. Conversely, well 90299 (dry since October 2007) was recharged following the 2nd quarter precipitation and provided samples in both the second and fourth quarters of 2011.

Well 45608, located on the constructed hillside south of former B991, was initially artesian but ceased artesian behavior in the spring of 2010; since that time, water levels were consistently measured below the top of well casing. The artesian flow previously observed has been interpreted as evidence that this well acts as an outlet for the water collected by the remnants of the French drain underlying this constructed hillside. Cessation of artesian flow appears to be correlated to the kink developing in this well (and development of a slump in this hillside), and therefore the change in flow conditions observed at well 45608 may be more a function of well or hillside conditions than a regional groundwater condition.

Groundwater flow paths in 2011 are consistent with conditions observed in 2010, as estimated from the potentiometric surface maps (Figure 155 and Figure 156). As noted above, unsaturated areas in 2011 are similar to several of those depicted in 2010. However, unlike typical seasonally-impacted groundwater conditions at Rocky Flats, in many areas of the Site the second quarter of 2011 was noticeably dryer than the fourth. Although the second quarter received ample precipitation, it followed a relatively dry first quarter (0.46 inches vs. an average of 1.25 inches, see Table 38). Most importantly, precipitation in the month of March 2011 was about 78 percent below the average (0.17 inch vs. an average of 0.79 inch for the period of 1993 through 2011, see Table 39). The water level measurements on which these potentiometric surface maps are based are performed in the first ten business days of the given quarter. Therefore, water level measurements in the second quarter immediately followed these dryer conditions and were not affected by the increased precipitation that occurred later in the second quarter (6.22 inches, see Table 38). A discussion of the hydrographs is presented below and provides more detail on selected wells.

Hydrographs

Water level measurements can provide fundamental indicators of the groundwater regime and are critical to a meaningful evaluation of groundwater quantity, quality, and flow. Hydrographs are used to evaluate the groundwater levels at Rocky Flats and are included in Appendix A. Selected hydrographs are discussed here, but it may be helpful to refer to the referenced hydrographs throughout the following discussion.

As in previous annual reports issued since the Site was closed (DOE 2007c, 2008c, 2009d, 2010d, 2011d), water level data for original and replacement wells are combined into a single hydrograph under the assumption that the corresponding data are continuous. As additional data are collected, this assumption may prove to be false at some locations, in which case the corresponding data will no longer be pooled. To date, this has not yet occurred at any well location. Water level data used for these hydrographs include routine, pre-sampling, and any requested nonroutine measurements.

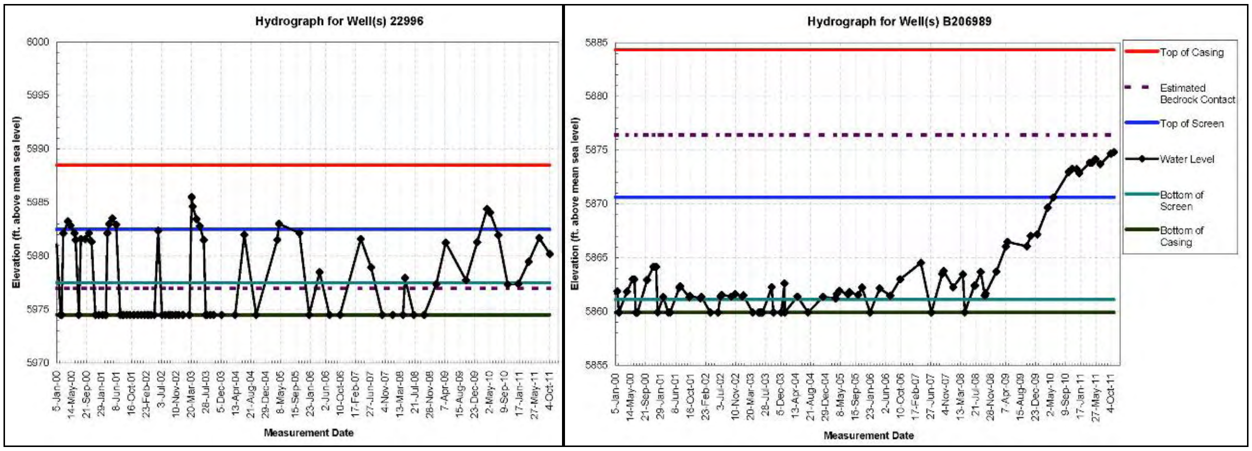
Water level elevations were calculated by subtracting the measured depth to water from the surveyed elevation of the top of the well casing. When wells were found to be dry, the water level posted on the hydrograph is equivalent to the elevation of the bottom of the well casing, as calculated from the total depth of well casing recorded during its installation. The same water level is posted when the measured water level is found to be below the bottom of the screened interval, because this water is not in hydraulic connection with saturated materials and is therefore likely not representative.

In December 2011 a high-level technical review of post closure analytical and water level data was completed by Integrated Hydro Systems, LLC. Prior to Site closure, the nature of water level changes was modeled as part of the Site-Wide Water Balance (K-H 2002a). This effort predicted an increase in head across most of the IA. Hydrographs generated from manual water levels do in fact display an increase in elevations from pre- to post-closure averages, generally agreeing with the direction of water level change (increase, static, decrease) predicted by this model. There are a number of reasons for an observed increase, including (but not limited to): increased infiltration and recharge of precipitation following removal of impervious surfaces, modification of groundwater flowpaths following the removal or disruption of drainages, utility corridors, foundation drains and other pipelines, and updates in sampling procedures.

The model anticipated removal and disruption of facilities, but did not incorporate changes in sampling methods as an input; this change was not considered or implemented until after Site closure. However, it has proven to be a significant factor in the rising water levels measured at several locations over the past years. Sampling procedures were formally updated on September 25, 2009. The new sampling procedures require less minimum purge volume before sample collection from a Category II well (defined by the SAP as wells that produce water at a rate less than 100 ml/min). In the past, Category II wells were typically dewatered (or three to five casing volumes purged) before sample collection, but the current method only requires purging one pump/tubing volume from a Category II well prior to sample collection. As a result of this change, wells are no longer routinely dewatered and samples are no longer being collected some time later from recharge. This change in sampling procedures can exert a moderate to great effect on the hydrographs for low-producing wells. The degree of this impact can be mitigated or increased by such factors as specific recharge events and the timing of water level measurements with respect to sampling. However, water levels are largely controlled by hydrogeologic conditions, such as the hydraulic conductivity of the geologic material being monitored.

Previous annual reports (e.g., DOE 2010d) have noted the effects of sampling on measured water levels, but it was not until after this procedural change was implemented that actual "formation water" conditions have become evident. Aquifer tests conducted in the early 1990s (EG&G 1994) demonstrated that some low-producing wells may not recharge fully for months; if a well is repeatedly sampled before the water level re-equilibrates, an accurate picture of the water level in the screened formation will not be evident from the hydrograph.

Many of the hydrographs in Appendix A illustrate the effects of sampling. These effects can be visually apparent by such patterns as steep drops in the water level that correspond to the dates of sampling events, or by water levels that are maintained at an artificially low level until after the sampling method was changed (this latter pattern would not be readily apparent until after sampling influences have been removed). Examples of impacts from sampling can be observed in hydrographs for wells in several areas across the Site (Appendix A), including the southern IA (well P416589), central IA (22996), former B371 (37705), former B771 (20505), North Walnut Creek (10594), near the SPPTS (P210089, 70099), near the MSPTS (15699), the East Trenches Plume (04091), and the PLF (73105, 73005, B206989). Two examples illustrating the patterns described above are provided in Figure 154.



Notes: Hydrograph on left represents well 22996, that on right is for well B206989. Legend on far right applies to both hydrographs.

Figure 154. Examples of Hydrographs Illustrating Effects of Sampling and Changes to Sampling Procedure

The hydrograph for well 22996, on the left in Figure 154, is located within the former IA just northeast of former B886. This well is an Evaluation well (sampled biennially), and the hydrograph for this well displays seasonal effects that are influenced by sampling events during the second quarter of even years. This well was typically dewatered during sampling events but after the sampling event in 2008 seasonal influences are more apparent. Sampling can still be seen to cause significant water level drawdown even though this well is no longer dewatered.

The hydrograph for well B206989, on the right in Figure 154, is located at the base of the Landfill Pond dam. The water level in this well was kept artificially low (and the well was frequently dewatered) until late 2008, when the water level began a gradual rise which appears to continue through 2011.

In both cases illustrated in Figure 154, and on many other hydrographs, the broader changes in water levels that may be apparent during this time frame are not related to Site closure activities, but rather to sampling events. Therefore, since procedural changes in 2009, hydrographs more accurately represent UHSU groundwater levels in monitored areas.

Water levels in CY 2011 were seasonally controlled and primarily dependent on climatic factors (precipitation), not on closure activities. Precipitation in CY 2011 was recorded at eight gage locations across the Site. The estimated "total" precipitation recorded at the Site in CY 2011 was 13.12 inches (as measured by unheated rain gages, which do not accurately reflect precipitation totals related to snowfall; therefore, this value typically under-represents the actual amount of precipitation received). This value (13.12 inches; Table 50) is slightly greater (by 6.4 percent) than the historical average total precipitation (CY1993−2010) of 12.33 inches (see Table 49). Precipitation totals for recent CYs are summarized in Figure 148, and precipitation in CY 2011 is compared, by quarter, against averages of measured precipitation in Table 51. (**Note:** the amount shown for 2003 incorporates March data from the Site's former 61-meter meteorology tower, which included a heated precipitation gage that recorded precipitation from the multi-foot

March 2003 snowstorm more accurately than did the unheated gages operated by the Water Programs Group.) See Section 3.1.3.4 for additional discussion of precipitation.

Previous annual reports have noted that water level stabilization following site closure activities took several years; similarly, water levels will require time to adjust from the effects of sampling in order to accurately represent the UHSU groundwater levels. Sampling influences have been reported and discussed in greater detail above. The monitoring network, in general, indicates that water levels in 2011 display seasonal variations with a strong correlation to precipitation events.

The hydrograph for Evaluation well 30900, located in the PU&D Yard source area, shows an extremely well-developed, cyclical (climatic) recharge pattern (Appendix A). Water levels are higher in late second quarter of each year, with the exception of dry years 2002, 2006, and 2008. During these years there was an average of 30 percent less precipitation than what is historically observed (average annual precipitation from 1993–2010 is 12.33 inches, see Table 49). This is represented on the hydrograph for well 30900 with little change in water levels throughout these dry years. This seasonal pattern is also evident, though not as clearly, on the hydrograph for well 70393, located nearby on the upgradient (west) side of the Present Landfill.

Table 50. Total CY 2011 Monthly Precipitation Data for the Site

Month	Precipitation (inches)
January	0.07
February	0.22
March	0.17
April	1.45
May	3.48
June	1.30
July	3.47
August	0.20
September	1.57
October	0.85
November	0.19
December	0.15
Total Annual	**13.12**

Note: Values are averaged from eight tipping bucket rain gages across the Site. This total does not include snowfall totals.

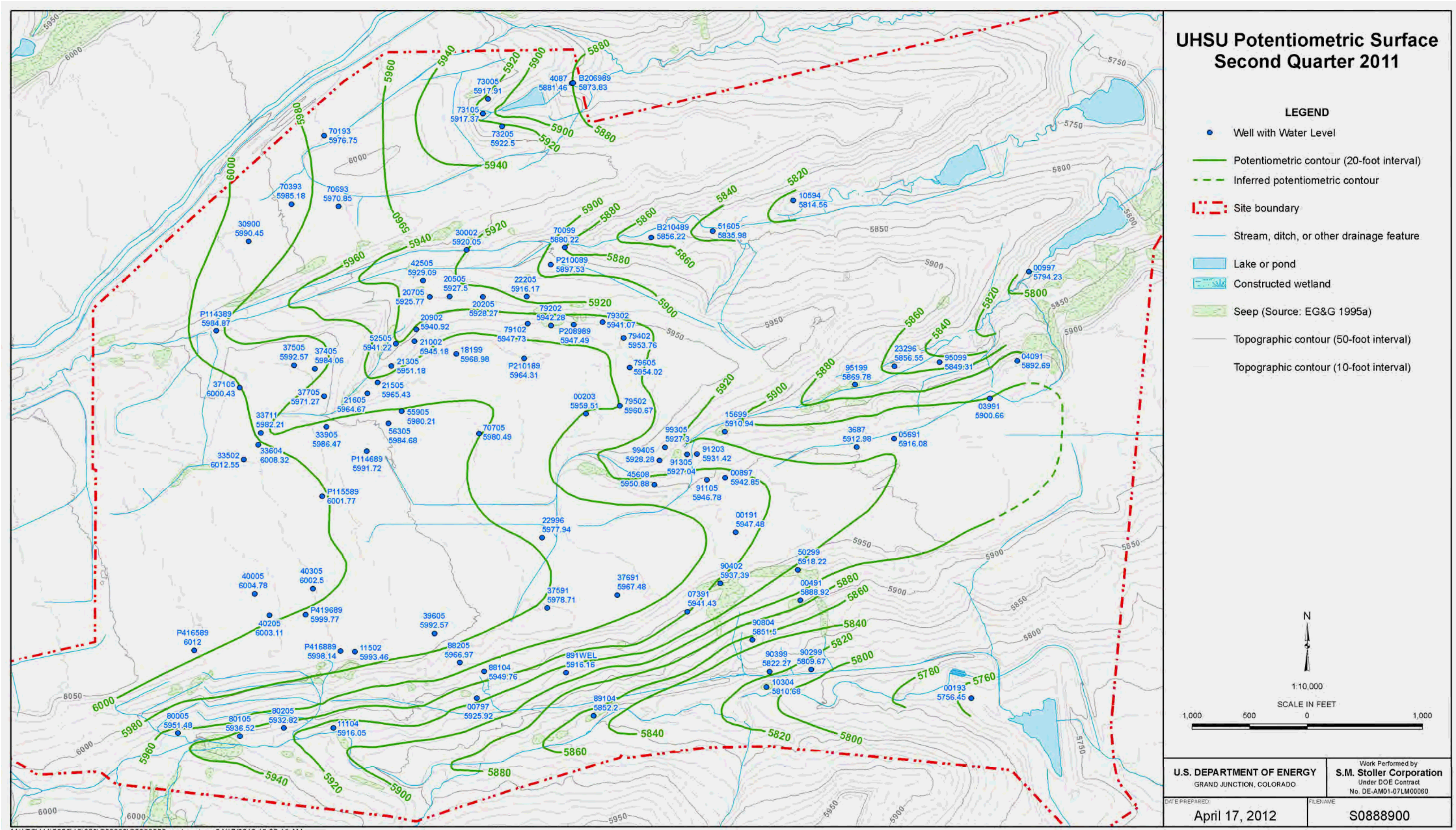


Figure 155. UHSU Potentiometric Contours: Second Quarter CY 2011

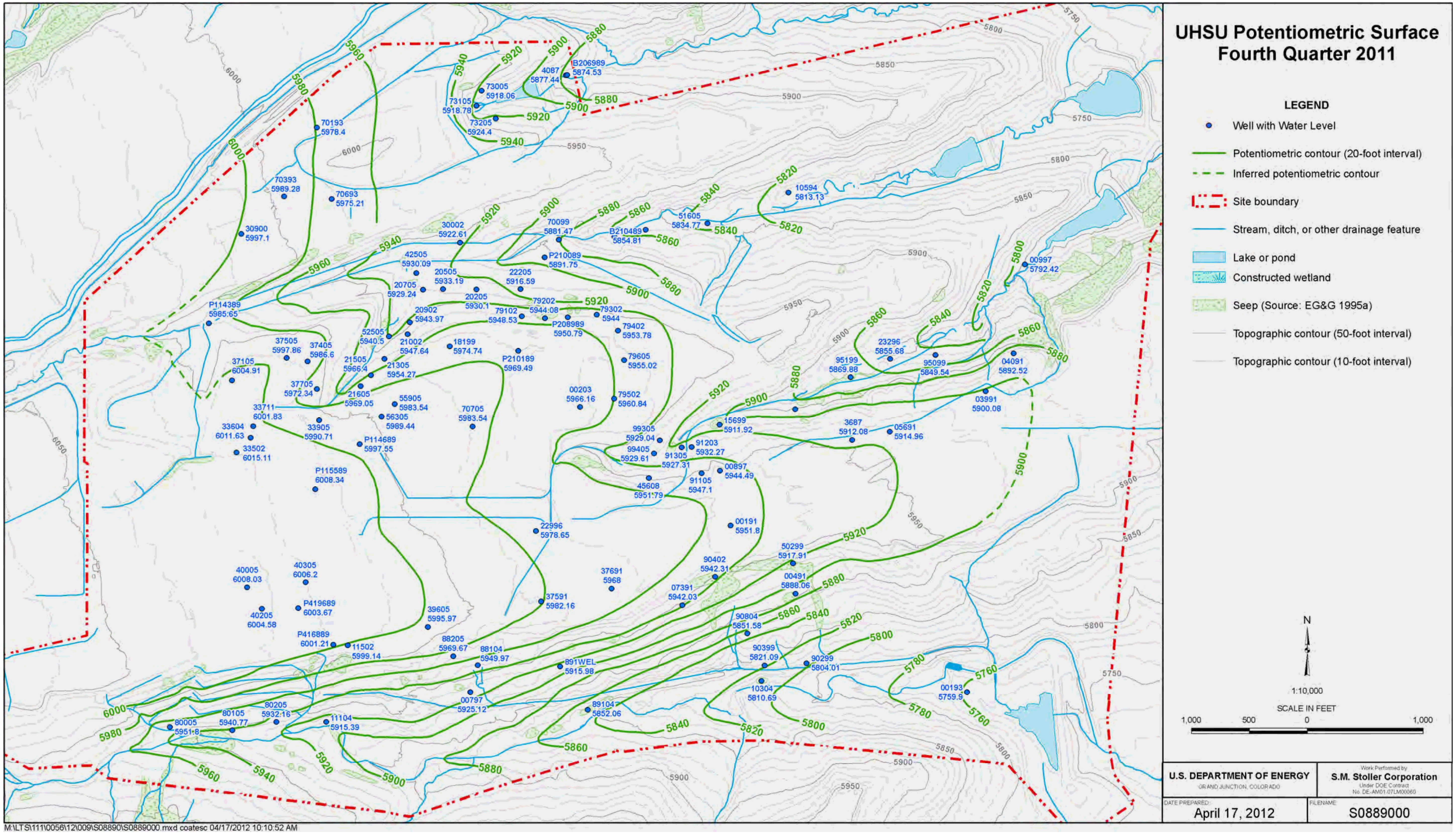


Figure 156. UHSU Potentiometric Contours: Fourth Quarter CY 2011

Table 51. Precipitation in CY11 by Quarter, Compared with Average Precipitation by Quarter

Period	CY 2011	Average (1993–2011)
1st Quarter (Jan-Mar)	0.46	1.25
2nd Quarter (Apr-June)	6.22	5.55
3rd Quarter (July-Sept)	5.24	4.01
4th Quarter (Oct-Dec)	1.19	1.52
Total Annual	13.12	12.33

Note: The precipitation for 2003 incorporates March data from the Site's former 61-meter meteorology tower, which included a heated precipitation gage that recorded precipitation from the multi-foot March 2003 snowstorm more accurately than did the unheated gages operated by the Water Programs Group

In most hydrographs water level behavior appears to be responding to precipitation events, but some locations are influenced by mechanisms other than seasonality. These instances can be explained by considering local conditions.

In addition to that for well B206989, which is discussed above, hydrographs that appear to be influenced by mechanisms other than seasonality include wells 23296 and 88104. These all reflect rising water levels. Well 23296, located downgradient of the groundwater intercept trench feeding the ETPTS and adjacent to South Walnut Creek at the base of the former Pond B-2 dam, exhibited water levels in 2011 that are above historical levels. These rising water levels date back to October 2008, which coincides with the Dam Breach project that started in September of that year. (Due to these rising water levels, the casing of this well was extended in May 2009.) The rising water levels exhibited by the hydrograph for well 23296 are therefore attributed to resumption of stream flows through South Walnut Creek, rather than routing water around the ponds via the bypass pipeline as had been the practice in prior years. In addition to rising water levels due to adjacent surface-water flows, the water level in this well shows a spring-2010 increase that appears to be related to precipitation.

Hydrograph for well 88104, located south of former B881, illustrates rising water levels, with a couple of minor interruptions since installation of the replacement well in 2005. (Well 88104 replaced well 88101.) Interruptions in the overall rising water level appear to be associated with sampling events in which this well was purged dry. This overall rise in water levels appears to be related to the groundwater flow regime following closure of former B883 and B881 building (see 2010 Annual Report, DOE 2011d), which contributed to the saturation of subsurface materials at and around well 88104. Revision of the sampling procedure appears to be a contributing factor. This is also a Category II well that was routinely dewatered (prior to 2009) during sampling events. The uninterrupted rising water levels observed since 2009 is therefore at least partly related to this procedural change.

Wells 33502, 33604, 33711, and 33905 monitor the buried drainage that hosts the VC Plume south of former B371 and upgradient of FC-2. Hydrographs for these wells show more pre-closure variation from one to the other than might be expected, given their close proximity to one another. Following closure, these hydrographs show fairly similar water levels. Hydrographs for these wells show strong seasonal patterns, with sharp spring water-level peaks and winter troughs. The casing of well 33703 developed a kink that eventually worsened to the point that, after May 2010, water level measurement was not possible. (Sample collection was still feasible via the dedicated tubing installed in the well.) This well was abandoned and replacement well 33711 was installed in March 2011. The hydrograph for well 33711 shows a lack of water at installation (it is common for wells at Rocky Flats to exhibit dry conditions immediately following their installation), followed by a sharp peak in the summer months. The water level in this well is expected to continue to show seasonal patterns similar to those demonstrated by other wells in this area.

In summary, CY 2011 water levels are predominantly controlled by climate. There appears to be an increase in head (higher water levels) across most of the IA when comparing average pre- vs. post-closure water levels. Modeled flow directions remain consistent with previous years. Groundwater flow velocities and directions are discussed in more detail below.

Groundwater Flow Velocities

Groundwater flow directions and velocities in 2011 are generally consistent with those reported in 2010. Flow directions, water level data, geological information, and completed well designs and locations support the selection of several well pairs for the calculation of linear groundwater flow velocities, also referred to as seepage velocities. In conjunction with the potentiometric surface maps, a pair of wells is potentially useful for these calculations if a line drawn between them is perpendicular (or nearly so) to the potentiometric contour lines between the two wells, and there are no intervening drainages or artificial groundwater control structures (such as the groundwater intercept trenches that are a component of three of the four treatment systems, and the GWIS at the PLF).

Well pairs selected for use in this report are the same as those selected in 2010 with a few additions. In the vicinity of the OLF, well pair 40005-80205 was evaluated for additional data on flow velocity. Well pairs 33502-33711, 33502-33604, and 33604-33711 at the former Oil Burn Pit #1 were also evaluated for flow velocities and travel times.

The seepage velocity (v) may be calculated using the Darcy equation:

$$v = \left(K/n \right) \left(dh/dl \right)$$

where

K = hydraulic conductivity
n = effective porosity
dh/dl = hydraulic gradient.

This calculation is most sensitive to the hydraulic gradient and value of K used, because for all calculations of v in this report a porosity of 0.1 (consistent with previous Annual RFCA Groundwater Monitoring Reports as well as post-closure RFLMA reports) is used.

The hydraulic gradients were calculated from groundwater elevation data collected in the second and fourth quarters of 2011. Results of the hydraulic gradient calculation typically differ slightly when data are used from different quarters, but the differences are typically not large, with several exceptions. The hydraulic gradients calculated for well pair 56305-21505 for second and fourth quarters are 0.060 and 0.072, respectively. This relatively large variation is a result of the combination of fairly consistent water elevations in well 21505 during 2011, and more widely varying elevations in well 56305. The water level in 56305 was approximately 5 feet higher as measured during fourth quarter, resulting in a steeper gradient. As stated earlier, groundwater levels measured during fourth quarter were generally higher across the site than second quarter, presumably due to the increase in precipitation received in the latter portion of the second quarter (after water levels were measured) and in the third quarter (see Table 51). Similarly, the gradients calculated for well pairs 88205-00797 (0.120 and 0.130) and P210189-79102 (0.055 and 0.069) indicate steeper gradients during fourth quarter compared to second quarter, likely the result of the relatively dry conditions in first quarter and early second quarter, and the subsequent increase in precipitation leading up to fourth quarter.

The opposite pattern is illustrated by several well pairs (i.e., a higher hydraulic gradient is observed during second quarter). In particular, gradients calculated for well pairs 33502-33711, 33502-33604, and 33604-33711, in the vicinity of the former Oil Burn Pit #1, were substantially higher during second quarter. Note that well 33711 (replacement for well 33703) was installed on March 30, 2011, and the water level had not stabilized at the time of second quarter water level measurements (i.e., April 5). A more representative water level was measured at well 33711 on June 1 and is used in the flow velocity calculations. Water levels measured in June were higher than those measured in April and thus the gradients observed during second quarter for well pairs 33502-33711 and 33604-33711 (using June data) were significantly higher than those calculated for fourth quarter (0.070 vs. 0.049 and 0.136 vs. 0.095, respectively). Although the majority of wells across the site exhibited a relatively higher water level during the fourth quarter of 2011, given the heterogeneous nature of the subsurface materials at the Site, it is not uncommon to see some localized areas experiencing the opposite pattern during second quarter.

Calculated seepage velocities are only useful as estimates. Table 52 presents the flow velocities calculated using the 2011 data for selected well pairs. These velocities are most often used to estimate the travel time of conservative (nonreactive) constituents. Reactive constituents tend to migrate more slowly than the calculated velocity. These calculated velocities do not take into account properties such as sorption and chemical reactions (e.g., precipitation, biodegradation, and volatilization) that can strongly influence the transport of groundwater contaminants.

For each well pair, the value of K, the hydraulic conductivity, selected for this calculation was based on the predominant lithologic unit comprising the saturated materials screened by each member of the well pair. This is based on the core logs for the respective wells and the published geology (EG&G 1995b), as well as information from the hydrographs (i.e., whether the saturated interval is typically restricted to the bedrock or includes surficial materials). If more than one lithology is represented in the screened interval of a well and, from the hydrographs, also appears to comprise a meaningful fraction of the saturated interval, an average K was calculated from the lithologies. K values used for these calculations are from the EG&G hydrogeologic report (EG&G 1995a), Table G-2, with subsequently modified values for Rocky Flats Alluvium and valley-fill alluvium (RMRS 2000a; Safe Sites 2001, 2002).

One factor that may cause significant error in estimated seepage velocities is the presence of artificial fill in many portions of the former IA. The K value for Rocky Flats Alluvium is used because the source of the fill was typically deposits of Rocky Flats Alluvium. However, it is unlikely that the backfilled (i.e., reworked) alluvium has the internal structure of or is as compacted as the original deposits, resulting in a higher effective porosity and K value than the published values for Rocky Flats Alluvium. Where well pairs cross former buildings that were backfilled with concrete rubble and alluvium, the effective porosity and K values may be higher still. For this report, well pairs crossing areas of sufficiently thick backfill deposits may use the K value for Rocky Flats Alluvium rather than that for the original lithology, under the assumption that the entire area of backfill/regrading has a hydraulic conductivity closer to that of Rocky Flats Alluvium than to a lower-permeability unit.

An example well pair illustrates some of the related difficulties. Well 18199 is located between former B776 and B771. It screens mainly sandstone of the Arapahoe Formation (the “No. 1 Sandstone”; EG&G 1995a) and Rocky Flats Alluvium. Groundwater in this area previously flowed toward the west as a result of the B771 foundation drain system. Following disruption of this drain, groundwater flow is anticipated to be more northerly, potentially through the rubble- and alluvium-backfilled subsurface remnants of B771. (Contaminant concentrations in downgradient B771 wells do not suggest this transport pathway is meaningful, despite the short travel times that are consistently calculated for this well pair. However, it still serves as an example for this discussion.) For this reason, well 20505 was selected as the downgradient well in this well pair. This latter well is screened in artificial fill, clays, claystone, and silty claystone. The transect from 18199 to 20505 is mostly occupied by the artificial fill of the B771 closure, and that fill is essentially reworked alluvium. During the fourth quarter of 2011, the water level in well 18199 was within the bedrock, while that in well 20505 was within the artificial fill. Therefore, an average hydraulic conductivity of the Arapahoe Formation No. 1 Sandstone (well 18199) and Rocky Flats Alluvium and claystone (well 20505) was used to calculate the fourth quarter seepage velocity between this well pair.

Table 52. Calculated Flow Velocities for 2011

Well Pair	Area	2011 Quarter	Geological Unit	WL Elevation, Well 1	WL Elevation, Well 2	dh (ft)	dl (ft)	dh/dl (hydraulic gradient)	Calculated K (cm/s)	v (ft/yr)	Time to Traverse Transect (yr)
P115589-P114689	North IA	2	Qrf	6001.77	5991.72	10.05	550.14	0.018	4.18E-04	79.01	6.96
P115589-P114689	North IA	4	Qrf	6008.34	5997.55	10.79	550.14	0.020	4.18E-04	84.82	6.49
P114689-21605	North IA/B559	2	Qrf / Qrf/KaKlclst	5991.72	5964.67	27.05	503.78	0.054	3.14E-04	174.29	2.89
P114689-21605	North IA/B559	4	Qrf / Qrf/KaKlclst	5997.55	5969.05	28.5	503.78	0.057	3.14E-04	183.79	2.74
56305-21505	B559	2	Qrf/KaKlclst	5984.68	5965.43	19.25	319.61	0.060	2.09E-04	130.52	2.45
56305-21505	B559	4	Qrf/KaKlclst	5989.44	5966.4	23.04	319.61	0.072	2.09E-04	155.88	2.05
18199-20505	B771	2	KaNo.1ss / Qrf/KaKlclst	5968.98	5927.5	41.48	500.43	0.083	4.99E-04	427.70	1.17
18199-20505	B771	4	KaNo.1ss / Qrf/KaKlclst	5974.74	5933.19	41.55	500.43	0.083	4.99E-04	428.43	1.17
P416589-80105	OLF	2	Qrf / Qrf/KaKlclst	6011.86	5936.52	75.34	846.63	0.089	3.14E-04	288.85	2.93
P416589-80105	OLF	4[a]	Qrf / Qrf/KaKlclst	6013.08	5940.97	72.11	846.63	0.085	3.14E-04	276.71	3.06
40005-80205	OLF	2	Qrf/KaKlclst	6004.78	5932.82	71.96	1194.95	0.060	2.09E-04	130.50	9.16
40005-80205	OLF	4	Qrf/KaKlclst	6008.03	5932.16	75.87	1194.95	0.063	2.09E-04	137.59	8.69
40305-39605	South IA	2	Qrf/KaKlslt / KaKlclst	6002.5	5992.57	9.93	1126.39	0.009	1.12E-04	10.23	110.12
40305-39605	South IA	4	Qrf/KaKlslt / KaKlclst	6006.2	5995.97	10.23	1126.39	0.009	1.12E-04	10.52	107.03
40005-P419689	South IA	2	Qrf/KaKlclst / KaNo.1ss	6004.78	5999.77	5.01	478.87	0.010	4.99E-04	53.98	8.87
40005-P419689	South IA	4	Qrf/KaKlclst / Qrf/KaNo.1ss	6008.03	6003.67	4.36	478.87	0.009	4.06E-04	38.27	12.51
P419689-11502	South IA	2	KaNo.1ss / KaKlclst	5999.77	5993.46	6.31	535.27	0.012	3.94E-04	48.11	11.13
P419689-11502	South IA	4	Qrf/KaNo.1ss / KaKlclst	6003.67	5999.14	4.53	535.27	0.008	3.02E-04	26.44	20.24

Table 52 (continued). Calculated Flow Velocities for 2011

Well Pair	Area	2011 Quarter	Geological Unit	WL Elevation, Well 1	WL Elevation, Well 2	dh (ft)	dl (ft)	dh/dl (hydraulic gradient)	Calculated K (cm/s)	v (ft/yr)	Time to Traverse Transect (yr)
40305-22996	South IA/ 800 Area	2	Qrf/KaKlclst / Qrf	6002.5	5977.94	24.56	2037.05	0.012	3.14E-04	39.13	52.05
40305-22996	South IA/ 800 Area	4	Qrf/KaKlclst / Qrf	6006.2	5978.65	27.55	2037.05	0.014	3.14E-04	43.90	46.40
88205-00797	881 Hillside	2	Qrf/KaKlclst / Qrf	5966.97	5925.92	41.05	343.12	0.120	3.14E-04	388.68	0.88
88205-00797	881 Hillside	4	Qrf/KaKlclst / Qrf	5969.67	5925.12	44.55	343.12	0.130	3.14E-04	421.82	0.81
00191-00491	903 Pad/Lip	2	Qrf/ Qrf/KaKlclst	5947.48	5888.92	58.56	816.98	0.072	3.14E-04	232.66	3.51
00191-00491	903 Pad/Lip	4	Qrf/KaKlclst	5951.8	5888.06	63.74	816.98	0.078	2.09E-04	169.06	4.83
07391-10304	Ryan's Pit/ Woman Ck.	2	Qrf/KaKlclst / Qc/KaKlclst	5941.43	5810.68	130.75	948.74	0.138	1.28E-04	182.89	5.19
07391-10304	Ryan's Pit/ Woman Ck.	4	Qrf/KaKlclst / Qc/KaKlclst	5942.03	5810.69	131.34	948.74	0.138	1.28E-04	183.34	5.17
33502-33711	Oil Burn Pit #1	2[b]	Qrf/ Qrf/KaKlclst	6017.45	5998.52	18.93	271.46	0.070	3.14E-04	226.35	1.20
33502-33711	Oil Burn Pit #1	4	Qrf/ Qrf/KaKlclst	6015.11	6001.83	13.28	271.46	0.049	3.14E-04	158.79	1.71
33502-33604	Oil Burn Pit #1	2	Qrf / Qrf/KaKlclst	6012.55	6008.32	4.23	177.63	0.024	3.14E-04	77.30	2.30
33502-33604	Oil Burn Pit #1	4	Qrf / Qrf/KaKlclst	6015.11	6011.63	3.48	177.63	0.020	3.14E-04	63.59	2.79
33604-33711	Oil Burn Pit #1	2[b]	Qrf/KaKlclst	6012.61	5998.52	14.09	103.49	0.136	2.09E-04	295.03	0.35
33604-33711	Oil Burn Pit #1	4	Qrf/KaKlclst	6011.63	6001.83	9.8	103.49	0.095	2.09E-04	205.20	0.50
91105-91203	Oil Burn Pit #2	2	Qrf/KaKlslt / KaKlclst	5946.78	5931.42	15.36	242.17	0.063	1.12E-04	73.59	3.29
91105-91203	Oil Burn Pit #2	4	Qrf/KaKlslt / KaKlclst	5947.1	5932.27	14.83	242.17	0.061	1.12E-04	70.96	3.41
P210189-79102	SEPs	2	KaKlslt / KaKlclst	5964.31	5947.73	16.58	301.98	0.055	1.48E-05	8.43	35.82
P210189-79102	SEPs	4	KaKlslt / KaKlclst	5969.49	5948.53	20.96	301.98	0.069	1.48E-05	10.66	28.33

Table 52 (continued). Calculated Flow Velocities for 2011

Well Pair	Area	2011 Quarter	Geological Unit	WL Elevation, Well 1	WL Elevation, Well 2	dh (ft)	dl (ft)	dh/dl (hydraulic gradient)	Calculated K (cm/s)	v (ft/yr)	Time to Traverse Transect (yr)
79102-22205	North of SEPs	2	KaKlclst / KaKlslt	5947.73	5916.17	31.56	235.62	0.134	1.48E-05	20.57	11.46
79102-22205	North of SEPs	4	KaKlclst / KaKlslt	5948.53	5916.59	31.94	235.62	0.136	1.48E-05	20.76	11.35
79502-99305	SEPs/B991	2	KaKlclst / Qrf/KaKlclst	5960.67	5927.3	33.37	532.37	0.063	1.05E-04	68.20	7.81
79502-99305	SEPs/B991	4	KaKlclst / Qrf/KaKlclst	5960.85	5929.04	31.81	532.37	0.060	1.05E-04	65.01	8.19
70393-70693	PU&D/PLF	2	Qrf	5985.18	5970.77	14.41	410.48	0.035	4.18E-04	151.82	2.70
70393-70693	PU&D/PLF	4	Qrf	5989.28	5975.21	14.07	410.48	0.034	4.18E-04	148.24	2.77
30900-30002	PU&D/ N. Walnut Ck.	2	Qrf/KaNo.1ss / KaKlclst	5990.45	5920.05	70.4	1890.74	0.037	3.02E-04	116.32	16.25
30900-30002	PU&D/ N. Walnut Ck.	4	Qrf/KaNo.1ss / KaKlclst	5997.1	5922.61	74.49	1890.74	0.039	3.02E-04	123.10	15.36

cm/s = centimeters per second

[a] Due to equipment malfunction, the water level measured in well P416589 as part of fourth quarter water level measurements (i.e., on October 5, 2011) was not recorded. For the purpose of calculating fourth quarter flow velocities for well pair P416589-80105, water level measurements recorded on November 8, 2011, prior to collection of groundwater samples, were used.

[b] When calculating second quarter flow velocities for well pairs 33502-33711 and 33604-33711, data from June 1-2, 2011, were used. Well 33711 was installed in March 30, 2011, and it took several days before the well contained water, and longer still before the water level equilibrated. As such, the water levels measured on April 4 as part of second quarter water levels were not representative of the formation. Water level measurements were next collected in early June, prior to collection of groundwater samples.

As noted above, these calculated velocities are based in part on data displayed on the hydrographs: where water is shown above the bedrock contact, hydraulic conductivities for the unconsolidated surficial material (e.g., Rocky Flats Alluvium or colluvium), as well as bedrock to account for water flowing through this unit, are included for this calculation. If the hydrographs show that water is typically restricted to the bedrock, the K value for the generalized bedrock type at that well is selected. Note that, similar to the highly heterogeneous alluvial deposits, the bedrock lithologies are also variable (e.g., from claystone to silty claystone to clayey siltstone to siltstone), as is often reflected in cores from the screened interval of a given well; however, a single K value is selected to represent the well.

Table 52 presents the results of the calculation of seepage velocities. Refer to Figure 155 and Figure 156 for the locations of the wells. Estimated seepage velocities in 2011 range from a low of 8.43 feet per year (ft/yr) within the bedrock from well P210189 to well 79102 in the vicinity of the former Solar Evaporation Ponds (SEPs), to a high of 428.43 ft/yr within the artificial fill and bedrock from well 18199 to well 20505 in the vicinity of the former Building 771 area. Note that the relatively high seepage velocity observed between wells 18199 and 20505 is due, in large part, to the presence of water solely in the sandstone of the Arapahoe Formation (the "No. 1 Sandstone"; EG&G 1995a) at well 18199. Together with valley-fill alluvium, the Arapahoe Formation sandstone has the highest hydraulic conductivity of those units observed at the Rocky Flats Site.

The corresponding travel time between each well in a well pair ranges from approximately 4 months (from well 33604 to well 33711 in the vicinity of the former Oil Burn Pit #1) to over 110 years (from well 40305 to well 39605 in the southern IA). However, once again these are estimated velocities for pure water; and second, the hydraulic gradients can be seen to change significantly from season to season between wells in some well pairs as a result of precipitation and seasonal recharge patterns. For example, the gradients between wells P419689 and 11502 (0.012 and 0.008 for second and fourth quarters, respectively) lead to corresponding calculated velocities of 48.11 ft/yr and 26.44 ft/yr—travel times of approximately 11 and 20 years, respectively. As illustrated, these estimates are very sensitive to measured water levels.

In general, the velocities calculated for 2011 are comparable to those calculated prior to Site closure (e.g., K-H 2004b) and are also similar to those presented in the 2010 Annual Report (DOE 2011d). For a more detailed discussion of flow between well pairs by area, refer to the 2006 and 2007 Annual Reports (DOE 2007c, 2008c).

As in previous years, there are instances in which the estimated travel times for a given well pair vary widely between the second and fourth quarter. This is related to differences in gradient, as explained above; when water levels are very similar in both members of a well pair, the low gradient results in a slow travel time, and when levels are very different, the gradient is steeper, increasing the calculated velocity. The well pairs discussed above in terms of gradients illustrate this scenario, as do other well pairs. Other wells that may be of interest due to contaminants in the groundwater monitored by them include well pair 00191–00491. The former well is near the 903 Pad Plume source area, and the latter is on the hillside southeast of the 903 Pad. The second-quarter travel time calculated for this well pair is 3.5 years, while the fourth-quarter travel time is estimated at almost 5 years. For well pair 91105–91203 (Oil Burn Pit #2 source area and downgradient well, respectively, though well 91203 is not directly downgradient of well 91105) the estimated 2011 travel times are almost identical for second and fourth quarters (3.3 years and 3.4 years, respectively). In 2010, travel times were approximately 1.9 years for second quarter and 3.6 years for fourth quarter. In this case, the second-quarter conditions leading to the corresponding estimate of shorter travel time may have been a factor in the increased contaminant concentrations reported at well 91203 in the fourth quarter of 2010, as discussed in the 2010 Annual Report (DOE 2011d). These higher water levels may have flushed residual contaminants from the vadose zone upgradient of well 91203, contributing to contaminants reported in the fourth-quarter samples collected at that well. Refer to Section 3.1.5.3 and the text on groundwater plumes for additional discussion of conditions in these areas.

Velocities and travel times were estimated for the Ryan's Pit Plume area, where the source area is monitored by Evaluation well 07391, and the pathway to surface water is monitored by AOC well 10304. The travel times estimated in 2011 (just over 5 years in both second and fourth quarters) are equivalent to those estimated in 2010 (DOE 2011d). Both of these wells were sampled in 2011. Data from AOC well 10304 did not include any confirmed detections of VOCs, potentially suggesting contaminant transport is substantially retarded by hydrologic processes and/or contaminants are degraded upgradient of the AOC well. See Section 3.1.5.3 for additional discussion of the 903 Pad/Ryan's Pit Plume.

Overall, groundwater flow paths and flow velocities in 2011 show little change from previous years.

3.1.3.6 Seeps

Seeps are common at the Rocky Flats Site. Seep distribution and occurrence are strongly controlled by geology and precipitation, and much of the discharge occurs at the contact between the Rocky Flats Alluvium and underlying claystone.

Seep locations posted on the second and fourth quarter CY 2011 potentiometric surface maps are from the 1995 Hydrogeologic Characterization Report (EG&G 1995a). Although this depiction of seeps has been the best available map of the seeps for the Site for several years, it is no longer accurate, having been most strongly affected by the removal of all artificial water sources, as well as land surface reconfiguration (e.g., excavations and placement of fill) in some areas. Thus, efforts to map existing seeps in the COU began in 2010. Although not a rigorous investigation, the project is designed to qualitatively establish the presence of seeps and document their general location.

One observation made during 2010 and 2011 is that seeps often occur where former building foundations, footer drains, and other features remain that have created preferential pathways for groundwater to reach the surface. This observation supports the design of the monitoring network, which considered the anticipated post-closure groundwater flow directions.

Figure 157 presents the locations where seeps and wet areas were observed during August of CY 2011. Note that many of the wet areas observed in 2010 were dry when visited the next summer, including most seeps on the OLF and those identified near the former Building 771 area. August, not surprisingly, is generally a drier month and the absence of seeps is expected. Efforts to expand the site seep mapping efforts are ongoing, with plans to delineate existing seeps during spring and summer of each year. General locations are being flagged for return visits and any occurrences will be documented.

New seeps and wet areas have developed at several locations throughout the COU where wetlands are developing naturally. The *Rocky Flats, Colorado, Site Wetland Mitigation Monitoring and Management Plan* (DOE 2006b) provides guidance for monitoring mitigation wetlands and reporting. The 2010 results are presented in the *Rocky Flats, Colorado, Site, 2010 Annual Wetland Mitigation Monitoring Report* (DOE 2011c).

3.1.4 Surface-Water Data Interpretation and Evaluation

3.1.4.1 Surface-water Quality Summaries

This section presents water quality summaries for selected analytes for the period January 1, 1997, through December 31, 2011 (CY 1997–2011) for the routine automated surface-water monitoring locations operational in CY 2011. Radionuclides summarized include Pu, Am,[13] and total U. Additionally, the POE metals (total beryllium [Be], dissolved Cd, total Cr, and dissolved silver [Ag]) and nitrate+nitrite as N are also summarized. Additional analyses are also performed based on the specific monitoring objective. The results and evaluation for these additional analytes are presented in Section 3.1.2.1 through Section 3.1.2.11 by monitoring objective.

The summary values in this section should not be confused with the RFLMA required water-quality evaluations according to Attachment 2 in the RFLMA. The Pu, Am, and total U standards noted in this section apply only to POE (GS10, SW027, and SW093; Section 3.1.2.2) and POC (WALPOC, WOMPOC, GS01, GS03, GS08, GS11, and GS31; Section 3.1.2.1) 30-day or 12-month rolling averages. Comparisons of standards to other summary statistics are noted in this section for reference only. POEs and POCs are highlighted in **bold** in the tables.

Radionuclides

The following summaries include all results that were not rejected through the validation process.[14] Data are generally presented to decimal places as reported by the laboratories. Accuracy should not be inferred; minimum detectable concentrations, activities, and analytical errors are often greater than the precision presented. When a negative radionuclide result (e.g., −0.002 pCi/L) is reported by the laboratory due to blank correction, a value of 0.0 pCi/L is used for calculation purposes. When a sample has a corresponding field duplicate, the value used in calculations is the arithmetic average of the "real" and "duplicate" values.[15] When a sample has multiple "real" analyses (e.g., Site requested "reruns"), the value used in calculations is the arithmetic average of the multiple "real" analyses.

[13] In this report, "plutonium" or "Pu" refers to plutonium-239,240; and "americium" or "Am" refers to americium-241.
[14] Summaries do not include supplemental post-closure grab samples for uranium from GS13 that were collected to assess modifications to the SPPTS; only routine continuous flow-paced samples are included.
[15] Arithmetic averaging of radionuclide pairs is performed only when the RER is less than or equal to 5. If the RER is greater than 5, the radionuclide results are determined to be nonrepresentative. These results are not used for the calculation of summary statistics. A more thorough discussion of data management is given in Appendix B.1, "Surface-Water Analytical Data Evaluation Methods."