# *HYDROLOGIC ASSESSMENT OF LOW FLOWS IN THE MATTOLE RIVER BASIN 2004-2011*

**Prepared for:**

**Sanctuary Forest, Inc.**
**Mattole Flow Program**

**By:**

**Randy D. Klein**
**Hydrologist**

**February, 2012**

## TABLE OF CONTENTS



## FIGURES



## TABLES

## *INTRODUCTION*

This report presents an analysis of low flows in the Upper Mattole River basin with the following objectives: 1) to analyze recent hydrologic data to compare and contrast summer discharges as they vary in time and space; and 2) to contribute to a technical basis supporting efforts designed to improve low flows in the Upper Mattole River for salmonids. This report builds upon earlier analyses by Klein (2004, 2007, 2009) by incorporating data collected by Sanctuary Forest staff in 2009-2011.

Lack of adequate late summer and early fall streamflow was recognized by the State of California as one of the most important limitations on salmonid habitat in the Mattole River basin (NCWAP, 2000). In recent years, juvenile salmonids have become stranded in pools due to excessively low flows, causing mortality and necessitating fish rescue operations. With the exception of 2005, 2010, and 2011, late summer and early fall discharges were quite low for most of the past decade, with the summer of 2008 being the driest in the 61-year record of flows on the Mattole River near Petrolia.

A variety of factors influence low flows, such as, climate (rainfall, temperature, relative humidity, wind speed), vegetation species and age distribution, ground disturbance, streambed sediment depth, water use for domestic and agricultural purposes. Of these, only vegetation, ground disturbance, human water use , and possibly riparian aquifer storage are subject to human influences and therefore might be modified to improve low flows. But the relationships between low flows and influential factors are complex, especially in a basin as large and diverse as the Mattole River. Reducing human water use is often a difficult and expensive undertaking, requiring technological adaptations, financial investments, and conservation practices. Sanctuary Forest has undertaken a program to reduce dry season pumping from the Upper Mattole by subsidizing purchases of large storage tanks for willing landowners and facilitating forbearance agreements that limit water pumping by riparian landowners from the Upper Mattole mainstem when flow falls below 0.7 cubic feet per second (cfs), which typically occurs during mid- to late-summer.

## *EXISTING DATA AND PREVIOUS STUDIES*

### *Climatic and Hydrologic Data*

The "Northcoast Watershed Assessment Program" (NCWAP) Mattole River report (NCWAP, 2000) provides a compilation of climatic and hydrologic data sources for the Mattole River. Appendix C of the NCWAP report, prepared by the California Department of Water Resources (DWR) lists all known official (government sponsored) data collection efforts in the Mattole and has assembled relevant data and performed some basic analyses, primarily of rainfall and streamflow. In addition to official data collection, numerous basin residents keep records of such basic information as temperature and rainfall.

Sanctuary Forest staff has been collecting streamflow data since summer, 2004, and their data form the basis for most analyses contained herein. In addition, streamflow data collected by the US Geological Survey (USGS) at Petrolia and near Ettersburg, along with rainfall and humidity data collected by C. Thompson in the Thompson Creek watershed were used.

### *Water Use*

Because water use was not a quantitative component of the present analysis, the reader is referred to the NCWAP (2001) study, which provides a listing of appropriative water rights granted within the Mattole River basin along with estimates of water use. Klein (2004) also summarized water use based on locally-derived estimates provided by Sanctuary Forest staff, but the accuracy of either of these estimates is unknown.

Since 2006, there has been a significant increase in awareness of the low flow problem and a community-wide response to increase water conservation as well as storage and forbearance (stopping pumping from streams) during the low flow season. Starting in 2006, Sanctuary Forest implemented a streamflow education and outreach program that includes public service announcements and website alerts about streamflow conditions, water conservation and water storage educational materials, community meetings and a prominent streamflow alert sign at Whitethorn Junction updated bi-weekly during the low flow season. Additionally Sanctuary Forest developed a water storage and forbearance program, with funding and implementation beginning in 2006. In 2007, storage systems were installed for the first two landowners along with legally recorded forbearance agreements to end all pumping at annually-specified dates during in the low flow season. As of December 2011, a total of 12 storage and forbearance systems have been installed totaling 750,000 gallons. Another estimated 25 households within the Mattole headwaters basin have installed water storage on their own and are also practicing forbearance voluntarily during the low flow season. Most of these households installed their storage following the 2002 extreme low flow year and up through 2011.

The Lower Critical Reach (aka, junction reach) has been selected as an effectiveness monitoring reach because of the high density of instream pump intakes for households and businesses, (14 pumps in the one mile between MS5 and MS6) and the high level of commitment to storage and forbearance. In the Lower Critical Reach the following progress has been made:

- 2002-2010: 4 landowners voluntarily implemented water storage and forbearance,
- 2007: 1 water storage and forbearance participant entered the program,
- 2008: 2 additional water storage and forbearance participants, including one small farm, entered the program (total = 3),
- 2009: 2 additional water storage and forbearance small farm participants (total = 5),
- 2010: 1 additional water storage and forbearance participant (total = 6).

By 2010, approximately 70% of the instream pumps in the Lower Critical Reach had joined the program either formally or on a voluntary basis, agreeing to cease water withdrawals when flows at the downstream end of the Lower Critical Reach (MS6 monitoring site) drop below the cutoff (0.7 cfs).

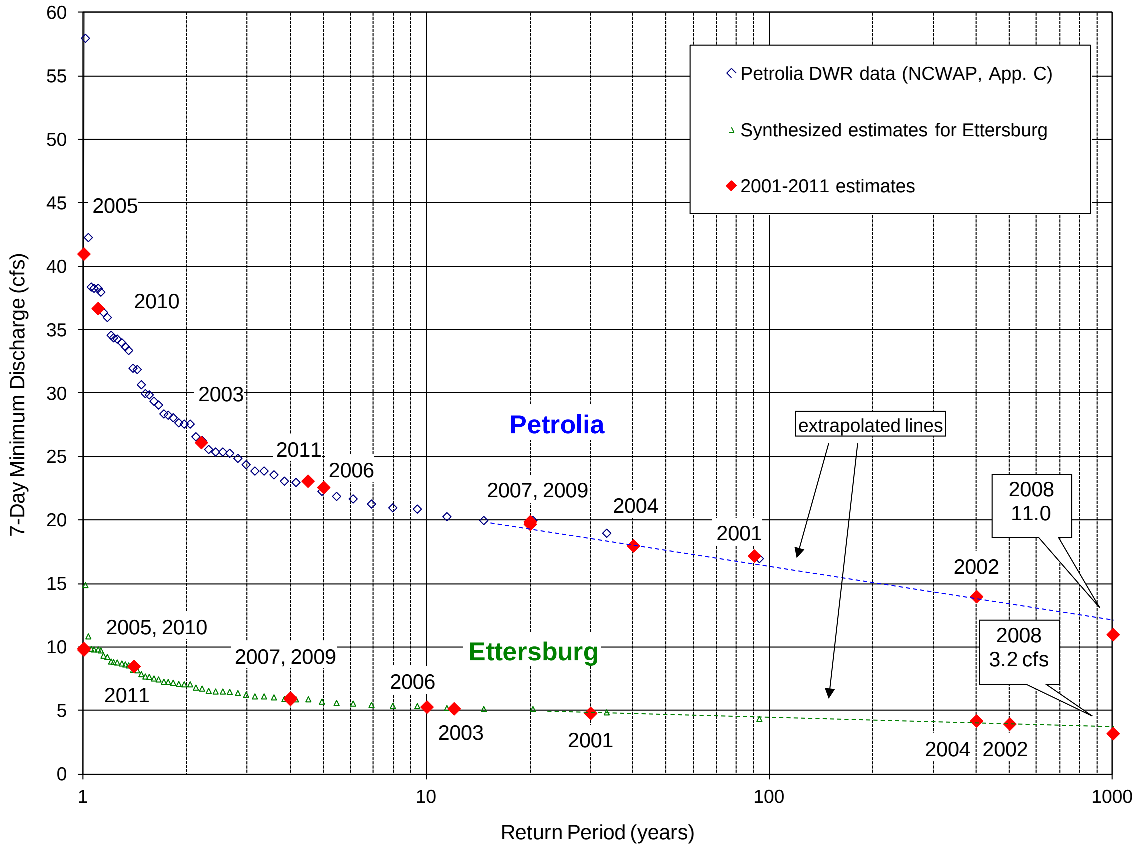
## *RAINFALL AND LOW FLOW HYDROLOGIC ANALYSES*

### *A Basin-wide Perspective on Low Flows*

The NCWAP (2000) report evaluated rainfall in the Mattole based on two long-term rain gages; one in Petrolia near the basin mouth, and the other in the Upper Mattole (according to Figure II-1 on page 4 of the NCWAP report, this gage is actually located in the lower part of the basin at an elevation of 255 feet). Based on analyses of historical rainfall, the NCWAP report concluded there are no discernable long-term trends in annual precipitation. The NCWAP (2000) report also presented and analyzed streamflow records in the Mattole River near Petrolia (USGS Gaging Station No. 11469000, drainage area 245 $mi^2$). Floods, low flows, and annual yields were analyzed for long term trends. They reported that there was ‘a slight decline with time in annual yields during the 50-year period and a much higher degree of variation during the last 25 years.’ They also report that the 7-day low flow running average ranged from a high of 42.3 cfs (1963) to a low of 17.0 cfs (1977). A ‘slight overall decline in low flow since…1951.’ was noted and tentatively attributed to increased water use. They conclude by reporting that ‘streamflow data within the region do not show any distinct long-term increase or decrease in annual runoff.’

Since the NCWAP analyses were done, twelve additional years of data have been collected at the USGS gages. While the low-flow frequency analysis was not re-done with these newer data, Figure 1 plots the 2001-2011 7-day low flows for both the Petrolia and Ettersburg gages on the NCWAP frequency estimates (reproduced from the NCWAP 2000 report). Because the Ettersburg gaging station lacks sufficient record length to perform low flow frequency analyses, frequency estimates were derived by synthesizing 7-day low flow discharge estimates from the Petrolia gage data using drainage area ratio and applying the frequency estimates from the NCWAP (2000) analysis.

Figure 1. Mattole River near Petrolia (No. 11469000; DA = 245 mi²) and near Ettersburg (No. 11468900; DA = 58.1 mi²) 7-day minimum low flow frequency, 2001-2011.




As shown in Figure 1, the 2008 7-day low flow was the lowest on record for the 60-year record length at Petrolia, so low that the NCWAP (2000) curve had to be extrapolated downward to accommodate the post-2000 data. Consequently, the return period of about 1000-years for the 2008 data may be an over-estimate, but is nonetheless indicative of the extreme drought conditions during this record-setting low flow year. The 2003-07 and 2009-11 low flows were substantially higher than those of 2008, although 2001, 2002, and 2004 can be considered extremely dry as well. Relatively high summer low flows on par with those of 2005 re-occurred in 2010, and 2011 was relatively wet as well. Table 1 shows the low flow statistics for both Petrolia and Ettersburg gages for the entire period (2001-2011) following the NCWAP (2000) analysis.

Table 1. Low flow dates and statistics for Petrolia (PET)and Ettersburg (ETT) stream gages, 2001-2011. The higher the return period, the more extreme the drought conditions.

| Statistic | Petrolia cfs | Petrolia cfs/sq mi | Petrolia date(s) | Return Period years | Ettersburg cfs | Ettersburg cfs/sq mi | Ettersburg date(s) | Return Period years | ETT/PET Ratio |
|---|---|---|---|---|---|---|---|---|---|
| 2001 1-DAY MIN | 17.0 | 0.07 | 9/24/2001 | --- | 4.6 | 0.08 | 9/10/2001 | --- | 1.141 |
| 2001 7-DAY MIN | 17.2 | 0.07 | 10/5-11/2001 | 90 | 5.0 | 0.09 | 9/3-9/2001 | 30 | 1.223 |
| 2002 1-DAY MIN | 14.0 | 0.06 | 9/26/2002 | --- | 3.7 | 0.06 | 10/10/2002 | --- | 1.114 |
| 2002 7-DAY MIN | 14.0 | 0.06 | 9/26-10/2/2002 | 400 | 4.0 | 0.07 | 10/7-13/2002 | 500 | 1.193 |
| 2003 1-DAY MIN | 26.0 | 0.11 | 10/26/2003 | --- | 4.9 | 0.08 | 10/15/2003 | --- | 0.795 |
| 2003 7-DAY MIN | 26.1 | 0.11 | 10/25-31/2003 | 2.2 | 5.2 | 0.09 | 10/23-29/2003 | 12 | 0.832 |
| 2004 1-DAY MIN | 18.0 | 0.07 | 9/26/2004 | --- | 4.0 | 0.07 | 9/9/2004 | --- | 0.937 |
| 2004 7-DAY MIN | 18.0 | 0.07 | 9/28-10/4/2004 | 40 | 4.2 | 0.07 | 9/7-13/2004 | 400 | 0.984 |
| 2005 1-DAY MIN | 40.0 | 0.16 | 10/12/2005 | --- | 9.4 | 0.16 | 10/12/2005 | --- | 0.991 |
| 2005 7-DAY MIN | 41.0 | 0.17 | 10/7-13/2005 | 1 | 9.9 | 0.17 | 10/8-14/2005 | 1 | 1.018 |
| 2006 1-DAY MIN | 22.0 | 0.09 | 9/27/2006 | --- | 5.2 | 0.09 | 9/26/2006 | --- | 0.997 |
| 2006 7-DAY MIN | 22.6 | 0.09 | 9/22-28/2006 | 5 | 5.3 | 0.09 | 9/24-30/2006 | 10 | 0.989 |
| 2007 1-DAY MIN | 19.0 | 0.08 | 9/27/2007 | --- | 5.7 | 0.10 | 9/3/2007 | --- | 1.265 |
| 2007 7-DAY MIN | 19.9 | 0.08 | 9/24-30/2007 | 20 | 6.0 | 0.10 | 8/31-9/6/2007 | 4 | 1.271 |
| 2008 1-DAY MIN | 11.0 | 0.04 | 9/9/2008 | --- | 3.1 | 0.05 | 9/9/2008 | --- | 1.188 |
| 2008 7-DAY MIN | 11.0 | 0.04 | 9/5-11/2008 | >1000 | 3.2 | 0.06 | 9/4-10/2008 | >1000 | 1.227 |
| 2009 1-DAY MIN | 19.0 | 0.08 | 9/29/2009 | --- | 5.8 | 0.10 | 9/28/2009 | --- | 1.287 |
| 2009 7-DAY MIN | 19.7 | 0.08 | 9/27-10/3/2009 | 20 | 5.9 | 0.10 | 9/25-10/1/2009 | 4 | 1.263 |
| 2010 1-DAY MIN | 34.0 | 0.14 | 10/15/2010 | --- | 9.4 | 0.16 | 10/21/2010 | --- | 1.166 |
| 2010 7-DAY MIN | 34.0 | 0.14 | 10/15-21/2010 | 1.1 | 9.8 | 0.17 | 10/15-21/2010 | 1 | 1.220 |
| 2011 1-DAY MIN | 20.0 | 0.08 | 9/23/2011 | --- | 7.9 | 0.14 | 9/23/2011 | --- | 1.666 |
| 2011 7-DAY MIN | 23.1 | 0.09 | 9/18-24/2011 | 4.5 | 8.5 | 0.15 | 9/18-24/2011 | 1.4 | 1.552 |

Klein (2004) analyzed relationships between seasonal rainfall and minimum low flows at the Petrolia gaging station for the period 1966-2003 and found that the magnitude of summer minimum flows was more strongly related to summer than spring rainfall amounts. Alternatively, a running calculation based on daily rainfall (antecedent precipitation index, or 'API') was examined to try and improve the rainfall-runoff relationships and low flow forecasting for the Upper Mattole River and is analyzed later in this report.

## *Mainstem Mattole River Discharge*

Figures 2-4 show Upper Mattole rainfall (as measured in Thompson Creek) along with Petrolia and Ettersburg discharges for the low flow seasons of 2009-2011, respectively (note that the vertical axes are at a logarithmic scale to better examine low flows; similar plots for earlier years are provided in Klein, 2007 and 2009). In 2009 (Fig. 2), about 1 inch of rain fell on September 12, increasing streamflow for about one week, and 4 inches on October 12 that marked the end of the low flow season. The minimum flow (0.01 cfs/mi$^2$ at Ettersburg) occurred in early October. Unusually heavy late spring rainfall in 2010 maintained higher lows flow throughout the dry season (Fig. 3). The higher moisture availability in 2010 allowed a relatively small amount of late summer rainfall (about 1 inch on Aug. 17, Fig. 3) to elevate flows more and for longer duration that a similar amount of rainfall in 2009. In 2011 (Fig. 4), low flows were slightly lower than in 2010 at Ettersburg. An unexplained drop in Petrolia low flows occurred on Aug. 8, 2011, and persisted through Sept. 24 when a small rainfall event elevated flows. The low flow season ended on Sept. 30 with the arrival of substantial rain.

Figure 2. Mattole River discharge and rainfall, June-October, 2009

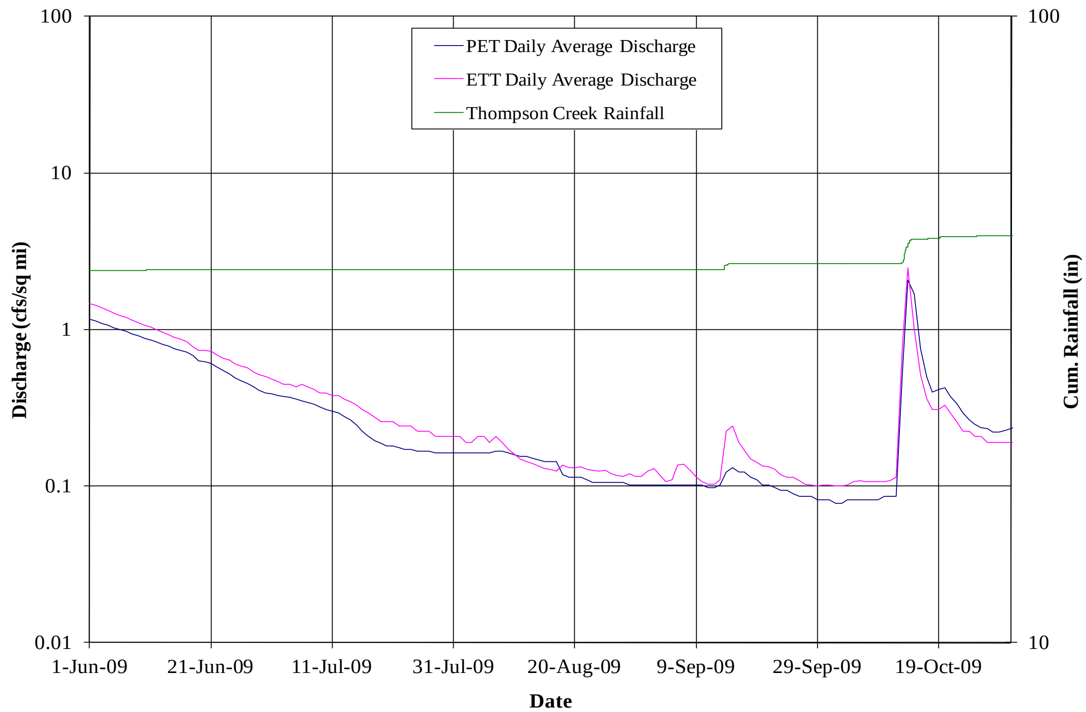



Figure 3. Mattole River discharge and rainfall, June-October, 2010

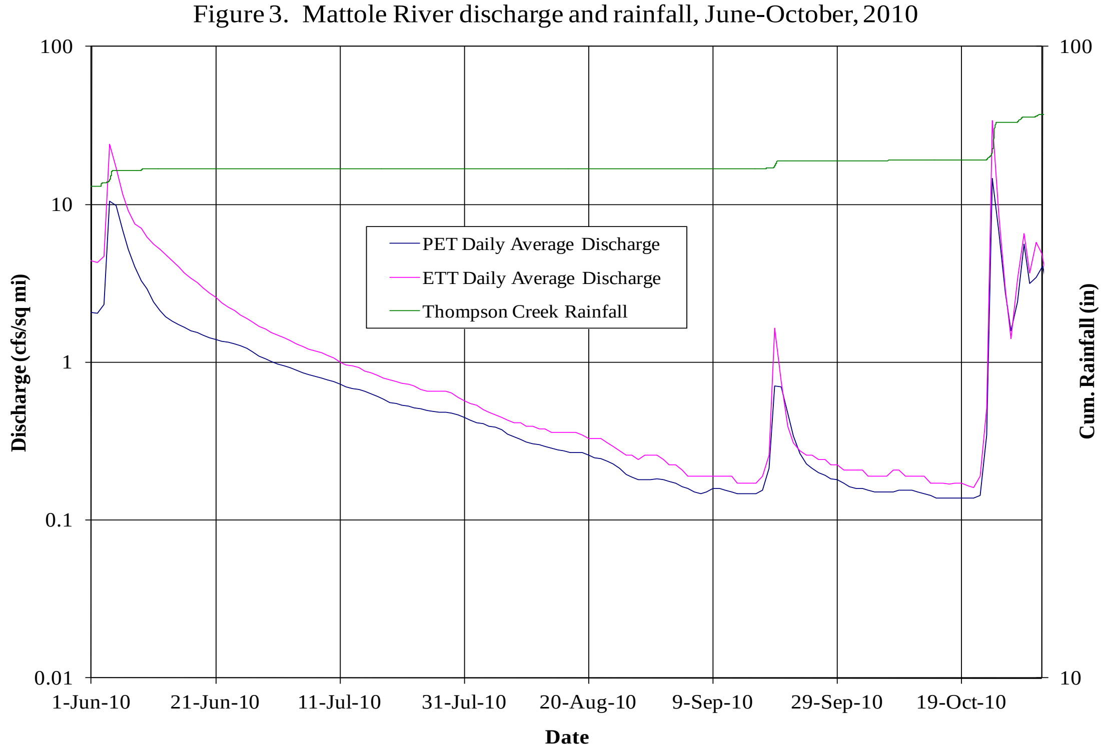
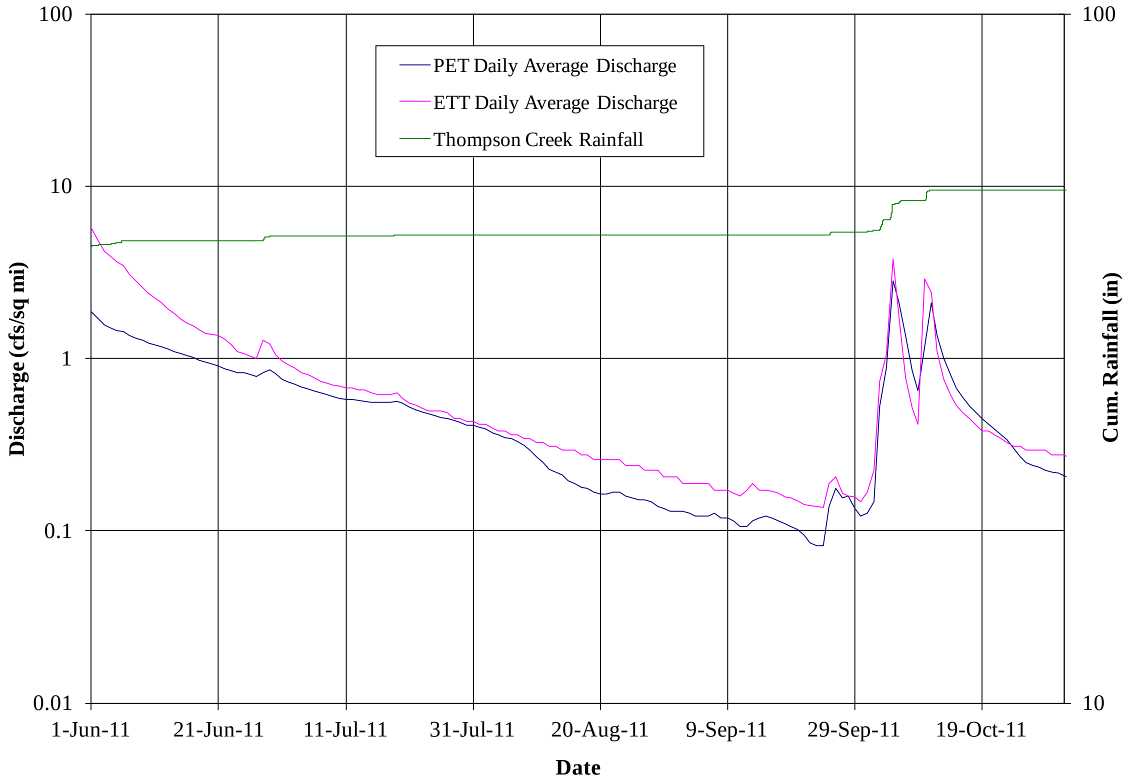


Figure 4. Mattole River discharge and rainfall, June-October, 2011




Beginning in August, 2004, flows were measured by Sanctuary Forest staff and volunteers at selected sites in the Upper Mattole River basin on both the main stem and selected tributaries. Main stem sites are numbered in a downstream direction (MS1 is at the upper end of the monitoring reach, MS6 is at the lower end. Site descriptions are listed below in Table 2, which includes the USGS sites as well. These data provided for a more detailed assessment of Upper Mattole low flows than was possible solely using USGS gage data. Measurements were made by collecting the flow at a confined section of the channel in a 5-gallon bucket and timing how long it took to fill the bucket (volumetric method), or with an electromagnetic current meter (Marsh-McBirney), depending on prevailing flow and site conditions. Occasionally, temporary wing-walls were set up in the channel to concentrate the flow area for increased measurement accuracy. Accuracy was judged to be good overall, with repeat measurements taken at times and with crew members frequently checking each others work. However, at extremely low flows, accuracy is made more difficult because of channel irregularities.

Table 2. Sanctuary Forest stream discharge monitoring sites, 2004-11 (note that MS3A was discontinued in 2006).

| ***Mainstem Sites*** | ***River Mile (RM)*** | ***Drainage Area (DA, mi$^2$)*** | ***Description*** |
|---|---|---|---|
| MS1 | 59.3 | 3.3 | downstream of Big Alder Creek |
| MS2 | 58.9 | 4.0 | upstream of Lost River confluence |
| MS3A | 58.7 | 6.0 | upstream of Thompson Creek confluence |
| MS4A | 57.2 | 12.3 | downstream of Gibson Creek confluence |
| MS5 | 53.2 | 23.1 | upstream of McKee Creek |
| MS6 | 52.2 | 25.6 | upstream of Bridge Creek |
| Ettersburg | 42.0 | 58.1 | near Ettersburg |
| Petrolia | 5.0 | 245.0 | at Petrolia |
| ***Tributaries*** | | | |
| Ancestor | 60.8 | 1.0 | near confluence with mainstem |
| Lost River | 58.8 | 1.4 | near confluence with mainstem |
| Helen Barnum | 58.7 | 0.6 | near confluence with mainstem |
| Thompson | 58.4 | 3.8 | near confluence with mainstem |
| Baker | 57.6 | 1.6 | near confluence with mainstem |
| Stanley | 57.1 | 0.8 | near confluence with mainstem |
| Gibson | 56.8 | 0.7 | near confluence with mainstem |
| Harris | 56.5 | 0.9 | near confluence with mainstem |
| Mill | 56.2 | 2.3 | near confluence with mainstem |
| Ravishoni | 55.8 | 0.7 | near confluence with mainstem |
| Anderson | 55.6 | 0.7 | near confluence with mainstem |
| Van Auken | 53.8 | 2.2 | near confluence with mainstem |
| McKee | 52.8 | 2.1 | near confluence with mainstem |
| Bridge | 52.1 | 4.3 | near confluence with mainstem |
| Buck | 52.0 | 0.8 | near confluence with mainstem |

Discharge data were collected at up to six main stem sites by Sanctuary Forest staff in 2005-2011. MS1 and MS2 bracket the Upper Critical Reach (UCR, aka, Gopherville Reach). As mentioned above, the Lower Critical Reach (LCR, aka Thorn Junction Critical Reach) at the lower end of the monitored reach is a location of particular interest due to habitat values and risks posed to juvenile salmonids from lack of sustaining stream discharges. Beginning in 2005, dry season flows were measured at both the upper and lower ends of the LCR (MS5 and MS6, respectively). Spot flows were measured periodically at all main stem sites, and data loggers were used to provide a continuous record for the 2009 and 2010 dry seasons at five sites (MS1, MS2, MS4, MS5 and MS6). In 2011, data loggers were deployed relatively late (mid-Sept.) at MS5 and MS6 only.

The closest Sanctuary Forest streamflow monitoring site to the Ettersburg gaging station is Mainstem Station 6 (MS6), located about 10 river miles upstream and operated with a continuous data logger during the 2007-2011 dry seasons. Figure 5 shows flows per square mile for 2009-2011 dry seasons and demonstrates that flows at these two stations correspond well, consistent with plots from earlier years (Klein, 2009). Flows at MS6 are key to the operation of the forbearance program; participants agreed to cease pumping from the main stem Mattole when flows at MS6 drop to 0.7 cfs (0.027 cfs/sq.mi.).

Figure 5. Discharge at MS6 and Ettersburg (ETT), June-October, 2009-2011

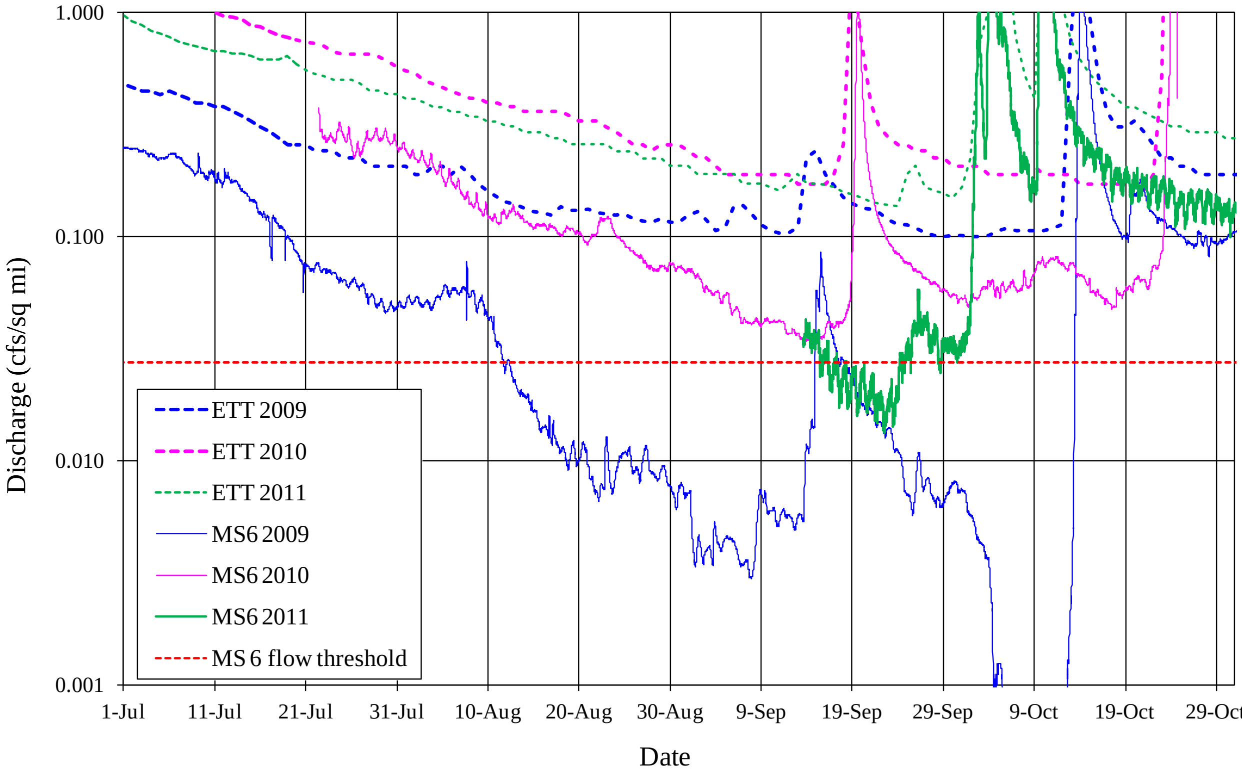



Figure 6-8 show continuous data for all operational main stem sites for 2009-2011. The data loggers recorded stream stage every 15 minutes. Periodic discharge measurements were used to develop stage-discharge rating curves for the data loggers so discharge could be estimated from the continuous stage data. For the most part, the rating curves were good estimators of discharge with the exception of MS2 and MS6, for which some inconsistencies were observed at the lowest flows measured.

Normally, discharge would be expected to increase in a downstream direction due to larger watershed area, however in late September and early October of 2009, MS4 dropped below the two upstream sites (MS1 and MS2) (Fig. 6) and MS2 appeared to fall below MS1 several times, which could be due to rating curve inaccuracies, leaves accumulating on the data logger's sensor and affecting recorded stage, water withdrawals, or some combination of these factors. Downstream accretion was more consistent in 2010 (Fig. 7) with the exception of a period in mid-Aug. when MS5 flows exceeded those at MS6 (losing reach condition). Late spring combined with late September rainfall in 2010 maintained relatively high streamflows for the entire dry season, so MS6 never fell below threshold (see Fig. 7). Only MS5 and MS6 had data loggers installed in 2011 (Fig. 8), and they were installed relatively late in the season, but spot measurements indicated a losing reach condition for about 2 weeks prior to data logger installation.

Figure 6. Continuous discharge at Upper Mattole mainstem sites, July-October, 2009

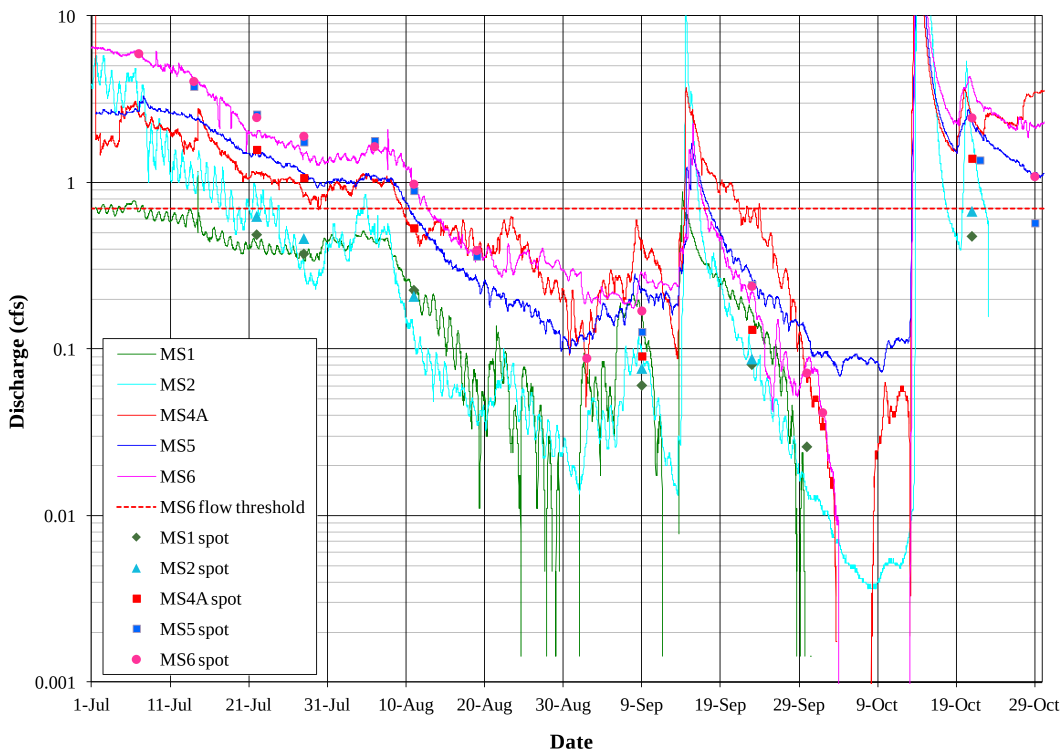



Figure 7. Continuous discharge at Upper Mattole mainstem sites, July-October, 2010

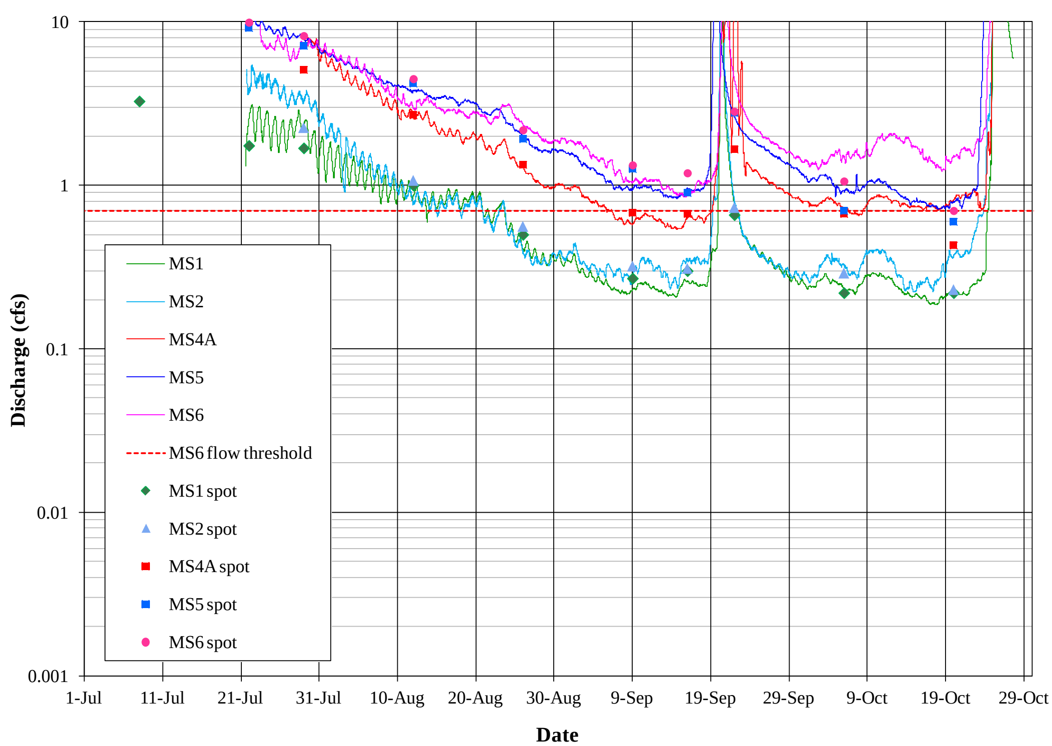


Figure 8. Continuous discharge at Upper Mattole mainstem sites, July-October, 2011

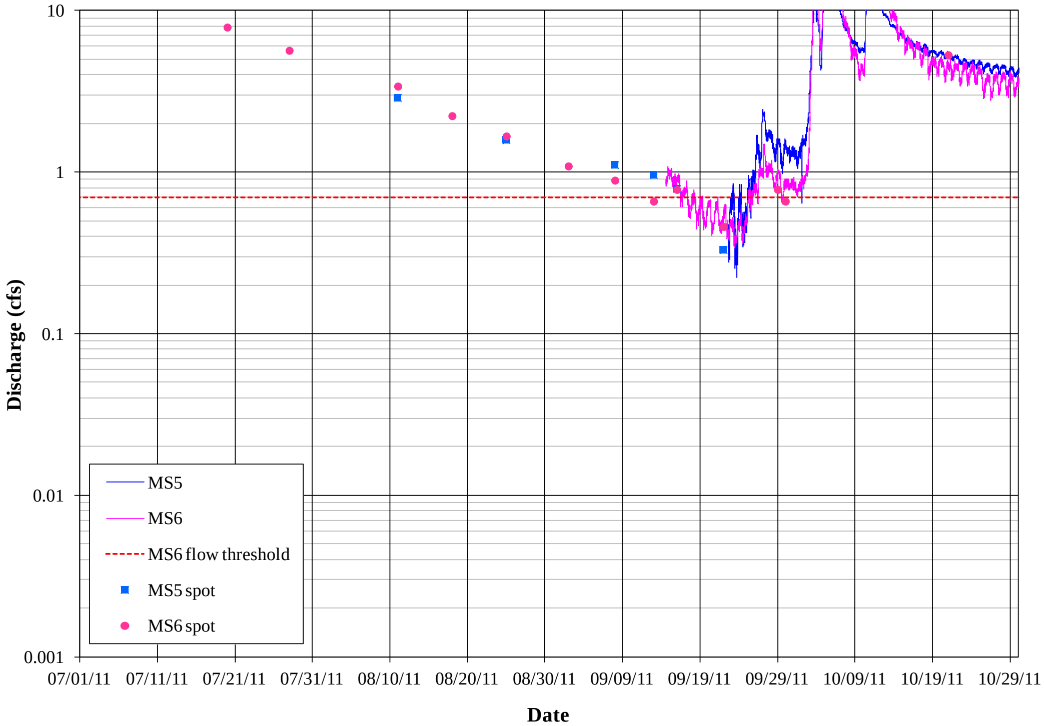
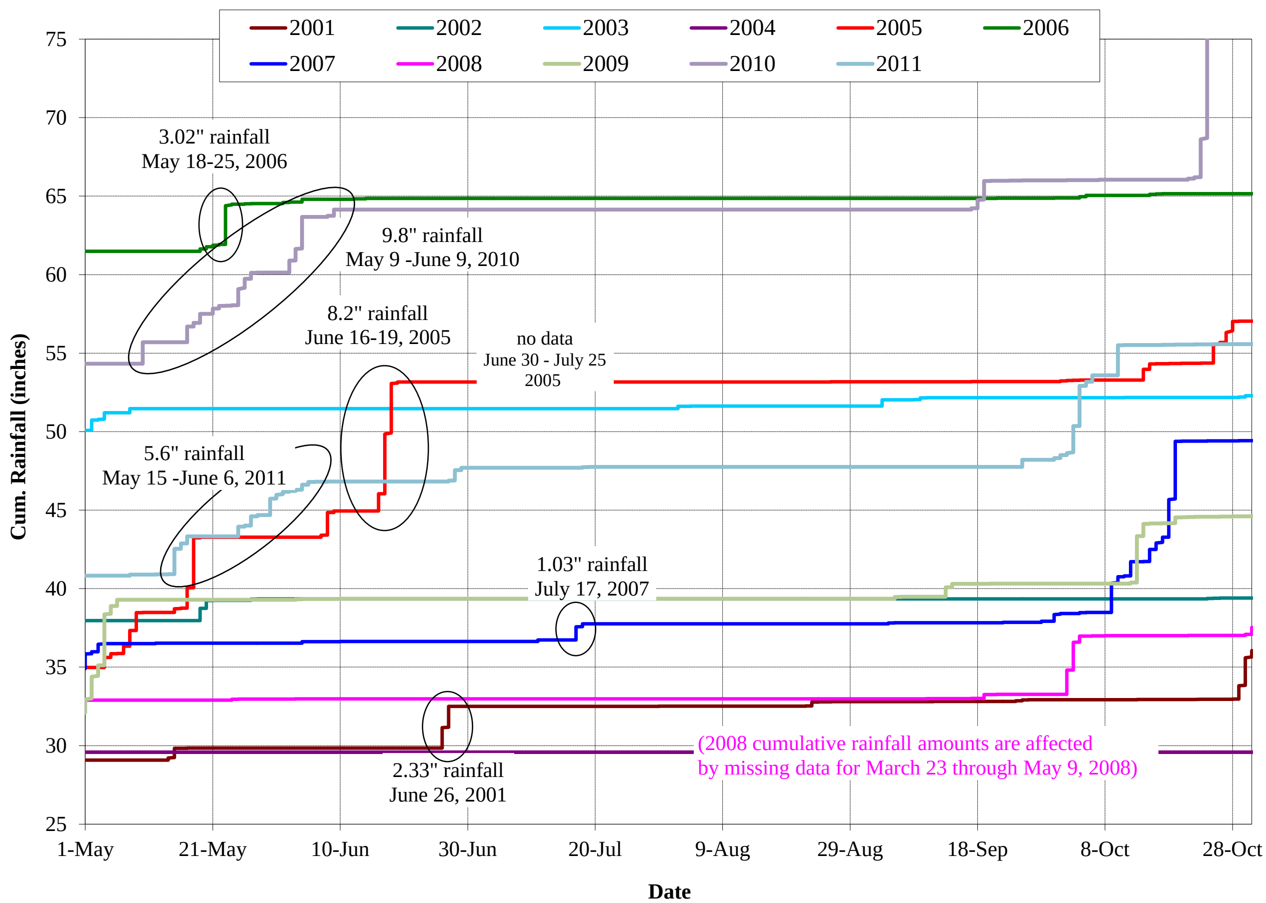


Figure 9 shows cumulative rainfall for 2001-2011. In 2005, 2010, and 2011, unusually heavy late spring rainfall events (8.2, 9.8, and 5.6 inches, respectively) occurred which account for high dry season discharges those years. The nearly continuous, steady rainfall of late spring, 2010, appears to have sustained flows in the absence of any appreciable summer rainfall and resulted in minimum flows similar to those of 2005, when spring rainfall arrived later. Dry season rainfall also occurred in 2001 (2.33 inches on June 26) and 2007 (1.03 inches on July 17). The rain in June, 2001, appears not to have been sufficient to avoid extreme low flows as this was the third driest year for the 2001-2010 period, whereas a lesser amount of rainfall in 2007 occurred later and caused a temporary rise in streamflow and was aided by a fog event in September.

Figure 9. Upper Mattole rainfall, May-October, 2001-2011




Discharge spot measurements taken by SFI staff from 2009-2011at the mainstem sites are shown in Figures 10-12. Time periods of cessation of pumping under then forbearance program are also shown. 2009 (Fig. 10) had the longest no pumping period of these three years, although MS6 flows remained higher than those upstream at MS5 for the season (i.e., no losing reach condition). Although riparian pumping likely played a role in this condition, other factors, such as evapotranspiration and seepage losses, also likely contributed to the steep decline of MS6 flows, which dropped below the 0.7 cfs cutoff on Aug. 28. The delayed fall rains kept MS6 flows below the cutoff until late Oct., 2009. In 2010 (Fig. 11), the higher flows stayed at or above threshold, but pumping was ceased anyway on Sept. 16 as a precautionary measure because flows were approaching the threshold. Similarly, in 2011, a somewhat drier year, pumping was disallowed for about 40 days (Fig. 12) as a result of extra caution despite the relatively short time period during which MS6 was below threshold (ten days).

Figure 10. Discharge measurements at Upper Mattole mainstem sites, 2009.

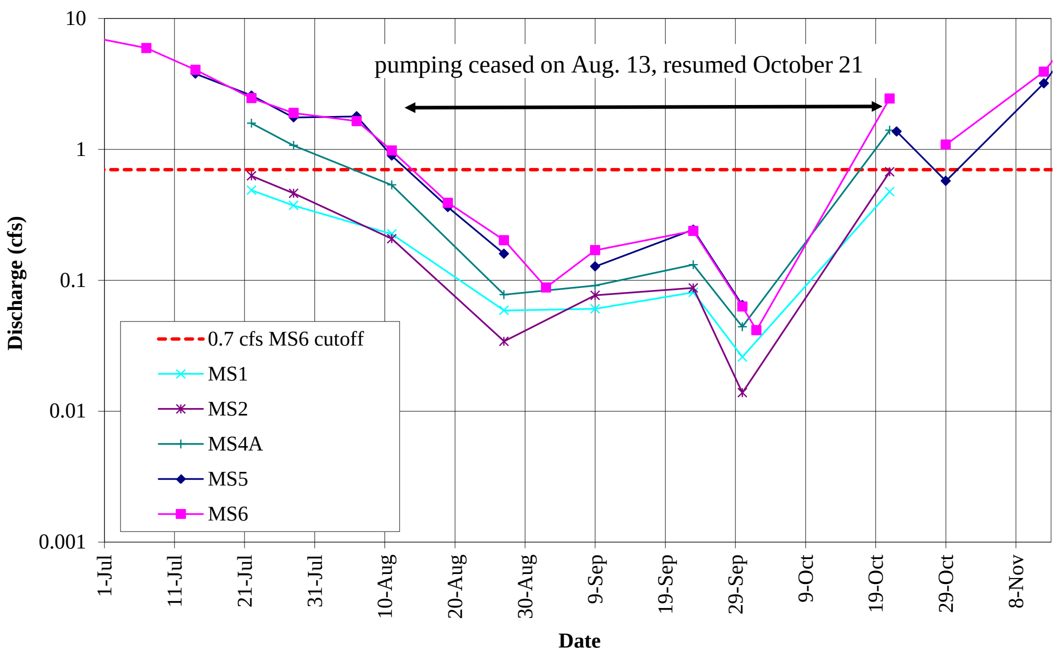



Figure 11. Discharge measurements at Upper Mattole mainstem sites, 2010.

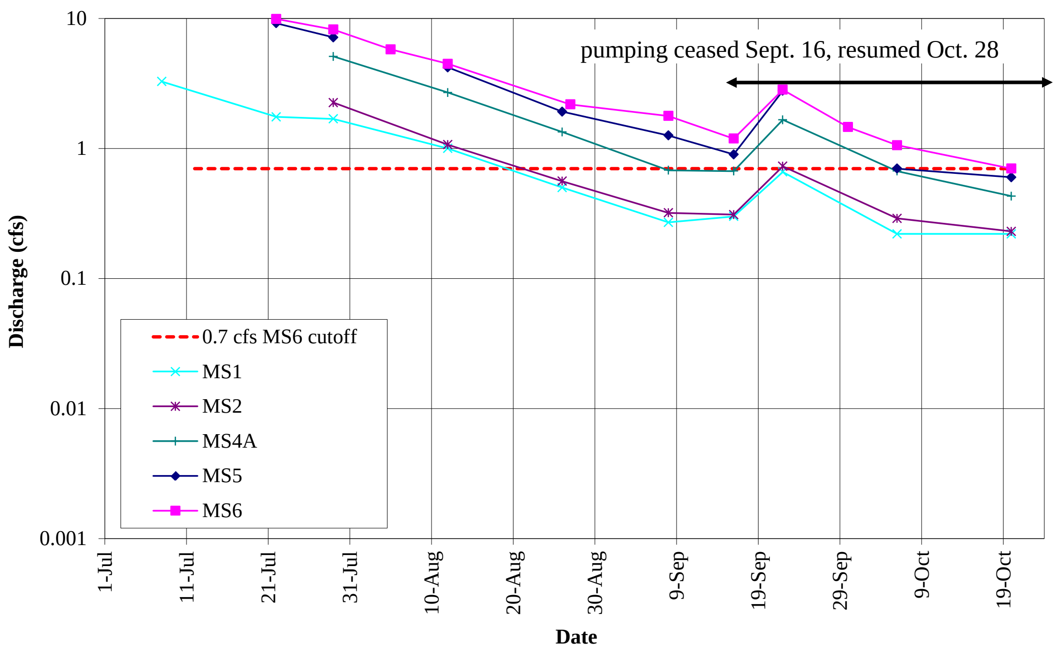


Figure 12. Discharge measurements at Upper Mattole mainstem sites, 2011.

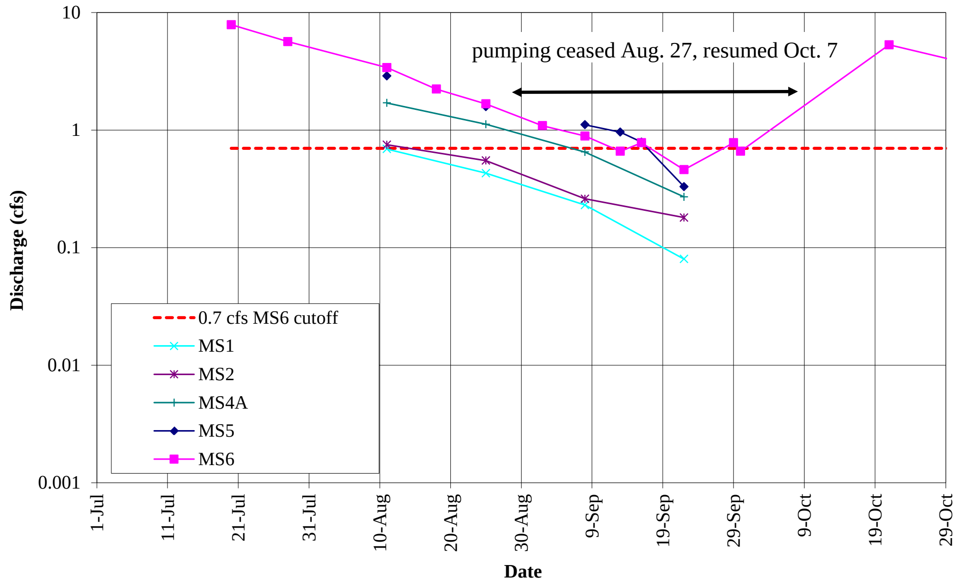
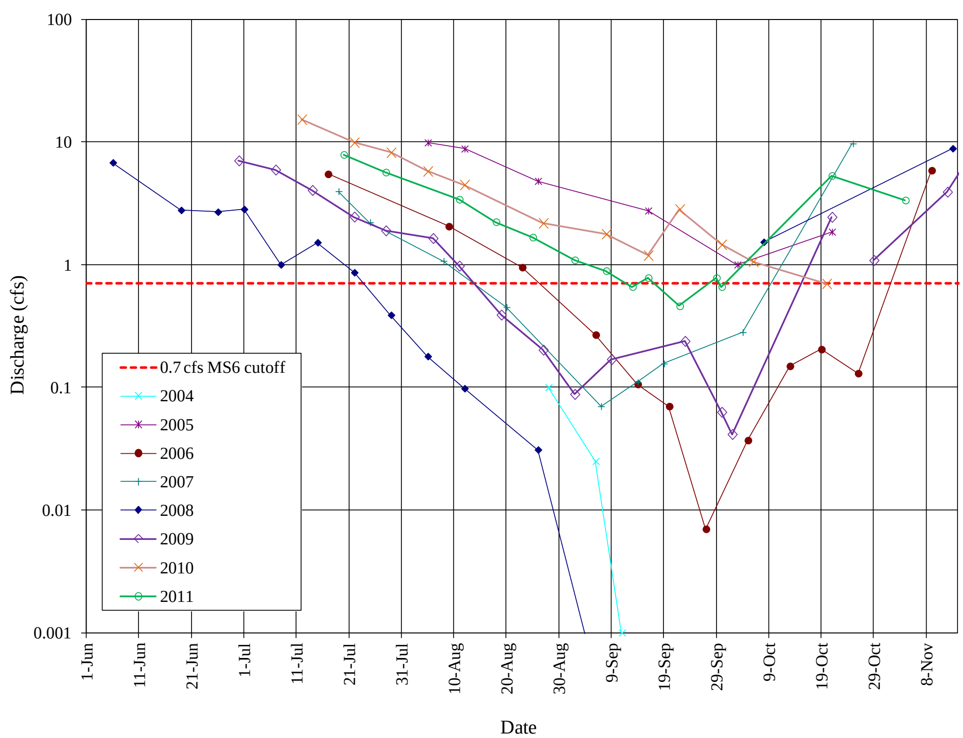



Figure 13 plots spot discharge measurements for MS6 across all monitoring years (2004-2011) along with the 0.7 cfs pumping cutoff. Although measurements were sparse in the earlier years, the effects of late spring rainfall can be readily seen in the delayed recessions in wetter years (e.g., 2005, 2010, 2011). 2008 was by far the driest with MS6 cutoff (0.7 cfs) reached in late July. In 2007, minimum flows were higher than in 2006 due to the small mid-summer rainfall and fog events, despite a drier spring.

Figure 13. Discharge measurements at MS 6, 2004-2011.



### *Tributary Flows*

In addition to mainstem flows, discharge at 15 tributaries was measured periodically in 2006-2011. Figures 14 and 15 show tributary discharges as percentages of the flows at MS6 to characterize their relative contributions to mainstem flows in the Lower Critical Reach. Figure 14 shows these percentages in simple discharge (cfs) while Figure 15 shows them in unit discharges (cfs/square mile). The tributaries are arranged by the bank from which each flows into the mainstem. All sites except for Bridge and Buck creeks are upstream of MS6.

In all but one case (Buck Creek), the right bank tributaries contributed much less to mainstem flows than did the left bank tributaries. In particular, Bridge Creek contributed substantial flows to the mainstem. Anderson Creek stands out as the smallest contributor to mainstem flows among the more prolific left bank tributaries.

Figure 14. Tributary discharges as percentages of MS6 discharge

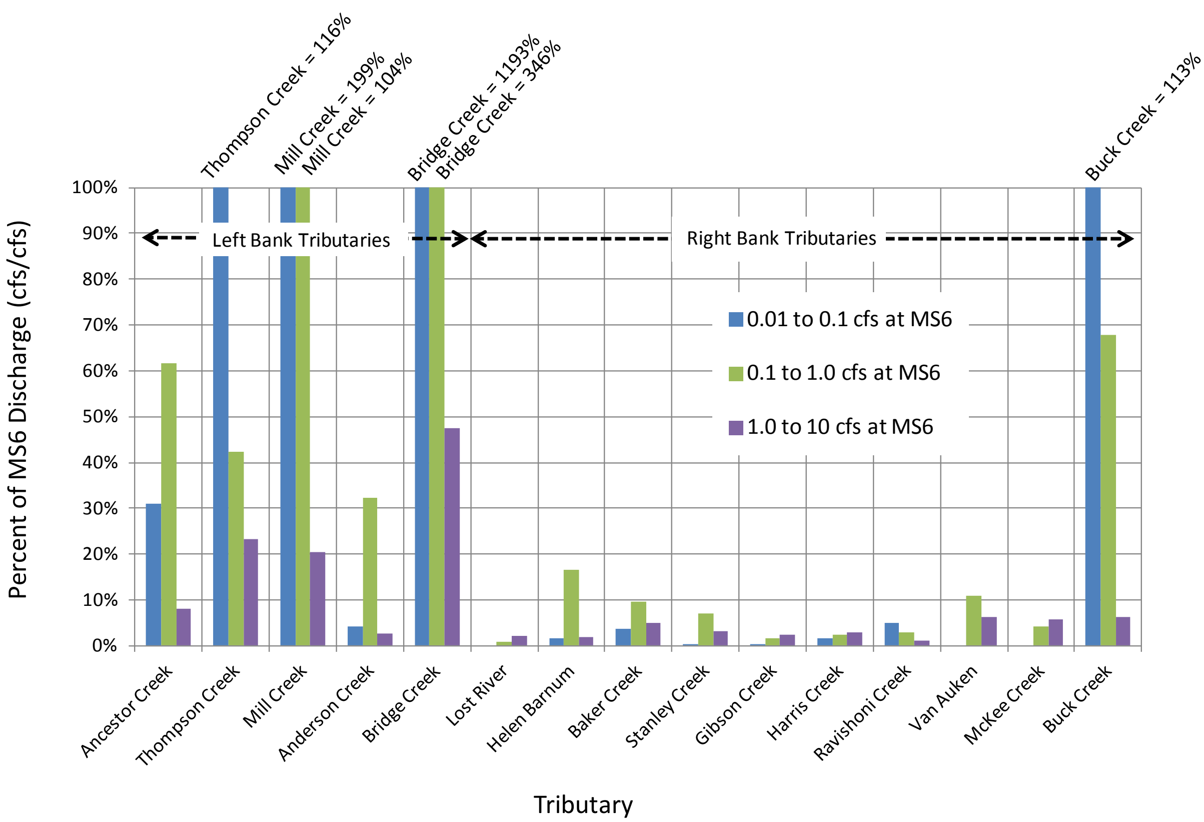
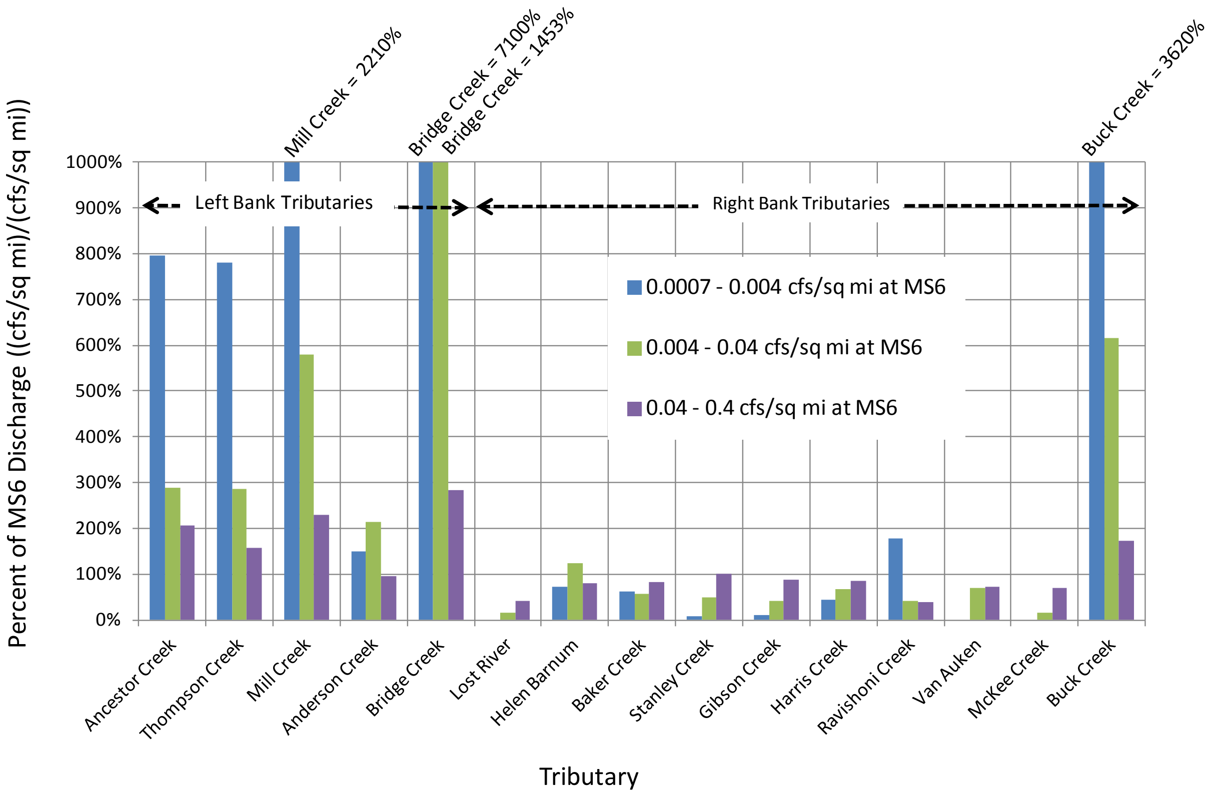


Figure 15. Tributary unit discharges as percentages of MS6 unit discharge




In Figures 16-18, three flow categories are plotted for monitoring performed within each category on different years. Figure 16 shows the lowest flow category (0.018 – 0.042 cfs at MS6), Figure 17 the medium flow category (0.18 – 0.22 cfs at MS6), and Figure 18 the highest flow category (0.78 to 1.07 cfs at MS6). These three flow categories were selected because they represent important thresholds in the mainstem. The lowest flow category , when flows are approaching zero, represent extreme drought conditions. Under these conditions, juvenile salmonids become trapped in disconnected pools and water quality becomes poor because of low dissolved oxygen. The medium flow category of approximately 0.2 cfs is the observed threshold above which most mainstem pools are connected. The highest flow category of approximately 1 cfs corresponds with the cutoff for the storage and forbearance program. Tributary monitoring in most years since 2006 has targeted monitoring these three categories for the purpose of evaluating each tributary's contribution to the mainstem as well as trend monitoring.

As with Figs. 14 and 15, left bank tributaries contribute much more to mainstem flows than right bank tributaries in the lowest category, and Buck Creek stands out as anomalously high among right bank tributaries. This generally holds true for the medium and highest flow categories, although Buck Creek's contributions diminish for the medium and higher flows. Lost River contributes the least across all categories.

The trend for each tributary across the years monitored is relatively constant among the three flow categories (see Figs. 17 and 18). For the lowest flow category, more variation between years is apparent particularly for the left bank tributaries. The right bank tributaries , with the exception of Buck Creek , consistently contribute almost no flow to the mainstem when flows at MS6 approach zero.

Figure 16. Dry season tributary discharges as percentages
of low MS6 discharges (0.018 - 0.042 cfs) for three different years.

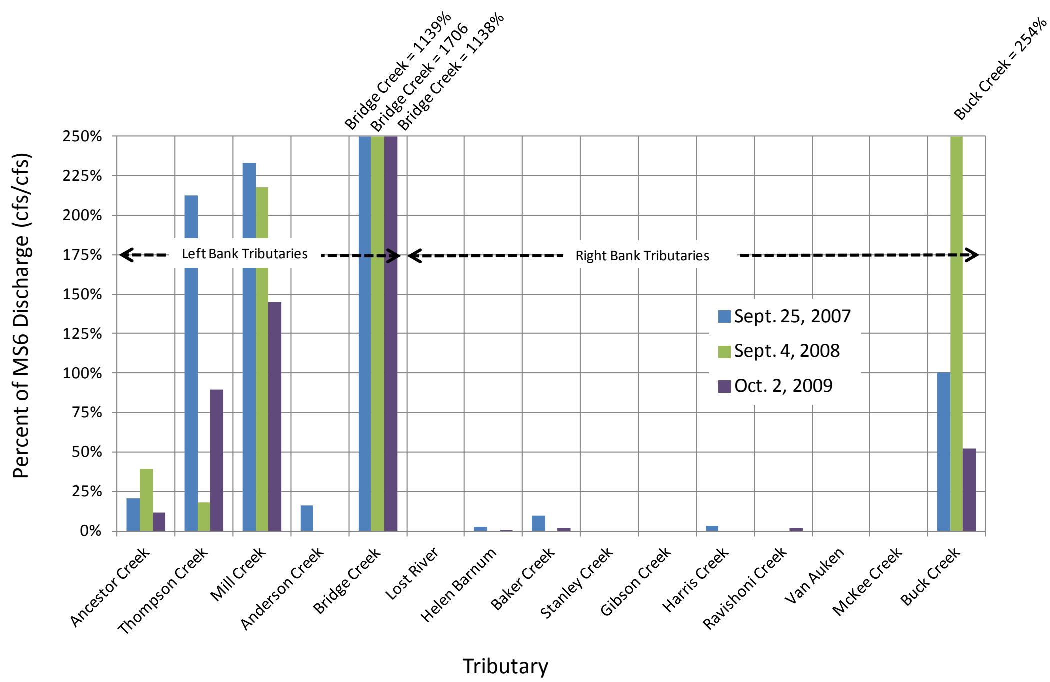



Figure 17. Dry season tributary discharges as percentages
of medium MS6 discharges (0.18 - 0.22 cfs) for three different years.

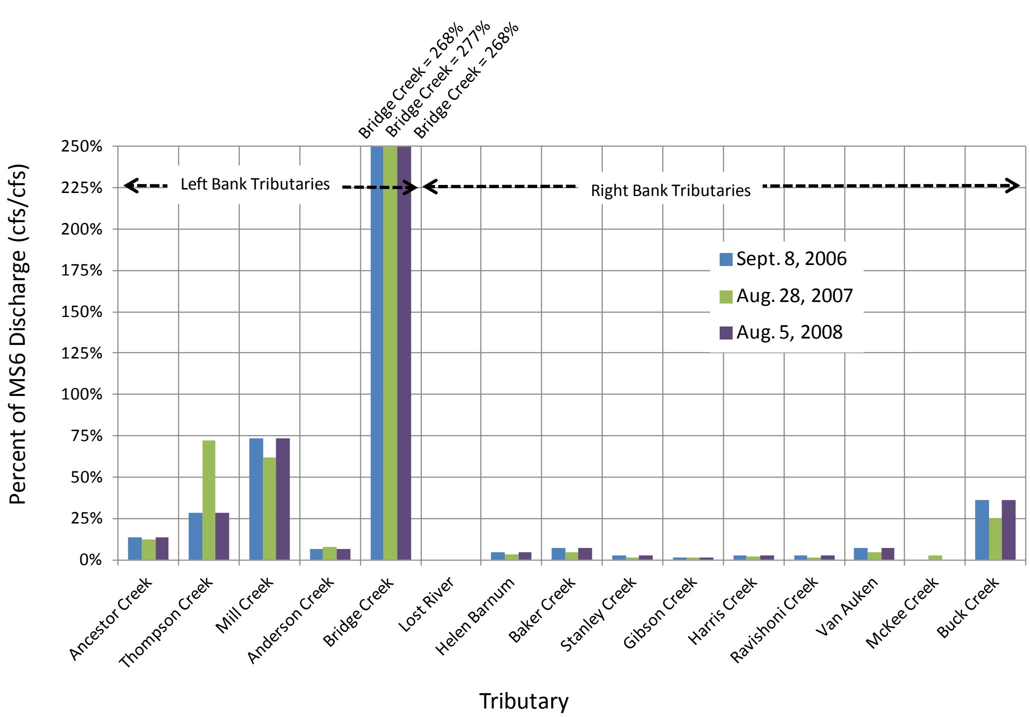
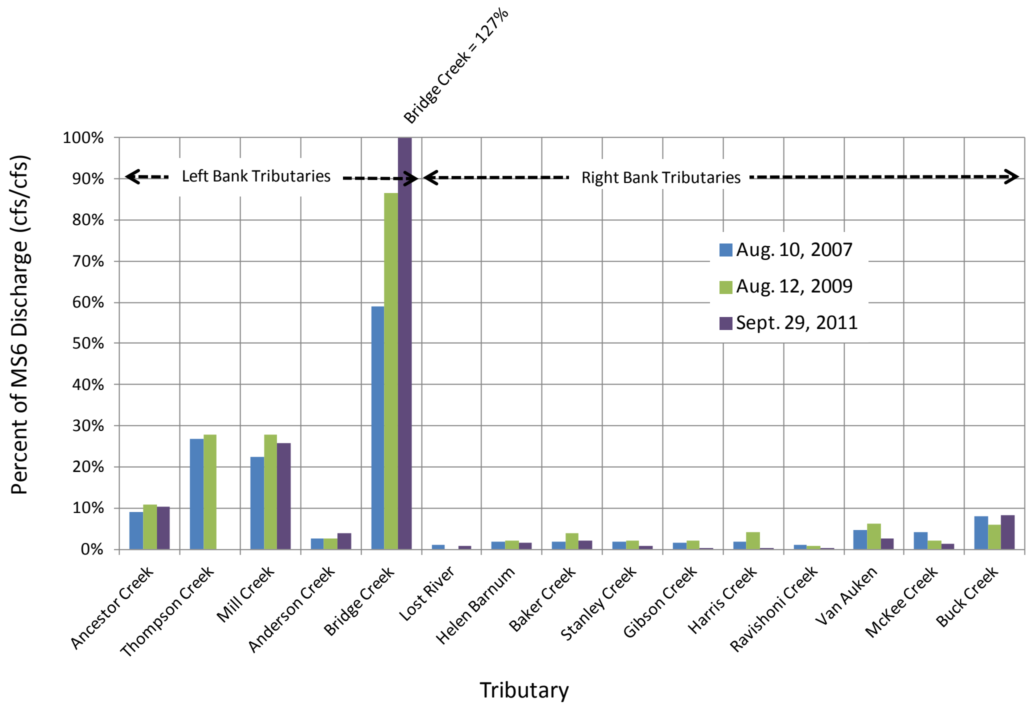


Figure 18. Dry season tributary discharges as percentages
of MS6 discharges (0.78 - 1.07 cfs) for three different years.



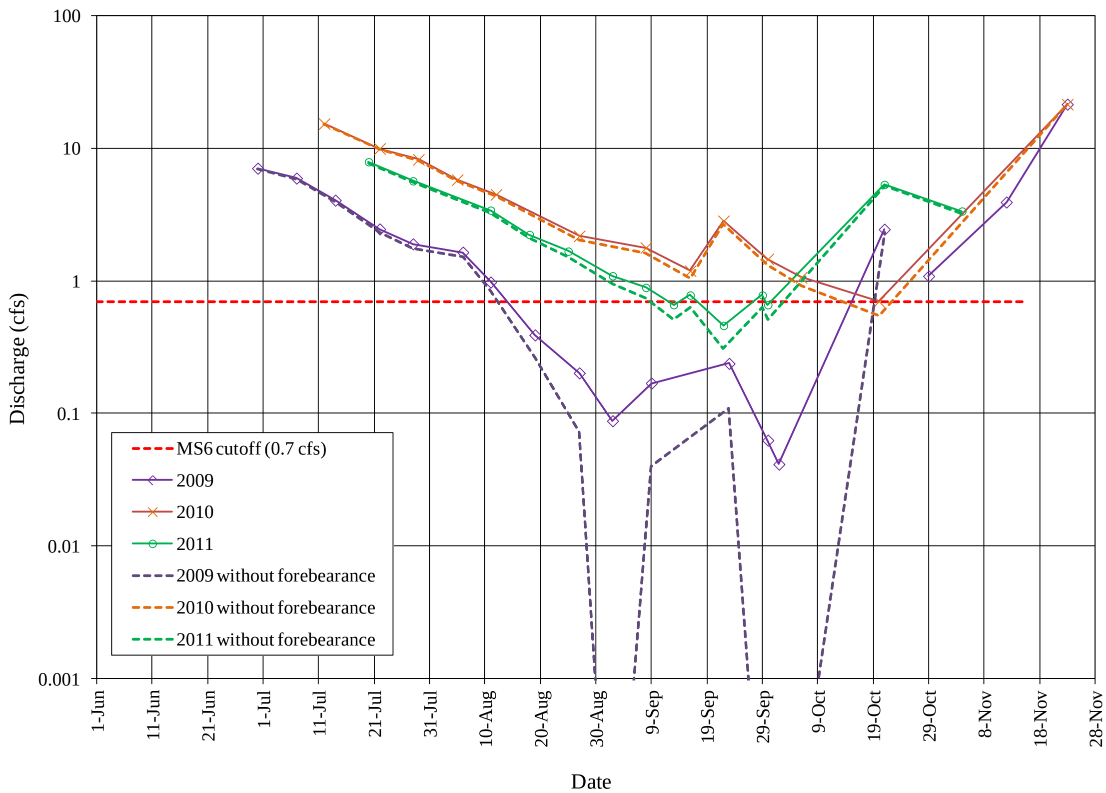

## *Forbearance Program Effectiveness and Flow Threshold Forecasting*

Table 3 lists the annual progress of the forbearance program in the junction reach located between MS5 and MS6. Maximum and average pumping rates for participants and subsequent estimates of reductions in water withdrawals are also listed. To examine the hydrologic benefits from the forbearance program, Figure 19 plots MS6 spot measurements for 2009-2011 and the lower flows expected in the absence of the program (no restrictions on pumping) based on the estimates in Table 3. In the wetter years (2010 and 2011), although flows are relatively unaffected by the reduced pumping, but in a dry year (2009) the number of days below the cutoff in lengthened by about one week. More importantly, the minimum flows are much lower, almost certainly causing flow at MS6 to cease for extended periods.

Table 3. Participation in the forbearance program from 2007 to 2011 for the junction reach with estimated pumping rates.

| Year | No. of landowners entering program | Cum. no. land-owners | Max. pump capacity (gpm) | Ave. pumping rate (gpm) | Cum. pump capacity reduction (gpm) | Cum. reductions in ave. pumping rate (gpm) | Cum. reductions in pumping capacity (cfs) | Cum. reductions in ave. pumping rate (cfs) |
|---|---|---|---|---|---|---|---|---|
| 2007 | 1 | 1 | 10 | 0.64 | 10 | 0.6 | 0.0223 | 0.0014 |
| 2008 | 2 | 3 | 20 | 2.65 | 30 | 3.3 | 0.0668 | 0.0073 |
| 2009 | 2 | 5 | 28 | 2.43 | 58 | 5.7 | 0.1292 | 0.0127 |
| 2010 | 1 | 6 | 10 | 0.28 | 68 | 6.0 | 0.1515 | 0.0134 |
| 2011 | 0 | 6 | --- | --- | 68 | 6.0 | 0.1515 | 0.0134 |
| Totals | 6 | --- | 68 | 6.00 | --- | --- | | --- |

Figure 19. Discharges at MS6 with and without forebearance, 2009-2011.




Daily rainfall data from the Thompson weather station was used to compute daily antecedent precipitation index (API, inches). API is a running computation indexing the moisture content of soils and may also correlate with groundwater levels. It is computed by taking each day's rainfall starting well before the dry season, adding any new rainfall each day to the previous day's API decayed by a constant. Testing indicated the best correlation of API and low flow was derived using a decay factor of 0.98. Figure 20 shows API for the 2006-2011 dry seasons, spanning the life of the program to date. The effect of summer rains can be seen in 2007, 2009 and 2010, as is the arrival of fall rains in late September most years except in 2006 and 2010 when fall rains were delayed.

Two years with similar API were selected from Figure 20 for comparison of low flow discharges to evaluate possible benefits of the forbearance program. The years 2007 and 2009 had similar API (see Fig. 20), and between these two years just four additional participants joined the forbearance program in the junction reach. Figure 21 plots MS5 and MS6 discharges and API for both years. MS6 discharge remained higher in 2009 than in 2007 for much of the dry season (early Aug. through mid-Sept.). Additionally, the losing reach between MS5 and MS6 persisted for most of August and September in 2007, while no losing reach occurred in 2009. Oddly, 2009 flows at MS6 dropped to a season-low after a summer rain on Sept. 11 until more substantial rainfall occurred a month later.

Figure 20. API for 2006-2011.

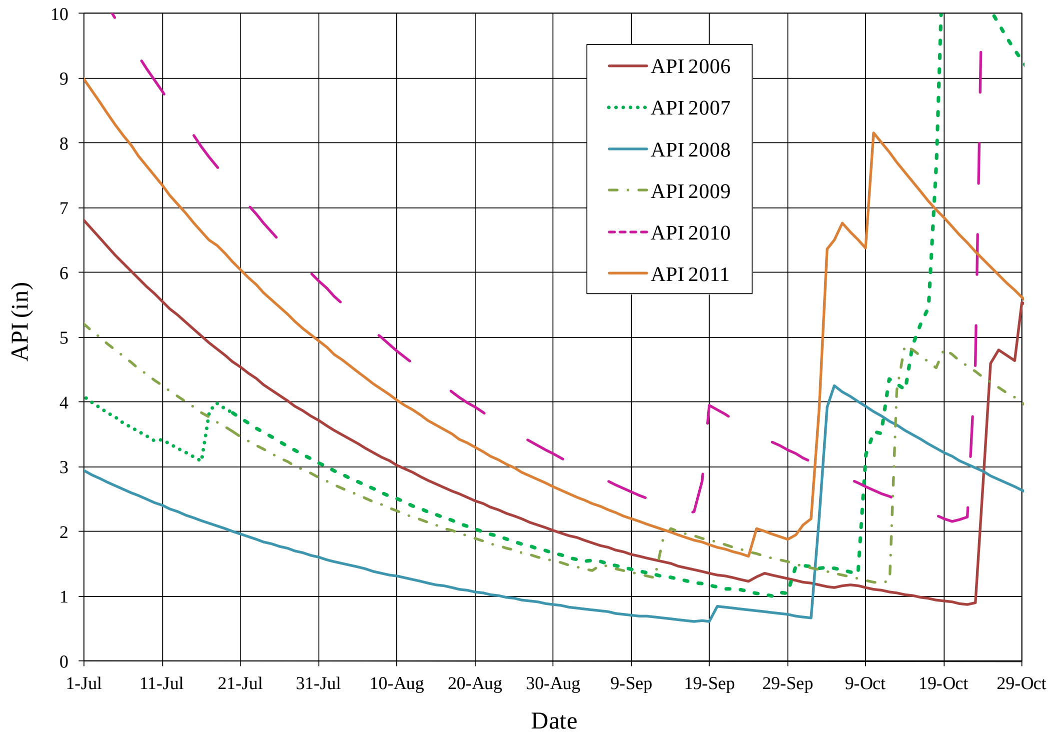



Figure 21. MS5 and MS6 discharges for 2007 and 2009.

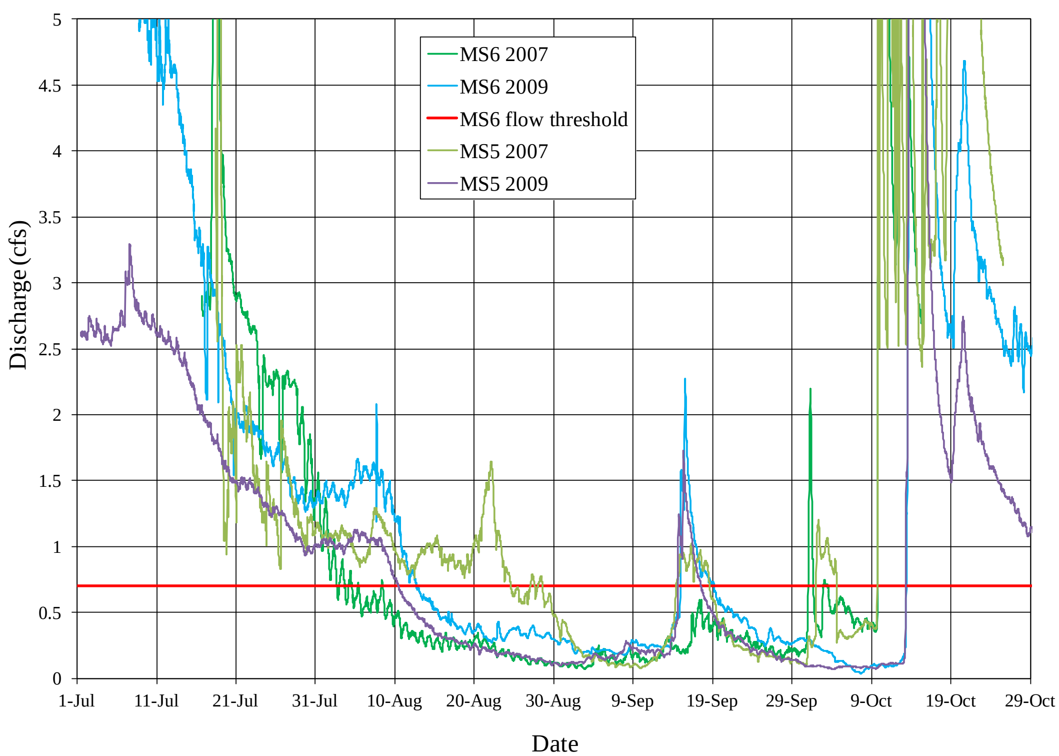


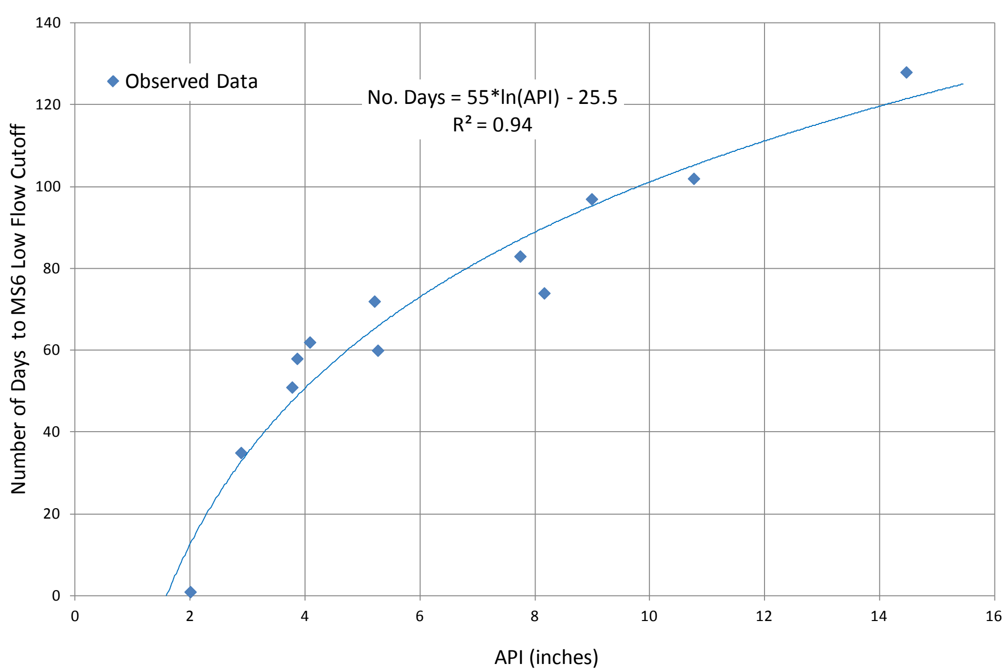
Table 4 lists annual pumping cessation data, API and Ettersburg low flows for 2006-2011. Notifying forbearance program participants in advance of when the flow threshold at MS6 (0.7 cfs) will be reached would allow water users to prepare for cessation of pumping from the river and thereby minimize disruptions related to water storage and use. July 1 each year partitions the spring season from the low flow season fairly well. API on July 1for all monitoring years was computed and regressed against the number of days after July 1 that the flow cutoff threshold at MS6 was reached. Figure 22 shows the plotted data and the regression equation derived from the data. A high R-squared of 0.91 indicates the utility of API for forecasting the date that the cutoff is attained. It must be remembered that any unusual weather events, such as summer rain or fog periods, will delay the arrival of the low flow threshold by an unknown time period. A spreadsheet is provided under separate cover to facilitate API computation each summer, using daily rainfall beginning the previous year, and cutoff date estimation. The running API can be adjusted for summer rainfall events by adding new rainfall to the spreadsheet as it occurs, but other weather events (e.g., fog, cooling periods) cannot.

Table 4. Dates and discharges bracketing pumping cessation, annual number of days of pumping cessation, API on July 1, and Ettersburg (ETT) 7-day low flow, 2006-2011.

| Year | No. days | Start date and discharge | | End date and discharge | | API (in) on July 1 | ETT 7-day low flow (cfs) |
|---|---|---|---|---|---|---|---|
| | | Date | Q (cfs) | Date | Q (cfs) | | |
| 2006 | 78 | 08/23/06 | 0.95 | 11/09/06 | 5.9 | 8.2 | 5.3 |
| 2007 | 56 | 08/20/07 | 0.45 | 10/15/07 | 4.8 | 4.1 | 6.0 |
| 2008 | 111 | 07/22/08 | 0.70 | 11/10/08 | 10 | 2.9 | 3.2 |
| 2009 | 69 | 08/13/09 | 0.70 | 10/21/09 | 2.4 | 5.2 | 5.9 |
| 2010* | 32 | 09/16/10 | 1.19 | 10/28/10 | >15 | 10.8 | 9.8 |
| 2011 | 17 | 08/27/11 | 1.60 | 10/07/11 | >15 | 9.0 | 8.5 |

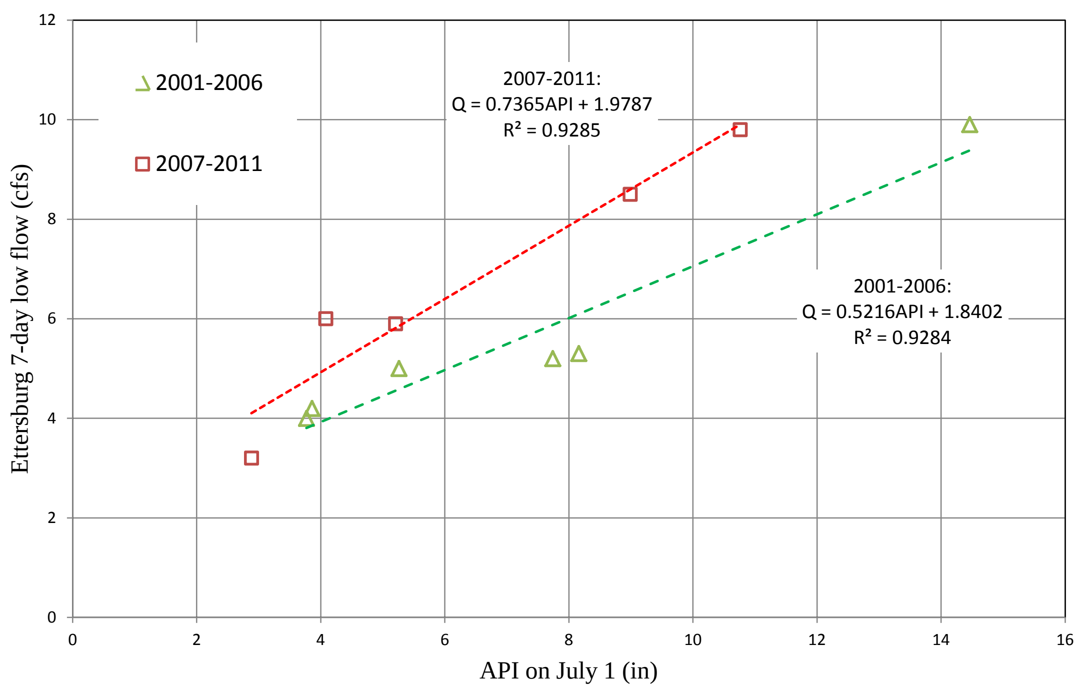
*Due to a precipitation event on 9/20/2010-9/21/2010 the actual no pump season lasted only seven days in 2010. Official notices of the no pump season ending weren't sent out until October 28th.

Figure 22. Predictive relationship for MS6 flow cutoff date from API.



API can also be compared to low flow discharges measured at the Ettersburg gaging station. Figure 23 shows API on July 1 vs. the 7-day low flow for Ettersburg for an eleven-year period (2001-2011). The period is divided in to that before the forbearance program had begun (2001-2006) and afterward (2007-2011). Linear regression lines are fit to the data for each period, forming two distinct, relatively strong relationships indicating the ability to forecast low flows from API at the onset of the low flow season. There appears to have been a shift in the relationship around 2006. As indicated, Ettersburg flows were much lower (slope = 0.52 for 2001-2006) prior to the beginning of the forbearance program (prior to 2006) than they are later (slope = 0.74 for 2007-2011). However, the flow increases in the latter period are too large to be due solely to the pump program. Other factors, such as summer rainfall, reduced evapotranspiration from recent fires and/or forest thinning, possible alterations in riparian pumping between MS6 and Ettersburg, or other unknowns may be primarily responsible for the increased flows of late. Investigating the causes for this apparent change in dry season hydrology at Ettersburg was beyond the scope of this study.

Figure 23. API vs. Ettersburg 7-day low flow for two periods.

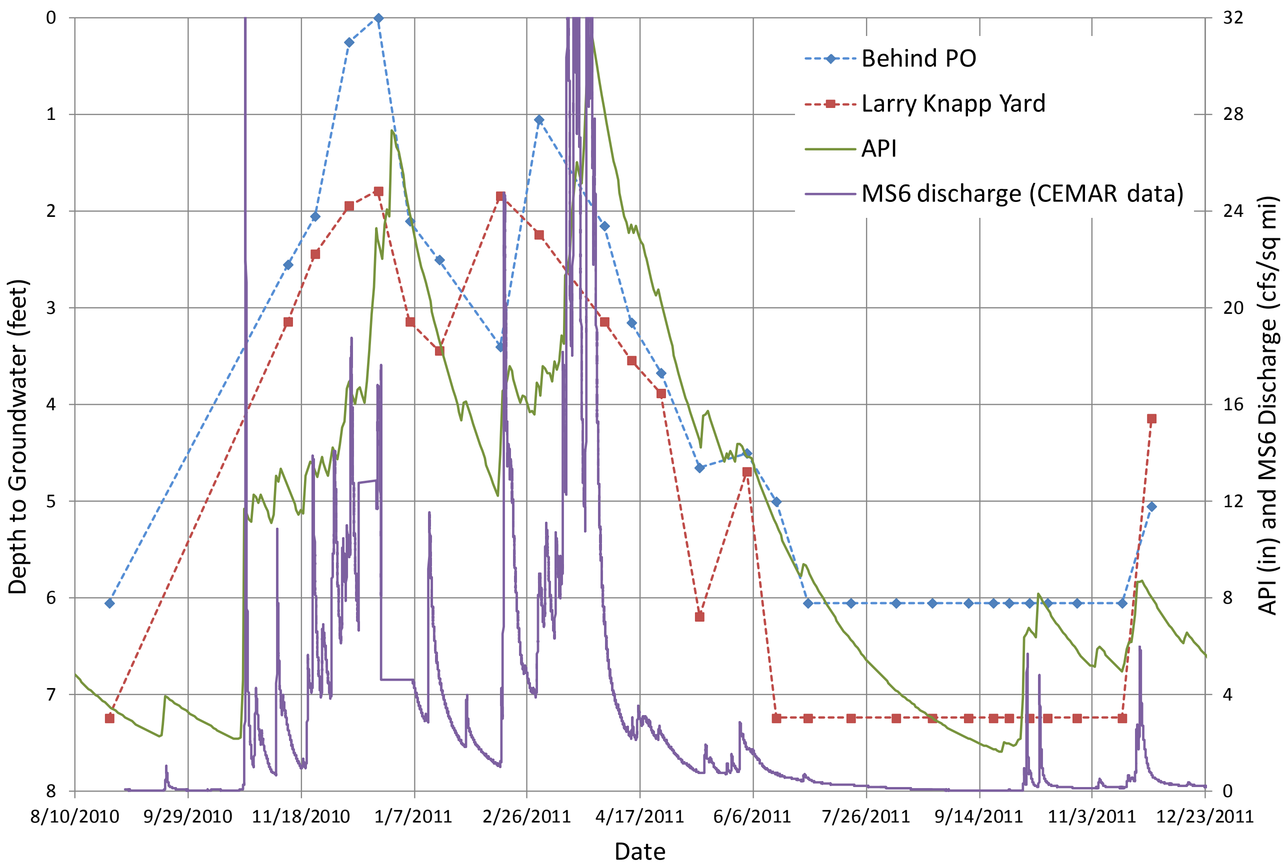



### *Groundwater Observations*

Groundwater is the sole source of streamflow during the dry season and thus important to the SFI low flow project. Beginning in 2007 SFI staff, in cooperation with BLM staff, measured groundwater levels in several wells, beginning a project to investigate the potential to augment low flows with localized groundwater enhancement. As mentioned above, Buck Creek was an unusually high contributor to mainstem flows among right bank tributaries. A characteristic that sets Buck Creek apart from its neighbors is the presence of four ponds along Buck Creek's main channel; these ponds elevate local groundwater levels, increasing aquifer storage and sustaining low flows, which would explain Buck Creek's anomalously high flow contributions to the mainstem. It is hypothesized that these ponds mimic a condition that existed long ago, before concerted efforts began to remove log jams that were perceived as barriers to upstream fish migration. Log jams typically store coarse sediment upstream and so could also augment aquifer storage to sustain summer flows. The potential exists, then, for restoring higher mainstem summer low flows by restoring log jams to tributaries.

Figure 24 shows depths to groundwater for two well sites near the MS6 mainstem discharge measurement site, MS6 discharges, and API (note the flat line portions of the groundwater data represent dry well conditions). There is considerable covariation in these data, suggesting interdependencies that might be exploited for predictive purposes beyond the scope of this study.

Figure 24. Groundwater depths near MS6, MS6 discharge and API, 2010-11.




## Conclusions and Recommendations

1. With the exception of 2005, 2010 and 2011, drought conditions have been unusually severe since 2002 in the Upper Mattole River, with 2008 being the driest of the 61-year discharge record for the Mattole River near Petrolia (7-day low flow return period >1000 years).

2. Substantial amounts of late spring rainfall postpone the date at which minimum low flows are attained, potentially shortening the amount of time low flow conditions persist and maintaining year-round flow at some reaches that might otherwise go dry.

3. Even small amounts of rainfall (e.g., 0.25”) in the driest time of the year can increase discharge and provide temporary relief for fish from drought conditions. In July, 2007, one inch of rainfall elevated subsequent flows for almost a two-week period. Fog in the Upper Mattole, a relatively unusual occurrence, can also reduce the recession rate of low flows and perhaps elevate low flows.

4. When flows at MS6 are just below the 0.7 cfs cutoff, fog and small rainfall events may cause flows to slightly exceed the cutoff, allowing pumping to resume for a time. However, resumption of pumping can reduce flows to below the cutoff, so streamflows following a resumption of pumping following small rainfall or fog events should be closely monitored.

5. The usefulness of API for predicting low flow discharge and its relationship to groundwater levels was investigated. API can be tracked as the dry season approaches to assist forecasting the date at which the MS6 flow threshold will be achieved. API can also be used to evaluate relationships between seasonal rainfall, groundwater levels and low flows. As such it is an important tool for evaluating the extent to which low flows are caused by timing and amount of rainfall.

6. Upper Mattole tributaries performed fairly consistently for the years 2006-2011 relative to their contribution to the mainstem. Right bank tributaries contributed much less than left bank tributaries with the exception of Buck Creek.

7. Based on limited data and analysis, declining groundwater levels correspond with declining streamflows and API. Restoration of groundwater hydrology and increased groundwater levels would likely result in higher summer streamflows. Further analysis of groundwater and streamflows data is needed to quantify potential streamflow benefits.

8. The junction reach (bracketed by MS5 and MS6) experienced a losing reach period most years prior to 2009, typically beginning in September. The likely explanations are a combination of human use becoming high relative to streamflow at that time, and reductions in downstream accretion (surface water and seepage contributions to the channel).

9. Beginning in 2009, the forbearance program's effectiveness, as indicated by reduced losing reach conditions in the junction reach (bracketed by MS5 and MS6), appeared to be providing measurable benefits to the low flow problem. With 70% of the pumps turned off, the losing reach period observed in most years prior to 2009 has significantly decreased both in length and magnitude. With growing participation in the forbearance program, additional benefits to summer low flows will continue to accrue and improve conditions for fish.

## *LITERATURE CITED*

Klein, R.D. 2004. Preliminary hydrologic assessment of low flows in the Mattole River Basin. Report to Sanctuary Forest, Inc. 22 p.

Klein, R.D. 2007. Hydrologic assessment of low flows in the Mattole River Basin. Report to Sanctuary Forest, Inc. 22 p.

North Coast watershed Assessment Program (NCWAP): Mattole River Assessment. 2000. Appendix C: Hydrology. 26 p.

## *APPENDIX A: UPPER MATTOLE RIVER MAINSTEM DISCHARGES, 2004-2011*

| Date | MS1 cfs | MS2 cfs | MS3 cfs | MS4 cfs | MS5 cfs | MS6 cfs | Date | MS1 cfs | MS2 cfs | MS3 cfs | MS4 cfs | MS5 cfs | MS6 cfs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 (former number) | | | *(MS1)* | *(MS2)* | | *(MS4)* | 2008 (continued) | | | | | | |
| 08/28/04 | | | 0.07 | 0.16 | | 0.10 | 10/23/08 | | | | | | |
| 09/06/04 | | | 0.01 | 0.04 | | 0.03 | 11/13/08 | 1.16 | 1.43 | | 5.45 | 8.15 | 8.85 |
| 09/11/04 | | | 0.00 | 0.02 | | 0.00 | 2009 | | | | | | |
| 09/21/04 | | | 0.00 | 0.01 | | 0.00 | 06/30/09 | | | | | | 7.05 |
| 09/28/04 | | | 0.00 | 0.00 | | 0.00 | 07/07/09 | | | | | | 5.94 |
| 2005 | | | | | | | 07/14/09 | | | | | 3.78 | 4.05 |
| 08/05/05 | | | 1.40 | 5.80 | 6.91 | 9.88 | 07/22/09 | 0.49 | 0.63 | | 1.58 | 2.57 | 2.46 |
| 08/12/05 | 0.87 | | | | | 8.80 | 07/28/09 | 0.37 | 0.46 | | 1.07 | 1.75 | 1.90 |
| 08/26/05 | 1.08 | | 1.57 | 5.95 | 4.75 | 4.80 | 08/06/09 | | | | | 1.78 | 1.64 |
| 09/16/05 | 0.47 | 0.52 | 0.58 | 1.80 | 1.86 | 2.75 | 08/11/09 | 0.23 | 0.21 | | 0.53 | 0.90 | 0.98 |
| 10/03/05 | 0.33 | 0.26 | 0.30 | 0.80 | 1.06 | 1.00 | 08/19/09 | | | | | 0.36 | 0.39 |
| 10/21/05 | 0.32 | | 0.47 | 1.16 | | 1.85 | 08/27/09 | 0.06 | 0.03 | | 0.08 | 0.16 | 0.20 |
| 2006 | | | | | | | 09/02/09 | | | | | | 0.09 |
| 07/17/06 | 1.12 | 1.18 | | | 4.40 | 5.47 | 09/09/09 | 0.06 | 0.08 | | 0.09 | 0.13 | 0.17 |
| 08/02/06 | 0.45 | 0.58 | | | | | 09/23/09 | 0.08 | 0.09 | | 0.13 | 0.24 | 0.24 |
| 08/09/06 | 0.47 | 0.53 | | 1.22 | 2.13 | 2.05 | 09/30/09 | 0.03 | 0.01 | | 0.04 | 0.06 | 0.06 |
| 08/23/06 | 0.19 | 0.22 | | 0.78 | 0.84 | 0.95 | 10/02/09 | | | | | | 0.04 |
| 09/06/06 | 0.06 | 0.11 | | 0.24 | 0.30 | 0.27 | 10/21/09 | 0.48 | 0.67 | | 1.40 | | 2.44 |
| 09/14/06 | 0.02 | 0.03 | | 0.09 | 0.18 | 0.11 | 10/22/09 | | | | | 1.37 | |
| 09/20/06 | 0.02 | 0.00 | | 0.03 | 0.12 | 0.07 | 10/29/09 | | | | | 0.57 | 1.09 |
| 09/27/06 | 0.03 | 0.00 | | 0.03 | 0.06 | 0.01 | 11/12/09 | | | | | 3.19 | 3.92 |
| 10/05/06 | 0.08 | 0.06 | | 0.11 | 0.23 | 0.04 | 11/23/09 | | | | | 20.47 | 21.39 |
| 10/13/06 | 0.06 | 0.03 | | 0.10 | 0.18 | 0.15 | 2010 | | | | | | |
| 10/19/06 | 0.11 | 0.08 | | 0.18 | 0.29 | 0.20 | 7/8/2010 | 3.27 | | | | | |
| 10/26/06 | | | | 0.09 | 0.19 | 0.13 | 7/12/2010 | | | | | | 15.28 |
| 11/09/06 | 0.95 | 1.28 | | | | 5.86 | 7/22/2010 | 1.75 | | | | 9.19 | 9.92 |
| 2007 | | | | | | | 7/29/2010 | 1.69 | 2.25 | | 5.10 | 7.15 | 8.21 |
| 07/09/07 | 0.59 | 0.70 | | | | | 8/5/2010 | | | | | | 5.78 |
| 07/19/07 | 0.89 | 1.15 | | 2.50 | | 3.96 | 8/12/2010 | 1.00 | 1.07 | | 2.69 | 4.20 | 4.48 |
| 07/25/07 | 0.49 | 0.62 | | 1.39 | 2.51 | 2.21 | 8/27/2010 | 0.50 | 0.56 | | 1.34 | 1.92 | 2.18 |
| 08/08/07 | 0.26 | 0.53 | 0.30 | 0.83 | 1.18 | 1.07 | 9/8/2010 | 0.27 | 0.32 | | 0.68 | 1.26 | 1.78 |
| 08/20/07 | 0.20 | 0.25 | 0.20 | 0.36 | 0.61 | 0.45 | 9/16/2010 | 0.30 | 0.31 | | 0.67 | 0.90 | 1.19 |
| 09/07/07 | 0.03 | 0.00 | 0.01 | 0.12 | 0.06 | 0.07 | 9/22/2010 | 0.66 | 0.73 | | 1.66 | 2.78 | 2.83 |
| 09/14/07 | | | | | 0.21 | 0.11 | 9/30/2010 | | | | | | 1.46 |
| 09/19/07 | 0.05 | 0.06 | 0.11 | | 0.32 | 0.16 | 10/6/2010 | 0.22 | 0.29 | | 0.67 | 0.70 | 1.06 |
| 10/04/07 | 0.20 | 0.05 | 0.07 | 0.08 | 0.40 | 0.28 | 10/20/2010 | 0.22 | 0.23 | | 0.43 | 0.60 | 0.70 |
| 10/25/07 | 1.12 | 1.32 | 1.73 | 6.37 | 8.86 | 9.70 | 11/23/2010 | | | | | | 21.39 |
| 2008 | | | | | | | 2011 | | | | | | |
| 06/06/08 | | | | | | 6.79 | 07/20/11 | | | | | | 7.88 |
| 06/19/08 | | | | | | 2.78 | 07/28/11 | | | | | | 5.66 |
| 06/26/08 | 0.44 | 0.53 | | 1.64 | 3.17 | 2.69 | 08/11/11 | 0.69 | 0.75 | | 1.70 | 2.89 | 3.40 |
| 07/01/08 | | | | | | 2.83 | 08/18/11 | | | | | | 2.23 |
| 07/08/08 | 0.25 | 0.24 | | 1.05 | 1.84 | 1.00 | 08/25/11 | 0.43 | 0.55 | | 1.12 | 1.58 | 1.67 |
| 07/15/08 | 0.27 | 0.26 | | 0.89 | 1.28 | 1.52 | 09/02/11 | | | | | | 1.09 |
| 07/22/08 | | | | | | 0.86 | 09/08/11 | 0.23 | 0.26 | | 0.65 | 1.11 | 0.89 |
| 07/29/08 | 0.08 | 0.08 | | 0.24 | 0.42 | 0.39 | 09/13/11 | | | | | 0.96 | 0.66 |
| 08/05/08 | | | | | | 0.18 | 09/16/11 | | | | | 0.79 | 0.78 |
| 08/12/08 | 0.03 | 0.02 | | 0.07 | 0.14 | 0.10 | 09/22/11 | 0.08 | 0.18 | | 0.27 | 0.33 | 0.46 |
| 08/26/08 | 0.00 | 0.00 | | 0.01 | 0.04 | 0.03 | 09/29/11 | | | | | | 0.78 |
| 09/09/08 | 0.00 | 0.00 | | 0.00 | 0.00 | 0.00 | 09/30/11 | | | | | | 0.66 |
| 09/24/08 | 0.00 | 0.00 | | 0.00 | 0.00 | 0.00 | 10/21/11 | | | | | | 5.31 |
| 10/08/08 | | 0.29 | | 1.68 | 1.72 | 1.53 | 11/04/11 | | | | | | 3.35 |

## *APPENDIX B: UPPER MATTOLE RIVER TRIBUTARY DISCHARGE, 2007-2011.*

**Discharge (cfs)**

| | 2007 | | | 2008 | | |
|---|---|---|---|---|---|---|
| Tributary | 8/10/2007 | 8/28/2007 | 9/25/2007 | 7/1/2008 | 8/5/2008 | 9/4/2008 |
| Ancestor Creek | 0.096 | 0.026 | 0.007 | 0.180 | 0.024 | 0.007 |
| Lost River | 0.012 | 0.000 | 0.000 | 0.096 | 0.000 | 0.000 |
| Helen Barnum | 0.019 | 0.007 | 0.001 | 0.056 | 0.009 | 0.000 |
| Thompson Creek | 0.286 | 0.156 | 0.071 | 0.592 | 0.051 | 0.003 |
| Baker Creek | 0.019 | 0.009 | 0.003 | 0.234 | 0.012 | 0.000 |
| Stanley Creek | 0.020 | 0.003 | 0.000 | 0.100 | 0.005 | 0.000 |
| Gibson | 0.016 | 0.003 | 0.000 | 0.058 | 0.002 | 0.000 |
| Harris Creek | 0.021 | 0.005 | 0.001 | 0.096 | 0.005 | 0.000 |
| Mill Creek | 0.239 | 0.133 | 0.078 | 0.630 | 0.131 | 0.039 |
| Ravishoni | 0.012 | 0.002 | 0.000 | 0.053 | 0.005 | 0.000 |
| Anderson Creek | 0.027 | 0.017 | 0.005 | 0.081 | 0.012 | 0.000 |
| Van Auken | 0.049 | 0.010 | 0.000 | 0.217 | 0.013 | 0.000 |
| McKee Creek | 0.044 | 0.006 | 0.000 | 0.212 | 0.000 | 0.000 |
| Bridge Creek | 0.631 | 0.598 | 0.380 | 1.110 | 0.480 | 0.304 |
| Buck | 0.085 | 0.054 | 0.034 | 0.235 | 0.065 | 0.045 |
| MS6 | 1.070* | 0.216 | 0.033 | 2.830 | 0.179 | 0.018 |

* actually measured on 8/8/2007.

| | 2009 | | | 2010 | 2011 |
|---|---|---|---|---|---|
| Tributary | 8/12/2009 | 9/2/2009 | 10/2/2009 | 8/5/2010 | 9/29/2011 |
| Ancestor Creek | 0.106 | 0.052 | 0.005 | 0.510 | 0.080 |
| Lost River | | 0.000 | 0.000 | | 0.006 |
| Helen Barnum | 0.020 | 0.003 | 0.000 | 0.107 | 0.013 |
| Thompson Creek | 0.273 | 0.140 | 0.037 | 1.810* | |
| Baker Creek | 0.039 | 0.004 | 0.001 | 0.430* | 0.016 |
| Stanley Creek | 0.021 | 0.001 | 0.000 | 0.230 | 0.007 |
| Gibson Creek | 0.021 | 0.001 | 0.000 | 0.206 | 0.001 |
| Harris Creek | 0.040 | 0.003 | 0.000 | 0.210 | 0.001 |
| Mill Creek | 0.271 | 0.193 | 0.060 | 0.980 | 0.200 |
| Ravishoni Creek | 0.007 | 0.017 | 0.001 | 0.009 | 0.002 |
| Anderson Creek | 0.025 | 0.000 | 0.000 | 0.140 | 0.030 |
| Van Auken | 0.059 | 0.000 | 0.000 | 0.360 | 0.020 |
| McKee Creek | 0.021 | 0.000 | 0.000 | | 0.010 |
| Bridge Creek | 0.844 | 0.771 | 0.472 | 2.560 | 0.990 |
| Buck Creek | 0.059 | 0.044 | 0.022 | 0.220* | 0.064 |
| MS6 | 0.977 | 0.088 | 0.042 | 5.780 | 0.780 |

* these measurements were actually made on 7/30/2010