Shrinking Streamflows in the Redwood Region[1]

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Abstract

The ongoing, severe drought in the redwood ecosystem has many ramifications, including loss of summer rearing habitat for juvenile salmonids. Many 'perennial' streams now cease to flow during parts of the summer and fall, either drying up completely or disconnecting pools as riffles go dry, subjecting fish to increased predation, high water temperatures, and desiccation. Numerous factors have contributed to this hydrologic impairment, including natural hydrologic cycles, legacy land use effects, human consumptive uses, and climate change. The search for solutions is now in full swing, and will be most effective if based on site-specific monitoring to identify controllable causes and a non-confrontational approach to changing water usage in time and space.

Monitoring of low flows in the region has been ramping up in recent years, led by the program pioneered by Sanctuary Forest, a non-profit group located in the Upper Mattole River. Their data collection program has run from 2004 through the present and consists of measuring low summer/fall stream discharge at a network of key locations in the watershed. The primary goals of hydrologic monitoring are to identify locations of extreme flow impairment and to guide efforts for water conservation.

A crucial element of Sanctuary Forest's program has been to heighten the awareness of landowners of the low flow problem and involve those willing in a forbearance program that offers increased water storage capacity in exchange for cessation of water withdrawals during drought conditions. The date of water withdrawal cessation varies each year, but this date is important for landowners involved with the program: it determines when their water sources switch from the creeks to their storage tanks. Correlations with online-accessible, real time streamflow and precipitation data have provided convenient means to determine, and even forecast, the date when pumps must be turned off.

Recent data show that Sanctuary Forest's forbearance program is having a positive effect on low flows. Measurable increases in low flows in the Upper Mattole River have been observed since 2009, elevating extreme low flows and reducing the number of days when flows fall below minimums needed for juvenile salmonid migration. With growing participation in the program, benefits to summer low flows will continue to accrue and improve conditions for fish in the Upper Mattole River.

Because of the success of Sanctuary Forest's monitoring and forbearance program, it is now being replicated in nearby watersheds. If the recent trend of worsening droughts proves to be the new 'normal', maintaining and augmenting forbearance in the Upper Mattole River, and indeed the entire redwood region, will become increasingly important for juvenile salmonids.

Keywords: drought, forbearance, low flow, streamflow, water withdrawal

Introduction

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 2001). 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 15 years, with the summer of 2008 being the driest and 2014 the second driest in the 67-year record of flows on the

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Mattole River near Petrolia. A variety of factors influence low flows, such as, climate (rainfall, air temperature, fog, 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.

Sanctuary Forest has undertaken a program to reduce dry season pumping from the Upper Mattole River and tributaries by subsidizing purchases of large storage tanks for willing landowners and facilitating forbearance agreements that strategically reduce water extraction from streams, thus improving low flows and relieving habitat stress for salmonids. This paper presents an analysis of low flows in the Upper Mattole River basin with the following objectives: 1) to put recent droughts into a longer-term perspective, and 2) to evaluate the effectiveness of the water storage and forbearance program in the Upper Mattole.

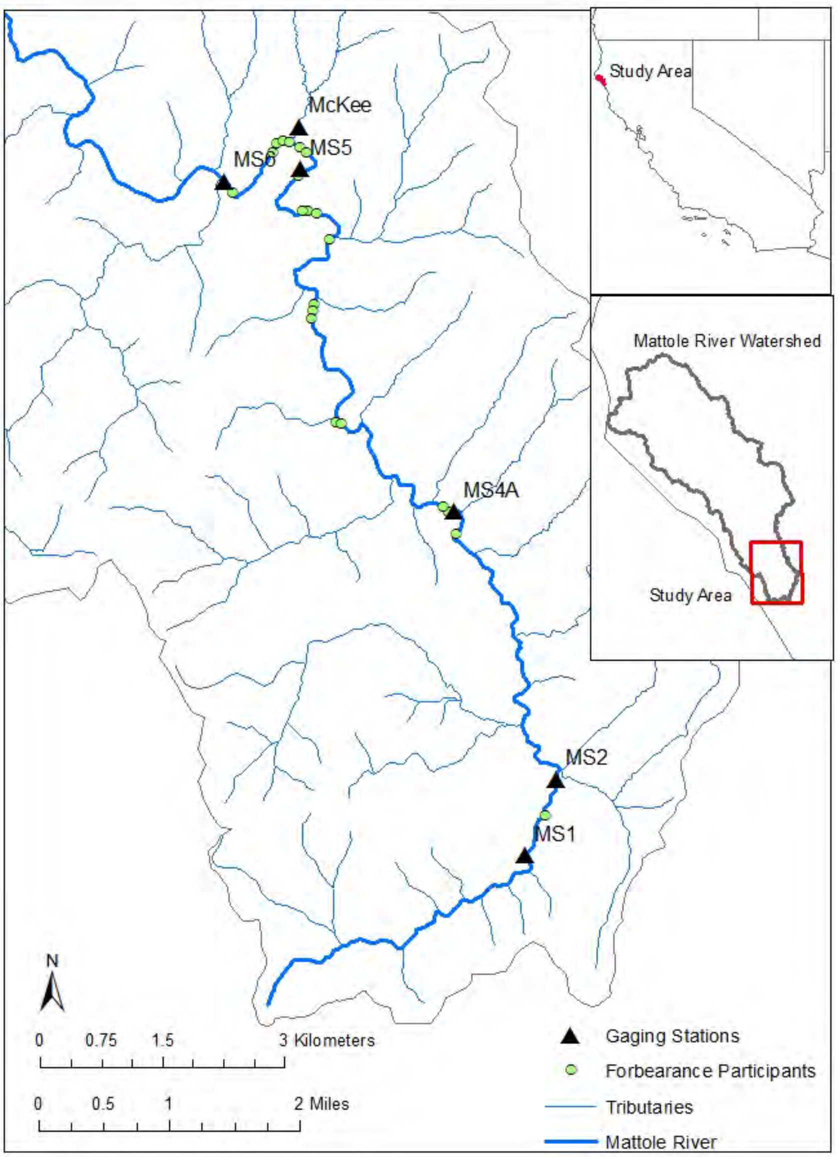

Figure 1—Upper Mattole watershed with monitoring sites and forbearance participants.

Study Area

The Upper Mattole River basin can be defined as that portion of the watershed upstream of the U.S. Geological Survey stream gaging station at Ettersburg (Sta. No. 11468900, drainage area = 151 km^2 (58 mi^2), fig. 1). The region has a Mediterranean climate, with virtually all precipitation falling as rainfall and averaging 191 cm/year (75 inches/year) occurring from October through the following June. Ranching and logging are the primary historical land uses, but marijuana cultivation has grown rapidly in recent years, and this so-called 'green rush' has become a focus for concerns over shrinking streamflows in salmonid-bearing streams (Bauer et al. 2015).

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 agreements that reduce water extraction during the low flow periods. 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, and community meetings. 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 specified flow thresholds. By 2015 a total of 25 storage tanks had been installed totaling 5,700 m^3 (1.5 million gallons) in storage volume. All 25 participants have forbearance agreements, and an additional estimated 20 landowners have purchased tanks on their own and are participating voluntarily.

During summer drought conditions, landowners cease pumping when flows dropped to the cutoff of 20 l/s (0.7 cfs) at the downstream end of the Upper Mattole forbearance program area (MS6 monitoring site, fig. 1). Forbearance participants are notified of the cutoff date directly through phone and written communications from Sanctuary Forest and a flow alert roadside sign is also maintained to give a 2 week notice to the entire community. The low flow benefits of "turning off" the 25 pumps are analyzed in this report relative to flows measured at the MS6 monitoring site to show the cumulative benefits of the program.

Existing Data and Previous Studies

The "Northcoast Watershed Assessment Program" (NCWAP) Mattole River report (NCWAP 2001) 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. 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 U.S. Geological Survey (USGS) at stream gaging stations at Petrolia (1912 to 1913 and 1951 to present) and near Ettersburg (2001 to present) were used for assessing drought severity. 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.

Stubblefield et al. (2012) measured water use by trees in the Mattole River, finding that although older and larger trees use more water, dense, younger tree stands use more per unit area. They project that, as forests are allowed to mature, the declining numbers of young trees will result in less total water use by forested areas. This, of course, assumes forests will be maturing despite ongoing timber harvest and future stand-replacing wildfires, should they occur.

Sawaske and Freyberg (2014) analyzed stream gaging records from Pacific coastal streams, finding that although spring discharge recession rates have remained relatively constant for the past 4 to 8 decades, summer recession rates have increased. Their results agree with those of Asarian and Walker (2016), who found that although precipitation-adjusted streamflow at pristine sites had not declined, September streamflow declined at 73 percent of un-dammed sites in northwest California and southwest Oregon in the latter part of the available record. They attributed this to water withdrawals and vegetation changes rather than precipitation or other climatic changes.

The burgeoning marijuana industry in north coastal California has been well-publicized. Bauer et al. (2015) conducted aerial inventories of ‘grows’ (signified by large greenhouses and outdoor gardens) relying primarily on Google Earth’s high-resolution images with some level of verification derived from law enforcement activities on the ground. They speculated that for the redwood region, from 23 percent to 100 percent of summer flows may be withdrawn at the time of their study (2012) for use by this industry, but that deriving more accurate numbers was hampered by grows being typically clandestine operations located on private property. Whatever the true rates of water withdrawals for marijuana growing operations (and they have likely risen since 2012), their proliferation adds to the cumulative effects of the other human-caused decreases in streamflows mentioned above.

Methods

The data from the USGS gaging stations at Petrolia and Ettersburg were analyzed by first computing the minimum 7-day low flow discharge. This was accomplished by scanning the daily average flow data for the dry months (July to October) each year for the 7-day period with the lowest flow of the season. The exceedence probability (the likelihood of a specific flow being equaled or exceeded in any given year) was then computed for each annual 7-day low flow, allowing an assessment of whether or not low flows have declined in recent years.

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; see fig. 1). Site descriptions are listed in Table 1, which also includes the USGS gaging stations used here (note that tributary data are not included in this paper due to length limitations, but can be found in Klein (2012).

Table 1—Mattole River mainstem monitoring sites and characteristics

Site name	Dist. upstream from mouth (km)	Drainage area (km^2)	Description
MS1	68.8	8.4	downstream of Big Alder Creek
MS2	68.3	10.3	upstream of Lost River confluence
MS4A	66.3	31.9	downstream of Gibson Cr. confluence
MS5	61.7	59.9	upstream of McKee Creek
MS6	60.6	66.4	upstream of Bridge Creek
USGS Ettersburg	48.7	150.5	near Ettersburg
USGS Petrolia	5.8	634.6	at Petrolia

The data collected by Sanctuary Forest enabled 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 19 liter (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. Data loggers were used to provide a continuous record at three mainstem sites (MS4A, MS5 and MS6) during some years.

Results

Low Flow Exceedence Probability

Table 2 shows the 7-day minimum low flows and exceedence probabilities for both Petrolia and Ettersburg gages for the entire period (2001 to 2015). In addition to the exceedence probabilities for the 7-day low flows plotted in fig. 2, table 2 includes the inclusive dates of the 7-day low flow period each year. In every case but one (2015), the minimum flows occurred in September and/or October.

Table 2—Low flow discharges (cms), dates and exceedence probabilities for Petrolia (PET) and Ettersburg (ETT) stream gages, 2001-2015

Water year	Petrolia (cms)	Petrolia (cms/km^2)	Petrolia dates	Exc. Prob. (%)	Ettersburg (cms)	Ettersburg (cms/km^2)	Ettersburg dates
2001	0.49	0.0008	10/5-11/2001	81	0.14	0.0009	9/3-9/2001
2002	0.40	0.0006	9/26-10/2/2002	90	0.11	0.0007	10/7-13/2002
2003	0.74	0.0012	10/25-31/2003	72	0.15	0.0010	10/23-29/2003
2004	0.51	0.0008	9/28-10/4/2004	88	0.12	0.0008	9/7-13/2004
2005	1.16	0.0018	10/7-13/2005	4	0.28	0.0019	10/8-14/2005
2006	0.64	0.0010	9/22-28/2006	70	0.15	0.0010	9/24-30/2006
2007	0.56	0.0009	9/24-30/2007	52	0.17	0.0011	8/31-9/6/2007
2008	0.31	0.0005	9/5-11/2008	97	0.09	0.0006	9/4-10/1/2008
2009	0.56	0.0009	9/27-10/3/2009	57	0.17	0.0011	9/25-10/12009
2010	0.96	0.0015	10/15-21/2010	10	0.28	0.0018	10/15-21/2010
2011	0.65	0.0010	9/8-24/2011	23	0.24	0.0016	9/18-24/2011
2012	0.55	0.0009	9/30-10/6/2012	64	0.16	0.0010	9/28-10/4/2012
2013	0.45	0.0007	9/10-16/2013	46	0.18	0.0012	9/9-15/2013
2014	0.40	0.0006	9/6-12/2014	93	0.11	0.0007	9/11-17/2014
2015	0.43	0.0007	8/22-28/2015	84	0.13	0.0008	10/4-10/2015

The NCWAP (2001) report presented and analyzed rainfall in the Mattole based on two long-term rain gages and streamflow records in the lower Mattole River near Petrolia (USGS Gaging Station No. 11469000, drainage area = 635 km^2 (245 mi^2)). Based on their analyses, they concluded there were no discernible long-term trends in annual precipitation and that there was only a modest decline in annual yields over the previous 25 years, which was attributed to increasing water withdrawals from streams.

Sixteen additional years of data have been collected at the two USGS gages currently in operation (Petrolia and Ettersburg) since the NCWAP (2001) analyses were done, some among the driest on record. An exceedence probability analysis of 7-day low-flows was done using the full period of record (fig. 2). Because the Ettersburg gaging station lacks sufficient record length to perform low flow frequency analyses, discharge was estimated for the pre-record (1912 to 2000) period by down-scaling the Petrolia data by drainage area ratio.

As shown in fig. 2, the 2008 7-day low flow was the lowest on record for Petrolia, and many other years since 2001 are clustered near the high end of exceedence probabilities (lowest flows) portion of the data shown. At 86 percent, the median exceedence probability of this latter period is much higher than that of the entire record, indicating a distinct shift to lower summer flows. The wettest years of the recent period were 2005 and 2010 to 2011. Although not as dry as 2008, 2014 was the second-driest on record at both Petrolia and Ettersburg.

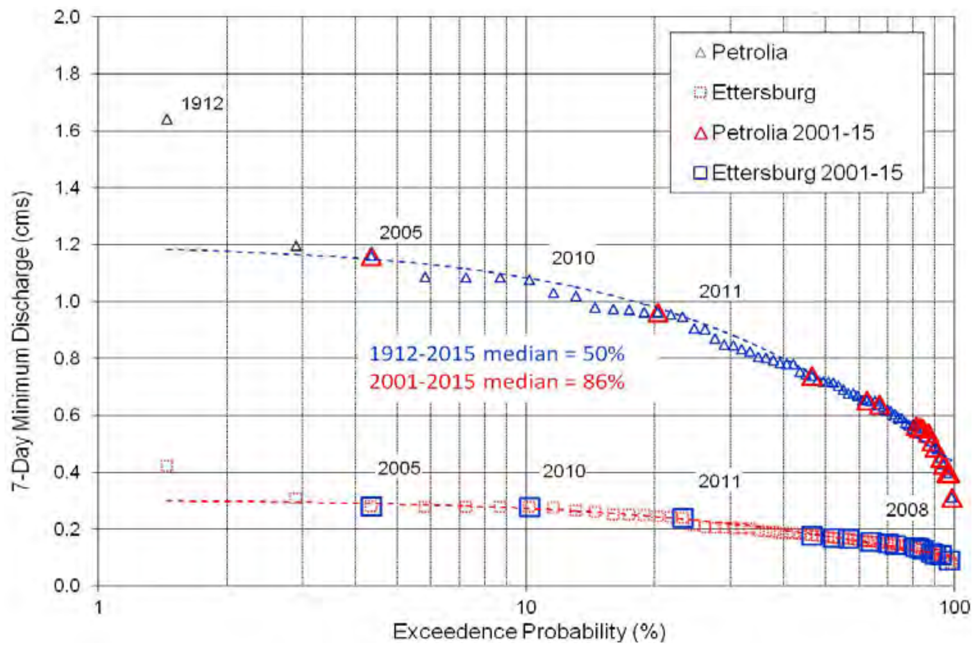

Figure 2—Exceedence probabilities for the annual 7-day low flow discharges for Mattole River at Petrolia and Ettersburg with recent data (WY2001-16) highlighted (note that data for Ettersburg prior to 2001 were estimated by down-scaling by drainage area from Petrolia records).

Forbearance Program Monitoring and Implementation

Figure 3 presents discharge measurements taken at the mainstem site MS6 for 2004-15. This is an important monitoring site because it is used in the forbearance program as the index site for determining when water withdrawals should cease when the established discharge threshold of 20 l/s (0.7 cfs) is attained. The beginning of the summer flow recession varied widely among the years shown, with the 2008 recession (driest year) starting in early June and not until early August in 2005 (the wettest year). Flows dropped to zero in 2004 and 2008. Flow recovery in all years did not occur until rains began in mid-September at the earliest and November at the latest.

The effects of late spring rainfall can be readily seen in the delayed recessions in wetter years (e.g., 2005, 2010, and 2011). The year 2008 was by far the driest, with the MS6 pumping cessation threshold (cutoff) of 20 l/s (0.7 cfs) reached in late July. Although 2014 was the second driest year at Ettersburg, fig. 3 shows that flows rebounded after pumping was ceased on July 20, 2014, and MS6 minimum flows were higher than in several other dry years.

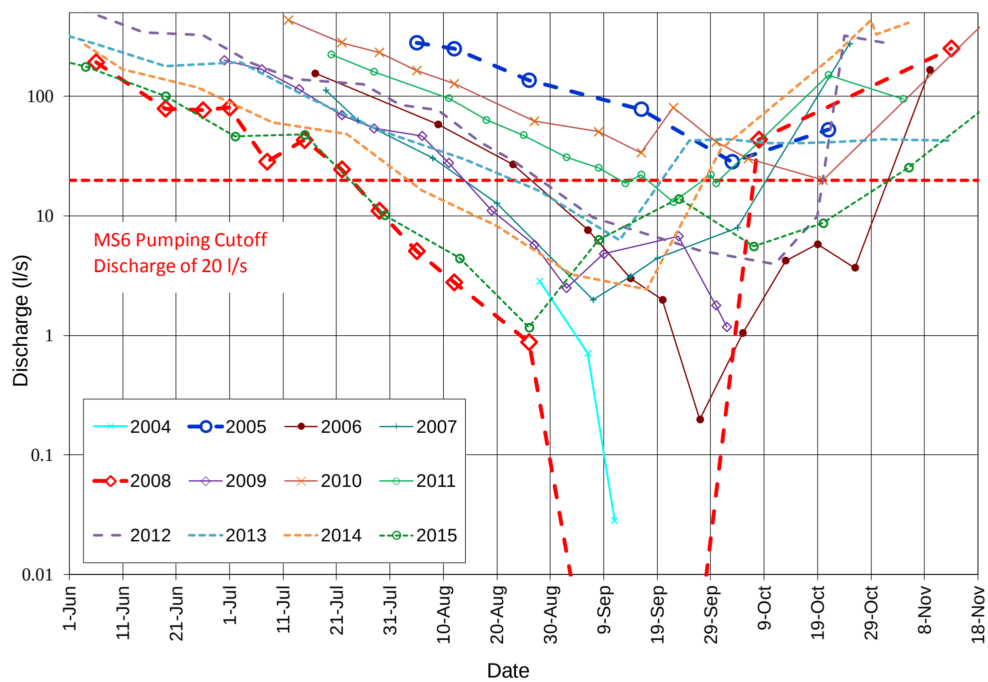

Figure 3—Discharge measurements at MS6, 2004-15 (all dates adjusted to 2016 for plotting). The discharge threshold for cessation of pumping (forbearance) for MS6 (20 l/s, or 0.7 cfs) is also shown. The two heaviest lines indicate flows during 2008 (driest year, dashed red line) and 2005 (wettest year, dashed blue line).

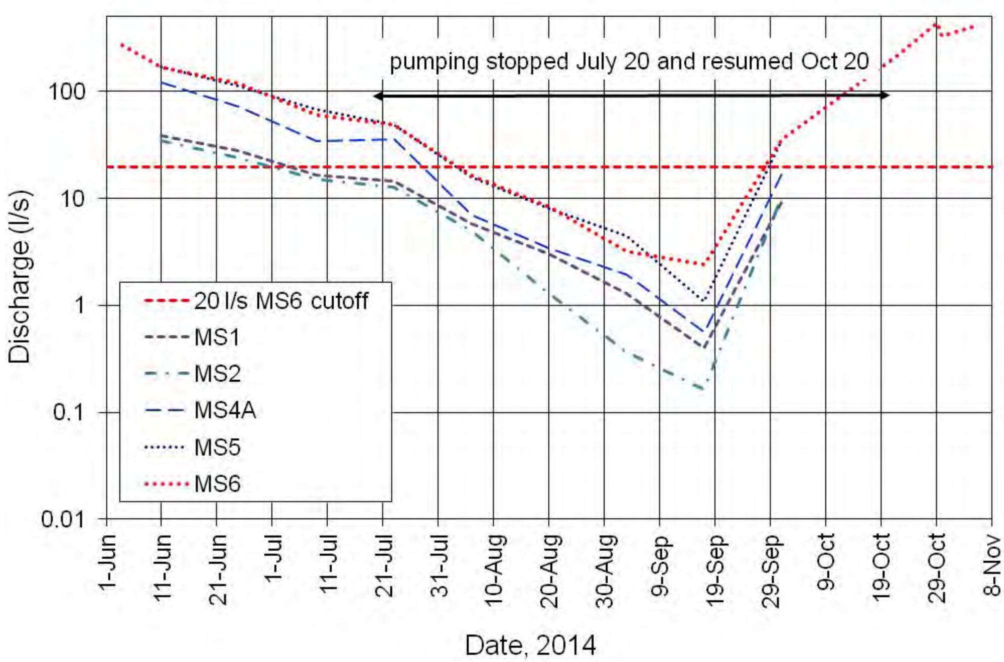

Figure 4—Discharge measurements along the Upper Mattole mainstem in 2014. Pumping cessation period (July 20 through October 20) is noted. Sites are numbered from upstream to downstream order.

Figure 4 shows discharge measurements for five mainstem gaging sites in 2014, with the forbearance pumping cessation period (July 20 through October 20) noted. Predictably, discharge generally increases with increasing drainage area (sites are numbered from upstream to downstream order). Landowners participating in the forbearance program were notified to cease pumping beginning July 20, ahead of the impending flow recession to the MS6 threshold (20 l/s). Pumping restrictions for participants were lifted in October after when rains finally alleviated the seasonal drought. Without forbearance, one or more of the three mainstem sites would almost certainly have gone dry for a lengthy period of the dry season.

Forbearance Program Effectiveness

Table 4 lists the annual progress of the forbearance program upstream of MS6 through 2015. Maximum instantaneous annual and cumulative pumping rates for participants are listed, and can be taken as the maximum reductions in water withdrawals when forbearance is invoked. As of 2015, the maximum potential pumping reduction achieved thus far is 13.6 /s (table 4), or about 0.5 cubic feet per second.

Table 4—Participation in the forbearance program from 2007 to 2015 for the Upper Mattole upstream of MS6 with estimated instantaneous pumping capacities of participating landowners

Year	No. of landowners turning off pumps	Annual storage installed (m^3)	Max instantaneous pump capacity (l/s)	Cum. instantaneous pump capacity (l/s)
2007-09	7	1,701	4.91	4.91
2010	4	567	1.26	6.17
2011	1	567	1.26	7.43
2012	4	699	0.63	8.06
2013	2	491	2.52	10.58
2014	2	680	1.26	11.84
2015	5	1,002	1.76	13.61

To estimate the hydrologic benefits from the forbearance program, fig. 6 plots MS6 discharge measurements for 2015 and the lower flows expected in the absence of the program (no restrictions on pumping) based on the cumulative instantaneous pump capacity reductions from table 4 (measured flows were reduced by the maximum instantaneous pumping capacity of 13.6 l/s (0.5 cfs) to estimate what flows would have been without the forbearance program). This hypothetical situation assumes all forbearance participants, had they not entered the program, would be pumping from Upper Mattole streams at full pump capacity at some point in time. Use of the maximum instantaneous pumping capacity might overestimate the benefits of the forbearance program, but there is some merit to the assumption that all pumps may be withdrawing water simultaneously during the driest part of the summer when water users lacking adequate storage would most likely be pumping from streams.

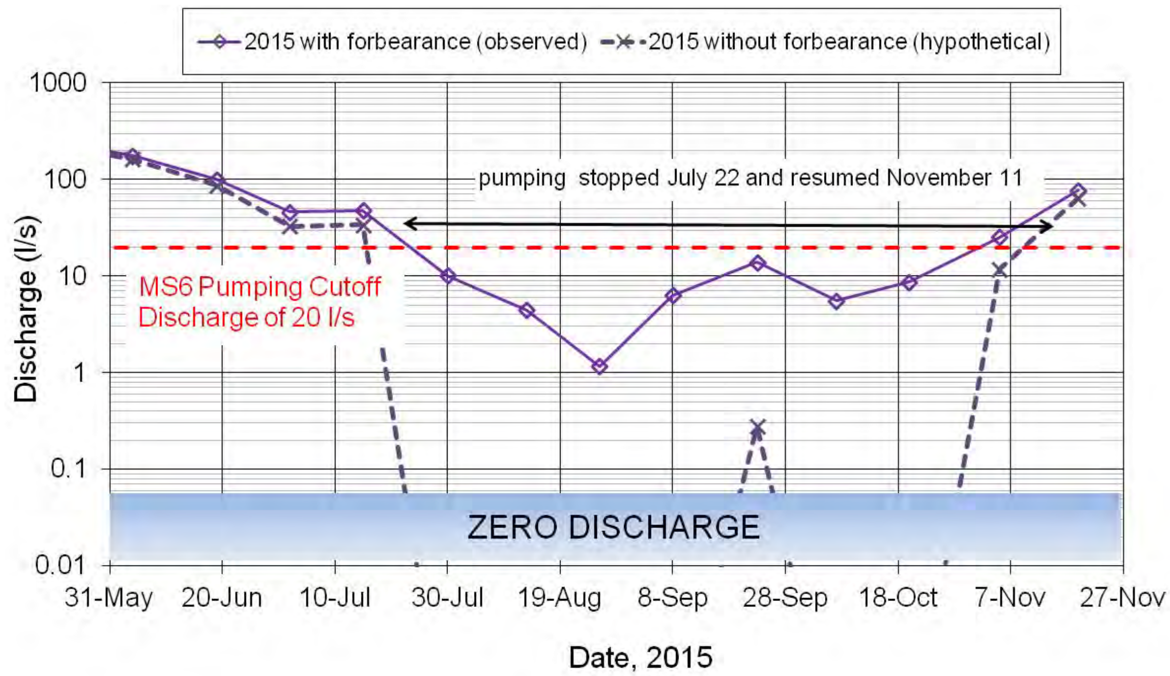

Figure 6—Discharge measurements at MS6 in 2015 (observed) and estimated (hypothetical) discharge without forbearance.

Predicting Discharge at MS6

Ettersburg provisional flow data are available online through the USGS website (http://waterdata.usgs.gov/ca/nwis). Estimating MS6 flows using Ettersburg real-time data offers a considerable convenience for anticipating and invoking forbearance events. Figure 9 shows the relationship between Ettersburg and MS6 flow for WY2004 to 2014. The relationship is strong enough to use the Ettersburg real-time flow data to provide reliable estimates of MS6 flows within the range of flows analyzed. Sanctuary Forest has been using the relationship with real-time flow data from Ettersburg, along with direct observations of flows, as an important tool in managing the forbearance program. Daily checking of Ettersburg flow and applying the regression equation in fig. 5 to that flow allows estimation of MS6 flows from the office. As the forbearance threshold is approached, participants can be forewarned of an upcoming pumping cessation period.

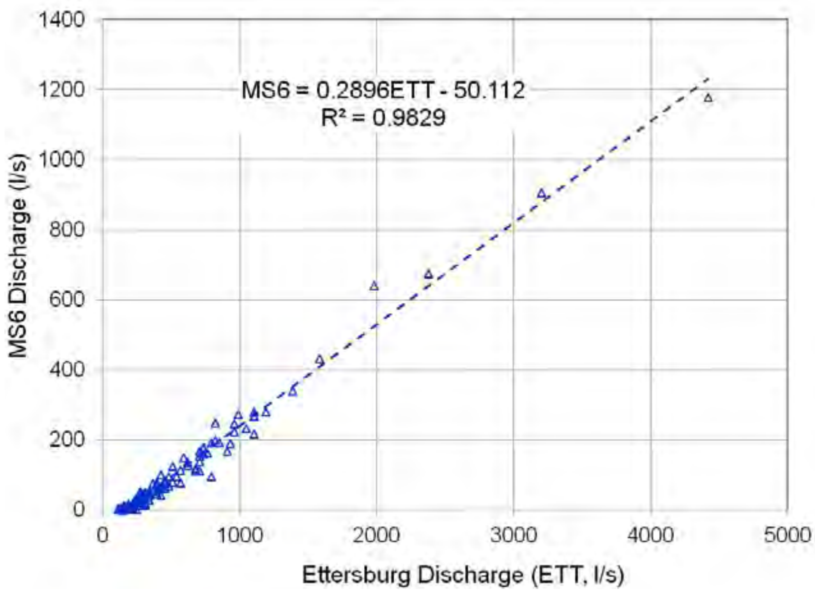

Figure 5—Relationship between discharge at the USGS Ettersburg gaging station and those taken at MS6, 2004-2015.

As an aside, the regression was also performed just using the 2012 to 2014 data to evaluate whether or not the relationship had shifted in a manner consistent with the increase of upstream storage and reduced pumping (i.e., increasing in MS6 flows relative to Ettersburg). No differences were found between the full dataset and the more recent data. At nearly twice the contributing drainage area of MS6, the low flow improvements due to the forbearance program would have to be higher than that computed below (13.6 l/s, see table 4) to be detected by a shift in the MS6-Ettersburg relationship.

Conclusions

1. With the exception of 2005, 2010 and 2011, drought conditions have been unusually severe since 2001 in the Upper Mattole River, with 2008 being the driest of the 67-year discharge record for the Mattole River near Petrolia. Median exceedence probability during this later period was 86 percent, compared to 50 percent for the entire record, indicating a distinct shift to lower summer flows.
2. Real-time Ettersburg flow data, available online, was demonstrated to be a useful tool for predicting flows at MS6 and will help facilitate implementation of the forbearance program.
3. Sanctuary Forest's forbearance program has caused measurable increases in low flows in the Upper Mattole River since 2009, elevating extreme low flows, reducing the number of days MS6 was below the cutoff, and almost certainly improving low flow conditions for fish than would be the case in the absence of the program.
4. With growing participation in the forbearance program, additional benefits to summer low flows will continue to accrue and improve conditions for fish. If the recent trend of worsening droughts becomes a longer term trend, maintaining and augmenting forbearance in the Upper Mattole River, and indeed the entire redwood region, will become increasingly important for juvenile salmonids.

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