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Monitoring Hydrologic and Water Quality Impacts of Meadow Restoration in the Sierra Nevada

National Fish and Wildlife Foundation

American Rivers
Rivers Connect Us

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Introduction

Sierra meadows have held a special place in human history and culture for millennia, evidenced by the widespread presence of cultural sites throughout Sierra meadows. In the decades following the gold rush, human use increased dramatically. Grazing, mining, logging and fire suppression significantly impacted meadow resources, and by 1930, the effects were being addressed by active restoration. Conifer removal and brush dams (Figure 1) were early methods of managing meadows with a recessed water table.

In the last 20 years, restoration effort has increased dramatically, supported by peer reviewed publications that demonstrate substantial benefits. As a result, numerous entities now promote meadow restoration throughout the Sierra. Private and public funders who are investing in the region include: the National Fish and Wildlife Foundation (NFWF), the Sierra Nevada Conservancy, the Bella Vista Foundation, the Resources Legacy Fund, and private landowners. In addition, meadow restoration is being discussed in a water supply and water quality context: several Integrated Regional Water Management Plans (IRWMP's) highlight restoration of degraded meadows as a key short-term goal. As interest has grown, the need for coordination and information sharing has also grown.

Conifer Removal 1933

Brush Dams 1934

Figure 1. Early examples of meadow restoration in the Sierra Nevada.

The National Fish and Wildlife Foundation (NFWF) has taken a lead role in the development of a framework to coordinate efforts throughout the Sierra and insure that sufficient information will be collected to evaluate and improve meadow restoration practices. Specific objectives for meadow restoration identified in the NFWF Business Plan (National Fish and Wildlife Foundation 2010) include:

1. Increased late-season water storage
2. Increased late-season flows downstream of restored meadows
3. Reduction in peak flood flows downstream of restored meadows
4. Increased populations of target taxa: birds, fish and amphibians

5. Increased areas of wetland and riparian habitat
6. Increased livestock forage value
7. Improved water quality
8. Decreased sedimentation downstream of restored meadows.
9. Increased carbon sequestration
10. Improved/conserved aesthetic, cultural and real estate values.

These goals are based on the conceptual model of meadow function and degradation presented by Hammersmark et al (2008) and Loheide et al (2009). Briefly, channel incision (including ditching and formation of new channels) leads to lowered flood frequencies, increased erosion and a deeper water table. The lowered water table produces changes in vegetation and habitat (see Groundwater Monitoring, below).

The monitoring methods[1] articulated here address goals 1-3, 5, 7, and 8 above. In addition, our work linking forage value and water table depth (Tate et al. 2011) provides a quantitative model for addressing goal 6 (increased forage value) using these monitoring data.

Three closely related publications that are also sponsored by NFWF detail methods for monitoring (1) birds, (2) fish, and (3) vegetation responses to meadow restoration (Loffland, Siegel, and Wilkerson 2011; Purdy 2011; Stillwater Sciences 2011). Where possible, these methods have been integrated, for example, groundwater and vegetation patterns are closely linked, as are their monitoring methods.

The goal of this nascent monitoring program is to spur data collection in support of three main purposes:

1. Monitoring enables post-project management. Adaptive management is especially important for restoration, where the goal is to employ natural processes, with the caveat that natural uncertainties are built in.

2. Monitoring also provides the information to gauge success. Documented successes and quantified benefits are critical for attracting investment and insuring continued support for meadow restoration.

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[1] Monitoring is defined as repeated measurements that span an extended time period and which are designed to measure magnitudes and rates of changes (Danielsen et al. 2000). A well-designed monitoring plan for meadow restoration will specify how a project will collect and report the information needed to make informed management decisions, identify problems, and quantify progress toward restoration goals.

3. Monitoring enables advancement of the state of the art. Effective monitoring enables learning and highlights unexpected outcomes. This is particularly important at this stage of meadow restoration because techniques continue to develop, established techniques are applied in new geomorphic settings, and climate change is predicted to have a significant effect on the hydrology of the Sierra Nevada.

In sum, monitoring is designed to improve management, promotes investment and enables innovation. The importance of integrating monitoring into the design and budget phases of a project cannot be overstated. Not only will this insure that sufficient pre-project information is collected, but a project with a stated monitoring plan will often be more successful, as it will be designed to match the project goals and evaluation criteria.

Purpose

Our purpose is to articulate methods for monitoring hydrologic and water quality impacts of meadow restoration in the Sierra Nevada. This includes recommended analyses and standard metrics that, if reported, will enable future regional studies to combine data across meadow restoration projects. These methods are not exhaustive, rather we identify the key indicators that should be monitored by all projects aiming to alter hydrology or water quality through meadow restoration.

Summary

Data collected are grouped into five categories based on the objectives they support: 1) groundwater elevation; 2) stream flow; 3) water temperature; 4) sedimentation; and 5) overview data, such as photographs and maps that support multiple monitoring objectives. Table 1 summarizes which data are collected and how they are reported. Tables and figures from the text are referenced as examples of how data are reported.

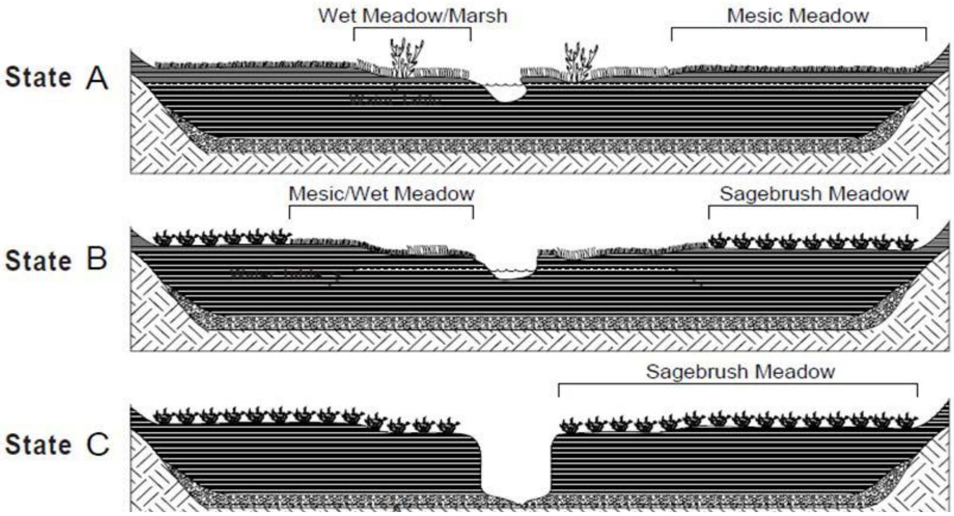
The goal of the monitoring program presented here is a standard, quantitative description, so that multiple restoration projects can be compared (See, for example Stewart 2009, Figure 2). When possible, hypothesis tests are suggested and results are linked to observed changes in vegetation (Stillwater Sciences 2011).

	Data Collected	Values Reported
Groundwater	Monthly groundwater elevations	Annual maximum and minimum water table depth at each location (Table 2)
		Plots of water table depth for each piezometer (Figure 6)
		Optional: changes in storage volume and duration water table is within rooting zones
	Meadow-width cross sections	Plot of cross section (Figure 5)
	Daily rainfall	Total rainfall for water year (Table 2)
Stream Flow	Stream stage logged every 15 minutes	Annual minimum discharge at upstream and downstream gauges (Table 3)
		Difference between gauges at time of minimum flows (Table 3)
		Plots of minimum flows at upstream and downstream gauges with overlay of daily rainfall (Figure 7)
		Peak flows: upstream peak, downstream peak, % attenuation, lag time for 20 flood peaks before and after restoration (Table 4)
		Optional: plot % attenuation vs. peak discharge, test for significant changes in attenuation and lag time before and after restoration
	Daily rainfall	Total rainfall for water year (Table 4)
Water Temperature	Water temperature every 15 minutes	Monthly average daily maximum temperature (Table 5)
		Annual maximum temperature
		Plot temperature data
Sediment	Channel cross sections	Plot cross sections. (Figure 8)
		Locations (monumented, GPS, verbal description and shown on map)
		Optional: rates of bank erosion, downcutting, change in cross sectional area and width/depth ratio
	Bank stability transects	% unstable banks for 3 locations
Overview Data	Photopoints, aerial photographs, map.	Map before and after showing restoration actions and monitoring activities
		Photopoints (in all 4 cardinal directions at each site)
		Aerial photographs before and after
		Submission to Natural Resource Project Inventory Database (U.C. Davis

Table 1. Categories of data collected and values to report or display graphically.

Groundwater

Meadow restoration methods like check dams, pond and plug, and riffle augmentation are designed to raise the water table by preventing groundwater drainage through a downcut channel.   The goal is to reverse the degradation pathway shown in Figure , and restore a meadow from State C to State A by raising the stream bed elevation, and thereby the water table.



State A – *high hydrologic function, wet and mesic plant communities, high water table*

State B – *impaired/at risk hydrologic function, mesic/wet, mesic, and some dry communities, dropping water table, eroding stream*

State C – *degraded hydrologic function, downcut, dry plant communities*

Figure 2. Illustration of the changes in stream channel depth, depth to water table, soil moisture, and vegetation types (plant community) which occur when a meadow stream channel downcuts and meadow hydrologic function is diminished from State A to State C. From BLM/USFS/NRCS Tech Rept. 1737-15 1998.

Although a raised water table may be a measureable objective of meadow restoration, the goals justifying the restoration effort are usually reflected in visible above-ground changes. For example, improvements in forage, habitat, and prolonged downstream flows are benefits that may result from elevated groundwater (SNEP 1996; Tate et al. 2011; Loheide et al. 2009). Thus, a monitoring program for groundwater elevation is most effective if it is linked with studies of these additional goals. For example, vegetation plots are located next to groundwater monitoring points, and groundwater wells are located and data are analyzed with stream gauging data in mind (see Stillwater, and Analysis sections)

Groundwater monitoring has been successful in a number of meadow restoration projects, and once piezometers are installed, data collection is straightforward and can be accomplished with minimal training (South Yuba River Citizens League 2011).

Procedure:

Piezometer Installation

Here we describe two of the simplest and most inexpensive methods for installing piezometers. There are numerous additional methods for piezometer installation, all of which yield equivalent groundwater elevation data. The ASTM standards (ASTM-D5092 2004) are the authority. The U.S. Army Corps of Engineers (S.W. Sprecher 2000) has also published a technical guide, as do commercial makers of drive points for pound-in piezometers (e.g., Solinist Canada Ltd.). These methods should be consulted if measurements in addition to ground water elevation (for example, conductivity or temperature) are planned, or in difficult substrates, where, for example an augur is required.

The first pound-in method uses PVC pipe, driven coaxially outside of a long section of rebar (Figure 3). The rebar protrudes about one inch from the bottom end of the PVC pipe and drives a hole that the pipe follows into the ground. The rebar also keeps the pipe from filling with sediment as it is driven. The lowest section of PVC pipe has holes drilled and serves as the screened section of the piezometer. Once the PVC piezometer has been driven to the correct depth (a fence post slide hammer is useful), the rebar is removed. A small hill of mineral dirt, is packed around the PVC to keep water from running into the ground through the torn earth along the outside of the PVC pipe. Finally, a cap is pushed onto the top of the pipe. In grazed pastures, or where animals may rub up against the well, it is a good idea to cut the well off short (above potential flood flows) and pound in a nearby marker (e.g., a fencepost) which can withstand rubbing. This installation method only works for shallow wells because the entire well is driven as a single section, and at the beginning, the entire length of pipe protrudes above the ground. Those who have driven ten-foot-tall fence posts will appreciate the challenge of driving a well that is much deeper than the height of the person driving it. (method from Amy Merrill, Stillwater Sciences)

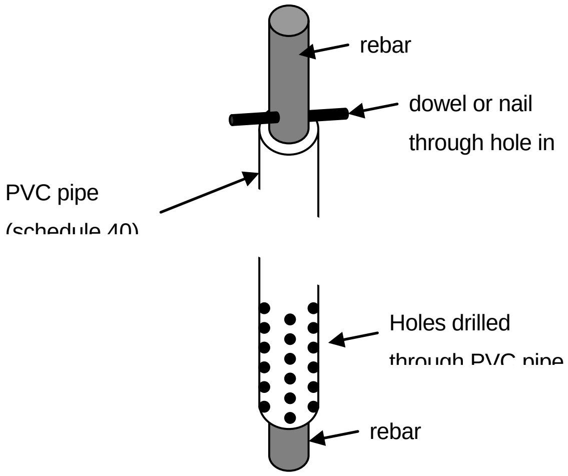


Figure 3. An inexpensive method for driving PVC piezometers into a meadow. See text for further description.

The second method uses ½ inch galvanized steel pipe capped on the bottom end. Holes are drilled into the bottom section, similar to the PVC installation above, and the pipe can be pounded into the ground in sections, if needed, with threaded couplings used to connect the sections. A coupling is also threaded onto the protruding pipe to protect the threads and provide a pounding surface. This installation is also capped and finished off with the same soil around the pipe as for the PVC well. The exposed length of galvanized pipe is also easily bent by cattle and may need protection.

The screened portions of the piezometers are installed at a depth such that they sample the soil strata connected to the stream channel. If flow-limiting layers are found during an inspection of the channel banks, piezometers screened above the impervious layer may be indicated, and would always be installed if the post-restoration channel is in different strata than the original channel.

Making a Measurement

The depth of the water table is measured from the top of the well. This can be done using an electronic water level sensor (e.g., Solonist Water Level Meter). The sensor is lowered into the well and beeps when it contacts the water surface. The depth is read off the graduated cable attached to the sensor. Alternatively, a tape measure and water soluble marker can be used (S.W. Sprecher 2000). Draw a line with the marker up the tape measure as you extend the tape into the well. When you are sure the end of the tape is below the water level, take a measurement (M1). Retract the tape and record where the water washed the marker off the tape (M2). The water table depth below the top of the well is the difference M1-M2.

The height of the well will have been measured when it is installed. In the office, subtract the well height from the field measurement and report the groundwater depths relative to the ground surface rather than the top of the well.

Sampling Array

Piezometers are installed along at least three meadow-wide transects and sited to represent the range of water table elevations present, as reflected by major changes in plant community and topography (Stillwater Sciences, 2011). The resulting sampling array is composed of piezometers irregularly spaced within transects, and transects opportunistically located to represent a variety of groundwater conditions along the length of the meadow (Figure 4).

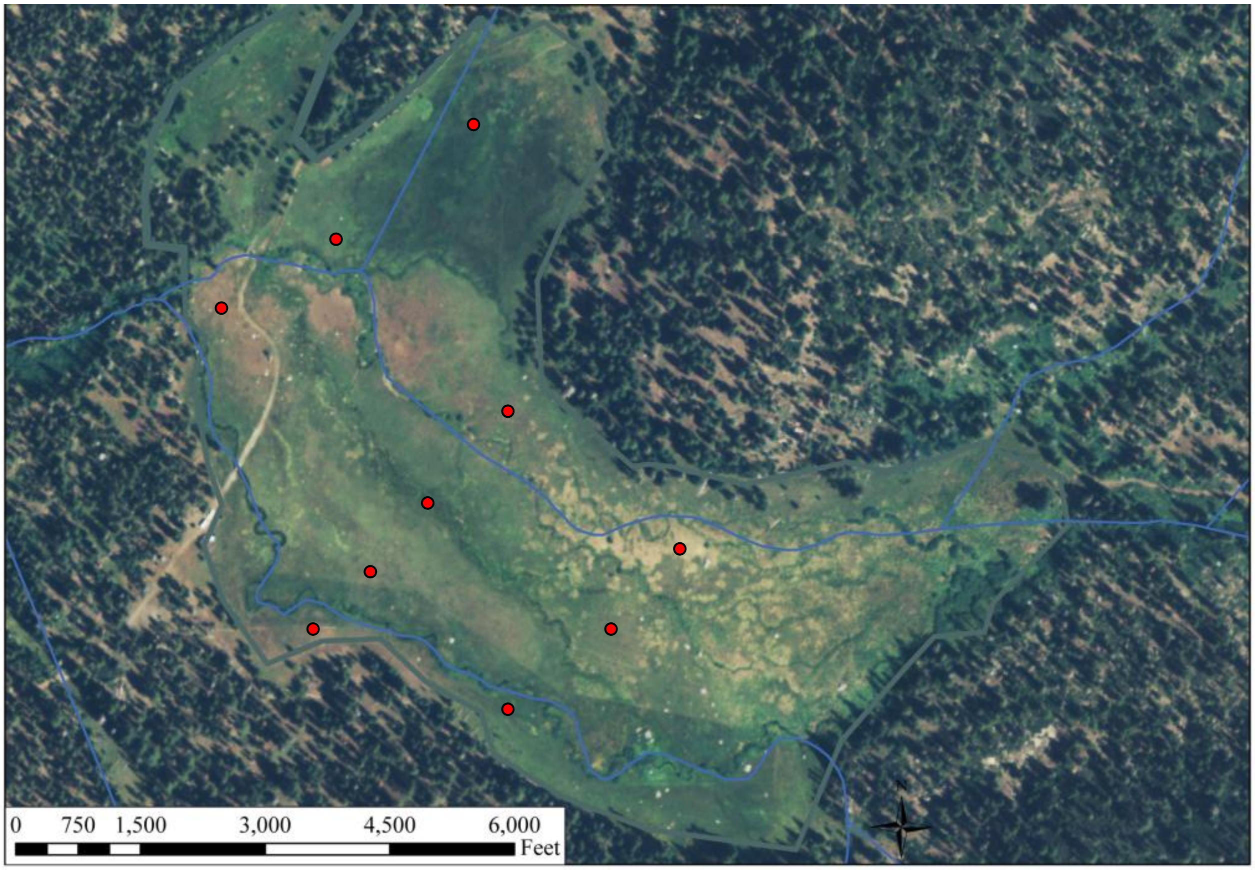


Figure 4. Aerial photograph showing piezometer locations (red circles). Transects sample representative groundwater conditions and vegetation communities throughout the meadow.

Along each transect, a cross section is surveyed, as shown in Figure to show well elevations relative to stream channels and any modification to the meadow or channel elevations.

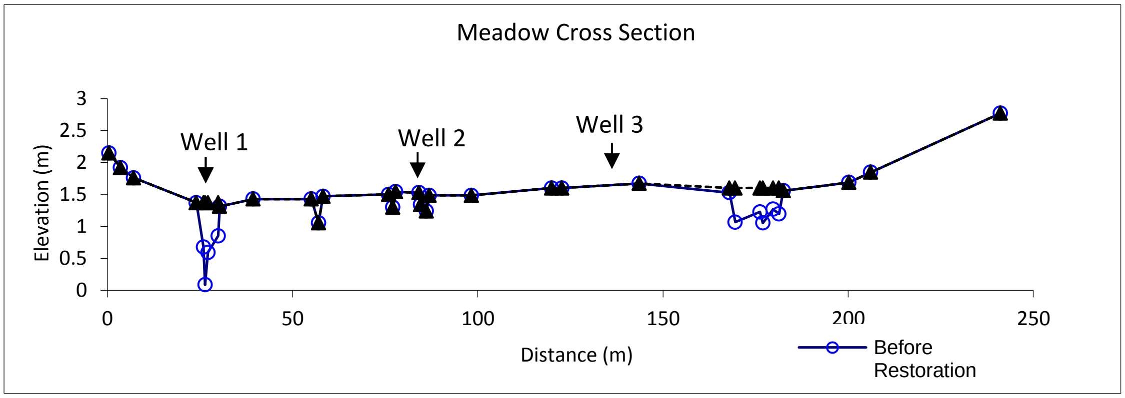


Figure 5. Surveyed cross section shows well locations and elevations relative to stream channels. In this case, the channel cross sections are changed by pond and plug restoration. (Data from Feather River Coordinated Resource Management Report 2004: Upper Last Chance Creek, Appendix B. http://www.feather-river-crm.org/project-files/CalfedAppend.pdf)

Reporting

To summarize the water table depth for each well, report the maximum and minimum water table depths for each monitoring year and the total rainfall (total precipitation) amounts for the year. Weather data are available from National Weather Service Co-op stations online at: http://www.nws.noaa.gov/os/coop/wfo-rfcmap.htm. Rainfall is reported for the water year (e.g., water year 2010 begins October 1, 2009), and groundwater depth data are reported for the calendar year. Reporting groundwater depth on a calendar-year basis is preferred because minimum groundwater elevations may occur on consecutive days (September 30th and October 1st) but be in different water years. This would make it appear that groundwater in consecutive years was very similar when, in fact, it may not have been; using the calendar year for groundwater and the water year for rainfall prevents this. Table 1 shows this information in a format that can be quickly scanned and compared amongst restoration projects.

				2009	2010	2011 ***Restoration***	2012	….
Rainfall by water year (cm)				150	170	110	160	
Upper Meadow Transect								
	Water Table Depths (cm)	Well 1a	max	10	8	12	8	
			min	0	0	0	0	
		Well 1b	max	80	60	80	50	
			min	20	20	25	10	
		Well 1c	max	170	150	170	90	
			min	80	60	100	50	
Middle Meadow Transect								
	Water Table Depths (cm)	Well 2a	max	11	8	12	8	
			min	0	0	0	0	
		Well 2b	max	60	80	40	20	
			min	20	20	25	10	
		Well 2c	max	110	110	100	90	
			min	40	30	50	50	

Table 2. Maximum and minimum water table depths are reported with seasonal rainfall amounts.

In addition, plot the water table depth through the entire period after Figure 6. From this figure it is evident that the key sampling period for maximum water table elevation is spring and summer, and the lowest water table occurs in late autumn. In this case, monthly samples from May until November would be minimally sufficient. Together with Table 1, the data reported provide quantified evidence (the computed changes in maximum and minimum water table depths) as well as presenting the complete data (the plot).

Hypothesis testing with data from a small number of wells (10 or less) is often inconclusive, unless a site-specific model of groundwater hydrology is developed. The sign test (Zar 1998; Gonick and Smith 1994) does not assume that all groundwater wells will move in concert (i.e. it is not based on a distribution of mean values) and can therefore be used to test the hypothesis that peak groundwater levels will rise following restoration. However, unless 9 out of ten show an increase, the results will not be significant at the 5% level

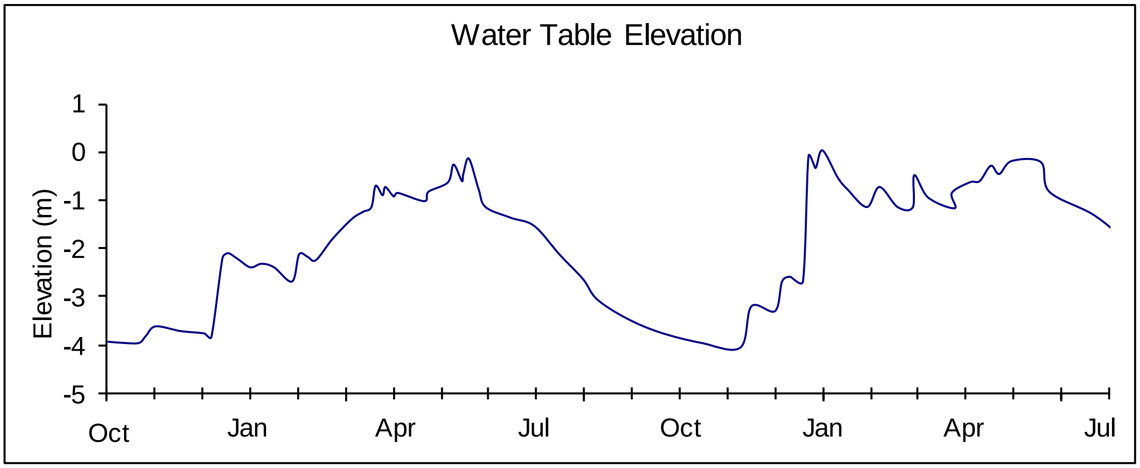


Figure 6. Continuous water table elevations (Data from Hammersmark et al. 2008)

Other Considerations:

Timing

The timing and duration of water availability within the rooting zone is one of the principal factors that determines the vegetation community found at a particular location. Researchers have classified meadow vegetation types by the maximum depth of the water table during the growing season and have generally found hydric wet-meadow vegetation where the water table is within 20 cm of the surface, mesic vegetation where the water table is slightly deeper, between 20 and 80 cm, and xeric vegetation when the water table drops below 80 cm (Allen-Diaz 1991; Ratliff 1985; Potter 2005; Loheide II and Gorelick 2007a). The precise cutoff values vary, but they are all generally between zero and 1 meter depth and there is sufficient consensus to develop a reporting standard for groundwater measurement around these values, for cases where groundwater measurements are taken sufficiently frequently. For the purpose of standardizing between studies, report the duration for which the water level is above 20 cm and 80 cm, and below 80 cm for each well.

Storage Volume

The absolute maximum and minimum groundwater elevations are also important groundwater metrics. The difference between the maximum and minimum elevation is the "drawdown". When the drawdown is used to calculate the maximum and minimum *volumes* of water stored in a meadow, the difference is called the "active storage" of a meadow. The same terms are used for reservoir operations, where the water level in the reservoir is visible and the water budget –how the inflows and outflows affect the surface elevation— is a primary concern. Active storage is much more difficult to calculate for a meadow than for a reservoir because the water table in a meadow is not horizontal, and soil porosities vary among strata and from place to place. Estimates of volumes will require additional data and simplifying assumptions (Cornwell and Brown 2008; Hammersmark, Rains, and Mount 2008), but may be useful indicators of project success.

Stream Flow

The goal of the monitoring program presented here is to describe how stream flow changed as a result of meadow restoration. In particular, data are summarized to describe changes in baseflow, annual discharge and flood peaks.

Low Flows

Meadow restoration has the potential to affect stream flow, both within the meadow and downstream. This is certainly a matter of intense interest in the arid west, and a common justification for investment in meadow restoration. Studies have shown increased baseflows downstream of restored meadows (Tague, Valentine, and Kotchen 2008; Hammersmark et al. 2010; Loheide, Deitchman, Cooper, Wolf, Hammersmark, and Lundquist 2009b; Heede 1979; Klein et al. 2007; Swanson, Franzen, and Manning 1987). However, flows within the meadow reach are difficult to predict, because of the interaction between surface water and groundwater. Simulations by Hammersmark and Lundquist (2009b) showed increased baseflows downstream of a pond and plug restoration, but lowered flows and complete drying of reaches within the meadow due to an increase in subsurface flows. Additionally, one pond and plug project in the Feather River Watershed (Long Valley) reduced summer flows within the meadow to the detriment of a within-meadow diversion. Because it is difficult to predict how streamflows will change within a meadow reach, restoration methods designed to raise the channel bed elevation may be risky if it is important to maintain flows within a meadow (for example if there are multiple landowners, diversions, or where perennial stream connectivity is a priority).

Annual Flows

Additionally, restoration may affect total annual runoff. Projects that raise the water table and convert xeric vegetation to wet meadow habitat increase the water lost by evapotranspiration (Loheide II and Gorelick 2007b). Increased groundwater storage during peak runoff may compensate for the increased loss and maintain or increase baseflows. However, total annual discharge is expected to decrease in these cases. This has not been documented to date (Hammersmark et al. 2010). None-the-less, we may expect a reservoir operator downstream to want these effects quantified, especially if the reservoir seldom spills and the entire annual runoff is fully appropriated.

Flood Flows

Restoration methods that raise the channel bed and increase the frequency of flooding on the meadow surface may also change flood patterns downstream (Hammersmark, Rains, and Mount 2008). Reduction in peak flows and a delay in the peak runoff have been observed in a number of projects in the Feather River Watershed for floods of moderate size (http://www.feather-river-crm.org). Funders and supporters of meadow restoration are very interested in the potential flood abatement benefits of meadow restoration, although the data for an analysis across meadow projects is not yet available.

Procedure

As noted above, it is important to consider possible groundwater pathways when siting stream gauges. Gauges are placed above and below the meadow at sites where all the flow is expected to be in the channel. That is, there are not ungauged groundwater paths, and diversions do not bypass gauges. To monitor stream flow downstream of a meadow, choose a site where groundwater flow paths have rejoined the channel above the gauge site, for example below a constriction in the valley bottom. If there are important stream uses within a meadow, such as a diversion, it may be important to monitor flow at that site, and recognize during the planning stage that restoration efforts which increase subsurface flow down valley may simultaneously reduced stream flows within the meadow.

Simplified instructions for installing a stream flow gauge and methods for developing the stage discharge relationship are included in Appendix 2. In addition, the standard methods of stream flow measurement are available online from the USGS (Rantz et al. 1982).

Reporting

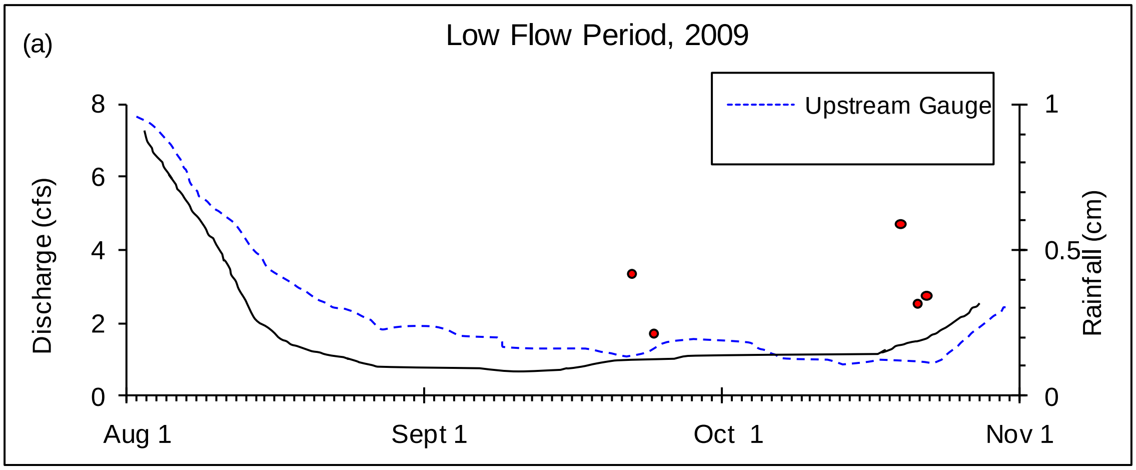
Low Flows

The key attributes to summarize for low flows are the (1) timing and (2) discharge of minimum flows. This is clearly communicated in a table such as Table 2. For every calendar year, report the date and mean daily discharge for the lowest flow recorded on both the upstream and downstream gauges. On those dates, also report the difference in flow between the downstream and upstream gauges. If there are multiple occurrences of minimum flow, for example a number of days with zero discharge, record the first minimum date, note this in the table and reference the plots described in the next section to provide information that cannot be easily summarized in table form.

Low Flow Summary	2009	2010	2011 **Restoration**	2012	….
Rainfall by water year (cm)	150	170	110	160	
Date of Minimum Flow @ Upstream Gauge (UG)	1-Oct	7-Sep	6-Oct	7-Sep	
UG (mean daily flow, cfs)	0.5	0	0.2	0.3	
DG(mean daily flow cfs)	0.5	1	0	0.5	
Difference (cfs: Downstream - Upstream)	0	1	-0.2	0.2	
Date of Minimum Flow @ Downstream Gauge (DG)	1-Oct	15-Sep	6-Oct	7-Sep	
UG (mean daily flow, cfs)	0.5	1	0.2	0.3	
DG(mean daily flow cfs)	0.5	1	0	0.5	
Difference (cfs: Downstream - Upstream)	0	0	-0.2	0.2	

Table 3. Summary of annual minimum flows. Rainfall is reported by water year as discussed in the Groundwater section above.

In addition to a low-flow summary table and narrative, provide overlay plots of the upstream gauge, downstream gauge, and rainfall events during the low flow period as shown in Figure 6. These plots are useful, as some aspects of the low-flow hydrograph are not easily summarized. For example, Figure 6a indicates a period of summer water diversion (before October 5th, when the downstream gauge exceeds the upstream gauge.) In contrast, Figure 6b shows the influence of a substantial source such as a tributary that adds flow between the two gauges.



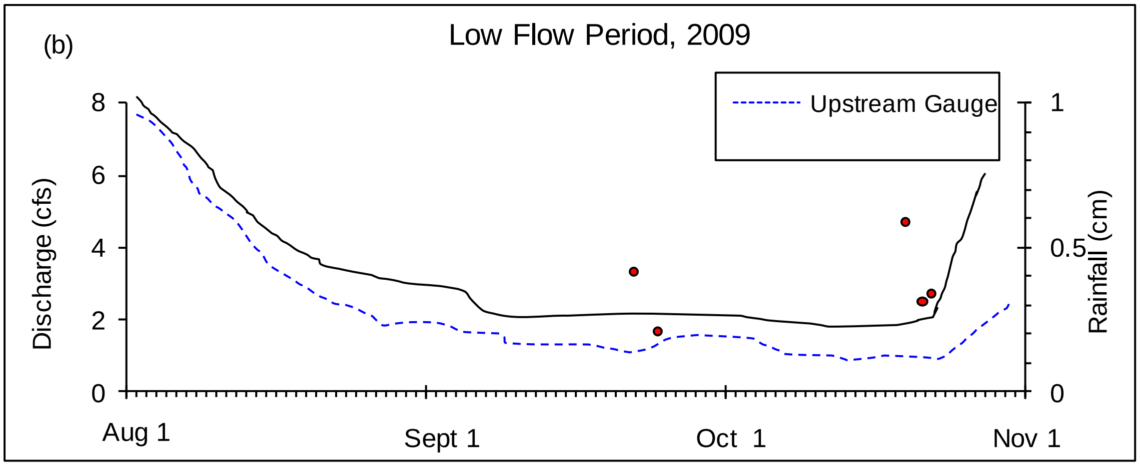


Figure 7. The hydrograph for the low flow indicates daily rainfall totals (red circles) on a second axis. (a) shows a seasonal diversion, when downstream flows are lower than upstream flows. (b) shows a source within the meadow such as a tributary, or substantial base flow.

Peak Flows

Restoration methods that enlarge the meadow's active floodplain have the potential to alter both the timing and magnitude of flood flows (Hammersmark, Rains, and Mount 2008). The key parameters that define flood attenuation are: 1) decreased peak flows and 2) delayed peak runoff. Decreased peak flows contribute less volume to downstream flood events, and peak flows that are delayed high in the watershed may not coincide with peak flows downstream and therefore contribute less to downstream flooding.

To report peak flows, identify the top 20 or more flow events measured at the upstream gauge in both the pre-restoration period and the post-restoration period and report summary values, as in Table 3. The peak attenuation is the difference between the downstream and upstream peak discharge values. The peak attenuation divided by the upstream discharge is the percent attenuation of peak flow for a given event. Also calculate the lag time as the delay between the time of upstream peak discharge and the time of the downstream peak. Report the date, the inflow peak discharge, the outflow peak discharge, the percent attenuation and the lag time for each high-flow event as in Table 4.

Date	Upstream Peak (cfs)	Downstream Peak (cfs)	% Attenuation	Lag Time (minutes)
3/1/2009	311	308	1.0%	45
3/4/2009	330	325	1.5%	34

Table 4. Peak flows summary values. Include at least the 20 largest peaks before and after restoration.

Other Considerations

It is often useful to plot the percent reduction of the high-flow events versus the upstream peak, and note the discharge where flooding in the meadow occurs. If the discharge at which flooding begins differs before and after restoration, it is illustrative to include both values. This plot will show how the flood attenuation varies with the size of the flood. Compare the plots using data from before and after restoration to illustrate the effect of restoration on flood peaks.

Finally, since attenuation of flood flows does not depend on a seasonal precipitation record, it may be possible to test the hypotheses that restoration increases peak attenuation and lag time. If floods are separated in time, each event can be considered an independent replicate in an analysis of variance to test for differences in attenuation and lag time before and after restoration.

Water Temperature

Meadow and riparian restoration efforts often aim to reduce maximum water temperatures (National Fish and Wildlife Foundation 2010; Jones and Stokes 2008), for example, by increasing riparian shade or increasing baseflow. Water temperature is an important indicator of water quality that affects numerous other water quality objectives such as dissolved oxygen and nutrient toxicity to fish (State Water Resources Control Board, Lahontan 1995; Central Valley Regional Water Quality Control Board 2011). It is also simple to measure with inexpensive and robust dataloggers.

Procedure

Temperature Logger Installation

If stream gauging is undertaken, water temperatures will be taken at gauging stations above and below the meadow, with the same datalogger that measures stream stage. If stream gauging is not planned, temperature can be measured alone, for example with a Hobo TidBit^{TM}. The logger can be attached directly to rock (preferably bedrock, or a very large boulder), or to a post driven deep into the stream bed. The logger should be mounted so it is protected from logs and rocks moving downstream, and be deep enough that it is always below the water level. Avoid sampling backwaters, large pools, and other areas where temperature stratification or anomalies are expected. Marine epoxy which cures underwater (such as Z-spar^{TM}) has been used successfully to attach temperature loggers in rivers and in the waveswept intertidal zone. The failure point is usually where the epoxy adheres to the rock. To improve adhesion to the rock, knead a lump of epoxy onto the rock until a secure bond is made. Then form another lump of epoxy around the logger. Before the epoxy begins to set up, push the epoxied logger onto the epoxy attached to the rock. This makes a much more secure bond than simply epoxying the logger and pressing it onto the rock. Expansion anchors similar to those used for attaching stream gauges (Appendix 2) are even more secure. However, they require more tools to place. Zip ties are tempting in their simplicity, but are most likely to fail. A better option when contemplating a zip tie is a pair of stainless steel hose clamps. Avoid hose clamps with a stainless steel band, but with a non-stainless screw that can corrode and make it difficult to remove the logger without cutting the band.

Calibration

Before installing the two (or more) temperature loggers, calibrate them by placing them together in a water bath and slowly varying the temperature (so the loggers are able to equilibrate at each temperature). Be sure to include a bath temperature near the maximum temperature expected.

Record the water temperature in the field with a mercury thermometer whenever the data are downloaded and use these spot temperature measurements to check the loggers for accuracy. Mercury thermometers are often easier to use than electronic probes when a reference temperature is needed, because their temperature readings do not drift and therefore they only need to be calibrated once. Temperatures should be logged at least every 15 minutes, and downloaded annually.

Reporting Water Temperatures

High water temperatures are of primary interest. The Regional Water Quality Control Boards sets temperature targets based on both annual maximum and monthly average daily maximum (MADM) temperatures (the average of the daily maximum temperatures over one month). For both upstream and downstream gauges, report MADM temperatures, as in Table 5. In a separate table, report annual maximum temperatures for upstream and downstream temperatures, noting the year of restoration and, if measured, the minimum flow at the downstream gauge.

Monthly Average Daily Maximum Temperatures	Upstream Gauge (°C)	Downstream Gauge (°C)	Difference (°C)
Jan, 2009	4.1	4.1	0
Feb, 2009	4.0	4.1	0.1
Mar, 2009	4.1	3.9	-0.2

Table 5. Summary values for monthly average daily maximum temperatures for upstream and downstream gauges.

In addition, overlay plot temperatures for upstream and downstream sites at a scale that makes it possible to discern variation in maximum temperature.

Other Considerations

In some meadows, baseflow entering the channel from within the meadow reduces stream temperatures so that, in the summer time, the water temperature decreases between the top and bottom of the meadow (American Rivers 2010). This would be visible in the plots, but should be highlighted along with a discussion of the timing (is there a crossover point, when downstream flows go from warmer to cooler than upstream flows?) and the magnitude of effect.

Sediment

Meadow restoration has often been undertaken to reduce sedimentation downstream. For example, Pacific Gas and Electric Company (PG&E), as a founding member of the Feather River CRM initiated a watershed-scale meadow restoration to protect downstream reservoirs from siltation (University of California Cooperative Extension 1996; London and Kusel 1996).

However, sediment transport is exceedingly costly to measure accurately and the effects of meadow restoration on downstream sediment transport have not been quantified to date (Jones and Stokes 2008). The Feather River CRM is in the early stages of a sediment monitoring effort (Feather River CRM 2010 Watershed Monitoring Report). The standard method is to continuously monitor turbidity and collect enough field samples of suspended sediment to construct a turbidity-suspended sediment relation similar to the stage-discharge rating curve described above for gauging stream flow. However the effort required to maintain a continuous turbidity monitoring station, along with the field work involved in measuring suspended sediment, is much greater than the effort required for gauging stream flow. Large amounts of sediment are transported during infrequent high flows, so these events are particularly important to sample adequately, although monitoring is a challenge, because a trained observer must be on call and able to go out during winter storms. Dave Shaw (Balance Hydrologics) estimates a ballpark cost of $30,000 per year to maintain a sediment monitoring program. Because sediment transport is important but difficult to quantify, it is a good candidate for research conducted on a subset of meadow restoration projects chosen for intensive study, in collaboration with a university and/or US Forest Service laboratory.

Because it is not likely that sediment will be directly monitored at a large number of restoration projects, we recommend methods based on estimates of bank stability and erosion rates. Collapsing banks are an obvious source of sediment supply from within the meadow, and this will be quantitatively described. However, these methods do not consider the potential for a restored floodplain to capture sediment carried into the meadow from an upstream source (see Wood 1975; Florsheim, Mount, and Rutten 2000).

Procedure and Reporting

Channel Cross Sections

At least three permanent channel cross sections will be established within the restored reach in conjunction with groundwater monitoring. Cross sections transect the entire meadow floodplain (Figure 2), with a higher density of points measured at locations with varied topography, such as near the channel. High precision is necessary to discern changes in the stream channel.

Cross sections are valuable long-term data that may be re-visited by a third party decades into the future, so it is critical that the site is documented in such a way that it can be re-surveyed long after funding for project-specific monitoring has lapsed. This lesson has unfortunately been learned many times, as these data have been difficult or impossible to find (Kondolf 1998; MACTEC Engineering and Consulting 2004). To ensure cross section data endure as long-term and baseline data, end points of the transect must be permanently marked (with capped rebar, a monument cemented into rock, a marked bearing tree, etc.) and recorded with GPS locations and the coordinate system (datum) used. In addition, a benchmark for vertical reference must be permanently identified or monumented. Record the cross section and benchmark locations on an aerial photograph and include a verbal description that allows one to find the reference points. For example, see the National Geodetic Survey station descriptions (http://www.ngs.noaa.gov/cgi-bin/dsformat.prl).

The USDA Forest Service has prepared a useful illustrated reference for basic field surveying techniques needed for measuring channel cross sections (Harrelson, Rawlins, and Potyondy 1994). Briefly, cross sections that are small can be surveyed with a tape and rod. Larger cross sections are best surveyed with a transit, rod and tape, or a total station. Critical points to survey are breaks in slope and the elevation of the lowest strip of continuous vegetation cover – the greenline (see Burton, Smith, and Crowley [2011] for a detailed description of how to identify the greenline).

At each cross section, also include four photographs: along the transect (across the channel) from each endpoint (show the marker in the photograph), looking upstream at the transect, and looking downstream at the transect (again, show or draw the transect in the photograph).

Cross sections likely will not need annual monitoring. Rather, cross sections may be resurveyed whenever it is determined that a change is likely to have occurred, for example, when a change is noted from a cross section photograph.

Cross section data are best shown graphically as separate overlay plots (Figure 8) for each transect. No standard summary metrics are suggested (for example changes in width-depth ratio, or rates of bank erosion), as the most relevant descriptors will vary, depending on the evolution of the cross section.

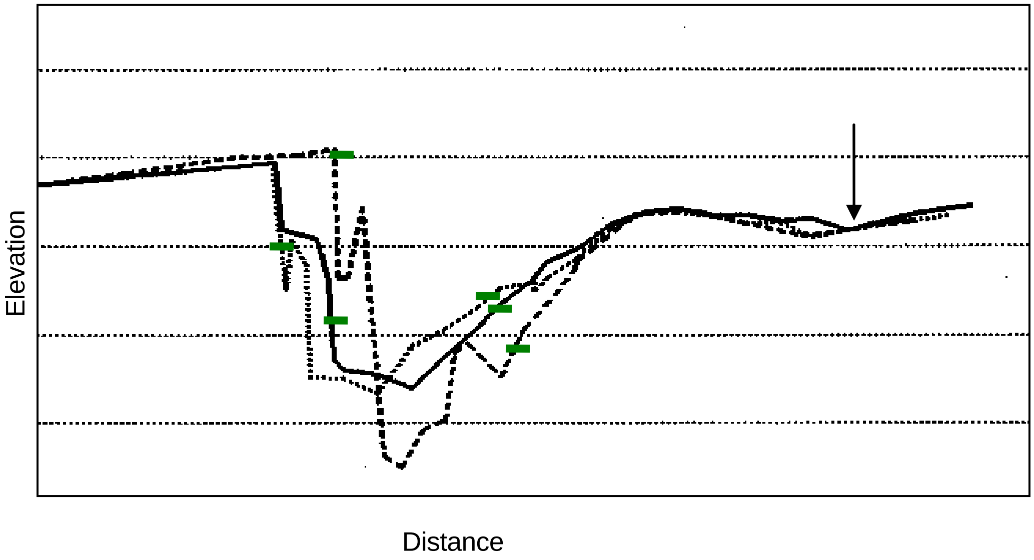


Figure 8. Three years of overlaid cross section measurements. Elevations are relative to a standard benchmark, here the transect origin. The arrow marks a historic channel on the meadow floodplain. Green bars indicate greenline positions for each bank (cross section data from Kondolf, 1998).

Stream Bank Stability

Eroding stream banks are a main source of meadow-derived sedimentation. Here the goal is to determine the fraction of stream bank that is eroding along permanent monitoring reaches. The goal is to choose representative reaches, so the measurements reflect the condition of the overall meadow. However, the caveat with intensive monitoring at a subset of locations is always that the data only will reflect changes at specific sites. If large changes in bank stability are noted outside the sampling area, these may be discussed, but reporting will focus on changes quantified in the designated sampling areas.

The method follows the BLM Multiple Indicators Monitoring Protocol (Burton, Smith, and Crowley 2011). However, the monitoring areas are not randomly chosen, but are located at stream cross sections, to minimize the number of monuments which must be maintained and recovered during each monitoring visit.

The sampling area is designated as both banks 110 meters either up or downstream of a channel cross section. Flip a coin to decide, and either record both banks downstream or both banks upstream. From the point where the channel cross section intersects the stream bank, pace along the bank top and at each pace record whether the bank is stable or unstable.

A bank is unstable and eroding if one of the following features exist: Either a (1) **fracture** (a crack is obvious along the top or on the face of the bank); (2) **slump** (a portion of the bank has slipped down as a separate block of soil or sod; or (3) **slough** (soil broken away or crumbled and accumulated at the base of the bank) or (4) if the bank is steep (within 10 degrees of vertical), and bare, for example on the outside of meander bends (Burton, Smith, and Crowley 2011).

Report the percent of each bank which is eroding (number of eroding observations/ total number of observations as a percentage) for each sampling area, and for each year.

Turbidity

Turbidity is often measured in the field because of the simplicity of the measurement and its use as a water quality indicator by the Regional Water Quality Control Boards. However, because turbidity varies over orders of magnitude over short time scales, for example when a storm begins, it is difficult to demonstrate effects of restoration without a substantial monitoring effort. Turbidity measures can be descriptive before and after restoration, if taken at similar flow conditions. However, the large potential for sampling error makes conclusions drawn from sporadic field samples of turbidity questionable.

Site Overview Data

In addition to the data reported above, it is important to include a map that shows where data are collected with respect to features within the meadow. Include stream gauge locations, groundwater wells, cross sections, bank stability transects, tributaries and diversions, and locations of sequential photographs (photo points) taken at key locations.

To ensure identical photopoints, follow these three steps: 1) take the photograph from the same place and at a constant height every time – for example, in front of a fence corner at your eye level. 2) center the photograph on the same landmark each time 3) use the same zoom, or alternatively, crop the photographs identically. As long as the 1) location and height 2) photograph center and 3) field of view are the same, the photographs will be easily comparable. Record the GPS coordinates of the photo point location. Coordinates can be entered into the metadata of a digital photograph (some GPS-enabled cameras do this automatically), included in the written report, or written on a white board and held in front of the camera so that it is readable in the image (also see the discussion of monumenting cross sections, above).

Also include before-and-after aerial photographs (often available from Google® Earth).

Sharing Reports and Data

Monitoring reports should be updated annually for the first three years and every five years thereafter as well as after a major change in management (Stillwater Sciences 2011). Each additional year of data should be added to the original report, so the entire record is accessible in one place. The monitoring data should be stored carefully for future analysis, preferably online and in a backed up location that is maintained by the project lead or sponsor.

The project should be submitted to an online index. In California, this is the Natural Resource Project Inventory (NRPI) at the Information Center for the Environment, U.C. Davis. Data and reports should be linked to this database, if possible and published online at a stable address. Also provide a durable point of contact, and for ease of searching, include “meadow” and “restoration” as search tags.

Reports submitted to funders are often published online. However these reports are very difficult to find, as they are not typically well indexed by search engines. Wherever your reports are housed online, submit them to Google® Scholar (http://support.google.com/scholar) so they will be indexed and easily found by a wide audience.

References

ASTM-D5092. 2004. *Standard Practice for Design and Installation of Groundwater Monitoring Wells*. ASTM International, West Conshohocken, PA.

Allen-Diaz, B.H. 1991. “Water table and plant species relationships in Sierra Nevada meadows.” *American Midland Naturalist*: 30–43.

American Rivers. 2010. *Headwaters Restoration in a Changing Climate: The Meadows of Bear Valley*. Sierra Nevada Conservancy. http://www.americanrivers.org/our-work/water-supply/storage-flows/bear-valley-meadow.html.

Burton, T.A., S.J. Smith, and E.R. Crowley. 2011. MIM protocol BLM.

Central Valley Regional Water Quality Control Board. 2011. Water Quality Control Plan for the Regional Water Quality Control Board, Central Valley Region. http://www.waterboards.ca.gov/rwqcb5/water_issues/basin_plans/.

Cornwell, Kevin, and K. Brown. 2008. *Physical and Hydrological Characterization of Clark’s Meadow*. California State University, Sacramento.

Danielsen, F., D.S. Balete, M.K. Poulsen, M. Enghoff, C.M. Nozawa, and A.E. Jensen. 2000. “A simple system for monitoring biodiversity in protected areas of a developing country.” *Biodiversity and Conservation* 9 (12): 1671–1705.

Florsheim, J.L., J.F. Mount, and L.T. Rutten. 2000. “Effect of baselevel change on floodplain and fan sediment storage and ephemeral tributary channel morphology, Navarro River, California.”

Gonick, Larry, and Woollcott Smith. 1994. *Cartoon Guide to Statistics*. 1st ed. Collins Reference, February 25.

Hammersmark, C.T., S.Z. Dobrowski, M.C. Rains, and J.F. Mount. 2010. “Simulated Effects of Stream Restoration on the Distribution of Wet-Meadow Vegetation.” *Restoration Ecology*.

Hammersmark, C.T., M.C. Rains, and J.F. Mount. 2008. “Quantifying the hydrological effects of stream restoration in a montane meadow, northern California, USA.” *River Research and applications* 24 (6): 735–753.

Harrelson, C. C., C. L. Rawlins, and J.P. Potyondy. 1994. *Stream channel reference sites: an illustrated guide to field technique*. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. http://www.stream.fs.fed.us/publications/PDFs/RM245E.PDF.

Jones and Stokes. 2008. *Consultant's Report Plumas Watershed Forum Program Review*. 630 K Street, Suite 400 Sacramento, CA 95814. http://www.nfwf.org/Content/ContentFolders/NationalFishandWildlifeFoundation/GrantPrograms/Keystones/WildlifeandHabitat/Plumas_Watershed_Forum_Abridged_Review.pdf.

Kondolf, G.M. 1998. "Lessons learned from river restoration projects in California." *Aquatic Conservation: Marine and Freshwater Ecosystems* 8 (1): 39–52.

Loffland, H. L., R.B. Siegel, and R.L. Wilkerson. 2011. *Avian Monitoring Protocol for Sierra Nevada Meadows: A tool for assessing the effects of meadow restoration on birds Ver. 1.0*. The Institute for Bird Populations, Point Reyes Station, CA.

Loheide II, S.P., and S.M. Gorelick. 2007a. "Riparian hydroecology: A coupled model of the observed interactions between groundwater flow and 4 meadow vegetation patterning."

Loheide, S. P, R. S Deitchman, D. J Cooper, E. C Wolf, C. T Hammersmark, and J. D Lundquist. 2009. "A framework for understanding the hydroecology of impacted wet meadows in the Sierra Nevada and Cascade Ranges, California, USA." *Hydrogeology Journal* 17 (1): 229–246.

London, J., and J. Kusel. 1996. Applied Ecosystem Management: Coordinated Resource Management in the Feather River Watershed. In *Sierra Nevada Ecosystem Project: Final report to Congress*. Vol. 3.

MACTEC Engineering and Consulting. 2004. *Upper Carson River Watershed Stream Corridor Condition Assessment*. http://ndep.nv.gov/bwqp/file/upper_carson_covertoc_1004.pdf.

National Fish and Wildlife Foundation. 2010. *Business Plan: Sierra Nevada Meadow Restoration*. National Fish and Wildlife Foundation. http://www.nfwf.org/Content/ContentFolders/NationalFishandWildlifeFoundation/GrantPrograms/Keystones/WildlifeandHabitat/Sierra_Meadow_Restoration_business_plan.pdf.

Potter, D.A. 2005. *Riparian Plant Community Classification: West Slope, Central and Southern Sierra Nevada, California. R5-TP-022.* USDA Forest Service, Pacific Southwest Region, Vallejo.

Purdy, Sabra. 2011. *Monitoring Approaches for Fisheries and Meadow Restorations in the Sierra Nevada of California*. UC Davis Center for Watershed Science.

Rantz, S. E. 1982. *Measurement and Computation of Streamflow*. USGS. http://pubs.usgs.gov/wsp/wsp2175/.

Ratliff, R.D. 1985. *Meadows in the Sierra Nevada of California: state of knowledge*. Vol. 84. US Dept. of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

S.W. Sprecher. 2000. *Installing Monitoring Wells/Piezometers in Wetlands*. U.S. Army Research and Development Center, Vicksburg, MS.

SNEP. 1996. *Sierra Nevada Ecosystem Project Final Report to Congress: Status of the Sierra Nevada*. Centers for Water and Wildland Resources, University of California.

South Yuba River Citizens League. 2011. *Sharing Stewardship: A Guide to Involving Volunteers in Assessment,Monitoring and Restoration of Meadows in teh Sierra Nevada*. American Rivers.

State Water Resources Control Board, Lahontan. 1995. Water Quality Control Plan for the Lahontan Regin. http://www.waterboards.ca.gov/lahontan/water_issues/programs/basin_plan/references.shtml.

Stewart, Iris T. 2009. “Changes in snowpack and snowmelt runoff for key mountain regions.” *Hydrological Processes* 23 (1) (January): 78-94. doi:10.1002/hyp.7128.

Stillwater Sciences. 2011. *Monitoring meadow vegetation response to restoration in the Sierra Nevada.* Prepared for American Rivers, Nevada City, California. http://americanrivers.org/meadowpubs.

Tate, K.W., L. Roche, A. Merrill, L.J.H Hunt, and George, H. 2011. *Forage and Cattle Response to Meadow Restoration in the Sierra Nevada*. http://americanrivers.org/meadowpubs.

University of California Cooperative Extension. 1996. *The Feather River Coordinated Resource Management Group (Fact Sheet)*. http://www.watershed.org/?q=node/235.

Wood, S.H. 1975. “Holocene stratigraphy and chronology of mountain meadows, Sierra Nevada, California.”

Zar, Jerrold H. 1998. *Biostatistical Analysis*. 4th ed. Prentice Hall, October 18.

Appendix 1: Required Equipment, Materials and Cost

The cost of equipment, in addition to necessary field equipment, such as tape measures, clipboards, etc. (see Stillwater Sciences 2011) is shown in Table A2. In some cases, such as stream discharge measurement, the complexity of measurement depends on stream size and may vary widely. For example, it is relatively simple to measure flood flows in a channel 1 meter wide. Measuring discharge of a flooding river from a bridge is much more complex and costly.

Equipment and Materials List

Groundwater	Nine or more piezometers	$30-$80 each
	optional water level indicator	$300
Stream Flow	Two pressure loggers (water level logger)	$800 each
	Materials for housing and attachment	$100 each
	Stage plates and attachment hardware	$50-$300 per guage depending on stream size
	Equipment for discharge measurement (see appendix 2)	$5000-$20,000 depending on stream size
Water Temperature	Two temperature loggers	$120 each
Sediment	Survey equipment. For a minimum, see (Harrelson et al. 1994)	$1,000-$20,000+
	Materials for monumenting three permanent cross sections: rebar, caps	$10 each
Overview Data	GPS	$300
	Digital camera	$300

Table A1. Equipment and materials specific to the measurements detailed in the text. See individual sections for additional information.

Appendix 2: Stream Gauging Summary AR.

2011

How to Install & Monitor a Low-Cost Stream Flow Gauge

American Rivers
Rivers Connect Us

Introduction

This document is meant as a guide to installing a relatively low-cost continuous recording water level monitoring station. In conjunction with discharge measurements, you will be able to develop and characterize the stage-discharge relationship at your site. This correlation describes the relationship between discharge, the volumetric rate of water flow (cubic feet per second) in a stream, and the stage (or water surface elevation) that corresponds to any given discharge. This relationship is graphically illustrated by the rating curve, which plots discharge values (x-axis) with their corresponding stage values (y-axis) – see page 8.

Stage is continuously recorded remotely by a submerged water level logger, and can also be read off of the stage plate during site visits. Discharge measurements are collected manually as often as possible in the beginning and only when the stream is wadeable. Once the rating curve is sufficiently established, one can simply read the water level from the stage plate and find the corresponding discharge on the curve without having to take discharge measurements, and you'll have a low-maintenance streamflow gaging station!

Procedures

1. Siting

In choosing where to install your **water level logger**, be sure to look for a site with *all* of the following :

- A flat, nearly vertical surface for attachment. For example, the logger can be attached to the flat face of a boulder or bedrock in the stream or a bridge abutment
- A site deep enough that the logger will always be submerged, even during the lowest flows.
- Avoid pools if possible so that you're recording flowing water, not pooled water
- Avoid areas of high and variable sediment deposition to reduce the rate at which your housing might fill in with sediment

Some examples...

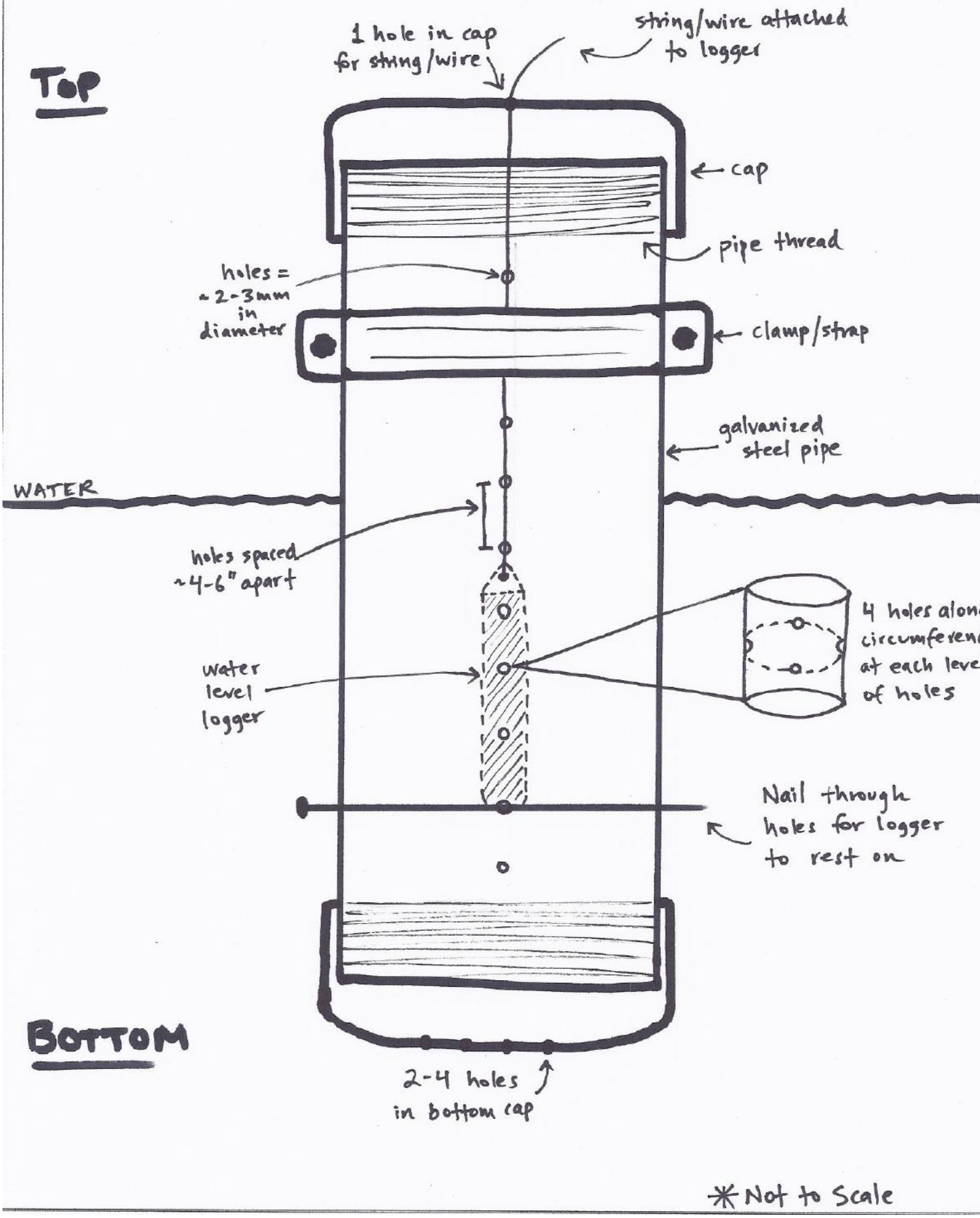
A nice flat surface to attach the housing and stage plate to

A big boulder on the edge and deepest part of the stream

An improvised gage due to high water levels at time of installation and location of site (on a large concrete slab in the middle and deepest of the stream). In this scenario, the upper horizontal arm has to be removed in order to pull out the logger, as opposed to just taking off the cap on a straight vertical housing

Streamflow Gage

Generalized Schematic



When choosing the location of the **cross-section** where discharge measurements for the gage will be made, make sure your stream reach meets as many of the following criteria as possible:

- A run or glide (the fast and smooth flowing sections often found between pools and riffles)
- Straight section with adequate depth
- Uniform and non-turbulent streambed
- Total flow confined in one channel

Excellent location for a cross section:

Poor location:

When determining a location to place your **stage plate(s)**, consider the following:

- Close to the gage
- Place as deep as possible to capture the very lowest flows
- Use pre-existing vertical flat surfaces if available (bridge abutment for example). Stage plates do need to be level in all dimensions, otherwise water level readings will be distorted
- With overlapping sections, make sure the transitions line up to maintain accuracy
- Site stage plates so that you can read them from some convenient distant location during high flows

Using a bridge abutment for the stage plates – these often provide a flat and level surface. In this case, the plates can be read with binoculars during high flows from the other side of the stream

2. Pre-Installation

- Assemble the housing:
    - Have pipe cut and threaded to necessary length for the site(s)
    - Drill the holes in the pipe (see figure on page 3)
- Make sure you have everything you need for the installation – use the equipment list provided below as a checklist, and be sure to plan ahead for anything you need to rent (roto-hammer or generator etc.) – a wheelbarrow helps!
- Program loggers before heading out – 15 minute (or less) recording interval is the preferred setting for water level data. Be sure your logger has enough memory to last until you plan to read it for the first time
- Be sure flows are low enough for the stream to be wadeable and for enough surface area to be available above water for you to have enough anchor points to securely fasten the straps that attach the housing
- Schedule consecutive days if possible so you maximize the cost-efficiency of rentals and staff time

3. Installation

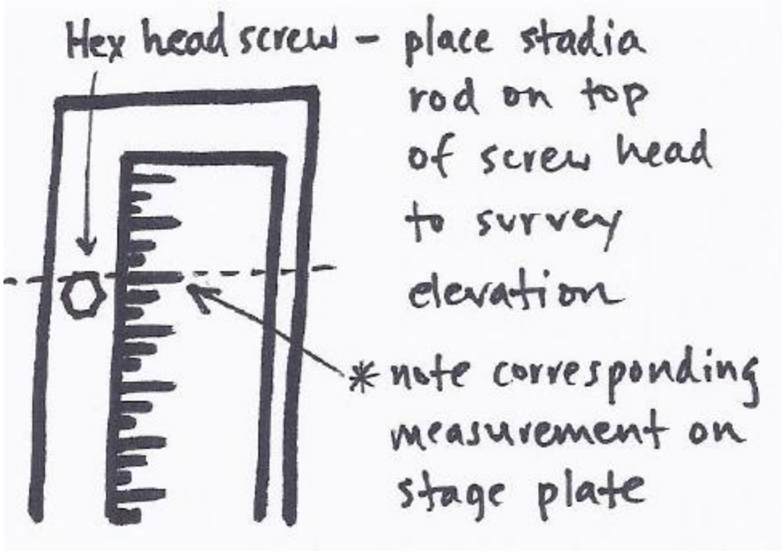
Start with the easiest site or a site where making mistakes is not crucial and can be learned from so you get a hang of how things will flow. For example, if you have a bridge or some sort of flat abutment in your line-up, start with that site since it most likely will be the easiest.

Gage:

First, pound a nail into the bottommost hole. It needs to stick out so that you can place the surveying rod onto it. The straps that anchor the pipe are held in place by expansion bolts ("Redheads" for example). Holes need to be pre-drilled for the bolts, so take some time in figuring out the exact depth of the hole, taking into account the length of the bolt, the depth of the nut and washers, and how much bolt you need exposed. Err on the side of drilling a hole that is too shallow so that you can drill deeper if need be (a too deep hole cannot be undone!). The generalized sequence would go strap, washer, lock washer, nut. This may look a little different if you need to use additional washers as spacers. Make sure you secure the pipe as much as possible (be liberal with your straps) – water and the material it carries is powerful! Brush some pipe thread compound over the threads of the cap and top of pipe so they do not lock up – you want to be able to open and close the cap as often as you need to for retrieving the data from the logger. Once you have the housing in place, tie some strong fishing line or wire to the top of the logger and place the logger inside of the housing, and tie the string outside of the pipe to a washer so that the string doesn't fall into the pipe and make it difficult to retrieve later on.

Stage Plate:

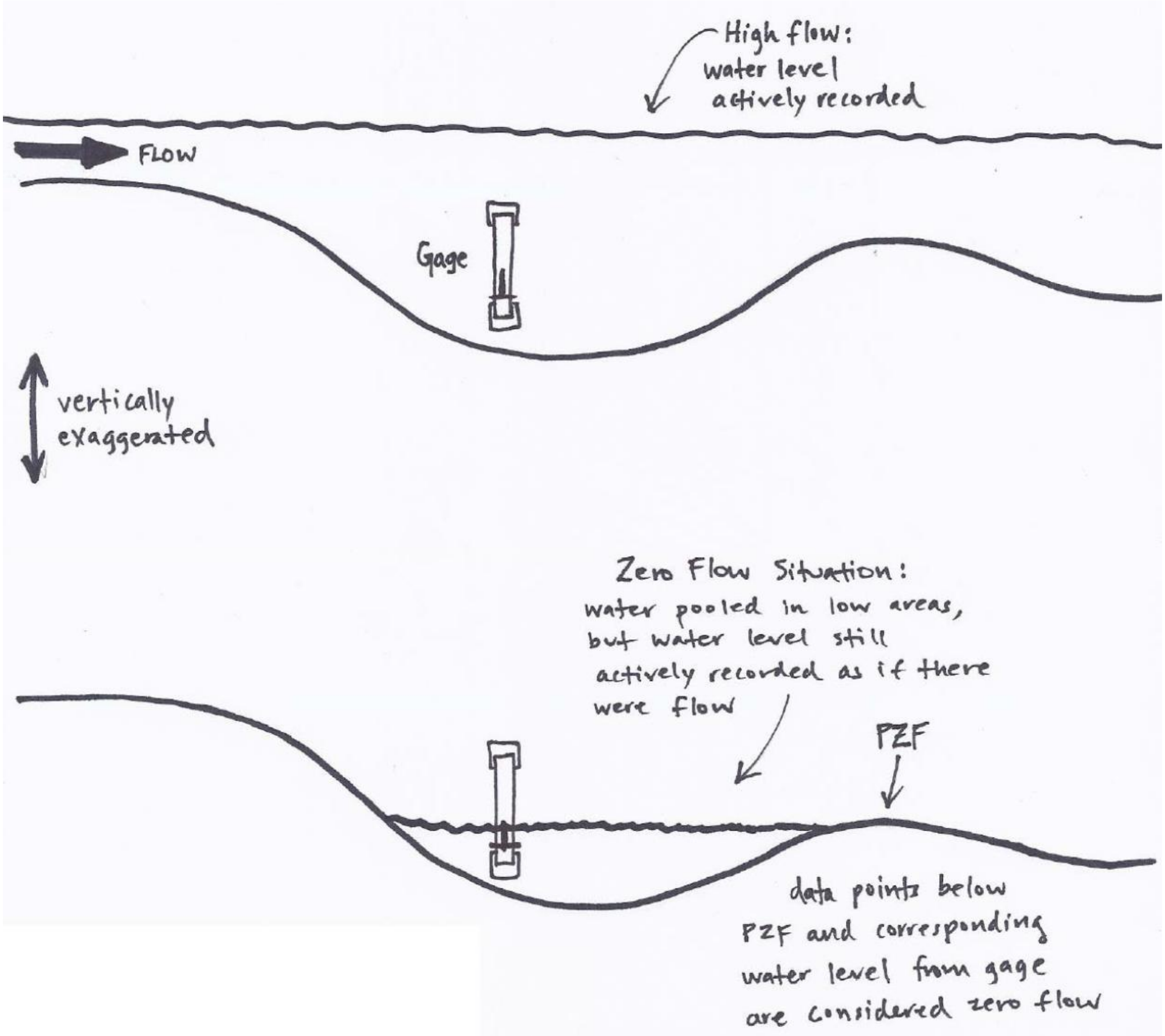
Secure the stream gage plate to a 2x6 piece of pressure treated wood with galvanized wood screws. The wood provides a stable and stiff platform for the stage plate (which is flexible). Screw a galvanized hex-headed wood screw into the wood adjacent to the stage plate so that one of the six edges of the screw head is horizontally level with one of the hash marks on the plate. The elevation of the screw will be surveyed in later, and provides a quantitative reference and relative elevation compared to the other equipment. The wood will also be anchored using the same expansion bolts, so pre-drill holes in the wood for these and take into account the depth of the wood in calculating the depth of the hole for the bolt. It is important that the gage plate is as vertically and horizontally level as possible, so you made need to use spacers to ensure this. It is also easiest if you secure the wood with one bolt, level it off of the edge of the stage plate (the plate needs to be level, not necessarily the wood), and then secure the second bolt.



Surveying:
You must survey in the equipment in order to monitor movement and readjust if necessary. You can use a simple transit or auto-level. Determine a benchmark for each site and measure elevations of the following with respect to the benchmark:

- Nail in the bottom of pipe (on which logger sits)
- Hex screw in wood (to which stage plates are attached)
- Point of Zero Flow (PZF) – this is the constraining elevation of the streambed downstream of the site below which water would essentially be pooled at your site and not actually flowing (but your logger will still record water level). You need to know this in order to know which data to consider as zero flow.

Generalized schematic depicting Point of Zero Flow

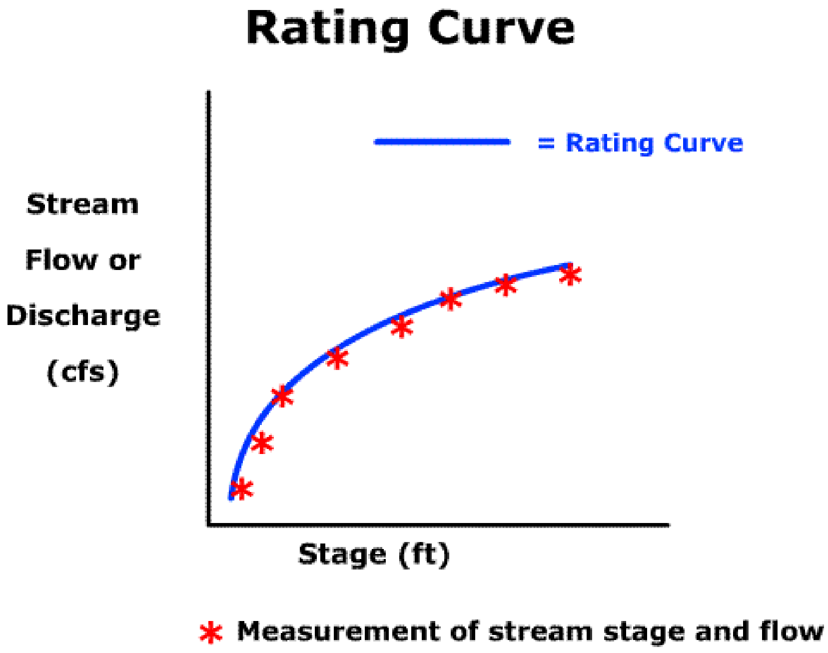


4. Monitoring & Maintenance

Measuring Discharge:
This document does not go into detail on the specific steps for measuring discharge – please see the USGS protocol for step by step guidance if needed:
http://pubs.usgs.gov/tm/tm3-a8

Developing the Rating Curve:

Once you have collected enough points, you can start to build a curve similar to the one shown below – this is the rating curve that describes the relationship between discharge and water level (or stage), which is measured by the gage and stage plates. Every time you take a discharge measurement you will also record the stage from the stream gage plate, which will give you a new point on the curve. Take discharge measurements as often as you can and at as many different flows as possible to capture the biggest range – and the higher the frequency of measurements, the quicker you will have a functional rating curve. Very high flows (spring snowmelt or intense rain events for example) will not be possible to capture unless you have a bridge or other structure to measure from (which requires a different set of equipment). This means that the top end of the curve is less accurate than the rest of the curve because it is a projection of the overall best-fit curve based on available data. Many of us are most concerned with low to no flow conditions, in which case this is not a big deal. Once the rating curve is established enough, one can simply go read the water level on the stream gage plate and find the corresponding discharge on the rating curve to know what the instantaneous discharge is. The logger gives us continuous water level data every 15 minutes (something we cannot do in person), and enables us to capture and plot very detailed hydrographs because those water levels are converted to discharge using the rating curve. Discharge measurements should continue to be taken over time in order to calibrate and correct the rating curve since streams are dynamic and channel morphology will change, especially after high flow events. The frequency of measurements can lessen over time once enough points have been taken to develop a robust curve.



(http://www.geology.sdsu.edu/classes/geol351/ratingcurve1.htm)

Maintenance:
Visually inspect gage housing and stage plates every once in a while, especially after high flow events. In addition, resurvey entire setup once or twice a year or after high flow events to make sure equipment has not moved. If it has, re-install at proper elevations and more securely.

Cost

For the water level recording station, the cost will roughly be between $600-800 for the equipment (water level logger, USB communication package – only need 1 for all loggers, galvanized pipe and hardware) - this does not include any tools or rentals you may need, as well as a barologger if air pressure data is not available (barologger is another $450 or so). Additional equipment may need to be purchased or borrowed for measuring discharge – this will not be estimated here as there are too many variables and unknowns in terms of what equipment is already in possession.

Equipment/Supplies/Tools

1. ***Streamflow Gage***
    - Stream gage plate(s) - come in 3.33ft sections
    - 2x6 pressure treated wood to mount stream gage plates onto (Doug Fir, Redwood, or Cedar) and cut into 4 foot sections
    - Galvanized wood screws to screw staff plate into wood
    - Expansion bolts (wedge anchors – "redheads") - we used 3/8" diameter bolts, and both $3^{3/4}$" and 5" in length depending on needs (and don't forget the nuts)
    - Flat Washers (with hole large enough for redheads)
    - Lock washers (with hole large enough for redheads)
    - Wood hex head screws (to place the survey rod onto)
    - Hammer
    - Nails (that fit into holes in pipe and are long enough to go through and provide a platform for survey rod)
    - Pipe clamps/straps (can use either two-hole or one-hole C-style clamps)
    - Pipe thread compound
    - Pipe wrench
    - Pipe (we recommend galvanized steel pipe) with threaded caps, and wide enough for logger to fit into – we used $1^{1/2}$" pipe
    - Tape measure
    - Water level logger (pressure transducer – we used the solinst levelogger gold)

- Barologger* (may not be necessary if a weather station or something similar already exists in close enough proximity to get relevant air pressure readings to calibrate water level readings)
- USB Communication Package for loggers
- String or wire to hang logger from
- Roto-hammer with concrete drill bit and mobile generator
- Extension cord
- Hand drill with drill bits
- Various screwdrivers
- Level (long one preferable – two feet long or more)
- Adjustable and/or socket wrench
- Sharpie, pens, pencils
- Hand wood saw and Hack saw(just in case)
- Work gloves
- Scissors and/or knife
- Waders or water shoes of some sort

2. *Discharge Measurements*

- Current Meter
    - Digital – flow tracker, flomate, aquaflow
    - Analog – pygmy meter, Price AA meter
- Counter (manual or digital)
- Measuring Tape (tagline) – use decimal feet
- Stakes (rebar or wood)
- Top Setting Wading Rod (optional but very helpful)