Section 5
Assessment of Program Effectiveness

The section addresses benefits of the ongoing watershed restoration work that has been conducted in the upper Feather River watershed since the mid-1980s, especially benefits to the State Water Project, and the prognosis for future benefits to be realized.

Need for Watershed Restoration

The scale of potential watershed restoration in the watershed is great, and efforts to date have only just begun to reverse the extensive degradation of the region's water resources. As described more fully in a series of studies[1], large scale instability of the region's soils and streams were induced in the 1880s primarily by grazing livestock in mountain meadows and adjoining uplands and unauthorized burning of the floodplains and neighboring forests for forage production. Additional watershed instability was induced by railroad and road construction, high-grade logging, and other human activities. These disturbances led to elevated rates of runoff and weakened streambanks due to loss of vegetative cover, leading to channel instability in the form of channel downcutting and, subsequent to 1940, channel widening.

The network of incised channels that spread throughout the alluvium-filled inter-montane basins today act as a drain of the near-surface sediments, preventing them from effectively storing winter precipitation or supporting vigorous, channel-stabilizing riparian vegetation. As a result of the loss of near-surface groundwater storage capacity, a significant shift in timing of runoff to the Feather River at Lake Oroville has occurred, diminishing streamflow during the dry season and increasing rapid runoff during winter storms. As a result of diminished riparian vegetation and the higher peak flows, the alluvial aquifers continue to be eroded and heavy sediment loads continues to enter downstream power reservoirs and Oroville Reservoir. Wildland fire in untreated upland vegetation continues to contribute episodically but substantially to the sediment load. These conditions have adverse effects on montane ecosystems, as changes in ground cover and vegetation type, and increased intermittency of some streamflow, translate into reductions in habitat suitability and species diversity.

[1] U.S. Soil Conservation Service 1989, Benoit et al 1989, Plumas Corporation 1992, Lindquist 1999, Lindquist and Wilcox 2000, Wilcox 2005, all available from http://www.feather-river-crm.org/publications.htm or by contacting the Feather River CRM, Quincy, CA.

Some government programs in past decades exacerbated the degradation episode. With the purpose of improving agricultural productivity of the meadowlands comprising the inter-montane alluvial basins, efforts were made to reduce seasonal flooding. Projects were undertaken to lower downstream grade controls (i.e. channel bedrock) and to remove riparian vegetation, so as to drain floodwaters more rapidly from meadow floodplains upstream. Unfortunately, these projects accelerated the process of stream downcutting and widening, and thereby diminished the production of meadow forage being used by the region's ranching/farming communities.

As environmental consciousness and knowledge became ascendant in the 1970s, the U.S. Forest Service, the U.S. Soil Conservation Service (now U.S. Natural Resource Conservation Service), and Pacific Gas and Electric Company began to understand the nature and societal price of the watershed degradation episode. Interest in watershed restoration among residents of the watershed grew rapidly, and organizations such as the U.S. Forest Service and the Feather River Coordinated Resource Management Group (CRM)—a consortium of local, state, and federal interests—began studying the problem and undertaking direct action to address it. Watershed consciousness grew through efforts of the CRM, teachers in the public school system, landowners and their organizations, local government, and state and federal agencies charged with stewardship of the region's natural resources. Today, a robust, diverse, and highly-active restoration program to counter the degradation episode is ongoing in the watershed, bringing benefits to local, state, and federal publics.

Benefits of watershed restoration described in this section of the program evaluation have been divided into three categories:

- water supply,
- water quality, and
- improved watershed awareness/ethic, with implications to both water supply and water quality.

As requested by the Forum, benefits to water supply are given the most in-depth evaluation.

Water Supply Benefits

Two of the Plumas Watershed Forum's four goals call for enhanced groundwater storage in intermontane alluvial basins in the Upper Feather River watershed, and a resultant increase in dry-season streamflow. Such augmented baseflow can conceivably be utilized by the State Water Project at Oroville Reservoir for water supply or to enhance instream environmental benefits through increased instream releases. Both uses have social utility and monetary value.

The baseflow-enhancement opportunity results from a unique geologic fact: that the Upper Feather River watershed is part of the Basin and Range province that drains westward across the northern end of the Sierra Nevada to the Sacramento Valley. The basins that alternate with ranges across the watershed are filled with large volumes of unconsolidated (non-indurated) alluvium, which store large quantities of groundwater. The watershed, which receives considerable precipitation because of its northern latitude and the reduced rain-shadow effect of the lower crest elevations at the north end of the range, drains to the Sacramento Valley into Oroville Reservoir, where waters can put to beneficial use throughout the State of California.

Before the Forum was created, sponsors of watershed restoration projects in the Feather River watershed (e.g. Feather River CRM) began their efforts with a focus on what would become the Forum's third goal—improved bank protection and reduced sediment yield—which reduces the rate of filling of downstream power reservoirs and, ultimately, Oroville Reservoir. Power production interests (i.e. PG&E) provided much of the initial financial support of the CRM.

Reductions in reservoir filling translate into water supply, flood management, and power production benefits, since more reservoir operational storage volume remains available. The benefits of Upper Feather River watershed restoration on sediment yield to date, as well as ultimate benefits once the restoration program is substantially complete, are considered by most investigators to be substantial.

This section, however, focuses on the water-supply benefits of reversing stream incision of the watershed's groundwater basins, to increase alluvial basin storage and delay water release into the dry season, when flood storage in Oroville Reservoir is no longer reserved. This augmented dry-season flow can potentially be utilized in the State Water Project, and valued at the marginal price of new water supply.

Is should be noted that this assessment of program effectiveness and benefits of augmented baseflow does not address implications of water rights law. One recommendation at the close of this section is that such a study be commissioned by the Forum.

Strategy: Reversing Stream Incision

Beginning in 1992, the Feather River CRM expanded its focus to include reversing stream incision (entrenchment) and restoring stream elevations in the intermontane alluvial groundwater basins. Entrenched stream systems dominate all of the basins. At least 190,000 acre-feet (190 TAF) of seasonal groundwater storage volume was lost to incision, based on an estimate described below. Without this storage, this volume is delivered to Oroville Reservoir during the rainy season when flood storage and releases to the ocean dominate water supply management and make it difficult to utilize the early-arriving water.

The Feather River CRM has developed a restoration approach—*pond and plug*—that obliterates the stream incision and restores the stream channel to the surfaces of the alluvial aquifer. The U.S. Forest Service has developed techniques to use road crossings to restore higher water surface elevations. Groundwater storage increases in relation to the increased elevation of the bottom of the channel, and proportionate to the width of the alluvial body through which the stream passes. This increase in groundwater storage volume from CRM projects has been substantial to date, but, a large potential increase remains. Once incision is reversed, the benefits of increased streamflow during the dry season are expected to last in perpetuity, if modern land management principles prevail over the long term.

The program to reverse the effects of the era of stream incision can result in important water-supply benefits and reduced sediment-handling costs that benefit citizens Statewide. Moreover, ancillary effects are also of great value, including increased riparian habitat, improved fish habitat, and increased forage for deer and livestock.

Approach and Basis for Estimating Water-Supply Benefits

To estimate water-supply benefits of the restoration program, potential physical changes in shallow groundwater storage volume must first be estimated. Most commonly this is directly related to the resulting rise in channel-bottom elevation. It is also governed by the specific yield (effective porosity) of the near-surface alluvium. Then, because raising water surface elevations induces greater plant cover, increases in evapotranspiration must be deducted from the volume increase. The effectiveness of the new storage volume on storing winter runoff and enhancing streamflow in the dry season must then be estimated. Finally, the temporal flow of costs and benefits is set forth and the economic efficiency is arrayed for a most-likely scenario and for other arguably-reasonable scenarios. These steps are described in the subsection *Potential Water-Supply Benefits* below. The scientific basis for each of these steps is described in this subsection.

Estimating Basin Storage Volume Lost to Incision. Estimates of average prevalent maximum incision depths for each alluvial basin in the watershed were based on U.S. Soil Conservation Service (1989) estimates as adjusted by the Feather River CRM's field hydrologist and stream restoration leader. These estimates generally apply to the incision in the central portion of each alluvial basin. They are used to estimate volume drained by incision by multiplying these maximum depths times the basin area, and applying a *shape factor* of 0.5. The shape factor results from assuming the resultant lowering of the water table is a wedge that extends from the incised stream to the edge of the basin, but diminishing proportionately to the thinning of the alluvium, to zero-lowering at the basin edge. (In cross section this is a very flat triangle on each side of the stream, whose area is one-half times the valley half-width times the maximum depth.)

Estimates of sizes of the eleven alluvial basins in the watershed were made by California Department of Water Resources (Bulletin 118).

Estimating Specific Yield. Specific yield is the percentage of the alluvial volume that can be filled with water and subsequent drained by gravity. Porosities and specific yield of sediments have been extensively studied over many years, primarily based on texture. Estimating methods vary and are difficult to apply. Results vary widely within and between alluvial bodies, even for the same textural classes. Considerable uncertainty in therefore involved in estimating average specific yield.

Silty fine sand is the most prevalent of the texture of the alluvial deposits in the watershed, with frequent gravel and cobble layers and less-frequent fine-grained (clayey) inclusions. Churchill (1988) refers to most of these soils as *loamy sands* and *sandy loams*. Recent studies in the watershed have documented this dominant sandy texture (preponderance of *silty sand*, *sandy gravel*, *sand*, and *sand-gravel mixes* [Cornwell and Brown 2008], and *clayey sand* [DWR 2002]). The dominant sandy texture suggests a relatively large specific yield.

Davis and DeWiest (1966) estimate values of 38-46% for sands, whereas USGS (1967) gives a range of 21-27%. The difference may be because Davis and DeWiest specifically address nonindurated sediments, which are present in the Feather River alluvial basins, whereas USGS refers to "rock textures" and appears to combine data from both indurated and nonindurated materials (indurated having correspondingly less porosity), as often comprise pumped groundwater aquifers. USGS reviewed a large number of scientific papers discussing SY estimations, some which are more in line with values of Davis and DeWiest.

In a study recently conducted at a meadow restoration site in the watershed along Clark's Creek, a tributary to Last Chance Creek (Cornwell and Brown 2008), an average porosity of 35% was estimated from a suite field samples, but used in subsequent calculations as if corresponded to specific yield, which is also known as *effective porosity*. This possible inconsistency needs to be rectified.

A specific yield of one third, or 33%, midway between the DeWeist and Davis and USGS (1967) values, is used in this section as the most likely value for purposes of estimating groundwater storage benefits for this program review. However, effects on calculated results are assessed for a range in specific yield values from 20 % to 33%.

Accommodating Evapotranspiration Losses. Watershed investigators have noted that restoring groundwater elevations to nearer the ground surfaces induces additional vegetative growth and thereby increases evapotranspiration (ET) losses of groundwater to the atmosphere, making some of the enhanced storage unavailable for streamflow enhancement. Thus, in converting storage enhancement to streamflow enhancement, it is necessary to first depreciate gross storage volume for annual evapotranspiration losses.

A recent study in the Upper Feather River watershed of ET losses utilizing spectral imagery and calibrated to ground conditions (Loheide and Gorelick 2005) provides a good estimate of the difference in growing-season ET losses between fully-degraded (incised) meadows and a fully-restored meadows. This work was also conducted in the Last Chance Creek watershed. It showed that daily ET losses in June were 3 mm per day from a fully-degraded site and 5 mm per day from a fully-restored site. Using the distribution pattern of ET throughout the year (large ET in June, minor ET in fall and winter) from the

CIMIS website (http://wwwcimis.water.ca.gov/cimis/welcome.jsp), data from Buntingville on the Modoc Plateau near the Upper Feather River watershed), these values were converted to annual values. The result is that restoration induces an estimated 1.7 feet of ET loss annually, between a fully-degraded site and a fully-restored site.

The full-degraded site used in the study had incision of up to 15 feet; for this assessment sites with 10 feet or more of incision were considered to be *fully degraded*. Lesser incised sites would induce proportionately less ET increases when restored. The result of this assumption is that 0.17 feet of each new foot of storage is lost to new ET. In other words, 83% of the new storage is available for delayed streamflow augmentation.

Converting New Storage to New Streamflow. Stream-groundwater interactions have been a subject of considerable study over the past 20 years. The water-supply issue for a program that restores near-surface groundwater storage capacity in the Feather River watershed is how the increased volume of storage translates to increased streamflow downstream during the dry season. A study of this relationship in the Upper Feather River watershed was recently conducted by Kavvas et al (2005), using the stream-profile restoration completed by the Feather River CRM in the Last Chance Subwatershed. Their results, based on a well-established method of modeling groundwater flow toward a discharge point, and examining actual streamflow data for a wet year, indicate that streamflow enhancement in the dry season (i.e. June-October) downstream of the project area is essentially equal to the volume of new seasonal storage created by the project. (The modeled flow enhancement was 2,258 AF for a project that created 2,265 AF of new storage capacity.) That is to say, the ratio of dry-season flow enhancement to created storage was shown to be 1.00. This modeling took into account actual floodplain geometry and hydraulic properties of floodplain materials.

The implication is that groundwater storage created by reversing stream incision in the Upper Feather River watershed, being shallow alluvial storage in a mesic environment, is likely to be utilized annually by the floodplain alluvial systems to defer runoff from the wet to the dry season. The source of waters recharging the new aquifer storage include streamflow infiltration through streambanks, shallow subsurface inflow from adjoining uplands (which is apparently significant; see Bohn 2007), and direct precipitation on the floodplain.

Determining Economic Efficiency. The economic efficiency of creating new shallow storage in alluvial aquifers is determined by estimating restoration costs, using the extensive experience of the Feather River CRM, and estimating value of the new volume of streamflow during the dry season.

A project would be considered economically efficient if the ratio of monetary benefits to costs is 1.0 or greater. However, prior to computing this *benefit-cost ratio* (BCR), all future costs and future benefits are discounted to their *present values*. For practical purposes , cost-benefit analysis can ignore inflation. The choice of an appropriate discount rate is crucial, however, and requires several considerations (National Center for Environmental Decision-Making Research 2008).

First, society, in making public investment should use a riskless discount rate, reflecting an assumption that the government will not default on its debts. Second, if a project displaces consumption by undertaking the public investment, then the appropriate discount rate is the consumer's after-tax time preference, a relatively low rate of return. If a project displaces private investment, the investment displaced is at a higher, before-tax rate of return.

Because most benefits will occur long into the future, almost any reasonable discount rate, even one reflecting consumption time preference rather than private rate of return, will suggest that the project is inefficient. For these reasons, attention turns from efficiency concerns, getting the right rate of private and public rates of return, to equity concerns, taking into account the rights of future generations. A zero rate means that the well-being of future generations is given equal weight to the well-being of the current generation.

The guidance given for federal decision-making by the federal Office of Management and Budget (OMB) is to use a 7 percent discount rate, but to conduct sensitivity analyses using 5 and 9 percent rates.

For intergenerational deliberations a lower rate is argued. Assuming future growth rate of per capita income of 1 to 2 percent and an elasticity of utility for marginal income of 1.5, discount rates as low as 1.5 to 3 percent may be selected, the latter corresponding to the rate of long-term U.S. Treasury bonds.

Accordingly, for the long-term watershed restoration project addressed in this section, OMB’s recommended rate is initially chosen, but implications of lesser rates (as low as 3%) are identified.

Potential Water-Supply Benefits

To estimate ultimate feasible water-supply benefits of the watershed restoration program, the methodology for estimating water-supply benefits as described at the beginning of the foregoing section was incorporated into an Excel spreadsheet model: *Appendix D – Upper Feather River Watershed Water Yield Enhancement Model*. The model computes annual monetary benefits and restoration costs over the period of years that would accrue in restoring stream and groundwater elevations in the watershed to their pre-incision condition wherever feasible.

The steps in computation performed by Appendix D, and the results, are as follows:

Volume Of Sediments Dewatered By Incision. This is accomplished by multiplying acreages of each alluvial groundwater basin in the Upper Feather River watershed (as inventoried by DWR) by estimates of maximum sustained incision depths for each basin. A shape factor of 0.5 is applied to account for gradual thinning of the dewatered sediment wedge to zero at the basin boundaries. The estimates of incision in USDA SCS and USFS 1989 from pre-1850 to 1989 provided the initial basis for the maximum sustained incision in each basin. Staff of Feather River CRM (Wilcox and Benoit per. comm.) compared these values to values in their inventory and project files and adjusted them accordingly. This procedure integrates the most extensive field data of the most experienced basin investigators. The estimates for each basin are likely accurate within 25% of the actual value, and with compensating errors, the final estimated sediment volume is probably accurate to within 10-20% of the actual volume. The estimated total dewatered sediment volume in the Upper Feather River watershed is about 576,000 AF, or 576 TAF.

Volume of Groundwater Storage Lost to Incision. This estimate is made by applying a specific yield or effective porosity of 33% to the foregoing dewatered sediment volume. The resulting water volume is about 190 TAF.

Maximum Feasible Extent Of Watershed Restoration and Attainable Storage Volume. Watershed restoration planners at the Feather River CRM estimated the percent of area within the combined groundwater basins that cannot feasibly be restored due to presence of infrastructure, towns, and residences. Their estimate of 70% feasibility reduces the potential new groundwater storage volume to about 133 TAF.

Increased Evapotranspiration and Net New Groundwater Storage. An ET loss estimate described above of 17% of each new vertical foot of storage, reduces the net groundwater available for baseflow augmentation during the dry season to about 110 TAF.

Enhancement Of Streamflow During The Dry Season (Baseflow Augmentation) Resulting From Natural Recharge of the New Groundwater Storage. Based on a factor of 1.00 resulting from groundwater flow modeling for a typical restoration project in the watershed (Kavvas et al 2005, discussed above), the baseflow augmentation would be about 110 TAF annually.

Comparison of Costs and Benefits. The approach used is to determine annual and cumulative income from, and costs of, achieving the new dry-season baseflow augmentation; compute the present values of each future income and cost using a discount rate of 7%, and from the present net value estimate the benefit/cost ratio for the restoration of shallow floodplain storage in the Upper Feather River watershed.

Value is measured as the current marginal value of a new acre-foot of water. The value of the potential baseflow augmentation is associated with its delivery to Lake Oroville, where it may be diverted to use or released instream as part of the environmental water account (EWA). The current price for the EWA is $150 per acre-foot. This price may undervalue the actual future cost of water, which is expected to rise faster than inflation.

The annual costs of the watershed restoration program required to restore all feasibly restorable watershed lands over a 50-year period were estimated from a summary of meadow projects (primarily pond and plug) conducted by Feather River CRM to date (Table 5-1). For each project, the summary includes an estimate of the rise in water table and the area over which the water table was affected. A shape factor of 0.5 was applied to these estimates to determine estimated new storage volume. The average cost determined from this project data is $550 per acre-foot of restored alluvial volume. When applied to the restorable alluvial volume, this data indicates that the feasible extent of restoration could be completed in 50 years at a cost of *$4.43 million per year*. If a shorter or longer restoration period is anticipated, the annual cost would increase or decrease proportionately.

As the watershed restoration program proceeds, annual benefits increase annually, as shown annually for the 50- restoration period and the 100-year analysis period in the Appendix D spreadsheet. Comparing the cumulative costs and benefits over the restoration period shows the program of reversing the dewatering effects of stream incision have a benefit-cost ratio (CBR) of about 1 if only the first 50 years are considered, but 1.14 if a 100-year period is considered. In the second 50-year period, no program costs are required, but benefits continue to accrue.

Benefits would continue to accrue for the time period beyond 100 years, but when a 7% discount rate is used, the contribution to present value of benefits becomes negligible.

Implications of Other Potentially-Reasonable Assumptions. The following alternative assumptions were also quantified and examined:

- In computing present new value, a 7% discount rate may be too high for such a long-term, intergenerational resource restoration project.
- The assumed average depth of incision may be too great or too small, or, equivalently, the estimated dewatered basin volume is too great or too small.
- The feasible extent of restoration may be too great or two small.
- The average specific yield of the alluvial basins may be lower than assumed.
- The ratio of baseflow augmentation to new storage volume may be overestimated.
- Because of way in which *areas of effect* were estimated by the Feather River CRM, the computed cost per acre foot of water-table restoration achieved may be too high
- The imminent value of an acre foot of water may be higher than assumed.

Table 5-2 - Model Sensitivity shows the outputs and economic efficiency (present net value) of the suite of potentially-reasonable scenarios. As the table shows:

- *Other discount rates.* As would be expected, the CBR based on present values would be less than 1.0 if the higher discount rate of 9% is used. However, as discussed under *Determining Economic Efficiency* above, lower discount rates may have more justification. Using a discount rate of 5%, for example, indicates a CBR of 1.21 during the restoration period (first 50 years) and 1.54 over the entire first 100-year period.

- *Other estimates of alluvial volume dewatered by incision.* As Table 5-4 indicates, the cost efficiency of the evaluated restoration program would not be different if the alluvial volume dewatered by incision has been over- or underestimated. Annual program costs would change, however, if a 50-year restoration period is maintained. A 25% over- or underestimate in alluvial volume would decrease or increase annual costs by about $1 million.

- *Other estimates of feasibly restorable volume.* Similarly, as Table 5-4 shows, the cost efficiency of the restoration program would not be different if the estimate of feasibly restorable lands has been over- or underestimated. Annual program costs would change, however. Rather than 70%, if only 50% of lands are restorable, annual program costs for 50 years would diminish to $3.2 million; if 85% of the lands are actually restorable, annual costs would rise to $5.4 million.

- *Lower average specific yield of shallow alluvium.* Table 5-4 indicates that cost efficiency is very sensitive to the average specific yield of the near-surface alluvial materials in the groundwater basins, and as discussed previously, the appropriate value to use for specific yield is difficult to determine. The results shown in the table indicate that if specific yield was only 20-25%, the CBR would be less than 1. However, additional calculations show that even in this case, a CBR of 1 would materialize over the 100-year project horizon if lower but potentially-acceptable discount rates are assumed. These lower rates (6.0% if specific yield is 25% rather than 33%, and 4.6% if specific yield is only 20%) are potentially acceptable for an intra-generational project.

- *Lower ratio of baseflow augmentation to new storage volume.* As previously discussed, Kavvas (2005) found that in one basin the characteristics of the near-surface aquifer are such that new storage volume translates to an equivalent volume of new baseflow augmentation. If the average ratio is not 1.0 however, but, for example, is 0.75, the CDR would be less than 1. As with specific yield, however, Table 5-4 shows that a CBR of 1 would materialize over the 100-year project horizon if a lower discount rate of 5.9% were assumed. This rate is potentially acceptable for an intra-generational project.

- *Lower cost per acre-foot of new storage.* For this study, a shape factor of 0.5 was applied to estimates of affected acreage by the Feather River CRM for its meadow restoration projects. This shape factor may be too low, however, since the acreage estimates probably reflect the area where the rise in groundwater would be evident, and would not include the greater extent where the new groundwater wedge tapers eventually to zero thickness. A shape factor of 1.0, on the other hand, would suggest that the CRM estimates are based on the area where the maximum rise in groundwater occurred. Accordingly an intermediate shape factor of 0.67 may be a reasonable alternative assumption. Such an assumption would be equivalent to a 25% reduction in unit cost, relative to the $550 per acre foot of alluvium used in the calculations above. As Table 5-4 indicates, this alternative assumption would increase the BCR over the first 50 years from 1.0 to 1.36.

- *Higher value of newly-produced streamflow.* If the assumed value of $150 per acre foot of augmented baseflow is too low, the CRB would increase. For example (as shown in Table 5-4), if a value $200 per acre foot is assumed, the CRB in the first 50 years would increase from 1 to 1.35. This higher average value of new water could easily materialize over the next few years; indeed, much higher prices are currently paid in some locations for additional water supplies, and water demand in California continues to rise faster than supply increases.

Water-Supply Benefits Achieved to Date

Aided significantly by Forum funding, to date nearly 10,000 AF of shallow alluvial aquifer storage has been restored by the Feather River CRM at an estimated cost of $550 per acre-foot of alluvial storage medium (Table 5-1). Applying the factors from Appendix B for specific yield, ET, and the ratio of new stored water to augmented baseflow, as described in steps 2, 4, and 3 above, the unit cost of augmented baseflow is equivalently $2,008 per AF . The cost is one-time, but benefit recurs annually in perpetuity. Assuming a value of $150 per acre foot, in 13.4 years the benefits exceed the costs, and the net will grow larger by $150 every year. After 25 years, for example, the one-time cost of $2,008 per acre-foot will have created $3,750 of water value, and in 50 years is will have created $7,500 of water value. Clearly, the CRM program, although not focused solely on water yield, has been cost effective in producing new water volume. Monitoring and research projects also partly funded by the Forum are demonstrating the effectiveness of meadow restoration in terms of reduced floodflow, augmented baseflow, and reduced dry-season water temperatures (reflecting the presence of temporary storage and late-season release).

The Forum has also funded programs to treat upland vegetation. A study conducted for the U.S. Forest Service, as part of the HFQLG Forest Recovery Act implementation, has estimated that flows will be augmented in the dry season by 17-26 AF per year because of canopy reduction, depending upon the level at which the Act is actually implemented (Troendle at al 2007). Additional augmentation is coming from aspen restoration projects involving removal of encroaching conifers that otherwise increase evapotranspiration. Some of this augmentation has already occurred, but most is still to be achieved. Added to the 110 AF per year for the most likely scenario for raising stream and groundwater elevations, *the overall watershed restoration program would result in 130-140 AF per year of augmented baseflow during the dry season*.

Summary and Conclusions Regarding Water-Supply Benefits

A reasonable estimate is that streamflow in the dry season delivered to Oroville Reservoir can be enhanced an estimated 110 TAF per year by stream-elevation restoration actions to reverse 70% of the stream entrenchment in the upper Feather River watershed, and that an additional 17-26 AF per year may be enhanced through continuation of canopy density control for reducing wildland fire hazards, and an unknown additional amount through aspen restoration.

An estimated 3 TAF/year of augmented baseflow has already been generated by meadow restoration actions taken by the Feather River CRM to date, and an unestimated augmentation has already occurred due to activities of the Quincy Library Group project and the Feather River Fire Safe Council. To accomplish the feasible extent of stream restoration, the current stream restoration program would need to be funded at about $4½ million per year for about 50 years.

Economic analyses suggests a favorable economic return in terms of new usable water volume that could be realized as a result of the stream restoration program. Uncertainty analysis, involving changing each of the input variables within a reasonable range, shows that the conclusion is robust—that a positive benefit-to-cost ratio would likely result from the program of reversing watershed incision in the Feather River watershed.

In addition to state-wide benefits of eventually producing 127-136 TAF of usable water per year, the restoration program creates local community benefits in terms of jobs and income, and results in highly-desirable fish and wildlife habitat improvement and reduced sediment yield to streams and downstream power and water-supply reservoirs. Although these other potential benefits have not been quantified and monetized, as have the water-supply benefits, they are clearly considerable. Given the estimated BCRs greater than 1.0 based only on water-supply benefits of stream restoration alone , the total restoration-program benefits appear to justify such a long-term public works program investing in California's water resources.

Forum funding, particularly of direct intervention projects including pond-and-plug projects, has contributed significantly to achieving these water supply benefits. Future funding, if it increases attention on water-supply parameters in watershed restoration, can be used to expand and make more cost effective the restoration of usable water resources.

Water Quality Benefits

The second goal of the Agreement is that water quality be improved through reduced sedimentation, and that streambank protection be improved.

Water quality benefits of the Feather River restoration program are of two types: reduced sediment from stream channel erosion, and from uplands due to reduced extent and intensity of wildland fire.

Streambank Protection and Reduced Sediment Yield

As previously noted, the benefits of Upper Feather River watershed restoration on sediment yield to date, as well as ultimate benefits once the restoration program is substantially complete, are considered by most investigators to be substantial. Monitoring programs are not in place to document the reduction in sediment yield due watershed restoration projects completed to date. Sediment movement is exceedingly complex and difficult to measure, especially given the attendant high streamflow conditions. In order to possibly obtain meaningful results that could lead to economic justification of the restoration program, an inordinate monitoring funding level would need to be maintained.

Of most direct consequence of sediment yield from the upper watershed, the rate of sedimentation (deposition of sediments) in PG&E power reservoirs on the North Fork and the State Water Project at Oroville Reservoir on the Middle Fork could be considered. The authors are not aware of monitoring that addresses possible change in sediment inflow since the initiation of watershed restoration in 1985. With the small portion of restoration completed to date, changes in rates of reservoir filling are unlikely to yet be substantial.

Monitoring of sediment yield is best accomplished through monitoring of stream geometry and vegetation cover of banks at and adjacent to restoration sites. Forum funding has contributed significantly to such monitoring, especially through the Feather River CRM. To date, almost all Feather River CRM projects are functioning as intended and are preventing channel widening or degradation, and the resultant sediment yield from the project stream reaches.

The extent of this restoration is shown on Table 5-1 (previously referenced) and Table 5-3. Both the meadow restoration projects previously described as well as other projects addressed primarily to channel stabilization reduce sediment yield. In total, these 63 projects conducted by the Feather River CRM from 1985 to the present have stabilized 44 miles of stream channel.

An inventory or estimate of the total extent of active channel degradation or widening in the upper Feather River watershed is not available. However, a review of Figure 5-2 suggests that 44 miles of channel encompasses a significant albeit still small part of the combined area of the alluvial basins. The accomplished reduction is sediment yield is therefore likely significant, and the watershed restoration program is therefore contributing well to attaining the second goals of the Agreement. The economic value of such reduction is unknown.

Reduced Extent and Intensity of Wildfire

The watersheds surrounding the intermontane alluvial basins are forested. The climate is Mediterranean, with dry summers. Occasional summer lightening storms often ignite multiple forest fires that spread to forest canopies and coalesce, causing major incidents that are highly destructive of watershed infiltration/runoff characteristics of soils. In the past two years, large stand-destroying fires have resulted extensively in intensively burned soils in the upper Feather River watershed (near Antelope Reservoir).

Unfortunately, the forested lands in the watershed are dominated by overly dense stands due to past harvesting practices, presenting fuel ladders from the ground to the canopies, and horizontally-continuous canopies. Ground fire is thereby allowed to reach canopies readily, and then to spread rapidly through the canopy. Ground forces are unable to work to control fires during these conditions, and reliance is mostly on aerial attack.

Several projects funded by the Forum have been intended to improve the condition of upland vegetation in the watershed, and thereby to achieve the third goal of the Agreement: “improve upland vegetation management”. Rather than simply focus on continuous vegetation cover as prescribed by the Feather River Management Strategy, the program has focused on reducing ladder fuels and canopy continuity, while maintaining continuous vegetation cover, in this fire-prone watershed. Project sponsors have included the Plumas Corporation, acting on behalf of the Quincy Library Group and the Plumas County Fire Safe Council, and the Feather River RCD. The latter two organizations provide planning, permitting, and funding for fuels reduction treatments. The Quincy Library Group achieves these results indirectly, since it acts to support and encourage efforts by the U.S. Forest Service focused on fuel reduction and provision of fuel environments that allow ground crews to gain control of wildland fires. A study commenced during the large fires in the watershed in 2007 (Fites et al 2007), and other studies in the northern Sierra Nevada in the past several years, indicate that the fuels reduction techniques, principally the creation of Defensible Fuel Profile Zones, are effective in bringing fire to the ground surface and reducing flame lengths so that fire containment can be achieved. These fuel activities are beginning to provide significant benefits to the watershed, in term of reduction in the severity and extent of hot fires that destroy watershed function, even as catastrophic fires continue to occur.

Benefits of Improved Watershed Awareness/Ethic

The Agreement does not include a specific goal of improved watershed awareness and improved watershed ethics. However, the Feather River Management Strategy adopted this goal in the form of a strategy for achieving the Agreement’s goals:

> The watershed forum will encourage the development of educational projects that convey the Strategy and restoration effort into schools. Field trips, field exercises, and educational projects that familiarize young people with the watershed and the science and engineering that are part of the restoration will be encouraged.

and the Forum adopted the following Bylaw:

> Bylaw 6 - Project Selection. The Forum shall be guided in its selection of projects by the following principles: ... Probability of increasing public education and awareness.

Although the focus of the strategy is on the community's students, the bylaw makes it clear that education and awareness extent to the public at large.

Watershed-wide watershed restoration would likely founder if public understanding and support for the restoration program were not strong. Fortunately, watershed restoration generally poses a "win-win" situation for the local community and the larger statewide and federal interests. Restoration involves augmented streamflows in summer, reduced flood peaks in winter, more vigorous and extensive riparian ecosystems, improved stream health and fisheries, and increase forage for livestock producers. Costs are relatively modest, and the both the intervention and intervention-support work represent jobs, local construction contracts, and salaries for local residents who are skilled in the required construction and administrative activities.

An important portion of Forum funding was directed at improved watershed awareness, watershed ethic, and outreach to landowners whose cooperation is needed for the program to succeed. Approximately 14% of Forum funding was expended for this purpose:

- 9.8% for landowner education, awareness, and outreach (projects B1, B5, B6)
- 2.7% for general public education and awareness (projects A2, B8), and
- 1.5 % watershed education in local schools (project B2).

Much of this funding was leveraged by project sponsors to obtain additional funding, and the capacity-building nature of most of this funding was universally effective in helping sponsors develop and initiate enduring programs for watershed education/ethic and outreach. The program initiated in the Plumas Unified Schools with Forum funding has been perpetuated through additional funding sources and has been fully integrated into the school system's curricula. The capacity building of the two RCDs has been successful in allowing these organizations to secure additional sources of funding to facilitate and fund district/landowner restoration actions and to reach out to landowners and obtain their approvals for large-scale restoration actions staged by the Feather River CRM.

The largest portion of these funds, 5.5% of total funding, was used to support the Plumas Corporation's administration of the Plumas County Fire Safe Council and the Quincy Library Group. As discussed in the *Water Quality Benefits, Reduced Extent and Intensity of Wildfire* and the *Water Supply Benefits, Water-Supply Benefits Achieved to Date* sections above, this activity has been successful in educating and supporting landowners in undertaking actions that have augmented baseflow, reduced sediment yield, and improved upland vegetation management—contributing considerably to meeting three of the goals of the Agreement.

Recommendations

Based on the discussions in this section, the following recommendations to the Forum should be considered:

- Recognize that the upper Feather River watershed restoration program—in the aggregate including intervention and intervention-support efforts of several organizations—is likely cost effective in augmenting baseflow and improving water quality and watershed condition , even considering only market values.
- Recognize that ancillary benefits of watershed restoration, especially benefits to biological resources, are significant, and seek to use these benefits to offset impacts of other DWR water-supply and flood-control enhancement actions in the State.
- Increase funding of direct intervention to accelerate the restoration of basin storage capacity and augmentation of baseflow, but maintain other funding levels as needed to ensure that education/outreach and fuel-reduction activities in the watershed are maintained.
- Use initial new Forum funding to develop a long-term funding arrangement involving water users and State and federal agencies, such that a multi-decade restoration effort can be sustained.
- Empower the Feather River CRM to lead the watershed restoration program locally, and ensure that Forum funds are sufficient to maintain the organization's functions. The CRM is ideally suited to develop projects involving multiple ownerships and to track restoration progress in meeting the goals of the Agreement through watershed-wide monitoring. It is also ideally suited as a funding recipient, being comprised of a number of federal, state, and local agencies.
- Develop a Forum-sponsored research plan to improve understanding of actual benefits of a long-term restoration program. The plan should focus attention on water-supply parameters in watershed restoration, to expand and make more cost effective the restoration of usable water resources. The plan, developed by an expanded Technical Advisory Committee (TAC) of the Forum, would specify important technical/scientific issues/questions that warrant research. Future research funding by the Forum would be in response to proposals addressing those specified issues. The expanded TAC would comprise in-watershed technical experts; agency and water user technical experts; and water-supply, watershed restoration, and water-resource experts from academia and the consulting community.
- Develop a monitoring plan focused upon parameters of interest to water user's and DWR's/ SWRCB's needs regarding the watershed intervention program, coordinated with the current monitoring program of the Feather River CRM, and delegated to the CRM for implementation via a new funding agreement.
- Increase funding of schools' watershed awareness programs.

- Fund additional landowner outreach activities as needed to ensure landowner education/outreach/cooperation with projects of the various sponsors.
- Continue funding upland vegetation management actions focused on reduced ladder and canopy fuels at a level similar to the initial funding period.
- Commission an examination of the relationship between baseflow augmentation resulting from the watershed restoration program, and existing and future water rights.
- Amend the Feather *River Watershed Management Strategy* to improve the focus Forum expenditures, as described in Section 2.
- Improve the tracking of project success in meeting the goals of the Agreement and the strategies of the Forum, as also described in Section 2.