Lee MacDonald, Ph.D.
15 February 2016

Comments on the Tetra Tech Report and the Draft Action Plan for the Upper Elk River Sediment TMDL

1. INTRODUCTION AND KEY POINTS

1.1. My Role

In 2013-14 I was contracted by Humboldt Redwood Company (HRC) to provide a scientific review of some of their monitoring activities, specifically with respect to best management practices, to review their watershed analysis of the Elk River and Salmon Creek watersheds. I also was contracted by HRC and Green Diamond Resource Company (GDRCo) to provide a scientific review of the Peer Review Draft: Staff Report to Support the Technical Sediment Total Maximum Daily Load for the Upper Elk River (NCRWQCB, 2013), and I provided two sets of comments (MacDonald, 2014a, 2014b). This work led to my helping HRC formulate the proposed project to evaluate Best Management Practices using a paired watershed design in Railroad Gulch, which has since been funded by Cal-Fire and HRC. Working with GDRCo I helped to formulate a project to evaluate the relative effects of forest management activities over time for two sub-basins in the Little River watershed, and this is being funded by Cal-Fire and GDRCo.

In fall 2015 I was contracted by HRC to provide science-based comments on the Technical Analysis for Sediment for the Upper Elk River (TTR, 2015). This memo sets out my comments based on my professional knowledge and experience, field trips on HRC and GDRCo lands, discussions with HRC and GDRCo staff, and numerous discussions with a wide range of scientists, agency personnel, and other parties interested in the Elk River Watershed and analogous sites.

I want to emphasize that these comments are submitted under my name and I am solely responsible for the content. I should note that my professional life has been devoted to trying to understand the effects of land use and other disturbances on runoff and erosion, especially in forested areas, and then use the results to guide management decisions (I'm sending my c.v. as a separate document). My overall objectives are that with better information society can make better management decisions, and we can further reduce the adverse effects of human activities on ecosystem sustainability and water resources at the site and watershed scales. This means that the following comments should be taken not as a critique, but as a means to better understand the Elk River watershed in order to help improve the proposed TMDL and guide future efforts to improve water quality and human welfare.

The goal of these comments is to help ensure that future regulations and restoration efforts are as effective as possible in terms of reducing the observed problems while still allowing for activities that yield important resource uses and economic benefits (e.g., domestic and agricultural water supply, timber harvest, salmonid production, etc.). Since the exact balance between these various uses and activities is ultimately a political decision, my hope is that this document and any subsequent discussions can help lead to a better understanding of the key issues and a broader consensus on how to move forward from here. I trust that these comments will be taken in this spirit, not only for the Elk River watershed, but by extension to other coastal watersheds under the jurisdiction of the North Coast Regional Water Quality Control Board (NCRWQCB).

1.2. Introduction

The TTR provides an improved summary of many of the key issues related to sediment in the Elk River watershed. It also provides a better overall context in terms of uplift in the upper watershed and subsidence in the lower part (TTR Figure 8). However, this conceptual context is not effectively or quantitatively used to more accurately define the broader geomorphic setting and processes that are largely determining the erosion rates, sediment dynamics, water quality issues, and restoration potential in the Elk River watershed. A more rigorous analysis of this spatial and temporal context, along with a more specific and quantitative analysis, is critical to defining both the relative effects of past and present management activities, and realistic water quality management goals.

A second main point is that—as noted in the TTR—there is a tremendous and relatively unique wealth of spatially and temporally explicit data available for the Elk River watershed. The problem is that the TTR does not effectively use this information to quantify and understand the relative importance of the fundamental causal processes in time and space as conceptually outlined in TTR Figure 12. In my comments my goal is to combine the broader context, process-based understanding, and existing data to provide a more specific and precise analysis that can then lead to more realistic, specific, and efficient management recommendations. The tremendous amount of data collected over time also must drive the adaptive management structure that the TTR recommends but does not actual applied (e.g., see the recent overall trends in sediment sources as shown in Figure 15 of the TTR, the sediment sources over time by subwatershed in TTR Table 7, and the linkages between the hillslope water quality indicators in TTR Table 5 and the trends in TTR Table 7/Figure 15).

Hence Section 2 of my comments address the overall geomorphic context, including the definition and applicability of the concept of dynamic equilibrium and the validity of the 1958-1967 period as a valid baseline for water quality. Section 3 of my comments addresses the trends and relative values of the different natural and management-related sediment sources. This analysis is combined with a process-based logic to help identify specific and realistic water quality indicators and management goals. Section 4 of my comments is a synthesis summarizes the resulting implications for the achievable water quality goals for the Elk River.

1.3. Key Points

The key points that are made in this document include:

1. The concept of dynamic equilibrium as defined in the TTR is not valid for the Elk River watershed as it does not define a time scale nor is the watershed in equilibrium given the rapid uplift, subsidence, and rise in sea level.
2. We cannot expect that sediment outputs from the affected reach should equal the sediment inputs.
3. The valley bottom was historically an active floodplain that was aggrading over time, and this floodplain would have had a complex channel network developed to accommodate the high flows and provide a greater sediment transport capacity than currently exists. In all

likelihood the mainstem of the Elk River was historically aggrading, which would then lead to periodic avulsions.

4. The human activities in the floodplain along the affected reach and further downstream have exacerbated, and are probably a major if not primary cause, of the increased inchannel deposition and overbank flooding. The anthropogenic changes in the floodplain and channel in the affected reach must be explicitly considered in the establishment of the TMDL and the design of recovery and restoration alternatives.
5. Similarly, any discussion of sediment, water quality, and recovery of the affected reach must include an explicit consideration of floodplain and channel changes from the lower end of the affected reach to the mouth of the watershed, as these have a direct effect on flooding and the sediment dynamics in the affected reach.
6. The infilling and loss of side channels, cutoff meanders, and other pre-European features of the valley bottom due to agriculture and rural development have not only altered the runoff and sediment dynamics of the affected reach, but also severely reduced the off-channel rearing habitat and refugia for the endangered salmonids. The current concerns over salmonid habitat in the affected reach must be placed into and compared with this larger context.
7. The broader geomorphic context and downstream alterations indicates that even if all anthropogenic sediment sources were immediately stopped, the mainstem of the Elk River would still continue to aggrade and overbank flooding would still occur on a regular basis (e.g., about every other year on average).
8. Watershed denudation rates can generally be expected to be in dynamic equilibrium with the uplift rate of around 0.5 mm yr^{-1}, so the long-term baseline erosion rates in most of the watershed are almost certainly greater than 1100 Mg km^{-2} yr^{-1} (approximately 3000 English tons mi^{-2} yr^{-1})[1].
9. The conditions during the period of USGS stream gaging (water years 1958-1967) are not an appropriate set of reference conditions because this was a relative quiescent period in terms of peak flows, the streambank vegetation had almost certainly been altered by human activities, and there is no explicit information on the extent to which this or other reaches had been subjected to channel and floodplain alterations.
10. Annual sediment yields are remarkably correlated with instantaneous annual maximum peak flows, confirming that the largest storms are responsible for most of the sediment yield. Annual rainfall or annual water yields are not an appropriate index for normalizing or predicting sediment yields.

---

[1] The TTR uses yd^3 mi^{-2} yr^{-1} for calculating sediment loads and deposition, which is a volumetric rate. Most larger-scale erosion and sediment yields in the scientific literature are expressed as Megagrams (Mg) km^{-2} yr^{-1}, which is a mass per unit area per unit time, where 1 Mg is 10^6 grams or 1000 kg or 1 metric ton and 1 kilometer is 0.386 mi^2. The assumed density of suspended sediment--and presumably the eroded sediment--in the TTR is 1.4 English tons/yd^3 (p. 65), and since 1 mi^2=2.59 km^2 and one English ton equals 0.907 metric tons (or Mg), 1 yd^3 mi^{-2} yr^{-1}= 0.49 Mg km^{-2} yr^{-1}. Conversely, 1 Mg km^{-2} yr^{-1}= 2.85 English tons mi^{-2} yr^{-1}, or just over 2 yd^3 mi^{-2} yr^{-1} using the assumed density of 1.4 English tons/yd^3. Note that for converting denudation rates to mass one should use the much higher rock density of 2.65 or 2.7 Mg m^{-3}, and the TTR uses an assumed density for the deposited sediment in the affected reach of 0.847 Mg/m3 or 0.71 English tons/yd^3. (Life would be much easier if we all just used metric units!)

11. Poor logging and road practices in the past have clearly increased sediment inputs into the Elk River. These exacerbated the natural tendency for channel aggradation and overbank flooding.
12. The sediment source analysis shows that there has been a major reduction in management-related sediment yields since the peak years of 1988-1997. Updates and additional studies since 2011 show that management-related landslides, harvest and skid trail erosion, and headward channel extension have been reduced to nearly negligible levels or zero; road erosion also has been greatly reduced. Given the observed peak flows during this time, the inevitable conclusion is that management changes through the Habitat Conservation Plans and California Forest Practice Rules as presented in the Report of Waste Discharge (HRC, 2015) have greatly reduced sediment from both current and legacy sources on industrial timberlands.
13. The sharp reduction in sediment production from current harvesting and roads is limiting the potential for further reductions, especially in comparison with the high natural sediment supply. The treatment and reduction of legacy sediment sources is more difficult, and these sources are becoming a larger proportion of the management-related sediment inputs to the Upper Elk River watershed.
14. Road-related surface erosion and sediment delivery cannot be reduced to zero given the high road and stream densities.
15. Continuing treatment of management-related discharge sites should continue to reduce this sediment source, and any sediment from these treatments is effectively a down payment to reduce further sediment inputs and hence beneficial in the long term. Sediment from untreated sites will continue to decline as the worst sites are treated and/or natural stabilization continues.
16. The values in the Tetra Tech Report for management-related streamside landslides and bank erosion relative to natural values are not consistent with measured stream densities, the expected volumes from deep-seated landslides and soil creep, or more recent data.
17. The Beck's Gulch BMP Effectiveness Monitoring study and post-harvest observations from recent timber harvest units show no evidence of any further headward extension.
18. The TTR presumes that the sediment contributions from the 2.1 mi^2 that includes Shaw Gulch and drains directly into the lower portion of the affected reach are negligible. This is not a valid assumption as this portion of the watershed has substantial areas with steep slopes, sensitive geologies, and a variety of land uses, including roads, agriculture, and residential. No quantitative assessment of these sources has been made, but the landscape characteristics and diversity of management activities suggests that per unit area sediment yields should be at least comparable to the value of 450 $yd^3\ mi^{-2}\ yr^{-1}$ (630 tons $mi^{-2}\ yr^{-1}$) for the upper watershed.
19. The TTR also does not consider the sediment from the 1.3 mi^2 of residential and 0.5 mi^2 of agriculture in the upper watershed. Anthropogenic sediment inputs from these sources should be quantified, and comparable efforts be made to reduce anthropogenic inputs as for the industrial timberlands.
20. The sediment source analysis shows a relatively dramatic reduction in management-related sediment inputs since 1988-1997, but the gaging record generally does not show a corresponding recovery in sediment yields or turbidity levels except in Bridge Creek.

21. The predicted peak flow changes due to forest harvest are less than 10% at the sub-watershed scale using the peak flow model developed from the Caspar Creek data. Any logging-induced increase in peak flows in the affected reach would be substantially less and well within the measurement uncertainty.
22. An increase in peak flows can be expected to increase suspended sediment yields according to the data from Caspar Creek, but it is not known to what extent these results can be extrapolated to Elk River; how much of the increase is due to an increase in transport capacity, bed incision, or bank erosion; how the increases might vary with channel slope, substrate, etc.; how the increases might affect substrate size; and hence how the peak flow increases might affect salmonids.
23. The hydrodynamic modeling confirms that the affected reach is inherently depositional, as deposition is predicted even if all management-related sediment sources were eliminated.
24. The calculated deposition of 640,000 yd^3 in the affected reach from 1988-2011 represents 76% of the total sediment inputs to the affected reach, which is a far higher percentage than suggested by the hydrodynamic modeling. This suggests that this volume is too high, and that natural sediment yields are substantially underestimated.
25. There is no explicit consideration or estimate of the amount and role of bedload with respect to the sediment sources, sediment transport capacity, or aggradation.
26. Given the differences in geology, slope, and rainfall between the different sub-watersheds, the forest practice prescriptions should be adjusted according to the relative site-specific risk rather than applying them equally across the entire Elk River watershed.
27. Given the geologic context of the affected reach and the modifications to the channel and floodplain through the affected reach to the mouth of the Elk River, the assimilative capacity cannot be restored simply by further reducing management-induced sediment inputs from the Upper Watershed. Nor is it possible to eliminate nuisance flooding, even if the channel capacity in the lower mainstem is restored to 2250 cfs, as this is substantially lower than the predicted 2-year flood.
28. The only path that can lead to substantial improvement in water quality in the affected and downstream reaches in the Elk River watershed is to restore some of the natural functioning of the floodplain while continuing to minimize the sediment inputs from all anthropogenic activities.

2. DYNAMIC EQUILIBRIUM AND DESIRED WATERSHED CONDITIONS

2.1. Uplift, Denudation Rates, and Natural Sediment Yields

The TTR report defines a functioning natural system as one in “dynamic equilibrium” (p. 40). It goes on to state that dynamic equilibrium can be defined as “the condition of a system in which inflow and outflow are balanced [Eastlick, 1993] and the character of the system remains unchanged”. The TTR then states that “The geomorphic role of rivers is to transport flows and sediment from the watershed while maintaining its dimension, pattern, and profile without aggrading or degrading significantly.” This last statement is not referenced, but it appears to be drawn directly from p. 1-3 in Rosgen (1996). A review of Rosgen’s (1996) text indicates his general belief that streams should be in equilibrium, but he notes that broad alluvial valleys often have braided or anastomosing channels that are often vertically accreting, but “kept in balance due to the subsidence effects of tectonically active basins” (p. 5-122). This general characterization of streams as being in equilibrium is in contrast to the more general view that landscapes can be in disequilibrium or nonequilibrium regardless of human activities (e.g., Renwick, 1992; Schumm, 1991; Knighton, 1998).

The TTR report notes that the feedback mechanism between sediment inputs and outputs is central to the dynamic equilibrium of a river channel (citing EPA, 2012), and that the relative balance in sediment input and output is central to the attainment of water quality standards. On page 41 the TTR report states that "The Elk River is aggrading … therefore it is not in dynamic equilibrium." and "Returning the river to a state of dynamic equilibrium that meets WQS is the ultimate water quality improvement goal for the Elk River."

The problem is that equilibrium is simply the state toward which rivers naturally trend and should not be confused with the state they are actually in. As stated by Kondolf et al. (2007) "In Mediterranean-climate coastal California, conventional notions of stability and equilibrium are usually not applicable. The highly dynamic nature of these channels must be considered when setting goals and choosing strategies more so than in regions with less variable hydrology."

The fundamental key concerns with respect to the use of dynamic equilibrium in the TTR are: 1) dynamic equilibrium is a meaningless term unless it has a specified time scale; 2) sediment inflows into the affected reach cannot be expected to be "balanced" or equal to the sediment being exported by the river out of that reach; 3) many rivers are naturally out of equilibrium; 4) the tectonic and geomorphic context means that the lower portion of the watershed is inherently aggradational independent of land use effects; 5) the conditions during the period of the USGS gaging station (water years 1958-1967) are not an appropriate reference conditions for evaluating the recovery and restoration of the affected reach; 6) there have been major anthropogenic alterations to the valley bottom floodplain in the affected reach and further downstream, and these must be considered when evaluating the sediment dynamics and expected conditions in the affected reach; and 7) the geomorphic and sediment dynamics in the affected reach cannot be considered independently of the conditions in what I term the lowest reach (i.e., from the downstream end of the affected reach to the mouth of the watershed, including the rise in sea level).

With respect to dynamic equilibrium, the widely acclaimed 2014 geomorphology textbook by Bierman and Montgomery states: "Landscapes may appear unchanging, but considered geologically, topography is dynamic because material is constantly being entrained, transported, and deposited. Over centuries to millennia, such changes result in a **dynamic equilibrium** that maintains topographic forms in an average sense even as individual slopes experience landslides; coastal landforms shift…; and rivers migrate across their floodplains. Over longer timescales, landforms evolve in concert with tectonic and climatic changes...." (p. 27, emphasis in the original). Figure 8 in the TTR provides an excellent conceptual diagram for evaluating the concept of dynamic equilibrium as it may or may not apply to the Elk River Watershed, and this is reproduced below but I with numbers to indicate our best estimate of the uplift and subsidence rates, respectively.

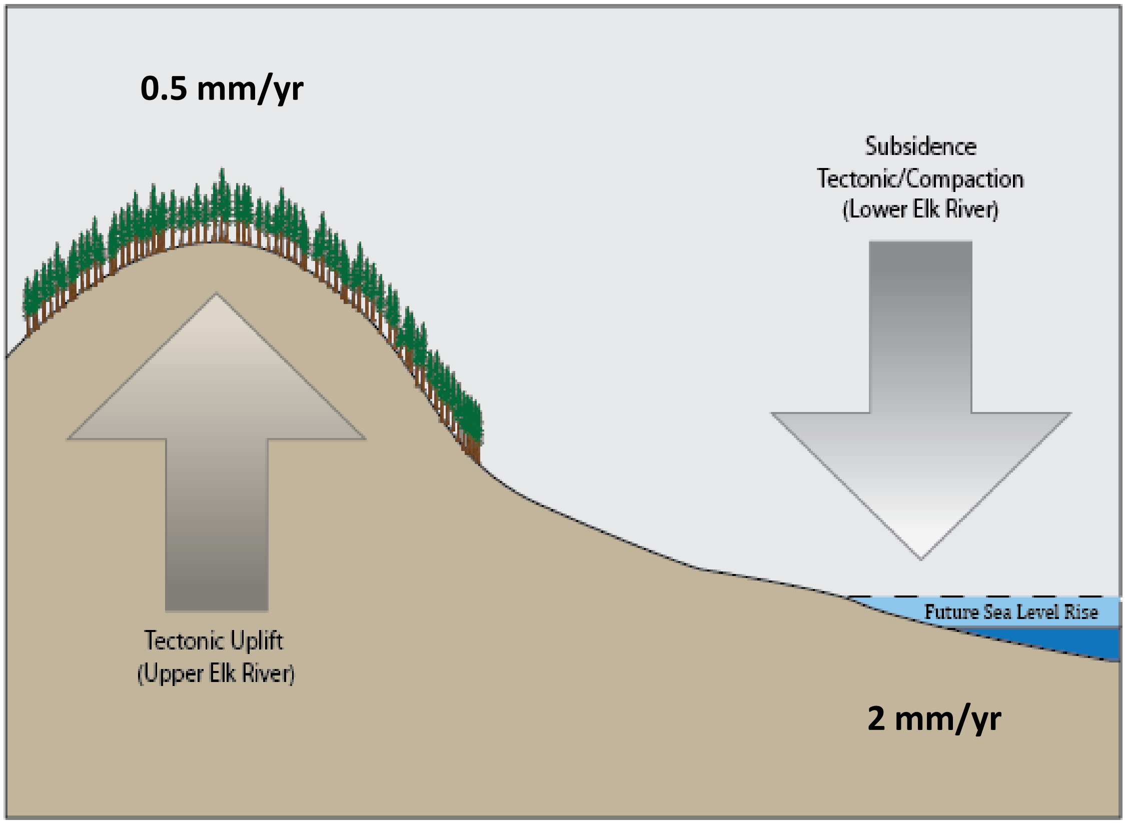


Figure 8. Relationship of tectonic uplift, subsidence, and sea level rise. The uplift and subsidence values shown on this figure were added.

The uplift rate is generally accepted to be around 0.5 mm per year (Stallman and Kelsey, 2006; Balco et al., 2013), and this is a relatively rapid rate of uplift compared to most other landscapes. If the landscape is in dynamic equilibrium, then the uplift and denudation rates should match. The TTR report notes that this tectonic uplift is "balanced by erosion via channel incision and steep slopes" (p. 17). Stallman and Kelsey (2006) reported bedrock incision rates of 0.85 mm yr^{-1} in the North Fork of the Elk River, but a denudation rate of only 0.10 mm yr^{-1} from the loss of an assumed rock volume. As noted in my comments on the Peer Review Draft (MacDonald, 2014b), beryllium-10 concentrations provide an accurate measure of denudation rates over periods of several thousand years or more.

Three studies have analyzed denudation rates using beryllium-10 for watersheds around the Elk River. Ferrier et al. (2006) reported rates of 0.07 to 0.44 mm yr^{-1} with a rate of 0.225 for Panther Creek. Balco et al. (2013) sampled extensively up and down the coast, and his data show a sharp increase in denudation rates in areas with rapid uplift, where uplift varies with latitude. These data are shown in Figure 2, and plotting the Elk River watershed on this graph based on its latitude of 40.7°N indicates that a denudation rate of 0.5 mm yr^{-1} may well be a conservative estimate. Given the importance of the long-term denudation rate for understanding the sediment dynamics in the Elk River watershed, six fluvial sand samples have been collected from different locations in the Elk River for Be-10 analysis with support from HRC and Cal-Fire. These include the North and South Forks as well as samples both the East and West Branches of Railroad Gulch, where a paired-watershed study is being initiated to rigorously evaluate the effectiveness of current best management practices for minimizing sediment production. Taken together, these samples will also indicate if there is any spatial variability in longer-term denudation rates within the Elk River watershed (we are betting that spatial variability will be minimal in the absence of any variation in the uplift rate).

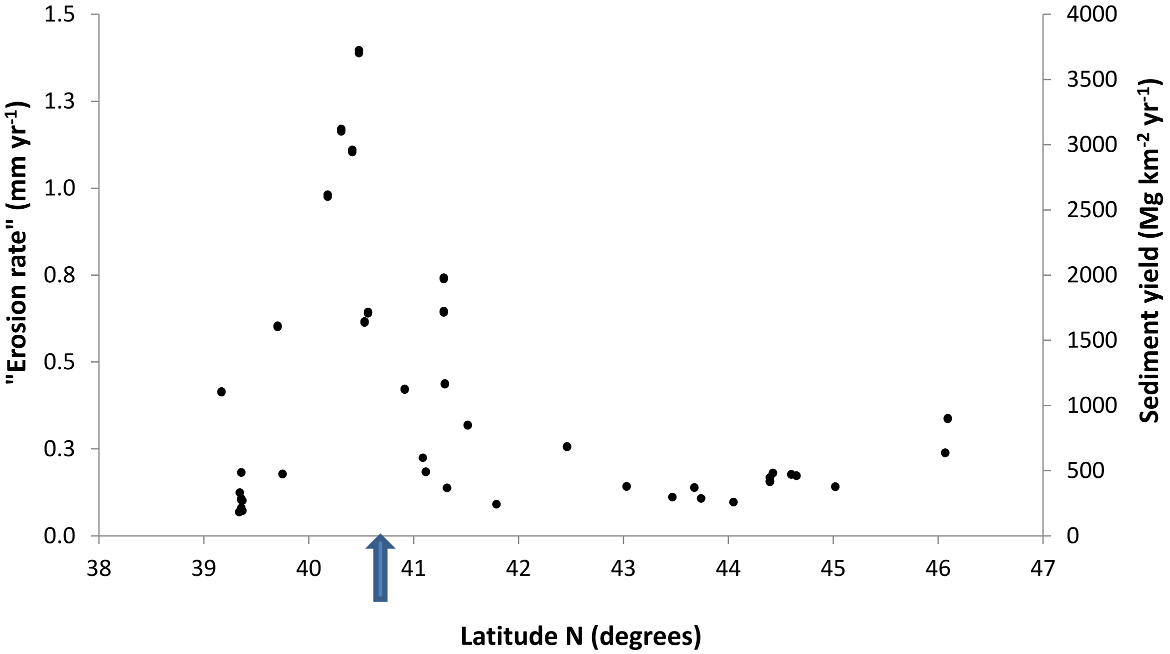


Figure 2. Plot of the calculated denudation rates for different watersheds along the North Coast versus latitude. The blue arrow indicates the latitude of the affected reach and the approximate center of the Upper Elk River watershed.

What the TTR report does not do is convert the estimated uplift rate of 0.5 mm yr^{-1} into a denudation rate and then an expected natural sediment yield. Assuming a standard rock density of 2.65 Mg m^{-3}, a denudation rate of 0.5 mm yr^{-1} converts to just over about 1300 Mg km^{-2} yr^{-1}. Since chemical dissolution generally accounts for only a small fraction of the denudation rate, the long-term average mineral sediment yield can reasonably be assumed to be around 1200-1300 Mg km^{-2} yr^{-1}. This converts to ~3500 English tons/yr or ~2500 yd^3 mi^{-2} yr^{-1} assuming a density 1.4 English tons yd^{-3} assumed in the Draft Sediment TMDL and TTR. This is nearly 20 times the mean natural sediment loading of 140 yd^3 mi^{-2} yr^{-1} for 1955-2011 given in the TTR (time-weighted average from Table 8). Hence either the natural erosion rate is underestimated by more than an order of magnitude in the TTR, or the watershed is dramatically out of equilibrium as over 90% of the material being uplifted is somehow being stored on the hillslopes and in the valleys.

This amount of storage is not a viable hypothesis given that the upper portions of the Elk River watershed have been experiencing substantial uplift for at least 500,000 years (S. Beach, HRC, pers. comm., 2016), and there is an inherent limit on slope steepness and hillslope/headwater sediment storage. Studies in other rapidly uplifting areas show that uplift and denudation rates are generally in dynamic equilibrium, and Stallman and Kelsey (2006) conclude that the establishment of a maritime climate and a mesic redwood ecosystem approximately 4000-8000 years ago has led to approximate equilibrium.

To help resolve this issue the amount of sediment stored in the Elk River watershed was further investigated by Dr. Patrick Belmont and a student at Utah State University. They used the TerEx tool (Stout and Belmont, 2014) to identify and map depositional terraces from the high resolution lidar data. The results generally indicate that there are few terraces above the confluence of the North and South Forks of the Elk River (Figure 3). Most of the terraces in the upper portion of the watershed are primarily along the North Fork and occur at relatively high elevations, 60-120 feet above the modern river. It is expected that these are strath terraces (cut into bedrock) and therefore do not represent significant stores of alluvial sediment that are readily available to the modern river, but field verification is necessary to confirm or refute that expectation. Nearby and downstream from the confluence of the North and South Forks are many large floodplain and terrace surfaces. Elevations from the lidar data indicate that these large floodplain/terrace features range from 8-30 feet in height and are likely to represent significant sources of sediment if the channel is indeed incised through these features as suggested by the lidar data. More work is needed to refine these results and attempt to identify smaller terraces.

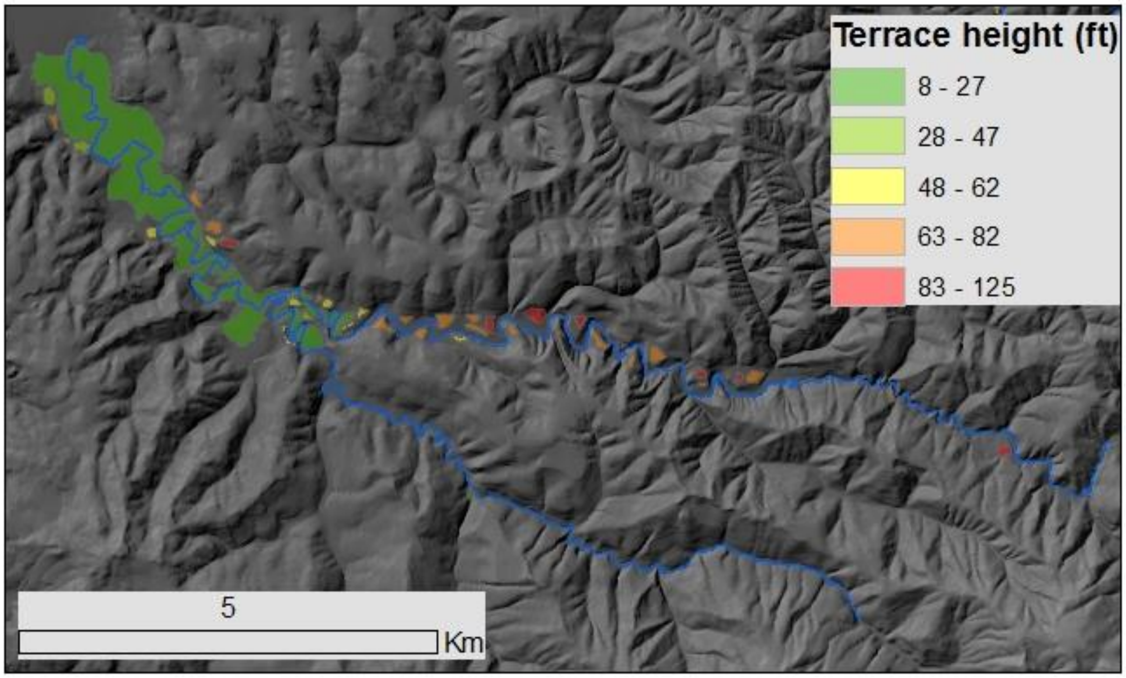


Figure 3. Map of the terraces identified in the Elk River Watershed by Dr. Patrick Belmont and his student at Utah State University. Figure courtesy of Dr. Patrick Belmont.

The argument for a much higher natural sediment yield is also supported by the longer-term measured sediment yields of 1100-3700 tons km^{-2} yr^{-1} from the Van Duzen, South Fork Eel, North Fork Eel, Mattole, and Navarro rivers (Andrews and Antweiler, 2012). The average natural sediment loading for five other TMDLs on the North Coast is 330 tons mi^{-2} yr^{-1} with a range of 275-380 tons mi^{-2} yr^{-1}. The mean of 330 tons mi^{-2} yr^{-1} is more than 60% higher than the estimated value for the Elk River of 202 tons mi^{-2} yr^{-1}, even though one would expect the Elk River watershed to have higher sediment yields due to the more rapid uplift (Figure 2) and erodible Wildcat and Hookton formations.

The expected sediment yield—given the uplift rate—of 1200 Mg km^{-2} yr^{-1} is more than four times the measured sediment yield of about 260 Mg km^{-2} yr^{-1} for the mainstem of the Elk River by Humboldt Redwoods Company (HRC) (station 509). Some of this discrepancy can be explained because the gaging stations operated by HRC, GDRCo, and Salmon Forever only measure suspended sediment loads; bedload can be an important part of the total sediment yield, especially in sand-bedded streams where the bed material can be relatively easily detached and transported. Bedload in Caspar Creek has been estimated at 30% of the measured suspended sediment yields (P. Cafferata, Cal-Fire, pers. comm., 2016), and bedload in Elk River is crudely estimated to be around 40% of the measured suspended load but could be as high as 50% (S. Beach and N. Harrison, HRC, pers. comm., 2016). Even if the unmeasured bedload component is assumed to equal 40% of the measured suspended sediment yield, this still leaves a nearly three-fold difference between the measured sediment yields and the expected natural long-term sediment yield. On the other hand, the measured sediment yields include the additional sediment from anthropogenic sources, which would increase the large discrepancy between the natural component of the measured sediment yields and the expected sediment yields based on uplift.

A key consideration in explaining the difference between the expected and measured sediment yields is to evaluate the effect of variations in precipitation and streamflow. The general principle that sediment yields follow a lognormal distribution (Figure 4). The long tail of this distribution means that the median sediment yield is much lower than the mean, so most years have relatively low sediment yields, while the less common large events account for the vast majority of long-term sediment yields. This lognormal distribution generally applies across different time scales—within a year, over decades, or over centuries to millennia. At the time scale of one year, Andrews and Antweiler (2012) found that half of the annual sediment yields for most north coastal rivers is produced in just one day. Warrick (2002) found that one-quarter of the 72-year sediment load in the Santa Clara River was transported in just four days. In the Mattole River 35 times more sediment was transported during a cool PDO (Pacific Decadal Oscillation) La Nina phase compared to a warm PDO with La Nina (Andrews and Antweiler, 2012). At even longer time scales the lognormal distribution explains why measured sediment yields—even if there is a 20- to 50-year record— are typically less than the long-term sediment yields as estimated by beryllium-10 concentrations (Kirchner et al., 2001). The implication is that watersheds may be **relatively** calm most of the time, and these more quiescent periods—which might appear to be a dynamic equilibrium—are punctuated by a continuum of increasingly large OMG (Oh My God) events along the long tail of the lognormal distribution that can reset the system and lead to long periods of disequilibrium or quasi-equilibrium (Schumm, 1991; Wohl et al., 2015).

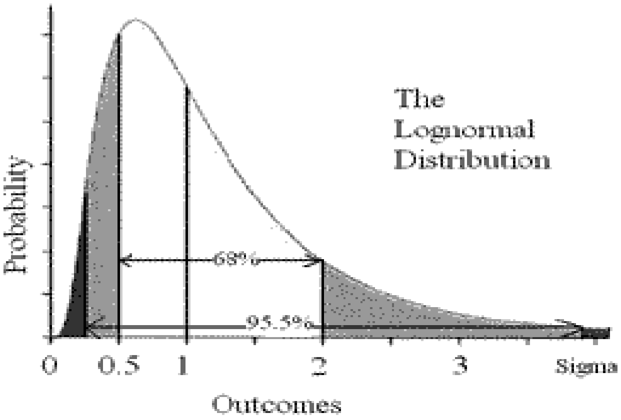


Figure 4. Example of a lognormal distribution showing the data that would fall within one and two standard deviations of the mean, respectively, using a log scale. Note that the mean will generally be larger than the median, and the mode will be less than the mean.

The overall conclusion is that the upper portion of the Elk River Watershed must have a very high average natural sediment production rate. The upper watershed should generally be in dynamic equilibrium with respect to the tectonic uplift, so the channel network generally has to be capable of transmitting this material to the lower portions of the watershed, including the affected reach.

2.2. Subsidence, Sediment Storage in the Lower Reaches, and Aggradation

The second part of Figure 8 (Figure 1 in this document) shows that the lower portion of the Elk River watershed is subsiding. The subsidence rate in Humboldt Bay increases to the southwest, and the estimated rate near the mouth of the Elk River is about 1-2 mm/yr (Cascadia Geosciences, 2013). Drilling near the mouth of the watershed has shown that there is approximately 130 feet of deposited sediment (S. Beach, HRC, pers. comm., 2015). It is logical to presume that this amount of sediment has accumulated since the last sea level minimum at the height of the last ice age approximately 19,000 years ago. Dividing this 40 m of deposition (40 m) by 19,000 years results in a rate of just over 2 mm per year. It should be noted that the surface accrual rate may be somewhat larger because the deposited sediments are compacted as new sediments are deposited.

The basic problem is that the TTR report effectively defines dynamic equilibrium as sediment (and water) inputs should equal sediment outputs (p. 40), but this is not correct. The fundamental continuity equation for both water and sediment is:

$$\text{Inputs} = \text{Outputs} + \Delta S \qquad (1)$$

where ΔS refers to the change in storage (e.g., Dietrich et al., 1982). For water, inputs and outputs almost always match over time scales over a year or longer, as it is simply not possible to continuously increase the amount of water in storage. However, in sediment budgets the storage component is much more important and very often dominant relative to sediment outputs, particularly at the watershed scale (e.g., Trimble et al., 1999). One needs only to look at the amount of sediment being eroded from the surrounding mountains into the Central Valley of California to see that this is a large-scale, long-term sediment sink, with most of this sediment never reaching San Francisco Bay.

The observed aggradation in the affected reach is used to justify the assertion in the TTR that the Elk River is not in dynamic equilibrium. There is no question that the affected reach has been aggrading, and the sediment from past management activities has contributed to the rate of aggradation documented over the past 30 years or so. However, the TTR does not address the basic issue of whether this aggradation is the normal condition in the lower portion of the watershed given the high uplift and denudation rates, the subsidence of the downstream portion of the watershed, and our understanding of watershed-scale sediment budgets. The alternative hypothesis that underlies much of the TTR and the associated management recommendations is that this aggradation is solely due to the higher sediment loads and other changes resulting from management activities from the industrial timberlands.

In gross terms, we can assume that most of the sediment eroded from the portion of the watershed that is experiencing uplift will be delivered to the hinge point in the lower portion of the watershed where there is no longer active uplift. The location of this hinge point is uncertain, but it is most likely in the upper half of the affected reach, and this is where one would expect high sediment deposition rates. It is striking that the valley bottom profile, which is too large of a feature to be significantly affected by recent anthropogenic sediment loads, shows a distinct, nearly zero gradient reach just below the confluence of the North and South Forks of the Elk River (Figure 5). This is about eight miles upstream of the mouth of the Elk River, and the length of this nearly zero gradient reach is shown as two miles, but is probably less as the length scale shown on the x axis does not appear to match the length scale of the mapped area. Geomorphically, it is not clear if this flat section is due to a long-term wedge of accumulated sediment, an unmapped fault, massive co-seismic landslides, or some combination of these. Regardless of its cause, this sharp decrease in valley gradient will induce considerable deposition due to the resulting decrease in fluvial sediment transport capacity.

Below this point the valley slope appears to increase, and then drop to near zero about two miles from the mouth of the watershed according to Figure 5. The thalweg profile surveyed by Bernard indicates a gradient of less than 0.01% from the mouth of the watershed for roughly 3.5 miles upstream (Pryor et al., 2015). This low gradient will limit the sediment transport capacity, and recent measurements indicate that the velocity of the storm peaks in the lower portion of the basin are less than two feet per second (Pryor, 2015). This low peak flow velocity indicates a limited capacity of the Elk River to efficiently transmit peak flows to the mouth of the watershed, and a correspondingly limited sediment transport capacity.

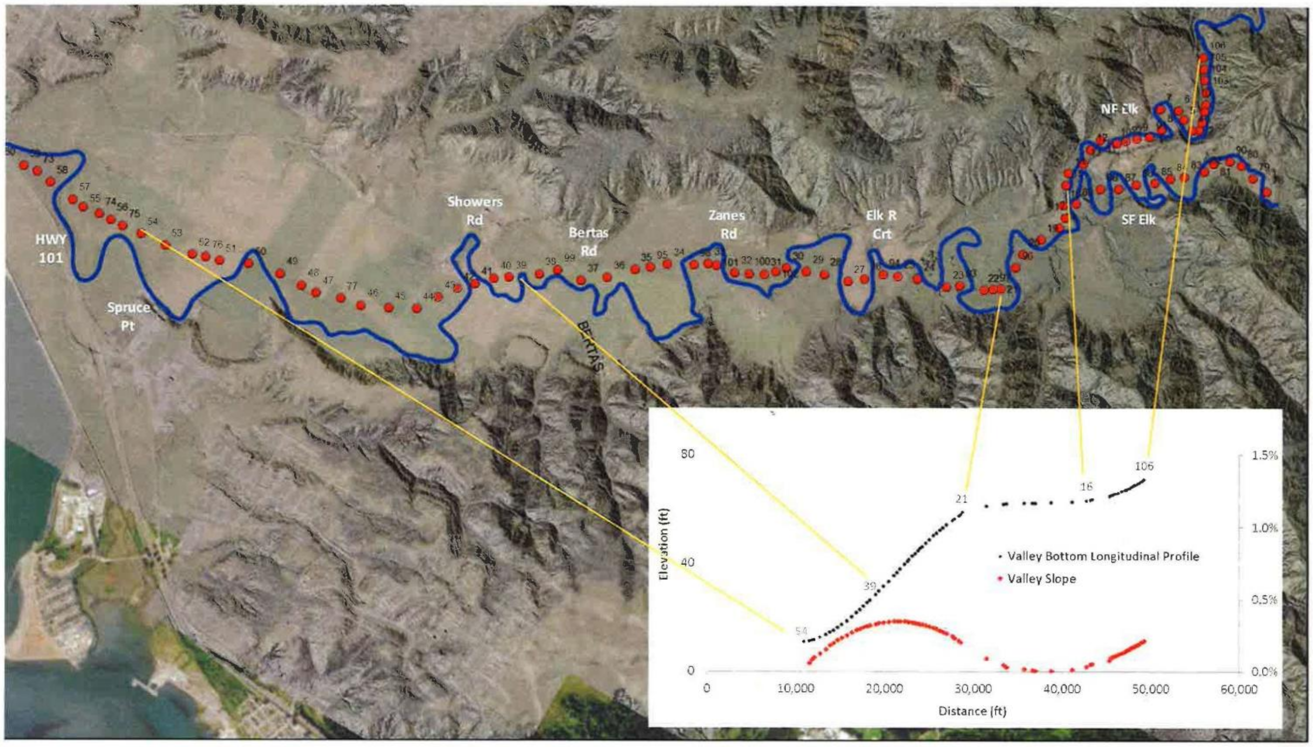


Figure 5. Longitudinal profile of the lower portion of the Elk River showing the distinct flattening of the valley bottom gradient just below the confluence of the North and South Forks of the Elk River. Figure taken from the presentation by J. Stallman at the Technical Advisory Committee meeting for the Elk River in November 2015. Note that the distances shown on the x axis in the inset do not appear to be proportionally to the distances shown on the map as indicated by the variable spacing of the points plotted in the inset and the even spacing of these points on the map.

Longitudinal profiles were plotted for the Elk River, including both the North and South Forks, to help confirm the overall geomorphic context. These profiles were derived from the USGS digital elevation models using the Stream Profiler tool (www.geomorphtools.org) by Dr. Patrick Belmont at Utah State University, and they are plotted in Figure 6. These show the expected relatively steep profiles in the upper portion of the Elk River watershed, but unexpectedly low gradients in the lower 8-20 km of the watershed. For both the North and South Forks the concavity of the lower reach is -1.5, while a value of -0.45 would be expected for a well graded channel (see theta values for the regression in the lower reach of the slope-area plots in Figures 7a and 7b). This high concavity indicates a high natural tendency for aggradation in the lower reaches of the Elk River.

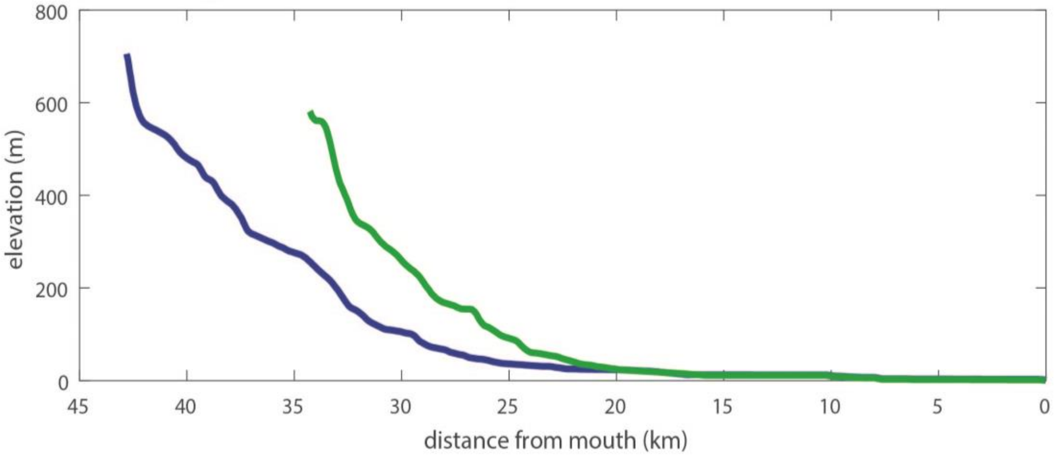


Figure 6. Longitudinal profiles of the North (blue) and South (green) Forks of the Elk River. Both profiles contain significant knickpoints (anomalous breaks in slope).

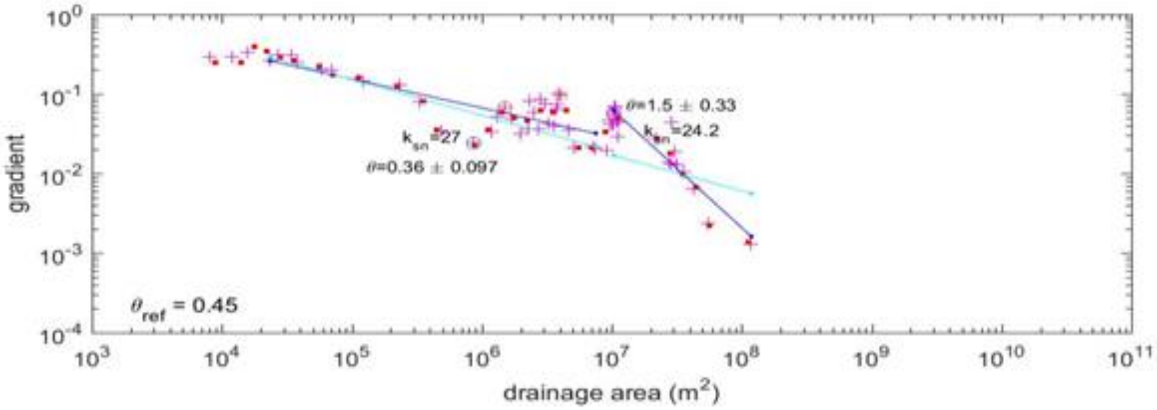


Figure 7a. Plot of local channel slope versus contributing area for the North Fork of the Elk River. Figure courtesy of Dr. Patrick Belmont, Utah State University.

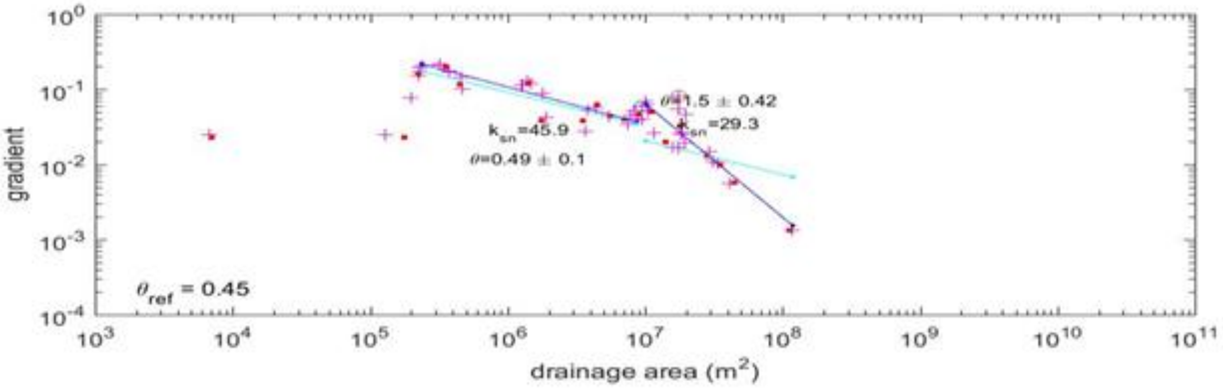


Figure 7b. Plot of local channel slope versus contributing area for the South Fork of the Elk River. Figure courtesy of Dr. Patrick Belmont, Utah State University.

The TTR and the discussions of water quality standards focus on aggradation and flow capacity in the main channels of the affected reach, but the water quality concerns and transport capacity in the affected reach cannot be separated from the geomorphic processes and anthropogenic changes in the adjacent floodplain and valley bottom. As explained below, the conditions in the affected reach also cannot be separated from the hydrologic and geomorphic processes in what I call the "lowest reach", which can be defined as the reach from the downstream end of the affected reach to the mouth of the watershed. Hence it is necessary to not only expand the temporal scale of the assessment in order to determine if the watershed is in dynamic equilibrium, but also to expand the spatial scale to include both the adjacent floodplain and the lowest reach.

While we unfortunately do not have clear and explicit documentation of the affected and lowest reaches prior to human settlement, the basic geomorphic context, residual features, and observations from analogous watersheds strongly indicate that the lower portion of the watershed was a complex, relatively wet system with multiple channels. Sitka spruce was probably the dominant tree species because of its salt tolerance, and the floodplain was well vegetated with a mix of trees, shrubs, and some forbs or grasses. Flows with a recurrence interval of two years or less were probably sufficient to induce overbank flow and floodplain deposition. The high natural sediment loads, low channel gradients, and wide valley bottom would have allowed for deposition, substantial channel migration, and avulsion during the more extreme events. These different channel processes operating at different time scales are why dynamic equilibrium has to be defined for a specified time scale (e.g., Schumm, 1991; Renwick, 1992). The combination of overbank deposition, channel migration, and avulsions was responsible for building the relatively flat valley bottom.

Evidence for this complex and evolving network of main and side channels can still be seen from the high resolution lidar and aerial photos (Figures 8, 9). The problem is that the floodplain and pre-European channel network has been severely altered by human settlement. The side channels have been filled in, levees have been constructed along the main channel, and the main channel has been severely altered (note the succession of five 90-degree bends in Figure 9). The construction of levees along the main channel is of particular concern because this will induce aggradation, while the loss of side channels has decreased the total channel capacity and thereby increased the amount of flow over the floodplain (e.g., Huang and Nanson, 2007).

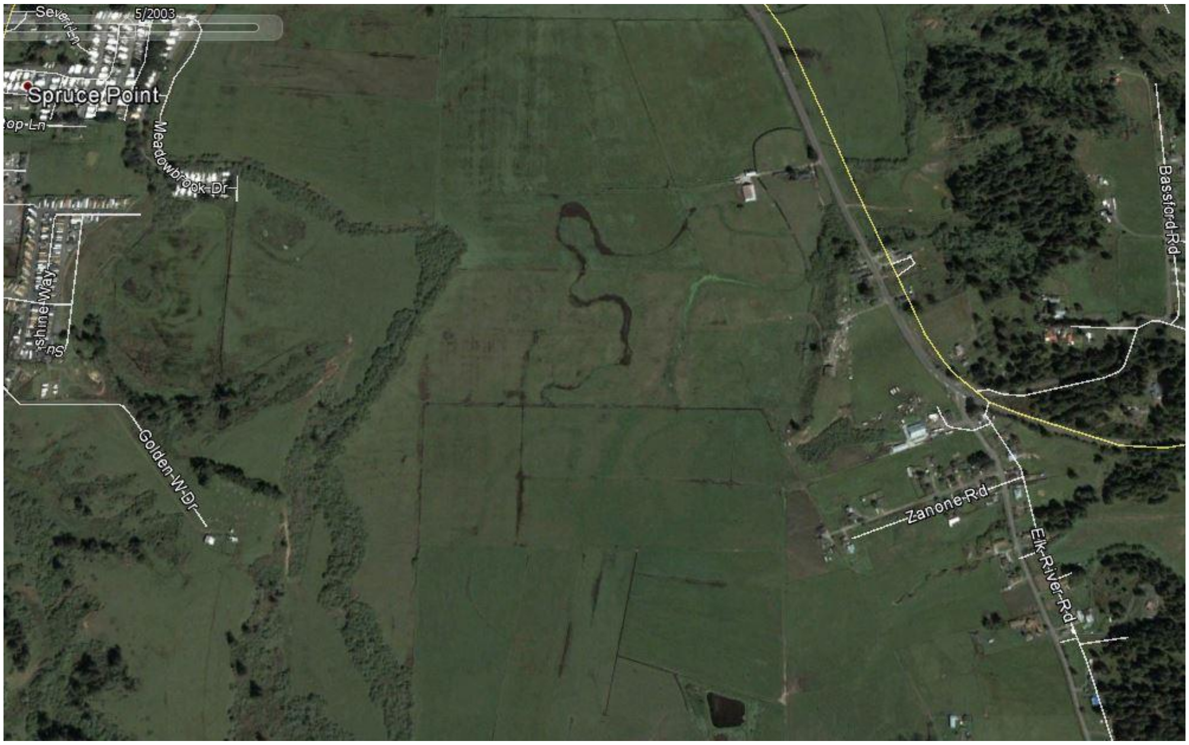


Figure 8. Section of the Elk River floodplain by Zanone Road showing a large number of former channels, indicating that the Elk River floodplain was a wet, multi-channeled system. Image from Google Earth.

Figure 9. Section of the Elk River floodplain in the affected reach with some residual channel features in the floodplain. The five right-angle bends in this image show the extent to which the main channel has been altered by human activities, and the presence of these sharp bends

will greatly reduce the sediment transport capacity and induce deposition and overbank flow as a result of the reduction in stream velocity. Image from Google Earth.

The Elk River Road hugs the northern side of the valley, and this indicates that the valley bottom was too wet and swampy to support the roadway. Redwood stumps extend only to about station 509 or the old USGS gaging station, and the implication is that the valley bottom below that point was too saline for redwoods. Management of the river and its lower floodplains was a common practice and there are many anecdotal accounts by residents, ranchers, and county managers of the need for stream clearing for flood management purposes (Palco, 2005). The early residents put dikes along the river banks to minimize overbank flooding, and all of these activities indicate that much of the valley bottom was inundated and therefore subject to sediment deposition during high flows. The 2015 map of the 100-year floodplain (Figure 10) includes nearly all of the valley bottom from the lower portion of the North and South Forks all the way to the mouth of the watershed, and this wide swath of designated floodplain cannot be attributed to any recent reduction in the capacity of the main channel.

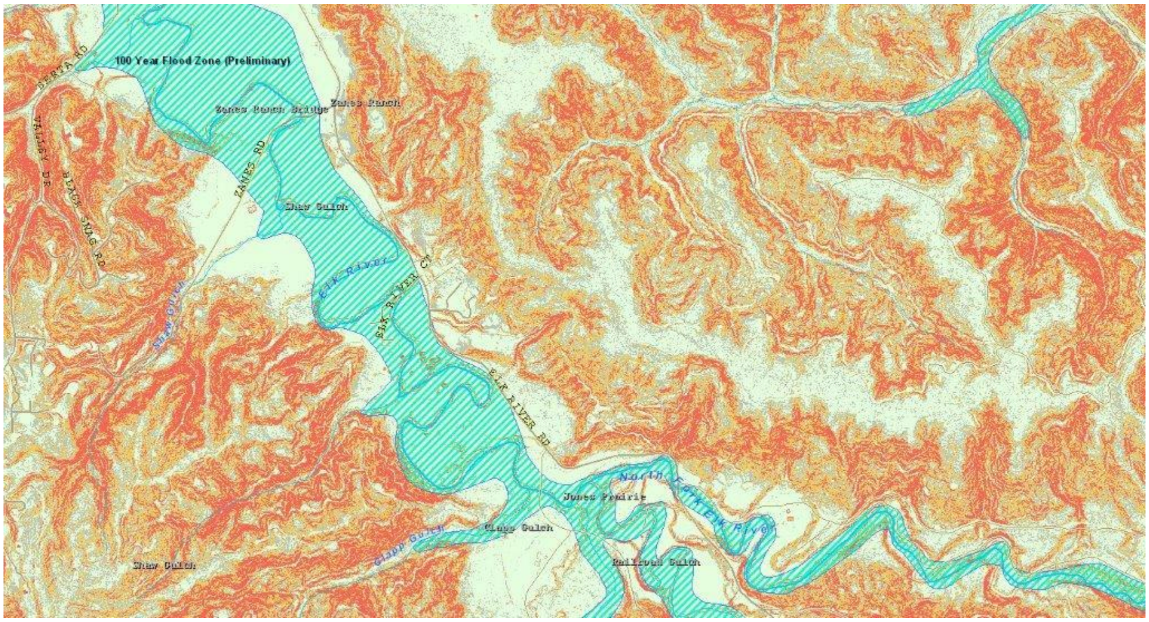


Figure 10. Map of the 100-year floodplain in the lower portion of the North and South Forks of the Elk River and the affected reach (Humboldt County, 2015).

Other studies provide strong evidence that the natural state of these wide, flat floodplains would include multiple channels (e.g., Beechie et al., 2006). Huang and Nanson (2007) show that self-adjusting alluvial channels can anabranch (build side channels) to alter their sediment transport capacity per unit stream power without adjusting channel slope. Sediment transport efficiency can be significantly increased by reducing channel width, which can occur as a result of vegetated alluvial islands and incision below the rooting depth. They also note that, as with other river patterns, anabranching can be characterized by stable equilibrium or accreting disequilibrium.

The hydrodynamic modeling provides further evidence that the affected reach is inherently aggradational. Model results predicted that 18% of the sediment entering the pilot model study area from 2003-2008 was stored within the channel and floodplain, 26% was deposited for the entire impacted reach, and 19% for current conditions (TTR, pp. 68-70). The modeling results and the observed aggradation are used to justify the conclusion that there is zero assimilative capacity. Yet the TTR also notes that even if the upstream influent load is reduced by 75%, which is the amount of sediment assigned to management in the TTR, only 86% of this greatly reduced sediment input would be transported out of the affected reach while 14% would still be deposited (p. 71).

In short, it is simply not valid to assume that the natural state for the affected reach is a single-thread channel where sediment inputs equal sediment outputs. The TTR report erroneously assumes that the natural state of the Elk River is one of dynamic equilibrium (i.e., a simple pipeline where the inputs of water and sediment to the affected reach are equal to the outputs). The box on page 46 states "Such a landscape can be said to be in dynamic equilibrium when the inputs match the outputs over time." The presence of the large floodplain means that considerable deposition has been occurring over a relatively long time period, so by definition sediment outputs are less than sediment inputs. The erroneous characterization of the affected reach as a single thread channel with no deposition results from the failure to consider the larger-scale processes that are the first-order controls on sediment transport and storage in the lower Elk River (see Schumm, 1991). Restoration efforts to recreate a more historically correct main channel, and to establish overflow or side channels, would still not eliminate flooding or sediment deposition on the valley bottom in the affected reach.

The presumption that sediment outputs from the affected reach should match the sediment inputs is further undermined by the failure to consider the conditions and controls on flows and sediment transport in the lowest reach. Figure 8 shows that sea level is rising, and the TTR notes that the conservative estimate for absolute sea level rise (i.e., independent of the subsidence) is 6 inches by 2020, 12 inches by 2050, and 36 inches by 2100 (p. 12). This rise in sea level is causing an increase in baselevel, which in turn causes a corresponding reduction in stream gradient and thus the water and sediment transport capacity in the lowest reach. This reduction in sediment transport capacity due to sea level rise will further exacerbate the ongoing channel and floodplain deposition in the lower portions of the Elk River basin, which in turn will preclude any transformation of the Elk River into a purely transport reach, especially over time scales longer than a year or so.

Even if the affected reach was dredged to remove all of the deposited sediment and increase the stream channel gradient, and all of the water and sediment delivered into the affected reach was exported at the downstream end, there is another six miles of channel with a gradient of no more than 0.12% in the lowest reach (Pryor et al., undated). If the hydrodynamic modeling and other data indicate substantial deposition in the affected reach and the valley gradient in the lowest reach is similar or even lower, it is not realistic to expect that all of the water and sediment being exported from the affected reach can then be transmitted through the lowest reach to the mouth of the watershed. Sediment deposition in the lowest reach, when added to the effect of high tides and the rise in sea level due to low pressure storms, will create even more of a backwater effect that could help reduce sediment transport capacity in the lowest portion of the affected reach.

The box on page 74 in the TTR states that "The loading capacity is defined as zero because:… During high flows (when sediment deposits would be scoured in a functioning system), incoming water and sediment overtops the channel bank and flows across the floodplain. This slows velocities and causes sediment to fall out of suspension." The classic textbook by Dunne and Leopold (1978) notes that "The channel is formed and maintained by the flow it carries but is never large enough to carry without overflow even discharges of rather frequent occurrence." (p. 599). On the next page Dunne and Leopold define a floodplain as "that flat area adjoining a river channel constructed by river in the present climate and overflowed at times of high discharge.", and note that "The floodplain is indeed part of the river under storm conditions." (p. 608).

The problem statement on page 30 of the TTR report notes that the impacted reach is impaired for sediment because excess sediment has been deposited on the floodplain. Yet the floodplain exists because the Elk River from the top of the affected reach to its mouth is essentially a leaky pipe. The storage of sediment predicted by the hydrodynamic modeling is said to be deposited "within the channel and on the floodplain" (p. 68). It is an inescapable conclusion that most if not all of the valley bottom in the affected reach must have been a floodplain at the time of European settlement, and therefore was regularly subjected to overbank flows and sediment deposition. This sediment would be predominantly fine-grained, and in a wet environment would be rapidly colonized by vegetation if the deposit was sufficiently deep to suppress the pre-existing vegetation. The soils and climate, plus observations from analogous systems, mean that the valley bottom of the Elk River was densely vegetated, and bare mineral deposits were only present for a very short period after particularly extreme sediment deposits. Yet the box on page 74 in the TTR goes on to state:

> "The loading capacity is defined as zero because: … Vegetation readily colonizes newly deposited sediment. This slows down flow due to resistance, causing additional sediment deposition. During high flows (when sediment deposits would be scoured in a functioning system), incoming water and sediment overtops the channel bank and flows across the floodplain. This slows velocities and causes sediment to fall out of suspension."

The analogous situation is in Freshwater Creek, where Dr. Lee Benda reviewed Dr. Matt O'Connor's report on channel aggradation, sediment transport, and flooding issues (Benda, 2000). Dr. Benda's final conclusion noted that human activity on the floodplain, particularly the filling of overflow channels by agricultural activities, would have exacerbated flooding, and this is a commonly documented impact on large floodplains in the region.

In summary the flat valley bottom in the lower portions of the North Fork, South Fork and mainstem of the Elk River are nothing more than a large store of deposited sediment. This downstream storage will continue as long as there is continuing uplift in the watershed above the affected reach, subsidence in the lower portion of the watershed, and rising sea levels. The TTR almost completely ignores the cumulative impacts of these processes on the frequency and magnitude of flooding and aggradation in the affected and lowest reaches. Yet these processes must be explicitly recognized in any effort to determine the causes of the current water quality impairment. This geomorphic setting has direct implications for the natural loading capacity and the extent to which the TMDL process can help the Elk River achieve water quality standards.

2.3. Use of the USGS Gaged Record as a Baseline and Target Condition

The TTR states the discharge data collected by the USGS gaging station for 10 water years from October 1957 to September 1967 “offer a baseline condition on the mainstem of the Elk River, which represents a target condition” (p. 11). It also states that “According to the Regional Water Board’s assessment, the domestic water supply use was supported and there was evidence that suggests excessive flooding did not regularly impact residents in the Upper Elk River during this period.” (p.11). Since I address whether the Elk River can meet drinking water standards in Section 3.3, here I only focus on the extent to which the flows recorded during water years 1958-1967 are valid for establishing a target condition. This will be done by comparing the peak flows measured at the USGS gaging station with recent peak flows measured from the HRC mainstem gaging station (509). Both sets of flow values are normalized to cubic feet per second per square mile (csm) to remove any possible effect of the very small difference in drainage areas.

The left-hand side of Figure 11 plots the instantaneous annual maximum flows from the USGS gaging station on Elk River for water years 1958 to 1967. The annual maximum peak flows over this period are notable because they only varied from 47 to 78 csm with a mean of 62 csm, and there is no apparent relationship between the annual precipitation at Eureka and the magnitude of the peak flow. The right-hand side plots the instantaneous annual maximum flows from HRC station 509 for water years 2003-14. The mean instantaneous annual maximum peak flow of 69 csm was only slightly larger than the mean recorded by the USGS fifty years earlier, but the range of 22 to 133 csm was much greater. Four years (2003, 2006, 2008, and 2011) had an instantaneous peak flow that was from 8% to 71% higher than any of the peak flows from the USGS record. This means that the relative lack of flooding from 1958-1967 should be attributed to the relatively low peak flows experienced during that period, and cannot be used to indicate that this area was generally not subjected to flooding.

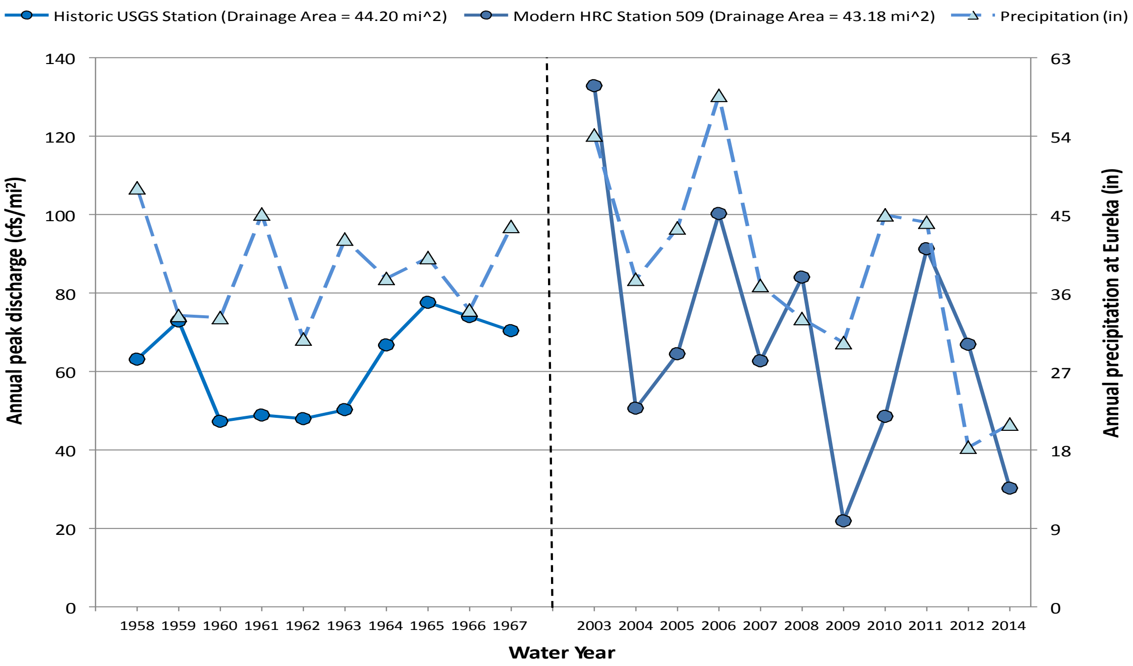
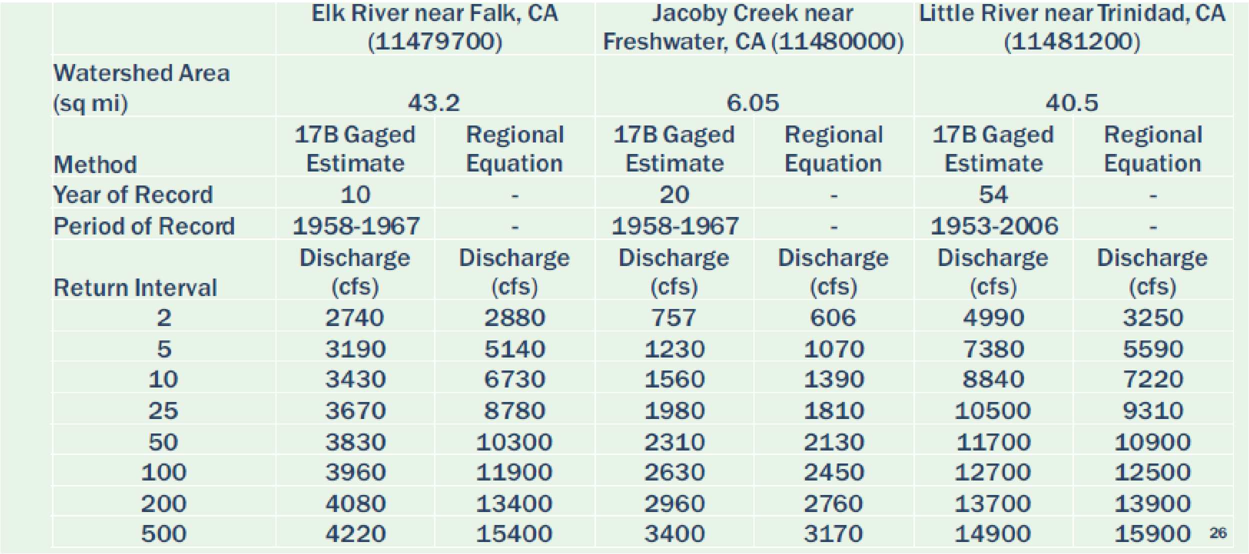


Figure 11. Comparison of the instantaneous annual maximum peak flows for the USGS gaging station near Falk for water years 1958-1967 and the corresponding annual precipitation at Eureka (left side), and the instantaneous annual maximum peak flows at the nearly co-located HRC station (509) for water years 2003-2014 and the corresponding annual precipitation at Eureka.

The relatively low magnitude of the peak flows from WY 1958-1967 is further confirmed by the flood-frequency analyses by B. Pryor (Pryor, 2015). This compared the 2- to 500-year peak flows predicted from the gaging station data at the Elk River near Falk, Jacoby Creek near Freshwater, and the Little River to the predicted flows using regional flood-frequency equations (Table 1). The results show that the 2- and 100-year peak flows predicted for the Elk River using the USGS data were only 2740 and 3960 cfs, respectively, while the predicted peak flows from the regional equations were 2880 and 11,900 cfs, respectively. The 2-year floods from the USGS record and the regional equation vary by only 5%, relatively similar, while the 100-year flood predicted by the regional flood-frequency equation is three times the value predicted from the gage data for 1958-1967. In contrast, the 2- and 100-year peak flows predicted from the gaged data for Jacoby Creek and Little River were very close to the predictions from the regional flood-frequency equations. This indicates that the regional flood-frequency equations are relatively valid, and on this basis the highest measured peak flow at Elk River from 1958-1967 (3430 cfs in WY 1965) is well below the predicted 5-year flood of 5140 cfs using the regional flood frequency equation. These comparisons clearly show that the measured peak flows for 1958 to 1967 were remarkable for their relative consistency and the lack of any high flows.



	Elk River near Falk, CA (11479700)		Jacoby Creek near Freshwater, CA (11480000)		Little River near Trinidad, CA (11481200)	
Watershed Area (sq mi)	43.2		6.05		40.5	
Method	17B Gaged Estimate	Regional Equation	17B Gaged Estimate	Regional Equation	17B Gaged Estimate	Regional Equation
Year of Record	10	-	20	-	54	-
Period of Record	1958-1967	-	1958-1967	-	1953-2006	-
Return Interval	Discharge (cfs)	Discharge (cfs)	Discharge (cfs)	Discharge (cfs)	Discharge (cfs)	Discharge (cfs)
2	2740	2880	757	606	4990	3250
5	3190	5140	1230	1070	7380	5590
10	3430	6730	1560	1390	8840	7220
25	3670	8780	1980	1810	10500	9310
50	3830	10300	2310	2130	11700	10900
100	3960	11900	2630	2450	12700	12500
200	4080	13400	2960	2760	13700	13900
500	4220	15400	3400	3170	14900	15900

26

Table 1. Flood frequency calculations based on gaged data and a regional flood frequency equation for Elk River, Jacoby Creek, and Little River (B. Pryor, 2015).

These flow analyses also indicate that the two major storms for 1959 and 1964 as identified in Figure 10 in the TTR report from the precipitation record at Eureka did not produce a large peak flow. Figure 10 also is used to claim that there were no major storms from 2006 to 2014, but this claim is belied by the fact that the measured peak flows in both 2008 and 2011 were 5% and 14% larger than any of the peak flows measured from 1958-1967 (Figure 11). The very poor linkage between the large storms as identified in the TTR and the measured peak flows in the Elk River means that the timing and importance of large storms in the TTR is not consistent with the recorded peak flows on the Elk River.

The TTR also states that “the channel was relatively stable near the Elk River gaging station in the period from 1955-1965, even given the enormity of the 1964 floods that dramatically impacted most other watersheds in the North Coast Region (NCRWCB, 2013b).” The analysis above indicates that the relative channel stability could be due primarily to the lack of any flows from water years 1958-1967 that exceeded about a 3-year recurrence interval using the regional flood-frequency equations. Contrary to the TTR, the USGS gaging station data show that the 1964 flood was **not** a large event in the Elk River basin, and this also was explicitly noted in the Peer Review Draft.

The low peak flow from the 1964 flood is generally attributed to the lack of snow in the Elk River basin, and this means that the extrapolation of precipitation and flood data from other locations to the Elk River watershed must be done with caution and careful attention to the causal processes. As one example, there is a relatively poor correlation between the instantaneous annual maximum peak flows on Little River and Elk River, and this is why I did not use the long-term flow data from Little River to reconstruct peak flows on the Elk River.

3. SEDIMENT SOURCE ANALYSIS AND TRENDS OVER TIME

3.1. Natural Sediment Sources

3.1.1. Accuracy of the Estimated Natural Sediment Sources. The time-averaged value for natural sediment sources in the TTR is 140 yd^3 mi^{-2} yr^{-1}. If a density is 1.4 English tons/yd^3 is assumed, then there is nearly a 20-fold discrepancy between the natural sediment loading as estimated in the TTR and the estimated natural sediment yield if denudation equals uplift. There are several probable reasons for this discrepancy, with the first being that the amount of deep-seated landslides and soil creep are greatly underestimated. Materials submitted by geologists working for the California Geological Survey (CGS) note that the amount of sediment from deep-seated landslide and soil creep is underestimated for other sediment TMDLs on the North Coast by at least an order of magnitude (Bedrossian and Custis, 2002; Bedrossian and Custis, 2003). A 2002 memorandum to the Regional Water Quality Control Board states “CGS concludes that natural/background erosion estimates of 300 to 3000 tons/sq mi/yr are more realistic for most North Coast watersheds underlain by Franciscan terrain”, and provides a long list of citations (Bedrossian and Custis, p. 16). A recent study in the Eel River found that 7% of the study area was covered by earthflows, and when these sources were averaged over the entire watershed they would contribute 1100 Mg km^{-2} yr^{-1} (Mackey and Roering, 2011).

A second reason is that the sediment source analysis largely focusses on void measurements to estimate sediment production. This means that the sediment source analysis does not include the sediment delivered to streams by soil creep and diffusive processes that deliver sediment to the streams but do not leave measurable voids. Diffusive processes such as treethrow, shrink-swell, freeze-thaw, and burrowing organisms are a very important source of sediment in steep, humid terrain (e.g., Swanston et al., 1995), but these are not easily quantified and appear to have been ignored in the TTR.

A third reason for the very low estimate of natural sediment yields is that the sediment source analysis is based on 1955 to 2011. A review of the instantaneous annual maximum peak flows at the Little River gaging station shows that from 1956-2014 there were four peak flows of 9-10,000 cfs, and six peak flows that were between 8000 and 9000 cfs. While these data cannot be directly extrapolated to the Elk River, they do indicate a lack of extreme events (e.g., larger than a 25-year recurrence interval) over the 50-year record (Table 1).

Similarly, the rate of natural shallow landslides in the TTR is estimated to be only 30 yd^3 mi^{-2} yr^{-1} (Table 8). This value is almost certainly too low because landslides are so episodic but there have not been any particularly large peak flows and by implication exceptional rainstorms from 1955-2011.

The similarities between estimated sediment sources and the measured sediment yields are taken as evidence “that the loading values estimated by this analysis are reasonable” (p.57). The problem is that the TTR does not recognize that the measured sediment loads only include suspended sediment, which is generally finer than 0.1 to 1 mm (MacDonald et al., 1991). As noted earlier, bedload is not being measured at any of the gaging stations, and this could easily add 40% to the measured sediment loads. Hence any comparison between sediment sources and measured sediment yields (e.g., Figure 17) needs to explicitly recognize that the measured sediment yields are underestimates because they do not include bedload (Edwards and Glysson, 1989).

My conclusion is that the natural sediment yields in the Peer Review Draft and the TTR are greatly underestimated, and this is due to the limitations of the methods used, the failure to include all sources, and the absence of any extreme storm events from 1955 to 2011. The underestimate of natural sediment sources then increases the relative importance of the management-related sediment sources, which in turn inflates the estimated potential reduction in sediment loads that can be achieved through additional regulations on industrial timberlands.

3.1.2. Weather Effects. A key issue is the extent to which the trends or variations in sediment sources over the different time periods are due weather rather than changes in management. The TTR tries to assess the effect of variations in rainfall by comparing the estimated sediment sources over time to the corresponding mean annual water yields from Little River (e.g., Figure 16 in the TTR). The problem is that annual water yields can be a poor predictor of annual sediment yields given that most of the sediment is generated by the biggest storms as documented in Section 2.1. Figure 11 showed virtually no correlation between annual precipitation at Eureka from 1958-1967 and the instantaneous annual maximum peak flows. Annual precipitation only accounts for about 30% of the variability in annual sediment yields for 2003-2014 for the mainstem Elk River station (509).

In contrast, 86% of the variability in annual suspended sediment yields for the mainstem Elk River (station 509) can be explained by the instantaneous annual maximum peak flow (Figure 12). Similarly, 78-80% of the variability in annual sediment yields for the North and South Fork gaging stations can be explained by their respective instantaneous annual maximum peak flows. These remarkably strong relationships confirm that annual sediment yields are primarily driven by the biggest flows. Our analysis also shows that annual sediment yields are very tightly correlated amongst nearly all of the HRC stations for nearly all years; this indicates that the relationship between annual peak flows and annual sediment yields is probably valid for all of the gaging stations in the Elk River watershed, and this is consistent with other studies (e.g., Andrews and Antweiler, 2011).

The TTR uses the poor relationship between sediment source values and annual water yields on the Little River to indicate that the high sediment loads for 1988-1997 were not caused by a difference in rainfall. This is problematic because water yields per unit area are much larger for Little River than Elk River, and water yields are not nearly as strongly correlated with sediment yields as the instantaneous annual maximum peak flow. Nevertheless, I also found little correlation between the estimated sediment sources for each time period and the corresponding mean instantaneous peak flows from Little River. Hence I agree that the differences in the management-related sediment sources over time are primarily due to differences in the amount and type of management activities rather than fluctuations in annual rainfall or annual maximum peak flows.

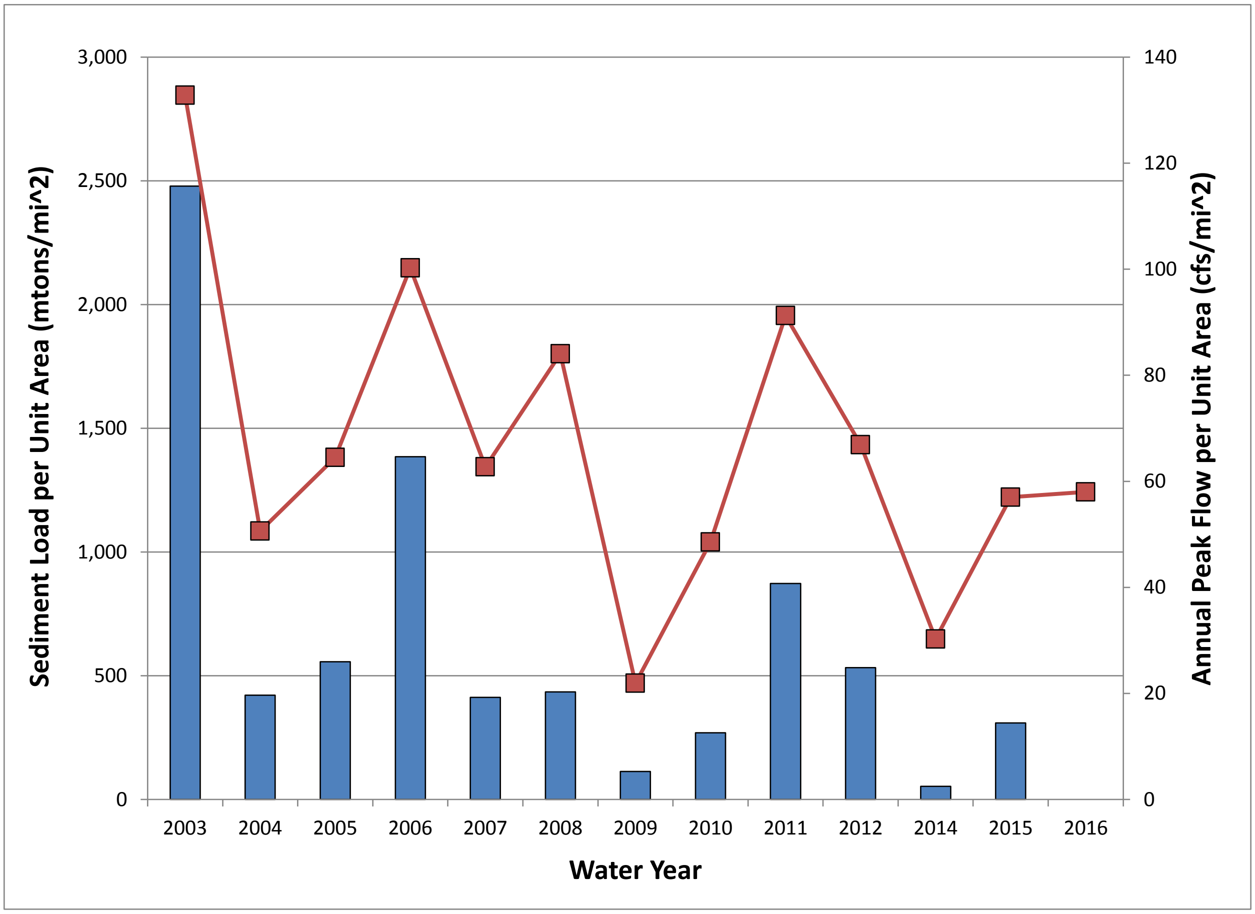


Figure 12. Plot of annual maximum instantaneous peak flows (red squares) and annual sediment yields (blue bars), both normalized by unit area, for the mainstem of Elk River (HRC station 509). Data are not available for 2013, and the peak flow of 58 csm for WY 2016 is only for data collected through 31 January 2016. The sediment yield for water year 2016 will be calculated at the end of the rainy season.

3.2. Anthropogenic Sediment Sources

3.2.1. Summary of trends over time. Table 8 and Figure 15 in the TTR show more than a 60% decline in total (natural and management related) sediment inputs from the peak of more than 1100 yd^3 mi^{-2} yr^{-1} in 1988-1997 to 450 yd^3 mi^{-2} yr^{-1} for the most recent period of 2004-2011. Management-related sediment loadings have dropped to just 32% of the value estimated for 1988-1997 (Figure 13). This sharp decline over the last 20 or so years indicate that the changes in management practices due to Habitat Conservation Plans, changes in California Forest Practice Rules, Waste Discharge Requirements, and timber harvest practices are effective in greatly reducing in management-related sediment yields.

The updated and revised analyses of each of the different management-related sediment sources in the following sections indicate an even greater decline. This decline in sediment from the industrial timberlands leads to questions of: 1) how much further reduction is possible; 2) what additional benefits in water quality and salmonid populations can be gained from more stringent controls on commercial timberlands versus other management or regulatory alternatives; and 3) the extent to which the water quality indicators in the TTR are achievable. To some extent these questions are discussed along with the validity of the estimates for each sediment source category in the TTR. Note that the order of the discussion of the different sources generally follows the order in the text on pages 54-56 in the TTR rather than the order in Table 8.

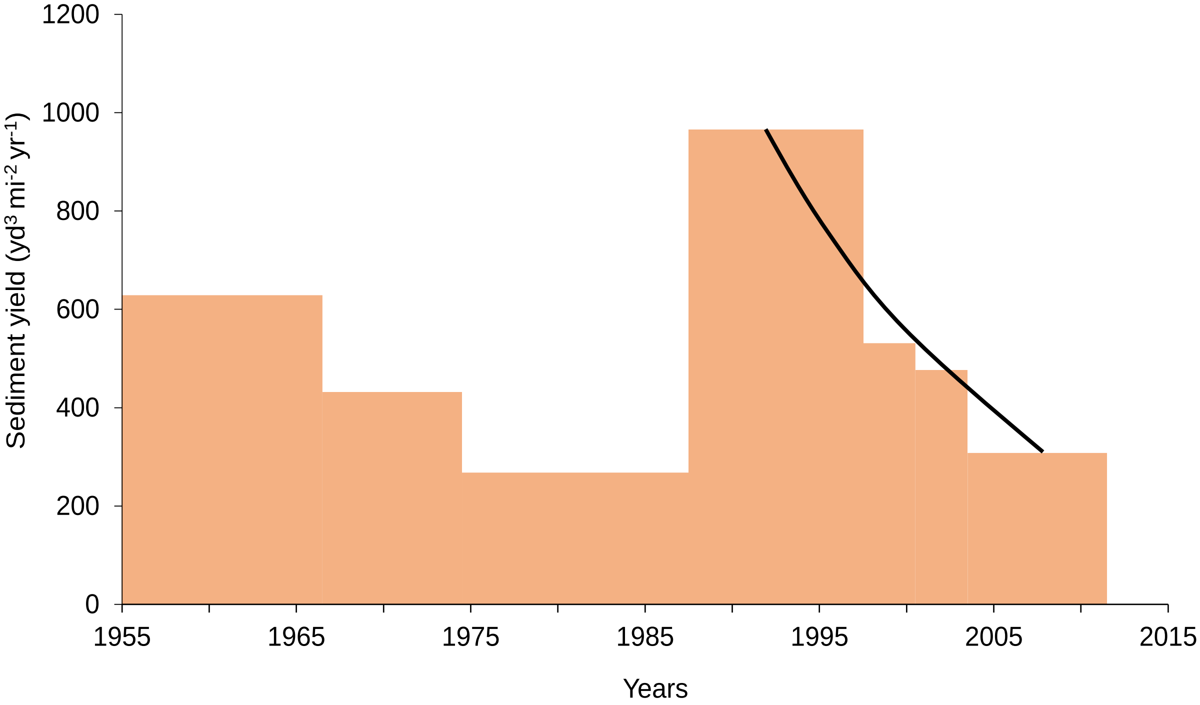


Figure 13. Total management related sediment sources over time (values from Table 8 in the TTR). The trend line was drawn by hand to help show the overall trend.

3.2.2. <u>In-channel management-related bank erosion and streamside landslides.</u> In-channel bank erosion and streamside landslides is the single largest source of management-related sediment in the TTR, accounting for 52% of the total management-related sediment sources in 2004-2011. Three studies provided rates, and the proportion attributed to management is based in large part by the relative drainage densities in unmanaged and managed areas. As noted in my previous comments (MacDonald, 2014a), the unmanaged drainage density of 5.6 mi mi^{-2} was derived from the median contributing area for just four channel heads in the Upper Little South Fork (Buffleben, 2009). The problem is that channel heads are typically a function of both area and local slope (e.g., Montgomery and Dietrich, 1988), and this was clearly true for the four channel heads used to define the median contributing area for unmanaged and unroaded areas (Figure 14).

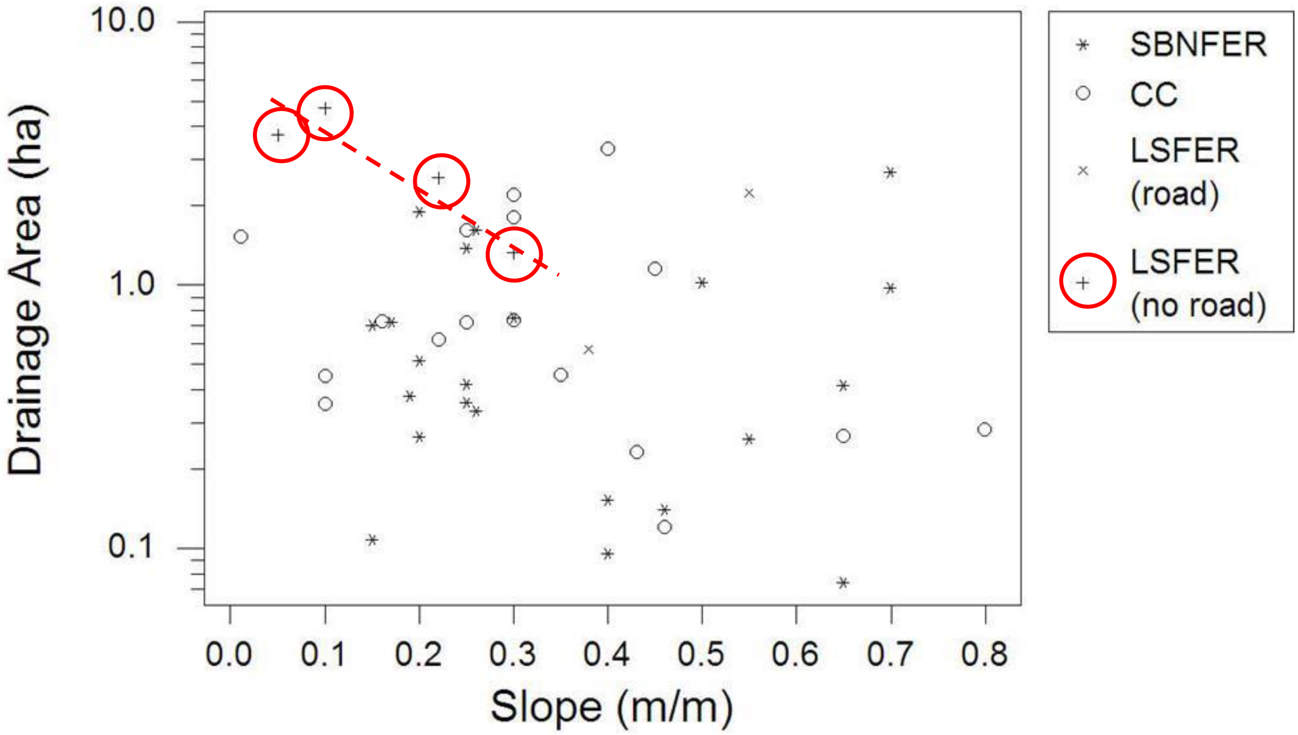


Figure 14. Plot of the channel heads identified in Buffleben (Figure 2.6, 2009). The four channel heads used to determine the drainage density in unmanaged areas are the four crosses in the upper left of this figure, and they clearly show a dependence on both drainage area and slope.

There are also issues with respect to the extremely small sample size used to determine the unmanaged drainage density, the use of a median value rather than a mean, and the inconsistent selection of data used for determining drainage density in both unmanaged and managed areas (MacDonald, 2014a). Although not explicitly stated in the TTR report, the drainage density in unmanaged areas did not vary with geology, while the drainage density for managed areas varied with geology from 16.5 mi mi^{-2} in Wildcat and Yager to 11.7 mi mi^{-2} in Franciscan terrain (NCRWQCB Peer Review Draft, 2013); it is not clear why geology would affect the drainage density in managed areas but not in unmanaged areas. The bottom line is that the drainage density for unmanaged areas is highly uncertain and this directly affects the relative proportion of sediment attributed to natural vs. management-induced bank erosion and streamside landslides.

In my comments on the Draft Peer Review and my presentation to the NCRWQCB (MacDonald, 2014a,c) I made a series of specific points with respect to the accuracy and methodology used to estimate streamside landslides for managed areas vs. unmanaged areas, and my difficulty in following exactly how all of the numbers were generated. The information in the TTR was much less detailed so again it was not possible to determine exactly how the values were determined for natural and management-related deep-seated landslides, streamside landslides, and bank erosion. I will not repeat my comments in detail and GDRCo are providing additional information on the drainage density issue, but briefly: 1) the streamside landslide rate for unmanaged areas was effectively based on just seven landslides larger than 10 yd^3 over a 28-year period from 1975-2003; 2) there was no attempt to relate the rates or size of streamside landslides and bank erosion to key factors such as geology, hillslope gradient, channel size or stream order, geology, amount of large woody debris, or between young forest and advanced second growth; 3) there was no analysis to determine how or why the bank erosion and landslide rates might vary across the three study areas used to generate the basic sediment production rates; 4) the relative rates of management-induced streamside landslides and bank erosion among the 17 sub-basins in Table 8 are constant except for 2003-2011, so the variations in management and site conditions amongst the different sub-basins cannot be related to the variations in bank erosion and streamside landslide rates; and 5) the TTR does not explicitly state how different forest management activities are directly causing the observed different rates of streamside landslides and bank erosion. With respect to these last two points, the various causal processes shown in Figure 12 and elsewhere include increased peak flows, “channel simplification”, “riparian zone simplification”, and reduced slope stability, but there is no effort to assess the relative importance of these different causes or the extent to which they are being addressed by improving best management practices (ROWD, 2015).

The net result is that the streamside landslide and bank erosion data are lumped and the only management guidance that can be provided is a blanket limit on timber harvest rates, regardless of geology, stream type, hillslope gradient, or other factors. If the recommendation is that timber harvest rates should be further restricted to reduce the rates of streamside landslides and bank erosion, there should be more recent data and analyses to support this recommendation, and to provide a clearer, process-based linkage between specific management practices and the rates of streamside landslides and bank erosion for different stream types, geologies, and site conditions. A process-based understanding is could then provide more specific guidance on what specific management activities are of greatest concern for which site conditions. This increased understanding is particularly important given that streamside landslides and bank erosion account for just over half of the estimated management-induced sediment inputs in the Upper Watershed (TTR Table 8).

The relative proportion of sediment from streamside landslides and bank erosion in managed and unmanaged areas is also incorrect because of the demonstrable errors in the assumed drainage densities in managed areas. Matt House of GDRCo is providing a more detailed analysis of this issue, but field mapping by GDRCo in the managed and geologically sensitive McCloud Creek watershed yielded a drainage density of 9.4 mi mi^{-2}. HRC also has provided data to the NCRWQCB that indicated a drainage density of just under 10 mi mi^{-2}, and this study was cited in the Peer Review Draft but this measured drainage density was not used in any of the calculations. The use of these values would reduce the estimated amounts of streamside landslides and bank erosion in managed areas by more than one-third, or around 50-60 yd^3 mi^{-2} yr^{-1}.

Recent data from a 2012 survey of 26 miles of channels yielded a streamside landslide and bank erosion rate of 71 yd^3 mi^{-2} yr^{-1} (SHN, 2012). One-quarter of this amount was due to legacy sources, while the primary causal mechanisms were most frequently related to unstable geology and natural flow deflection. Causal mechanisms due to recent management were virtually non-existent (SHN, 2012). This indicates that current management-related streamside landslides and bank erosion could be as low as 20 yd^3 mi^{-2} yr^{-1} instead of the value of 160 yd^3 mi^{-2} yr^{-1} in the TTR for 2004-2011. A shift of most of the streamslide landslides and bank erosion from management to natural sources would increase loading from natural sources from 144 yd^3 mi^{-2} yr^{-1} to at least 250 yd^3 mi^{-2} yr^{-1}.

The related Water Quality Indicator (WQI) in the Draft Action Plan for the Upper Elk River Sediment TMDLs (NCRWQCB, 2015) is "decreasing length of channel with actively eroding banks", and this is for Class I, II, and III channels. It follows from the above discussion that there are three primary issues associated with this indicator, and these are: 1) what is the true background rate for the percent of actively eroding channel lengths? 2) how well can background rates be separated from natural rates if there the streams have a 50-150 foot buffer? and 3) what are the realistic expectations for the amount of channels with actively eroding banks in an area with highly erosive rock types and rapid uplift? These issues make this WQI particularly difficult to implement. The bottom line is that changing practices appear to have greatly reduced the estimated volume of sediment from streamside landslides and bank erosion in the industrial timberlands, and the values in the TTR for both managed and unmanaged areas are highly questionable.

3.2.3. Low order channel incision. Low order channel incision is estimated to have dropped by one-third from 21 yd^3 mi^{-2} yr^{-1} in 1988-97 to 14 yd^3 mi^{-2} yr^{-1} in 2003-11 (Table 8). The problem is that the recent calculated values for low order channel incision are based on two key assumptions that cannot be readily supported by the available data. The first assumption is that 75% of the increase in channel density occurred by 1950-59, and there has been a consistent 5% increase in drainage density for each subsequent decade (Table 4.1 in the Peer Review Draft). By 2000-2009 drainage densities in managed areas are assumed to have reached the (demonstrably erroneous) values of 16.5 mi mi^{-2} for the Wildcat, Yager and Hookton geology, and 11.7 mi mi^{-2} for Franciscan geology. Given these assumptions there is no clear justification for the assumed increase in low order channel incision from 12 yd^3 mi^{-2} yr^{-1} for 2001-2003 to 14 yd^3 mi^{-2} yr^{-1} for 2004-2011 in Table 8 in the TTR. More importantly, if the drainage density has reached its maximum extent, there should be no more headward extension.

Buffleben (2009, p. 38) states "Most channel heads in the managed watersheds are associated with some type of management feature, the most common of which are skid trails." The current designation of channel heads and their associated equipment exclusion zones, when combined with the shift to either uneven-aged management or shovel logging in the case of even-aged management, means that current harvest practices are not causing the concentrated surface runoff that was largely responsible for the expanding channel network. As noted in my previous comments (MacDonald, 2014a), unpublished results from the Beck's BMPEP monitoring project have shown no headward channel extension as a result of recent management activities (D. Manthorne, HRC, pers. comm., 2013). The new paired-watershed project in Railroad Gulch will provide a more detailed and sensitive test by tracking the locations of at least 30 channel heads over time in sensitive geologies.

The second key assumption is to use the erroneous channel densities in managed areas to estimate the amount of sediment being generated from low order channel incision. If the true drainage density is less than 10 mi mi^{-2}, the amount of sediment from headward channel incision would drop by more than one-third.

A key issue with this sediment source is that it does not clearly separate headward channel extension from headwater channel incision. The assumptions underlying headward channel extension are questionable, and there is no process-based logic or physical evidence to suggest that this is an important process. Headwater channel incision has not been directly measured, and can only be inferred from work in Caspar Creek. Until more specific data show otherwise, the current rate of management-related sediment from low order channels is probably much less than 14 yd^3 mi^{-2} yr^{-1}, but there are no recent quantitative data for this source.

3.2.4. Road-related Landslides. One of the biggest apparent success stories is the sharp decline in road-related landslides from the peak value of over 300 yd^3 mi^{-2} yr^{-1} in 1988-97 to just 25 yd^3 mi^{-2} yr^{-1} in 2004-2011 (Figure 15). About 85% of the latter value is due to one large slide in the Lower South Fork, and if this is excluded the rate of road-related landslides drops to less than 4 yd^3 mi^{-2} yr^{-1} as shown by the dashed black line for 2004-2011 in Figure 15.

A compilation of more recent data from HRC and GDRCo from 2012 through the storms of January 2016 indicates that there have been only nine road-related landslides, and the average sediment input from these is only 1.6 yd^3 mi^{-2} yr^{-1}. The sharp decline in road-related landslides since 1997 shows that the extensive road stormproofing and decommissioning has greatly reduced the risk of road-induced landslides on industrial timberlands. The observed rates do have the caveat that the maximum measured peak flow in 2003 of 5740 cfs in the mainstem of the Elk River has an estimated recurrence interval of seven years using the regional regression equation, but the adaptive management approach means that present practices and road stormproofing efforts be maintained continued until there is evidence to suggest that these are not sufficient. Storm recurrence intervals as a cause for road-related landslides have not been calculated from the Eureka rainfall record as the data from this gage are compromised by adjacent vegetation and the uncertain applicability of the Eureka data to the Elk River watershed.

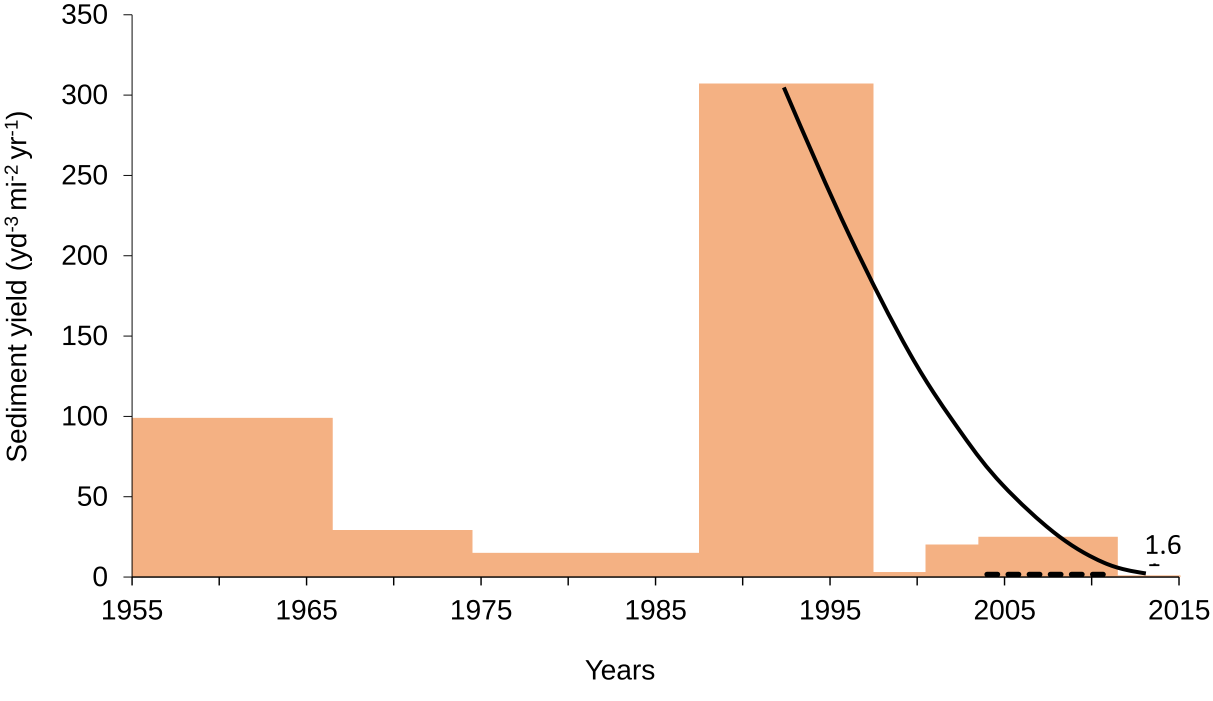


Figure 15. Delivered sediment from road-related landslides over time. Data through 2011 are from Table 8 in the TTR, and the black dashed line for 2004-2011 indicates the unit area rate if the one very large landslide in the Lower South Fork is excluded. The value of 1.6 indicates the average rate from 2012 through January 2016, and the black trend line is drawn by hand to indicate the overall trend.

<u>3.2.5. Open Slope Shallow Landslides.</u> Sediment produced from open slope shallow landslides shows a similar but more consistent trend as road-related landslides. The estimated amount of delivered sediment from this source has dropped from just over 200 yd^3 mi^{-2} yr^{-1} in 1988-97 to just 5 yd^3 mi^{-2} yr^{-1} in 2004-2011 (Figure 16). Virtually all of the sediment from 2004-11 was from just one failure in the Upper South Fork, and a compilation of data from HRC and GDRCo for 2012 through the storms of January 2016 indicate that there have been only two small landslides that can be fully or partially attributed to timber harvest. Hence the average amount of sediment delivered per year from 2012 through January 2016 is less than 0.1 yd^3 mi^{-2} yr^{-1}. This shows that the on-site evaluations and more stringent regulations (HRC, 2015) have greatly reduced the landslide risk in areas subjected to timber harvest. There is still the caveat that the Elk River has not been subjected to a peak flow with more than a seven year recurrence interval since the gaging records began in WY 2003, but the principle of adaptive management would suggest that current regulations be maintained until there is evidence that current practices are inadequate.

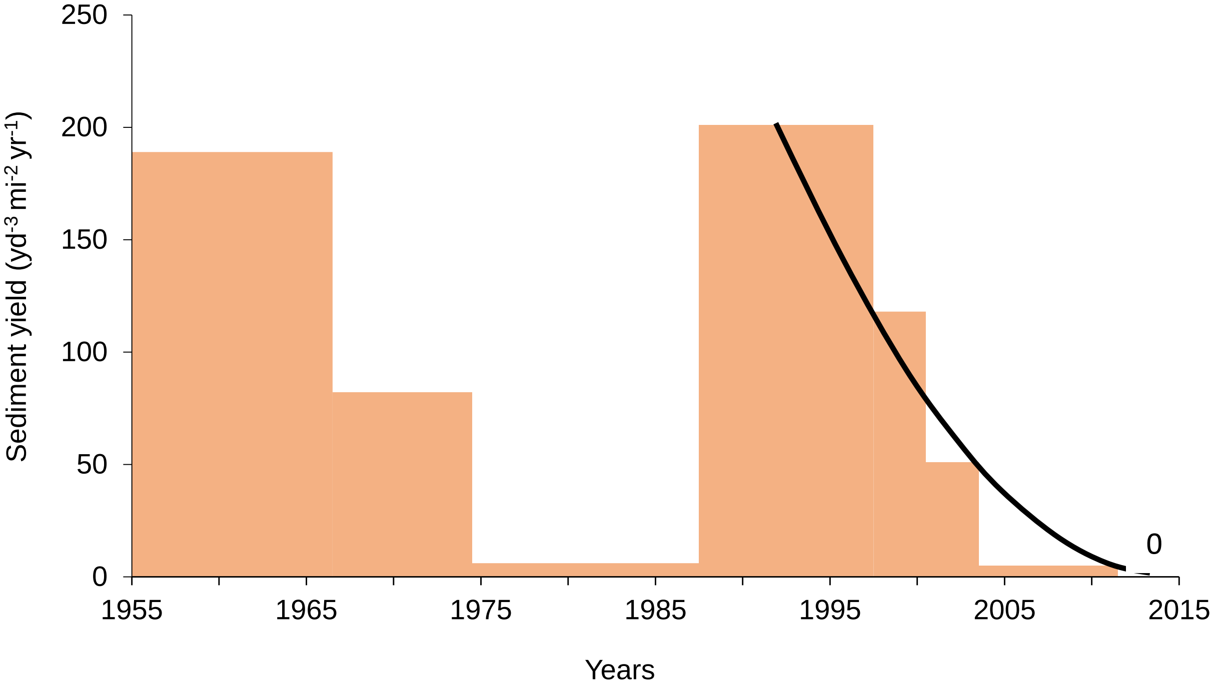


Figure 16. Delivered sediment from open-slope shallow landslides over time. Data through 2011 are from Table 8 in the TTR. The value of 0 indicates the average rate from 2012 through January 2016, and the black trend line is drawn by hand to visually indicate the overall trend.

3.2.6. Skid Trails. The estimated amounts of sediment delivered from skid trails over time from TTR Table 8 are presented in Figure 17. This graph is notable in that it shows a general increase over time, with the highest value of 15 $yd^3\ mi^{-2}\ yr^{-1}$ for 2001-11. The values from 1955 to 2003 in this figure and the TTR are identical to the values in the Peer Review Draft (2013), but the TTR report appears to have simply applied the estimated value of 15 $yd^3\ mi^{-2}\ yr^{-1}$ for 2001-03 to 2004-11 without any explanation or justification. The estimated sediment delivery from skid trails also varies by subwatershed from 1954 to 2000, while from 2000 all watersheds have the same rate of 15 $yd^3\ mi^{-2}\ yr^{-1}$. The Peer Review Draft (NCRWQB, 2013) was very clear in documenting the calculations behind the values presented the associated uncertainty, and this clarity was very much appreciated.

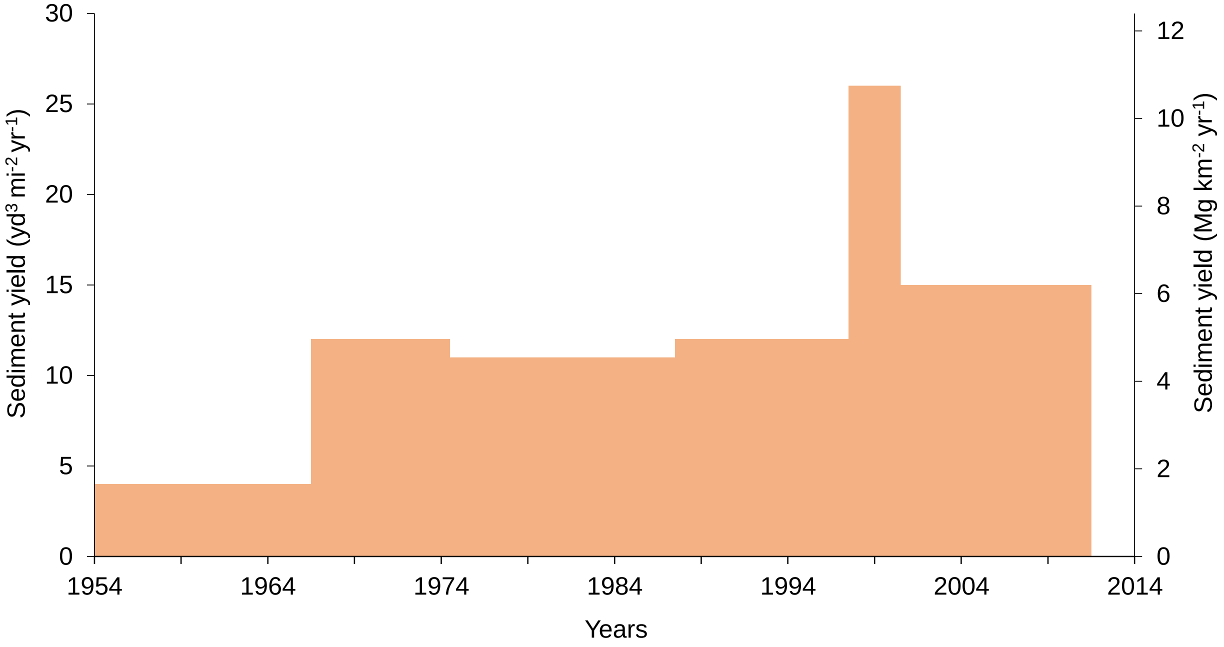


Figure 17. Estimated sediment delivery from skid trails over time. Data through 2011 are from Table 8 in the TTR.

From an adaptive management perspective, the sediment from skid trails should be divided into a legacy portion and sediment from current management, including cable rows. The values presented in the TTR were derived in part from Cleanup and Abatement Orders, and the Peer Review Draft (NCRWQCB, 2013) assumed future delivery will occur uniformly over the next 50 years (this is presumably the basis for extrapolating the 15 $yd^3\ mi^{-2}\ yr^{-1}$ value forward in time). From a process-based perspective, an exponential decay of sediment delivery from historic skid trails would be more realistic as the worst sites are treated, an increasingly small proportion of the remaining unstable sites fail, and the sites that have not been treated or fail revegetate and stabilize. The remaining legacy sites that are suitable for treatment will be treated over time as they are incorporated in Timber Harvest Plans (HRC, 2015).

Sediment production from skid trails in current harvest units is believed to be near zero given the shift to shovel logging and selection harvest. Shovel logging in even-aged management should largely eliminate skid trail erosion because there are no more skid trails, and the temporary roads need to be slash packed, water barred, or otherwise treated if there is any threat of surface erosion being delivered to a stream. Skid trails in ground-based uneven-aged management should be treated to preclude the generation of concentrated overland flow that can initiate surface rilling and delivery of sediment to a stream. The procedures to minimize, if not eliminate, skid trail erosion are well known, and the sediment from skid trails and cable rows in current harvest activities should be close to zero; any problems observed in post-harvest inspections should be immediately treated. The bottom line is that the value of 15 $yd^3\ mi^{-2}\ yr^{-1}$, while only representing about 5% of the management-related sediment yields according to TTR Table 8, is a legacy rate and sediment production from this source should decline over time.

3.2.7. Land-use Related Sediment Discharge Sites. This is the second most important source of management-related sediment according to TTR Table 8, and this refers to the erosion from a wide variety of legacy watercourse crossings, gullies, skid trails, and other features. Figure 18 shows that the peak rate of sediment production from these sources was 80 $yd^3\ mi^{-2}\ yr^{-1}$ from 1975-1987, and this has since dropped to 39 $yd^3\ mi^{-2}\ yr^{-1}$. This reduction is due to the systematic attempt to identify and inventory these, and then treat sites on the basis of their relative priority and as feasible given access and the disturbance associated with treating a given site (HRC, 2015). In 2015 there were still 112 sites that needed be treated with a potential delivery of just over 22,000 yd^3 (HRC, 2015) These are supposed to be treated by the end of 2017, so the sediment loading from these sources should rapidly decline to a near zero value.

A separate survey of 12,300 acres that were subjected to significant ground-based disturbance due to timber harvest identified 143 potentially controllable off-road sites. Nearly half of these have been treated, and the majority of the untreated sites either cannot be readily treated or the benefits in terms of sediment savings are not sufficient to justify treatment. Taken together, these data indicate that this source will continue declining and will become a relatively small value by the end of 2017.

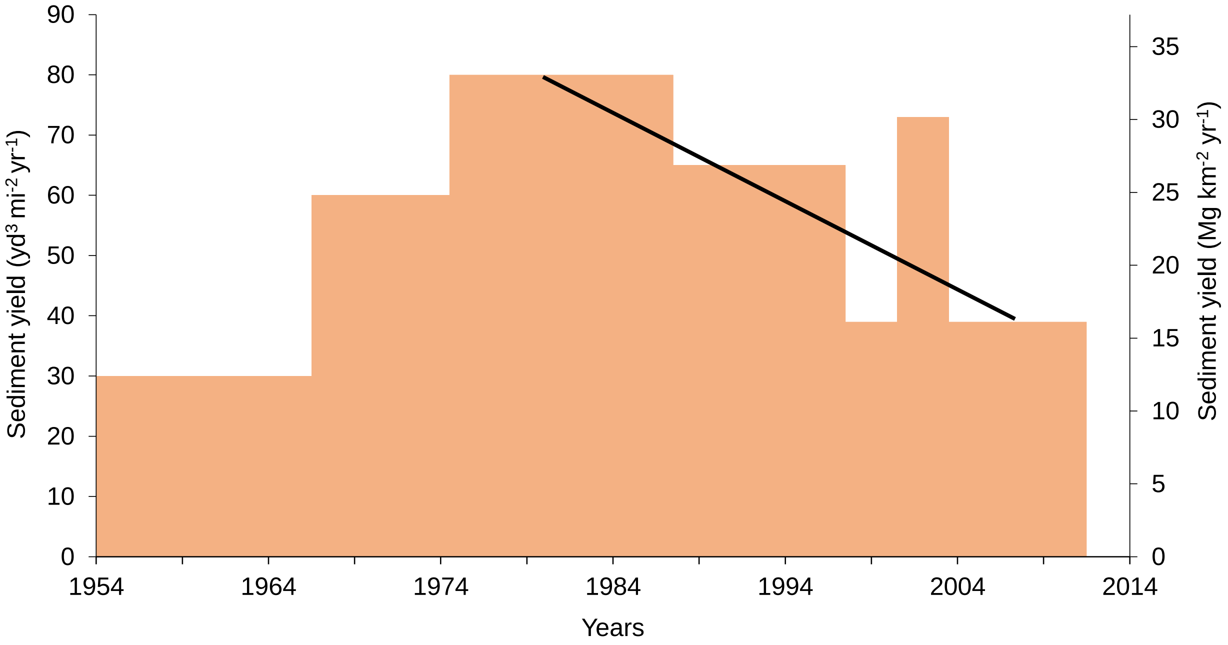


Figure 18. Estimated sediment delivery from management-related discharge sites over time. Data through 2011 are from Table 8 in the TTR, and a relatively rapid decline is projected from 2012 through 2017. The black line is drawn by hand to indicate the overall trend.

3.2.8. Treatment of Management Discharge Sites. This refers to the sediment generated by treating a legacy problem associated with a watercourse crossing, road, skid trail, gully, or other feature. This is the only sediment source that has increased over time, as in 1998-2000 it was estimated at 13 yd^3 mi^{-2} yr^{-1} and as 24 yd^3 mi^{-2} yr^{-1} for 2004-2011 (TTR Table 8). This increase presumably reflects the increased number and size of sites that have been treated in 2004-2011. As such, this sediment source represents a down payment to reduce future sediment sources. Over time the volume of sediment from treated sites should decline as the worst sites are treated and stabilize, and with increasing experience HRC and GDRCo have been seeing a smaller proportion of the sediment being lost as a channel or site adjusts.

3.2.9. Road Surface Erosion. Road surface erosion is another sediment source that has sharply declined from the estimated peak value of 137 yd^3 mi^{-2} yr^{-1} in 1988-1997 to just 22 yd^3 mi^{-2} yr^{-1} in 2004-2011, or an 84% reduction (Figure 19). This reduction has been achieved in large part by stormproofing nearly 80% of the roads on HRC property and decommissioning another 50 miles of roads (HRC, 2015). This process of stormproofing and decommissioning is continuing, so the expectation is that road surface erosion has dropped further from 2012 to 2015, but no data are available on this.

The Draft Action Plan and the TTR call for 100% of roads to be disconnected, but this is not realistic given that road densities are typically around 6 mi mi^{-2} but can reach 10 mi mi^{-2} in some watersheds (NCRWQCB, 2013). Since the drainage density in managed areas is about 10 mi mi^{-2}, it follows that there will be numerous stream crossings and a certain length of road has to drain directly into the stream. Road-stream connectedness can be minimized by draining the road prior to the stream crossing and minimizing the length of the road segments draining directly into the stream at a road crossing, but road=stream connectivity cannot be reduced to zero. Sediment delivery from connected road segments can be reduced by rocking to reduce the road sediment production. The combination of minimizing road-stream connectivity and reducing sediment production on connected road segments is reducing reduce road sediment delivery to a relatively small number, but it cannot be reduced to zero.

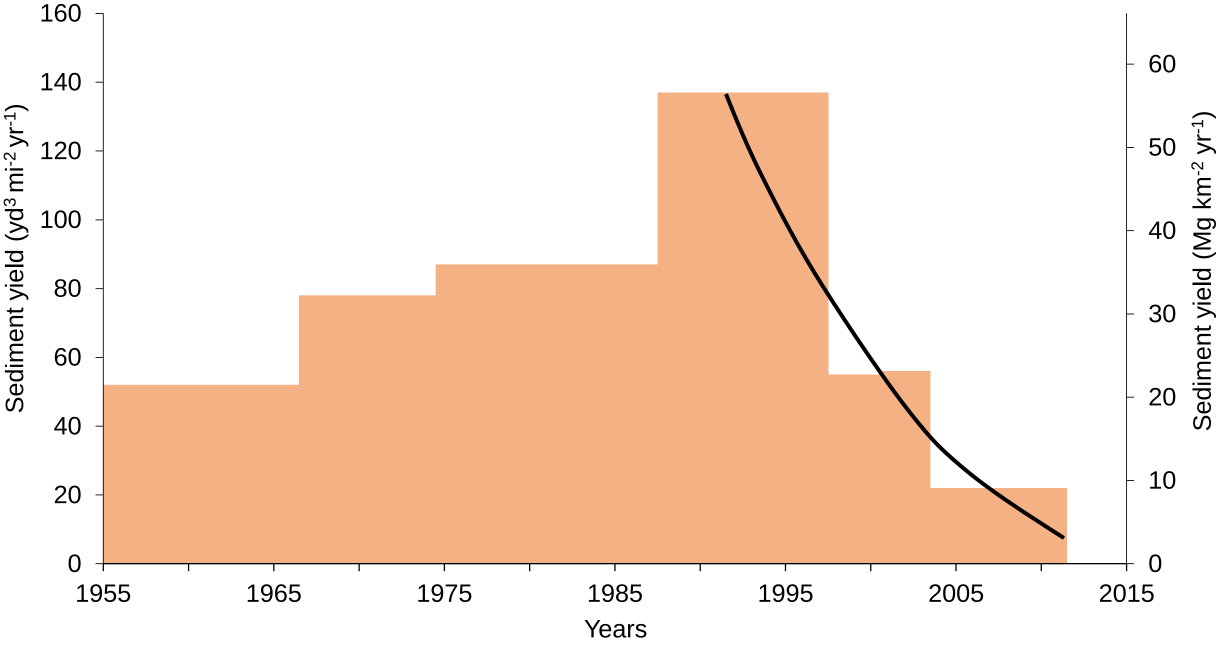


Figure 19. Estimated sediment from road surface erosion over time. Data through 2011 are from Table 8 in the TTR, and the black line is drawn by hand to indicate the overall trend.

3.2.10. Harvest Surface Erosion. Harvest surface erosion is a relatively minor source of sediment, as this has been estimated at just 2-6 yd^3 mi^{-2} yr^{-1} over the different time periods (TTR Table 8). These values are probably too high given the tendency of the WEPP model to overestimate erosion, particularly in wet areas (e.g., Miller et al., 2011). The proposed hillslope water quality indicator in the Draft Action Plan is that “100% of harvest areas have ground cover sufficient to prevent surface erosion”. No specific value of cover is provided, but published relationships between erosion and ground cover indicate that 70-80% cover should be sufficient to minimize surface erosion in all but the most intense rainstorms (Figure 20). In particularly sensitive areas close to streams consideration should be given to ripping the skid trails to increase infiltration and slash packing, but cover still needs to be added (Sosa-Perez and MacDonald, in preparation). Providing a high level of cover, when combined with the use of buffer strips, will minimize rainsplash impact and surface sealing, and slow overland flow. The combination of such treatments and the use of buffer strips should ensure that little or no surface runoff and erosion is produced or delivered from harvest units.

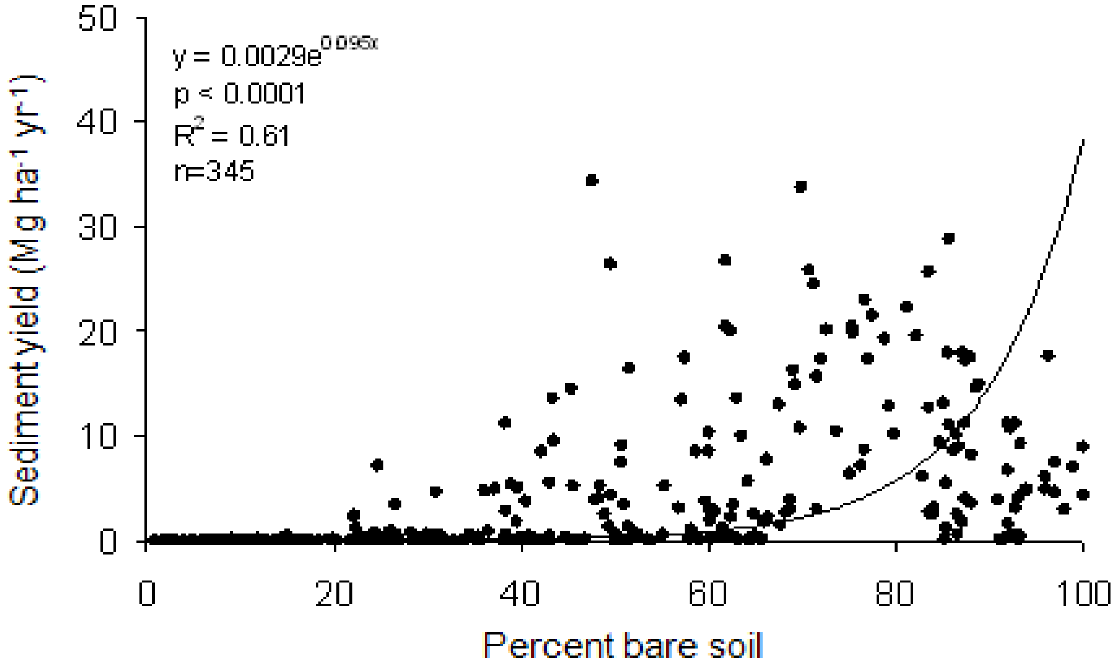


Figure 20. Sediment yield versus percent bare soil (Larsen et al., 2009). Hillslopes with more than 80% cover are highly unlikely to produce any surface erosion.

3.2.11. Summary of Management-induced Sediment Loads. From the above discussion it should be clear that current amount of sediment from low order channel incision, road-related landslides, open slope shallow landslides, current skid trails, road surface erosion, harvest surface erosion in harvest units, and management-related discharge sites have all declined sharply and are continuing to decline as a result of improved management practices and treatment of legacy sites. Collectively I would roughly estimate these sources at roughly 20-30 yd^3 mi^{-2} yr^{-1} for land use-related sediment discharge sites, 15 yd^3 mi^{-2} yr^{-1} for post-treatment discharge sites, 10 yd^3 mi^{-2} yr^{-1} each for legacy skid trails and road surface erosion, less than 5 yd^3 mi^{-2} yr^{-1} each for road-related landslides and low order channel incision, and no more than about 1 yd^3 mi^{-2} yr^{-1} for open slope landslides and surface erosion from harvest units, including current skid trails. This would make a total of about 70 yd^3 mi^{-2} yr^{-1}, with the majority of this being legacy sources and the 15 yd^3 mi^{-2} yr^{-1} from treated discharge sites being an investment for reducing future sediment loading.

The estimated total of about 70 yd^3 mi^{-2} yr^{-1} points out the importance of more accurately quantifying both the natural and management-related values for streamside landslides and bank erosion. The estimate of 160 yd^3 mi^{-2} yr^{-1} for 2004-2011 for management-related streamside landslides and bank erosion is almost certainly too high (Section 3.2.2), and more recent surveys and the revised drainage density values would suggest that the current rate should be around 20 yd^3 mi^{-2} yr^{-1}. This would make the total for all management-related sediment sources around 100 yd^3 mi^{-2} yr^{-1}, with most of this coming from legacy sources. HRC’s Watershed Analysis (2014) estimated legacy sources at close to 150 yd^3 mi^{-2} yr^{-1} and current sources at 34 yd^3 mi^{-2} yr^{-1} for a total of roughly 180 yd^3 mi^{-2} yr^{-1}. Their estimated natural erosion rate was 190 yd^3 mi^{-2} yr^{-1}, which was roughly equal to the management-related sediment sources and about 30% higher than the estimate for natural sediment sources in the TTR (Table 9). The total of 370 yd^3 mi^{-2} yr^{-1} still converts to only about 130 Mg km^{-2} yr^{-1} if a density of 1.4 English tons/yd^3 is assumed, and this less than 40% of the mean suspended sediment yield measured at HRC station 509 on the mainstem of the Elk River. This supports the view that there is much more sediment being produced from unmeasured sources such as soil creep and from deep-seated landslides as noted in Section 2.1.

Two other sediment sources that were not considered in the TTR are: 1) the sediment from other portions of the watershed that drain to the affected reach; and 2) sediment from other land uses in the Upper Watershed. Each of these are discussed below, and they both need to be included in the estimated sediment loading to the affected reach, the TMDL, and the Draft Action Plan.

3.3. Additional Natural and Management-Related Sediment Sources for the Affected Reach

As noted above, the sediment source analysis in the TTR is inherently flawed in that it does not include all the area draining into the affected reach, nor does it include all the land uses in the Upper Elk Watershed. The TTR states that the drainage area above the affected reach (“Upper Elk Watershed”, p. 7 in TTR) is 44 mi^2, and the sum of all the different sub-watersheds in Tables 7 and 8 is 44.13 mi^2. The problem is that the maps in Figures 6 and 7 with the numbered subwatersheds all show the lower boundary of the upper watershed as concave in the upstream direction, while the map of the numbered subwatersheds in Figure 1 shows the lower boundary as being convex in the downstream direction. A closer analysis shows that the area attributed to area #3 is entirely excluded from the sediment source analysis, but 2.11 mi^2 of subwatershed 3 is included in the Upper Watershed according to Figure 1. This missing 2.11 mi^2 is highlighted in Figure 21, and this includes Shaw Gulch as well as numerous smaller tributaries.

The TTR appears to recognize this discrepancy and states that this area “is not anticipated to contribute significant sediment loads” (p. 7); hence only the upper 17 subwatersheds were used to calculate sediment loading. This exclusion is noted to be “consistent with the load estimates in all the supporting documentation”. The problem is that all of the supporting documentation also ignored this area, and this does not justify excluding both natural and anthropogenic sediment loads from this area. All of the sediment from this area will be part of the total sediment loading into the affected reach, and must be considered in any sediment TMDL.

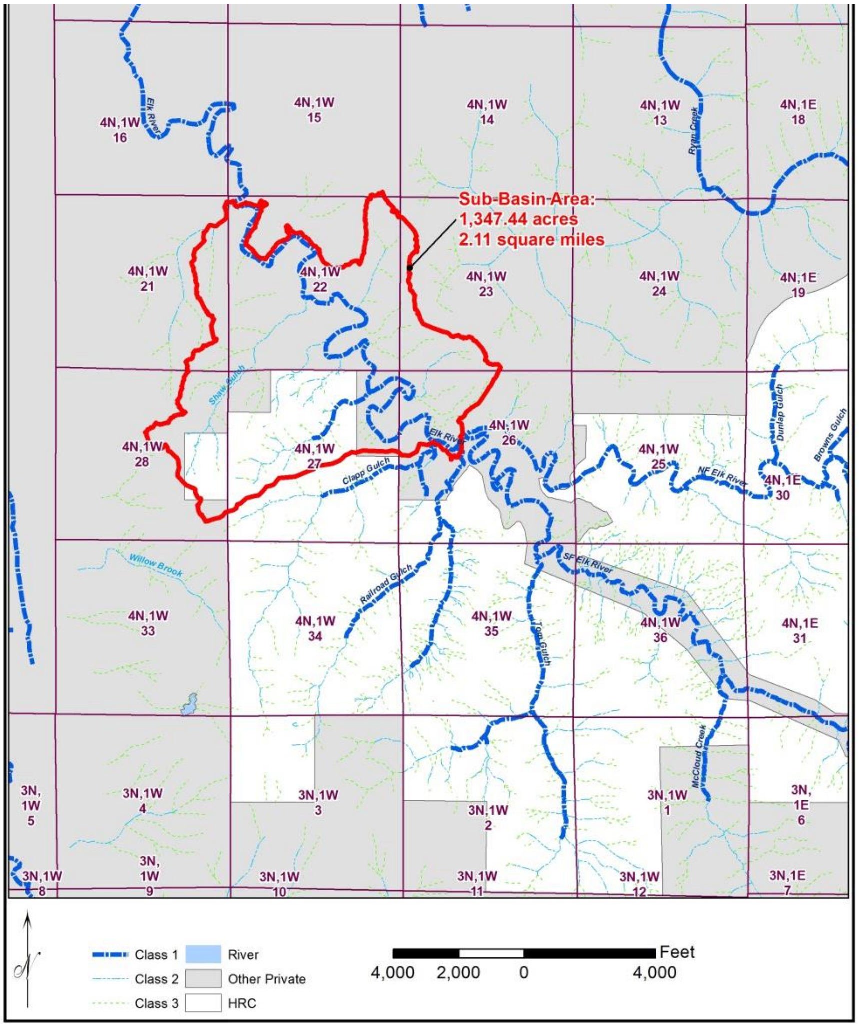


Figure 21. Map of the 2.11 mi^2 of area draining to the affected reach that is not included in the sediment source analysis in Tables 7 and 8.

The land use and ownership map (TTR Figure 3) shows that most of this area is residential, agricultural, or used for timber production by smaller landowners, and this plus Figure 4 suggests that this area is probably densely roaded. The slope gradient map (TTR Figure 6) shows that a substantial portion of this area has gradients similar to the upper watershed. The geologic map in TTR Figure 7 and data from Hart-Crowser (2000) indicates that 44% of the area draining to the affected reach is Wildcat, with quaternary marine and nonmarine sediments adjacent to the alluvium in the valley bottom. The highly erosive Hookton formation occupies 21% of the lower basin as opposed to just 7% in the Upper Watershed (Hart-Crowser, 2000).

A map of the lower basin provided by S. Beach (geologist, HRC) provides a closer view of this area (Figure 22). This shows the presence of earthflows on each side of the Elk River and confirms the extensive roading (Figure 21). Commercial timber harvest also has occurred in this area (S. Beach, HRC, pers. comm., 2015). The relative proximity of this area and these land uses to the affected reach may give them added significance as there is less potential storage. Given these site conditions and land uses, it is clear that the sediment delivery from this area cannot be assumed to be insignificant. It follows that these areas should be subjected to management requirements under the TMDL in order to minimize sediment production and delivery into the affected reach.

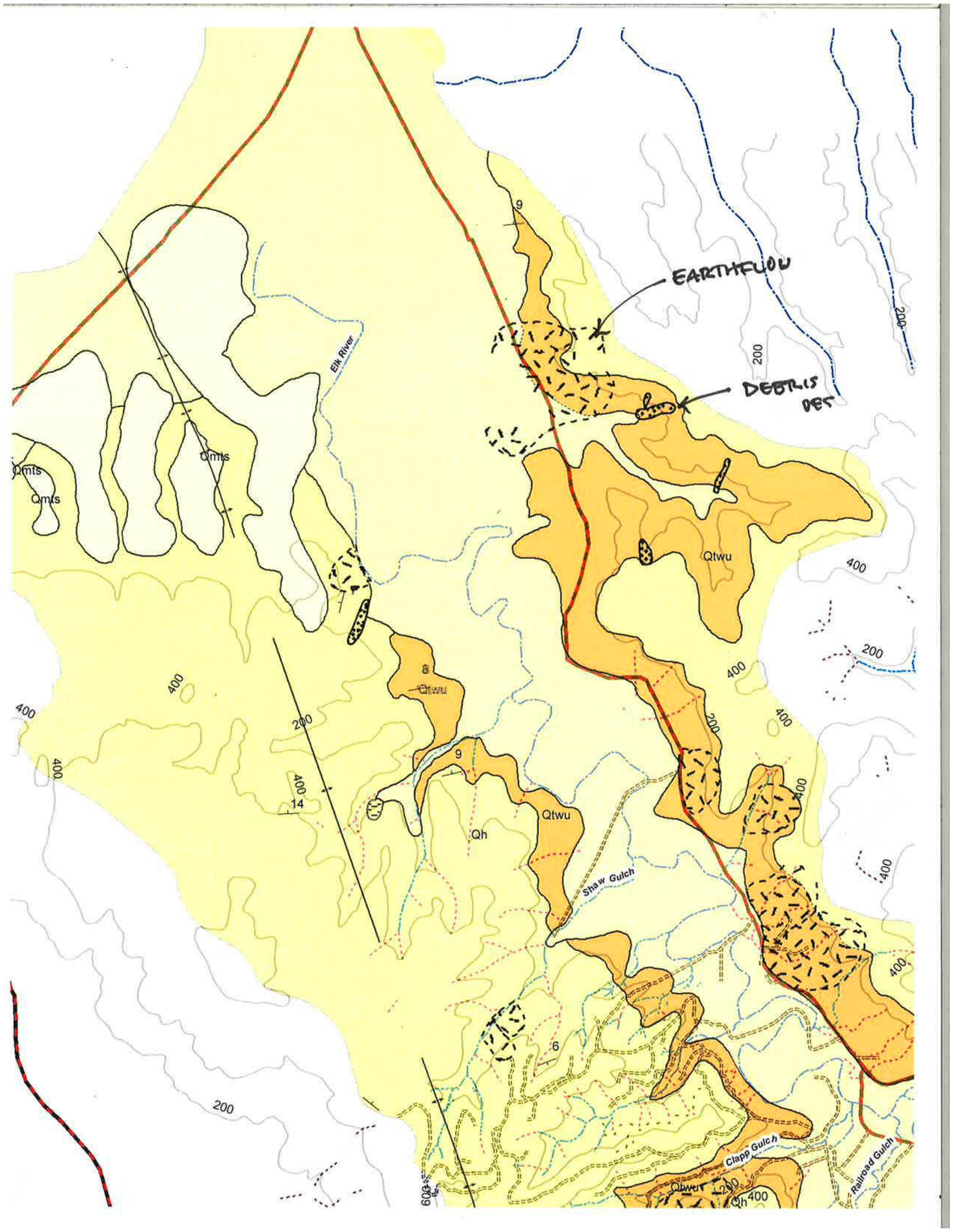


Figure 22. Map of the lower portions of the Elk River Watershed immediately adjacent to the affected reach showing the dense road networks in some portions of the area and the presence of deep-seated earthflows (unpublished figure from S. Beach, HRC, 2015).

The second limitation of the sediment source analysis is that it does not account for all of the land uses in the Upper Watershed. TTR Table 2 indicates that land used in the Upper Elk River Watershed (now 44.6 mi^2) includes 1.3 mi^2 of residential and 0.5 mi^2 of agricultural land uses, but neither of these land uses are included in the sediment source analysis. Again one would expect a relatively dense road network and a variety of other sediment sources depending on the exact land uses and practices. It is beyond the scope of my comments to even try to estimate the magnitude of the sediment being delivered from these two land uses in the Upper Watershed. The first step is to identify and quantify the management-related sediment inputs from these land uses, and then the burden of reducing sediment loads to the affected reach needs to be fairly apportioned amongst all the sources and landowners.

3.4. Accuracy of the Estimated Aggradation in the Affected Reach

A final issue is the accuracy of the estimated volume of 640,000 yd^3 of sediment that has been stored in the impacted reach (TTR Table 10). This number is “based on calculations of cross-sectional changes identified primarily as of 1993” (TTR, p. 66), and the data appear to go through 2011, so dividing volume of 640,000 yd^3 by 18 years leads to a mean deposition rate of roughly 35,000 yd^3 per year. The Draft Action Plan states that this volume of 640,000 yd^3 has accumulated since 1988, which would result a mean rate of about 28,000 yd^3 per year from 1988-2011.

The TTR states that 18% of the sediment entering the pilot hydrodynamic study area during the simulation period of 2003-2008 is stored within the channel and floodplain. While the pilot modeling reach does not extend to the top of the affected reach on the North and South Forks, the TTR states “estimated upstream inputs likely don’t change too much on the upper end of the model, although there may be a reduction in the suspended sediment load due to deposition between the top of the impacted reach and the top of the pilot reach” (p. 68). The TTR also notes that “the pilot model extends past station 509, but also does not extend to the downstream end of the impacted reach, ending at Berta Road”.

A sum of the total natural plus management-related sediment loads from 1998-2011 (452-707 $yd^3\ mi^{-2}\ yr^{-1}$ according to Table 8) times 44 mi^2 times the appropriate number of years yields a total summed sediment loading for this 24-year period of 840,000 yd^3. This means that 76% of the estimated sediment loading was deposited just in the main channel of the Elk River in the affected reach over this period. The Peer Review Draft also has pictures of roughly 1-4 feet of sediment deposition on the floodplain, and this volume is presumably not included in the 640,000 yd^3 of assumed deposition. On this basis it appears that the sum of the deposition is larger than the total sediment load as estimated in the sediment source analysis.

A comparison of the deposited volume to the measured sediment load at HRC station 509 indicates that the suspended sediment load was about 50,000 yd^3 per year assuming a density of 0.71 English tons/yd^3. This means that 54% of the suspended sediment load was being deposited in the affected reach if one assumes the average annual deposition rate of 28,000 yd^3. Some of this discrepancy can be explained by the failure to include bedload in the sediment loading and measured sediment yields, and by the fact that the hydrodynamic modeling reach was shorter than the affected reach. However, the mass balance calculations in the previous paragraphs clearly show that the assumed deposition of 640,000 yd^3 is unrealistic, and this should not be surprising given the variability in channel change over closely-spaced cross-sections and the fact that there were only 11 cross-sections reach, or an average of one cross-section every 0.4 miles. The large magnitude of the discrepancy between the assumed depositional volume, the measured sediment yields, and the modeled percent deposition must be resolved before an action plan can be formulated to address this assumed amount of deposition. A much higher natural sediment load will directly affect the relative reductions that can be expected from additional regulations on the industrial timberlands and the extent to which the natural sediment yields can be stored or delivered through the existing channels. These discrepancies also undermine any engineering-based restoration plan, and there is a substantial history of failed channel restoration projects due to the highly dynamic nature and high natural sediment loads of California coastal rivers (Kondolf, 1998).

3.5. Achieving the Water Quality Standard for Unfiltered Domestic Water Supply

A key water quality concern and indicator in the Peer Review Draft and the TTR is the ability of the Elk River to meet the water quality criterion for turbidity for unfiltered drinking water. This criterion is <5 NTU with no more than two exceedences in twelve months or five exceedances in 120 months. This criterion is clearly unattainable, as Klein et al. (2012) showed that the value of 5 NTUs was exceeded more than 5% of the time in five pristine streams, and the number of hours with turbidity values greater than 25 NTU in these five streams ranged from 34 to 227 hours. A review of the continuous turbidity data from the Little South Fork of the Elk River from 2007-2014 indicates that 5 NTU is exceeded at least ten times per year, even in the very dry year of 2014.

The Draft amendments to the Basin Plan appear to recognize this limitation, as it specifies that the Elk River should meet this criterion between storms without providing a more specific numerical target. The expectation for between-storm turbidity values below 5 NTU was assessed by examining the continuous turbidity data from the Little South Fork for 2004-2014. The data for the first three years were excluded as these showed much greater fluctuations than any of the other years, and the poor quality of the early data was noted by Sullivan et al. (2012) and in my earlier comments to the Regional Water Quality Control Board (MacDonald, 2015a). Data for water year 2013 also were not available. For each of the remaining seven years the continuous turbidity measurements were plotted with a line at 5 NTU. The percent of time and the number of hours greater than 5 NTU were calculated for each year.

A visual review showed that each year had at least ten storm events that exceeded the water quality threshold of 5 NTU, and some years had substantially more than ten events. The average number of hours per year with turbidities greater than 5 NTU was 754 hours, with a range of 447 to 1101 hours. If one assumes an average of 10-15 storms that have peak turbidities greater than 5 NTU, the mean duration of those exceedances is 2-3 days. The mean percent of time greater than 5 NTUs was 13%. In 2011 turbidity values in excess of 5 NTUs occurred 22% of the time. Figure 23 presents the turbidity data from water year 2012, and the shape of the turbidigraph indicates the strong dependence of turbidities on storm precipitation and duration. This shows how compound storms can lead to longer periods of high turbidities, and how the ability to meet the proposed criterion will depend in part on how a storm is defined.

In conclusion, turbidity levels in tectonically active areas in the North Coast region will exceed the unregulated drinking water criterion of 5 NTU during most storm events, and this exceedance will typically continue for several days.

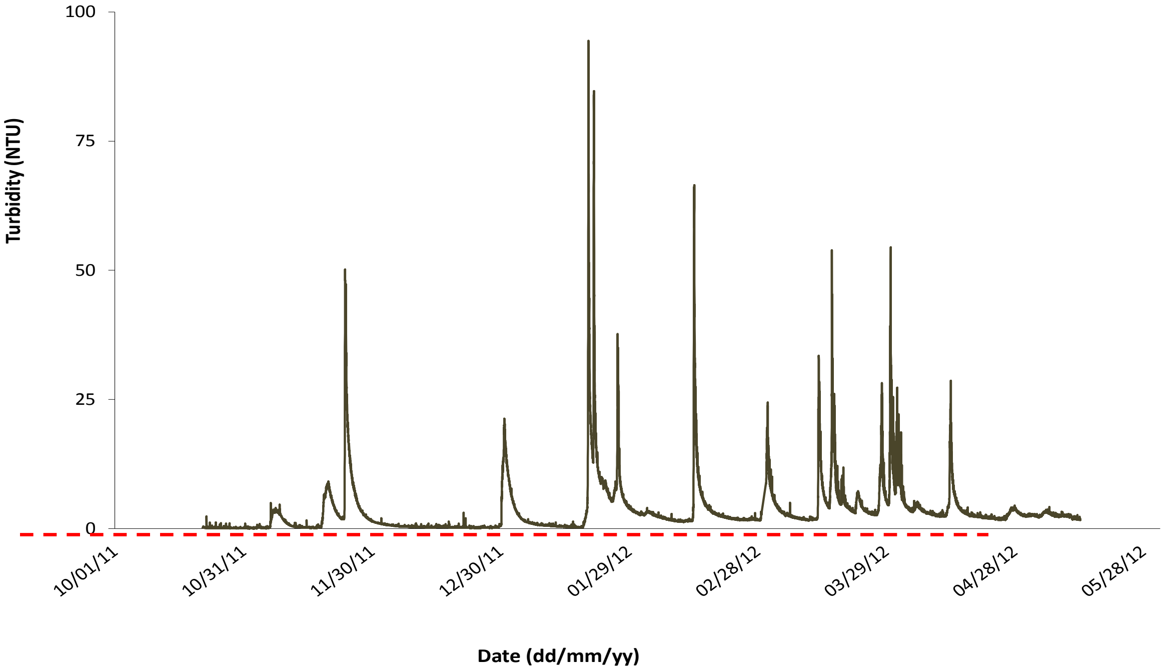


Figure 23. Turbidities in the undisturbed Little South Fork of the Elk River watershed for water year 2012. The dashed red line represents the unfiltered drinking water criterion of 5 NTU, and this was exceeded for 840 hours or 17% of the time.

3.6. Changes in Peak Flows

The TTR and Draft Action Plan set a hillslope water quality indicator and numeric target of less than a 10% increase in peak flows in 10 years related to timber harvest for Class II/III catchments. In the TTR this is justified on the basis of containing flood flows within the channel bankfull discharge, supporting the use of surface water for drinking and agricultural use, and supporting salmonids throughout their historical range (p. 28). With respect to the first issue, the modelled increases in peak flows are less than 10% at the subwatershed scale using the Caspar Creek peak flow model (Cafferata and Reid, 2013) (HRC, 2015).

The increase in peak flows at the scale of the affected reach will be substantially smaller because of the dilution effect from other subwatersheds, hydrodynamic dispersion, floodplain storage, transmission losses, and the peak flows from the different managed subwatersheds are highly unlikely to be synchronized (MacDonald and Coe, 2007; Grant et al., 2008). These principles mean that control of hydrologic changes at the site or small watershed scale will effectively preclude cumulative hydrologic effects at larger scales (MacDonald, 2000; Grant et al., 2008).

The lumped modeling for the North Fork and South Fork did not take hydrodynamic dispersion, floodplain storage, or transmission losses into consideration, but the predicted increase for the North Fork is declining from 10% to 7% due to regeneration (CRWQCB North Coast Region, Resolution No. R1-2006-0038). No peak flow related harvest limit was established for the South Fork watershed as nuisance flooding in this tributary was not as well documented and the Caspar Creek flow model indicated that timber management would increase peak flows by less than 5 percent (HRC, 2015, p. 27). The stage-discharge relationships for the HRC gaging stations on the mainstem, lower North Fork, and lower South Fork (509, 510, and 511) indicate that a 5% increase in peak flow would increase the stage by only 5-8 cm (2-3 inches).

The very large interrannual variability in the size of peak flows shown in Figure 11 means that any management-induced increases in peak flows will be trivial compared to the much larger interrannual variability in peak flow, and a reduction in the amount of downstream flooding cannot realistically be achieved by further restrictions on the rates of timber harvest. (If one really wants to reduce the amount of overbank flooding, this could be most effectively done by restoring the side and overflow channels in the lower portion and floodplains of the Elk River watershed. This downstream restoration also would be much more beneficial to salmonids in terms of providing off-channel rearing habitat, and reducing the tendency for aggradation.)

It should also be noted that the TTR also is concerned about the opposite problem, namely the "reduction in flow capacity of the channel, effectively reducing the achievable water velocities and the sediment transport capacity of Upper Elk River" (p. 64). It also notes the lack of flow velocities to scour out the channel and coarsen the bed material, but both of these would be improved by an increase in peak flows. On the other hand, bed scour would increase turbidities and sediment loads (Cafferata and Reid, 2013), so the TTR and the Water Board need to clarify to what extent and where an increase in peak flows would be beneficial as opposed to detrimental.

With respect to water quality, the data presented here indicate that turbidities commonly exceed 5 NTUs for at least ten storm hydrographs a year in the undisturbed Little South Fork. The modeled increase in peak flows can be put into the measured relationships between flow and turbidity, or between flow and suspended sediment concentrations and hence sediment yields. While this has not been done, the incremental effect of any increase in peak flows will be dwarfed by the interannual variability in peak flows and sediment yields described and quantified in these comments (see Figures 24a-c).

The effect of timber harvest on the larger peak flows that drive most of the sediment yields is still uncertain, as most paired watershed studies have shown that timber harvest does not cause a detectable increase in the size of the larger peak flows (NRC, 2008). A change in the size of peak flows for a series of paired watershed studies in western Oregon and Washington only found changes in the size of peak flows for recurrence intervals of 6 years or less, and that roads appeared to be a very significant contributor to the observed increases in the size of peak flows (Grant et al., 2008). In theory the larger peak flows could be increased if the rainfall interception rate is maintained for these more extreme storms (Reid and Lewis, 2009), but this has not been documented in the forest hydrology literature (Grant et al., 2008; NRC, 2008).

The applicability of the Caspar Creek model to Elk River is also not known given the differences in timber harvest practices, particularly the surface disturbance due to ground-based skidding. There also are differences in geology and other site factors (e.g., Dhakal and Sullivan, 2006), and again the Railroad Gulch study should help resolve some of these issues.

The TTR also does not explain how the proposed restriction on the increase in peak flows would help improve conditions for salmonids. In the lower order channels it is difficult to postulate a significant geomorphic effect of the predicted increase in peak flows. To quote from the abstract in Grant et al. (2008): “When present, peak flow effects on channel morphology should be confined to stream reaches where channel gradients are less than 0.02 and streambeds are composed or gravel and finer material.” It is only in the downstream areas where these channel conditions would be met, but in these downstream reaches the management-induced increases in peak flows will be very small as noted above. Hence it is very difficult to quantitatively link the predicted increases in peak flows in the headwater channels with stream channel conditions in the larger streams used by salmonids.

A final point is that more stringent limitations on the amount of timber harvest over a 10-year period in a given Class II or Class III drainage will force a greater dispersal of timber harvest activities. If there is a total amount of timber that needs to be harvested in order to maintain economic viability, then the dispersal of timber harvest will result in an overall net increase in the amount of ground-disturbing activities and traffic as more areas are entered per year. An economically viable timber industry is important for addressing legacy sites, maintaining and improving the existing road network, and for assisting with restoration. Hence there is a trade-off between allowing for a small increase in sediment from current operations in order to reduce the legacy sources versus stopping timber harvest and having no funds for maintaining and improving the current road system and management-related discharge sites.

3.7. Additional Evidence and Implications for Modeling and Restoration

My comments have shown or postulated: 1) much higher natural sediment loads than in either the Draft Peer Review or the TTR; 2) comparatively small amounts of sediment being generated by current management activities on the industrial timberlands; and 3) the lognormal distribution of sediment yields. Each of these three precepts have important implications for the Draft Action Plan, the likelihood of meeting water quality standards, and what remediation and restoration efforts are most likely to be successful. This section presents three additional analyses using data from HRC’s gaging network to help document these points.

First, an analysis of the sediment yield data from the mainstem station (509) shows that the largest peak flow from 2003-20014 was 5730 cfs in 2003, and this has an estimated recurrence interval of approximately 7 years (Section 2.3). The annual sediment yield for this year was 960 Mg km^{-2}, which is close to the value of around 1200 Mg km^{-2} yr^{-1} (3400 English tons mi^{-2} yr^{-1}) that I postulated as a long-term mean. The next largest peak flow in 2006 had only about a 3-4 year recurrence interval, and the associated annual sediment yield was substantially smaller at 530 Mg km^{-2}. Annual sediment yields in 2009 and 2014 were both exceptionally low. This distribution of sediment yield data appears to be almost exactly what one would expect from a lognormal distribution, and I believe that the mean value of about 300 Mg km^{-2} yr^{-1} measured at station 509 is low because of the lack of high flows, and that a longer record would yield a substantially higher average value.

The logic for this argument is that years with a larger peak flow (e.g., recurrence intervals of 15 or more years) would be expected to produce substantially more than the 960 Mg km^{-2} yr^{-1} that was measured in 2003 due to the nonlinear increase in sediment yields with increasing discharge. If we extrapolate from the relationship shown in Figure 24a below, a 25-year peak flow of 8780 cfs or just about 200 csm (Table 1) would generate an annual sediment yield of about 3000 Mg km^{-2} yr^{-1} (8500 tons mi^{-2} yr^{-1}). The estimated 100-year storm of 11,900 cfs (270 csm) is projected to generate an annual sediment yield of about 7000 Mg km^{-2} yr^{-1} (20,000 tons mi^{-2} yr^{-1}) . While I would not normally do such extrapolations because of the high uncertainty, I have done so here because of the unusually strong R^2 between the instantaneous annual peak flows and annual sediment yields, and the need to illustrate the potential magnitude of the sediment yields that can be expected from the Elk River watershed in more extreme storm events. Shane Beach of HRC said jokingly that if we had flows similar to what was observed on the Eel River in 1964 that we would fill up Humboldt Bay with sediment, and without doing the calculations it seems that there is some truth to this statement!

The second data set from Bridge Creek indicates the relatively low impact of current management on sediment yields. This is the only watershed in the HRC gaging network that has shown a clear decline in sediment yields over the period of record beginning in 2003. This decline has occurred even though 30% of the basin was harvested—primarily by cable-yarded clearcuts—from 2001-2011, and another 7% was harvested from 2013-2015. The basic story of this watershed is that there were large landslides in 1997-1998, and these caused the very high sediment yields in the first years of monitoring. The subsequent timber harvest activities have had no apparent effect on sediment yields given the large amount of natural recovery from the landslides in the late 1990s, and this is consistent with the estimated volumes of management-related sediment sources in Section 3 of my comments.

The third set of data comes from the sediment yields being measured at the gaging stations in the East and West Branches of Railroad Gulch. This monitoring is in preparation for the paired watershed experiment to evaluate the effectiveness of current best management practices in a highly erosive watershed. The gaging stations are now in their third year of monitoring, and in water year 2015 the measured sediment yields were 660 and 1070 Mg km^{-2} yr^{-1} (1900 and 3000 English tons mi^{-2} yr^{-1}), while in water year 2016 the sediment yields are expected to be higher if there is normal late winter and spring precipitation. The highly sensitive geology means this study will be a sensitive test of best management practices, and a critical contribution to the adaptive management approach advocated in the Peer Review Draft and the TTR.

It is of interest that the estimated natural and management sediment loading for Railroad Gulch in the TTR for 2004-2011 is 430 yd^3 mi^{-2} yr^{-1}. This converts to only 230 Mg km^{-2} yr^{-1} at a density of 1.4 tons/yd^3, or roughly one-quarter of the mean measured sediment yield for water year 2015, which had lower than average sediment yields at the mainstem HRC stations. While it is not yet possible to say how much of this sediment is due to legacy effects versus natural sediment sources, the magnitude of these measured sediment yields is entirely consistent with the expected mean annual sediment yield in Section 2.1. Taken together, these data indicate that any remediation or restoration project must recognize the potential for very high sediment yields from only moderately extreme events (e.g., peak flows with a 25- to 100-year recurrence interval).

4. SYNTHESIS AND IMPLICATIONS FOR RECOVERY

The data presented earlier clearly show that the natural sediment sources estimated in the TTR (140 $yd^3 mi^{-2} yr^{-1}$) are too low. For the short term this value is too low by at least a factor of two as indicated by the measured sediment yields, and in the long-term it is at least an order of magnitude too low given the uplift rate, beryllium-10 data, and measured sediment yields in other North Coast watersheds.

The TTR and the analysis in Section 3 both show that the estimated sediment from management-related sources in the industrial timberlands have greatly declined from their peak in 1988-1997. The values for 2004-2011 in the TTR indicate a nearly 70% reduction in management-related sources, while my updated analysis in Section 3 suggests a decline of approximately 80% since 1998-97.

If the management-related sediment sources are the primary cause of the observed impairment in the affected reach as indicated in the Peer Review Draft and the TTR, I would expect to see an improving trend in the measured turbidities and sediment yields, and also in the habitat characteristics from HRC's Aquatic Trend Monitoring data. The discharge, turbidity, and suspended sediment data are of very good quality, but an initial analysis shows relatively little evidence of improving trends in terms of the duration of high turbidity values or suspended sediment concentrations. Jack Lewis also has found little evidence of an improvement in terms of suspended sediment concentrations or loads from the Salmon Forever gaging stations in the Elk River watershed (Lewis, presentation to the MSG).

Section 3.1.2 noted the very strong relationship between the annual maximum peak flows and the annual suspended sediment yields for each of the downstream HRC stations (R^2=0.78-0.86). If sediment inputs were declining substantially, one would expect the more recent years to plot below the overall regression line. Figures 24a-c do not show a clear recovery over the period of record (water years 2003-2015), although there may be a weak signal of recovery in the North Fork (Figure 23c). The ATM data presented in the Peer Review Draft and my subsequent review of those data for HRC provide a few tantalizing hints that the bed material in some locations is coarsening or that pool depths may be increasing, but there is not a consistent or strong trend as might be expected given the relatively dramatic decrease in sediment sources from the industrial timberlands over the last twenty years.

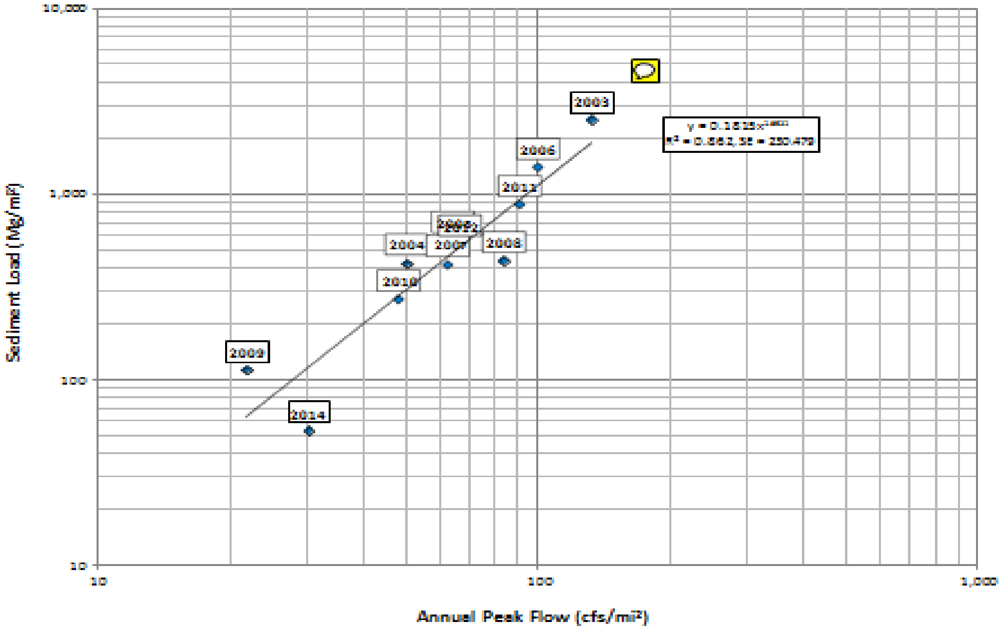


Figure 24a. Plot of annual sediment yields versus the corresponding instantaneous annual maximum peak flows for HRC station 509 on the mainstem of the Elk River. Note the very high R^2 value of 0.86.

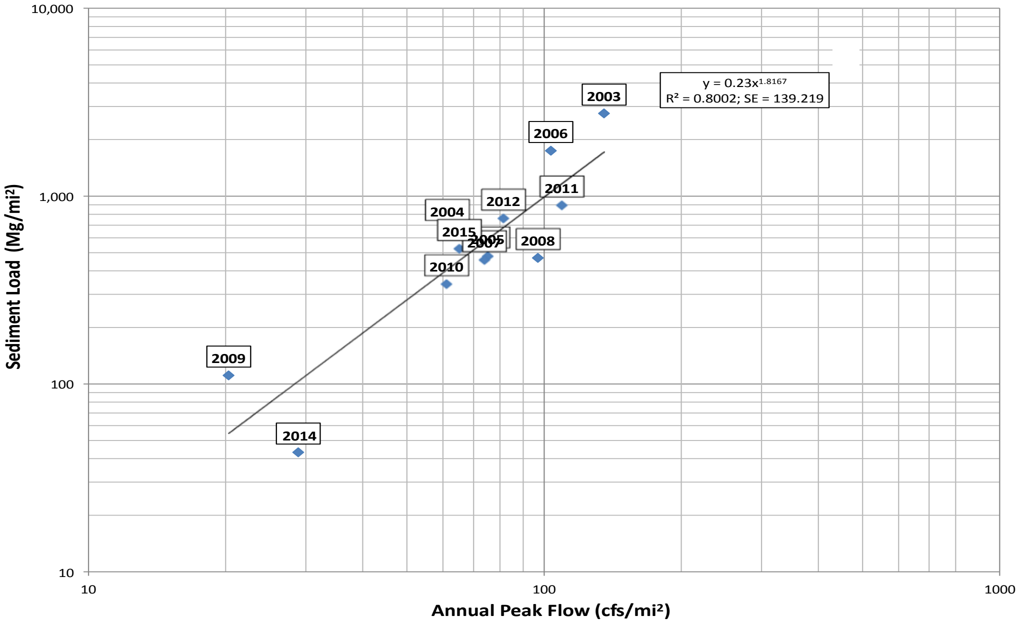


Figure 24b. Plot of annual sediment yields versus the corresponding instantaneous annual maximum peak flows for HRC station 510 on the lower mainstem of the South Fork of the Elk River. Note the high R^2 value of 0.80.

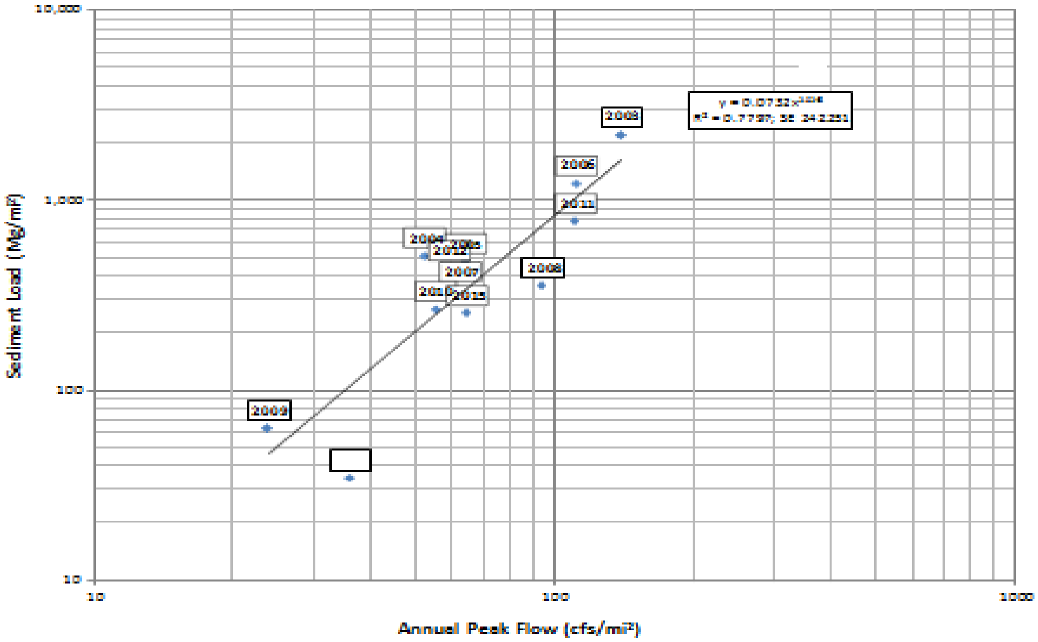


Figure 24c. Plot of annual sediment yields versus the corresponding instantaneous annual maximum peak flows for HRC station 511 on the lower mainstem of the North Fork of the Elk River. The unlabeled box is 2014, and there is a tendency for the more recent years to fall below the regression line. Note the high R^2 value of 0.78.

This apparent lack of recovery for the three downstream gaging stations is somewhat surprising and can be attributed to one or more of the following four hypotheses:

1) There is so much sediment stored from past management activities that it will take many years to flush this out; this hypothesis appears to be favored in the TTR and the Draft Action Plan as a two-phase TMDL is proposed and recovery is expected over the next 10-15 years;
2) The HRC gaging stations and ATM data have not been able to consistently show any recovery because the data are too confounded by the interannual variations in precipitation and runoff, plus the data are too inaccurate and/or noisy;
3) Natural sediment yields are very high and the geologic setting means that the lower portion of the Elk River watershed is inherently aggradational; hence one cannot expect a sharp change in either water quality or stream channel conditions; or
4) The downstream floodplain has been so severely altered by human activities that downstream aggradation and nuisance flooding are inevitable.

It is possible that the lack of recovery is due to some combination of these four hypotheses. Hypotheses 3 and 4 can be easily combined, while hypotheses 1 and 3 represent almost opposite and competing explanations for the lack of recovery.

Hypothesis 2 can be partly denied given that Jack Lewis' analysis indicates some recovery in Freshwater Creek for a similar time period and roughly similar management history (Lewis, 2013[?]). As noted above, the gaging station data are generally of excellent quality, and some of the uncertainty in the estimates of sediment loads can be quantified from the variability in the stage-discharge and turbidity-suspended sediment relationships. Evaluating the accuracy of the pumped water samples and hence the true suspended sediment concentrations is much more difficult (e.g., Edwards and Glysson, 1988). Statistical techniques can help eliminate the weather-induced variations in turbidities, sediment concentrations, and sediment yields, but any assessment of trends in annual sediment yields is limited by the relatively short length of record compared to the longer-term trends sediment sources. Trends in the ATM data are more difficult to establish because the data have much more unexplained variation, and monitoring stream channel conditions is very difficult given the high temporal and spatial variability and the different responses in different stream types (MacDonald and Montgomery, 2002; Roper et al., 2010). Nevertheless, it is my best professional judgment that a decline of 75-80% in management-related sediment yields as indicated by the sediment source analysis should be detectable IF anthropogenic sediment is the primary cause of water quality impairment as indicated in the TTR and the Peer Review Draft (NCRWQCB, 2013).

The choice among the remaining hypotheses (1, 3, and 4) is critical because these have very different implications for how much improvement can be expected, and what changes in management are most likely to lead to the desired future condition. The uplift, beryllium-10 data, and measured sediment yields from other North Coast watersheds all strongly support hypothesis #3 (see Section 2). Similarly, the longitudinal profiles, presence of the floodplain, and high rate of subsidence support the concept that the affected reach and the lowest reach are both inherently aggradational.

A key issue that could help us distinguish between hypothesis 1 and hypothesis 3 is the amount of stored sediment, but unfortunately there is very little quantitative data on this in the Upper Watershed. The TTR notes the lack of cross-section change at the USGS gaging station from 1958-1967, but only quantifies the amount of sediment stored in the affected reach since 1988. As shown in Section 3.4, the calculated volume of 640,000 yd^3 deposited since 1988 is clearly excessive when compared to the sediment source analysis and the measured sediment yields. The TerEx analysis was a first attempt to estimate sediment storage in a much larger proportion of the watershed, and the results do not show massive deposition (Figure 3). The rapid uplift, and the general principle that denudation rates equal uplift rates, both suggest an overall dynamic equilibrium between uplift and denudation for the Upper Elk River Watershed.

From a scientific perspective, I am forced to choose the combination of hypotheses 3 and 4 as the most plausible explanation for the current water quality impairment in the Elk River watershed, and the lack of recovery despite the large, 20-year decline in management-related sediment sources. If the TTR favors hypothesis 1 and this is to be used as the basis for the Action Plan and the sediment TMDL for the Elk River watershed, scientific evidence must be presented to support hypothesis 1 and refute hypothesis 3. Such evidence is not presented in the TTR or the other documents relating to the sediment TMDL.

Similarly, hypothesis 4 is very consistent with hypothesis 3, but is generally inconsistent with hypothesis 1. When I started reviewing the TTR report I expected to focus on the Upper Watershed, but the geologic context, geomorphic processes, and scientific data all led me to formulate and ultimately accept hypotheses 3 and 4. The selection of hypotheses 3 and 4 as the primary cause of water quality impairment has direct and important implications for the proposed Action Plan and TMDL as discussed below.

The TTR proposes a two-phase TMDL, and sets the loading (assimilative) capacity at zero (p. 74). On page 75 the TTR states "In sum, Phase I of the TMDL is proposed to include a current sediment loading capacity of zero to prevent and minimize sediment delivery to the impacted reach." The Draft Action Plan identifies three main components for the implementation program associated with phase 1 of the TMDL, and these are: 1) regulatory programs to reduce sediment loads on lands in the Upper Elk River Watershed; 2) a feasibility assessment of sediment remediation and channel restoration activities; and 3) watershed stewardship, which would include both health and safety as well as remediation and restoration activities (p. 7).

With respect to the first component, which is to reduce sediment loads on lands in the Upper Elk Watershed, the Draft Action Plan identifies 12 hillslope and water quality indicators. Most of these already are being met on the industrial timberlands, but it is not clear how the remaining indicators would either significantly reduce sediment delivery (e.g., 150 foot characteristics of riparian zones on Class III watercourses), or if they are all physically feasible (e.g., 100% of roads to be hydrologically disconnected). At a minimum, the TTR and Draft Action Plan should provide a science-based justification for estimating the magnitude of the additional sediment reductions that could be expected from the indicators that are not yet being met, and compare the expected reductions to an updated estimate of natural sediment sources.

There also is no indication as to how the NCRWQCB will estimate and attempt to reduce sediment inputs from the residential and agricultural lands in the Upper Watershed that are not yet included in the sediment source analysis, or the additional area draining into the affected reach that also has not been included in the sediment source analysis (see Section 3.3). Including these land uses and areas is a necessary step for a fair estimate of loading and a fair allocation of effort to reduce sediment loadings. Each of these steps also is essential to quantitatively put the expected reductions in sediment loading from the industrial timberlands into context, and to improve cold water fisheries.

In Phase II "the sediment loading capacity of the impacted reach could be recalculated and allocations redistributed" (TTR, p. 75). On page 75 the TTR states "The goal of proposed remediation **and channel restoration** [emphasis added] is to restore a dynamic equilibrium in which WQS are attained in the Upper Elk River watershed. This is expected to expand the sediment loading capacity and restore hydrologic function, bringing into balance the sediment output from the impacted reach with the sediment input…". Section 2.1 already noted that it is not realistic to expect sediment outputs to equal sediment inputs, so the goal of balancing sediment inputs and outputs is not attainable given the basic principles of river-floodplain interactions.

It is not explicitly stated but the "sediment remediation" presumably refers to inchannel or floodplain projects rather than reducing sediment inputs (item #1 above). It is striking that two of the three components of the Action Plan are directed at channel remediation and restoration activities, and that channel restoration is explicitly identified in the TTR as an important accomplishment towards completing phase 1 of the TMDL (Section 8.2). The Action Plan assumes on page 6 that "Normal sediment and water transport occur with 1.5 to 2-year flood events are contained within the bankfull stream channel." This goal also is fundamentally flawed because: 1) overbank flooding in many streams occurs every 1.5-2 years, and wouldn't this cause nuisance flooding and floodplain deposition? and 2) the Elk River is implicitly characterized as a single-thread river, when the geomorphic evidence and the restoration alternatives recognize that overflow channels were probably important for transporting water and sediment from the lower magnitude peak flows (e.g., 1.5-2 year events).

I find it somewhat inconsistent that channel remediation and restoration are two of the three main components in the Draft Action Plan, indicating their importance for achieving water quality standards. The list of potential recovery actions includes new channel construction, levee construction or modification, creation of inset floodplains, high flow channels, and placement of instream large wood debris. This list implies that the existing floodplain and channel of the Elk River have been heavily modified, yet the anthropogenic changes to the mainstem channels and floodplain (other than aggradation) are never identified as a potential contributing cause to the nuisance flooding and floodplain sedimentation. This discrepancy should be addressed when characterizing the relative causes of the observed water quality impairment.

In summary, the geologic and geomorphic context indicate that the Elk River would regularly overflow its banks to build the present floodplain. The high natural sediment yields from the Upper Watershed, when combined with the relatively rapid subsidence in the lower watershed and the low valley gradient, would have resulted in a consistent pattern of aggradation prior to any European settlement. The Elk River floodplain would have had a complex network of overflow channels and wetlands rather than a single main channel, and these overflow channels were needed to help convey the peak flows and high sediment yields to the mouth of the watershed. Further efforts to minimize the anthropogenic sediment inputs from timberlands is important, but the residents and NCRWQCB cannot expect that further reductions in the amount of sediment generated from the industrial timberlands will solve the water quality problems that caused the Elk River to be listed as impaired for sediment. It also is not clear to what extent channel remediation and restoration activities can reduce, much less eliminate, the existing impairment given the high natural sediment yields, low stream gradients, and inevitable occurrence of Oh My God events of varying magnitude. One can dream of a stable channel in dynamic equilibrium where sediment inputs equal sediment outputs with no overbank flooding and low turbidities, but I do not believe that this is a realistic vision for the Elk River.

5. ACKNOWLEDGMENTS

A large number of people have generously contributed to my understanding of both the science and the human concerns related to the Elk River Watershed, and I am extremely grateful to them. While I cannot list them all, I want to particularly thank staff of HRC, especially Mike Miles, Shane Beach and Nick Harrision; staff of Green Diamond Resource Company, particularly Matt House, David Lamphear, and Jason Woodward; staff of the various agencies, including the California Geological Survey, North Coast Regional Water Quality Control Board, Cal-Fire, and USDA Forest Service Redwood Sciences Lab; my academic colleagues, including Drs. Dave Montgomery, Patrick Belmont, Ellen Wohl, Lee Benda, and Ken Ferrier; and numerous other dedicated individuals too numerous to name. Needless to say, I take sole responsibility for the views expressed here.

6. REFERENCES

Andrews, E.D., and R.C. Antweiler, 2012. Sediment fluxes from California coastal rivers: the influence of climate, geology, and topography. *Journal of Geology* 120(4): 349-366.

Balco, G., N. Finnegan, A. Gendaxzek, J.O.H. Stone, and N. Thompson, 2013. Erosional response to northward-propagating crustal thickening in the coastal ranges of the U.S. Pacific Northwest. *American Journal of Science* 313: 790-806.

Bedrossian, T., and K. Custis, 2002. Review of July 2002 EPA analysis of impacts of timberland management on water quality. Memorandum submitted to Ross Johnson from the California Geological Survey, 27 November 2002, 23 pp.

Bedrossian, T., and K. Custis, 2003. Importance of deep-seated landslides in determining background rates of sedimentation for Total Maximum Daily Loads on California's North Coast. Conference abstract, Association of Environmental and Engineering Geologists.

Beechie, T.J., M. Liermann, M.M. Pollock, S. Baker, and J. Davies, 2006. Channel pattern and floodplain dyanamics in forested mountain river systems. *Geomorphology* 78: 124-141.

Benda, L., 2000. Review of: Analysis of erosion and sedimentation and its effects on flooding in Fresahwater Creek: Freshwater Creek between Graham Gulch and Little Freshwater Creek (6/26/00). 6 pp.

Bierman, P.R., and D.R. Montgomery, 2014. Key concepts in geomorphology. W.H. Freeman and Co., New York, NY. 494 pp.

Buffleben, M.S., 2009. Assessment of soil creep sediment generation for total maximum daily load development in a northern coastal California watershed. Ph.D. dissertation, University of California at Los Angeles, Los Angeles, CA. 143 pp.

Cafferata, P., and L. Reid, 2013. Applications of long-term watershed research to forest management in California: 50 years of learning from the Caspar Creek Experimental Watersheds. California Forestry Report No. 5, The Natural Resources Agency, Sacramento, CA. 110 pp.

Cascadia Geosciences, 2013. Tectonic land level changes and their contribution to sea level rise, Humboldt Bay region, California: 2013 status update. Report to the U.S. Fish and Wildlife Service Coastal Program, 9 pp.

Dhakal, A.S., and K. Sullivan, 2006. Application of Caspar Creek model to predict increase in peak flow following harvesting in large watersheds: selection of parameters, probabilistic approach, and limitations of the model. Palco, Scotia, CA. 56 pp.

Dietrich, W.E., T. Dunne, N.F. Humphrey, and L.M. Reid, 1982. Construction of sediment budgets for drainage basins. In *Sediment budgets and routing in forested drainage basins*, USDA General Technical Report PNW-141, pp. 5-23.

Edwards, T.K., and G.D. Glysson, 1999. Field methods for measurement of fluvial sediment. U.S> Geological Survey Techniques of Water Resources Investigations, book 3, chapter C2.

Ferrier, K.L., J.W. Kirchner, and R.C. Finkel, 2005. Erosion rates over millennial and decadal timescales at Caspar Creek and Redwood Creek, Northern California Coast Ranges. *Earth Surface Processes and Landforms* 30: 1025-1038.

Grant, G.E., S.L. Lewis, F.J Swanson, J.H. Cissel, and J.J. McDonnell, 2008. Effects of forest practices on peak flows and consequent channel response: a state-of-science report for western Oregon and Washington. USDA Forest Service Gen. Tech. Report PNW-GTR-760, Portland, OR. 76 pp.

HRC, 2015. Report of waste discharge. Humboldt Redwood Company, LLC, Scotia, CA. 66pp.

Huang, H.Q., and G.C. Nanson, 2007. Why do some alluvial rivers develop an anabranching pattern. *Water Resources Research* 43, doi:10.1029/2006WR005223, 12 pp.

Kirchner, J.W., R.C. Finkel, C.S. Riebe, D.E. Granger, J.L. Clayton, J.G. King, and W.F. Megahan, 2001. Mountain erosion over 10 y., 10 k.y., and 10 m.y. time scales. *Geology* 29(7): 591-594.

Klein, R.D., J. Lewis, and M. Buffleben, 2011. Logging and turbidity in the coastal watersheds of Northern California. *Geomorphology* 139: 136-144.

Knighton, D., 1998. Fluvial forms and processes. John Wiley and Sons, N.Y., 383 pp.

Kondolf, G.M., 1998. Lessons learned from river restoration projects in California. *Aquatic Conserv: Mar. Freshw. Ecosyst.* 8:39-52. doi: 10.1002/(SICI)1099-0755(199801/02)8:1<39::AID-AQC250>3.0.CO;2-9

Larsen, I.J., L.H. MacDonald, E. Brown, D. Rough, M.J. Welsh, J.H. Pietraszek, Z. Libohova, J. de Dios Benavides-Solorio, and K. Schaffrath, 2009. Causes of post-fire runoff and erosion: water repellency, surface cover, or soil sealing. *Soil Science Society of America Journal* 73(4): 1393-1407.

Lehre, A.K., 1982. Sediment budget of a small Coast Range drainage basin in north-central California. In *Sediment budgets and routing in forested drainage basins*, USDA General Technical Report PNW-141, pp. 67-77.

MacDonald, L.H., 2000. Evaluating and managing cumulative effects: process and constraints. *Environmental Management* 26(3): 299-315.

MacDonald, L.H. (with A. Smart and R.C. Wissmar), 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA/910/9-91-001, U.S. Environmental Protection Agency Region 10, Seattle, WA. 166 pp.

MacDonald, L., 2014a. Initial comments on the Peer Review Draft. Document dated 17 January and submitted to the North Coast Regional Water Quality Control Board. 29 pp.

MacDonald, L., 2014b. Additional comments on the Peer Review Draft. Document dated 2 February and submitted to the North Coast Regional Water Quality Control Board. 10 pp.

Mackey, B.H., and J.J. Roering, 2011. Sediment yield, spatial characteristics, and the long-term evolution of active earthflows determined from airborne LiDAR and historical aerial photographs, Eel River, California. *Geological Society of America Bulletin* 123: 156—1576.

MacDonald, L.H., and D. Coe, 2007. Influence of headwater streams on downstream reaches in forested areas. *Forest Science* 53(2): 148-168.

Miller, M.E., L.H. MacDonald, P.R. Robichaud, and W.E. Elliot, 2011. Predicting post-fire erosion in the western U.S. *International Journal of Wildland Fire* 20: 982-999.

Montgomery, D.R., and W.E. Dietrich, 1988. Where do channels begin? *Nature* 336: 232-234.

Montgomery, D.R and L.H. MacDonald, 2002. Diagnostic approach to stream channel assessment and monitoring. *J. of the American Water Resources Association* 38(1):1-16.

NRC, 2008. *Hydrologic effects of a changing forest landscape*. National Research Council, National Academies Press, Washington, D.C. 142 pp.

NCRWQCB, 2013. Peer review draft: staff report to support the technical sediment total maximum daily load for the Upper Elk River. North Coast Regional Water Quality Control Board, Santa Rosa, CA.

NRWQB, 2015. Draft action plan for the Upper Elk River Sediment TMDL. 10 pp.

Pryor, B., 2015. A restoration strategy for the Elk River. Presentation at the Elk River Technical Advisory Committee.

Pryor, B., J. Stallman, D. Mireau, and A. White, 2015. A multi-faceted approach to restoring the sediment impaired Elk River. Presentation to the Salmon Restoration Foundation.

Renwick, W.H., 1992. Equilibrium, disequilibrium, and nonequilibrium landforms in the landscape. *Geomorphology* 5:265-276.

Roper, B.B., J.M. Buffington, S. Bennett, S.H. Lanigan, E. Archer,S.T. Downie, J. Faustini, T.W. Hillman, S. Hubler, K. Jones, C. Jordan, P.R. Kaufmann, G. Merritt, C. Moyer, and A. Pleus, 2010. A comparison of the performance and compatibility of protocols used by seven monitoring groups to measure stream habitat in the Pacific Northwest. *North American Journal of Fisheries Management* 30:565-587, doi: 10.1577/M09-061.1.

Rosgen, D., 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Schumm, S.A., 1991. To interpret the earth: ten ways to be wrong. Cambridge University Press, Cambridge, MA. 133 pp.

Stallman, J.D., and H. Kelsey, 2006. Transient geomorphic response to late Pleistocene baselevel change and climate forcing in the southern Cascadia thrust-and-fold belt, north coastal California. Friends of the Pleistocene Field Guide, 17 pp.

Stout, J.C., and P. Belmont, 2014. TerEx toolbox for semi-automated selection of fluvial terrace and floodplain features from lidar. *Earth Surface Processes and Landforms* 39: 569-580.

Sullivan, K., D. Manthorne, R. Rossen, and A. Griffith, 2012. Trend in sediment-related water quality after a decade of forest management implementing an Aquatic Habitat Conservation Plan. Humboldt Redwoods Company, Scotia, CA. 187 pp.

Swanston, D.N., R. R. Ziemer, and R.J. Janda, 1995. Rate and mechanics of progressive hillslope failure in the Redwood Creek basin, northwestern California. U.S. Geological Survey Professional Paper 1454-E, Washington D.C.

Trimble, S.W., 1999. Decreased rates of alluvial sediment storage in the Coon Creek Basin, Wisconsin, 1975-93. Science 285: 1244-1246.

Walling, D.E., 1983. The sediment delivery problem. *Journal of Hydrology* 65: 209-237.

Wohl, E., B.R. Bledsoe, R.B. Jacobson, N.L. Poff, S.L. Rathburn, D.M. Walters, and A.C. Wilcox, 2015. The natural sediment regime in rivers: broadening the foundation for ecosystem management. *BioScience* 65(4): 358-371.