Aquatic Habitat Conditions in Battle Creek and Their Relationship to Upland Management

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Executive Summary

Kier Associates provided geographic data (GIS) and technical assistance to Terraqua (2004) in assessing upland conditions and potential sediment sources in the Battle Creek watershed. The information below is not part of the *Battle Creek Watershed Assessment*, but was produced independently as was the upland characterization (Kier Associates 2003). Both were provided to Terraqua (2004) and information in this report was also circulated to the Battle Creek Watershed Conservancy (BCWC) and the Battle Creek Working Group (BCWG) for consideration in web page format as part of the KRIS Battle Creek V 2.0. A major private timberland owner with a seat on the BCWC requested that discussion of upland conditions and linkage to aquatic habitat be omitted from the final version and there was no request for retention by the BCWG. Below each type of aquatic habitat data collected by Terraqua (2004) is analyzed and relationships with upland conditions (i.e. steepness, unstable soil types) and land management (logging, road building) explored.

Terraqua (2004) collected aquatic habitat data following U.S. Forest Service (USFS) Aquatic and Riparian Ecosystem Monitoring Protocols (AREMP)(Gallo et al. 2003) that were in turn interpreted through use of the Ecosystem Management Decision Support (EMDS) model (Reynolds 2001). The rating curves that score various types of habitat data are based on thousands of stream samples throughout the Pacific Northwest, including reference or control streams with light damage. The EMDS results suggest that Battle Creek aquatic habitat is in poor to very poor ecological condition with regard to its ability to support salmonid species. Aquatic conditions are consistent with the high rate of watershed disturbance and expected channel response due to cumulative watershed effects (Montgomery and Buffington 1993, Ligon et al. 1999, Dunne et al. 2001, Collison et al. 2003). Fore example, Terraqua (2004) reported maximum pool depths of six feet in the lowest reach of Battle Creek, which was a major reduction from depths prior to the January 1997 storm (Thomas Payne Associates 1988). The cumulative effects from timber harvest have, therefore, caused substantial diminishment of holding capacity for winter run Chinook salmon that are the target of restoration efforts in the watershed (Ward and Kier 1999).

The California Department of Forestry has allowed almost complete removal of old trees on private industrial timberlands in the Battle Creek watershed and construction of extensive road networks with high numbers of road-stream crossings (Kier Associates 2003). Data related to these timber sales is not available from CDF in electronic form, which makes cumulative effects analysis very challenging. While the Lassen National Forest (LNF) in the headwaters of Battle Creek has recognized problems related to cumulative effects (Napper 2001) and is managing its lands accordingly, there is currently no similar admission by private industrial timberland owners. Private timberland ownership is concentrated between 3500 and 6000 feet, which is in the rain-on-snow zone; consequently risk of damaging increased peak flow and excess sediment yield is high and will likely remain so (Harr et al. 1988, Heeswijk et al. (1995).

Aquatic Habitat Conditions

Aquatic Macroinvertebrate Data

The Battle Creek Watershed Assessment (WA) (Terraqua, 2004) collected baseline data on aquatic insects to understand stream health and Ward and Kvam (2003) created rating curves for use in the Ecosystem Decision Support Model (EMDS) (Reynolds, 2001). Data were collected at 44 of 50 Battle Creek Watershed Assessment sites in Fall 2001, Spring 2002 and Fall 2002 using River Invertebrate Prediction And Classification System (RIVPACS) protocol (Hawkins et al. 2001). Metrics used for interpretation included standard ones, such as the Richness, EPT Richness and Percent Dominant taxa (Ward and Kvam, 2003), but also more complex biotic integrity indices that combine several scores (Karr, 1991; Hafele and Mulvey 1998).

Figure 1 shows a map of the Benthic Index of Biotic Integrity (B-IBI) as EMDS scores for various sites in the Battle Creek watershed and was taken from the Battle Creek WA. The best scores are on upper tributaries of the South Fork, Rock Creek and the middle North Fork. "Benthic Index of Biotic Integrity (B-IBI) scores averaged 38 and ranged from 24 to 48. EMDS analysis indicates, with reasonable or high certainty, that B-IBI scores were favorable for salmonid production at 20 sites and were unfavorable at 6 sites. Sites with favorable B-IBI scores were notably absent from most of South Fork Battle Creek. Three sites with unfavorable B-IBI scores were located in South Fork Battle Creek while the other three were scattered in North Fork Battle Creek including one high elevation site in the wilderness of Lassen Volcanic National Park" Terraqua (2004).

Figure 2 shows the B-IBI in chart form for all Battle Creek Watershed Assessment sites measured in Fall 2001, Spring 2002 and Fall 2002. The B-IBI has a maximum score of 50 and streams in good health have scores of 44 or higher and those with scores lower than 27 are most impaired (1991). The highest scores (best health) are in lower Digger Creek (#007), Summit Creek (#001) and South Fork Digger Creek on USFS lands (#026) and on private lands just downstream (#063). The lowest scores (poorer health) were at sites #016 (Bailey Creek) and #019 (SF Battle). Data from Ward and Kvam (2003) but chart from KRIS Battle Creek V 2.0.

<u>Regional Literature on Use of Macroinvertebrates and Understanding Stream Health</u>: Erman (1996) noted damage to aquatic macroinvertebrate communities of the Sierra Nevada Ecosystem associated with land use: "Discrete, local disturbance from failed road crossings associated with logging caused a decline in the number of taxa downstream. Where wide buffer areas (strips) were left unlogged along the streams, invertebrate communities showed little difference from those of unlogged streams. However, narrow buffers incompletely protected streams, and the narrower the buffer, the greater the impact of logging on stream invertebrate communities. High levels of stored sediment remained in the set of streams logged without buffers when the streams were re-sampled five to six years later and compared to control streams. Full recovery of invertebrate communities required nearly twenty years after the initial disturbance from logging." Additional literature review of current use of macroinvertebrates for understanding stream health can be found in Ward and Kvam (2003).

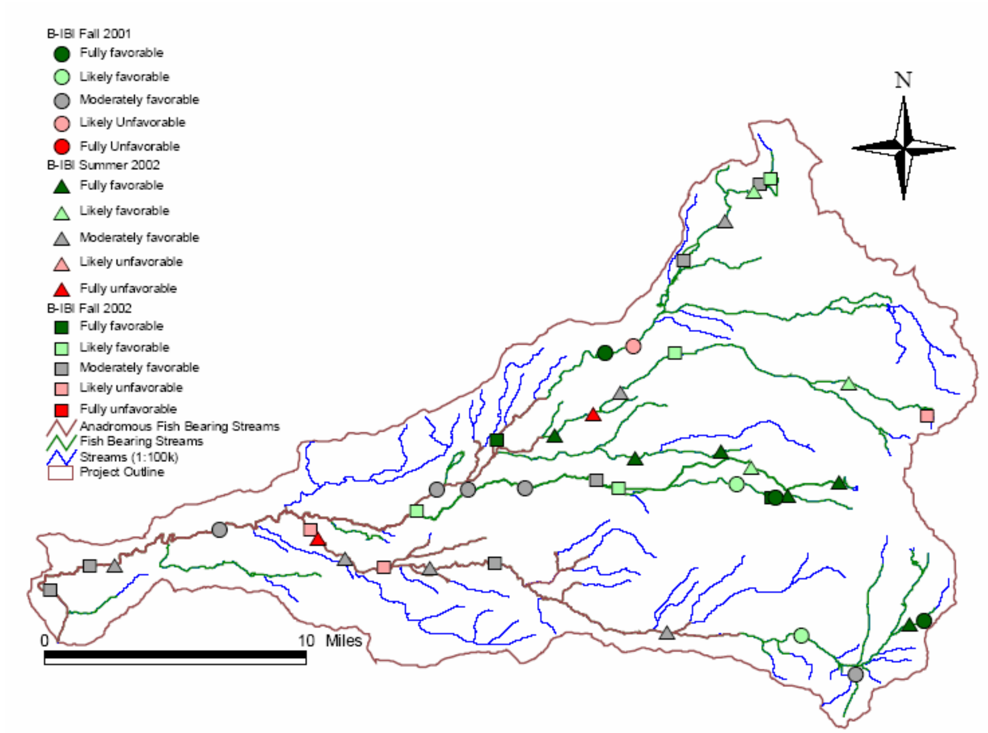

Figure 1. The B-IBI scores for 50 locations in the Battle Creek watershed show major ecological problems in the South Fork and lower reaches of Bailey Creek and the lower mainstem Battle Creek. From Terraqua (2004) and KRIS Battle Creek V 2.0.

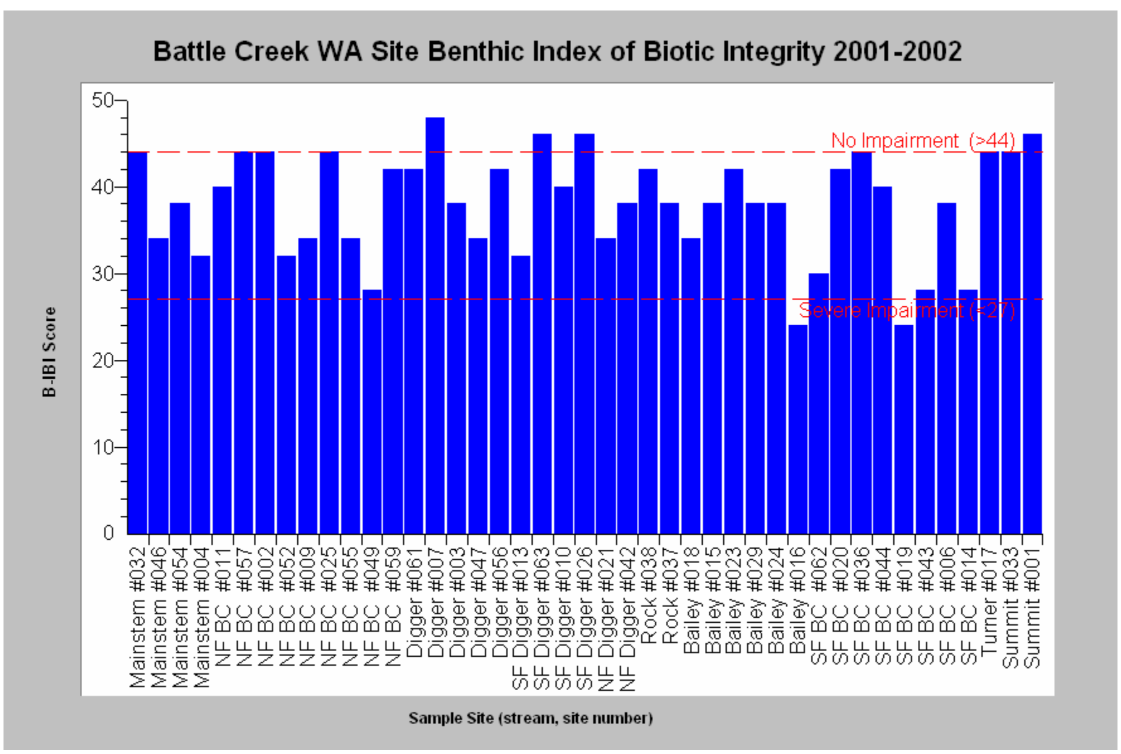

Figure 1. The B-IBI scores for 50 locations in the Battle Creek watershed in chart form indicate severe impairment on the NF Battle, Bailey, and at several South Fork sites. From Terraqua (2004).

Other Aquatic Habitat Indicators Consistent with B-IBI Scores: Sediment deposition or bedload movement can disrupt aquatic habitats used by macroinvertebrates and cause declines in species diversity (Erman, 1996). Several of the aquatic insect metrics collected for the Battle Creek WA showed "fully functional" conditions on sites in streams draining lightly managed U.S. Forest Service lands. Conversely, "fully nonfunctional" sites often occur in stream reaches in the most intensively managed landscapes. Negative scores are not expected at all otherwise impaired sites because aquatic macroinvertebrates are constantly redistributed by stream currents, and animals from small healthy tributaries may drift downstream and partially mask ecological problems at sites on larger stream reaches. In addition, the lack of positive scores in the lower mainstem and South Fork Battle Creek for almost any aquatic macroinvertebrate index is consistent with the pattern of upland disturbance and cumulative watershed effects. Macroinvertebrates are excellent indicators of aquatic health and continued monitoring should reflect improvement in conditions, if restoration activities abate sediment problems. Future samples, however, should probably be more strategically located above and below the mouths of major tributaries so that trend monitoring focuses sub-basin contributions to cumulative effects can be discerned.

Battle Creek Channel Morphology and Suitability for Salmonids

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Terraqua (2004) assessed channel width-to-depth ratios, channel types, large wood availability, pool frequency and pool depth as part of the Battle Creek Watershed Assessment (WA). Results for channel profiles are shown below, along with other information useful for analysis. Potential linkage between upland disturbance (Kier Associates, 2003) and aquatic impairment are offered where logical linkages are apparent.

Terraqua (2004) measured channel profiles in accordance with Rosgen (1996) as one indicator of aquatic health. Channels may adjust to changes in sediment or flow. Sediment build up, or aggradation, often results in widening of stream channels and may cause multiple channels to form. The Battle WA findings for channel profiles were as follows:

> "Significant stream avulsions and/or overflow channels were noted during field surveys at 12 of 49 sites. At these sites, multiple bankfull channels were separated by land higher than the bankfull elevation in at least one or more survey transects. Most of the disturbance at these sites appeared to be the result of recent flooding, probably the result of a large flood in January 1997. The two lowermost sites (sites #032 and #046) and a mid-elevation site located in a meadow (site #029), had multiple channels typical of low-gradient Rosgen D-type reaches and showed no apparent flood effects. Most sites with multiple channels were located at elevations above the dominant rain-on-snow zone (Figure 14) and also showed signs of significant bank erosion. Three mid-elevation sites with multiple channels, particularly site #057 on North Fork Battle Creek, did not show significant erosive effects of flooding (e.g., no significant bank erosion) but did show signs of bedload aggradation that forced the stream to carve multiple channels at higher flow."

Figure 3 shows a map of stream reaches with multiple channels indicating cumulative effects shown in red, and those Battle Creek channels with single channels and no aggradation shown are in green. The back drop shows the rain-on-snow region of Battle Creek (3500'-5000'), which is relevant because peak flows can contribute to channel disruptions (Montgomery and Buffington 1993).

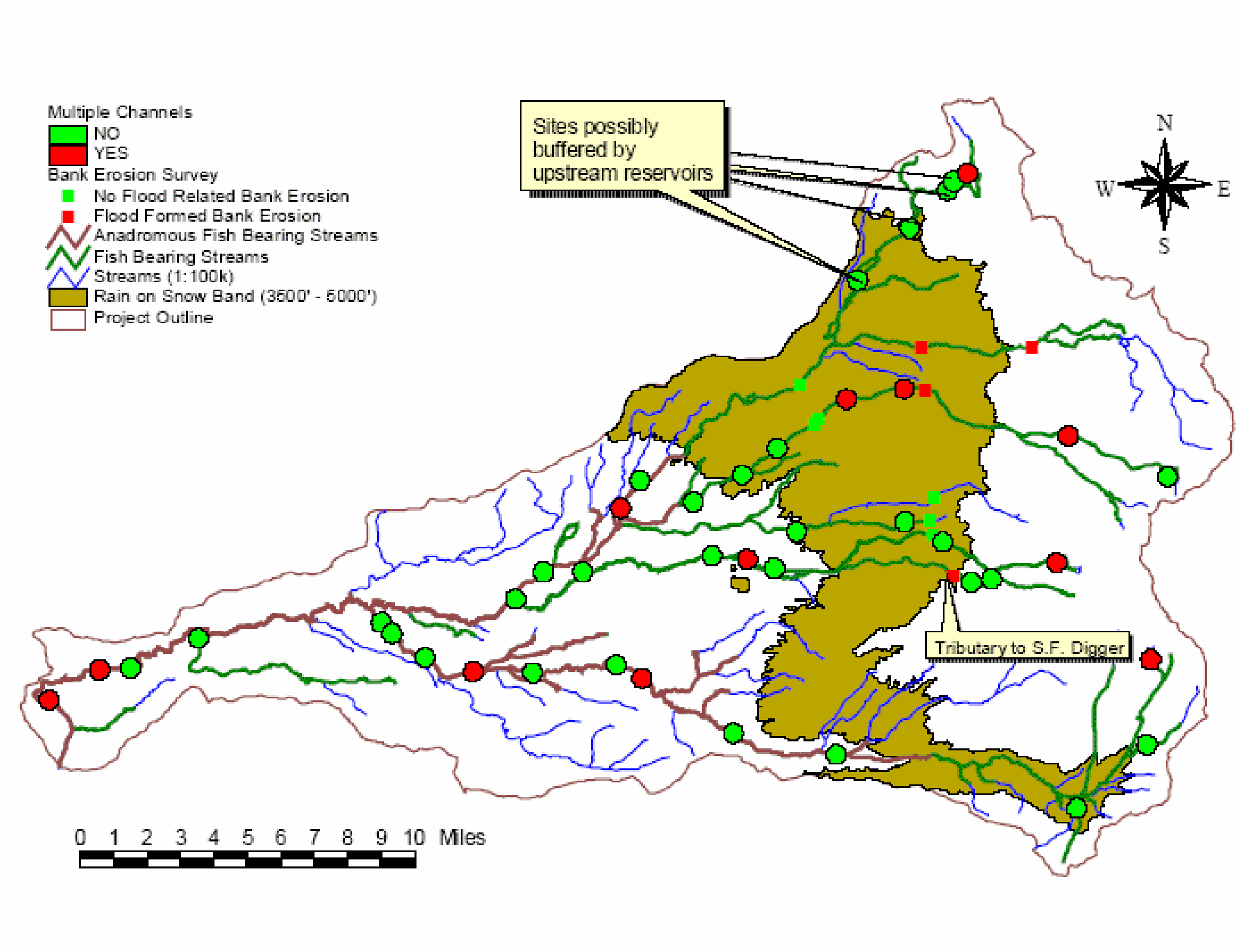

Figure 3. Battle Creek reaches exhibiting multiple channels (red dots) indicative of aggradation and cumulative effects are widespread throughout the watershed. From Terraqua (2004).

Terraqua (2004) notes that sites on upper North Fork Battle would likely be buffered from upstream cumulative watershed effects by the North Fork Battle Creek Reservoir.

The Battle Creek WA describes "sediment waves" that might be passing through the watershed, citing corollary information regarding channel changes such as streamside alder mortality on the middle North Fork:

> "Evidence for such a wave of bedload was directly observed in an approximately 1,100 meter long reach extending from Site #057 (in the middle reaches of North Fork at about 2,300' elev.) downstream to near the confluence with Bailey Creek. Within this reach, perhaps one to two feet of aggraded gravel to cobble sized material (the D50 at Site #057 was 356 mm) spanned the width of the stream channel and buried the trunks of mature alders closest to the stream. The wetted stream channel and bankfull channel was higher than it would have been at the time of alder colonization because of general aggradation of the stream channel: many mature alders were within the wetted width and the recent bankfull width indicators were found bank-side of mature alders in many places. We estimated that this sediment aggradation was no older than three to five years because many mature alders were still alive while the dead trees had not been dead for long. Channel

avulsions at Site #057 were also considered to be indicators of an unstable stream channel at this site."

Regional Literature on Channel Adjustments Related to Changes in Sediment and Flow: Dietrich et al. (1989) stated that "aggradation, braiding, medial gravel bars, presence of sand stripes, and a wide active channel are indicative of high sediment supply." Montgomery and Buffington (1993) note that channels respond differently to sediment inputs depending on factors such as gradient and confinement:

> "In general, steep alluvial channels (step-pool and cascade) tend to maintain their morphology while transmitting increased sediment loads. In contrast, low-gradient channels (regime and pool-riffle) typically respond to increased sediment loads through morphologic adjustment. In essence, steep channels effectively act as sediment delivery conduits connecting zones of sediment production on hillslopes to downslope low-gradient channels."

Low gradient plane-bed channels and pool/riffle channels respond to additional sediment by widening, bank cutting and forming braided channels (Montgomery and Buffington, 1993). Kondolf et al. (1996) noted widespread stream channel changes in the Sierra Nevada ecosystem: "Cumulative effects can degrade aquatic habitat and can potentially lead to the erosion of banks supporting riparian vegetation and the conversion of well-vegetated valley bottoms into wide, open, gravel bed channels."

Dose and Roper (1994) studied the South Fork Umpqua River and noted while channel widening occurred in 13 of 14 streams impacted by timber harvest only 1 of 8 showed a widening trend in watersheds draining Wilderness. They found a relationship between increasing channel width and timber harvest, road density and the amount of large organic debris remaining within the active stream channel. Dose and Roper (1994) made the following conclusions: "These findings suggest that timber harvest and road construction may have resulted in changes in channel characteristics. These channel changes may also be a factor in the observed decline of three of the four populations of anadromous salmonids within the basin."

Upland Conditions in the Battle Creek Watershed and Potential Linkage to Channel Braiding: Armentrout et al. (1998) noted a conversion of the North Fork Deer Creek from a meandering channel with healthy aquatic habitat to a braided channel as a result of logging on erodible soils:

> "The location with the clearest channel response to anthropogenic watershed disturbance is North Fork Deer Creek. As described earlier, this channel apparently changed from a meandering to a braided channel sometime during the 1960s. This corresponds with a high degree of timber management activity (as evidenced by the road density values) in the sub-watersheds upstream of the alluvial reach. It should also be noted that much of the watershed above this reach has rhyolitic soils."

The "response" reaches in Battle Creek (Montgomery and Buffington, 1993), those most likely to change in response to sediment flux, are lower Battle Creek, lower South Fork Battle and stream reaches with mild gradient and unconfined valleys on benches at higher elevation, such as Battle Creek Meadows. It is highly unlikely that 12 of 49 locations measured by Terraqua (2004) would be manifesting channel widening, braiding and bank erosion, if there were not an excess of sediment in transport (Montgomery and Buffington, 1993). Many of the reaches with braided channels, shown in Figure 3, are below areas with intensive timber harvest and high road densities, which are potential sediment sources and causal mechanisms for increased peak flows.

Some natural land sliding may occur in steep headwater swales, such as upper Nannie Creek, but Napper (2001) noted that cumulative effects from logging and road building in Summit Creek had caused drainage structures to fail and the stream to aggrade and erode its banks. No similar studies are available for private lands and response to the January 1997 storm, but cumulative effects risk is greater there than on USFS lands. Response reaches, such as the South Fork as it flows through Battle Creek Meadows (Figure 4) and in the lower mainstem Battle Creek (Figure 5), show major signs of aggradation, including channel braiding, which would be consistent with elevated sediment supply.

Figure 4. Upper South Fork in Battle Creek Meadows shows a wide, shallow profile with small average particle size distribution consistent with cumulative watershed effects and recent sediment yield. The USFS (Napper, 2001) documented road crossing failures and other cumulative effects in Summit Creek, upstream of this site, as a result of the January 1997 storm. This sediment avulsion and peak flow event would be plausible mechanisms for shaping channel conditions that persist at the site as depicted five years later. From KRIS Battle Creek V 2.0

Figure 5. Lower Battle Creek, as shown in this April 1997 photo, has substantial deposits of fine sediment on terraces well as bar formation and channel braiding. This is a response reach of Battle Creek, where effects of sediment would be expected to cause changes in the channel. As Montgomery and Buffington (1993) explained, sediment deposited in these reaches may be persistent because stream power is limited. Aggradation has also triggered bank failures in this reach, causing land owners to seek assistance in protecting valuable grazing land. Photo taken by Harry Rectinwald, CDFG. From KRIS Battle Creek V 1.0. April 1997.

The large number of Battle Creek WA sites showing indications of channel aggradation and widening strongly suggest high sediment supply, and possibly increased peak flows. High bedload movement can cause very high mortality to Pacific salmon species egg and alevin survival (Frissell 1992) and high fine sediment from upland disturbance can smother redds (Cordone and Kelly, 1961). Risk factors for sediment yield in the Battle Creek watershed are high in some places (Kier Assoc., 2003), and an upland sediment budget may be necessary to better quantify disturbance in order to discover linkages. Changes in channel width over time in response reaches can be used to judge cumulative watershed effects (Grant, 1988) and studies using historical aerial photos of lower Battle Creek or other response reaches could help to better explain the effects of past storm events and gauge recovery in the future.

Large Wood Availability and Battle Creek Riparian Conditions

Terraqua (2004) measured large woody debris (LWD) in Battle Creek using standard methods compatible with the EMDS model that was used, in part, for analysis in the Battle Creek Watershed Assessment (WA). Below are their findings, along with information from Pacific Northwest literature related to large wood recruitment and information related to riparian conditions in Battle Creek and its implications for LWD contributions (Kier Associates, 2003).

> The Battle Creek WA used methods similar to Gallo (2002) to inventory large wood with these exceptions: "Because we counted or estimated the number of pieces within debris jams and included these in total site counts, our counts of large wood could be positively biased compared to counts of wood by other researchers using Gallo (2002)."

Figure 6 shows a EMDS ratings for large woody debris with the fewer than half rating likely and fully favorable and seven falling into the fully unfavorable category. Unfavorable ratings were found at two mainstem North Fork Battle Creek locations below Manzanita Creek, two on Bailey Creek, two in Digger Creek and one in the lower South Fork Battle Creek. Figure 7 shows the full range of large wood values from 50 locations throughout the watershed, although these values are not scaled by channel width that is used in EMDS scoring.

<u>Regional Literature on Large Wood Recruitment and Effect on Channel Processes:</u> Montgomery and Buffington (1993) pointed out how large wood helps shape stream profiles and route sediment:

> Large woody debris (LWD), for example, provides transient storage sites for bed material (e.g., Heede, 1972; Beschta, 1979; Keller and Swanson, 1979; Mosley, 1981; Pearce and Watson, 1983; Bilby, 1984), stabilizes gravel bars (Lisle, 1986), and can provide hydraulically sheltered locations that allow fine sediment to accumulate (e.g., Zimmerman et al., 1967; Megahan, 1982). The morphology of smaller channels may respond dramatically to changes in the input, transport, and decay of LWD. For example, removal of large organic debris from small channels rapidly accelerates sediment transport (e.g., Beschta, 1979; Bilby, 1984; Smith et al., in press). Pool morphology and area extent in some channels are strongly correlated to LWD loading (Smith and Buffington, 1991). Changes in the supply of LWD to a channel may trigger significant changes in sediment storage, channel roughness, and pool morphology.

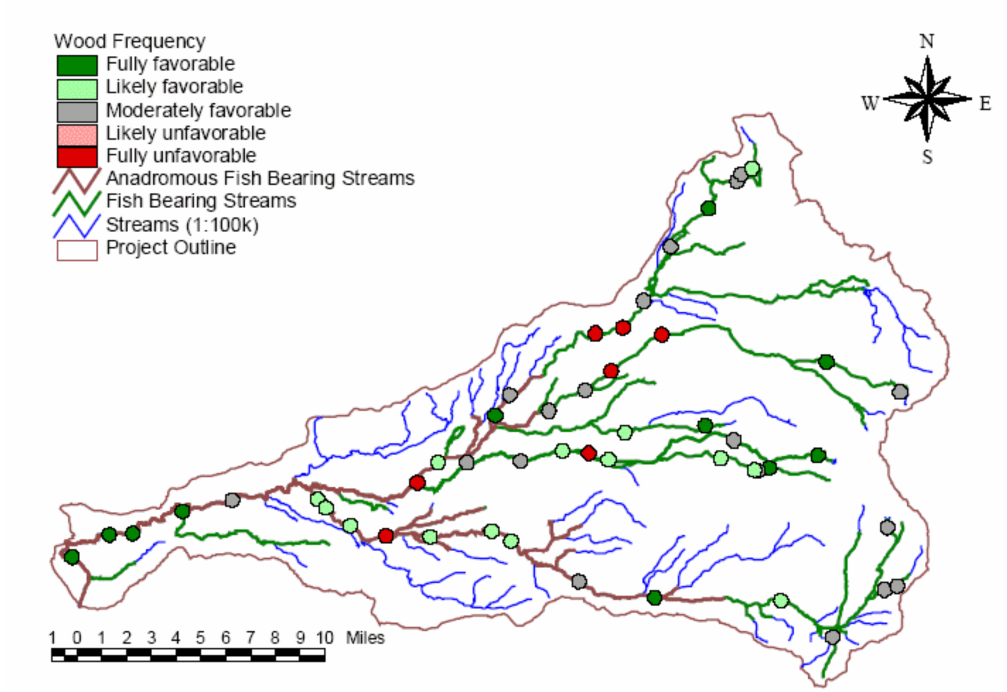

Figure 6. Frequency distribution chart based on EMDS ratings for large woody debris. Red dots show the "fully unfavorable for salmonid production" ratings at seven sites, green dots the "fully favorable" rating sites.

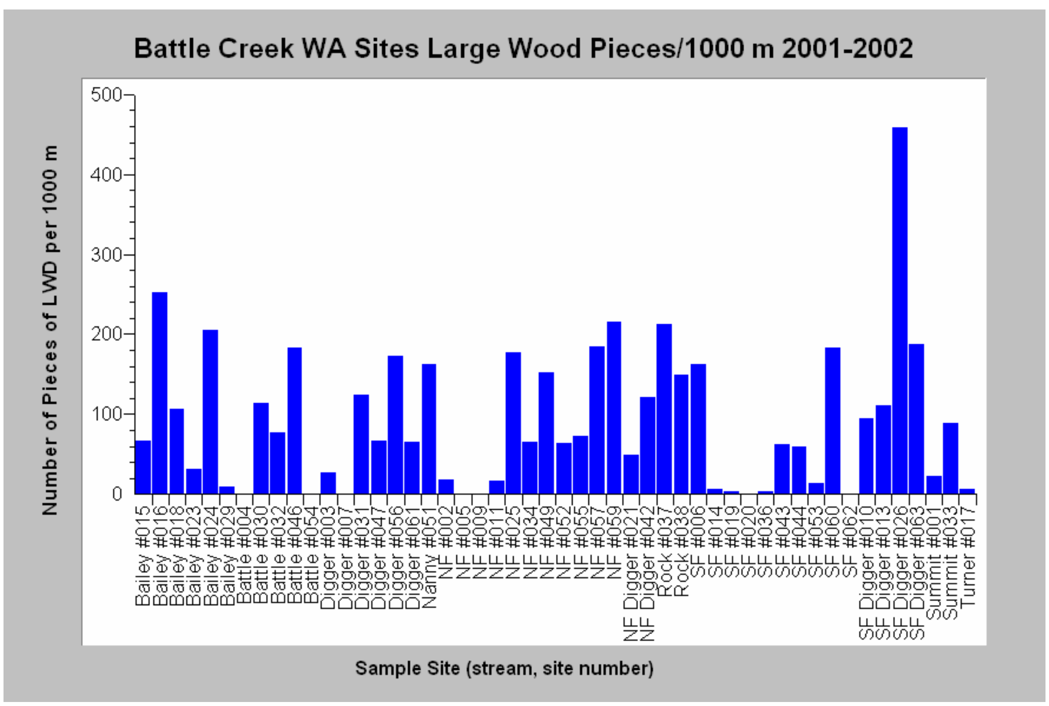

Figure 7. Battle Creek large wood per 1,000 m of stream at 50 sites ranged from . 0 to 458, but watershed wide scores show very low large wood at many locations. Chart from KRIS Battle Creek V 2.0.

Montgomery and Buffington (1993) note that LWD may profoundly influence low gradient streams and cited Lisle (1986) who demonstrated that LWD may anchor and stabilize pool and bar forms. They describe pool formation by large wood as "forced" because of changes in hydraulic currents surrounding the log or rootwad obstructing the channel. Low gradient response reaches of streams in forested areas rely on large woody debris for pool formation and sediment storage and are particularly sensitive to changes in the size, species, and amount of recruited LWD (Bryant, 1980). Large wood in steep, small channels can form stair steps of pools and cascades that slow the flow of nutrients through a stream system and provide storage areas for sediment (Sedell et al., 1988). If the large wood supply to a stream diminishes, it will have reduced sediment storage capacity, and effects of high sediment yield during storm events may impact downstream reaches more severely (Pacific Watershed Associates, 1998).

Reeves et al. (1993) described a strong relationship between forest harvest and large wood availability in Oregon coastal streams: "Streams in basins with low timber harvest had more complex habitat, as manifested by more large pieces of wood per 100 m ($P < 0.01$)." In small coastal Oregon streams, House and Boehne (1986) found only 0.4 pieces/100 m of wood large enough to influence channel morphology in streams in watersheds that were 50% logged over a 20 year period. In a nearby control stream (undisturbed watershed) they found 18 pieces of LWD per 100 m large enough to influence the channel.

Ligon et al. (1999) stated that riparian zone protection from timber harvest in California is insufficient to insure optimal large wood recruitment in Pacific salmon streams. They also noted that large wood may be recruited through landsliding and that timber harvest on steep slopes can reduce this important source of wood. Potential for large wood recruitment in Sierra Nevada coniferous forests has been greatly reduced by logging activity and road construction near streams (Kondolf et al., 1996). Hardwoods that replace coniferous trees in early succession after logging do not provide long lasting wood in streams because they decay much faster than mature conifers (Cedarholm et al., 1997). Replenishment of wood large enough to be of lasting value in shaping aquatic habitats may require 40 to 100 years or more to grow, depending on site conditions and whether there is continuing timber harvest (McHenry et al., 1998). Increased flood flows from rain-on-snow events in managed watersheds may mobilize large wood more frequently than natural storm cycles (Montgomery and Buffington, 1993).

<u>Large Wood in Battle Creek Reaches, Potential Future Recruitment and Riparian Conditions:</u>
Although 1:100000 USGS hydrology was not sufficiently accurate to quantify riparian zones accurately, GIS data do allow reconnaissance that suggests potential relationships between riparian stands, timber harvest, and LWD in adjacent stream reaches (Kier Associate, 2003). The average finding of 97 pieces of large wood per 1000 m at Battle Creek WA sites may be appropriate for larger streams because large wood tends to re-mobilize, however, smaller streams in the Sierran Mixed Conifer zone should more closely approximate the findings of House and Boehne (1986), who found 180 pieces per 100 m. This value is used for comparison in KRIS Battle Creek Version 2.0 for the universe of tributary streams scaled for 1000 m (180 pieces/1000 m) and indicate low wood supply at many Battle Creek WA sites in small tributaries.

Historic California Department of Fish and Game file reports (Fisk et al., 1966) noted logging damage to Battle Creek and other northern California streams after the 1964 flood. These findings were contrasted with recent riparian conditions and changes since 1991 according to Landsat imagery of vegetation, which allows comparison of regeneration and recent timber management on public and private land since the 1960s. Fisk et al. (1966) used four categories to describe stream and riparian damage (Figure 7). Severe (100% streamside canopy removal), Moderate, Light or Undisturbed. Riparian zone vegetation maps below show patterns of change in riparian tree size on the same reaches where damage was reported (Figure 8).

Warbington et al. (1998) provide tree size data based on Landsat imagery that allows analysis of Battle Creek watershed vegetation patterns and the age of the forest, which is related to forest harvest cycles. Figure 8 uses classified 1996 Landsat imagery in a 100 meter band on each side of the stream at a one hectare scale. Results indicate mostly Small-Medium trees (12-19.9" dbh) with patches of Non-Forest. The comparison between areas highlighted as highly damaged by Fisk et al. (1966) have riparian zones that remain in early seral conditions with low large woody debris recruitment potential 40 years later. The only Large-Medium (20-29.9") trees in riparian zones are on USFS lands in the upper reaches of the North Fork Battle (Figure 9), Manzanita, Bailey, Onion and Digger creeks. Some riparian Non-Forest may be meadow (which shows as white on USGS topo backdrop), but sites not located in meadows may be caused by streamside roads or timber harvest. Individual large trees may be missed due to the one hectare scale. Figure 9 clearly shows that USFS riparian zones have the only large trees and that adjacent private land reaches have Small-Medium (12-19" dbh) trees and even patches of Small (5-11.9" dbh) trees

The 100 meter riparian zone based on 1996 Landsat imagery of Onion and Rock Creeks is shown as Figure 10 and is combined with Landsat "change-scene detection" from 1991-1996 and 1994-1999 (Levien et al., 2002). Active logging in the riparian zone of 100 m is indicated by the orange and red change-scene colors, which is further evidence of recent reduction of sources of potential large wood in these Battle Creek tributaries. Small diameter trees may represent hardwood or conifer species colonizing streamside areas after logging, which have much less lasting values for habitat formation if recruited to adjacent stream reaches (Cedarholm et al. 1996).

USFS Landsat derived vegetation data show early seral conditions and recent canopy reductions adjacent to most reaches that have "fully unfavorable" large wood conditions for salmonid production. Studies are needed to look at the seral stage of riparian stands and their relationship to potential LWD recruitment. High resolution data, such as timber inventories ("cruise" data) in riparian areas, and small scale aerial photos should be used to more closely test this hypothetical relationship. Such studies could frame possible management alternatives that help attain fully functional levels of large wood in Battle Creek tributaries in the future. Ligon et al. (1999) recommended increased conifer retention and limited, selective logging of small diameter trees to accelerate growth of large trees to speed future LWD availability. Large wood depletion potentially could also be linked to low pool frequency at some *Battle Creek WA* sites as well.

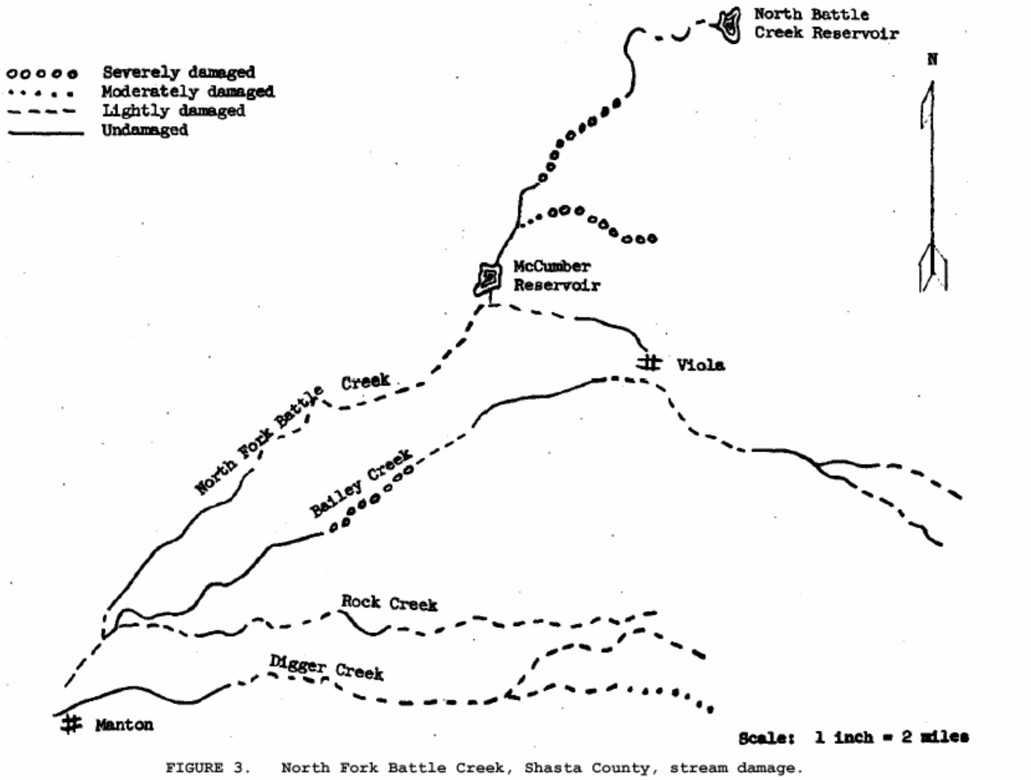

Figure 7. Map captured from Fisk et al. (1966) showing levels of damage to streams caused by logging that could be related to lack of large wood in Terraqua (2004) samples.

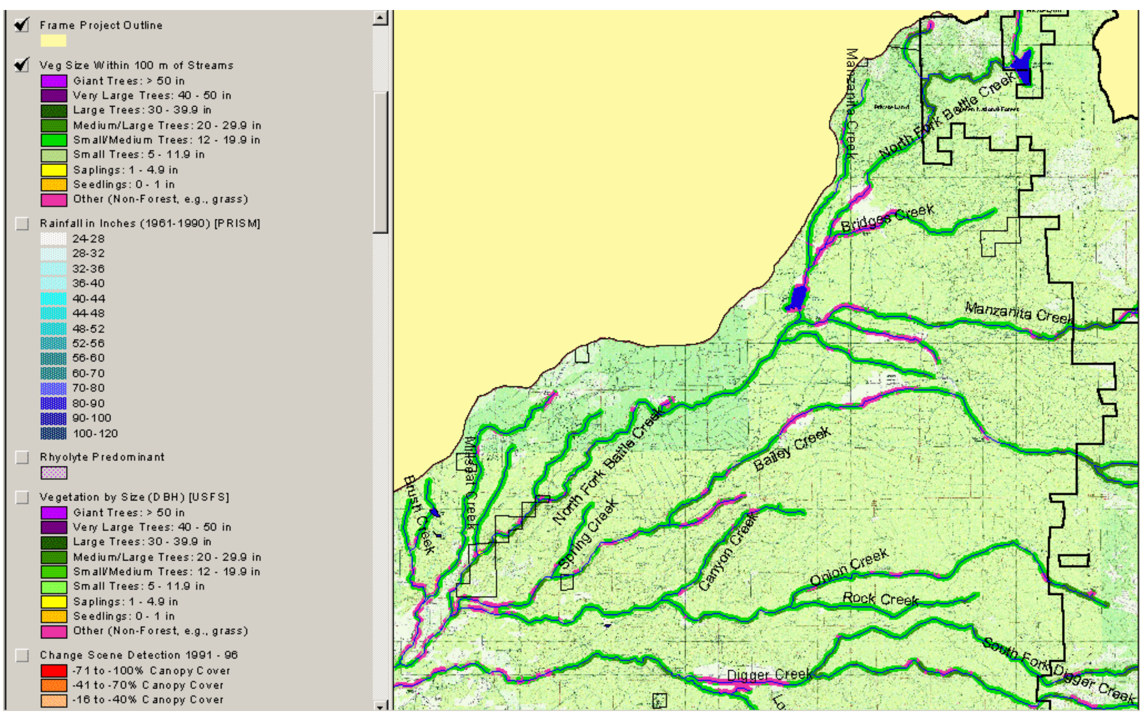

Figure 8. This map shows Landsat derived vegetation data provided by the U.S. Forest Service based on a 1996 image (Warbington et al., 1998). The buffer zones are 100 meter band on each side of the stream at a one hectare scale and the area displayed is similar to that of Fisk et al. (1996).

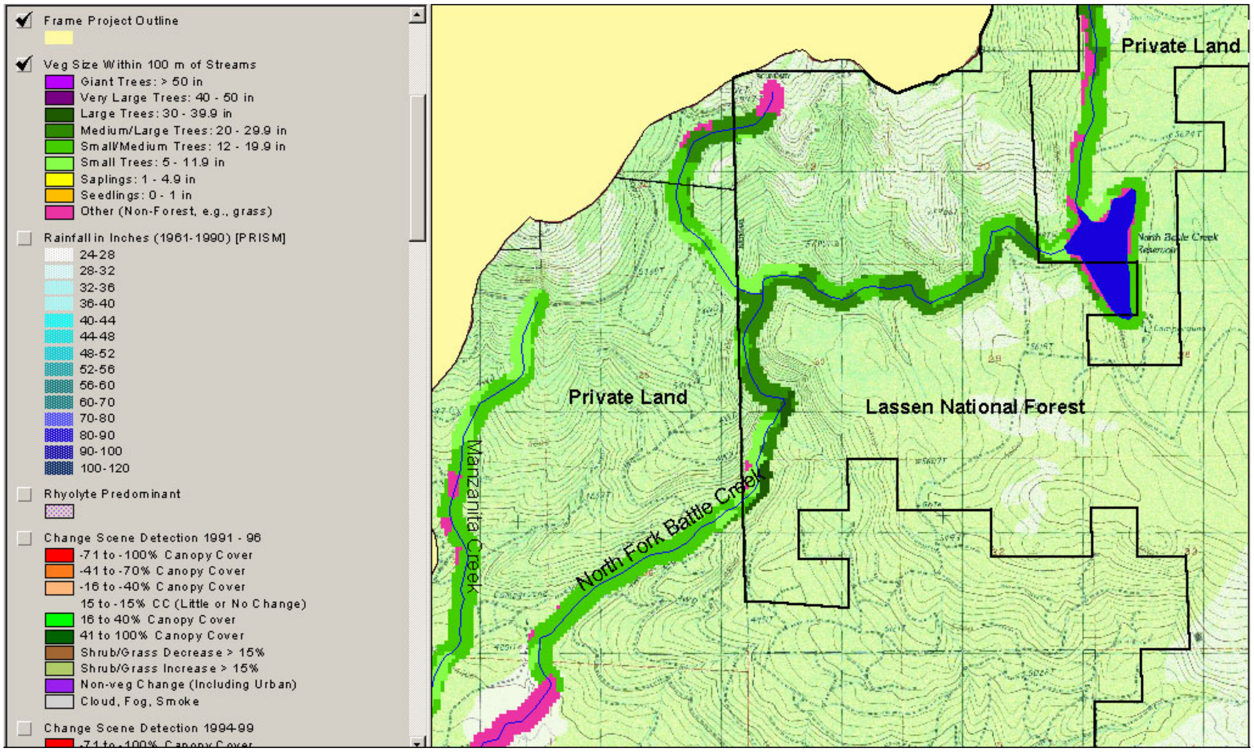

Figure 9. Landsat derived vegetation data from the USFS showing tree size in 100 M riparian zone of Battle Creek with almost all larger diameter trees on Lassen National Forest streams.

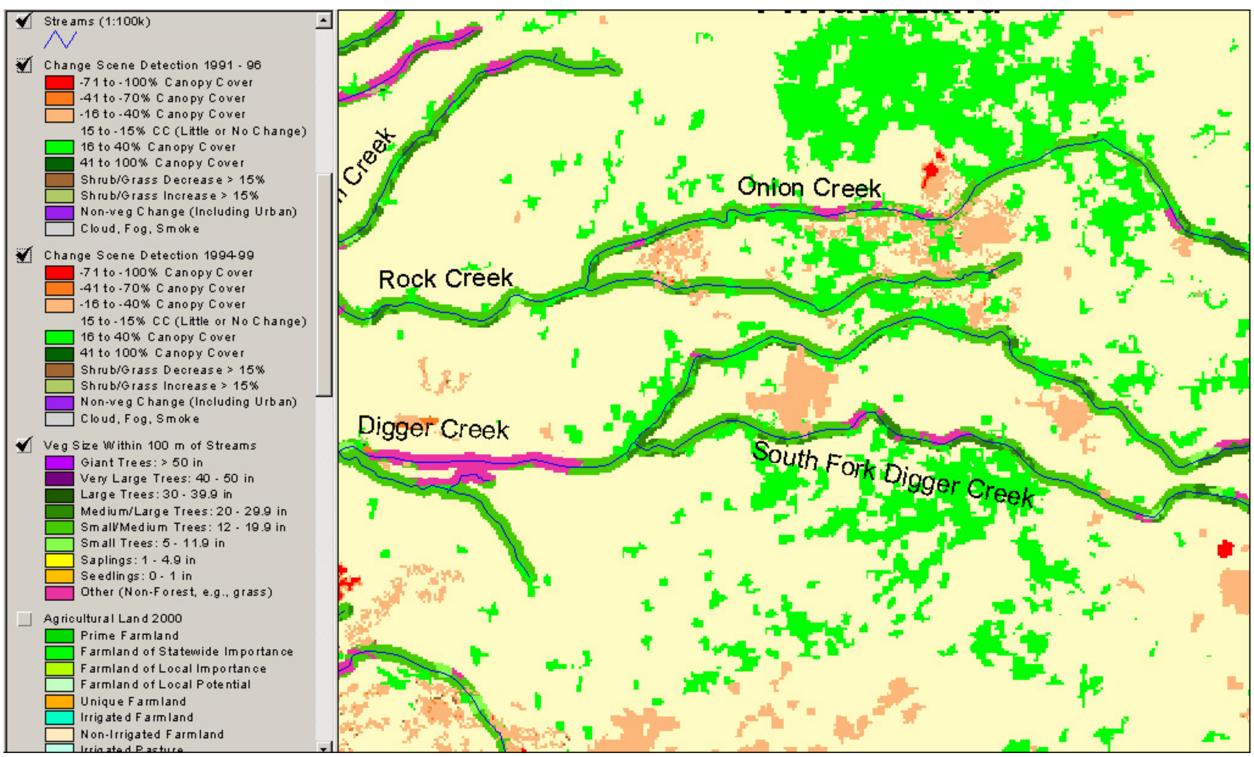

Figure 10. USFS vegetation size data overlain with change scene detection spanning from 1991-1999 indicating widespread riparian logging, but also substantial forest growth of young trees.

Battle Creek Sediment and Salmonid Habitat

The Battle Creek Watershed Assessment (Terraqua, 2004) examined surface fine sediment in pool tail crests and median particle size distribution (D50) at 50 sites throughout the Battle Creek watershed. An exception in the study is fine sediment samples were not taken at several locations because the stream bottom was covered with algae.

Surface Fines: Surface fine sediment less than 2 mm at pool tail crests was measured at 35 of 50 sites as a result of algae at 7 sites and lack of scour pools at 8 sites. Surface fine sediment is easy to measure yet the location in pool tail crests gives an indication of accumulation of sediment in areas that would be chosen by salmonids for spawning. With regard to surface fine sediment, Terraqua (2004) found sites ranged from 4 to 85 percent with a mean percent fine sediment of 31 percent and fine sediment conditions at 8 of 35 sites were fully or likely favorable, while fine sediment conditions at 22 sites rated as fully or likely unfavorable according to EMDS criteria (Figure 11). Figure 12 shows the surface fines (< 2mm) data as a bar chart and shows that many sites are showing extremely high surface fines levels of greater than 50% when the threshold for high quality salmonid habitat is 12.5%. Fines were very high (> 50%) at numerous South Fork Battle Creek locations, on the lower mainstem, at two Bailey Creek sites, on the North Fork above the NF Battle Creek Reservoir, and at one location on Digger Creek.

Terraqua (2004) found no relationship of surface fine sediment to upland factors using a power analysis. The analysis of surface fines was run against factors such as elevation and watershed area, road density, near-stream road density, road-stream crossing frequency, rain-on-snow area, rhyolite soil, near-stream meadow area and forest cover.

Median Particle Size Distribution: Terraqua (2004) captured data on median particle size, also known as D50, at 49 sites throughout the Battle Creek watershed. Their findings were that D50 ranged from 1 mm to 356 mm, mean D50 values were highest in the South Fork basin, and that 11 of 49 sites were fully or likely favorable for salmonid production while D50 conditions at 33 sites were fully or likely unfavorable. At sites with unfavorable D50 values, the median particle size was too small at 20 sites and too large at 13 sites (Figure 13). Fine sediment dominates sites with D50 values less than 45 mm, but larger unsuitable values (>128 mm) are poorly suited for salmonids because they are too large for spawning use.

Again the Battle Creek WA found no relationship to upland conditions using a power analysis: "In other words, variability in none of the sediment source factors was statistically related to observed particle size in the Battle Creek watershed."

<u>Regional Literature on Sediment in Streams and the Relationship to Upland Disturbance:</u>
Armentrout et al. (1998), in the *Watershed Analysis for Deer, Mill and Antelope Creeks*, set targets for surface fine sediment less than 2 mm at pool tail crests of 10% in mainstem environments, 15% in tributaries within watersheds without rhyolitic soils and 20% in rhyolitic basins. They measured surface fines in Mill and Deer Creek mainstem locations and found them to be less than 7% on average, with 19 and 42 sites surveyed in each creek, respectively.

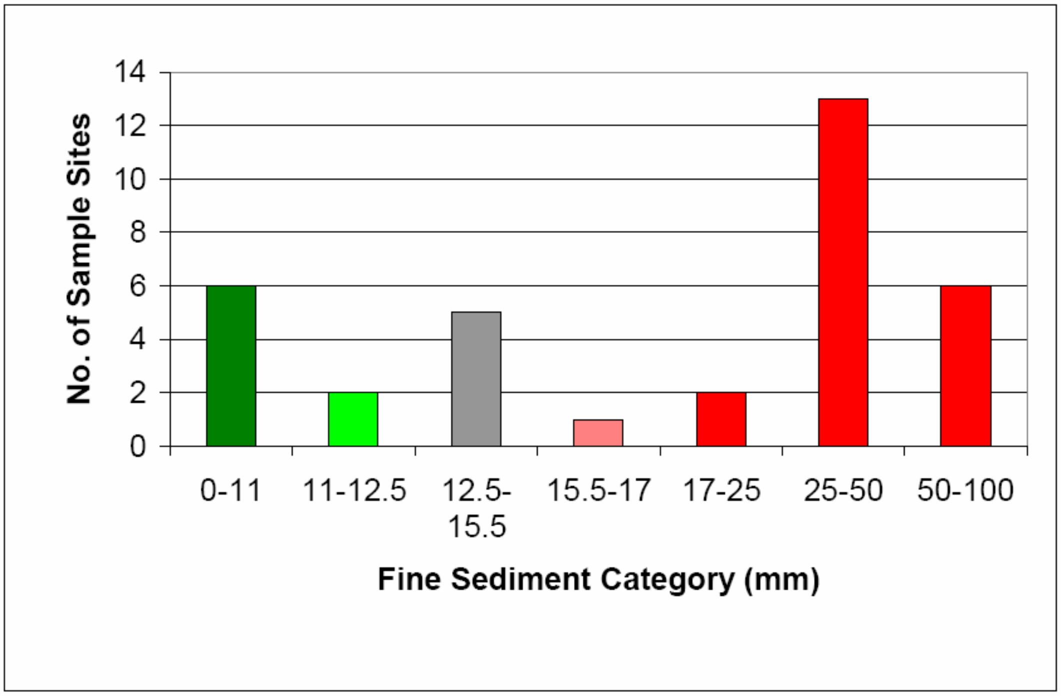

Figure 11. This chart summarizes results of surface fine sediment measurements in 2001-2002 with colors of bars related to the EMDS suitability for salmonids. Fines less than 11% are fully suitable (dark green), 11-15.5% somewhat suitable (light green/grey), 15.5-17% somewhat unsuitable (pink) and over 17% fully unsuitable (red). Chart from Figure 5 in Terraqua (2004). .

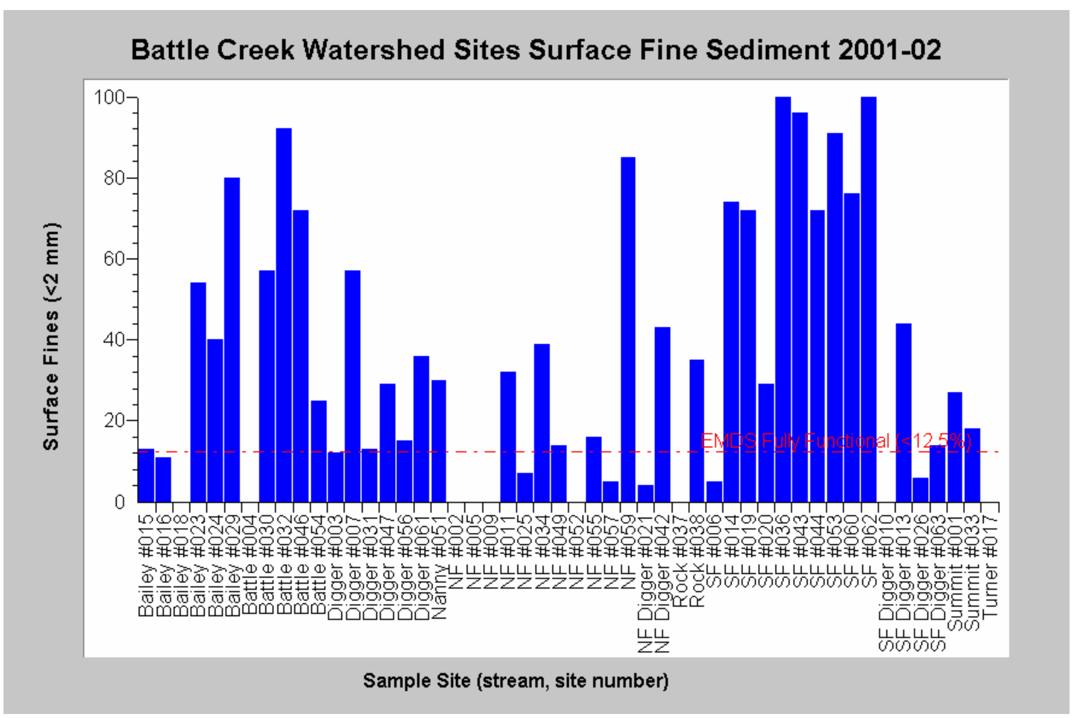

Figure 12. Surface fine sediment at 38 Battle Creek locations shows extremely high values at a number of locations. Twelve locations had no pools and no pool crests to sample or crests were covered with aquatic plants. Charts from KRIS Battle V 2.0.

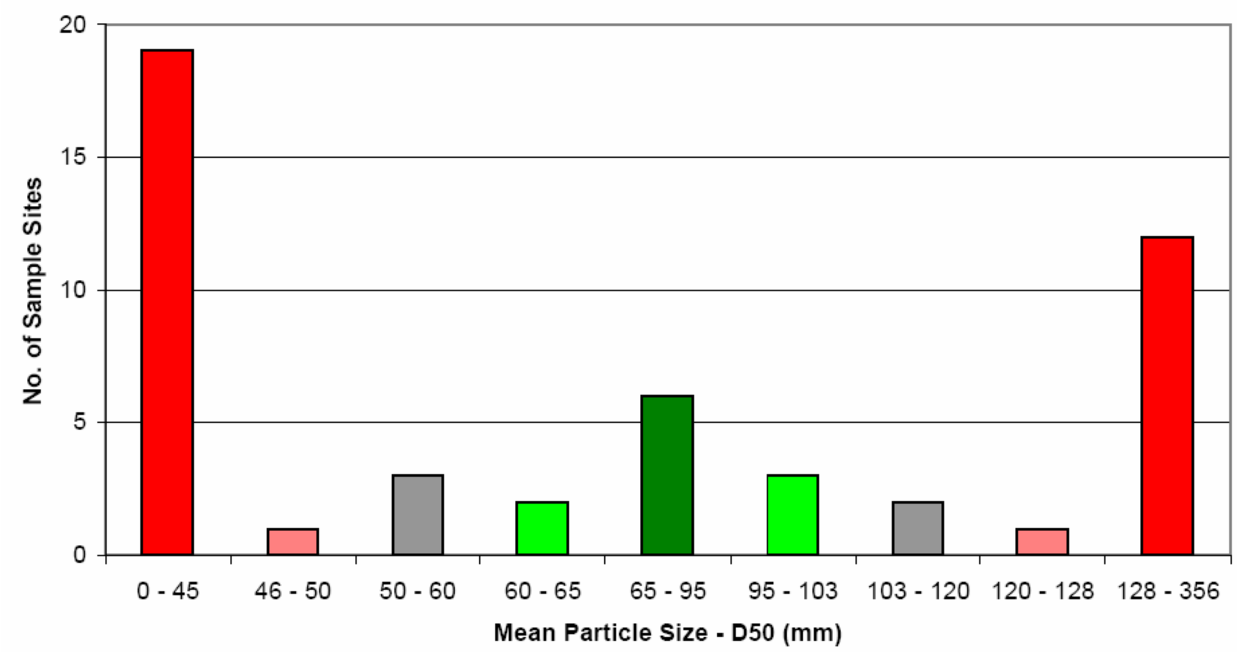

Figure 13. Median particle size categories from EMDS with color codes from highly suitable (dark green), likely suitable (light green), likely unsuitable (pink) and fully unsuitable (red).

Cordone and Kelly (1961) studied the effects of sediment processes on salmonids and noted problems in the same Mill Creek in the 1955 flood: "The shifting of the channel and the eroding and smothering action of silt and sand apparently caused a complete kill of the developing young salmon." Gangmark and Bakkala (1960) created a silt-free side channel to Mill Creek as an experiment to gauge survival of spring Chinook salmon eggs versus the natural channel. They found mortality of salmon eggs in Mill Creek itself was 98.3%, which they attributed to "reduced seepage in the gravel" due to high fine sediment supply. While survival of eggs in side channels was greater, and not effected by bedload shift, fines carried by high flows infiltrated the redds and caused egg mortality.

Montgomery and Buffington (1993) note that increases in sediment delivery can cause "filling of pools, and increase in fine particles in spawning gravels" and that impacts are most likely to occur in flatter stream reaches because "they are more depositional in nature than the steeper mainstem reaches." In cases of extremely high fine sediment supply, sand stripes may be visible on the surface of the stream bed and deposited in areas of the active channel. Montgomery and Buffington (1993) discuss sources of such material:

> "Fine sediment in transit during low-flow events must, therefore, represent either material mobilized from the surface of the channel bed (such as fine sediment stored in pools) or sediment delivered to the channel by runoff produced during storms that do not generate armor-mobilizing discharges. The latter could come from road surface runoff, or from erosion of bare ground."

Dietrich et al. (1989) showed that smaller bed load materials were readily transported and that decreasing median particle size distribution was indicative of recent contributions of sediment in a watershed. Knopp (1993) found that the D50 of northwestern California streams could be related to intensity of watershed management, specifically that a D50 less than 38 mm was indicative of a high level of watershed disturbance and sediment contributions. Studies of aggraded streams with reduced median particle size show that they may be unstable when used by salmonids for spawning, resulting in increased mortality of eggs and alevins (Frissell, 1992).

Woods-Smith and Buffington (1996) studied streams in watersheds disturbed by logging and found an increase in the "ratio of critical shear stress of the median surface grain size to bankfull shear stress", which could cause a coarsening of the stream bed. Timber harvest and road building may increase peak flows from storm events, especially if disturbance falls within the transient snow zone (Jones and Grant, 1996). Montgomery and Buffington (1993) found that "increased discharge can coarsen the bed, potentially causing an increase in the relative roughness and thus the turbulent energy dissipation."

The extremely high levels of fine sediment found at Battle Creek sites is to be expected given the high degree of watershed disturbance and high road densities in the watershed (Kier Associates 2003). Haynes et al. (1997) studied surface fine sediment and road density classes in several thousand Interior Columbia River Basin watersheds and found a the relationship as levels rose above 1.7 miles of road per square mile of landscape (mi./mi.^{2}) (Figure 13). They also found that bull trout, an aquatic indicator species for the Rocky Mountain region, were absent in watersheds with higher than 1.7 (mi./mi.^{2}).

<u>Sediment in Battle Creek Reaches and the Potential Relationship to Upland Conditions:</u> Levels of fine sediment and median particle size distribution (D50) found by Terraqua (2004) are often outside the optimal range according to EMDS criteria. These results are consistent with high sediment supply and increased peak discharge and Battle Creek GIS data show patterns of upland disturbance that are plausible causal mechanisms for these perturbations (Kier Associates, 2003).

The USFS measured fine sediment in control streams and managed streams throughout California and for Lassen National Forest (LNF). These results are combined with those from Battle Creek as a whole, which has substantial private land holdings (Figure 14). The Battle Creek watershed had surface fine levels (44%) four times the fully functional EMDS level and more than twice as high as measurements for USFS control streams. The 16% surface fines in transport reaches (over EMDS 12.5% reference) are indicative of high supply and deposition. The difference in results suggest different sediment yield from USFS lands and private lands in Battle Creek where land use management more intensive. The presence of soil and sand sized particles in the active channel supporting algae beds (Terraqua 2004) is indicative of sediment oversupply and algae may actually be colonizing "sand stripes" as described by Montgomery and Buffington (1993). Build up of median gravel bars at several Battle Creek WA locations and channel braiding in response reaches (see Battle Creek Channel Morphology) are also consistent with high sediment supply.

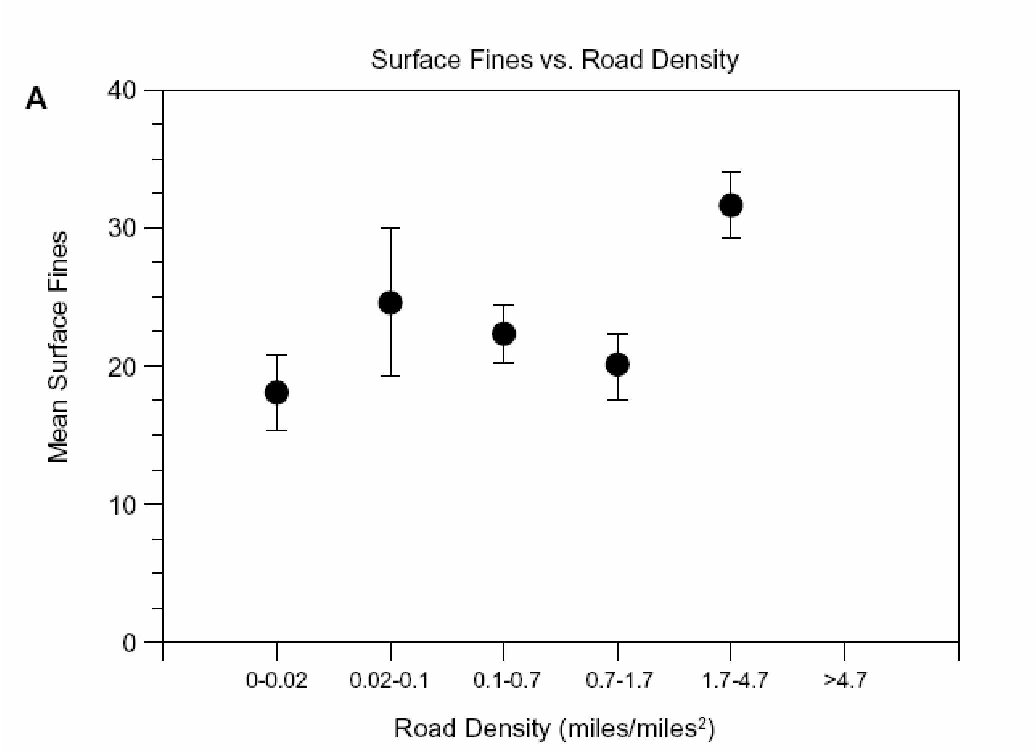

Figure 13. USFS Interior Columbia River Basin (Haynes et al. 1997) studies of several thousand watersheds found the above relationship of road density and surface fine sediment in streams indicating a positive correlation.

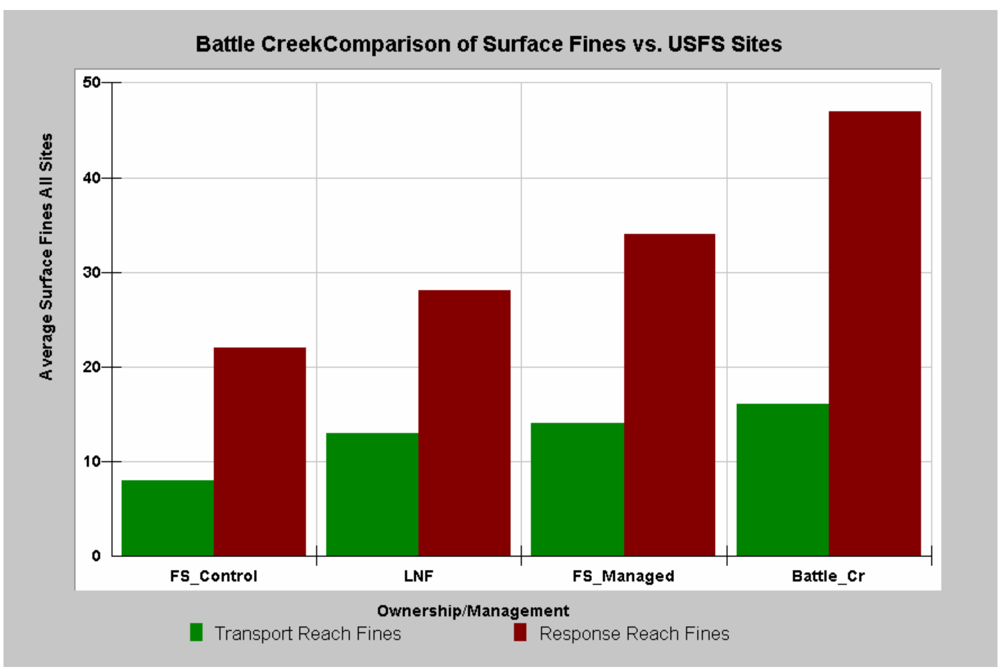

Figure 14. Surface fine sediment data from Terraqua (2004), USFS Region 5 (FS) and Lassen National Forest (LNF) samples. Battle Creek, which includes private timber lands, had the highest levels of surface fines both in transport (16%) and response reaches (44%). KRIS Battle Cr.V 2.0.

Kier Associates (2003) describe locations of unstable soil types, particularly decomposed rhyolite, that tend to have high surface and gully erosion risk. Recent intensive land use has taken place on rhyolitic soils within the Battle Creek watershed (Figure 15). Logging and road building in the Soap Creek drainage of the South Fork Battle Creek watershed would appear to be capable of supplying sediment that is related to high surface fine sediment scores. Montgomery and Buffington (1993) suggest that increased fine sediment in streams often comes from roads, and there are high road densities, miles of near stream roads and dozens of crossings in Battle Creek sub-basins. According to USFS studies (Armentrout et al., 1998; Napper, 2001), increased sediment supply is likely when rhyolitic soil types are disturbed by road building and timber harvest.

The high number of locations in Battle Creek with less than optimal D50 is similar to the findings of Small median particle size at Battle Creek WA sites (<45 mm) indicate recent contributions of sediment (Dietrich et al., 1989) and are parallel to findings of Knopp (1993) that north coastal watersheds disturbed by logging had small median particle size distribution. However, high D50 values outside the range of suitable for salmonids are likely resulting from increased peak flows (Montgomery and Buffington 1993). High road densities are known to trigger increased fine sediment levels and also to change watershed hydrology, particularly if located in the rain-on-snow zone (Jones and Grant 1996). Figure 16 very high road densities in Soap Creek on industrial timberlands in the SF Battle Creek watershed rain-on-snow zone (Figure 16). Downstream D50 values are the highest in Battle Creek and consistent with increased peak discharge.

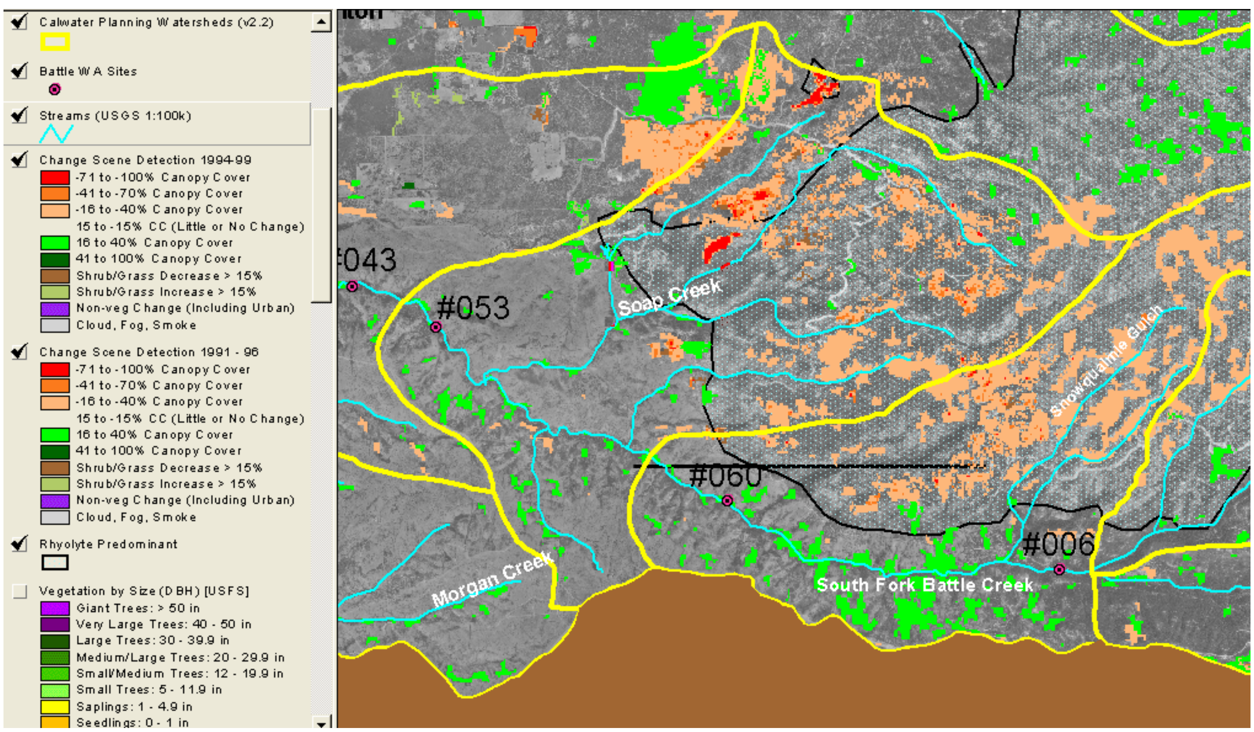

Figure 15. Middle SF Fork Battle Creek watershed map with rhyolitic soils (blue stipple w/ black outline) and 1991-1999 change scene detection (Levien et al., 2001). Canopy removal on unstable soils range from 15-40% (light orange), 40-70% (orange) to >70%. High fine sediment values at sites #060, #053 and #043 are consistent with high sediment supply.

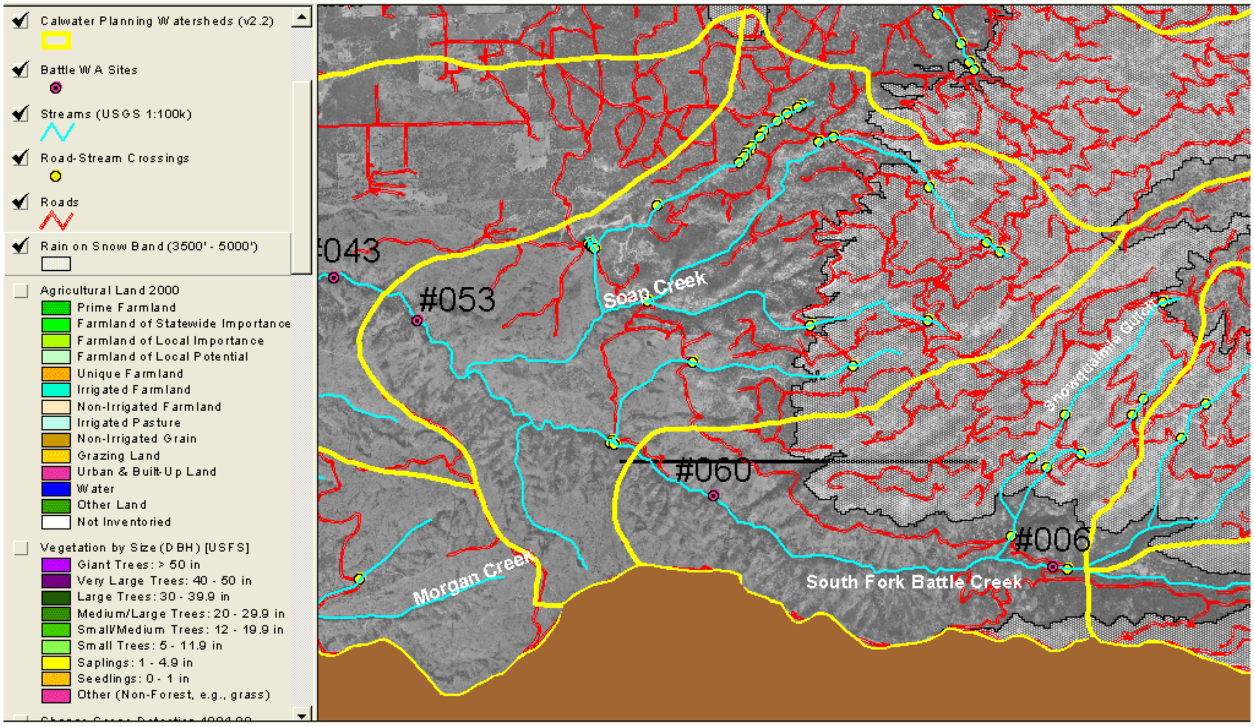

Figure 16. Map of the middle South Fork Battle Creek with an orthophoto backdrop and digitized main haul roads (red), road stream crossings (yellow dots) and the rain-on-snow zone (3500-5000'). Skid roads, temporary roads, and landings are not mapped. Roads data from SPI.

The EMDS model is based on data from thousands of streams with both undisturbed watersheds and those disturbed by management. Consequently, Battle Creek values measured by Terraqua (2004) are well outside the normal range of suitability for salmonids show that the majority of sites within the watershed are showing signs of profound disturbance. The scores are not surprising when one considers the widespread nature of disturbance such as high road densities, near stream roads and rapid logging rates. Both surface fines and D50 should continue to be measured in the Battle Creek watershed to test for decreasing trends in surface fines and return to normal ranges of D50 as restoration in the watershed proceeds.

Pool Frequency and Depth in Battle Creek

Terraqua (2004) measured the frequency of pools and residual pool depth following Aquatic and Riparian Effectiveness Monitoring Program (AREMP) protocols (Gallo, 2002). Terraqua (2004) found the mean number of scour pools per 100 meters "was 1.7 scour pools per 100 meters of stream while pool frequency at individual sites ranged from 0 to 6.9 scour pools per 100 meters of stream." EMDS Battle Creek watershed results for pool frequency (Figure 17) show that the only reaches with fully favorable conditions for salmonids are the four within lower Battle Creek and one on the South Fork above Panther Creek.

Terraqua (2004) characterized pools 3 feet deep or more as suitable for anadromous fish, but pools 3 feet to 10 feet deep as optimal for over-summer holding of adult salmon. Pools 1 foot deep or more were characterized as "fully favorable" for resident trout. They found the "mean pool depth in habitat accessible to anadromous salmonids was 0.92 meters, and the maximum observed pool

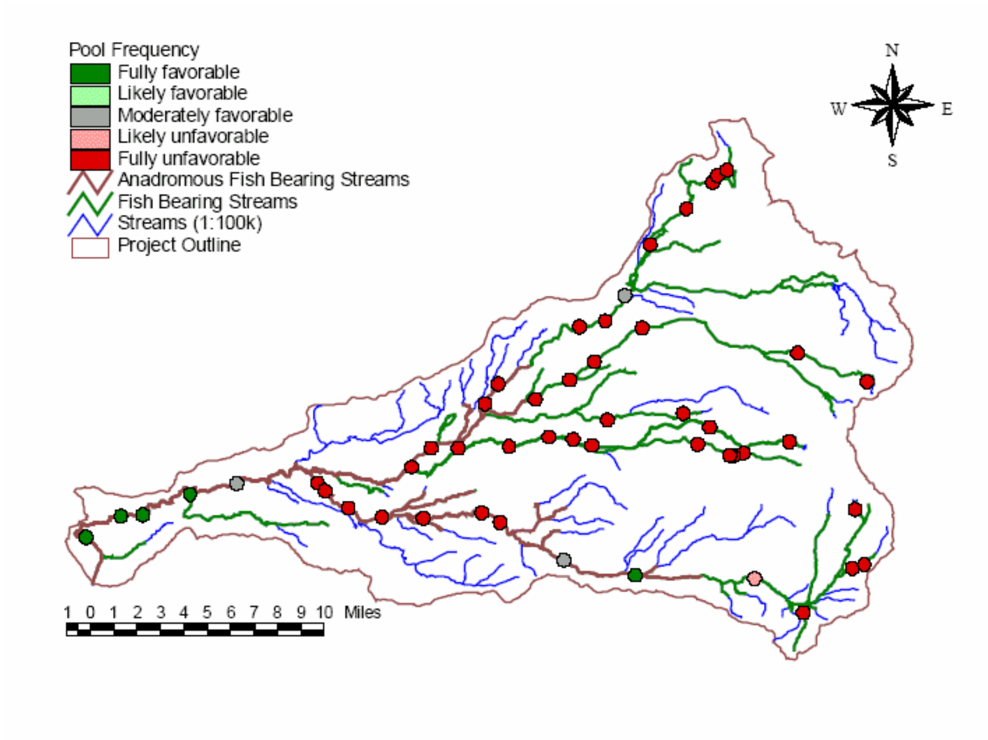

Figure 17. Terraqua (2004) pool frequency results based on EMDS rating curves show levels fully unfavorable to salmonids throughout the Battle Creek watershed.

depth was 2.46 meters. At sites accessible to anadromous salmonids, 60 percent of the pools were considered fully unfavorable (depths < 1.0 meter) for adult spring Chinook salmon holding." Terraqua (2004) "found 25 pools fully favorable for adult spring Chinook holding within the 5,168 meters of habitat accessible to anadromous salmonids that we surveyed", however, the array of pool depths (Figure 18) shows that most would not allow survival of winter run or spring run Chinook during low flow periods.

<u>Regional Literature on Pool Frequency and Depth and Factors that Affect Them</u> Chen (1991) used pool depth as a surrogate for cumulative effects, under the assumption that steelhead yearlings would survive better in deeper pools and that pool frequency and depth reflect land management. Wood-Smith and Buffington (1996) designed a study of 23 forest stream reaches to obtain an "objective, geomorphic discrimination of pristine and disturbed channel conditions." They found significant relationships between land use management and "total number of pools per reach, the ratio of mean residual pool depth to mean bankfull depth, and the ratio of critical shear stress of the median surface grain size to bankfull shear stress." They also found that "abundance of pool-related large woody debris is highly correlated with pool frequency and is an important factor determining channel morphology."

Montgomery and Buffington (1993) note that stream channels where sediment is in equilibrium have pools "rhythmically spaced about every 5-7 channel widths in self-formed channels without significant LWD loading." They describe how pool formation differs in steep channels and those with mild gradient, with stepped-bed morphology in high gradient reaches, and pool-riffle or plain-form beds in flatter reaches. While low gradient reach bedload movement is limited by stream power and transport capacity, steeper reaches are "supply limited". Pool frequency and depth may decrease in response to increased sediment supply as storage increases, particularly in low gradient "response" reaches (Montgomery and Buffington, 1993). If sediment supply is very excessive, stepped-bed morphology of steeper reaches may also be disrupted (Grant et al., 1990).

Reeves et al. (1993) studied coastal Oregon basins and found much less diversity of Pacific salmon species in basins that had been logged in more than 25% of their watershed area, and also noted a relationship to pool frequency: "Streams in low-harvest basins also had 10-47% more pools per 100 m than did streams in high-harvest basins." Increased peak flows from rain-on-snow events in intensively managed watersheds may also mobilize pool-riffle beds in low gradient reaches and can dislodge large woody debris and "these effects are similar to those occurring from natural large-discharge events, but a change in their frequency could impact biologic systems and the reach-level sediment transport rate" (Montgomery and Buffington, 1993). Montgomery and Buffington (1993) recognize that pool-riffle channels are the areas of highest productivity for anadromous salmonids, but that they are the "those most likely to experience significant, persistent impacts."

<u>Battle Creek Pool Frequency and Depth and Potential Relationship to Upland Conditions:</u>
Armentrout et al. (1998) studied Deer, Antelope and Mill creeks, immediately to the south of the Battle Creek watershed, and noted that low gradient reaches tended to be subject to pool filling and fines accumulation and, therefore, sensitive to sediment increases. Montgomery and Buffington (1993) point out that sediment over-supply will show up first in response reaches, but low pool frequency and depth in Battle Creek transport reaches is an indication of the level of excessive sediment. The same sources of watershed stress described above for increasing fine sediment and changing D50 would also tend to decrease pool frequency and depth (Montgomery and Buffington 1993). Intensive land use in Battle Creek watershed sub-basins with high risk for sediment yield and increased peak flows (Kier Associates, 2003) are likely contributing to low pool frequency and depth. The Battle Creek WA found a relationship between decreased residual pool depth and area of the watershed at elevations susceptible to rain-on-snow effects. This is consistent with increased peak flows expected with intensive private timberland management at mid-elevation across the Battle Creek watershed.

While the Battle Creek WA compared pool frequency of reaches surveyed earlier by Thomas R. Payne and Associates (TRPA, 1988), habitat typing data cannot be used for monitoring purposes because of observer bias (Roper and Scarnecchia, 1995). Measurements of maximum pool depths are repeatable, however, and additional studies are needed to compare residual pool depths between the Battle Creek WA and TRPA (1988) and on-going surveys. Pool depth is simple and inexpensive to monitor and trends in pool frequency and depth should both improve as sediment problems in the watershed are abated. Surveys should be conducted at least in years with flow events capable of significant bedload transport. Monitoring pool depths in lower Battle Creek and lower North and South Forks reaches is important for restoration assessment and adaptive management because winter and spring run Chinook require deep holding pools during summer low flow periods.

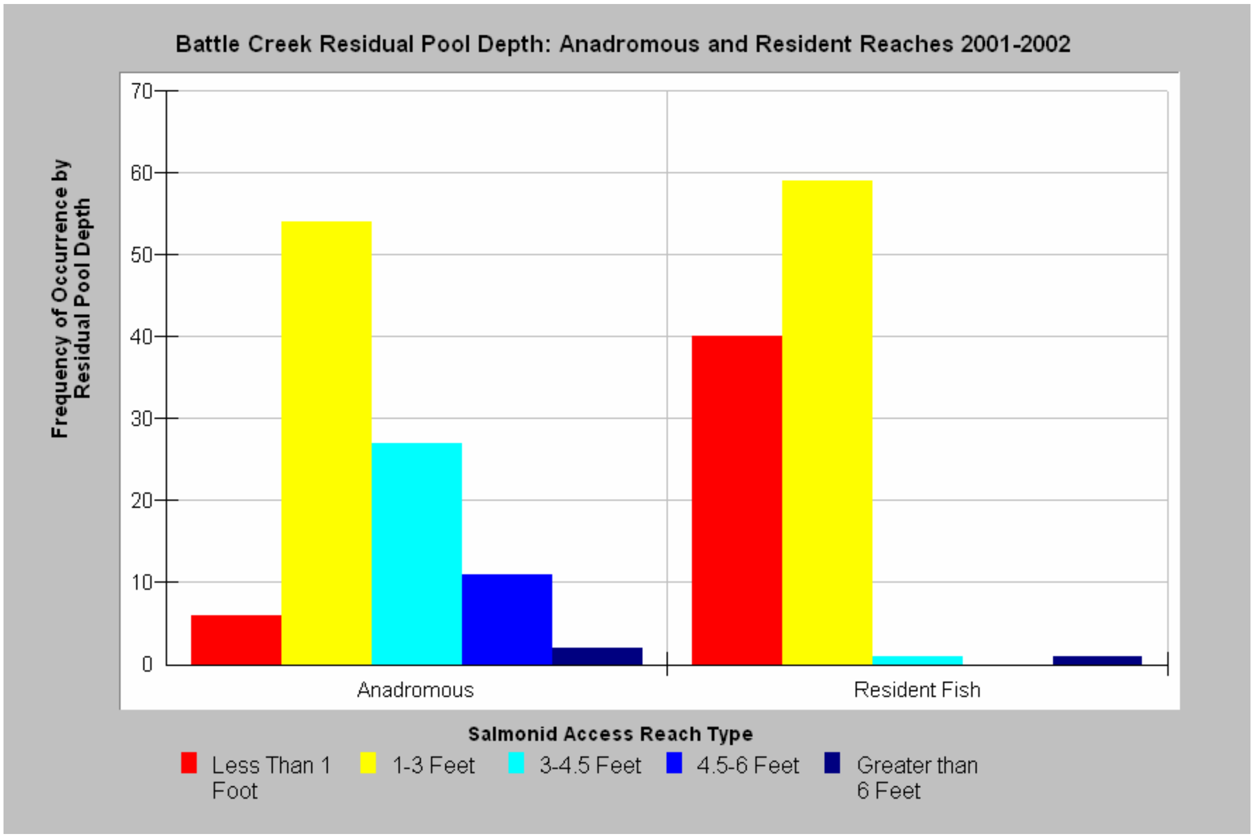

Figure 18. Pool frequency of occurrence by depth at all 50 Battle Creek sites monitored by Terraqua (2004) shows fully unfavorable conditions at 40% of resident trout sites and at 60% of sites accessible to anadromous fish (<3 ft. deep). Chart from KRIS Battle Creek V 2.0.

Cumulative Watershed Effects and Potential for Maintaining and Restoring Battle Creek Winter run Chinook Salmon

Although Terraqua (2004) was limited in scope to assessing sediment sources and gathering and interpreting aquatic baseline data, the data they collected clearly show a pattern of widespread cumulative effects damage as evidenced by poor ratings for salmonid suitability throughout the Battle Creek basin. Cumulative watershed effects (CWE) related to timber harvest have been the subject of three recent California studies (Ligon et al., 1999; Dunne et al., 2001; Collison et al., 2003), which all describe the lack of effectiveness of California Forest Practice Rules (FPR) in protecting aquatic habitat and salmon and steelhead populations. The Timber Harvest Permit (THP) process set up under the California FPR's are supposed to serve in lieu for the California Environmental Quality Act (CEQA), which specifically acknowledges and defines CWE:

- “Cumulative impacts’ are defined as ‘two or more individual effects which, when considered together, are considerable or which compound or increase other environmental impacts.

- Individual effects may be changes resulting from a single project or a number of separate projects.

- The cumulative impacts from several projects is the change in the environment which results from the incremental impact of the project when added to other closely related past, present, and reasonably foreseeable future projects. Cumulative impacts can result from individually minor but collectively significant projects taking place over a period of time."

<u>Regional Literature on Cumulative Watershed Effects:</u> Ligon et al. (1999) studied California CWE problems related to timber harvest and found them to be driven by the extent of disturbance and that they may be manifest in channel systems well downstream and offsite. Ligon et al (1999) said that "FPRs, particularly in their treatment of assessing cumulative effects, are not adequate to ensure achievement of properly functioning habitat conditions for salmonids" and the "primary deficiency of the FPRs is the lack of a watershed analysis approach capable of assessing cumulative effects attributable to timber harvesting and other non-forestry activities on a watershed scale."

Dunne et al. (2001) defined potential damage of CWE from forestry:

> "Watershed impacts that have been shown to result from timber harvest (and other land–cover manipulations) include effects on: sediment, water temperature, in-channel volumes of organic debris, chemical contamination, the amount and physical nature of aquatic habitat, and increases in peak discharges during storm runoff."

They also state that California FPRs do not deal with "the need to protect the runoff regulating functions of forests." Dunne et al. (2001) caution, however, not to attribute all flood damage during large storm events to natural causes: "If the analysis of the resulting, unwelcome changes is reduced to defining which of these agents is 'to blame', it misses the point that a land-cover change and associated infrastructure can often increase the risk of a landscape's unwelcome response to rainstorms."

Reeves et al. (1993) described decreased species diversity of Pacific salmon in Oregon coastal watersheds when more than 25% of the watershed area was logged over a 30 year period. Swanson et al. (1998) found major CWE damage from a 1996 storm event to stream channels in the Oregon Cascades in a watershed that was 20-30% logged. Dose and Roper (1994) found channel changes in response to logging in the SF Umpqua River basin, and loss or reduction of three of four anadromous salmonid populations. Further work in the Cascades of Oregon by Jaeger and Fluharty (2002) discovered that standing crops of salmonids were much higher in streams flowing from undisturbed forest and concluded that: "Timber harvesting has had significant, long-term, detrimental impacts on salmon populations due to their impact on freshwater habitats." . Frissell (1992) noted that resilience of salmonid populations is diminished if all sub-basins of a watershed are disturbed in a relatively short period of time, and no intact areas are available to serve as refugia.

Kondolf et al. (1996) asserted that CWE due to timber harvest in the Sierra Nevada Ecosystem were "widespread but poorly documented." They faulted the U.S. Forest Service for not conducting more comprehensive studies on CWE in the region despite their significant ownership. Dunne et al. (2001) also critiqued the USFS Equivalent Road Acres (ERA) CWE assessment as ineffective. Lassen National Forest, however, has begun to study CWE and is taking preventative measures to reduce damage from logging and roads in the Battle Creek watershed (Napper, 2001).

Road related CWE, such as increased sediment yield or changes in frequency of peak flows, may be more long lasting than perturbations related to timber harvest (Jones and Grant 1996), where watershed hydrology and erosion may return to normal as the forest re-grows (Dunne et al., 2002). Montgomery (1994) ascertained that drainage densities were increased by 20% to 67% in streams flowing from watersheds with high logging road densities and that partially decommissioned road beds not in active use still intercepted flows and routed them to streams. Gucinski et al. (2002) noted on a regional scale that there had been a "40% extension of the stream network length in a Cascade Range watershed" as a result of logging roads capturing streams. Montgomery and Buffington (1993) described the consequences: "The increased erosion and greater drainage density resulting from channel network expansion may greatly increase sediment delivery and alter hydrograph characteristics for downstream channels." Increases in peak flows are of even more likely, if high road densities occur in the transient snow zone (Jones and Grant, 1996). Collison et al. (2003) note that watershed rest or controlling the rate of harvest may be necessary to protect and improve water quality.

Reynolds (2001) cautioned against attempting watershed analysis without having the data suitable for analyzing all critical factors: "Tailoring analyses to suit existing data is undesirable because the assessment becomes driven by the data at hand rather than the questions that are really of interest."

<u>Battle Creek Cumulative Watershed Effects and Salmon, Steelhead and Trout</u>: Napper (2001) noted cumulative watershed effects from previous land use in upper South Fork Battle Creek tributaries as a result of the January 1, 1997 storm:

> “Pulse sedimentation has occurred in the analysis area as a result of rain on snow events that overwhelmed the drainage features on the roads in the area. Large amounts of material including snow melt, debris, and bedload began to move through the fluvial system. Where roads intercepted this process, many of the drainage structures were breached and the channel either removed large road fills, or was diverted. As the stream cut a new channel tremendous volumes of sediment entered the system. Although every system receives some sedimentation due to natural processes this was above what would occur naturally.”

No basin-wide post-1997 storm study was conducted in the Battle Creek watershed, but the pattern of impacts suggests that rain-on-snow effects extended well above the typical transient snow zone elevation. Rain on snow effects would also be expected to extend to lower elevations where intensive land use is widespread. Figure 19 shows Landsat derived vegetation and tree size data (Warbington et al. 1998) with multiple patches showing non-vegetated conditions in upper Onion Creek in the rain-on-snow zone. The companion orthophoto (Figure 20) shows bare ground due to landings, roads, recent logging and poor re-growth of forests. The end result is an enormous cumulative effects risk for both sediment yield and increased peak discharge.

The question of the periodicity of the January 1997 storm is a major one in Battle Creek. If the storm was of moderate recurrence interval (35 year event) like the Klamath Mountains (de al Fuente and Elder 1998) and yet caused enormous channel damage, then it represents a major problem for salmon recovery. Channel morphology may take two to three decades to recover (Reeves et al. 1995), but channel resets may occur during recovery or shortly thereafter, if watershed hydrology is altered and increased flood frequency and magnitude is resulting.

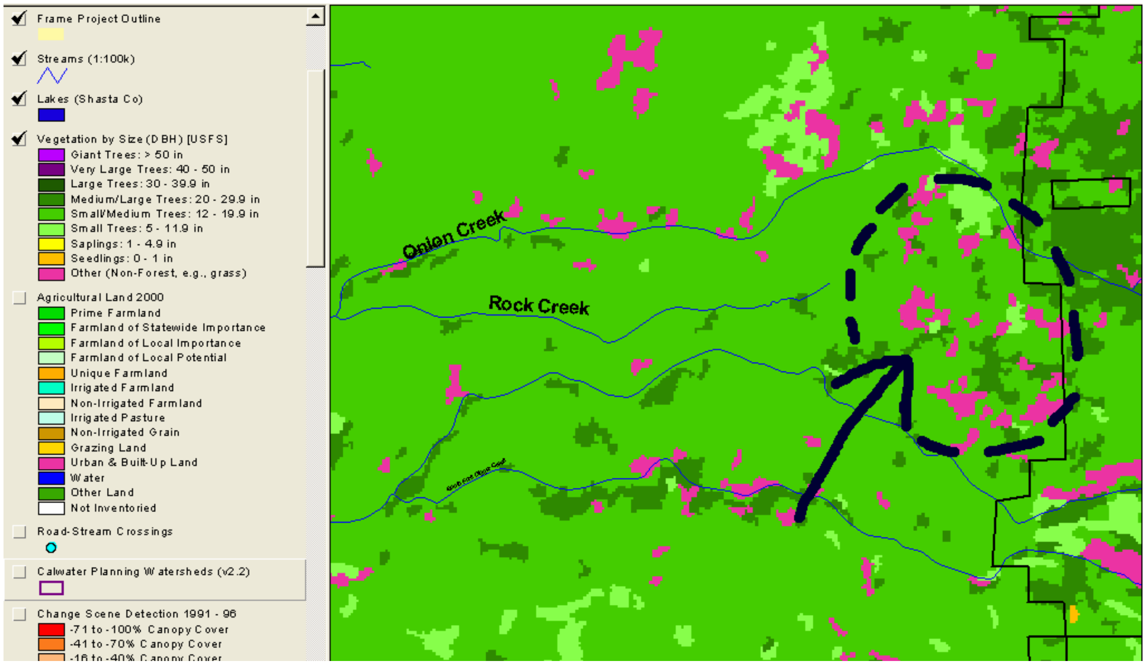

Figure 18. Vegetation type and tree size based on 1996 Landsat data in upper Rock, Onion and Digger creeks shows large trees on USFS lands to the east (right) and few large trees on private industrial timber land to the west. Each pixel in this coverage represents one hectare.

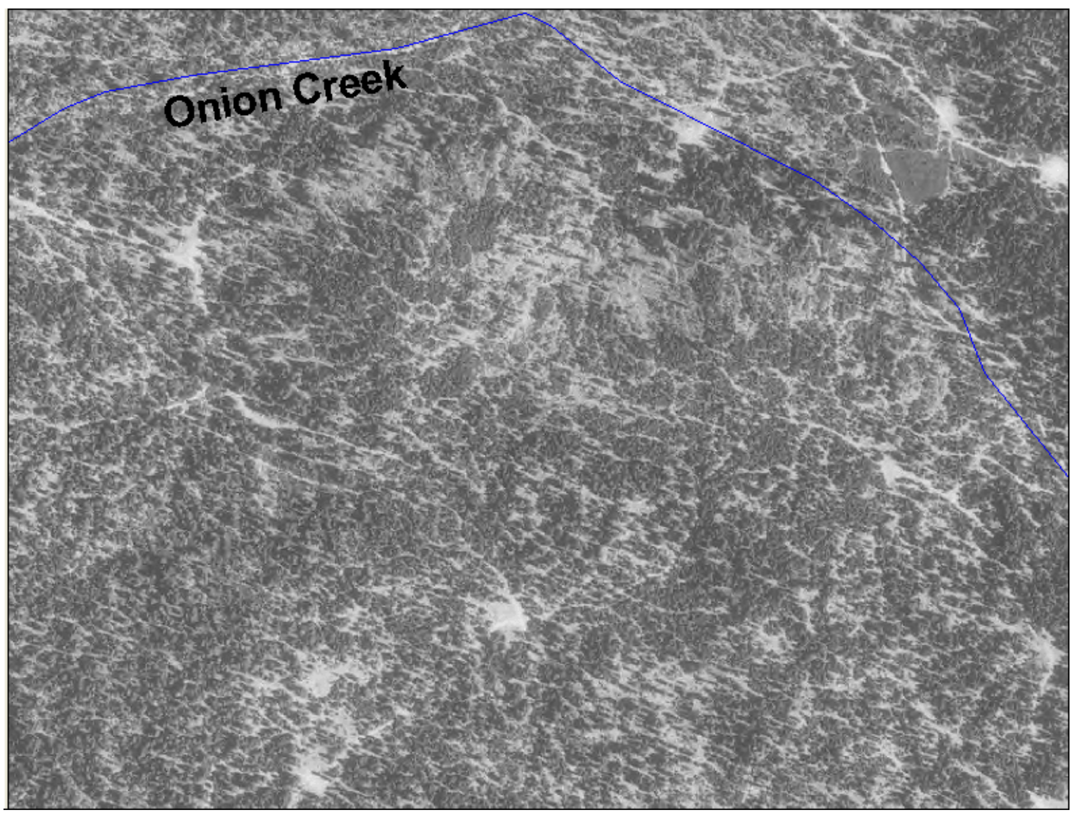

Figure 19. Zoom in near Onion Creek showing extensive bare areas that are of concern with regard to erosion potential and changes in patterns of runoff, especially since this area is in the rain-on-snow zone.

Need for Improved Data Tools for Future Analysis

Geographic information system data used for reconnaissance of watershed conditions in Battle Creek by Kier Associates (2003) was not optimal for quantifying landscape conditions because of critical data gaps or quality of data. Short comings included:

- Lack of 10 meter digital elevation model (DEM) data, which prohibited accurate, basin-wide stream gradient calculation and prevented use of the shallow landslide stability model (SHALSTAB) to help assess risk on slopes susceptible to debris flows;
- Lack of accurate hydrology data, preventing quantitative assessment of riparian conditions using remote sensing data; and
- Lack of timber harvest data, which could be only partially remedied using USFS and CDF Landsat derived vegetation data. Consequently, widespread logging in the Battle Creek watershed could not be quantified.

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