APPENDIX B

Water Quality

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1. Introduction

The watershed of the Yankee Fork has been home to mining activities since the 19th century. The Yankee Fork and its tributaries were placer mined in the early 1870s. Later, several hard rock mines were opened in the watershed beginning in the 1880s. For almost a decade, during much of the 1940s to the early 1950s, a floating barge dredge operated in the Yankee Fork. These mining activities have potentially led to elevated concentrations of trace elements such as mercury and selenium in the watershed. Although the processes that may have led to the elevated concentrations for these elements are significantly different and could result in drawing different conclusions for each element when considering remediation or undertaking habitat projects in the watershed.

In the case of mercury, mining activities included the use of mercury as an amalgamating material to increase the capture of gold particles from the dredging, smelting, and milling operations. Consequently, these activities may have led to localized concentrations of mercury near the old stamp mills and smelters in addition to potentially elevated concentrations in the dredge spoils. Selenium, on the other hand, is naturally occurring in the watershed and not used in any mining related process. However, the mining activities have potentially led to elevated concentrations in the watershed due to the mining activities increasing the exposure of parent material that is high in selenium to leaching, weathering, and other erosion processes.

It is also important to recognize that mercury and selenium are both naturally occurring elements. Because of this, decay processes such as oxidation or reduction do not destroy them. Both exist in multiple oxidation states and have complex geochemical cycles involving inorganic and organic forms. Multiple forms of each exist in the aquatic environment as well as the terrestrial environment. Both mercury and selenium also have forms that readily bioaccumulate in the aquatic food web. In addition, selenium is an essential micronutrient necessary for an organism's cellular function and is metabolically important in the formation of several enzymes.

While forms of both elements may bioaccumulate, other factors may exist to limit or inhibit bioaccumulation deferentially to one element or the other. For example, the more toxic forms of selenium occur in oxidizing environments (Van Deveert and Canton 1997). The oxidization state of selenium also affects the compounds' mobility and bioconcentrations in aquatic environments (Oremland et al. 1989). On the other hand, methylmercury, the most toxic form of mercury, is generated in the aquatic environment through microbial action under anoxic and reducing conditions (Wiener et al. 2006). In addition, there is growing evidence that selenium concentrations may inhibit the biological assimilation or toxicity of mercury (Berlin 1978; Cuvin-Aralar and Furness 1991).

1.1 Background

Due to the rich mining history and the geological setting in the Yankee Fork Drainage, some concern has been voiced about the potential for elevated mercury and selenium concentrations in the watershed. A report recently published by the U.S. Geological Survey (USGS) investigated this very concern (Frost and Box 2009). In an additional study conducted by the USGS, the concentrations of various trace metals were investigated in the fish tissues and biota of the Yankee Fork drainages (Rhea et al. 2008). These and other reports were reviewed to determine the extent and magnitude of mercury and selenium concentrations in the sediments of the Yankee Fork. In addition, these and other reports were reviewed to determine the expression of those mercury and selenium sediment concentrations into the food web and biota of the drainage. Finally, a literature review was conducted to determine the toxic endpoints for each of these trace elements and any factors that may mitigate or reduce any risks in exposing the sediments during habitat improvement projects.

Through the review of existing reports and studies, it was determined that, ultimately, the extent to which mercury and selenium might be released into the watershed is dependent upon the mercury and selenium found within the soils and sediments associated with any habitat improvement project. The USGS assessed the sediment along both the Yankee Fork and Jordan Creek drainages for trace elements. These findings provide the clearest picture of mercury gradients associated with milling, dredging, and mining operations. In that same report, the USGS found that selenium, rather than existing along a gradient associated with anthropogenic disturbance, is more likely found in undisturbed alluvium and in the sediments retained by the existing ponds and pools in both stream systems.

1.2 Bioaccumulation

Mercury and selenium are both considered bioaccumulative elements (Lemly 1987 and Morel et al. 1998). In general, this means that the concentration of these and other elements increases in the tissues of organisms the higher in the food chain an organism exists. However, these bioaccumulative elements do not increase in the food web equally. Mercury bioconcentrates more strongly than selenium; that is increases in concentration from water to algae, it then further concentrates or bio-magnifies so that in fish tissue, it is tens-of-thousands to hundreds-of thousands times greater than its concentration in water (EPA 2000). While selenium does bioaccumulate, its role as a micronutrient leads to some loss from an organism. As a result, selenium concentrations are much lower and can be upwards of 40,000 times greater in the bodies of aquatic organism in comparison with concentrations found in water (Exponent 2010).

The chemical form of an element affects the process of bio-concentration and then bio-magnification, and so does the conversion from inorganic to organic forms. This is especially true in the case of elemental mercury's conversion to its organic form of methylmercury (Morel et al. 1998). The oxidation states of selenium play a big role in the compounds' mobility and thus toxicity in aquatic environments. Organic forms of selenium bioconcentrate more strongly than inorganic forms, but little is known of the ambient concentrations of organic forms (Lemly 2002). Selenate may be more of a problem than selenite in aquatic environments simply because selenate is the predominant oxidation state, coupled with greater solubility leading to higher bioavailability. Although, in some laboratory toxicity tests, selenite is more acutely toxic than selenate (EPA 2004), but those tests ignore dietary exposure of fish, which may be the more important pathway for selenium toxicity (Stewart et al. 2004).

Methylmercury is the most toxic form of mercury, and it also bioaccumulates more strongly than inorganic mercury (Morel et al. 1998). Methylmercury is generated from inorganic mercury in the aquatic environment through microbial action. Mercury is also chemically and environmentally unique due to its volatility. The natural environmental cycle of mercury involves air as well as water, biota, and sediment, with re-emission from soil and water causing recycling to the atmosphere.

Because of mercury's volatility and mobility, much of the mercury released to the air ends up in water and ultimately fish (Morel et al. 1998). This volatility and mobility lead to an elaborate chain of transport, wet and dry deposition, re-emission, biochemical conversion to methylmercury, and then uptake and biomagnification in the aquatic food chain which makes unraveling mercury in fish tissue exceedingly complex.

Selenium is also unique among these bioaccumulative contaminants in that it is an essential micronutrient for animals in low doses (Lemly 1993). Selenium quickly becomes toxic at only moderately higher intake levels (Lemly 1993). The lower rates of selenium biomagnification may be explained by an organism's physiology working to control selenium concentration in their tissues.

1.3 Chemical Concentrations

There have been several mercury and selenium studies conducted in the Yankee Fork watershed. In 2001, the USGS conducted a sediment-sampling program within the watershed (Frost and Box 2009). In this study, they found mercury ranging from 0.02 milligram per kilogram (mg/kg) to 7 mg/kg. The consensus based probable effects level (PEL) for mercury in sediments is 0.486 mg/kg while the threshold effects level (TEL) is 0.174 mg/kg (MacDonald et al. 2000). The USGS found mercury concentrations in the fine-fraction sediment samples much higher than in the medium-sized fractions (see Figure 1 and Figure 2). In addition, Frost and Box (2009) determined that generally mercury concentrations were elevated downstream from town sites, mills, and mines. The results were that 28 of the 69 samples collected by the USGS in this study fell below the TEL. These samples were mainly collected in undisturbed alluvium, at upstream reference locations upstream from the Custer town site, in the West Fork of the Yankee

Fork, and in Jordan Creek upstream from the Grouse Creek Mine. Thirteen of the 69 samples exceeded the PEL and several were located in close proximity to the town site of Custer. Several other mercury hot spots were located in the downstream areas of the mainstem near the Polecamp Flat and Flat Rock campgrounds. The remaining 28 samples were below the PEL but above the TEL. For the most part, these samples were collected in the mainstem Yankee Fork downstream from the Custer town site and downstream from the Jordan Creek confluence.

As a comparison, the USGS also sampled sediments downstream from Sunbeam Hot Springs, a geothermal spring on the mainstem Salmon River approximately one mile upstream from the confluence with the Yankee Fork. Geothermal springs introduce mercury into the aquatic environment through hydrothermal activities and are known to naturally contain elevated mercury. For example, geothermal springs in the Salmon Falls Creek watershed of Idaho have water-column mercury concentrations of 12 to 16 ng/L while the nearby Shoshone Creek and Salmon Falls Creek had mercury concentrations of 2 to 4 ng/L (Lay and Shumar 2007). In the Salmon River downstream from the Sunbeam Hot Spring, the USGS found mercury concentrations in the sediments of 4 and 5 mg/kg. In some cases, the sediments of the Yankee Fork contained much higher levels of mercury than the sediments downstream from the natural mercury sources cited here.

The results of the sediment survey indicate that mercury in the mainstem downstream from Custer and in Jordan Creek downstream from the Grouse Creek Mine may pose a risk to the benthic biota and mercury is potentially available to bioconcentrate. The USGS did not discuss the bioavailability of mercury in this study of the Yankee Fork. However, the study does confirm that mercury is common, at moderate to low levels compared to sediment PEL, throughout the watershed. However, the USGS did find localized hot spots in several locations along the mainstem and Jordan Creek. Other factors such as selenium antagonism (selenium inhibition of methylmercury assimilation), low organic carbon, and limited methylation may reduce the mercury hazard in this watershed. Ultimately, fish tissue mercury concentrations are the expression of concentration of mercury in the sediment or water of a system and the intervening factors that reduce or eliminate its bioconcentration.

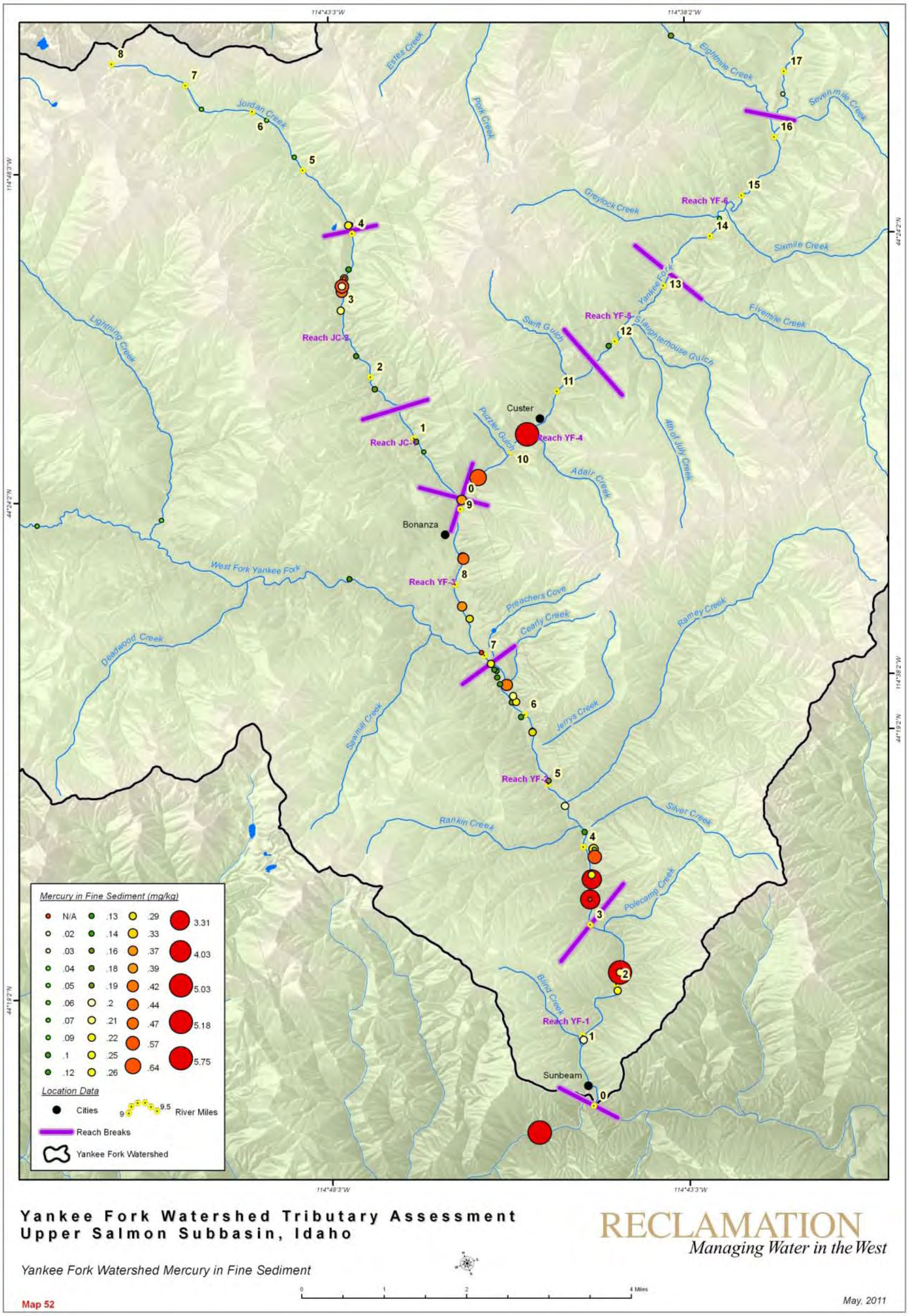

Figure 1. Mercury concentrations found in fine sediment fraction (adapted from Frost and Box 2009)

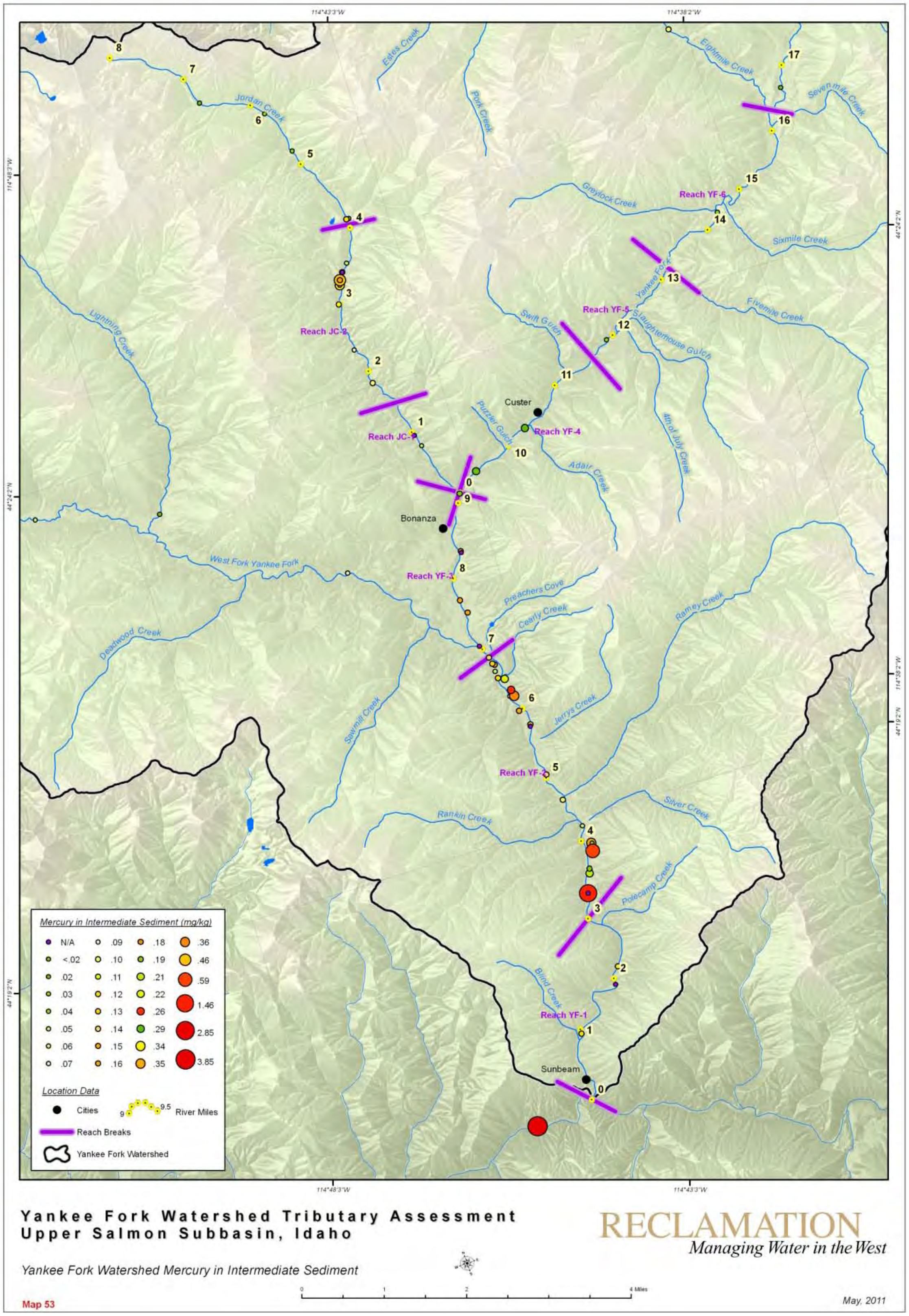

Figure 2. Mercury concentrations found in intermediate sediment fraction (adapted from Frost and Box 2009)

Selenium sediment concentrations found by Frost and Box (2009) ranged from 0.2 to 4.25 mg/kg. The highest concentrations were found in undisturbed alluvium samples and in pond sediments. Mainstem samples were all below 1 mg/kg and showed no spikes of selenium in relation with disturbance sites around town sites, mills, or mines like mercury did in the fine-fraction sediments (see Figure 3 and Figure 4). Aside from the differences in selenium concentration between pond sediments and riverine sediments, the most discernable trend appears to be elevated selenium in the disturbance zone near and upstream from the Grouse Creek Mine and decreasing concentrations in samples collected downstream along Jordan Creek through to the ponds and undisturbed alluvium along the lower portions of the mainstem Yankee Fork. However, in this study, all samples but one from the undisturbed alluvium were below the high hazard or observed affect level of 4 mg/kg dry weight derived by Van Derveer and Canton (1997). The low hazard predicted adverse effect level of 2.5 mg/kg (Van Derveer and Canton 1997) was exceeded only in pond sediments, undisturbed alluvium samples, and one sample collected downstream from the Sunbeam Hot Spring.

The USGS data seems to indicate that selenium is present throughout the watershed in low to moderate levels and may be accumulating in pond sediments or simply that the ponds are closer to a localized natural high concentration. The slow accumulation of selenium in the pond sediments is likely, as the reducing environment of the pond sediments should lead to the reduction of selenate to selenite and potentially into insoluble elemental selenium (Lortie et al. 1992).

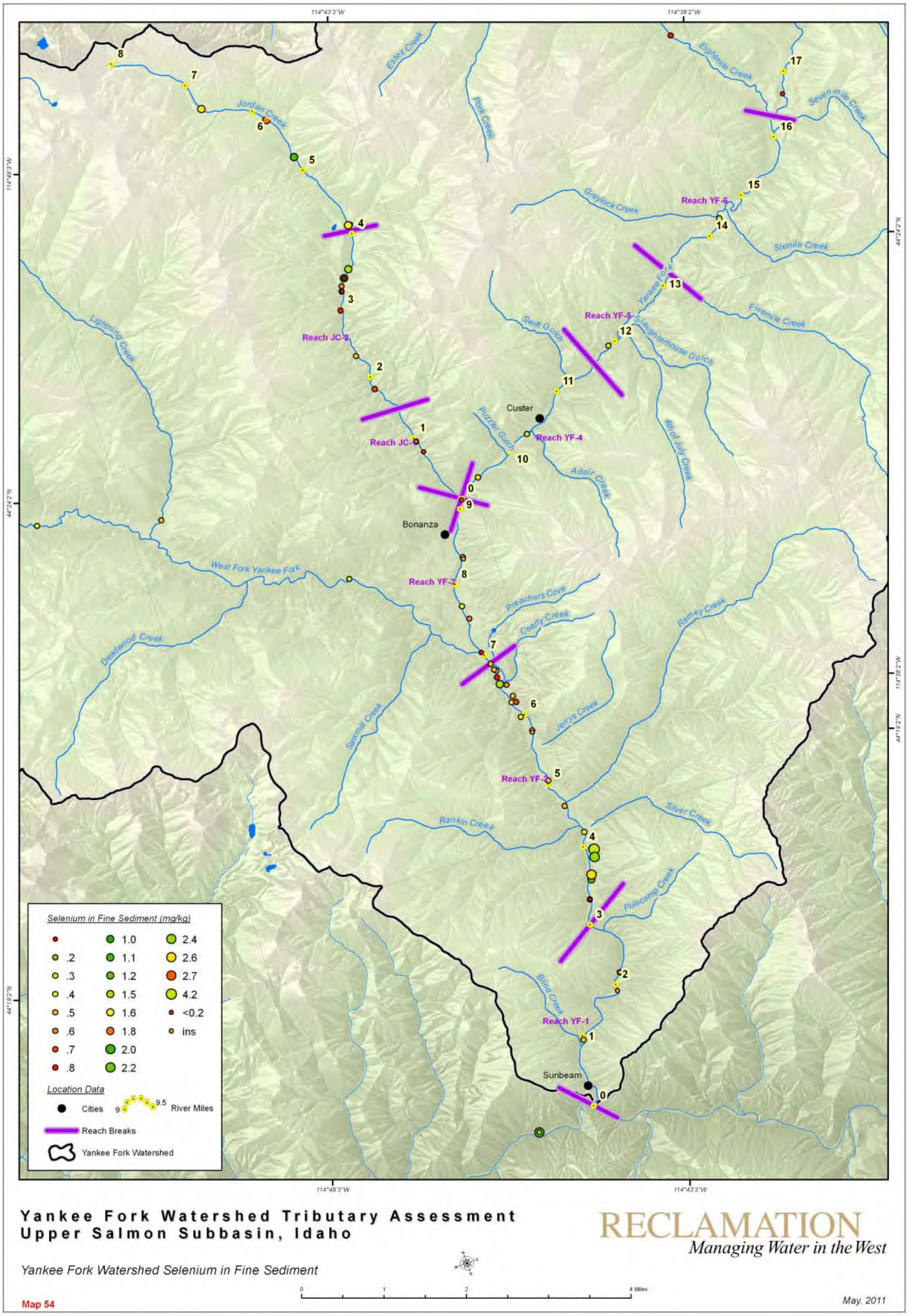

Figure 3. Selenium concentrations found in fine sediment fraction (adapted from Frost and Box 2009)

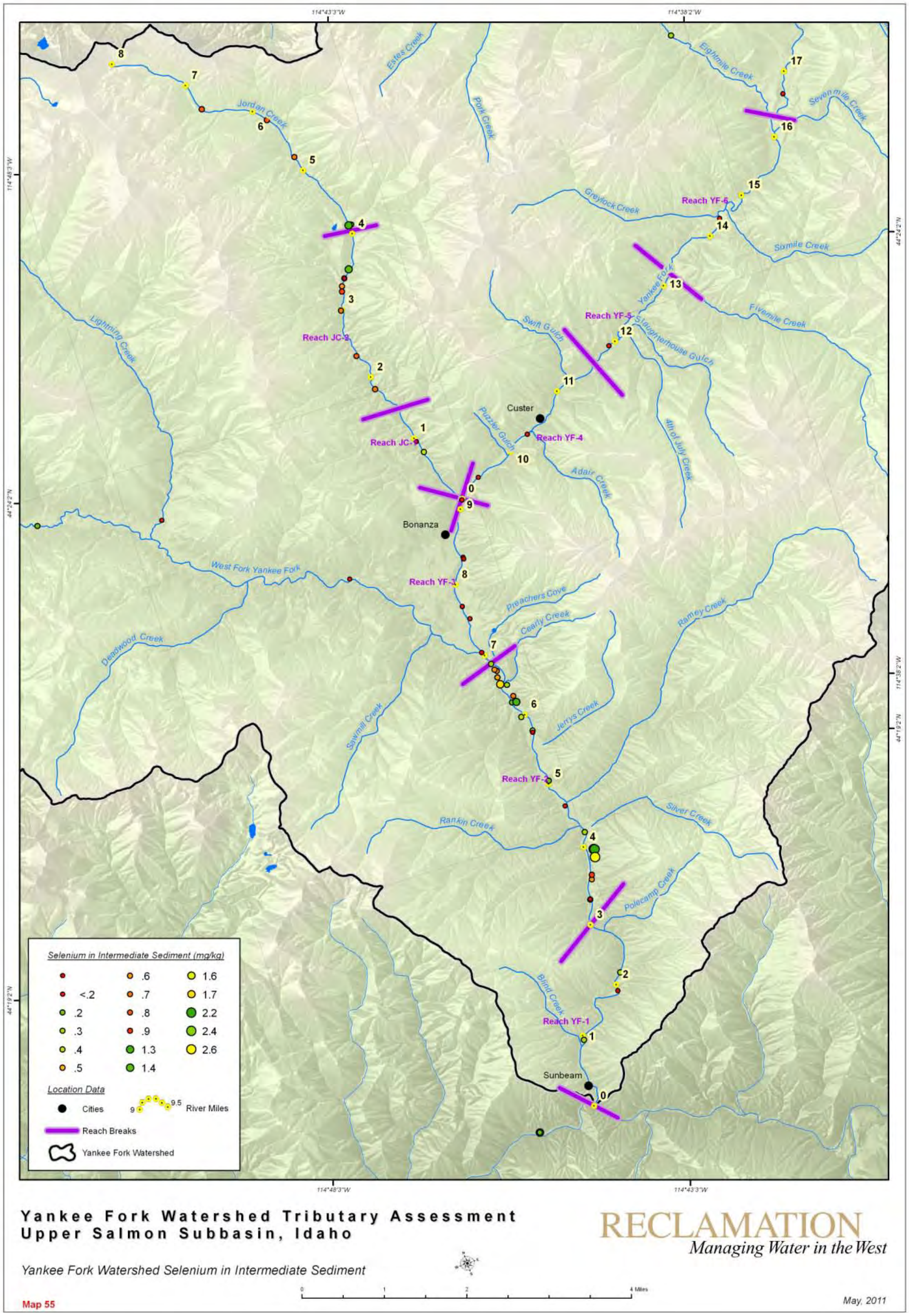

Figure 4. Mercury concentrations found in intermediate sediment fraction (adapted from Frost and Box 2009)

Another USGS study conducted in the Yankee Fork in 2001 and 2002 (Rhea et al. 2008) looked at the mercury and selenium concentrations found in biofilm, macroinvertebrates, and fish tissues. A study such as this should provide an expression of ambient concentrations of these trace elements into the biofilm and tissue of the biota of the Yankee Fork. Based on the sediment concentrations of these two trace elements and the fact that they both bioconcentrate, it should be expected that mercury concentrations will be higher in the biofilm and then higher in each succeeding trophic level, to potentially approaching levels that affect aquatic life and human health concern criteria in the third trophic levels. Selenium on the other hand, should be only marginally elevated and below any toxicity thresholds. However, this was not the case in this study of the Yankee Fork.

In the 2008 USGS study, Rhea et al. collected samples near the Custer town site as a background or reference location. Unfortunately, this site corresponded to some of the highest mercury sediment samples collected in the previously described study. At the Custer town site sample location, USGS found the highest values for mercury in the biofilm and macroinveretbrates in comparison with the other downstream and pond locations. Mercury concentrations in the biofilm at the Custer town site were 0.1075 and 0.105 mg/kg wet weight in the two years of sample collection. Once methylated, mercury is readily incorporated into the lowest trophic levels or biofilms composed mainly of diatoms, simple algal cells, and other microorganisms. It is often seen in many lakes that the biomagnification of meHg is a factor of 100,000 in the algae and a factor of 10 in each following trophic level (Environment Canada www.ec.gc.ca/ceqg-rcqe). Trophic level two organisms are those species that are considered herbivores; trophic level three fishes are those species which consume zooplankton, macroinvertebrates, or small herbivorous fishes; and trophic level four fishes are those species which are normally piscivorous and consume both trophic level two and trophic level three fishes.

In the Yankee Fork, the mercury concentrations (0.06 and 0.0625 mg/kg) found in the macroinvertebrate community, which are predominantly trophic level two organisms, were much lower than in the biofilm or at trophic level one over the same two-year period. Fish tissue mercury concentration, due to biomagnifications, would have been predicted to increase by a factor of ten as well, but in this study, concentrations in the third trophic level remained near 0.07 mg/kg wet weight.

The U.S. Environmental Protection Agency (EPA) and the State of Idaho’s criteria for mercury in fish tissue is 0.3 mg/kg wet weight. Although this criterion is a human health criterion, the Idaho Department of Environmental Quality (IDEQ) argues that it is also protective of aquatic life. The current Idaho aquatic life criterion for chronic exposure to mercury is 0.012 µg/L, and for acute exposure is 2.1 µg/L. However, in some Idaho cases it has been documented that the fish tissue human health criteria is exceeded, while the chronic exposure mercury criteria is not exceeded. In Salmon Falls Creek Reservoir, walleye exceed 0.3 mg/kg and can be found with mercury concentration approaching 1.25 mg/kg (Lay and Shumar 2007). In this same reservoir and in the tributaries feeding the system, mercury concentrations ranged from 0.001 to 0.010 µg/L (Lay and Shumar 2007). As a result, IDEQ has attempted to set their aquatic life criteria for mercury at the tissue based human health concern criteria of 0.3 mg/kg. In this Yankee Fork assessment, we must rely on concentrations found in fish tissues and sediments as water column data could not be located at this time. As water column data is collected, a comparison with both the chronic and acute aquatic life criteria can be made.

Setting the argument concerning the protectiveness of the human health concern criteria aside, the values reported by the USGS indicate that there is little bioconcetration of mercury from the sediments to the fish tissues in the Yankee Fork. In comparison with the EPA and State of Idaho human health concern criteria, there is little or no risk to human health and the aquatic environment from mercury in the fish tissues of the second and third trophic level fishes analyzed in the Yankee Fork watershed. The mechanism that is causing the lower than expected mercury accumulations is still unknown at this time.

The USGS studied both sculpin and whitefish in 2008. Most fish biologists would consider both of these species trophic level three fish as their diets consist mainly of macroinvertebrates. Whole body mercury tissue concentrations for both species were low ranging from 0.07 to 0.1 mg/kg wet weight for whitefish and 0.08 to 0.16 for sculpin. In comparison, the EPA, as part of a larger stream and river survey, conducted a fish tissue survey from 626 streams and rivers in 12 western states. In this study, trophic level three, nonpiscivorus fish, averaged 0.09 mg/kg (Peterson et al. 2007), and only 26 percent of the stream miles assessed contained nonpiscivorus fish with tissue concentrations greater than 0.1 mg/kg. This may indicate that in the Yankee Fork, the mercury concentrations found in whitefish represent reference conditions seen across the western United States. In addition, most of the data from the sculpin samples were very low and in this same category. However, sculpin concentration data also reflect the localized hotspots within the watershed.

Aside from the low mercury tissue concentrations found in the Yankee Fork, important information can be obtained in comparing these two species. These two fish are very different in size, shape, and mobility. Whitefish are larger and more mobile in comparison with the Shorthead sculpin. In Rhea et al. (2008), it appears that the less mobile sculpin collected near Custer have higher mercury tissue concentrations than sculpin collected in other areas within the Yankee Fork drainage. Variation within the sculpin samples was small but pronounced; in that most of the variation was the result of the samples from the Custer site. In comparison, the more mobile whitefish mean mercury tissue concentrations were not significantly different from that of the sculpin ($p = 0.066$). However, variation within the whole body tissues samples of sculpin was an order of magnitude less than whitefish. What this may indicate is that the whitefish may be a better watershed model as they may represent the mercury contamination integrated from a wider area of the drainage, while sculpin are better models for mercury hot spots within the watershed. In contrast, if future studies are directed at hot spot localization, then sculpin would likely be a more appropriate model in that they would integrate the mercury concentration from a smaller portion of the watershed.

In contrast, fish tissue selenium accumulations reported by the USGS in the 2008 study are markedly different from the mercury concentrations. Selenium concentration guidelines developed by the EPA are twofold. If any sample exceeds 5.85 mg/kg dry weight, wintertime samples are recommended. Secondly, the average whole fish concentration should be less than 7.91 mg/kg dry weight at all times. Other authors have suggested 3 mg/kg as a threshold for diet items of fish (Lemly 1993) in addition to the whole fish criteria developed by EPA. This may be overly conservative as Hilton et al. (1980) showed chronic selenium toxicity occurring at 13 µg/g in the dry feed of rainbow trout.

The USGS found mean selenium concentrations in the biofilm at four locations along the mainstem Yankee Fork, which ranged from 0.27 to 0.68 mg/kg dry weight. Mean selenium concentrations reported from the rearing ponds were significantly higher in comparison to the mainstem samples of biofilm and were 3.41 and 1.99 mg/kg dry weight. The reduction of selenate to selenite may explain the differences in the rearing pond biofilm samples. The uptake of selenate (likely the dominate form of selenium in the river sediments) by aquatic plants in the river system is lower than the uptake of Selenite in the pond system (the likely dominate form of selenium in the pond sediments).

The samples collected from the macroinvertebrate tissues in the mainstem were all above the recommended diet item threshold concentration of 3 mg/kg dry weight. This indicates that there is a significant bioaccumulation from the very low sediment concentrations to moderately low biofilm concentrations and to high concentrations in the second trophic level organisms in the river. However, the macroinvertebrate tissue samples collected from the rearing ponds were significantly lower (1.88 and 2.71 mg/kg dry weight) than the means from the river samples collected the same year (4.15 and 4.66 mg/kg dry weight). The mechanisms that would explain the low values in the pond system is unknown, but may be related again to the reducing environment and the likely form of selenium in the pond systems being selenite or even elemental selenium and differential bioaccumulation rates of selenite in comparison with selenate in the river.

The jump to the next trophic level, in some cases, begins to exceed the EPA recommended criteria of 5.85 mg/kg dry weight, which would require wintertime samples collected to ensure adequate critical period information is collected. However, the samples collected never exceeded the 7.91 mg/kg dry weight criteria. It is unclear if the fish collected for this study included fish collected in the wintertime. Whole fish concentrations for whitefish ranged from 3.92 and 5.05 mg/kg dry weight in the rearing ponds and 6.49 and 6.58 mg/kg dry weight for river system whitefish. A second year of whitefish collection from the river system resulted in mean selenium concentrations ranging from 4.78 to 6.13 mg/kg dry weight. Again, the USGS found a slightly lower to significantly lower concentration of selenium in the whitefish of the rearing pond in comparison with those found in the river system.

The mean selenium concentrations in whole shorthead sculpin collected from the river system in both years were similar to the concentrations found in the river system whitefish, and ranged from 5.38 to 7.10 mg/kg dry weight.

The Hecla Mining Company also sponsored several years of mercury and selenium monitoring in the Yankee Fork. Three monitoring locations were surveyed several times a year beginning in 2000 running to 2008 (GEI Consultants 2009). As with the USGS samples the upstream location was near the Custer town site, the middle site was located 1.5 km downstream from the Jordan Creek confluence, and a downstream rearing pond near Clearly Creek were sampled. Because of the site convergences between all the studies, the results from the different efforts can be compared.

Sediment mercury concentrations were much lower on average than the 2001 USGS study, but still within the range of their reported values from the whole of the Yankee Fork. GEI found mercury in the upstream location from 0.10 to 1.51 mg/kg while the sites near Custer investigated by the USGS were reported to be between 1 to 6 mg/kg. In the Hecla findings, the consensus based PEL for mercury was exceeded only in the replicate samples collected by the consultants in October 2000 and April 2001 (GEI Consultants 2009). In addition, only one additional set of replicate samples, collected in August 2005, exceeded the TEL for mercury. The remaining seven replicate sets were below levels that would indicate risk. At the rearing pond, nearly all replicate sets averaged above the TEL for mercury. These pond sediment results were more consistent with the 2001 USGS report.

The Hecla studies also collected fish tissue at the same two riverine sample locations, the uppermost site corresponds with Rhea et al.'s (2008) uppermost site as well. The Hecla study found fish tissue mercury concentrations from less than 0.05 to 0.14 mg/kg. All these values are well below the Idaho Human Health Criteria and are near the range measured by the USGS for whole body concentrations of white fish (0.07 to 0.08 mg/kg wet weight). Samples collected for Hecla cover a wider range of years and seasons than the USGS samples, but convey the same information that the mercury accumulation into the fish community is low at presumably one of the most impaired locations in the watershed.

In addition, the Hecla study investigated selenium concentrations at the two Yankee Fork river sites and the one rearing pond location. The mean values from the river samples were all very low at both sites. Mean values were below 1 mg/kg and in most cases were much lower. The range mean values from the river samples were less than 0.10 to 0.81 mg/kg dry weight (GEI Consultants 2009). Similarly, the USGS found selenium concentrations in the river segments below 1 mg/kg as well. As with the USGS study, the Hecla consultants reported much higher mean selenium values from the rearing pond sediments. The range of mean values from the pond sediments in this study was 0.60 to 1.90 mg/kg dry weight. The USGS found selenium concentrations from pond sediments to range from detection limits to 2.6 mg/kg dry weight. The lower concentrations were found in the more upstream ponds studied by the USGS and would include the pond sampled for Hecla.

As seen in the USGS bioaccumulation study, the Hecla study also clearly indicates that selenium is bioaccumulating in the whitefish from the river sites. Dry weight selenium concentrations over the study period ranged from 5.43 to 10.38 mg/kg dry weight. In many cases, the EPA recommended criteria of 5.85 was exceeded, indicating the need for wintertime samples. Furthermore, in August of 2007, the mean whole-body selenium concentrations at both river sites exceeded the recommended EPA selenium fish tissue criteria of 7.91 mg/kg dry weight. No fish tissue data were presented for the pond system.

1.4 Mercury Assessment

Mercury concentrations in the Yankee Fork appear to have low to no risk for human health concerns, and by extension then to the aquatic life of the system. However, mercury sediment concentrations are elevated in many locations along the mainstem and Jordan Creek. Ultimately, the low expression of these high mercury concentrations in the aquatic life tissues should be considered the measure of risk in the watershed. Several factors exist within the watershed that may contribute to the low expression of mercury in the fish tissues.

Currently, the Yankee Fork has very low organic carbon, which corresponds well with low mercury methylation (Miskimmin et al. 1992; Chalmers et al. 2010); as a result, the bioconcentration of mercury from the sediments to the higher trophic levels is very low. In addition, the watershed also contains low to moderate levels of selenium that has been shown to ameliorate the effects or the accumulation of mercury in higher trophic level tissues (Beijer and Jernelove 1978; Ganther 1978; Skerfving 1978; Nuutinen and Kukkonen 1998; Peraza et al. 1998; Chen et al. 2001; Kaneko and Ralston 2007). In addition to this antagonism towards mercury accumulation, the biota of the Yankee Fork consists of fishes that also behaviorally lower the risk of mercury accumulation. The anadromous fish leave the system after rearing for a time. During this rearing period they are also functionally feeding on small, low, trophic level organisms. Consequently, they would bioaccumulate mercury at a lower rate than a large resident piscivore. In effect, they would be more similar trophically to the whitefish sampled by the USGS. In addition, they are absent from the watershed for most of their lives. As a result, their body burdens of toxins are expressions of ocean conditions rather than the natal streams.

The other resident fishes surveyed in the Yankee Fork are also low trophic level feeding fishes such as sculpin and whitefish. These fish have been documented in several studies in the Yankee Fork as accumulating a low level of mercury. However, the type of fish with the greatest concern for mercury accumulation would be large resident piscivores, and these fish have not been studied in the Yankee Fork. Bull trout fit into this category of high trophic level fish. However, the life history of this species may also act to minimize the risk from mercury in the Yankee Fork sediments. Bull trout in this drainage may use the Yankee Fork much like the anadromous fishes do. They use the Yankee Fork in the fall to spawn; the juveniles live for a time in the Yankee Fork before they out migrate to the Salmon River to over winter and over summer. The adult bull trout would then return to the Yankee Fork each fall to repeat the cycle. Consequently, the bull trout body-burdens would be more representative of the mainstem Salmon River toxics load than the Yankee Fork toxics load. However, bull trout fish tissue samples from the Yankee Fork are currently unavailable for several reasons. As a surrogate for bull trout, tissue samples should be collected from large rainbow trout in the system. These resident fish would integrate the toxics load from the Yankee Fork, they would include higher levels of piscivory, and they would also be more representative of the fish consumed from the system by the human population in comparison with whitefish and sculpin.

When considering remediation or habitat improvement projects in the Yankee Fork in regards to mercury accumulation, care should be given to minimize the eutrophication of the system. Increases in riparian communities can increase the allochthonous carbon inputs into a system, increasing the total organic carbon and potentially the ability of the system to methylate mercury. However, increased riparian protection can also reduce the inputs of sediments and nutrient transport from the uplands to the river system. As a result, the tradeoff between riparian carbon input and upland nutrient sequestration should be reviewed periodically as future remediation or habitat projects become established and mature. The periodic collection of total organic carbon samples would allow for a quick review of any net carbon increase within the system.

Increases in pond environments can also increase the potential for mercury methylation in the system, but this may already be mediated by the selenium concentrations found in the system and the life histories for the biota that would use the rearing ponds. To minimize the apparent small risk associated with mercury accumulation, any future rearing pond development should consider the sediment concentration of mercury in the site selection. It would be prudent to avoid locations near old mill sites or other known mercury hot spots in the system. If those sites are the more preferable locations for this type of development, then the design and construction of the rearing ponds should also give consideration to and minimize factors that would lead to the depletion of oxygen in the system and potentially to increased methylation of mercury.

1.5 Selenium Assessment

Background Selenium concentrations in the sediments of the Yankee Fork appear to have low to no risk for the aquatic life of the system. However, selenium concentrations are elevated in the prey base and in the fish tissues. As with mercury, the expression of these concentrations in the aquatic life tissues should be considered the measure of risk in the watershed not necessarily the sediment or water column concentrations. Consequently, there is a slightly elevated risk for the aquatic life in the Yankee Fork from the naturally occurring selenium found within the watershed. Multiple fish tissue studies in the Yankee Fork have occasional exceedances of EPA guidelines and are suggestive that reproductive effects may be occurring in the resident fish community (EPA 2004). However, many of these studies only collected samples during the summer. These samples exceeded the first prong of EPA's two prong selenium guideline. Based on that guideline, it is recommended or indicated that wintertime samples should be collected to more appropriately classify the risk of selenium concentrations in the fish tissues in Yankee Fork. This two pronged guideline is based on many studies that indicated selenium is more toxic during cold temperatures (EPA 2004). It is unknown at this time if winter samples from the Yankee Fork would be indicative of more or less risk than indicated by the summer samples.

The factors that may contribute to the elevated expression of selenium in the fish tissues are markedly different from those that mediate the expression of mercury. The mainstem Yankee Fork is a well-oxygenated, mixed system that promotes the oxidized states of selenium (Chau et al. 1976; Maiers 1988; Lortie et al. 1992). Selenate is more toxic and more soluble than the reduced forms of selenium. Selenite, a reduced form of selinum, may be less toxic and appears to have higher uptake into the plant community where it can be transferred into the food chain or stored and released back into the aquatic system. As a result, the biomagnification of selenium from the sediments is very high in the river system.

Conversely, the rearing pond environment appears to provide some relief from the naturally occurring selenium in the watershed. The pond sediments may provide a reducing environment that would detoxify selenate to selenite and even to elemental selenium. At the same time, the reduction increases the plant uptake, but in the pond environment, the emergent vegetation and filamentous algae that are more common often may have higher uptake than the biofilm diatoms and algae (Lemly 1987). If the plant uptake is not markedly different between biofilm and the emergent vegetation, these large plants and algae mats are often less palatable to the macroinvertebrate community and would contribute less to the body burdens of the macroinvertebrates and in turn the fishes inhabiting the rearing ponds. Along with the toxicity reduction, the solubility of selenium decreases as selenate is reduced to selenite and then to elemental selenium. Both factors may explain why, in some cases, the pond sediments appear to be higher in selenium than the river sediments, but the biofilm and macroinvertebrates from the ponds contain less selenium in comparison with the river samples.

The life histories of the species of concern will also mediate the risk from selenium toxicity in the Yankee Fork. The anadromous salmon and fluvial bull trout are absent from the watershed for portions of their lives and as a result their body burdens are the integration of the toxic loads from other water bodies. Whereas, the resident fish will spawn in the stream conditions and then the juveniles may move to the less toxic rearing ponds to feed, rest, and rear before moving back to the river environment as larger juveniles and adults. These fish should have lower body burdens than resident fish that spend their entire life history in the river environment and are exposed to a slightly more toxic environment.

When considering remediation or habitat improvement projects in the Yankee Fork, in regards to selenium accumulation it should be recognized that selenium is a naturally occurring element in the watershed, and that disturbance in the uplands and banks could liberate or expose additional sources to erosion processes.

In the design and construction of habitat projects, an understanding of the role of plant uptake and chemical reduction in the sequestration and toxicity of selenium should also be incorporated to mediate the risk to the aquatic biota. For example, shallow water habitats designed for emergent vegetation will assist in the sequestration of selenium in less palatable vegetation, while deep quiescent zones where sediment deposition can occur fosters a reducing environment to shift the selenium species composition towards the less toxic and less soluble elemental selenium.

2. Conclusion

Mercury and selenium are both naturally occurring elements, but with contrasting sources in the Yankee Fork. Mercury was used in mining and milling operations at various locations along the mainstem and in Jordan Creek, while selenium is naturally occurring in the parent material of the watershed. Because of their elemental nature, decay processes such as oxidation or reduction do not destroy them. Both exist in multiple oxidation states and have complex geochemical cycles involving inorganic and organic forms. Multiple forms of each exist in the aquatic environment as well as the terrestrial environment. Both mercury and selenium also have forms that readily bioaccumulate in the aquatic food web.

The Yankee Fork is dominated by fast water habitat with few depositional areas and little organic carbon. This leads to the contrasting toxicity and bioaccumulation of mercury and selenium. Because of this environment, mercury is less likely to methylate, is less toxic, and is less likely to bioaccumulate at a fast rate. In addition, selenium acts as an antagonistic in the uptake or storage of mercury in the tissues of fish. These factors lead to low to no risk to human health and the aquatic life in the Yankee Fork from the existing mercury in the stream sediments.

Conversely, due to the oxidizing environment, selenium is more likely to be in the form of selenate and selenite and consequently is more toxic, more soluble, and more likely to bioaccumulate at a fast rate. Several factors exist that can be used to minimize the impact of selenium in the Yankee Fork. The mechanism that leads to mercury antagonism is currently unknown, but may be tied to the fact that selenium is an essential micronutrient. As such, the body burdens of selenium in the aquatic life of the Yankee Fork can be biomodulated or metabolized over time. In addition, while completely untested, the selenium-mercury antagonism mechanism that ameliorates the effects of mercury on an organism, may work in a mirrored way to increase the metabolism of selenium in the presence of mercury.

Future remediation or habitat improvement projects in the Yankee Fork should consider the change in the primary productivity of the system on both elements. Increases in carbon inputs from the uplands and riparian zones can potentially increase the rate of mercury methylation, but also lead to a more reduced and less toxic form of selenium. These projects need to also recognize the counter point that, increased riparian protection can also reduce the inputs of sediments and nutrient transport from the uplands to the river system. This reduction would slow the rate of eutrophication of the system, which would be beneficial from a mercury standpoint, and can also be beneficial from a selenium standpoint. Any disturbance in the uplands and streambanks could liberate or expose additional sources of selenium to erosion processes and transport to the aquatic system. Habitat and riparian projects designed to slow the transport of sediments from the uplands would cut off or reduce the upland sources of selenium.

Site selection of future habitat or riparian projects may be the single most important factor when considering the effects of both mercury and selenium on the aquatic biota of the Yankee Fork. Planning and site location can be used to minimize the existing risk associated with mercury accumulation. Site selection should consider old mill sites or other known mercury hot spots in the system. If those sites are the more preferable locations for this type of development, the design and construction of the habitat features should also give consideration to and minimize factors that would lead to the depletion of oxygen in the system and potentially to increased methylation of mercury.

The construction and design of new habitat features can minimize some risk to the biota from mercury and selenium. Design considerations that incorporate shallow water habitats for emergent vegetation will assist in the sequestration of selenium in less palatable vegetation, and if the features remain well oxygenated, may not promote increased mercury methylation. The inclusion of deep, sediment and organic material depositional, areas within a pond should also be considered. Although a pond may increase mercury methylation, selenium transport to these areas may mediate some of this risk. In addition to providing a depositional area for upland sources of selenium, these features provide a reducing environment to shift the selenium species composition towards the less toxic and less soluble elemental selenium.

To illustrate these gradients and hot spots along the Yankee Fork and to help inform the Yankee Fork Tributary Assessment, Figures 1 through 4 have been developed from data in the USGS sediment survey study (Frost and Box 2009).

Other factors such as the life histories of many of the species of concern that result in long periods of absence from the watershed also protect some of the aquatic life from the harmful effects of elevated selenium and mercury concentrations. This life history protection is particularly important when considering habitat and riparian projects that may liberate either element. If the goal of a project is to enhance anadromous fish production, then the biota of concern will not be present in the watershed for most of their lives. Consequently, the levels of mercury and selenium found within the Yankee Fork watershed may represent a very minor risk to these species.

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