5.0 SUMMARY OF FINDINGS

The following sections summarize the findings on the nature of metal contamination in source area soil and sediment, groundwater, and surface water in the basin, as well as transport of metal contamination and sediment via surface water.

5.1 SOURCE TYPES, SOIL, AND SEDIMENT CHARACTERIZATION

Building on the conceptual site model summarized in Section 2, the nature and extent of metals in source areas and impacted soil/sediment in the basin, and their fate and transport, are presented in this section.

5.1.1 Source Characterization

The Bureau of Land Management (BLM) identified approximately 1,080 mining-related source areas in the basin. The number of BLM source areas, number of producing mines, and details on ore and tailings production for each watershed are summarized in Table 4-1. Within these source areas, five different primary source types were identified: mine workings, waste rock, tailings, concentrates and other process wastes, and artificial fill. Secondary sources include affected media (e.g., floodplain deposits) that act as sources of metals to other media or receptors. Of these source types, a limited number of samples were collected and analyzed. Results of these analyses are presented in this section.

Available data for source types were grouped into the following categories for analysis:

- Adit and seep drainage
- Floodplain sediments
- Floodplain tailings
- Floodplain waste rock
- Upland concentrates and process wastes
- Upland waste rock
- Upland tailings

Metals concentrations for the source types sampled and analyzed are summarized in Attachment 1 for each watershed and for the basin as a whole. For each of the ten COPCs, the number of samples analyzed, frequency of detection, the average concentration and the number of results exceeding 1x, 10x, and 100x the screening levels are shown. As shown in Attachment 1, measured concentrations in all source types exceeded the screening levels for at least one of the ten COPCs. To illustrate, pooled metal concentration data from the entire basin were used to calculate the probability that the true average concentration of a metal in a given source type is greater than the applicable screening level. Results for arsenic, cadmium, lead, and zinc for the seven source types evaluated are presented in Part 1, Section 4.2.4 and summarized in Table 5.1.1-1. As shown in Table 5.1.1-1, except for arsenic in adit and seep drainage, for these four metals the probability that the average concentration exceeds screening levels is high, ranging from 45 to 100 percent.

Mass loading data, along with sampling location maps and background reference documents, were used to further evaluate source areas identified by the BLM. Two representative source areas, the Tamarack No. 7 in Canyon Creek and the Rex No. 2 in Ninemile Creek were selected to illustrate the nature and extent of metals in the different source types, and to show the movement of metals from the primary sources to affected media (e.g., soil, sediment, groundwater and surface water). The Tamarack No. 7 source area is adjacent to Canyon Creek and includes an adit, waste rock piles and tailings piles. Soil, sediment, groundwater and surface water samples were collected from this source area. The Rex No. 2 source area is approximately 0.2 mile northwest of Ninemile Creek and includes an adit, a mill, waste rock piles and tailings ponds. Cadmium, lead and zinc concentrations are summarized in Tables 5.1.1-3 through 5.1.1-9. Physical features are shown in Figures 5.1.1-1 and 5.1.1-2.

As shown in Figures 5.1.1-1 and 5.1.1-2, the adits, tailings ponds and waste rock piles are the primary source of metals in the Tamarack No. 7 and Rex No. 2 source areas. Adit, waste rock and tailings metals concentrations were several times greater than screening levels and were significantly higher than metals concentrations at off-site locations. Metals from the waste rock piles and tailings ponds are transported either by groundwater (dissolved phase) or surface water (both particulate and dissolved phase) directly to surface water. Metals from the adits drain via groundwater and surface flow to surface water. Metals from these sources may be deposited in sediments and alluvium in the creek beds (e.g., South Fork impacted floodplain) or transported downstream by surface water flow. Sediment and alluvium metals concentrations reflect both adjacent sources (e.g., Tamarack No. 7) as well as upgradient source areas.

In addition, one representative impacted area, the floodplain of the South Fork near Osburn, Idaho, was selected to illustrate the nature and extent of metals in affected media, and to show the movement of metals through this media to other affected media (e.g., groundwater and surface water). Cadmium, lead and zinc concentrations are summarized in Table 5.1.1-10. Physical features and sampling locations are shown in Figures 5.1.1-3 and 5.1.1-4. Metals concentrations were several times greater than screening levels and were significantly higher than metals concentrations at off-site locations. Metals from the impacted floodplain are transported either by groundwater (dissolved phase) or surface water (both particulate and dissolved phase), where they are transported farther downstream.

A total of 114 adits and 20 seeps with documented drainage were identified during the remedial investigation. Available data are summarized in Table 5.1.1-11. Data presented in Table 5.1.1-11 were summarized from information presented in the Restoration Alternatives Plan (RAP) (Gearheart et al. 1999). Appendix A to the RAP is included as Appendix J to this RI report.

For each adit and seep, average discharge, average total zinc concentration, average total zinc mass loading, and associated source areas, are shown in Table 5.1.1-11. Mass loading was calculated from average concentration and discharge data if more than one sampling result was available. Adits considered major loaders (generally with a loading of more than 10 pounds zinc per day or 1 pound lead per day) include the following:

- Hercules No. 5 (BUR098)
- Tamarack No. 7 (BUR067)
- Gem No. 3 (BUR190)
- Success No. 3 (OSB089)
- Star 1200 Level (MUL012)
- Sidney (MAS081)

The total average zinc load from all adits and seeps is estimated to be about 126 pounds per day.

5.2 GROUNDWATER IMPACTS

During evaluation of contaminant transport in the South Fork, North Fork and their tributaries, bedrock was found to be an important aspect of the physical system. Within the upper portion of the basin (above the confluence of the North and South Forks), bedrock geometry, to a large extent, influences the geometry and the volume of the overlying unconsolidated alluvium. In the South Fork, North Fork and tributaries, water table aquifers (groundwater flowing through the alluvial material) were present. Aquifers identified in each watershed are summarized in Table 4-1.

As observed and studied in Canyon Creek, narrow sections of the canyon, in which bedrock is near or at the surface, limit the volume of alluvium present. Conversely, wider sections of the canyon (where bedrock has been more deeply eroded) allow for the deposition of a larger volume of alluvium. The streams in these areas usually have a wide floodplain. When the volume of alluvium that contains groundwater is reduced it tends to force the groundwater to the surface and act as recharge to the surface water in the creek. When the volume of alluvium increases (wider or deeper floodplain) surface water tends to move downward through the stream bed into the groundwater. The U.S. Geological Survey (Barton 2000) studied the surface water/groundwater interaction in Canyon Creek and in the South Fork. The findings of their work confirm this interaction of surface water/groundwater. This is an important mechanism in the transport of metals between surface water and groundwater. The results of these studies are presented in the individual watershed reports.

Perched groundwater conditions are expected to occur locally in upland portions of the basin where sufficiently thick soil and colluvial material overlie the native low-permeability bedrock. Perched groundwater could be expected to occur most frequently at or near the soil/bedrock interface and likely would be present as a relatively thin, seasonal zone of saturation following periods of snowmelt or heavy precipitation. Perched groundwater is not believed to be regionally significant, but can serve as a source of recharge to the underlying bedrock aquifer system at the local level.

Distinct and generally localized hydrogeologic flow systems also can develop within mine waste areas such as constructed tailings impoundments. Dozens of these mine waste impoundment areas are present within the basin (Gross 1982; Morilla et al. 1975; Dames and Moore 1991), ranging from less than an acre to almost 200 acres in size. Four of the larger flotation tailing impoundments are the Central Impoundment Area (CIA) near Kellogg (approximately 190 acres) and Page Tailings Area near Smelterville (approximately 70 acres), Hecla-Star Tailing Ponds, and ponds associated with the Lucky Friday, Golconda and Sunshine mine/mill facilities.

The majority of these tailings impoundments are present within the South Fork valley and its major tributaries. Groundwater, when present within these impounded mine wastes, shows varying degrees of hydraulic interaction with shallow alluvial aquifer systems that often underlie the impoundment areas. Where the mine waste materials are predominantly finer grained flotation tailings (e.g., Page tailing pile), groundwater mounding can occur. Morilla et al. (1975) found that water levels in the regional alluvial aquifer beneath the tailings pile were not significantly affected by the groundwater mound within the pile due to the large differences in vertical hydraulic conductivity between the tailings and the underlying alluvial material. Other tailing impoundments containing predominantly coarser grained jig tailings may remain unsaturated year-round, or portions of the pile may be seasonally saturated and hydraulically interactive with a shallow alluvial aquifer system.

Similarly, large areas of the valley floors of Canyon Creek, Ninemile Creek, and the South Fork are blanketed with a variable thickness of tailings. The tailings were deposited over broad portions of the valley floodplain during flooding events that caused many tailings impoundment dams (i.e., coffer dams) to fail (Norbeck 1974; Houck and Mink 1994). These coarser grained deposits generally do not support the development of a separate groundwater flow system, but may become seasonally saturated and hydraulically connected with underlying alluvial aquifer systems during periods of high snowmelt and precipitation.

Groundwater was also found to occur in the underlying bedrock. However, the volume of flow is limited and confined to fractures and faults. In much of the upper basin, groundwater moves from bedrock fractures into the alluvial aquifers or discharges from seeps and eventually enters the streams and rivers. Groundwater in bedrock in the upper portion of the basin was not identified as a major pathway for contaminant migration.

Limited data are available on groundwater metal concentrations. Available data for community drinking water systems that draw water from groundwater were reviewed to evaluate potential exceedances of federal drinking water standards (maximum contaminant levels [MCL]). Results are summarized in Table 5.2-1. The frequency of homes showing exceedances of the MCLs is low, with lead and cadmium showing the highest number of exceedances. The following section summarizes the findings from Canyon Creek, where numerous groundwater monitoring wells were installed and sampled for the RI/FS. Detailed groundwater studies have not been conducted in the basin. Additional groundwater data may be collected if needed to support remedial design.

5.2.1 Canyon Creek

The groundwater aquifer in Canyon Creek is expected to be typical of most impacted areas of groundwater in the upper basin. While the South Fork is less of a high energy system than most of its tributaries, groundwater and metal contamination is expected to behave in a similar manner.

Table 5.2-2 is a summary of dissolved zinc concentrations for a 1998 groundwater sampling event conducted as part of the remedial investigation. Zinc was selected to show the distribution of concentrations because it is transported mostly as a dissolved metal and should behave similarly in surface water and groundwater. All the wells (listed in the table from upstream to downstream) were sampled over a period of a few weeks.

As shown in the table, the range of concentrations is highly variable from well to well, and less variable for samples collected from different depths in the same well. At depths up to 10 feet the concentration range between wells is approximately 16 to 40,500 micrograms per liter. The variability in the concentrations between wells continues with depth. A trend of increasing concentrations in groundwater is noted in well samples adjacent to and downstream of the Hecla Star Tailings pile and the Silver Valley Natural Resource Trustees repository (wells below CC453) as a result of the presence of mining waste. This is an area where contaminated floodplain material had been removed and placed in the nearby repository. It is also an area where, based on the USGS seepage study and the estimated expected mass loading data, the stream is losing water to the groundwater. It is difficult to separate out the impacts in this area from source material verses contamination entering the groundwater from upgradient surface water.

Based on the data in Canyon Creek, groundwater is substantially impacted. Metal contamination is expected to be highly variable and depend on both the aquifer properties and losing/gaining nature of stream reaches. Based on stream channel morphology, the high degree of variability observed in Canyon Creek is expected to occur throughout most of the tributaries and South Fork. This will make it difficult to predict the levels of contamination moving in the groundwater system at different times of the hydrologic cycle.

5.3 SURFACE WATER

The movement of metals and sediment from upland and floodplain source areas to streams and rivers of the basin are summarized in this section. A probabilistic model was used to estimate average surface water discharge, metals concentrations, and metals mass loading in the South Fork, North Fork, Main Stem Coeur d'Alene River, Spokane River, and important tributaries. Available sediment data were used to evaluate transport of fine-grained and bedload sediment within the basin. Surface water and sediment within Coeur d'Alene Lake were independently evaluated using mass balance and benthic flux measurements and calculations.

5.3.1 Probabilistic Model Description

Understanding the movement, or fate and transport, of metals from source areas to other parts of the basin is a key piece of both the remedial investigation (RI) and the feasibility study (FS). To understand a large natural system like the Coeur d'Alene River Basin, it is important to answer the what, where, and how questions of metal movement.

What is the best way to describe metal movement and deal with the large variation in the natural world and the data? A mathematical model, called a *probabilistic model*, was selected as the best tool to handle the complex issues involved. For selected stream monitoring points in the basin (e.g., the mouth of Canyon Creek, Pinehurst, and Harrison), the model is used to:

- Predict metal concentrations in the stream
- Predict metal loading in the stream (i.e., how much metal is flowing in the stream)
- Quantify the uncertainty associated with the predictions in a consistent and coherent manner

The portion of the model used for the RI is limited to current conditions in the basin. In the FS, the complete model is used to make quantitative estimates of the potential remedial performance associated with each remedial alternative. Because it helps quantify the degree of certainty that a remedial action will actually result in meeting cleanup goals, the model can be used in the remedy selection process to help decision-makers select and prioritize cleanup efforts. The modeling methodology is summarized in Part 1, Section 5.4.2, and presented in detail in a separate technical memorandum (URSG 2001).

5.3.2 Discharge

Estimated expected values were calculated for 41 sampling locations, beginning at the most upgradient location in the Upper South Fork (SF220 below Mullan) to the most downgradient location on the Spokane River (SR85 above Lake Roosevelt). These results are presented in detail in Parts 2 through 6. For this discussion, results for thirteen sampling locations were selected to summarize discharge, metals concentrations and mass loading in the South Fork, North Fork, and their tributaries, as well as the Main Stem, Lower Coeur d'Alene River, Coeur d'Alene Lake, and the Spokane River. Results for these thirteen sampling locations are summarized in Table 4-1.

As anticipated, the estimated expected value of the discharge generally increases as one progresses from the upper watersheds to the South Fork. The estimated expected value of the discharge approximately doubles between sampling locations SF228 below Trowbridge Gulch in the Upper South Fork (114.6 cfs) and SF239 at Silverton (230 cfs). Canyon (53.4 cfs) and Ninemile Creeks (19.8 cfs) enter the South Fork in this reach and account for a significant portion (65 percent) of this expected increase in discharge.

A reach is defined as the distance between any two adjacent sampling locations. Reaches may be either gaining or losing. Losing reaches occur where the gradient lessens, the valley widens into alluvial floodplains, and surface water discharges to groundwater. Losing reaches were identified in Woodland Park in Canyon Creek and between Silverton (SF239) and Osburn (SF249) on the South Fork.

Gaining reaches occur where the valley narrows and groundwater discharges to surface water or where tributaries discharge to main channels. Gaining reaches were identified where the canyon begins to narrow between SF259 above the confluence with Big Creek (279.6 cfs) and SF268 near Elizabeth Park (345 cfs). Estimated expected discharges continue to increase as one progresses downstream through the Bunker Hill Superfund site. Between SF271 at Pinehurst and LC60 at Harrison, the expected estimated discharge increases by approximately 2,300 cfs. The North Fork, with an expected discharge of 1,660 cfs, enters the South Fork in this reach and can account for the majority of this increase. Based on estimated expected discharge values at sampling locations found at Cataldo (LC50), Rose Lake (LC55), and upstream from Harrison (LC60), the discharge in the Main Stem Coeur d'Alene River remains relatively constant. Any groundwater interactions occurring along the Coeur d'Alene River between Cataldo and Harrison apparently have little net effect on discharge.

Data indicate that more water exits Coeur d'Alene Lake than enters it from the Coeur d'Alene River at Harrison. The estimated expected discharge at Post Falls Dam (SR50) (7,530 cfs) is approximately 4,720 cfs larger than the expected discharge into the Lake from the Coeur d'Alene River (LC60) (2,810 cfs). This difference is likely accounted for by the additional discharges to Coeur d'Alene Lake from other rivers including St. Joe River, St. Maries River, Wolf Lodge Creek, Carlin Creek, Plummer Creek, and Fighting Creek. However, the estimated expected discharges in the Spokane River are less certain because fewer samples were collected along the Spokane River than along the South Fork and the Coeur d'Alene River. In addition to the limited number of data points, the Post Falls Dam affects the water-surface elevation and discharge from the lake to the Spokane River. Discharge increases along the Spokane River from SR50 at Post Falls (7,530 cfs) to SR85 at Long Lake (8,120 cfs), due most likely to contributions from tributaries.

5.3.3 Concentrations

Estimated expected values for dissolved cadmium, total lead, and dissolved zinc concentrations for selected sampling locations are summarized in Table 4-1. Surface water metals concentrations were compared to screening levels to identify locations impacted by mining activities. Screening level exceedances for the thirteen selected locations are summarized in Table 4-1.

Beginning at the sampling location (SF228) below Trowbridge Gulch, dissolved cadmium concentrations exceed screening levels and continue to do so throughout the South Fork and Lower Coeur d'Alene River to Harrison. Dissolved cadmium concentrations also exceed screening levels in Beaver Creek, Canyon Creek, Ninemile Creek, and Big Creek. Dissolved cadmium concentrations were low in Coeur d'Alene Lake and the Spokane River.

Beginning at the sampling location (SF239) at Silverton, total lead concentrations exceed screening levels and continue to do so throughout the South Fork and Lower Coeur d'Alene River. Total lead concentrations in Canyon Creek and Ninemile Creek also exceed screening levels. Increases in estimated total lead concentrations may result from increased discharges and increased suspended sediment loads to which the lead is adsorbed. Total lead concentrations increase between Elizabeth Park and Pinehurst as the South Fork moves through the Bunker Hill Superfund site. Estimated expected total lead concentrations increase approximately 75 percent (from 32 to 56 μg/L). Total lead concentrations in the South Fork decrease significantly (between 60 and 70 percent) after the North Fork converges with the South Fork but are still greater than screening levels throughout the Lower Coeur d'Alene River. Estimated expected total lead concentrations are less than screening levels in the Spokane River; however, seasonal exceedances of water quality criteria are observed (Ecology 1998).

Beginning at the sampling location (SF228) below Trowbridge Gulch, dissolved zinc concentrations exceed screening levels and continue to do so throughout the South Fork and through the basin to the Spokane River at Long Lake. With few exceptions, estimated dissolved zinc (and cadmium) concentrations generally increase in the downstream direction in the South Fork and Lower Coeur d'Alene River. The estimated expected dissolved zinc concentration increases almost 50 percent (from approximately 980 to 1,430 μg/L) between Elizabeth Park (SF268) and Pinehurst (SF271) as the South Fork flows through the Bunker Hill Superfund Site. Dissolved cadmium concentrations increase over 30 percent (from 6.8 to 9.1 μg/L) in this same reach. Estimated expected values of dissolved zinc (and cadmium) concentrations decrease at locations where tributaries, like the North Fork, with low concentrations and high discharges flow into the South Fork and dilute the cadmium and zinc concentrations.

5.3.4 Concentration Versus Discharge

Dissolved metal concentrations typically decrease with increased discharge as dilution occurs. In contrast to dissolved metal concentrations, total metal concentrations generally increase with increasing discharge because increased discharge results in increased sediment concentrations to which some metals (e.g., lead) adsorb.

To illustrate the range of concentrations associated with low-flow and high-flow events, estimated expected metal concentrations at the 10th and 90th percentile discharges are listed in Table 5.3.4-1. Dissolved cadmium and zinc and total lead concentrations are presented because the majority of the cadmium and zinc in surface waters is found in the dissolved form while the majority of the lead is associated with particulates. The 10th percentile was used to represent a low-flow event that might occur in the summer months while a 90th percentile discharge represents a high-flow event that is more likely coincident with spring snowmelt and runoff. As presented in Table 5.3.4-1, dissolved cadmium and zinc concentrations decrease as the discharge increases from the 10th percentile discharge to the 90th percentile discharge. Estimated expected values of total lead concentrations show the opposite trend with concentrations most often increasing with increasing discharge. Estimated expected metal concentrations at the 10th and 90th percentile discharges were also compared with screening levels. Screening level exceedances are summarized in Table 4-1.

5.3.5 Mass Loading

Estimated expected values for dissolved cadmium, total lead, and dissolved zinc mass loading for selected sampling locations are summarized in Table 4-1. All 42 sampling locations evaluated by probabilistic modeling are shown in Figure 5.3.5-1. Mass loading results are shown in Figures 5.3.5-2 through 5.3.5-10. The estimated expected values are compared to the 90th percentile total maximum daily loads (TMDLs) at locations for which TMDLs are available (USEPA 2000). The 90th percentile TMDL values for dissolved cadmium and zinc are exceeded at all locations except at the mouth of the North Fork. Estimated total lead loads exceed the calculated TMDLs by more than an order of magnitude at all locations for which TMDLs were developed. TMDL exceedances are summarized in Table 5.3.5-1. TMDLs for mass loading have not been developed for the Spokane River. (TMDLs for the Spokane River are the ambient water quality criteria adjusted for site-specific hardness.)

As shown in Table 4-1, the dissolved zinc and cadmium and total lead loads increase by nearly an order of magnitude between Trowbridge Gulch (SF228) and the sampling location (SF239) at Silverton. Ninemile Creek and Canyon Creek enter the South Fork in this reach and account for the majority of this increase. Estimated dissolved zinc and cadmium loads decrease between Silverton and Osburn because of decreases in discharges, and total lead loads decrease because of decreases in concentrations.

Expected total lead loads increase dramatically in the BHSS [between Elizabeth Park (SF268) and Pinehurst (SF271)]. Based on the expected values presented in Figures 5.3.5-2, 5.3.5-5, and 5.3.5-8, the BHSS contributes between approximately 50 and 70 percent of the dissolved zinc and cadmium and total lead loads measured in the South Fork at Pinehurst. The BHSS is estimated to contribute between approximately 40 and 50 percent of the dissolved cadmium and zinc loads, but only between approximately 10 and 20 percent of the total lead load measured at Harrison.

The expected lead load between Cataldo and Harrison approximately doubles from 700 pounds/day at Cataldo to 1,500 pounds/day at Harrison. The expected discharges are relatively constant in this same reach. The dissolved cadmium and zinc loads increase by a smaller percentage between Cataldo and Harrison, going from approximately 27 to 29 pounds cadmium/day and from approximately 3,200 to 4,200 pounds zinc/day.

Of the tributaries, Canyon Creek exhibited the largest expected dissolved zinc (714.3 pounds/day) and cadmium (5.6 pounds/day) loads. Because the estimated discharge of the North Fork (approximately 1,600 cfs) is over 30 times the discharge in Canyon Creek, the total lead load of the North Fork is approximately double that of Canyon Creek even though the North Fork's concentrations are significantly lower than those measured at the mouth of Canyon Creek.

To summarize: the largest dissolved zinc and cadmium loading takes place in the BHSS and the largest increases in the total lead load occur in the Lower Coeur d'Alene River.

5.3.6 Dissolved Versus Total Concentration

To illustrate which metals tend to be in the dissolved phase or the particulate (total) phase, the estimated percentages of dissolved cadmium, lead and zinc were calculated for locations throughout the Coeur d'Alene basin. Results were calculated using the MIT diffuse-layer model. Calculation methods are presented in Part 1, Section 5.4.1.5. Results are listed in Table 5.3.6-1.

Cadmium and zinc transport occurs predominantly in the dissolved phase. Dissolved cadmium and zinc concentrations typically constitute 80 to 100 percent of the total metal concentration.

Lead exhibits the opposite trend. Except for measured lead concentrations at the mouths of two tributaries, Ninemile Creek and Pine Creek, the estimated dissolved lead concentration constitutes less than 30 percent of the total lead concentration and, in several instances, is less than 10 percent of the total lead concentration.

5.3.7 Sediment

In general, the suspended and bedload sediment loads increase with increasing discharge. Tributary streams of the South Fork tend to have higher gradients as compared to sites on the South Fork, Main Stem, and the Lower Coeur d'Alene River. Higher gradients indicate a more dramatic response in transport of suspended sediment to changes in stream discharge. Lower stream gradients and velocities indicate a less reactive response to changes in stream discharge. Sediment particles of different size classes begin to be mobilized and transported by stream flow at different thresholds of discharge rates.

Based on a limited number of data points (four), Clark and Woods (2000) estimated the threshold of the fine bedload in Canyon Creek as approximately 170 cfs and the coarse bedload threshold to be approximately 200 cfs. The site selected was 2.8 miles upstream of the confluence of Canyon Creek and the South Fork. The fine materials were defined as being less than 8 mm in diameter and the coarse materials as greater than 8 mm in diameter.

A similar threshold analysis was performed in Canyon Creek at the same location for suspended sediments (McBain and Trush 2000). For suspended sediments, the data were divided into the sand fraction (> 0.0625 mm) and fine material (< 0.0625 mm). Evaluation of the data indicated that fine sediment transport begins from 100 to 170 cfs, with larger inflections in transport occurring between 200 and 300 cfs.

Threshold values were also estimated by McBain and Trush for Pine Creek. The estimated threshold value for transport of sand-sized (> 0.0625 mm) suspended sediments was 200 to 275 cfs.

Ninemile Creek transports significantly more suspended sediment per unit discharge than does Canyon Creek. For example, at a discharge of 53 cfs Canyon Creek transports an estimated 0.75 ton/day. In contrast, at a discharge of only 44 cfs Ninemile Creek transports an estimated 1.53 tons/day of suspended sediment.

Similarly, the South Fork at Silverton transports significantly more suspended sediment per unit discharge as compared to the downstream site at Pinehurst. This probably occurs because of the intervening inflow from Pine Creek, which dilutes suspended sediment concentrations in the South Fork at Pinehurst. There is also a large decrease in suspended sediment transport per unit discharge between Pinehurst and the Coeur d'Alene River at Rose Lake and Harrison. This results from inflow of the North Fork and deposition of sediment in the Coeur d'Alene River upstream of Rose Lake and Harrison.

For most locations, there is not a large difference in the transport characteristics of fine- and sand-sized material. At Rose Lake and Harrison, when stream discharge is less than 10,000 cfs most of the suspended sediment discharge is composed of fine-grained material. For example, at a discharge of approximately 6,300 cfs at Harrison, the estimated discharge of fines is 417 tons/day while the estimated discharge of sand-sized particles is only approximately 35 tons/day. Harrison and Rose Lake are characterized by relatively slow water velocities that appear to be insufficient to transport sand-sized sediment at lower stream discharges. Not until stream discharge exceeds 10,000 cfs does the discharge of sand-sized material at Rose Lake and Harrison approximate the discharge of fine-grained material.

Unlike suspended sediment transport, transport of bed material is not always evident. When bedload discharge does occur, it is often extremely variable both spatially within the stream channel and temporally during steady stream-discharge conditions. The particle-size distribution of bedload sediment samples is proportionately coarser as stream discharge increases.

5.3.8 Coeur d'Alene Lake

The analysis of fate and transport of metals within Coeur d'Alene Lake focused on the following three central questions. One, what happens to metals and nutrients after they enter the lake? Two, what is the role of the lakebed sediments in regulation of metal and nutrient concentrations in the lake's water column? Three, what determines the amount of metals and nutrients discharged from the lake into the Spokane River? The answers to those three questions were developed by integrating a large amount of hydrologic and water-quality data and information in order to examine the interaction of physical, chemical, and biological processes as they relate to the fate and transport of metals and nutrients in Coeur d'Alene Lake.

Once metals and nutrients enter the lake, either in a dissolved or particulate fraction, their fate and transport is highly dependent upon the lake's hydrodynamic characteristics. The lake's short hydraulic-residence time (about one-half year on average), coupled with a propensity for routing riverine inflows as overflow, facilitates advective transport of particulate and dissolved constituents within the lake. During periods of spring snowmelt runoff and winter rain-on-snow events, portions of the overflow plumes are routed through the lake and discharged into the Spokane River within a few days. Conversely, riverine inflows delivered in the late fall and early winter were often routed as underflows into the lake's hypolimnion. During periods of convective or discharge-induced water column mixing, constituents stored in the hypolimnion were circulated throughout the lake's water column.

Mass-balance calculations, using dissolved and particulate loads from riverine and benthic sources, suggest that about 50 percent of the dissolved zinc, inorganic nitrogen, and orthophosphorus that entered the lake was transformed to the particulate fraction. For dissolved cadmium, about 75 percent was transformed; about 90 percent of dissolved lead was transformed to particulate lead. For metals associated with the particulate fraction, about 90 percent were sedimented within the lake. Therefore, geochemical transformation of dissolved (including colloidal) constituents into the particulate fraction was an important process by which sedimentation of metals was augmented; this was in addition to those metal loads initially delivered to the lake in the particulate fraction. Biological processes also affected fate and transport of metals and nutrients. Phytoplanktonic assimilation of dissolved inorganic nitrogen and orthophosphorus converted those constituents into new particulate organic matter; that is, new phytoplankton. Such conversions were not necessarily unidirectional; subsequent death and lysis of phytoplankton transformed particulates back to the dissolved fraction. Phytoplankton also affected dissolved metals via adsorption of dissolved cadmium and zinc; this process was well-illustrated by summertime declines in euphotic zone concentrations of dissolved zinc in Coeur d'Alene Lake. The net result of physical, chemical, and biological processes within the lake was to retain the following approximate percentages of its riverine and benthic input loads (dissolved plus particulate): cadmium, 50 percent; lead, 90 percent; zinc, 35 percent; nitrogen, 5 percent; and phosphorus, 30 percent.

The lakebed sediments played a role in the regulation of metal and nutrient concentrations within the lake's water column. The lake's substantial depth, routing of inflow plumes primarily as overflow, and sedimentation characteristics indicated that scouring of the lakebed sediments was an insignificant source for delivery of particulate and dissolved constituents back into the water column. Therefore, the lakebed sediments served as a major repository for metals and nutrients that had been removed from the water column via sedimentation. However, geochemical processes within the lakebed sediments and near the sediment-water interface facilitated releases of previously deposited metals and nutrients back into the lake's water column. On the basis of benthic-flux measurements made in August 1999, fluxes of dissolved cadmium, zinc, inorganic nitrogen, and orthophosphorus from the lakebed sediments were of similar magnitude to those delivered to the lake by the Coeur d'Alene and St. Joe Rivers. However, the contribution of these benthic fluxes to the lake's water column was muted by adsorption and sedimentation within the lower hypolimnion at or near the sediment-water interface.

The mass balance of metals and nutrients in the lake was used to evaluate the relative contribution of riverine and benthic-flux loads on water-column concentrations. When calculated with annual loads the mass balances indicated that, except for dissolved inorganic nitrogen, the riverine loads of cadmium, lead, zinc, and orthophosphorus were in excess of those discharged from the lake; therefore, one could conclude that benthic fluxes were not needed to account for water-column concentrations. When the mass balances were calculated with monthly loads it was apparent that output loads exceeded input loads during parts of the year for dissolved zinc and inorganic nitrogen; thereby indicative of the potential for benthic fluxes to affect water-column concentrations of these two constituents. However, another geochemical process could also explain why output loads exceeded input loads during part of the year. If riverine-derived particulate matter was remineralized as it was delivered to the hypolimnion via sedimentation, then this transformed source of dissolved zinc and inorganic nitrogen could account for all, or part, of the excess output load. Given the established presence of a positive benthic flux, the internally generated supply of dissolved zinc and inorganic nitrogen is probably a combination of benthic flux and remineralization of riverine-derived loads.

The amount of metals and nutrients discharged from Coeur d'Alene Lake into the Spokane River is determined by the cumulative effect of in-lake physical, chemical, and biological processes acting on metals and nutrients delivered to the lake from riverine and benthic sources. One of the most important processes is sedimentation; either of particulate-bound metals and nutrients delivered by riverine inputs, or of particulate constituents formed by geochemical and biological transformations of dissolved constituents delivered either by riverine or benthic sources. The overall effect of sedimentation is to increase the ratio of dissolved to particulate constituents between their entry into the lake and their discharge from it. On a yearly basis, the majority of cadmium and zinc input to the Spokane River was in the dissolved fraction, whereas only about 15 percent of the lead was dissolved.

Annual discharge volume was another important influence on the amount of metals and nutrients discharged to the Spokane River from Coeur d'Alene Lake. Both dissolved and particulate loads had strong, positive correlations with discharge. Within a particular year, the temporal variation of discharge volume and the in-lake routing of inflows played an important role in determination of the amount of metals and nutrients discharged to the Spokane River. The predominance of overflow, especially, during periods of elevated inflow discharges, increased the frequency at which riverine loads of metals and nutrients could traverse the lake for delivery to the Spokane River. Alternatively, late autumn and winter inflows were usually routed as underflows into the hypolimnion. Underflows affected the hypolimnion in two important ways. Under low discharge conditions, hypolimnetic concentrations could be enriched as additional metals and nutrients were routed deep into the lake. Under elevated discharge conditions, the underflows could displace hypolimnetic water with its associated metal and nutrient loads and result in discharge out of the lake.

A large amount of hydrologic and water-quality data and information from numerous sources was employed in the foregoing evaluation of the fate and transport of metals and nutrients in Coeur d'Alene Lake. Obviously, a myriad of physical, chemical, and biological processes are in operation over a wide range of temporal and spatial scales. Given this complexity, no one process can be identified as being the "master variable" in control of the lake's metal and nutrient geochemistry. However, over a multiple-year time scale, the hydrological (physical) effects on the quantities of metals and nutrients delivered to and routed within the lake are very important determinants of the lake's existing water-column and lakebed-sediment geochemistry. The influence of chemical and biological processes also occur over a multiple-year time scale, but may be more easily detected within the context of seasonal changes within one year. Coeur d'Alene Lake is also spatially complex because of its long and narrow axis, well-indented shoreline, and wide range in depth. Such spatial variability affects the relative influence of physical, chemical, and biological processes among different locations within the lake.

Although considerable information has been gathered on the fate and transport of metals and nutrients in Coeur d'Alene Lake, several important issues remain unclear; most notably, the relative role of riverine and benthic sources in the determination of water-column concentrations and the export of metals and nutrients to the Spokane River. Inexorably tied to this is the spatial and temporal effects of transformation and remineralization reactions on dissolved and particulate metals and nutrients within the water column and at the water-sediment interface.

5.3.9 Spokane River

Metals discharged from Coeur d'Alene Lake in dissolved and particulate form are carried down the Spokane River. The Spokane River regularly exceeds water quality criteria for zinc. Criteria for lead and cadmium are also frequently exceeded, especially at higher flows (Ecology 1998). Fine-grained sediment in the Spokane River is contaminated with lead and zinc, with generally decreasing concentrations from upstream to downstream. Sediment screening levels are exceeded in several locations where fine-grained sediment accumulates, most notably in segment SpokaneRSeg02 upstream of the City of Spokane, and behind dams and in reservoir sediments in segment SpokaneRSeg03.

Concentrations of dissolved zinc exceed ambient water quality criteria through most of the year in the upper portions of the river and exceed ambient water quality criteria in lower portions of the river during high flows associated with snowmelt events and spring runoff. Concentrations of dissolved cadmium, lead, and zinc typically exceed the ambient water quality criteria during high flows. Fine-grained sediment in depositional areas, including natural shoreline beach and bar deposits (places used for water-contact recreation), show elevated concentrations of lead.

The main depositional areas are behind Upriver Dam, behind the low dam at Spokane Falls in Spokane, the Upper Falls hydropower facility in Spokane at Riverfront Park, and behind Ninemile Dam downstream from Spokane. Pockets of fine-grained sediments are located behind boulders and on small beaches throughout the segment. The backwater areas behind the dams contain small amounts of habitats such as riparian wetlands, that are otherwise not common along the Spokane River. Hangman Creek enters the Spokane River just west of downtown Spokane. The flow and water dilution contributed by Hangman Creek is typically small, but substantial amounts of clean Palouse-derived sediment (with low metals concentrations) are discharged during high spring flows.

Concentrations of metals in the sediment of Long Lake are slightly elevated. Concentrations of metals in sediments in the upper part of the Spokane Arm of Lake Roosevelt are slightly elevated (mainly zinc).