

9. WATER QUALITY

9.1 Introduction

The water quality study was undertaken to collect baseline data to provide scientific documentation of the naturally occurring constituents (NOCs) present, their concentrations, and their variability in surface water and groundwater. Water quality data for rivers, lakes, and seeps were collected in the mine study area throughout a 965-square-mile area that includes the North Fork Koktuli River (NFK), South Fork Koktuli River (SFK), Upper Talarik Creek (UT), and Kaskanak Creek (KC) drainages (Figure 1-2a in Chapter 1). NFK and SFK drain into the Nushagak River, which discharges to Bristol Bay. KC drains into the Kvichak River, south of Iliamna Lake. UT drains into Iliamna Lake, which in turn drains into the Kvichak River. Water quality data also were collected from streams that traverse typical areas of the transportation-corridor study area and from Iliamna Lake.

Field work was conducted from 2004 through 2008. Samples were analyzed for physical parameters, dissolved and total major ions, nutrients, dissolved and total trace elements, cyanides, and dissolved organic carbon. Selected surface water samples were also analyzed for organic compounds.

To assist with the data interpretation, data were plotted on box and whisker diagrams, time series diagrams, spatial diagrams, and Piper diagrams and were analyzed with statistical tests. To provide context, the data also were compared with the most stringent Alaska Department of Environmental Conservation (ADEC) water quality criterion for each parameter.

9.2 Results and Discussion

9.2.1 Mine Study Area—Surface Water

A comprehensive network of stations was established in the mine study area for sampling surface water from streams, lakes, and seeps. Stream samples were collected from 44 locations during 50 sampling events from April 2004 through December 2008. Lake and pond samples were collected from 19 lakes once or twice per year during 2006 and 2007. Seep samples were collected from 11 to 127 sample locations, depending on the year, two to five times per year. Altogether, over 1,000 samples were collected from streams, more than 600 samples from seeps, and approximately 50 samples from lakes.

The surface water in the mine study area was characterized by cool, clear waters with near-neutral pH that were well oxygenated, low in alkalinity, and generally low in nutrients and other trace elements. Water types ranged from calcium-magnesium-sodium-bicarbonate to calcium-magnesium-sodium-sulfate. Water quality occasionally exceeded the maximum criteria for concentrations of various trace elements. Additionally, cyanide was occasionally present in detectable concentrations; there were consistently detectable concentrations of dissolved

organic carbon; and no detectable concentrations of petroleum hydrocarbons, polychlorinated biphenyls (PCBs), or pesticides were found.

Some differences in water quality between watersheds and some trends in water quality along streams were noted. Sulfate, copper, zinc, nickel, and molybdenum concentrations were greatest in the SFK, consistent with the headwaters of this river passing through the deposit area and multiple sample locations present in this area. Significantly higher concentrations of copper, molybdenum, nickel, zinc, and sulfate were present in the SFK than in the NFK, consistent with the SFK's proximity to the deposit area. Total dissolved solids (TDS), pH, sodium, alkalinity, hardness, nitrogen (total nitrate+nitrite), and nickel concentrations were greatest in the UT drainage. The UT, which in the uppermost reach passes through a portion of the general deposit area, also had significantly higher concentrations of all of these NOCs, except copper, than in the NFK. Total suspended solids, potassium, chloride, iron, and arsenic concentrations were highest in KC, while cadmium and lead concentrations were highest in the NFK drainage. These characteristics of KC and NFK likely indicate that these parameters are unrelated to the deposit area and represent water quality signatures that are distinct from the other drainage areas. The following paragraphs discuss some of the specifics of the sample results and trends.

The mean levels for TDS in streams, by watershed, ranged from 37 to 51 milligrams per liter, which is 10 percent or less of the most stringent ADEC water quality maximum criterion. Of the three streams that originate close to the deposit area, the UT and SFK had significantly higher TDS levels than the NFK. Furthermore, a decrease in the TDS levels with distance along the stream was more pronounced in the SFK and UT watersheds than in the NFK watershed. Higher TDS in the UT and SFK watersheds with decreasing trends downstream were expected, because the deposit area lies within their watersheds and the oxidation of sulfide minerals associated with the deposit would release dissolved solids. The mean levels for TDS in lakes and seeps were similar to those for streams, with values of 49 and 42 milligrams per liter, respectively.

The highest value for total suspended solids was in KC, and the lowest was in the NFK. The mean for total suspended solids in lakes and seeps was similar to that for streams.

The pH values in surface water were close to neutral. The mean pH, by watershed, for streams ranged from 6.7 to 7.0. Therefore, even though the oxidation of sulfide minerals was expected to be releasing acid in the deposit area, carbonate minerals appear to provide effective pH buffering. The mean pH values for lakes and seeps were 7.2 and 6.5, respectively. While the mean pH values fell within the range for pH specified in the most stringent ADEC criterion, 34 percent of all individual water quality samples did not meet the water quality criteria for pH. The frequency of this trend in seeps was at least double that of streams, depending on the watershed.

The alkalinity of the surface water samples was low. The mean alkalinity, by watershed, for streams ranged from 17 to 32 milligrams per liter. The mean alkalinity for lakes and seeps was 19 and 23 milligrams per liter, respectively. Alkalinity was the parameter that was most frequently detected outside the range of the most stringent ADEC criterion. In all, 43 percent of all surface water samples were below the most stringent ADEC minimum criterion for alkalinity.

The frequency with which alkalinity values for lakes and seeps were below the minimum criterion was 10 to 20 percent higher than the frequency for streams.

The mean water temperature in streams ranged from 4.0 to 4.8 °C, depending on the watershed. The coefficient of variation was close to 1 for each watershed, indicating a high level of variability. The lakes were considerably warmer, with a mean temperature of 12 °C, and the seeps were slightly cooler, with a mean temperature of 3.4 °C.

Dissolved oxygen (DO) concentrations in streams were very similar in all watersheds, with mean concentrations that ranged from 10.2 to 10.5 milligrams per liter. These values are close to the theoretical solubility of oxygen of 12.3 milligrams per liter at 900 feet above sea level and a water temperature of 4 °C. While most samples indicated high DO, 7 percent of the samples had DO concentrations lower than the most stringent ADEC minimum criterion.

The water type of most samples from the streams ranged from calcium-magnesium-sodium-bicarbonate to calcium-magnesium-sodium-bicarbonate-sulfate. The cation composition was dominated by calcium and was relatively consistent. The anion composition had a wider range, with most stream samples being dominated by carbonate. The average water type of the lakes and seeps was generally the same as the streams; however, the seeps had a slightly greater range of water types, and the distribution of water types was slightly different. Specifically, the seeps included samples with a higher proportion of sulfate, and the samples also were distributed more evenly across the spectrum of anion composition rather than being weighted toward the bicarbonate end of the spectrum.

Nutrients, which included total ammonia, nitrate+nitrite, total phosphorous, and orthophosphate, had generally low concentrations, especially in lakes and seeps. Orthophosphate was generally not present at detectable levels, with one exception in the KC watershed. Total ammonia was detected in 19 to 36 percent of all surface water samples, and mean concentrations ranged from 0.03 to 0.05 milligrams per liter, depending on whether the samples were from streams, lakes, or seeps. Nitrate+nitrite and phosphorous were detected in 66 to 98 percent of all surface water samples. Mean concentrations of nitrate+nitrite ranged from 0.1 to 0.3 milligrams per liter, and mean concentrations of total phosphorous ranged from 0.02 to 0.04 milligrams per liter. None of the nutrient concentrations exceeded the most stringent ADEC maximum criterion. The coefficients of variation for nutrients were high compared to most other parameters, often in the range of 1 to 2.

The trace elements aluminum, antimony, arsenic, barium, cadmium, copper, iron, lead, manganese, molybdenum, mercury, nickel, and zinc were detected in surface water, although at low concentrations. The frequency of detection depended on the watershed and on whether the sample was collected from a stream, a lake, or a seep. Total and dissolved aluminum, barium, copper, iron, manganese, and molybdenum were typically the most frequently detected trace elements in the streams and lakes. In streams and lakes the frequency of detection generally ranged from 85 to 100 percent. The most frequently detected elements in the seeps were generally the same as those for the streams and lakes, but the frequency of detection was lower in the seeps (53 to 99 percent rather than 85 to 100 percent). Exceptions to this general pattern included a frequency of detection for total and dissolved arsenic in KC of more than 98 percent. The trace elements arsenic, lead, nickel, and zinc had an intermediate frequency of detection,

with the exception of zinc, which had a higher frequency of detection (98 percent) in lakes. Cadmium had the lowest frequency of detection. Some trace element concentrations in stream samples exceeded the most stringent ADEC maximum criteria. Copper from the SFK watershed exceeded the water quality criterion most frequently, with total copper exceeding the criterion in 42 percent of samples and dissolved copper exceeding the criterion in 34 percent of samples. In contrast, copper had one of the lowest frequencies of exceedence in other watersheds. The relatively high frequency of exceedence in the SFK watershed is probably related to the proximity of the deposit. Total aluminum exceeded the most stringent ADEC maximum criterion in 12 to 22 percent of the stream samples from the SFK, UT, and KC watersheds and in 6 percent of the samples from the NFK watershed. In contrast, dissolved aluminum exceeded the criterion in only 1 percent of the stream samples and only in the UT watershed; therefore, aluminum exceedences seem to be almost exclusively associated with suspended solids. Total lead exceeded the most stringent criterion in 8 to 16 percent of the stream samples and was generally the next most frequently exceeded criterion after total aluminum. Dissolved lead exceeded the criterion in 1 to 6 percent of the stream samples and was second only to copper for frequency of exceedence for dissolved elements. Total manganese exceeded the criterion in 15 percent of the stream samples from the SFK and UT watersheds, in 3 percent of the samples from the NFK watershed, and in none of the samples from the KC watershed. Similar to aluminum, manganese exceedences appear to be associated with suspended solids. Concentrations of total antimony, cadmium, iron, mercury, and zinc for the stream samples rarely exceeded the criteria (0.3 to 4 percent).

In samples from lakes and seeps, exceedences of the most stringent maximum criteria included total and dissolved aluminum, total and dissolved copper, total and dissolved iron, total and dissolved nickel, total and dissolved lead, total and dissolved cadmium, and dissolved manganese.

Cyanide was occasionally detected in the surface water samples. Total cyanide was detected in 2 to 15 percent of all samples, and weak acid dissociable cyanide was detected in 5 to 13 percent of all samples, depending on whether the samples were collected from streams, lakes, or seeps. Concentrations of weak acid dissociable cyanide in samples were compared with the most stringent ADEC maximum criterion and exceeded this criterion in 1 to 3 percent of the stream samples, depending on the watershed.

Dissolved organic carbon was detected in 93 to 100 percent of the stream samples, and the mean concentrations ranged from 1 to 2 milligrams per liter, depending on the watershed.

Concentrations of petroleum hydrocarbons, volatile and semi-volatile organic compounds, polychlorinated biphenyls, and pesticides were not detectable above the method reporting limit.

9.2.2 Mine Study Area—Groundwater

Thirty-nine groundwater wells of depths up to 200 feet were installed in the mine study area. One deep drillhole (DH-8417) was used for sampling at depths ranging from 640 to 4,050 feet. The results for groundwater are discussed here as median values for individual wells. Most groundwater samples from depths of 200 feet or less were typically characterized by median

levels of TDS less than 100 milligrams per liter (comparable to surface water), median pH values between 5.8 and 7.4, median DO concentrations greater than 8 milligrams per liter, and concentrations of trace elements below the most stringent ADEC water quality maximum criteria. Concentrations of TDS in groundwater generally decreased with distance from the deposit area. Monitoring well MW-14D in the SFK watershed was the only well with a relatively high TDS level that was not consistent with this general pattern. Most of the groundwater samples had a composition that ranged from calcium-bicarbonate to calcium-magnesium-bicarbonate to calcium-sodium-bicarbonate. Some samples from relatively close to the deposit area had a higher proportion of sulfate, suggesting that the groundwater in this area is influenced by oxidation of the sulfide minerals that are associated with the deposit. As the sulfide minerals oxidize, iron, sulfate acid, and probably trace elements are released. The acid is neutralized by carbonate minerals such as calcite and dolomite, which release calcium, magnesium, manganese, carbonate, and usually some trace elements. This series of geochemical reactions increases the concentration of TDS and the proportion of sulfate in the groundwater.

Although sulfides appear to be oxidizing in the deposit area, the groundwater is not acidic. The lowest median pH values were 4.9 and 5.3. All other median pH values were greater than 5.8. Eight of the wells (six completed in overburden, two in bedrock) had median pH values greater than 7.0, and three of these wells (all completed in overburden) had the highest median TDS concentrations.

The DO measured in the groundwater was usually quite high. Twenty-seven of the 39 wells had median DO concentrations of 8 milligrams per liter or greater, which suggests that the aquifer solids in most of the study area do not include abundant reducing agents such as organic carbon or sulfide minerals. Short groundwater transit times through the aquifers may also help to maintain high DO concentrations. In general, the concentration of TDS was inversely correlated with the concentration of DO. TDS and sulfate concentrations were generally positively correlated with the concentration of calcium. Furthermore, the highest concentrations of iron and manganese tended to occur in samples that had a DO concentration of less than 1 milligram per liter. These correlations among parameter are all consistent with the interpretation that relatively high TDS might be due to oxidation of sulfide minerals.

The wells with relatively high TDS also generally had relatively high concentrations of arsenic, barium, and molybdenum compared with other wells in the study area. All of the wells with more than two trace metals at relatively high concentrations were located closer to the deposit area.

Early in the sampling record, several wells had decreasing concentrations over time, indicating that the geochemistry around the wells was equilibrating during that time. Well MW-14D in the SFK watershed was the only well that had many parameters with concentrations that increased consistently year to year throughout the sampling record. A few wells, such as well MW-12D, had a few parameters that increased slightly over time.

Some systematic differences in concentrations were observed with depth, as indicated by the differences in concentration between wells that were completed in overburden and those that were completed in bedrock. Specifically, the concentrations of antimony, arsenic, copper, iron, manganese, and molybdenum tended to be higher in wells in bedrock than in those in

overburden. Conversely, the concentrations of DO and nickel tended to be lower in wells in bedrock than in wells in overburden.

A single round of deep groundwater samples was collected during hydraulic testing from drillhole DH-8417 at eight depths ranging from 640 to 4,050 feet. The TDS levels in these samples increased with depth from about 200 milligrams per liter from a depth of 640 feet to a range of 1700 to 2200 milligrams per liter from depths between 2000 and 4000 feet. The sample collected at 640 feet was of the calcium-bicarbonate type, similar to samples from the shallow wells located away from the deposit area. The samples collected from depths of more than 640 feet were of the sodium-calcium-sulfate type. This composition is distinct from the shallower groundwater samples, which consistently had a lower proportion of sodium and almost always had a lower proportion of sulfate.

9.2.3 Transportation-corridor Study Area—Surface Water

Sixteen surface-water sampling stations were established and sampled in the transportation-corridor study area during 2004 and 2005. The surface water sampled at these stations was characterized by low levels of TDS (2 to 126 milligrams per liter), mostly near-neutral pH (4.6 to 8.8), and high DO concentrations (9 to 19 milligrams per liter). During months when surface water samples were collected, the temperature ranged from 0.1°C to 23°C. The full annual range of water temperatures could not be characterized because samples were not collected during November, December, or January. The cation composition of the water samples was dominated by calcium. The anion composition was typically dominated by bicarbonate, but some samples were dominated by sulfate. The water composition at most stations was consistent between sampling events, but a few stations had an anion composition that varied over time. Concentrations of nutrients were low; specifically, most ammonia and phosphorous concentrations were below the method reporting limit. Total nitrate+nitrite averaged 1 milligram per liter. Concentrations of the trace elements aluminum, copper, lead, and zinc were above the most stringent ADEC maximum criterion in a few cases.

9.2.4 Transportation-corridor Study Area—Drinking Water Wells

Drinking water samples from the transportation-corridor study area were collected from four drinking water wells: Nondalton City Well, Newhalen Public Well #2, Iliamna Weathered Inn Well, and the Pedro Bay Tribal Council Well. Five samples were collected from each well from July 2004 through October 2005. The mean concentration of TDS, by well, ranged from 57 to 100 milligrams per liter. The water composition of the samples from the Iliamna Weathered Inn, Nondalton, and Pedro Bay wells was classified as calcium-bicarbonate, and water from the Newhalen well was classified as sodium-bicarbonate. Nutrient concentrations were low; specifically, mean concentrations of nitrite+nitrate ranged from 0.23 to 0.40 milligrams per liter, and mean concentrations of phosphorous ranged from 0.05 to 0.07 milligrams per liter. The results for most parameters were within the limits of the ADEC drinking water standards (DWS). Arsenic and field pH were the only parameters that did not meet the DWS. For total and dissolved arsenic, the results for all samples collected from the Nondalton well were above the DWS, and the results for one sample from the Pedro Bay well were above the DWS. Most of the samples collected had pH results outside the DWS range.

9.2.5 Iliamna Lake

Nine sampling sites for the Iliamna Lake study were selected based on their proximity to the transportation-corridor study area and populated villages. Not all sites were sampled every year, but samples were collected during 2005, 2006, and 2007. The sample data suggest that Iliamna Lake has water-quality conditions similar to the natural conditions of other regional lakes. Only aluminum, copper, iron, lead, manganese, zinc, and alkalinity were detected at concentrations that were outside the most stringent ADEC water quality criteria. Cation and anion dominance was generally characteristic for temperate lakes. Concentrations of major ions did not vary with depth, suggesting that the water at the sampling sites were well mixed. The concentrations of several major ions and TDS were lower earlier in the summer, peaked in September, and declined again in October. These temporary increases may be associated with the influence of inflow from streams and precipitation. Samples from Pile Bay and Knutson Bay tended to have similar concentrations, which were usually higher than samples from the other three sites.

Water Quality—Bristol Bay Drainages



Using a multi-probe meter to measure in situ water conditions in the North Fork Kaktuli River during early spring.



Collecting water quality samples from the South Fork Kaktuli River during late summer.

Water Quality—Bristol Bay Drainages



Collecting groundwater samples and measuring in situ water conditions in March.