Pebble Project

NORTHERN DYNASTY MINES INC.

DRAFT ENVIRONMENTAL BASELINE STUDIES
2005 STUDY PLANS

CHAPTER 4. SURFACE WATER HYDROLOGY

NOVEMBER 2005

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ACRONYMS

AASHTO	American Association of State and Highway Transportation Officials
ABA	acid base accounting
ACHP	Advisory Council on Historic Preservation
ACLS	alternative cleanup levels
ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
agl	above ground level
AHRS	Alaska Heritage Resource Survey
AKNHP	Alaska Natural Heritage Program
APE	area of potential effect
ARD/ML	acid rock leaching/metal leaching
ASCI	Alaska Stream Condition Index
BEESC	Bristol Environmental & Engineering Services Corporation
BMR	baseline monitoring report
CAD	computer-aided drafting
CC	comprehensive stations with continuous-stage monitoring
CIR	color infrared
CQ	continuous discharge
CWOC	comprehensive stations without continuous-stage monitoring
DECD	Alaska Department of Economic and Community Development
DEM	digital elevation model
DNR	State of Alaska Department of Natural Resources
DO	dissolved oxygen
DOT&PF	State of Alaska Department of Transportation & Public Facilities
DQOs	data quality objectives
EC	environmental consequences
EIS	environmental impact statement
EPA	Environmental Protection Agency
EBD	environmental baseline document
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FSP	field sampling plan
GIS	geographic information system
GPS	global positioning system
HGM	hydrogeomorphic

IEE	Initial Environmental Evalution
IM	initial monitoring station
KC	Kaskanak Creek
KR	Koktuli River main stem
LDN	Land Design North
LDNPP	Lake Clark National Park and Preserve
MCHTWG	Mulchatna Caribou Herd Technical Working Group
MDC	mine development concept
mg/L	milligrams per liter
mm	millimeters
MODIS	moderate resolution imaging spectroradiometer
MRLs	method reporting limits
NASA	National Aeronautics and Space Administration
NDM	Northern Dynasty Mines Inc.
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NK	North Fork of the Koktuli River
NOAA	National Oceanic & Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NRHP	National Register of Historic Places
NWI	National Wetlands Inventory
ORP	oxidation reduction potential
PJD	preliminary jurisdictional determination
PSD	prevention of significant deterioration
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
SHPO	State Historic Preservation Officer
SK	South Fork of the Koktuli River
SOPs	standard operating procedures
SRB&A	Stephen R. Braund & Associates
SWANCC	Solid Waste Agency of Northern Cook County v. U.S. Army Corp of Engineers
SWE	snow/water equivalent
TIN	triangulated irregular network
TPH	total petroleum hydrocarbons
USACE	United States Army Corp of Engineers
USFWS	United States Fish and Wildlife Service

USGS	United States Geological Survey
UT	Upper Talarik Creek
WMC	Water Management Consultants
WMP	water monitoring plan
WQ	water quality

4. SURFACE-WATER HYDROLOGY

The characterization of site hydrology includes both the surface-water hydrology and the snow-course survey program. HDR Alaska, Inc. (HDR), will lead the surface-water hydrology work on the mine site, and Bristol Environmental & Engineering Services Corporation (BEESC) will complete the surface-water hydrology work for the road and port. ABR, Inc., will lead the snow-course survey program.

4.1 Mine Site

4.1.1 Objectives of Study

Objectives of the baseline surface-water hydrology program include the following:

- Characterization of current site conditions and site resources.
- Collection of surface-water baseline data for comparison to future conditions (for example, construction, operations, and closure).
- Collection of data for design of facilities, including water-management and water-supply structures.
- Collection of data to evaluate the exchange of groundwater and surface water.
- Collection of data to support assessments of aquatic resources, fish resources, and wetlands habitat.

This baseline study provides physical flow information for surface-water systems in the vicinity of the proposed mine, mill, and tailings-disposal facilities. The surface-water hydrology study is interfacing with a concurrent groundwater baseline study (discussed in Section 5) to assist with the evaluation of gaining and losing reaches of the various drainages. Surface-water flow data will be used by the surface water-quality program to provide estimates of baseline surface-water load from the mineralized area to down-gradient surface-water systems. This information will allow description of current conditions and will provide a baseline for the evaluation of potential future changes during operation and closure. Groundwater monitoring and water quality monitoring are addressed in separate sections of the 2005 study plan.

Data gaps in the 2004 surface-water hydrology program were identified through analysis of the 2004 data and from agency comments. The surface-water hydrology program for 2005 was developed to correct these data gaps and address agency issues. Changes to the program in 2005 include the addition of one surface-water monitoring station in the South Fork of Koktuli River, designated SK124A and located on the “Bear Valley” tributary. Specific studies such as low-flow stream profiling, groundwater/surface-water exchange measurements, and hyporheic temperature measurements are also included in the 2005 study. Further details are described in Section 4.1.4, Major Activities.

The snow-course survey is designed to complement concurrent surface-water hydrology studies by characterizing the distribution, snow/water equivalent (SWE), and ablation rates of late-season (pre-breakup) snow across the landscape of the mine region. This information on winter precipitation and the

contribution to surface water in the area will be critical for the design of tailings-storage areas and water-management plans for the mine. Specific objectives of this study are as follows:

- Mapping of late-season snow distribution using data from field surveys, terrain characteristics, and MODIS satellite imagery.
- Mapping of snowpack ablation rates from field-survey data, terrain characteristics, and climate data.
- Paired field measurements of snow depths and densities at meteorological stations to compare with automated precipitation-gauge measures.
- Evaluation of records from proximal snow-survey sites administered by the Natural Resources Conservation Service (NRCS) and Federal Aviation Administration as appropriate proxies for historical snowpack data.

4.1.2 Proposed Study Plan

4.1.2.1 Study Area/Scope

The proposed Pebble Project is located in southwest Alaska, about 18 miles northwest of the town of Iliamna. The project area watersheds are shown in Figure 4-1. The project study area—including the ore body and potential mine, mill, and tailings-disposal facilities—is drained by the North Fork and South Fork of the Koktuli River, Upper Talarik Creek, and tributaries of these waterbodies. These drainages are shown in Figure 4-2. The Kaskanak Creek watershed is southwest of the ore body and was monitored to identify potential interbasin transfer from the South Fork of the Koktuli River. Kaskanak Creek drains to the Kvichak River below Iliamna Lake. These streams within the project-area drainage are part of the Nushagak or Kvichak river watersheds. These watersheds encompass 965 square miles, including the mineralized area, and are shown in Figure 4-1. The long-term mean annual precipitation in the mine-site area is estimated to be 34.1 inches (87 centimeters), of which approximately 30 percent falls as snow (Knight-Piesold, 2004).

4.1.2.2 Methods/Approach

Site Selection and Nomenclature

Monitoring stations for surface-water hydrology were selected with consideration of a number of hydrologic criteria, including the following:

- Surface waterbodies that have the potential to be affected by project activities.
- Locations upstream and downstream of potential mine-facility locations.
- Major watercourses that may be crossed with streams of hydrologic importance (stations to provide data on groundwater and surface-water interactions).
- Streams that could be potential receiving waters for releases from the project.

- Stations that coincide with historical (Cominco) monitoring stations and the information obtained from those studies and related literature.
- Waterbodies in areas of potential water supply.

Additionally, selection and development of station locations was a coordinated process involving the engineering design team and other monitoring program teams, including those studying water chemistry, fisheries and aquatic resources, and sediment and trace metals. Through this process, 15 sites were selected for continuous flow monitoring. The U.S. Geological Survey (USGS) has installed its standard stream-gauging equipment at three of these 15 sites. Conceptual-level understanding of surface and groundwater regimes and the preliminary project alternatives for facilities were used to help define the surface-water monitoring program. The locations of the surface-water monitoring stations and their associated watersheds are shown in Figure 4-3 through 4-7 and are listed in Table 4-1.

TABLE 4-1
2005 Surface-water Monitoring Sites

Location ID	Operator	Data Type	Rationale	Period of Continuous Record1
			North Fork Koktuli River	
NK100C	HDR	Continuous stage and discharge	NK "basin" integrator for NK headwaters	Jul-Oct 2004
NK119A	HDR	Continuous stage and discharge	Downstream of G tailings site	Jul-Oct 2004
NK119B	HDR	Instantaneous discharge only	Drains "back side" of ore body	
NK100A	USGS	Continuous stage and discharge	Lower main stem NK near SK confluence	Aug 2004-Current
NK100B	HDR	Instantaneous discharge only	Downstream of MDC Option G; integrates NK100C and NK100A.	
			South Fork Koktuli River	
SK136B	HDR	Instantaneous discharge only	Drains ore body	
SK136A	HDR	Instantaneous discharge only	Drains ore body	
SK134A	HDR	Instantaneous discharge only	South of ore body (control)	
SK133A	HDR	Instantaneous discharge only	South of ore body (control)	
SK100G	HDR	Continuous stage and discharge	Upper main stem; integrates mine/mill; outside MDC Options A and J; upstream of Frying Pan Lake; same reach as Cominco Stations 6 and 14	Jul-Oct 2004
SK131A	HDR	Instantaneous discharge only	Drains Koktuli Mountain; control stream	

TABLE 4-1
2005 Surface-water Monitoring Sites

Location ID	Operator	Data Type	Rationale	Period of Continuous Record1
SK100F	HDR	Continuous stage and discharge	Main stem downstream of Frying Pan Lake (poss. sink); same reach as Cominco CQ Station 17	Aug, Sep 1991; Jun-Oct 1992; Jul-Oct 2004
SK100D	HDR	Instantaneous discharge only	Main stem downstream of flow loss; Cominco Station 5	
SK100C	HDR	Continuous stage and discharge	Main stem downstream of MDC Options A and J; upstream of flow gain; Cominco CQ Station 16	Jul-Oct 1993; Jul-Oct 2004
SK119A	HDR	Continuous stage and discharge	Tributary downstream of MDC Options A and J; flow to "aquifer recharge-discharge" area; Cominco Stations 18 and 20	Jul-Oct 2004
SK124A	HDR	Continuous stage and discharge	Provides flow data for Bear Valley; downstream of MDC Option J	
SK100B	USGS	Continuous stage and discharge	Main stem downstream of MDC Options A and J; downstream of flow gain	Aug 2004-Current
SK100A	HDR	Continuous stage and discharge	Lower main stem SK near confluence with NK	Jul-Oct 2004
			Upper Talarik Creek	
UT100E	HDR	Continuous stage and discharge	Upper reach of UT; downstream of potential flow gain from NK; upstream of drainage from ore body; control for MDC options; same reach as Cominco Station 8	Jul-Oct 2004
UT146A	HDR	Instantaneous discharge only	Drains ore body; headwaters in mineralized zone	
UT141A	HDR	Instantaneous discharge only	Low point for new drainage north of MDC Options A5 and J5, mine area; added Q to UT	
UT100D	HDR	Continuous stage and discharge	Integrates all UT from mine, mill, embankment effects for MDC Option A5; Cominco CQ Station 13	Aug-Sep 1991; Jun-Oct 1992; Sep-Oct 1993; Jul-Oct 2004
UT138A	HDR	Instantaneous discharge only	Drains "Pig"	
UT135A	HDR	Instantaneous discharge only	Major UT tributary near confluence with main stem of UT; winter flow contribution; Cominco CQ Station 19	Aug-Oct 1993; May-Sep 1994
UT119B	HDR	Instantaneous discharge only	Downstream of flow gain from SK and MDC J Option sites	
UT119A	HDR	Continuous stage and discharge	Integrates mine/mill groundwater effects on UT from reduced flow from SK for MDC J Options; WQ and biological sampling	Jul-Oct 2004

TABLE 4-1
2005 Surface-water Monitoring Sites

Location ID	Operator	Data Type	Rationale	Period of Continuous Record1
UT100B	USGS	Continuous stage and discharge	Lower reach of UT; downstream of UT-1.190 effects; downstream of mineralized zone	Aug 2004-Current
UT100A	HDR	Instantaneous discharge only	Downstream of mineralized zone; integrates all of UT	
			Kaskanak Creek	
KC100A	HDR	Continuous stage and discharge	Evaluate potential interbasin transfer of water from SK	Jul-Oct 2004
			Main Stem Koktuli River	
KR100A	HDR	Instantaneous discharge only	Integrates NK and SK; lowest watershed site	

Notes:

1. Continuous-stage data collected when ice is present are suspect because of a continuously changing cross-section and other variables.

CQ = Continuous Discharge

MDC = Mine Development Concepts

Q = Flow or Discharge

WQ = Water Quality

Surface-water site nomenclature was determined as follows:

- KC = Kaskanak Creek
- KR = Koktuli River Main Stem
- NK = North Fork of Koktuli River
- SK = South Fork of Koktuli River
- UT = Upper Talarik Creek
- Main stream channels are designated as 100, and each tributary stream is numbered sequentially starting at the mouth and moving upstream (101, 102, . . . 135, 136, etc.).
- Each stream identification number was followed by a sequential (from mouth moving upstream) sample-site identifier letter (A, B, C, etc.).

For example, sample site "UT119A" refers to the most downstream sample (A) taken from the 19th mapped tributary (119) upstream of the mouth of Upper Talarik Creek (UT). Sample site "SK100B" refers to the second-most downstream sample site (B) on the main stem (100) of the South Fork of Koktuli Rive (SK).

The three sites for the USGS installations were determined during the May 2004 field trip and are SK100B, NK100A, and UT100B. Table 4-2 provides details about these stations.

TABLE 4-2
Local USGS Stream Gauge Locations

USGS Station Number	Location ID	Datalogger Installed
15302250	NK100A	August 2004
15302200	SK100B	August 2004
15300250	UT100B	August 2004

Equipment and Installation

HDR-installed dataloggers used for this project are MiniTROLL units manufactured by In-Situ, Inc. Each datalogger is designed to record water depth and water temperature. A five-pounds-per-square-inch pressure transducer in the MiniTROLL unit records changes in water surface elevation and has an accuracy rating to 0.01 foot. The units are set to observe water depth and temperature on a one-minute interval. One-minute observations are recorded only for changes in water depth of 0.01 foot or greater; however, observations are recorded every 10 minutes, regardless of changes in water depth. Temperature is recorded for every depth recording. The units are installed by driving a steel angle iron into the streambed until the angle is solidly anchored. In most cases, this depth has constituted approximately 2 feet. A prefabricated polyvinyl chloride (PVC) housing shell is connected to the angle iron at the channel bottom with steel clamps. PVC conduit is then installed above the housing, and the MiniTROLL unit is placed in the housing with the cable secured in the conduit. A junction box to protect the cable connection is installed at the top of conduit. The top of the PVC housing remains open, and holes are drilled in the sides of the PVC to allow free water pressure over the sensors.

Continuous-Stage Discharge Data

The USGS downloads and analyzes its stage data and converts it into provisional discharge before providing it to HDR for reporting. The following procedures are typically used to analyze the continuous-stage data collected by HDR. Raw data are downloaded from the dataloggers during monthly trips to the sites. The values reported from the dataloggers include date, time, elapsed time (seconds), channel temperature, and channel pressure (feet of water) for the period between trips to the sites.

The date, time, and channel pressure for each period of record are copied into a single file for data analysis and adjustment. “Adjusted-stage” data are created by adding the datalogger depth value recorded at the time of installation to each channel pressure reading, thereby ensuring that all stage readings are positive values.

During 2004, it was noted during the monthly site visits that the dataloggers had experienced a drift or shift during measurements. This shift was found by comparing the transducer-elevation value recorded at each monthly site survey to the value recorded on the installation date. Drift in measurements over time is typical for data of this type and is corrected mathematically. The total of the shift is divided by the number of days measured, and an estimated shift in the datalogger for each day is established. The

underlying assumption is that the shift occurs over time and not in large increments. This daily shift is added to each of the adjusted-stage data readings and recorded as a shifted-stage value.

The date and time of the monthly instantaneous discharge measurement are correlated, within a few minutes, to a channel pressure reading recorded by the datalogger. In this way, the pressure readings from the datalogger can be compared to the actual flow of the stream. The instantaneous discharge measurements collected each month are plotted on the Y axis of a logarithmic graph, and the stage (the shifted-stage value corresponding to that measurement) is plotted on the X axis of a logarithmic graph. This plot is developed for each station to produce a logarithmic trend line, or stage-discharge rating curve, for each station. The equation of the logarithmic trend line is calculated for application to the continuous-stage data. The equation is applied to the continuous shifted-stage values to find Q, or discharge, at every time step.

Once the Q for every reading by the datalogger is established, the data are separated into monthly groups. In this format, the daily and monthly means for each continuous surface-water station can be calculated and graphed. This analysis follows the accepted practice of displaying hydrologic data by separating the data into water years. The water year begins on October 1—which usually corresponds to the end of the summer dry period—and ends on September 31 of the following year. To facilitate comparison of flows at different stations or of flow regimes between watersheds, it is useful to normalize the flow by dividing by drainage area upstream of the station. Minimum mean daily discharge per unit area is calculated by finding the lowest mean daily value, which can be accomplished with the use of a geographic information system (GIS) to find drainage areas of surface-water stations and lengths of stream segments between stations.

Continuous-stage monitoring equipment will be removed for winter months from all 15 locations following the October 2005 field event. Continuous-discharge records for Alaskan streams are not typically obtainable because stage-discharge relationships are not applicable under ice-affected conditions (Nolan and Jacobson, 2000). Instead, winter discharge hydrographs will be estimated using instantaneous discharge measurements in conjunction with meteorological data.

Field Methods

A channel cross-section is surveyed at each datalogger upon installation. Two or three temporary benchmarks are established at each site to provide local data for vertical control. A minimum of one temporary benchmark on each bank defining the cross-section is established. Cross-section distances are measured with a survey tape, and a survey level is used for vertical measurements. The datalogger is tied to the surveyed cross-section by surveying the elevation of the top of the angle iron post and the water surface elevation at the angle iron post.

Field procedures defined by the USGS (Rantz et al., 1982) and the *Draft Environmental Baseline Studies Proposed 2005 Quality Assurance Project Plan* (NDM, 2005) are used to obtain instantaneous discharge measurements. Both Price AA, Pygmy, and Marsh McBirney flow meters will be used, depending on stream depths and velocities.

Instantaneous discharge measurements are being collected at each sampling location in January and in March through October. During 2004, exceptions to this process occurred because of high water, which was considered too dangerous to wade. Measurements are typically taken using top-setting wading rods.

If the water is too deep or swift to wade in 2005, a boat will be employed to obtain discharge measurements. A sounding weight may also be used with the boat to help stabilize the current meter. In a few cases, measurements were not collected in 2004 because of equipment malfunctions. HDR will keep backup current meters on hand in 2005 to avoid this issue.

Winter measurements will be collected in January and March. This work will include measurement of instantaneous discharges measured through the ice or in open channels. As much as is practical, HDR will attempt to collect these data from all 30 of the locations described on Figures 4-3 through 4-7 and Table 4-1. However, the exact number and locations of the winter measurements will be determined in the field according to safety considerations and the effects of icing on channel control. Winter discharge measurements will follow the USGS procedures described in *Stream Discharge Measurements Under Ice Cover* (Nolan and Jacobson, 2000).

Snow-Course Surveys

In 2005, additional field survey locations will be added in the upper reaches of the North Fork of Koktuli River (see Figure 4-8). These locations are being added to provide site-specific data for surface-water hydrology studies in the local area. Data from the newly established meteorological-stations snow gauge will be incorporated into the final analysis of the ablation rate to differentiate sublimation and meltwater component processes. An additional field visit was included in 2005 to allow collection of additional data on snow ablation rates in the case of a prolonged breakup season.

The approach to mapping spring snow distribution will rely on a combination of detailed field surveys and a terrain model that incorporates the predominant variables that influence snow accumulation (elevation, aspect, slope, and vegetation canopy). To determine the spring snow distribution across the study site, snow depths and density will be measured along 13 to 15 slope/aspect transects and two permanent snow courses. Sampling along the slope/aspect transects will extend from ridge tops to valley bottoms with snow depths and densities measured at 100-foot-elevation intervals. At each measurement location, SWE will be calculated from three measures of snow depth and snow density. Percent snow cover will be visually estimated at each measurement site. Slope and aspect will also be determined at each site for use in the snow distribution model. Slope/aspect transects will range from 0.6 mile to 1.9 miles and will cover the predominant elevation spans and aspect present in the major drainage basins in the study area. Three of the slope/aspect transects will include (begin or end) meteorological station locations. At each meteorological station, snow depth and density will be measured at five locations situated on a10-foot radius around the station.

Two permanent snow courses will be established to provide data suitable for comparison with existing NRCS snow-course sites and to provide precise inter- and intra-annual comparison of SWE. One snow course will be located at 2,000 feet on a ridge near Groundhog Mountain, and the other at 1,100 feet on a hill in the headwaters of Upper Talarik Creek. Each snow course will consist of a 1- to 2-mile circuit around a small ridge or knob with 10 to 16 stations located to cover all slope aspects. Additional spring field surveys, in conjunction with calibrated MODIS (moderate resolution imaging spectroradiometer) snow data, local meteorological data, and the snow-gauge record, will be used to estimate snowpack ablation and provide runoff estimates. Initial snow surveys will be performed in April 2005, with follow-up snow ablation-rate surveys at biweekly intervals through April and May 2005.

4.1.2.3 Major Activities

Activity 1: Monthly Surface-water Hydrologic Data Collection

HDR will collect surface-water hydrology data at the mine site from 30 stations during nine field events (January and March through October) in 2005. Instantaneous discharges will be measured at each site during the field visits. The methods described above will be used to collect these data. Water quality data will be collected at these same stations and concurrently as described in Section 6 of this study plan.

During initiation of the surface-water hydrology program in 2004, both continuous and instantaneous data were lacking for the spring freshet. Likewise, instantaneous data were not collected during the period of relatively high-flow events experienced in the fall. These data gaps will be addressed in 2005.

In addition to the three sites operated by USGS, HDR will install dataloggers at 12 locations (Table 4-1) in 2005 in time to collect continuous-stage data for the spring freshet. In 2004, continuous-stage monitoring equipment at the mine site was often installed nearer the center of the stream during summer months because of low-flow conditions. A similar installation is not practical during spring breakup because floating debris would likely disturb the equipment. Therefore, HDR will (as necessary) set up the continuous-stage monitoring equipment in more protected locations—likely nearer the edges of stream channels—to capture data from the spring freshet. The equipment locations may be moved (and resurveyed) to a center-stream location once stream flows have adequately receded for summer.

Instantaneous discharges in 2004 were not collected during high-flow events because steams were too dangerous to wade. This problem will be addressed in 2005 by collecting discharge data from a boat attached to a line that will be fixed to both shores of the stream. In all cases, standard USGS methods will continue to be used.

Activity 2: Upper Hyporheic Zone Measurements

Potential changes resulting from the proposed mine include altered hydraulic exchange between the groundwater and streams. Temperatures within the hyporheic zone (the saturated zone under a river or stream comprising substrate with the interstices filled with water) are important to the spawning success of salmonoids (Rubin, 1995). Comparison of temperatures in the hyporheic zone to those in the adjacent groundwater and the above in-stream water column may be used to better understand the hydraulic connections between these systems.

HDR plans to measure temperature at four locations within the mine study area. Locations and additional details for the hyporheic measurements will be completed in spring 2005 in consultation with Water Management Consultants (WMC) and the Alaska Department of Natural Resources. Shallow groundwater monitoring wells will also be installed adjacent to the hyporheic stations. Continuously logged thermistors will be installed to measure groundwater temperature at two depths at each location. The installation of the hyporheic monitoring stations is planned for June 2005. After the stations have been installed, HDR will download the thermistor data once per month, according to the same schedule as for the surface-water monitoring program.

Activity 3: Low-Flow Stream Profiling

An evaluation of baseline hydrology, as well as potential changes to watersheds from the proposed mine, requires characterization of the hydraulic connections between surface-water and groundwater resources. To aid the hydrogeology study, a series of low-flow streamflow profiles will be completed. These profiles will consist of 10 to 15 instantaneous discharge measurements each along the North Fork of Koktuli River, South Fork of Koktuli River, Upper Talarik Creek, and tributaries for a total of up to 45 measurements. The measurements will be collected during the low-flow period following spring runoff (planned for late June or early July). Measurements will be collected using the same field methods described above for the monthly discharge measurements.

The specific stream reaches to be surveyed during the summer low-flow period will be determined in consultation with WMC. Reaches of surface water that receive substantial gain from groundwater may be visually indicated in winter months by the presence of open (ice-free) water. In preparation for the summer low-flow measurements, each stream will be traversed by helicopter in January and March to record reaches of open water. Losing reaches, such as in the area near SK100C (Figure 4-4) that went dry in August 2004, will be identified using data such as the 2004 surface-water hydrographs, surficial geology, and groundwater elevations.

Activity 4: Groundwater/Surface-water Exchange Measurement

In conjunction with the streamflow measurements specified in Activity 3, mini-piezometers and seepage meters are planned for 12 of the low-flow streamflow measurement stations. HDR, with input from WMC, will install a pair of mini-piezometers at each station in June to evaluate the direction of groundwater flow (gaining or losing) during low-flow conditions. The mini-piezometers will be driven into the hyporheic zone (in-stream measurements) and the saturated zone (adjacent groundwater location) using a vibrating hammer and will be left in place.

Water samples will be collected from the stream and from the mini-piezometers. These water samples will be analyzed for major ions and selected isotopes. The resulting data will be provided to WMC to be used in conjunction with other groundwater and surface-water samples to interpret groundwater recharge and discharge patterns.

Seepage-meter measurements will also be recorded at these locations to document the quantity of groundwater flux into or out of the streambed. Four seepage meters will be constructed in Anchorage from 55-gallon drums, as described by Lee and Cherry (1978). These meters will be sent to the study area for installation.

4.1.3 Deliverables

The following products will be prepared in conjunction with the 2005 surface-water hydrology study:

- A 2005 progress report documenting activities, details on station installation, results, and data interpretations for surface-water monitoring.
- Contribution on surface-water hydrology to the environmental baseline document.

- A GIS-compatible raster grid with an expected resolution of 10 to 20 feet (depending on the horizontal resolution of the final digital elevation model [DEM]) representing snow depth, SWE, and spring ablation rates for each year of the study (currently 2004 and 2005).
- An Access-compatible database of field data and site photographs collected during the snow survey that is suitable for integration into the overall data management system for the proposed mine.

Other data products produced to support this study will include the following:

- Delineation of watersheds in the study area with the use of National-Aeronautics-and-Space-Administration shuttle topography-DEM data (as available).
- Calculation of slope, aspect, and equivalent latitude grids of the mine study area.
- Oblique aerial photography of the mine study area in mid-April, early May, and mid-May to assist in delineation of large snow beds.
- Additional data sets to support other aspects of the proposed project and that will be used to enhance maps of snow distribution:
  - High-resolution elevation surveys.
  - Habitat mapping (vegetation canopy classifications).
  - Daily precipitation records (on-site meteorological stations).

4.2 Road/Port

4.2.1 Objectives of Study

The objectives of the baseline surface hydrology studies along the road corridor and at the port site area are as follows:

- Identify and describe the existing surface-water conditions at the road crossings, along the preferred road corridor identified by the Alaska Department of Transportation and Public Facilities (DOT&PF).
- Identify and describe the processes that control the hydrologic balance within the project watersheds.
- Provide baseline information to evaluate the potential impacts the proposed road may have on the upstream and downstream environment.

4.2.2 Proposed Study Plan

This proposed study plan uses guidelines established by DOT&PF, the Federal Highway Administration (FWHA), and the American Association of State and Highway Transportation Officials (AASHTO).

4.2.2.1 Study Area/Scope

The study area includes all watersheds located between the Newhalen River and the preferred port site that are intersected by the preferred road corridor, as shown on Figure 4-9. The preferred road corridor, as identified by DOT&PF, crosses 18 larger streams that will require study in order to properly evaluate them for Title 41 (AS § 41.14.870) permits. Work completed in 2004 included monitoring of 15 Title 41 streams.

4.2.2.2 Methods/Approach

All data collection and the analysis of these data will conform to the established procedures of DOT&PF, USGS, and FWHA. The data will be collected so as to ensure that there is sufficient information from within the preferred alternative road corridor to allow evaluation of environmental impacts to the hydrologic regimes.

Existing data from the USGS gauging station on the Iliamna River and historical published weather data suggest two distinct climatic zones along the road corridor, with Canyon Creek being the approximate boundary between the two zones. The USGS will re-establish a gauging station in Roadhouse Creek in the summer of 2005 in order to establish flow characteristics on a smaller watershed with less intense rainfall in the western portion of the study area. The Iliamna River records will be used for analysis of streams east of Canyon Creek, and Roadhouse Creek gauge records will be used for streams west of Canyon Creek. Regression equations have been developed using basin characteristics for each of the two zones and will be refined using field observations.

Computational analysis for annual high-flow and seasonal low-flow statistics for streamflow recorded by existing USGS gauging stations on the Iliamna River and Road House Creek will be used to calibrate the data collected on the selected ungauged streams in the project area. The statistical data will be used to predict high- and low-flow characteristics on the ungauged streams using USGS Water-Resources Investigations Reports 03-4114 and 03-4188.

The field data-collection effort includes monitoring eight (six by BEESC, two by USGS) of the 15 gauge stations installed in 2004 along the proposed road corridor. The locations of the gauges are shown in Figure 4.9. Gauge locations have been determined based on location of the road corridor, land ownership status- and hydrologic and geomorphic considerations. At each location, a crest gauge is established to record high water levels between monitoring events. Stream cross-sections are surveyed at apparent ordinary high water (OHW) and photographic documentation upstream and downstream of the crest gauge is also collected. Monthly instantaneous flow-velocity measurements and crest-gauge readings are taken and compiled.

4.2.2.3 Major Tasks/Activities

The major tasks for this study are statistical stream-flow modeling, data compilation, and the documentation of existing conditions. The work will consist primarily of researching existing information, computational analysis, and field data collection in those stream reaches that would be crossed by the preferred alternative road corridor.

Research sources include:

- Agencies: DOT&PF, Alaska Department of Environmental Conservation, Alaska Department of Community and Economic Development, USGS, U.S. Army Corps of Engineers, Federal Aviation Administration, and others as necessary,
- Anecdotal information from local residents, and
- Aerial photography and other remote-sensing data inspection and analysis.

Field work will consist of the following:

- Surface-water (discharge) measurements on selected rivers and streams that require a Title 41 permit for proposed crossings (Figure 4-9).
- Surveys of stream cross-sectional dimensions and elevations to be tied in to crest-gauge elevation.
- Crest-gauge monitoring.

A basin-characteristics file will be created for each stream that the preferred road corridor will cross. The data will be stored in a GIS database.

Information to be collected for each basin includes:

- Corridor station number,
- Stream name,
- Latitude and longitude,
- Location map (USGS quadrangle map designation),
- Drainage area (square miles),
- Mean channel slope (feet per mile),
- Channel length (miles),
- Surface-water area of lakes and ponds (square miles),
- Total storage area (square miles),
- Precipitation data (mean annual inches) provided by National Weather Service,
- Mean basin elevation (feet above sea level),
- Forested area (square miles),
- Glaciated area (square miles),
- Mean January temperature data (degrees Fahrenheit) provided by National Weather Service,
- Digital photos of the stream reach that the corridor crosses including views looking upstream and downstream of the corridor,
- Title 41 classification,

- All existing surface hydrological measurements and flood-record data provided by the USGS, Water Resources Branch,
- Stream classification (stable, transitional, or unstable; and sinuous, straight, braided, alluvial, or incised) within the corridor reach,
- Geomorphologic data (description of sediment scour and deposition trends, stability of form over time, bed and bank material identification),
- Estimates of expected maximum and minimum flows,
- Flow measurements collected during field programs, and
- Base images:
  - Aerial photography copies of 2003 Aerial Photography taken by others,
  - "U2" false color infrared photography provided by Northern Dynasty Mines, and
  - USGS topographic maps.

4.2.3 Deliverables

Deliverable products will include:

- Basin-characteristics file for each stream crossed by the preferred road corridor;
- Estimation of flow conditions for all Title 41 streams and tributaries in study area;
- Field notes, calculations, and interim progress reports; and
- Hydrologic and hydraulic summary for all crossings, in accordance with DOT&PF, Alaska Highway Drainage Manual, Appendix B.

4.3 References

Knight-Piesold Consulting. 2004. Northern Dynasty Mines Inc. Pebble Project, Hydrometeorology. KP Report Reference No. VA101-00176/07-6, Appendix B. November 30.

Lee, D.R., and J.A. Cherry. 1978. "A Field Exercise on Groundwater Flow Using Seepage Meters and Mini-Piezometers." Journal of Geologic Education, Vol. 27, pp. 6-10.

Nolan, K. Michael, and Nathan Jacobson. 2000. Stream Discharge Measurements Under Ice Cover. U.S. Geological Survey Water Resources Investigation Report 00-4257.

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Rantz, S.E., et al. 1982. Measurement and Computation of Streamflow. Volume 1: Measurement of Stage and Discharge. U.S. Geological Survey Water Supply Paper 2175.

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FIGURES

Northern Dynasty Mines Inc.

Pebble Project

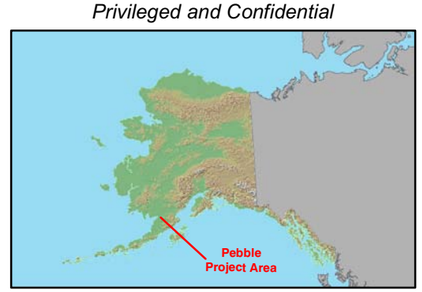
Project Area Watersheds
Figure: 4-1

Legend

- Villages
- Kvichak Watershed
- Nushagak Watershed
- Project Study Area

Sites from HDR, file date 02/03/2005

Privileged and Confidential



N

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0 10 20 40 60 80 Kilometers

Scale 1:1,427,778

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

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Version: 1	**Author: HDR-DS**

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155°48'0"W
155°36'0"W
155°24'0"W
155°12'0"W
155°0'0"W
60°0'0"N
59°48'0"N

North Fork Koktuli River
Ore Body
Upper Talarik Creek
KR100A
NK100A
Koktuli River
SK100A
South Fork Koktuli River
Kaskanak Creek
KC100A
UT100A

Northern Dynasty Mines Inc.

Pebble Project

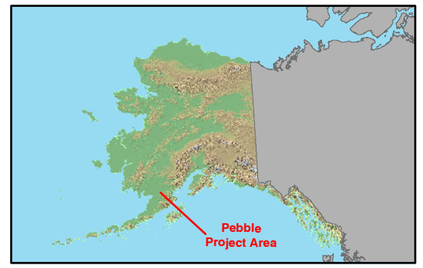
Monitoring Site Drainages
Figure 4-2

Legend

- Most Downstream Monitoring Site In Drainage
- Ore Body
- Monitoring Site Drainages

Sites from HDR, file date 02/03/2005

Privileged and Confidential



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Scale 1:175,754

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

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60°0'0"N

59°48'0"N

NK100B

NK100C

NK119A

NK119B

Ore Body

North Fork Koktuli River Watershed

North Fork Koktuli River

NK100A

Northern Dynasty Mines Inc.

Pebble Project

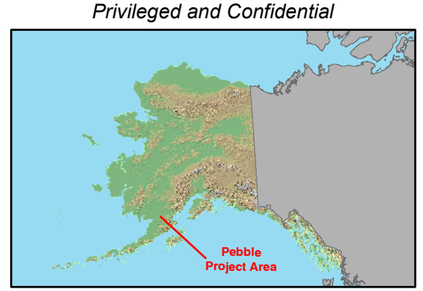
North Fork Koktuli River Watershed
Figure: 4-3

Legend

- North Fork Koktuli River Monitoring Sites
- Ore Body
- North Fork Koktuli River Watershed
- Monitioring Site Drainage Basins

Sites from HDR, file date 02/03/2005

Privileged and Confidential



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0 0.5 1 2 3 4 Kilometers

Scale 1:107,132

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

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Version: 1	**Author: HDR-DS**

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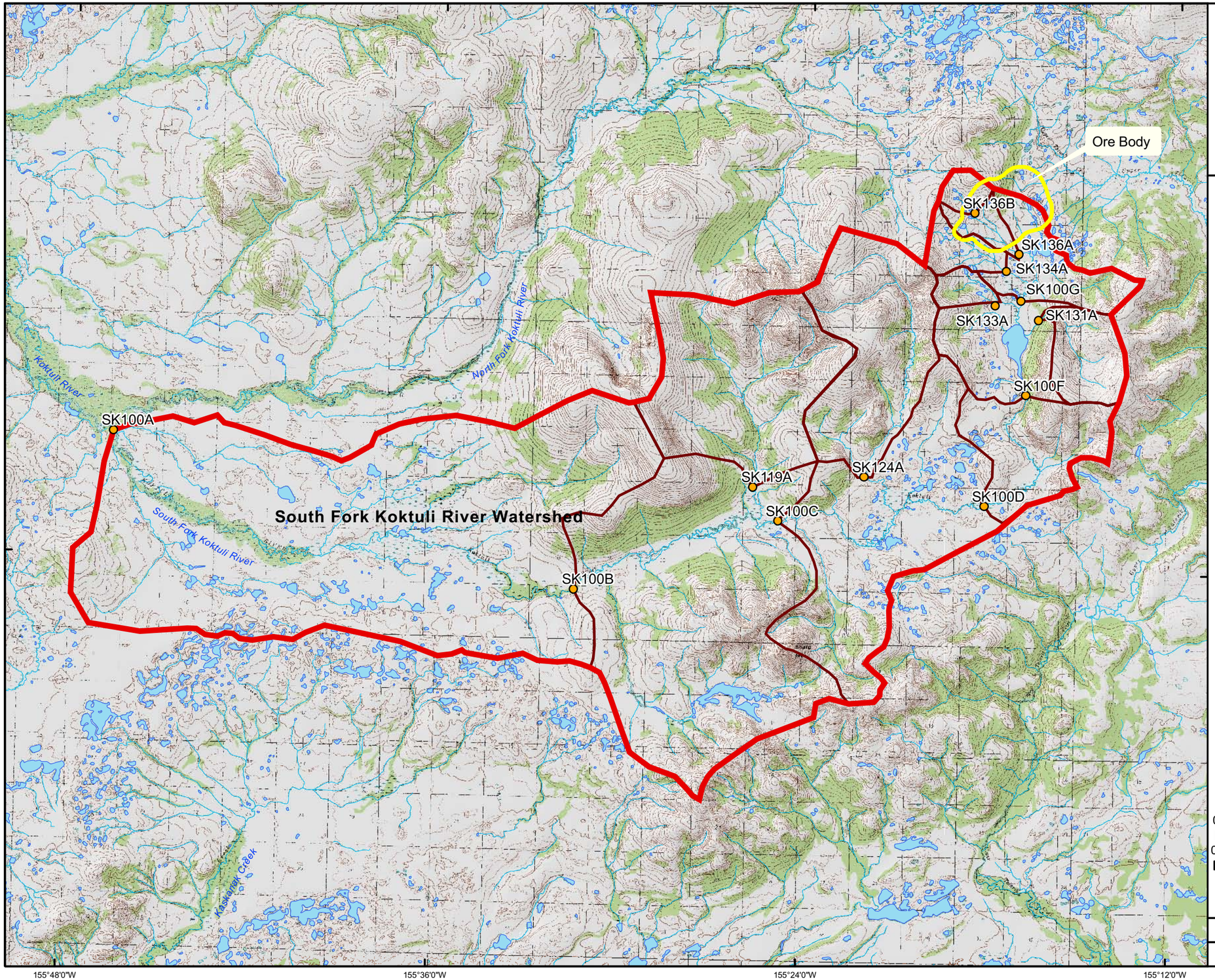
59°48'0"N



Northern Dynasty Mines Inc.

Pebble Project

South Fork Koktuli River Watershed
Figure: 4-4

Legend

- South Fork Koktuli River Monitoring Sites
- Ore Body
- South Fork Koktuli River Watershed
- Monitoring Site Drainage Basins

Sites from HDR, file date 02/03/2005

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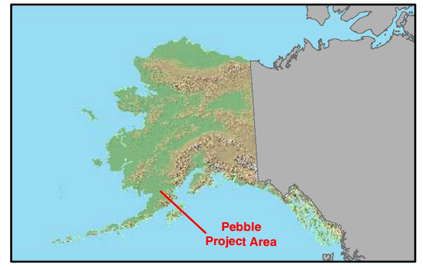

N

0 0.5 1 2 3 4 Miles

0 1 2 4 6 8 Kilometers

Scale 1:118,969

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

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155°24'0"W

155°12'0"W

155°0'0"W

59°48'0"N

Ore Body

UT100E

UT146A

UT100D

UT138A

UT141A

UT135A

Upper Talarik Creek Watershed

UT119B

UT119A

UT100B

UT100A

Northern Dynasty Mines Inc.

Pebble Project

Upper Talarik Creek Watershed
Figure: 4-5

Legend

- Upper Talarik Creek Monitoring Sites
- Ore Body
- Upper Talarik Creek Watershed
- Monitoring Site Drainage Basins

Sites from HDR, file date 02/03/2005

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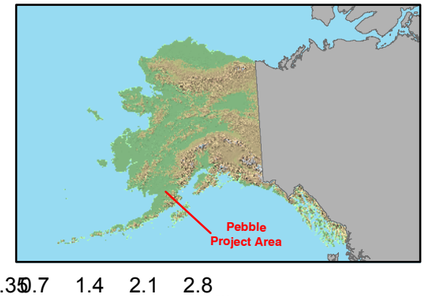

N

0 0.35 0.7 1.4 2.1 2.8 Miles

0 1 2 4 6 8 Kilometers

Scale 1:123,571

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

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155°48'0"W

155°36'0"W

155°24'0"W

59°48'0"N

Okuli River

Ore Body

Kaskanak Creek Watershed

KC100A

155°48'0"W

155°36'0"W

155°24'0"W

Northern Dynasty Mines Inc.

Pebble Project

Kaskanak Creek Watershed
Figure: 4-6

Legend

- Kaskanak Creek Monitoring Site
- Ore Body
- Kaskanak Creek Watershed

Sites from HDR, file date 02/03/2005

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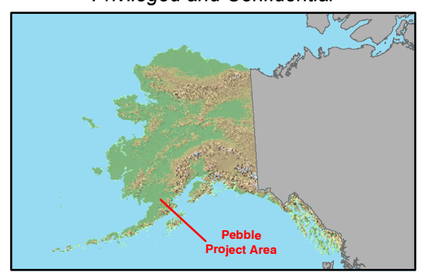

N

0 0.5 1 2 3 4 Miles

0 0.5 1 2 3 4 Kilometers

Scale 1:109,976

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

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155°36'0"W
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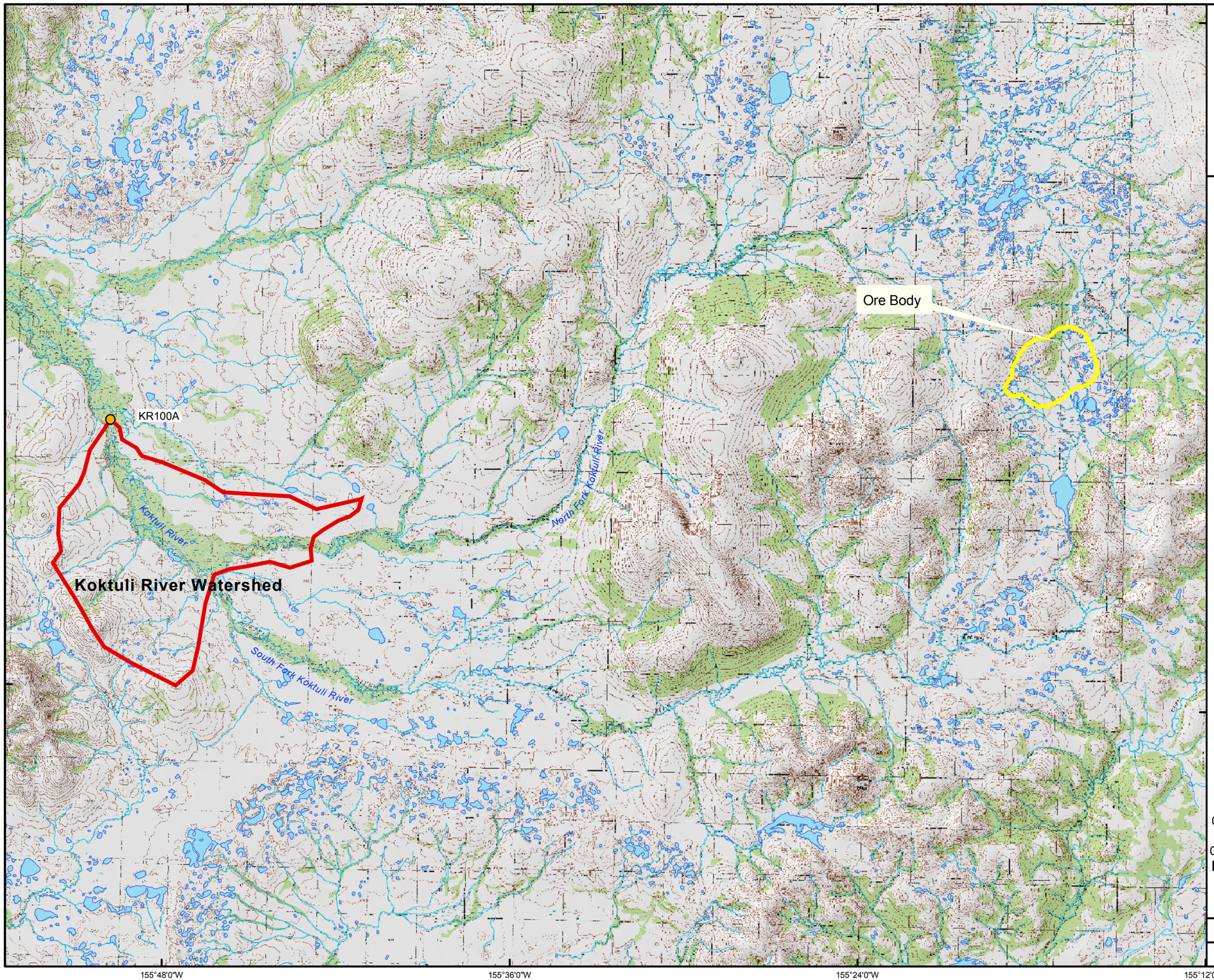

Northern Dynasty Mines Inc.

Pebble Project

Koktuli River Watershed
Figure: 4-7

Legend

- Koktuli River Monitoring Site
- Ore Body
- Koktuli River Watershed

Sites from HDR, file date 02/03/2005

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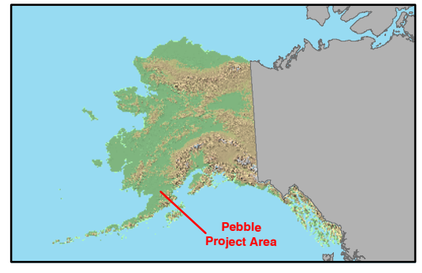

N

0 0.5 1 2 3 4 Miles

0 1 2 4 6 8 Kilometers

Scale 1:126,095

Alaska State Plane Zone 5 (units feet)
1983 North American Datum

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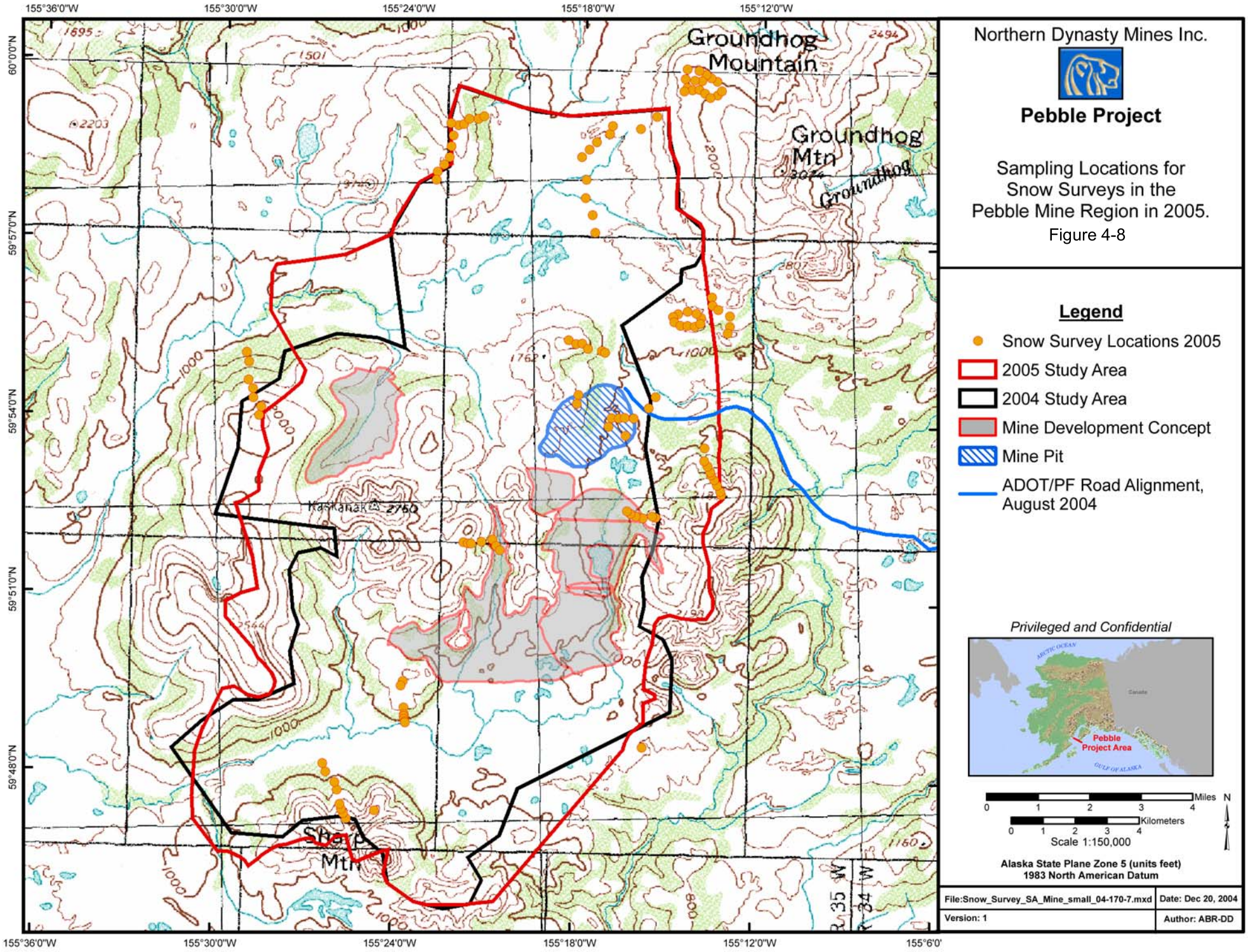

Northern Dynasty Mines Inc.
Pebble Project
Sampling Locations for Snow Surveys in the Pebble Mine Region in 2005.
Figure 4-8
Legend
Snow Survey Locations 2005
2005 Study Area
2004 Study Area
Mine Development Concept
Mine Pit
ADOT/PF Road Alignment, August 2004
Privileged and Confidential
Pebble Project Area
Miles
Kilometers
Scale 1:150,000
Alaska State Plane Zone 5 (units feet)
1983 North American Datum
File:Snow_Survey_SA_Mine_small_04-170-7.mxd
Date: Dec 20, 2004
Version: 1
Author: ABR-DD
Groundhog Mountain
Groundhog Mtn
Groundhog
Kaskanak
Sharp Mtn
155°36'0"W
155°30'0"W
155°24'0"W
155°18'0"W
155°12'0"W
155°6'0"
60°0'0"N
59°57'0"N
59°54'0"N
59°51'0"N
59°48'0"N

1,400,000 1,450,000 1,500,000 1,550,000 1,600,000 1,650,000 1,700,000 1,750,000

2,250,000 2,200,000 2,150,000 2,100,000 2,050,000 2,000,000

Nondalton

GS-14b GS-11a GS-8a GS-4a GS-17a GS-20 Pedro Bay GS-3a

Iliamna

Newhalen

GS-21

Iliamna Lake

Cook Inlet

Northern Dynasty Mines Inc.

Pebble Project

Surface Water and
Groundwater Monitoring
Figure 4-9.

Legend

- Groundwater Well Sample Location
- 2005 Surface Water Monitoring Stations
- 2004 Surface Water Monitoring Stations
- Port Site 1
- Preferred DOT&PF Road Corridor

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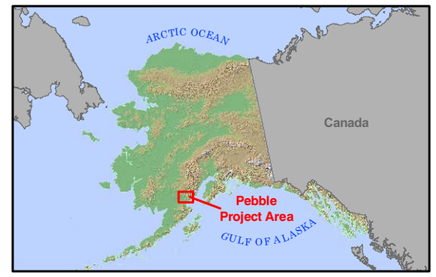

Feet
0 16,000 32,000 48,000 64,000

Meters
0 5,000 10,000 15,000 20,000

Scale 1:361,929

N

Alaska State Plane Zone 5 (units US feet)
1983 North American Datum

File: Water_Mon_V06.mxd	Date: September 2, 2005
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