Long-Range Hydrology Study

Northshore Mining Company
Final Report

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1.0 Introduction

As part of continuing operations, and as shown in its Permit to Mine documentation, Northshore Mining Company will be mining ore that now forms an in-pit dike separating the Peter Mitchell pit into two drainage basins. The removal of this ore is permitted under Northshore's existing Permit to Mine and will result in changes to the local hydrology and divert water from the Partridge River in the Superior Basin watershed to the Dunka River in the Rainy River watershed upon cessation of mining activities. Pit dewatering during mining activity will allow discharge waters to be returned to the appropriate watershed.

This action represents an interbasin transfer of water from the Superior Basin to the Rainy River Basin. This issue has been addressed by the MDNR, which has concluded that this action is allowed under Northshore Mining Company's current permit to mine, which was issued prior to adoption of applicable regulations on interbasin transfer. The action has been approved by the MDNR, and is anticipated to begin within the next year. As part of this operation, Northshore Mining Company is required to develop an estimate of hydrologic impacts of this action. This study is prepared to provide such an estimate.

The objective of this study is to quantify the changes in hydrology within the Partridge River, Dunka River, Langley Creek, and an unnamed tributary to Dunka River occurring between the present and post-closure steady state conditions sometime around 2070. The work will also include an estimate of the time to fill the ultimate pit and an estimate of post-closure pit discharge.

The Peter Mitchell pit is located approximately four miles south of Babbitt, MN (see Map 1). The mining of this ore will result in progression of the pit towards the Ultimate Pit Limit and alter the local topography. During active mining, pits form hydrologic sinks as they capture surface and ground water inflow. When mining operations cease and dewatering stops, water continues to flow into the pit causing water levels to rise until they reach a state of equilibrium. Whether or not a pit outflows at equilibrium depends on two factors: 1) the lowest elevation around the pit rim and 2) the water balance (inflows and outflows) of the pit. Uncontrolled discharge of water could potentially lead to negative downstream impacts such as flooding, erosion and decreased water quality. It is therefore useful to predict the hydrologic conditions of post-closure pit complexes. This study is an evaluation of the long-term hydrologic impacts of the operation, closure, and ultimate filling of the Peter Mitchell pit on the local minor and major watersheds.

This report documents the first two phases (Phase I and Phase II) and provides a final report detailing the expected long range hydrology of Northshore's Peter Mitchell Mine pit. Phases I and II included the collection of relevant data from Northshore and public sources, evaluation of historical and current hydrologic conditions, estimates of pit filling time and discharge, and the evaluation of anticipated impacts to the local hydrology after mine closure. This document presents the background data collected for this investigation and hydrologic conditions evaluated or predicted for three conditions:

- Prior to Mining Activity (1941 – 1951)
- Present (2007)
- After Pit Filling

These three conditions are referred to as historical conditions, current conditions, and post-closure conditions, respectively, throughout this report.

The Peter Mitchell Mine is located at a major watershed divide separating the Rainy River and St. Louis River watersheds. Post-closure changes to the hydrology of the following rivers and streams were evaluated: the Partridge River, the Embarrass River, Langley Creek, the Dunka River, and an unnamed tributary to the Dunka River located north of Langley Creek (see Map 2).

The analysis presented in this report represents a first approximation based on water balances and area-discharge relationships. Future data to be collected by Northshore Mining Company will allow further refinement of the estimates presented in this report and the determination of appropriate mine pit filling and discharge management options.

1.1 Site Description

This study focuses on Northshore's Peter Mitchell pit located approximately 4 miles south of Babbitt, MN (see Map 1). The Mine Site is defined for this study as the limit of post-closure mine pit provided by Northshore. The Mine Site is over one mile wide in some locations and about 10 miles long. Large scale mining at the site was initiated by Reserve Mining Company in 1955 and continued through Reserve's bankruptcy in 1986. The Mine Site was reopened in 1989 as Cyprus Northshore Mining Company and subsequently purchased by Cleveland-Cliffs in 1994 and operated as Northshore Mining Company.

The Mine Site covers approximately 5,350 acres and contains 4,750 acres of land disturbed by mining activity (i.e. pits, haul roads, mine facilities, railroads, stockpiles). The remaining area is mostly brush and wetlands. Undisturbed, non-mining areas surrounding the Mine Site are covered mostly by northern hardwood forest. Average precipitation for the National Weather Service (NWS) climate normal period (1971-2001) is 28.4 inches per year. Mean annual evapotranspiration for the Mesabi Iron Range is estimated to be 15 to 21 inches per year (Baker, 1979).

As shown on Map 1, the Mine Site straddles two major drainage basins, the Rainy River Basin and the Lake Superior Basin. Locally, drainage from within and around the western half of the Mine Site that does not reach the pit drains to the Embarrass River and Partridge River in the St. Louis River watershed (see Map 2). In the eastern half of the Mine Site, runoff drains to Langley Creek and an unnamed stream, both tributary to the Dunka River in the Rainy River watershed (see Map 2). During operations, dewatering from the mine pits has been regulated through several MDNR water appropriations permits. The upper reaches of the Partridge River, Langley Creek, and the unnamed Dunka River tributary north of Langley Creek have received discharge from the dewatering of the Peter Mitchell pit.

The mine pit is excavated into the Biwabik Iron Formation (BIF). Ground water movement in the BIF is generally through fractures, faults and joints. Recharge to the BIF is generally through infiltration of the overlying glacial drift. Where the drift has been stripped off of open pit mines, recharge enters the BIF directly (Cotter et al 1965). The general ground water movement in the Mesabi Iron Range tends to be to the south and southeast from the Laurentian Divide. Local movement is towards lakes, mining pits and streams for both the BIF and stratified glacial drift aquifers (Cotter et al 1965).

2.0 Data Sources

This section details the data collected as part of Phase I of this study. Data for Phase I were collected from publicly available records and provided by Northshore.

2.1 Flow Data

Streamflow data recorded from United States Geological Survey (USGS) gages exist for locations on the Partridge River (main stem and south branch), Dunka River, Embarrass River, and Second Creek. The gage locations are summarized in Table 1 and shown in Map 3. Flow records available for these sites are presented in Figures 1 through 5. Intermittent flow data consisting of about 60 measurements taken between 1974 and 2004 for two locations along Langley Creek (S002-759 and S002-806, see Map 3) are available from the MPCA's Environmental Data Access website (http://www.pca.state.mn.us/data/edaWater/index.cfm). Observed streamflows in Langley Creek are presented in Figure 6.

2.2 Climate Data

2.2.1 Precipitation Data

Precipitation data collected within 20 miles of the Mine Site extend back as far as 1895. Daily precipitation data for Babbitt were retrieved using Minnesota Climatology Working Group's high-density precipitation archive. The complete data set is presented in Figure 7. Average precipitation computed from the 1971-2001 climate normal period (as defined by the National Weather Service) is 28.4 inches per year. The average annual precipitation computed over the entire period is 27.3 inches per year. For this study, all climatic data are based on the 30-year climate normal period of 1971 to 2001.

2.2.2 Evapotranspiration Data

Average annual evapotranspiration rates estimated for the region containing the Mine Site vary from 15 inches to 21 inches depending upon the analytical method (Baker, 1979). Pan evaporation rates evaluated between 1960 and 1977 averaged 26.7 inches per year for the City of Hoyt Lakes, located 10 miles southwest of the Mine Site (Baker, 1979).

2.3 Pumping Records

Mine pit dewatering is regulated through MDNR water appropriations permits. All water appropriations permits located within and around the Mine Site were identified using a GIS shapefile created by the MDNR (see Map 4). These records include the permit status (active, standby, abandoned, or terminated), permittee, permit use (e.g. mine dewatering), reservoir name, annual permitted pumping volume, and annual pumping volume as far back as 1988. The available pumping data for dewatering permits near the Mine Site are summarized in Table 2.

A general history of dewatering from the Peter Mitchell pit to the Partridge River was also provided by Northshore. Dewatering from the Peter Mitchell pit to the Partridge River ceased in 1986 following the bankruptcy of Reserve Mining Company, effectively removing approximately 7 square miles from the Partridge River watershed. Discharge to the Partridge River did not occur again until sometime between 1992 and 1995, when 700 acres of pit lake reached levels allowing outflow to continue to the Partridge River. Dewatering of the Peter Mitchell pit to the Partridge River resumed in 2003 (see Table 2).

2.4 Topography

Pre-mining topography was assembled using USGS quad maps dating from 1949 to 1951 for the Mine Site and surrounding area. Current topography for the area surrounding the Mine Site was based on current USGS quad maps. Current (2007) topography for the Mine Site was supplied by Northshore as “DWG” files which Barr converted to a three-dimensional surface in UTM coordinates using ArcGIS software. Current Mine Site topography is presented in Map 5. Post-closure Mine Site topography including in-pit stockpiles was provided by Northshore and converted to a three-dimensional surface in UTM coordinates (see Map 6). The area and volume of the portion of the Peter Mitchell pit currently being dewatered to Langley Creek were calculated using GIS software. The area and volume of the post-closure pit discharging to the unnamed tributary to Dunka River were also evaluated (see Table 3). Storage-elevation curves for the current and post-closure mine pit (including in-pit stockpiling) are presented in Figure 8.

2.5 Watershed Delineations

Pre-mining watersheds were delineated using the MDNR 24K minor watersheds delineation as a starting point and adjusting the 24K minor watersheds based on the historical USGS quad data (1949 to 1951) where appropriate (see Map 7). Current watersheds are primarily based on the DNR 24K minor watersheds. At the Mine Site, watershed boundaries were modified from the MDNR 24K minor watersheds based on delineations performed for other mining projects and current USGS quad maps (see Map 2). These changes include the boundary between the Langley Creek/Partridge River watersheds, the boundary between the Langley Creek/unnamed tributary in the Dunka River watershed, and minor changes along the Partridge River/Embarrass River watershed boundary. Post-closure watersheds were delineated based on the current watershed delineation modified according to the post-closure Mine Site topography provided by Northshore (see Map 8). Cumulative watershed areas for minor and major watersheds were computed using GIS software and are summarized in Table 4.

2.6 Bedrock Stratigraphy and Hydrogeology

Map 9 presents all non-exploratory wells located within 15 miles of the Mine Site based on the Minnesota County Well Index (CWI). The Peter Mitchell pit is excavated into the Biwabik Iron Formation (BIF). Three wells within 15 miles of the Mine Site pump water from the BIF, and are summarized in Table 5 and shown southwest of the Mine Site on Map 9.

Pre-mining exploration drilling data were also provided by Northshore and provide bedrock elevation and overburden thickness for approximately 2500 point locations throughout the Mine Site. These data were converted to a three-dimensional surface using GIS software. The resulting bedrock elevations within the Mine Site are presented in Map 10, merged with estimated bedrock elevations for the region provided by the Minnesota Geological Survey (MGS). Overburden thickness for the Mine Site is presented in Map 11. The average bedrock elevation is 1,654 feet and the average overburden thickness is 14.1 feet and ranges from zero to 98 feet. Selected cross-sections of current and post-closure mine pit stratigraphy are presented as Map 12 and Map 13, respectively.

3.0 Hydrologic Parameters of Impacted Watersheds

Phases I and II of this study include the estimation of hydrologic parameters of the affected watersheds for historical, current, and post-closure conditions. Watersheds that will be impacted by permitted mining include: the Embarrass River, Partridge River, Langley Creek, unnamed tributary to Dunka River, and Dunka River watersheds. This section describes the methods used to estimate historical, current, and post-closure flow characteristics in these watersheds. Additional watershed characterization may be performed based on feedback from the client, MDNR, and availability of additional data.

3.1 Statistical Characterization of Streamflow

The following flow statistics were computed by Barr for the Embarrass River, Partridge River, South Branch of the Partridge River, Dunka River, and Second Creek based on USGS gage data: average annual flow, average monthly flow, average maximum annual flow, average annual minimum 7-day flow, and average annual minimum 30-day flow. These flow statistics are summarized in Table 6. The parameters listed above could not be calculated for Langley Creek due to the lack of consecutive data. Instead, the maximum, minimum, and average of all recorded flows were computed and listed in Table 6. In the absence of a time-series data record for Langley Creek, exceedence-probability relationships for flows at the two data locations in Langley Creek were generated by Barr based on the available flow data (see Figure 9).

A basic approximation of post-closure impacts to streamflow includes the determination of area-flow relationships for each watershed based on current or historical flow and watershed area data, and then extrapolating those relationships to post-closure watershed areas. Flow data are available for all streams receiving discharge from the Mine Site except the unnamed tributary to the Dunka River (see Table 6), allowing the development of unit area-discharge relationships. This method was used for most streams and rivers in this study, with some modification, as described in this section.

3.1.1 Streamflow Characteristics: Embarrass River

Unit area-discharge (cfs per square mile) values for each flow statistic listed in Table 6 were computed for the Embarrass River based on USGS flow data and tributary area from gage 04017000. The resulting unit area-discharge relationships are presented in Table 7. These values were then multiplied by the historical, current, and post-closure Embarrass River watershed areas to estimate flows for each condition (see Table 8).

The Embarrass River currently drains a watershed area of 88.3 square miles. Permitted mining activities will add approximately 30 acres (0.05 square miles) to the drainage area, increasing the total Embarrass River watershed area upstream of USGS gage 04017000 by less than a tenth of a percent. Table 8 shows that flows are expected to increase by 0.06 percent relative to current conditions.

3.1.2 Streamflow Characteristics: Partridge River

3.1.2.1 Partridge River Flows Based on Unit Area-Discharge

Unit area-discharge (cfs per square mile) values for each flow statistic listed in Table 6 were computed for the Partridge River based on flow data from USGS gage 04015475 and tributary area provided by the USGS. The resulting unit area-discharge relationships are presented in Table 7. These values were then multiplied by the historical, current, and post-closure Partridge River watershed area to estimate flows for each condition.

Permitting mining at the Peter Mitchell Mine will remove approximately 7 square miles of tributary area from the headwaters of the Partridge River, or about 7 percent of the total watershed area above Colby Lake. The flows predicted at the location of USGS gage 04015475 will decrease accordingly and are presented in Table 9.

3.1.2.2 Partridge River Flows Based on XP-SWMM Model

An XP-SWMM model was developed by Barr for the Partridge River above Colby Lake in 2007. The model includes approximately 7 square miles that will cease to be tributary to the Partridge River under post-closure conditions (see Map 8). The XP-SWMM model was run for a 10-year simulation period (1978-1988) under two conditions: with the 7 square mile area tributary to the Partridge River (simulating current conditions), and with the 7 square mile area removed from the Partridge River watershed (simulating post-closure conditions). The XP-SWMM model was not run using historical watershed areas. The results were evaluated at the following locations along the Partridge River: at the crossing of Dunka Road (~4.5 miles from the Partridge River headwaters), just upstream of the confluence with the South Branch of the Partridge River, just downstream of the confluence with the South Branch of the Partridge River, and at the USGS gage 04015475 above Colby Lake (see Map 3).

The XP-SWMM model results predict that the change from current to post-closure conditions will result in a 5 percent decrease in average annual flow above Colby Lake, equivalent to 4.2 cfs (see Table 9). This reduction is smaller than that estimated using the unit area-discharge method.

Changes to the extreme high and low flows estimated using the XP-SWMM model are also less than those estimated using the unit area-discharge relationships.

The XP-SWMM model also provides estimates of flows at three additional locations along the Partridge River: at the crossing of Dunka Road (~4.5 miles from the Partridge River headwaters), just upstream of the confluence with the South Branch of the Partridge River, and just downstream of the confluence with the South Branch of the Partridge River (see Map 3). Table 10 presents the predicted flows and percent change from current conditions for these three locations.

Because the watershed changes are localized at the Partridge River headwaters, reductions in flow will be greater in the upstream reaches. Impacts to reaches upstream of the Partridge River at Dunka Road (see Map 3) are likely to be greater than those presented in Table 9. Conversely, the confluence of the main stem of the Partridge River with the South Branch of the Partridge River significantly reduces the impact of the lost tributary area, reducing the drop in average annual flow from 24 percent above the confluence to 10 percent below the confluence. The relative changes to the extreme high and low flows are less than those to the average annual flow at these locations, similar to what was predicted for the Partridge River at Colby Lake (and presented in Table 9).

3.1.3 Streamflow Characteristics: Langley Creek

Simple unit area-discharge relationships for the entire Langley Creek watershed may not be extrapolated to historical or post-closure conditions because the discharge measurements from 1974 to 2005 include flow from mine pit dewatering (the same is true for the Partridge River, but is less significant due the small ratio of dewatering discharge to average streamflow). When dewatering ceases at mine closure, the unit area-discharge relationship developed using data that included mine pit dewatering will no longer be applicable. Therefore, the pit dewatering must be factored out of the total streamflow to accurately compute a unit area-discharge that will be applicable to pre- or post-mining conditions (i.e. pit dewatering). In addition, watershed changes occurring prior to closure will significantly alter the ratio of undisturbed areas to those disturbed by mining activity, likely affecting runoff characteristics of the watershed.

To determine unit area-discharge relationships for Langley Creek, the watershed was divided into areas upstream of S002-759 and areas between S002-759 and S002-806. The area of the pit contributing to dewatering was included in the drainage area upstream of S002-759. The average flow at S002-759 of 6.4 cfs was subtracted from the average flow recorded at S002-806 (8.85 cfs) to get an incremental inflow of 2.45 cfs between S002-759 and S002-806. These two subwatersheds were then divided into areas classified as “undisturbed” and areas classified as “mining features” based on aerial photography and a MDNR mining features GIS shapefile. It was assumed that “undisturbed” areas and “mining features” areas have different unit area-discharges, but that the unit area-discharge for each land cover is equivalent between subwatersheds. A system of two equations (a water balance equation for each subwatershed) was solved to determine a unit area-discharge for undisturbed/non-mining areas and a unit area-discharge for mining features (including pit and non-pit area). The resulting unit area discharges were 0.64 cfs/square mile for undisturbed/non-mining areas and1.36 cfs/square mile for mining features (both pit and non-pit), corresponding to approximately 30 percent and 65 percent of the annual precipitation, respectively.

Both the surface water runoff and groundwater inflow components of the pit dewatering to Langley Creek have been implicitly combined in this analysis because the groundwater component cannot be estimated separately. This will result in a mining features unit area-discharge that is higher than would be observed if the pit were not present, and should be noted when extrapolating these relationships to areas tributary to Langley Creek after mine closure.

Historical flows in Langley Creek were estimated using pre-mining watershed area and the undisturbed unit area-discharge rate. Post-closure flows in Langley Creek were estimated using the unit area-discharge relationships developed for mining features and undisturbed areas (see Table 11) applied to the post-closure Langley Creek watershed area consisting of 160 acres of mining features and 3,231 acres of undisturbed area. The resulting flow statistics are presented in Table 12.

3.1.4 Streamflow Characteristics: Unnamed Tributary to Dunka River

Flow data are not available for the unnamed tributary to Dunka River located north of Langley Creek. Topographic data for this watershed indicate most of the current tributary area drains to the pit prior to being pumped to the unnamed tributary. Field observations performed by Northshore indicated that there is almost no flow through the unnamed tributary unless the pit is being dewatered, even during periods of high runoff (e.g. spring snowmelt). Dewatering flows for this location averaged 2.9 cfs for the past 17 years and may be used as a basis to estimate current flows in the unnamed tributary.

The average annual unit area-discharge upstream of the dewatering location is 1.05 cfs/square mile based on a total drainage area to the pit of 2.74 square miles (including pit areas). This is similar to the 1.03 cfs/square mile unit area-discharge observed for Langley Creek upstream of S002-759 (see Table 11) and suggests similarity between the watersheds. Based on this similarity, additional inflow to the unnamed tributary occurring downstream of the dewatering location was estimated by multiplying the downstream tributary areas (19 acres of mining features and 176 acres of undisturbed area) by the corresponding unit area-discharges established for Langley Creek (see Table 11). This method resulted in a current average annual flow estimate of 3.1 cfs for the unnamed tributary to Dunka River. The unnamed tributary historical watershed area (1,947 acres) was multiplied by 0.64 cfs/square mile (the undisturbed unit area-discharge relationship established for Langley Creek) to calculate a historical (pre-mining) average annual flow of 1.9 cfs.

Continued mining and subsequent filling of the Peter Mitchell pit upon closure will change the characteristics of the unnamed tributary. Most of the post-closure watershed area of the unnamed tributary will drain to the developed ultimate pit prior to discharging to the channel. Average annual post-closure flow was estimated by summing the average post-closure pit discharge and the additional inflow to the tributary occurring downstream of the pit discharge. Estimates of post-closure pit discharge are presented in Section 3.2.2. Discharge from the small tributary area that is not routed through the pit (120 acres) was estimated using the unit area-discharge relationships for undisturbed areas developed for Langley Creek (see Section 3.1.3). The resulting average post-closure flow ranges from 18.0 cfs to 21.5 cfs depending upon the range of estimated post-closure pit discharge (see Section 3.2.2). This range is a preliminary estimate based on currently available information. Post-closure monitoring of the pit during flooding will allow more accurate estimates of pit lake outflow.

Flows in the unnamed tributary were estimated only for average flow conditions in Phase I of this study. The relationship between average and extreme flows in other watersheds may not be used accurately as a proxy for the unnamed tributary due to the hydrologic and hydraulic impacts of the mine pit.

3.1.5 Streamflow Characteristics: Dunka River

Unit area-discharge (cfs per square mile) values were computed for the Dunka River based on flow data and tributary area from USGS gage 05126000 (see Table 7). The current watershed area of the Dunka River will increase by 7 square miles by mine closure due to permitted mining activities at the Peter Mitchell Mine. Using a single unit area-discharge for the post-closure Dunka River watershed, however, may not accurately account for the significant land use changes to Langley Creek and the unnamed tributary watersheds. Therefore, the average flow in the Dunka River was estimated by multiplying the Dunka River unit area-discharge relationship for average annual flow by the post-closure watershed area excluding the watersheds of Langley Creek and the unnamed tributary (resulting in a total drainage area of 35.4 square miles) and then adding the predicted average discharges from Langley Creek (3.6 cfs) and the unnamed tributary (18 to 21.5 cfs), calculated in Sections 3.1.3 and 3.1.4, respectively. The average flow in the unnamed tributary was calculated as a range in Section 3.1.4. The central value of that range (19.8 cfs) was used in this analysis.

The analysis of post-closure average annual flow in the Dunka River described above predicts an average annual flow (54.0 cfs). This is an increase of 32 percent over current conditions, due to a much greater post-closure discharge from the unnamed tributary relative to current conditions. Post-closure streamflow characteristics beyond average flow were not computed for Langley Creek or the unnamed tributary. Therefore, additional post-closure flow statistics for the Dunka River may not be accurately predicted and were also omitted from this analysis (see Table 13). Post-closure monitoring of Langley Creek, the unnamed tributary, and Dunka River may be necessary to determine the impact on flows in the Dunka River downstream of the altered tributaries.

In addition, a control structure at the mine pit outlet will be constructed prior to surface water discharging from the pit lake. The design of the mine pit lake outlet structure will provide an opportunity to modify the hydrograph of pit discharge and allow some engineering control over the hydrologic characteristics of unnamed tributary, and ultimately, the Dunka River.

3.2 Estimating Post-Closure Mine Pit Discharge

During mining operations, the pit will be dewatered with water being discharged to the appropriate watersheds as listed in the Permit to Mine. After mining operations cease around 2070, the pit will be allowed to fill due to groundwater inflow and runoff to the mine pit. When the pit is filled it will discharge at the northeast end to the unnamed tributary to Dunka River. As part of Phase I of this study, the average steady state discharge after the pit is filled was estimated. This discharge is also critical to determine the downstream impacts to the unnamed tributary to Dunka River.

3.2.1 Estimating Groundwater Inflow

A water balance for the current mine pit area discharging to Langley Creek was performed to estimate rates of groundwater inflow into the pit. These rates were extrapolated to the post-closure mine pit area to estimate groundwater inflow under post-closure conditions (see Section 3.2.2).

Components of a mine pit water balance include direct net precipitation onto the pit, groundwater inflow/outflow, surface runoff, and surface water discharge. Current surface runoff rates and groundwater inflow rates are not explicitly known, but may be estimated using the dewatering data from the mine pit and the assumptions regarding mining feature runoff rates, as described below..

The average dewatering rate to Langley Creek is 5.5 cfs, as determined by pumping records. This flow is a combination of surface runoff from mining features and undisturbed area into mine pit, as well as groundwater inflow into the pit. The groundwater inflow to the pit was estimated by subtracting the other components from the total average dewatering rate of 5.5 cfs. The surface area tributary to the pit (including the pit area itself) includes approximately 450 acres is undisturbed area and 1,860 is mining features. It was assumed that the runoff from the undisturbed area is equal to that of Langley Creek, previously determined to be 0.64 cfs/square mile (see Section 3.1.3). The inflow from mining features, however, may not be assumed equal to the 1.36 cfs/square mile derived for the Langley Creek watershed (see Section 3.1.3) because groundwater inflow was implicitly considered in that calculation. Therefore, an assumption was made regarding the unit area runoff from mining features. Due to the uncertainty of such an assumption, upper and lower limits of reasonable values were chosen to bracket the range of possible groundwater inflow rates. These bounding assumptions were:

1) surface runoff from mining features is equivalent to that of undisturbed areas (0.64 cfs/square mile), and

2) surface runoff from mining features is twice that of the undisturbed areas (1.28 cfs/square mile).

The choice of upper limit of runoff from mining features is arbitrary set at double the lower limit, but is an appropriate upper bound considering that a unit area-discharge of 1.36 cfs/square mile was calculated for mining features in the Langley Creek watershed when pit dewatering was included (see Section 3.1.3).

Multiplying the areas tributary to the mine pit by the appropriate unit area-discharge rates yields a total surface runoff of 2.3 and 4.2 cfs for assumptions 1 and 2, respectively. These values were subtracted from the pit dewatering rate (5.5 cfs) to arrive at groundwater inflow rates of 3.2 to 1.3 cfs for assumptions 1 and 2, respectively.

The range of groundwater inflow rates was divided by the three-dimensional surface area of the exposed walls and bottom of the pit area that is currently dewatered to Langley Creek (about 800 acres). This resulted in a unit area-discharge relationship for groundwater inflow per square mile of exposed pit surface ranging from 2.56 cfs/square mile to 1.04 cfs/square mile (corresponding to assumptions 1 and 2 described above, respectively). These results are presented in Table 14.

3.2.2 Post-Closure Mine Pit Water Balance

The post-closure discharge from the Peter Mitchell pit was estimated using the range of groundwater estimates calculated in Section 3.2.1. Inputs to the mine pit include surface runoff from mining features, surface runoff from undisturbed areas, groundwater inflow, and direct net precipitation over the pit. Surface water outflow was assumed to be zero during pit filling. Surface discharge after filling was assumed equal to the net pit inflow from all sources. The assumed pit outfall is 1500 feet-MSL based on existing topography and the assumption that mining will take place in the eastern half of the southeast quarter of Section 9, T60N, R12W. The corresponding pit lake surface area is approximately 2,050 acres.

Precipitation over the mine pit was assumed equal to the 30-year climate normal average precipitation (28.4 inches) and no climate variability was considered. Average annual evaporation over the mine pit was assumed to be 20 inches based on the range provided in Baker (1979). The resulting net precipitation was 8.4 inches per year. These assumptions result in a steady state inflow of 1,440 acre-ft/year (~2 cfs) based on a pit lake surface area of 2,050 acres

The estimated groundwater inflow rates calculated for current conditions (see Section 3.2.1) were applied to the post-closure mine pit surface area below 1580 feet (~3,100 acres), resulting in groundwater inflow rates ranging from 2,300 gpm (5.1) to 5,600 gpm (12.4 cfs) depending upon the assumed rate of surface runoff from mining features. The lower surface runoff rate for mining features (0.64 cfs/sq. mile) was paired with the higher groundwater inflow rate (2.56 cfs/sq. mile), while the lower surface runoff rate for mining features (1.28 cfs/sq. mile) was paired with the higher groundwater inflow rate (1.04 cfs/sq. mile). This pairing was chosen because the groundwater inflow rates were estimated based on the corresponding unit area-discharge relationship assumed for mining features (see Section 3.2.1). These two pairings correspond to assumptions 1 and 2, respectively, described in Section 3.2.1. The high estimates of surface runoff from mining features may not be combined with the high estimate of groundwater inflow because the resulting water balance based on the current dewatering to Langley Creek would not close. Similar, the lower rate of surface runoff from mining features and lower rate of groundwater inflow may not be combined. Groundwater inflow rates to the mine pit were assumed independent of water surface elevation within the pit.

The surface runoff from undisturbed areas was estimated by multiplying the undisturbed area tributary to the mine pit at closure (3,090 acres) by the unit area-discharge of 0.64 cfs/square mile. The resulting inflow is 3.1 cfs. A range of possible surface runoff from mining features was estimated by multiplying the post-closure mining features area (3,865 acres, excluding the pit lake) by the unit area-discharge assumptions made to estimate groundwater inflow rates and described in Section 3.2.1 (0.64 cfs/square mile and 1.28 cfs/square mile). The estimated inflow to the mine pit from mining features ranges from 3.9 cfs to 7.7 cfs

The components of the post-closure mine pit water balance were summed to estimate the post-closure average annual discharge. The average pit discharge based on the high groundwater inflow rate (2.56 cfs/sq. mile) and the low surface runoff rate from mining features (0.64 cfs/square mile, assumption 1 in Section 3.2.1) is 21.4 cfs. The average pit discharge based on the low groundwater inflow rate (1.04 cfs/sq. mile) and the high surface runoff rate from mining features (1.28 cfs/square mile, assumption 2 in Section 3.2.1) is 17.9 cfs. Values other than the steady state average were not estimated in Phase I of this study. Table 15 presents a summary of the pit discharge analysis and results.

4.0 Conclusions

Northshore Mining Company will be mining ore that now forms an in-pit dike separating the Peter Mitchell pit into two drainage basins. Northshore will begin removing this ore in the near future in accordance with their permit to mine. The potential impacts resulting from this permitted action have been evaluated and summarized in this report for the following waterbodies and their tributary watersheds: the Embarrass River, the Partridge River, Langley Creek , an unnamed tributary to Dunka River, and the Dunka River.

Impacts to the Embarrass River will be inconsequential, as the tributary watershed area will be reduced by less than 50 acres (0.1 percent of the total watershed area) in post-closure conditions.

Post-closure flows in Langley Creek are predicted to be about half of those observed for current conditions due to a loss of watershed area and the cessation of pit dewatering to the creek. The predicted changes in hydrology, however, will result in a unit area-discharge similar to that of the greater Dunka River watershed, and possibly more representative of pre-mining conditions within the Langley Creek watershed itself.

4.1 Partridge River Hydrology

The Partridge River upstream of Colby Lake will experience a drainage area reduction of approximately 7 square miles between current conditions and post-closure conditions. This reduction is located at the headwaters of the river. Post-closure flows at the Dunka Road crossing are estimated to be as high as forty percent. Flow reductions in the 4.5 mile reach upsteam of Dunka Road will be greater, as the area removed from the watershed represents a greater percentage of the total tributary area. Flows in the Partridge River immediately downstream of the post-closure watershed boundary may be reduced by close to 100 percent relative to current conditions. Impacts to flows in the Partridge River downstream of the confluence with the South Branch of the Partridge River will be less pronounced, although post-closure average annual flows at Colby Lake are still predicted to be between 4 cfs and 6 cfs less than current conditions, a reduction of 5 to 7 percent, respectively.

Although substantial flow reductions are anticipated in the headwaters of the Partridge River, similar hydrologic conditions have been experienced in the past. Discharge from the Peter Mitchell pit to the

Partridge River stopped entirely when Reserve Mining entered bankruptcy in 1986 and did not resume until sometime between 1992 and 1995, when 700 acres of pit lake reached levels allowing outflow to continue to the Partridge River. Active dewatering to the Partridge River did not resume until 2003. The Partridge River experienced between six and nine years of zero discharge from the Peter Mitchell Pit, followed by periods of seasonal outflow from pit lakes with periods of high flow while portions of the pit lake were being dewatered. During these periods, negative environmental and ecological impacts in the Partrdige River were not reported. It is likely that the ecology of the Partridge River is tolerant of prolonged periods of variable flows related to periods of pit filling and dewatering. The post-closure hydrologic regime of the Partridge River above Colby Lake will be similar to that experienced often within the past two decades. It is unlikely that changes observed in post-closure will vary from those observed in the past.

There are no reasonable means to offset the impacts to the Partridge River by pumping or diverting flow. Northshore Mining Company is evaluating mitigation strategies to offset the potential environmental impacts of reduced flows in the Partridge River. Northshore is considering managing the in-pit stockpiling of rock to create shallow water aquatic habitat in the post-closure mine pit where practical.

4.2 Dunka River Hydrology

The drainage area removed from the Partrdige River watershed will be added to the Dunka River watershed via the unnamed tributary. The increase in discharge to the unnamed creek and Dunka River will be greater than the reduction to the Partridge River due to the interception of groundwater by the mine pit. The anticipated post-closure average annual discharge to Dunka River via unnamed creek is between 17 cfs and 21 cfs. The post-closure average annual flow in the Dunka River is predicted to be 11 cfs greater than current conditions.

A control structure at the mine pit outlet will be constructed prior to surface water discharging from the pit lake. The control structure will be designed to modify the pit discharge hydrograph to achieve the desired hydrologic results in unnamed creek and, ultimately, the Dunka River. The outlet may be designed to reduce the peak discharge to prevent scour and erosion, or to maintain baseflows for aquatic wildlife. The channel downstream of the outlet structure can also be engineered to minimize negative hydraulic impacts.

4.3 Future Actions

Understanding the hydrologic impacts of pit closure is critical to future natural resource management and environmental protection. This study represents a preliminary analysis of the anticipated hydrologic impacts. The analysis presented in this report predicts it will take between ten and twelve years to fill the pit after dewatering ceases. This period provides adequate time to assess the observed rate of pit filling and re-evaluate the results of this study in light of new data. At closure, Northshore will initiate a monitoring plan that will aid more accurate estimates of pit filling time and eventual pit lake overflow rates. This monitoring will include:

- Accurate post-mining bathymetric maps of the pit
- Pit filling records for each cell, including continuous records of pit filling rates
- On-site collection of precipitation data

Other elements may be added to the pit flooding monitoring plan as required. Within two years of the pit overflowing, a design for the pit outlet to the unnamed tributary will be proposed. Northshore will design and construct an outlet structure and channel engineered to reduce the hydrologic impacts on downstream waterbodies.

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Tables

Table 1. USGS stream gages located near study area

USGS Gage Number	USGS Gage Name	Period of Record	Total Drainage Area (sq. miles)	Contributing Drainage Area (sq. miles)	Drainage Basin
04015475	Partridge River above Colby Lake	1978-1988	106.0	100.0	Superior
04015455	South Branch Partridge River near Babbitt, MN	1977-1980	18.5	-- [1]	Superior
04017000	Embarrass River at Embarrass, MN	1942-1964	88.3	-- [1]	Superior
05126000	Dunka River near Babbitt, MN	1951-1962, 1975-1980	53.4	49.4	Rainy River
04015500	Second Creek near Aurora, MN	1956-1980	29.0	22.4	Superior

[1] Data not provided by USGS

Table 2. Mine dewatering data from MDNR water appropriations permits near the Peter Mitchell Mine

Current/Last Permit Holder	Cyprus Northshore Mining	Northshore Mining Company [1]		
Permit No.	**1982-2096**	**1982-2097**		
Installation No.	**1**	**1**	**2**	**3**
Permit Status	Terminated [2]	Active	Active	Active
Watershed	Dunka River via Unnamed Creek	Dunka River via Unnamed Creek	Dunka River via Langley Creek	Partridge River
Permitted Use	Mine Dewatering	Mine Dewatering		
Permit (MGY)	1300	5500		
Permit (GPM)	9400	29700		
1988 Use (MGY)	886	--	0	0
1989 Use (MGY)	518	--	86	0
1990 Use (MGY)	1050	--	842	0
1991 Use (MGY)	2325 [2, 3]			0
1992 Use (MGY)	--	2067 [3]		0
1993 Use (MGY)	--	2000 [4]		0
1994 Use (MGY)	--	2040 [5]		0
1995 Use (MGY)	--	1355	999	0
1996 Use (MGY)	--	2009	2009	0
1997 Use (MGY)	--	2919 [3]		0
1998 Use (MGY)	--	946	1247	0
1999 Use (MGY)	--	1877	2003	0
2000 Use (MGY)	--	2307	1246	0
2001 Use (MGY)	--	1742	1501	0
2002 Use (MGY)	--	1365	1317	0
2003 Use (MGY)	--	330	1121	818
2004 Use (MGY)	--	616	1349	1221
2005 Use (MGY)	--	884	1715	0
2006 Use (MGY)	--	662	1361	1702
2007 Use (MGY)	--	890	1834	1339
Average (non-zero)	818	1235	1261	1270

[1] Northshore Mining Company obtained permit number 1982-2097 in 1994

[2] Permit 1982-2096 terminated in 1991 and appropriations consolidated with 1982-2097

[3] Reported as single appropriation to Dunka River. Records from 1990, 1995, and 1996 suggest a 53% / 47% split between Unnamed Creek / Langley Creek, respectively.

[4] Mine dewatering records indicate 905 MGY to Unnamed Creek, 1100 MGY to Langley Creek

[5] Mine dewatering records indicate 1120 MGY to Unnamed Creek, 921 MGY to Langley Creek

Table 3. Current and post-closure mine pit volumes and surface areas

Elevation (ft)	Current Conditions		Post-Closure Conditions	
	Surface Area (acres)	Volume (acre-ft)	Surface Area (acres)	Volume (acre-ft)
1200	--	--	0.67	0.75
1250	--	--	86.6	1,345.1
1300	--	--	288.7	8,475.71
1350	--	--	537.7	23,258.4
1400	10.9	117.0	935.7	47,002.5
1450	77.8	1,731.1	1,427.5	83,589.9
1500	218.9	9,021.6	2,124.1	136,522.9
1550	521.4	25,885.2	2,799.4	214,036.0
1600	1,677.9	73,801.5	4,759.3	321,383.2

Table 4. Cumulative watershed areas for historical, current, and post-closure conditions

Minor Watershed Name	Major Watershed/ Drainage Basin	Drainage Area (square miles)			
		Historic (1950)	Current (2007)	Post-closure (Pit filling)	Post-closure (Pit filled)
Embarrass River above USGS 04017000	St. Louis/Superior	88.3	88.3	88.4	88.4
Partridge River above South Branch	St. Louis/Superior	26.4	25.2	18.3	18.3
Partridge River above Colby Lake	St. Louis/Superior	104.6	103.4	96.4	96.4
St. Louis River	--/Superior	2,853.0	2,851.8	2,844.9	2,844.9
Langley Creek	Dunka/Rainy	8.5	9.9	5.3	5.3
Unnamed Tributary to Dunka River	Dunka/Rainy	3.0	2.7	0.2	14.3
Dunka River above USGS 05126000	Dunka/Rainy	55.0	56.2	49.0	63.1
Dunka River above Birch Lake	Dunka/Rainy	56.1	57.3	50.2	64.3
Rainy River	--/Rainy River	2,508.6	2,509.8	2,502.6	2,516.7

Table 5. Summary of local wells pumping from the Biwabik Iron Formation

Well Number	Elevation (ft)	Static Water Level (ft)	Depth to Bedrock (feet)	Bottom of Screen/ Borehole (ft)	Screen Thickness (ft)	Radius (inches)	Trans-missivity (ft^2/day)	K (ft/day)
189323	1,505	-- [1]	17	162	-- [1]	6	-- [2]	-- [2]
233048	1,427	90	140	278	10	16	-- [2]	-- [2]
584559	1,669	18.7	19	406	-- [1]	6	483,174 [3]	335 [3]

[1] Data not provided
[2] Insufficient data for calculation of parameter
[3] Calculated using Driscoll Method

Table 6. Summary of streamflow statistics based on available data

Statistic (All Units are CFS)	Partridge River 04015475	S. Branch Partridge 04015455	Embarrass River 04017000	Dunka River 05126000	Second Creek 04015500	Langley Creek (S-3)	Langley Creek (S-2)
Average Annual Flow	87.1	15.3	63.6	38.7	22.2	6.4	8.9
Avg. January Flow	7.5	1.0	6.7	3.8	9.2	NA[1]	NA[1]
Avg. February Flow	6.4	0.8	5.0	2.5	8.9	NA[1]	NA[1]
Avg. March Flow	15.9	1.0	22.0	7.1	15.5	NA[1]	NA[1]
Avg. April Flow	241.6	47.4	190.5	119.5	46.8	NA[1]	NA[1]
Avg. May Flow	219.7	35.8	194.0	95.0	34.2	NA[1]	NA[1]
Avg. June Flow	104.6	21.7	114.0	66.4	29.5	NA[1]	NA[1]
Avg. July Flow	103.6	10.9	63.2	34.3	22.9	NA[1]	NA[1]
Avg. August Flow	55.4	8.4	31.3	21.1	19.9	NA[1]	NA[1]
Avg. September Flow	86.5	26.1	49.9	47.0	24.5	NA[1]	NA[1]
Avg. October Flow	116.1	13.4	45.8	27.1	24.1	NA[1]	NA[1]
Avg. November Flow	63.0	11.5	32.8	26.3	19.6	NA[1]	NA[1]
Avg. December Flow	20.3	4.4	14.0	10.6	12.1	NA[1]	NA[1]
Avg. Annual 1-day Max Flow	683.4	169.3	657.6	349.3	NA[2]	18.5 [3]	29 [3]
Avg. Annual 7-day Low Flow	4.4	0.3	3.6	1.8	NA[2]	NA[1]	NA[1]
Avg. Annual 30-day Low Flow	6.1	0.5	3.8	2.9	NA[2]	NA[1]	NA[1]

[1] Insufficient data to compute monthly averages and "consecutive-day" statistics
[2] Data averaged for day of year based on all years prevents computation of "consecutive-day" statistics
[3] Maximum flow measurement on record

Table 7. Unit area-discharge relationships for USGS-gaged streams impacted by the Mine Site

Flow Statistic	Units	Partridge River 04015475	Embarrass River 04017000	Dunka River 05126000
Drainage Area	sq. miles	106.0	88.3	53.4
Avg. Annual Flow	cfs/sq.mi.	0.82	0.72	0.73
Avg. January Flow	cfs/sq.mi.	0.07	0.08	0.07
Avg. February Flow	cfs/sq.mi.	0.06	0.06	0.05
Avg. March Flow	cfs/sq.mi.	0.15	0.25	0.13
Avg. April Flow	cfs/sq.mi.	2.28	2.16	2.24
Avg. May Flow	cfs/sq.mi.	2.07	2.20	1.78
Avg. June Flow	cfs/sq.mi.	0.99	1.29	1.24
Avg. July Flow	cfs/sq.mi.	0.98	0.72	0.64
Avg. August Flow	cfs/sq.mi.	0.52	0.35	0.40
Avg. September Flow	cfs/sq.mi.	0.82	0.57	0.88
Avg. October Flow	cfs/sq.mi.	1.10	0.52	0.51
Avg. November Flow	cfs/sq.mi.	0.59	0.37	0.49
Avg. December Flow	cfs/sq.mi.	0.19	0.16	0.20
Avg. Annual 1-day Max Flow	cfs/sq.mi.	6.45	7.45	6.54
Avg. Annual 7-day Low Flow	cfs/sq.mi.	0.04	0.04	0.03
Avg. Annual 30-day Low Flow	cfs/sq.mi.	0.06	0.04	0.05

[1] Insufficient data to compute monthly averages and "consecutive-day" statistics
[2] Based on single maximum flow measurement on record

Table 8. Embarrass River streamflows at USGS gage 04017000 based on watershed area

Flow Statistic	Units	Historical Conditions	Current Conditions	Post-closure Conditions (Pit Full)	Percent Change from Current [1]
Drainage Area	sq. miles	88.29	88.30	88.35	+ 0.06 %
Avg. Annual Flow	cfs	63.6	63.6	63.7	+ 0.06 %
Avg. January Flow	cfs	6.7	6.7	6.7	+ 0.06 %
Avg. February Flow	cfs	5.0	5.0	5.0	+ 0.06 %
Avg. March Flow	cfs	22.0	22.0	22.0	+ 0.06 %
Avg. April Flow	cfs	190.5	190.5	190.6	+ 0.06 %
Avg. May Flow	cfs	194.0	194.0	194.1	+ 0.06 %
Avg. June Flow	cfs	114.0	114.0	114.1	+ 0.06 %
Avg. July Flow	cfs	63.2	63.2	63.2	+ 0.06 %
Avg. August Flow	cfs	31.3	31.30	31.32	+ 0.06 %
Avg. September Flow	cfs	49.9	49.9	49.9	+ 0.06 %
Avg. October Flow	cfs	45.8	45.8	45.9	+ 0.06 %
Avg. November Flow	cfs	32.8	32.8	32.9	+ 0.06 %
Avg. December Flow	cfs	14.0	14.0	14.0	+ 0.06 %
Avg. Annual 1-day Max Flow	cfs	657.5	657.6	658.0	+ 0.06 %
Avg. Annual 7-day Low Flow	cfs	3.7	3.7	3.7	+ 0.06 %
Avg. Annual 30-day Low Flow	cfs	3.8	3.8	3.8	+ 0.06 %

[1] Percent change equivalent for all statistics based on unit area-discharge analysis

Table 9. Partridge River streamflows at USGS gage 04015475 based on watershed area and XP-SWMM model

Flow Statistic	Units	Historical Conditions	Current Conditions	Unit Area Method		XP-SWMM Model	
				Post-closure Conditions (Pit Full)	Percent Change from Current [1]	Post-closure Conditions (Pit Full)	Percent Change from Current
Drainage Area	sq. miles	104.6	103.4	96.4	- 6.7 %	96.4	- 6.7 %
Avg. Annual Flow	cfs	86.0	85.0	79.3	- 6.7 %	80.8	- 5.0 %
Avg. January Flow	cfs	7.4	7.3	6.9	- 6.7 %	6.7	- 8.7 %
Avg. February Flow	cfs	6.0	6.0	5.6	- 6.7 %	5.9	- 2.4 %
Avg. March Flow	cfs	15.6	15.5	14.4	- 6.7 %	15.1	- 2.4 %
Avg. April Flow	cfs	238.4	235.7	219.8	- 6.7 %	223	- 5.0 %
Avg. May Flow	cfs	216.7	214.3	199.9	- 6.7 %	196.9	- 8.1%
Avg. June Flow	cfs	103.2	102.0	95.2	- 6.7 %	97.4	- 4.5 %
Avg. July Flow	cfs	102.2	101.0	94.2	- 6.7 %	97.6	- 3.4 %
Avg. August Flow	cfs	54.7	54.1	50.4	- 6.7 %	52.5	- 2.9 %
Avg. September Flow	cfs	85.3	84.4	78.7	- 6.7 %	81.1	- 3.9 %
Avg. October Flow	cfs	114.5	113.2	105.6	- 6.7 %	107.3	- 5.2 %
Avg. November Flow	cfs	62.1	61.4	57.3	- 6.7 %	57.5	- 6.4 %
Avg. December Flow	cfs	20.0	19.8	18.4	- 6.7 %	17.9	- 9.7 %
Avg. Annual 1-day Max Flow	cfs	674.2	666.6	621.6	- 6.7 %	657.3	- 1.4 %
Avg. Annual 7-day Low Flow	cfs	4.3	4.3	4.0	- 6.7 %	4.3	- 0.8 %
Avg. Annual 30-day Low Flow	cfs	6.0	6.0	5.6	- 6.7 %	5.8	- 3.8 %

[1] Percent change equivalent for all statistics based on unit area-discharge analysis

Table 10. Estimated post-closure streamflows along the Partridge River based on XP-SWMM model

Flow Statistic	Units	XP-SWMM Model Post-closure Flows			Percent Change from Current Conditions		
		At Dunka Road Crossing	Upstream of South Branch	Downstream of South Branch	At Dunka Road Crossing	Upstream of South Branch	Downstream of South Branch
Drainage Area	sq. miles	55.4	76.1	87.2	- 46.4 %	- 26.4 %	- 15.7 %
Avg. Annual Flow	cfs	52.7	64.9	76.5	- 38.0 %	- 23.6 %	- 10.0 %
Avg. January Flow	cfs	3.6	4.7	6.2	- 50.9 %	- 35.9 %	- 15.3 %
Avg. February Flow	cfs	4.7	5.3	5.7	- 22.2 %	- 12.5 %	- 4.9 %
Avg. March Flow	cfs	11.8	13.4	14.7	- 24.0 %	- 13.3 %	- 5.2 %
Avg. April Flow	cfs	141.4	178.0	211.4	- 40.0 %	- 24.5 %	- 10.3 %
Avg. May Flow	cfs	103.9	139.3	179.8	- 51.5 %	- 35.0 %	- 16.1 %
Avg. June Flow	cfs	68.2	81.5	93.3	- 33.1 %	- 20.1 %	- 8.5 %
Avg. July Flow	cfs	70.5	82.4	93.0	- 30.2 %	- 18.4 %	- 7.9 %
Avg. August Flow	cfs	39.2	45.6	50.5	- 27.5 %	- 15.8 %	- 6.6 %
Avg. September Flow	cfs	58.2	68.7	77.7	- 31.0 %	- 18.6 %	- 7.9 %
Avg. October Flow	cfs	68.8	85.5	101.3	- 39.2 %	- 24.5 %	- 10.5 %
Avg. November Flow	cfs	33.6	43.8	53.8	- 45.3 %	- 28.7 %	- 12.4 %
Avg. December Flow	cfs	8.0	11.6	16.1	- 59.4 %	- 41.3 %	- 18.5 %
Avg. Annual 1-day Max Flow	cfs	550.6	615.9	651.9	- 17.4 %	- 7.6 %	- 2.2 %
Avg. Annual 7-day Low Flow	cfs	4.2	4.1	4.3	- 3.2 %	- 4.4 %	- 1.1 %
Avg. Annual 30-day Low Flow	cfs	4.6	5.0	5.4	- 22.7 %	- 17.0 %	- 9.6 %

Table 11. Unit area-discharge relationships determined for Langley Creek

Flow Statistic	Units	Undisturbed Area	Mining Features Area	Langley Creek above S002-759	Langley Creek between S002-759 and S002-806	Langley Creek above S002-806
Drainage Area	sq. miles	--	--	6.2	3.7	9.9
Avg. Annual Flow	cfs/sq.mi.	0.64	1.36	1.03	0.67	0.89
Avg. Max Flow	cfs/sq.mi.	2.9	3.1	3.0	2.9	2.9

Note that additional unit area-discharge statistics cannot be calculated due to non-consecutive data

Table 12. Langley Creek streamflows at S002-806 based on watershed area

Flow Statistic [1]	Units	Historical Conditions	Current Conditions	Post-closure Conditions	Percent Change from Current Conditions
Drainage Area	sq. miles	8.5	9.9	5.3	- 46.5 %
Average Flow	cfs	5.4	8.9	3.6	- 59.7 %
1-day Max Flow [2]	cfs	24.3	29.0	15.2	-47.6 %

[1] Insufficient data to compute monthly averages and “consecutive-day” statistics
[2] Based on single maximum flow measurement on record

Table 13. Dunka River streamflows at USGS gage 05126000 based on watershed area

Flow Statistic	Units	Historical Conditions	Current Conditions	Unit Area + Langley Creek + Unnamed Tributary	
				Post-closure Conditions (Pit Full) [2]	Percent Change from Current [2]
Drainage Area	sq. miles	56.2	56.2	63.1	+ 12.3 %
Avg. Annual Flow	cfs	39.9	40.8	54.0	+ 32.3 %
Avg. January Flow	cfs	4.0	4.0	--[2]	--[2]
Avg. February Flow	cfs	2.6	2.6	--[2]	--[2]
Avg. March Flow	cfs	7.3	7.5	--[2]	--[2]
Avg. April Flow	cfs	123.1	125.8	--[2]	--[2]
Avg. May Flow	cfs	97.9	100.0	--[2]	--[2]
Avg. June Flow	cfs	68.4	69.9	--[2]	--[2]
Avg. July Flow	cfs	35.3	36.1	--[2]	--[2]
Avg. August Flow	cfs	21.7	22.2	--[2]	--[2]
Avg. September Flow	cfs	48.4	49.4	--[2]	--[2]
Avg. October Flow	cfs	27.9	28.5	--[2]	--[2]
Avg. November Flow	cfs	27.1	27.7	--[2]	--[2]
Avg. December Flow	cfs	10.9	11.1	--[2]	--[2]
Avg. Annual 1-day Max Flow	cfs	359.8	367.6	--[2]	--[2]
Avg. Annual 7-day Low Flow	cfs	1.8	1.9	--[2]	--[2]
Avg. Annual 30-day Low Flow	cfs	3.0	3.1	--[2]	--[2]

[1] Percent change equivalent for all statistics based on unit area-discharge analysis
[2] Flows other than average annual may be modified based on the design of the mine pit lake outlet structure and downstream channel.

Table 14. Summary of estimation of groundwater inflow rates into pit

Assumption (Section 3.2.1)	Undisturbed Area Runoff (cfs/sq. mile)	Mine Feature Runoff (cfs/sq. mile)	Total Surface Inflow to Pit (cfs)	Groundwater Inflow to Pit (cfs)	Groundwater Inflow to Pit (gpm/acre)	Groundwater Inflow to Pit (cfs/sq. mile)
1	0.64	0.64	2.3	3.2	1.8	2.56
2	0.64	1.28	4.2	1.3	0.7	1.04

Table 15. Summary and results of post-closure mine pit discharge analysis

Assumption (Section 3.2.1)	Undisturbed Area Runoff (cfs)	Mine Feature Runoff (cfs)	Groundwater Inflow to Pit (cfs)	Direct Net Precipitation (cfs)	Steady State Pit Discharge (cfs)
1	3.1	3.9	12.4	2.0	21.4
2	3.1	7.7	5.1	2.0	17.9

Figures

Figure 1. Streamflow record for the Embarrass River (USGS gage 04017000)

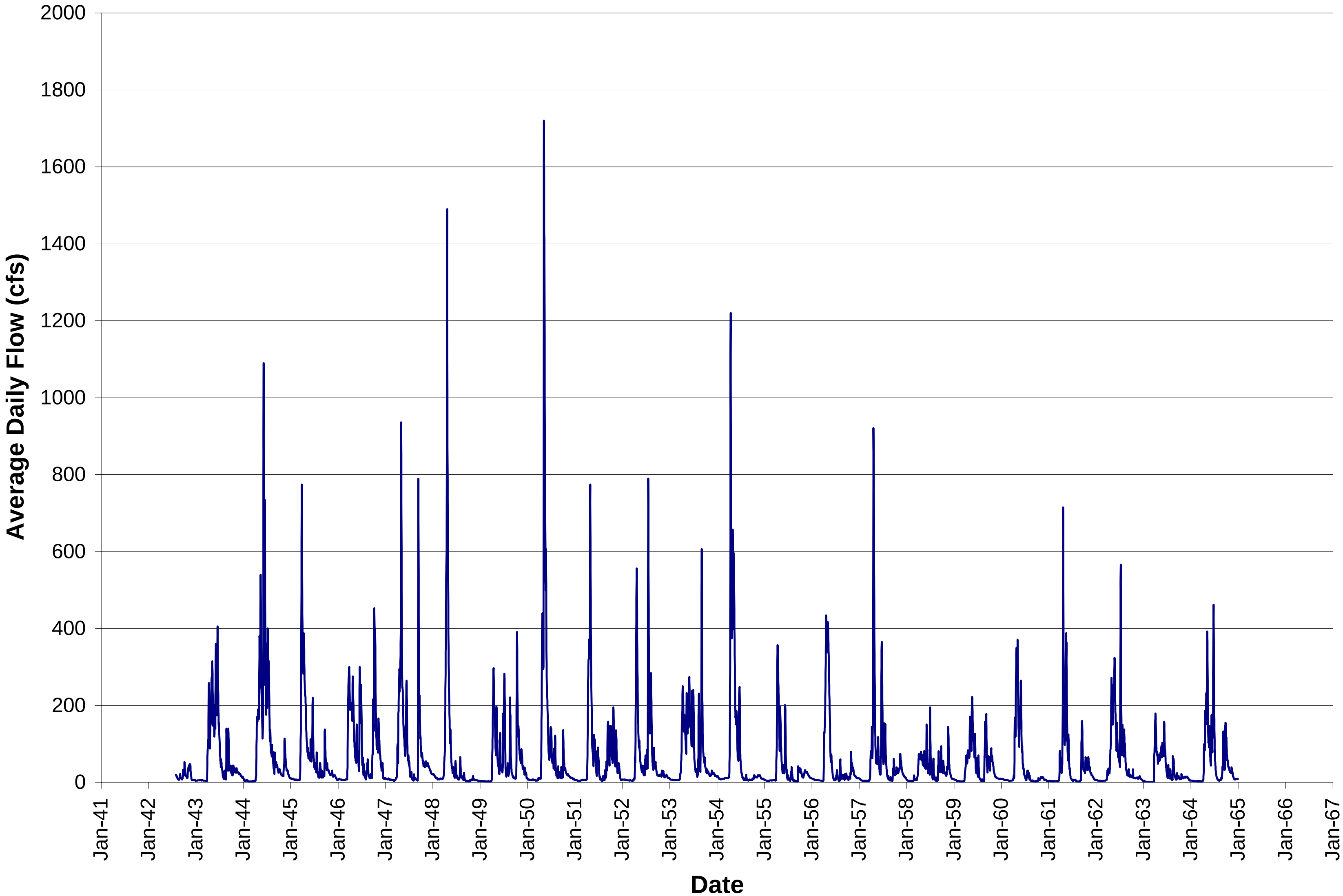


Figure 2. Streamflow record for the Partridge River above Colby Lake (USGS gage 04015475)

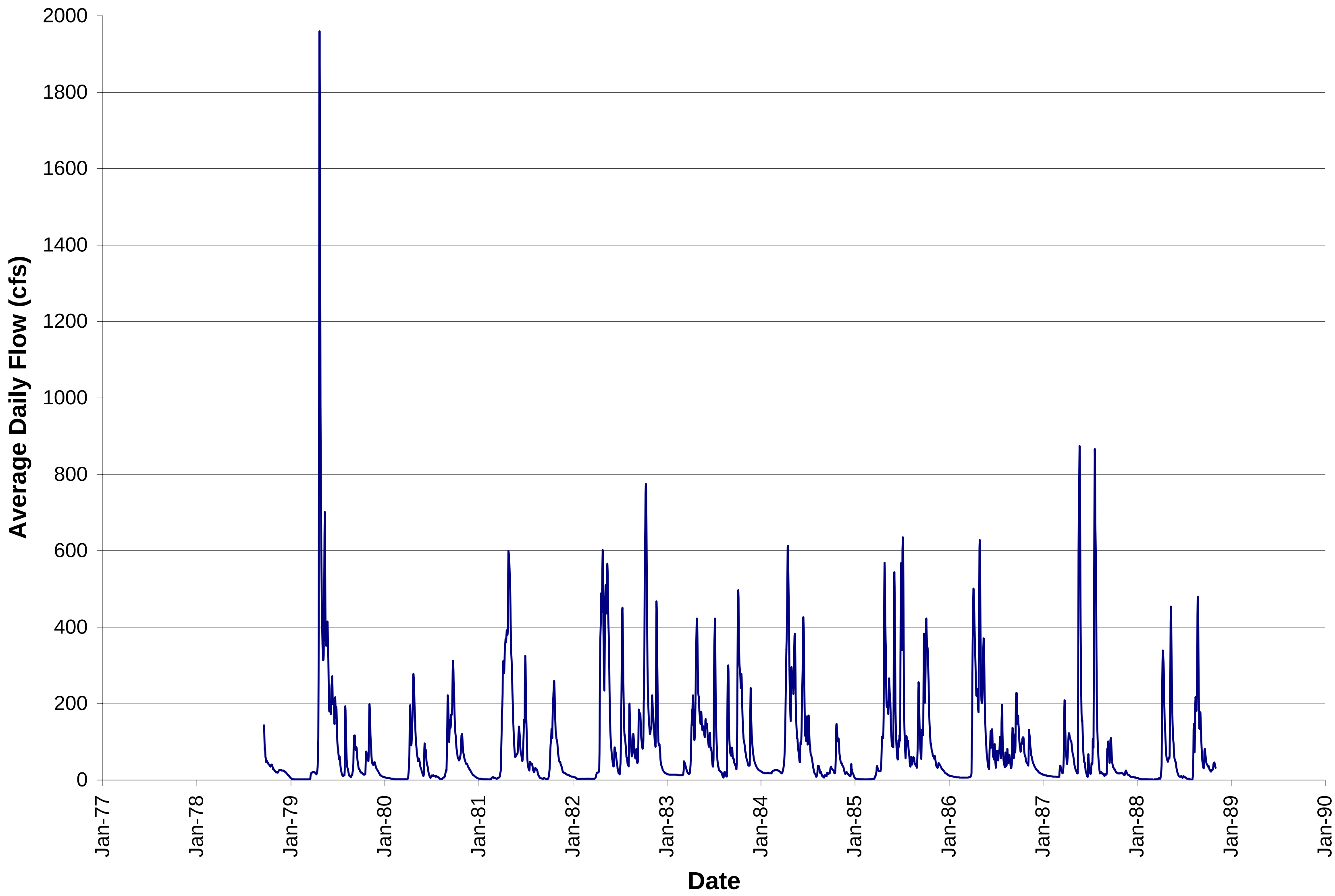


Figure 3. Streamflow record for the South Branch of the Partridge River (USGS gage 04015455)

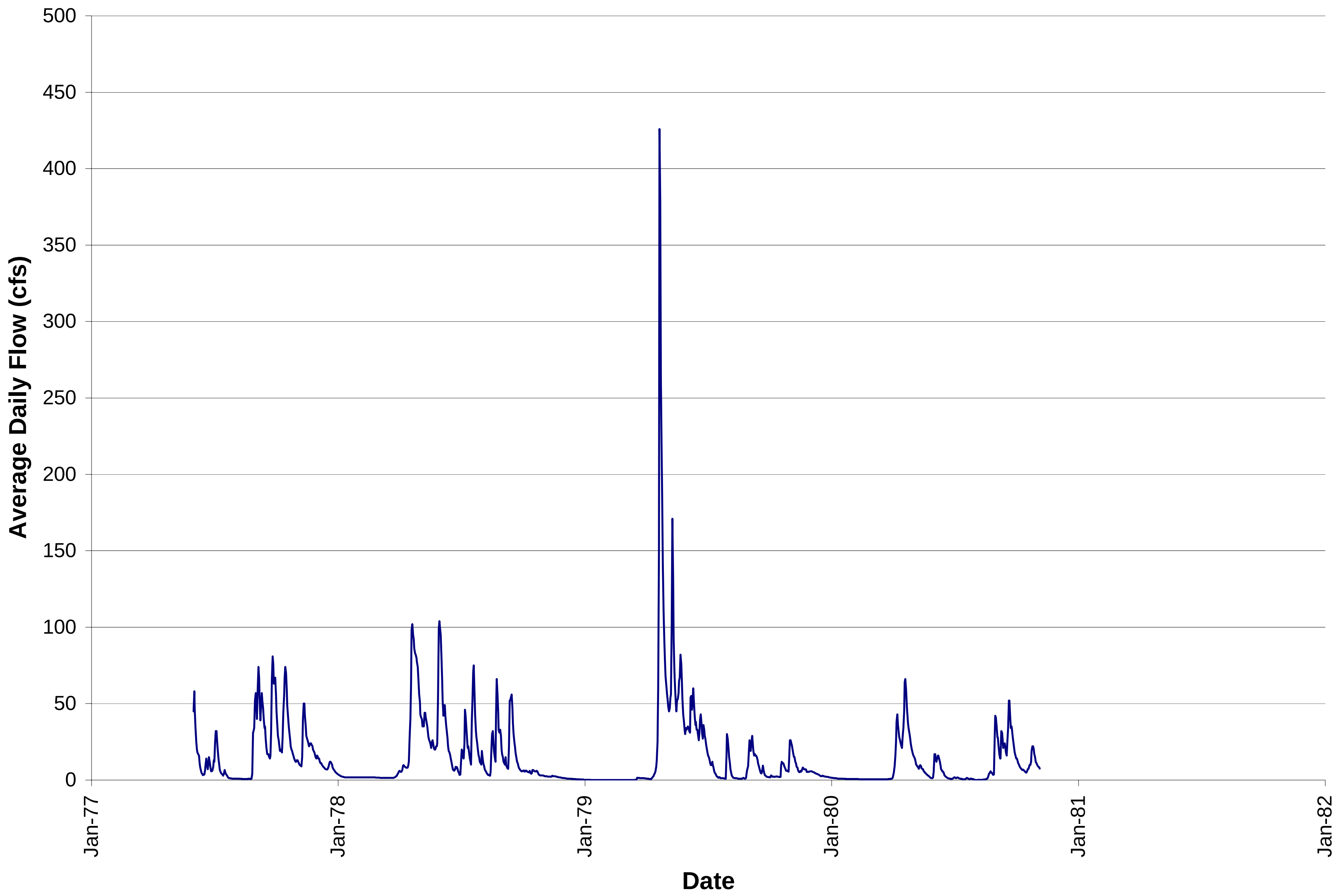


Figure 4. Streamflow record for the Dunka River near Babbitt (USGS gage 05126000)

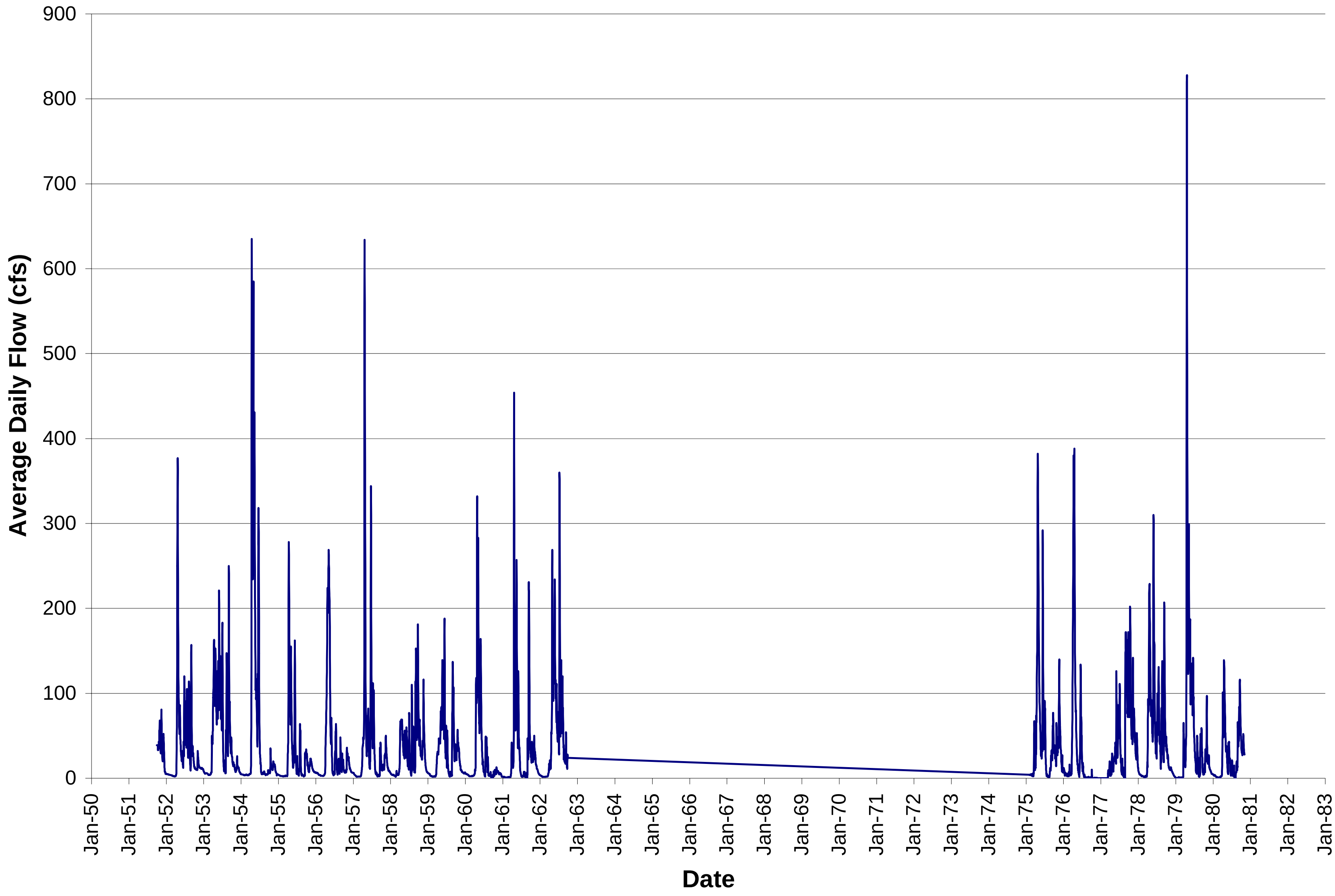


Figure 5. Streamflow record for Second Creek near Aurora (USGS gage 04015500)

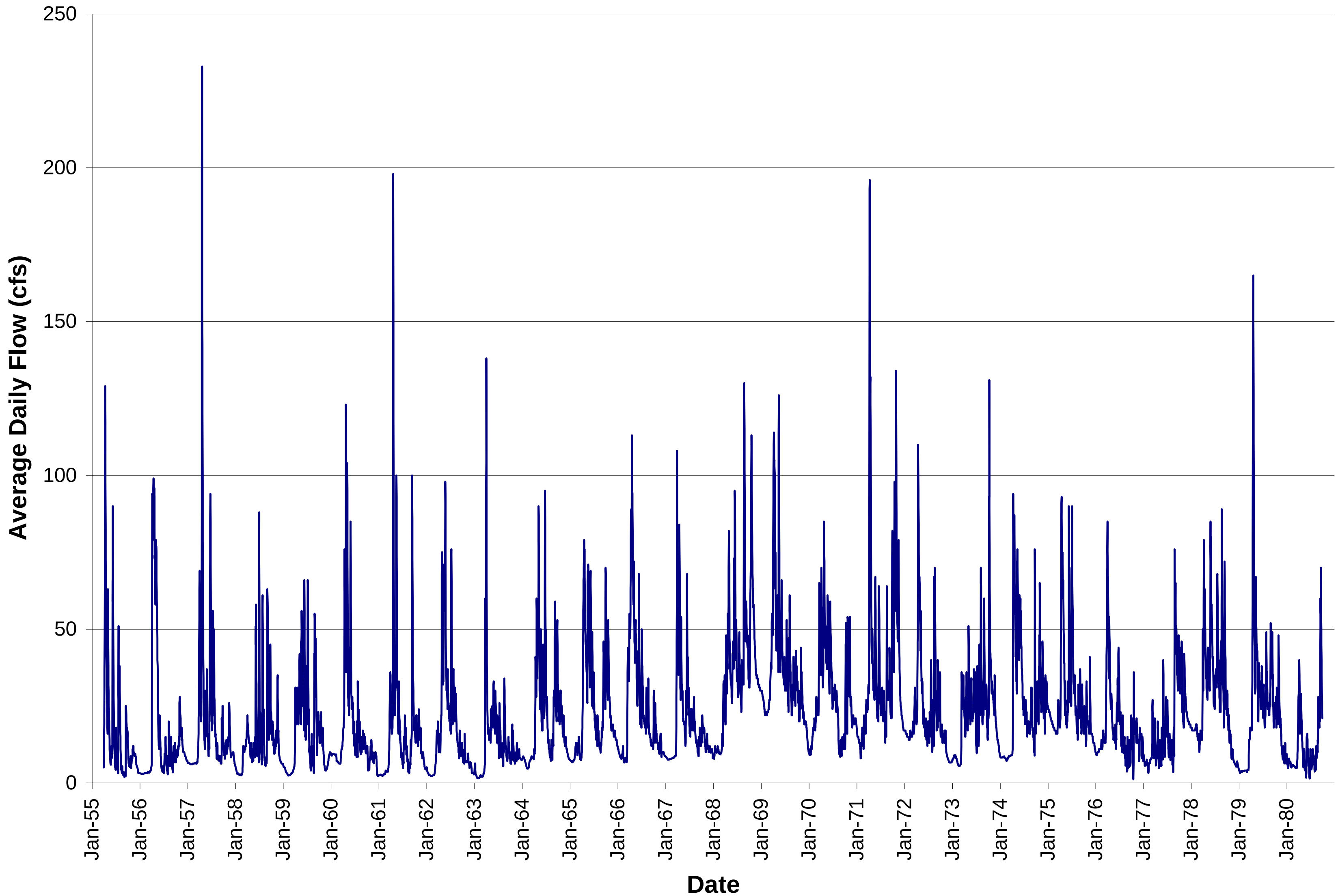


Figure 6. Measured streamflow for Langley Creek (S002-759 and S002-806)

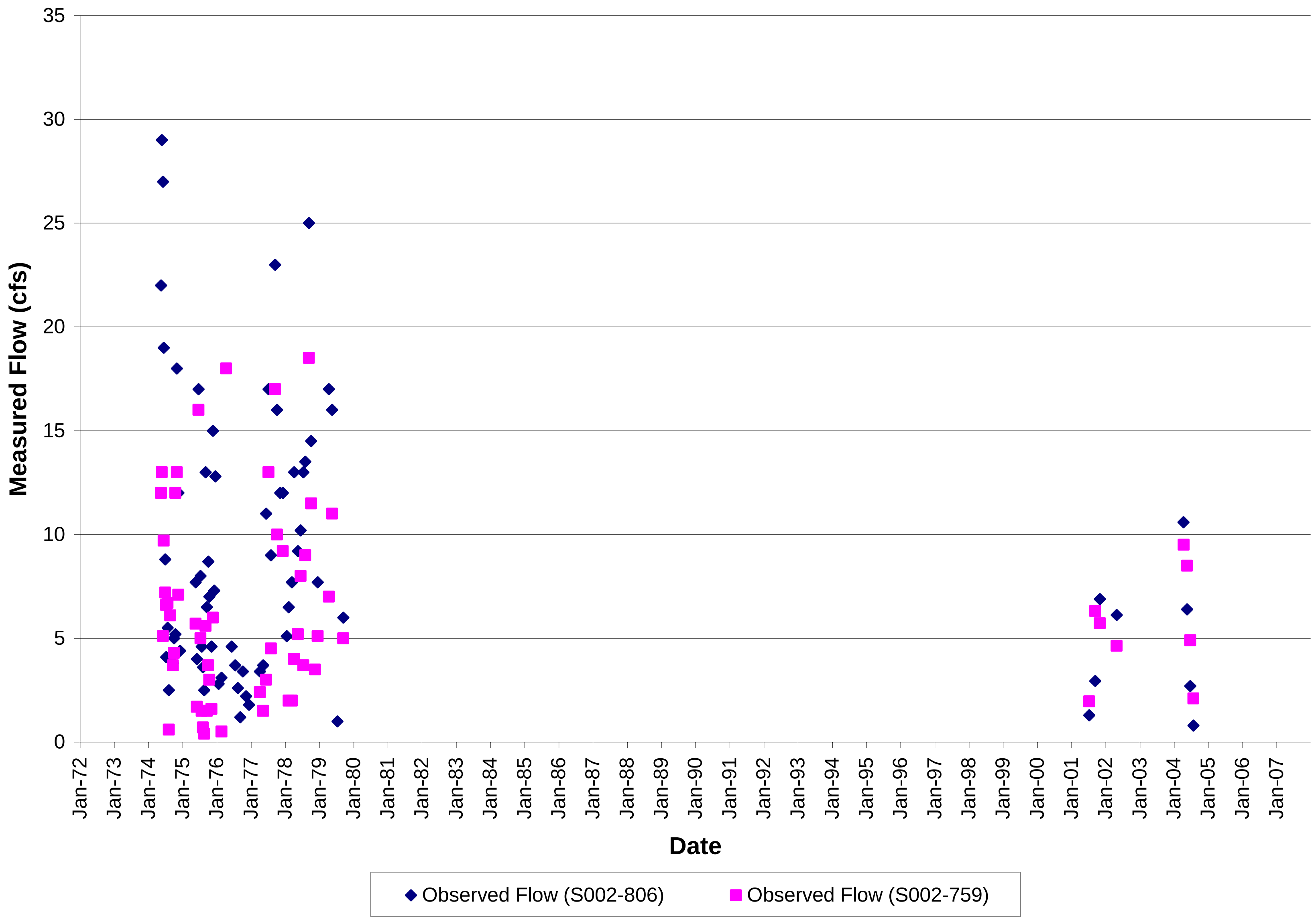


Figure 7. Precipitation record for Babbitt, MN

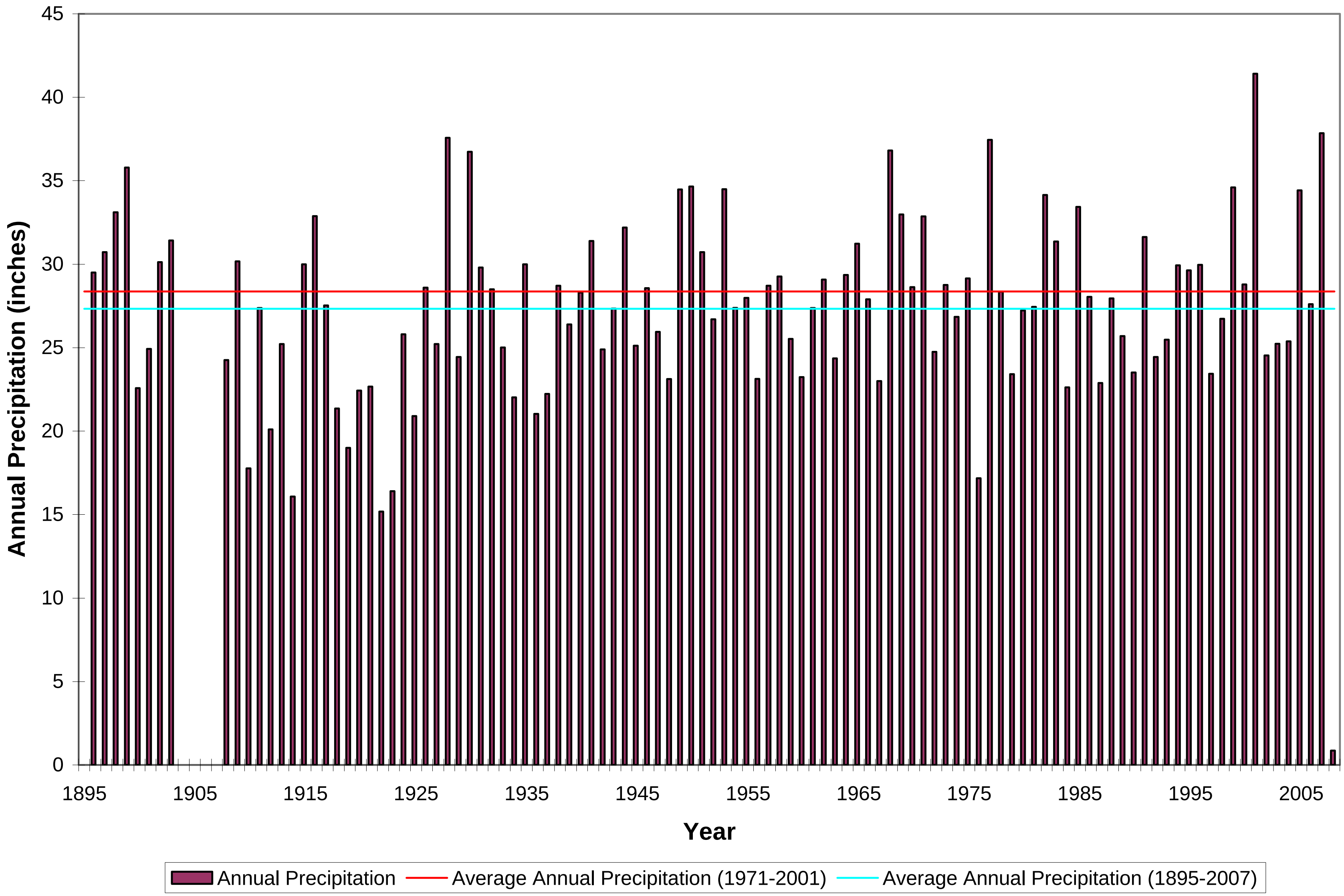


Figure 8. Storage-elevation curves for mine pit: current and post-closure conditions

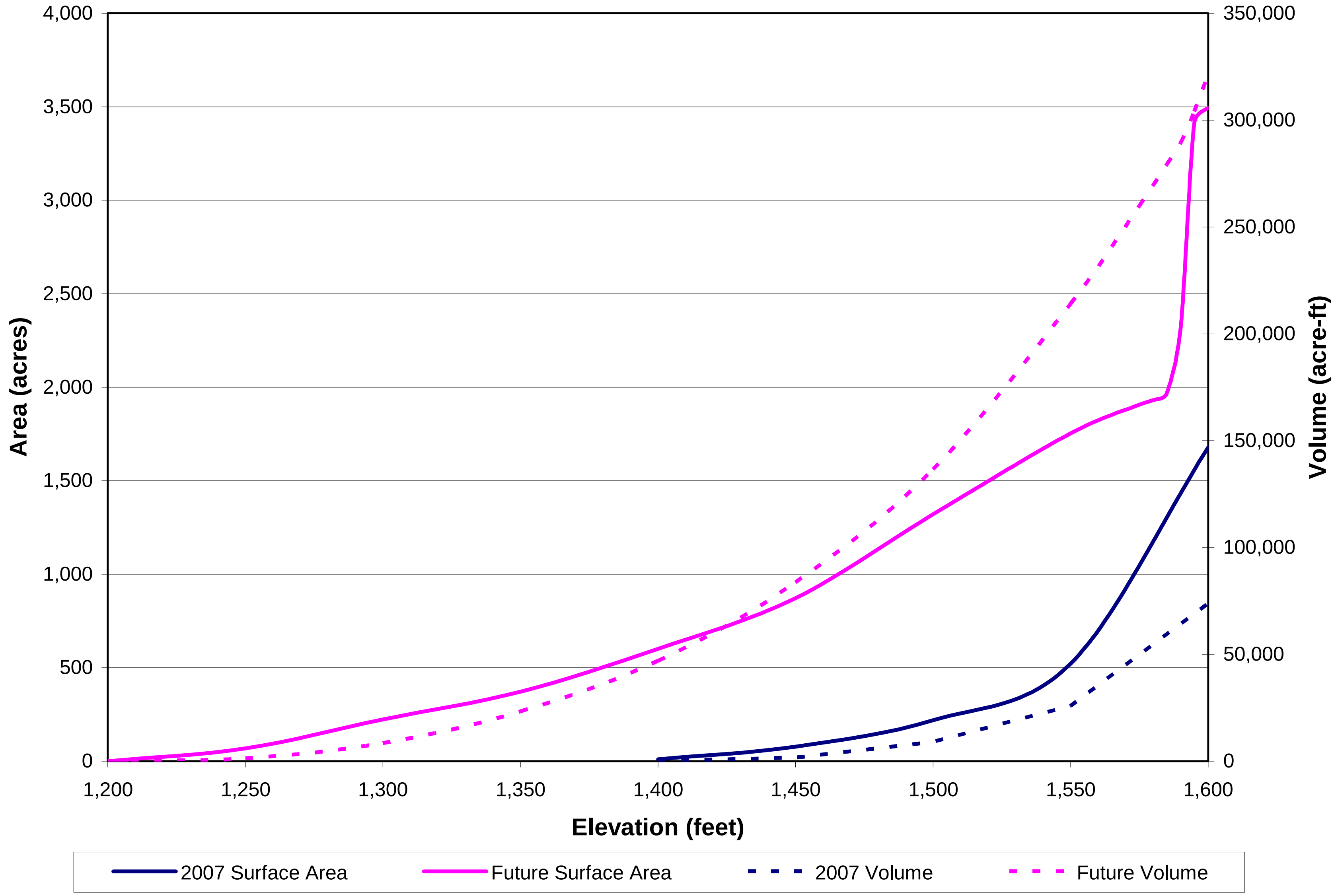
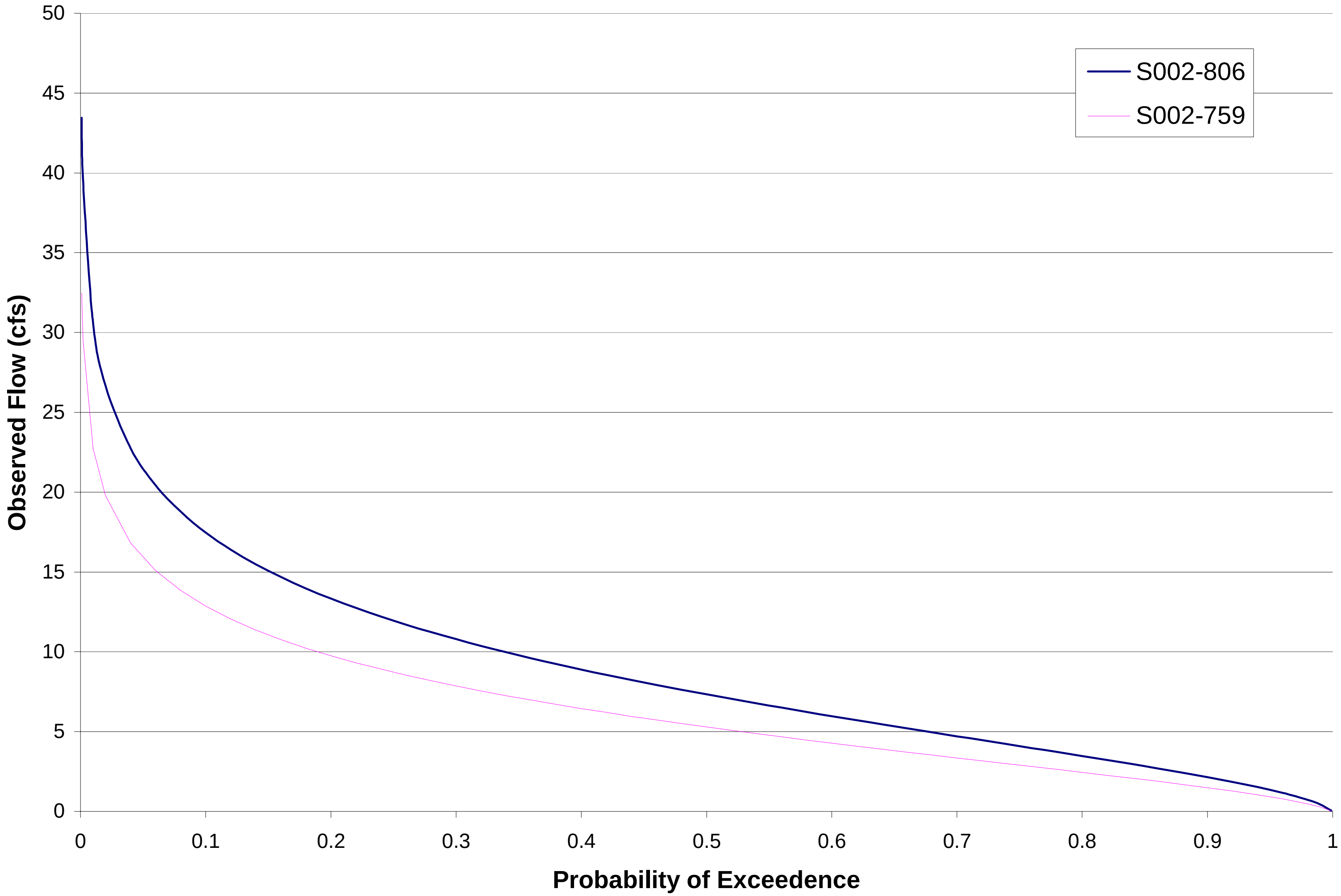


Figure 9. Probability-exceedence curve for flow observed in Langley Creek (S002-759 and S002-806)



Note: Probability based on normal distribution of cubed root transform of observed flows