**Elsa Reclamation and Development Company**

**Keno Hill Silver District**

**Mass Loading Model 2008 Update**

**June 2009**

Prepared by:

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# 1.0 INTRODUCTION

As part of the 1996 Site Characterization Report (UKHM, 1996) a site wide mass balance model was developed and a template for this was constructed in Microsoft Excel® to enable an assessment of site wide contaminant loadings. The model used data collected from the water quality monitoring program and site hydrological conditions to generate site wide loading estimates that would provide an understanding of how and if metals loads from various mine site components were affecting local receiving waters. In 2007, the site meteorological and hydrological conditions were appraised and updated by Clearwater Consulting Ltd. as part of a hydrological assessment for the project area. This study confirmed the continued use of hydrological input parameters used in the 1996 mass balance model.

The mass loading model update builds upon the existing excel loading model to refine the model for closure assessment purposes and uses the water quality and hydrology stored in the EQWIN database and makes it more readily accessible and user friendly using and ArcGIS package that interfaces with the site water quality database. This tool will then be used during consultation and discussions with stakeholders and regulatory authorities as part of the closure planning process to visualize and analyze the effect of the closure options being considered on water quality at specific points in local surface receiving waters.

# 2.0 MODEL OBJECTIVES

The primary mass loading model objectives are to quantify the volume of contaminants transported by water pathways on the Keno Hill property and thus to develop an understanding of the impact loading sources have on downstream waters. Beyond that, the model attempts to give insights into the ways in which contaminants are transported and the magnitude of their production and attenuation into the receiving environment. Results of the model can then be used to assess various closure options planned for the site and their effects to local receiving waters.

## 2.1 METHODS

### 2.1.1 Using the Regional Hydrological Model to Determine MAR

A hydrological model was developed in 1996 and used to estimate the mean annual runoff (MAR) in catchments within the Keno Hill area where no gauging data have been historically collected. The hydrology was developed on a regional level for basins outside of, but near the Keno Hill Mine to be used as an approximation of conditions in the Keno Hill area. The approach used an empirical model to establish a regional relationship between MAR and median elevation within a specific catchment. This relationship was used to extrapolate MAR conditions at ungauged Keno Hill stations.

Monthly streamflow distribution from Water Survey of Canada (WSC) stream gauging locations in the vicinity of the Keno Hill mine were obtained to assist in pairing gauged catchment basins with ungauged catchments located on the property. WSC catchments that most closely resembled the basin and streamflow characteristics of Keno Hill catchments were used to approximate MAR conditions at ungauged Keno Hill stations. The selection was based primarily on the median elevation of each catchment. In 2007, site meteorological and hydrological conditions were reviewed by Clearwater Consulting Ltd. and the information to the model was updated as part of a broader hydrological assessment for the project area. Tables 1 and 2, extracted from the Clearwater report, summarize the mine site catchments and MAR.

The MAR for a given catchment at Keno Hill is generally incorporated into the loading model in terms of annual runoff. However, the loading model can also be broken down by quarter, to refine the model and more precisely determine the amount of load produced by a catchment (Table 3). This is done by using the annual streamflow distribution to identify how much of the MAR passes through a catchment during a specific quarter.

### 2.1.2 Other Sources of Catchment Runoff

The regional hydrology is established through the above model, but does not take account of the influence of adits and open pits to the flow of water in the catchment. For that reason, open pits and adits have been worked into the hydrology separately (Table 4). For adit drainage, these are treated as node inputs to the model and are *added* to the MAR for the catchment within which they are located. Much of the runoff generated in enclosed areas that drain into open pits and glory holes ultimately report to the adits, and as a result the water drained by these areas may be counted in the model twice. Therefore, these areas are *subtracted* from each catchment MAR.

At adits, particularly treatment site adits, flow data are collected regularly on either a daily or monthly basis. These data are used to supplement the information estimated from the regional hydrological study.

**Table 1 Monthly Average Discharge Record for Christal Creek at KV7 ($m^3/s$)**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | | | | | | | | 0.420 | 0.510 | | | |
| 2004 | | | 0.150 | 0.166 | 1.153 | 0.314 | 0.119 | 0.112 | 0.163 | 0.135 | 0.103 | 0.101 |
| 2005 | | 0.122 | 0.112 | 0.391 | 1.540 | 0.264 | 0.294 | 0.398 | 0.335 | 0.259 | 0.189 | 0.150 |
| 2006 | 0.166 | 0.138 | 0.120 | 0.124 | 1.089 | 0.519 | 0.397 | 0.278 | 0.415 | 0.368 | 0.203 | 0.142 |
| 2007 | 0.151 | 0.120 | | | 0.757 | 0.327 | 0.540 | 0.218 | 0.335 | 0.154 | | |
| **Average** | 0.159 | 0.126 | 0.127 | 0.227 | 1.135 | 0.356 | 0.337 | 0.285 | 0.352 | 0.229 | 0.165 | 0.131 |

**Mean annual runoff = ~0.304 $m^3/s$, or 221 mm.**

**Table 2 Monthly Average Discharge Record for Lightning Creek at KV41 ($m^3/s$)**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | | | | | | | | 0.433 | 0.315 | 0.240 | 0.153 | 0.125 |
| 2005 | 0.098 | 0.067 | 0.056 | 0.130 | 1.802 | 1.418 | 0.989 | 1.111 | 0.958 | 0.637 | 0.452 | 0.299 |
| 2006 | 0.219 | 0.192 | 0.194 | 0.272 | 0.793 | 1.994 | 1.326 | 0.921 | 1.083 | 0.889 | 0.554 | 0.447 |
| 2007 | | | | | 1.231 | 1.926 | 1.193 | | | | | |
| **Average** | 0.159 | 0.129 | 0.125 | 0.201 | 1.275 | 1.779 | 1.169 | 0.821 | 0.785 | 0.589 | 0.386 | 0.290 |

**Mean annual runoff = ~0.645 $m^3/s$, or 344 mm.**

**Table 3 Details of Mine Site Catchments**

| Element | Outflow Station | Catchment Description | Catchment Area ($km^2$) | Catchment Median Elevation (m.a.s.l.) | MAR - Mean Annual Runoff (mm) | Jan - Mar | Apr - Jun | Jul - Sept | Oct - Dec | 1000m3/yr |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Average monthly flows for minesite streams | | | % MAR | 4.8 | 54.8 | 28.5 | 11.9 | 100 |
| Element 1 | KV-6 | Christal Creek above Station KV-6 | 7.7 | 990 | 240 | 87.5 | 998.4 | 519.2 | 216.8 | 1821.9 |
| Element 2 | KV-7 | Christal Creek between Stations KV-6 and KV-7 | 35.8 | 970 | 230 | 392.3 | 4478.9 | 2329.4 | 972.6 | 8173.2 |
| Element 3 | KV-55 | Sandy Creek above LES-63 | 2.3 | 1180 | 290 | 31.2 | 355.9 | 185.1 | 77.3 | 649.5 |
| Element 4 | KV-21 | No Cash Creek above LES-21 | 1.5 | 1200 | 300 | 18.7 | 213.1 | 110.8 | 46.3 | 388.8 |
| Element 5 | KV-2 | South McQuesten River above S10 and below LES-1, S 19, LES-21, and LES-63 | 32.9 | 650 | 150 | 233.0 | 2660.3 | 1383.5 | 577.7 | 4854.5 |
| KV-1 | KV-1 | South McQuesten River above LES-1 | 476 | 940 | 230 | 5255.0 | 59995.0 | 31201.8 | 13028.1 | 109480.0 |
| Element 6 | KV-12 & KV-58 | Catchment of Dam No. 3 of Elsa Tailings Impoundment | 4.3 | 760 | 180 | 37.2 | 424.2 | 220.6 | 92.1 | 774.0 |
| Element 7 | KV-47 | Porcupine Creek Diversion Channel above LES-47 | 10.1 | 1110 | 270 | 130.9 | 1494.4 | 777.2 | 324.5 | 2727.0 |
| Element 8 | KV-59 | Galena Creek above the mouth | 10.9 | 970 | 240 | 122.8 | 1402.5 | 729.4 | 304.6 | 2559.3 |
| Element 9 | KV-9 | Flat Creek above S9 and below LES-57, LES-47, and S1 | 31.2 | 700 | 170 | 254.6 | 2906.6 | 1511.6 | 631.2 | 5304.0 |
| Element 10 | KV-4 | South McQuesten River above S11 and below S10 and S9 | 29.9 | 670 | 160 | 229.6 | 2621.6 | 1363.4 | 569.3 | 4784.0 |
| Element 11 | KV-5 | South McQuesten River above LES-5 and below S11 and LES-10 | 95 | 850 | 200 | 912.0 | 10412.0 | 5415.0 | 2261.0 | 19000.0 |
| LES-10 | LES-10 | Haldane Creek above South McQuesten Road | 88.8 | 830 | 200 | 852.5 | 9732.5 | 5061.6 | 2113.4 | 17760.0 |

**Table 4 Details of Enclosed Basins Created by Open Pits**

| | | Enclosed Basin Description | Catchment Area ($km^2$) | Catchment Median Elevation (m.a.s.l.) | MAR - Mean Annual Runoff (mm) | 1000m3/yr |
|---|---|---|---|---|---|---|
| Element 1 | | Open pits within catchment of Element 1 (Calumet "C" and Onek) | 0.09 | 1180 | 290 | 26.1 |
| Element 2 | | Open pits within incremental catchment of Element 2 (sime 6, Sime 4, 35 Vein, and Miller) | 0.19 | 1280 | 320 | 60.8 |
| Element 3 | | Open pits within catchment of Element 3 (Western portion of Calumet 4-11 Veins) | 0.05 | 1400 | 350 | 17.5 |
| Element 4 | | Open pits within catchment of Element 4 (Bermingham and Bermingham SW) | 0.18 | 1350 | 340 | 61.2 |
| Element 5 | | Open pits within incremental catchment of Element 5 (Calumet 3, Calumet 2, and part of Calumet 4-11 Veins) | 0.23 | 1380 | 350 | 80.5 |
| Element 8 | | Open pits within catchment of Element 8 (Silver King) | 0.27 | 860 | 210 | 56.7 |

### 2.1.3 Contaminant Monitoring and Data Collection

Contaminant concentration data are regularly captured under a water surveillance network sampling program. This program has existed in various incarnations over a period of time dating from the 1970s. Data considered reliable for use in the model dates from 1994, but consistent comprehensiveness of the network of nodes was not achieved until ERDC took over care and maintenance of the site in 2006. For that reason, it is not possibly to accurately determine loadings for many common parameters before 1996.

### 2.1.4 Modeled Parameters

For the purposes of this study, the major contaminant of concern, zinc, and a tracer parameter, silicon, were studied. Dissolved zinc was used over total zinc, as a result of its immobility by virtue of it being in solution. Total zinc is more readily picked up and removed from suspension and can be influenced by morphological factors. For example, erosion along stream banks where contaminant residue may be present can provide a significant input of a given contaminant to waterways.

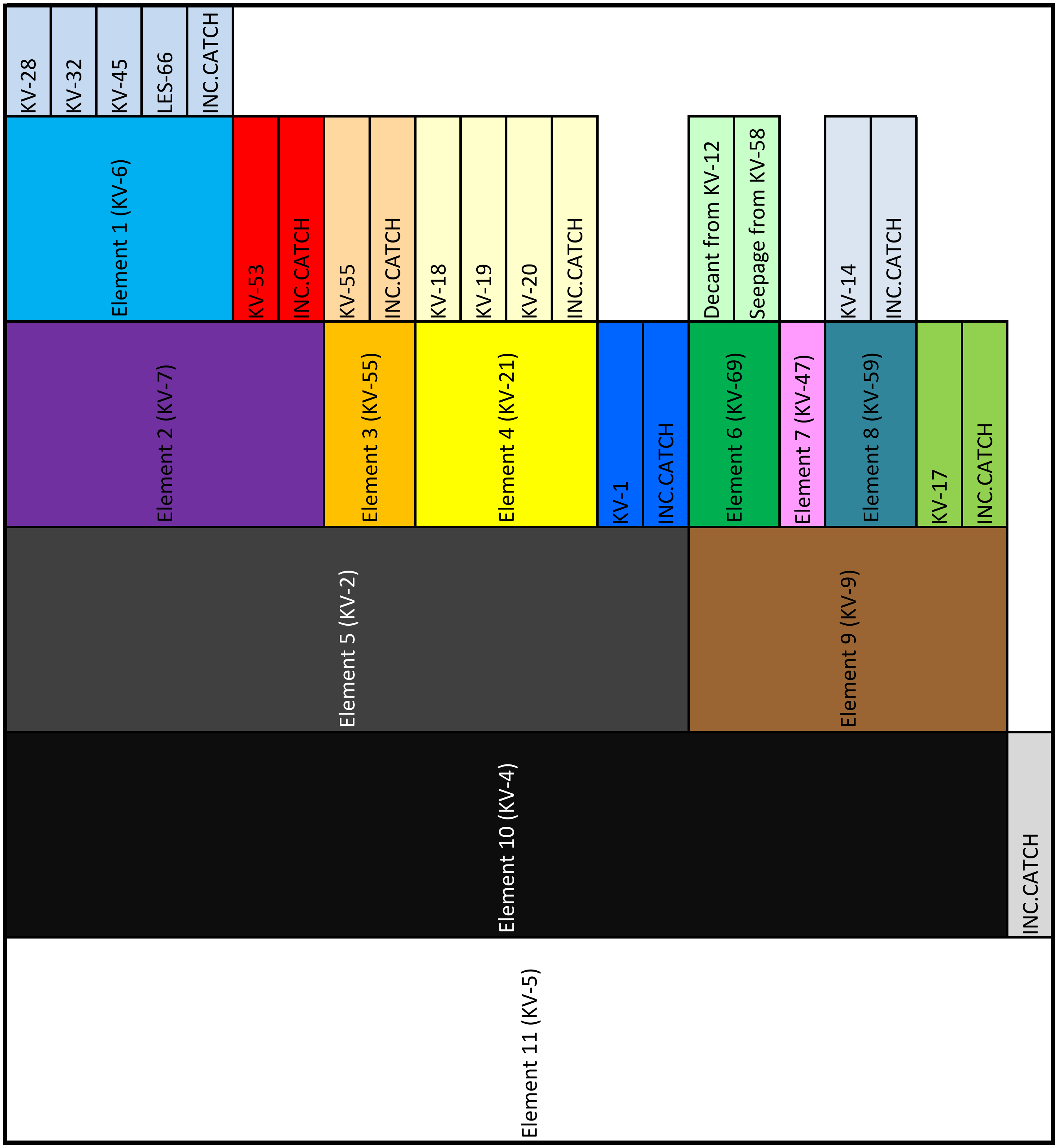
### 2.1.5 Calculating Catchment Loads

Loading data is mathematically calculated from a combination of the runoff inputs (both MAR and adit/open pit drainage) and contaminant concentrations measured at sites in the monitoring network.

### 2.1.6 Structure of the Loading Model

The loading model is structured after the reality of the drainage at Keno Hill. The Keno Hill Property contains three main watersheds: Flat Creek, Christal Creek and Lightning Creek. Two of these (Flat and Christal Creeks) drain into the South McQuesten River before they leave the property owned by ERDC. Therefore, the model is built in two parts, one to determine contaminant loadings in the South McQuesten River, and the other to determine loadings to Lightning Creek (for watershed delineation, see Figures 1).

Figure 1 Mass Loading Model Inputs Flow Diagram




INC.CATCH: Incremental catchment

The model is further broken down into element components, which can be considered loading 'checkpoints' that are geographically smaller, more accurate representations of the input data. The network of sampling nodes captures smaller drainage basins via an output node (station) at the outlet of flow for each area. The data captured by output nodes is threefold in nature, with the intention of estimating the total runoff drained at that point. This includes all data measured at nodes within that basin, plus data from the output nodes of upstream basins and meteoric runoff from the incremental catchment. Table 5 describes the relationship of input nodes, output nodes, and incremental catchment runoff. In the case of Keno Hill, there are eleven basins that make up drainage reporting to the South McQuesten River, and three basins that make up drainage reporting to Lightning Creek (refer to Figure 2 for drainage basin locations).

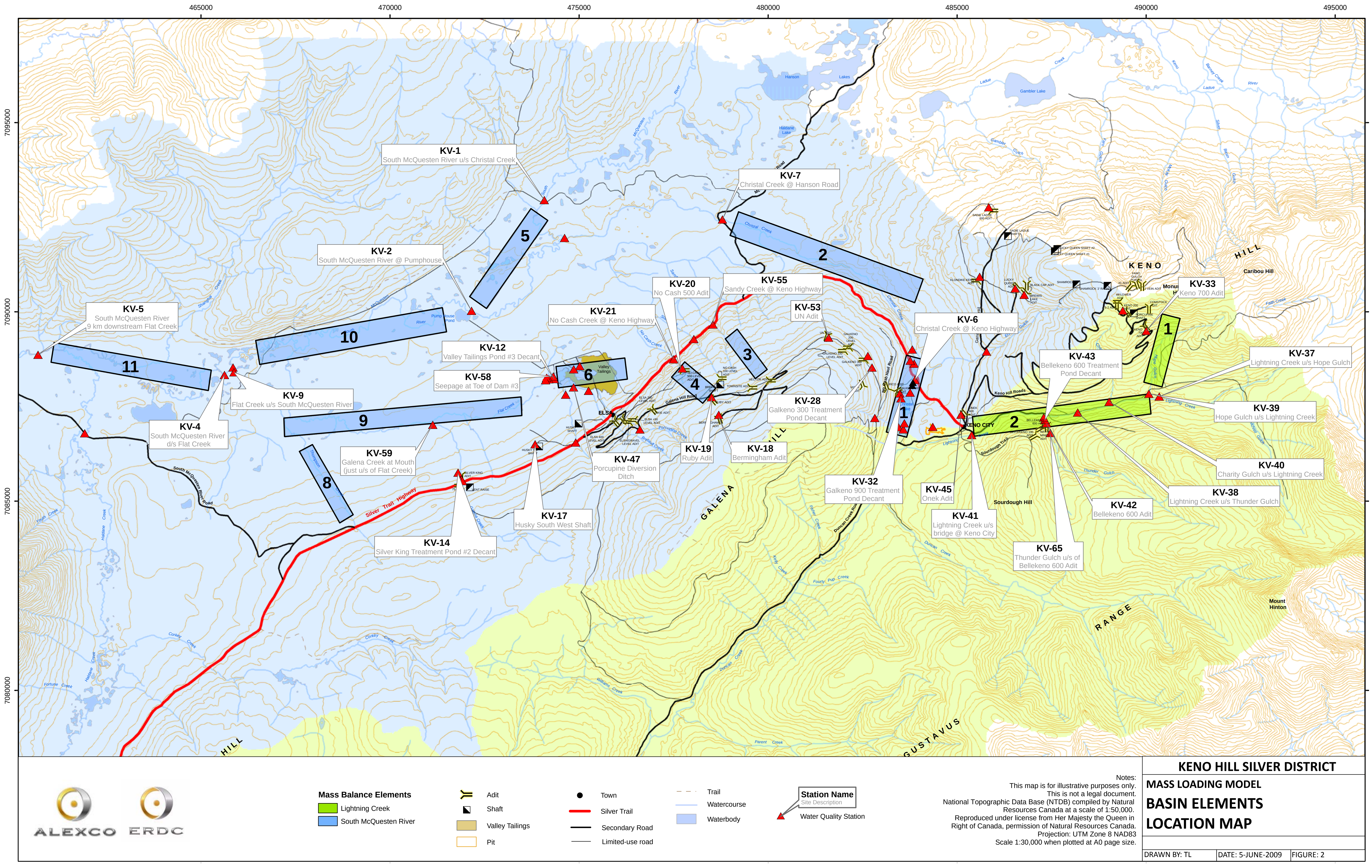
At the smallest level, the model is made up of all of model 'nodes' or what are effectively the sampling stations of the monitoring network. Raw data is collected at this level and agglomerated to form basins, which are in turn agglomerated to form the larger watersheds.

The network of nodes that form the basis of the mass balance model include adit and stream discharges. These two inputs are additives to the loading balance. Data collected at these points are discharges and water quality, as discussed above.

### 2.1.7 Calculating Load and Attenuation

There are two ways of calculating the total load produced by a watershed. The first method involves calculating the mass loading at the final outlet on the South McQuesten and Lightning Creek waterways based on observed flows and concentrations at the outlet station. The second method involves calculating the amount of load produced by watershed elements and summing those loads, irrespective of what the observed downstream loads are. The model is structured in such a way as to incorporate both of these methods and use them as a means for literally balancing the model. There is a feedback mechanism incorporated where the observed load feeds back into the calculated load to determine the net loading (or attenuating) capacity of the specific basin.

The result is that the model is balanced and produces at a minimum an order of magnitude estimate of the natural attenuating or contaminating capacity of each drainage basin.

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# KENO HILL SILVER DISTRICT

## MASS LOADING MODEL

## BASIN ELEMENTS LOCATION MAP

DRAWN BY: TL | DATE: 5-JUNE-2009 | FIGURE: 2

# 3 DATA AND RESULTS

Appendix I contains the mass loading model. Catchment runoff, adit and pit drainage, water quality monitoring results, and loading calculations are all stored and processed within this spreadsheet.

## 3.1 MEASURED CONTAMINANT CONCENTRATIONS AT NODES

In general, contaminant concentrations at Keno trend higher together in linear correlation (Figure 3). Concentrations at adit sites draining the mine workings are significantly higher than concentrations measured at stream waterways. In the Christal Creek watershed, this is especially pronounced at Onek Adit, which produces the highest zinc and cadmium levels of any adit on the site, and to a lesser extent at No Cash 500 and Bermingham Adits.

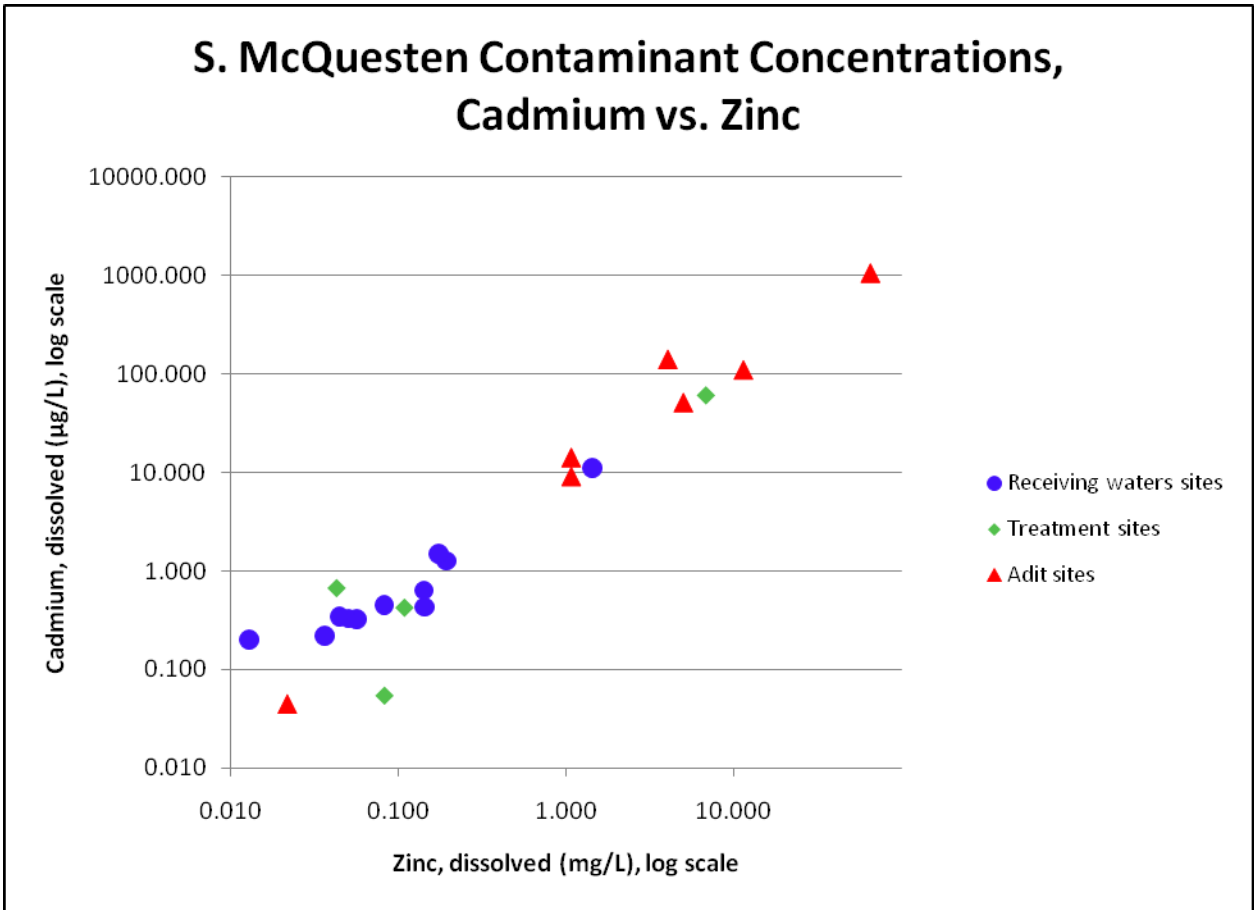



**Figure 3 South McQuesten River Cadmium and Zinc Concentrations, by Station Type**

### 3.2 CALCULATED CONTAMINANT LOADING AT NODES

Contaminant loading at sites within the South McQuesten watershed is to a certain degree, a function of the volume of water passing through that particular site (Figure 4). Receiving waters sites produce the most water on an annual basis of any site type, by virtue of their being streams and other significant water pathways. Contaminant concentrations at these locations, being lower than at adit sites, produce vastly smaller loads than the loads produced at adit sites for the same volume of water. Viewed another way, for the same or similar loading levels, receiving waters will show an order of magnitude or more than adits in terms of water volume. At adit sites, overall loads are high even at low flows as a result of higher contaminant concentrations. At treatment sites, the general trend between the volume of water passing through the site and the contaminant load that is produced there is along the same trend as what is seen in receiving waters.

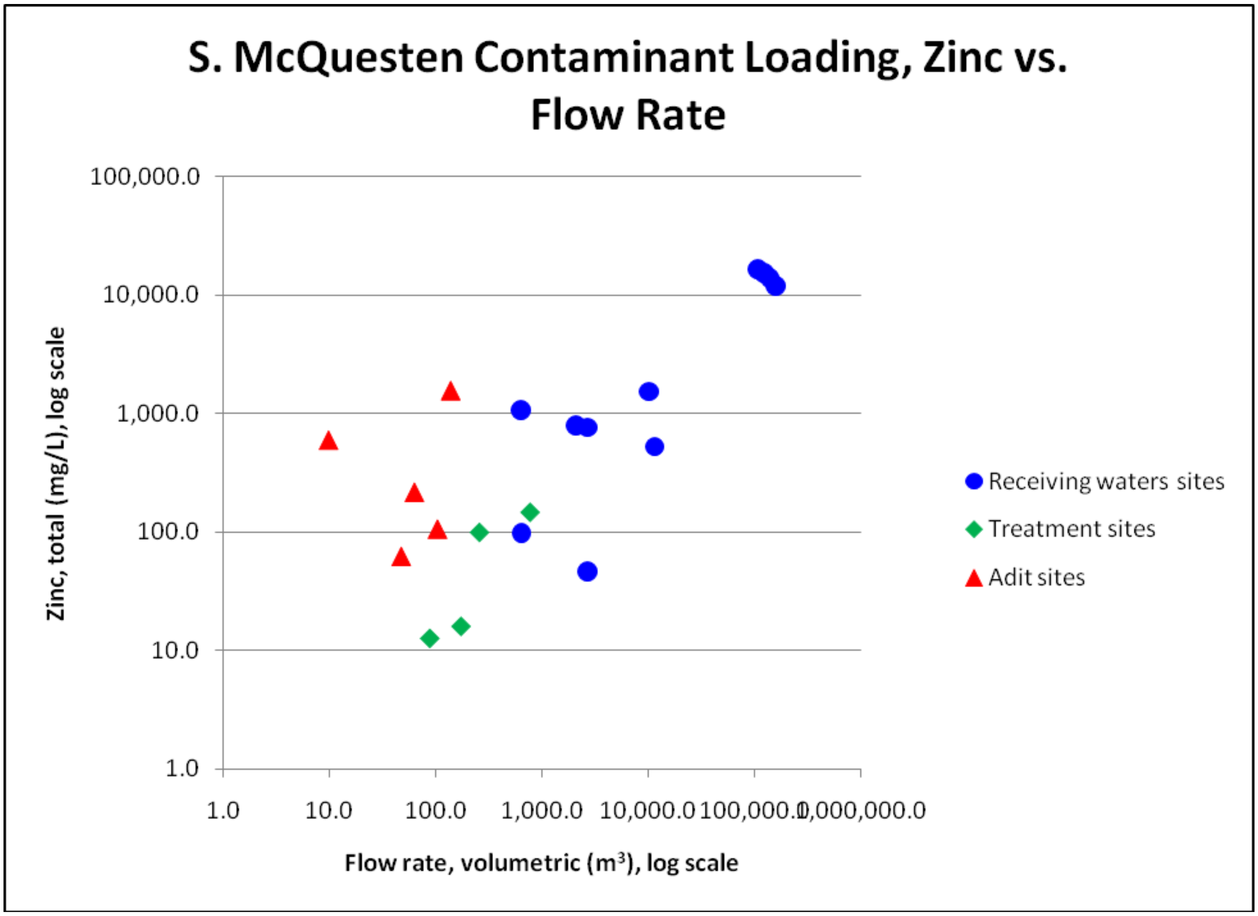



**Figure 4 South McQuesten River Cadmium and Zinc Loading versus Annual Volumetric Flow ($m^3$) by Station Type**

## 3.3 ADIT SITE LOADS

Adit sites are the heaviest producers of contamination on the site. Adit waters in some cases flow directly to watercourses, while other adits report to ground. This fact accounts for the discrepencies witnessed in receiving waters where large loads from adits are not seen in downstream waters (Figures 5a through 6b). Table 5 displays the results of field monitoring and contaminant concentrations for adits which contribute a zinc load to the property.

**Table 5 Adit Flows and Loads, 2006 - 2008**

| Site | Description | 2006 | 2007 | 2008 | 2006 | 2007 | 2008 | 2006 | 2007 | 2008 | Source of Data/Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Flow (1000m$^3$) | | | Concentration (mg/L) | | | Load (Kg/year) | | | |
| KV-32 | Galkeno 900 Adit | 101.97 | 114.55 | 88.36 | 0.02 | 0.18 | 0.14 | 2.35 | 20.05 | 12.55 | Ongoing data collected by ERDC |
| KV-45 | Onek Adit | 9.78 | 9.78 | 9.78 | 97.70 | 114.00 | 61.10 | 955.79 | 1115.25 | 597.73 | Average of measured flows (ERDC/Access data) |
| LES-66 | Natural spring near Christal Lake | 78.89 | 78.89 | 78.89 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Average of two spot measurements taken in 1995 by LES |
| KV-28 | Galkeno 300 Adit | 322.52 | 315.58 | 258.77 | 38.23 | 13.73 | 0.38 | 12329.57 | 4331.60 | 98.07 | Ongoing data collected by ERDC |
| KV-53 | UN Adit | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | Dry |
| KV-18 | Bermingham Adit | 63.12 | 63.12 | 63.12 | 4.05 | 4.87 | 3.43 | 255.62 | 307.37 | 216.49 | Average of measured flows (ERDC/Access data) |
| KV-19 | Ruby 400 Adit | 47.34 | 47.34 | 47.34 | 1.27 | 1.23 | 1.31 | 60.12 | 58.22 | 62.01 | Average of measured flows (ERDC/Access data) |
| KV-20 | No Cash 500 Adit | 138.85 | 138.85 | 138.85 | 12.60 | 14.00 | 11.30 | 1749.55 | 1943.95 | 1569.04 | Average of measured flows (ERDC/Access data) |
| KV-58 | Dam No.3 seepage | - | - | - | - | - | - | - | - | - | No data available - assumed negligible |
| KV-14 | Silver King Adit | 205.12 | 205.12 | 205.12 | 0.17 | 0.14 | 0.09 | 35.28 | 27.90 | 18.67 | Average of measured flows (ERDC/Access data) |
| KV-17 | Husky SQ Adit | 104.14 | 104.14 | 104.14 | 0.94 | 2.03 | 1.01 | 97.79 | 211.40 | 105.39 | Average of measured flows (ERDC/Access data) |
| KV-43 | Bellekeno 600 Adit | 72.58 | 72.58 | 72.58 | 0.33 | 0.75 | 0.21 | 23.59 | 54.07 | 15.17 | Average of measured flows (ERDC/Access data) |
| KV-33 | Keno 700 Adit | 66.27 | 66.27 | 66.27 | 1.23 | 1.46 | 1.58 | 81.65 | 96.56 | 104.71 | Average of measured flows (ERDC/Access data) |

High flows (>100,000m$^3$/year)

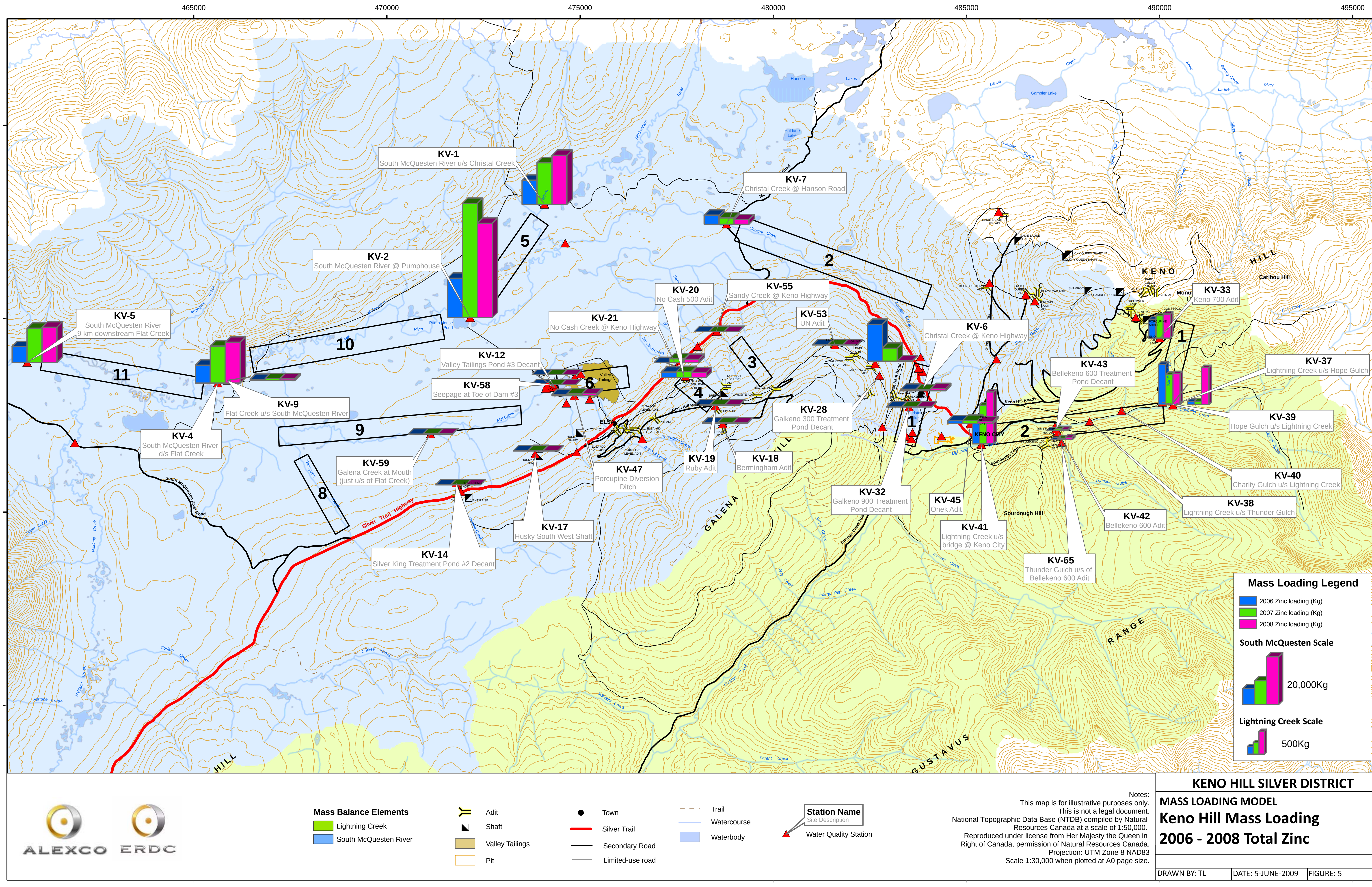
High concentrations (>5mg/L)

High loads (>500Kg/year)

## 3.4 CONTAMINANT LOADING BY WATERSHED

As discussed, the drainage in each basin is determined by the sum of the flow at nodes within that basin, including both the incremental flow to the outlet node and the flow from outlet nodes of upstream basins. Ultimately, these data sum to obtain the total annual contaminant load within the South McQuesten and Lightning Creek watersheds (Figure 5).

Under the first method of load estimation, the mass loading at the final outlet on the South McQuesten and Lightning Creek waterways is based on observed flows and concentrations at the outlet station. This provides a real-world view of the contamination present in Keno Hill waters. These data calculations are graphically presented in figures 6 and 8. By the second method of load estimation, the attenuation capacity of the site is not factored in and the loads represent the amount of contamination produced by all sources that may end up in Keno Hill waters and land resources (figures 7 and 9).




Mass Balance Elements
- Lightning Creek
- South McQuesten River

- Adit
- Shaft
- Valley Tailings
- Pit
- Town
- Silver Trail
- Secondary Road
- Limited-use road
- Trail
- Watercourse
- Waterbody

Station Name
Site Description
Water Quality Station

ALEXCO ERDC

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## KENO HILL SILVER DISTRICT

MASS LOADING MODEL

## Keno Hill Mass Loading 2006 - 2008 Total Zinc

| DRAWN BY: TL | DATE: 5-JUNE-2009 | FIGURE: 5 |
|---|---|---|

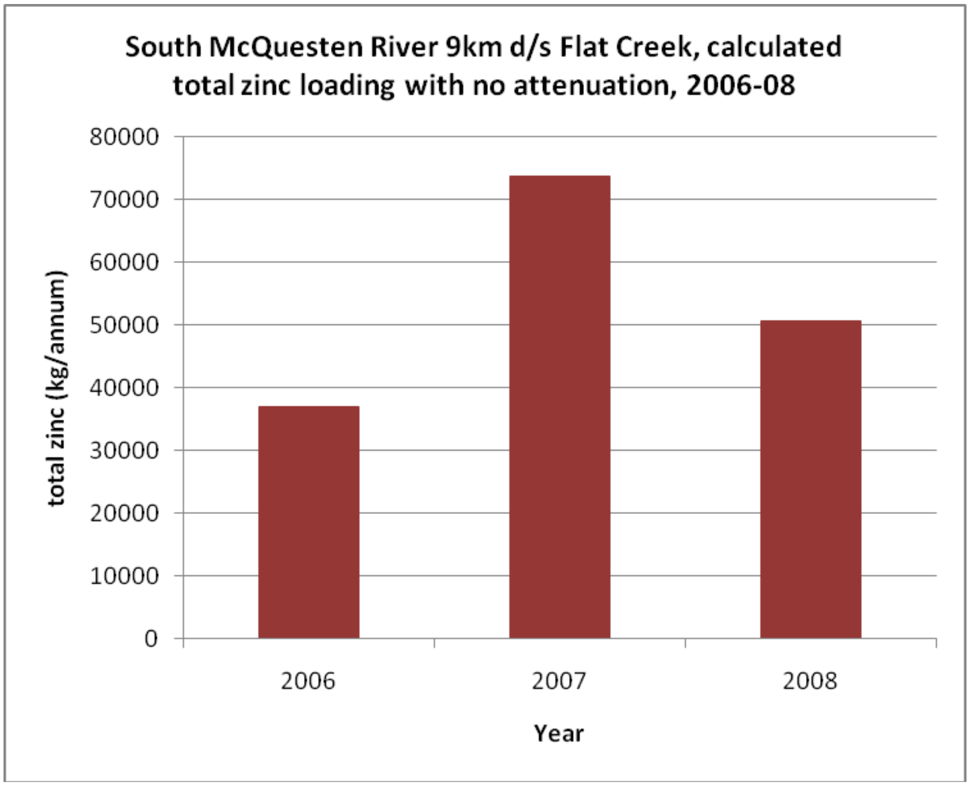


**Figure 6 Total Zinc Loading (kg/yr) at the South McQuesten River; All Sources Before Attenuation**

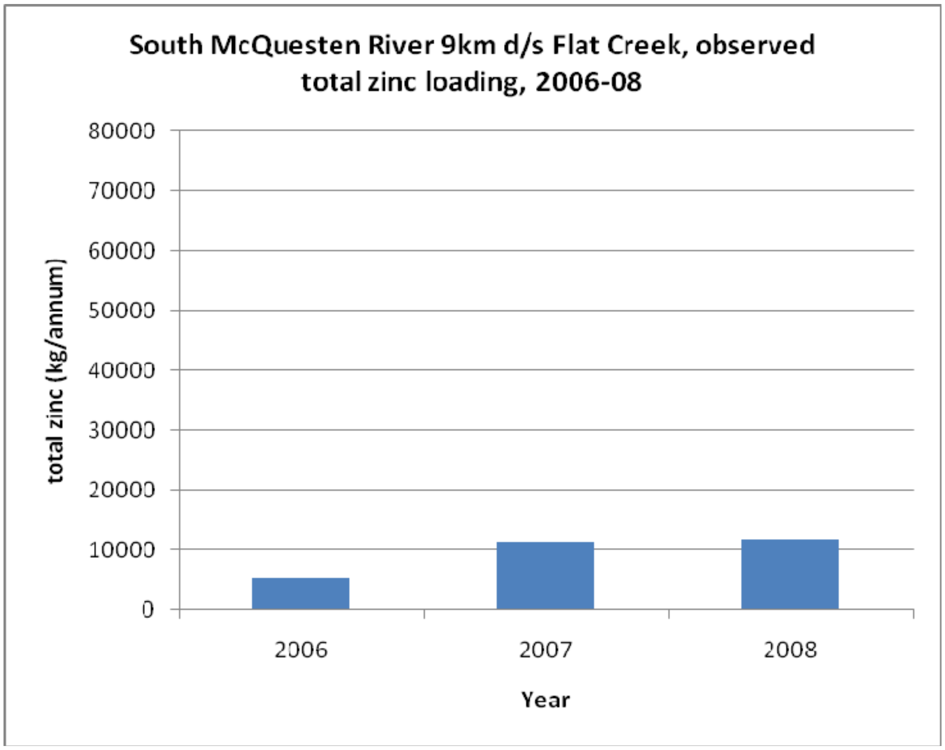


**Figure 7  Total Zinc Loading (kg/yr) at the South McQuesten River, Observed**

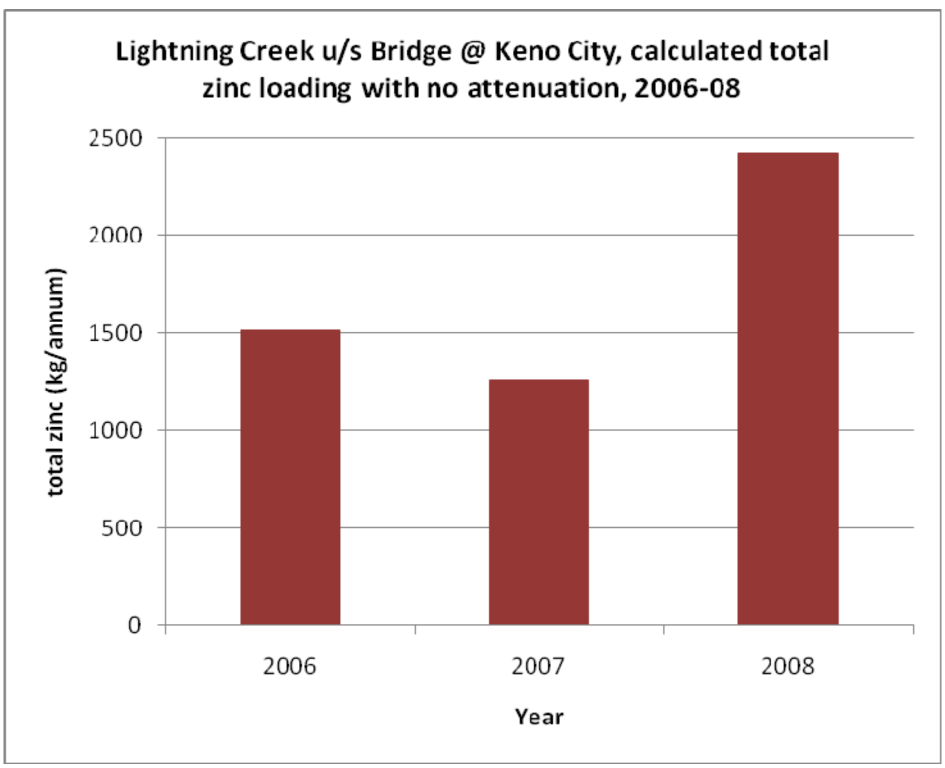


**Figure 8  Zinc Loading (kg/yr) at Lightning Creek; All Sources Before Attenuation**

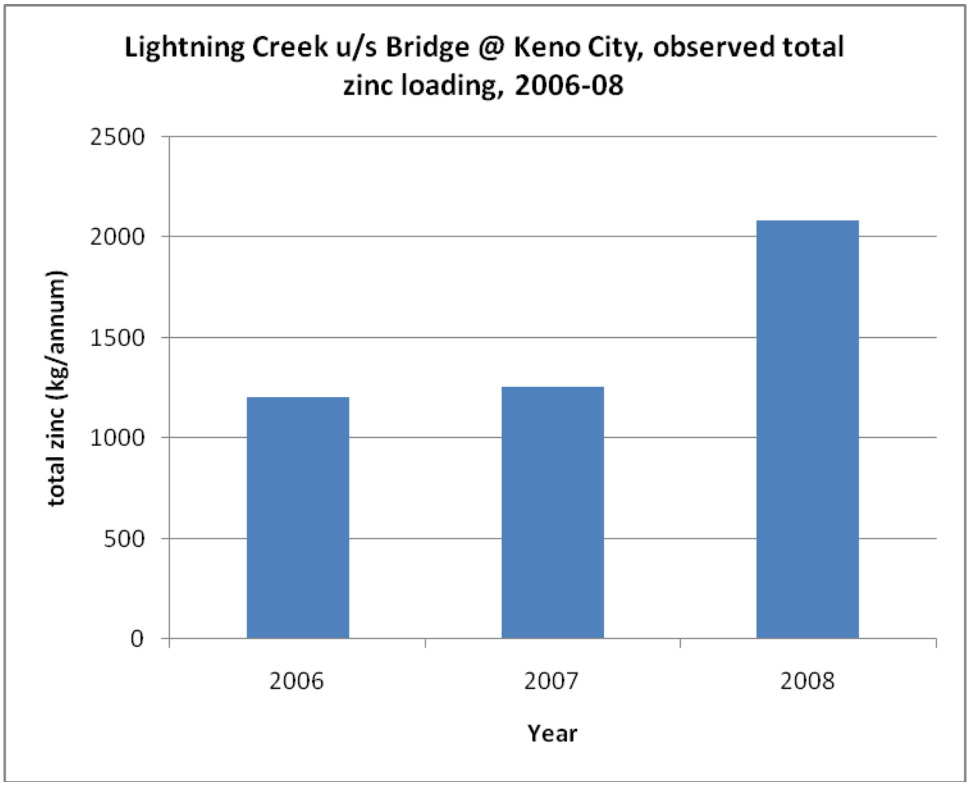


**Figure 9  Total Zinc Loading (kg/yr) at Lightning Creek, Observed**

# 4 CONCLUSIONS

The mass loading model has provided a valuable tool for determining the level of contaminant loading from various parts of the Keno Hill site, as well as the level of actual contamination observed downstream. This has lead to a method for estimating the capacity for the site to absorb contaminants and reduce overall loads produced by contamination sources.

The model will be used to model the effects of varoius perferred closure options and assess the degree to which they may be successful or appropritate at a given site, particualry for water managmnet at the mine adits and valley tailings.