

GALKENO 900
SITE #12
MINFILE # 105M001m

1. LOCATION AND ACCESS

The Galkeno 900 site is at the eastern base of Galena Hill at an elevation of 880m, roughly 200m west of the north end of Christal Lake (Site #12, Figure 1). It is located at the approximate UTM co-ordinates 7 087 700m N and 483 600m E. Two wheel drive vehicle access is possible via an all-weather gravel road that branches off to the southwest from Highway 2 (2km west of Keno City). The site is about 0.6km from this junction along Galkeno 900 road.

2. SITE PHYSIOGRAPHY

The east facing Galkeno 900 site is on the gently sloping toe of Galena Hill at an elevation about 20m higher than Christal Lake. The ground around the site area contains a thick layer (>3m) of moss, soil and glacial overburden. The overburden is for the most part permanently frozen. The area is well vegetated with spruce trees and shrubs.

All surface water from this site flows into Christal Lake. Treated mine waters flow to Christal Lake from the site through a 3m deep creek gully that has formed since 1995. A small volume of untreated mine water is diverted into a constructed trial wetland. Water drains from the constructed trial wetland through a natural wetland and into Christal Lake. A seep from beside the constructed wetland also flows through the natural wetland and into Christal Lake.

3. GEOLOGY AND MINERALIZATION

The host rock is a medium to thick-bedded quartzite with graphitic schist and phyllite (Minfile #105M 001m). The vein is a zone of shearing and brecciation about 10m wide. Although open, the adit was not entered to examine the rock and mineralization types.

4. SITE HISTORY

The Galkeno 900 adit was constructed between the late 1950's and the early 1960's, and extends to a total length of 1,910m. The adit was constructed for a variety of reasons: to explore the down-dip extensions of the upper Galkeno workings, to provide a lower elevation haulage level, and to dewater the McLeod Vein workings. The adit was abandoned due to poor ground conditions, and has never entered production. The Galkeno 900 underground workings do not connect to other mine workings at higher elevations, including mined out stopes (United Keno Hill Mines Limited, 1996).

In 1994, a concrete bulkhead was installed 380m in from the portal to flood the adit and plug mine water discharge that contained high zinc concentrations. Flooding of the underground workings re-directed water to previously-dry workings located at higher elevation, most notably the Galkeno 300 adit, and to springs not associated with the underground workings. The apparent failure of the bulkhead approach has required the installation of a small water treatment facility in the portal of the Galkeno 900 adit and the construction of two settling ponds. A trial wetland was constructed 75m east of the adit during the summer of 1995 to reduce the metals content of the mine discharge waters. Results of the constructed trial wetland project are summarized in Attachment 3.

5. MINE DEVELOPMENT

Mine development at the site consists of the Galkeno 900 adit and associated waste rock piles, a constructed wetland, a small water treatment facility and two settling ponds. Site details can be found on Figure 1; see Attachment 1 for site photos.

5.1 Mine Openings and Excavations

The Galkeno 900 Adit is the only mine opening/excavation located at this site.

Galkeno 900 Adit (photo 12-1)

Location: Constructed into the base of the east side of Galena Hill, 200m west of Christal Lake.

Dimensions (L x W x H): 1,910m x 4.5m x 4.0m

Supports: A timber frame supports the portal.

Condition: The portal framing is in fair condition and appears stable.

Accessibility: The portal has wooden doors that are kept unlocked. It is possible to enter the adit beyond the treatment facility; however, the accessible length of the adit was not explored.

5.2 Waste Rock Disposal Areas

Waste rock from the adit is located in two small piles outside the adit, and was likely used to construct the settling ponds and the road. A geologist examined waste rock; no mineralised rock was found and no evidence of oxidation was observed. Based on visual observations and a previous assessment (UKHM, 1996), the waste dump consists of unmineralized development rock. No waste rock samples were collected.

Road

Waste rock was likely used in the construction of the road.

Location: The road travels east from the entrance to the adit for 45m and then turns south to the second settling pond.

Dimensions (L x W x H): 250m x 8m x 1m (estimated depth)

Waste Rock Pile #1 (photo 12-2)

The top of the rock pile has been levelled and forms a clearing along the road. The western edge of the pile slopes at a 30° angle down to the constructed trial wetland below.

Location: The waste rock pile begins 50m east of Galkeno 900 portal and ends at the western edge of the constructed trial wetland.

Dimensions (L x W x H): 20m x 28m x 4m

Stability: There is no evidence of the waste rock pile slumping. The waste rock pile appears stable.

Waste Rock Pile #2 (photo 12-3)

This waste rock pile has been levelled and a log frame structure has been built upon it.

Location: Just south of waste rock pile #1 and the constructed trial wetland.

Dimensions (L x W x H): 30m x 25m x 2m

Stability: The edges of the waste rock pile are gently sloped and there is no evidence of slumping.

Settling Pond Embankments

Waste rock has been used to reslope the eastern embankment to a 10° slope. The northern, southern and western sides of the settling ponds are roads and have been included in the volume of the roads above.

Location: The eastern side of the settling ponds.

Dimensions (L x W x H): 28m x 25m x 3m (estimated depth)

5.3 Tailings Impoundments

No tailings were reportedly processed at the Galkeno 900 site, and no tailings were encountered. The nearby MacKeno Mines mill did not process any of the Galkeno ore.

5.4 Mine Site Water Treatment

A water treatment plant is now in operation to lower concentrations of zinc and other metals in the mine water. The treatment plant is located within the portal. At the time of inspection, water was seeping around the bulkhead and being treated at a rate of 4L/s. Mine water seepage has been reported as high as 10L/s (Bill Dunn, interviewee). Treated adit water flows through underground pipes into a series of two settling ponds. The discharge water from the second settling pond has created a small creek that flows east into Christal Lake.

Wastewater treatment facility (photo 12-4)

Type: Lime treatment plant

Dimensions (L x Diameter): 10m x 1m

Location: Within the portal to the Galkeno 900 adit.

Drainage: According to site personnel, at the time of the site visit the treatment facility was treating approximately 4.5 L/s. United Keno Hill Mines Limited (1996) states that the drainage of mine water from the Hector-Calumet underground workings discharge flows to Galkeno 900 this site via the upper Galkeno workings and the McLeod vein fault.

Piping: The nature of the piping from the bulkhead to the treatment facility was not investigated. The piping is buried from the treatment facility to the settling ponds.

Settling ponds (photos 12-5, 12-6)

At the time of the site inspection, the two ponds were close to capacity with water.

Dimensions (L x W x Depth): 19m x 19m x 30cm (both ponds)

Location: 85m southeast of the adit entrance, south of the waste rock piles and the constructed trial wetland.

Drainage: The second settling pond drains to the south, creating a small creek that runs east into Christal Lake.

Stability: The eastern retaining wall has been recently resloped to increase stability. However, tension cracks in the eastern retaining wall were observed (photo 12-6). One crack (about 5 m in length) was oriented across the slope approximately 3m downslope from the settling ponds. Other cracks were seen along the edge of settling pond #2 and along the eastern edge of the resloped material. These cracks appear to be associated with the collapse of the soil adjacent to where the creek gully has formed. Tension cracks indicate the eastern retaining wall may be slumping.

Piping: A steel pipe 5m in length connects the two settling ponds. A collapsible, blue plastic pipe had been installed to direct the outflow of the water from settling pond number #2 to Christal Lake; however, only the first 10m of this pipe is currently in use, directing water flow to the creek gully. The remainder of the piping has been disconnected but remains in place.

Impacted vegetation: At the time of the site visit, the banks of the stream were stable and vegetation was healthy along the banks.

Constructed Trial Wetland (photo 12-7)

In the summer of 1995, a trial wetland was constructed to investigate the ability of the wetland to treat mine water. Sods of the sedge *Carex aquatilis* were transplanted from the reservoir that provides drinking water to Elsa and planted in an excavated plot. The wetland has one source of water input and one point of discharge. It has three plywood baffles across its width to help control the flow of water. It was designed to treat approximately 0.3L/s of the total discharge from the adit (Bill Dunn, interviewee).

Dimensions (L x W x Depth): 18.5m x 9m x 0.5m

Location: Located at the eastern side of waste rock pile #1, 75m east of the adit entrance.

6. MINE SITE INFRASTRUCTURE

Infrastructure at the Galkeno 900 site is minimal. The site mainly contains buildings and rail infrastructure. Site details can be found on Figure 1; see Attachment 1 site photos.

6.1 Buildings

There are three buildings at this site; a simple storage building that is still in use, a partial log cabin and an outhouse.

Building 12A: Storage Building (photos 12-8)

Dimensions (L x W x H): 8m x 4m x 3m

Location: 20m east of adit entrance

Construction: wood frame, wood siding, and wood roof; entrance is covered by a tarp

Stability: The building appears to be stable.

Paint: none observed

Asbestos: none observed

Contents: 4 steel pipes (8m x 6cm), 1 steel pipe (8m x 10cm), 1 galvanised/corrugated pipe (8m x 20cm), small amount of PVC piping, electrical centre for lights, pumps etc.

Foundation: none

Hazardous products: 1m² oil stain in the dirt

Building 12B: Log cabin frame (photo 12-9)

Dimensions (L x W x H): 5m x 5m x 1m

Location: 100m southeast of adit entrance

Construction: log frame – has only been partially completed, no roof

Stability: The logs are in good repair and the log frame appears stable.

Paint: none observed

Asbestos: none observed

Contents: filled part way with dirt

Foundation: none

Hazardous products: none observed

Building 12C: Wooden Outhouse

Dimensions (L x W x H): 1.5m x 1.5m x 2.2m

Location: 60m east of adit entrance

6.2 Fuel Storage

There were no fuel drums or storage tanks encountered at this site.

6.3 Rail and Ties

Fabrication: steel rail and wooden ties

Amount of materials: approximately 60m in length

Condition: The rails are rusted. Both the rails and ties are off of the road and pose no safety hazard.

6.4 Milling and Processing Infrastructure

There was no milling or processing done at the Galkeno 900 site.

6.5 Electrical Equipment

There is electricity supplied to the site. There is one transformer that is attached to a pole near building 12A that is currently in use.

7. SOLID WASTE DUMPS

There were no solid waste dumps observed at this site.

8. POTENTIAL CONTAMINANTS OF CONCERN

8.1 Out-of-Service Transformers

No out-of-service transformers were observed.

8.2 Metals and Hydrocarbons in Soil

Background information and the on-site investigation did not indicate any concerns regarding metals or hydrocarbons in the soil; therefore no soil samples were taken.

8.3 Liquid Hazardous Materials

No liquid hazardous materials were encountered at this site.

8.4 Solid Hazardous Materials

No solid hazardous materials were encountered at this site.

9. WATER QUALITY (photos 12-10 through to 12-13)

Water was seen to be discharging from two points on the site: from the adit and from a seep just north of the constructed trial wetland. As stated in Section 5.4, adit water is treated in the lime treatment plant and piped to the settling ponds. Site details can be found on Figure 1; see attachment 1 for site photos.

The seep discharges approximately 2m from the northern berm of the constructed trial wetland, at the same elevation. The seep water is slightly reddish in colour and iron oxides have precipitated onto the streambed. Water from the seep stagnates in a small natural wetland 5m east of the constructed trial wetland. The natural wetland measures 11.6m x 3.7m x 0.23m. Water quality samples were collected from the seep, settling pond #1, the stream and at the stream outlet into Christal Lake.

In addition to the mine discharge waters there are three small ponds just east of the constructed trial wetland, each measuring approximately 6m x 8m x 0.5m. These three ponds are likely settling ponds that were constructed in 1992. At that time, in order to facilitate the bulkhead construction, the adit was dewatered and the mine waters treated by a small lime treatment plant. The ponds were created to allow the precipitate to settle prior to being discharged from the system (United Keno Hill Mines Limited, 1996). There is a small steel pipe that ends in the westernmost pond that had no water flowing through it at the time of inspection: instead water enters the pond via a seep in the upper bank just above water level. The origin of the water is unknown; however, the constructed trial wetland is just upgradient of the ponds. The water from the three ponds discharge into a swampy area and eventually drains into Christal Lake. Water quality samples were collected from the first pond and from the swamp just prior to the drainage point into the lake.

A total of 6 water quality samples were collected. A complete list of samples, locations, field tests and laboratory results is attached to this report.

10. RECLAMATION

Since the site is still in use, vegetation is sparse on the roads. Some grass has grown on the sides of the waste rock piles. In August of 1996, wetland vegetation was planted in the area between Christal Lake and the constructed trial wetland. The planted vegetation as well as the surrounding vegetation appears healthy. The drainage from the settling ponds has melted the permafrost and created a creek gully with slumped soil and vegetation along its banks. The vegetation appears healthy and has continued to grow within the slumped soil.

11. OTHER SOURCES OF INFORMATION AND DATA

Further information on this site can be found in the United Keno Hill Mines Limited (1996) report. This report provides a detailed discussion on the installation of the adit bulkhead as well as the construction and monitoring of the constructed trial wetland. Ten water sampling stations were installed in the constructed trial wetland and monitored every four days during the summer of 1995. There has been no monitoring of the wetland since March of 1997. Additional water samples were collected from the adit, the natural wetland, the settling ponds, and from seeps at the site. A waste rock sample was collected from waste rock pile #2.

A table of previous samples and results from this site is provided in Part A of Appendix A.

12. REFERENCES

United Keno Hill Mines Limited. 1996. *United Keno Hill Mines Limited – Site Characterization*. Report No. UKH/96/01, prepared by Access Mining Consultants Limited.

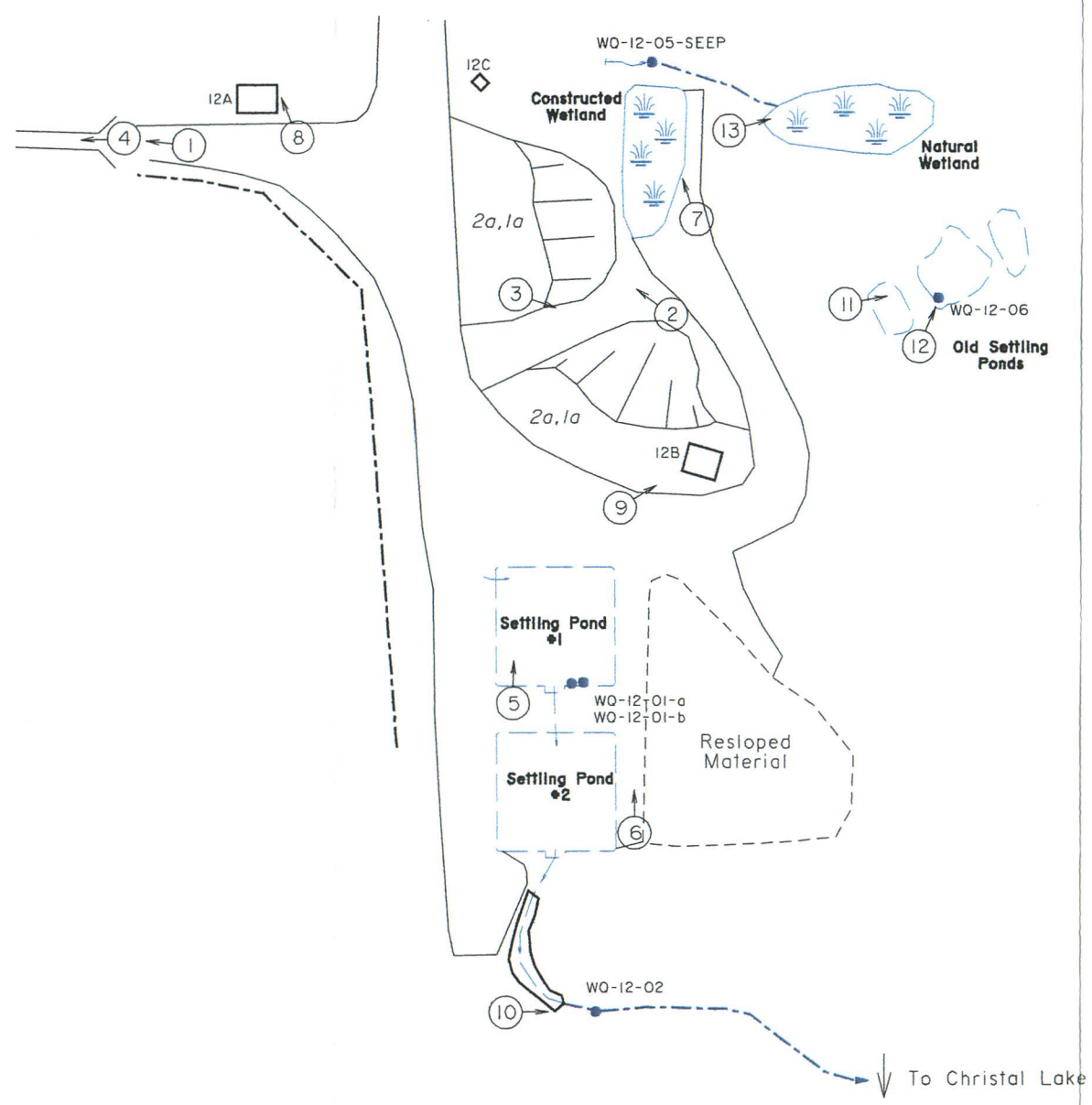
United Keno Hill Mines Limited. 1996. *United Keno Hill Mines Limited – Site Characterization, Technical Appendices I-VI*. Report No. UKH/96/01, prepared by Access Mining Consultants Limited.

Interviewees:

Bill Dunn, Former UKHM Mine Manager

Galkeno 900 water treatment plant operators

- Building (22A: building site present reference*)
- 22A Indicates Asbestos Material
- Collapsed Building
- Adit
- Collapsed Adit
- Shaft
- Collapsed/Backfilled Shaft
- Mine Rock Dump
- Bedrock Open Pit
- Trench
- Stripped Overburden Stockpile
- Stripped / Disturbed Area
- Outcrop Boundary
- Highway
- Road (gravel, 2 wheel drive)
- Road (gravel, 4X4 accessible)
- Road (inaccessible)
- Trail
- Culvert
- 24501-01 1999 Soil Sample (this study)
- Pre 1999 Soil Sample (other sources)
- 25WR04-01 1999 Waste Rock Sample (this study)
- Pre 1999 Waste Rock Sample (other sources)
- WO-12-06 1999 Water Sample
- Pre 1999 Water Sample
- Tension Cracks
- Mass Movement (note: for Forms: BelleKeno)
- Groundwater Seep
- Surface Water Flow (Stream, Creek, River)
- Lake
- Settling Pond / Water Treatment Pond
- Tailings Dam / Tailings Pond / Mill Tails
- Ponded Water / Trench
- Barrels
- Abandoned Equipment (compressors, ore cars, rails, air and water pipe)
- Mine Rails / Trestle
- Collapsed Trestle
- Solid Waste Disposal Site
- Area of Soil Contamination
- *(6) Transformer Location (number of transformer in brackets)
- Power Line
- Power Line Collapsed
- Aerial Transmission Towers
- (5) Photo Site (arrow shows view direction)
- GPS Survey Location
- Former Building Site (Elsa)



Waste Rock Geological Legend

This legend intended for use as a key to the observed lithological content of the mine dumps and stockpiles of surficial materials investigated. It does not represent regional stratigraphy and no stratigraphic sequence is implied.

Pyrite content as percent: eg. Py 2%. Occurs as an alteration halo adjacent to vein fault structure.

Oxidation: Weak (wOx), moderate (mOx) and intense (iOx).

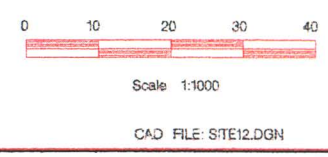
Quaternary: (5) Undifferentiated, unconsolidated colluvium, glacial till.

Veins: (4a) Quartz veins;
(4b) Quartz-pyrite veins;
(4c) Quartz-siderite + trace galena-sphalerite veins;
(4d) Siderite-quartz + trace galena-sphalerite veins;

Greenstone: (3) Amphibole-chlorite-plagioclase metadiorite or metagabbro.

Quartzite: (2a) Thick bedded, blocky gray quartzite;
(2b) Thin bedded, broken, quartzite with carbonaceous phyllite interbeds;
(2c) Calcareous quartzite.

Phyllite: (1a) Broken sericite-chlorite phyllite;
(1b) Carbonaceous phyllite.



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| Public Works And Government Services Canada Architectural & Engineering Services Western Region | Travaux publics et Services gouvernementaux Canada | designed by: _____ date: _____ conçu par: _____ |
| | | drawn by: C.S. Nov. / 99 dessiné par: _____ approved by: _____ approuvé par: _____ |
| Drawing title: Galkeno 900 Site #12 Site Assessment Yukon Territory | | Titre du dessin: _____ revisions: _____ |
| project no. no. du projet: 125-12.01 | drawing no. dessin no.: 1 of 1 | |



Photo 12-1: Galkeno 900 portal with spilt lime out front, the water treatment facility is located within the adit. (Azimuth 270°)



Photo 12-2: Waste rock pile #1 with the outhouse in the background. (Azimuth 330°)



Photo 12-3: Waste rock pile #2, Christal Lake and building 12B in background. (Azimuth 135°)



Photo 12-4: Water treatment facility within the portal. (Azimuth 270°)

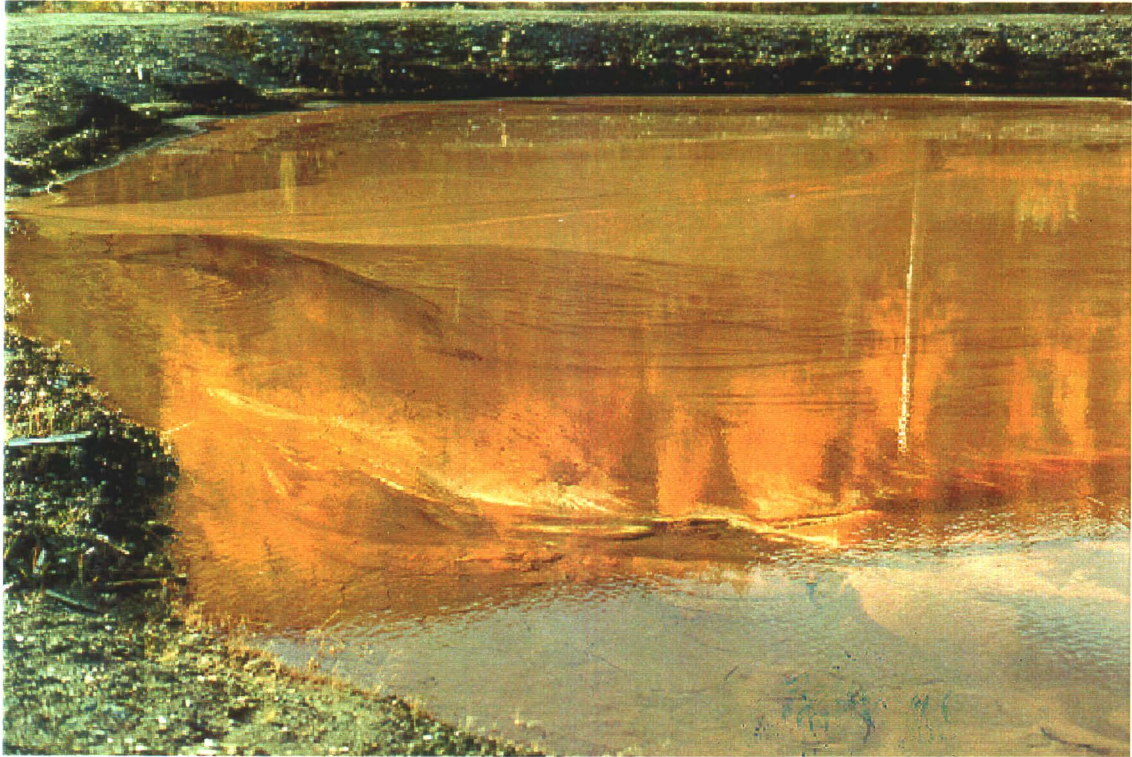


Photo 12-5: Settling pond #1, precipitate flows in from the left through an underground pipe. (Azimuth 010°)



Photo 12-6: Tension cracks in the settling pond retaining wall. (Azimuth 000°)



Photo 12-7: Constructed wetland plot with wooden baffles. (Azimuth 345°)



Photo 12-8: Building 12A - a storage building currently in use. (Azimuth 320°)



Photo 12-9: Building 12B - log frame structure with Christal Lake in background. (Azimuth 045°)

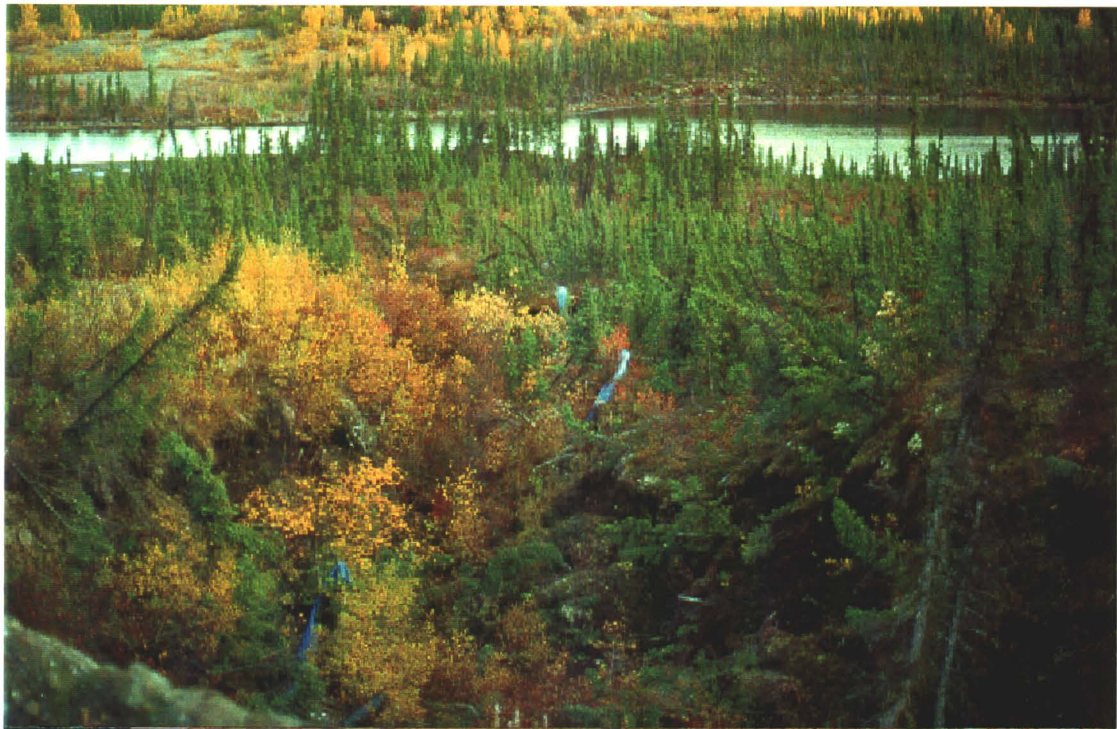


Photo 12-10: Blue piping heading to Christal Lake, stream gully roughly follows piping route. (Azimuth 100°)



Photo 12-11: 3 small ponds, most likely old settling ponds.(Azimuth 070°)

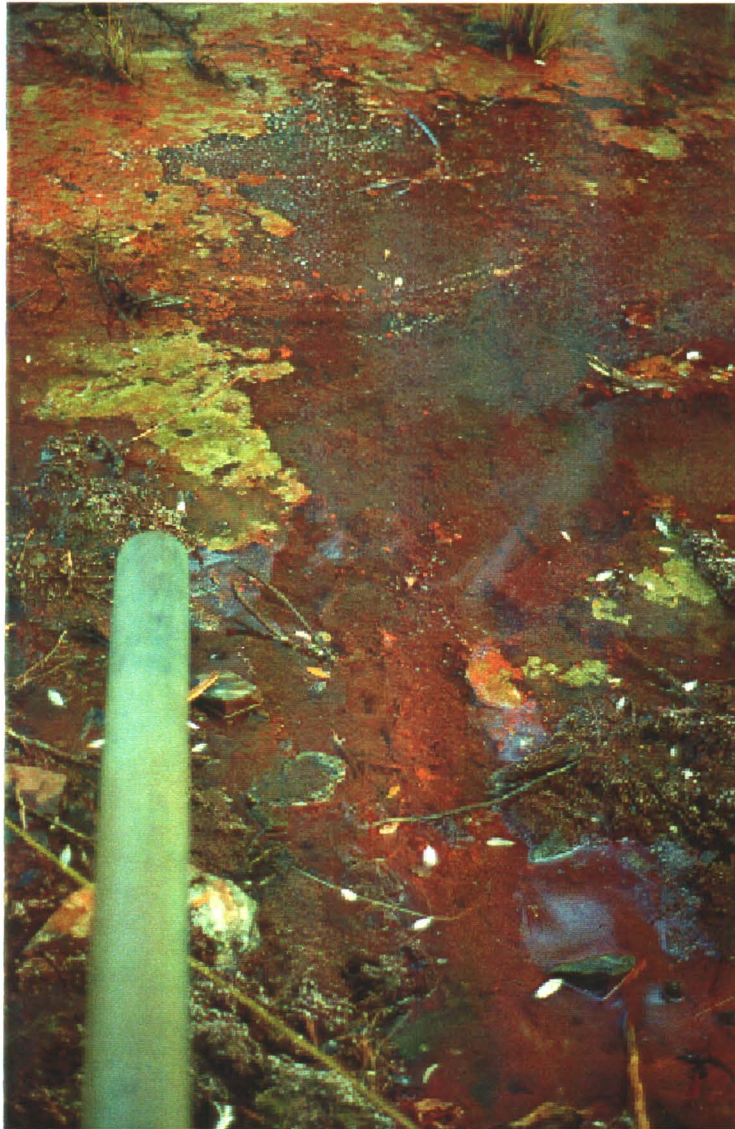


Photo 12-12: Pipe leading to the westernmost old settling pond.
Note the iron precipitate in the water. (Azimuth 090°)



Photo 12-13: Natural wetland located just east of the trial wetland.
(Azimuth 075°)

ATTACHMENT 2: 1999 GALKENO 900 WATER SAMPLE

LABORATORY RESULTS

| Sample Number | Detection Limit | Units | 12-01-Water-a - Galkeno 900 - Sept 18/99 | 12-01-Water-b - Galkeno 900 - Sept 18/99 | 12-02-Water - Galkeno 900 - Sept 18/99 |
|-------------------------------|-----------------|------------|--|--|--|
| | | | Settling pond #1 | Settling Pond #1 - Duplicate | Settling Pond #2 drainage |
| Site Description | | | | | |
| pH (field) | N/A | pH | 9.9 | 9.9 | 10.1 |
| Conductivity (field) | N/A | µS/cm | 1866 | 1866 | 1833 |
| pH (lab) | 0.01 | pH | 7.6 | 7.48 | 9.08 |
| Conductivity (lab) | 0.01 | µS/cm | 1900 | 1900 | 1900 |
| Total Alkalinity | 5 | mg CaCO3/L | 18 | 25 | 12 |
| Chloride | 0.5 | mg/L | <0.5 | <0.5 | <0.5 |
| Hardness (CaCO3 equiv) | 5 | mg/L | 1360 | 1380 | 1550 |
| Nitrate-N | 0.05 | mg/L | 0.1 | na | na |
| Nitrate-N | 0.1 | mg/L | na | <0.1 | <0.1 |
| Nitrite-N | 0.003 | mg/L | 0.003 | <0.003 | 0.003 |
| Sulphate | 1 | mg/L | 1160 | 1170 | 1160 |
| Total Dissolved Solids | 5 | mg/L | 1710 | 1740 | 1720 |
| Analysis by ICP | | | | | |
| Aluminum | 0.0008 | mg/L | 0.0055 | 0.0035 | 0.0047 |
| Antimony | 0.005 | mg/L | <0.005 | <0.005 | <0.005 |
| Arsenic | 0.01 | mg/L | <0.01 | <0.01 | <0.01 |
| Barium | 0.00004 | mg/L | 0.00281 | 0.00406 | 0.00393 |
| Beryllium | 0.00001 | mg/L | <0.00001 | <0.00001 | <0.00001 |
| Bismuth | 0.0004 | mg/L | <0.0004 | <0.0004 | <0.0004 |
| Boron | 0.002 | mg/L | <0.002 | <0.002 | <0.002 |
| Cadmium | 0.00006 | mg/L | 0.00006 | 0.00011 | 0.00011 |
| Calcium | 0.002 | mg/L | 450 | 449 | 451 |
| Chromium | 0.00006 | mg/L | <0.00006 | <0.00006 | <0.00006 |
| Cobalt | 0.00003 | mg/L | 0.00122 | 0.00143 | 0.00156 |
| Copper | 0.00003 | mg/L | 0.00038 | 0.00038 | 0.00043 |
| Iron | 0.00001 | mg/L | 0.029 | 0.031 | 0.077 |
| Lead | 0.0003 | mg/L | <0.0003 | <0.0003 | <0.0003 |
| Lithium | 0.001 | mg/L | 0.06 | 0.061 | 0.059 |
| Magnesium | 0.0005 | mg/L | 27.8 | 27.9 | 21.6 |
| Manganese | 0.00002 | mg/L | 3.1 | 3.23 | 1.85 |
| Mercury | 0.0001 | mg/L | <0.0001 | <0.0001 | <0.0001 |
| Molybdenum | 0.00007 | mg/L | 0.0004 | 0.00043 | 0.00048 |
| Nickel | 0.00001 | mg/L | 0.012 | 0.0129 | 0.0097 |
| Phosphorus | 0.03 | mg/L | <0.03 | <0.03 | <0.03 |
| Potassium | 0.4 | mg/L | 0.8 | 0.8 | 0.8 |
| Selenium | 0.004 | mg/L | <0.004 | <0.004 | <0.004 |
| Silicon | 0.004 | mg/L | 1.2 | 1.2 | 1.14 |
| Silver | 0.00005 | mg/L | 0.00026 | 0.00028 | <0.00005 |
| Sodium | 0.004 | mg/L | 1.8 | 1.8 | 1.7 |
| Strontium | 0.00002 | mg/L | 0.567 | 0.572 | 0.579 |
| Sulphur | 0.008 | mg/L | 422 | 418 | 414 |
| Thallium | 0.001 | mg/L | 0.004 | 0.004 | 0.002 |
| Titanium | 0.00002 | mg/L | <0.00002 | <0.00002 | <0.00002 |
| Vanadium | 0.00003 | mg/L | <0.00003 | <0.00003 | <0.00003 |
| Zinc | 0.0002 | mg/L | 0.135 | 0.149 | 0.491 |
| Zirconium | | mg/L | | | |
| Analysis by Hydride AA | | | | | |
| Arsenic | 0.0002 | mg/L | 0.0041 | 0.0044 | 0.0037 |
| Selenium | 0.0001 | mg/L | <0.0001 | <0.0001 | <0.0001 |

ATTACHMENT 2: 1999 GALKENO 900 WATER SAMPLES

LABORATORY TESTING

| Sample Number | Detection Limit | Units | 12-03-Water - Galkeno 900 - Sept 18/99 | 12-04-Water - Galkeno 900 - Sept 18/99 | 12-05-Seep - Galkeno 900 - Sept 18/99 |
|------------------------------------|-----------------|-------------------------|---|--|---|
| Site Description | | | Foot of stream prior to entering Christal Lake | Downstream of Old Settling Ponds | Seep beside the Constructed Trial Wetland |
| pH (field) | N/A | pH | 8.0 | 7.6 | 7.1 |
| Conductivity (field) | N/A | µS/cm | 1784 | 1991 | 2060 |
| pH (lab) | 0.01 | pH | 7.41 | 7.13 | 6.83 |
| Conductivity (lab) | 0.01 | µS/cm | 1900 | 2050 | 2050 |
| Total Alkalinity | 5 | mg CaCO ₃ /L | 51 | 51 | 232 |
| Chloride | 0.5 | mg/L | <0.5 | <0.5 | <0.5 |
| Hardness (CaCO ₃ equiv) | 5 | mg/L | 1620 | 1820 | 1760 |
| Nitrate-N | 0.05 | mg/L | na | na | na |
| Nitrate-N | 0.1 | mg/L | 0.2 | <0.1 | <0.1 |
| Nitrite-N | 0.003 | mg/L | 0.01 | <0.003 | <0.003 |
| Sulphate | 1 | mg/L | 1120 | 1250 | 1060 |
| Total Dissolved Solids | 5 | mg/L | 1660 | 1850 | 1620 |
| Analysis by ICP | | | | | |
| Aluminum | 0.0008 | mg/L | 8.34 | 0.0023 | 0.0721 |
| Antimony | 0.005 | mg/L | <0.005 | <0.005 | <0.005 |
| Arsenic | 0.01 | mg/L | 0.06 | <0.01 | 0.04 |
| Barium | 0.00004 | mg/L | 0.41 | 0.00257 | 0.029 |
| Beryllium | 0.00001 | mg/L | 0.00032 | <0.00001 | <0.00001 |
| Bismuth | 0.0004 | mg/L | <0.0004 | <0.0004 | <0.0004 |
| Boron | 0.002 | mg/L | 0.02 | <0.002 | 0.004 |
| Cadmium | 0.00006 | mg/L | 0.00227 | 0.00015 | 0.00014 |
| Calcium | 0.002 | mg/L | 473 | 449 | 446 |
| Chromium | 0.00006 | mg/L | 0.0158 | <0.00006 | 0.00041 |
| Cobalt | 0.00003 | mg/L | 0.0158 | 0.00087 | 0.0245 |
| Copper | 0.00003 | mg/L | 0.0795 | 0.00062 | 0.00082 |
| Iron | 0.00001 | mg/L | 33.4 | 0.22 | 9.26 |
| Lead | 0.0003 | mg/L | 0.0363 | <0.0003 | 0.0011 |
| Lithium | 0.001 | mg/L | 0.068 | 0.039 | 0.062 |
| Magnesium | 0.0005 | mg/L | 33 | 49.9 | 44.2 |
| Manganese | 0.00002 | mg/L | 3.15 | 2.27 | 6.96 |
| Mercury | 0.0001 | mg/L | 0.0001 | <0.0001 | <0.0001 |
| Molybdenum | 0.00007 | mg/L | 0.00221 | 0.00013 | 0.0022 |
| Nickel | 0.00001 | mg/L | 0.0512 | 0.0112 | 0.11 |
| Phosphorus | 0.03 | mg/L | 1.57 | <0.03 | <0.03 |
| Potassium | 0.4 | mg/L | 1.6 | 0.8 | 1.1 |
| Selenium | 0.004 | mg/L | <0.004 | <0.004 | <0.004 |
| Silicon | 0.004 | mg/L | 13.3 | 2.77 | 4.7 |
| Silver | 0.00005 | mg/L | 0.00082 | 0.00012 | 0.00138 |
| Sodium | 0.004 | mg/L | 2.2 | 2.4 | 1.8 |
| Strontium | 0.00002 | mg/L | 0.591 | 0.563 | 0.505 |
| Sulphur | 0.008 | mg/L | 406 | 456 | 372 |
| Thallium | 0.001 | mg/L | <0.001 | 0.002 | 0.015 |
| Titanium | 0.00002 | mg/L | 0.196 | <0.00002 | 0.00169 |
| Vanadium | 0.00003 | mg/L | 0.0254 | <0.00003 | <0.00003 |
| Zinc | 0.0002 | mg/L | 0.616 | 0.326 | 2.68 |
| Zirconium | | mg/L | | | |
| Analysis by Hydride AA | | | | | |
| Arsenic | 0.0002 | mg/L | 0.065 | 0.0025 | 0.024 |
| Selenium | 0.0001 | mg/L | 0.0014 | 0.0005 | <0.0001 |

ATTACHMENT 2: 1999 GALKENO 300 WATER SAMPLES

LABORATORY RESULTS

| Sample Number | Detection Limit | Units | 12-06-Water - Galkeno 900 - Sept 18/99 |
|-------------------------------|-----------------|------------|--|
| Site Description | | | Drainage into Old Settling Ponds |
| pH (field) | N/A | pH | 6.9 |
| Conductivity (field) | N/A | µS/cm | 2250 |
| pH (lab) | 0.01 | pH | 7.28 |
| Conductivity (lab) | 0.01 | µS/cm | 2350 |
| Total Alkalinity | 5 | mg CaCO3/L | 223 |
| Chloride | 0.5 | mg/L | <0.5 |
| Hardness (CaCO3 equiv) | 5 | mg/L | 2090 |
| Nitrate-N | 0.05 | mg/L | na |
| Nitrate-N | 0.1 | mg/L | <0.1 |
| Nitrite-N | 0.003 | mg/L | 0.003 |
| Sulphate | 1 | mg/L | 1300 |
| Total Dissolved Solids | 5 | mg/L | 2120 |
| Analysis by ICP | | | |
| Aluminum | 0.0008 | mg/L | 0.0016 |
| Antimony | 0.005 | mg/L | <0.005 |
| Arsenic | 0.01 | mg/L | <0.01 |
| Barium | 0.00004 | mg/L | 0.00588 |
| Beryllium | 0.00001 | mg/L | <0.00001 |
| Bismuth | 0.0004 | mg/L | <0.0004 |
| Boron | 0.002 | mg/L | <0.002 |
| Cadmium | 0.00006 | mg/L | 0.0258 |
| Calcium | 0.002 | mg/L | 511 |
| Chromium | 0.00006 | mg/L | 0.00033 |
| Cobalt | 0.00003 | mg/L | 0.0139 |
| Copper | 0.00003 | mg/L | 0.00138 |
| Iron | 0.00001 | mg/L | 2.75 |
| Lead | 0.0003 | mg/L | <0.0003 |
| Lithium | 0.001 | mg/L | 0.055 |
| Magnesium | 0.0005 | mg/L | 64.7 |
| Manganese | 0.00002 | mg/L | 6.81 |
| Mercury | 0.0001 | mg/L | <0.0001 |
| Molybdenum | 0.00007 | mg/L | 0.0002 |
| Nickel | 0.00001 | mg/L | 0.0897 |
| Phosphorus | 0.03 | mg/L | <0.03 |
| Potassium | 0.4 | mg/L | 1.6 |
| Selenium | 0.004 | mg/L | <0.004 |
| Silicon | 0.004 | mg/L | 4.37 |
| Silver | 0.00005 | mg/L | 0.00136 |
| Sodium | 0.004 | mg/L | 2.3 |
| Strontium | 0.00002 | mg/L | 0.573 |
| Sulphur | 0.008 | mg/L | 482 |
| Thallium | 0.001 | mg/L | 0.015 |
| Titanium | 0.00002 | mg/L | <0.00002 |
| Vanadium | 0.00003 | mg/L | <0.00003 |
| Zinc | 0.0002 | mg/L | 4.03 |
| Zirconium | | mg/L | |
| Analysis by Hydride AA | | | |
| Arsenic | 0.0002 | mg/L | 0.0032 |
| Selenium | 0.0001 | mg/L | <0.0001 |

ATTACHMENT 3: 1995 GALKENO 900 PILOT WETLAND

1. PILOT WETLAND TREATMENT SYSTEM (from Microbial Technologies, 1995)

In the summer of 1995, a pilot wetland treatment system was constructed downgradient from the Galkeno 900 adit. This system included a settling pond receiving untreated Galkeno 900 water and a small wetland located downgradient from and fed by the settling pond. They were fed mine water starting in July 1995 and monitored until late September for their effect on water quality. Additional on-site tests, including a settling test with untreated Galkeno 900 water and the establishment of *in situ* microcosms (i.e., columns holding cores of wetland sediments and plants), were conducted to generate more precise kinetic data on metal removal. Results from this test program provided the basis for designing a full-scale treatment system. These results are presented below.

1.1 Performance of Settling Pond

Historical data on the composition of Galkeno 900 water indicated that some metals (iron, manganese, and zinc) were present in particulate form which could be retained by a 0.45 micron filter. To determine how quickly and/or whether this material could settle out, a 4 Litres plastic container completely filled with untreated Galkeno 900 water was left to stand within the Galkeno 900 adit. Over a seven day period, the water pH (6.5), alkalinity (204 mg/L as CaCO₃), and most metal concentrations remained unchanged. However, iron concentrations decreased by half during this time, as shown in Figure 1.

The apparent increase in zinc concentrations on Figure 1 simply reflects sampling and analytical error: in fact zinc concentrations remained unchanged during the test. The residue filtered from the incubated mine water was found to contain some iron, minor amounts of zinc, and some calcium.

These data indicate that little removal of zinc could be achieved by letting particulates settle out of Galkeno 900 water. However, the removal of iron was of interest, as it would compete with

zinc in binding onto organic matter. Therefore, a settling pond was constructed between the Galkeno 900 adit and the pilot Galkeno constructed wetland to remove iron.

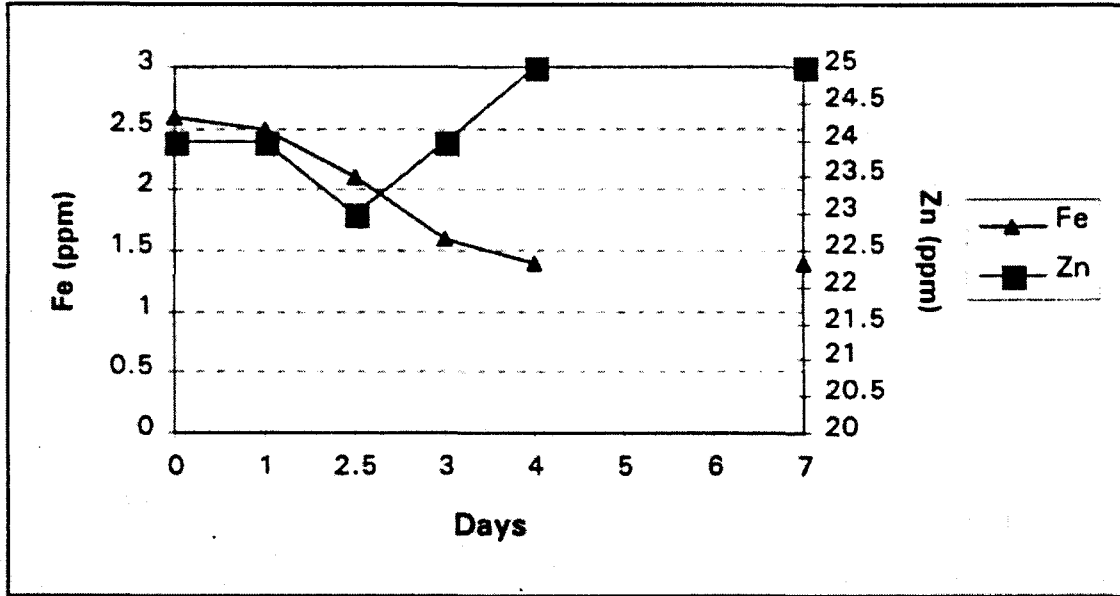


Figure 1. Iron and zinc concentrations (Total metal) in standing Galkeno 900 water.

The plastic-lined 7.6 x 7.0 x 2.0 m settling pond was excavated and filled with Galkeno 900 water (see Photograph 7). A pipe inserted just below the water surface supplied water to the Galkeno constructed wetland. A flow rate of 3 L/min. was used during the monitoring phase of the test program, giving a retention time of approximately 20 days. Unfortunately, no data are available to establish its effect on metal concentrations. Data from 1994 and 1995 indicate that total iron concentrations in Galkeno 900 water average approximately 4.1 ± 1.3 ppm, whereas water entering the Galkeno constructed wetland averaged 1.0 ± 0.11 ppm, consistent with its anticipated effect. Total zinc concentrations in Galkeno 900 water averaged 27 ± 1.2 ppm when measured in 1994 and 1995, but they averaged 24 ± 0.61 ppm¹ in the water entering the Galkeno constructed wetland. This indicates that only low amounts of zinc were retained in the settling pond before entering the constructed wetland. Orange deposit, obviously an iron oxide, was seen to accumulate in the settling pond, again consistent with its anticipated effect.

¹ There is an outlier in the data set for zinc concentrations in the wetland inflow: eliminating this outlier yields an average of 25 ± 0.19 ppm.

This indirect evidence indicates that iron concentrations are substantially decreased, and zinc concentrations are little decreased when Galkeno 900 water is retained in the settling pond. Thus, the settling pond was effective in attaining its stated objective of decreasing concentrations of iron entering the Galkeno constructed wetland.

1.2 Performance of the Galkeno Constructed Wetland

A pilot-scale wetland was constructed to treatment water from the Galkeno 900 adit. The specific purposes for building this wetland were:

1. To establish the feasibility of constructing a wetland in a sub-arctic climate
2. To determine its effectiveness in improving the quality of water produced by the Galkeno 900 adit
3. To develop performance parameters for the design of a full-scale system that would discharge water of a quality that does not impact on the receiving environment
4. To determine its long-term effectiveness in removing metals

This part of the field program was successful in meeting these specific objectives, as described below.

1.2.1 Wetland construction and plant growth

Construction of the test wetland (from hereon referred to as the Galkeno constructed wetland) was initiated on May 17th 1995. A bare, exposed, South-facing plot below the Galkeno 900 adit was marked and excavated to approximately 9 x 18.5 x 0.5 metres. See and Photograph 8 Appendix 1. A very small trickle of groundwater could be seen to emerge from the excavated bank, but too little water was produced to obtain a sample for analysis. It was felt that this input of groundwater would not significantly influence the results from the test.

A donor site with a stand of the sedge *Carex aquatilis* (Taylor, 1983, or *C. Stans*, Porsild, 1973)

for the Galkeno constructed wetland was identified. This site was located in the reservoir providing drinking water to the hamlet of Elsa, which is fed by the South McQuesten River and is judged to be uncontaminated by mine drainage. On May 19, 1995, sods of sedges and underlying soil/peat were dug out (down to permafrost, approximately 30 cm below the surface), loaded onto flatbed trucks, and immediately placed into the excavated plot. Fertilizer (21-7-7) was broadcast at a rate of approximately 185 kg/ha onto the ground prior to transplanting the sods. The excavated plot was filled as completely as practical with sods and filled with lime-treated mine water. Contaminated mine water was not introduced until good plant growth was seen.

Plant growth in the constructed wetland was compared with that at the donor site. Individual *Carex* clumps were demarcated at four stations in the constructed wetland and five stations in the donor site, and the height of the tallest shot at each station was measured. These measurements indicated that the onset of plant growth was slightly delayed in the Galkeno constructed wetland, but that it was otherwise comparable with that at the donor site (see Figure 4). By mid-August, (after having received contaminated mine water) plant coverage varied from 30% to 70%. Numerous side shoots were observed, indicative of healthy vegetative growth. Moreover, many plants had fruit-bearing spikelets, indicating that plant reproduction was unaffected. These data and observations indicate that a wetland could be constructed which sustains normal plant growth and reproduction in a mining environment.

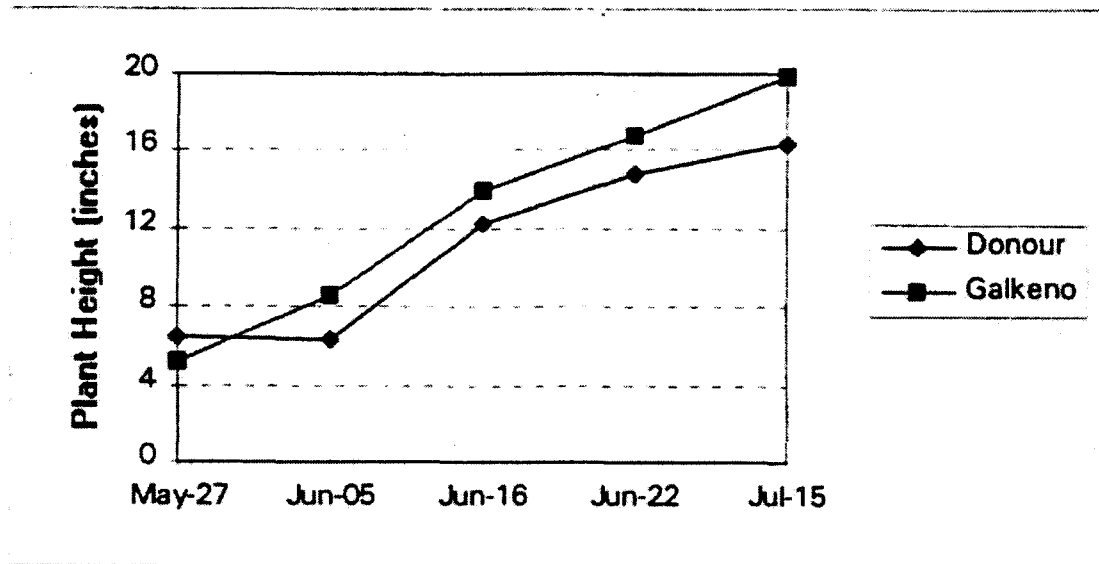


Figure 2. Plant growth at the donor site and Galkeno constructed wetland.

1.2.2 Metal removal

Lime-treated Galkeno 900 mine water was circulated into the constructed wetland until good plant growth was established. Starting in July 1995, untreated water was circulated first throughout the settling pond (Section 3.3.1), thence to the constructed wetland. The flow rate was established at 0.3 L/sec (18 *Lmin.*), giving a nominal retention time in the wetland of approximately 3 days. Until mid-August 1995, water sampled periodically indicated that little metal removal occurred in the wetland. Typical zinc concentrations in the inflow and decant measured approximately 25 and 18 ppm (*mg/L*), respectively. These results indicated that water probably had an insufficient retention time, since earlier tests indicated that letting the mine water sit for seven days decreased zinc concentrations to approximately 15 ppm (Section 3.3.1).

A site visit in mid-August indicated that the inflow was likely by-passing a portion of the wetland as well². Measurements of water characteristics further confirmed this view. Ten stations were established in the wetland, five on the inflow side and five on the decant side of the wetland, as shown in Figure 5. Examination of the water pH, Eh, and temperature reveals that Stations 4

² This is not unusual during the first year, as sods transplanted in the excavated cell slow settle.

and 5, and probably Station 3 on the inflow side were different from the other stations (Table 7). Their distinctly higher temperature and lower Eh were indicative of stagnating water⁸³.

The low Eh at Stations 4 and 5 indicated that reducing substances (such as hydrogen sulphide) were produced in the water column. To corroborate this hypothesis, sediment samples were collected near these stations and tested for the presence of hydrogen sulphide (by smell), for Eli, and for the presence of sulphate-reducing bacteria (SRB). One sediment sample near Station 5 had an Eli of -147 mV (moderately reduced), had a characteristic sulphur odour and pitch black colour, indicating that sulphate reduction was occurring. Analysis of this sample for SRB indicated that it harboured a healthy population of 2.9×10^6 MPN⁴/dry g. For a comparison, sediments from an experimental constructed wetland at the former Bell Copper mine harboured SRB populations averaging 5×10^3 MPN/dry g at the onset of the growing season, and 4×10^3 MPN/dry g before the onset of the dormant season (Gormely *et al.*, 1994). Another sample taken nearby Station 3 also had a low Eli (-127 mV), but not other characteristics typical of sulphate reduction. In contrast, a sediment sample taken from the centre of the wetland had an Eli of 42 mV. Thus, the wetland was functioning as an anaerobic treatment system.

Table 1. Water characteristics in constructed wetland, before installation of baffles.

³ The higher temperature would result from a greater warming from sunlight (temperature was measured at the surface in all cases), whereas the lower Eli would result from the lower mixing and more complete consumption of oxygen, both of which occur when water stagnates.

⁴ MPN stands for Most Probable Number, and is essentially equivalent to the cell number in a sample.

| | <i>Station 1</i> | <i>Station 2</i> | <i>Station 3</i> | <i>Station 4</i> | <i>Station 5</i> |
|---|------------------|------------------|------------------|------------------|------------------|
| | Inflow | | | | |
| pH | 6.45 | 6.76 | 6.80 | 6.86 | 6.5 |
| Eh | 54.7 | 85.4 | 41.0 | -28.9 | -18 |
| Temperature (° C) | 12.5 | 12.6 | 14.3 | 15.6 | 15.0 |
| Alkalinity (mg/L as CaCO ₃) | 176 | 160 | 150 | 356 | 218 |
| Zinc (ppm) | 22.6 | - | 19.8 | - | 0.33 |
| | Decant | | | | |
| pH | 6.69 | 6.76 | 6.69 | 6.61 | 6.78 |
| Eh | 83.2 | 72.3 | 75.8 | 76 | 92.3 |
| Temperature (° C) | 13.1 | 13.0 | 13.9 | 13.9 | 13.7 |
| Alkalinity (mg/L as CaCO ₃) | 158 | 155 | 147 | 140 | 141 |
| Zinc (ppm) | 19.3 | - | 19.7 | - | 17.5 |

The data on zinc concentrations are noteworthy. The decrease in zinc concentrations between the wetland inlet and outlet is not very large, decreasing from 22.6 to 17.5 ppm. The short-circuiting suggested by the above arguments likely accounts for this poor performance. However, zinc concentrations sampled in Station 5 decreased to 0.33 ppm. Repeat sampling the following day yielded zinc concentrations of 1.44 ± 0.87 ppm (0.58 ± 0.095 ppm if one outlier is excluded), which are nearing environmentally acceptable discharge concentrations. Given the above arguments that water sampled in Station 5 stagnated (i.e., had a long retention time), these results provided the first indication that the constructed wetland could remove zinc, given enough time.

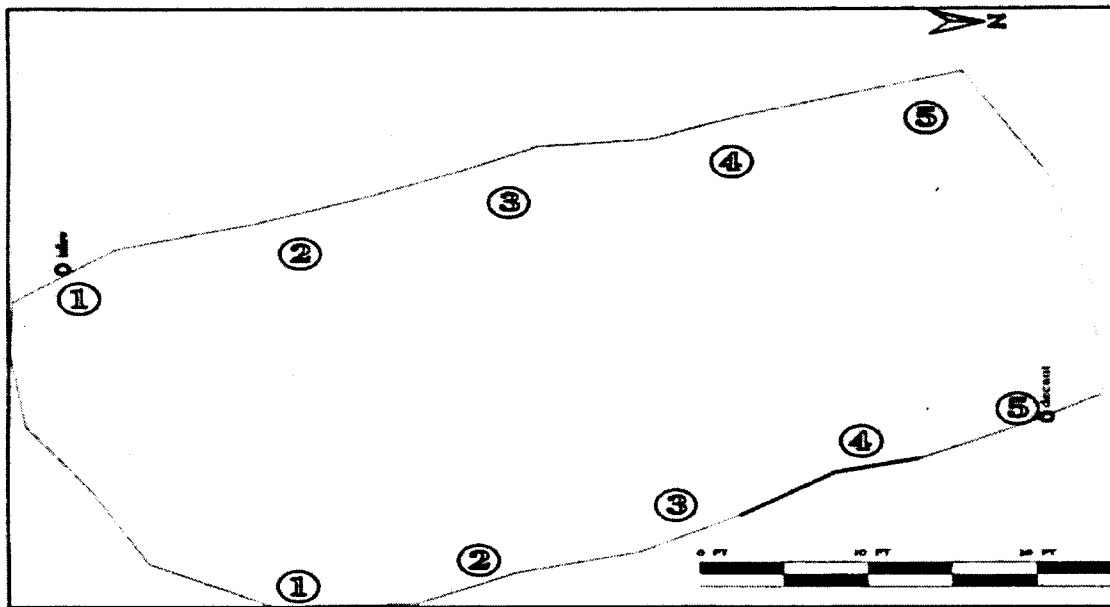


Figure 3. Sampling stations to characterize water flowing through wetland.

To remedy the problem of short-circuiting, plywood baffles were inserted across the wetland, redirecting water to flow past the high point in the wetland (Station 5 in Figure 3). These baffles (shown in Figure 6) were installed on August 22 and 23. With the baffles in place, water from the Galkeno adit was redirected to be retained within the first baffle, and its flow was re-established at 3 LI/min. This gave a nominal retention time of 19.3 days.

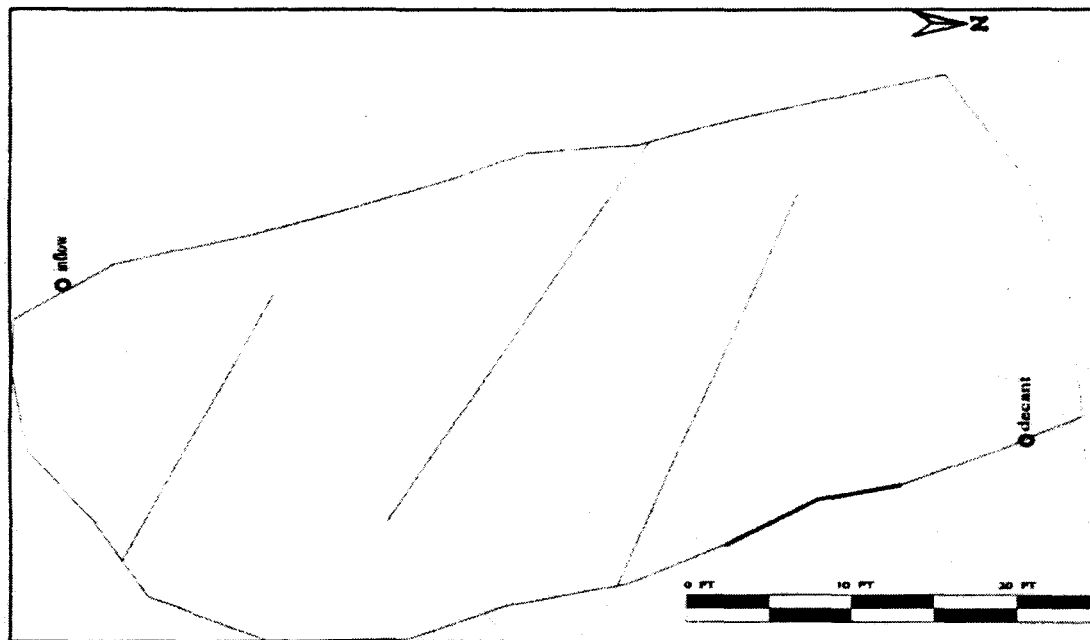


Figure 4. Placement of baffles in Galkeno constructed wetland.

Installing the baffles did not completely establish the desired flow of the water across the wetland. A zone of high permeability was found below the inflow which allowed water to escape out of the wetland. On August 24, this zone of high permeability was covered with soil and the flow of water was again redirected away from it and around the first baffle. From that time onward, water flowed around the baffles and decanted out as planned.

Zinc concentrations (total metal) measured at the wetland inflow and decant from August 26 to September 20 are shown in Figure 7.

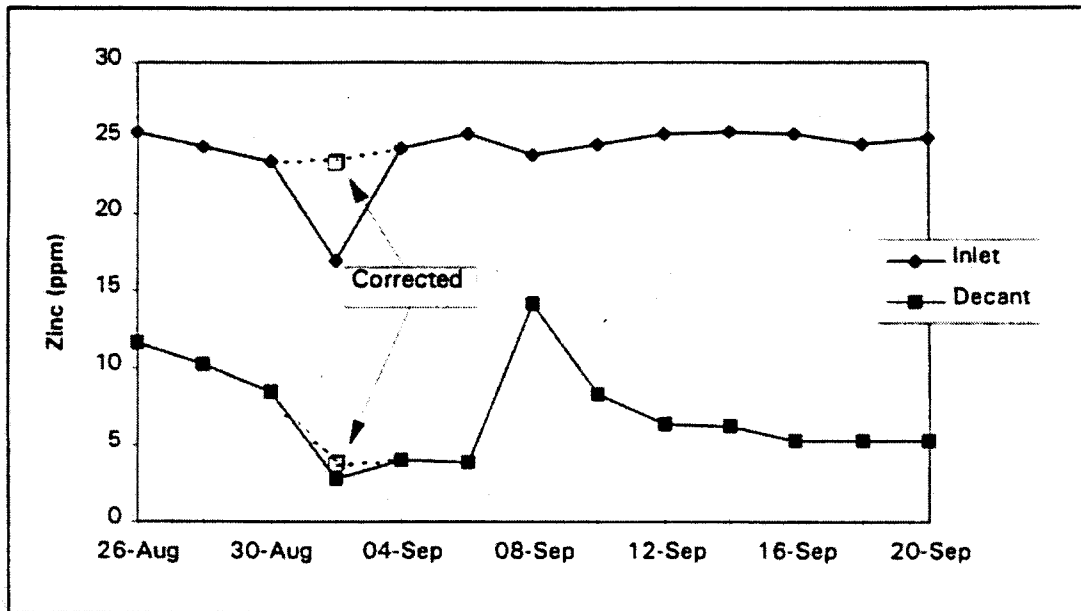


Figure 5. Zinc concentrations in inflow and decant of the Galkeno constructed wetland.

Figure 5 shows that zinc concentrations in the inflow were largely constant at 25 ppm. Concentrations in the decant initially decreased to 3-4 ppm. However, conditions in the wetland changed in early September, causing a release of zinc which peaked around September 8. Zinc concentrations in the decant decreased thereafter, but never to less than 5 ppm. Such upsets are not uncommon for newly established systems, because sediments are not completely vegetated and flow pattern are not fully developed (i.e., water channelization is common). Nonetheless, these data show that zinc concentrations were consistently reduced in the wetland by approximately 90%. They also show that the system had not yet reached a steady state, otherwise *constant* zinc concentrations would have been obtained in the decant. This precludes calculation of a metal removal rate.

A noticeable decrease in inflow concentrations of zinc occurred on September 2. This can be explained by noting a similar decrease in magnesium concentrations in the wetland inflow and decant (Figure 8)⁵. All other element concentrations decreased similarly in the inflow and decant

⁵ The steady increase observed in late September is likely due to its release by senescing plants, and other related events associated with the end of the growing season.

(e.g., Figure 9 to Figure 12). Assuming that magnesium behaves as a conservative tracer, these data suggest that heavy rainfall diluted the mine water. A dilution factor was calculated and applied to the inflow and decant zinc concentrations on September 2 (Figure 7). This correction shows somewhat more readily that zinc concentrations were leveling off at approximately 4 ppm before September 8.

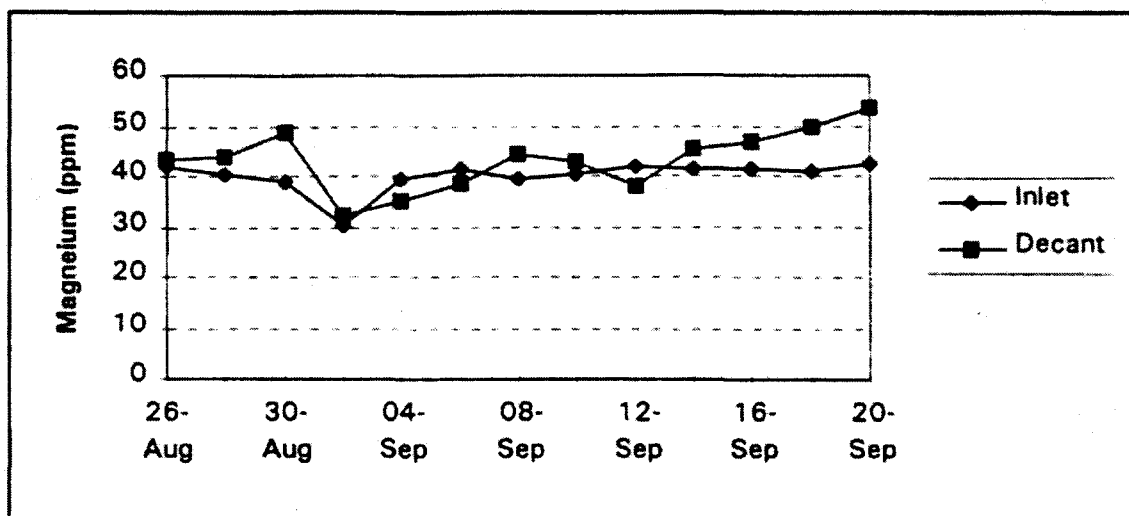


Figure 6. Magnesium concentrations in the inflow and decant of the Galkeno constructed wetland.

Nickel was also removed in the wetland (Figure 9). Inflow concentrations remained nearly constant at approximately 0.44 ppm, whereas decant concentrations appeared to stabilize at approximately 0.1 mg/L. Interestingly, the same pattern as for zinc was observed for nickel concentration in the decant: they leveled off to below 0.1 ppm until September 8, whereupon they suddenly increased. Subsequently, decant concentrations leveled off at slightly more than 0.1 ppm.

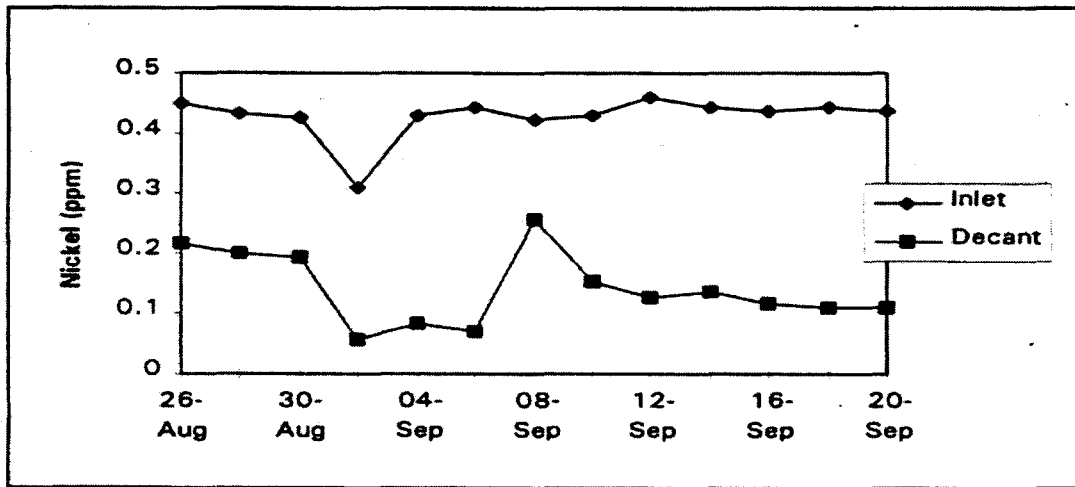


Figure 7. Nickel concentrations in inflow and decant of the Galkeno constructed wetland.

Manganese concentrations (total metal) also decreased in the wetland (Figure 10). Manganese concentrations in the decant also showed the same pattern as zinc concentrations. That is, they initially decreased to about 13 ppm until early September, whereupon they increased to a peak on September 8, leveling to about 20 ppm by the end of the sampling period.

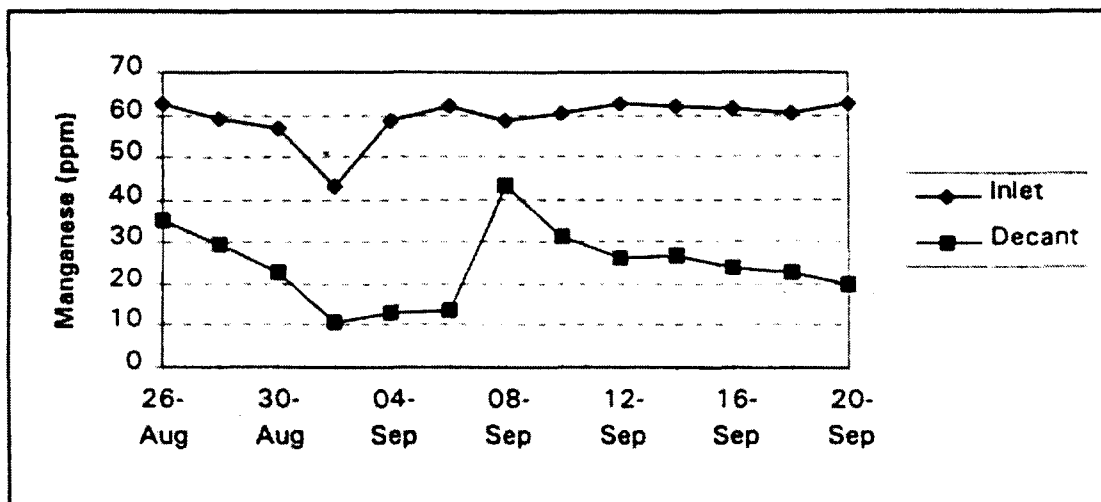


Figure 8. Manganese concentrations in inflow and decant of the Galkeno constructed

wetland.

Information about some of the processes responsible for removing these metals was obtained by conducting additional water analyses on site. The data presented in Table 7 indicated that the water pH increased slightly as it flowed across the wetland, increasing from approximately 6.5 to 6.8. Water alkalinity exhibits a decreasing trend as it flows to the decant, indicating that it is consumed. Since the water pH increases in this interval, these data suggest that acidity is being neutralized or that carbonates are retained in wetland sediments.

Another important treatment process is the formation of insoluble sulphide minerals, as indicated earlier (Sections 2.2.3 and 3.2.2) and as suggested by the data presented in Table 7. Sulphate concentrations were measured at the inflow and decant to assess how much sulphate was reduced to hydrogen sulphide and retained in the wetland (Figure 11).

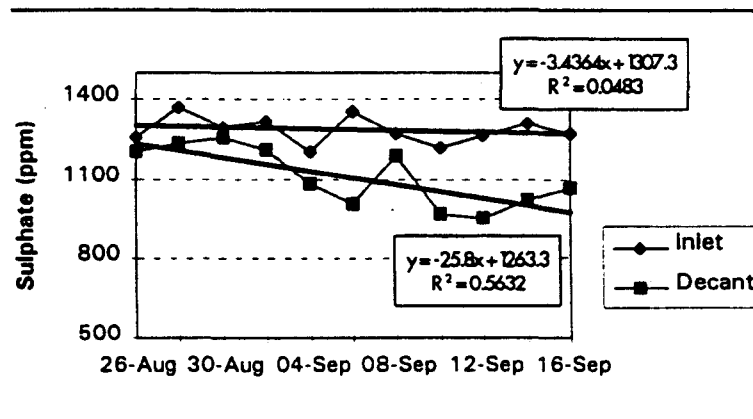


Figure 9. Sulphate concentrations in inflow and decant of the Galkeno constructed wetland.

Two observations can be made from these data.

1. Sulphate concentrations in the decant were gradually decreasing during the test period, indicating that insoluble sulphides (or, less likely, sulphur) were increasingly being retained in the wetland. This indicates that steady state conditions had *not* yet been attained, otherwise, lower, but *constant* sulphate concentrations would be expected in the decant.

2. A sudden jump of the decant sulphate concentrations observed on September 8. Such an

increase in sulphate concentrations can only mean that anoxic sediments were stirred up and that sulphides were resuspended in the water column⁶. This explanation appears quite reasonable, given that the area near the decant is relatively unvegetated and sediments there are prone to being disturbed.

The latter observation provides a reasonable explanation for the jump in zinc and manganese concentrations in the decant observed on September 8. These metals were probably retained as sulphides in sediments and they became reoxidized — and redissolved — when the sediments were stirred up.

The fact that steady state conditions were not attained probably reflects the slow maturation of the system. In this instance, the capacity to retain sulphate (as sulphur or sulphides) was increasing during the test. SRB populations were probably still increasing in the wetland sediments during the test, which would explain this increasing capacity to retain sulphate (i.e., the overall rate of sulphate reduction to sulphide was increasing throughout the test period). These observations strongly suggest that metals were (partly) retained in the Galkeno constructed wetland as insoluble sulphides.

Given that sulphate reduction produce two moles of bicarbonate for each mole of sulphate reduced, a concomitant increase in alkalinity in the decant would have been expected. The fact that a *decrease* was found instead (Table 7) suggests that insoluble carbonates were also retained within the wetland. A previous leachate test with sediments from natural wetlands indicated that they accumulated substantial quantities of carbonate (Table 5). A comparison of calcium concentrations in the inflow and decant of the Galkeno constructed wetland indicated that it was also retained in the Wetland (See Figure 12). Note that, again, the system was perturbed in early September. Specifically, a peak of calcium in the decant is measured on September 8, as was observed for zinc, manganese, and sulphate. These observations suggest that sediments were disturbed on that date, resuspending sulphates and carbonates previously deposited therein.

⁶ Unfortunately, the samples collected in September were not filtered, and it is impossible to determine whether the increased metal and sulphate concentrations measured in the decant arise from resuspended particles dissolved by the nitric acid added to preserve the sampled water or truly dissolved species.

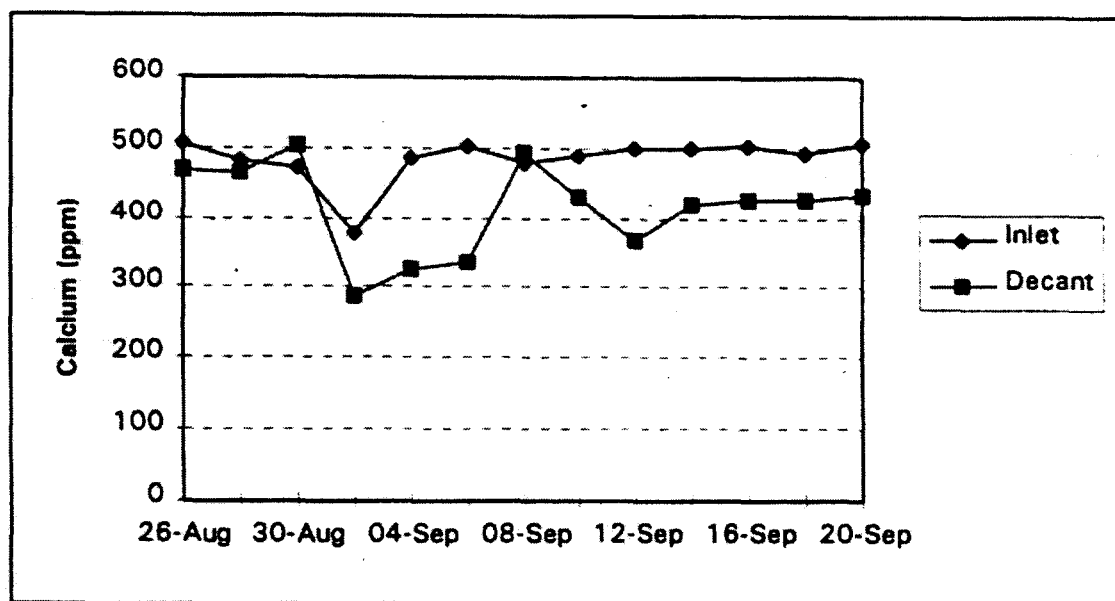


Figure 10. Calcium concentrations in inflow and decant the Galkeno constructed wetland.

These data not only confirm that the Galkeno constructed wetland functioned similarly to the natural wetlands, they indicate that a full-scale wetland treatment system is likely to store a tremendous buffering capacity in sediments. Such a buffering capacity may be important in mitigating potential increases in the acidity of the mine drainage being treated.

Cobalt and nickel concentrations at the wetland decant exhibited a pattern similar to that of zinc and manganese: an initial decrease, followed by a transient increase which peaked on September 8, and finally declining gradually until the end of the test period. Cadmium was also removed by the wetland, but it did not show the same pattern as the other metals. This is presumed to result from its low inflow and decant concentrations (15 and 5 ppb, respectively). The low inflow concentrations (in the ppb range) for cobalt and nickel indicated that they were of no environmental significance. However, the same pattern of removal observed for all these metals (except cadmium) indicate that:

1. Similar processes affected metals present in the Galkeno mine water, and

2. Metal removal was upset by some event(s) occurring in early September.

The lower metal removal rate in the later part of September could also have resulted from lower temperatures, which would slow biological processes. These processes undoubtedly play an important role in metal removal. Temperature data from the Mayo airport for September 1995 confirm this⁷. The mean temperature remained above 100 C from September 1-3, 6-13, and 19-26. The period of September 14-19 exhibited low temperatures, which would be expected to result in lower microbial activity, such as reduced sulphate reduction by SRB.

The 1995 field program has not allowed to address the question of treatment performance during the winter. A survey of the Galkeno natural wetland, nearby the pilot wetland, indicated that water was flowing under the ice in mid-November. Unfortunately, the temperature at the time was -35^o C, which thwarted attempts to sample the water to determine metal concentrations. Despite this low temperature, it is expected that some metal removal will occur through sorption onto organic matter and onto precipitated iron and manganese oxides. The lack of data prevent prediction of metal removal rates, and it is recommended that such data be developed in the future.

1.2.3 Column Study Results

One drawback anticipated with the Galkeno constructed wetland was that the short snow-free season limited the amount of data that could be collected during the field program. Several *in situ* microcosms were established on August 18 within the Galkeno constructed wetland to augment data from the pilot wetland. These microcosms consisted of translucent plastic columns (13.1 cm inner diameter x 25 cm height) containing cores of wetland sediments and. The cores were sealed at the bottom, drained, and replenished with 1.4 Litres of untreated Galkeno 900 water (Columns 4, 5, and 6) or Galkeno 900 water diluted 1:2 with South

⁷ The temperatures at Elsa for the same month were significantly lower, as seen in the table below:

| | <u>Mayo</u> | <u>Elsa</u> |
|------------|-------------|-------------|
| Max Temp. | 12.3 | 9.9 |
| Mean Temp. | 6.5 | 5.1 |
| Mm. Temp. | 0.7 | 0.3 |

McQuesten water (Columns 1, 2, and 3). Microcosms thus prepared were re-introduced into the wetland where they were originally obtained.

Overall zinc (total metal) removal measured in the columns was better than in the Galkeno constructed wetland (Figure 13). Metal removal during the first 6 days was recorded, but the field technician (and the sampling procedure) changed on August 26, such that the results prior to this date are not comparable with the later results. Therefore, only the data from August 26 onwards are presented and discussed:

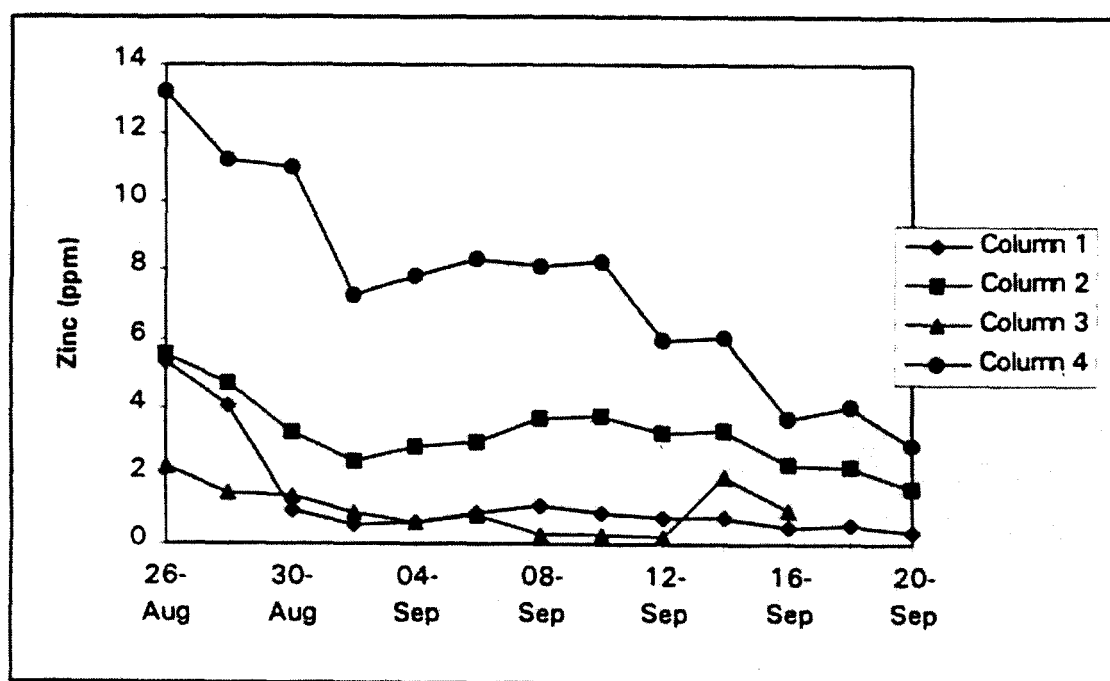


Figure 11. Zinc removal in the Galkeno constructed wetland *in situ* microcosms.

Data from columns 5 and 6 were lost because they were damaged midway through the study. In addition, the data from Column 2 are suspect, because of the increase in zinc concentrations in early September, which persisted until the end of the study. Results from these columns were removed from the data set, and only the data from Columns 1, 3, and 4 were considered further.

The results from Column 4 indicate that zinc was removed at a steady rate through the study. Similarly, zinc was constantly removed from Columns 1 and 3, except for the last two sample

points for Column 3. These data were combined into a single, continuous data set to compute a zinc removal rate, and are plotted in Figure 14. That is, the zinc data from Column 4 were merged with those averaged from Columns 1 and 3 at the point where zinc concentrations coincided⁸.

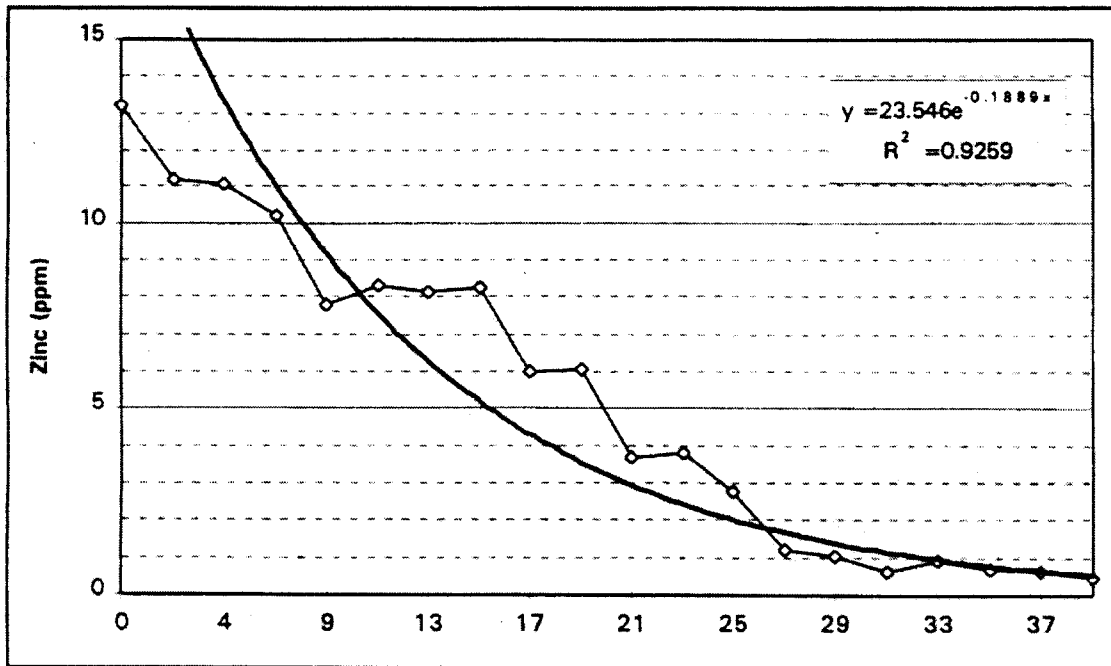


Figure 12. Combined data from Columns 1, 3, and 4 for zinc removal.

Despite the different waters used in the columns, the data obtained from combining the available data set produced a curve which fitted very well with an exponentially-decaying trendline ($R^2 = 0.93$). Applying the same removal rate to the zinc concentration data from the Galkeno natural wetland (Section 3.1.3), the predicted retention time should be approximately 14 days vs an retention time of 11.4 days estimated from field data. This close agreement suggests that the above rate of zinc removal is reasonable. Applying this removal rate to the data from the Galkeno constructed wetland⁹ indicated that it had a retention time of approximately 14.7 days vs a nominal retention time of 19.3 days. This is again in reasonably

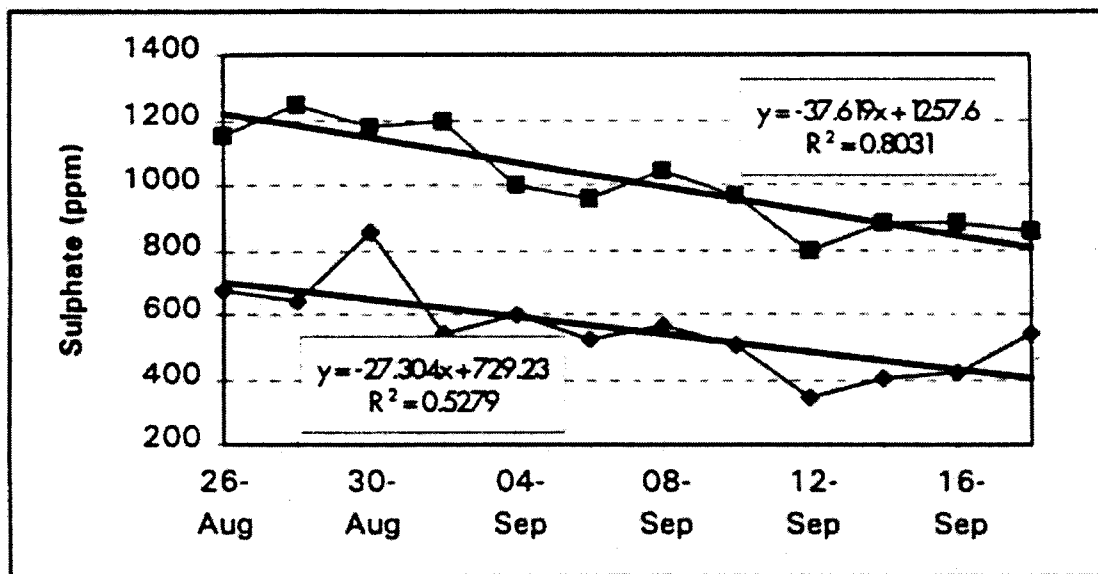
⁸ This approach is justifiable if the zinc removal processes operating at high and low concentrations are the same. Data presented later in the section suggest that this is a valid assumption.

⁹ Inflow concentrations of 25 ppm; decant concentrations of 3.95 ppm, before September 8.

close agreement, considering that the flow rate was changed on August 19, and that its pattern was modified by the placement of baffles in the wetland.

Water samples collected from the columns were analyzed for sulphate to determine whether sulphate reduction was taking place in the enclosed sediments. The data shown in Figure 15 indicate that cores with untreated Galkeno water and diluted Galkeno: South McQuesten water both sustained considerable levels of sulphate reduction. It is worth noting that the sudden increase in sulphate concentrations observed on September 8 in the pilot wetland (Figure 11) was not observed in the columns, indicating that sulphate reduction was relatively unperturbed for the duration of the test.

Figure 13. Sulphate concentrations in columns in the Galkeno constructed wetland.



The rate of sulphate reduction computed from the trendline fitted to the data is approximately 25 mmol/m²/day. This rate compares favorably with rates of sulphate reduction published in the scientific literature. For instance, the average rate of sulphate reduction for 27 marshes on the Atlantic Coast and in the U.K. was 77.4 mmol/m²/day (minimum 1.8, maximum 280 mmol/m²/day) (Skyring, 1987).

From the rate of sulphate reduction computed above, it is predicted that bicarbonate alkalinity will be generated from wetland sediments at a rate of 50 mmol/m²/day. Therefore, sediments

in the columns are predicted to inject 41.5 mg HCO₃/day, as in Equation 1:

$$50 \text{ mmol HCO}_3/\text{m}^2/\text{day} \times 0.013 \text{ m}^2 \times 61 \text{ mg/mol} = 41.5 \text{ mg HCO}_3/\text{day} \quad \text{Eq. 1}$$

With a volume of 1.4 Litre/column, an increase in alkalinity of approximately 20 mg/L/day would be expected. The alkalinity measured in the columns two days after adding the mine water increased as predicted by Equation 1 (Table 8). However, the alkalinity remained at these levels thereafter, indicating that it was removed from the mine water. Some alkalinity was undoubtedly lost as CO₂¹⁰. but some is likely to have reacted with calcium and metals, forming insoluble carbonates. However, calculating the amount of metals lost from the water column as carbonates is very difficult (see footnote 15).

Table 2. Bicarbonate production in columns in the Galkeno constructed wetland.

| | Galkeno | | 1:2 Galk:McQ | |
|---|--|---|--|---|
| | pH | Alkalinity mg/L as CaCO ₃ | pH | Alkalinity mg/L as CaCO ₃ |
| Day 0 | 6.02 | 139 | 6.04 | 95 |
| Day 2 | 6.55 | 175 | 6.24 | 125 |
| Day 5 | 7.01 | 162 | 6.97 | 130 |
| Rate of HCO ₃ ⁻ production from sediments by Day 2 | 25.2 mg HCO ₃ ⁻ /day | | 21.0 mg HCO ₃ ⁻ /day | |

Nonetheless, these results indicate that a significant amount of alkalinity will retained in the

¹⁰ This was counteracted by the production of CO₂ from the decomposition of detritus. CO₂ concentrations measured in the columns concurrently with the measurements presented in Table 8 are as follows:

| | Galkeno | 1:2 Galk: McQ |
|-------|----------------------|----------------------|
| | CO ₂ (aq) | CO ₂ (aq) |
| | m~/L | mg/L |
| Day 0 | 40 | 18 |
| Day2 | 18 | 43 |

While no there was no increase in dissolved CO₂ concentration in the [Galkeno] columns, there was a considerable increase in the [1:2 GaLkeno: McQuesten] columns. Moreover, the system is clearly very dynamic: both CO₂ and HCO₃ are continually produced microbiologically and lost physically (volatilization) and chemically (equilibration the carbonate system, reaction with dissolved species). This complicates any attempt at modelling the carbonate system or the formation of insoluble carbonates based on these data.

wetland sediments, as has been noted by others (Hedin *et al.*, 1994). This alkalinity will buffer water pH, which might be important in case the mine drainage gradually becomes acidified. For instance, it would preserve the pore water pH to a level that permits continued activity of sulphate-reducing bacteria.

The information presented above provides the basis for designing a wetland treatment system. While the field work focused on (and assumed the need for) treatment of the discharge from the Galkeno 900 adit, it is clear that such a design could be applied to other discharges on the property, should there be need for treatment.

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