Katahdin Iron Works and its Effect On the Water Quality of the West Branch of the Pleasant River

Katahdin Iron Works Township
(T6 R9 NWP)
Piscataquis County, Maine, USA

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Ore Excavation Pit, Ore Mountain, Photo by Mark Whiting
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I. Introduction and Background Information:

The Pleasant River is a tributary to the Maine's largest river, the Penobscot. The Penobscot River watershed has the vast majority of the federally-listed endangered Atlantic salmon in Maine, accounting for 95% of the adult returns. Furthermore, this watershed is likely to play an increasingly important role in the conservation of Maine Atlantic salmon. In 2004, an agreement was signed to restore 11 sea-run fish species on the Penobscot River, while at the same time preserving hydroelectric power capacity. The non-profit Penobscot River Restoration Trust was created to raise money and coordinate the activities of the restoration partners. These include the Penobscot Indian Nation, six environmental groups, the hydropower dam owner, and State and Federal agencies. The project involves the removal of the two lower dams on the river, Veazie and Great Works. The Milford dam will have improved fish passage and the Howland dam will be decommissioned and by-passed by a natural-looking river channel. To find out more about the restoration program visit the Penobscot River Restoration Trust website (http://www.penobscotriver.org/).

The Piscataquis River is one of the major western tributaries to the Penobscot. The Howland Dam controls upstream access for fish in this large system. The topic of this paper, the Pleasant River is part of the Piscataquis drainage. The Pleasant is divided into three parts, the West, Middle and East Branches, which unite in the town of Brownville. Of the three branches, the best Atlantic salmon habitat is found in the West Branch. The Maine Department of Marine Resources (DMR) Bureau of Sea-Run Fisheries and Habitat has an active salmon stocking program on the West Branch, the East Branch, and the mainstem of the Pleasant River. Juvenile salmon do moderately well in the West Branch, but there is some speculation that they should be doing better.

Also of interest to this study is the Katahdin Iron Works (KIW) State Historical Site located about 5 miles north of Brownville Junction. In the 19^{th} Century, this was one of the few large-scale successful commercial iron smelting operations in Maine. From 1840 to 1890 iron ore was dug from pits on Ore Mountain and was carried by wagons to the smelter located near the banks of the West Branch of the Pleasant. There molten iron was cast into "pigs" that were exported by rail. The smelter and one of the charcoal kilns are preserved and maintained by the Maine Department of Conservation, Bureau of Parks and Lands.

Long before there was a Katahdin Iron Works, prehistoric people sought red ochre from what we know today as Ore Mountain. Ochre was used to dye and paint skins and tools, and had ceremonial significance at burial sites (William Sawtell, undated book). The Katahdin iron ore is a "pyrrhotite" (an iron sulfide) which is located on the northern slope of Ore Mountain. The deposit is estimated to exceed 200 million tons, which is thought to be one of the largest sulfide deposits in the world (Maine Geological Survey). The Iron Works used the weathered surface layer (called "gossan") which is enriched in iron oxide. This was easier to purify than the parent sulfides. Analysis of samples of the ore shows a range of composition from 43-45% iron, 26-28% sulfur, 0.01-0.1% copper, 0.2% nickel, and 0.1% cobalt (Maine Geological Survey). By modern standards, the quality of this ore is poor and it has attracted very little interest from newer mining operations. In fact, the development of better quality iron sources in the American Midwest was a significant factor in the abandonment of the KIW site. For more information on the history of the Iron Works, its geological setting, and for historical photos see the Maine Geological Survey website (http://www.maine.gov/doc/nrimc/mgs/explore/mining/sites/sept03.htm).

Blood Brook is a tributary to the West Branch that originates on the north slope of Ore Mountain. This stream is listed by the State as having impaired water quality (DEP 2008). Maine's Water Classification Act (38 MRSA, Section 464) adopted narrative aquatic life standards for each water classification (Table 1). For instance, in order to sustain aquatic life in Class A and AA waters, invertebrate communities are supposed to be "as naturally occurs." What is considered "natural" is determined by studies of undisturbed sites (control sites), the identification of indicator species (species that thrive only in the cleanest waters), and by mathematical prediction models (DEP 2002). In addition to biological standards, numerical criteria are used for some chemical variables, such as dissolved oxygen and bacteria (Table 1). Blood Brook was classified as impaired due to its' poor water chemistry and impaired biological communities.

Table 1. A summary of Maine's water quality criteria for Class AA, A and B waters for rivers and streams.

Class AA

Aquatic uses	Suitable for drinking water supply after disinfection, fishing, recreation in and on the water and as habitat for fish and other aquatic life
Habitat	Shall be characterized as free-flowing and natural
DO Bacteria	Shall be as naturally occurs. Shall be as naturally occurs.
Discharges	No direct discharges of pollutants.

Class A

Aquatic uses	Suitable for drinking water supply after disinfection, fishing, recreation in and on the water and as habitat for fish and other aquatic life
Habitat	Shall be characterized as natural
DO	Shall not be less than 7.0 ppm or 75% whichever is higher.
Bacteria	Shall be as naturally occurs.
Discharges	Shall be of equal or better quality than receiving waters

Class B

Aquatic uses	Suitable for drinking water supply after treatment, fishing, recreation in and on the water and as habitat for fish and other aquatic life
Habitat	Shall be characterized as unimpaired
DO	Shall not be less than 7.0 ppm or 75% whichever is higher, except that for the period from October 1st through May 14th, in order to ensure spawning and egg incubation of indigenous fish species the 7-day mean DO shall not be less than 8.0 ppm in identified fish spawning areas. However, were natural conditions, including marshes bogs, and abnormal concentrations of wildlife cause DO to fall below the minimum standards, those waters will not be considered to be failing.
Bacteria	Between May 15th and September 30th, the number of Escherichia coli bacteria of human origin in these waters may not exceed a geometric mean of 64 colonies per 100 ml or an instantaneous level of 427 colonies per 100 ml
Discharges	Shall not cause adverse impact to aquatic life in that the receiving waters shall be sufficient quality to support indigenous species without detrimental changes to resident aquatic communities.

The aquatic life criteria are established and evaluated by DEP's Biomonitoring Program which uses aquatic macroinvertebrates (i.e., large enough to be visible to the eye, mostly insects, but also worms, arachnids, snails, etc.), aquatic plant, and algal communities as indicators of water and habitat quality. For instance, a high quality stream (like a Class AA or Class A stream) should be supporting invertebrate communities that have many individuals, many different taxa (high biodiversity) and species that are typical of these streams. The West Branch is listed as a Class AA salmon river, and its tributaries are supposed to attain Class A. The macroinvertebrate models do not differentiate between Classes AA and A (since both should have macroinvertebrate communities that are typical of natural waters).

Blood Brook is located on the far side of the West Branch (southwest) from the Iron Works, but on the same side as Ore Mountain as the mine excavation sites (Figure 1). Blood Brook is so named because of the red staining on rocks from iron deposits. The stream and the immediately downstream reach of the West Branch are listed as impaired due to "legacy pollutants" due to iron mine contamination (DEP 2008). The macroinvertebrate collections at Blood Brook are very poor (just four individuals were recovered, including a midge, one beetle larva, a mayfly and a water mite from three rock baskets). The sample not only did not meet Class A criteria, but did not even meet the Class C criteria (the lowest water quality class) (Table 2). This acidic and iron-stained stream has no fish, and has very little evidence of any animal life. In fact, the problem appears to be classic acid mine drainage (low pH, high sulfate, and high metals content). A more recent collection for algae at the lower Blood Brook site has not been evaluated (because the models have not been created yet for algae). However, the algal species from this sample are extreme acidophilic or “pH indifferent” taxa.

Macroinvertebrate samples taken from the West Branch just below the confluence with Blood Brook and just below the KIW site did not meet the criteria in 1996. But these results need to be tempered by the fact that there were problems with the rock basket deployments (some baskets were exposed by low water and some had been rolled out of place by high flows). The sample from 2001 was a good deployment, but the results were somewhat equivocal. The model suggested something on the dividing line between A and B quality streams. Given the excellent species diversity, the sample was accepted as attaining its classification. A small stream nearby, with no known name, also attains Class A criteria.

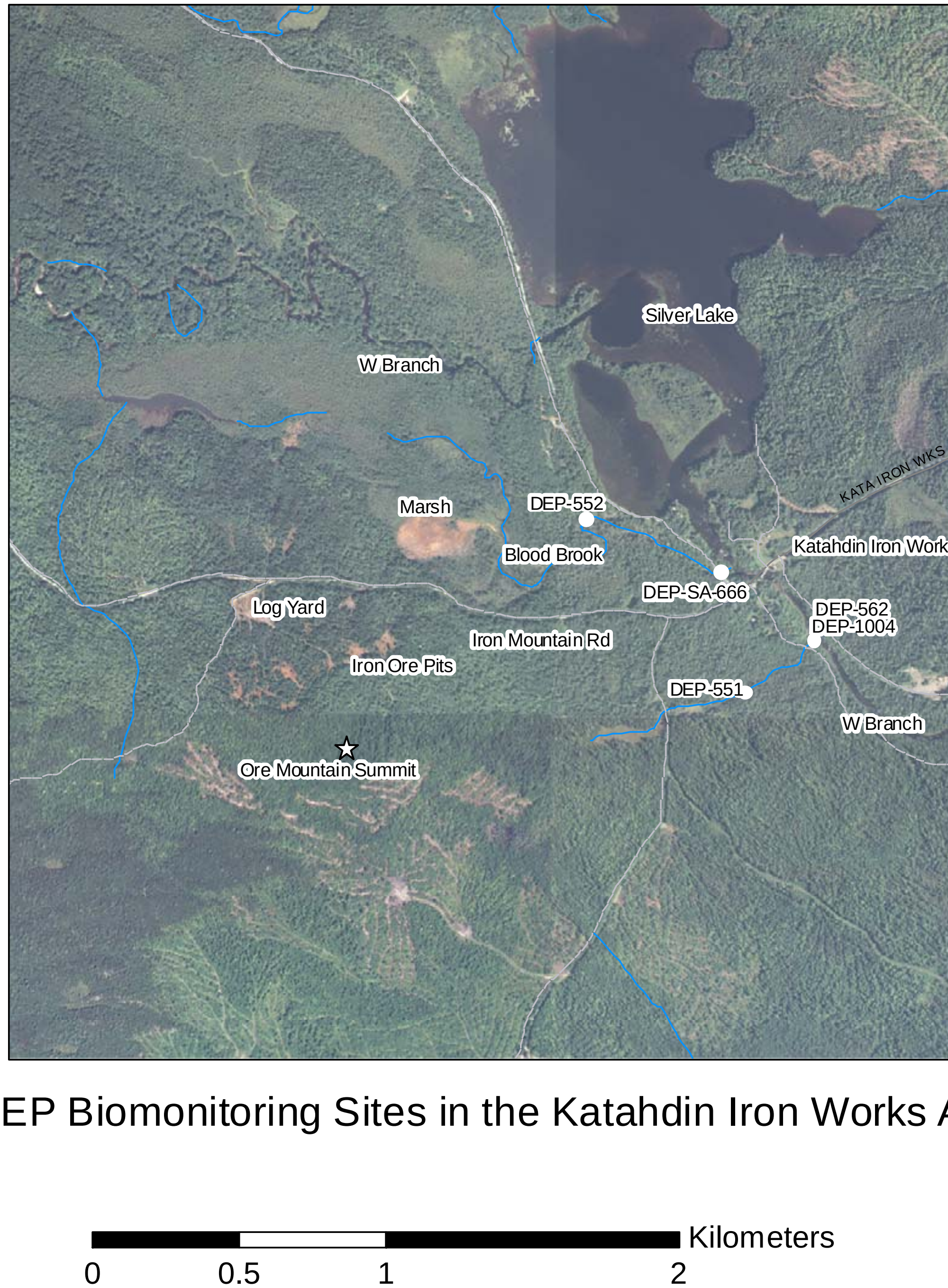


Figure 1. Aerial photograph of the Katahdin Iron Works area showing the DEP Biomonitoring Program study sites. The Ore Mountain summit is indicated with a star. Blood Brook enters the West Branch of the Pleasant River just below Silver Lake. Blood Brook was sampled in 1996 for macroinvertebrates (at the upstream site) and was sampled again in 2003 (at the lower site) for algal communities. Samples were taken

from the West Branch in 1996 and 2001. No-name Brook enters the West Branch just below the KIW site and was sampled in 1996.

Table 2. Summary of DEP Biomonitoring results available to date. All of these were macroinvertebrate samples, except for one of the Blood Brook samples (2003) which was sampled for algal communities.

	Sample No.	Date	Stream Classification	Attains	Notes
Blood Brook (bugs)	DEP-S281	1996	A	No	Attributed to legacy pollutants, metals and pH
Blood Brook (algae)	DEP SA-666	2003	A		Not determined yet, many acidophils present
W Branch of Pleasant R	DEP-562	1996	AA	No	Some rock baskets were exposed by low water
W Branch of Pleasant R	DEP-1004	2001	AA	Yes	
No-name Stream	DEP-551	1996	A	Yes	

Acid mine drainage is expected any time that sulfide-rich and carbonate-poor deposits are disturbed by deep excavations and thereby exposed to weathering (Acid Drainage Technology Initiative, ACTI website). Often these are coal or metallic mines, but deep highway cuts and other kids of construction can also be a source of acid mine drainage. Pyrite and marcasite (FeS_2) are the most common acid sources, although other metal sulfides can also be important. Pyrrhotite is a relatively rare hexagonal crystalline structure of variable ratios of Fe:S with troilite (FeS) being the simplest form. Pyrrhotite is a strong acid former, both from the oxidation of sulfide and the oxidation of ferrous to ferric iron. The equations below are for FeS (adapted from the ACTI website).

(1.) $3FeS(solid) + 4O_2 + 4H_2O = 3\,Fe^{2+}(aq) + 3SO_4^{-2} + 4H^+$
(2.) $4Fe^{2+}(aq) + O_2 + 4H^+ = 4Fe^{3+}(aq) + 2H_2O$
(3.) $Fe^{3+}(aq) + 3H_2O = Fe(OH)_3(solid) + 3H^+$

Both aqueous and solid phases are indicated. Equation 2 is facilitated by bacteria (especially Thiobacillus). These bacteria thrive in low pH and low oxygen environments. In equation 3, the resulting iron hydroxide is yellow. A combination of hydroxides, oxides and oxy-hyroxides (Wikipedia) produce the yellow-red deposits that are visible on the rocks of Blood Brook.

The present investigation was initiated at the request of the Department of Marine Resources (DMR) Bureau of Sea-Run Fishes and Habitat. DMR was concerned that Blood Brook has a negative impact on the West Branch and on juvenile salmon habitat. DEP also wanted to assess the nature of the impairment (especially relative to heavy metals), determine if there was an obvious source of the mine drainage, and whether any remedial action is needed at the KIW site or the Ore Mountain mining pits.

II. Study Design and Methods:

To determine the impact of KIW and Blood Brook on the West Branch, water samples were collected from 12 sites (Figure 2). One sample site was established on Blood Brook (BB-1). A control site was established on the West Branch (WBP-1) above the confluence with Blood Brook. Five downstream sites were established on the West Branch. The first (WBP-2) was just downstream of the confluence with Blood Brook and was adjacent to the Iron Works. The second downstream site (WBP-3), was located on the west shore 628 meters below the KIW bridge, and was thought to be far enough below Blood Brook that the intervening rocky riffles would completely mix the water from the two streams. The third downstream site (WBP-4) was at the upper end of the passable part of the ATV road on the west side of the river. The fourth site (WBP-5) on the West Branch was just above the confluence with Roaring Brook. The fifth site (WBP-6) was on the West Branch accessed from the ATV road at the end of Front Street from Brownville Junction. Three sites were chosen to represent other parts of the Pleasant River watershed. Houston Brook (HB-1) has headwaters on Ore Mountain; but this watershed originates on the south and east slopes which do not have the sulfide deposits. Another site was on the main stem of the Pleasant River (PR-1) in Brownville Junction below the confluences of the West, Middle and East Branches. The third site was on the East Branch of the Pleasant (EBP-1) above the confluence with the Middle Branch. Two final sites were chosen from the Piscataquis River watershed (not shown on this map) and also served as control sites. These were the Piscataquis River at Route 11 in Abbott (PEN-18) and Kingsbury Stream at the Coles Corner Road in Parkland (PEN-19).

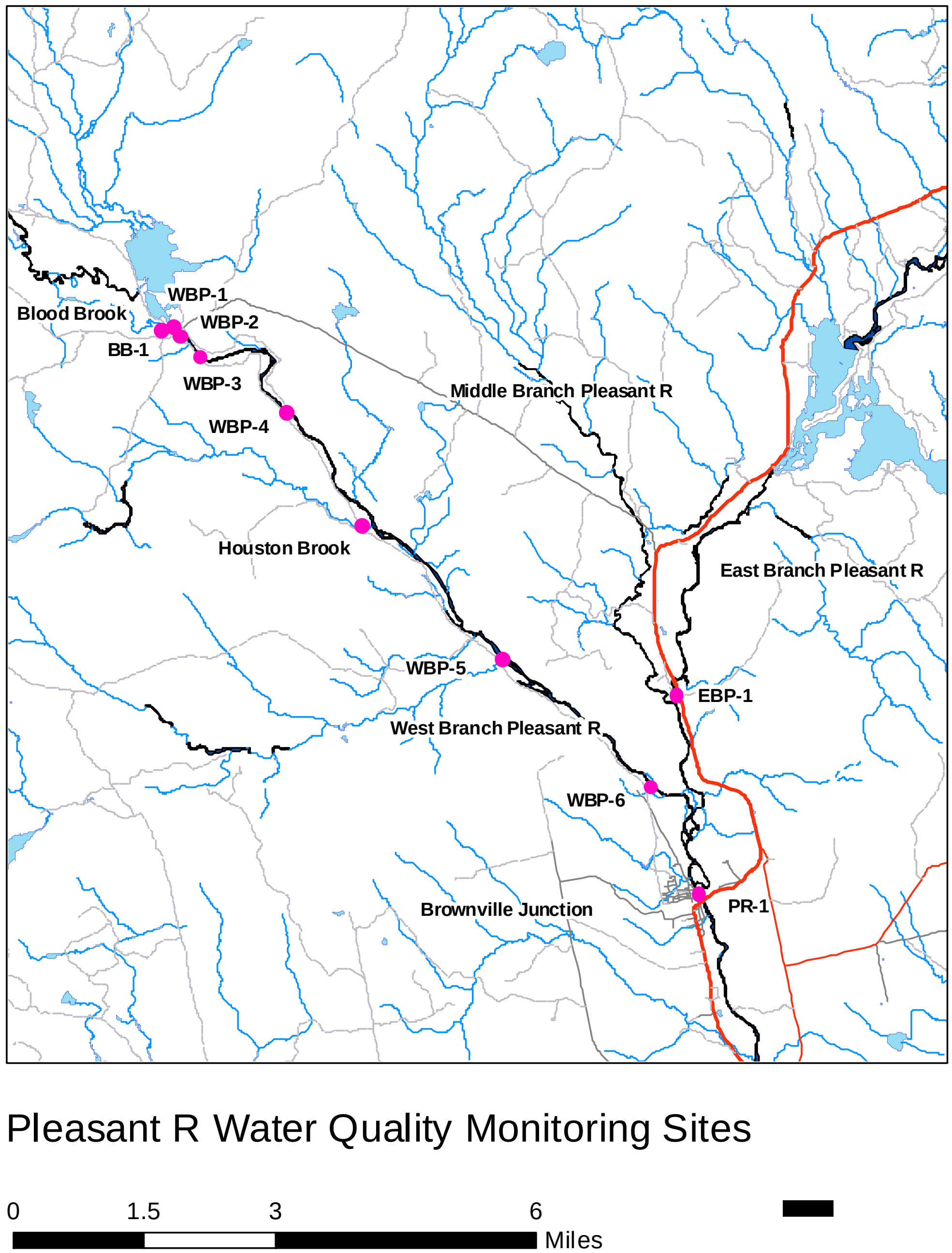


Figure 2. Map of the Katahdin Iron Works study area showing the study sites and the relationship between the different branches of the Pleasant River. The three branches of the Pleasant River combine in Brownville. Rivers are in dark blue, streams and lakes are in light blue.

Water samples were collected for lab analysis in 2007 during the spring, summer and fall, and again in 2009 during the spring and fall. Not all sites were sampled each time, but there were always some downstream West Branch samples. Sample times were selected to represent both high flow and baseflow conditions when roads were passable (these are gravel logging roads and ATV trails).

The water quality analysis initially consisted of pH, alkalinity (measured as Acid Neutralizing Capacity or ANC), major cations (calcium, sodium, potassium and magnesium), major anions (chloride, sulfate, nitrate), dissolved organic carbon (DOC), and aluminum species (total Al, dissolved Al, organic Al, and the toxic ionic Al). Later, in order to save money, only pH and aluminum were analzed at some sites. Summaries of this data are given as ranges and medians. A median represents a central tendency among values and is less influenced by single extreme values than an average. All of our lab chemistry was from the University of Maine Sawyer Environmental Chemistry Research Lab.

For this study, the most important water quality indicators were pH, aluminum speciation, and trace metals. Generally, we were looking for thresholds at which fish or other aquatic life are threatened. Acidity is measured by a logarithmic pH scale. A pH of 7 is neutral (i.e., sources of acids and bases are in balance) while lower numbers are acidic and higher numbers are alkaline (or basic). A range of pH 6-8 is normal for most Maine rivers, streams, and lakes with the majority of our surface waters on the slightly acidic side. Each unit of pH represents an order of magnitude, so a pH of 5 is 10 times as acidic as pH 6. Alkaline waters (pH 7-8) are common in Aroostook County where limestone deposits are more adundant than in the rest of Maine. Values between pH 6-8 are healthy ranges for most fishes. However, values below pH 6 can be problematic for fish, especially if the values go below 5.6 and if there are other stress factors (such as high summer temperatures or high metals). Salmon and brook trout are more tolerant than other fish to acidic waters, but do not occur in warm waters (above 24ºC, more than 75.2ºF) or in waters that are both acidic and high in aluminum. At values below pH 6, aluminum species that are generally harmless like the particulate and organic forms, are converted into the ionic and toxic form (here called "exchangeable Al" or Alx). At values below pH 6 any exchangeable Al value above 10 ug/L (parts per billion or ppb) can be harmful for young salmon if exposed long enough (McCormick and Monette 2007). Exchangeable Al values of 39 ug/L that last for at least 6 days have been found to be harmful, and will damage fish gills and affect body salt balance. Values of 120 ug/L Alx can be lethal to salmon pre-smolts after 6 days of exposure in freshwater, or can result in failure to survive a transition to seawater (McCormick & Monette 2007). Aluminum speciation is related to the amount of total Al and pH. The particulate, dissolved, and exchangeable fractions are chemically interchangeable. Alx is lowest when pH moderate (pH 6-7) and highest when pH is extreme on either side of this range.

When evaluating trace metal thresholds needed to maintain freshwater species diversity, DEP uses administrative rules at 06-096 CMR 584 Surface Water Quality Criteria for Toxic Pollutants (see a summary in Table 3). These were adopted from US

Environmental Protection Agency ambient water quality criteria (AWQC) (EPA 1986). The trace metal data presented in this paper are total metals (which includes both particulate and dissolved fractions). Notice that the toxicity of some metals will vary according to their charge (or valence) (i.e., there are different standards for chromium +3 and chromium +6). Selenium is even more complicated where the two forms (selenium +4 and selenium +6) often occur together. Three initial samples were taken on April 24, 2007 for heavy metal screening (Aluminum, Arsenic, Cadmium, Copper, Iron, Lead and Zinc). Following positive results for aluminum, iron and zinc, a more comprehensive suite of tests were conducted on samples taken on June 26 and October 23 in 2007 (Aluminum, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Nickel, Selenium, Silicon, Silver, Strontium, Thallium, Tin, Titanium, Vanadium and Zinc).

Table 3. A summary of Maine DEP's Chapter 584 for Statewide Water Quality Criteria for toxic pollutants. The metal symbols are (in order): Silver, Aluminum, Arsenic, Beryllium, Cadmium, Cobalt, Chromium, Copper, Iron, Manganese, Nickel, Lead, Antimony, Selenium, Silicon, Tin, Strontium, Titanium, Thallium, Vanadium and Zinc. Threshold values are in ug/L (ppb). See details on Maine's toxicity rules at http://www.maine.gov/sos/cec/rules/06/096/096c584.doc

	Ag	**Al**	**As**	**Be**	**Cd**	**Co**	**Cr (III)**	**Cr (VI)**	**Cu**	**Fe**	**Mn**	**Ni**
Priority Pollutant	Y	N	Y	Y	Y	N	N	Y	Y	N	N	Y
Carcinogen	N	N	Y	Y	N	N	N	N	N	N	N	N
Freshwater Acute Criteria	0.23	750	340		0.42		483	16	3.07			120
Freshwater Chronic Criteria		87	150		0.08		23	11	2.36	1000	500	13.4

	Pb	**Sb**	**Se**	**Si**	**Sn**	**Sr**	**Ti**	**Tl**	**V**	**Zn**
Priority Pollutant	Y	Y	Y	N	N	N	N	Y	N	Y
Carcinogen	N	N	N	N	N	N	N	N	N	N
Freshwater Acute Criteria	10.5		*							30.6
Freshwater Chronic Criteria	0.41		5							30.6

* CMC = 1((f1/185.9)+(f2/12.83)) where f1 and f2 are the fractions of total Se that are selanite and selanate respectively

Stream stage and recent weather were noted in the field to help interpret water chemistry data. For instance, sometimes pollutants are diluted by large storms, while natural acidity is often strongest after storms. Weather stations for Maine can be found on the web (at http://www.wunderground.com/) for current or historical data. Click on "History data" to get precipitation, air temperatures, etc. for a given site on a given day.

Sources of high acidity and iron staining (indicating metals) were investigated on Ore Mountain using field pH and conductivity meters (a YSI 100 pH meter and an Oakton EC tester 11). The iron ore excavations were located off the Iron Mountain Road with the help of Bill Sawtell at the North Maine Woods gate at Katahdin Iron Works and aerial photographs. Background information on the Katahdin Iron Works was available from the Maine Geological Survey website and a book by Mr. Sawtell.

III. Principal Findings:

Based on water chemistry, Blood Brook does appear to be influenced by acid mine drainage. It had the lowest median pH (5.26) and the greatest range (Table 4). Fortunately, all of the West Branch and control sites maintained healthy pH values (except for a single value below pH 6 at WBP-2 on April 25, 2007 during a period of very high spring flow).

Table 4. Summary of lab pH values ("closed-cell pH") for all Blood Brook, West Branch of the Pleasant, and for control sites. The number of samples taken, the median and ranges are listed.

	ID	#	median	range
West Br Pleasant R above KIW	WBP-1	3	6.56	6.11-6.90
Blood Brook	BB-1	3	5.26	4.80-6.60
West Br Pleasant R below KIW	WBP-2	3	6.61	5.58-6.96
WBr Pleasant R farther below KIW	WBP-3	0		
WBr Pleasant R at end of ATV Rd	WBP-4	0		
Houston Brook ATV Bridge	HB-1	2	6.53	6.44-6.61
WBr Pleasant R above Roaring Brook	WBP-5	2	6.75	6.72-6.77
WB Pleasant R Brownville Jct on ATV Rd	WBP-6	1	6.76	
Pleasant River in Brownville at old dam site	PR-1	2	6.43	6.03-6.82
E Branch Pleasant River	EBP-1	2	6.69	6.61-6.77
Piscataquis R at Abbott	PEN18	4	6.97	6.26-7.00
Kingsbury Stream at Coles Corner Rd	PEN19	2	6.89	6.88-6.89

Blood Brook also had the highest median value and range for the toxic exchangeable aluminum (Alx) (Table 5). While Blood Brook sometimes had Alx values that were safe (i.e., one summer baseflow value where the pH was 6.6 and Alx was only 25 ug/L) it often had extreme values. With a median value of 620 ug/L and only one value below 120 ug/L, it is no wonder that this stream is fishless. A single high value at WBP-2 coincided with the lowest pH recorded at this site (pH 5.58 during the same spring high flow mentioned above). While it is possible that this is evidence of mixing with Blood Brook water, Blood Brook at this time had relatively moderate total Al and Alx (261 ug/L and 133 ug/L respectively). There is no evidence of Blood Brook's influence at a lower site (WBP-3) during low flows when Alx was 620 ug/L or during two other sample days with medium flows when Alx was 1322 or 1405 ug/L. The median values at WBP-2 are no different than the upstream or downstream sites.

The apparent on-again off-again influence of Blood Brook is difficult to explain. Exchangeable aluminum is another indicator of acid mine drainage (Table 5). Certainly, Blood Brook was a strong source of Alx with 2 out of 5 samples above 1000 ug/L. If Blood Brook were the only source of low pH and high Alx, then the highs and lows should occur together at the two sites. However, the highest value at WBP-2 co-occurred with a moderate value 133 ug/L, the second lowest value at BB-1). The West Branch (with the one exception on April 25, 2007) and the control sites maintained acceptable Alx values, even in different flow conditions. The out of phase maxima at WBP-2 and BB-1 suggest there may be another source of contamination and that it might be driven by spring snow melt (April 2007 had a record snow pack) at the Katahdin Iron Works site.

Table 5. Summary of lab Alx values ("exchangeable aluminum") for all Blood Brook, West Branch of the Pleasant, and for control sites. The number of samples taken, the median and ranges are listed.

	Site ID	#	median ug/L	range ug/L
West Br Pleasant R above KIW	WBP-1	3	10	6-14
Blood Brook	BB-1	5	620	25-1405
West Br Pleasant R below KIW	WBP-2	3	11	5-75
WBr Pleasant R farther below KIW	WBP-3	2	22.5	16-29
WBr Pleasant R at end of ATV Rd	WBP-4	1	15	
Houston Brook ATV Bridge	HB-1	2	22.5	18-27
WBr Pleasant R above Roaring Brook	WBP-5	2	18.5	16-21
WB Pleasant R Brownville Jct on ATV Rd	WBP-6	1	13	
Pleasant River in Brownville at old dam site	PR-1	1	14	
E Branch Pleasant River	EBP-1	2	9.5	5-14
Piscataquis R at Abbott	PEN18	4	14	6-22
Kingsbury Stream at Coles Corner Rd	PEN19	2	15.5	10-21

The spatial distribution of Alx in Blood Brook and in downstream sites is illustrated in Figures 3-4. Both of these represent "worst case" scenarios where the Alx concentration at Blood Brook was highest. The May 20, 2009 sample (Figure 3) represented spring baseflow conditions where the water level was "medium" (the choices on the field form were high, medium or low). Flows in the West Branch were also moderate. Alx values in the West Branch and control sites were low. On October 19, 2009 (Figure 5) stream flows were at low baseflow conditions. The downstream West Branch site WBP-3 had relatively high Alx (the highest value recorded at that site), and higher than farther downstream (WBP-5) and the East Branch. It is possible that this was due to the extremely high Alx in Blood Brook. However, notice that the control site Houston Brook (27 ug/L) was essentially the same as WBP-3 (29 ug/L).

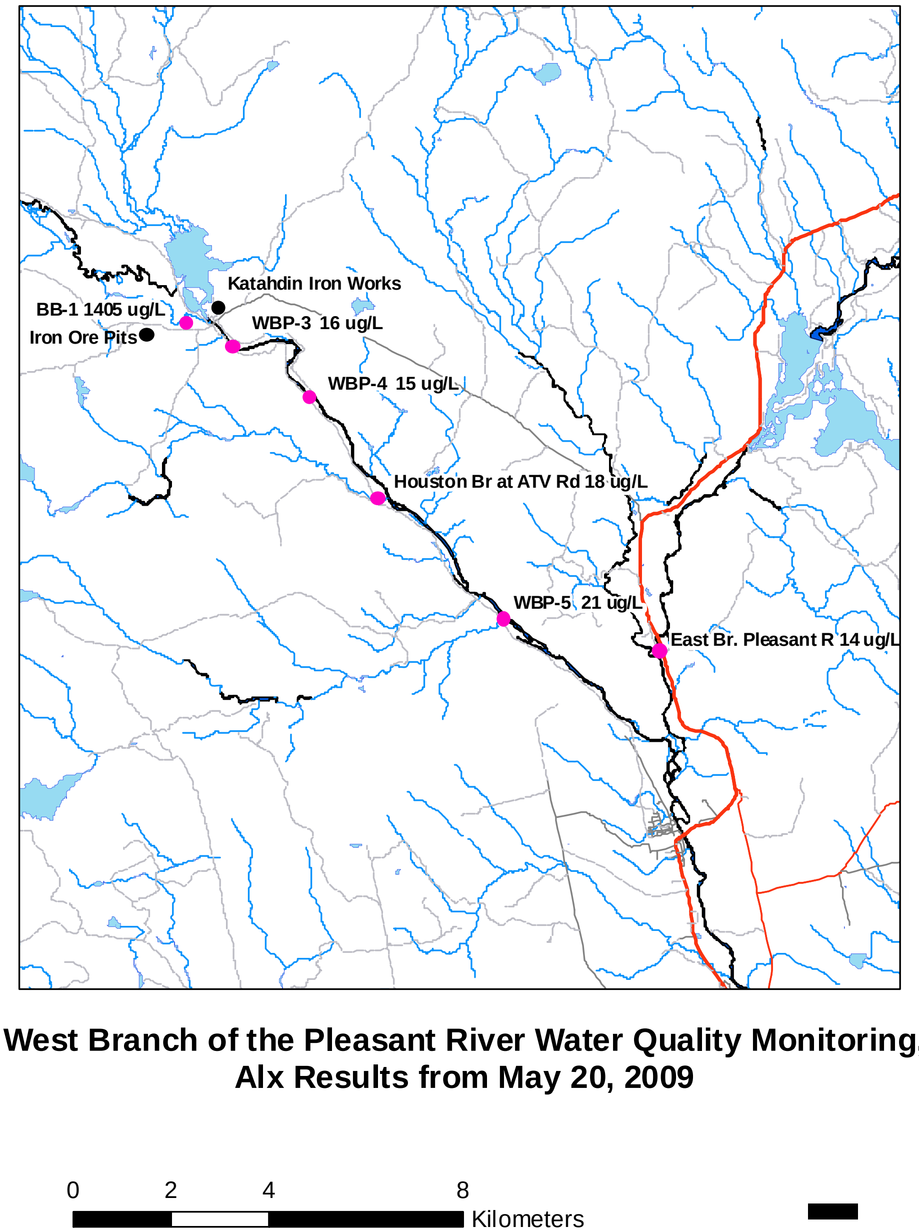
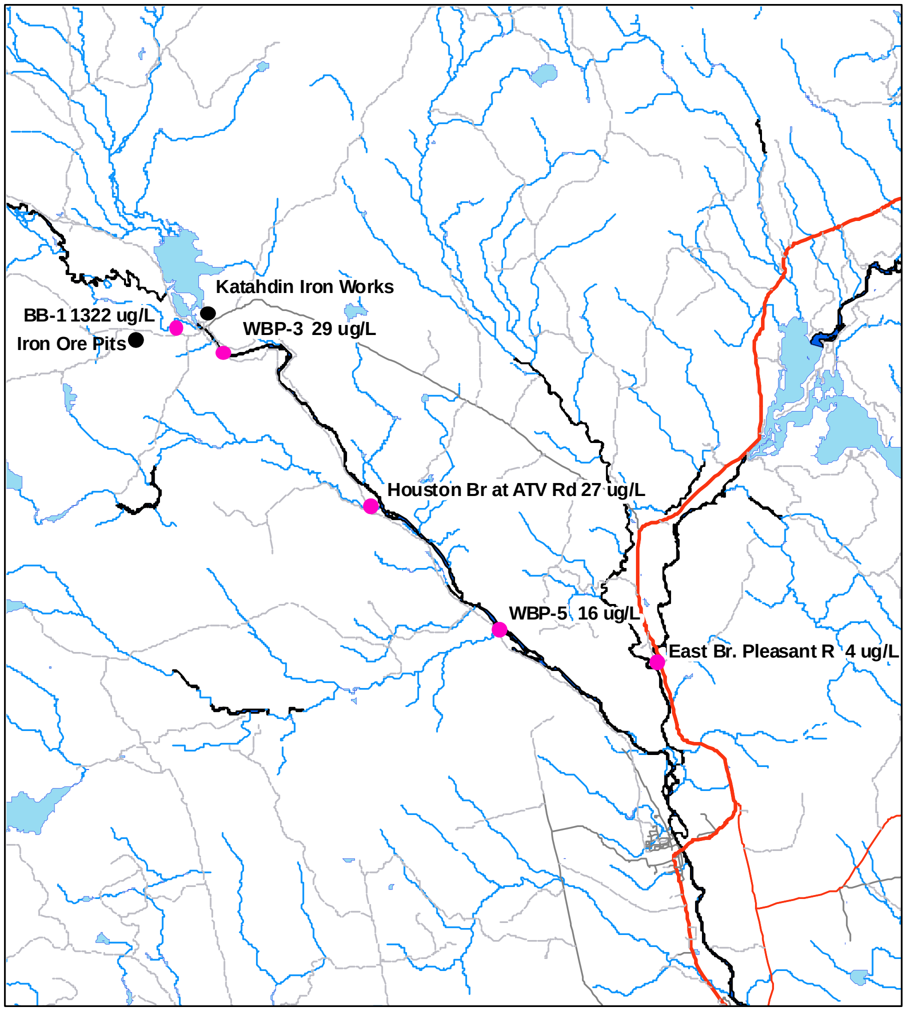


Figure 3. Exchangeable aluminum results for samples from May 20, 2009, West Branch of the Pleasant River, Maine.



West Branch of the Pleasant River Water Quality Monitoring,
Alx Results from October 19, 2009

Figure 4. Exchangeable aluminum results from samples taken on October 19, 2009, West Branch of the Pleasant River, Maine.

The single low pH and high Alx at WBP-2, just below Blood Brook and immediately below KIW, was apparently due to acid mine drainage. Sulfate is a third indicator of acid mine drainage. A summary of sulfate medians (Table 6) demonstrates that Blood Brook was a strong source of sulfuric acid. The median value for WBP-2 was higher than upstream and other control sites. What we can not see from the summary is what happened on April 25, 2007. Acidity at WBP-2 on this date (expressed in hydrogen ion concentration) increased 3.4-fold while sulfate (expressed in equivalents) increased 2.9-fold (sulfate goes from 36 ueq/L at WBP-1 to 103 ueq/L at WBP-2, while BB-1 is relatively low 134 ueq/L). Sulfate accounted for more than 80% of the increase in acidity; but at the same time, sulfate was out of phase with Blood Brook (this highest value at WBP-2 coincides with the lowest value at BB-1). From equations 2 & 3 in the Introduction, we know that additional acidity comes from the oxidation and precipitation of iron. However, the acidity does not have to come from Blood Brook alone. After 50 years of smelting at KIW, the general contamination of the area with waste from the smelter might be a second source of weathered ore (see section below on metals). KIW is an upland site, presumably with well drained soils. A heavy snow pack (such as the late spring of 2007) will drain soils that are contaminated with spilled ore and discarded smelter slag. This might explain why a problem in the West Branch was only seen in April of 2007. The first sample from 2009 was taken in May.

Table 6. Summary of lab sulfate (SO4) values for all Blood Brook, West Branch of the Pleasant, and for control sites. The number of samples taken, the median and ranges are listed.

	Site ID	#	median ug/L	range ug/L
West Br Pleasant R above KIW	WBP-1	2	39.5	36-43
Blood Brook	BB-1	3	1408	134-2060
West Br Pleasant R below KIW	WBP-2	2	79	55-103
WBr Pleasant R farther below KIW	WBP-3			
WBr Pleasant R at end of ATV Rd	WBP-4			
Houston Brook ATV Bridge	HB-1	2	41	39-43
WBr Pleasant R above Roaring Brook	WBP-5	2	51	49-53
WB Pleasant R Brownville Jct on ATV Rd	WBP-6	1	67	
Pleasant River in Brownville at old dam site	PR-1			
E Branch Pleasant River	EBP-1	2	34	33-35
Piscatiquis R at Abbott	PEN18	4	47.5	37-54
Kingsbury Stream at Coles Corner Rd	PEN19	2	42	41-43

The metals found in Blood Brook mostly match the composition of the Ore Mountain deposit and local soils (Table 7). Specifically, the iron, nickel, copper and cobalt come from the ore deposits while the aluminum and silica come from local soils. Aluminum is mobilized by low pH. The strong strontium and manganese presence in Blood Brook was a surprise, since these are not listed in the composition of the ore samples. In comparing the West Branch above and below KIW, there was sometimes an enrichment of iron, aluminum and manganese from Blood Brook (such as for April 25, 2007). This relationship was not seen at other times (such as June 26, 2007). As noted above, not all of the iron, aluminum and manganese would have to come from Blood Brook. Since the banks of the West Branch include a lot of waste material from the smelting operations at Katahdin Iron Works metals might have a more local source. Of these trace metals, aluminum and nickel exceeded state standards for chronic exposures. Nickel was only exceeded in Blood Brook samples. Total Al was often in the 100-200 ug/L range in Maine waters and is a function of our acidic and organic soils and the dissolved organic matter content of our streams and rivers. In terms of toxicity, the form (speciation) of aluminum is much more important than the total.

Table 7. Summary of the total metals results. The metals are listed alphabetically by abbreviations. In order, the abbreviations are Silver, Aluminum, Arsenic, Beryllium, Cadmium, Cobalt, Chromium, Copper, Iron, Manganese, and Nickel. The second row is Lead, Antimony, Selenium, Silica, Tin, Strontium, Titanium, Thallium, Vanadium, and Zinc. Values in yellow exceed EPA recommended thresholds needed to protect aquatic communities from chronic concentrations.

Sample ID		**Flow**	**Ag µg/L**	**Al ug/L**	**As µg/L**	**Be µg/L**	**Cd µg/L**	**Co µg/L**	**Cr µg/L**	**Cu µg/L**	**Fe µg/L**	**Mn µg/L**	**Ni µg/L**
WBP-1	**4/25/07**	**melt, very high**		108	<2.0		<0.5			<10	185		
BB-1	**4/25/07**	**melt, very high**		261	<2.0		<0.5			<10	406		
WBP-2	**4/25/07**	**melt, very high**		210	<2.0		<0.5			<10	336		
WBP-1	**6/26/07**	**baseflow**	<2	46	<2	<0.02	<0.50	<5	<2	<10	270	29	<2
BB-1	**6/26/07**	**baseflow**	<2	120	<2	0.03	<0.50	13.7	<2	<10	336	702	17.9
WBP-2	**6/26/07**	**baseflow**	<2	46	<2	<0.02	<0.50	<5	<2	<10	273	31	<2
PEN18	**6/26/07**	**baseflow**	<2	37	<2	<0.02	<0.50	<5	<2	<10	62	13	<2
BB-1	**10/23/07**	**low baseflow**	<2	727	0:00	0.07	<0.50	32.0	<2	<10	369	403	36.0
WBP-6	**10/23/07**	**low baseflow**	<2	133	<2	<0.02	<0.50	<5	<2	<10	292	10	<2

Sample ID		**Flow**	**Pb µg/L**	**Sb µg/L**	**Se µg/L**	**Si ug/L**	**Sn µg/L**	**Sr ug/L**	**Ti µg/L**	**Tl µg/L**	**V µg/L**	**Zn µg/L**
WBP-1	**4/25/07**	**melt, very high**	<2.0									1.3
BB-1	**4/25/07**	**melt, very high**	<2.0									1.6
WBP-2	**4/25/07**	**melt, very high**	<2.0									1.4
WBP-1	**6/26/07**	**baseflow**	<2	<2	<10	2.67	<10	11	<5	<10	<5	<5
BB-1	**6/26/07**	**baseflow**	<2	<2	<10	7.23	<10	95	<5	<10	<5	<5
WBP-2	**6/26/07**	**baseflow**	<2	<2	<10	2.68	<10	11	<5	<10	<5	<5
PEN18	**6/26/07**	**baseflow**	<2	<2	<10	1.30	<10	15	<5	<10	<5	<5
BB-1	**10/23/07**	**low baseflow**	<2	<2	<10		<10		<5	<10	<5	9
WBP-6	**10/23/07**	**low baseflow**	<2	<2	<10		<10		<5	<10	<5	<5

IV. The Search for Problem Sources:

In order to evaluate the metals and low pH sources, aerial photos (such as Figure 1) were used to locate potential ore pits. The pits were investigated on foot from the Iron Mountain Road. Three pits were found and photographed (Figure 5). The log yard appeared to have been excavated long before it became a storage area for modern logging crews (Figures 6 & 7). This pit was shallow, only a few feet of overburden had been removed, exposing bedrock immediately below. Due to the general lack of soils and recent disturbance due to log storage, this pit had very little plant cover. The second pit was very small (Figure 8). It was dug into the mountain side leaving large stones behind. The third pit (Figure 9) was the second largest and the deepest. This pit was internally draining and had some sparse grass cover. Only the first pit had any evidence of surface water drainage, and this was extremely small given that there had been 1.02 inches of rain the previous day (October 7, 2009 as recorded in Millinocket). A field pH meter recorded a pH of 2.2 in the runoff. Surface runoff from this site crossed under the Iron Mountain Road and flowed down the mountain side toward Blood Brook.

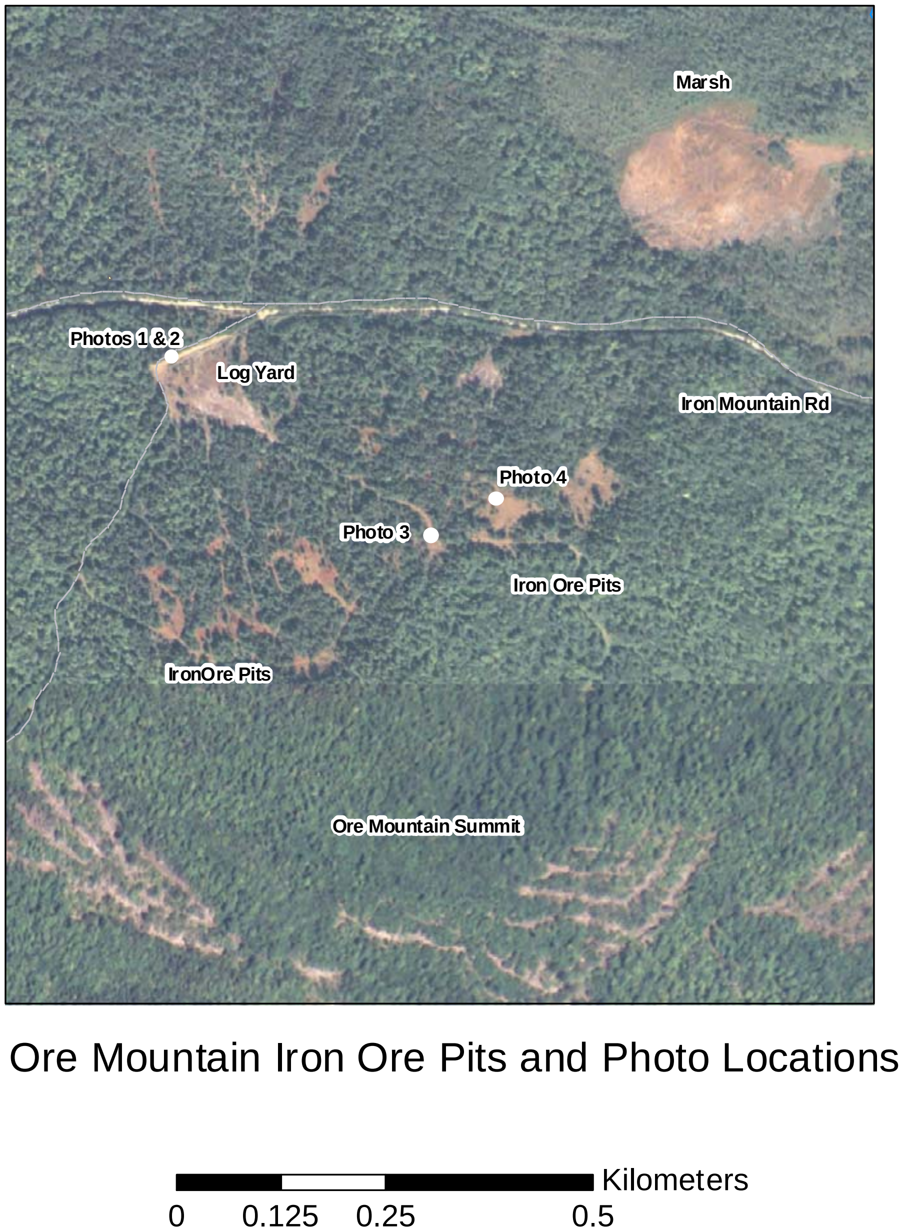


Figure 5. Locations of ore pits and of photos taken on Ore Mountain on October 8, 2009. The parallel roads on the bottom of the figure are modern logging roads and skidder trails.

Figure 6. Photo 1 was taken from the bottom of the log yard/lower pit (along the Ore Mountain Road) after a rainstorm of 1.02 inches the previous day. The photo is looking west. This pit had a lot of exposed bedrock and a few small springs. Woody debris was common and there was very little plant cover.

Figure 7. Photo 2 was taken in the bottom of the first pit, showing a small amount of surface water drainage after over an inch of rain the previous day. The pH of this runoff water was 2.2.

Figure 8. Photo 3 showing the second pit, looking northwest.

Not all pits were visited. However, the ore pits are some distance from Blood Brook and the only surface water drainage that was found was small and probably intermittent (rain dependent). Some more investigations of the pits are planned for the 2010 field season, but at this time it seems likely that the connections between the ore deposit and Blood Brook are primarily through groundwater. So there seems to be no easy solution to the acid mine drainage (i.e., it is not as simple as diverting surface drainage into limestone filled drywells, for instance). It is even possible that the conditions documented in Blood Brook are natural, and have always been that way.

Figure 9. Photo 4 was taken from the bottom of the third pit while looking south.

V. Conclusions:

The water quality of Blood Brook is very poor, having been strongly impacted by acid mine drainage. Both pH and exchangeable aluminum were detected at levels that are lethal to most animals. Due to the weak surface water connections from the ore pits to Blood Brook, it appears that the impact to Blood Brook may be primarily due to groundwater and natural processes. Without better point sources for the acidity and metals, it would be difficult to design a mitigation program.

There is very little evidence at this time that Blood Brook has a noticeable impact on the quality of the West Branch of the Pleasant River. One sample from the West Branch immediately below Blood Brook taken on April 25, 2007, had a low pH with elevated iron, aluminum and sulfur concentrations. Weathering of pyrrhotite appears to be the acidity source. However, the impact does not extend more than a few hundred feet downstream. What little enrichment was documented, may be due to a combined influence of Blood Brook and more local sources such as the slag and other waste materials that have accumulated at the Iron Works.

VI. References and Resources:

Acid Drainage Technology Initiative website http://aciddrainage.com/amd.cfm

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