FIELD DISSOLUTION OF TEST PILES OF DULUTH COMPLEX ROCK

Report to the US Bureau of Mines
Salt Lake City Research Center

Minnesota Department of Natural Resources
Division of Minerals

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Cooperative Agreement No. C0219003

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ABSTRACT

This report describes the quality of drainage and the release of sulfate, calcium, and magnesium from five test piles of Duluth Complex with sulfur contents of 0.63 (three piles), 0.79, and 1.41 percent. The periods of record for the piles ranged from twelve to fourteen years. The pH of drainage from the piles decreased as the time of dissolution and solid-phase-sulfur content increased, as was the case in laboratory experiments. At the end of the period of record the drainage pH values ranged from about 5 for the 0.63-percent-sulfur piles to 3.5 for the 1.41-percent-sulfur piles.

Over the entire period of record, average rates of sulfate release ranged from 2.1 to 10.5 millimoles per ton per day, increasing as the solid-phase-sulfur content of the pile increased. Average rates of calcium release ranged from 1.2 to 2.4 millimoles per ton per day and were relatively constant with respect to solid-phase-sulfur content. Average rates of magnesium release ranged from 0.55 to 3.7 millimoles per ton per day and increased with solid-phase-sulfur content. Annual release rates for sulfate and calcium were relatively constant over time, while those for magnesium tended to increase over time. These trends were consistent with previous observations in the laboratory. Annual release rates for all three parameters increased with increased annual drainage volume, a variable not examined in the laboratory.

The pH of drainage from the 0.63-percent-sulfur rock in the field approximated that observed in the laboratory for rock of similar sulfur content. In contrast, the pH of field drainage from the 0.79- and 1.41-percent-sulfur rock was about one unit lower than the corresponding laboratory drainage. Release rates for sulfate, calcium, and magnesium in the field were typically 10 to 40 percent of those observed in the laboratory. Neutralization potentials in the field were typically 5 to 50 percent of the corresponding laboratory values.

The differences between the field and laboratory results are apparently due to differences in particle size distribution and hydrologic behavior of the field piles. Additional analysis of the field data and laboratory experimentation will elucidate the influence of these variables on the quality of drainage from waste rock. A better understanding of these and other factors is critical for modelling the quality of drainage from waste rock, as well as the design and interpretation of laboratory tests for drainage quality prediction.

INTRODUCTION

In 1974, AMAX Exploration Inc. reached an agreement with Bear Creek Mining Company and assumed their leases for properties located in T60N, R12W, about four miles southeast of Babbitt, Minnesota. The state owns the land and mineral rights on much of the property, and AMAX requested permission to construct an exploratory shaft. In 1974, very little information existed on the potential drainage problems associated with copper-nickel development in Minnesota. The state and AMAX agreed to commence field leaching tests on Duluth Complex rock.

In 1975 shaft development began, and in 1977 AMAX constructed six test stockpiles containing lean ore material. Water quality samples were collected periodically from each pile in 1977 and the data were compiled by AMAX (1978). The test pile studies were conducted from 1978 through the present by the Minnesota Department of Natural Resources (MNDNR), Division of Minerals. Kennecott Minerals Company assumed the leases in 1981 and terminated them in 1989.

This report presents data on the quantity and quality of drainage from the test piles. It is the third in a series of reports on dissolution of Duluth Complex rock. The two previous reports describe laboratory experiments on the dissolution of drill core and blast hole samples of Duluth Complex rock (Lapakko, 1993a; Lapakko, 1993b). The results from the laboratory and field studies will be used by the Salt Lake City Research Center to aid in development of a mathematical dissolution model and for comparison with laboratory data generated at the Center.

OBJECTIVES

As presented in Cooperative Agreement No. C0219003, the objectives of this report on the drainage quality from field test piles of Duluth Complex rock are to:

a) describe the variation of drainage quality with respect to time;
b) determine the chemical mass release of sulfate, calcium, and magnesium;
c) describe the variation of drainage quality and mass release with respect to flow;
d) describe the variation of drainage quality and mass release with respect to sulfur content;
e) determine the buffering capacities, or neutralization potentials, of the Duluth Complex rock samples examined; and
f) compare field results with those generated in the laboratory.

METHODS

Climate

Annual precipitation in the study area averages 72.1 cm (Hickok and Associates, 1977), and the average watershed runoff is 26.2 cm/yr (Siegel and Ericson, 1980). Temperatures are extreme, averaging -14°C in January and 19.1°C in July, with an annual mean of 3.6°C; the ground is covered with snow for an average of 140 days per year (Hickok and Associates, 1977).

Test Pile Construction

Materials

Six test stockpiles containing 820 to 1300 metric tons of low grade copper-nickel material were constructed in 1977 (figure 1). Stockpiles 1 to 4 were constructed of rock mined during the shaft sinking operation, while piles 5 and 6 contain material from underground drifts. The chemical compositional ranges for the piles are 0.30 to 0.35 percent Cu, 0.083 to 0.085 percent Ni, and 0.63 to 1.41 percent S (table 1). A grab sample was taken from test pile FL1 for more extensive chemical (table 2) and mineralogical analyses. The major sulfide minerals present in the gabbro are pyrrhotite, chalcopyrite, cubanite, and pentlandite, but over 90 percent of the rock is composed of silicate minerals. The major silicate minerals are plagioclase, pyroxenes, and olivine (table 3).

Approximately 40 percent of test pile FL4 was removed in 1982, and a representative sample, weighing over three tons, was collected for analysis of particle size distribution, specific surface area, chemistry, and mineralogy. Particle size distribution was determined by manual measurement, box screen, and a Sweco[1] separator. Boulders were measured with a tape measure and removed manually. The remaining material was raked through screens (0.9 by 1.2m) which were sloped about 20 percent, and had openings of 152, 76.2 and 25.4 mm. The material finer than 25.4 mm was then sieved with a Sweco Vibro-Energy Separator, with screen openings of 19.0, 12.7, 6.40, 2.00, and 1.41 mm. A representative sample of the less than 2.00 mm (10 mesh) material was then dry sieved on a Ro-Tap Sieve Shaker. Masses of 500 to 600 g were sieved for 20 minutes with screen openings of 0.50, 0.177, 0.149, 0.105, 0.074, and 0.053 mm. Finally, representative samples of each of the seven finest fractions were submitted to the Minnesota Department of Transportation (DOT) for a standard dry sieve/hydrometer analysis. Sieve openings of 0.84, 0.42, 0.250, 0.149, 0.105, and 0.074 mm were used. Hydrometer analysis was conducted on the less than 0.074 mm fraction to separate the less than 0.053 mm fraction. The particle size distribution data presented in table 4 are based on the unmodified coarse material separation plus the fine material dry-sieving as modified by the DOT results.

[1] Reference to specific trade names does not imply endorsement by the MNDNR.

The sand, silt, and clay fractions were analyzed for specific surface area, chemistry, and mineralogy; the coarse fraction was excluded because its specific surface area is relatively small, and is therefore less influential in chemical reactions. The values determined represent both the Duluth Complex solids and precipitates which accumulated during leaching in the stockpile. The specific surface area of the fine fractions was roughly inversely proportional to the particle size diameter (table 5). The pH decreased and the sulfide and trace metal content increased with decreasing particle size of the gabbro material (table 5). The finer sand, silt, and clay fractions had S, Cu, and Ni contents above the 0.634 pct S, 0.348 pct Cu, and 0.083 pct Ni levels estimated for the FL4 stockpile as a whole.

X-ray diffraction (XRD) analyses were conducted on the 0.053 to 0.075 mm, the 0.075 to 0.105 mm, and the 0.105 to 0.149 mm size fractions of the rock. Approximately half of this material was plagioclase (with a Na:Ca ratio of about 2:3) and half a mixture of olivine (with a Fe:Mg ratio of 1:4 to 1:9), pyroxene, and biotite. Lesser amounts of magnetite, amphibole, chlorite, and possibly smectite and/or vermiculite were also identified. The phyllosilicate minerals (biotite, chlorite, smectite, vermiculite) were more common in the finer size fractions.

Reclamation Treatments

Three of the piles were left uncovered, as controls, and the remaining three piles were covered (May 1978) with 18 to 29 cm of soil obtained from a nearby borrow pit. Pile 2 was covered with fertile topsoil obtained from the top 30 cm of the borrow pit, while piles 3 and 5 were covered by infertile coarse sand. In 1980, an additional 30 cm of sandy till was added to pile 5.

In June of 1978, all covered piles were fertilized with 10-20-30 fertilizer (392 kg/ha), broadcast seeded, and mulched with straw (3.4 m/ha). Minnesota Highway #5, United States Forest Service wildlife mix, and native seed mixes were applied at rates of 34 and 67 kg/ha. In 1979, an additional plot containing jack pine, red pine, trembling aspen, and an upland willow was established on each of the covered piles. Additional seed was also applied to piles 3 and 5. When the sandy till was applied to pile 5 in 1980, the entire pile was reseeded with a mixture of alfalfa, U.S. Forest Service wildlife mix, and sweet clover at rates of 45, 67, and 113 kg/ha, respectively. A 13-12-12 fertilizer (730 kg/ha) was added to piles 2, 3, and 5 at this time. Additional details on vegetation, fertilization, as well as the application of lime-stabilized sludge to pile FL3 (1980, 1982) and a sodium-lauryl-based bactericide to FL5 (1982), are available in Eger and Lapakko (1985) and from the MNDNR.

In 1982 approximately 40 percent of test pile FL4 was removed for use in another study of stockpile reclamation techniques (Eger et al., 1984). Piles FL1, FL3, and FL6 were partially covered by plastic at the end of the 1989 field season, for the practical purpose of reducing the volume of drainage which the MNDNR was required to treat. The plastic covers were shredded during 1990 by exposure to the elements. A more robust Hypalon cover was placed onto FL3, thereby terminating flow from this pile at the end of the 1989 field season.

Water Sampling and Analysis

Volumes of input precipitation were measured with a standard rain gauge (Science Associates, Inc. NWS Spec. 450.230). Time and duration of rain events were obtained using a recording rain gauge (Science Associates, Inc., NWS Spec. 450.220) through 1984.

For drainage collection, each pile is underlain by an impervious Hypalon liner (30 mil) which is sloped toward a 15.2 cm perforated plastic pipe (figure 2). The drainage collected from the piles flows to a common sump. A limited number of water quality samples were collected in 1977, but no flow measurements were made. Since methods in this year deviated from those over the remainder of the study and the data were sparse, the results are not addressed in the text. During 1978, each pile was fitted with a cumulative flow meter, event recorder, and a flow-weighted-composite sampler (figure 3). For each pump discharge, a fixed volume of sample was placed into the compositing container. (The timing of flow was more precisely registered on a Rustrak event recorder (Model 292-4) from 1978 through 1984.)

The composite samples were analyzed weekly through 1990 and bi-weekly subsequently. Samples were filtered through 0.45-micron filters to remove suspended materials prior to analysis. Routine analyses included pH, alkalinity, specific conductance, sulfate, copper, nickel, cobalt, zinc, calcium, and magnesium, although calcium and magnesium were not analyzed in 1983. (Some samples were also analyzed for sodium, potassium, chloride, and dissolved organic carbon.) Specific conductance was analyzed using a Myron L conductivity meter. pH was determined using a Radiometer 29 pH meter from 1978 to 1988, and subsequently using an Orion SA 720 with a Ross combination electrode (8165). Sulfate was analyzed using either the barium sulfate turbidimetric technique (APHA et al., 1975) or occasionally, for low concentrations, a Technicon autoanalyzer. Metals were analyzed with a Perkin Elmer 603 atomic absorption spectrophotometer.

Calculations

From the weekly and bi-weekly analyses of composite samples, monthly-flow-weighted-mean concentrations were calculated. This concentration and the volume of drainage which occurred during the period were assigned to the date in the middle of the period. The mass of sulfate, calcium, and magnesium released during the period was calculated as the product of the flow-weighted-mean concentration and the drainage volume. Missing concentrations were estimated for the mass release calculation as the time-weighted mean of the previous and subsequent concentrations. Missing values occurring at the beginning (or end) of the year were estimated as the first (or last) measured concentration in that year.

Annual mass release was calculated as the sum of the mass release values for the individual periods for each year. Annual-flow-weighted-mean concentrations were calculated by dividing the annual mass release by the annual flow. The annual rates of release were calculated as the annual mass release divided by the product of the number of days of flow

and the mass of the pile (metric tons). Average rates of release for the entire period of record were calculated by dividing the total mass release by the number of days of flow.

Neutralization potentials (NP) were calculated to determine the amount of acid neutralized by the solids prior to the drainage pH decreasing and, for the duration of the period of record, remaining below pH values of 7, 6, 5, 4.5, 4, and 3.5. The acid neutralized was calculated by two methods: as the a) cumulative sulfate release (expressed as mg $CaCO_3$/g rock) and b) cumulative calcium and magnesium release (expressed as mg $CaCO_3$/g rock) prior to the drainage pH decreasing and remaining below the specified pH value. If the drainage pH from a given solid never decreased permanently below a specified value, the NP was reported as "greater than" the total sulfate release for the period of record. Additional detail on calculation of mass release and neutralization potential are presented in appendix 1.

RESULTS AND DISCUSSION

The generation of acidic drainage is the major water quality concern associated with mine wastes. Acid is produced as a result of the oxidation of iron sulfide minerals. The rate of this oxidation, and the attendant acid production, is proportional to the iron sulfide surface area available for reaction. The solids examined in this study were mined from a shaft and drifts in Duluth Complex rock. It is assumed the iron sulfide surface area is roughly proportional to the solid-phase-sulfur content. This assumption is predicated on the concept that the size distribution of rocks in the various piles is similar, and the grain size and degree of liberation of sulfide minerals does not vary greatly among the piles. The non-sulfide mineralogy of the rock was also assumed to be fairly uniform, although some exceptions most likely occurred. This suggests that the acid-neutralizing ability of the solids was somewhat uniform.

The test piles typically produced drainage between the middle of March and the middle of November, with an average flow season of 245 days. As was the case in laboratory studies, and consistent with the aforementioned assumptions, drainage pH decreased as the solid-phase sulfur content increased. The variation of drainage quality and chemical mass release with time, solid-phase sulfur content, and drainage volume is presented first. This presentation, in conjunction with the NP values determined for the test piles, provides the background necessary for comparison of the field results with those from the laboratory. The period of record for test pile 4 was only five years, as compared with 12 to 14 years for the remaining five piles. Although tabular and graphical data for this pile are presented, they are not discussed due to the short period of record.

Drainage Quality

Annual median pH and annual-flow-weighted-mean concentrations of sulfate, calcium, and magnesium are presented to describe the variation of drainage quality with respect to time,

solid-phase-sulfur content, and annual drainage volume. These values are presented in table 6. Detail on drainage quality variation over shorter periods is presented in appendix 2.

The pH of drainage from the test piles generally decreased over time, and decreased as the solid phase sulfur content increased (figure 4). At the beginning of 1978, the pH of drainage from all piles was between 7 and 8. For the three piles containing 0.63-percent sulfur, drainage pH decreased gradually from circumneutral to the range of 4.8 to 5.3. The pH of drainage from the piles containing 0.79 and 1.4 percent sulfur decreased and plateaued within a range of about 0.2 to 0.3 pH units. The pH of drainage from the 0.79-percent sulfur pile decreased until 1982 and subsequently oscillated in the typical range of 4.0 to 4.3. The pH of drainage from the 1.41-percent sulfur pile decreased to a lower level, from a median value of 5.5 in 1978 to a typical range of 3.4 to 3.6 from 1979 to 1991. The flow-weighted-median values actually increased from 1982 (3.40) to 1991 (3.60).

In general, annual-flow-weighted-mean sulfate concentrations for the individual piles increased during the first three to four years and then oscillated within a fairly constant range; increased as the solid-phase-sulfur content increased (figure 5); and were independent of flow (appendix 2). Some deviations from the general trends were observed. Most notably, sulfate concentrations in drainage from the 1.41-percent-sulfur pile increased to peak levels between 1981 and 1985, and then decreased. From 1987 to 1991, the flow-weighted-mean sulfate concentrations from this pile were comparable to, or lower than, those from the 0.79-percent-sulfur pile. Sulfate concentrations from the 0.79-percent sulfur pile increased over time (figure 5). However, these temporal variations from 1981 through 1991 were relatively small. In general the maximum annual-flow-weighted-mean sulfate concentrations were typically within a factor of two of the minimum value observed during this period.

Annual-flow-weighted-mean magnesium concentration variations over time were generally parallel to those observed for sulfate (figure 6), and were independent of flow volume (appendix 2). With respect to solid-phase-sulfur concentration, annual-flow-weighted-mean magnesium concentrations were lowest for the 0.63-percent-sulfur piles and in a similar range for the two piles of higher sulfur content. For the individual piles, annual-flow-weighted-mean magnesium concentrations tended to decrease as the annual median pH decreased.

Annual-flow-weighted-mean calcium concentrations were typically fairly constant, ranging from about 4 to 7 millimoles per liter (figure 7). As implied by the constant range, there was little dependence of annual-flow-weighted-mean calcium concentrations on time of dissolution, sulfur content, or flow. The values for the 1.41-percent-sulfur pile appeared to parallel the decreasing trend observed for sulfate concentrations from 1985 to 1991. As a result of the temporal parallelism of magnesium and sulfate concentrations, the sum of calcium and magnesium concentrations tended to parallel sulfate concentrations over time (figure 8).

Annual Rates of Release

The annual rate of sulfate release from each pile oscillated within a fairly constant range (tables 7-12). In general, annual sulfate release increased with the solid-phase-sulfur content of the pile, although the rates for the 0.79-percent-sulfur pile were comparable to or exceeded those for the 1.41-percent-sulfur pile from 1984 to 1991 (figure 9). Sulfate release also increased with annual flow (appendix 4), and temporal variations in the annual rate were largely due to variations in annual flow. A graphic example of the flow dependence is the low sulfate-release rate from the 0.79-percent-sulfur pile in 1990, during which the pile was partially covered with plastic. The drainage volume and sulfate mass release were consequently low.

Variations in magnesium release followed similar trends. Similar to the sulfate-release rates from 1984 through 1991, magnesium release from the 0.79-percent-sulfur pile was usually higher than that from the 1.41-percent-sulfur pile (figure 10). In contrast, the annual rates of calcium release typically fell into the range of one to three moles per ton per day (figure 11). They did not vary with time or solid-phase-sulfur content, but did increase linearly with annual flow (appendix 4). The average rates of sulfate, calcium, and magnesium release for the period of record are presented in table 13.

Neutralization Potential

The NP values calculated based on the sum of calcium and magnesium release ranged from 55 to 90 percent of those calculated based on sulfate release, which was deemed excessive. The combined copper and nickel sulfide content comprised 15 to 35 percent of the total sulfide mineral content in the test piles, a considerably higher fraction than for the laboratory samples. It was concluded that a significant amount of the sulfate release from the test piles was due to oxidation of trace metal sulfides (as opposed to iron sulfides). Since this oxidation does not necessarily lead to acid production, the sulfate release overestimates acid production. Consequently, the neutralization potential data presented are based on the sum of calcium and magnesium release.

The pH of drainages from the 0.63-percent rock did not decrease permanently below pH 5.0, although the pH of drainage from pile 3 appeared to be near this point at the end of 1989. The approximate ranges of NP values determined for endpoint pH values of 7.0 (NP_{pH7}) and 6.0 (NP_{pH6})were 0.2 to 0.4 mg $CaCO_3$/g rock and 0.4 to 1.3 mg $CaCO_3$/g rock, respectively (table 14). The 1.3 mg $CaCO_3$/g rock value determined for pile 3 is assumed to be near the NP_{pH5} for this pile.

The lowest NP endpoint pH values for the piles with sulfur contents of 0.79 and 1.41 were pH 4.5 and pH 4.0, respectively. The NP_{pH7} and NP_{pH6} values for these piles were lower than those from the lower-sulfur rock (table 14). Furthermore, the NP values for the 1.41-percent rock were lower than those for the 0.79-percent rock. This trend of decreasing NP with increasing sulfur content was also observed with laboratory samples.

Comparison of Field and Laboratory Data

Certain similarities were apparent between the field data and laboratory data (table 15).

1) Drainage pH generally decreased, or decreased and plateaued, as the time of dissolution increased. A subtle variation on this trend was a possible slight increase in the pH of drainage from the 1.41-percent-sulfur pile from 1982 to 1991 (median annual pH values of 3.40 and 3.60, respectively).

2) In both laboratory and field drainage pH values decreased as solid-phase-sulfur content increased.

3) The rates of sulfate release were fairly constant over time. The ratio of maximum-sulfate-release rate to minimum-sulfate-release rate for a laboratory sample was typically less than 3:1. This ratio was observed to increase if drainage pH decreased below about 4. The corresponding ratios for the test piles ranged from 2.7:1 to 3.9:1.

4) In both laboratory and field tests the rate of sulfate release increased with solid-phase-sulfur content. Sulfate release rates from the test piles also increased with drainage volume, a variable not examined in laboratory tests.

5) Rates of calcium release were relatively constant over time, although it must be noted that laboratory data on calcium release are limited.

6) Rates of calcium release were relatively constant with respect to sulfur content. The rates of calcium release from the test piles also increased with drainage volume, a variable not examined in laboratory tests.

7) Rates of magnesium release increased as time increased, although it must be noted that laboratory data on magnesium release are limited.

8) Rates of magnesium release increased as solid-phase-sulfur content increased. The rates of magnesium release from the test piles also increased with drainage volume, a variable not examined in laboratory tests.

9) Neutralization potential values were low and decreased with increasing sulfur content.

Field and laboratory data can also be quantitatively compared based on drainage pH, neutralization potentials, and rates of release. The minimum drainage pH values observed for the 0.63-percent-sulfur rock in the field ranged from 4.71 to 4.96, and were reasonably consistent with the laboratory relationship between drainage pH and solid-phase-sulfur content. However, the minimum pH of drainages from the test piles with sulfur contents of 0.79 and 1.41 percent sulfur were about one unit lower than expected based on laboratory

data (figure 12). (The minimum pH values observed were typically isolated excursions, and recurrent low pH values were typically 0.1 to 0.2 units higher.)

The discrepancy between laboratory and field drainage pH data suggests that the laboratory tests either inhibited the rate of acid production or enhanced the rate of acid neutralization relative to the field tests. Drainage pH in the field may have been lower due to a higher iron sulfide surface area than indicated by the sulfur content alone. Twelve percent of the rock in the piles was smaller than two millimeters in diameter (table 4). The specific surface areas of this material were in the range of 0.6 to 4.7 m^2/g (table 5). This was considerably higher than the 0.061 to 0.239 m^2/g and 0.020 to 0.039 m^2/g ranges estimated for the gravel and boulder/cobble fractions. The sulfur content of the smaller size fractions ranged from 0.67 to 1.94 percent (table 5), as compared to the bulk sulfur content of 0.63. Therefore, the fraction of the total available surface area contributed by the small particles is quite high relative to the larger particles. Due to their higher sulfur content, a greater fraction of the surface area is composed of iron sulfides. Thus, the fraction of the rock comprised of iron sulfide was most likely higher than indicated by the sulfur content of 0.63 percent. In contrast, the solids in the laboratory study were in the size range $0.053 <$ particle diameter ≤ 0.149 mm, and the potential of preferentially concentrating sulfides in a smaller size fraction was limited.

The acid neutralization may have been enhanced in the laboratory due to the consistently small particle size. As is the case with sulfide mineral oxidation, the dissolution of silicate minerals is a surface reaction. If the specific surface area of silicate minerals present in the laboratory samples exceeded that in the test piles, the laboratory solids would be expected to neutralize acid more efficiently.

The neutralization potentials of the test piles were lower than those for laboratory samples, which is consistent with the lower drainage pH levels observed in the field. The NP values for the 0.63-percent-sulfur rock were roughly 25 to 50 percent of those observed for laboratory samples of similar sulfur content (table 16). Although the NP_{pH6} and NP_{pH7} values from pile 3 were higher than this range, the NP_{pH5} value was 46 percent of the corresponding value for laboratory samples.

The field NP values for the 0.79-percent-sulfur rock were 13 to 54 percent of the corresponding values for laboratory samples of similar sulfur content. The ratios of field to laboratory NP were lowest for the 1.41-percent-sulfur rock, typically five percent or less than those determined in the laboratory.

The low field NP values may have been influenced by factors similar to those discussed regarding drainage pH. First, preferential flow in the field piles would reduce the amount of silicate minerals which could contribute to acid neutralization. For example, if flow through the pile contacted only half the silicate minerals, the observed neutralization potential of the rock would be half the actual value for the entire pile. Second, if the specific surface area of silicate minerals present in the laboratory samples exceeded that in

the test piles, the laboratory solids would be expected to neutralize acid more efficiently. Third, the ratio of available reactive surface area of sulfide minerals to that of silicate minerals present in the test pile rock may have been greater than that in the laboratory. This would be equivalent to increasing the sulfur content of rock in the laboratory. As was observed in the laboratory, neutralization potential tended to decrease as sulfur content increased.

For the entire period of record, average rates of sulfate release ranged from 2.0 to 10 millimoles per metric ton per day, and increased as sulfur content and drainage volume increased. The average rates of calcium release ranged from 2.1 to 2.4 millimoles per ton per day and were fairly constant with respect to sulfur content. Average rates of magnesium release ranged from 0.55 to 3.7 millimoles per ton per day and were lowest for the low-sulfur solids and highest for the solids containing 0.79-percent sulfur.

The rates of sulfate, calcium, and magnesium release observed for the test piles were compared to laboratory rates for the Duluth Complex blast hole samples of similar sulfur content. The laboratory rates were from the last 15 to 36 weeks of the period of record. The ratios of field rates to laboratory rates, or retardation factors, ranged from 0.053 to 0.46, with most values in the range of about 0.1 to 0.36 (table 17). This indicates that the laboratory rates were roughly three to ten times those in the field.

Several factors most likely contributed to the slower rates observed in the field. First, the rates of sulfide and silicate mineral dissolution (per unit mass rock) may be slower than those observed in the laboratory. As discussed previously with respect to drainage pH, the surface area of sulfide and silicate minerals per unit mass rock in the field most likely differs from that in the laboratory. This would affect the rates of sulfide oxidation and silicate mineral dissolution, since both are surface reactions. The reaction environment in the field, where temperatures are colder, may also retard reaction rates. Furthermore, potential lower levels of oxygen within the test piles may limit the rate of sulfide mineral oxidation.

Limited transport of reaction products in the field also may have reduced rates of release. Hydrologic variables which were not influential in the laboratory could have contributed to this transport limitation. The volume of rinse water per unit mass solids yielded approximately 300 L per ton rock per day of drainage in the laboratory, roughly three orders of magnitude greater than the yields of 0.27 to 0.38 L per ton rock per day in the field. The relatively low flow in the field may have limited transport. This is supported by the observation that release rates in the field increased with flow. Furthermore, the flow of the laboratory rinse water through the solids was fairly uniform, whereas preferential flow was probable in the field setting. Preferential flow would limit the transport of reaction products from some rock surfaces. This would essentially reduce the amount of rock in the test piles which was actually contributing to the observed chemical release.

The degree of transport in the field may also be limited by chemical precipitation of dissolution reaction products. In particular, the formation of gypsum might limit the rates

of sulfate and calcium release. Gypsum formation was not a problem in the laboratory since the high rinse water to solid ratio produced relatively low concentrations of sulfate and calcium in the drainages.

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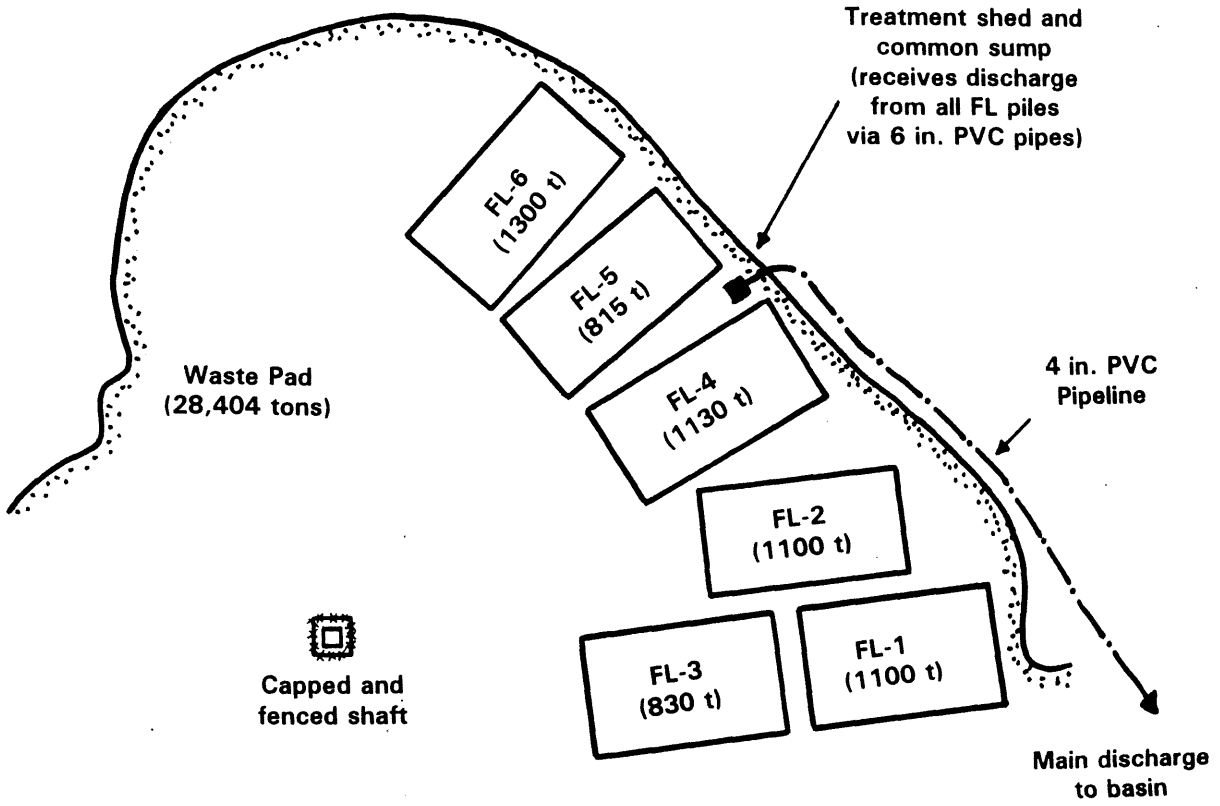

Figure 1. Test piles and drainage collection system layout.

Forty percent of FL-4 was removed in 1982 (leaving approximately 680 of the original 1130 t of material in the pile), thereby terminating the period of record. FL-3 was covered with a synthetic liner at the end of the 1989 field season, thereby terminating the periof of record. Additional information on the test piles is presented in table 1.

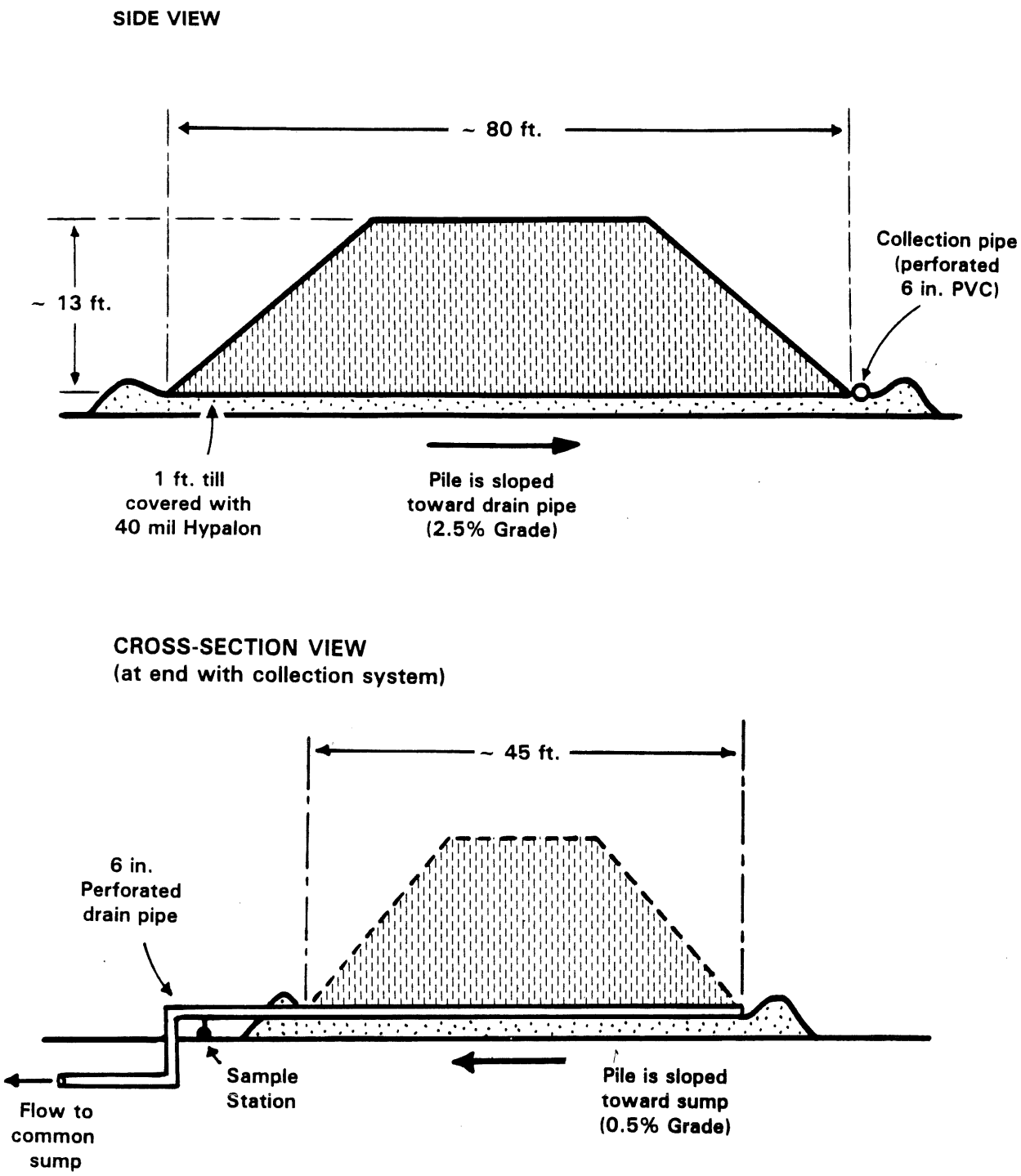

Figure 2. Leachate collection system beneath test piles (schematic; not to scale).

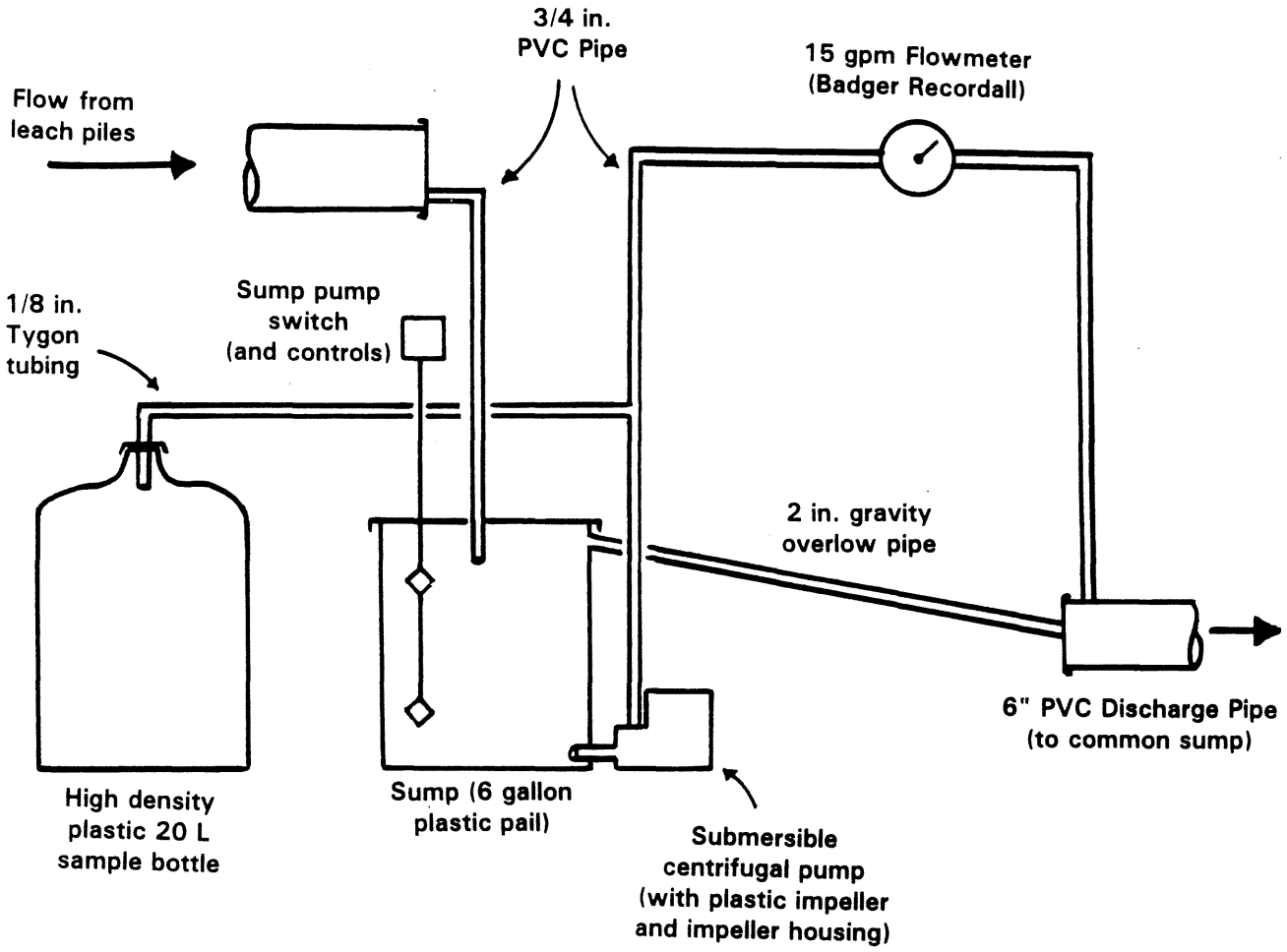

Figure 3. Flow-proportional sampler.

Figure 4. Annual median pH over time for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

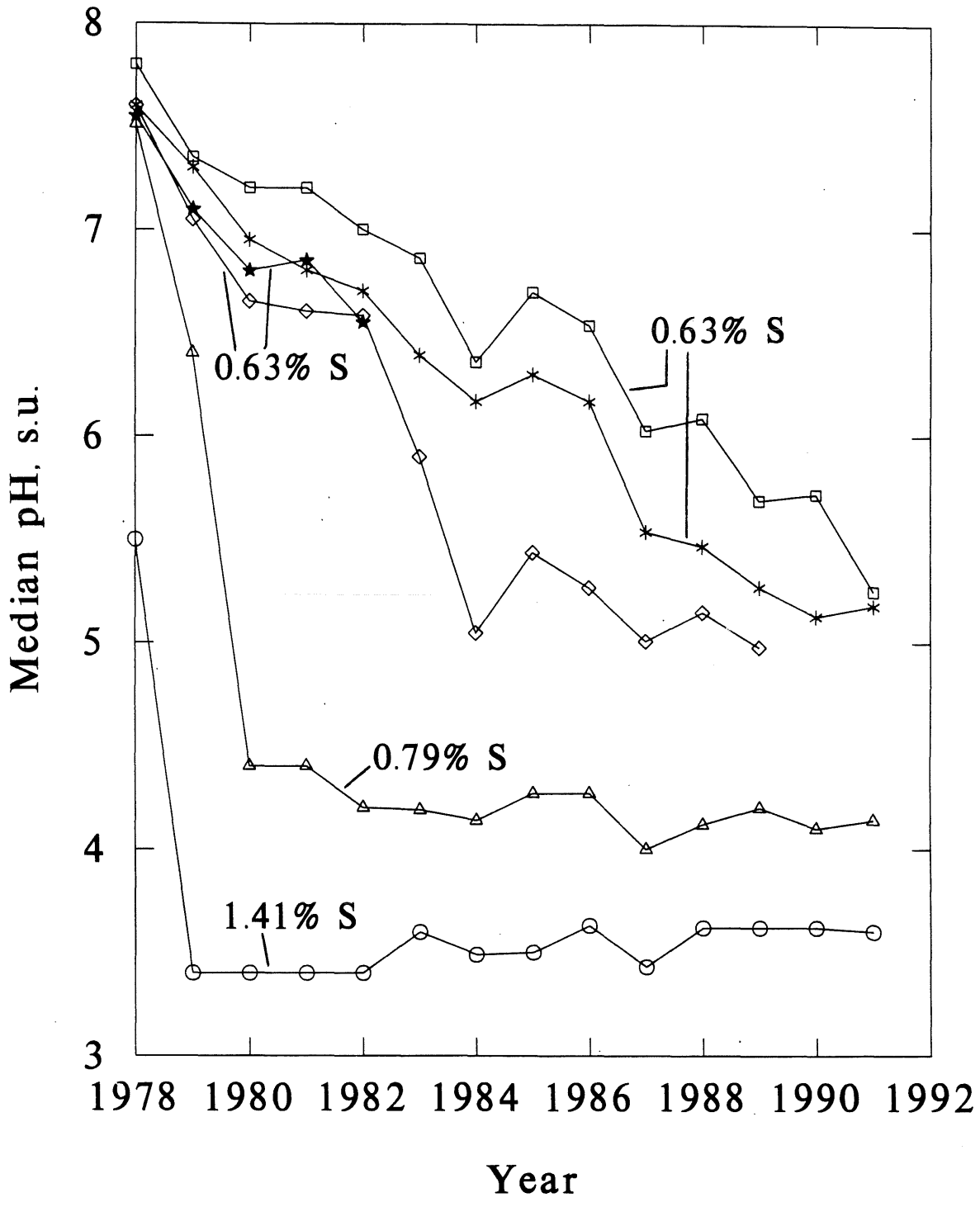

Figure 5. Annual-flow-weighted-mean sulfate concentration over time for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

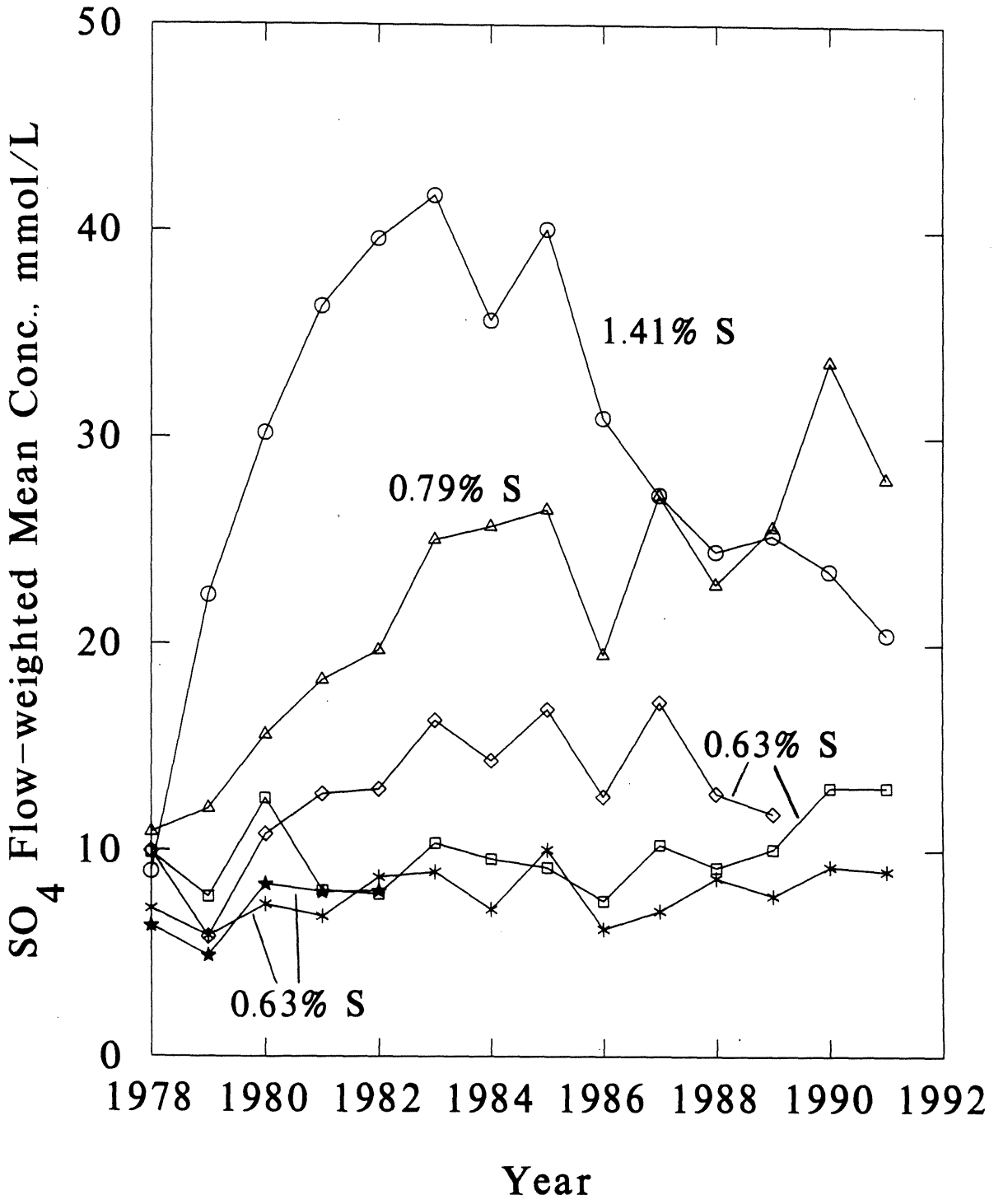

Figure 6. Annual-flow-weighted-mean magnesium concentration for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

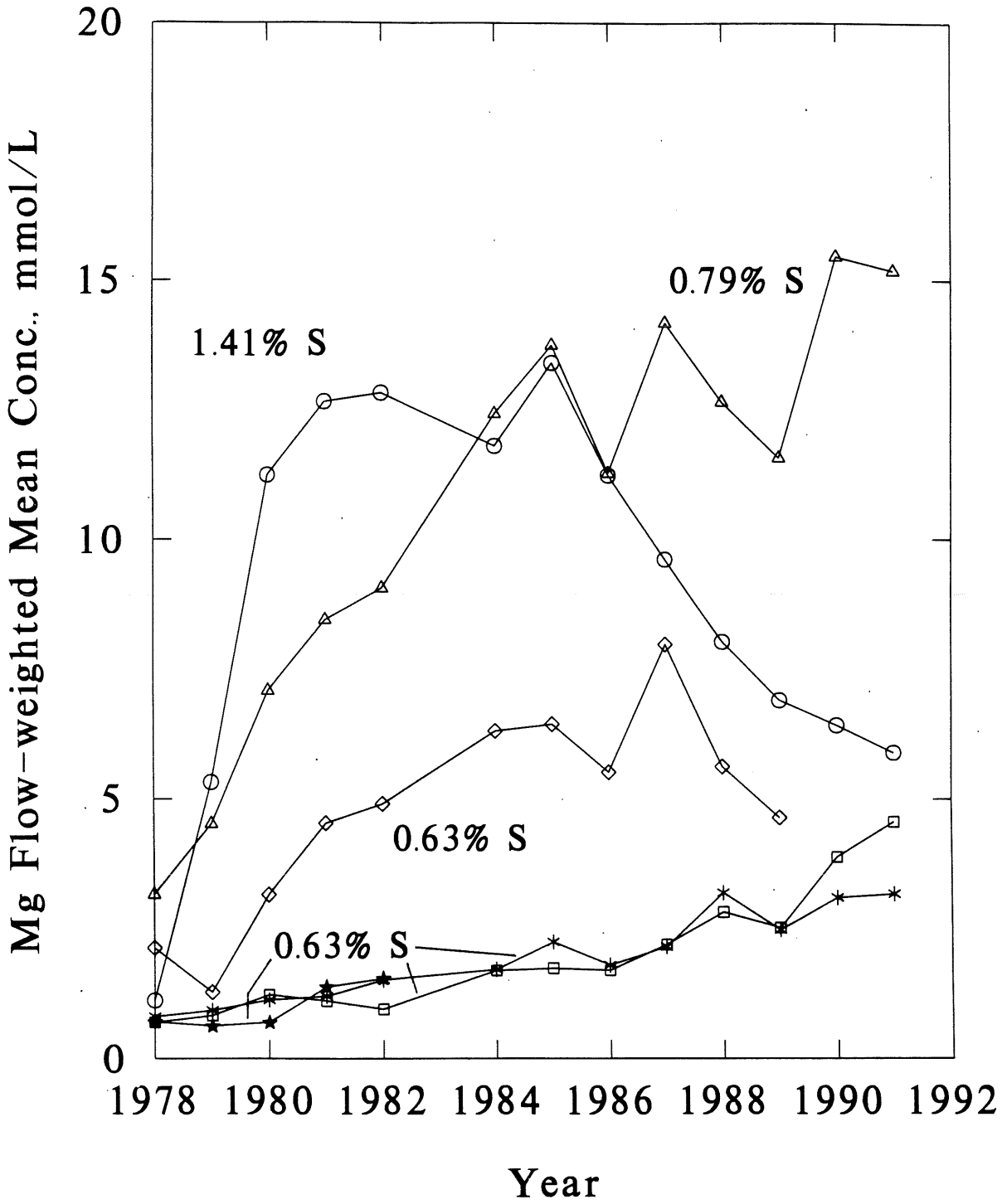

Figure 7. Annual-flow-weighted-mean calcium concentration for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

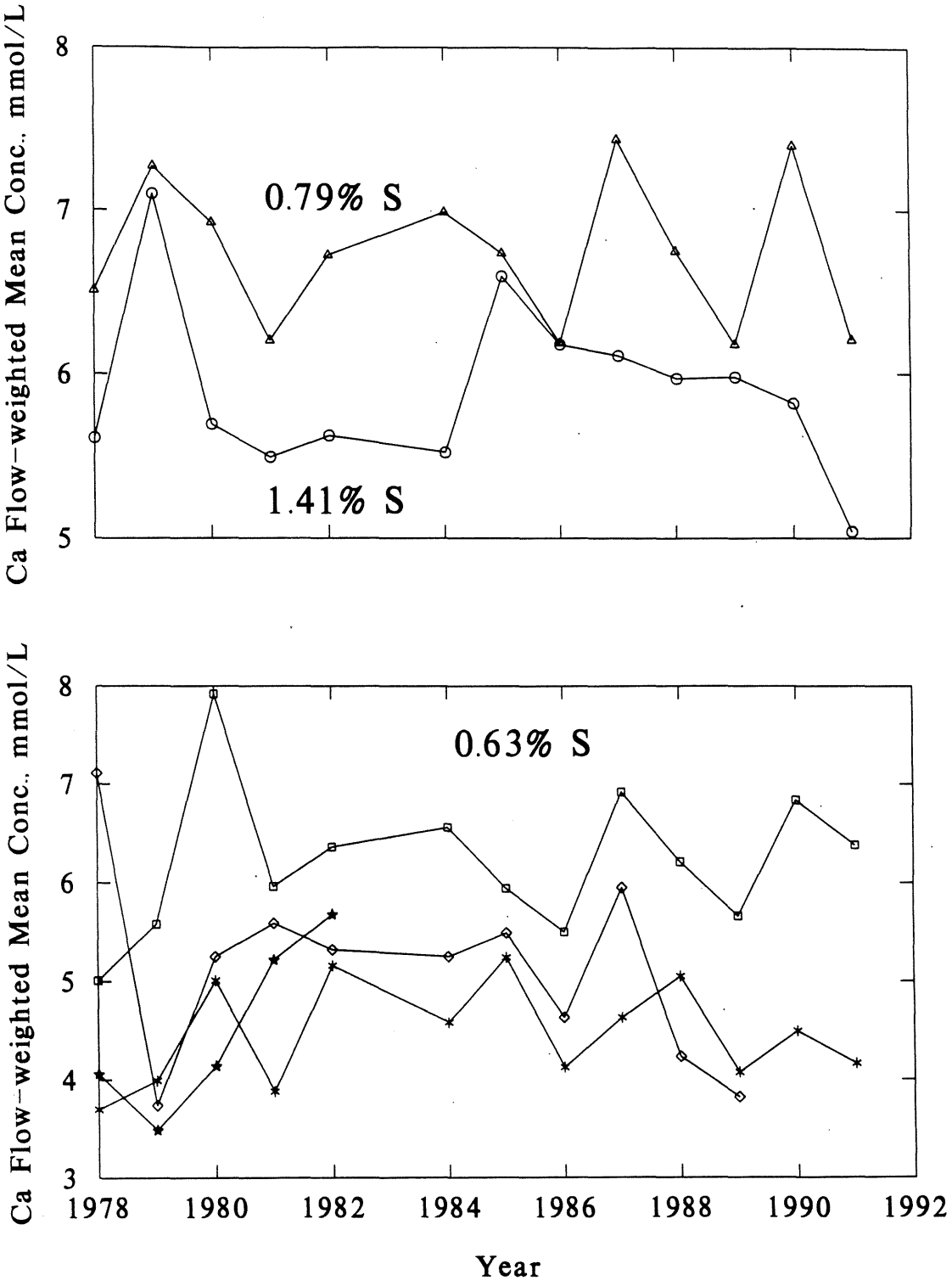

Figure 8. Annual-flow-weighted-mean calcium plus magnesium concentration for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

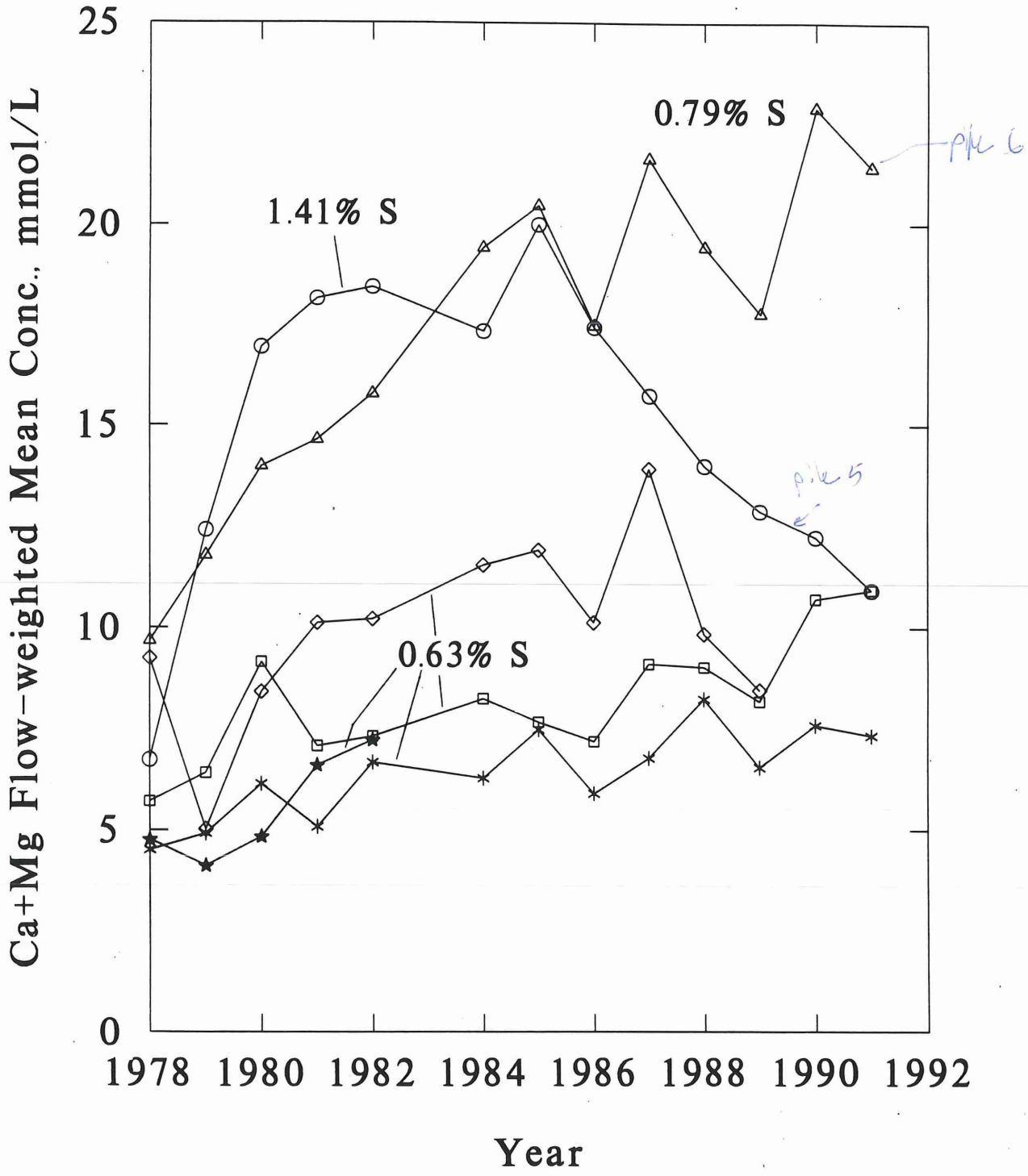

Figure 9. Annual sulfate release rate over time for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

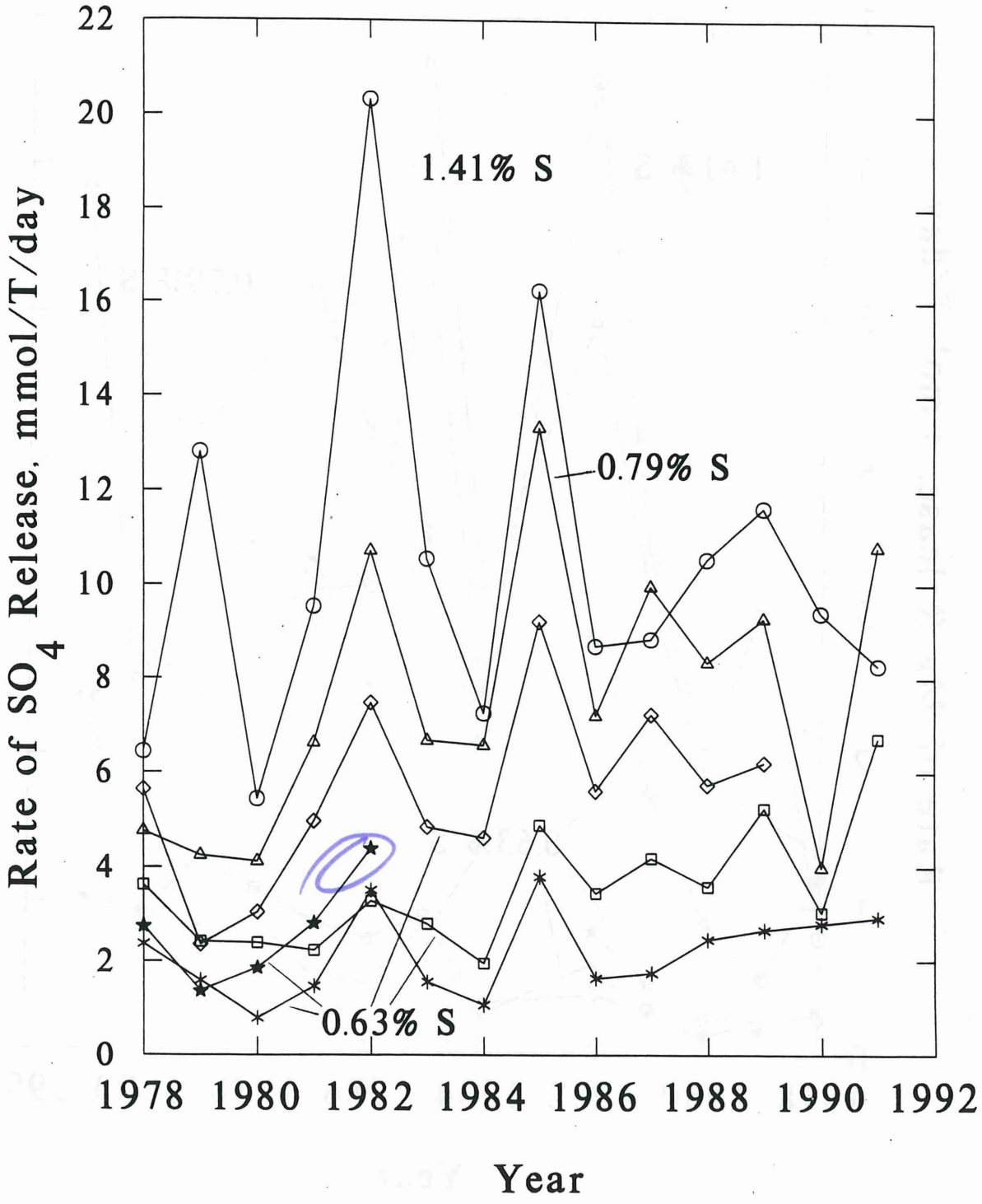

Figure 10. Annual magnesium release rate over time for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

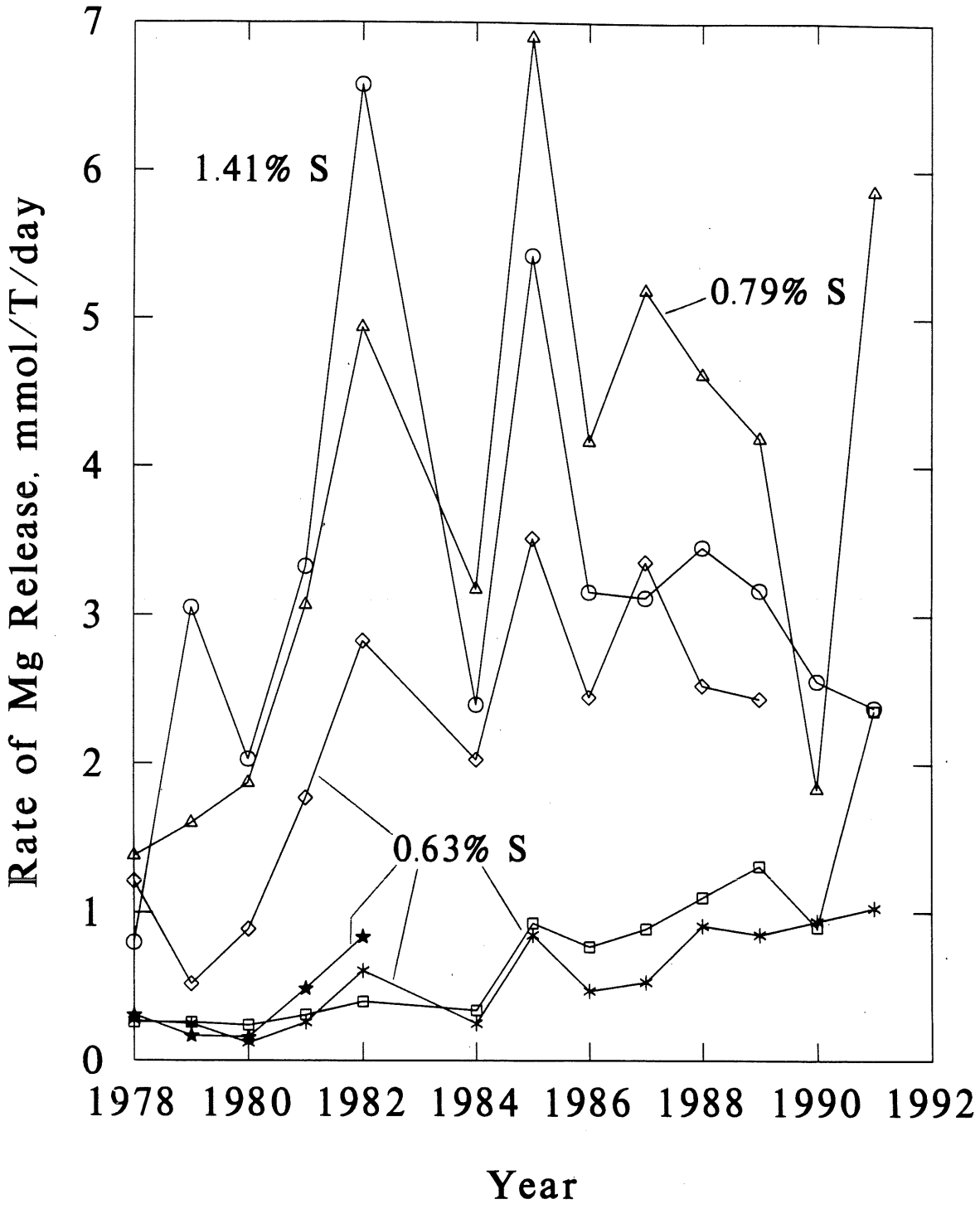

Figure 11. Annual calcium release rate over time for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

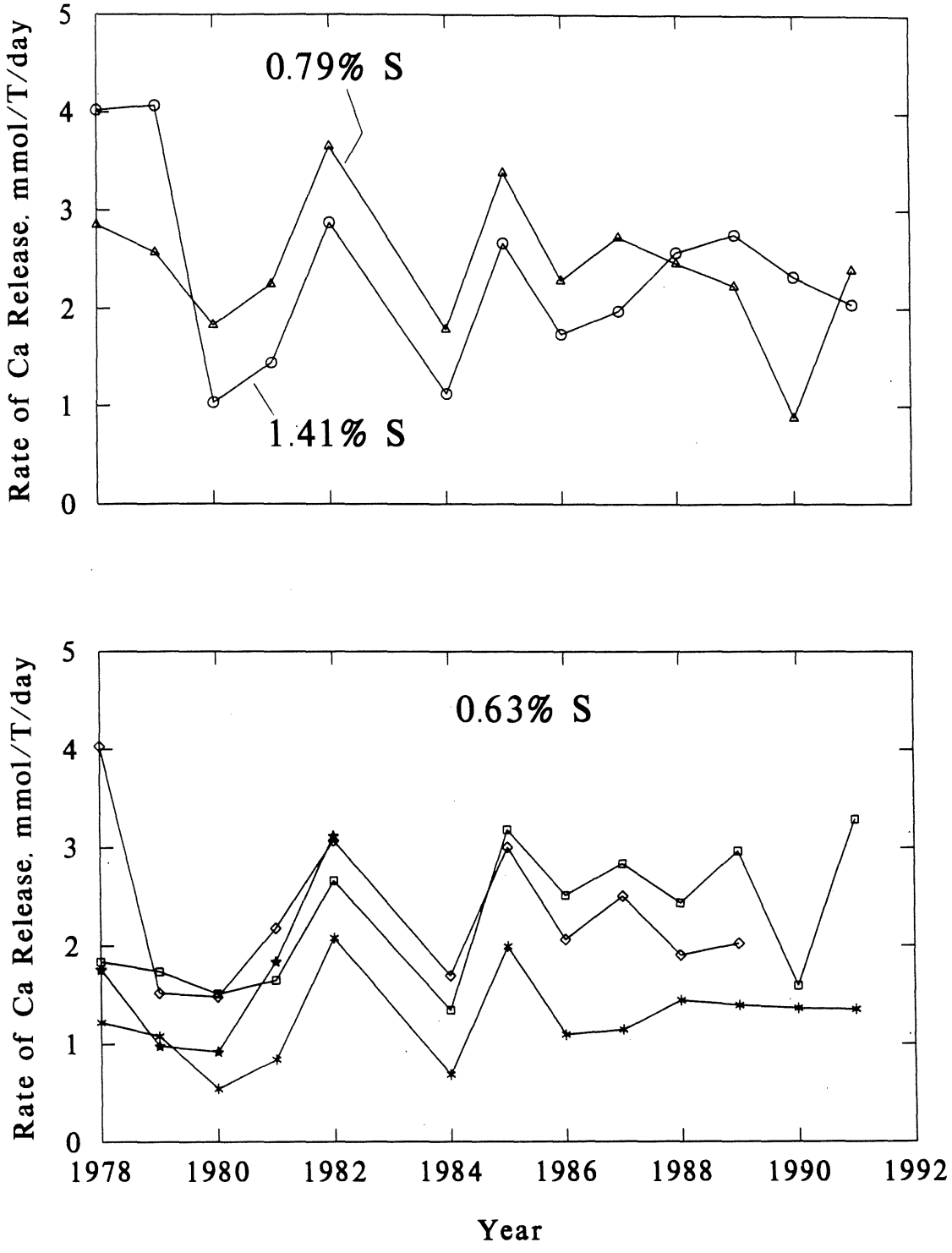

Figure 12. Comparison of minimum drainage pH in field (▲) and laboratory (○).

Field data represents overall recurrent minimum pH from the Duluth Complex test piles. Laboratory data represents drainage pH after 150 weeks of dissolution of Duluth Complex blast hole samples. The curve was generated with the log smoothing feature of the Systat statistical software package.

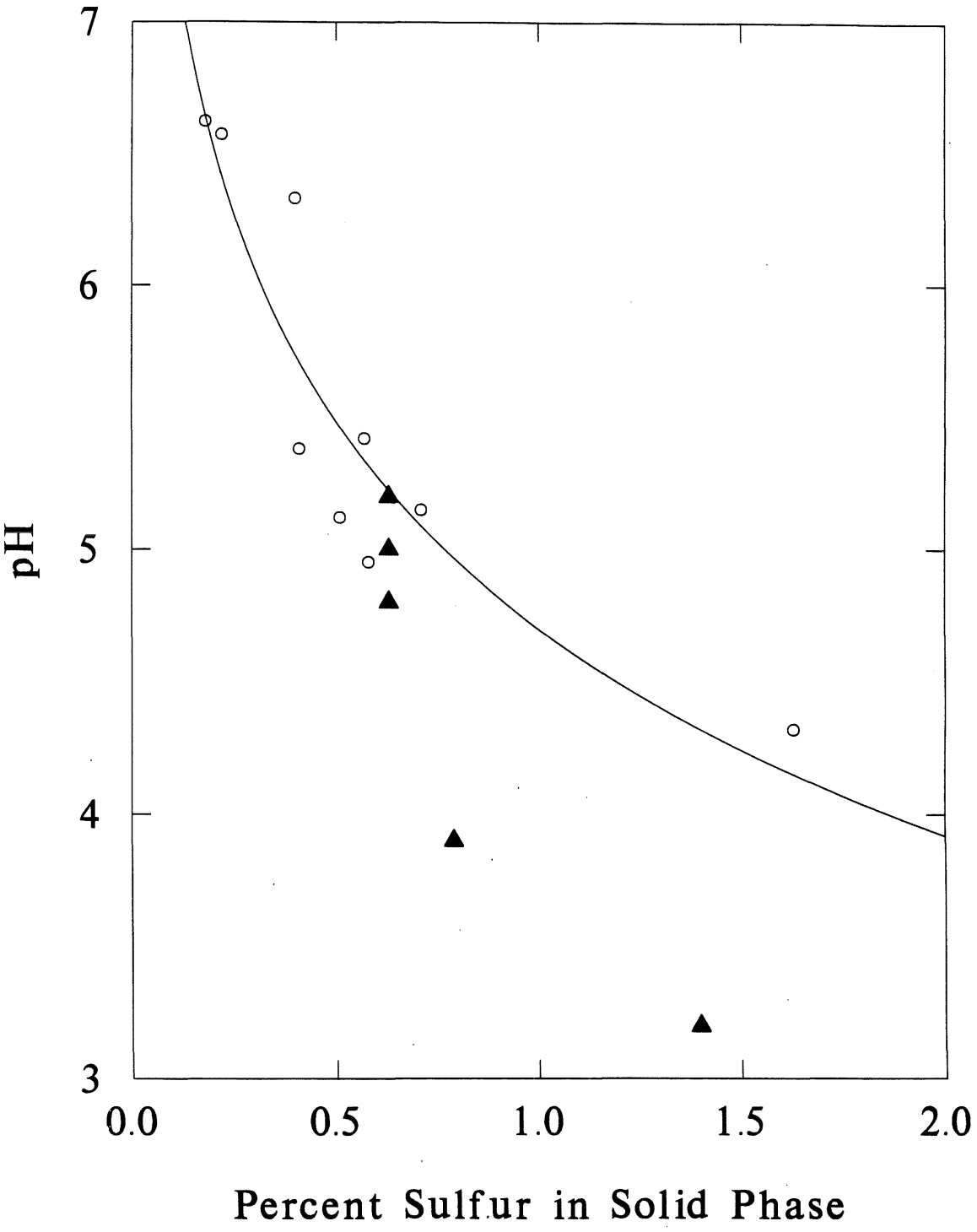

Table 1. Summary of chemical and physical characteristics of test piles.

	Pile 1	Pile 2	Pile 3	Pile 4	Pile 6	Pile 5
Date completed	4/20/77	4/20/77	4/20/77	4/20/77	9/30/77	9/10/77
% S	0.63	0.63	0.63	0.63	0.79	1.41
% Cu	0.35	0.35	0.35	0.35	0.34	0.30
% Ni	0.083	0.083	0.083	0.083	0.084	0.085
Mass, T	1100	1100	830	1130[1]	1300	815
Volume, m^3	540	530	400	830[1]	630	400
Collecting area, m^2	290	340	300	330[1]	320	340
Surface area, m^2	330	450	430	350[1]	390	370
Cover material	None	Topsoil	Glacial Till (coarse sand)	None	None	Sandy till over coarse sand
Avg. cover depth, cm	0	23	34	0	0	54
Vegetated	No	Yes	Yes	No	No	Yes

[1]Approximately 40 pct of FL4 was removed in September, 1982.

Table 2. Chemical composition of a grab sample from test pile 1.

Element	Concentration	Unit
S	0.655	Pct
Cu	0.306	Pct
Ni	0.073	Pct
Fe (S)[1]	0.696	Pct
Co	0.009	Pct
Zn	0.016	Pct
Si (SiO_2)	22.80 (48.81)	Pct
Al (Al_2O_3)	8.98 (16.96)	Pct
Fe (FeO)	9.22 (11.86)	Pct
Mg (MgO)	4.31 (7.15)	Pct
Ca (CaO)	5.55 (7.76)	Pct
Na (Na_2O)	2.00 (2.70)	Pct
K (K_2O)	0.32 (0.39)	Pct
Ti (TiO_2)	1.41 (2.35)	Pct
P (P_2O_5)	0.02 (0.05)	Pct
Mn (MnO)	0.12 (0.16)	Pct
Cr (Cr_2O_3)	0.03 (0.15)	Pct
B	662.00	ppm
Ba	1173.00	ppm
Be	1.00	ppm
Sr	279.00	ppm
Pb	0	ppm
Ag	1.35	ppm
As	0	ppm
Hg	1.00	ppm
Mo	0.50	ppm
Cd	0	ppm
V	276.50	ppm
Th	6.40	ppm
Zr	80.00	ppm

[1] Iron associated with sulfur.

Table 3. Mineralogical composition of a grab sample from test pile 1 (volume percent).

Opaques[1]	5.098
Chalcopyrite-cubanite	0.769
Pentlandite	0.037
Pyrrhotite	0.844
Ilmenite-magnetite	3.447
Graphite	-
Plagioclase	59.112
Sericite	2.176
Olivine	10.510
Clinopyroxene	11.185
Orthopyroxene	3.716
Monocrystalline amphibole	3.567
Fibrous amphibole	0.288
Chlorite	1.136
Serpentine	0.257
Iddingsite	0.075
Talc	-
Biotite	1.738
Smectite	0.021
Caladonite	-
Spinel	-
Myrmekite	-
Apatite	0.085
Epidote	0.953
Allanite	-
Calcite	0.056
Quartz	-
Cordierite	0.027

[1] The value shown for opaques is the sum of the five following values.

Table 4. Particle size distribution rock from test pile 4.

	Particle diameter (mm)	Percent finer than	
Boulders and cobbles	305	89.0	100
	152	82.2	96.6
Gravel	76.2	67.7	80.3
	25.4	38.3	38.8 (e)
	19.0	33.8	32.5
	12.7	27.1	20.4
	6.4	19.2	18.8
Sand	2.00	12.2	11.1
	1.41	10.8	6.1
	0.84	10.6	
	.425	7.7	
	.250	6.1	
	.149	4.6	3.0
	.105	3.4	2.5
Silt and clay	.074	3.1	1.9
	.053	1.4 to 1.7[1]	0

Note: Boulders, cobbles, gravel, sand, and silt refer to U.S. Department of Agriculture (USDA) classification definitions.

[1]Estimated based on hydrometer analysis of the less than 0.074 mm fraction.

d, mm min	d, mm max	pct	A_s
305	450	11	0.0205
152	305	6.8	0.0270
76.2	152	14.5	0.0394
25.4	76.2	29.4	0.0613
19.0	25.4	4.5	0.0964
12.7	19.0	6.7	0.116
6.4	12.7	7.9	0.153
2.0	6.4	7.0	0.239
0.5	2.0	4.0	0.60
0.177	0.50	1.7	0.78
0.149	0.177	1.9	1.1
0.105	0.149	1.2	1.6
0.075	0.105	0.3	1.7
0.053	0.075	1.5	2.6
<0.053		1.6	4.7

Table 5. Characterization of fine fractions, joint disposal bin gabbro material.

Size Fraction mm	pH	Total Sulfur %	Sulfide %	Cu %	Ni %	Co %	Zn %	Specific Surface Area m^2/g
Sand								
0.50-2.00	6.56	0.67	0.65	0.337	0.062	0.012	0.015	0.60
.177-.50	6.37	0.80	0.75	0.381	0.078	0.013	0.015	0.78
.149-.177	6.18	0.88	0.80	0.391	0.103	0.015	0.015	1.1
.105-.149	NA	1.12	1.05	0.495	0.147	0.019	0.017	1.6
.075-.105	5.95	1.37	1.30	0.585	0.221	0.022	0.019	1.7
Silt and clay								
.053-.075	5.78	1.65	1.57	0.647	0.253	0.024	0.019	2.6
<.053	5.77	1.94	1.86	0.814	0.295	0.027	0.023	4.7

NA = not available.

Table 6. Annual median pH, flow-weighted mean concentrations, and drainage volume for Duluth Complex test piles.

Pile	Sulfur %	Parameter	Flow-weighted Mean Concentration, mg/L, and Volume, L x 10^{-3}													
			1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
FL1	0.63	pH	7.80	7.35	7.20	7.20	7.00	6.86	6.36	6.70	6.54	6.03	6.09	5.69	5.72	5.25
		SO4	949	743	1202	772	755	993	920	880	723	986	879	965	1254	1253
		Ca	201	224	318	239	255	NA	263	238	221	277	249	227	274	256
		Mg	17	20	30	27	23	NA	41	42	41	53	69	61	94	111
		Volume	83.1	86.6	53.8	83.8	118.6	82.4	66.9	133.4	119.6	104.8	106.3	122.5	60.1	121.0
FL2	0.63	pH	7.60	7.30	6.95	6.80	6.70	6.39	6.17	6.30	6.17	5.54	5.47	5.27	5.13	5.18
		SO4	689	561	707	652	834	858	685	963	593	676	829	748	884	863
		Ca	148	160	201	156	207	NA	183	210	165	186	203	163	180	167
		Mg	20	23	28	29	37	NA	41	54	43	52	78	60	75	77
		Volume	70.2	75.6	29.5	67.2	100.4	52.8	40.4	94.6	69.3	63.2	78.9	80.2	78.5	76.0
FL3	0.63	pH	7.60	7.05	6.65	6.60	6.58	5.90	5.05	5.44	5.27	5.01	5.15	4.98	NA	NA
		SO4	957	557	1035	1223	1244	1566	1378	1620	1210	1653	1225	1132	NA	NA
		Ca	285	150	211	224	213	NA	211	220	186	238	170	153	NA	NA
		Mg	52	31	77	110	119	NA	153	156	134	194	137	113	NA	NA
		Volume	90.8	87.1	58.3	92.4	125.6	68.5	78.1	103.1	89.2	81.4	94.1	94.9	NA	NA
FL4	0.63	pH	7.55	7.10	6.80	6.85	6.55	NA	NA	NA	NA	NA	NA	NA	NA	NA
		SO4	610	470	801	765	771	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Ca	163	140	166	209	228	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Mg	17	15	17	34	37	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Volume	92.2	74.0	53.2	109.9	147.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
FL6	0.79	pH	7.51	6.40	4.40	4.40	4.20	4.19	4.14	4.27	4.27	4.00	4.12	4.20	4.10	4.14
		SO4	1046	1154	1496	1752	1891	2406	2469	2550	1873	2615	2201	2466	3234	2692
		Ca	261	292	277	249	270	NA	280	270	248	299	271	248	297	249
		Mg	77	110	172	205	220	NA	302	334	274	344	308	281	376	369
		Volume	117.2	118.2	82.3	130.5	117.2	96.0	99.2	148.3	114.4	108.1	117.1	102.0	36.2	106.8
FL5	1.41	pH	5.50	3.40	3.40	3.40	3.40	3.60	3.49	3.50	3.63	3.43	3.62	3.62	3.62	3.60
		SO4	862	2147	2900	3488	3805	4007	3424	3852	2973	2618	2355	2429	2264	1968
		Ca	225	285	228	220	225	NA	221	265	248	245	239	240	233	202
		Mg	27	129	273	308	311	NA	287	326	273	234	195	168	156	143
		Volume	120.5	117.3	35.7	58.9	105.8	57.2	49.6	83.2	54.5	60.1	70.9	82.5	76.4	70.2

Table 7. Annual total mass release and rate of release of sulfate, calcium, and magnesium for Duluth Complex test pile FL1 (0.63% S, 1100 T, no cover). Percent of total original sulfur released = 6.02.

Year	Total Volume L	Period Days	Number of Cases	Total Mass Release mol			Rate of Release[1] mmol/T•day			Median pH
				SO_4	Ca	Mg	SO_4	Ca	Mg	
1978	83100	206	9	821	416	58	3.62	1.84	0.26	7.80
1979	86600	252	33	670	483	71	2.42	1.74	0.26	7.35
1980	53800	256	28	673	426	66	2.39	1.51	0.23	7.20
1981	83800	275	28	673	499	93	2.22	1.65	0.31	7.20
1982	118600	258	28	932	755	113	3.28	2.66	0.40	7.00
1983	82400	277	10[2]	852	NA	NA	2.80	NA	NA	6.86
1984	66879	298	11	640	439	113	1.95	1.34	0.34	6.36
1985	133396	227	9	1221	793	231	4.89	3.18	0.93	6.70
1986	119551	238	9	900	658	202	3.44	2.51	0.77	6.54
1987	104768	233	9	1075	725	229	4.19	2.83	0.89	6.03
1988	106298	247	10	972	660	300	3.58	2.43	1.10	6.09
1989	122463	213	9	1230	693	308	5.25	2.96	1.31	5.69
1990	60101[3]	235	9	784	411	233	3.03	1.59	0.90	5.72
1991	120980	213	9	1577	772	552	6.73	3.29	2.36	5.25

[1] Rates were calculated over the period of flow.
[2] Calcium and magnesium were not measured in 1983.
[3] FL1 was partially covered with plastic during 1990.

Table 8. Annual total mass release and rate of release of sulfate, calcium, and magnesium for Duluth Complex test pile FL2 (0.63% S, 1100 T, cover of topsoil). Percent of total original sulfur released = 3.60.

Year	Total Volume L	Period Days	Number of Cases	Total Mass Release mol			Rate of Release[1] mmol/T•day			Median pH
				SO_4	Ca	Mg	SO_4	Ca	Mg	
1978	70200	193	6	503	260	57	2.37	1.22	0.27	7.60
1979	75600	253	32	441	302	70	1.58	1.09	0.25	7.30
1980	29500	250	27	217	148	33	0.79	0.54	0.12	6.95
1981	67200	283	28	456	261	81	1.46	0.84	0.26	6.80
1982	100400	226	16	872	518	151	3.51	2.08	0.61	6.70
1983	52800	277	9[2]	472	NA	NA	1.55	NA	NA	6.39
1984	40431	247	10	288	185	69	1.06	0.68	0.25	6.17
1985	94649	227	9	948	496	212	3.80	1.99	0.85	6.30
1986	69334	238	9	428	286	124	1.63	1.09	0.47	6.17
1987	63221	233	9	445	293	136	1.74	1.14	0.53	5.54
1988	78948	252	10	681	399	252	2.46	1.44	0.91	5.47
1989	80188	213	9	624	326	199	2.66	1.39	0.85	5.27
1990	78458	235	9	722	352	243	2.79	1.36	0.94	5.13
1991	76029	213	9	683	316	241	2.92	1.35	1.03	5.18

[1] Rates were calculated over the period of flow.
[2] Calcium and magnesium were not measured in 1983.

Table 9. Annual total mass release and rate of release of sulfate, calcium, and magnesium for Duluth Complex test pile FL3 (0.63% S, 830 T, cover of glacial till (coarse sand)). Percent of total original sulfur released = 8.36.

Year	Total Volume L	Period Days	Number of Cases	Total Mass Release mol			Rate of Release[1] mmol/T•day			Median pH
				SO_4	Ca	Mg	SO_4	Ca	Mg	
1978	90800	193	5	904	646	194	5.64	4.03	1.21	7.60
1979	87100	258	34	505	326	111	2.36	1.52	0.52	7.05
1980	58300	249	30	628	306	184	3.04	1.48	0.89	6.65
1981	92400	285	31	1176	516	418	4.97	2.18	1.77	6.60
1982[2]	125600	262	21	1626	668	615	7.48	3.07	2.83	6.58
1983	68500	277	10[3]	1116	NA	NA	4.85	NA	NA	5.90
1984	78088	292	11	1120	410	493	4.62	1.69	2.03	5.05
1985	103131	227	9	1738	566	664	9.22	3.00	3.52	5.44
1986	89161	241	10	1123	413	491	5.61	2.06	2.45	5.27
1987	81412	233	9	1400	484	650	7.24	2.50	3.36	5.01
1988	94121	252	10	1200	398	529	5.74	1.90	2.53	5.15
1989[4]	94924	217	9	1118	363	440	6.21	2.02	2.44	4.98

[1] Rates were calculated over the period of flow.
[2] Fertilizer and 1500 gallons of lime-stabilized sludge were applied on May 19, 1982.
[3] Calcium and magnesium were not measured in 1983.
[4] FL3 was covered with plastic and subsequently hypalon, thereby terminating flow from the pile at the end of the 1989 field season.

Table 10. Annual total mass release and rate of release of sulfate, calcium, and magnesium for Duluth Complex test pile FL4 (0.63% S, 1130 T, no cover). Percent of total original sulfur released = 1.55.

Year	Total Volume L	Period Days	Number of Cases	Total Mass Release mol			Rate of Release[1] mmol/T·day			Median pH
				SO_4	Ca	Mg	SO_4	Ca	Mg	
1978	92200	188	7	585	374	65	2.75	1.76	0.31	7.55
1979	74000	233	26	362	258	46	1.37	0.98	0.17	7.10
1980	53200	211	18	444	220	37	1.86	0.92	0.16	6.80
1981	109900	276	29	875	574	152	2.81	1.84	0.49	6.85
1982	147500	238	15	1183	838	227	4.40	3.12	0.84	6.55

[1] Rates were calculated over the period of flow.

FL 6

300,000 L ≈ 300 m^3

815 T ≈ 900 T

$\gamma = 3$

300 m^3 rock

Say $\eta = 0.4$ voids = 200 m^3

Table 11. Annual total mass release and rate of release of sulfate, calcium, and magnesium for Duluth Complex test pile FL6 (0.79% S, 1300 T, no cover). Percent of total original sulfur released = 10.42.

Year	Total Volume L	Period Days	Number of Cases	Total Mass Release mol			Rate of Release[1] mmol/T•day			Median pH
				SO_4	Ca	Mg	SO_4	Ca	Mg	
1978	117200	206	6	1275	764	370	4.76	2.85	1.38	7.51
1979	118200	257	36	1420	860	534	4.25	2.57	1.60	6.40
1980	82300	239	28	1281	570	582	4.12	1.83	1.87	4.40
1981	130500	276	30	2379	809	1103	6.63	2.25	3.07	4.40
1982	177200	250	19	3486	1191	1606	10.73	3.66	4.94	4.20
1983	96000	277	10[2]	2404	NA	NA	6.68	NA	NA	4.19
1984	99158	298	12	2548	693	1233	6.58	1.79	3.18	4.14
1985	148259	227	9	3934	1000	2037	13.33	3.39	6.90	4.27
1986	114434	238	9	2230	708	1291	7.21	2.29	4.17	4.27
1987	108134	227	9	2943	805	1533	9.97	2.73	5.19	4.00
1988	117127	247	10	2682	791	1483	8.35	2.46	4.62	4.12
1989	101975	217	9	2617	630	1181	9.28	2.23	4.19	4.20
1990	36196[3]	235	9	1218	268	560	3.99	0.88	1.83	4.10
1991	106787	213	9	2991	663	1622	10.80	2.39	5.86	4.14

[1] Rates were calculated over the period of flow.
[2] Calcium and magnesium were not measured in 1983.
[3] FL6 was partially covered with plastic during 1990.

Table 12. Annual total mass release and rate of release of sulfate, calcium, and magnesium for Duluth Complex test pile FL5 (1.41% S, 815 T, cover of sandy till over coarse sand). Percent of total original sulfur released = 8.08.

Year	Total Volume L	Period Days	Number of Cases	Total Mass Release mol			Rate of Release[1] mmol/T•day			Median pH
				SO_4	Ca	Mg	SO_4	Ca	Mg	
1978	120500	206	9	1081	676	135	6.44	4.03	0.80	5.50
1979	117300	251	34	2621	833	624	12.81	4.07	3.05	3.40
1980	35700	243	30	1077	203	402	5.44	1.03	2.03	3.40
1981	58900	275	29	2138	323	746	9.54	1.44	3.33	3.40
1982	105800	253	20	4189	595	1356	20.32	2.89	6.58	3.40
1983[2]	57200	277	27[3]	2385	NA	NA	10.56	NA	NA	3.60
1984	49625	299	12	1768	274	586	7.26	1.12	2.40	3.49
1985	83220	252	10	3336	549	1115	16.24	2.67	5.43	3.50
1986	54523	238	9	1687	337	613	8.70	1.74	3.16	3.63
1987	60084	227	9	1637	367	578	8.85	1.98	3.12	3.43
1988	70886	202	10	1737	423	569	10.55	2.57	3.46	3.62
1989	82485	220	9	2085	493	569	11.63	2.75	3.17	3.62
1990	76442	235	9	1801	445	491	9.40	2.32	2.56	3.62
1991	70171	213	9	1437	354	413	8.28	2.04	2.38	3.60

27,898

[1] Rates were calculated over the period of flow.
[2] Bactericide was applied in July, 1983.
[3] Calcium and magnesium were not measured in 1983.

For heap leach considerations:

$28{,}000 \text{ moles} \times \frac{98 \text{ g}}{\text{mole}} \times \frac{\text{kg}}{1000 \text{ g}} = 2744 \text{ kg } SO_4 = 915 \text{ kg S}$

$2.7 \text{ t} / 815 \text{ t} = 0.0033 \text{ t/t} =$

$6.6 \text{ lb} / 2000 \text{ lb.}$

S present = $0.014 \times 815 \times 1000 = 11{,}410$ kg

$915 / 11{,}410 = 0.080$

1.4% x 31.25

Table 13. Average rates of mass release and minimum drainage pH.

Percent Sulfur	Period of Record	Minimum pH[1]	Average Observed Rates of Release,[2] mmol/T•day			
			SO_4	Ca	Mg	Ca + Mg
0.63 (FL1)	1978-1991[3]	4.96	3.4	2.2	0.74	2.9
0.63 (FL2)	1978-1991	4.87	2.1	1.2	0.55	1.8
0.63 (FL3)	1978-1989	4.71	5.5	2.4	2.1	4.5
0.79 (FL6)	1978-1991[3]	3.70	7.3	2.4	3.7	6.1
1.41 (FL5)	1978-1991	3.08	10.5	2.3	3.2	5.5

[1] The minimum pH values usually occurred as isolated excursions. The recurrently observed minimum pH values were typically 0.2 to 0.3 units higher.

[2] This represents the release rate during the period of flow. 1983 was not included for the rates of Ca and Mg release, since these parameters were not analyzed in this year.

[3] Partially covered by plastic during 1990.

Table 14. Neutralization potentials as determined by drainage quality of Duluth Complex test piles.

Sulfur %	Pile	Neutralization Potential[1], mg $CaCO_3$/g rock					
		pH 7	pH 6	pH 5	pH 4.5	pH 4	pH 3.5
0.63	FL1	0.346	0.781	>1.059	>1.059	>1.059	>1.059
0.63	FL2	0.179	0.393	>0.642	>0.642	>0.642	>0.642
0.63	FL3	0.442	1.254	>1.340	>1.340	>1.340	>1.340
0.79	FL6	0.157	0.172	0.226	1.702	>2.074	>2.074
1.41	FL5	0.044	0.044	0.096	0.130[2]	0.136[2]	>1.889

1 Neutralization potential (NP) was calculated using the cumulative calcium and magnesium release (see methods section of report).

2 Neutralization potential was calculated as of 1978, although two pH values of 4.6 and 4.0 were observed in spring runoff in 1980 and 1989, respectively.

Table 15. Qualitative comparison of test pile and laboratory data.

	Laboratory Drill Core[1]	Laboratory Blast Holes[2]	Field Test Piles
Drainage pH:			
as time increased	pH decreased	pH decreased	gradually decreased (0.63 pct S); decreased and plateaued (10.79 pct S); decreased and slightly increased (1.41 pct S)
as pct S increased	pH decreased	pH decreased	pH decreased
Sulfate Release Rate:			
as time increased max. rate: min. rate[3]	fairly constant, 1:1 to 3:1 for pH >4.5, 6:1 for some samples with pH~4	fairly constant, 1:1 to 3:1 for pH >4, 6:1 to 7:1 for pH <4	fairly constant, 2.7:1 to 3.9:1
as pct S increased	increased	increased	increased
as flow increased	no data	no data	increased
Calcium Release Rate:			
as time increased	fairly constant	limited data	fairly constant
as pct S increased	fairly constant	fairly constant	fairly constant
as flow increased	no data	no data	increased
Magnesium Release Rate:			
as time increased	increased	limited data	increased
as pct S increased	increased	increased	general increase although release from 0.79 pct S rock exceeded that from 1.41 pct S rock
as flow increased	no data	no data	increased

[1] Lapakko, 1993a.
[2] Lapakko, 1993b.
[3] Ratio of maximum release rate to minimum release rate for a solid.

Table 16. Comparison of field and laboratory neutralization potentials.

Percent S	pH 7	pH 6	pH 5	pH 4.5	pH 4	pH 3.5
Laboratory neutralization potential, mg $CaCO_3$/g rock[1]						
0.63	0.67	1.5	2.9	>2.9	>2.9	>2.9
0.79	0.29	0.75	1.7	>1.8	>1.8	>1.8
1.41	0.26	0.79	>1.7	>2.9	>3.1	>3.1
Ratio of field NP to laboratory NP						
0.63(FL1)	0.52	0.52	NAp	NAp	NAp	NAp
0.63(FL2)	0.27	0.26	NAp	NAp	NAp	NAp
0.63(FL3)	0.66	0.84	NAp	NAp	NAp	NAp
0.79(FL6)	0.54	0.23	0.13	NAp	NAp	NAp
1.41(FL5)	0.17	0.056	<0.056	<0.045	<0.044	NAp

NAp: not applicable

[1] See appendix 1 for sources of laboratory data.

Table 17. Comparison of field and laboratory blast hole release rates. Rates expressed in mole (g rock)$^{-1}$ s^{-1} x 10^{14}.

Percent Sulfur	Field Rate			Lab Rates			Retardation Factor			
	SO_4	Ca	Mg	SO_4	Ca	Mg	SO_4	Ca	Mg	Avg.
0.63[1] (FL1)	3.9	2.5	0.86	25[1]	6.7[1]	12[1]	0.16	0.37	0.072	0.20
cov 0.63[1] (FL2)	2.4	1.4	0.64	25	6.7	12	0.096	0.21	0.053	0.12
cov 0.63[1] (FL3)	6.4	2.8	2.4	25	6.7	12	0.26	0.42	0.20	0.29
0.79[2] (FL6)	8.5	2.8	4.3	26[2]	6.1[2]	12[2]	0.33	0.46	0.36	0.38
cov 1.41[3] (FL5)	12	2.7	3.7	66[3]	19[3]	21[3]	0.18	0.14	0.18	0.17

1 The arithmetic mean of average rates from blast hole samples with sulfur contents of 0.57, 0.58, and 0.71 percent (150 week period of record) was used for comparison with 0.63-percent-sulfur rock. Minimum pH values for these samples ranged from 4.82 to 5.38 as compared to 4.7 to 5.0 in the field.

2 Rates were linearly extrapolated based on sulfur content using average rates from blast hole samples with sulfur contents of 0.71 and 1.16 percent (150- and 69-week periods of record, respectively). Minimum pH values for these samples ranged from 4.6 to 5.0, about one unit higher than the pH 3.7 minimum value for the field pile.

3 The arithmetic mean of average rates from blast hole samples with sulfur contents of 1.40 and 1.44 percent was used (69 week period of record) for comparison with the 1.41-percent-sulfur pile. Minimum drainage pH for these samples ranged from 4.4 to 4.9, about 1.5 units higher than the minimum drainage pH for the field pile and and one unit higher than its recurrent minimum pH.

Kevin Morin

$\frac{\text{mole}}{g\ s} \times \frac{96.1 \times 10^3 mg}{\text{mole}} \times 86,400 \times 7 \times 1000$

15

14.5

A_s ~ 25 m²/kg feldspar

.025 m²/g

250 cm²/g. mostly Ca feldspar.

Nevada.

APPENDICES

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Appendix 4: Rates of Release

Appendix 5: Neutralization Potential

APPENDIX 1

METHODS

Appendix 1: Methods

Text A1.1. Neutralization potential calculation.

Individual drainage volume measurements were missing for given periods of record. Approximately half of the samples in the 1978 period of record for each test pile did not have an associated drainage volume value. One or two measurements were missing in 1982 and 1984 for each test pile. Calculation of the annual drainage volumes for this report omitted the missing values. When compared with the annual drainage volumes for 1978 through 1984 found in Eger and Lapakko (1985), discrepancies were revealed between the two sets of values. While most of the calculated values were generally five to twenty percent lower than the associated values in Eger and Lapakko (1985), the calculated 1978 values were several times lower.

To account for the discrepancies, the mass release values obtained using the calculated volumes were multiplied by adjusting factors. The factors were ratios of the annual volumes obtained in Eger and Lapakko (1985) over the calculated annual volumes for the respective piles. Adjusted mass release rates were calculated with the adjusted mass release values. The resulting rates compared favorably with those obtained in Eger and Lapakko (1985) (Table A1.2). The adjusted annual mass release and rates of release are used throughout this report. The annual drainage volumes for 1978 to 1984 obtained in Eger and Lapakko (1985) are used throughout the report as well.

The adjusted cumulative mass release values allowed more accurate determination of neutralization potentials (NP). These were calculated to determine the amount of acid neutralized by the solids prior to the drainage pH decreasing and, for the duration of the experiment, remaining below pH values of 7, 6, 5, 4.5, 4, and 3.5. The acid neutralized was calculated by two methods: as the a) cumulative sulfate release (expressed as mg $CaCO_3$/g rock) and b) cumulative calcium and magnesium release (expressed as mg $CaCO_3$/g rock) prior to the drainage pH decreasing and remaining below the specified pH value. If the drainage pH from a given solid never decreased permanently below a specified value, the NP was reported as "greater than" the total sulfate release for the period of record.

(a) Cumulative sulfate release to a given pH threshold:

$$NP = (\Sigma SO_4 \times 1.04) / m_p, \text{ where}$$

NP	=	neutralization potential, in mg $CaCO_3$/g rock
ΣSO_4	=	cumulative sulfate release to a given pH threshold, in milligrams
1.04	=	100 mg $CaCO_3$ / 96.1 mg SO_4
m_p	=	mass of pile, in grams

(b) Cumulative calcium plus magnesium release to a given pH threshold:

$$NP = [(\Sigma Ca \times 2.49) + (\Sigma Mg \times 4.12)] / m_p, \text{ where}$$

ΣCa	=	cumulative calcium release to a given pH threshold, in milligrams
2.49	=	100 mg $CaCO_3$ / 40.1 mg Ca
ΣMg	=	cumulative magnesium release to a given pH threshold, in milligrams
4.12	=	100 mg $CaCO_3$ / 24.3 mg Mg

Two steps were taken to increase the accuracy of the NP values by obtaining a more continuous record of cumulative release. First, mass release had to be estimated for 1977, when the piles were constructed. Mass release was estimated as the product of the mass of the pile, the number of days between the construction of the pile and freeze-up in November, 1977, and the mean rate of release from the pile for subsequent years. Rates of release from FL1 for 1978 to 1991 were used as representative rates for FL2 and FL3, because FL1 was uncovered for its entire period of record, while FL2 and FL3 were uncovered only in 1977.

The second step taken was to estimate mass release for 1983, when no calcium or magnesium concentrations were measured. Mass release for 1983 was estimated as the mean of the 1982 and 1984 flow-weighted-mean concentrations multiplied by the 1983 drainage volume. The estimated 1983 mass release was added only to those NP values corresponding to pH thresholds reached later than 1983. The pH 7 threshold for FL1 was reached in May, 1983, after one-fifth of the field season had passed. For that case, one-fifth of the estimated 1983 mass release was added to the NP_{pH7}.

Table A1.1. Monthly and annual precipitation at the Duluth Complex test piles site, 1978 - 1991.

Month	Precipitation, cm[1]													
	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
January	1.70	1.30	2.44	1.24	2.36	3.68[2]	0.43	1.14	1.80	1.17	3.07	3.23	2.36	0.00
February	0.81	4.85	1.68	3.40	1.07	1.68[2]	1.63	1.27	2.34	1.45	0.76	1.04	2.34	0.00
March	1.70	6.98	2.31	1.88	1.78	1.68[2]	0.61	1.88	1.12	0.89	6.10	3.33	5.46	3.07
April	3.25	2.50	1.90	11.2	2.41	1.40	3.00	6.81	6.76	0.56	0.23	1.30	10.4	1.83
May	9.35	9.73	1.32	2.46	11.1	4.24	3.48	10.7	4.80	14.5	7.65	8.15	2.18	8.13
June	4.90	10.1	9.09	15.5	6.65	5.13	15.2	12.1	11.0	3.12	6.58	18.3	13.3	12.1
July	19.1	7.04	6.27	4.29	16.4	8.51	4.80	8.41	10.2	16.8	6.50	2.84	6.43	13.4
August	14.1	5.89	13.4	4.39	12.5	12.4	6.43	9.73	9.12	9.45	30.5	11.2	3.58	6.25
September	8.23	5.08	10.8	5.97	9.70	8.48	4.83	16.2	13.3	8.05	6.27	10.7	7.77	13.3
October	2.59	7.59	3.66	9.55	13.3	11.0	7.16	4.75	2.39	2.06	4.83	4.93	8.99	4.67
November	2.46	1.40	2.84	1.60	5.21	8.86[2]	1.70	6.07	5.26	1.32	5.77	2.84	0.08	0.00
December	1.37	0.89	3.10	2.01	4.04	3.76[2]	4.27	1.04	0.94	0.97	2.84	1.40	1.57	0.00
TOTAL	69.6	63.3	58.8	63.4	86.5	70.9	53.5	80.1	69.0	60.3	81.1	69.3	64.5	62.8

[1] From Kennecott raingage unless otherwise noted.
[2] From Babbitt raingage.

$\bar{P} = 72.1$

Table A1.2. Comparison of adjusted rates and those obtained in the 1985 Heavy Metals Study. See Methods for more information.

Pile	Year	Adj. SO_4 Rate mmol/T/day	Adj. Ca Rate mmol/T/day	Adj. Mg Rate mmol/T/day	HMS SO_4 Rate mmol/T/day	HMS Ca Rate mmol/T/day	HMS Mg Rate mmol/T/day	Adj. SO_4/ HMS SO_4	Adj. Ca/ HMS Ca	Adj. Mg/ HMS Mg
FL1	1978	3.62	1.84	0.26	4.47	2.49	0.33	0.81	0.74	0.77
	1979	2.42	1.74	0.26	2.39	1.75	0.26	1.01	1.00	0.99
	1980	2.39	1.51	0.24	2.39	1.50	0.23	1.00	1.01	1.01
	1981	2.23	1.65	0.31	2.19	1.65	0.30	1.02	1.00	1.01
	1982	3.28	2.66	0.40	2.71	2.49	0.39	1.21	1.07	1.01
	1983	2.79	NA	NA	2.81	NA	NA	0.99	NA	NA
FL2	1978	2.37	1.22	0.27	3.23	1.87	0.37	0.73	0.65	0.71
	1979	1.59	1.08	0.25	1.46	1.10	0.26	1.09	0.99	0.98
	1980	0.79	0.54	0.12	0.80	0.55	0.12	0.98	0.98	0.99
	1981	1.46	0.84	0.26	1.46	0.85	0.26	1.00	0.99	0.99
	1982	3.51	2.08	0.61	3.02	1.95	0.58	1.16	1.07	1.06
	1983	1.55	NA	NA	1.56	NA	NA	0.99	NA	NA
FL3	1978	5.64	4.03	1.21	3.54	2.29	0.66	1.60	1.76	1.84
	1979	2.36	1.52	0.52	2.50	1.57	0.53	0.94	0.97	0.97
	1980	3.04	1.48	0.89	3.02	1.47	0.91	1.01	1.01	0.98
	1981	4.97	2.18	1.77	4.99	2.17	1.77	1.00	1.01	1.00
	1982	7.48	3.07	2.83	6.87	2.99	2.67	1.09	1.03	1.06
	1983	4.85	NA	NA	4.89	NA	NA	0.99	NA	NA
FL4	1978	2.75	1.76	0.31	3.75	2.37	0.40	0.73	0.74	0.78
	1979	1.37	0.98	0.17	1.35	1.00	0.18	1.01	0.98	0.94
	1980	1.86	0.92	0.16	1.87	0.92	0.16	0.99	1.00	1.00
	1981	2.81	1.84	0.49	2.81	1.85	0.49	1.00	0.99	1.00
	1982	4.40	3.12	0.84	3.95	2.99	0.78	1.11	1.04	1.08

Table A1.2. Comparison of adjusted rates and those obtained in the 1985 Heavy Metals Study. See Methods for more information.

Pile	Year	Adj. SO_4 Rate mmol/T/day	Adj. Ca Rate mmol/T/day	Adj. Mg Rate mmol/T/day	HMS SO_4 Rate mmol/T/day	HMS Ca Rate mmol/T/day	HMS Mg Rate mmol/T/day	Adj. SO_4/ HMS SO_4	Adj. Ca/ HMS Ca	Adj. Mg/ HMS Mg
FL6	1978	4.76	2.85	1.38	7.91	5.74	2.26	0.60	0.50	0.61
	1979	4.25	2.57	1.60	4.06	2.49	1.60	1.05	1.03	1.00
	1980	4.12	1.83	1.87	4.06	1.85	1.89	1.02	0.99	0.99
	1981	6.63	2.25	3.07	6.66	2.27	3.09	1.00	0.99	1.00
	1982	10.73	3.66	4.94	9.16	3.24	4.53	1.17	1.13	1.09
	1983	6.68	NA	NA	6.66	NA	NA	1.00	NA	NA
FL5	1978	6.44	4.02	0.80	9.47	5.99	1.11	0.68	0.67	0.72
	1979	12.81	4.07	3.05	12.49	3.99	2.96	1.03	1.02	1.03
	1980	5.44	1.03	2.03	5.41	1.02	2.02	1.01	1.00	1.01
	1981	9.54	1.44	3.33	9.57	1.45	3.33	1.00	1.00	1.00
	1982	20.32	2.88	6.58	19.77	2.74	6.58	1.03	1.05	1.00
	1983	10.56	NA	NA	10.41	NA	NA	1.02	NA	NA

Table A1.3. Laboratory neutralization potential data (for values listed as "greater than" averages represent "best guess").

Percent Sulfur	Sample Type[1]	Period of Record (weeks)	Neutralization Potential					
			pH 7	pH 6	pH 5	pH 4.5	pH 4	pH 3.5
For comparison with 0.63 percent sulfur rock in field								
0.57	B	150	1.32	2.0	>3.1	>3.1	>3.1	>3.1
0.58	B	150	0.35	1.4	2.9	>3.0	>3.0	>3.0
0.71	B	150	0.35	1.1	>2.6	>2.6	>2.6	>2.6
Avg.			0.67	1.5	2.9	>2.9	>2.9	>2.9
For comparison with 0.79 percent sulfur rock in field								
0.71	B	150	0.35	1.1	>2.6	>2.6	>2.6	>2.6
0.80	D	17	0.32	>0.39	>0.39	>0.39	>0.39	>0.39
0.92	D	34	0.19	0.40	0.77	>0.93	>0.93	>0.93
Avg.			0.29	0.75[2]	1.7[3]	>1.8[4]	>1.8[4]	>1.8[4]
For comparison with 1.41 percent sulfur rock in field								
1.35	D	30	0	0	0	3.1	>3.7	>3.7
1.40	B	78	0.41	1.6	>3.0	>3.0	>3.0	>3.0
1.44	B	78	0.38	0.77	2.0	>2.7	>2.7	>2.7
Avg.			0.26	0.79	>1.7	>2.9	>3.1	>3.1

[1] D:drill core, B:blast hole
[2] (1.1 + 0.4)/2
[3] (2.6 + 0.77)/2
[4] (2.6 + 0.93)/2

Table A1.4. Release rates for drill core samples (Lapakko, 1993a).

Percent Sulfur	Period (weeks)	Rates, mole (g rock)$^{-1}$s^{-1}			Minimum pH
		SO_4	Ca	Mg	
0.47	2-13	13	19	3.3	6.85
0.59	7-17	22	26	6.4	7.30
0.80	6-17	36	34	7.9	6.75
0.80	9-17	35	30	9.3	6.90
0.92	23-34	82	28	28	4.60
0.92	27-34	42	17	19	4.90
1.17[1]	11-17	45	(78)[2]	12	8.30
1.17[1]	13-17	58	(83)[2]	13	8.20
1.24	2-21	49	26	14	5.70
1.24	2-21	45	25	14	5.70
1.26[3]	1-21	27	20	3.5	6.20
1.26[3]	1-21	28	19	3.7	5.95
1.35	6-25	93	18	20	4.20
1.47[4]	13-21	190	37	31	4.40
1.47[4]	14-21	310	39	38	4.25
1.74[4]	11-21	350	82	73	4.30
1.74[4]	14-21	170	59	50	4.55
1.87	17-34	150	59	59	5.05
1.87	17-34	160	53	72	4.90
2.01	17-30	380	24	15	3.70
2.17[5]	15-21	190	29	42	4.30
2.17[5]	9-21	76	19	17	4.65
2.57[5]	16-21	110	8.2	11	4.20
2.57[5]	16-21	170	14	13	4.10

1 Sample contained three percent $CaCO_3$ which is atypical of Duluth Complex rock.

2 Parentheses indicate anomalous value.

3 Sample underwent oxidation previously in a test pile.

4 Sample was amphibole-rich and thus atypical of Duluth Complex rock.

5 Contained a significant amount of quartz and was, therefore, atypical of Duluth Complex rock.

Table A1.5. Release rates for blast hole samples during period of Ca, Mg analysis (Lapakko, 1993b).

Percent Sulfur	Period, weeks		Rates, mole (g rock)$^{-1}s^{-1}$			Minimum pH
	SO_4	Ca, Mg	SO_4	Ca	Mg	
0.18	134-150	134-150	13	7.8	6.3	6.29
0.18	136-150	132-148	12	7.4	6.9	6.30
0.22	134-150	134-146	11	6.7	8.9	6.52
0.22	134-150	132-148	11	10	7.6	6.33
0.40	135-150	134-150	24	25	0.79	6.17
0.40	134-150	136-148	22	23	0.79	6.30
0.41	136-150	127-150	14	6.0	5.4	5.30
0.41	134-150	132-144	14	5.6	5.0	5.32
0.51	136-150	127-150	16	6.2	6.0	5.08
0.51	136-150	132-148	18	6.3	5.0	4.98
0.57	134-150	134-150	24	6.3	12	5.38
0.57	137-150	132-148	26	8.0	14	5.35
0.58	140-150	134-150	28	7.6	12	4.85
0.58	136-150	132-148	32	9.4	14	4.82
0.71	135-150	127-146	22	4.9	13	4.98
0.71	137-150	132-148	20	4.0	10	5.05
1.12	35-69	53-65	(100)[2]	(62)	(5.8)	4.62
1.12	37-69	51-65	(97)	(61)	(7.0)	4.75
1.16	53-69	47-69	48	11	17	4.69
1.16	50-69	51-67	51	17	16	4.60
1.40	35-57	46-65	79	29	21	4.78
1.40	33-69	51-67	75	25	24	4.92
1.44	37-69	53-65	56	9.8	19	4.59
1.44	36-69	51-65	56	11	20	4.41
1.63	117-145[1]	138-150	62	8.1	23	4.37
1.63	119-150	127-148	180	12	35	3.90
1.64	55-69	53-69	76	18	30	4.42
1.64	25-69	51-67	95	21	32	4.32

1 dSO_4/dt = 83 for wks 146-150

2 Parentheses indicate anomalous value.

Table A1.6. Comparison of field and laboratory drill core data.

Percent Sulfur	Field Rate			Min Field pH	Lab Rates			Min Lab pH	Retardation Factor				
	SO_4	Ca	Mg		SO_4	Ca	Mg		SO_4	Ca	Mg	Ca+Mg	Avg.
0.63 (FL1)[1]	3.9	2.5	0.86	4.96	25	27	6.7	6.8-7.3	0.16	0.092	0.13	0.10	0.13
0.63 (FL2)[1]	2.4	1.4	0.64	4.87	25	27	6.7	6.8-7.3	0.096	0.052	0.096	0.061	0.081
0.63 (FL3)[1]	6.4	2.8	2.4	4.71	25	27	6.7	6.8-7.3	0.26	0.10	0.36	0.15	0.24
0.79[2]	8.5	2.8	4.3	3.70	36	32	8.6	6.8-6.9	0.24	0.088	0.50	0.17	0.28
1.41[3]	12	2.7	3.7	3.08	170	28	27	4.2-4.4	0.070	0.096	0.14	0.12	0.10

1 Lab rates for 0.63-percent-sulfur determined by interpolation of rates from 0.59 and 0.80-percent-sulfur samples (17 week period of record) and assuming rates varied linearly with sulfur content.

2 Lab rates for 0.79-percent-sulfur from 0.80-percent-sulfur sample (17 week period of record).

3 Lab rates for 1.41-percent-sulfur sample determined by averaging rates for samples with sulfur contents of 1.35 (34 week period of record) and 1.47 (21 week period of record) percent.

APPENDIX 2

DRAINAGE QUALITY

Appendix 2: Drainage Quality

Figure A2.1. pH over time for Duluth Complex test pile FL1 (0.63% S).

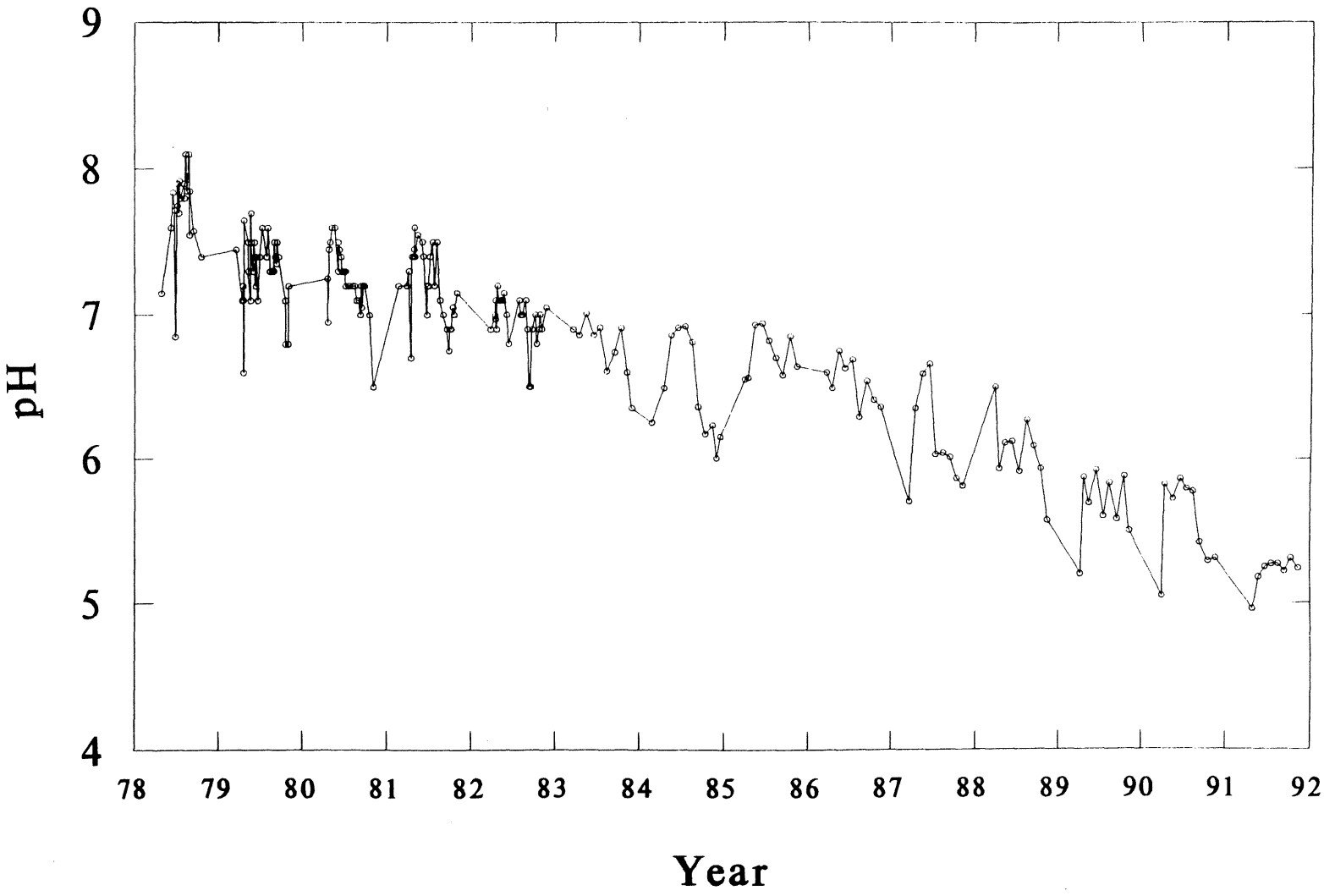

Figure A2.2. Sulfate concentrations over time for Duluth Complex test pile FL1 (0.63% S).

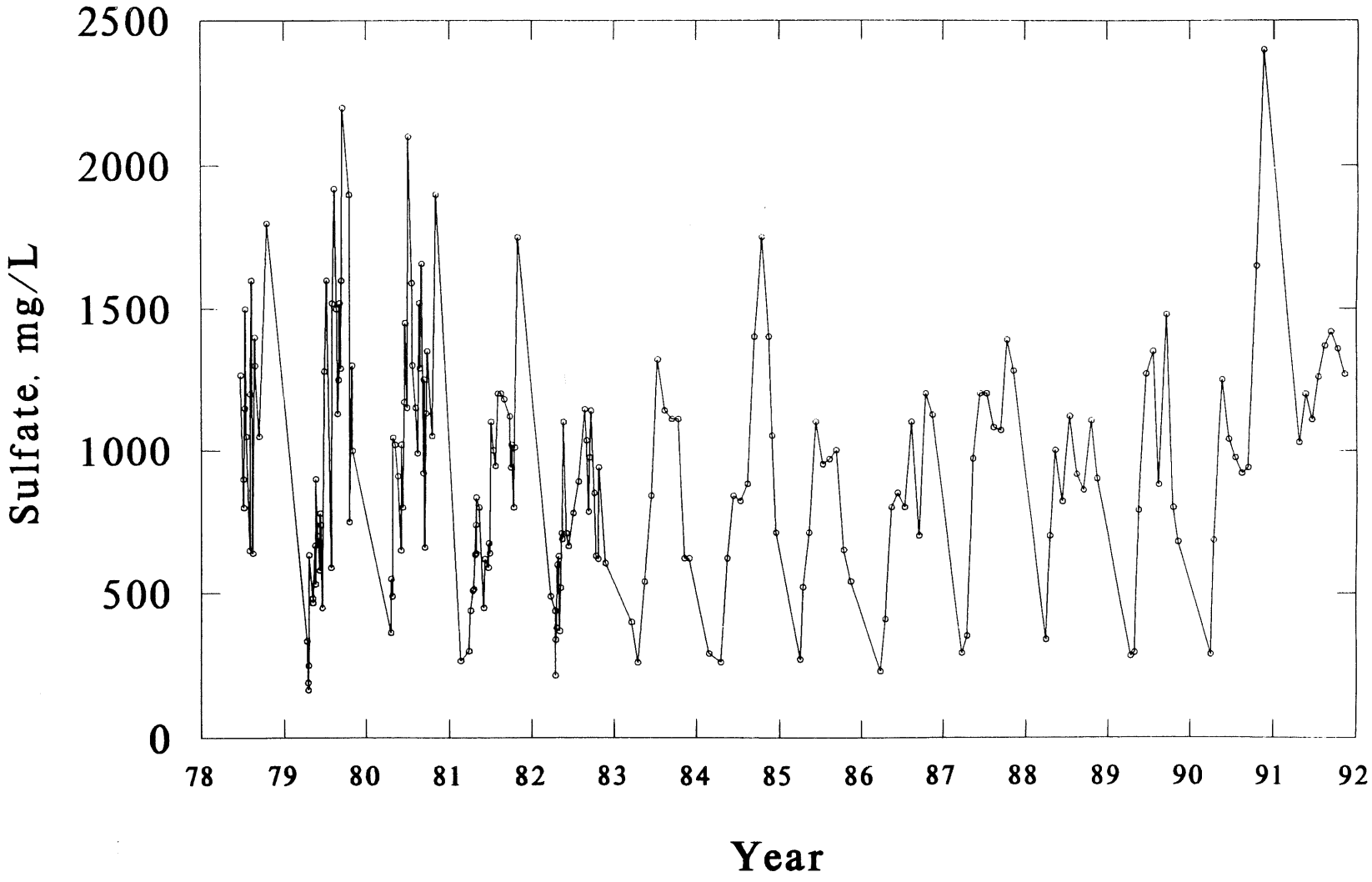

Figure A2.3. Calcium concentrations over time for Duluth Complex test pile FL1 (0.63% S).

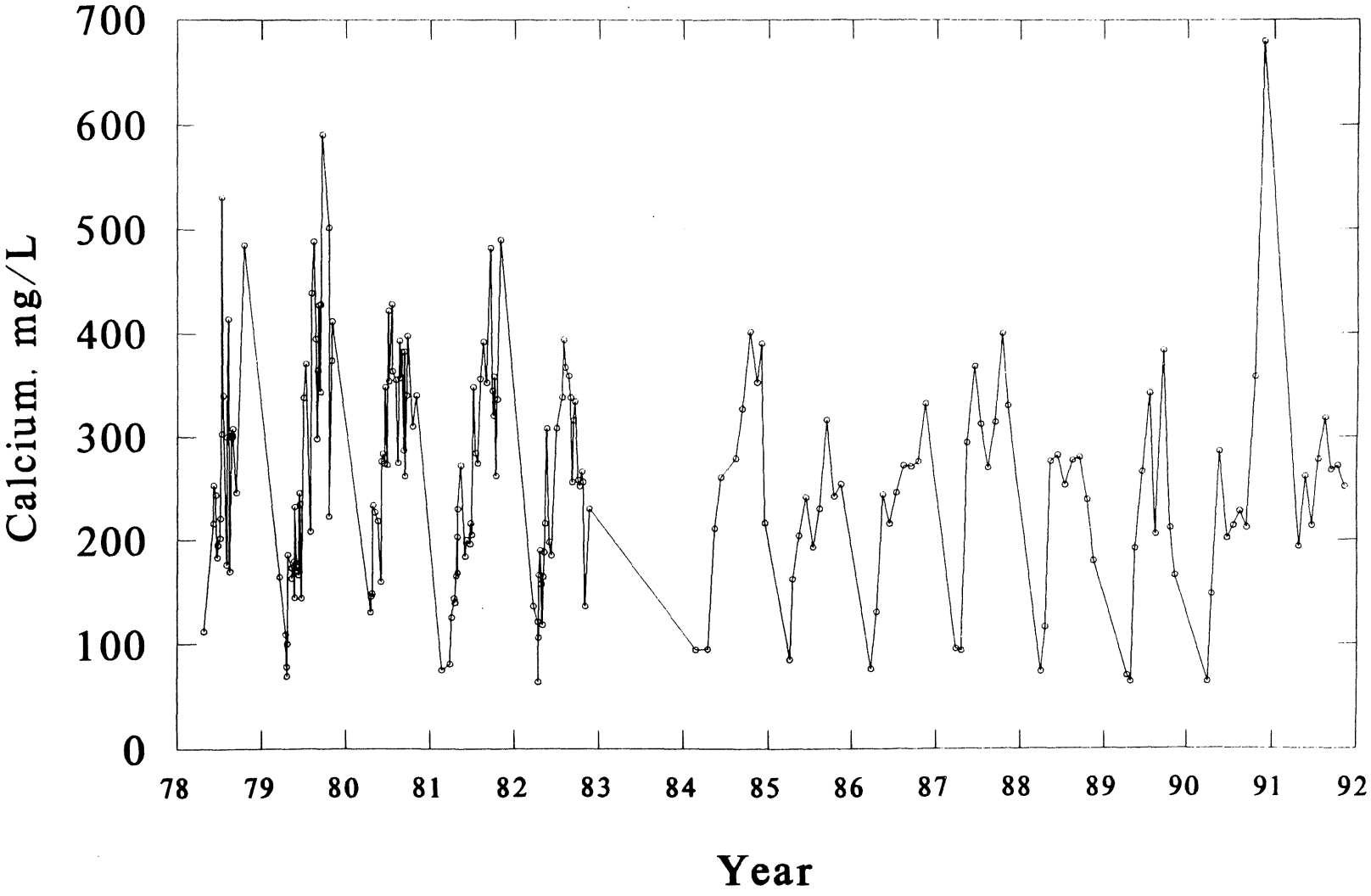

Figure A2.4. Magnesium concentrations over time for Duluth Complex test pile FL1 (0.63% S).

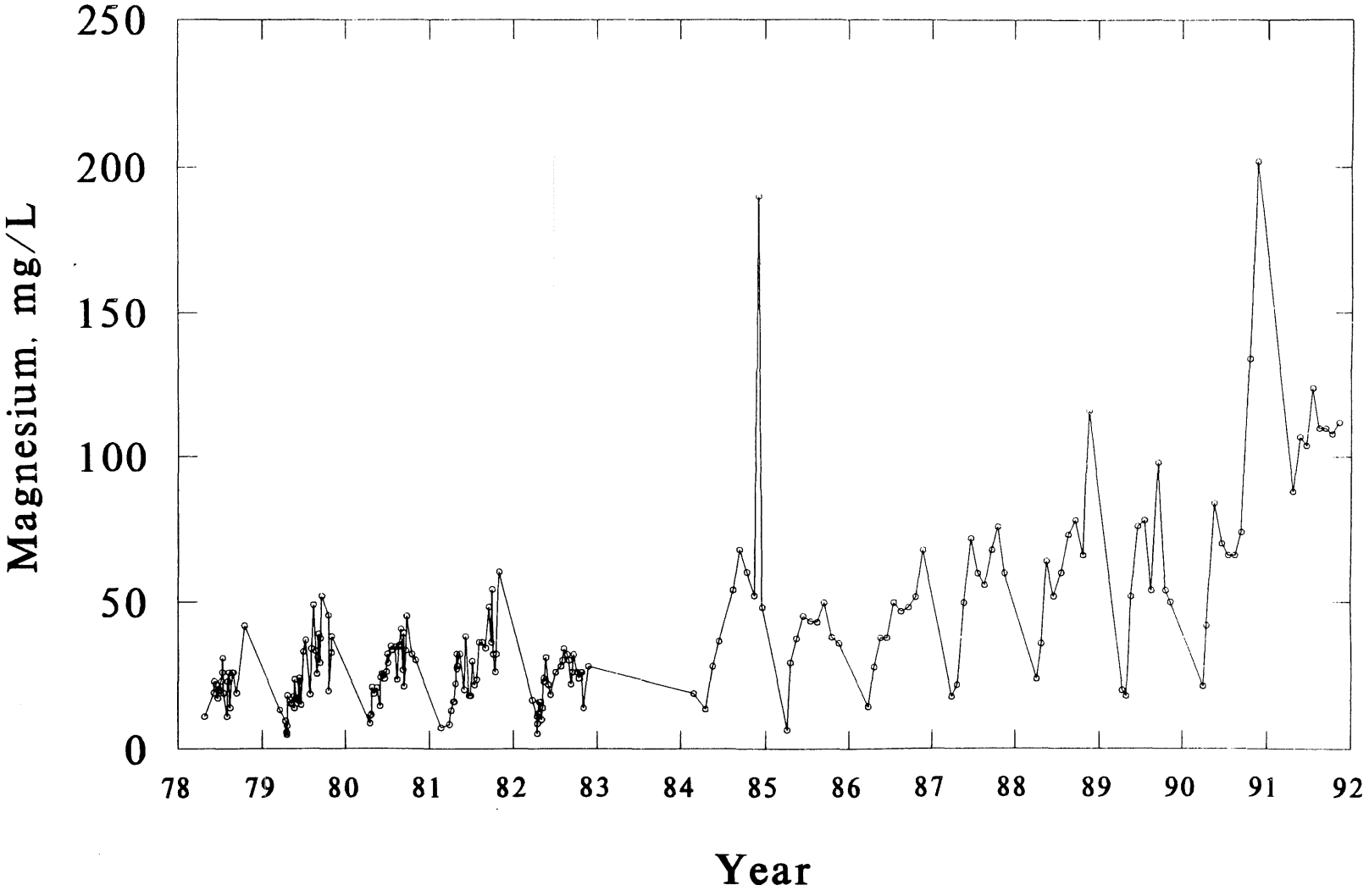

Figure A2.5. pH over time for Duluth Complex test pile FL2 (0.63% S).

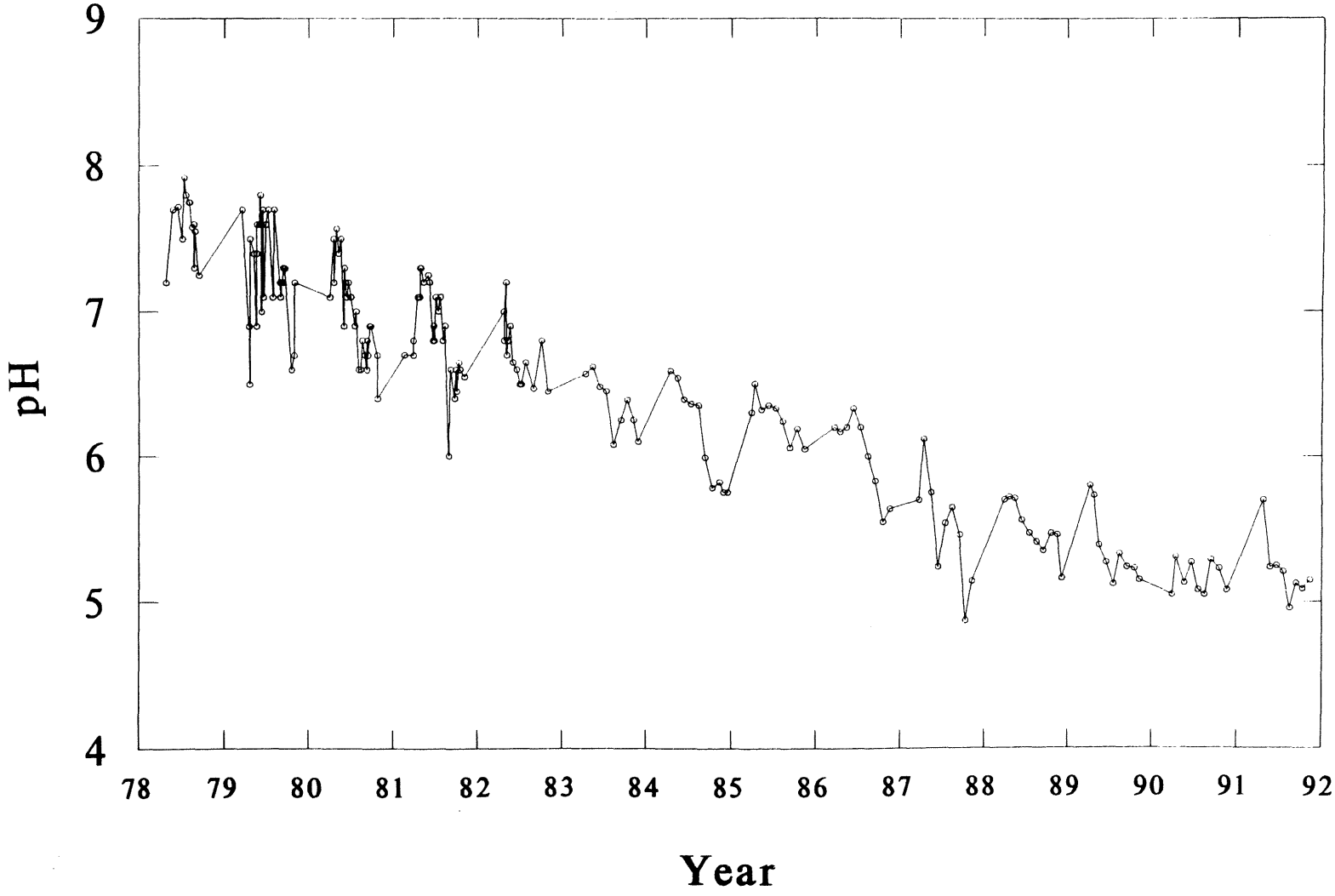

Figure A2.6. Sulfate concentrations over time for Duluth Complex test pile FL2 (0.63% S).

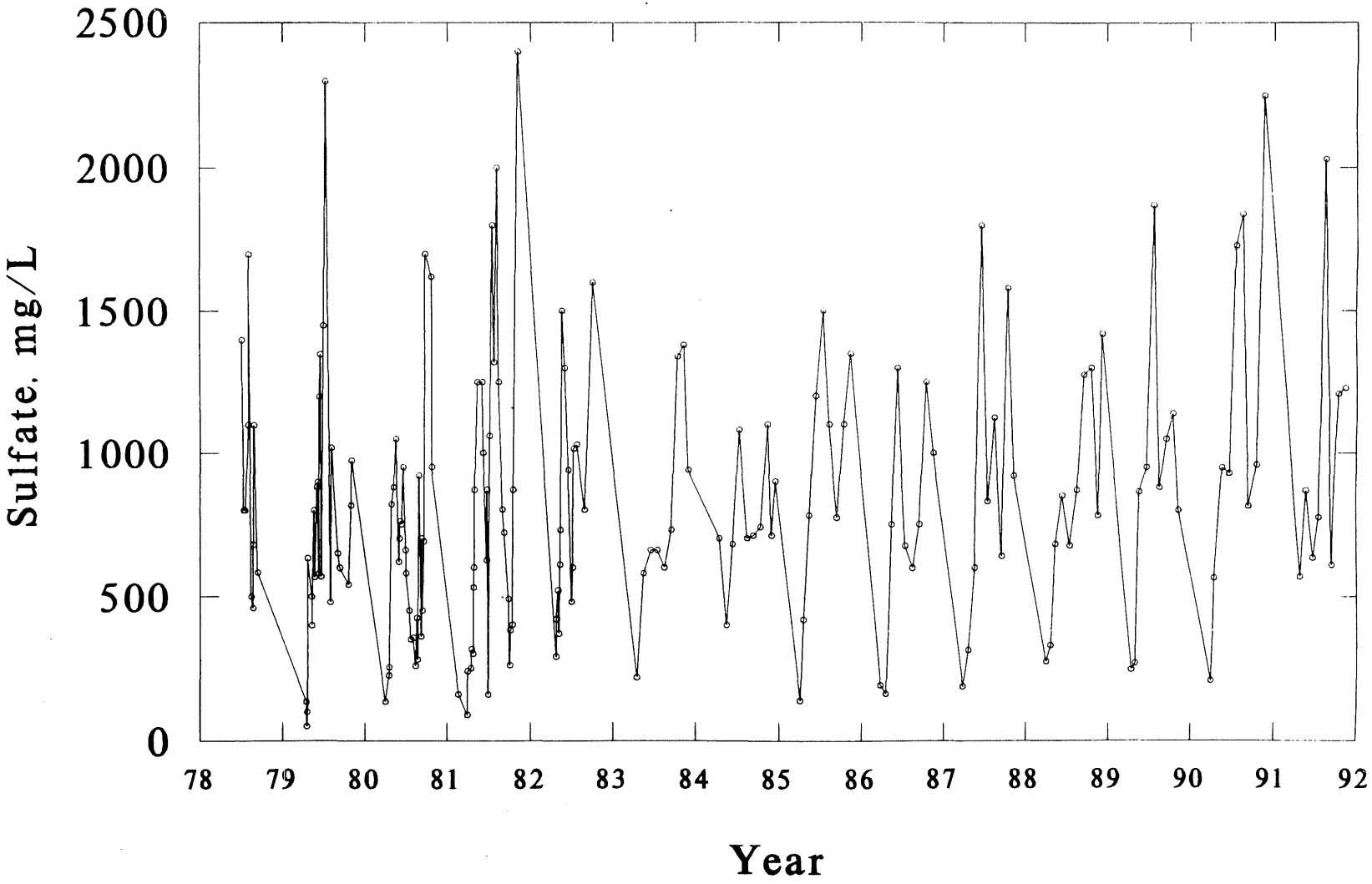

Figure A2.7. Calcium concentrations over time for Duluth Complex test pile FL2 (0.63% S).

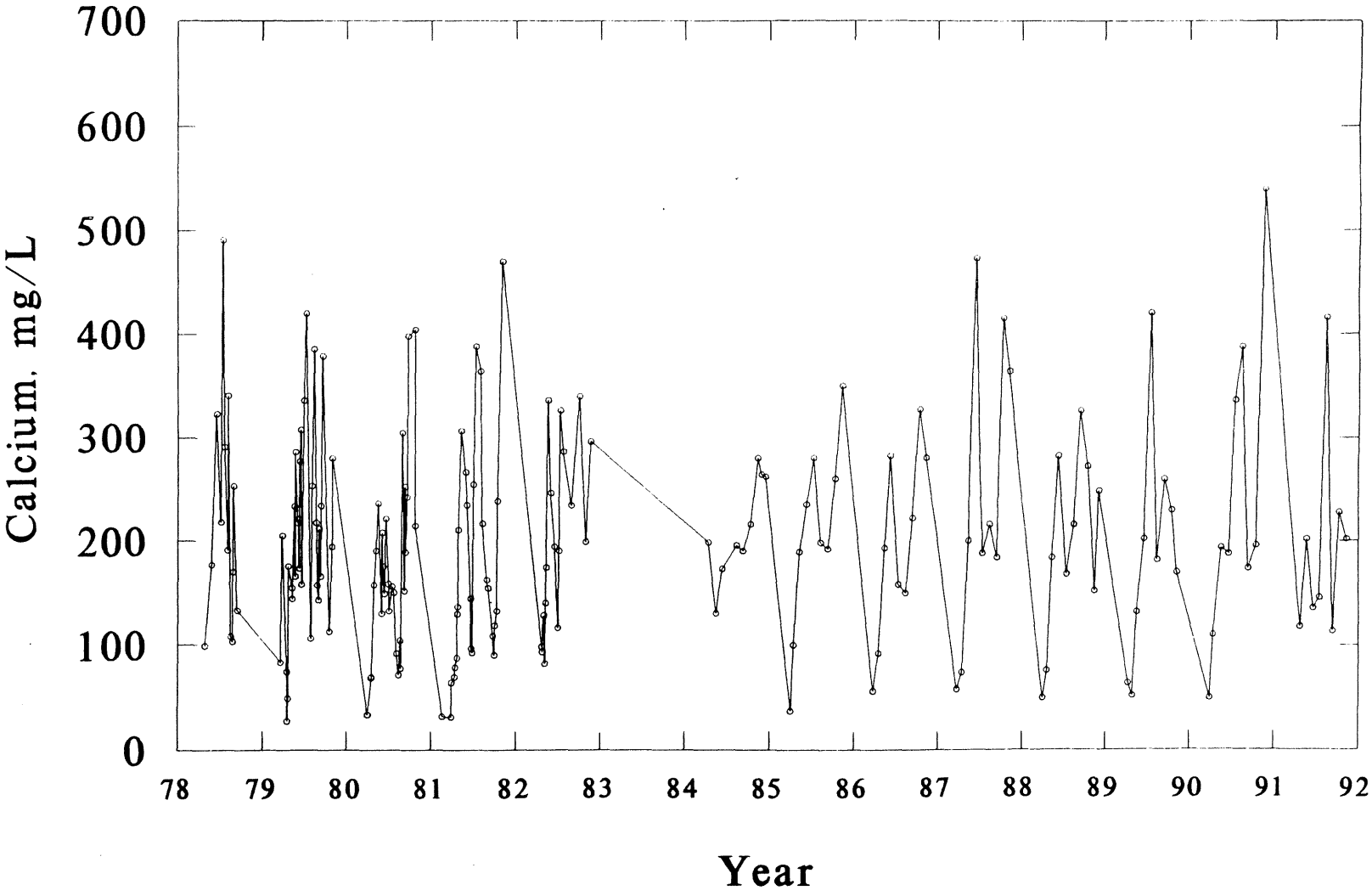

Figure A2.8. Magnesium concentrations over time for Duluth Complex test pile FL2 (0.63% S).

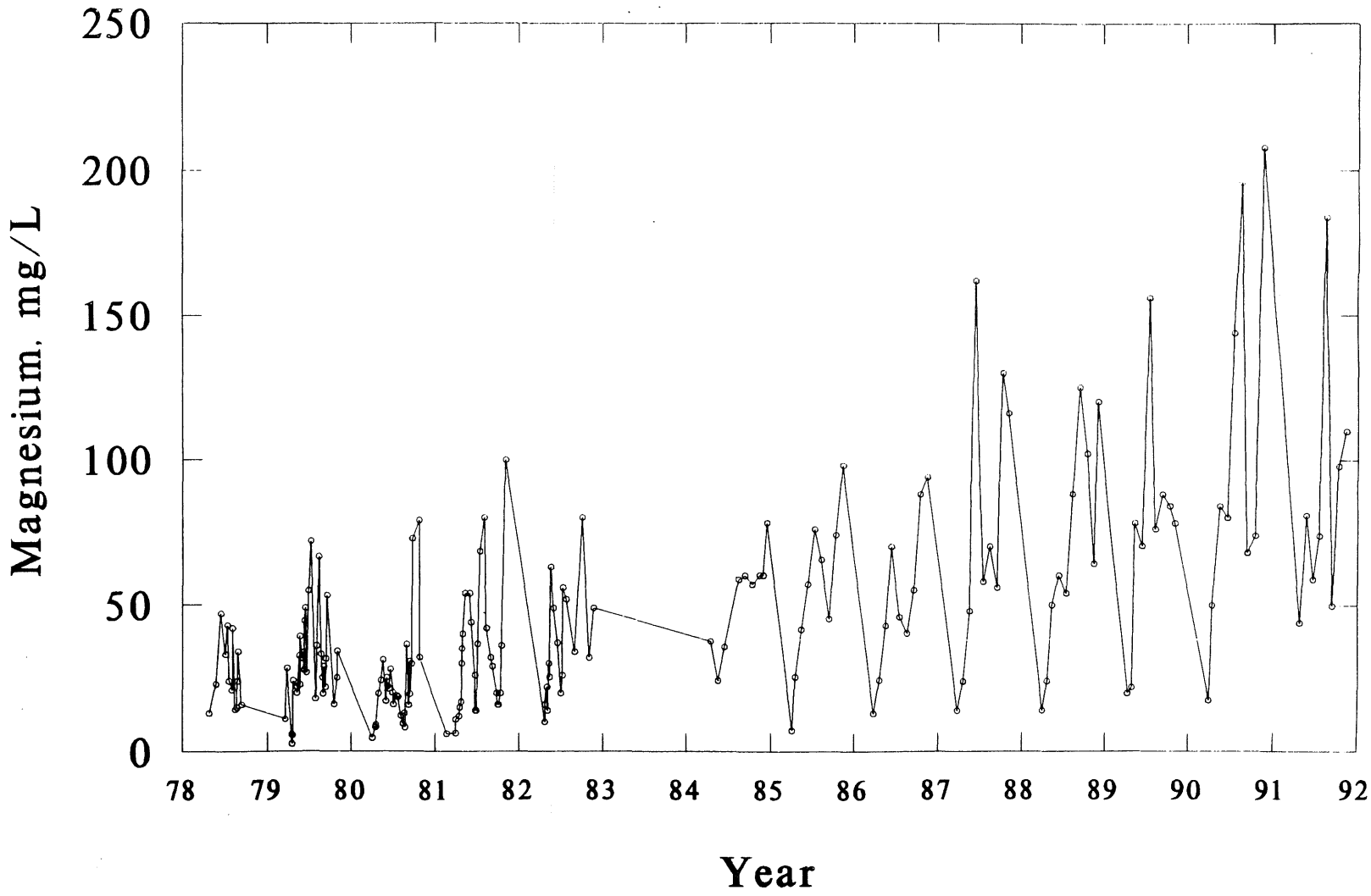

Figure A2.9. pH over time for Duluth Complex test pile FL3 (0.63% S).

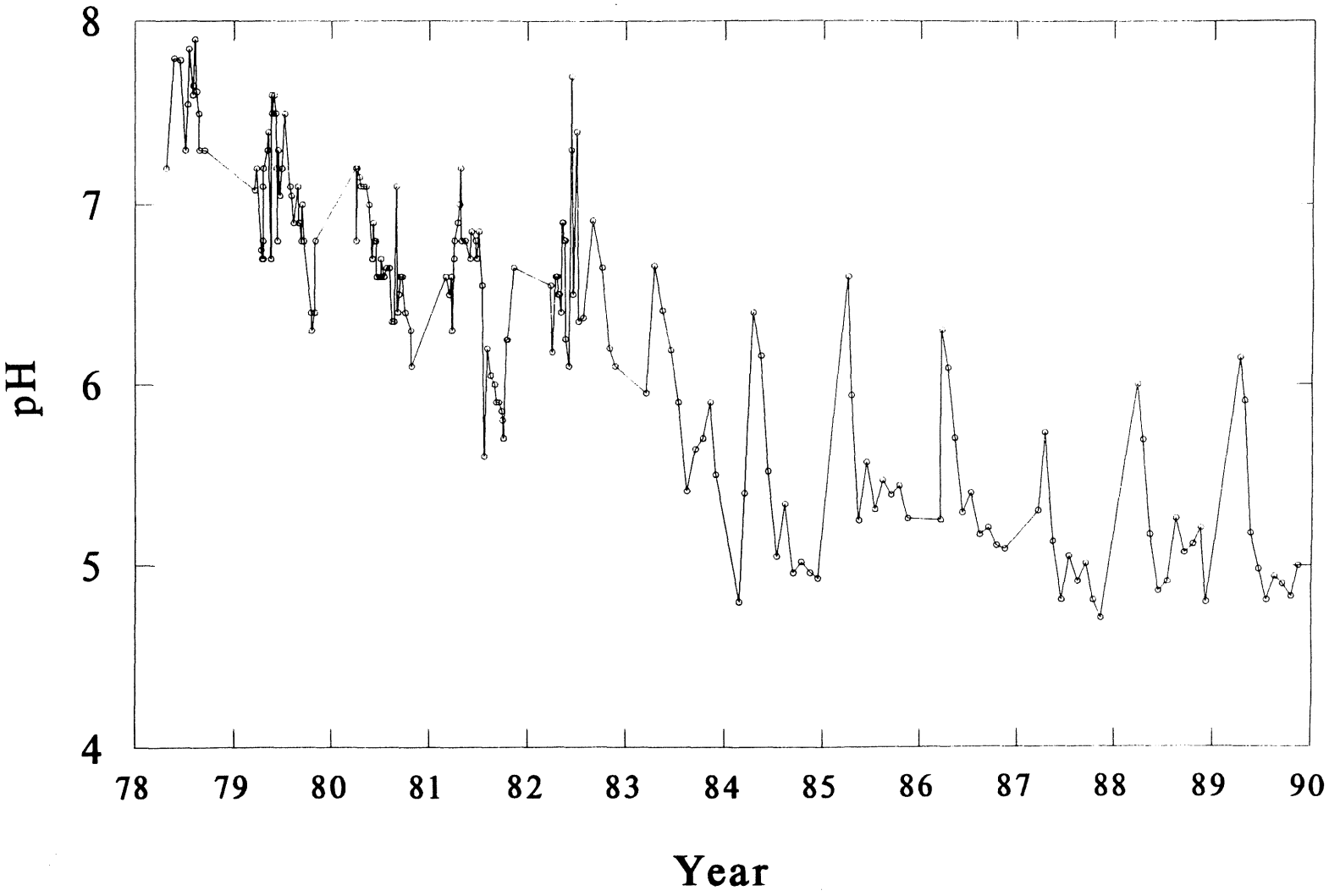

Figure A2.10. Sulfate concentrations over time for Duluth Complex test pile FL3 (0.63% S).

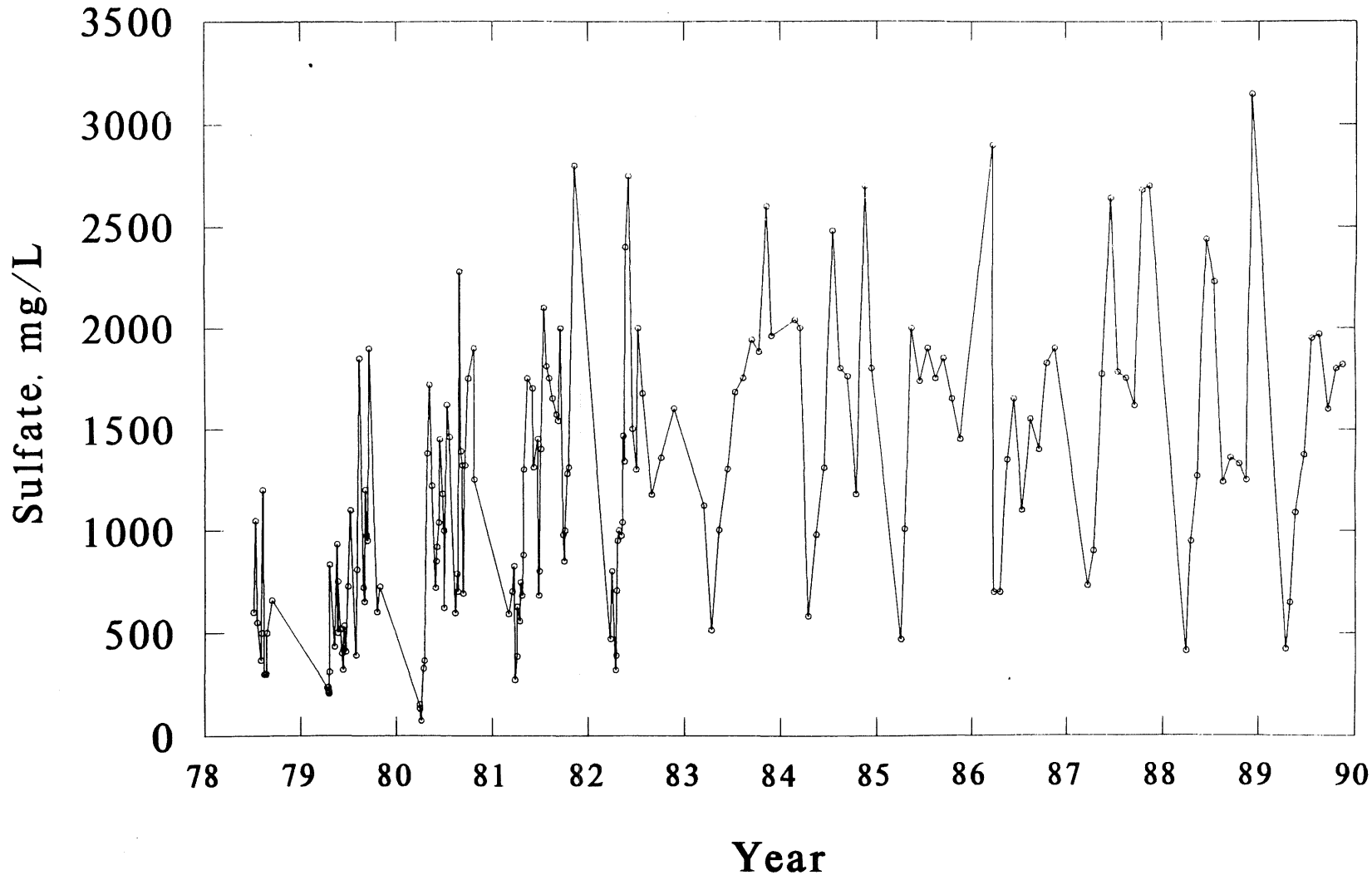

Figure A2.11. Calcium concentrations over time for Duluth Complex test pile FL3 (0.63% S).

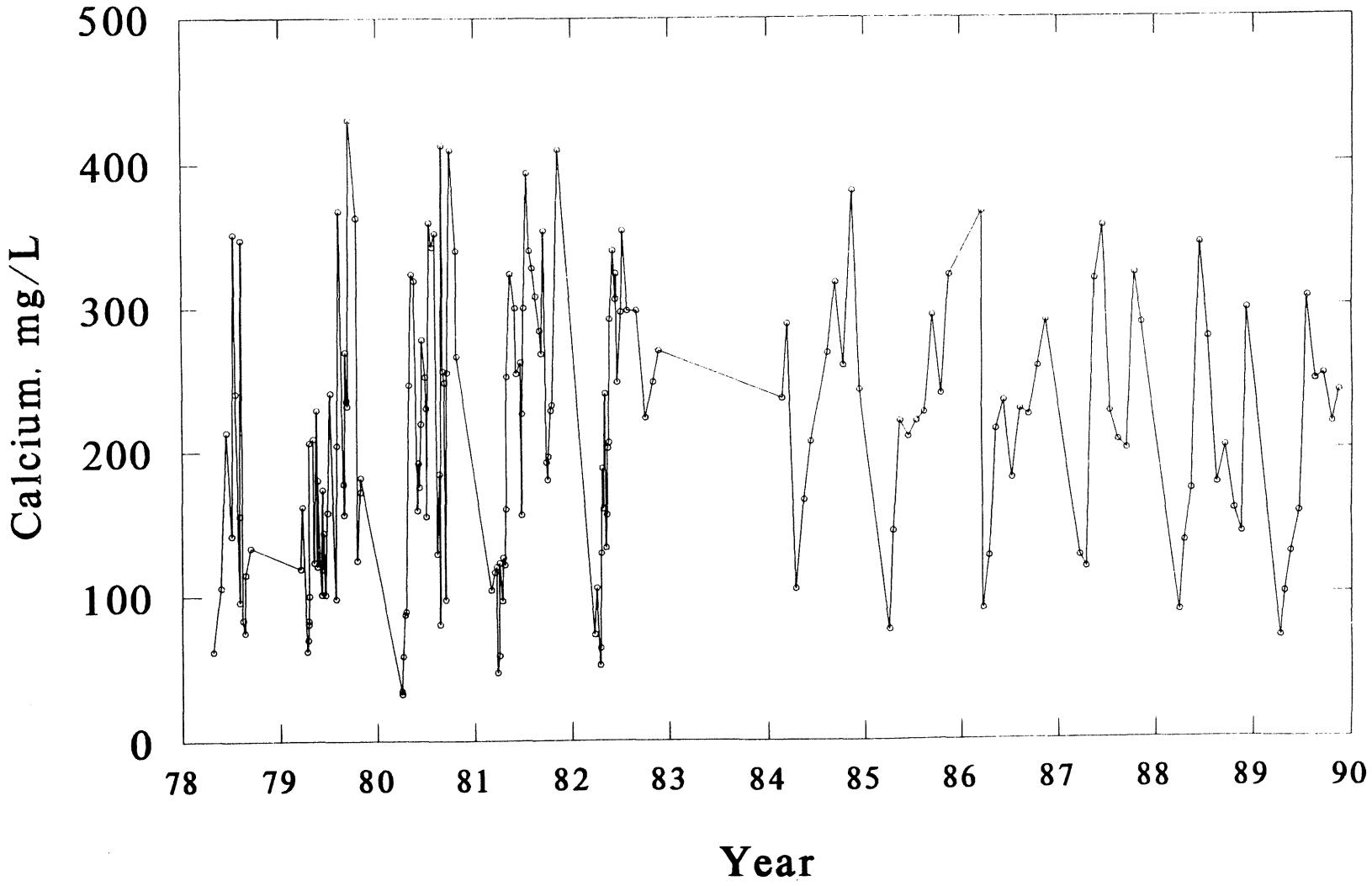

Figure A2.12. Magnesium concentrations over time for Duluth Complex test pile FL3 (0.63% S).

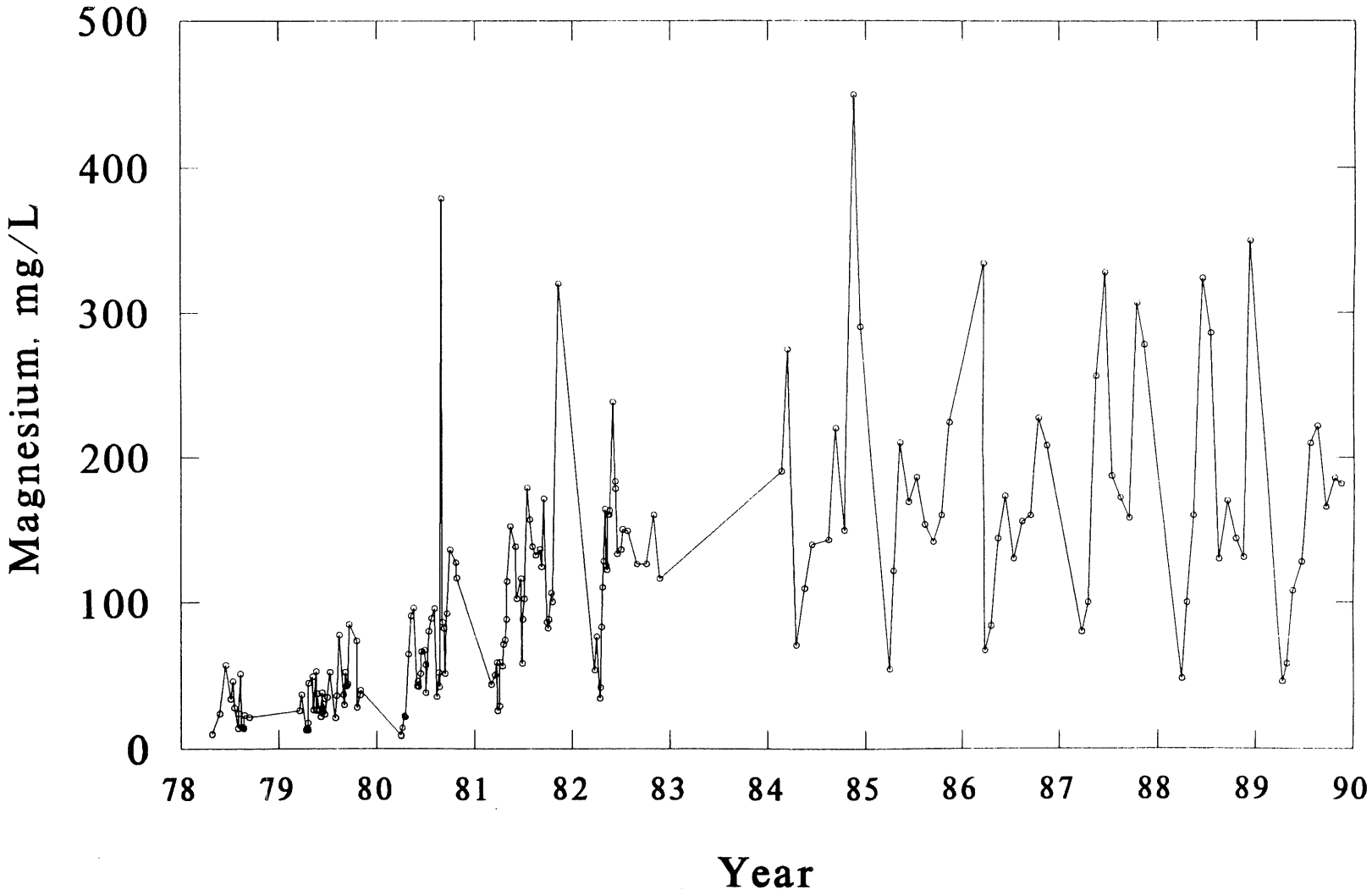

Figure A2.13. pH over time for Duluth Complex test pile FL4 (0.63% S).

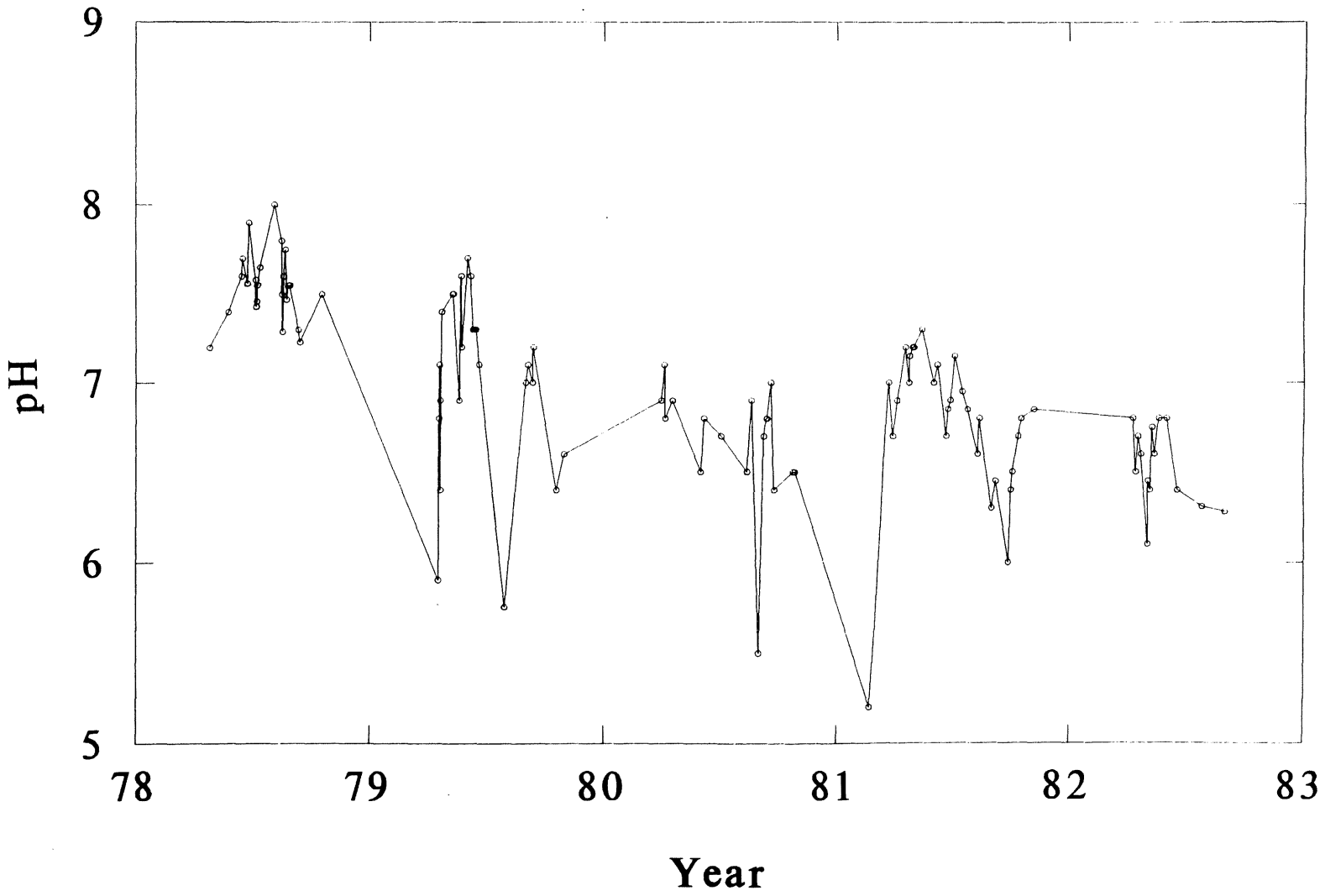

Figure A2.14. Sulfate concentrations over time for Duluth Complex test pile FL4 (0.63% S).

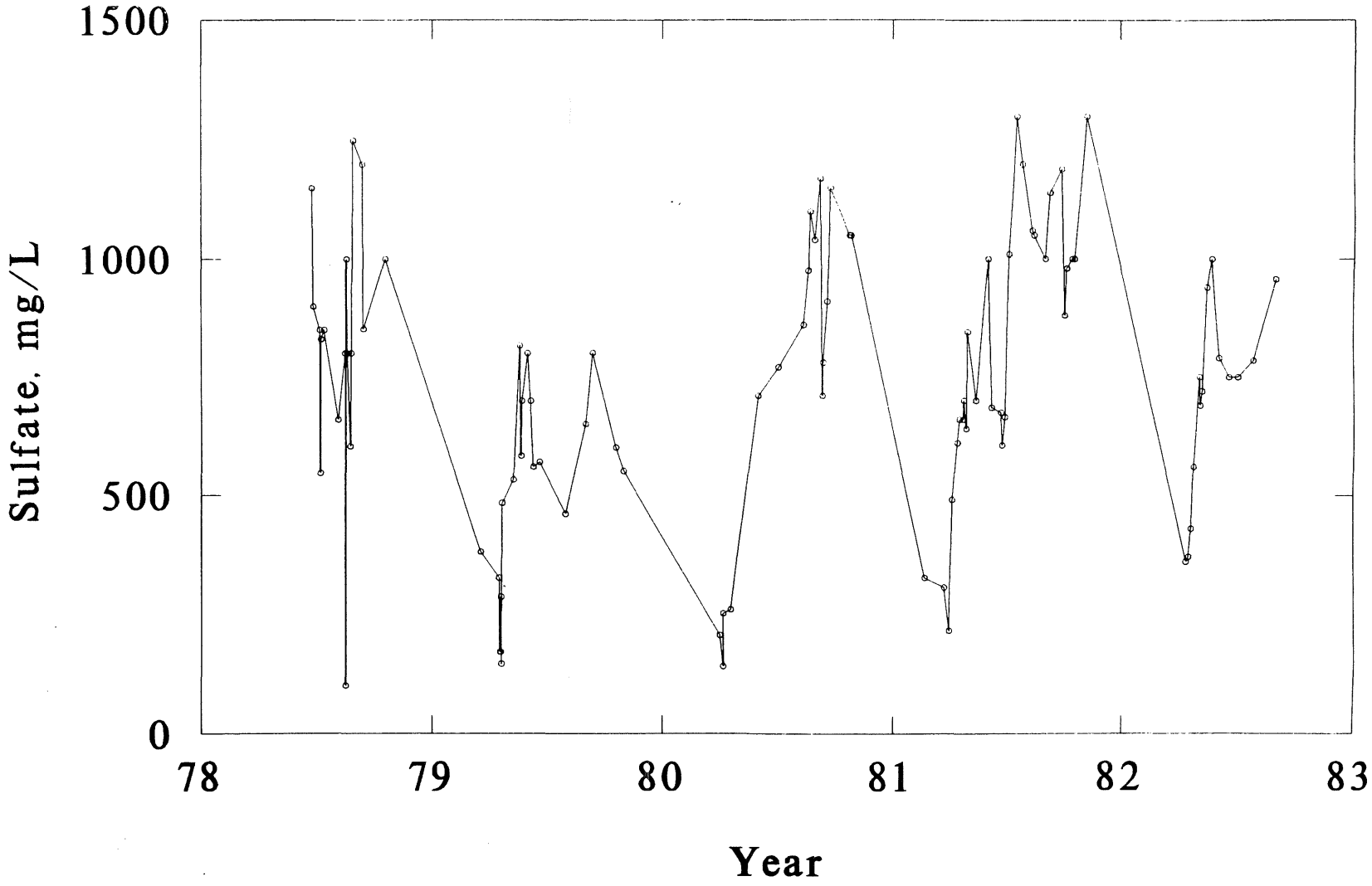

Figure A2.15. Calcium concentrations over time for Duluth Complex test pile FL4 (0.63% S).

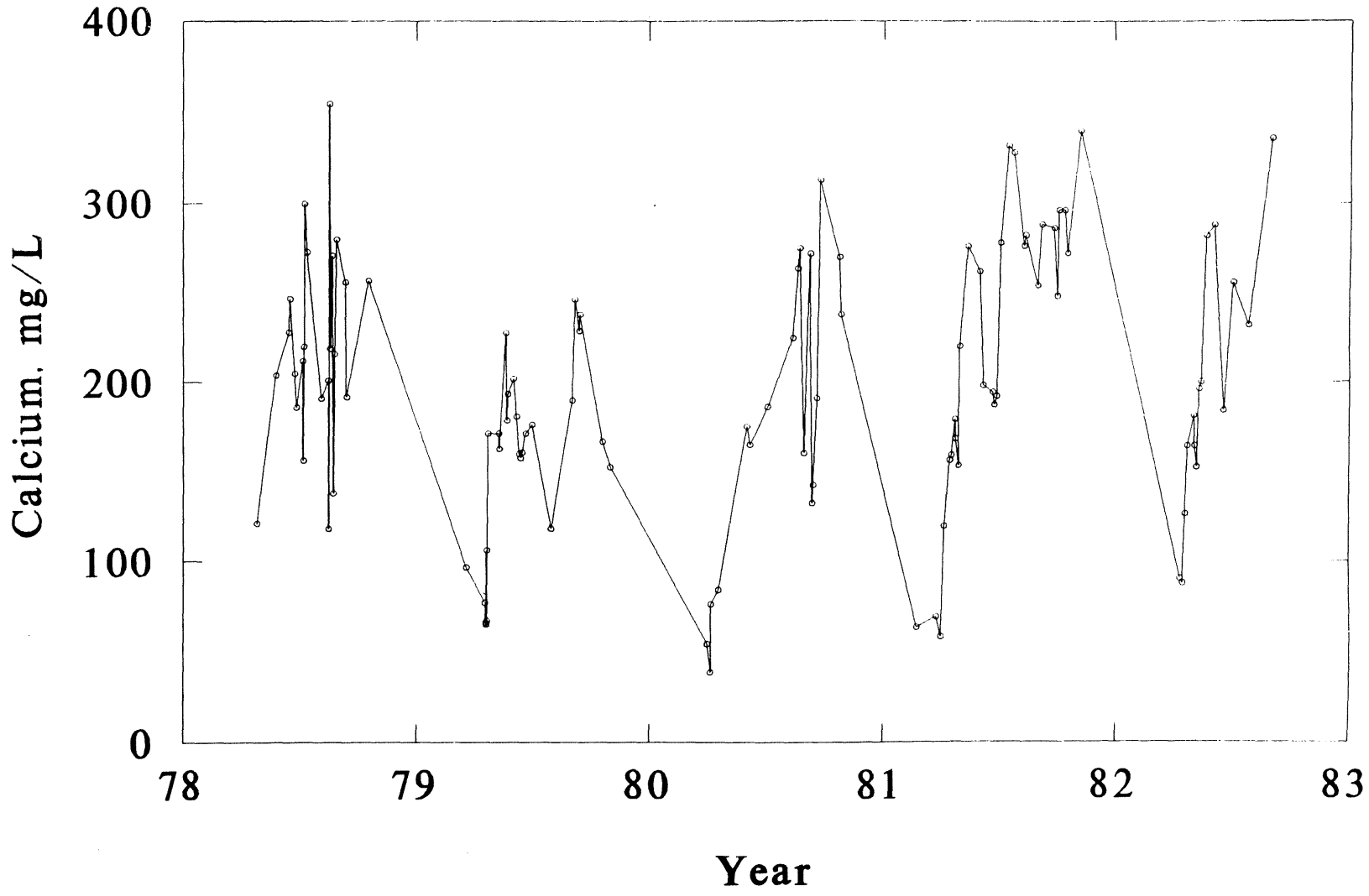

Figure A2.16. Magnesium concentrations over time for Duluth Complex test pile FL4 (0.63% S).

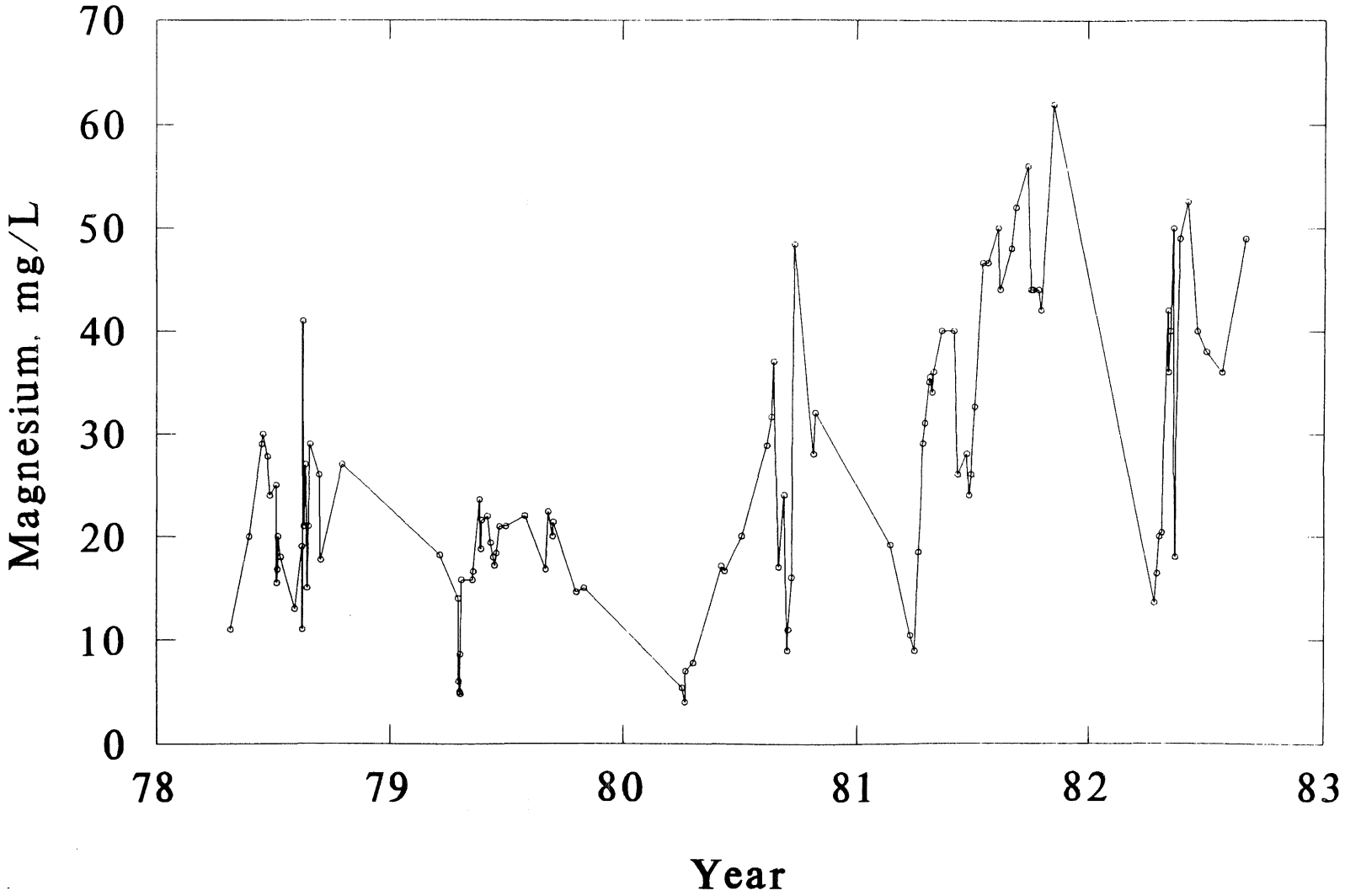

Figure A2.17. pH over time for Duluth Complex test pile FL6 (0.79% S).

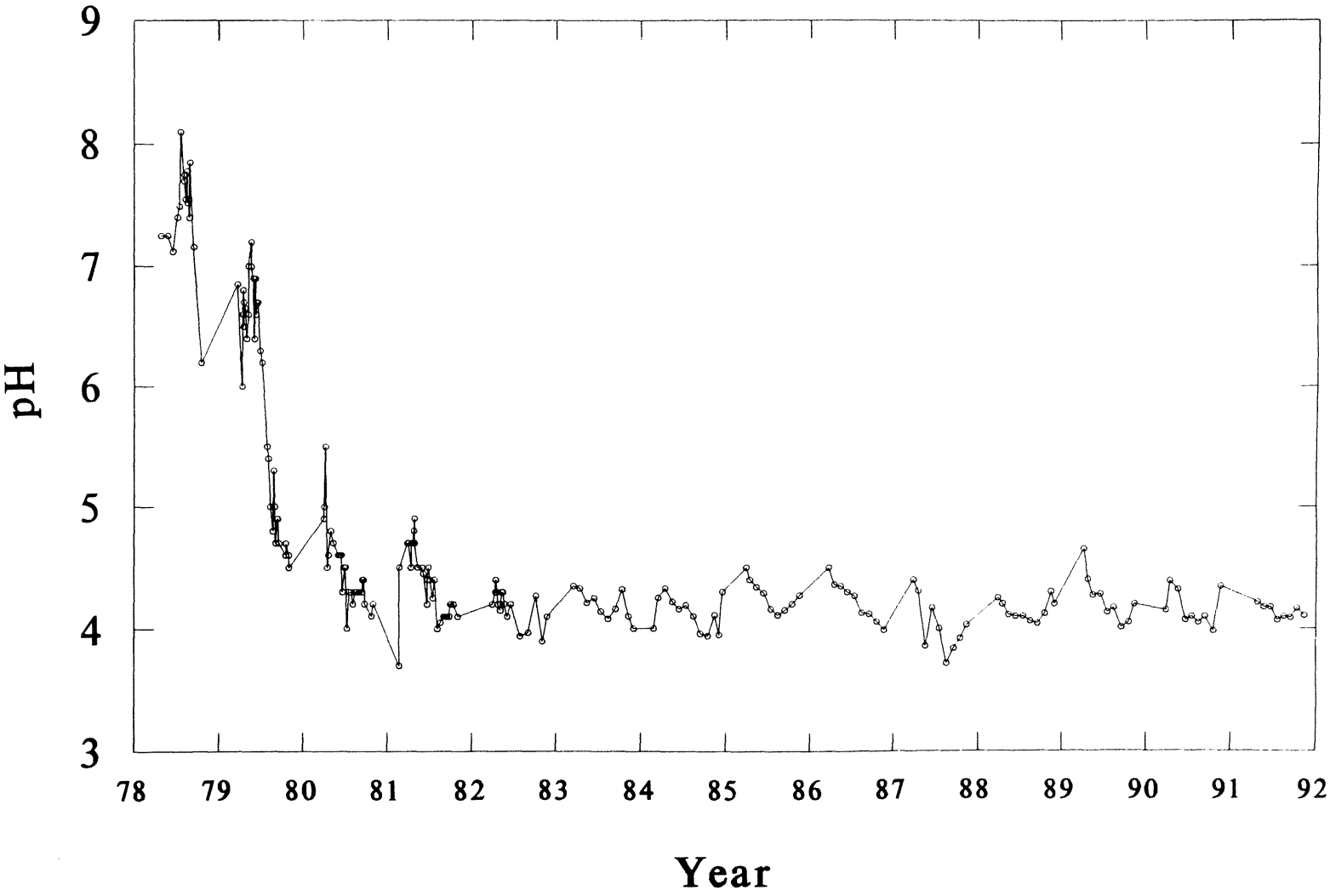

Figure A2.18. Sulfate concentrations over time for Duluth Complex test pile FL6 (0.79% S).

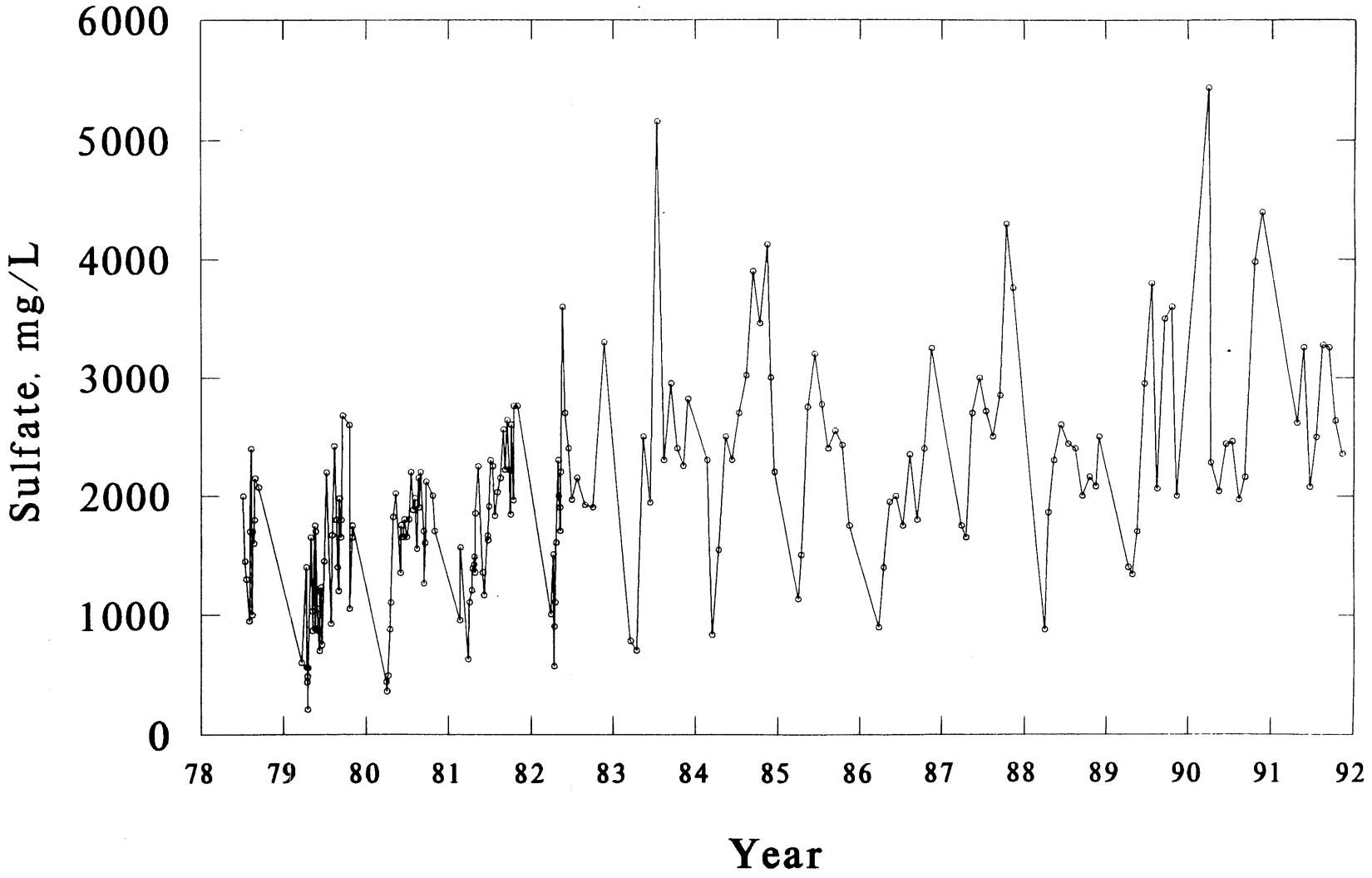

Figure A2.19. Calcium concentrations over time for Duluth Complex test pile FL6 (0.79% S).

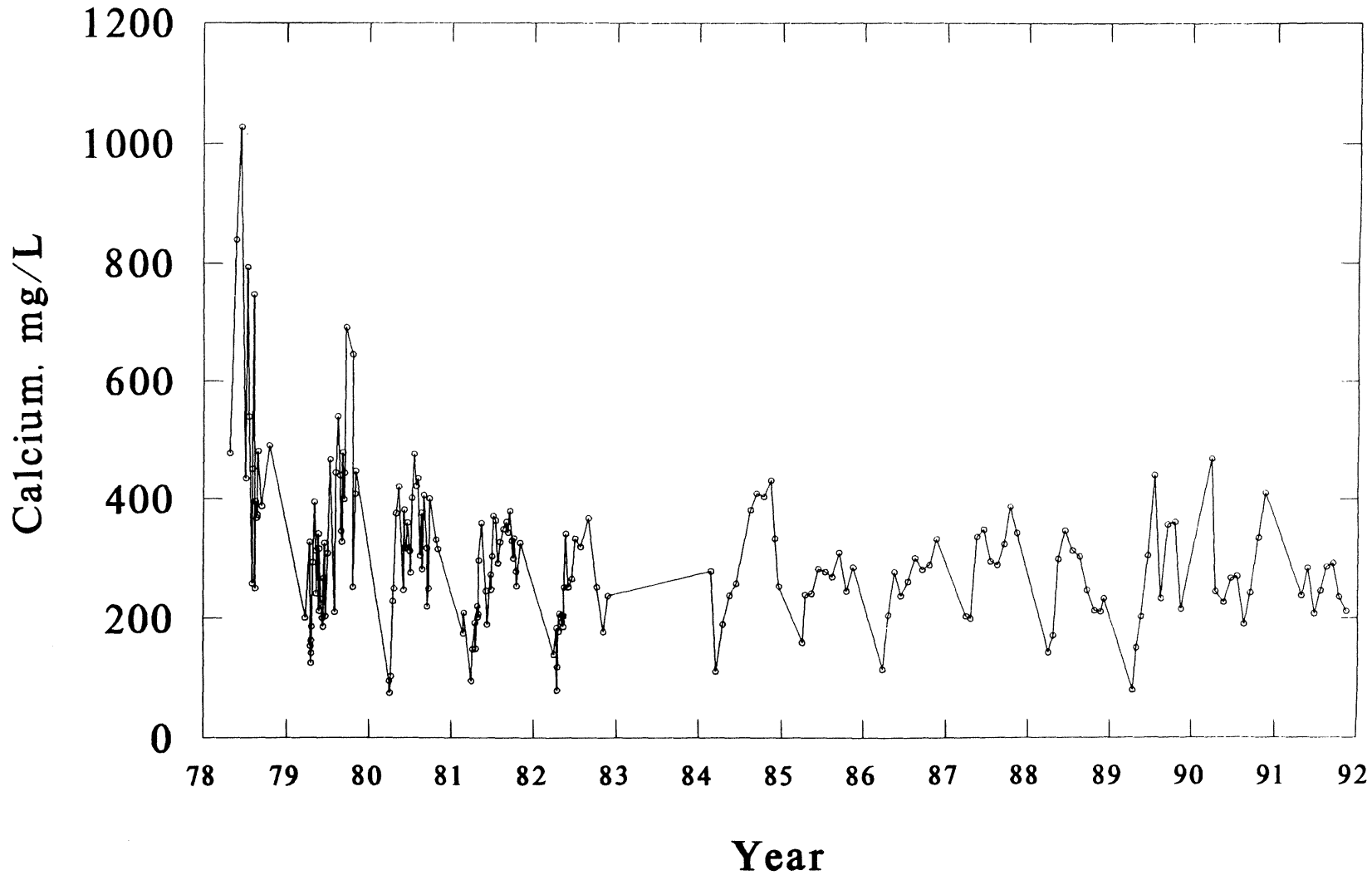

Figure A2.20. Magnesium concentrations over time for Duluth Complex test pile FL6 (0.79% S).

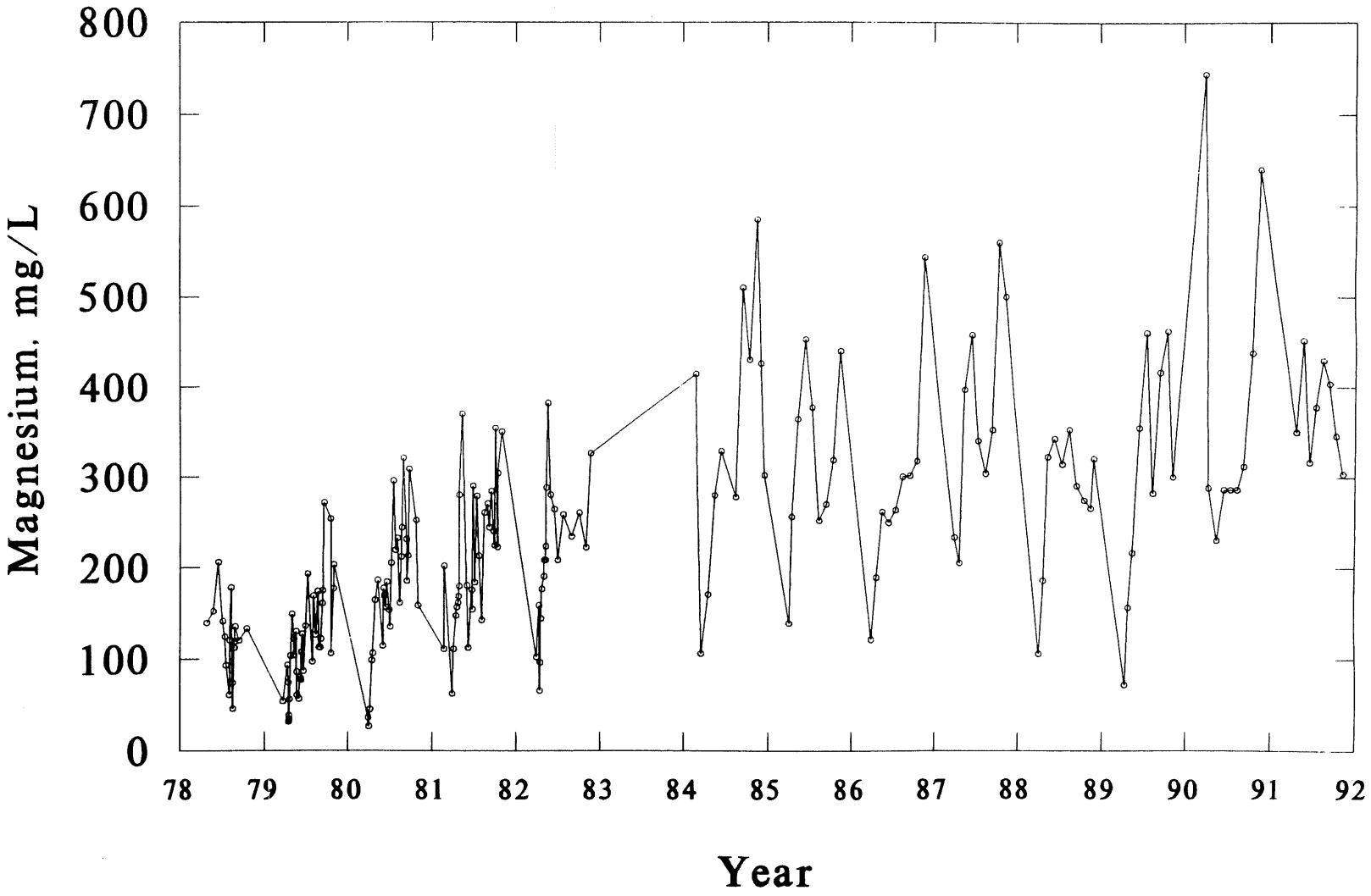

Figure A2.21. pH over time for Duluth Complex test pile FL5 (1.41% S).

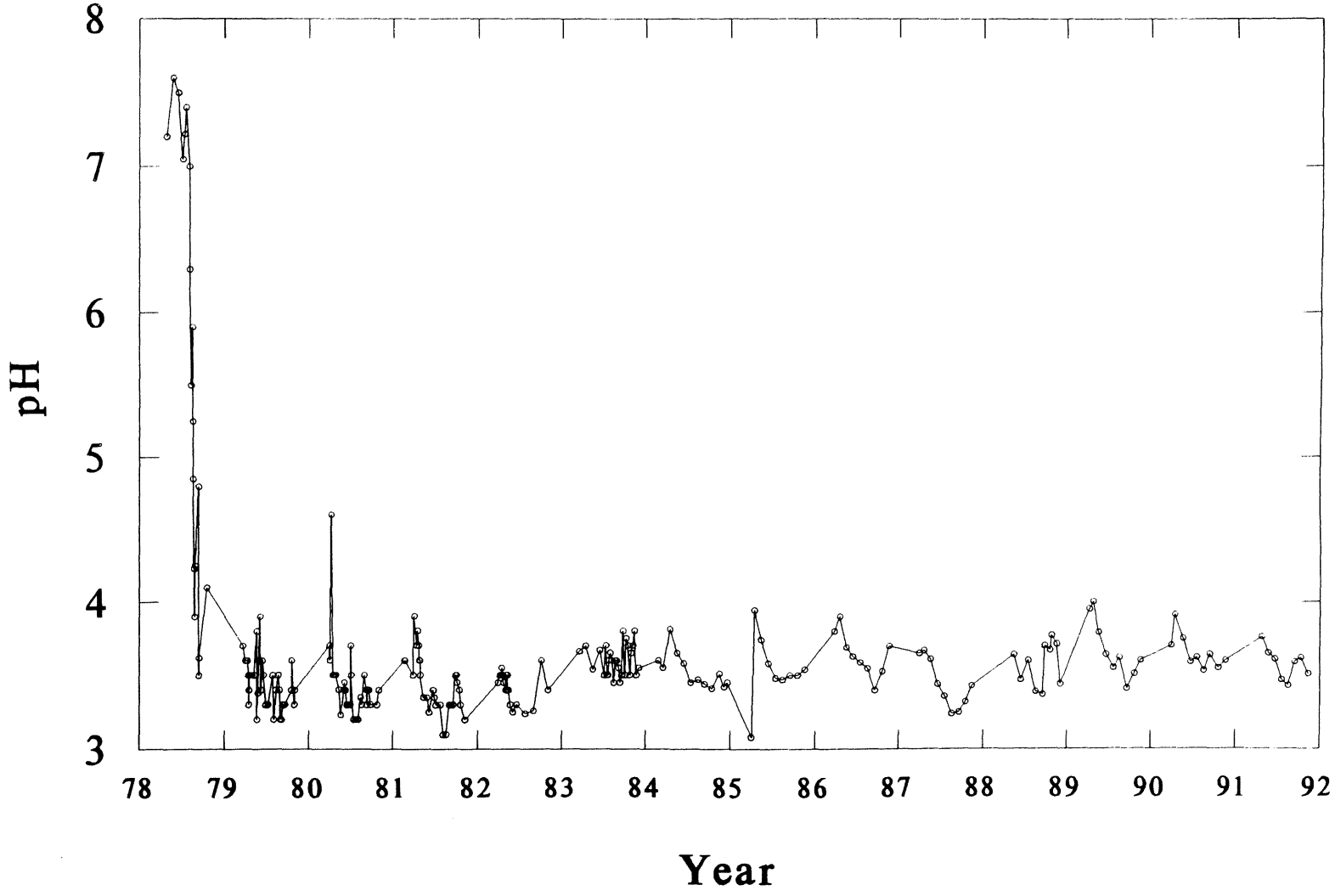

Figure A2.22. Sulfate concentrations over time for Duluth Complex test pile FL5 (1.41% S).

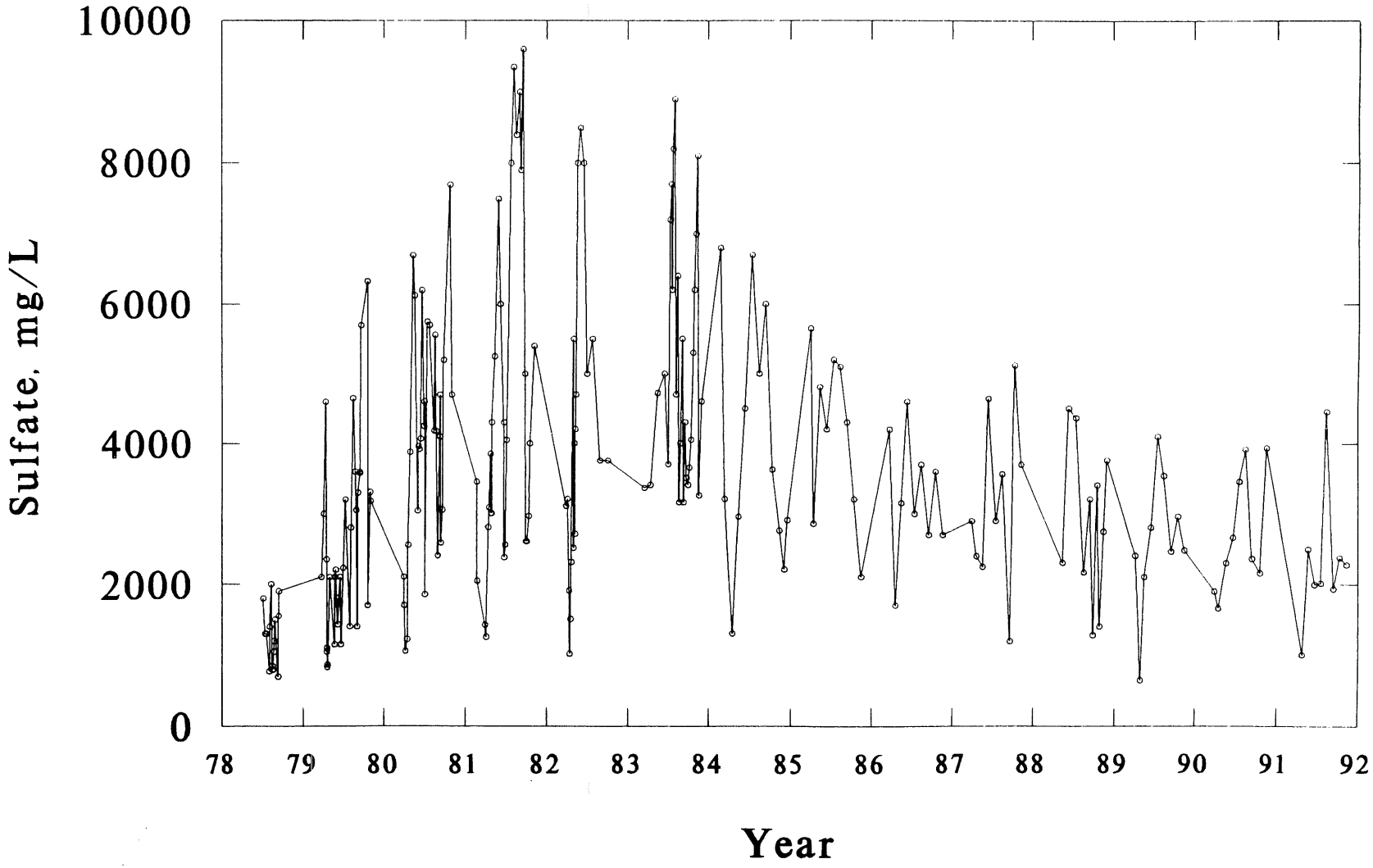

Figure A2.23. Calcium concentrations over time for Duluth Complex test pile FL5 (1.41% S).

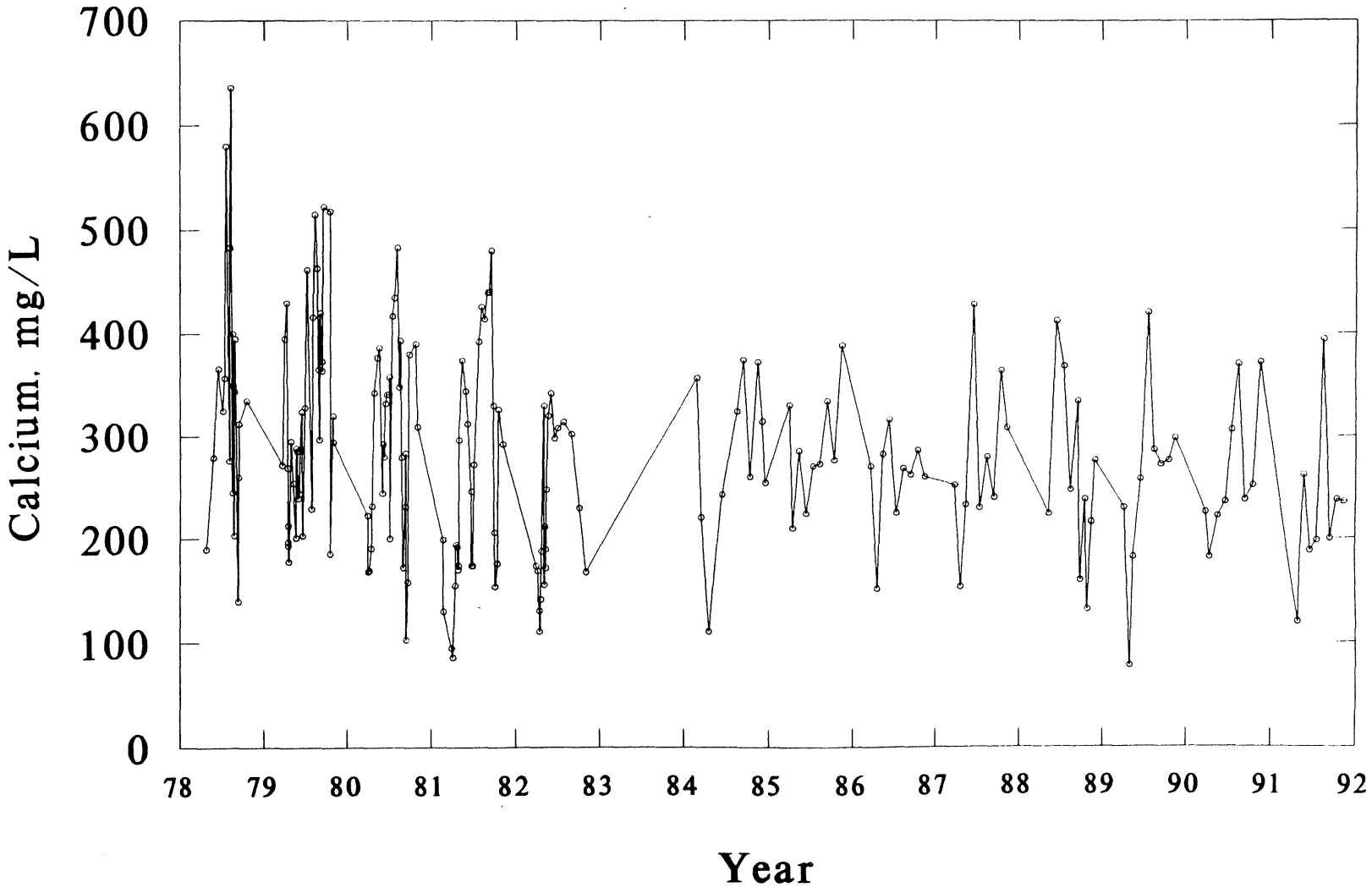

Figure A2.24. Magnesium concentrations over time for Duluth Complex test pile FL5 (1.41% S).

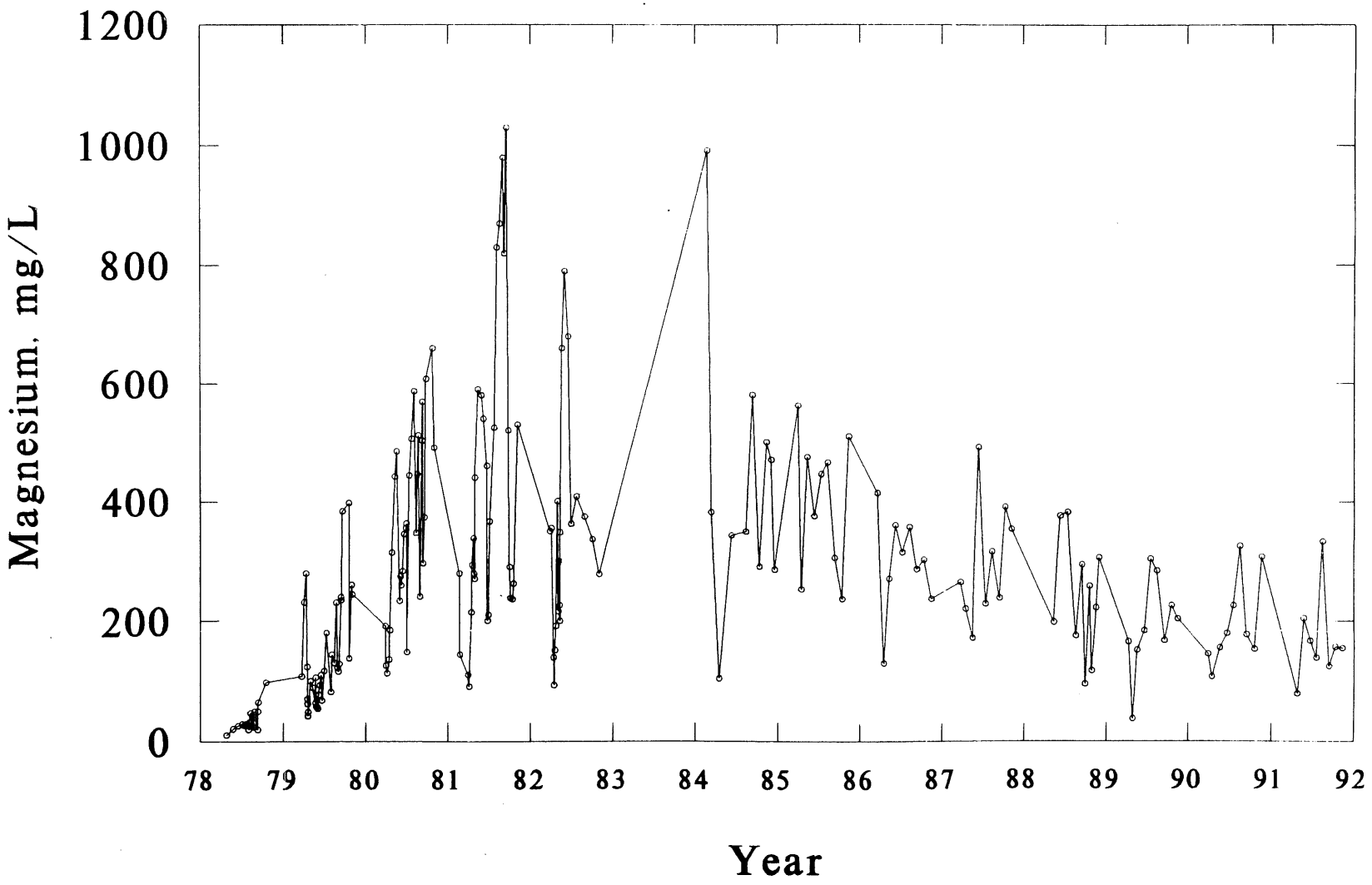

Figure A2.25. Annual flow-weighted mean concentrations of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL1 (0.63% S).

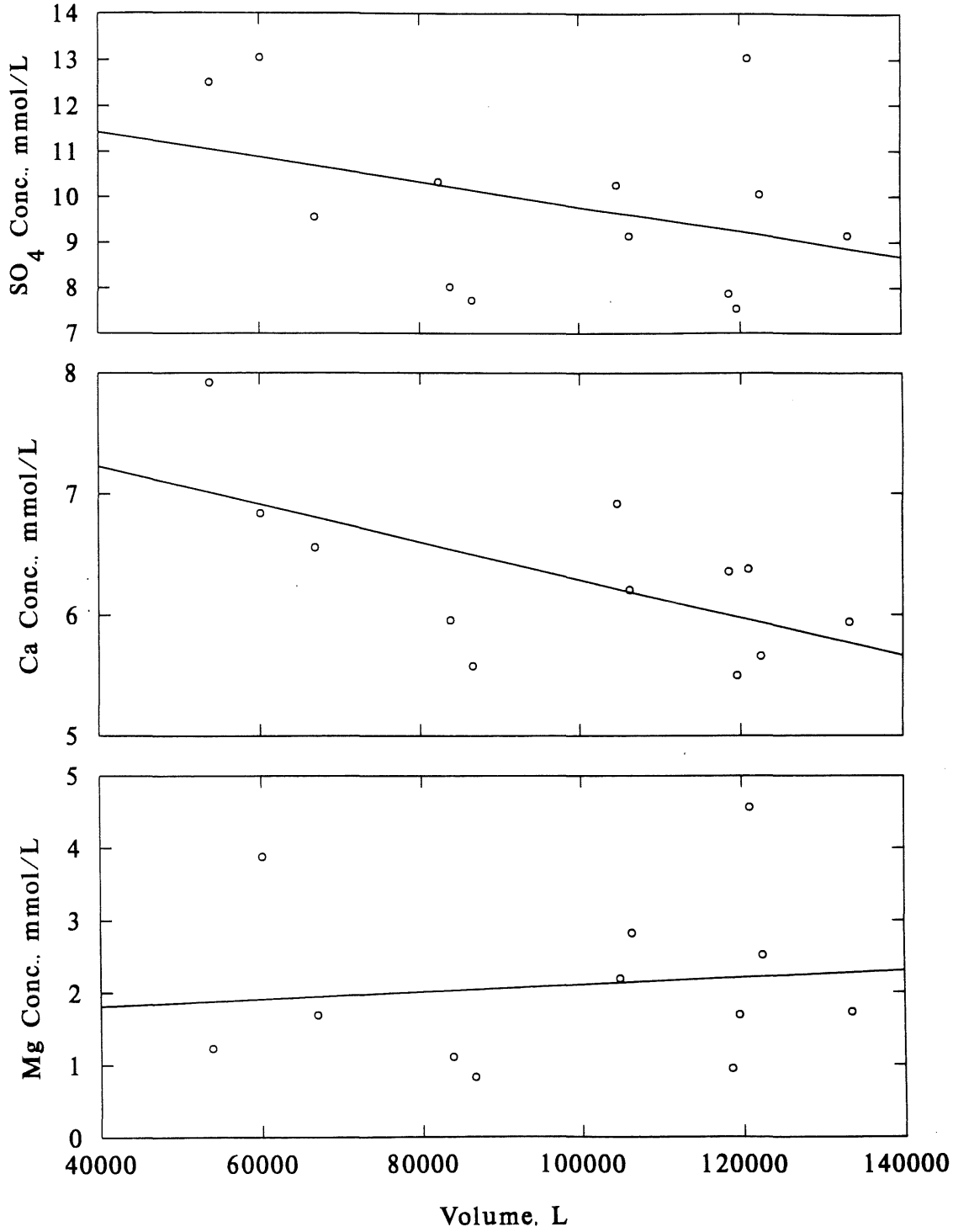

Figure A2.26. Annual flow-weighted mean concentrations of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL1 (0.63% S).

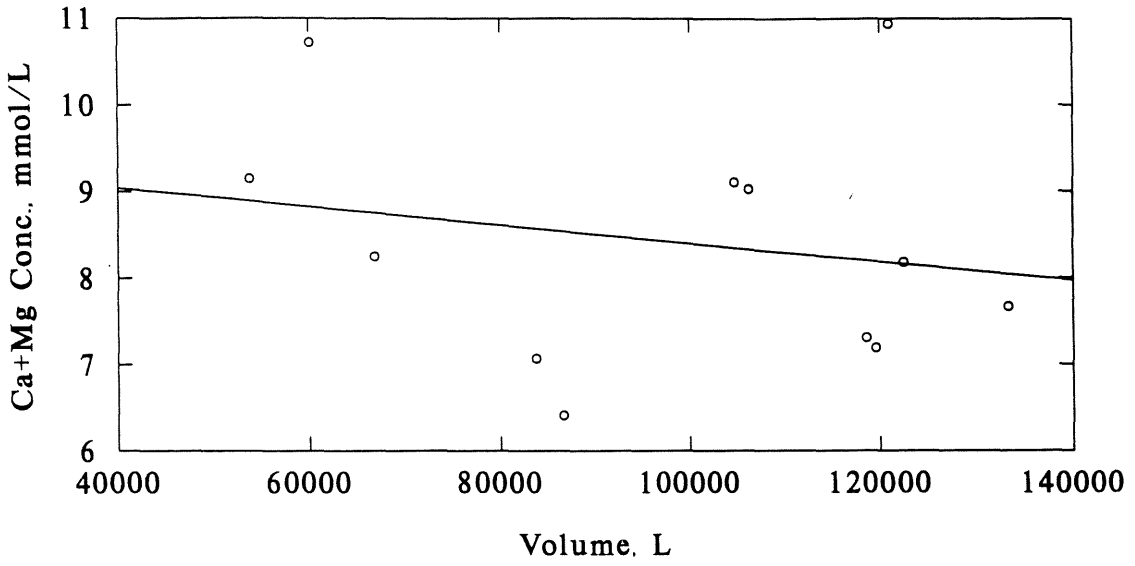

Figure A2.27. Annual flow-weighted mean concentrations of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL2 (0.63% S).

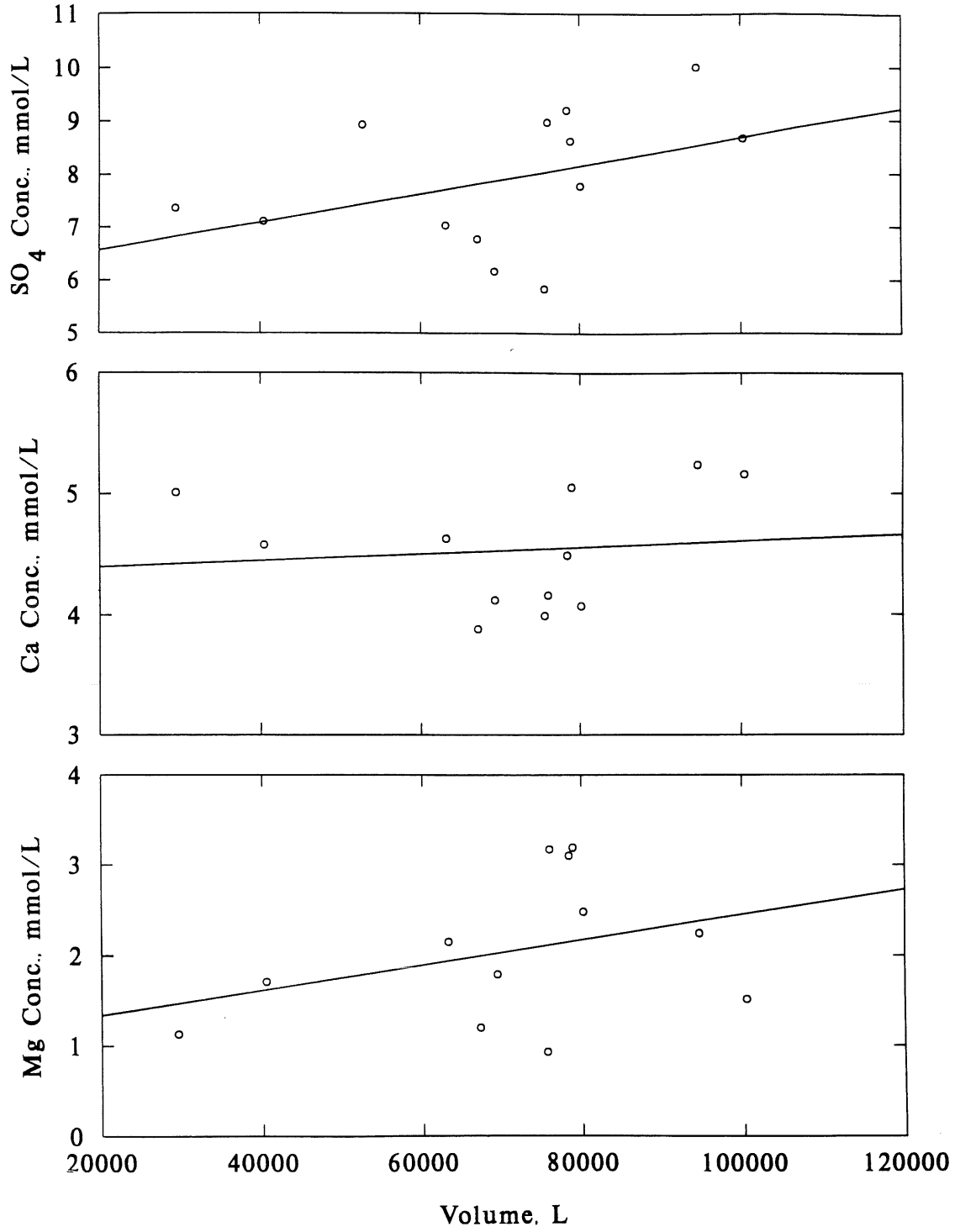

Figure A2.28. Annual flow-weighted mean concentrations of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL2 (0.63% S).

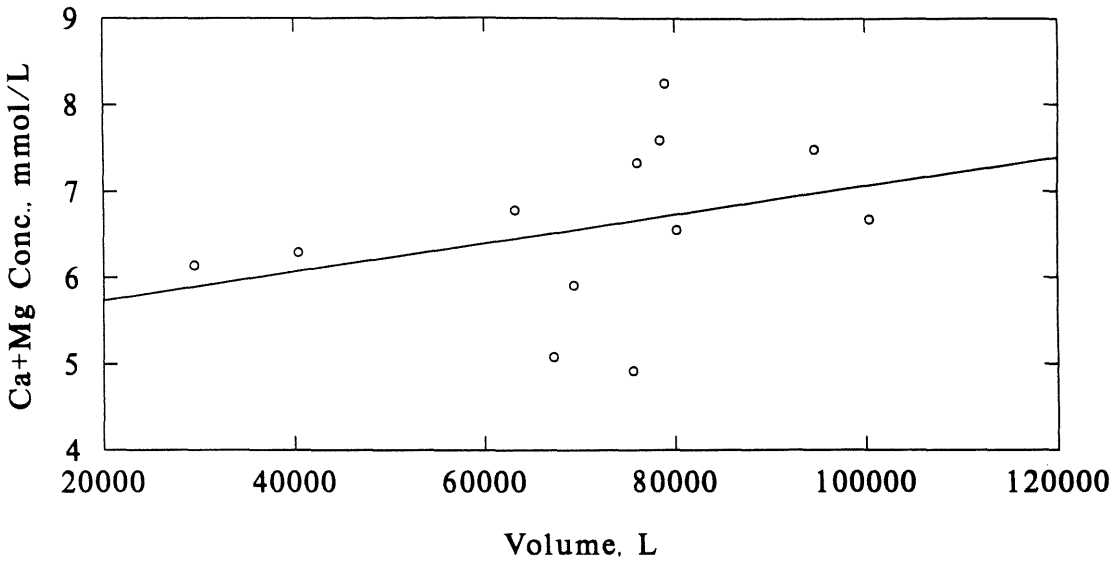

Figure A2.29. Annual flow-weighted mean concentrations of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL3 (0.63% S).

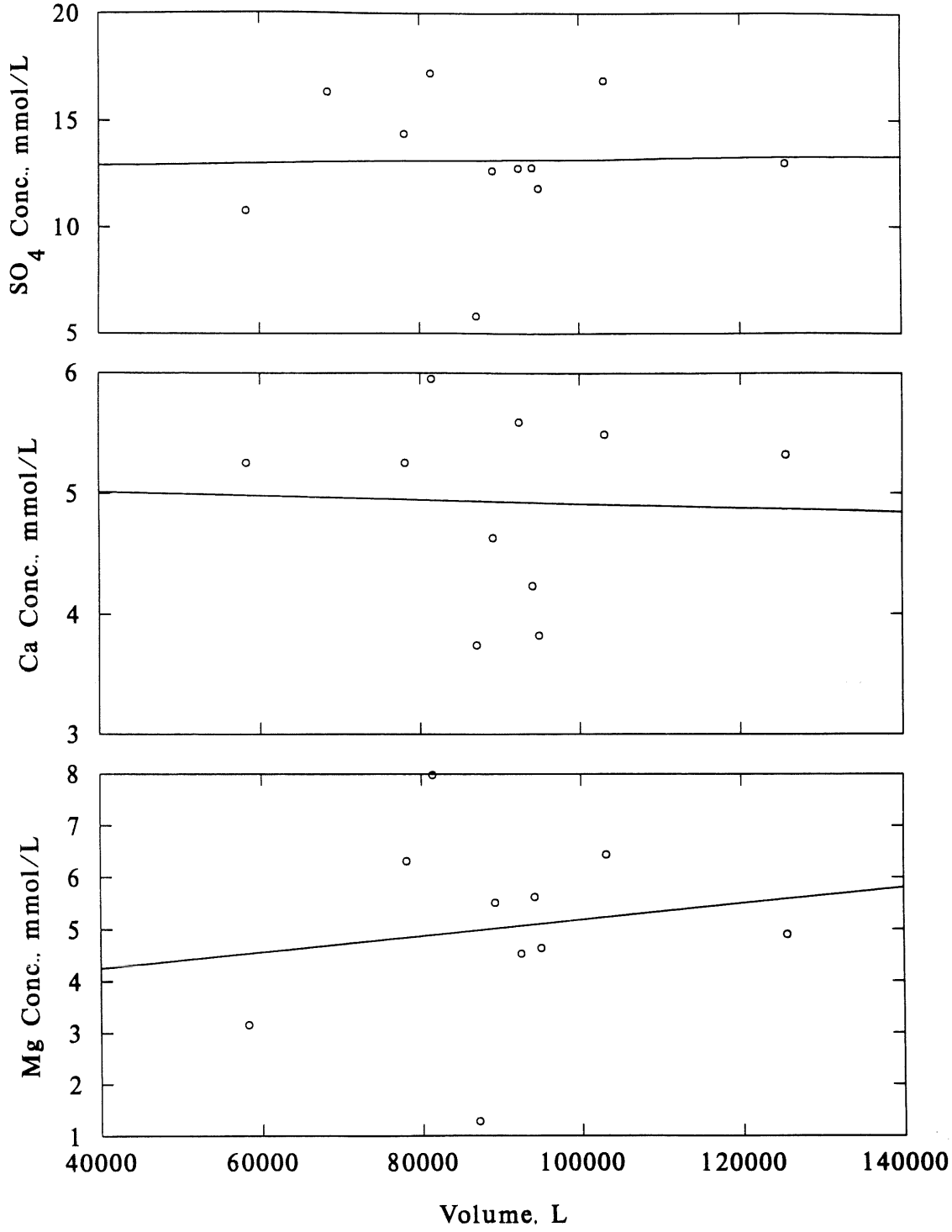

Figure A2.30. Annual flow-weighted mean concentrations of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL3 (0.63% S).

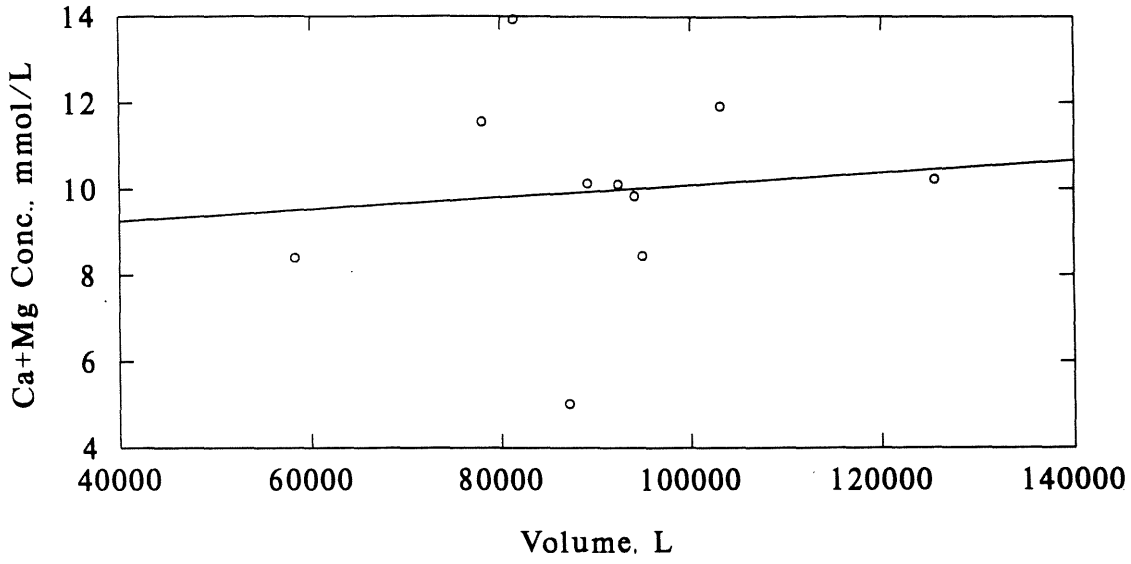

Figure A2.31. Annual flow-weighted mean concentrations of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL6 (0.79% S).

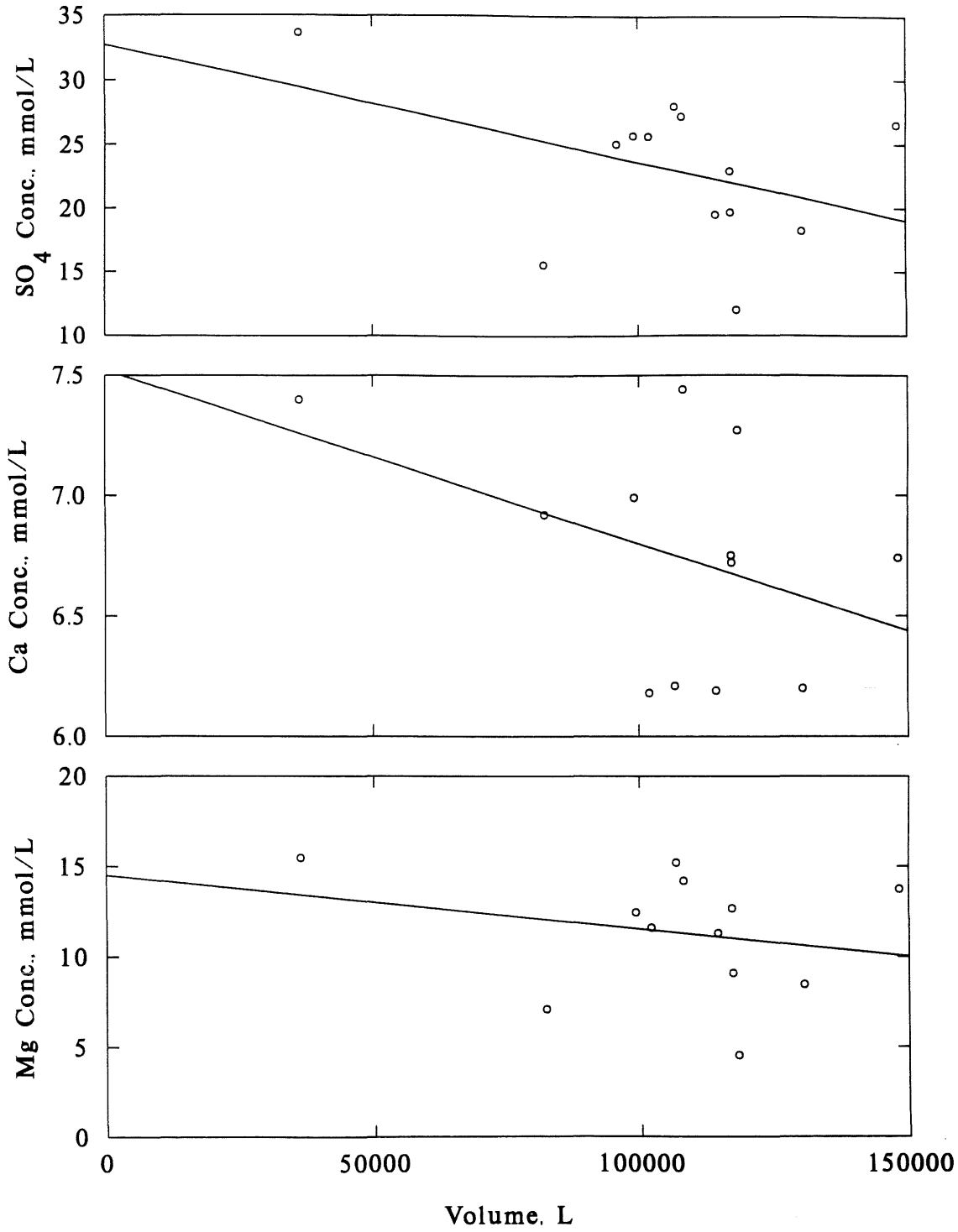

Figure A2.32. Annual flow-weighted mean concentrations of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL6 (0.79% S).

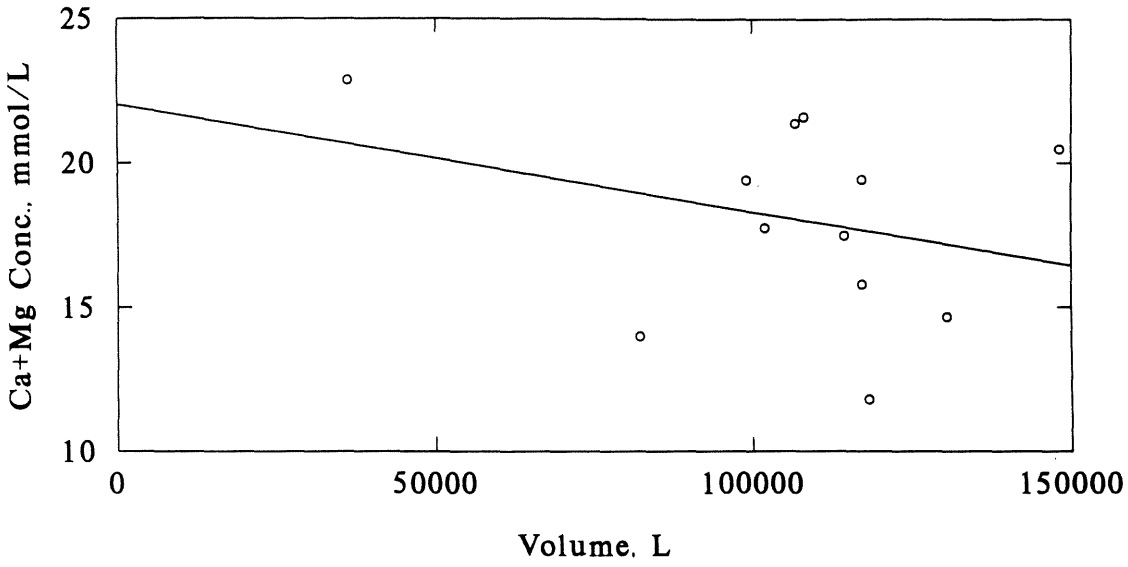

Figure A2.33. Annual flow-weighted mean concentrations of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL5 (1.41% S).

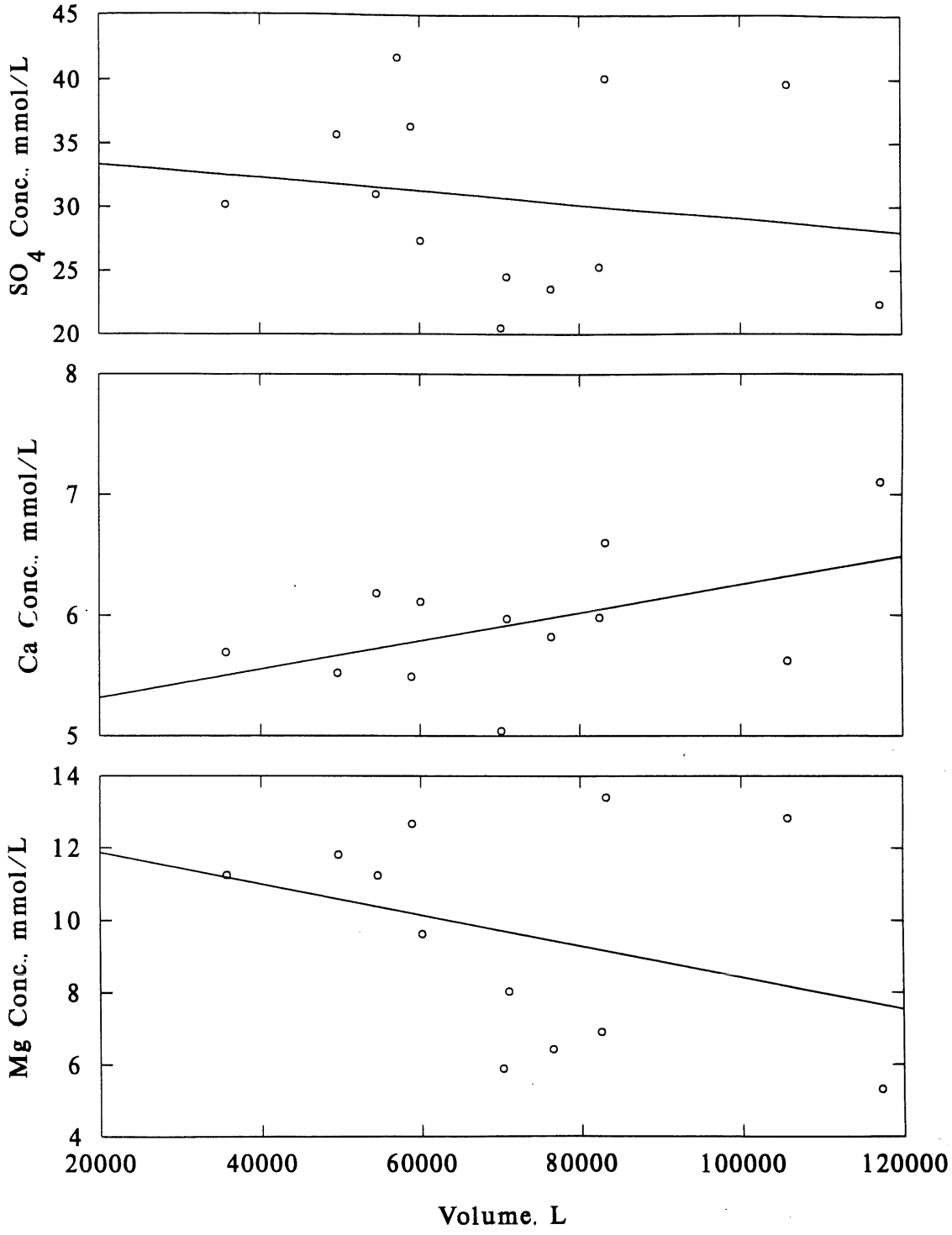

Figure A2.34. Annual flow-weighted mean concentrations of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL5 (1.41% S).

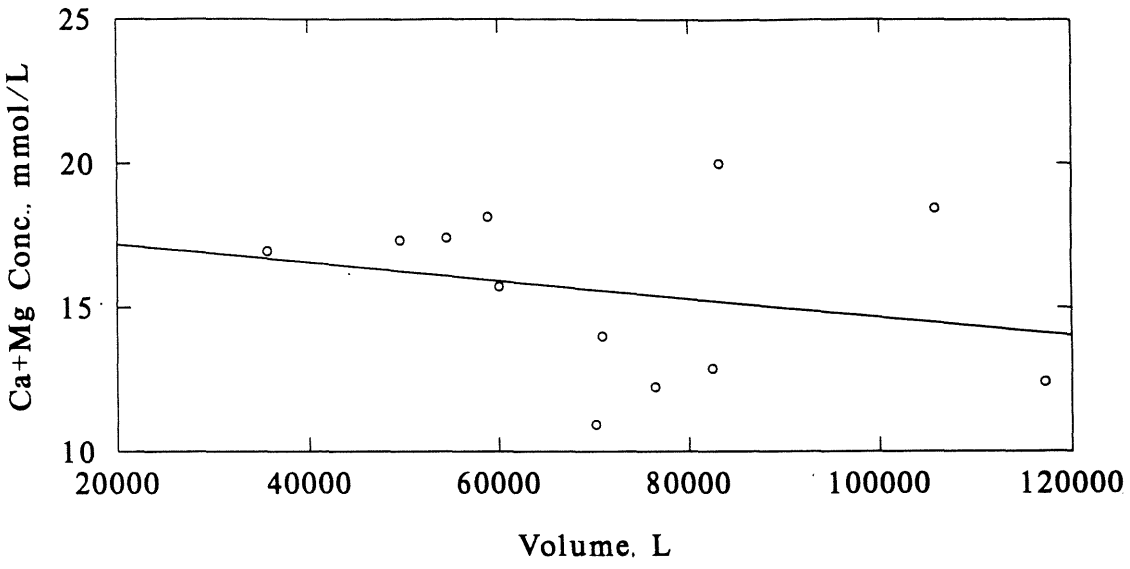

Table A2.1. Drainage quality data from Duluth Complex test pile FL1, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/26/78	7.15	NA	1120	NA	112.0	11.0	113.0	13.0	0.032	NA	0.003	0.017	NA	0.06	NA	NA	NA	NA	NA	NA	0	9.0
06/06/78	NA	NA	1900	NA	216.0	19.0	268.0	20.0	0.030	0.250	0.009	0.002	0.02	0.13	NA	NA	NA	NA	NA	2558	0	7.0
06/07/78	7.60	NA	3325	NA	253.0	23.0	327.0	23.0	0.041	0.272	0.005	0.030	0.03	0.15	NA	NA	NA	NA	NA	NA	0	NA
06/16/78	7.84	NA	2700	NA	244.0	22.0	368.0	22.0	0.028	0.155	0.001	0.002	0.05	0.14	NA	NA	NA	NA	NA	120	0	11.0
06/23/78	7.72	NA	2042	1267	183.3	17.3	288 3	21.3	0.025	0.251	0.012	0.003	0.02	0.09	5.0	NA	NA	NA	NA	170	0	13.0
06/26/78	6.85	NA	2400	NA	195.0	20.0	313.0	21.0	0.024	0.294	0.014	0.010	0.04	0.09	NA	NA	NA	NA	NA	59	0	15.0
07/05/78	7.75	NA	2100	900	202.0	20.0	206.0	28.0	0.018	0.206	0.007	NA	0.01	0.09	4.0	NA	NA	NA	NA	177	0	14.0
07/07/78	7.90	NA	1900	800	221.0	23.0	222.0	34.0	0.024	0.285	0.019	0.005	0.04	0.09	4.0	5.7	0.44	0.08	NA	NA	0	19.0
07/11/78	7.70	NA	2450	1150	303.0	26.0	286.0	38.0	0.027	0.388	0.026	0.010	0.03	0.14	5.0	5.7	0.64	0.08	NA	NA	0	NA
07/13/78	7.92	NA	NA	1500	531.0	31.0	395.0	45.0	0.027	0.405	0.026	NA	0.01	0.16	4.0	6.2	0.55	0.08	NA	NA	0	NA
07/18/78	7.80	NA	1400	1050	340.0	19.0	220.0	34.0	0.023	0.255	0.019	0.003	0.01	0.11	1.0	3.9	0.50	0.08	NA	NA	0	NA
08/02/78	7.90	NA	1100	650	176.0	11.0	127.0	25.0	0.027	0.210	0.010	0.010	0.01	0.09	1.0	3.4	0.70	0.08	NA	NA	0	22.0
08/04/78	7.80	NA	1650	1200	300.0	23.0	209.0	37.0	0.034	0.330	0.016	0.013	0.03	0.13	3.0	5.0	0.06	0.10	NA	167	0	22.0
08/10/78	8.10	70.0	2400	1600	414.0	26.0	317.0	46.0	0.030	0.460	0.030	0.025	0.02	0.16	4.0	NA	0.10	0.08	NA	70	0	24.0
08/16/78	7.85	42.0	1538	640	169.5	14.0	102.0	25.0	0.020	0.185	0.020	0.015	0.02	0.07	2.0	2.5	NA	0.08	NA	3441	0	19.5
08/24/78	8.10	50.0	2600	1400	302.0	26.0	240.0	40.0	0.040	0.360	0.040	0.020	0.06	0.14	1.0	5.0	NA	0.08	NA	NA	0	NA
08/25/78	7.55	47.0	2500	1300	300.0	26.0	229.0	43.0	0.040	0.350	0.030	0.020	0.02	0.14	1.0	4.6	0.40	0.20	NA	NA	0	22.0
08/28/78	7.85	59.0	2700	NA	308.0	26.0	280.0	40.0	0.050	0.420	0.070	0.020	0.04	0.15	NA	NA	NA	NA	NA	NA	0	NA
09/13/78	7.58	40.5	2088	1050	246.0	19.0	160.0	39.5	0.045	0.275	0.020	0.010	0.03	0.12	1.5	NA	NA	0.08	NA	426	0	14.0
10/17/78	7.40	41.0	3207	1800	485.0	42.0	322.0	41.0	0.050	0.540	0.070	0.040	0.02	0.17	8.0	6.5	0.64	0.20	NA	NA	0	NA
03/19/79	7.45	21.0	807	NA	164.0	13.2	43.0	13.0	0.030	0.330	0.040	0.040	0.02	0.08	3.0	NA	NA	NA	2.9	2631	1986	NA
04/13/79	7.10	41.0	693	335	109.0	9.4	36.8	11.2	0.028	0.210	0.012	0.030	0.02	0.05	4.0	NA	NA	NA	3.6	2616	390	NA
04/18/79	7.20	33.0	436	190	78.0	5.6	27.0	6.0	0.023	0.106	0.008	0.020	0.02	0.04	1.0	1.3	NA	NA	NA	3665	3966	NA
04/19/79	7.10	35.0	360	165	69.0	4.8	27.0	5.0	0.025	0.102	0.008	0.010	0.02	0.03	2.0	0.8	0.12	NA	NA	4652	4029	NA
04/20/79	6.60	39.0	534	250	100.0	7.8	55.0	7.2	0.025	0.138	0.080	0.020	0.02	0.05	2.0	1.0	0.10	NA	3.1	3664	2274	NA
04/22/79	7.65	27.0	1194	633	185.9	18.1	69.8	15.5	0.028	0.315	0.020	0.040	0.02	0.09	4.0	2.2	0.23	NA	NA	4153	1200	NA
05/09/79	7.50	NA	983	483	173.0	15.2	60.6	14.8	0.025	0.250	0.015	0.020	0.02	0.08	4.0	NA	NA	NA	NA	685	815	NA
05/10/79	7.30	NA	1057	467	162.8	15.6	57.6	15.4	0.027	0.260	0.015	0.030	0.01	0.10	3.0	NA	NA	NA	NA	6572	2979	NA
05/20/79	7.10	NA	1144	667	179.6	17.8	75.6	16.2	0.031	0.320	0.020	0.030	0.03	0.10	3.0	NA	NA	NA	6.9	2991	784	NA
05/22/79	7.70	NA	897	533	144.4	13.8	60.4	14.0	0.027	0.220	0.015	0.020	0.01	0.09	1.0	NA	NA	NA	6.0	1386	848	NA
05/23/79	7.50	NA	1720	900	232.4	23.6	118.4	21.4	0.031	0.340	0.023	0.030	0.02	0.13	3.0	NA	NA	NA	5.0	2400	596	NA
06/01/79	7.30	NA	1185	700	170.2	17.2	88.8	18.4	0.033	0.290	0.020	0.020	0.03	0.12	2.0	NA	NA	NA	6.9	2468	737	NA
06/06/79	7.50	NA	1204	675	174.0	17.0	53.0	21.2	0.028	0.260	0.017	0.010	0.01	0.09	3.0	NA	NA	NA	NA	2230	941	NA
06/10/79	7.40	54.0	1168	580	166.0	16.4	49.9	20.4	0.031	0.225	0.011	0.010	0.01	0.09	3.0	NA	NA	NA	NA	2143	1098	20.0
06/12/79	7.20	45.0	1687	780	245.8	24.0	67.0	32.8	0.028	0.280	0.013	0.020	0.01	0.12	4.0	NA	NA	NA	NA	1181	416	NA
06/15/79	7.40	48.4	1488	740	234.8	23.0	68.4	28.6	0.028	0.270	0.009	0.010	0.01	0.11	5.0	NA	NA	NA	NA	545	494	20.0
06/21/79	7.10	30.0	1030	450	144.0	15.0	60.0	19.0	0.020	0.170	0.012	0.010	0.04	0.07	2.0	NA	NA	NA	NA	2343	1073	15.0
06/30/79	7.40	NA	1349	1280	338.0	33.0	160.0	32.0	0.030	0.370	0.025	0.020	0.02	0.11	4.0	NA	NA	NA	12.0	488	149	19.0
07/10/79	7.60	37.0	2120	1600	371.0	37.0	164.0	37.0	0.030	0.380	0.025	0.020	0.01	0.15	4.0	NA	NA	NA	11.0	1132	137	18.0
07/30/79	7.40	20.8	1221	589	208.5	18.5	50.0	22.0	0.020	0.210	0.014	0.010	0.01	0.07	3.0	NA	NA	NA	6.3	3449	2274	23.0
08/04/79	7.60	26.8	2094	1520	439.0	34.0	106.0	41.0	0.020	0.390	0.025	0.020	0.02	0.12	3.0	NA	NA	NA	6.1	1314	212	23.0
08/13/79	7.30	31.2	2562	1920	488.8	49.0	260.0	52.0	0.040	0.530	0.023	0.030	0.03	0.17	5.0	NA	NA	NA	11.0	345	47	13.0
08/23/79	7.30	24.8	1976	1500	394.8	33.2	174.0	38.6	0.030	0.430	0.023	0.030	0.02	0.13	5.0	NA	NA	NA	9.1	371	151	9.0
08/28/79	7.30	18.0	1642	1130	298.0	25.4	95.0	29.8	0.040	0.320	0.015	0.030	0.05	0.09	28.0	NA	NA	NA	8.3	548	458	20.0
09/01/79	7.50	23.2	2014	1250	364.0	31.0	80.2	33.0	0.040	0.450	0.020	0.030	0.03	0.10	5.0	NA	NA	NA	7.8	3710	1929	22.0
09/05/79	7.40	25.2	2145	1520	427.2	39.0	134.4	42.2	0.040	0.490	0.008	0.030	0.02	0.12	4.0	NA	NA	NA	10.0	742	550	18.0
09/10/79	7.35	24.0	1794	1290	343.4	29.2	135.0	35.9	0.035	0.415	0.019	0.030	0.02	0.10	5.0	NA	NA	NA	8.9	2608	516	17.5
09/13/79	7.50	24.0	2112	1600	428.2	37.6	165.6	41.0	0.050	0.520	0.023	0.030	0.01	0.12	5.0	NA	NA	NA	9.3	1408	500	16.0
09/19/79	7.40	25.2	3010	2200	590.8	52.0	232.0	53.2	0.050	0.660	0.060	0.040	0.03	0.12	8.0	NA	NA	NA	12.0	886	141	11.5
10/18/79	7.10	20.8	2603	1900	502.0	45.4	204.0	46.4	0.050	0.640	0.030	0.040	0.01	0.12	11.0	NA	NA	NA	11.0	352	733	NA
10/19/79	6.80	19.2	1318	750	223.0	19.6	56.0	20.8	0.040	0.460	0.021	0.030	0.01	0.05	3.0	NA	NA	NA	5.9	821	1222	NA

Table A2.1. Drainage quality data from Duluth Complex test pile FL1, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
10/31/79	6.80	20.8	1959	1300	374.0	32.6	90.0	30.8	0.041	0.740	0.026	0.040	0.02	0.10	3.0	NA	NA	NA	7.2	4315	1513	NA
11/01/79	7.20	24.8	2364	1000	412.0	38.2	114.0	34.2	0.030	0.820	0.060	0.050	0.02	0.10	6.0	NA	NA	NA	8.5	2695	966	10.0
04/17/80	7.25	32.2	790	364	130.2	8.6	21.8	8.4	0.030	0.260	0.030	0.030	0.02	0.06	1.0	NA	NA	NA	NA	314	454	NA
04/18/80	6.95	38.0	NA	550	145.4	11.2	28.6	10.8	0.020	0.040	0.020	0.050	0.02	0.05	2.0	NA	NA	NA	2.4	927	907	NA
04/23/80	7.45	45.4	NA	490	148.0	11.6	22.6	11.0	0.010	0.390	0.040	0.050	0.02	0.06	2.0	NA	NA	NA	2.2	927	216	NA
04/27/80	7.50	52.7	1442	1045	233.7	20.8	58.5	17.0	0.020	0.505	0.040	0.040	0.03	0.12	3.0	NA	NA	NA	NA	2131	157	12.5
05/05/80	7.60	45.1	1330	1020	227.0	18.6	49.8	14.8	0.020	0.370	0.040	0.030	0.02	0.12	3.0	NA	NA	NA	4.5	420	201	11.0
05/18/80	7.60	46.2	1300	910	218.4	20.6	71.4	20.0	0.030	0.400	0.040	0.030	0.01	0.15	9.0	NA	NA	NA	NA	806	50	19.0
05/31/80	7.30	30.8	950	650	159.3	14.5	41.1	16.0	0.030	0.300	0.012	0.020	0.02	0.07	5.0	NA	NA	NA	6.3	1798	1190	NA
06/01/80	7.50	36.9	1575	1020	276.2	24.2	57.5	23.6	0.060	0.520	0.022	0.030	0.01	0.10	5.0	NA	NA	NA	6.2	893	441	NA
06/07/80	7.45	32.0	1475	800	283.6	25.4	67.2	25.6	0.020	0.450	0.014	0.020	0.03	0.02	5.0	NA	NA	NA	NA	799	189	NA
06/14/80	7.40	29.7	1700	1170	274.0	25.0	70.0	26.0	0.030	0.460	0.029	0.020	0.06	0.10	5.0	NA	NA	NA	NA	579	139	NA
06/18/80	7.30	31.9	2200	1450	348.0	23.7	101.0	32.8	0.040	0.530	0.012	0.030	0.03	0.12	6.0	NA	NA	NA	NA	367	46	NA
06/27/80	7.30	25.3	1700	1150	273.0	26.0	72.0	28.0	0.043	0.039	0.036	0.030	0.01	0.08	5.0	NA	NA	NA	8.2	996	245	NA
07/02/80	7.30	33.0	2300	2100	422.0	32.0	99.0	33.0	0.024	0.660	0.034	0.050	0.03	0.11	5.0	NA	NA	NA	8.8	1060	1272	NA
07/04/80	7.20	19.6	1850	NA	354.0	29.0	65.0	27.0	0.030	0.670	0.040	0.040	0.02	0.01	NA	NA	NA	NA	NA	727	1017	NA
07/17/80	7.20	28.6	2500	1590	428.4	34.8	190.3	42.4	0.040	0.630	0.040	0.040	0.03	0.12	5.5	NA	NA	NA	NA	1022	356	NA
07/20/80	7.20	30.8	2100	1300	363.8	33.4	169.0	37.8	0.040	0.550	0.040	0.040	0.02	0.10	6.0	NA	NA	NA	NA	1026	171	NA
08/03/80	7.20	24.2	2100	1150	355.2	34.4	131.6	37.4	0.060	0.540	0.026	0.060	0.04	0.13	6.0	NA	NA	NA	10.0	496	311	NA
08/12/80	7.20	9.8	1500	990	275.0	23.4	57.4	25.2	0.050	0.600	0.080	0.040	0.09	0.10	5.0	NA	NA	NA	6.1	1995	1239	NA
08/19/80	7.10	18.7	2000	1520	393.4	34.6	85.2	34.8	0.050	1.010	0.050	0.050	0.02	0.13	5.0	NA	NA	NA	NA	1643	350	NA
08/22/80	NA	NA	1850	1290	357.2	35.2	76.8	30.0	0.032	1.220	0.060	0.050	0.04	0.11	4.0	NA	NA	NA	NA	1344	657	NA
08/29/80	7.10	23.4	1850	1658	382.2	40.6	94.4	34.0	0.060	0.890	0.060	0.060	0.07	0.10	4.0	NA	NA	NA	7.5	8112	3456	NA
09/07/80	7.00	20.4	1500	920	287.0	26.6	80.6	30.0	0.035	0.660	0.040	0.050	0.04	0.08	4.0	NA	NA	NA	NA	2703	1050	NA
09/09/80	7.20	22.1	1760	1250	382.8	39.2	93.2	33.8	0.036	0.860	0.047	0.050	0.06	0.10	3.0	NA	NA	NA	NA	1147	361	14.0
09/12/80	7.05	20.0	1215	660	262.0	21.0	55.6	22.4	0.038	0.680	0.050	0.040	0.02	0.08	4.0	NA	NA	NA	4.9	3536	1890	16.0
09/18/80	7.20	21.0	1535	1130	340.0	33.2	84.0	29.2	0.046	0.740	0.033	0.050	0.06	0.08	4.0	NA	NA	NA	NA	7896	2008	12.0
09/23/80	7.20	21.3	2117	1350	398.0	45.0	122.0	10.8	0.050	0.840	0.070	0.060	0.04	0.08	4.0	NA	NA	NA	6.9	1938	588	14.0
10/15/80	7.00	20.4	1719	1050	310.0	32.0	87.8	30.0	0.050	0.700	0.040	0.060	0.03	0.07	5.0	NA	NA	NA	7.0	1741	101	8.0
10/31/80	6.50	17.0	1773	1900	340.0	30.0	65.0	29.0	0.070	1.590	0.070	0.090	0.02	0.10	4.0	NA	NA	NA	NA	1257	48	11.0
02/18/81	7.20	18.7	525	266	74.8	7.2	16.2	NA	0.020	0.630	0.030	0.040	NA	NA	1.0	NA	NA	NA	NA	832	722	8.0
03/27/81	7.20	19.2	600	300	80.6	8.3	15.8	NA	0.020	0.710	0.040	0.050	NA	NA	NA	NA	NA	NA	3.0	4742	2270	NA
04/03/81	7.30	27.2	800	440	124.8	13.0	20.8	NA	0.050	1.470	0.060	0.070	NA	NA	NA	NA	NA	NA	NA	4410	1459	NA
04/13/81	6.70	17.6	900	510	143.0	16.0	22.0	NA	0.090	1.290	0.060	0.060	NA	NA	NA	NA	NA	NA	NA	2441	1050	NA
04/17/81	7.40	30.4	1000	515	139.0	16.0	23.0	NA	0.040	1.280	0.050	0.050	NA	NA	NA	NA	NA	NA	3.6	1696	988	NA
04/23/81	7.40	28.8	1350	635	165.0	22.0	30.0	NA	0.040	1.260	0.060	0.060	NA	NA	NA	NA	NA	NA	NA	2350	2515	NA
04/27/81	7.45	29.2	1500	740	203.0	32.0	39.0	NA	0.040	1.350	0.070	0.060	NA	NA	NA	NA	NA	NA	NA	6162	2089	2.0
04/28/81	7.60	36.0	1250	640	168.0	27.0	36.0	NA	0.040	1.070	0.060	0.060	NA	NA	NA	NA	NA	NA	4.3	3785	1698	NA
04/29/81	7.40	37.0	1430	835	230.0	28.0	46.0	NA	0.040	1.050	0.080	0.070	NA	NA	NA	NA	NA	NA	NA	3323	1040	NA
05/12/81	7.55	38.4	1587	800	272.0	32.0	68.0	NA	0.030	0.830	0.040	0.070	NA	NA	NA	NA	NA	NA	6.2	3686	203	17.0
06/01/81	7.50	26.0	1064	450	184.0	20.0	46.0	NA	0.040	0.490	0.030	0.040	NA	NA	NA	NA	NA	NA	NA	2626	790	16.0
06/06/81	7.40	13.3	1202	620	200.0	38.0	56.0	22.0	0.040	0.880	0.050	0.050	NA	NA	NA	NA	NA	NA	3.6	1840	207	18.0
06/22/81	7.00	15.2	1112	590	196.0	18.0	32.0	NA	0.050	1.120	0.060	0.050	NA	NA	NA	NA	NA	NA	NA	4148	2105	NA
06/24/81	7.20	16.0	1216	675	216.0	18.0	30.0	NA	0.060	1.280	0.070	0.050	NA	NA	NA	NA	NA	NA	NA	3274	1541	16.0
06/28/81	7.20	15.2	1143	640	205.0	18.0	32.0	NA	0.040	1.040	0.050	0.040	NA	NA	NA	NA	NA	NA	3.0	4690	2922	15.0
07/04/81	7.40	21.4	1786	1100	348.0	29.6	65.6	NA	0.040	1.100	0.060	0.050	NA	NA	NA	NA	NA	NA	NA	2154	117	21.0
07/15/81	7.50	15.0	1586	1000	284.0	21.6	65.8	NA	0.060	0.670	0.050	0.040	NA	NA	NA	NA	NA	NA	NA	606	40	19.0
07/24/81	7.20	14.2	1464	945	274.0	23.4	48.2	NA	0.070	0.800	0.060	0.050	NA	NA	2.0	NA	NA	NA	3.7	1094	238	19.0
08/04/81	7.50	13.4	1798	1200	356.0	36.0	76.0	NA	0.050	0.980	0.050	0.090	NA	NA	NA	NA	NA	NA	NA	722	75	18.0
08/17/81	7.10	12.2	1936	1200	392.0	36.0	65.0	NA	0.060	1.220	0.080	0.080	NA	NA	NA	NA	NA	NA	NA	602	20	22.0
09/01/81	7.00	9.6	2275	1180	352.0	34.0	56.0	NA	0.140	1.840	0.060	0.140	NA	NA	NA	NA	NA	NA	NA	772	100	NA

Table A2.1. Drainage quality data from Duluth Complex test pile FL1, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
09/16/81	6.90	4.8	2700	NA	482.0	48.0	75.0	NA	0.140	2.700	0.150	0.200	NA	NA	NA	NA	NA	NA	NA	148	5	NA
09/26/81	6.75	5.6	1850	1120	344.0	36.0	42.0	NA	0.270	4.300	0.190	0.230	NA	NA	NA	NA	NA	NA	6.7	1037	587	NA
10/01/81	6.90	6.4	1800	940	320.0	54.0	32.0	NA	0.390	6.500	0.290	0.300	NA	NA	NA	NA	NA	NA	NA	3043	1895	NA
10/04/81	6.90	8.8	1700	1020	358.0	32.0	40.0	30.0	0.280	5.750	0.230	0.260	NA	NA	NA	NA	NA	NA	NA	2642	1354	NA
10/13/81	7.05	10.8	1500	800	262.0	26.0	40.0	26.0	0.140	2.980	0.140	0.160	NA	NA	NA	NA	NA	NA	3.5	3622	1799	NA
10/17/81	7.00	11.2	1700	1010	336.0	32.0	50.0	32.0	0.170	3.820	0.180	0.180	NA	NA	NA	NA	NA	NA	NA	8856	1213	NA
10/30/81	7.15	6.4	2600	1750	490.0	60.0	108.0	46.0	0.120	2.040	0.090	0.110	NA	NA	NA	NA	NA	NA	6.2	3104	271	NA
03/24/82	6.90	10.8	950	490	136.0	16.6	14.0	12.0	0.390	7.700	0.300	0.250	NA	NA	NA	NA	NA	NA	NA	715	NA	NA
04/13/82	7.00	10.8	850	440	121.0	11.2	18.0	10.0	0.160	3.940	0.160	0.160	NA	NA	NA	NA	NA	NA	NA	1090	NA	NA
04/14/82	6.97	7.7	500	215	63.8	5.2	8.0	6.0	0.070	1.430	0.055	0.060	NA	NA	NA	NA	NA	NA	NA	4141	NA	NA
04/15/82	7.10	15.3	700	340	106.0	8.6	12.0	8.0	0.110	2.220	0.090	0.090	NA	NA	NA	NA	NA	NA	NA	2854	NA	NA
04/19/82	6.90	14.4	825	380	166.0	12.0	35.0	7.2	0.130	3.840	0.130	0.110	NA	NA	NA	NA	NA	NA	NA	912	NA	NA
04/23/82	7.20	18.0	1050	600	190.0	16.0	20.0	14.0	0.110	3.420	0.140	0.110	NA	NA	NA	NA	NA	NA	NA	1238	NA	NA
04/28/82	7.10	19.8	1175	630	157.0	16.0	22.0	16.0	0.080	2.840	0.110	0.080	NA	NA	NA	NA	NA	NA	NA	3274	NA	NA
05/03/82	7.10	12.6	750	370	118.0	10.0	16.0	10.0	0.100	1.610	0.090	0.070	NA	NA	NA	NA	NA	NA	NA	409	NA	NA
05/07/82	7.10	18.9	1030	520	164.0	14.0	22.0	12.0	0.080	3.050	0.140	0.090	NA	NA	NA	NA	NA	NA	NA	5167	NA	NA
05/11/82	7.10	18.0	1225	710	188.0	24.0	24.0	20.0	0.080	4.150	0.150	0.120	NA	NA	NA	NA	NA	NA	NA	3819	NA	NA
05/14/82	7.10	21.6	1200	690	216.0	22.8	26.6	20.4	0.060	3.000	0.110	0.080	0.04	0.12	NA	NA	NA	NA	NA	4038	NA	NA
05/21/82	7.15	NA	1800	1100	308.0	31.0	48.7	25.8	0.055	2.835	0.105	0.090	0.04	0.14	NA	NA	NA	NA	NA	1688	NA	NA
06/02/82	7.00	12.6	1275	710	198.0	21.8	39.0	14.0	0.050	1.660	0.070	0.070	0.04	0.11	NA	NA	NA	NA	NA	1253	NA	NA
06/11/82	6.80	NA	1175	665	185.0	18.5	23.0	18.0	0.050	3.245	0.125	0.090	0.03	0.14	NA	NA	NA	NA	NA	719	NA	NA
07/02/82	NA	NA	NA	780	308.0	26.0	36.0	26.0	0.060	3.540	0.160	0.080	0.01	0.13	NA	NA	NA	NA	NA	19809	NA	NA
07/26/82	7.10	12.6	1400	890	338.0	28.0	44.0	28.0	0.080	2.520	0.110	0.070	0.01	0.11	NA	NA	NA	NA	NA	1382	NA	NA
08/02/82	7.00	NA	1900	NA	394.0	30.0	42.0	32.0	0.090	3.400	0.150	0.070	0.02	0.13	NA	NA	NA	NA	NA	8025	NA	NA
08/09/82	7.00	17.1	2100	NA	367.0	34.0	62.0	36.0	0.100	5.170	0.220	0.090	0.02	0.13	NA	NA	NA	NA	NA	1817	NA	NA
08/23/82	7.10	8.1	1850	1145	359.0	32.0	48.0	34.0	0.130	7.020	0.310	0.120	0.02	0.17	NA	NA	NA	NA	NA	1790	NA	NA
08/30/82	6.90	9.9	1850	1035	338.0	30.0	44.0	30.0	0.120	5.940	0.270	0.120	0.30	0.17	NA	NA	NA	NA	NA	1147	NA	NA
09/08/82	6.50	10.8	1350	785	256.0	22.0	26.0	22.0	0.280	7.890	0.370	0.150	0.02	0.22	NA	NA	NA	NA	NA	4009	NA	NA
09/13/82	6.50	11.2	1300	975	316.0	26.0	32.0	28.0	0.190	7.350	0.280	0.140	0.02	0.19	NA	NA	NA	NA	NA	4190	NA	NA
09/20/82	6.90	NA	1900	1140	334.0	32.0	46.0	32.0	0.190	7.300	0.290	0.140	0.01	0.19	NA	NA	NA	NA	NA	810	NA	NA
10/04/82	7.00	16.2	1425	850	258.0	26.0	34.0	26.0	0.180	6.170	0.300	0.110	0.02	0.17	NA	NA	NA	NA	NA	15259	NA	NA
10/11/82	6.80	15.3	1400	630	252.0	24.0	38.0	26.0	0.110	4.570	0.150	0.080	0.01	0.12	NA	NA	NA	NA	NA	3782	NA	NA
10/21/82	6.90	13.0	1000	620	266.0	26.0	38.0	26.0	0.110	4.390	0.170	0.080	0.19	0.12	NA	NA	NA	NA	NA	1200	NA	NA
10/25/82	7.00	13.1	1830	940	256.0	26.0	34.0	28.0	0.150	5.640	0.240	0.100	0.03	0.14	NA	NA	NA	NA	NA	708	NA	NA
11/01/82	6.90	9.0	1000	NA	136.0	14.0	20.0	14.0	0.120	4.660	0.210	0.070	0.02	0.10	NA	NA	NA	NA	NA	1730	NA	NA
11/22/82	7.05	4.5	1400	605	230.0	28.0	32.0	NA	0.120	5.090	0.150	0.120	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/18/83	6.90	13.3	745	400	NA	NA	NA	NA	0.300	5.650	0.240	0.180	NA	NA	NA	NA	NA	NA	NA	2495	NA	NA
04/14/83	6.86	14.8	544	260	NA	NA	NA	NA	0.130	2.910	0.120	0.130	NA	NA	NA	NA	NA	NA	NA	4984	NA	NA
05/15/83	7.01	15.3	910	540	NA	NA	NA	NA	0.070	3.260	0.140	0.110	NA	NA	NA	NA	NA	NA	NA	6196	NA	NA
06/16/83	6.86	11.8	1348	840	NA	NA	NA	NA	0.070	4.870	0.190	0.100	NA	NA	NA	NA	NA	NA	NA	2168	NA	NA
07/14/83	6.91	12.6	1663	1320	NA	NA	NA	NA	0.260	7.470	0.280	0.230	NA	NA	NA	NA	NA	NA	NA	11710	NA	NA
08/14/83	6.61	7.5	1497	1140	NA	NA	NA	NA	0.730	9.950	0.400	0.340	NA	NA	NA	NA	NA	NA	NA	14114	NA	NA
09/15/83	6.74	7.1	1507	1110	NA	NA	NA	NA	0.780	10.220	0.460	0.350	NA	NA	NA	NA	NA	NA	NA	8997	NA	NA
10/13/83	6.91	9.8	1714	1110	NA	NA	NA	NA	0.520	8.350	0.370	0.240	NA	NA	NA	NA	NA	NA	NA	24777	NA	NA
11/09/83	6.60	5.4	900	620	NA	NA	NA	NA	0.570	6.470	0.290	0.220	NA	NA	NA	NA	NA	NA	NA	3459	NA	NA
11/30/83	6.35	5.4	900	620	NA	NA	NA	NA	0.830	13.350	0.540	0.360	NA	NA	NA	NA	NA	NA	NA	738	NA	NA
02/24/84	6.25	6.3	580	290	93.9	18.9	9.6	NA	0.730	12.000	0.500	0.300	NA	NA	NA	NA	NA	NA	NA	1222	NA	NA
03/15/84	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/15/84	6.49	4.9	429	260	94.7	13.6	8.2	NA	0.390	4.850	0.210	0.200	NA	NA	NA	NA	NA	NA	NA	6389	NA	NA
05/16/84	6.86	10.7	865	620	210.6	28.1	17.5	NA	0.360	9.000	0.290	0.200	NA	NA	NA	NA	NA	NA	NA	10099	NA	NA
06/13/84	6.91	7.9	1065	838	260.1	36.6	27.7	NA	0.590	12.400	0.430	0.290	NA	NA	NA	NA	NA	NA	NA	21645	NA	NA

Table A2.1. Drainage quality data from Duluth Complex test pile FL1, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/l	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/l	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
07/14/84	6.92	9.0	1145	820	NA	NA	25.0	NA	0.300	9.600	0.350	0.190	NA	NA	NA	NA	NA	NA	NA	5190	NA	NA
08/15/84	6.81	6.8	1395	880	278.4	53.9	27.2	NA	0.870	24.000	0.880	0.380	NA	NA	NA	NA	NA	NA	NA	5678	NA	NA
09/12/84	6.36	3.3	1425	1400	326.6	67.8	33.5	NA	1.540	16.250	1.020	0.530	NA	NA	NA	NA	NA	NA	NA	1809	NA	NA
10/13/84	6.17	4.3	1425	1750	401.2	60.0	31.5	NA	3.300	27.900	1.790	0.790	NA	NA	NA	NA	NA	NA	NA	10556	NA	NA
11/14/84	6.23	4.9	1050	1400	352.0	52.0	32.4	NA	1.860	18.100	0.560	0.540	NA	NA	NA	NA	NA	NA	NA	2430	NA	NA
12/01/84	6.00	2.1	975	1050	390.0	190.0	25.0	NA	5.400	23.300	1.030	0.780	NA	NA	NA	NA	NA	NA	NA	409	NA	NA
12/18/84	6.15	4.2	875	710	216.0	48.0	20.0	NA	2.490	23.800	0.860	0.570	NA	NA	NA	NA	NA	NA	NA	1452	NA	NA
04/02/85	6.55	1.1	420	270	85.0	6.6	5.6	NA	0.470	3.090	0.120	0.120	NA	NA	NA	NA	NA	NA	NA	308	NA	NA
04/16/85	6.56	7.6	845	520	162.0	29.3	12.4	NA	1.770	14.500	0.550	0.440	NA	NA	NA	NA	NA	NA	NA	16654	NA	NA
05/14/85	6.93	6.9	1200	710	204.0	37.5	19.3	NA	0.670	12.300	0.450	0.270	NA	NA	NA	NA	NA	NA	NA	10821	NA	NA
06/14/85	6.94	2.6	1425	1100	241.0	45.1	25.4	NA	1.170	15.200	0.510	0.350	NA	NA	NA	NA	NA	NA	NA	33032	NA	NA
07/15/85	6.82	7.6	1350	950	193.0	43.4	28.5	NA	0.840	12.900	0.480	0.310	NA	NA	NA	NA	NA	NA	NA	12354	NA	NA
08/13/85	6.70	3.3	1350	968	230.2	43.1	25.0	NA	1.400	17.900	0.690	0.450	NA	NA	NA	NA	NA	NA	NA	12188	NA	NA
09/13/85	6.58	1.6	1475	1000	316.0	49.8	26.0	NA	1.750	16.100	0.630	0.450	NA	NA	NA	NA	NA	NA	NA	28330	NA	NA
10/15/85	6.85	5.2	1275	650	242.0	38.0	22.0	NA	1.300	10.600	0.320	0.300	NA	NA	NA	NA	NA	NA	NA	18471	NA	NA
11/15/85	6.64	1.1	1175	540	254.0	36.0	24.0	NA	0.800	7.250	0.220	0.220	NA	NA	NA	NA	NA	NA	NA	1238	NA	NA
03/23/86	6.60	1.1	570	230	76.0	14.6	5.8	NA	2.090	13.000	0.460	0.280	NA	NA	NA	NA	NA	NA	NA	18543	NA	NA
04/16/86	6.49	2.8	775	410	131.0	28.1	9.6	NA	2.400	17.800	0.580	0.380	NA	NA	NA	NA	NA	NA	NA	12687	NA	NA
05/14/86	6.75	5.2	1025	800	244.0	38.0	14.0	NA	1.540	15.900	0.600	0.360	NA	NA	NA	NA	NA	NA	NA	12884	NA	NA
06/11/86	6.63	5.6	1175	850	216.0	38.0	24.0	NA	1.270	14.100	0.520	0.330	NA	NA	NA	NA	NA	NA	NA	6703	NA	NA
07/12/86	6.69	5.9	1375	800	246.0	50.0	20.0	NA	2.740	20.400	0.800	0.520	NA	NA	NA	NA	NA	NA	NA	19489	NA	NA
08/13/86	6.29	4.2	1550	1100	272.0	47.0	26.0	NA	3.580	23.100	0.900	0.430	NA	NA	NA	NA	NA	NA	NA	11835	NA	NA
09/14/86	6.54	3.0	1500	700	271.0	48.4	22.0	NA	3.460	18.700	0.800	0.360	NA	NA	NA	NA	NA	NA	NA	23641	NA	NA
10/16/86	6.41	5.2	1925	1200	276.0	52.0	26.0	NA	2.720	19.800	0.700	0.490	NA	NA	NA	NA	NA	NA	NA	4621	NA	NA
11/16/86	6.36	3.4	1750	1125	332.0	68.0	26.0	NA	5.700	23.000	0.870	0.640	NA	NA	NA	NA	NA	NA	NA	9148	NA	NA
03/22/87	5.70	6.1	575	294	96.0	18.0	8.0	NA	3.600	19.800	0.540	0.390	NA	NA	NA	NA	NA	NA	NA	10068	NA	NA
04/15/87	6.35	4.6	725	352	94.0	22.0	8.0	NA	3.750	14.600	0.590	0.420	NA	NA	NA	NA	NA	NA	NA	3009	NA	NA
05/16/87	6.59	6.0	1500	970	294.0	50.0	20.0	NA	4.900	21.000	0.800	0.800	NA	NA	NA	NA	NA	NA	NA	32721	NA	NA
06/16/87	6.66	6.6	1900	1200	368.0	72.0	34.0	NA	1.970	16.000	0.500	0.290	NA	NA	NA	NA	NA	NA	NA	2328	NA	NA
07/15/87	6.03	7.4	1850	1200	312.0	60.0	28.0	NA	4.800	20.500	0.800	0.560	NA	NA	NA	NA	NA	NA	NA	25288	NA	NA
08/15/87	6.04	5.4	1600	1080	270.0	56.0	26.0	NA	5.400	27.000	0.900	0.680	NA	NA	NA	NA	NA	NA	NA	12176	NA	NA
09/16/87	6.01	4.3	2275	1070	314.0	68.0	26.0	NA	6.930	29.000	0.920	0.700	NA	NA	NA	NA	NA	NA	NA	16525	NA	NA
10/13/87	5.86	1.8	2150	1390	400.0	76.0	34.0	NA	4.700	25.000	0.780	0.650	NA	NA	NA	NA	NA	NA	NA	1764	NA	NA
11/10/87	5.81	2.9	1850	1280	330.0	60.0	30.0	NA	5.900	26.000	0.980	0.750	NA	NA	NA	NA	NA	NA	NA	889	NA	NA
03/28/88	6.50	5.1	675	340	74.0	24.0	6.0	NA	6.800	16.400	0.900	1.000	NA	NA	NA	NA	NA	NA	NA	7169	NA	NA
04/17/88	5.93	2.3	970	700	116.0	36.0	8.0	NA	9.500	33.000	1.400	1.500	NA	NA	NA	NA	NA	NA	NA	5008	NA	NA
05/12/88	6.11	6.7	1500	1000	276.0	64.0	18.0	NA	8.500	41.000	1.600	1.600	NA	NA	NA	NA	NA	NA	NA	11014	NA	NA
06/12/88	6.12	4.8	1320	820	282.0	52.0	18.0	NA	5.100	33.000	1.200	1.300	NA	NA	NA	NA	NA	NA	NA	3160	NA	NA
07/15/88	5.91	5.3	1450	1120	253.0	60.0	21.0	NA	9.000	49.000	1.800	1.900	NA	NA	NA	NA	NA	NA	NA	3565	NA	NA
08/16/88	6.27	7.1	1575	915	277.0	73.0	26.0	NA	5.600	38.500	1.100	0.800	NA	NA	NA	NA	NA	NA	NA	56169	NA	NA
09/16/88	6.09	3.0	1600	860	280.0	78.0	26.0	NA	5.200	42.000	1.200	0.900	NA	NA	NA	NA	NA	NA	NA	11276	NA	NA
10/18/88	5.93	3.6	1575	1105	239.0	66.0	20.0	NA	8.350	36.500	1.600	1.750	NA	NA	NA	NA	NA	NA	NA	3346	NA	NA
11/15/88	5.57	2.4	1200	900	180.0	116.0	18.0	NA	12.700	38.000	1.800	1.700	NA	NA	NA	NA	NA	NA	NA	5583	NA	NA
11/30/88	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8	NA	NA
04/07/89	5.20	1.0	530	284	70.0	20.0	8.0	NA	5.200	20.500	0.800	0.700	NA	NA	NA	NA	NA	NA	NA	26374	NA	NA
04/24/89	5.87	3.7	575	296	64.0	18.0	6.0	NA	4.000	18.000	0.800	0.800	NA	NA	NA	NA	NA	NA	NA	7483	NA	NA
05/16/89	5.69	1.3	1325	790	192.0	52.0	14.0	NA	8.000	37.000	1.700	1.700	NA	NA	NA	NA	NA	NA	NA	13668	NA	NA
06/17/89	5.92	6.3	1725	1270	266.0	76.0	28.0	NA	8.000	46.000	1.800	1.200	NA	NA	NA	NA	NA	NA	NA	37191	NA	NA
07/17/89	5.60	4.4	1900	1350	342.0	78.0	30.0	NA	6.700	30.000	1.100	1.100	NA	NA	NA	NA	NA	NA	NA	3959	NA	NA
08/14/89	5.83	5.1	1400	880	206.0	54.0	20.0	NA	7.500	41.000	1.400	1.200	NA	NA	NA	NA	NA	NA	NA	4285	NA	NA
09/14/89	5.58	5.5	2100	1480	384.0	98.0	30.0	NA	13.100	39.000	2.300	1.600	NA	NA	NA	NA	NA	NA	NA	26192	NA	NA

Table A2.1. Drainage quality data from Duluth Complex test pile FL1, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
10/16/89	5.88	2.3	1400	800	212.0	54.0	22.0	NA	5.900	25.000	1.900	1.000	NA	NA	NA	NA	NA	NA	NA	2566	NA	NA
11/06/89	5.50	2.4	1175	680	166.0	50.0	16.0	NA	5.300	25.000	2.600	1.000	NA	NA	NA	NA	NA	NA	NA	745	NA	NA
03/26/90	5.05	3.8	600	290	64.0	21.4	7.4	NA	10.200	19.000	10.200	1.010	NA	NA	NA	NA	NA	NA	NA	742	NA	NA
04/12/90	5.82	1.1	975	685	148.0	42.0	10.0	NA	9.430	32.000	1.540	1.540	NA	NA	NA	NA	NA	NA	NA	5984	NA	NA
05/17/90	5.72	2.1	1800	1250	286.0	84.0	20.0	NA	10.000	39.000	1.910	1.780	NA	NA	NA	NA	NA	NA	NA	7127	NA	NA
06/18/90	5.86	2.0	1685	1040	202.0	70.0	22.0	NA	7.780	30.000	1.270	1.140	NA	NA	NA	NA	NA	NA	NA	10465	NA	NA
07/16/90	5.79	3.2	1650	975	214.0	66.0	20.0	NA	7.820	27.000	1.250	1.190	NA	NA	NA	NA	NA	NA	NA	6972	NA	NA
08/13/90	5.77	1.6	1575	920	228.0	66.0	22.0	NA	5.210	21.000	1.010	0.930	NA	NA	NA	NA	NA	NA	NA	1544	NA	NA
09/10/90	5.42	3.2	1715	940	212.0	74.0	18.0	NA	20.000	56.000	2.820	2.270	NA	NA	NA	NA	NA	NA	NA	3978	NA	NA
10/15/90	5.29	2.7	2600	1650	358.0	134.0	30.0	NA	35.000	93.000	4.350	3.100	NA	NA	NA	NA	NA	NA	NA	22191	NA	NA
11/16/90	5.31	1.9	3875	2400	680.0	202.0	54.0	NA	29.000	88.000	4.040	3.550	NA	NA	NA	NA	NA	NA	NA	1098	NA	NA
04/08/91	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4179	NA	NA
04/22/91	4.96	2.5	1650	1030	194.0	88.0	16.0	NA	19.900	68.000	2.600	1.800	NA	NA	NA	NA	NA	NA	NA	8005	NA	NA
05/20/91	5.18	2.5	2375	1200	262.0	107.0	20.0	NA	20.300	68.000	2.400	1.500	NA	NA	NA	NA	NA	NA	NA	11983	NA	NA
06/17/91	5.25	2.0	2050	1110	214.0	104.0	20.0	NA	27.000	71.000	3.000	1.600	NA	NA	NA	NA	NA	NA	NA	11987	NA	NA
07/15/91	5.27	3.1	2725	1260	278.0	124.0	26.0	NA	21.000	59.000	2.400	1.500	NA	NA	NA	NA	NA	NA	NA	32415	NA	NA
08/12/91	5.27	2.4	2550	1370	318.0	110.0	34.0	NA	18.000	54.000	2.300	1.300	NA	NA	NA	NA	NA	NA	NA	3463	NA	NA
09/09/91	5.22	3.6	2675	1420	268.0	110.0	28.0	NA	30.000	84.000	3.400	2.000	NA	NA	NA	NA	NA	NA	NA	19792	NA	NA
10/07/91	5.31	3.6	2575	1360	272.0	108.0	32.0	NA	21.000	67.000	2.700	1.700	NA	NA	NA	NA	NA	NA	NA	7025	NA	NA
11/07/91	5.24	3.1	2475	1270	252.0	112.0	30.0	NA	27.000	80.000	3.200	2.100	NA	NA	NA	NA	NA	NA	NA	22131	NA	NA

NA: Not analyzed.

'Dates represent intermediate dates for measurement periods.

Table A2.2. Drainage quality data from Duluth Complex test pile FL2, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u	Alk. mg/l	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/L	K mg/l	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/l	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/26/78	7.20	NA	1000	NA	99.0	13.0	101.0	12.0	0.038	NA	0.003	0.020	NA	0.07	NA	NA	NA	NA	NA	NA	NA	4.0
05/25/78	7.70	NA	1900	NA	177.0	23.0	241.0	15.0	0.040	0.240	0.008	0.028	0.05	0.16	NA	NA	NA	NA	NA	NA	NA	NA
06/16/78	7.72	NA	4200	NA	323.0	47.0	555.0	23.0	0.056	0.200	0.015	0.075	0.03	0.31	NA	NA	NA	NA	NA	496	NA	11.0
07/05/78	7.50	NA	2700	1400	218.0	33.0	313.0	28.0	0.057	0.316	0.021	0.084	0.04	0.22	34.0	NA	NA	NA	NA	293	NA	12.0
07/13/78	7.92	NA	NA	800	491.0	43.0	376.0	37.0	0.049	0.410	0.033	0.090	0.03	0.29	30.0	12.0	1.00	0.08	NA	NA	NA	NA
07/19/78	7.80	NA	1300	800	291.0	24.0	189.0	28.0	0.062	0.240	0.014	0.033	0.01	0.16	41.0	10.0	0.75	0.10	NA	NA	NA	NA
08/02/78	7.75	NA	2000	1100	191.0	21.0	241.0	26.0	0.080	0.260	0.010	0.060	0.04	0.18	14.0	8.0	0.20	0.20	NA	NA	NA	19.0
08/04/78	7.75	NA	2500	1700	341.0	42.0	410.0	33.0	0.070	0.440	0.029	0.113	0.05	0.28	19.0	11.0	0.06	0.08	NA	1000	NA	22.0
08/16/78	7.58	39.5	1092	500	108.0	14.3	95.7	16.7	0.140	0.180	0.023	0.027	0.05	0.09	17.0	NA	0.10	0.08	NA	30	NA	23.0
08/23/78	7.60	31.0	1100	460	103.0	15.0	86.0	18.0	0.140	0.180	0.020	0.020	0.04	0.10	15.0	5.3	1.10	0.10	NA	6379	NA	NA
08/25/78	7.30	35.0	1600	680	170.0	24.0	125.0	28.0	0.110	0.240	0.030	0.050	0.01	0.15	25.0	3.6	NA	0.10	NA	NA	NA	23.0
08/28/78	7.55	48.0	2300	1100	253.0	34.0	196.0	32.0	0.100	0.380	0.045	0.090	0.01	0.23	34.0	8.5	1.30	0.08	NA	NA	NA	NA
09/13/78	7.25	29.0	1338	584	133.0	16.0	106.0	26.5	0.120	0.190	0.020	0.050	0.03	0.11	12.0	5.5	0.06	0.08	NA	451	NA	15.0
03/19/79	7.70	NA	1043	NA	83.2	11.0	43.8	15.8	0.119	0.170	0.016	0.050	0.06	0.08	NA	NA	NA	NA	12.0	2612	1891	NA
03/27/79	NA	NA	NA	NA	205.0	28.4	86.0	24.6	0.180	0.460	0.060	0.060	0.05	0.18	NA	NA	NA	NA	NA	53	NA	NA
04/17/79	6.90	22.0	388	136	74.2	5.8	25.6	11.8	0.108	0.134	0.008	0.030	0.06	0.05	10.0	136.0	NA	NA	14.0	5151	3480	NA
04/18/79	6.90	16.5	177	51	27.5	2.6	18.0	6.1	0.091	0.040	0.004	0.020	0.05	0.03	5.5	1.2	NA	NA	10.5	6056	3654	NA
04/20/79	6.50	21.0	296	100	49.0	5.6	22.0	8.0	0.113	0.080	0.008	0.020	0.06	0.05	12.0	2.2	0.45	NA	11.0	3263	3830	NA
04/22/79	7.50	18.0	1163	633	175.4	24.2	82.8	18.6	0.100	0.300	0.020	0.060	0.04	0.16	30.0	11.0	0.11	NA	NA	5020	1296	NA
05/09/79	7.40	NA	1217	500	154.6	22.0	83.0	18.1	0.084	0.295	0.020	0.040	0.04	0.14	26.0	NA	NA	NA	NA	825	1083	NA
05/10/79	7.40	NA	1009	400	144.4	20.0	59.6	16.6	0.100	0.250	0.015	0.040	0.03	0.13	22.0	NA	NA	NA	NA	6810	3129	NA
05/20/79	6.90	NA	1562	800	233.4	32.6	116.8	23.2	0.100	0.330	0.023	0.050	0.03	0.18	25.0	NA	NA	NA	14.0	3611	1034	NA
05/22/79	7.40	NA	1128	567	165.8	22.8	83.6	18.4	0.180	0.280	0.020	0.040	0.04	0.14	20.0	NA	NA	NA	16.0	1639	1041	NA
05/23/79	7.60	NA	1976	NA	286.0	39.2	174.4	28.6	0.100	0.440	0.027	0.070	0.21	0.23	NA	NA	NA	NA	4.7	2286	609	NA
06/02/79	7.60	NA	1683	883	217.2	31.8	164.2	24.0	0.160	0.340	0.023	0.050	0.07	0.18	23.0	NA	NA	NA	16.0	1518	474	NA
06/06/79	7.80	NA	1749	900	220.8	33.8	85.0	29.6	0.170	0.300	0.021	0.050	0.03	0.17	23.0	NA	NA	NA	NA	1999	531	NA
06/10/79	7.60	45.0	1414	580	173.4	27.8	71.8	24.6	0.190	0.270	0.013	0.030	0.06	0.13	19.0	NA	NA	NA	NA	2021	1211	22.0
06/12/79	7.00	43.0	2317	1200	277.0	44.6	107.2	40.0	0.132	0.370	0.017	0.070	0.02	0.29	27.0	NA	NA	NA	NA	1033	361	NA
06/16/79	7.70	51.0	2365	1350	307.4	49.1	179.0	39.8	0.131	0.415	0.029	0.080	0.03	0.23	31.0	NA	NA	NA	NA	1344	368	25.0
06/20/79	7.10	36.0	1363	570	158.0	27.0	139.0	22.0	0.130	0.220	0.017	0.040	0.04	0.12	15.0	NA	NA	NA	NA	2200	1011	18.0
06/30/79	7.60	59.0	2536	1450	336.0	55.0	339.0	31.0	0.070	0.430	0.036	0.090	0.03	0.13	31.0	NA	NA	NA	16.0	1132	170	12.0
07/10/79	7.70	45.0	3294	2300	420.0	72.0	430.0	38.0	0.060	0.590	0.052	0.110	0.02	0.34	28.0	NA	NA	NA	NA	1249	142	19.0
07/30/79	7.10	17.8	980	480	106.0	18.0	88.0	17.0	0.110	0.170	0.014	0.030	0.03	0.09	16.0	NA	NA	NA	14.0	2779	2096	22.0
08/04/79	7.70	30.8	1826	1020	253.0	36.0	183.0	32.0	0.070	0.360	0.030	0.070	0.07	0.19	15.0	NA	NA	NA	9.2	443	65	23.0
08/13/79	NA	NA	NA	NA	385.6	66.6	408.0	38.6	0.050	0.650	0.035	0.080	0.04	0.30	NA	NA	NA	NA	NA	91	11	NA
08/23/79	NA	NA	NA	NA	217.2	33.2	200.0	25.8	0.100	0.470	0.027	0.070	0.04	0.21	NA	NA	NA	NA	14.0	114	70	NA
08/28/79	7.20	13.6	1338	NA	157.0	25.2	132.6	20.0	0.150	0.360	0.021	0.060	0.07	0.15	NA	NA	NA	NA	15.0	326	293	23.0
09/01/79	7.10	18.4	1087	650	142.8	19.8	84.2	19.8	0.150	0.280	0.020	0.050	0.05	0.10	9.0	NA	NA	NA	13.0	1526	905	21.0
09/04/79	7.20	20.8	1380	NA	211.4	29.0	101.4	25.8	0.120	0.370	0.020	0.070	0.02	0.16	NA	NA	NA	NA	13.0	1775	179	20.0
09/10/79	7.20	15.2	1134	600	165.6	22.0	104.0	21.2	0.150	0.340	0.020	0.050	0.03	0.14	9.0	NA	NA	NA	14.0	1268	249	17.0
09/13/79	7.30	17.6	1587	NA	233.8	31.6	156.0	26.8	0.150	0.450	0.026	0.090	0.05	0.20	NA	NA	NA	NA	14.0	367	211	18.0
09/19/79	7.30	20.8	2592	NA	379.0	53.4	238.2	37.2	0.060	0.760	0.070	0.120	0.02	0.30	NA	NA	NA	NA	13.0	129	22	18.0
10/19/79	6.60	12.8	914	542	112.5	16.1	64.0	14.9	0.195	0.365	0.020	0.040	0.06	0.10	5.0	NA	NA	NA	14.0	1726	2456	NA
10/31/79	6.70	13.6	1319	817	194.0	25.2	84.0	20.8	0.160	0.490	0.050	0.090	0.05	0.16	4.0	NA	NA	NA	13.0	2835	1118	NA
11/01/79	7.20	17.6	1659	975	280.0	34.2	98.0	25.8	0.110	0.550	0.060	0.080	0.02	0.16	10.0	NA	NA	NA	13.0	1215	637	NA
04/01/80	7.10	17.3	350	135	33.2	4.6	17.8	7.8	0.135	0.095	0.010	0.030	0.08	0.04	3.5	NA	NA	NA	10.0	1582	382	10.5
04/16/80	7.50	35.0	600	225	68.2	8.2	33.8	13.2	0.130	0.130	0.030	0.060	0.03	0.06	5.0	NA	NA	NA	NA	856	831	NA
04/17/80	7.20	33.5	NA	253	69.0	9.0	30.2	10.3	0.150	0.210	0.020	0.050	0.07	0.07	5.5	NA	NA	NA	12.0	1893	774	NA
04/29/80	7.57	41.5	1105	820	157.1	19.8	46.0	16.0	0.100	0.360	0.025	0.060	0.02	0.12	9.0	NA	NA	NA	NA	1117	163	13.0
05/08/80	7.40	34.1	1230	880	190.0	24.2	58.6	18.8	0.070	0.450	0.040	0.060	0.02	0.14	10.0	NA	NA	NA	9.5	541	51	11.0
05/18/80	7.50	30.8	1500	1050	236.0	31.2	92.0	23.0	0.050	0.600	0.050	0.100	0.03	0.18	23.0	NA	NA	NA	NA	371	26	19.0

Table A2.2. Drainage quality data from Duluth Complex test pile FL2, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/l	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/l	K mg/l	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/l	Mn mg/l	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
05/31/80	6.90	16.5	875	620	129.4	17.2	45.5	16.2	0.030	0.300	0.022	0.020	0.02	0.10	14.0	NA	NA	NA	15.0	1703	1084	NA
06/03/80	7.30	25.3	1400	700	207.4	25.2	68.8	21.6	0.110	0.570	0.030	0.100	0.02	0.13	15.0	NA	NA	NA	9.8	174	50	NA
06/06/80	7.20	23.1	1300	760	174.6	22.2	63.2	20.0	0.150	0.490	0.025	0.090	0.03	0.12	14.0	NA	NA	NA	NA	371	235	NA
06/13/80	7.10	20.9	1200	750	148.8	21.4	65.6	19.6	0.150	0.450	0.022	0.080	0.03	0.11	12.0	NA	NA	NA	NA	265	197	NA
06/19/80	7.20	23.1	1650	950	221.0	28.0	98.8	23.4	0.110	0.580	0.021	0.110	0.06	0.15	16.0	NA	NA	NA	NA	23	12	NA
06/30/80	7.10	17.6	1150	660	158.0	20.0	58.0	17.0	0.130	0.480	0.070	0.100	0.05	0.13	10.0	NA	NA	NA	10.0	114	38	NA
07/02/80	7.10	15.3	950	580	132.0	16.0	45.0	16.0	0.170	0.380	0.022	0.090	0.04	0.10	9.0	NA	NA	NA	NA	246	96	NA
07/17/80	6.90	17.6	1150	450	155.6	19.0	58.4	19.6	0.140	0.500	0.030	0.090	0.03	0.14	10.0	NA	NA	NA	NA	95	124	NA
07/23/80	7.00	17.6	1100	350	149.8	18.6	66.4	19.2	0.110	0.470	0.060	0.090	0.02	0.15	9.0	NA	NA	NA	NA	95	525	NA
08/03/80	6.60	12.1	725	355	91.4	12.2	35.0	14.8	0.260	0.400	0.022	0.070	0.05	0.12	9.0	NA	NA	NA	16.0	106	95	NA
08/12/80	6.60	9.8	600	258	70.9	9.3	25.7	12.8	0.260	0.340	0.015	0.050	0.10	0.11	7.0	NA	NA	NA	14.0	1026	525	NA
08/19/80	6.80	10.2	700	424	103.6	13.0	28.8	16.0	0.190	0.450	0.024	0.080	0.05	0.16	6.0	NA	NA	NA	NA	379	106	NA
08/22/80	NA	NA	600	280	77.1	8.1	24.1	11.7	0.220	0.390	0.050	0.070	0.07	0.12	6.0	NA	NA	NA	NA	428	329	NA
08/29/80	6.70	15.3	1450	920	304.0	36.4	68.2	27.0	0.170	0.830	0.080	0.160	0.06	0.22	11.0	NA	NA	NA	10.0	2271	1473	NA
09/07/80	6.60	10.2	843	360	151.4	15.8	44.0	16.4	0.190	0.610	0.050	0.110	0.04	0.16	7.0	NA	NA	NA	NA	1450	1000	NA
09/10/80	6.80	11.5	1238	700	252.2	30.6	71.0	22.8	0.180	0.860	0.060	0.150	0.04	0.23	10.0	NA	NA	NA	NA	345	88	13.2
09/12/80	6.70	12.0	969	450	188.4	19.6	47.6	17.4	0.210	0.590	0.050	0.110	0.06	0.16	9.0	NA	NA	NA	13.0	2309	1578	17.5
09/18/80	6.90	12.3	1231	690	241.8	29.8	70.6	20.2	0.240	0.760	0.060	0.130	0.08	0.16	11.0	NA	NA	NA	NA	5330	1938	13.0
09/23/80	6.90	12.8	2527	1700	398.0	72.8	204.0	40.0	0.200	1.780	0.140	0.250	0.04	0.31	25.0	NA	NA	NA	13.0	1821	612	15.0
10/22/80	6.70	13.6	2664	1620	404.0	79.0	330.0	48.4	0.240	1.910	0.120	0.310	0.04	0.35	29.0	NA	NA	NA	13.0	1628	322	10.0
10/23/80	6.40	8.5	1763	950	214.0	32.0	170.0	23.0	0.190	1.260	0.090	0.200	0.04	0.25	31.0	NA	NA	NA	NA	795	268	12.0
02/18/81	6.70	8.5	408	160	31.8	6.0	39.0	NA	0.210	0.295	0.020	0.060	NA	NA	10.0	NA	NA	NA	NA	1760	1300	6.0
03/29/81	6.70	8.8	330	90	31.2	6.2	24.7	NA	0.210	0.220	0.020	0.050	NA	NA	NA	NA	NA	NA	15.0	6719	1726	NA
03/30/81	6.80	12.8	525	240	63.7	10.9	20.8	NA	0.280	0.490	0.030	0.080	NA	NA	NA	NA	NA	NA	NA	4236	1700	NA
04/13/81	NA	NA	800	250	69.0	12.0	21.0	NA	0.290	0.770	0.060	0.080	NA	NA	NA	NA	NA	NA	NA	2142	1281	NA
04/16/81	7.10	14.0	800	315	78.0	15.0	22.0	NA	0.250	0.920	0.060	0.090	NA	NA	NA	NA	NA	NA	15.0	1427	212	NA
04/23/81	7.10	13.6	900	300	87.0	17.0	27.0	NA	0.260	0.970	0.050	0.090	NA	NA	NA	NA	NA	NA	NA	2423	2478	NA
04/25/81	7.10	19.2	1155	530	129.0	30.0	36.0	NA	0.240	1.180	0.080	0.100	NA	NA	NA	NA	NA	NA	NA	4857	1589	NA
04/27/81	7.30	24.0	1250	600	136.0	35.0	48.0	NA	0.260	1.260	0.080	0.100	NA	NA	NA	NA	NA	NA	14.0	3869	2091	NA
04/30/81	7.30	24.0	1596	870	210.0	40.0	80.0	NA	0.200	1.700	0.100	0.140	NA	NA	NA	NA	NA	NA	NA	3206	994	NA
05/12/81	7.20	23.0	2179	1250	306.0	54.0	166.0	NA	0.130	2.100	0.140	0.170	NA	NA	NA	NA	NA	NA	14.0	3539	203	17.5
06/01/81	7.25	14.0	2116	1250	266.0	54.0	200.0	NA	0.160	1.160	0.070	0.150	NA	NA	NA	NA	NA	NA	NA	2370	705	17.0
06/06/81	7.20	18.2	1959	1000	234.0	44.0	174.0	NA	0.170	0.960	0.070	0.130	NA	NA	NA	NA	NA	NA	13.0	1522	150	18.0
06/22/81	6.80	11.2	1270	625	144.0	26.0	102.0	NA	0.200	0.710	0.060	0.090	NA	NA	NA	NA	NA	NA	NA	2411	1030	16.0
06/24/81	6.90	12.0	793	870	96.0	14.0	46.0	NA	0.250	0.550	0.040	0.060	NA	NA	NA	NA	NA	NA	NA	1874	993	17.0
06/28/81	6.80	11.2	718	160	92.0	14.0	36.0	NA	0.300	0.640	0.040	0.070	NA	NA	NA	NA	NA	NA	18.0	2612	1938	15.0
07/04/81	7.10	13.5	1630	1060	254.0	36.6	98.0	NA	0.270	1.370	0.090	0.140	NA	NA	NA	NA	NA	NA	NA	1037	53	22.0
07/15/81	7.00	11.7	2769	1800	388.0	68.4	259.6	NA	0.140	2.550	0.150	0.220	NA	NA	NA	NA	NA	NA	NA	575	26	19.0
07/24/81	7.10	10.5	2142	1320	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	21.0	NA	NA	NA	9.1	492	122	20.0
08/04/81	6.80	8.4	2864	2000	364.0	80.0	154.0	NA	0.190	2.440	0.160	0.310	NA	NA	NA	NA	NA	NA	NA	246	25	18.0
08/13/81	6.90	12.2	1926	1250	216.0	42.0	184.0	28.0	0.130	1.260	0.110	0.170	NA	NA	NA	NA	NA	NA	NA	64	6	22.0
08/31/81	6.00	8.0	1700	800	162.0	32.0	140.0	NA	0.420	1.230	0.090	0.160	NA	NA	NA	NA	NA	NA	15.0	454	382	NA
09/07/81	6.60	6.8	1800	720	154.0	29.0	124.0	NA	0.280	1.190	0.080	0.160	NA	NA	NA	NA	NA	NA	NA	284	255	NA
09/26/81	6.40	4.8	1093	490	108.0	20.0	70.0	NA	0.380	1.060	0.060	0.140	NA	NA	NA	NA	NA	NA	11.0	768	530	NA
10/01/81	6.60	4.8	750	260	90.0	16.0	32.0	NA	0.350	0.880	0.070	0.120	NA	NA	NA	NA	NA	NA	NA	1968	1257	NA
10/04/81	6.45	4.4	825	380	118.0	16.0	34.0	16.0	0.310	0.960	0.080	0.160	NA	NA	NA	NA	NA	NA	NA	852	1060	NA
10/13/81	6.65	5.0	950	400	132.0	20.0	34.0	18.0	0.310	1.370	0.100	0.200	NA	NA	NA	NA	NA	NA	9.7	3937	1603	NA
10/17/81	6.60	5.6	1600	870	238.0	36.0	58.0	28.0	0.510	4.200	0.240	0.360	NA	NA	NA	NA	NA	NA	NA	3896	810	NA
11/05/81	6.55	6.4	3800	2400	470.0	100.0	304.0	56.0	1.000	5.200	0.300	0.510	NA	NA	NA	NA	NA	NA	9.6	2839	99	NA
04/24/82	7.00	14.4	620	290	98.0	10.0	32.0	12.0	0.130	0.570	0.030	0.110	NA	NA	NA	NA	NA	NA	NA	3691	NA	NA
04/26/82	6.80	11.5	870	420	93.0	16.0	29.5	14.0	0.315	1.770	0.100	0.140	NA	NA	NA	NA	NA	NA	NA	4047	NA	NA

Table A2.2. Drainage quality data from Duluth Complex test pile FL2, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/l	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
05/03/82	7.20	10.8	1000	520	128.0	22.0	56.0	16.0	0.160	1.850	0.110	0.170	NA	NA	NA	NA	NA	NA	NA	969	NA	NA
05/07/82	6.70	9.0	780	370	82.0	14.0	20.0	12.0	0.320	1.800	0.110	0.130	NA	NA	NA	NA	NA	NA	NA	4789	NA	NA
05/11/82	6.80	12.2	1150	610	140.0	30.0	36.0	16.0	0.440	3.230	0.160	0.190	NA	NA	NA	NA	NA	NA	NA	3937	NA	NA
05/14/82	6.80	13.5	1450	730	174.0	25.4	40.4	14.6	0.320	2.100	0.100	0.140	0.03	0.15	NA	NA	NA	NA	NA	2623	NA	NA
05/21/82	6.90	15.3	2500	1500	336.0	63.0	143.0	32.0	0.410	4.030	0.210	0.270	0.04	0.24	NA	NA	NA	NA	NA	2248	NA	NA
06/02/82	6.65	12.6	2100	1300	246.0	49.0	134.0	26.0	0.350	2.500	0.130	0.200	0.04	0.20	NA	NA	NA	NA	NA	1787	NA	NA
06/18/82	6.60	11.7	1775	940	194.0	37.0	124.0	25.0	0.280	1.920	0.100	0.160	0.03	0.15	NA	NA	NA	NA	NA	390	NA	NA
07/02/82	6.50	8.1	950	480	116.0	20.0	56.0	16.0	0.350	1.300	0.060	0.100	0.03	0.11	NA	NA	NA	NA	NA	1098	NA	NA
07/08/82	6.50	9.0	1100	600	190.0	26.0	46.0	18.0	0.440	2.350	0.130	0.130	0.06	0.15	NA	NA	NA	NA	NA	3373	NA	NA
07/12/82	NA	NA	NA	1015	326.0	56.0	144.0	30.0	0.460	3.030	0.200	0.180	0.01	0.23	NA	NA	NA	NA	NA	4119	NA	NA
07/26/82	6.65	9.7	2171	1030	286.0	52.0	146.0	32.0	0.320	4.110	0.250	0.180	0.05	0.26	NA	NA	NA	NA	NA	6568	NA	NA
08/30/82	6.47	6.1	1356	800	234.0	34.0	76.0	24.0	0.460	2.040	0.130	0.160	0.06	0.17	NA	NA	NA	NA	NA	5765	NA	NA
10/04/82	6.80	8.8	2888	1600	340.0	80.0	216.0	42.0	0.800	5.890	0.380	0.250	0.07	0.38	NA	NA	NA	NA	NA	4096	NA	NA
11/01/82	6.45	5.2	1662	NA	199.0	32.0	76.0	16.0	0.360	2.205	0.125	0.100	0.03	0.13	NA	NA	NA	NA	NA	1643	NA	NA
11/22/82	NA	NA	NA	NA	296.0	49.0	192.0	NA	0.545	2.715	0.155	0.160	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/14/83	6.57	7.0	522	220	NA	NA	NA	NA	0.450	1.820	0.100	0.130	NA	NA	NA	NA	NA	NA	NA	9591	NA	NA
05/15/83	6.62	7.3	1115	580	NA	NA	NA	NA	0.590	3.470	0.200	0.270	NA	NA	NA	NA	NA	NA	NA	3826	NA	NA
06/16/83	6.48	6.2	1171	660	NA	NA	NA	NA	0.390	2.030	0.130	0.150	NA	NA	NA	NA	NA	NA	NA	1778	NA	NA
07/14/83	6.45	5.2	1164	660	NA	NA	NA	NA	0.620	3.580	0.190	0.240	NA	NA	NA	NA	NA	NA	NA	3993	NA	NA
08/14/83	6.08	3.9	1064	600	NA	NA	NA	NA	0.830	3.920	0.190	0.280	NA	NA	NA	NA	NA	NA	NA	6223	NA	NA
09/15/83	6.25	3.7	1200	730	NA	NA	NA	NA	1.140	4.710	0.280	0.380	NA	NA	NA	NA	NA	NA	NA	5095	NA	NA
10/13/83	6.39	5.0	1739	1340	NA	NA	NA	NA	2.120	6.830	0.400	0.460	NA	NA	NA	NA	NA	NA	NA	16559	NA	NA
11/09/83	6.25	2.7	1025	1380	NA	NA	NA	NA	1.580	4.770	0.270	0.360	NA	NA	NA	NA	NA	NA	NA	5053	NA	NA
11/30/83	6.10	2.7	1325	940	NA	NA	NA	NA	1.520	5.450	0.300	0.400	NA	NA	NA	NA	NA	NA	NA	276	NA	NA
04/15/84	6.59	9.9	936	700	198.3	37.5	45.8	NA	0.410	3.210	0.170	0.400	NA	NA	NA	NA	NA	NA	NA	7737	NA	NA
05/16/84	6.54	4.9	641	400	130.1	24.2	19.9	NA	0.670	4.120	0.140	0.190	NA	NA	NA	NA	NA	NA	NA	7835	NA	NA
06/13/84	6.39	4.9	950	680	172.7	35.6	32.7	NA	1.340	5.440	0.260	0.290	NA	NA	NA	NA	NA	NA	NA	11065	NA	NA
07/14/84	6.36	6.1	1460	1080	NA	NA	71.9	NA	1.300	6.330	0.240	0.300	NA	NA	NA	NA	NA	NA	NA	2710	NA	NA
08/15/84	6.35	4.8	1260	700	195.4	58.6	53.2	NA	0.950	4.820	0.270	0.270	NA	NA	NA	NA	NA	NA	NA	2172	NA	NA
09/12/84	5.99	3.4	1150	710	190.0	59.9	64.2	NA	1.250	5.310	0.310	0.330	NA	NA	NA	NA	NA	NA	NA	1086	NA	NA
10/13/84	5.78	2.7	1075	740	215.9	56.9	29.2	NA	1.920	8.500	0.600	0.540	NA	NA	NA	NA	NA	NA	NA	5443	NA	NA
11/14/84	5.82	3.2	1140	1100	280.0	60.0	51.0	NA	2.500	8.850	0.410	0.640	NA	NA	NA	NA	NA	NA	NA	1162	NA	NA
11/30/84	5.75	2.1	1125	710	264.0	60.0	54.0	NA	2.500	11.060	0.400	0.620	NA	NA	NA	NA	NA	NA	NA	98	NA	NA
12/18/84	5.75	2.1	1175	900	262.0	78.0	46.0	NA	3.900	14.400	0.830	0.810	NA	NA	NA	NA	NA	NA	NA	1123	NA	NA
04/02/85	6.30	4.5	260	140	37.2	7.2	8.4	NA	0.410	1.260	0.030	0.230	NA	NA	NA	NA	NA	NA	NA	867	NA	NA
04/16/85	6.50	7.6	650	420	100.0	25.4	17.8	NA	1.010	5.620	0.270	0.390	NA	NA	NA	NA	NA	NA	NA	15760	NA	NA
05/14/85	6.32	5.7	1215	780	189.0	41.6	27.5	NA	2.210	10.100	0.490	0.530	NA	NA	NA	NA	NA	NA	NA	7403	NA	NA
06/14/85	6.35	3.5	1525	1200	235.0	57.0	42.8	NA	3.170	11.600	0.490	0.520	NA	NA	NA	NA	NA	NA	NA	21991	NA	NA
07/15/85	6.33	6.2	1900	1500	280.0	76.0	97.0	NA	3.180	10.600	0.490	0.540	NA	NA	NA	NA	NA	NA	NA	8334	NA	NA
08/13/85	6.24	5.0	1425	1100	198.0	65.4	64.0	NA	1.960	6.990	0.360	0.390	NA	NA	NA	NA	NA	NA	NA	4129	NA	NA
09/13/85	6.06	3.2	1275	772	192.0	45.3	35.8	NA	1.890	8.670	0.420	0.450	NA	NA	NA	NA	NA	NA	NA	16188	NA	NA
10/15/85	6.19	3.5	1675	1100	260.0	74.0	58.0	NA	3.230	9.060	0.360	0.440	NA	NA	NA	NA	NA	NA	NA	17240	NA	NA
11/15/85	6.05	2.2	1925	1350	350.0	98.0	88.0	NA	3.340	9.200	0.390	0.510	NA	NA	NA	NA	NA	NA	NA	2737	NA	NA
03/23/86	6.20	5.0	440	195	56.0	13.0	8.2	NA	0.930	4.300	0.170	0.190	NA	NA	NA	NA	NA	NA	NA	17252	NA	NA
04/16/86	6.17	4.5	675	165	92.0	24.4	12.6	NA	1.620	7.300	0.310	0.290	NA	NA	NA	NA	NA	NA	NA	9550	NA	NA
05/14/86	6.20	3.8	1000	750	193.0	43.0	19.0	NA	2.940	13.300	0.480	0.390	NA	NA	NA	NA	NA	NA	NA	9357	NA	NA
06/11/86	6.33	5.1	1750	1300	282.0	70.0	64.0	NA	304.000	11.700	0.550	0.530	NA	NA	NA	NA	NA	NA	NA	2623	NA	NA
07/12/86	6.20	4.2	1125	675	158.0	46.0	36.0	NA	2.030	6.900	0.340	0.320	NA	NA	NA	NA	NA	NA	NA	4326	NA	NA
08/13/86	6.00	3.5	1150	600	150.0	40.4	36.0	NA	2.270	7.300	0.400	0.270	NA	NA	NA	NA	NA	NA	NA	3619	NA	NA
09/14/86	5.83	3.0	1475	750	222.0	55.2	32.0	NA	4.400	14.000	0.700	0.440	NA	NA	NA	NA	NA	NA	NA	11941	NA	NA
10/16/86	5.55	2.5	2150	1250	327.0	88.0	66.0	NA	6.200	19.000	0.800	0.770	NA	NA	NA	NA	NA	NA	NA	4372	NA	NA

Table A2.2. Drainage quality data from Duluth Complex test pile FL2, from 1978-1991 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/l	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/l	K mg/L	Cu mg/L	Ni mg/L	Co mg/l	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
11/16/86	5.64	3.1	1950	1000	280.0	94.0	62.0	NA	8.000	19.400	0.930	0.870	NA	NA	NA	NA	NA	NA	NA	6294	NA	NA
03/22/87	5.70	6 1	350	190	58.0	14.0	10.0	NA	1.100	3.900	0.150	0.170	NA	NA	NA	NA	NA	NA	NA	9599	NA	NA
04/15/87	6.12	4.3	600	316	74.0	24.0	12.0	NA	1.670	5.900	0.280	0.320	NA	NA	NA	NA	NA	NA	NA	1957	NA	NA
05/16/87	5.75	4.3	1100	600	200.0	48.0	26.0	NA	3.400	10.900	0.500	0.310	NA	NA	NA	NA	NA	NA	NA	24103	NA	NA
06/16/87	5.24	3.2	2750	1800	473.0	162.0	103.0	NA	7.300	17.900	0.800	0.690	NA	NA	NA	NA	NA	NA	NA	2165	NA	NA
07/15/87	5.54	4.1	1475	830	188.0	58.0	34.0	NA	4.900	15.900	0.800	0.660	NA	NA	NA	NA	NA	NA	NA	12335	NA	NA
08/15/87	5.65	3.5	1600	1125	216.0	70.0	46.0	NA	5.200	15.100	0.700	0.670	NA	NA	NA	NA	NA	NA	NA	4500	NA	NA
09/16/87	5.46	3.2	1650	640	184.0	56.0	32.0	NA	3.870	12.370	0.550	0.560	NA	NA	NA	NA	NA	NA	NA	6953	NA	NA
10/13/87	4.87	1.9	2850	1580	415.0	130.0	82.0	NA	9.000	31.000	1.250	1.150	NA	NA	NA	NA	NA	NA	NA	1041	NA	NA
11/10/87	5.14	2.4	2525	920	364.0	116.0	78.0	NA	8.300	27.000	1.110	1.110	NA	NA	NA	NA	NA	NA	NA	568	NA	NA
03/28/88	5.70	3.0	400	275	50.0	14.0	6.0	NA	1.500	5.200	0.300	0.500	NA	NA	NA	NA	NA	NA	NA	6737	NA	NA
04/17/88	5.72	3.3	675	330	76.0	24.0	8.0	NA	2.400	7.800	0.500	0.800	NA	NA	NA	NA	NA	NA	NA	3384	NA	NA
05/12/88	5.71	4.0	1200	680	184.0	50.0	220.0	NA	4.700	14.600	0.900	1.400	NA	NA	NA	NA	NA	NA	NA	7127	NA	NA
06/12/88	5.56	3.6	1390	850	282.0	60.0	24.0	NA	6.200	22.000	1.100	1.600	NA	NA	NA	NA	NA	NA	NA	1605	NA	NA
07/15/88	5.47	3.5	1175	675	168.0	54.0	28.0	NA	5.000	13.000	1.000	1.300	NA	NA	NA	NA	NA	NA	NA	836	NA	NA
08/16/88	5.41	2.4	1550	870	216.0	88.0	40.0	NA	6.500	37.000	1.300	1.200	NA	NA	NA	NA	NA	NA	NA	43138	NA	NA
09/16/88	5.35	3.2	2025	1275	326.0	125.0	79.0	NA	6.650	35.500	1.250	1.250	NA	NA	NA	NA	NA	NA	NA	7926	NA	NA
10/18/88	5.47	3.2	1975	1300	272.0	102.0	51.0	NA	5.900	20.500	1.100	1.400	NA	NA	NA	NA	NA	NA	NA	1893	NA	NA
11/15/88	5.46	2.9	1275	780	152.0	64.0	28.0	NA	5.700	22.000	1.200	1.400	NA	NA	NA	NA	NA	NA	NA	5182	NA	NA
12/05/88	5.16	2.2	2125	1420	248.0	120.0	42.0	NA	13.400	53.000	2.600	2.900	NA	NA	NA	NA	NA	NA	NA	1120	NA	NA
04/07/89	5.80	4.4	500	248	64.0	20.0	10.0	NA	2.700	13.200	0.700	0.700	NA	NA	NA	NA	NA	NA	NA	20677	NA	NA
04/24/89	5.73	3.6	565	270	52.0	22.0	8.0	NA	2.900	15.000	0.700	0.800	NA	NA	NA	NA	NA	NA	NA	6249	NA	NA
05/16/89	5.39	3.6	1100	865	132.0	78.0	20.0	NA	20.000	61.000	3.800	4.100	NA	NA	NA	NA	NA	NA	NA	7907	NA	NA
06/17/89	5.27	3.3	1475	950	202.0	70.0	32.0	NA	7.600	44.000	2.000	1.600	NA	NA	NA	NA	NA	NA	NA	22827	NA	NA
07/17/89	5.12	3.2	2650	1870	420.0	156.0	76.0	NA	12.100	46.000	1.900	2.600	NA	NA	NA	NA	NA	NA	NA	1900	NA	NA
08/14/89	5.33	3.3	1450	880	182.0	76.0	38.0	NA	5.500	26.000	0.900	1.000	NA	NA	NA	NA	NA	NA	NA	1874	NA	NA
09/14/89	5.24	3.6	1750	1050	260.0	88.0	32.0	NA	10.000	39.000	2.700	2.100	NA	NA	NA	NA	NA	NA	NA	14311	NA	NA
10/16/89	5.23	2.0	1500	1140	230.0	84.0	44.0	NA	8.400	29.000	2.600	1.900	NA	NA	NA	NA	NA	NA	NA	2562	NA	NA
11/06/89	5.15	2.6	1340	800	170.0	78.0	34.0	NA	6.500	24.000	2.800	1.500	NA	NA	NA	NA	NA	NA	NA	1881	NA	NA
03/26/90	5.05	2.4	500	210	50.0	17.6	6.6	NA	2.700	9.120	0.480	0.600	NA	NA	NA	NA	NA	NA	NA	6601	NA	NA
04/12/90	5.31	3.0	982	565	110.0	50.0	12.0	NA	9.260	32.000	1.840	1.850	NA	NA	NA	NA	NA	NA	NA	19731	NA	NA
05/17/90	5.13	2.7	1600	950	194.0	84.0	24.0	NA	11.000	36.000	2.120	2.170	NA	NA	NA	NA	NA	NA	NA	11597	NA	NA
06/18/90	5.27	2.0	1750	930	188.0	80.0	32.0	NA	7.210	25.000	1.220	1.420	NA	NA	NA	NA	NA	NA	NA	11752	NA	NA
07/16/90	5.08	3.9	2850	1730	336.0	144.0	50.0	NA	14.000	42.000	2.430	2.680	NA	NA	NA	NA	NA	NA	NA	6283	NA	NA
08/13/90	5.05	3.0	3110	1840	388.0	196.0	70.0	NA	14.000	40.000	2.330	2.460	NA	NA	NA	NA	NA	NA	NA	1272	NA	NA
09/10/90	5.29	2.1	1545	815	174.0	68.0	30.0	NA	6.020	20.000	1.160	1.240	NA	NA	NA	NA	NA	NA	NA	3376	NA	NA
10/15/90	5.23	2.8	1700	960	196.0	74.0	28.0	NA	11.000	36.000	2.010	1.800	NA	NA	NA	NA	NA	NA	NA	16476	NA	NA
11/16/90	5.08	2.2	3750	2250	540.0	208.0	74.0	NA	22.000	69.000	3.740	3.860	NA	NA	NA	NA	NA	NA	NA	1370	NA	NA
04/08/91	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	712	NA	NA
04/22/91	5.70	4.0	1025	570	118.0	44.0	16.0	NA	4.400	17.000	0.700	0.800	NA	NA	NA	NA	NA	NA	NA	10579	NA	NA
05/20/91	5.24	3.2	1925	870	202.0	81.0	20.0	NA	9.900	36.000	1.500	1.200	NA	NA	NA	NA	NA	NA	NA	13471	NA	NA
06/17/91	5.25	2.0	1250	635	136.0	59.0	18.0	NA	6.900	23.000	1.100	0.800	NA	NA	NA	NA	NA	NA	NA	5185	NA	NA
07/15/91	5.21	2.3	1700	775	146.0	74.0	20.0	NA	9.000	30.000	1.400	1.000	NA	NA	NA	NA	NA	NA	NA	17070	NA	NA
08/12/91	4.96	2.0	3525	2030	416.0	184.0	72.0	NA	18.000	58.000	2.700	2.100	NA	NA	NA	NA	NA	NA	NA	1639	NA	NA
09/09/91	5.13	3.0	1350	610	114.0	50.0	20.0	NA	8.000	30.000	1.400	0.900	NA	NA	NA	NA	NA	NA	NA	9693	NA	NA
10/07/91	5.09	3.0	2375	1210	228.0	98.0	38.0	NA	13.000	43.000	2.100	1.700	NA	NA	NA	NA	NA	NA	NA	3051	NA	NA
11/07/91	5.15	3.0	1875	1230	202.0	110.0	30.0	NA	22.000	69.000	3.400	2.600	NA	NA	NA	NA	NA	NA	NA	14629	NA	NA

NA: Not analyzed.

'Dates represent intermediate dates for measurement periods.

Table A2.3. Drainage quality data from Duluth Complex test pile FL3, from 1978-1989 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/L	K mg/L	Cu mg/L	.Ni mg/L	Co mg/l	Zn mg/L	Fe mg/l	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/26/78	7.20	NA	675	NA	62.0	10.0	52.0	12.0	0.023	0.060	NA	NA	0.70	0.05	NA	NA	NA	NA	NA	NA	NA	4.5
05/25/78	7.80	NA	1200	NA	106.0	24.0	122.0	15.0	0.013	0.042	0.050	0.020	0.04	0.09	NA	NA	NA	NA	NA	NA	NA	NA
06/16/78	7.79	NA	3000	NA	214.0	57.0	372.0	21.0	0.026	0.185	0.012	0.059	0.06	0.24	NA	NA	NA	NA	NA	192	NA	6.0
07/05/78	7.30	NA	1600	600	142.0	34.0	102.0	23.0	0.200	0.321	0.017	0.037	0.02	0.17	78.0	NA	NA	NA	NA	133	NA	9.0
07/13/78	7.55	NA	NA	1050	352.0	46.0	207.0	32.0	0.049	0.405	0.030	0.092	0.03	0.24	34.0	23.0	0.70	0.08	NA	NA	NA	NA
07/19/78	7.85	NA	1000	550	241.0	28.0	NA	27.0	0.092	0.235	0.020	0.060	0.01	0.15	35.0	24.0	0.55	0.08	NA	NA	NA	NA
08/02/78	7.60	NA	650	367	96.0	14.0	60.0	21.0	0.080	0.210	0.010	0.025	0.03	0.16	12.0	19.0	0.80	0.08	NA	NA	NA	22.0
08/04/78	7.65	NA	950	500	156.0	24.0	88.0	26.0	0.080	0.320	0.020	0.044	0.02	0.16	17.0	26.0	0.06	0.08	NA	100	NA	22.0
08/10/78	7.90	40.0	1900	1200	348.0	51.0	188.0	49.0	0.060	0.565	0.090	0.073	0.01	0.28	48.0	10.5	NA	0.45	17.0	851	NA	24.0
08/16/78	7.62	29.0	750	300	83.7	14.7	46.0	17.7	0.117	0.207	0.017	0.020	0.07	0.08	10.0	9.4	NA	0.08	NA	NA	NA	20.3
08/23/78	7.50	33.0	750	300	75.0	14.0	45.0	17.0	0.100	0.190	0.016	0.020	0.07	0.08	7.0	17.0	0.64	0.08	NA	NA	NA	NA
08/25/78	7.30	25.0	1150	500	115.0	23.0	67.0	23.0	0.080	0.250	0.010	0.030	0.04	0.10	11.0	24.0	NA	0.10	NA	NA	NA	24.0
09/13/78	7.30	36.0	690	659	133.5	21.5	74.5	27.5	0.085	0.300	0.020	0.040	0.04	0.12	7.0	13.0	0.08	0.08	NA	130	NA	14.0
03/19/79	7.08	NA	794	NA	118.8	25.9	50.1	15.9	0.080	0.790	0.050	0.110	0.08	0.10	NA	NA	NA	NA	9.3	3179	1765	NA
03/27/79	7.20	40.0	1233	NA	162.0	36.8	73.8	22.2	0.060	0.780	0.070	0.110	0.02	0.12	NA	NA	NA	NA	NA	1877	442	NA
04/13/79	6.75	NA	484	233	61.9	12.8	29.6	10.1	0.106	0.296	0.024	0.040	0.13	0.06	5.0	NA	NA	NA	NA	1877	442	NA
04/17/79	6.70	28.0	587	235	69.8	13.8	32.2	10.8	0.088	0.292	0.026	0.050	0.09	0.08	8.0	NA	NA	NA	5.3	3039	3576	NA
04/19/79	6.80	23.0	503	215	80.5	13.4	41.5	9.3	0.064	0.220	0.020	0.040	0.12	0.07	5.0	1.5	0.10	NA	NA	4341	4304	NA
04/19/79	7.10	27.0	532	205	83.0	12.6	31.0	8.6	0.072	0.238	0.020	0.050	0.05	0.07	4.0	1.5	NA	NA	11.0	3312	4304	NA
04/20/79	6.70	33.0	623	310	100.0	17.6	42.0	11.0	0.069	0.278	0.032	0.050	0.06	0.09	4.0	3.4	0.10	NA	4.7	4126	2592	NA
04/22/79	7.20	19.0	1356	833	206.4	44.6	121.6	24.8	0.056	0.920	0.051	0.120	0.03	0.17	11.0	6.9	0.04	NA	NA	8607	1630	NA
05/07/79	7.30	NA	1562	NA	209.2	49.0	131.6	27.6	0.046	0.890	0.047	0.110	0.03	0.18	NA	NA	NA	NA	NA	479	308	NA
05/10/79	7.40	NA	959	433	123.2	26.4	62.4	17.0	0.068	0.520	0.031	0.070	0.03	0.11	10.0	NA	NA	NA	NA	7070	3099	NA
05/20/79	6.70	NA	1711	933	229.2	52.6	130.8	29.6	0.060	0.750	0.047	0.120	0.02	0.16	13.0	NA	NA	NA	5.9	2619	900	NA
05/22/79	7.60	NA	1537	500	120.4	26.2	60.8	16.8	0.090	0.440	0.023	0.080	0.04	0.08	6.0	NA	NA	NA	7.6	1559	784	NA
05/23/79	7.50	NA	1331	750	180.4	37.4	92.2	24.4	0.058	0.620	0.040	0.080	0.04	0.12	7.0	NA	NA	NA	4.9	2449	838	NA
06/01/79	7.60	NA	998	517	122.8	26.6	59.8	17.4	0.100	0.460	0.023	0.060	0.08	0.10	6.0	NA	NA	NA	6.7	1938	369	NA
06/06/79	7.50	NA	824	400	101.0	21.8	33.4	15.6	0.081	0.370	0.021	0.050	0.03	0.08	4.0	NA	NA	NA	NA	1768	515	NA
06/10/79	7.20	35.0	725	320	173.8	38.0	50.8	38.8	0.100	0.310	0.010	0.040	0.02	0.05	4.0	NA	NA	NA	NA	1771	938	20.0
06/12/79	6.80	33.0	912	420	118.8	25.2	36.0	22.8	0.071	0.410	0.013	0.070	0.01	0.07	5.0	NA	NA	NA	NA	1011	361	NA
06/15/79	7.30	33.0	1081	533	143.8	30.4	42.4	23.4	0.061	0.470	0.013	0.050	0.01	0.08	7.0	NA	NA	NA	NA	329	325	20.0
06/21/79	7.05	30.5	823	409	101.0	23.5	42.0	19.0	0.070	0.340	0.021	0.040	0.02	0.06	4.0	NA	NA	NA	NA	2195	1070	16.5
06/30/79	7.20	29.0	1175	725	158.0	35.0	68.0	25.0	0.050	0.490	0.032	0.070	0.02	0.24	5.0	NA	NA	NA	5.6	1389	169	12.0
07/10/79	7.50	26.0	1649	1100	241.0	52.0	105.0	37.0	0.040	1.700	0.046	0.090	0.01	0.16	12.0	NA	NA	NA	5.3	734	74	18.0
07/30/79	7.10	12.0	772	390	98.0	21.0	31.0	19.0	0.090	0.580	0.040	0.060	0.01	0.10	1.0	NA	NA	NA	7.7	2597	1907	23.0
08/04/79	7.05	13.4	1277	809	204.5	36.0	53.0	33.0	0.080	0.980	0.045	0.105	0.03	0.15	4.0	NA	NA	NA	9.6	602	138	23.0
08/13/79	6.90	12.0	2064	1850	368.0	77.6	150.8	55.2	0.100	1.460	0.090	0.180	0.04	0.23	10.0	NA	NA	NA	5.2	295	46	14.0
08/28/79	7.10	12.4	1172	720	177.8	36.8	50.0	27.2	0.170	1.190	0.080	0.140	0.01	0.20	14.0	NA	NA	NA	8.2	208	161	21.0
09/01/79	6.90	12.0	1002	650	156.6	29.8	36.6	23.2	0.150	1.280	0.062	0.110	0.01	0.13	4.0	NA	NA	NA	6.1	3895	1538	20.0
09/05/79	6.90	12.0	1575	1200	269.6	52.0	69.0	36.6	0.140	1.640	0.090	0.150	0.01	0.17	5.0	NA	NA	NA	6.2	500	292	18.0
09/10/79	6.80	9.6	1401	975	235.6	42.6	77.4	33.0	0.140	1.440	0.110	0.130	0.02	0.17	6.0	NA	NA	NA	5.7	1983	408	18.0
09/13/79	7.00	11.2	1499	950	231.8	44.0	80.6	32.8	0.150	1.630	0.090	0.130	0.03	0.18	6.0	NA	NA	NA	5.3	1332	408	17.0
09/19/79	6.80	12.0	2598	1900	430.8	84.8	144.0	56.8	0.180	2.570	0.140	0.260	0.02	0.26	12.0	NA	NA	NA	5.0	863	109	15.0
10/17/79	6.40	7.2	2192	NA	363.2	73.4	122.8	48.0	0.190	2.560	0.140	0.270	0.01	0.29	NA	NA	NA	NA	4.6	337	200	NA
10/19/79	6.30	8.0	938	600	124.4	28.0	44.0	18.8	0.190	1.630	0.070	0.140	0.03	0.13	3.0	NA	NA	NA	5.9	1177	1297	NA
10/31/79	6.40	9.6	1233	725	172.0	36.5	54.2	23.9	0.220	2.840	0.140	0.195	0.02	0.19	3.0	NA	NA	NA	4.5	3963	1450	NA
11/01/79	6.80	12.8	1258	NA	182.0	39.6	60.0	25.6	0.190	2.540	0.120	0.180	0.02	0.15	NA	NA	NA	NA	4.5	3316	944	12.0
03/31/80	7.20	19.0	355	150	34.1	9.2	7.1	5.9	0.090	0.960	0.045	0.070	0.11	0.07	2.0	NA	NA	NA	4.0	1571	496	10.7
04/01/80	6.80	12.6	335	130	32.2	8.8	10.6	6.2	0.120	0.810	0.060	0.060	0.07	0.05	2.0	NA	NA	NA	3.1	1041	775	NA
04/06/80	7.20	21.3	500	73	58.2	14.2	14.0	8.8	0.110	1.000	0.040	0.090	0.04	0.09	2.0	NA	NA	NA	NA	2271	1300	NA
04/14/80	7.15	21.0	NA	326	86.7	22.3	23.6	12.0	0.105	1.490	0.080	0.100	0.03	0.12	7.0	NA	NA	NA	NA	1590	515	NA

Table A2.3. Drainage quality data from Duluth Complex test pile FL3, from 1978-1989 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/l	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/l	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/18/80	7.10	23.0	NA	364	88.8	21.6	24.8	11.8	0.120	2.100	0.100	0.130	0.02	0.18	4.0	NA	NA	NA	2.9	3449	703	NA
04/29/80	7.10	22.0	1860	1380	246.4	64.2	87.2	30.8	0.290	4.310	0.210	0.300	0.01	0.35	10.0	NA	NA	NA	NA	2082	180	11.0
05/08/80	7.10	20.9	2352	1720	324.0	90.4	136.0	42.6	0.260	4.290	0.240	0.370	0.02	0.34	13.0	NA	NA	NA	3.5	863	130	11.5
05/18/80	7.00	15.4	2300	1220	319.2	95.8	152.6	43.0	0.230	4.620	0.260	0.430	0.03	0.38	21.0	NA	NA	NA	NA	856	57	19.0
05/31/80	6.70	12.1	1300	720	159.2	42.7	57.9	24.3	0.270	3.140	0.180	0.250	0.01	0.23	36.0	NA	NA	NA	7.1	1673	775	NA
06/03/80	6.90	13.8	1500	850	191.8	45.8	57.2	27.4	0.250	3.790	0.210	0.280	0.01	0.26	46.0	NA	NA	NA	4.9	613	191	NA
06/06/80	6.80	11.0	1400	920	175.2	42.0	55.0	25.6	0.280	3.050	0.180	0.240	0.02	0.21	39.0	NA	NA	NA	NA	598	254	NA
06/13/80	6.80	11.0	1700	1040	219.2	50.9	73.9	30.3	0.315	3.370	0.195	0.290	0.03	0.24	28.0	NA	NA	NA	NA	413	207	NA
06/16/80	6.60	9.9	2200	1450	278.0	66.0	97.6	35.4	0.320	4.520	0.260	0.390	0.02	0.30	30.0	NA	NA	NA	NA	443	82	NA
06/27/80	6.60	11.0	2000	1180	252.0	67.0	89.0	35.0	0.230	3.490	0.230	0.360	0.02	0.28	18.0	NA	NA	NA	8.1	610	187	NA
07/02/80	6.60	11.0	1700	1000	230.0	57.0	66.0	29.0	0.460	3.760	0.270	0.370	0.04	0.30	27.0	NA	NA	NA	4.9	681	722	NA
07/02/80	6.70	8.5	1200	620	155.0	38.0	38.0	20.0	0.430	3.020	0.180	0.280	0.02	0.24	35.0	NA	NA	NA	NA	803	577	NA
07/13/80	6.60	12.1	2600	1620	359.6	80.0	133.6	51.0	0.560	5.350	0.280	0.480	0.02	0.41	30.0	NA	NA	NA	NA	598	108	NA
07/23/80	6.65	12.1	2350	1460	342.6	88.8	201.6	49.9	0.505	5.195	0.300	0.480	0.02	0.45	23.0	NA	NA	NA	NA	538	45	NA
08/03/80	6.65	11.0	NA	NA	352.4	95.4	162.0	50.4	0.530	6.240	0.310	0.540	0.02	0.51	NA	NA	NA	NA	5.9	189	80	NA
08/12/80	6.35	5.1	1100	595	128.8	35.3	44.6	21.4	0.670	3.570	0.200	0.300	0.06	0.34	12.0	NA	NA	NA	8.1	837	521	NA
08/20/80	6.35	5.1	1300	788	184.2	51.6	46.2	27.8	1.170	7.630	0.400	0.560	0.01	0.65	17.0	NA	NA	NA	NA	1030	166	NA
08/22/80	NA	NA	1400	700	80.0	42.0	42.0	20.0	1.360	7.040	0.410	0.590	0.04	0.62	21.0	NA	NA	NA	NA	655	269	NA
08/29/80	7.10	28.0	4850	2280	413.0	379.0	591.0	48.0	0.750	5.340	0.310	0.360	0.06	0.43	925.0	NA	NA	NA	9.5	1514	2500	NA
09/03/80	6.40	7.6	2020	1390	256.0	86.0	123.0	40.0	1.650	12.550	0.670	0.760	0.03	0.95	50.0	NA	NA	NA	NA	2105	512	NA
09/08/80	6.50	7.7	1912	1320	248.0	82.0	116.0	39.0	2.120	13.890	0.770	0.810	0.02	1.10	44.0	NA	NA	NA	NA	1336	758	15.0
09/12/80	6.60	11.0	1448	690	97.0	51.0	80.0	25.0	1.620	9.450	0.550	0.530	0.04	0.76	52.0	NA	NA	NA	4.0	3184	1512	18.0
09/19/80	6.60	11.0	2057	1320	255.0	92.0	128.0	39.0	2.660	12.780	0.670	0.720	0.05	0.90	77.0	NA	NA	NA	NA	7809	1846	13.0
10/01/80	6.40	10.2	2984	1750	410.0	136.0	181.0	NA	2.720	17.700	0.800	1.010	0.03	1.04	77.0	NA	NA	NA	3.4	2506	244	14.0
10/22/80	6.30	13.6	2575	1900	340.0	127.0	178.0	52.0	2.330	12.300	0.650	0.900	0.02	0.89	116.0	NA	NA	NA	4.3	1408	327	10.0
10/25/80	6.10	6.8	2205	1250	266.3	116.3	125.3	43.7	3.970	19.500	0.940	1.090	0.03	1.29	56.0	NA	NA	NA	NA	2044	321	10.0
03/02/81	6.60	6.8	900	590	103.4	43.6	42.2	NA	1.100	13.000	0.620	0.550	NA	NA	15.0	NA	NA	NA	NA	284	100	NA
03/16/81	6.50	6.4	1200	700	115.7	49.9	55.9	NA	1.300	23.000	0.950	0.800	NA	NA	NA	NA	NA	NA	NA	931	1393	NA
03/23/81	6.60	7.2	1224	825	119.6	58.5	60.7	NA	1.410	21.000	0.920	0.870	NA	NA	NA	NA	NA	NA	NA	821	526	9.0
03/26/81	6.30	5.6	600	272	46.8	25.9	19.5	NA	0.910	8.200	0.390	0.380	NA	NA	NA	NA	NA	NA	7.2	1158	723	NA
04/02/81	6.70	12.0	775	385	58.5	28.9	22.1	NA	1.590	15.000	0.690	0.550	NA	NA	NA	NA	NA	NA	NA	2055	506	NA
04/03/81	6.80	12.0	1350	625	122.2	58.8	66.3	NA	5.150	33.000	1.450	1.150	NA	NA	NA	NA	NA	NA	NA	3710	1229	NA
04/13/81	NA	NA	1100	555	96.0	56.0	33.0	NA	3.630	17.000	0.800	0.660	NA	NA	NA	NA	NA	NA	NA	2839	993	NA
04/17/81	6.90	10.4	1600	745	126.0	71.0	56.0	NA	3.730	19.000	0.860	0.710	NA	NA	NA	NA	NA	NA	NA	2680	1199	NA
04/23/81	7.00	14.4	1500	680	121.0	74.0	56.0	NA	2.300	13.000	0.620	0.550	NA	NA	NA	NA	NA	NA	NA	2063	2237	NA
04/28/81	7.20	16.0	1850	880	160.0	88.0	65.0	NA	2.760	17.000	0.830	0.730	NA	NA	NA	NA	NA	NA	3.2	4467	2436	NA
04/30/81	6.80	14.8	2176	1300	252.0	114.0	92.0	NA	3.680	25.800	1.230	1.070	NA	NA	NA	NA	NA	NA	4.0	3350	1200	10.0
05/13/81	6.80	8.8	2545	1750	324.0	152.0	120.0	NA	4.010	22.000	1.440	1.310	NA	NA	NA	NA	NA	NA	3.6	4115	100	17.0
06/02/81	6.70	9.1	2406	1700	300.0	138.0	118.0	NA	3.250	21.000	1.270	1.170	NA	NA	NA	NA	NA	NA	NA	1586	473	17.0
06/06/81	6.85	9.1	2157	1310	254.0	102.0	100.0	NA	3.290	18.000	1.190	1.060	NA	NA	NA	NA	NA	NA	4.1	2555	67	18.0
06/22/81	6.80	14.4	1250	1450	262.0	116.0	128.0	NA	2.840	19.000	1.110	0.880	NA	NA	NA	NA	NA	NA	NA	3482	1273	16.0
06/26/81	6.70	12.8	1330	680	156.0	58.0	42.0	NA	4.050	19.840	0.950	0.630	NA	NA	NA	NA	NA	NA	NA	3013	958	15.0
06/28/81	6.70	14.4	1862	800	226.0	88.0	70.0	NA	4.880	20.000	1.230	0.800	NA	NA	40.0	NA	NA	NA	3.5	4130	2493	15.0
07/04/81	6.85	13.5	2098	1400	300.0	102.0	88.8	NA	4.850	25.000	1.150	0.960	NA	NA	NA	NA	NA	NA	NA	2600	385	22.0
07/15/81	6.55	6.2	3046	2100	394.0	178.6	158.6	NA	6.200	37.000	1.650	1.530	NA	NA	NA	NA	NA	NA	NA	1283	120	20.0
07/25/81	5.60	NA	2564	1810	340.0	156.6	134.6	NA	5.400	30.000	1.430	1.360	NA	NA	23.0	NA	NA	NA	3.1	961	177	21.0
08/04/81	6.20	4.4	2574	1750	328.0	138.0	118.0	NA	5.500	30.000	1.470	1.320	NA	NA	NA	NA	NA	NA	NA	863	66	19.0
08/17/81	6.05	5.4	2485	1650	308.0	132.0	108.0	52.0	5.270	25.000	1.300	1.440	NA	NA	NA	NA	NA	NA	NA	723	46	22.0
09/01/81	6.00	4.8	2575	1570	284.0	136.0	98.0	NA	5.450	26.000	1.240	1.610	NA	NA	NA	NA	NA	NA	7.4	348	100	NA
09/07/81	5.90	3.2	2800	1540	268.0	124.0	88.0	NA	6.240	25.000	1.330	1.610	NA	NA	NA	NA	NA	NA	NA	390	129	17.0
09/16/81	5.90	3.8	3300	2000	354.0	171.0	115.0	NA	10.010	41.500	2.040	2.440	NA	NA	NA	NA	NA	NA	NA	265	22	NA

Table A2.3. Drainage quality data from Duluth Complex test pile FL3, from 1978-1989 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/l	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/l	K mg/l	Cu mg/L	Ni mg/l	Co mg/L	Zn mg/l	Fe mg/l	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
09/27/81	5.85	2.4	1775	980	192.0	86.0	50.0	NA	6.300	22.000	1.140	1.330	NA	NA	NA	NA	NA	NA	4.7	598	251	NA
10/01/81	5.80	2.0	1700	850	180.0	82.0	32.0	NA	10.670	34.000	1.710	1.620	NA	NA	NA	NA	NA	NA	NA	2279	1459	NA
10/04/81	5.70	2.4	1700	1000	196.0	88.0	34.0	28.0	12.000	36.000	1.880	1.730	NA	NA	NA	NA	NA	NA	NA	1287	1013	NA
10/14/81	6.25	4.8	2150	1280	228.0	106.0	64.0	40.0	9.000	39.000	1.940	1.550	NA	NA	NA	NA	NA	NA	3.4	3165	1597	NA
10/18/81	6.25	4.0	2000	1310	232.0	100.0	56.0	38.0	9.000	36.000	1.880	1.430	NA	NA	NA	NA	NA	NA	NA	10569	1210	NA
11/09/81	6.65	11.2	4500	2800	410.0	320.0	240.0	84.0	10.980	62.000	2.480	2.250	NA	NA	NA	NA	NA	NA	3.5	4997	108	NA
03/25/82	6.55	7.2	900	470	73.0	53.4	20.0	14.0	4.140	19.000	0.940	0.690	NA	NA	NA	NA	NA	NA	NA	2839	NA	NA
04/01/82	6.18	5.2	1325	800	105.0	76.4	28.0	18.0	6.275	31.000	1.470	1.490	NA	NA	NA	NA	NA	NA	NA	3975	NA	NA
04/13/82	6.60	7.2	690	320	52.0	34.4	14.0	10.0	2.860	13.000	0.670	0.490	NA	NA	NA	NA	NA	NA	NA	4728	NA	NA
04/15/82	6.60	9.0	750	390	63.8	41.6	16.0	12.0	2.120	13.000	0.580	0.420	NA	NA	NA	NA	NA	NA	NA	3774	NA	NA
04/19/82	6.60	7.7	1125	705	129.0	83.0	29.0	20.0	3.395	19.500	1.010	0.640	NA	NA	NA	NA	NA	NA	NA	1961	NA	NA
04/23/82	6.50	5.4	1500	950	188.0	110.0	80.0	24.0	4.450	26.000	1.340	0.860	NA	NA	NA	NA	NA	NA	NA	2438	NA	NA
04/28/82	6.50	7.7	1875	1000	160.0	128.0	68.0	32.0	4.520	25.000	1.380	0.950	NA	NA	NA	NA	NA	NA	NA	3721	NA	NA
05/03/82	6.40	5.4	2290	NA	240.0	164.0	104.0	42.0	6.490	40.000	2.030	1.360	NA	NA	NA	NA	NA	NA	NA	466	NA	NA
05/07/82	6.90	17.4	1960	975	133.0	125.0	109.0	25.0	3.630	20.300	1.105	0.740	NA	NA	NA	NA	NA	NA	NA	4527	NA	NA
05/11/82	6.90	21.2	1800	1040	156.0	122.0	64.0	28.0	4.410	24.000	1.400	0.890	NA	NA	NA	NA	NA	NA	NA	2782	NA	NA
05/14/82	6.80	16.2	2500	1465	202.0	160.0	110.0	40.0	7.250	44.000	2.410	1.650	NA	NA	NA	NA	NA	NA	NA	750	NA	NA
05/18/82	6.80	18.9	2450	1340	206.0	160.0	128.0	40.0	6.800	42.000	2.270	1.580	NA	NA	NA	NA	NA	NA	NA	681	NA	NA
05/21/82	6.25	NA	3200	2400	292.0	163.0	93.0	53.0	10.160	70.000	2.560	2.010	0.04	2.81	NA	NA	NA	NA	NA	3062	NA	NA
06/02/82	6.10	9.9	3600	2750	340.0	238.0	129.5	63.5	11.405	79.500	3.015	2.580	0.06	3.36	NA	NA	NA	NA	NA	1298	NA	NA
06/11/82	7.30	NA	3150	NA	306.0	183.0	139.0	52.0	5.230	45.000	1.920	1.480	0.05	1.96	NA	NA	NA	NA	NA	NA	NA	NA
06/12/82	7.70	NA	3450	NA	324.0	178.0	174.0	46.0	3.330	29.000	1.300	0.970	0.05	1.27	NA	NA	NA	NA	NA	NA	NA	NA
06/18/82	6.50	9.9	2500	1500	248.0	133.0	65.0	39.0	6.950	43.000	1.870	1.520	0.04	1.89	NA	NA	NA	NA	NA	148	NA	NA
07/02/82	7.40	81.6	2750	1300	297.0	136.0	178.0	34.0	2.290	21.090	0.770	0.560	0.03	0.78	NA	NA	NA	NA	NA	2824	NA	NA
07/08/82	6.35	11.7	2700	2000	354.0	150.0	108.0	48.0	8.850	67.000	2.300	1.560	0.02	2.56	NA	NA	NA	NA	NA	7291	NA	NA
07/26/82	6.37	10.6	2705	1675	298.0	149.0	77.0	51.0	7.570	79.500	3.240	1.610	0.39	3.03	NA	NA	NA	NA	NA	6261	NA	NA
08/30/82	6.91	50.3	2087	1175	298.0	126.0	70.0	40.0	6.240	45.000	1.710	1.150	0.13	1.98	NA	NA	NA	NA	NA	7779	NA	NA
10/04/82	6.65	14.6	2145	1357	223.0	126.0	59.0	44.0	9.520	80.000	3.220	1.620	0.13	2.94	NA	NA	NA	NA	NA	20301	NA	NA
11/01/82	6.20	3.6	2825	NA	248.0	160.0	72.0	54.0	9.490	91.000	3.650	1.870	0.02	3.52	NA	NA	NA	NA	NA	1257	NA	NA
11/22/82	6.10	4.5	2140	1600	270.0	116.0	64.0	NA	13.750	91.000	3.340	2.190	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/18/83	5.95	3.0	1775	1120	NA	NA	NA	NA	9.010	65.000	2.590	2.030	NA	NA	NA	NA	NA	NA	NA	8206	NA	NA
04/14/83	6.66	16.3	1070	510	NA	NA	NA	NA	5.010	41.000	1.410	1.060	NA	NA	NA	NA	NA	NA	NA	7414	NA	NA
05/15/83	6.41	6.9	1574	1000	NA	NA	NA	NA	6.440	58.000	2.140	1.690	NA	NA	NA	NA	NA	NA	NA	5109	NA	NA
06/16/83	6.19	6.9	1782	1300	NA	NA	NA	NA	5.360	43.000	1.720	1.280	NA	NA	NA	NA	NA	NA	NA	2717	NA	NA
07/14/83	5.90	5.0	2008	1680	NA	NA	NA	NA	12.030	54.000	2.830	2.320	NA	NA	NA	NA	NA	NA	NA	7748	NA	NA
08/14/83	5.41	3.4	2095	1750	NA	NA	NA	NA	16.750	71.000	3.300	2.880	NA	NA	NA	NA	NA	NA	NA	5553	NA	NA
09/15/83	5.64	2.5	2123	1940	NA	NA	NA	NA	16.500	75.000	3.590	3.080	NA	NA	NA	NA	NA	NA	NA	4565	NA	NA
10/13/83	5.70	3.8	2422	1880	NA	NA	NA	NA	19.000	78.000	3.770	3.140	NA	NA	NA	NA	NA	NA	NA	20303	NA	NA
11/09/83	5.90	3.6	2300	2600	NA	NA	NA	NA	20.400	99.000	4.440	3.320	NA	NA	NA	NA	NA	NA	NA	3925	NA	NA
11/30/83	5.50	2.7	2175	1960	NA	NA	NA	NA	20.200	89.600	4.050	3.040	NA	NA	NA	NA	NA	NA	NA	2589	NA	NA
02/24/84	4.80	0.9	1900	2040	236.3	189.9	50.7	NA	30.600	102.000	4.500	3.840	NA	NA	NA	NA	NA	NA	NA	2907	NA	NA
03/15/84	5.40	2.7	2375	2000	288.3	274.4	65.1	NA	35.000	144.000	7.000	4.890	NA	NA	NA	NA	NA	NA	NA	4375	NA	NA
04/15/84	6.40	10.4	878	580	104.0	70.6	19.9	NA	7.490	34.000	1.680	1.300	NA	NA	NA	NA	NA	NA	NA	15221	NA	NA
05/16/84	6.16	6.9	1190	980	165.6	109.4	31.2	NA	12.000	51.000	2.400	1.820	NA	NA	NA	NA	NA	NA	NA	8861	NA	NA
06/13/84	5.52	2.6	1519	1310	205.9	139.6	40.8	NA	17.500	69.400	3.150	2.290	NA	NA	NA	NA	NA	NA	NA	17886	NA	NA
07/14/84	5.05	2.5	2130	2480	NA	NA	57.4	NA	19.000	121.300	4.000	3.200	NA	NA	NA	NA	NA	NA	NA	6064	NA	NA
08/15/84	5.34	3.0	2050	1800	267.8	142.9	49.6	NA	16.100	73.760	4.880	2.360	NA	NA	NA	NA	NA	NA	NA	4478	NA	NA
09/12/84	4.96	2.3	2340	1760	317.1	220.0	70.5	NA	26.500	105.000	7.120	3.440	NA	NA	NA	NA	NA	NA	NA	1340	NA	NA
10/13/84	5.02	2.1	1860	1180	259.1	149.5	43.2	NA	34.000	92.000	6.830	3.010	NA	NA	NA	NA	NA	NA	NA	10579	NA	NA
11/14/84	4.96	1.6	2190	2700	381.0	450.0	84.7	NA	38.600	138.000	5.380	4.180	NA	NA	NA	NA	NA	NA	NA	2918	NA	NA
12/12/84	4.93	0.8	1585	1800	242.0	290.0	62.0	NA	26.500	108.800	4.840	3.490	NA	NA	NA	NA	NA	NA	NA	3459	NA	NA

Table A2.3. Drainage quality data from Duluth Complex test pile FL3, from 1978-1989 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/02/85	6.60	17.9	800	470	75.8	54.2	14.5	NA	5.800	27.000	1.070	0.860	NA	NA	NA	NA	NA	NA	NA	2394	NA	NA
04/16/85	5.94	9.0	1360	1010	144.0	121.6	28.6	NA	18.500	70.000	2.800	2.090	NA	NA	NA	NA	NA	NA	NA	16699	NA	NA
05/14/85	5.25	3.9	2400	2000	220.0	210.0	53.0	NA	24.000	100.000	4.710	2.830	NA	NA	NA	NA	NA	NA	NA	6828	NA	NA
06/14/85	5.57	4.0	2150	1736	209.0	169.0	46.3	NA	27.000	103.000	4.140	3.210	NA	NA	NA	NA	NA	NA	NA	26461	NA	NA
07/15/85	5.31	4.3	2300	1900	220.0	186.0	51.0	NA	23.000	99.000	4.310	3.490	NA	NA	NA	NA	NA	NA	NA	7630	NA	NA
08/13/85	5.47	4.0	2125	1750	226.0	153.4	48.0	NA	22.400	89.000	4.240	3.170	NA	NA	NA	NA	NA	NA	NA	5761	NA	NA
09/13/85	5.39	3.8	2325	1850	294.0	141.8	44.0	NA	39.000	100.600	4.820	3.560	NA	NA	NA	NA	NA	NA	NA	18187	NA	NA
10/15/85	5.44	4.7	2425	1650	239.0	160.0	43.0	NA	37.600	102.800	4.660	3.010	NA	NA	NA	NA	NA	NA	NA	17222	NA	NA
11/15/85	5.26	2.6	2675	1450	322.0	224.0	60.0	NA	41.800	133.000	6.020	4.020	NA	NA	NA	NA	NA	NA	NA	1949	NA	NA
03/20/86	5.25	2.2	3100	2900	366.0	334.0	78.0	NA	52.400	220.000	7.900	5.200	NA	NA	NA	NA	NA	NA	NA	401	NA	NA
03/23/86	6.30	9.5	975	700	90.0	67.2	13.0	NA	17.000	48.000	2.120	1.310	NA	NA	NA	NA	NA	NA	NA	17998	NA	NA
04/16/86	6.09	7.4	1175	700	126.0	84.0	18.0	NA	17.000	51.000	2.540	1.590	NA	NA	NA	NA	NA	NA	NA	13743	NA	NA
05/14/86	5.70	4.4	1650	1350	214.0	144.0	28.0	NA	29.000	120.000	5.220	2.330	NA	NA	NA	NA	NA	NA	NA	10995	NA	NA
06/11/86	5.29	3.6	2425	1650	234.0	173.0	49.0	NA	31.000	108.000	4.360	3.690	NA	NA	NA	NA	NA	NA	NA	3509	NA	NA
07/12/86	5.40	3.7	1775	1100	180.0	130.0	32.0	NA	27.000	80.000	3.350	2.690	NA	NA	NA	NA	NA	NA	NA	7104	NA	NA
08/13/86	5.17	3.0	2200	1550	228.0	155.6	40.0	NA	37.000	95.000	4.200	2.280	NA	NA	NA	NA	NA	NA	NA	4273	NA	NA
09/14/86	5.21	3.0	2000	1400	224.0	159.8	36.0	NA	41.000	98.000	5.100	2.360	NA	NA	NA	NA	NA	NA	NA	18682	NA	NA
10/16/86	5.11	2.1	2900	1825	258.0	227.0	48.0	NA	48.000	142.000	5.750	4.150	NA	NA	NA	NA	NA	NA	NA	4557	NA	NA
11/16/86	5.09	2.7	3150	1900	290.0	208.0	62.0	NA	72.000	161.000	9.100	6.100	NA	NA	NA	NA	NA	NA	NA	7899	NA	NA
03/22/87	5.30	7.1	1125	730	126.0	80.0	22.0	NA	20.200	60.000	2.780	1.930	NA	NA	NA	NA	NA	NA	NA	8656	NA	NA
04/15/87	5.73	4.6	1450	900	118.0	100.0	22.0	NA	28.000	68.000	3.070	2.240	NA	NA	NA	NA	NA	NA	NA	3861	NA	NA
05/16/87	5.13	4.5	2300	1770	319.0	256.0	56.0	NA	51.000	129.000	5.700	4.700	NA	NA	NA	NA	NA	NA	NA	24103	NA	NA
06/16/87	4.81	3.0	3550	2640	356.0	328.0	70.0	NA	63.000	197.000	6.000	4.100	NA	NA	NA	NA	NA	NA	NA	2048	NA	NA
07/15/87	5.05	5.7	2325	1780	226.0	187.0	45.0	NA	53.000	131.000	5.200	3.950	NA	NA	NA	NA	NA	NA	NA	18842	NA	NA
08/15/87	4.91	3.4	2425	1750	206.0	172.0	42.0	NA	43.000	121.000	4.800	3.720	NA	NA	NA	NA	NA	NA	NA	8501	NA	NA
09/16/87	5.01	2.8	2650	1615	200.0	158.0	36.0	NA	42.000	105.000	4.510	3.120	NA	NA	NA	NA	NA	NA	NA	12195	NA	NA
10/13/87	4.81	2.1	3825	2680	323.0	307.0	70.0	NA	71.000	192.000	7.730	5.430	NA	NA	NA	NA	NA	NA	NA	2142	NA	NA
11/10/87	4.71	1.8	3350	2700	288.0	278.0	64.0	NA	59.000	174.000	6.880	4.930	NA	NA	NA	NA	NA	NA	NA	1064	NA	NA
03/28/88	6.00	11.1	900	414	88.0	48.0	12.0	NA	11.000	32.000	1.600	1.600	NA	NA	NA	NA	NA	NA	NA	8653	NA	NA
04/17/88	5.69	6.3	1575	950	136.0	100.0	22.0	NA	24.000	90.000	3.800	4.100	NA	NA	NA	NA	NA	NA	NA	7297	NA	NA
05/12/88	5.17	3.4	1985	1270	172.0	160.0	38.0	NA	37.000	129.000	5.200	6.100	NA	NA	NA	NA	NA	NA	NA	10624	NA	NA
06/12/88	4.86	2.9	3500	2440	344.0	324.0	67.0	NA	70.000	178.500	10.200	11.500	NA	NA	NA	NA	NA	NA	NA	1654	NA	NA
07/15/88	4.91	3.5	3175	2230	278.0	286.0	58.0	NA	59.000	161.000	8.800	11.200	NA	NA	NA	NA	NA	NA	NA	995	NA	NA
08/16/88	5.26	2.5	1910	1240	176.0	130.0	34.0	NA	37.000	125.000	4.700	4.200	NA	NA	NA	NA	NA	NA	NA	45053	NA	NA
09/16/88	5.07	2.7	2300	1360	202.0	170.0	44.0	NA	41.000	145.000	5.700	5.300	NA	NA	NA	NA	NA	NA	NA	8134	NA	NA
10/18/88	5.12	3.0	2000	1330	158.0	144.0	32.0	NA	33.000	93.000	5.000	5.500	NA	NA	NA	NA	NA	NA	NA	3376	NA	NA
11/15/88	5.21	3.6	1625	1250	142.0	131.0	26.0	NA	32.500	87.000	4.700	5.000	NA	NA	NA	NA	NA	NA	NA	6654	NA	NA
12/05/88	4.80	3.2	3300	3150	298.0	350.0	62.0	NA	73.000	238.000	11.900	10.000	NA	NA	NA	NA	NA	NA	NA	1681	NA	NA
04/07/89	6.15	9.9	650	425	70.0	46.0	12.0	NA	12.700	32.000	1.900	1.700	NA	NA	NA	NA	NA	NA	NA	23758	NA	NA
04/24/89	5.91	6.5	1075	650	100.0	58.0	12.0	NA	16.000	46.000	2.500	2.500	NA	NA	NA	NA	NA	NA	NA	7638	NA	NA
05/16/89	5.18	3.9	1593	1090	128.0	108.0	20.0	NA	28.000	79.000	4.500	5.300	NA	NA	NA	NA	NA	NA	NA	9284	NA	NA
06/17/89	4.98	3.3	1821	1375	156.0	128.0	30.0	NA	41.000	119.000	6.800	5.000	NA	NA	NA	NA	NA	NA	NA	29326	NA	NA
07/17/89	4.81	2.2	2800	1950	306.0	210.0	46.0	NA	66.000	185.000	8.700	9.100	NA	NA	NA	NA	NA	NA	NA	2967	NA	NA
08/14/89	4.94	3.1	2900	1970	248.0	222.0	48.0	NA	61.000	240.000	8.200	8.200	NA	NA	NA	NA	NA	NA	NA	1328	NA	NA
09/14/89	4.90	2.7	2400	1600	252.0	166.0	36.0	NA	56.000	148.000	9.500	6.700	NA	NA	NA	NA	NA	NA	NA	17888	NA	NA
10/16/89	4.83	0.6	2775	1800	218.0	186.0	46.0	NA	47.000	161.000	12.100	8.400	NA	NA	NA	NA	NA	NA	NA	1835	NA	NA
11/10/89	5.00	2.8	2400	1820	240.0	182.0	40.0	NA	42.000	137.000	14.800	7.700	NA	NA	NA	NA	NA	NA	NA	900	NA	NA

NA: Not analyzed.

'Dates represent intermediate dates for measurement periods.

Table A2.4. Drainage quality data from Duluth Complex test pile FL4, from 1978-1982 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/26/78	7.20	NA	1100	NA	121.0	11.0	84.0	27.0	0.018	NA	0.004	0.048	NA	0.10	NA	NA	NA	NA	NA	NA	NA	4.0
05/25/78	7.40	NA	1750	NA	204.0	20.0	165.0	35.0	0.012	0.210	0.012	0.112	0.02	0.19	NA	NA	NA	NA	NA	NA	NA	NA
06/14/78	7.60	NA	2500	NA	228.0	29.0	262.0	37.0	0.024	0.220	0.016	0.128	0.04	0.21	NA	NA	NA	NA	NA	125	NA	9.0
06/16/78	7.70	NA	2600	NA	247.0	30.0	277.0	41.0	0.026	0.175	0.015	0.120	0.04	0.26	NA	NA	NA	NA	NA	94	NA	11.0
06/23/78	7.56	NA	2402	1150	205.0	27.8	271.4	39.5	0.022	0.308	0.023	0.134	0.03	0.21	25.5	NA	NA	NA	NA	307	NA	12.7
06/26/78	7.90	NA	2150	900	186.0	24.0	260.0	41.0	0.021	0.260	0.019	0.084	NA	0.18	28.0	NA	NA	NA	NA	5	NA	17.0
07/06/78	7.58	NA	1825	850	212.0	25.0	182.0	52.0	0.019	0.275	0.019	0.073	0.03	0.18	11.0	NA	NA	0.10	NA	88	NA	17.0
07/07/78	7.43	NA	1306	546	156.0	15.5	129.9	31.4	0.015	0.183	0.019	0.064	0.03	0.11	7.8	1.6	0.73	0.08	NA	4957	NA	11.0
07/08/78	7.46	NA	1406	830	220.2	16.8	127.0	41.1	0.014	0.206	0.020	0.058	0.03	0.14	6.8	NA	NA	0.08	NA	NA	NA	NA
07/09/78	7.55	NA	1550	NA	300.0	20.0	149.0	46.0	0.009	0.240	0.017	NA	0.02	0.16	NA	NA	NA	NA	NA	NA	NA	NA
07/13/78	7.65	NA	NA	850	273.0	18.0	153.0	44.0	0.012	NA	0.015	NA	0.02	0.14	7.0	2.2	0.90	0.08	NA	NA	NA	NA
08/04/78	8.00	NA	1100	660	191.0	13.0	115.0	43.0	0.020	0.200	0.010	0.052	0.02	0.14	3.0	1.2	0.06	0.08	NA	95	NA	22.0
08/15/78	7.80	39.0	1275	800	201.0	19.0	158.0	39.0	0.020	0.240	0.010	0.070	0.02	0.15	6.0	1.2	1.20	0.08	NA	NA	NA	21.0
08/16/78	7.50	28.0	825	100	118.0	11.0	60.0	26.0	0.020	0.130	0.020	0.030	0.03	0.09	1.0	1.2	NA	0.08	NA	NA	NA	NA
08/17/78	7.29	29.0	1175	1000	355.0	41.0	158.0	12.0	0.030	0.200	0.020	0.050	0.04	0.12	13.0	2.2	NA	0.08	NA	NA	NA	NA
08/18/78	7.60	36.0	1850	800	219.0	21.0	110.0	42.0	0.020	0.240	0.040	0.070	0.02	0.16	3.0	1.4	NA	0.08	NA	NA	NA	NA
08/21/78	7.75	NA	2050	NA	271.0	27.0	142.0	50.0	0.080	0.320	0.040	0.100	NA	0.20	NA	NA	NA	NA	NA	NA	NA	NA
08/23/78	7.47	30.0	1217	603	137.7	15.0	84.7	32.3	0.020	0.143	0.023	0.037	0.02	0.10	2.3	1.4	1.08	0.08	NA	NA	NA	23.0
08/25/78	7.55	33.0	1750	800	216.0	21.0	115.0	46.0	0.020	0.240	0.030	0.060	0.01	0.14	2.0	1.4	1.00	0.08	NA	NA	NA	23.0
08/28/78	7.55	41.8	2350	1250	280.0	29.0	187.0	60.0	0.030	0.340	0.040	0.100	0.02	0.19	2.0	2.4	NA	0.08	NA	NA	NA	NA
09/11/78	7.30	35.0	2300	1200	256.0	26.0	219.0	59.0	0.030	0.340	0.050	0.080	0.06	0.20	10.0	NA	NA	0.08	NA	NA	NA	NA
09/13/78	7.23	34.0	1650	852	191.7	17.7	107.3	44.3	0.023	0.210	0.033	0.053	0.06	0.14	2.5	1.4	0.06	0.08	NA	NA	NA	12.0
10/17/78	7.50	31.0	1800	1000	257.0	27.0	157.0	34.0	0.020	0.290	0.040	0.090	0.02	0.18	6.0	1.4	0.06	0.08	NA	NA	NA	NA
03/19/79	NA	NA	861	380	96.6	18.2	39.4	11.2	3.000	14.600	0.256	0.400	0.03	1.08	8.0	NA	NA	NA	4.1	2660	2428	NA
04/17/79	5.90	7.0	635	325	77.0	14.0	34.4	10.6	1.120	12.310	0.240	0.240	1.46	1.11	7.0	NA	NA	NA	3.5	6041	4676	NA
04/18/79	6.80	22.0	401	170	66.0	6.0	25.0	9.0	0.069	0.373	0.064	0.050	0.02	0.15	3.0	1.2	NA	NA	NA	4644	5152	NA
04/19/79	7.10	21.0	391	170	65.0	5.0	23.0	8.6	0.016	0.098	0.008	0.040	0.02	0.07	1.0	0.5	NA	NA	NA	5560	5332	NA
04/20/79	6.90	29.0	568	285	106.0	8.6	NA	14.2	0.064	0.210	0.008	0.040	0.02	0.10	3.0	0.6	0.12	NA	2.2	4364	3329	NA
04/20/79	6.40	22.0	364	145	67.0	4.8	24.0	17.8	0.014	0.089	0.008	0.030	0.02	0.07	2.0	0.4	0.05	NA	NA	3077	3329	NA
04/22/79	7.40	19.0	980	483	171.0	15.8	42.6	24.4	0.021	0.270	0.020	0.070	0.03	0.14	4.0	1.0	0.03	NA	NA	4599	1534	NA
05/09/79	7.50	NA	1039	NA	171.2	15.8	48.2	27.4	0.016	0.310	0.023	0.070	0.03	0.17	NA	NA	NA	NA	NA	647	1239	NA
05/10/79	7.50	NA	1010	532	162.4	16.6	50.4	25.6	0.021	0.280	0.020	0.060	0.01	0.15	4.0	NA	NA	NA	NA	8717	4417	NA
05/20/79	6.90	NA	1363	817	227.8	23.6	77.9	35.2	0.026	0.375	0.029	0.080	0.02	0.17	5.0	NA	NA	NA	5.7	3062	1080	NA
05/22/79	7.60	NA	984	583	178.4	18.8	68.8	30.0	0.025	0.320	0.023	0.080	0.01	0.15	3.0	NA	NA	NA	3.5	1904	1278	NA
05/23/79	7.20	NA	1264	700	193.4	21.6	74.0	32.8	0.030	0.360	0.027	0.070	0.02	0.16	4.0	NA	NA	NA	4.5	3357	699	NA
06/01/79	7.70	NA	1334	800	201.8	22.0	80.4	34.8	0.027	0.350	0.027	0.080	0.03	0.17	5.0	NA	NA	NA	4.7	2290	662	NA
06/06/79	7.60	NA	1213	700	180.6	19.4	48.4	48.2	0.023	0.300	0.021	0.080	0.01	0.14	5.0	NA	NA	NA	NA	2044	1227	NA
06/10/79	7.30	36.0	1116	560	159.4	18.0	45.0	41.6	0.023	0.240	0.013	0.060	0.03	0.11	4.0	NA	NA	NA	NA	2161	1411	22.0
06/12/79	7.30	32.0	1107	NA	157.0	17.2	43.6	40.8	0.013	0.240	0.009	0.060	0.01	0.11	NA	NA	NA	NA	NA	681	245	NA
06/15/79	7.30	33.0	1138	NA	160.4	18.4	45.8	37.6	0.016	0.280	0.009	0.060	0.01	0.12	NA	NA	NA	NA	NA	469	442	21.0
06/20/79	7.10	30.0	1347	570	171.0	21.0	72.0	38.0	0.020	0.260	0.020	0.070	0.03	0.97	5.0	NA	NA	NA	NA	2854	1339	17.0
06/30/79	NA	NA	NA	NA	176.0	21.0	73.0	35.0	0.010	0.270	0.020	0.050	0.01	0.10	NA	NA	NA	NA	NA	526	NA	NA
07/30/79	5.75	32.0	907	460	118.0	22.0	38.0	20.0	0.700	4.140	0.260	0.180	0.01	0.55	11.0	NA	NA	NA	4.9	2324	2847	23.0
09/01/79	7.00	10.4	1112	650	189.6	16.8	40.4	33.8	0.040	0.510	0.028	0.090	0.01	0.14	4.0	NA	NA	NA	4.0	4307	1988	20.5
09/05/79	7.10	14.4	1333	NA	246.4	22.4	46.8	40.0	0.040	0.670	0.034	0.120	0.01	0.19	NA	NA	NA	NA	5.1	337	270	20.0
09/12/79	7.00	12.8	1250	800	228.6	20.0	45.6	38.2	0.060	0.780	0.060	0.130	0.01	0.19	6.0	NA	NA	NA	3.7	1158	417	20.0
09/13/79	7.20	NA	1321	NA	237.8	21.4	55.6	43.4	0.030	0.710	0.035	0.110	0.02	0.18	NA	NA	NA	NA	NA	91	270	20.0
10/19/79	6.40	7.2	980	600	166.4	14.6	24.0	27.8	0.080	1.260	0.070	0.160	0.01	0.13	2.0	NA	NA	NA	1.9	541	307	NA
10/31/79	6.60	8.8	1025	550	152.0	15.0	38.0	28.8	0.080	1.040	0.060	0.140	0.01	0.12	3.0	NA	NA	NA	2.2	1764	908	NA
03/31/80	6.90	15.0	470	205	54.2	5.4	12.6	11.6	0.030	0.395	0.035	0.090	0.02	0.06	2.0	NA	NA	NA	1.8	1207	1154	NA
04/05/80	7.10	17.2	325.	140	38.5	4.0	8.0	8.3	0.040	0.270	0.010	0.070.	0.02	0.04	1.0	NA	NA	NA	1.0	5326	2260	NA

Table A2.4. Drainage quality data from Duluth Complex test pile FL4, from 1978-1982 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/06/80	6.80	16.1	575	250	76.0	7.0	11.2	13.0	0.050	0.410	0.030	0.100	0.03	0.12	2.0	NA	NA	NA	NA	1298	1349	NA
04/18/80	6.90	12.7	NA	258	83.9	7.8	13.3	14.5	0.035	0.695	0.035	0.150	0.02	0.14	2.0	NA	NA	NA	1.0	2215	450	NA
06/01/80	6.50	6.6	950	710	174.9	17.1	25.1	30.8	0.160	2.030	0.120	0.230	0.02	0.25	4.0	NA	NA	NA	NA	579	313	NA
06/06/80	6.80	6.6	1100	NA	164.6	16.6	24.4	28.6	0.180	2.250	0.160	0.270	0.03	0.27	NA	NA	NA	NA	NA	246	232	NA
07/03/80	6.70	7.6	1150	770	186.0	20.0	33.0	29.0	0.250	2.140	0.120	0.280	0.02	0.24	3.0	NA	NA	NA	NA	1344	615	NA
08/12/80	6.50	6.0	1400	860	224.8	28.8	34.4	35.6	1.140	8.380	0.440	0.510	0.01	0.46	3.0	NA	NA	NA	2.3	1090	683	NA
08/19/80	6.90	8.5	1500	975	263.8	31.6	51.9	43.5	0.690	5.990	0.300	0.460	0.01	0.53	4.0	NA	NA	NA	NA	1594	464	NA
08/22/80	NA	NA	1650	1100	275.0	37.0	57.0	36.0	0.490	4.080	0.250	0.350	0.03	0.38	6.0	NA	NA	NA	NA	1503	1084	NA
08/29/80	5.50	3.4	1360	1040	160.0	17.0	52.0	34.0	0.750	4.810	0.310	0.270	0.06	0.46	11.0	NA	NA	NA	3.4	11432	7250	NA
09/07/80	6.70	13.6	1695	1170	272.0	24.0	99.0	48.0	0.400	2.700	0.150	0.250	0.03	0.29	6.0	NA	NA	NA	NA	2142	1860	NA
09/11/80	6.80	11.5	1246	710	132.0	9.0	59.0	36.0	0.170	1.840	0.100	0.200	0.04	0.23	5.0	NA	NA	NA	NA	969	655	15.0
09/12/80	6.80	12.8	1275	780	142.0	11.0	60.0	35.0	0.350	2.180	0.110	0.190	0.04	0.23	4.0	NA	NA	NA	2.6	4895	3026	16.0
09/18/80	7.00	14.4	1450	910	191.0	16.0	67.0	38.0	0.310	1.850	0.090	0.180	0.04	0.18	5.0	NA	NA	NA	NA	10209	3354	14.0
09/23/80	6.40	17.8	1822	1150	313.2	48.4	96.0	12.8	0.320	2.610	0.140	0.270	0.03	0.22	5.0	NA	NA	NA	3.3	1579	878	14.0
10/23/80	6.50	12.7	1598	1050	270.0	28.0	73.0	45.0	1.240	5.800	0.280	0.420	0.01	0.40	6.0	NA	NA	NA	2.5	1571	250	10.0
10/26/80	6.50	8.5	1576	1050	238.0	32.0	60.0	46.0	0.480	4.160	0.230	0.310	0.02	0.36	5.0	NA	NA	NA	NA	568	148	13.0
02/20/81	5.20	2.6	635	325	63.7	19.2	27.3	NA	1.360	7.100	0.450	0.270	NA	NA	5.0	NA	NA	NA	NA	1601	264	7.0
03/23/81	7.00	6.4	598	305	69.5	10.5	19.5	NA	0.140	1.470	0.085	0.160	NA	NA	NA	NA	NA	NA	NA	1949	750	10.0
03/30/81	6.70	7.2	500	215	58.5	9.0	10.4	NA	0.260	1.720	0.110	0.150	NA	NA	NA	NA	NA	NA	1.7	9089	2006	NA
04/05/81	6.90	12.0	877	490	119.6	18.5	22.1	NA	0.520	4.210	0.220	0.310	NA	NA	NA	NA	NA	NA	NA	6367	1136	NA
04/14/81	NA	NA	NA	610	156.0	29.0	27.0	NA	0.460	3.230	0.170	0.260	NA	NA	NA	NA	NA	NA	NA	3660	1760	NA
04/17/81	7.20	13.6	1300	660	159.0	31.0	30.0	NA	0.340	2.900	0.150	0.230	NA	NA	NA	NA	NA	NA	1.7	2862	2063	NA
04/23/81	7.00	13.6	1400	660	179.0	35.0	31.0	NA	0.320	2.540	0.140	0.220	NA	NA	NA	NA	NA	NA	NA	3895	2177	NA
04/24/81	7.15	18.6	1400	700	168.0	35.5	32.0	NA	0.220	1.860	0.100	0.160	NA	NA	NA	NA	NA	NA	NA	7730	2460	NA
04/28/81	7.20	NA	1325	640	153.0	34.0	31.0	NA	0.180	1.580	0.100	0.140	NA	NA	NA	NA	NA	NA	1.7	4376	3237	NA
04/30/81	7.20	20.8	1430	845	220.0	36.0	38.0	NA	0.180	1.920	0.100	0.190	NA	NA	NA	NA	NA	NA	NA	4092	856	12.0
05/13/81	7.30	18.4	1574	700	276.0	40.0	48.0	NA	0.160	2.290	0.120	0.230	NA	NA	NA	NA	NA	NA	2.6	1749	42	18.5
06/01/81	7.00	16.1	1638	1000	262.0	40.0	64.0	NA	0.720	4.620	0.260	0.380	NA	NA	NA	NA	NA	NA	NA	3028	1563	16.0
06/07/81	7.10	9.1	1264	685	198.0	26.0	42.0	NA	0.360	3.000	0.170	0.270	NA	NA	NA	NA	NA	NA	3.6	2688	202	18.0
06/22/81	6.70	10.4	1240	675	194.0	28.0	42.0	NA	0.610	3.950	0.220	0.250	NA	NA	NA	NA	NA	NA	NA	5617	2156	16.0
06/24/81	6.85	8.0	1152	605	187.0	24.0	31.0	NA	0.450	2.980	0.160	0.190	NA	NA	NA	NA	NA	NA	NA	4747	1760	16.0
06/28/81	6.90	10.4	1197	665	192.0	26.0	36.0	NA	0.380	2.300	0.130	0.160	NA	NA	NA	NA	NA	NA	2.5	6488	2244	15.0
07/04/81	7.15	13.8	1528	1010	278.0	32.6	50.4	NA	0.240	1.690	0.090	0.180	NA	NA	NA	NA	NA	NA	NA	4247	167	22.0
07/17/81	6.95	12.0	1916	1300	332.0	46.6	81.0	NA	0.830	4.790	0.230	0.470	NA	NA	NA	NA	NA	NA	NA	787	481	20.0
07/25/81	6.85	8.4	1903	1200	328.0	46.6	75.8	NA	1.600	7.420	0.370	0.540	NA	NA	2.0	NA	NA	NA	1.9	1291	256	19.0
08/10/81	6.60	7.4	1711	1060	276.0	50.0	68.0	NA	2.000	8.000	0.470	0.590	NA	NA	NA	NA	NA	NA	NA	1548	560	18.0
08/13/81	6.80	10.6	1767	1050	282.0	44.0	64.0	48.0	0.690	6.000	0.390	0.460	NA	NA	NA	NA	NA	NA	NA	333	55	22.0
08/31/81	6.30	4.8	1800	1000	254.0	48.0	60.0	NA	3.840	11.290	0.590	0.740	NA	NA	NA	NA	NA	NA	1.9	496	337	NA
09/07/81	6.45	4.8	2250	1140	288.0	52.0	60.0	NA	3.030	12.000	0.640	0.730	NA	NA	NA	NA	NA	NA	NA	893	771	NA
09/26/81	6.00	3.2	2025	1190	286.0	56.0	58.0	NA	3.840	15.000	0.830	0.850	NA	NA	NA	NA	NA	NA	1.6	1688	1105	NA
10/01/81	6.40	4.8	1750	880	248.0	44.0	40.0	NA	1.680	9.610	0.510	0.600	NA	NA	NA	NA	NA	NA	NA	3838	2234	NA
10/04/81	6.50	4.8	1800	980	296.0	44.0	40.0	44.0	1.080	10.000	0.470	0.530	NA	NA	NA	NA	NA	NA	NA	7219	2033	NA
10/13/81	6.70	5.6	1850	1000	296.0	44.0	48.0	46.0	0.810	7.000	0.360	0.470	NA	NA	NA	NA	NA	NA	1.5	9596	2851	NA
10/17/81	6.80	7.2	1220	1000	272.0	42.0	52.0	48.0	0.650	5.320	0.300	0.360	NA	NA	NA	NA	NA	NA	NA	8725	2038	NA
11/06/81	6.85	6.4	2100	1300	340.0	62.0	68.0	58.0	0.710	5.100	0.250	0.270	NA	NA	NA	NA	NA	NA	2.5	3562	65	NA
04/11/82	6.80	4.8	750	360	90.2	13.6	14.0	16.0	0.590	3.930	0.210	0.300	NA	NA	NA	NA	NA	NA	NA	1832	NA	NA
04/15/82	6.50	4.5	750	370	87.6	16.4	14.0	14.0	0.700	5.380	0.310	0.330	NA	NA	NA	NA	NA	NA	NA	2074	NA	NA
04/19/82	6.70	6.3	800	430	126.0	20.0	16.0	18.0	0.620	6.210	0.340	0.350	NA	NA	NA	NA	NA	NA	NA	1754	NA	NA
04/23/82	6.60	6.3	1050	560	164.0	20.4	22.0	24.0	0.860	9.190	0.480	0.490	NA	NA	NA	NA	NA	NA	NA	1881	NA	NA
05/03/82	6.10	4.1	1300	750	181.0	42.0	30.0	30.0	1.660	11.355	0.620	0.620	NA	NA	NA	NA	NA	NA	NA	829	NA	NA
05/04/82	6.45	5.8	1250	690	164.0	36.0	22.0	28.0	0.900	8.715	0.460	0.460	NA	NA	NA	NA	NA	NA	NA	4281	NA	NA

Table A2.4. Drainage quality data from Duluth Complex test pile FL4, from 1978-1982 (0.63% S, 0.35% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
05/07/82	6.40	6.3	1290	720	152.0	40.0	22.0	26.0	0.810	8.520	0.460	0.420	NA	NA	NA	NA	NA	NA	NA	7730	NA	NA
05/11/82	6.75	9.9	1500	NA	196.0	50.0	30.0	32.0	0.660	8.150	0.430	0.400	NA	NA	NA	NA	NA	NA	NA	5129	NA	NA
05/14/82	6.60	9.9	1550	940	200.0	18.0	20.0	16.0	0.270	2.680	0.130	0.150	0.02	0.19	NA	NA	NA	NA	NA	5462	NA	NA
05/21/82	6.80	8.1	1850	1000	282.0	49.0	41.0	39.0	0.470	6.800	0.330	0.430	0.03	0.40	NA	NA	NA	NA	NA	1408	NA	NA
06/02/82	6.80	7.2	1980	790	288.0	52.6	48.8	42.6	0.950	8.310	0.400	0.560	0.06	0.53	NA	NA	NA	NA	NA	1594	NA	NA
06/18/82	6.40	9.9	1300	750	184.0	40.0	31.0	31.0	1.090	6.720	0.350	0.420	0.03	0.45	NA	NA	NA	NA	NA	984	NA	NA
07/02/82	NA	NA	NA	750	256.0	38.0	36.0	36.0	1.130	7.000	0.340	0.320	0.02	0.44	NA	NA	NA	NA	NA	25536	NA	NA
07/26/82	6.31	6.2	1520	785	232.0	36.0	40.0	40.0	1.150	8.860	0.460	0.330	0.10	0.47	NA	NA	NA	NA	NA	13832	NA	NA
08/30/82	6.28	4.4	1707	958	336.0	49.0	40.0	46.0	1.655	9.360	0.450	0.410	0.01	0.57	NA	NA	NA	NA	NA	10815	NA	NA

NA: Not analyzed.

'Dates represent intermediate dates for measurement periods.

Table A2.5. Drainage quality data from Duluth Complex test pile FL6, from 1978-1991 (0.79% S, 0.34% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/l	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/l	K mg/L	Cu mg/L	Ni mg/L	Co mg/l	Zn mg/l	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/26/78	7.25	NA	5000	NA	478.0	139.0	535.0	12.0	0.088	0.540	0.030	0.022	0.28	0.60	NA	NA	NA	NA	NA	NA	NA	4.0
05/25/78	7.25	NA	NA	NA	840.0	152.0	862.0	18.0	0.121	0.740	0.062	0.003	0.12	1.14	NA	NA	NA	NA	NA	NA	NA	NA
06/16/78	7.12	NA	8860	NA	1028.0	206.0	1106.0	22.0	0.258	0.665	0.059	0.033	0.12	1.64	NA	NA	NA	NA	NA	135	NA	15.0
07/05/78	7.40	NA	4610	2000	435.0	141.0	491.0	17.0	0.060	0.735	0.051	0.006	0.02	0.70	420.0	NA	NA	NA	NA	223	NA	12.0
07/13/78	7.49	NA	NA	1450	794.0	124.0	685.0	16.0	0.118	1.080	0.067	0.014	0.08	0.95	607.0	400.0	100.00	0.08	NA	NA	NA	NA
07/19/78	8.10	NA	3700	1300	540.0	93.0	508.0	12.0	0.092	0.860	0.052	0.006	0.05	0.75	312.0	160.0	100.00	1.90	NA	NA	NA	18.0
08/02/78	7.70	NA	2600	950	258.0	61.0	260.0	9.0	0.060	0.630	0.035	0.020	0.05	0.62	180.0	48.0	70.00	0.10	NA	NA	NA	23.0
08/04/78	7.75	NA	4150	1700	451.0	120.0	NA	12.0	0.120	0.930	0.140	0.030	0.04	1.04	320.0	210.0	100.00	0.10	NA	287	NA	22.0
08/10/78	7.55	47.0	6840	2400	748.0	178.0	700.0	22.0	0.170	1.430	0.280	0.050	0.15	1.68	600.0	NA	160.00	0.08	NA	77	NA	24.0
08/16/78	7.78	40.0	2225	1000	250.0	74.0	257.0	6.0	0.095	0.935	0.160	0.030	0.06	0.82	150.0	140.0	NA	0.08	NA	28390	NA	22.0
08/17/78	7.52	46.0	4600	1700	396.0	46.0	200.0	14.0	0.130	1.480	0.270	0.050	0.05	1.38	190.0	120.0	NA	0.08	NA	NA	NA	NA
08/23/78	7.55	30.0	4320	1600	368.0	112.0	396.0	12.0	0.130	1.540	0.240	0.050	0.05	1.40	280.0	170.0	NA	0.08	NA	NA	NA	NA
08/25/78	7.40	40.0	4750	1800	373.0	119.0	432.0	12.0	0.150	1.700	0.270	0.050	0.07	1.53	220.0	140.0	98.00	0.08	NA	NA	NA	23.0
08/28/78	7.85	57.0	5290	2150	481.0	135.0	681.0	15.0	0.180	2.150	0.390	0.070	0.07	1.82	390.0	230.0	NA	0.08	NA	NA	NA	NA
09/13/78	7.16	25.5	3400	2075	387.5	120.0	446.5	14.0	0.285	2.335	0.220	0.120	0.05	2.14	270.0	NA	NA	0.10	NA	667	NA	13.0
10/17/78	6.20	6.7	5320	NA	491.0	133.0	609.0	13.0	1.160	4.120	0.400	0.360	0.04	3.15	NA	NA	NA	NA	NA	NA	NA	NA
03/23/79	6.85	10.0	1562	600	200.0	54.0	97.2	4.0	0.200	4.590	0.360	0.150	0.02	1.74	10.0	NA	NA	NA	5.7	2290	46	NA
04/12/79	6.00	NA	2714	1400	327.0	93.2	201.0	6.2	0.740	10.250	0.710	0.290	0.03	3.40	95.0	NA	NA	NA	NA	1665	840	NA
04/16/79	6.60	NA	1358	560	152.6	74.2	91.6	3.4	0.120	2.320	0.210	0.080	1.02	1.17	45.0	NA	NA	NA	NA	3168	1308	NA
04/17/79	6.60	12.0	1146	440	124.6	31.6	76.2	3.0	0.120	2.350	0.210	0.090	0.02	1.18	28.0	NA	NA	NA	4.7	3641	3916	NA
04/18/79	6.80	16.0	1318	488	162.0	38.4	86.0	2.6	0.170	2.630	0.230	0.100	0.02	1.38	30.0	62.0	NA	NA	NA	6529	2997	NA
04/19/79	6.50	15.0	1054	210	141.0	34.0	72.0	2.0	0.130	2.140	0.200	0.190	0.03	1.12	29.0	50.0	11.00	NA	NA	3971	3862	NA
04/20/79	6.70	16.5	1498	559	185.0	56.1	95.0	3.0	0.130	3.145	0.290	0.100	0.02	1.58	51.0	67.5	13.50	NA	4.2	5257	3929	NA
04/25/79	6.65	14.0	2613	NA	292.4	103.4	205.6	4.6	0.280	5.250	0.420	0.200	0.03	2.74	110.0	120.0	24.00	NA	NA	5001	719	NA
05/02/79	6.40	4.0	3460	1650	394.4	149.0	270.0	7.0	0.510	9.000	0.590	0.300	0.05	4.07	171.0	190.0	23.00	NA	NA	3387	1902	NA
05/09/79	6.60	NA	3482	1030	312.0	122.0	238.0	4.0	0.490	7.000	0.480	0.270	0.04	3.23	15.0	NA	NA	NA	NA	1654	1286	NA
05/10/79	7.00	NA	2432	867	240.2	104.2	200.2	4.4	0.340	4.470	0.360	0.180	0.01	2.48	111.0	NA	NA	NA	NA	10250	4690	NA
05/20/79	NA	NA	NA	1750	341.0	130.0	292.0	5.0	0.470	7.440	0.470	0.290	0.03	3.23	152.0	NA	NA	NA	8.6	4644	1266	NA
05/22/79	7.20	NA	2201	883	211.0	86.0	170.0	3.0	0.330	3.900	0.290	0.170	0.02	2.02	94.0	NA	NA	NA	16.0	2188	1399	NA
05/23/79	7.00	NA	3377	1700	316.0	60.4	269.0	6.6	0.490	6.110	0.460	0.250	0.06	3.05	143.0	NA	NA	NA	7.9	2653	1007	NA
06/01/79	6.90	NA	2668	1050	231.2	56.6	212.6	5.2	0.435	4.160	0.350	0.215	0.05	2.28	111.5	NA	NA	NA	7.1	2567	729	NA
06/06/79	6.40	NA	2196	867	199.4	79.8	86.6	2.0	0.330	3.360	0.240	0.170	0.01	1.79	94.0	NA	NA	NA	NA	2570	1130	NA
06/10/79	6.90	14.0	1916	700	184.8	77.6	79.4	3.8	0.380	3.520	0.126	0.140	0.02	1.60	79.0	NA	NA	NA	NA	2574	1433	20.0
06/12/79	6.60	10.0	2673	1200	266.3	107.5	154.0	3.3	0.375	4.500	0.350	0.210	0.01	2.26	104.0	NA	NA	NA	NA	1506	494	NA
06/16/79	6.70	9.9	3450	1230	325.6	127.0	189.0	4.4	0.520	5.660	0.430	0.290	0.04	2.77	139.0	NA	NA	NA	NA	1612	442	23.0
06/21/79	6.70	11.0	2411	750	202.0	87.0	155.0	4.0	0.390	3.880	0.240	0.180	0.01	5.57	91.0	NA	NA	NA	NA	2233	1687	13.0
06/30/79	6.30	6.6	3074	1450	308.0	136.0	249.0	6.0	0.720	5.820	0.380	0.320	0.03	2.59	128.0	NA	NA	NA	8.9	1991	230	NA
07/10/79	6.20	4.8	4599	2200	467.0	193.5	409.5	9.5	1.755	9.960	0.620	0.665	0.03	4.10	220.0	NA	NA	NA	9.0	1628	98	19.0
07/30/79	5.50	3.0	2006	925	209.0	97.0	105.0	4.0	1.450	6.010	0.390	0.290	0.01	2.04	79.0	NA	NA	NA	6.3	5269	3374	22.0
08/04/79	5.40	4.0	3438	1670	444.0	169.0	242.0	9.0	2.720	10.150	0.660	0.580	0.04	3.72	118.0	NA	NA	NA	8.7	1957	284	23.0
08/13/79	5.00	2.4	4690	2420	540.0	126.2	438.0	13.8	4.810	15.000	1.130	1.010	0.07	6.13	181.0	NA	NA	NA	9.1	753	108	14.0
08/23/79	4.80	1.6	3739	1800	439.4	174.0	232.0	11.4	4.220	14.300	1.080	0.840	0.03	5.24	153.0	NA	NA	NA	8.3	1192	342	9.0
08/28/79	5.30	6.0	3154	1400	345.0	112.6	260.0	8.2	3.790	13.700	1.000	0.700	0.06	4.23	113.0	NA	NA	NA	6.6	848	709	20.0
09/01/79	5.00	2.0	2576	1200	327.2	112.4	136.0	6.8	3.380	11.300	0.820	0.510	0.05	3.35	86.0	NA	NA	NA	6.3	5553	2337	22.0
09/05/79	4.70	0.4	3819	1980	478.8	121.6	308.0	10.6	5.270	16.200	1.180	0.840	0.05	5.33	102.0	NA	NA	NA	7.8	988	611	18.0
09/11/79	4.90	2.0	3364	1650	398.8	160.8	229.0	9.8	4.730	14.000	1.040	0.720	0.06	4.70	107.0	NA	NA	NA	7.3	3842	846	17.0
09/13/79	4.90	2.8	3745	1800	444.0	175.0	238.0	10.2	5.020	15.400	1.130	0.760	0.08	5.00	29.0	NA	NA	NA	9.8	2112	699	19.0
09/19/79	4.70	2.4	5710	2680	692.0	272.0	478.0	16.2	6.800	23.600	1.700	1.310	0.16	8.10	201.0	NA	NA	NA	9.0	1567	176	13.5
10/18/79	4.60	0.8	5168	2600	646.0	254.0	450.0	14.6	5.960	26.600	1.910	1.340	0.30	8.45	174.0	NA	NA	NA	8.5	931	758	NA
10/19/79	4.70	2.4	2356	1050	251.0	106.0	142.0	5.6	4.400	15.500	1.090	0.630	0.04	3.70	64.0	NA	NA	NA	4.3	2161	1863	NA
10/31/79	4.60	0.8	3448	1650	408.0	177.0	198.0	7.8	7.200	24.000	2.090	1.020	0.11	5.78	99.0	NA	NA	NA	5.8	6423	2331	NA

Table A2.5. Drainage quality data from Duluth Complex test pile FL6, from 1978-1991 (0.79% S, 0.34% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/l	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/l	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/l	Vol. L	DailyFlow L	Temp. °C.
11/01/79	4.50	NA	3702	1750	447.0	203.5	230.0	9.1	8.535	25.500	2.170	1.085	0 13	6.18	102.0	NA	NA	NA	6.7	4921	1170	NA
03/29/80	4.90	2.3	1050	440	94.2	35.9	48.5	2.3	1.880	7.360	0.445	0.220	0.05	1.23	18.0	NA	NA	NA	2.1	1363	390	13.0
04/01/80	5.00	3.4	800	360	74.0	26.4	27.6	1.4	1.180	4.630	0.300	0.150	0.02	1.00	12.0	NA	NA	NA	1.4	2536	1173	NA
04/06/80	5.50	4.6	1025	490	101.6	45.0	36.6	2.1	1.790	7.045	0.445	0.260	0.03	1.44	19.5	NA	NA	NA	NA	4543	1789	NA
04/14/80	4.50	NA	NA	875	226.8	98.2	92.8	4.0	5.290	18.000	1.290	0.750	0.04	4.11	44.0	NA	NA	NA	NA	3785	540	NA
04/18/80	4.60	1.2	NA	1100	248.0	106.0	106.0	4.4	5.670	21.300	1.490	0.820	0.13	4.71	61.0	NA	NA	NA	3.5	2044	568	NA
04/28/80	4.80	3.3	3590	1820	375.0	164.0	184 6	6.6	8.810	34.000	2.320	1.270	0.10	7 82	68.0	NA	NA	NA	NA	1817	200	11.0
05/10/80	4.70	2.2	3975	2020	420.4	186.0	210 0	8.0	9.250	38.000	2.440	1.360	0.10	8 78	75.0	NA	NA	NA	5.4	583	171	17.0
05/31/80	4.60	2.2	2400	1350	246.0	114.0	101.6	5.0	5.870	21.130	1.420	0.760	0.05	4.24	84.0	NA	NA	NA	1.3	3059	1946	NA
06/03/80	4.60	NA	3350	1750	381.0	177.0	149.0	6.6	7.620	27.700	1.890	1.010	0.05	5.99	110.0	NA	NA	NA	6.7	1018	207	NA
06/06/80	4.60	1.1	3100	1650	316.0	169.0	131.6	6.0	7.630	21.000	1.790	1.000	0.06	5.50	90.0	NA	NA	NA	NA	935	537	NA
06/13/80	4.60	1.1	3300	1650	317.0	156.0	142.8	6.6	7.940	27.270	1.810	0.950	0.10	5.41	86.0	NA	NA	NA	NA	689	464	NA
06/18/80	4.30	NA	3800	1800	359.2	184.0	171.0	7.4	7.710	27.700	1.840	0.970	0 13	5.80	110.0	NA	NA	NA	NA	348	49	NA
06/28/80	4.50	NA	3400	1650	311.0	153.0	148.0	6.4	7.350	25.000	2.100	1.040	0.10	5.55	83.0	NA	NA	NA	5.9	1321	476	NA
07/02/80	4.50	NA	2500	NA	274.7	134.7	91 5	6.0	9.500	24.500	2.000	1.020	0.07	4 57	NA	NA	NA	NA	NA	4334	1305	NA
07/07/80	4.00	NA	3800	1800	401.0	205.0	172.0	7.4	12.000	35.000	2.640	1.290	0.09	6.52	96.0	NA	NA	NA	10.0	1374	238	NA
07/17/80	4.30	NA	5000	2200	475.8	296.0	318.0	11.8	13.450	42.000	2.680	1.560	0 28	9.00	26.0	NA	NA	NA	NA	1253	458	NA
07/26/80	4.30	NA	4450	1880	421.2	219.0	244.0	9.8	11.180	32.000	2.250	1.280	0 11	7.18	126.0	NA	NA	NA	NA	1465	329	NA
08/03/80	4.20	NA	4800	1980	434.2	232.5	323.0	10.4	11.000	40.000	3.040	1.520	0.14	8.25	130.0	NA	NA	NA	6.8	958	528	NA
08/12/80	4.30	NA	3150	1550	303.0	161.0	152.0	7.4	13.000	33.000	2.460	1.190	0.14	6.17	81.0	NA	NA	NA	4.9	2271	900	NA
08/19/80	4.30	NA	3400	2150	375.6	211.6	166.6	9.0	20.000	44.000	3.510	1.740	0.17	7 90	93.0	NA	NA	NA	NA	2832	464	NA
08/22/80	NA	NA	3150	1900	280.5	244.0	126.5	3.5	19.000	38.000	2.670	1.530	0 19	6.88	82.0	NA	NA	NA	NA	1927	922	NA
08/29/80	4.30	NA	3625	2200	406.0	321.0	229.0	8.0	18.000	45.000	3.160	1.800	0.41	8.99	105.0	NA	NA	NA	8.5	1363	5237	NA
09/11/80	4.30	NA	2845	1700	316.0	231.0	172.0	7.0	16.000	35.000	2.640	1.520	0 15	6 98	78.0	NA	NA	NA	NA	950	589	13.0
09/12/80	4.40	NA	2383	1260	218.0	185.0	118.0	4.0	19.000	35.500	2.565	1.440	0.20	6.32	53.5	NA	NA	NA	4.9	5209	2795	21.0
09/18/80	4.40	NA	2625	1600	248.0	213.0	147 0	4.0	18.000	34.000	2.400	1.430	0.14	5.63	69.0	NA	NA	NA	NA	8108	2740	15.0
09/23/80	4.20	NA	3846	2120	400.0	309.0	226.0	31.0	20.900	54.600	3.150	1.990	0.24	8.82	114.0	NA	NA	NA	5.9	3592	798	14.0
10/22/80	4.10	NA	3160	2000	330.0	252.0	166 0	8.0	20.700	56.200	3.210	1.910	0.52	8.25	85.0	NA	NA	NA	4.8	2881	710	11.0
10/30/80	4.20	NA	2250	1700	314.0	158.0	84.0	5.0	17.000	40.000	2.470	1.380	0.12	5.79	64.0	NA	NA	NA	NA	1170	85	10.0
02/19/81	3.70	NA	2050	950	172.9	110.5	123.5	NA	13.300	50.000	2.540	1.270	NA	NA	36.0	NA	NA	NA	NA	1472	1423	5.0
02/21/81	4.50	NA	2550	1560	207.4	201.5	158.0	NA	20.600	82.500	4.190	2.320	NA	NA	NA	NA	NA	NA	NA	1484	325	24.0
03/28/81	4.70	0.8	1300	625	94.9	62.4	48.1	NA	14.400	41.000	2.110	1.100	NA	NA	NA	NA	NA	NA	2.3	8842	3797	NA
04/03/81	4.70	1.6	1900	1100	146.9	110.5	84.5	NA	20.300	64.000	3.300	1.830	NA	NA	NA	NA	NA	NA	NA	7692	2030	NA
04/13/81	4.50	NA	2500	1200	191.0	147.0	69.0	NA	20.200	60.000	3.480	1.870	NA	NA	NA	NA	NA	NA	NA	3376	1436	NA
04/17/81	4.70	1.6	2700	1380	148.0	156.0	58.0	NA	18.600	56.000	3.280	1.940	NA	NA	NA	NA	NA	NA	4.4	2858	1439	NA
04/23/81	4.70	1.6	3000	1415	219.0	161.0	97.0	NA	18.400	57.000	3.380	1.980	NA	NA	NA	NA	NA	NA	NA	3978	3580	NA
04/25/81	4.80	2.4	3100	1480	200.0	168.0	95.0	NA	18.400	57.000	3.420	2.090	NA	NA	NA	NA	NA	NA	NA	8260	2934	NA
04/28/81	4.90	4.0	2950	1350	205.0	179.0	99.0	NA	16.300	51.000	3.050	1.860	NA	NA	NA	NA	NA	NA	3.2	5534	2409	NA
04/29/81	4.70	NA	3515	1850	295.0	280.0	134.0	NA	17.700	43.000	3.600	2.170	NA	NA	NA	NA	NA	NA	NA	5307	1392	12.0
05/12/81	4.50	NA	3708	2250	358.0	370.0	184.0	NA	19.940	73.000	4.600	2.670	NA	NA	NA	NA	NA	NA	5.3	3441	272	19.0
06/01/81	4.50	NA	2660	1350	244.0	180.0	110.0	NA	16.620	38.000	2.870	1.790	NA	NA	NA	NA	NA	NA	NA	2960	1196	15.0
06/06/81	4.45	NA	1872	1160	188.0	112.0	52.0	NA	13.340	26.000	2.270	1.330	NA	NA	NA	NA	NA	NA	3.1	3274	289	18.0
06/22/81	4.20	NA	2650	1660	271.0	175.0	93.0	NA	17.920	43.000	3.360	1.730	NA	NA	NA	NA	NA	NA	NA	4766	2996	17.0
06/24/81	4.40	NA	2342	1620	246.0	154.0	70.0	NA	22.240	68.000	3.680	1.950	NA	NA	NA	NA	NA	NA	NA	4993	2335	16.0
06/28/81	4.50	NA	1657	1910	302.0	290.0	112.0	NA	20.570	42.000	3.550	1.760	NA	NA	NA	NA	NA	NA	3.4	6878	3559	13.0
07/04/81	4.40	NA	3568	2300	370.0	183.3	166.2	NA	29.500	68.000	3.820	2.530	NA	NA	NA	NA	NA	NA	NA	6197	295	22.0
07/15/81	4.25	NA	3526	2250	362.0	278.6	175.0	NA	29.000	72.000	4.100	2.660	NA	NA	NA	NA	NA	NA	NA	1628	102	19.0
07/24/81	4.40	NA	2830	1830	290.0	212.6	108.0	NA	26.500	56.000	3.310	2.050	NA	NA	49.0	NA	NA	NA	3.5	1938	437	19.0
08/04/81	4.00	NA	2951	2030	326.0	142.0	108.0	NA	27.500	71.500	3.920	1.980	NA	NA	NA	NA	NA	NA	NA	1783	106	18.0
08/17/81	4.05	NA	3238	2150	348.0	260.0	108.0	8.0	27.500	65.000	3.670	2.230	NA	NA	NA	NA	NA	NA	NA	1033	47	22.0
08/31/81	4.10	NA	3930	2560	360.0	270.0	128.0	NA	34.000	95.000	5.170	3.020	NA	NA	NA	NA	NA	NA	5.1	1136	1000	NA

Table A2.5. Drainage quality data from Duluth Complex test pile FL6, from 1978-1991 (0.79% S, 0.34% Cu, 0.08% Ni).

Date'	prl s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/L	K mg/L	Cu mg/L	Ni mg/l	Co mg/L	Zn mg/l	Fe mg/l	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/l	P mg/L	DissOrgC mg/l	Vol. L	DailyFlow L	Temp. °C.
09/07/81	4.10	NA	4200	2220	342.0	244.0	104.0	NA	34.000	84.000	4.420	2.660	NA	NA	NA	NA	NA	NA	NA	1109	588	NA
09/16/81	4.10	NA	4300	2640	378.0	284.0	114.0	NA	33.000	92.000	4.890	2.920	NA	NA	NA	NA	NA	NA	NA	431	20	NA
09/26/81	4.10	NA	3550	2220	328.0	240.0	74.0	NA	38.000	82.000	4.360	2.570	NA	NA	NA	NA	NA	NA	3.7	1949	1176	NA
10/01/81	4.20	NA	3225	1840	298.0	224.0	56.0	NA	42.000	80.000	4.460	2.280	NA	NA	NA	NA	NA	NA	NA	4675	2859	NA
10/04/81	4.20	NA	3700	2600	332.0	354.0	76.0	10.0	52.000	107.000	8.000	3.760	NA	NA	NA	NA	NA	NA	NA	3607	1859	NA
10/14/81	4.20	NA	3400	1960	276.0	222.0	90.0	8.0	39.000	78.000	5.000	3.080	NA	NA	NA	NA	NA	NA	3.5	5216	1771	NA
10/15/81	4.20	NA	4000	2760	252.0	304.0	100.0	22.0	123.000	306.000	21.000	10.000	NA	NA	NA	NA	NA	NA	NA	9906	2503	NA
11/01/81	4.10	NA	4000	2760	324.0	350.0	118.0	8.0	54.000	120.000	6.700	3.360	NA	NA	NA	NA	NA	NA	4.1	3516	193	NA
03/30/82	4.20	NA	1825	1000	138.0	102.0	34.0	4.0	19.000	49.000	2.800	1.500	NA	NA	NA	NA	NA	NA	NA	2336	NA	NA
04/11/82	4.30	NA	2350	1500	182.0	158.0	48.0	4.0	29.000	75.000	4.400	2.340	NA	NA	NA	NA	NA	NA	NA	1669	NA	NA
04/13/82	4.40	NA	1050	570	78.8	65.7	16.0	2.0	10.000	24.000	1.400	0.700	NA	NA	NA	NA	NA	NA	NA	4906	NA	NA
04/15/82	4.40	NA	1500	900	117.6	96.4	24.0	2.0	13.000	37.000	2.300	1.050	NA	NA	NA	NA	NA	NA	NA	4179	NA	NA
04/19/82	4.30	NA	1775	1100	176.0	144.0	34.0	4.0	22.000	52.000	3.000	1.490	NA	NA	NA	NA	NA	NA	NA	2245	NA	NA
04/23/82	4.20	NA	2425	1600	206.0	176.0	58.0	4.0	34.000	83.000	4.700	2.430	NA	NA	NA	NA	NA	NA	NA	2392	NA	NA
05/03/82	4.15	NA	3100	2300	204.0	190.0	78.0	6.0	55.000	128.000	8.100	4.200	NA	NA	NA	NA	NA	NA	NA	572	NA	NA
05/04/82	4.20	NA	2900	2000	192.0	208.0	62.0	6.0	46.000	110.000	6.100	3.380	NA	NA	NA	NA	NA	NA	NA	4902	NA	NA
05/10/82	4.30	NA	2875	1900	184.0	208.0	56.0	6.0	46.000	104.000	5.800	3.220	NA	NA	NA	NA	NA	NA	NA	4664	NA	NA
05/11/82	4.30	NA	3100	1700	202.0	223.0	84.0	6.0	49.500	123.500	6.900	3.890	NA	NA	NA	NA	NA	NA	NA	5337	NA	NA
05/14/82	4.30	NA	3400	2200	250.0	288.0	84.0	6.8	42.000	114.000	5.200	3.150	0.06	7 82	NA	NA	NA	NA	NA	5773	NA	NA
05/21/82	4.20	NA	5000	3600	340.0	382.0	95.0	8.0	57.000	169.000	7.600	4.360	0.13	11.44	NA	NA	NA	NA	NA	2052	NA	NA
06/02/82	4.10	NA	3700	2700	250.0	280.0	100.0	6.6	39.000	121.000	5.700	3.720	0.14	7.77	NA	NA	NA	NA	NA	1794	NA	NA
06/18/82	4.20	NA	3400	2400	264.0	264.0	79.0	6.8	40.000	106.000	5.100	3.300	0.11	6.89	NA	NA	NA	NA	NA	1185	NA	NA
07/02/82	NA	NA	NA	1965	332.0	208.0	78.0	8.0	47.000	111.000	5.300	2.560	0.10	7.44	NA	NA	NA	NA	NA	31423	NA	NA
07/26/82	3.94	NA	3531	2150	318.0	258.0	84.0	8.0	42.000	163.000	7.400	3.150	1.28	9.10	NA	NA	NA	NA	NA	14021	NA	NA
08/30/82	3.97	NA	3319	1920	366.0	234.0	76.0	8.0	58.000	125.000	5.900	2.790	0.30	8.03	NA	NA	NA	NA	NA	16239	NA	NA
10/04/82	4.27	NA	3073	1900	250.0	260.0	70.0	8.0	53.000	168.000	7.500	3.300	0.21	9.17	NA	NA	NA	NA	NA	20358	NA	NA
11/01/82	3.90	NA	2980	NA	176.0	222.0	62.0	6.0	41.000	141.000	6.300	2.800	0.25	7.57	NA	NA	NA	NA	NA	2491	NA	NA
11/22/82	4.10	NA	4100	3300	236.0	326.0	136.0	NA	41.600	213.000	8.900	3.820	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/18/83	4.35	NA	1425	780	NA	NA	NA	NA	24.000	37.000	18.000	1.380	NA	NA	NA	NA	NA	NA	NA	3286	NA	NA
04/14/83	4.33	NA	1387	700	NA	NA	NA	NA	22.000	40.000	2.450	1.400	NA	NA	NA	NA	NA	NA	NA	12694	NA	NA
05/15/83	4.21	NA	2532	2500	NA	NA	NA	NA	56.000	1.100	6.400	3.490	NA	NA	NA	NA	NA	NA	NA	6279	NA	NA
06/15/83	4.25	NA	2173	1940	NA	NA	NA	NA	40.000	76.000	3.400	1.880	NA	NA	NA	NA	NA	NA	NA	5022	NA	NA
07/14/83	4.14	NA	3960	5160	NA	NA	NA	NA	87.000	174.000	10.190	5.740	NA	NA	NA	NA	NA	NA	NA	9466	NA	NA
08/14/83	4.08	NA	2861	2300	NA	NA	NA	NA	68.000	120.000	6.450	3.720	NA	NA	NA	NA	NA	NA	NA	14103	NA	NA
09/15/83	4.16	NA	3486	2950	NA	NA	NA	NA	85.000	164.000	9.000	5.060	NA	NA	NA	NA	NA	NA	NA	8668	NA	NA
10/13/83	4.32	NA	3405	2400	NA	NA	NA	NA	77.000	136.000	8.000	4.340	NA	NA	NA	NA	NA	NA	NA	19970	NA	NA
11/09/83	4.10	NA	2750	2250	NA	NA	NA	NA	82.000	133.000	7.400	4.170	NA	NA	NA	NA	NA	NA	NA	4269	NA	NA
11/30/83	4.00	NA	2700	2820	NA	NA	NA	NA	73.400	125.000	6.950	3.970	NA	NA	NA	NA	NA	NA	NA	628	NA	NA
02/24/84	4.00	NA	2175	2300	276.8	414.3	56.6	NA	49.000	106.000	5.110	3.420	NA	NA	NA	NA	NA	NA	NA	75	NA	NA
03/15/84	4.25	NA	1100	830	110.4	105.7	17.3	NA	26.000	41.400	2.050	1.250	NA	NA	NA	NA	NA	NA	NA	4023	NA	NA
04/15/84	4.33	NA	1472	1540	188.2	170.3	27.2	NA	46.000	67.000	3.750	2.200	NA	NA	NA	NA	NA	NA	NA	20316	NA	NA
05/16/84	4.22	NA	1958	2500	236.3	279.5	42.0	NA	65.000	110.000	7.000	3.360	NA	NA	NA	NA	NA	NA	NA	11761	NA	NA
06/13/84	4.16	NA	2320	2300	256.1	328.6	52.1	NA	68.000	119.600	6.400	3.540	NA	NA	NA	NA	NA	NA	NA	23280	NA	NA
07/14/84	4.19	NA	2930	2700	NA	NA	NA	NA	95.600	186.000	6.600	4.000	NA	NA	NA	NA	NA	NA	NA	8771	NA	NA
08/15/84	4.10	NA	3385	3020	379.7	277.6	71.8	NA	90.100	160.420	11.600	5.080	NA	NA	NA	NA	NA	NA	NA	7737	NA	NA
09/12/84	3.96	NA	4095	3900	408.2	510.0	88.2	NA	107.500	225.000	15.700	6.630	NA	NA	NA	NA	NA	NA	NA	2612	NA	NA
10/13/84	3.94	NA	2720	3459	402.6	430.0	65.3	NA	109.500	169.000	12.700	5.240	NA	NA	NA	NA	NA	NA	NA	15261	NA	NA
11/14/84	4.11	NA	3160	4125	430.0	585.0	93.8	NA	135.000	255.000	12.400	6.800	NA	NA	NA	NA	NA	NA	NA	2615	NA	NA
12/01/84	3.95	NA	2150	3000	332.0	426.0	61.0	NA	90.800	152.000	7.900	4.160	NA	NA	NA	NA	NA	NA	NA	492	NA	NA
12/18/84	4.30	NA	2025	2200	252.0	302.0	52.0	NA	70.300	108.800	5.410	3.060	NA	NA	NA	NA	NA	NA	NA	2215	NA	NA
04/02/85	4.50	NA	1625	1130	158.0	138.8	21.0	NA	32.000	63.000	2.840	1.820	NA	NA	NA	NA	NA	NA	NA	2551	NA	NA

Table A2.5. Drainage quality data from Duluth Complex test pile FL6, from 1978-1991 (0.79% S, 0.34% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/l	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/l	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/l	Fe mg/l	Mn mg/L	Cl mg/l	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/16/85	4.40	NA	2200	1500	238.0	256.0	37.6	NA	63.000	98.000	4.820	2.870	NA	NA	NA	NA	NA	NA	NA	16537	NA	NA
05/14/85	4.34	NA	3100	2750	240.0	364.0	48.5	NA	83.000	128.000	7.200	3.800	NA	NA	NA	NA	NA	NA	NA	9852	NA	NA
06/14/85	4.29	NA	3500	3200	281.0	453.0	63.0	NA	91.000	160.000	7.800	4.460	NA	NA	NA	NA	NA	NA	NA	34814	NA	NA
07/15/85	4.16	NA	3100	2773	276.0	377.0	55.0	NA	78.300	130.600	6.500	4.690	NA	NA	NA	NA	NA	NA	NA	14584	NA	NA
08/13/85	4.11	NA	2700	2400	268.0	252.0	46.0	NA	76.400	94.000	4.880	2.870	NA	NA	NA	NA	NA	NA	NA	15114	NA	NA
09/13/85	4.15	NA	3100	2550	309.0	270.0	48.0	NA	75.000	104.200	5.440	3.330	NA	NA	NA	NA	NA	NA	NA	31741	NA	NA
10/15/85	4.20	NA	3300	2430	244.0	319.0	43.1	NA	77.100	106.500	5.470	2.510	NA	NA	NA	NA	NA	NA	NA	20420	NA	NA
11/15/85	4.27	NA	3250	1750	284.0	440.0	56.0	NA	88.800	144.600	7.340	3.800	NA	NA	NA	NA	NA	NA	NA	2646	NA	NA
03/23/86	4.50	NA	1500	900	114.0	122.0	15.8	NA	34.000	55.000	2.910	1.580	NA	NA	NA	NA	NA	NA	NA	17289	NA	NA
04/16/86	4.36	NA	2025	1400	204.0	190.0	26.2	NA	59.000	86.000	4.840	2.280	NA	NA	NA	NA	NA	NA	NA	16332	NA	NA
05/14/86	4.35	NA	2325	1950	276.0	262.0	28.0	NA	72.000	133.000	8.000	2.920	NA	NA	NA	NA	NA	NA	NA	12740	NA	NA
06/11/86	4.30	NA	2750	2000	236.0	250.0	38.0	NA	63.000	100.000	4.800	3.100	NA	NA	NA	NA	NA	NA	NA	7631	NA	NA
07/12/86	4.27	NA	2650	1750	260.0	264.0	36.0	NA	65.000	100.000	4.420	2.850	NA	NA	NA	NA	NA	NA	NA	2365	NA	NA
08/13/86	4.13	NA	3200	2350	300.0	301.0	45.0	NA	80.000	99.000	6.200	2.550	NA	NA	NA	NA	NA	NA	NA	13346	NA	NA
09/14/86	4.12	NA	3000	1800	280.0	302.0	38.0	NA	76.000	94.000	6.600	2.400	NA	NA	NA	NA	NA	NA	NA	27335	NA	NA
10/16/86	4.06	NA	3425	2400	288.0	318.0	44.0	NA	93.000	122.000	6.000	3.510	NA	NA	NA	NA	NA	NA	NA	6442	NA	NA
11/16/86	3.99	NA	3475	3250	332.0	544.0	64.0	NA	156.000	169.000	8.800	5.300	NA	NA	NA	NA	NA	NA	NA	10954	NA	NA
03/28/87	4.40	NA	2300	1750	202.0	234.0	30.0	NA	83.000	110.000	5.390	3.140	NA	NA	NA	NA	NA	NA	NA	12608	NA	NA
04/18/87	4.31	NA	2150	1650	198.0	206.0	26.0	NA	68.000	95.000	4.520	2.580	NA	NA	NA	NA	NA	NA	NA	2525	NA	NA
05/16/87	3.86	NA	2750	2700	335.0	397.0	44.0	NA	97.000	115.000	5.600	3.400	NA	NA	NA	NA	NA	NA	NA	28020	NA	NA
06/16/87	4.17	NA	3950	3000	348.0	458.0	58.0	NA	106.000	163.000	5.800	3.420	NA	NA	NA	NA	NA	NA	NA	1419	NA	NA
07/15/87	4.00	NA	3325	2715	294.0	340.0	46.0	NA	92.000	117.000	5.200	3.430	NA	NA	NA	NA	NA	NA	NA	29811	NA	NA
08/15/87	3.72	NA	3050	2500	288.0	304.0	42.0	NA	93.000	112.000	5.000	3.130	NA	NA	NA	NA	NA	NA	NA	13350	NA	NA
09/16/87	3.84	NA	4400	2850	323.0	352.0	47.0	NA	101.000	113.000	5.090	3.050	NA	NA	NA	NA	NA	NA	NA	16885	NA	NA
10/13/87	3.92	NA	5000	4300	386.0	560.0	72.0	NA	138.000	173.000	7.560	4.550	NA	NA	NA	NA	NA	NA	NA	1915	NA	NA
11/10/87	4.03	NA	4375	3760	342.0	500.0	64.0	NA	128.000	165.000	7.330	4.510	NA	NA	NA	NA	NA	NA	NA	1601	NA	NA
03/28/88	4.25	NA	1500	880	142.0	106.0	14.0	NA	34.000	52.000	2.500	2.100	NA	NA	NA	NA	NA	NA	NA	7574	NA	NA
04/17/88	4.20	NA	2125	1860	170.0	186.0	18.0	NA	52.000	81.000	3.700	3.100	NA	NA	NA	NA	NA	NA	NA	6635	NA	NA
05/12/88	4.11	NA	3275	2300	298.0	322.0	50.0	NA	113.000	153.000	6.800	6.500	NA	NA	NA	NA	NA	NA	NA	12044	NA	NA
06/12/88	4.10	NA	3325	2600	346.0	342.0	40.0	NA	118.000	146.000	7.500	7.100	NA	NA	NA	NA	NA	NA	NA	2858	NA	NA
07/15/88	4.10	NA	3250	2440	312.0	314.0	36.0	NA	105.000	132.000	6.500	6.500	NA	NA	NA	NA	NA	NA	NA	4553	NA	NA
08/16/88	4.06	NA	3475	2400	302.0	352.0	52.0	NA	85.000	133.000	6.300	5.100	NA	NA	NA	NA	NA	NA	NA	60076	NA	NA
09/16/88	4.04	NA	3050	2000	246.0	290.0	44.0	NA	76.000	80.000	5.500	4.400	NA	NA	NA	NA	NA	NA	NA	12025	NA	NA
10/18/88	4.12	NA	2950	2160	212.0	274.0	30.0	NA	75.000	88.000	5.100	4.700	NA	NA	NA	NA	NA	NA	NA	3664	NA	NA
11/15/88	4.30	NA	2625	2080	210.0	265.0	26.0	NA	71.000	81.500	4.550	4.400	NA	NA	NA	NA	NA	NA	NA	7017	NA	NA
11/30/88	4.20	NA	3600	2500	232.0	320.0	32.0	NA	78.000	98.000	5.100	4.800	NA	NA	NA	NA	NA	NA	NA	681	NA	NA
04/07/89	4.65	1.1	900	1400	80.0	72.0	10.0	NA	18.600	23.000	1.400	1.100	NA	NA	NA	NA	NA	NA	NA	18641	NA	NA
04/24/89	4.40	NA	1975	1340	150.0	156.0	18.0	NA	45.000	57.000	3.400	3.000	NA	NA	NA	NA	NA	NA	NA	8804	NA	NA
05/16/89	4.27	NA	2550	1700	202.0	216.0	28.0	NA	66.000	79.000	4.700	4.300	NA	NA	NA	NA	NA	NA	NA	11620	NA	NA
06/17/89	4.28	NA	3500	2950	304.0	354.0	54.0	NA	91.000	159.000	10.200	6.300	NA	NA	NA	NA	NA	NA	NA	35500	NA	NA
07/17/89	4.13	NA	4625	3800	440.0	460.0	58.0	NA	131.000	204.000	11.300	9.700	NA	NA	NA	NA	NA	NA	NA	2952	NA	NA
08/14/89	4.17	NA	2950	2060	232.0	282.0	34.0	NA	82.000	138.000	5.700	5.500	NA	NA	NA	NA	NA	NA	NA	4466	NA	NA
09/14/89	4.01	NA	4325	3500	356.0	416.0	50.0	NA	123.000	176.000	9.900	8.200	NA	NA	NA	NA	NA	NA	NA	17161	NA	NA
10/16/89	4.05	NA	4800	3600	360.0	462.0	56.0	NA	137.000	149.000	16.400	9.400	NA	NA	NA	NA	NA	NA	NA	1832	NA	NA
11/10/89	4.20	NA	3050	2000	214.0	300.0	36.0	NA	94.000	96.000	15.300	7.000	NA	NA	NA	NA	NA	NA	NA	999	NA	NA
03/26/90	4.15	NA	5000	5440	468.0	744.0	93.0	NA	202.000	253.000	16.200	14.100	NA	NA	NA	NA	NA	NA	NA	34	NA	NA
04/12/90	4.39	NA	3125	2280	244.0	288.0	26.0	NA	96.000	108.000	5.610	5.440	NA	NA	NA	NA	NA	NA	NA	3883	NA	NA
05/17/90	4.32	NA	2675	2040	226.0	230.0	22.0	NA	84.000	78.000	4.630	4.260	NA	NA	NA	NA	NA	NA	NA	927	NA	NA
06/18/90	4.07	NA	3550	2440	266.0	286.0	28.0	NA	83.000	74.000	4.200	4.380	NA	NA	NA	NA	NA	NA	NA	2998	NA	NA
07/16/90	4.10	NA	3490	2460	270.0	286.0	26.0	NA	93.000	73.000	4.410	4.290	NA	NA	NA	NA	NA	NA	NA	1658	NA	NA
08/13/90	4.05	NA	3100	1970	190.0	286.0	28.0	NA	75.000	78.000	4.900	4.130	NA	NA	NA	NA	NA	NA	NA	700	NA	NA

Table A2.5. Drainage quality data from Duluth Complex test pile FL6, from 1978-1991 (0.79% S, 0.34% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/l	S.C µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/l	NH3 mg/l	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
09/10/90	4.10	NA	3300	2160	242.0	312.0	24.0	NA	63.000	71.000	4.120	3.150	NA	NA	NA	NA	NA	NA	NA	5583	NA	NA
10/15/90	3.98	NA	4295	3980	334.0	438.0	36.0	NA	88.000	112.000	6.410	4.330	NA	NA	NA	NA	NA	NA	NA	20246	NA	NA
11/16/90	4.35	NA	5000	4400	410.0	640.0	58.0	NA	144.000	165.000	9.990	9.180	NA	NA	NA	NA	NA	NA	NA	167	NA	NA
04/08/91	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10795	NA	NA
04/22/91	4.22	NA	3625	2620	238.0	350.0	30.0	NA	106.000	116.000	5.200	3.300	NA	NA	NA	NA	NA	NA	NA	7960	NA	NA
05/20/91	4.18	NA	4675	3260	284.0	452.0	40.0	NA	133.000	163.000	6.900	4.400	NA	NA	NA	NA	NA	NA	NA	9122	NA	NA
06/17/91	4.18	NA	3350	2080	208.0	317.0	28.0	NA	91.000	103.000	5.000	2.800	NA	NA	NA	NA	NA	NA	NA	10000	NA	NA
07/15/91	4.07	NA	4800	2500	246.0	378.0	34.0	NA	107.000	117.000	5.900	4.600	NA	NA	NA	NA	NA	NA	NA	29610	NA	NA
08/12/91	4.10	NA	5000	3280	286.0	430.0	56.0	NA	137.000	150.000	7.600	6.300	NA	NA	NA	NA	NA	NA	NA	1185	NA	NA
09/09/91	4.09	NA	5000	3260	292.0	404.0	48.0	NA	119.000	130.000	6.600	4.900	NA	NA	NA	NA	NA	NA	NA	20079	NA	NA
10/07/91	4.17	NA	4450	2640	236.0	346.0	42.0	NA	105.000	114.000	5.600	4.600	NA	NA	NA	NA	NA	NA	NA	6344	NA	NA
11/07/91	4.11	NA	4775	2360	212.0	304.0	34.0	NA	96.000	98.000	5.000	4.000	NA	NA	NA	NA	NA	NA	NA	11692	NA	NA

NA: Not analyzed.

'Dates represent intermediate dates for measurement periods.

Table A2.6. Drainage quality data from Duluth Complex test pile FL5, from 1978-1991 (1.41% S, 0.30% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
04/26/78	7.20	NA	1750	NA	190.0	11.0	153.0	6.0	0.020	0.445	0.045	NA	NA	0.27	NA	NA	NA	NA	NA	NA	NA	6.0
05/25/78	7.60	NA	2500	NA	279.0	21.0	273.0	10.0	0.021	0.780	0.136	0.096	0.02	0.89	NA	NA	NA	NA	NA	NA	NA	NA
06/16/78	7.50	NA	3300	NA	366.0	26.0	336.0	15.0	0.044	0.835	0.160	0.174	0.03	1.40	NA	NA	NA	NA	NA	192	NA	13.0
07/05/78	7.05	NA	2950	1800	325.0	29.0	231.0	13.0	0.140	5.100	0.195	0.257	0.02	1.29	78.0	NA	NA	NA	NA	370	NA	13.0
07/13/78	7.22	NA	NA	1300	357.0	27.0	248.0	14.0	0.090	6.700	0.810	0.230	0.04	1.67	50.0	39.0	13.00	0.08	NA	NA	NA	NA
07/19/78	7.40	NA	2050	1300	580.0	29.0	245.0	16.0	0.141	21.500	2.160	0.396	0.02	2.40	59.0	54.0	12.00	0.08	NA	NA	NA	NA
08/02/78	7.00	NA	1725	775	276.0	20.0	144.5	13.0	0.265	10.280	1.240	0.400	0.05	2.08	25.0	66.5	5.70	0.24	NA	NA	NA	21.0
08/04/78	6.30	NA	2350	1400	483.0	32.0	238.0	17.0	0.420	3.230	1.860	0.774	0.05	3.32	44.0	83.0	7.50	0.08	NA	333	NA	22.0
08/10/78	5.50	7.0	4000	2000	636.0	47.0	338.0	20.0	1.280	3.310	2.200	1.220	0.12	4.29	52.0	NA	8.50	0.08	NA	147	NA	22.0
08/16/78	5.90	8.0	1492	850	245.3	26.0	104.7	9.7	1.157	22.453	3.790	0.623	7.96	3.06	19.5	41.0	4.00	0.08	NA	5948	NA	17.7
08/17/78	5.25	5.0	2100	800	400.0	40.0	178.0	33.0	2.530	40.380	6.730	1.240	11.54	5.14	27.0	55.0	NA	0.08	NA	1714	NA	NA
08/18/78	4.85	4.0	3100	800	350.0	44.0	354.0	8.0	2.980	42.210	7.220	1.450	5.28	5.87	34.0	67.0	NA	0.08	NA	498	NA	16.0
08/23/78	4.23	NA	1775	1050	203.5	24.5	107.0	10.0	1.450	20.240	3.400	0.625	4.01	2.99	16.5	34.5	4.00	0.08	NA	NA	NA	NA
08/25/78	3.90	NA	2800	1200	344.0	42.0	177.0	15.0	3.150	39.400	6.360	1.180	2.78	5.40	22.0	54.0	8.30	0.08	NA	NA	NA	21.0
08/28/78	4.25	NA	3250	1500	395.0	50.0	220.0	18.0	3.950	48.000	7.760	1.490	2.38	6.47	30.0	64.0	NA	0.08	NA	NA	NA	NA
09/11/78	4.80	NA	1475	700	140.0	20.0	79.0	9.0	1.810	18.000	1.510	0.560	0.75	2.90	8.0	NA	NA	0.20	NA	8801	NA	17.0
09/12/78	3.50	NA	2650	1550	260.0	50.0	133.0	17.0	7.280	67.000	4.880	1.750	24.00	10.00	9.0	NA	NA	0.08	NA	NA	NA	NA
09/13/78	3.62	NA	3250	1900	312.0	65.0	183.0	21.0	10.300	83.000	6.170	2.460	23.00	13.00	15.0	46.0	0.10	NA	NA	721	NA	13.0
10/17/78	4.10	NA	3300	NA	335.0	98.0	211.0	15.0	11.450	79.000	5.730	3.290	0.63	10.00	NA	NA	NA	NA	NA	NA	NA	NA
03/23/79	3.70	NA	2445	2100	271.6	108.0	121.8	14.8	44.000	169.000	14.000	5.000	4.01	11.80	11.0	NA	NA	NA	7.6	2801	283	NA
04/03/79	3.60	NA	4435	3000	395.0	231.0	286.0	28.0	91.000	335.000	25.000	11.000	11.00	28.00	18.0	NA	NA	NA	NA	2574	167	NA
04/11/79	3.60	NA	4766	4600	430.0	280.0	338.0	30.0	107.000	406.000	31.000	13.000	10.00	35.00	22.0	NA	NA	NA	NA	1983	129	NA
04/16/79	3.50	NA	2822	2350	269.0	124.0	146.8	15.2	38.000	173.000	14.000	5.000	8.73	15.70	14.0	NA	NA	NA	NA	4148	3192	NA
04/17/79	3.30	NA	1769	1050	197.0	70.6	70.0	8.2	15.000	87.000	6.000	2.080	7.70	8.50	8.0	9.8	NA	NA	NA	5098	3235	NA
04/18/79	3.40	NA	1769	1100	213.0	62.4	68.0	7.2	13.000	74.000	5.190	1.900	13.33	7.22	5.0	8.1	NA	NA	NA	6906	4242	NA
04/19/79	3.40	NA	1475	833	193.0	42.2	52.0	6.4	8.980	48.000	3.690	1.360	11.62	4.89	2.0	5.5	0.40	NA	NA	1843	2946	NA
04/20/79	3.50	NA	1380	867	178.0	49.0	65.0	6.6	14.000	53.000	4.300	1.890	3.78	5.35	4.0	8.5	0.64	NA	3.3	7210	2394	NA
04/30/79	3.50	NA	2562	2100	294.8	100.0	185.6	12.2	40.000	107.400	8.400	3.950	4.54	10.72	13.0	26.0	1.10	NA	NA	6431	364	NA
05/11/79	3.50	NA	2341	NA	254.0	89.0	133.0	9.0	33.000	94.000	7.400	3.600	1.80	9.60	NA	NA	NA	NA	NA	409	2115	NA
05/22/79	3.80	NA	1767	1150	201.0	64.0	79.0	7.0	23.000	71.000	4.860	2.370	3.61	6.65	9.0	NA	NA	NA	6.9	1813	1031	NA
05/23/79	3.20	NA	2713	2100	288.2	105.8	162.8	14.0	41.600	116.000	8.600	4.160	4.03	10.09	12.0	NA	NA	NA	5.4	3157	982	NA
05/27/79	3.38	NA	2578	2200	285.4	57.7	151.2	13.1	35.900	104.000	7.800	3.680	4.64	9.42	12.0	NA	NA	NA	3.7	3073	508	NA
06/01/79	3.60	NA	2227	1800	239.2	54.6	121.4	11.6	30.800	84.600	5.570	3.000	3.00	7.75	10.0	NA	NA	NA	3.9	2290	561	NA
06/06/79	3.90	NA	2154	1430	243.8	77.2	60.8	9.2	26.000	80.000	5.180	2.830	3.17	7.49	12.0	NA	NA	NA	NA	2358	788	NA
06/10/79	3.40	NA	2538	1750	287.6	93.0	68.2	11.0	30.000	94.000	6.260	3.310	7.32	8.70	13.0	NA	NA	NA	NA	3407	1308	NA
06/16/79	3.60	NA	2890	2100	324.0	110.0	115.0	14.8	40.000	115.000	7.570	4.130	5.41	10.10	11.0	NA	NA	NA	NA	935	244	23.0
06/20/79	3.50	NA	1891	1150	203.0	68.0	71.0	11.0	14.000	59.000	4.320	2.220	3.06	0.11	7.0	NA	NA	NA	NA	1798	1300	19.0
06/30/79	3.30	NA	2754	2225	328.0	117.0	132.0	16.5	25.500	96.500	7.205	3.890	6.78	9.38	19.0	NA	NA	NA	4.8	1904	296	14.0
07/10/79	3.30	NA	3830	3200	462.0	180.0	204.0	29.0	50.000	163.000	14.000	5.950	4.83	14.10	28.0	NA	NA	NA	5.4	1348	110	19.0
07/30/79	3.50	NA	1926	1400	229.0	82.0	63.0	12.0	7.000	46.000	4.420	2.320	2.10	6.32	6.0	NA	NA	NA	6.5	3179	3202	22.0
08/04/79	3.20	NA	3170	2800	416.0	144.0	120.0	21.0	25.000	132.000	8.190	4.470	8.49	13.32	13.0	NA	NA	NA	5.6	1442	322	23.0
08/13/79	3.40	NA	4636	4650	514.8	130.4	322.0	32.6	76.000	259.000	19.000	9.590	11.10	22.80	82.0	NA	NA	NA	8.7	712	87	14.0
08/23/79	3.50	NA	3708	3600	463.2	230.2	202.0	27.2	44.000	202.000	12.000	7.460	6.90	17.89	9.0	NA	NA	NA	8.7	855	243	12.0
08/28/79	3.40	NA	3332	3050	365.0	122.2	158.6	21.8	26.000	142.000	12.000	5.800	5.24	14.20	15.0	NA	NA	NA	8.3	424	330	20.0
09/01/79	3.20	NA	2923	1400	296.4	115.8	98.2	18.0	31.000	138.000	8.000	4.560	19.60	13.34	17.0	NA	NA	NA	6.2	5708	2338	21.0
09/05/79	3.20	NA	4197	3300	420.2	128.6	192.8	28.4	77.000	227.000	18.000	8.490	26.20	20.20	39.0	NA	NA	NA	8.6	11	523	19.0
09/13/79	3.30	NA	4120	3600	363.8	239.6	197.0	26.2	77.000	224.000	17.000	8.140	22.85	19.20	10.0	NA	NA	NA	7.7	2449	811	17.0
09/13/79	3.30	NA	3906	3580	372.8	234.0	192.6	26.6	78.000	219.000	16.000	8.290	22.00	19.00	14.0	NA	NA	NA	8.3	2615	811	17.0
09/19/79	3.30	NA	5852	5700	522.0	384.0	286.0	39.2	131.000	348.000	24.000	10.130	25.50	28.00	51.0	NA	NA	NA	11.0	1726	220	12.0
10/18/79	3.40	NA	5446	6330	518.0	398.0	272.0	36.4	91.000	347.000	25.000	10.130	15.76	28.00	9.0	NA	NA	NA	10.0	840	360	NA
10/19/79	3.60	NA	2356	1700	185.6	138.0	76.0	12.8	18.000	115.000	10.000	4.390	4.16	10.09	3.0	NA	NA	NA	5.4	1730	1591	NA

Table A2.6. Drainage quality data from Duluth Complex test pile FL5, from 1978-1991 (1.41% S, 0.30% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/l	Vol. L	DailyFlow L	Temp. °C.
10/31/79	3.30	NA	3937	3310	320.0	260.0	150.0	22.0	49.000	268.000	25.100	8.110	10.60	19.45	6.0	NA	NA	NA	7.0	4046	1743	NA
11/01/79	3.40	NA	3567	3180	294.0	244.0	132.0	22.6	63.000	268.000	24.600	8.000	11.77	18.60	8.0	NA	NA	NA	6.2	4345	1671	NA
03/29/80	3.70	NA	3500	2100	222.7	190.9	90.8	15.0	41.110	206.500	15.110	6.530	2.26	15.00	7.0	NA	NA	NA	4.9	1401	994	16.0
03/31/80	3.60	NA	2450	1700	168.2	125.6	57.4	10.0	34.080	144.000	8.940	3.870	7.29	11.00	3.0	NA	NA	NA	2.5	3369	1070	NA
04/05/80	4.60	NA	2288	1055	169.4	112.6	49.0	9.0	21.855	124.000	7.725	3.300	8.13	9.25	2.5	NA	NA	NA	NA	4543	1984	NA
04/14/80	3.50	NA	NA	1220	190.4	135.6	63.6	10.4	30.600	131.000	9.000	4.140	5.90	11.00	4.0	NA	NA	NA	NA	2271	497	NA
04/18/80	3.50	NA	NA	2550	231.8	184.0	86.6	12.6	46.000	187.000	14.000	5.930	7.91	17.00	4.0	NA	NA	NA	3.5	1590	497	NA
04/27/80	3.50	NA	4825	3880	342.4	314.0	166.6	20.4	97.000	321.000	21.000	14.000	10.77	28.00	7.0	NA	NA	NA	NA	530	50	13.0
05/10/80	3.40	NA	6110	6700	376.8	442.0	210.6	26.4	133.000	423.000	30.000	18.000	15.00	37.00	10.0	NA	NA	NA	7.9	451	109	12.0
05/18/80	3.23	NA	6000	6125	386.4	485.0	223.6	29.6	140.000	464.500	35.500	20.000	12.19	40.00	13.0	NA	NA	NA	NA	640	21	19.0
05/31/80	3.40	NA	3450	3040	244.4	233.0	112.8	18.2	54.000	245.000	15.100	8.400	6.94	19.00	15.0	NA	NA	NA	4.2	791	134	NA
06/03/80	3.45	NA	4750	3960	292.2	274.0	139.8	22.0	58.000	273.000	17.600	9.760	6.08	20.00	15.0	NA	NA	NA	7.3	303	134	NA
06/07/80	3.40	NA	4550	3920	279.6	259.0	125.2	20.8	54.000	261.000	16.500	9.200	6.45	19.00	16.0	NA	NA	NA	NA	382	128	NA
06/13/80	3.30	NA	5000	4070	332.0	283.0	152.2	23.4	63.000	289.000	19.100	10.250	7.50	20.00	12.0	NA	NA	NA	NA	299	140	NA
06/19/80	3.30	NA	5000	6200	341.0	345.0	181.0	26.2	80.000	360.000	23.200	12.050	8.33	26.00	12.0	NA	NA	NA	NA	155	18	NA
06/28/80	3.30	NA	4674	4250	341.0	355.0	147.0	23.0	59.000	269.000	24.000	12.000	9.00	24.00	10.0	NA	NA	NA	9.2	507	158	NA
06/30/80	3.70	NA	5000	4600	358.0	363.0	155.0	23.0	67.000	330.000	28.000	13.000	8.00	26.00	14.0	NA	NA	NA	17.0	329	64	NA
07/02/80	3.50	NA	2600	1850	200.0	148.0	57.0	12.0	23.000	129.000	12.000	4.660	5.73	10.00	9.0	NA	NA	NA	NA	409	257	NA
07/13/80	3.20	NA	6360	5750	417.0	444.0	220.0	31.0	84.000	415.000	28.000	15.000	9.90	36.00	15.0	NA	NA	NA	NA	284	34	NA
07/23/80	3.20	NA	5000	5700	435.0	506.0	232.0	30.0	80.000	411.600	30.000	14.000	9.90	37.00	16.0	NA	NA	NA	NA	295	20	NA
08/03/80	3.20	NA	5000	NA	483.0	587.0	274.0	34.0	90.000	582.000	36.000	19.000	13.00	47.00	NA	NA	NA	NA	9.1	34	111	NA
08/12/80	3.35	NA	4750	4180	348.0	347.0	134.0	24.0	36.000	279.000	19.000	9.000	7.75	25.00	12.0	NA	NA	NA	9.3	492	316	NA
08/17/80	3.30	NA	5000	5560	393.0	446.0	162.0	28.0	46.000	357.000	25.000	11.000	7.45	30.00	13.0	NA	NA	NA	NA	261	26	NA
08/22/80	NA	NA	4900	4180	279.0	512.0	133.0	17.0	31.000	266.000	21.000	11.000	6.50	22.00	13.0	NA	NA	NA	NA	231	112	NA
08/29/80	3.50	NA	2540	2400	172.0	240.0	65.0	12.0	22.000	141.000	10.420	5.300	5.22	12.00	19.0	NA	NA	NA	8.2	1319	700	NA
09/08/80	3.40	NA	4078	4100	231.0	503.0	133.0	21.0	44.000	262.000	21.000	10.000	8.83	22.00	15.0	NA	NA	NA	NA	522	134	NA
09/09/80	3.30	NA	4350	4700	283.0	569.0	154.0	22.0	54.000	296.000	22.000	12.000	7.30	25.00	13.0	NA	NA	NA	NA	102	600	14.0
09/12/80	3.40	NA	2694	2580	103.0	296.0	75.0	13.0	28.000	174.000	11.000	8.000	5.16	14.00	11.0	NA	NA	NA	NA	916	596	18.0
09/18/80	3.40	NA	3310	3050	158.0	373.0	94.0	15.0	56.000	217.000	15.000	9.000	5.45	17.00	16.0	NA	NA	NA	NA	3691	2740	14.0
09/25/80	3.30	NA	5588	5200	380.0	608.0	189.0	38.0	60.000	443.000	26.500	15.500	8.71	35.00	22.0	NA	NA	NA	11.0	1109	288	14.0
10/23/80	3.30	NA	5742	7700	390.0	660.0	202.0	32.0	59.300	472.000	28.800	16.900	8.68	38.00	19.0	NA	NA	NA	9.4	757	593	10.0
10/31/80	3.40	NA	5148	4700	309.0	491.0	187.0	26.0	75.000	353.000	28.000	14.000	6.00	33.00	16.0	NA	NA	NA	NA	647	91	11.0
02/19/81	3.60	NA	3692	3450	198.9	279.0	148.0	NA	49.300	270.000	18.100	8.850	NA	NA	17.0	NA	NA	NA	NA	908	1419	8.0
02/21/81	3.60	NA	2500	2040	130.0	144.2	87.1	NA	26.800	183.000	11.000	4.920	NA	NA	14.0	NA	NA	NA	NA	1344	549	NA
03/29/81	3.50	NA	2000	1420	94.9	110.5	53.3	NA	20.200	123.000	7.600	3.680	NA	NA	NA	NA	NA	NA	4.9	3702	773	NA
04/03/81	3.90	NA	1825	1250	85.8	91.0	46.8	NA	23.600	115.000	6.900	3.590	NA	NA	NA	NA	NA	NA	NA	4364	927	NA
04/13/81	3.70	NA	4000	2800	155.0	214.0	69.0	NA	71.000	239.000	13.800	7.900	NA	NA	NA	NA	NA	NA	NA	1033	405	NA
04/17/81	3.80	NA	4500	3080	194.0	293.0	100.0	NA	76.000	264.000	14.800	8.510	NA	NA	NA	NA	NA	NA	7.3	806	413	NA
04/23/81	3.70	NA	4350	3850	192.0	338.0	108.0	NA	107.000	331.000	17.300	10.700	NA	NA	NA	NA	NA	NA	NA	1453	1594	NA
04/25/81	3.60	NA	4575	3000	170.0	279.0	81.0	NA	76.000	251.000	14.700	8.050	NA	NA	NA	NA	NA	NA	NA	6057	1715	NA
04/28/81	3.60	NA	4200	3000	174.0	270.0	76.0	NA	70.000	233.000	14.200	7.730	NA	NA	NA	NA	NA	NA	7.0	4168	2146	NA
04/29/81	3.50	NA	5004	4300	296.0	440.0	114.0	NA	105.000	312.000	20.300	8.150	NA	NA	NA	NA	NA	NA	NA	3736	1098	9.0
05/12/81	3.35	NA	6386	5250	374.0	590.0	200.0	NA	159.000	501.000	26.300	9.780	NA	NA	NA	NA	NA	NA	12.0	2165	119	18.0
05/28/81	3.35	NA	5952	7500	344.0	580.0	182.0	NA	137.000	500.000	25.200	9.630	NA	NA	NA	NA	NA	NA	NA	893	2146	16.0
06/06/81	3.25	NA	5709	6000	312.0	540.0	158.0	NA	102.000	441.500	25.910	9.580	NA	NA	NA	NA	NA	NA	9.6	621	51	19.0
06/22/81	3.40	NA	4570	4300	246.0	460.0	114.0	NA	63.000	354.000	21.750	7.990	NA	NA	NA	NA	NA	NA	NA	1143	607	16.0
06/24/81	3.40	NA	3150	2370	174.0	200.0	56.0	NA	34.000	199.000	13.200	5.700	NA	NA	NA	NA	NA	NA	NA	1189	659	17.0
06/28/81	3.35	NA	3032	2550	174.0	210.0	58.0	NA	45.000	204.500	13.800	5.600	NA	NA	NA	NA	NA	NA	6.6	2036	1352	15.0
07/04/81	3.30	NA	4298	4050	272.0	366.0	106.0	NA	117.000	307.500	22.000	11.000	NA	NA	NA	NA	NA	NA	NA	4891	173	22.0
07/24/81	3.30	NA	7122	8000	392.0	524.6	242.0	NA	185.000	550.000	43.000	21.500	NA	NA	33.0	NA	NA	NA	7.9	386	70	21.0
08/04/81	3.10	NA	8085	9350	426.0	830.0	256.0	NA	129.500	676.000	50.000	25.500	NA	NA	NA	NA	NA	NA	NA	291	22	18.0

Table A2.6. Drainage quality data from Duluth Complex test pile FL5, from 1978-1991 (1.41% S, 0.30% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/L	K mg/l	Cu mg/L	Ni mg/l	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
08/17/81	3.10	NA	8037	8400	414.0	870.0	260.0	34.0	104.000	630.000	43.000	20.000	NA	NA	NA	NA	NA	NA	NA	182	4	22.0
08/31/81	3.30	NA	8900	9000	440.0	980.0	250.0	NA	108.000	741.000	47.000	25.000	NA	NA	NA	NA	NA	NA	9.8	106	36	17.0
09/07/81	3.30	NA	7500	7900	440.0	820.0	210.0	NA	80.000	660 000	42.000	22.000	NA	NA	NA	NA	NA	NA	NA	121	58	NA
09/16/81	3.30	NA	5000	9600	480.0	1030.0	260.0	NA	92.000	762.000	49.000	26.000	NA	NA	NA	NA	NA	NA	NA	72	4	NA
09/26/81	3.50	NA	4965	5000	330.0	520.0	120.0	NA	39.000	381.000	24.000	12.000	NA	NA	NA	NA	NA	NA	8.0	329	210	NA
10/01/81	3.50	NA	4375	2600	206.0	290.0	86.0	NA	23.000	240.000	16.000	8.000	NA	NA	NA	NA	NA	NA	NA	693	983	NA
10/04/81	3.45	NA	3900	2600	154.0	238.0	64.0	14.0	32.000	200.000	16.000	6.000	NA	NA	NA	NA	NA	NA	NA	1136	706	NA
10/14/81	3.40	NA	3950	2960	176.0	236.0	68.0	14.0	53.000	198.000	15.000	8.000	NA	NA	NA	NA	NA	NA	5.6	4554	1622	NA
10/18/81	3.30	NA	5000	4000	326.0	262.0	102.0	10.0	58.000	119.000	7.000	4.130	NA	NA	NA	NA	NA	NA	NA	6337	1288	NA
11/06/81	3.20	NA	5000	5400	292.0	530.0	140.0	26.0	140.000	412.000	26.000	11.000	NA	NA	NA	NA	NA	NA	6.6	3585	105	NA
03/30/82	3.45	NA	4200	3100	174.0	350.0	68.0	12.0	55.000	233.000	18.000	8.050	NA	NA	NA	NA	NA	NA	NA	3218	NA	NA
04/06/82	3.50	NA	4200	3200	169.0	355.0	70.0	11.0	65.000	253.000	17.500	8.180	NA	NA	NA	NA	NA	NA	NA	2657	NA	NA
04/13/82	3.50	NA	2600	1900	131.0	140.0	36.0	8.0	36.000	138.000	8.900	4.100	NA	NA	NA	NA	NA	NA	NA	5443	NA	NA
04/15/82	3.55	NA	1950	1015	111.1	94.0	23.0	6.0	28.000	88.500	6.200	2.430	NA	NA	NA	NA	NA	NA	NA	5182	NA	NA
04/19/82	3.50	NA	2250	1500	142.0	152.0	38.0	10.0	39.000	126.000	8.100	3.750	NA	NA	NA	NA	NA	NA	NA	2014	NA	NA
04/23/82	3.45	NA	3050	2300	188.0	192.0	70.0	12.0	62.000	197.000	12.200	5.470	NA	NA	NA	NA	NA	NA	NA	1344	NA	NA
05/03/82	3.40	NA	4010	5500	330.0	400.0	126.0	22.0	126.000	405.000	28.000	12.000	NA	NA	NA	NA	NA	NA	NA	114	NA	NA
05/04/82	3.50	NA	3450	2500	156.0	216.0	66.0	12.0	58.000	142.000	12.200	5.710	NA	NA	NA	NA	NA	NA	NA	867	NA	NA
05/07/82	3.40	NA	5000	4000	212.0	300.0	136.0	16.0	105.000	316.000	22.000	10.000	NA	NA	NA	NA	NA	NA	NA	1889	NA	NA
05/10/82	3.50	NA	3650	2700	172.0	226.0	74.0	12.0	72.000	204.000	12.700	5.740	NA	NA	NA	NA	NA	NA	NA	3751	NA	NA
05/11/82	3.40	NA	4250	4200	190.0	200.0	10.0	14.0	88.000	251.000	20.000	9.000	NA	NA	NA	NA	NA	NA	NA	4698	NA	NA
05/14/82	3.40	NA	4550	4700	248.0	348.0	86.0	16.4	88.000	254.000	16.300	7.780	3.63	17.04	NA	NA	NA	NA	NA	6787	NA	NA
05/21/82	3.30	NA	4725	8000	320.0	660.0	153.0	21.0	135.000	416.000	28.000	14.000	4.01	24.00	NA	NA	NA	NA	NA	2006	NA	NA
06/02/82	3.25	NA	6160	8500	342.0	790.0	190.0	26.0	156.000	549.000	32.000	20.000	4.51	33.00	NA	NA	NA	NA	NA	723	NA	NA
06/18/82	3.30	NA	5424	8000	298.0	680.0	155.0	22.0	113.000	440.000	30.000	16.000	3.05	28.00	NA	NA	NA	NA	NA	185	NA	NA
07/02/82	NA	NA	NA	5000	308.0	362.0	110.0	18.0	97.000	359.000	21.800	8.900	3.57	19.57	NA	NA	NA	NA	NA	7908	NA	NA
07/26/82	3.24	NA	5266	5500	314.0	408.0	120.0	20.0	102.000	443.000	25.000	10.500	5.52	23.29	NA	NA	NA	NA	NA	6908	NA	NA
08/30/82	3.26	NA	4421	3750	302.0	374.0	122.0	18.0	86.000	344.000	21.200	8.500	3.26	18.89	NA	NA	NA	NA	NA	4376	NA	NA
10/04/82	3.60	NA	4316	3750	230.0	336.0	92.0	16.0	92.000	389.000	20.000	8.300	5.44	20.50	NA	NA	NA	NA	NA	23454	NA	NA
11/01/82	3.40	NA	4200	NA	168.0	278.0	76.0	12.0	58.000	291.000	17.200	7.000	3.03	17.60	NA	NA	NA	NA	NA	1363	NA	NA
03/18/83	3.66	NA	3154	3360	NA	NA	NA	NA	38.000	161.000	13.000	5.380	NA	NA	NA	NA	NA	NA	NA	1537	NA	NA
04/14/83	3.70	NA	3209	3400	NA	NA	NA	NA	40.000	174.000	14.000	5.690	NA	NA	NA	NA	NA	NA	NA	3311	NA	NA
05/15/83	3.54	NA	3873	4720	NA	NA	NA	NA	90.000	240.000	18.000	8.540	NA	NA	NA	NA	NA	NA	NA	2361	NA	NA
06/16/83	3.67	NA	4471	5000	NA	NA	NA	NA	84.000	307.000	16.600	6.490	NA	NA	NA	NA	NA	NA	NA	507	NA	NA
07/04/83	3.50	NA	3825	3700	NA	NA	NA	NA	109.000	256.000	18.400	8.200	NA	NA	NA	NA	NA	NA	NA	5314	NA	NA
07/11/83	3.70	NA	5000	7200	NA	NA	NA	NA	123.000	480.000	32.400	14.800	NA	NA	NA	NA	NA	NA	NA	731	NA	NA
07/17/83	3.50	NA	6572	7700	NA	NA	NA	NA	127.000	418.000	28.300	15.200	NA	NA	NA	NA	NA	NA	NA	284	NA	NA
07/20/83	3.50	NA	6608	6200	NA	NA	NA	NA	140.000	392.000	28.000	13.400	NA	NA	NA	NA	NA	NA	NA	825	NA	NA
07/25/83	3.60	NA	6250	8200	NA	NA	NA	NA	154.000	510.000	36.200	16.200	NA	NA	NA	NA	NA	NA	NA	341	NA	NA
07/31/83	3.65	NA	6405	8900	NA	NA	NA	NA	142.000	535.000	38.000	16.800	NA	NA	NA	NA	NA	NA	NA	148	NA	NA
08/07/83	3.60	NA	4860	4700	NA	NA	NA	NA	70.600	314.000	23.800	10.600	NA	NA	NA	NA	NA	NA	NA	590	NA	NA
08/15/83	3.45	NA	6376	6400	NA	NA	NA	NA	81.000	384.000	29.600	12.600	NA	NA	NA	NA	NA	NA	NA	307	NA	NA
08/22/83	3.60	NA	3500	3150	NA	NA	NA	NA	71.000	201.000	14.640	5.920	NA	NA	NA	NA	NA	NA	NA	3653	NA	NA
08/28/83	3.60	NA	4300	4000	NA	NA	NA	NA	89.000	265.000	18.480	8.140	NA	NA	NA	NA	NA	NA	NA	1393	NA	NA
09/04/83	3.55	NA	5537	5500	NA	NA	NA	NA	110.000	349.000	23.500	10.830	NA	NA	NA	NA	NA	NA	NA	636	NA	NA
09/11/83	3.45	NA	3975	3150	NA	NA	NA	NA	75.000	237.000	16.790	7.370	NA	NA	NA	NA	NA	NA	NA	1298	NA	NA
09/18/83	3.50	NA	4500	4300	NA	NA	NA	NA	85.000	289.000	19.760	8.780	NA	NA	NA	NA	NA	NA	NA	560	NA	NA
09/25/83	3.80	NA	3725	3500	NA	NA	NA	NA	69.000	240.000	17.000	7.380	NA	NA	NA	NA	NA	NA	NA	874	NA	NA
10/02/83	3.50	NA	4475	3400	NA	NA	NA	NA	108.000	241.000	18.000	7.460	NA	NA	NA	NA	NA	NA	NA	10401	NA	NA
10/08/83	3.75	NA	4725	3650	NA	NA	NA	NA	106.000	258.000	15.500	7.820	NA	NA	NA	NA	NA	NA	NA	6018	NA	NA
10/15/83	3.70	NA	4624	4050	NA	NA	NA	NA	116.000	290.000	19.000	8.600	NA	NA	NA	NA	NA	NA	NA	6964	NA	NA

Table A2.6. Drainage quality data from Duluth Complex test pile FL5, from 1978-1991 (1.41% S, 0.30% Cu, 0.08% Ni).

Date'	pH s.u.	Alk. mg/L	S.C. µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/l	Cu mg/L	Ni mg/L	Co mg/L	Zn mg/L	Fe mg/L	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/L	Vol. L	DailyFlow L	Temp. °C.
10/23/83	3.50	NA	5538	5300	NA	NA	NA	NA	130.000	357.000	23.000	10.350	NA	NA	NA	NA	NA	NA	NA	1480	NA	NA
10/30/83	3.65	NA	5576	6200	NA	NA	NA	NA	149.000	410.000	29.000	13.600	NA	NA	NA	NA	NA	NA	NA	1083	NA	NA
11/06/83	3.70	NA	6116	7000	NA	NA	NA	NA	131.800	473.000	32.800	15.200	NA	NA	NA	NA	NA	NA	NA	333	NA	NA
11/13/83	3.80	NA	6958	8100	NA	NA	NA	NA	136.000	520.000	36.800	17.400	NA	NA	NA	NA	NA	NA	NA	212	NA	NA
11/20/83	3.50	NA	3800	3250	NA	NA	NA	NA	82.000	236.000	16.200	7.800	NA	NA	NA	NA	NA	NA	NA	2120	NA	NA
12/01/83	3.55	NA	4875	4600	NA	NA	NA	NA	117.600	314.000	21.600	10.400	NA	NA	NA	NA	NA	NA	NA	1881	NA	NA
02/24/84	3.60	NA	6110	6800	356.5	991.3	165.9	NA	133.800	478.000	32.200	17.400	NA	NA	NA	NA	NA	NA	NA	889	NA	NA
03/15/84	3.55	NA	3225	3200	220.6	381.1	73.2	NA	77.000	220.000	15.000	7.200	NA	NA	NA	NA	NA	NA	NA	1211	NA	NA
04/15/84	3.81	NA	1260	1300	110.9	104.8	23.0	NA	31.000	62.000	4.400	2.300	NA	NA	NA	NA	NA	NA	NA	11004	NA	NA
05/16/84	3.65	NA	2392	2950	NA	NA	NA	NA	83.000	160.000	12.500	5.340	NA	NA	NA	NA	NA	NA	NA	8396	NA	NA
06/13/84	3.58	NA	2985	4500	242.8	342.5	69.3	NA	90.200	207.000	14.000	6.600	NA	NA	NA	NA	NA	NA	NA	11254	NA	NA
07/14/84	3.45	NA	5230	6700	NA	NA	122.0	NA	142.000	356 000	23.000	7.000	NA	NA	NA	NA	NA	NA	NA	2498	NA	NA
08/15/84	3.47	NA	4760	5000	323.7	348.7	115.6	NA	107.000	334.560	34.400	10.540	NA	NA	NA	NA	NA	NA	NA	2252	NA	NA
09/12/84	3.44	NA	5175	6000	374.0	580.0	146.5	NA	105.800	425.000	44.000	14.600	NA	NA	NA	NA	NA	NA	NA	886	NA	NA
10/13/84	3.41	NA	2870	3625	260.1	290.0	74.3	NA	88.700	218 000	21.600	7.700	NA	NA	NA	NA	NA	NA	NA	7066	NA	NA
11/14/84	3.51	NA	3150	2750	372.0	500.0	115.8	NA	134.700	338.000	19.400	10.700	NA	NA	NA	NA	NA	NA	NA	2074	NA	NA
12/05/84	3.42	NA	2470	2200	314.0	470.0	89.0	NA	100.100	260.000	15.500	8.500	NA	NA	NA	NA	NA	NA	NA	651	NA	NA
12/19/84	3.45	NA	2650	2900	254.0	285.0	88.0	NA	97.300	223.000	13.400	6.720	NA	NA	NA	NA	NA	NA	NA	1444	NA	NA
04/02/85	3.08	NA	5000	5650	330.0	562.0	135.6	NA	104.000	348.000	23.000	13.480	NA	NA	NA	NA	NA	NA	NA	489	NA	NA
04/16/85	3.94	NA	2745	2850	210.0	252.0	51.2	NA	86.000	157.000	13.000	5.400	NA	NA	NA	NA	NA	NA	NA	14152	NA	NA
05/14/85	3.74	NA	4640	4808	285.0	475.0	95.0	NA	150.000	279.000	10.500	18.800	NA	NA	NA	NA	NA	NA	NA	3970	NA	NA
06/14/85	3.58	NA	3850	4200	224.0	375.0	70.0	NA	110.000	211.000	14.600	7.100	NA	NA	NA	NA	NA	NA	NA	22384	NA	NA
07/15/85	3.48	NA	4900	5200	270.0	446.0	102.0	NA	110.000	269.000	17.000	7.800	NA	NA	NA	NA	NA	NA	NA	4534	NA	NA
08/13/85	3.47	NA	4450	5100	272.0	466.0	96.0	NA	96.000	266.000	17.800	6.380	NA	NA	NA	NA	NA	NA	NA	2203	NA	NA
09/13/85	3.50	NA	4325	4300	334.0	305.0	78.0	NA	103.000	221.000	14.800	6.500	NA	NA	NA	NA	NA	NA	NA	16207	NA	NA
10/15/85	3.50	NA	4075	3200	276.0	236.0	60.0	NA	94.000	174.000	12.500	5.320	NA	NA	NA	NA	NA	NA	NA	17676	NA	NA
11/15/85	3.54	NA	5200	2100	388.0	510.0	100.0	NA	119.000	296.000	20.700	8.570	NA	NA	NA	NA	NA	NA	NA	1499	NA	NA
12/10/85	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	106	NA	NA
03/23/86	3.80	NA	4800	4200	270.0	414.0	86.0	NA	67.000	250.000	22.000	7.340	NA	NA	NA	NA	NA	NA	NA	7244	NA	NA
04/16/86	3.90	NA	1950	1700	152.0	130.0	28.6	NA	47.000	97.000	11.600	3.010	NA	NA	NA	NA	NA	NA	NA	9909	NA	NA
05/14/86	3.69	NA	3000	3150	282.0	270.0	44.0	NA	92.000	251.000	11.000	5.000	NA	NA	NA	NA	NA	NA	NA	10125	NA	NA
06/11/86	3.63	NA	4750	4600	316.0	360.0	90.0	NA	124.000	260.000	14.000	8.200	NA	NA	NA	NA	NA	NA	NA	1711	NA	NA
07/12/86	3.59	NA	1725	3000	225.0	314.0	61.0	NA	77.000	180.000	12.700	6.300	NA	NA	NA	NA	NA	NA	NA	3085	NA	NA
08/13/86	3.55	NA	4100	3700	268.0	357.0	78.0	NA	79.000	206.000	22.400	7.400	NA	NA	NA	NA	NA	NA	NA	1597	NA	NA
09/14/86	3.40	NA	3550	2700	262.0	286.0	56.0	NA	98.000	159.000	19.400	5.980	NA	NA	NA	NA	NA	NA	NA	10795	NA	NA
10/16/86	3.53	NA	4400	3600	286.0	302.0	68.0	NA	110.000	203.000	13.700	7.150	NA	NA	NA	NA	NA	NA	NA	3982	NA	NA
11/16/86	3.70	NA	3550	2700	260.0	236.0	60.0	NA	110.000	158.000	10.600	7.200	NA	NA	NA	NA	NA	NA	NA	6075	NA	NA
03/28/87	3.65	NA	3075	2900	252.0	264.0	48.0	NA	75.000	160.000	10.800	5.160	NA	NA	NA	NA	NA	NA	NA	7835	NA	NA
04/18/87	3.67	NA	2625	2400	154.0	220.0	40.0	NA	63.000	137.000	10.000	4.440	NA	NA	NA	NA	NA	NA	NA	1620	NA	NA
05/16/87	3.61	NA	2700	2250	233.0	172.0	34.0	NA	73.000	97.000	6.700	3.730	NA	NA	NA	NA	NA	NA	NA	18573	NA	NA
06/16/87	3.44	NA	4900	4640	428.0	492.0	116.0	NA	153.000	331.000	18.600	25.200	NA	NA	NA	NA	NA	NA	NA	1400	NA	NA
07/15/87	3.36	NA	3000	2900	230.0	228.0	48.0	NA	82.000	140.000	9.000	4.930	NA	NA	NA	NA	NA	NA	NA	16908	NA	NA
08/15/87	3.24	NA	3950	3565	279.0	316.0	68.0	NA	97.000	193.000	12.200	6.590	NA	NA	NA	NA	NA	NA	NA	3948	NA	NA
09/16/87	3.25	NA	4100	1200	240.0	238.0	50.0	NA	79.000	135.000	7.980	4.660	NA	NA	NA	NA	NA	NA	NA	7612	NA	NA
10/13/87	3.32	NA	4950	5120	364.0	391.0	88.0	NA	132.000	220.000	13.010	7.250	NA	NA	NA	NA	NA	NA	NA	1457	NA	NA
11/10/87	3.43	NA	4325	3700	308.0	354.0	78.0	NA	9.300	193.000	11.240	6.360	NA	NA	NA	NA	NA	NA	NA	731	NA	NA
05/12/88	3.64	NA	3000	2300	224.0	198.0	54.0	NA	89.500	156.500	8.950	8.450	NA	NA	NA	NA	NA	NA	NA	7275	NA	NA
06/12/88	3.47	NA	4850	4500	412.0	376.0	72.0	NA	163.000	232.000	18.600	23.000	NA	NA	NA	NA	NA	NA	NA	1098	NA	NA
07/15/88	3.60	NA	4525	4360	368.0	382.0	74.0	NA	134.000	234.000	17.600	16.000	NA	NA	NA	NA	NA	NA	NA	757	NA	NA
08/16/88	3.39	NA	2900	2165	247.0	176.0	43.0	NA	72.000	152.000	8.800	6.250	NA	NA	NA	NA	NA	NA	NA	32744	NA	NA
09/16/88	3.37	NA	4275	3200	334.0	294.0	74.0	NA	93.000	117.000	14.300	10.300	NA	NA	NA	NA	NA	NA	NA	6310	NA	NA

Table A2.6. Drainage quality data from Duluth Complex test pile FL5, from 1978-1991 (1.41% S, 0.30% Cu, 0.08% Ni).

Date'	pH s.u.	Alk mg/l	S.C µmho/cm	SO4 mg/L	Ca mg/L	Mg mg/l	Na mg/l	K mg/L	Cu mg/L	Ni mg/L	Co mg/l	Zn mg/L	Fe mg/l	Mn mg/L	Cl mg/L	NO3 mg/L	NH3 mg/L	P mg/L	DissOrgC mg/l	Vol. L	DailyFlow L	Temp. °C.
09/24/88	3.70	NA	1875	1280	160.0	96.0	26.0	NA	36.000	71.000	4.300	3.700	NA	NA	NA	NA	NA	NA	NA	6934	NA	NA
10/18/88	3.67	NA	3700	3400	238.0	258.0	50.0	NA	64.000	143.000	10.900	8.700	NA	NA	NA	NA	NA	NA	NA	1790	NA	NA
10/24/88	3.77	NA	1980	1400	132.0	118.0	26.0	NA	43.000	88.000	4.900	4.400	NA	NA	NA	NA	NA	NA	NA	3819	NA	NA
11/15/88	3.71	NA	2975	2740	216.0	222.0	42.0	NA	68.000	107.000	8.200	7.200	NA	NA	NA	NA	NA	NA	NA	7494	NA	NA
11/30/88	3.44	NA	4200	3760	276.0	306.0	56.0	NA	102.000	169.000	11.500	9.300	NA	NA	NA	NA	NA	NA	NA	2665	NA	NA
04/07/89	3.95	NA	2700	2400	230.0	166.0	38.0	NA	55.000	98.000	9.800	7.000	NA	NA	NA	NA	NA	NA	NA	17581	NA	NA
04/24/89	4.00	NA	1050	650	78.0	38.0	10.0	NA	18.000	26.000	1.800	1.600	NA	NA	NA	NA	NA	NA	NA	7850	NA	NA
05/16/89	3.79	NA	2582	2100	182.0	152.0	34.0	NA	62.000	94.000	7.300	6.100	NA	NA	NA	NA	NA	NA	NA	5802	NA	NA
06/17/89	3.64	NA	3150	2800	258.0	184.0	52.0	NA	80.000	145.000	13.700	7.700	NA	NA	NA	NA	NA	NA	NA	25560	NA	NA
07/17/89	3.55	NA	4325	4100	420.0	304.0	62.0	NA	118.000	210.000	17.700	10.900	NA	NA	NA	NA	NA	NA	NA	2248	NA	NA
08/14/89	3.62	NA	3800	3540	286.0	284.0	58.0	NA	89.000	245.000	15.400	10.200	NA	NA	NA	NA	NA	NA	NA	1158	NA	NA
09/14/89	3.41	NA	2900	2460	272.0	168.0	36.0	NA	68.000	91.000	11.800	6.600	NA	NA	NA	NA	NA	NA	NA	16325	NA	NA
10/16/89	3.51	NA	3700	2960	276.0	226.0	52.0	NA	83.000	116.000	17.700	9.600	NA	NA	NA	NA	NA	NA	NA	2203	NA	NA
11/13/89	3.60	NA	3200	2480	298.0	204.0	44.0	NA	74.000	105.000	21.000	8.900	NA	NA	NA	NA	NA	NA	NA	3758	NA	NA
03/26/90	3.70	NA	2500	1900	226.0	146.0	31.2	NA	41.000	73.000	6.350	7.310	NA	NA	NA	NA	NA	NA	NA	3615	NA	NA
04/12/90	3.91	NA	1950	1660	182.0	108.0	20.0	NA	53.000	57.000	4.380	3.980	NA	NA	NA	NA	NA	NA	NA	20708	NA	NA
05/17/90	3.75	NA	2725	2300	222.0	156.0	26.0	NA	70.000	80.000	6.570	5.560	NA	NA	NA	NA	NA	NA	NA	10783	NA	NA
06/18/90	3.59	NA	3475	2660	236.0	180.0	38.0	NA	72.000	92.000	9.170	7.640	NA	NA	NA	NA	NA	NA	NA	9421	NA	NA
07/16/90	3.62	NA	4175	3460	306.0	226.0	40.0	NA	92.000	108.000	9.600	8.610	NA	NA	NA	NA	NA	NA	NA	6684	NA	NA
08/13/90	3.53	NA	4785	3920	370.0	326.0	62.0	NA	106.000	166.000	13.100	11.200	NA	NA	NA	NA	NA	NA	NA	757	NA	NA
09/10/90	3.64	NA	3260	2360	238.0	178.0	38.0	NA	54.000	99.000	7.280	5.380	NA	NA	NA	NA	NA	NA	NA	2434	NA	NA
10/15/90	3.55	NA	3415	2160	252.0	154.0	32.0	NA	74.000	88.000	6.510	5.000	NA	NA	NA	NA	NA	NA	NA	20643	NA	NA
11/16/90	3.60	NA	5000	3940	372.0	308.0	62.0	NA	120.000	142.000	12.170	12.440	NA	NA	NA	NA	NA	NA	NA	1397	NA	NA
04/08/91	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9777	NA	NA
04/22/91	3.76	NA	1700	1010	120.0	80.0	14.0	NA	34.000	41.000	2.200	1.600	NA	NA	NA	NA	NA	NA	NA	5598	NA	NA
05/20/91	3.65	NA	4175	2500	262.0	205.0	32.0	NA	94.000	103.000	5.600	4.200	NA	NA	NA	NA	NA	NA	NA	8687	NA	NA
06/17/91	3.61	NA	2975	2000	188.0	168.0	26.0	NA	64.000	84.000	5.300	3.300	NA	NA	NA	NA	NA	NA	NA	3388	NA	NA
07/15/91	3.47	NA	3225	2020	198.0	140.0	24.0	NA	66.000	69.000	4.600	3.500	NA	NA	NA	NA	NA	NA	NA	16938	NA	NA
08/12/91	3.43	NA	5000	4460	394.0	334.0	72.0	NA	124.000	176.000	11.900	8.700	NA	NA	NA	NA	NA	NA	NA	1268	NA	NA
09/09/91	3.59	NA	3225	1940	200.0	126.0	32.0	NA	54.000	73.000	4.600	3.700	NA	NA	NA	NA	NA	NA	NA	6079	NA	NA
10/07/91	3.62	NA	3775	2380	238.0	158.0	38.0	NA	72.000	87.000	5.500	5.600	NA	NA	NA	NA	NA	NA	NA	3656	NA	NA
11/07/91	3.51	NA	3300	2280	236.0	156.0	34.0	NA	75.000	80.000	5.100	5.100	NA	NA	NA	NA	NA	NA	NA	14780	NA	NA

NA: Not analyzed.

'Dates represent intermediate dates for measurement periods.

Table A2.7. Annual flow-weighted mean concentration vs. annual drainage volume regression statistics[1].

Sulfur %	Pile	Flow-weighted Mean Concentration (mmol/L) = a • volume (L) + b											
		Sulfate			Calcium			Magnesium			Calcium plus Magnesium		
		a x 10^5	r^2	n	a x 10^5	r^2	n	a x 10^5	r^2	n	a x 10^5	r^2	n
0.63	FL1	-2.7	0.136	13	-1.6	0.380	12	0.5	0.013	12	-1.1	0.041	12
0.63	FL2	2.6	0.168	13	0.3	0.011	12	1.4	0.119	12	1.7	0.110	12
0.63	FL3	0.4	0.000	11	-0.2	0.001	10	1.6	0.021	10	1.4	0.010	10
0.79	FL6	-9.1	0.173	13	-0.7	0.175	12	-3.0	0.059	12	-3.7	0.089	12
1.41	FL5	-5.4	0.027	13	1.2	0.248	12	-4.3	0.114	12	-3.2	0.062	12

[1] Regressions excluded 1978 flow-weighted mean concentration data.

APPENDIX 3

MASS RELEASE

Appendix 3: Mass Release

Table A3.1. Percent of total original sulfur released.

Table A3.1. Percent of total original sulfur released.

Pile	Sulfur %	Mass of Pile metric T	Mass Release of SO_4 metric T	% of Original S Released
FL1	0.63	1100	1.25	6.02
FL2	0.63	1100	0.75	3.60
FL3	0.63	830	1.31	8.36
FL4	0.63	1130	0.33	1.55
FL6	0.79	1300	3.21	10.42
FL5	1.41	815	2.78	8.08

APPENDIX 4

RATES OF RELEASE

Appendix 4: Rates of Release

Figure A4.1. Annual flow-weighted mean calcium plus magnesium concentration for 1978 through 1991 for FL1 (□), FL2 (*), FL3 (◊), FL4 (★), FL6 (△), and FL5 (○).

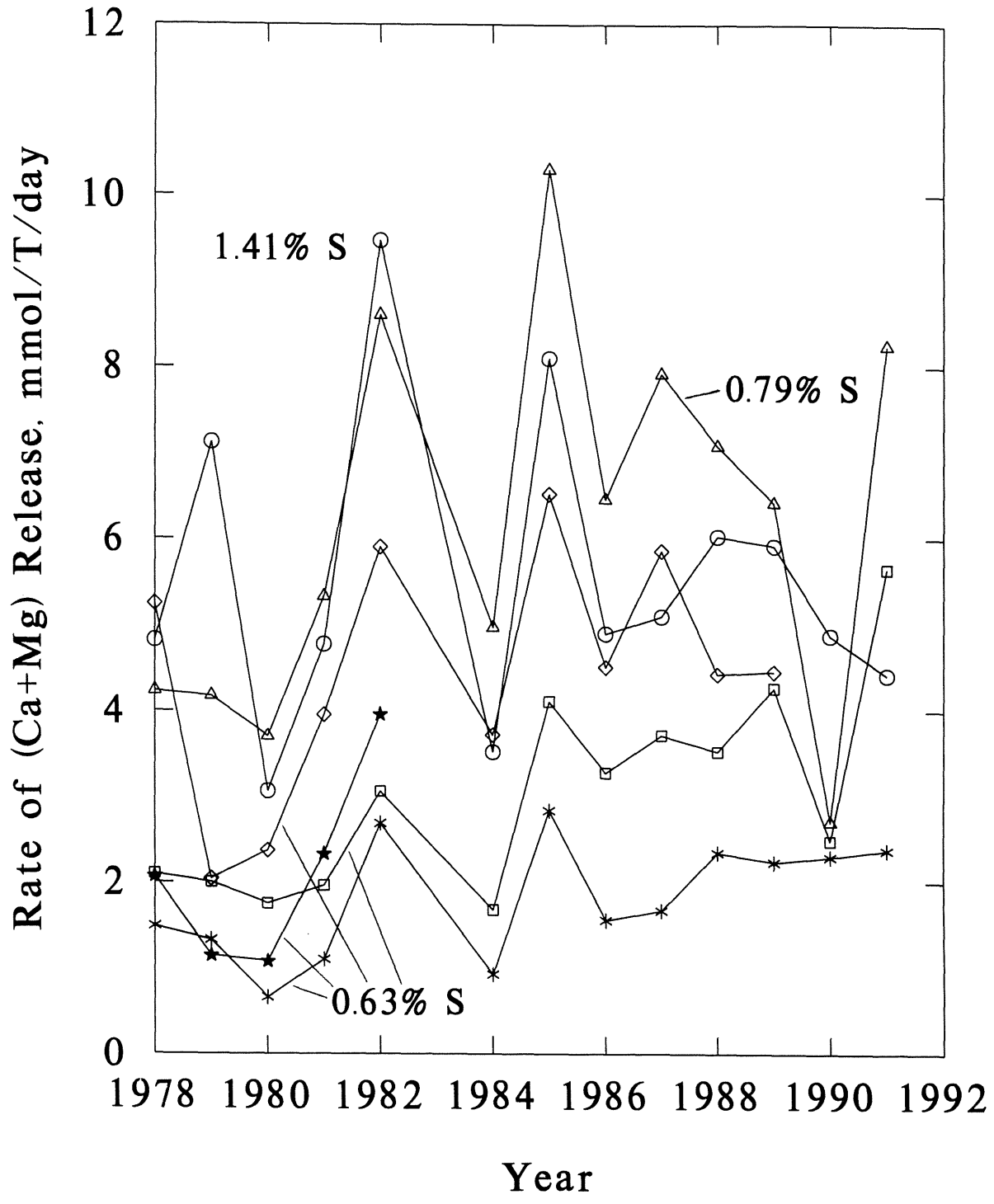

Figure A4.2. Average rates of release of sulfate, calcium, magnesium, and calcium plus magnesium vs. sulfur content for Duluth Complex test piles.

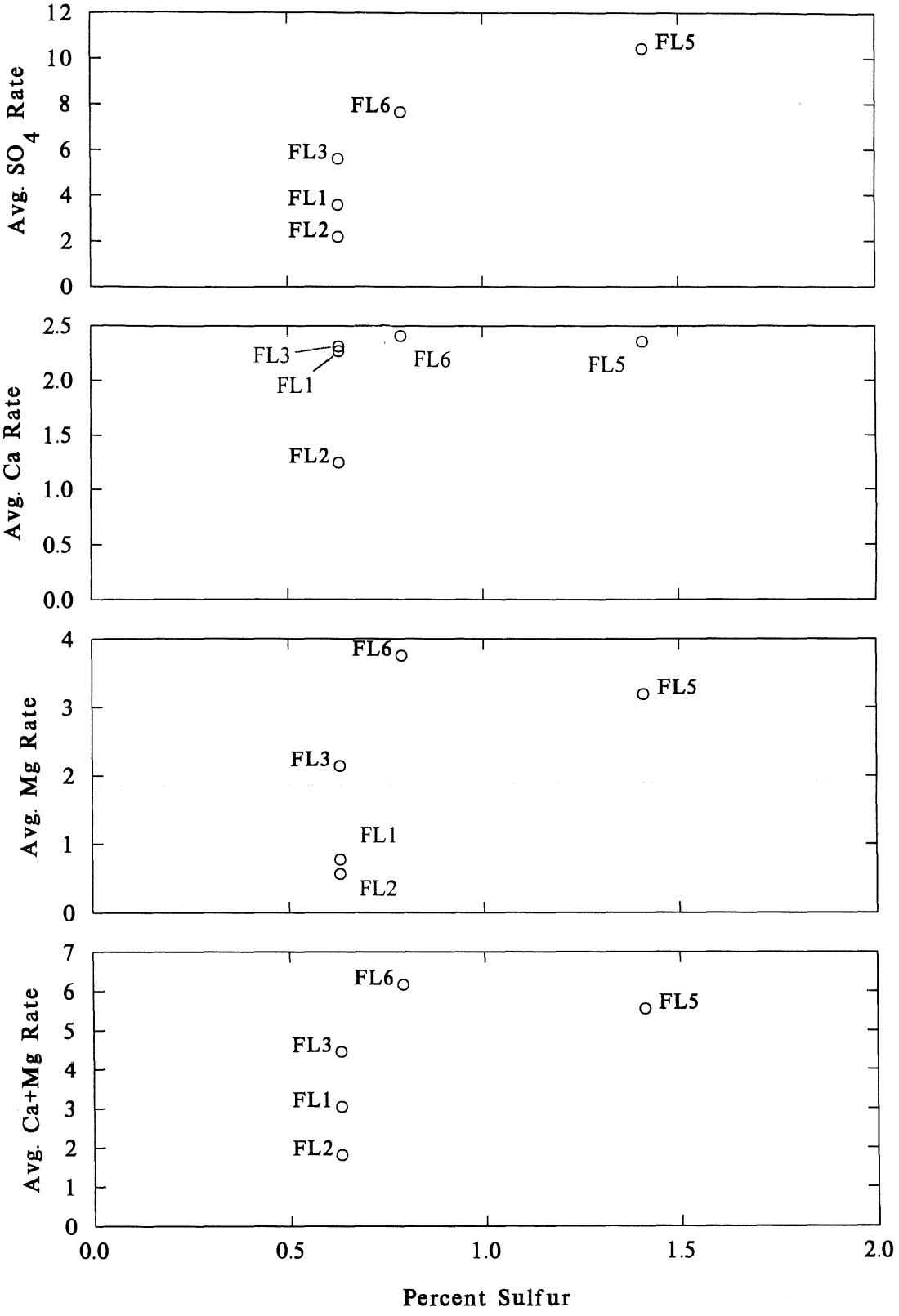

Figure A4.3. Annual rates of release of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL1 (0.63% S).

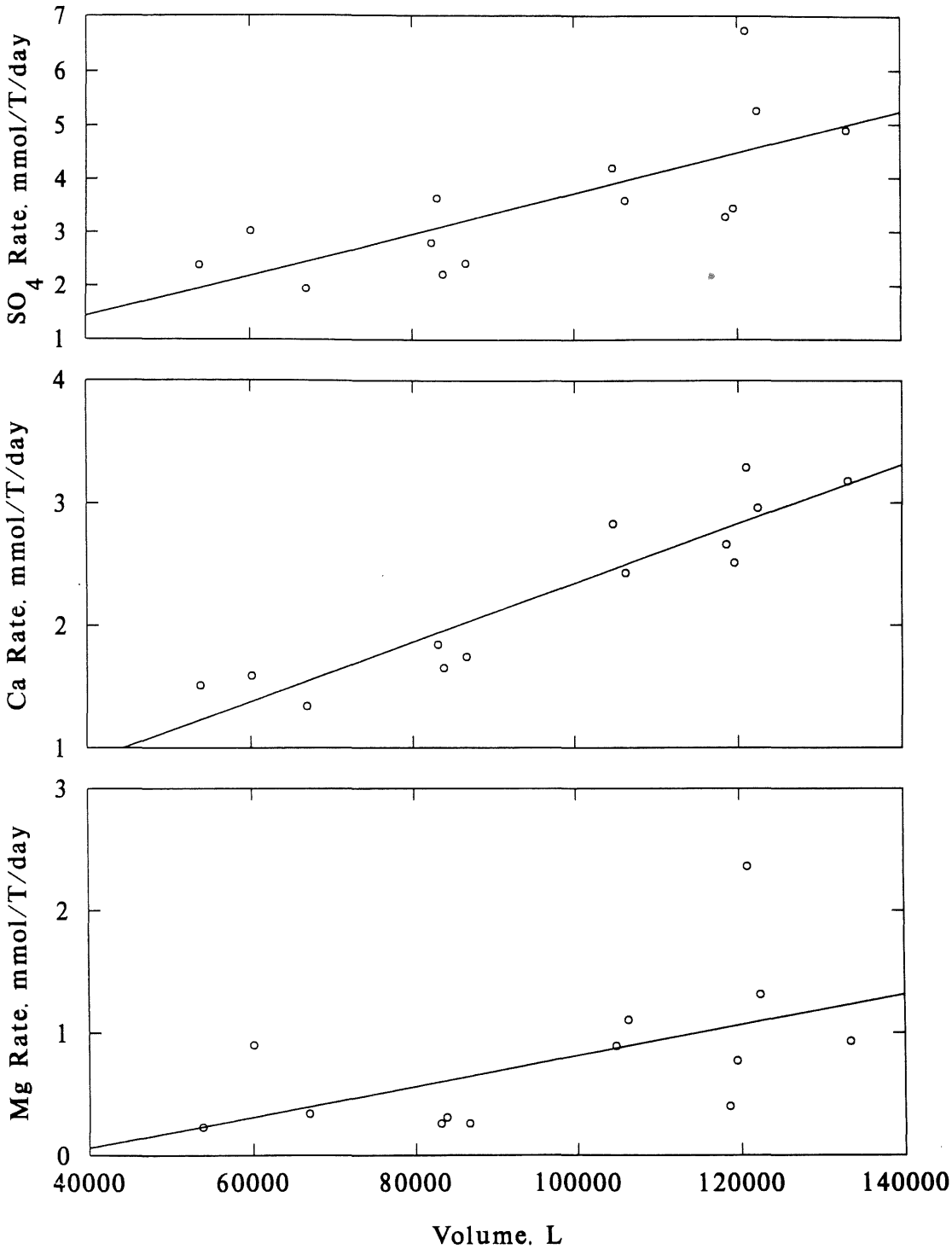

Figure A4.4. Annual rates of release of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL1 (0.63% S).

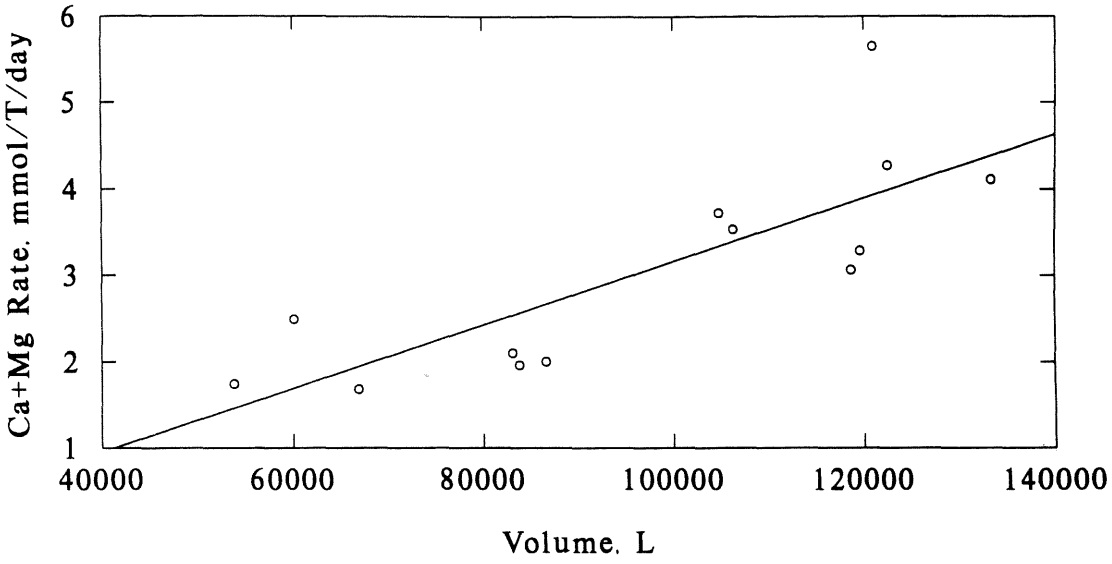

Figure A4.5. Annual rates of release of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL2 (0.63% S).

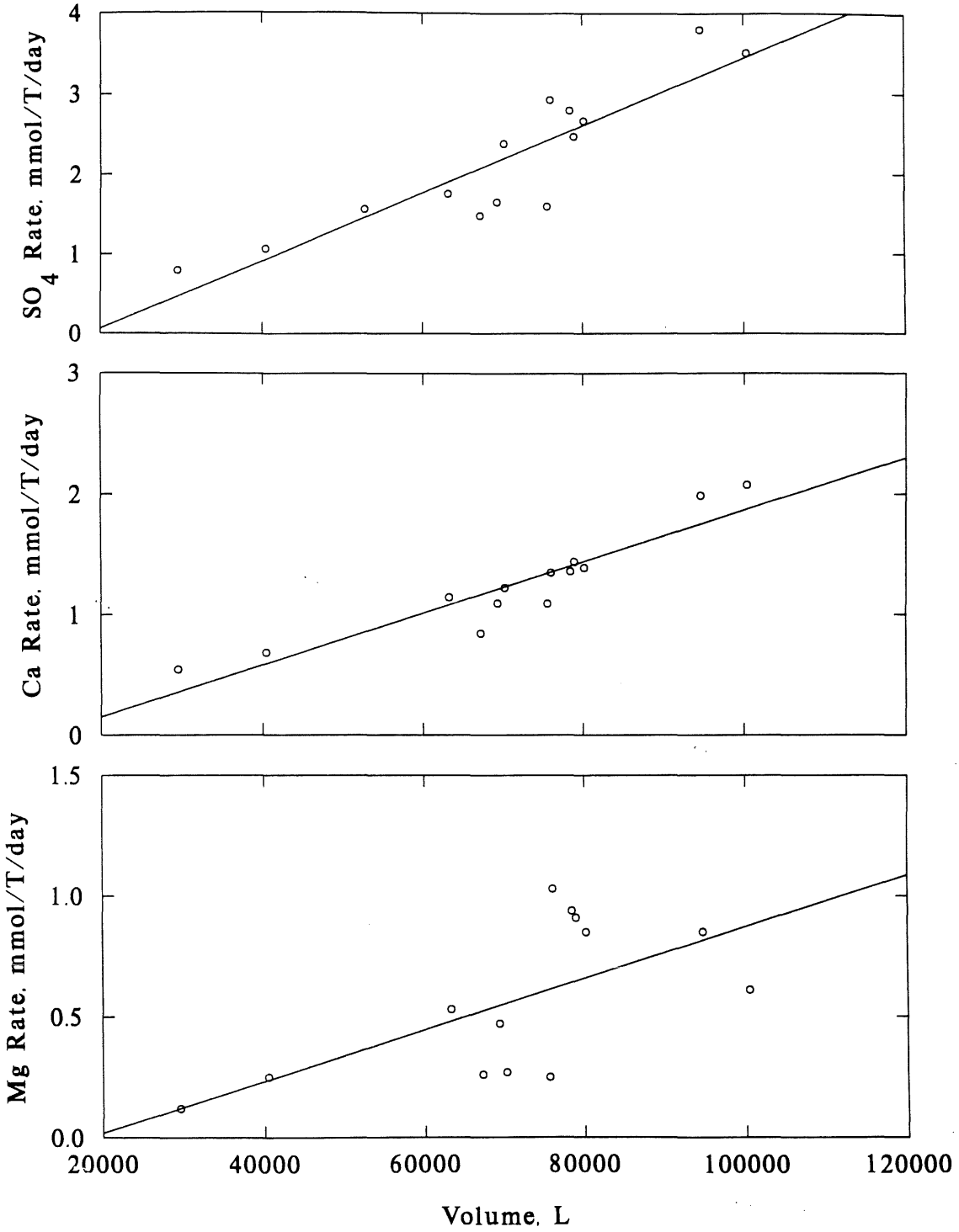

Figure A4.6. Annual rates of release of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL2 (0.63% S).

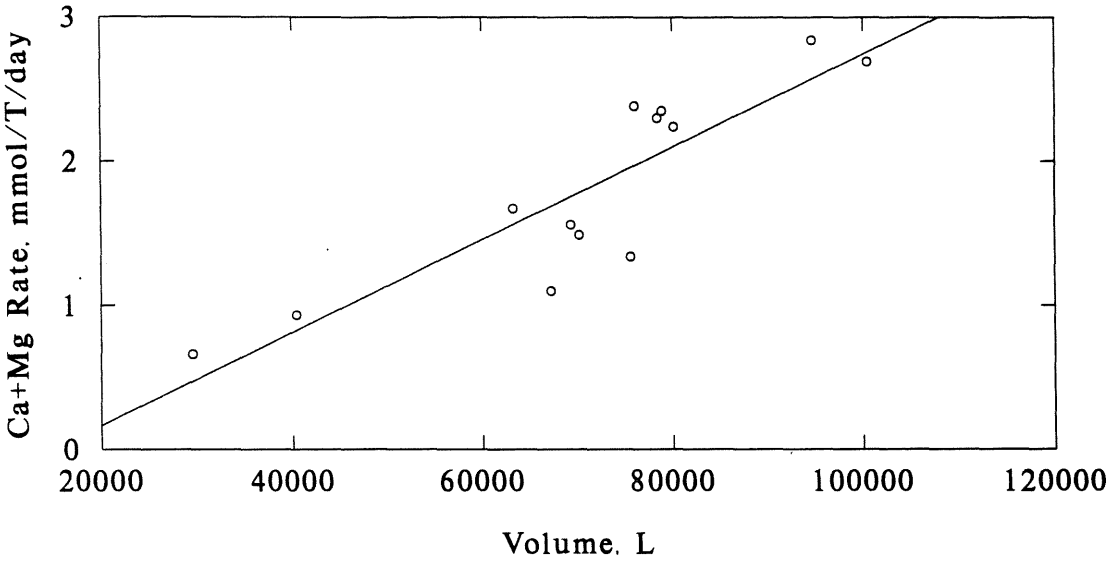

Figure A4.7. Annual rates of release of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL3 (0.63% S).

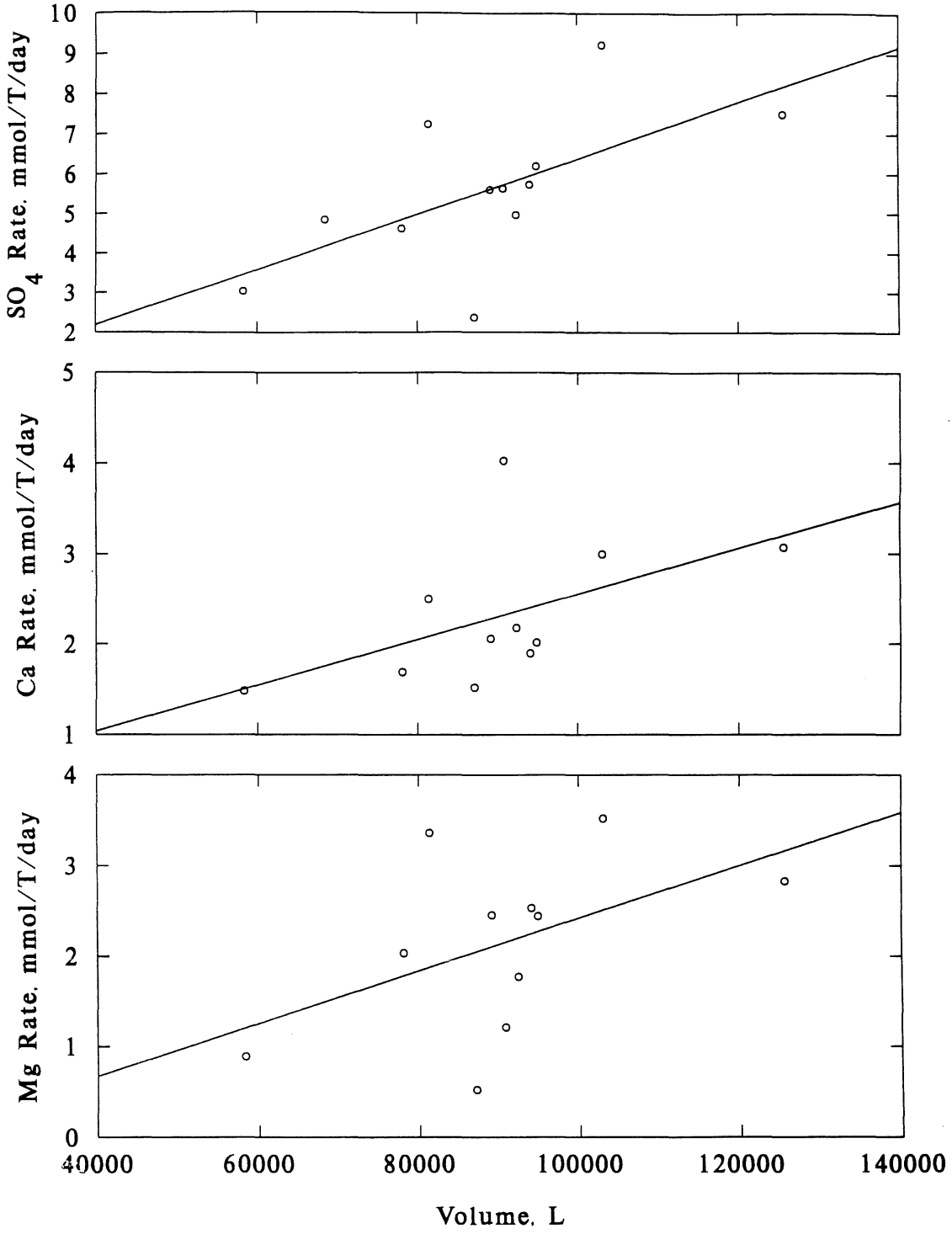

Figure A4.8. Annual rates of release of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL3 (0.63% S).

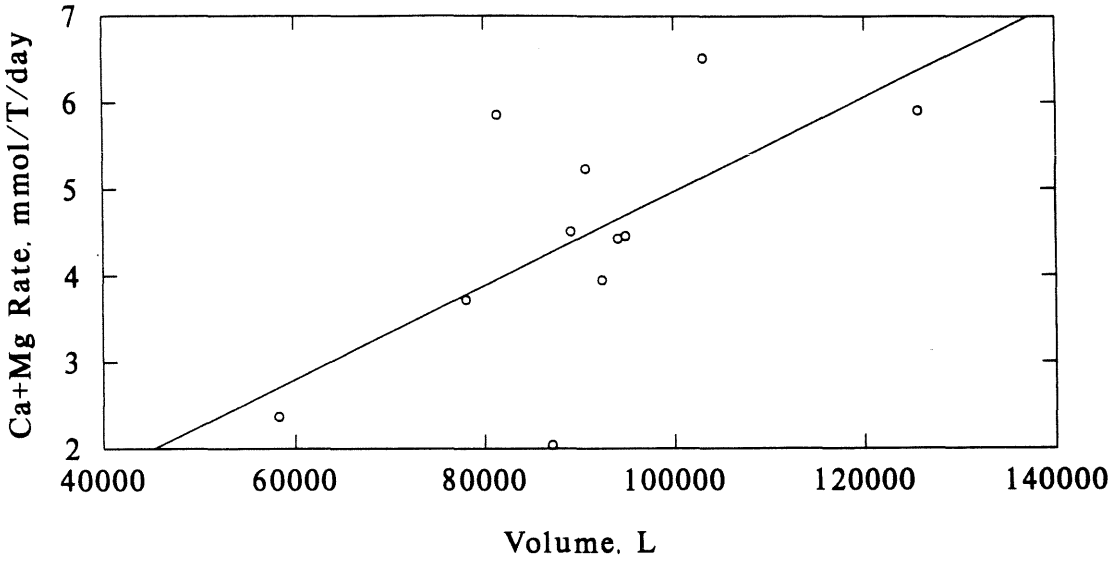

Figure A4.9. Annual rates of release of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL6 (0.79% S).

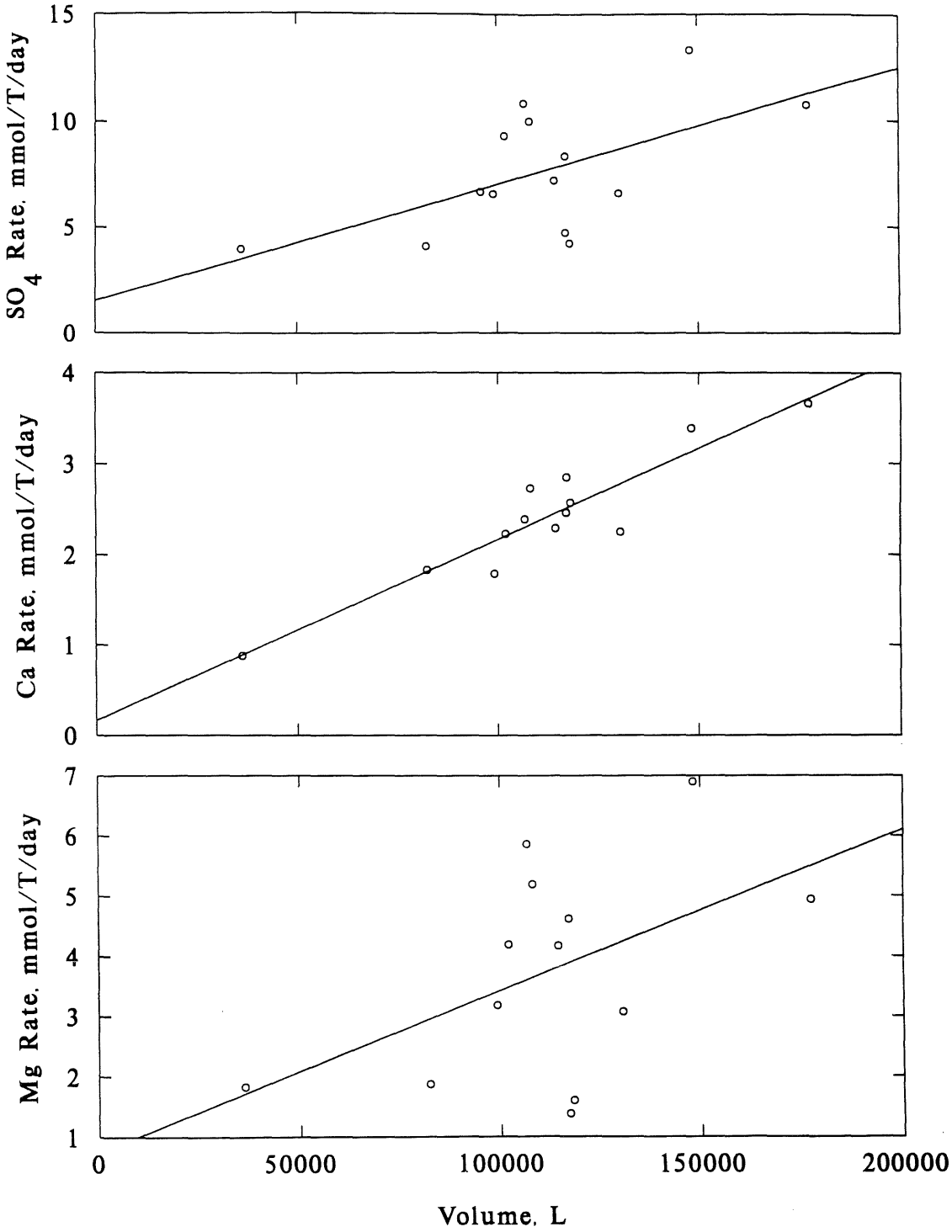

Figure A4.10. Annual rates of release of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL6 (0.79% S).

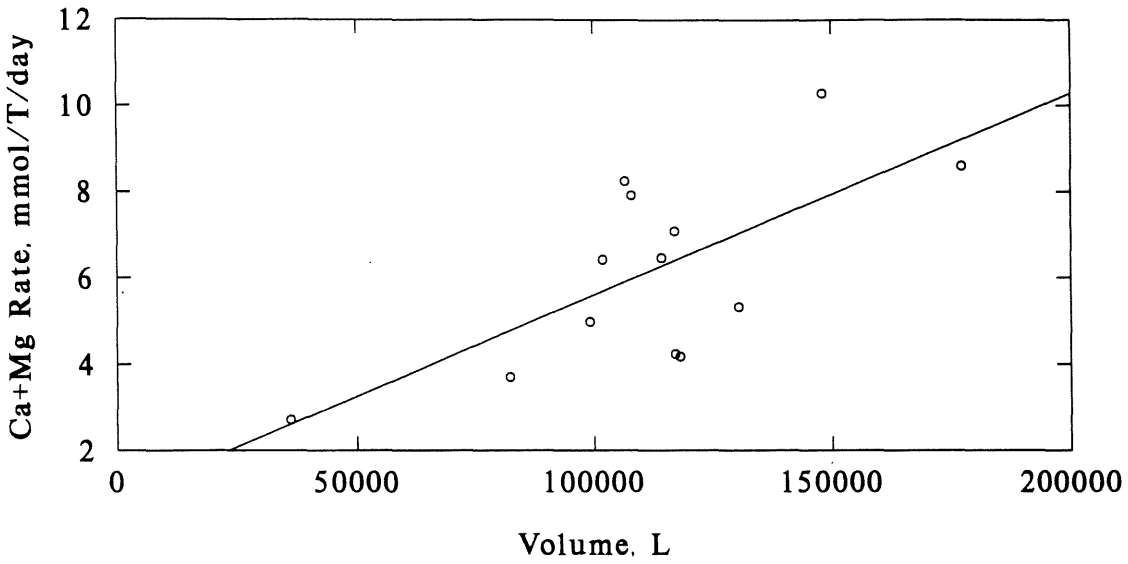

Figure A4.11. Annual rates of release of sulfate, calcium, and magnesium vs. annual drainage volume for Duluth Complex test pile FL5 (1.41% S).

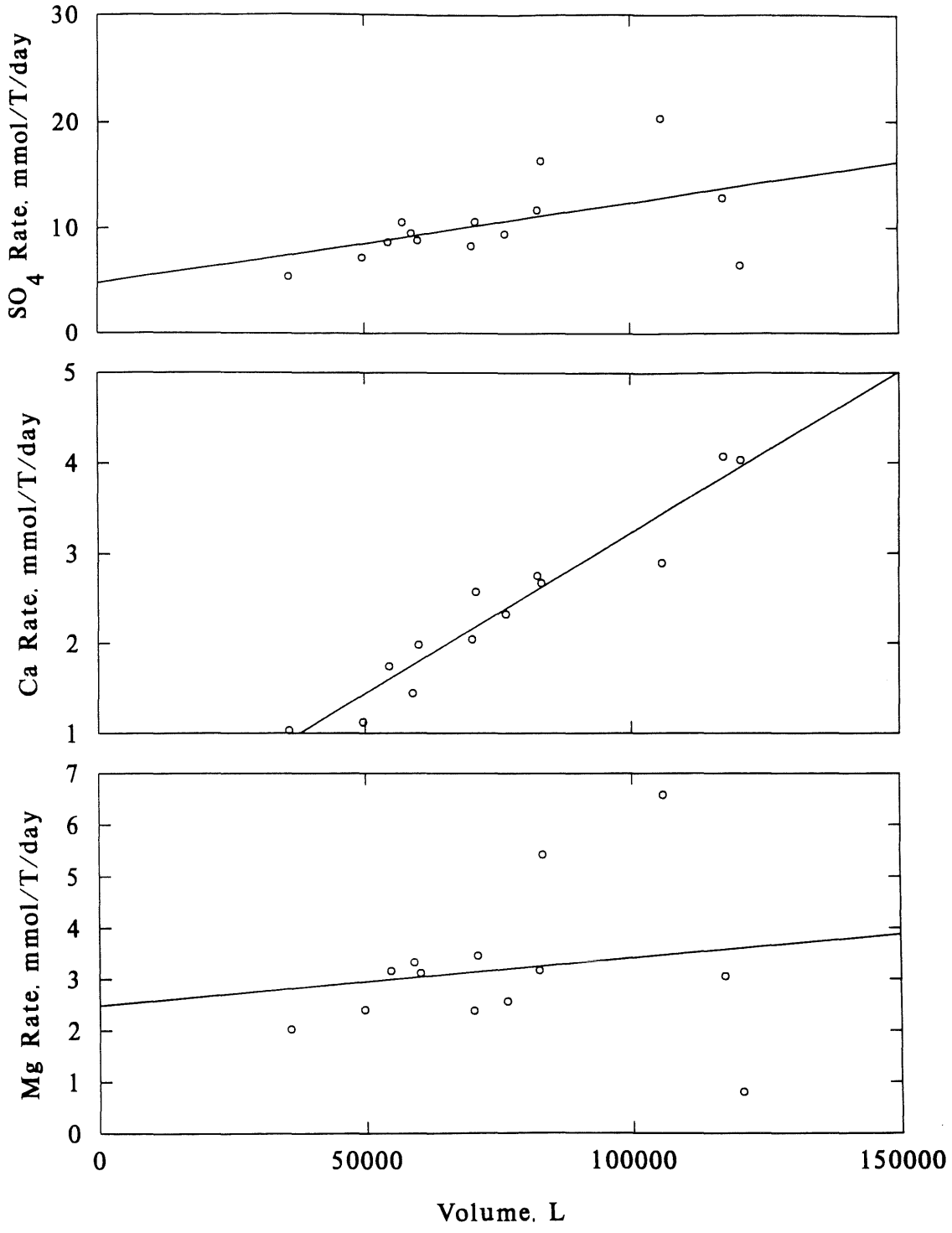

Figure A4.12. Annual rates of release of calcium plus magnesium vs. annual drainage volume for Duluth Complex test pile FL5 (1.41% S).

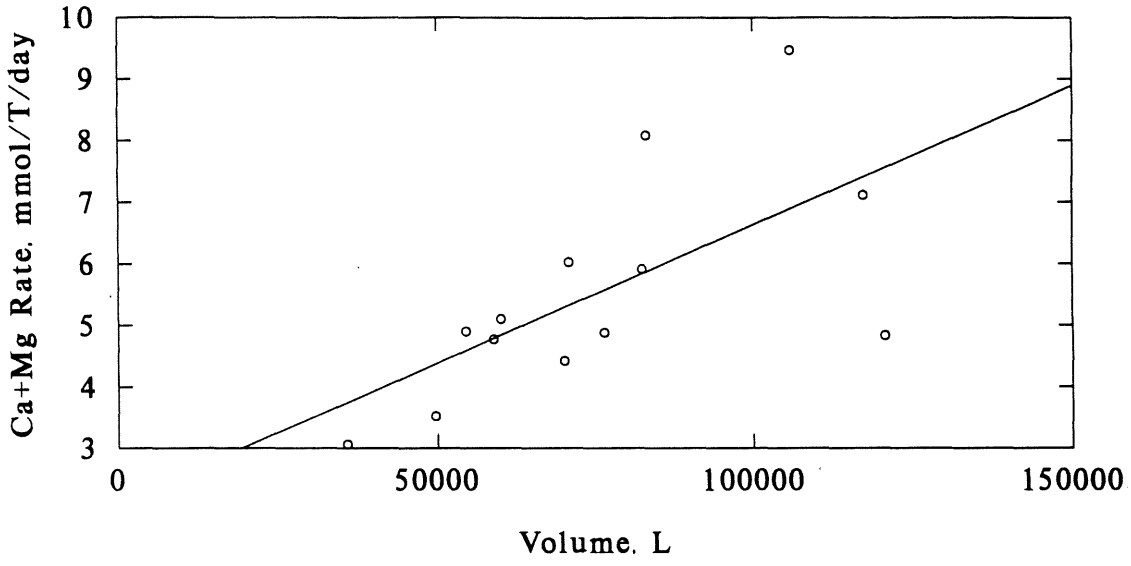

Figure A4.13. Annual magnesium release rate vs. annual median pH for Duluth Complex test pile FL1 (0.63% S).

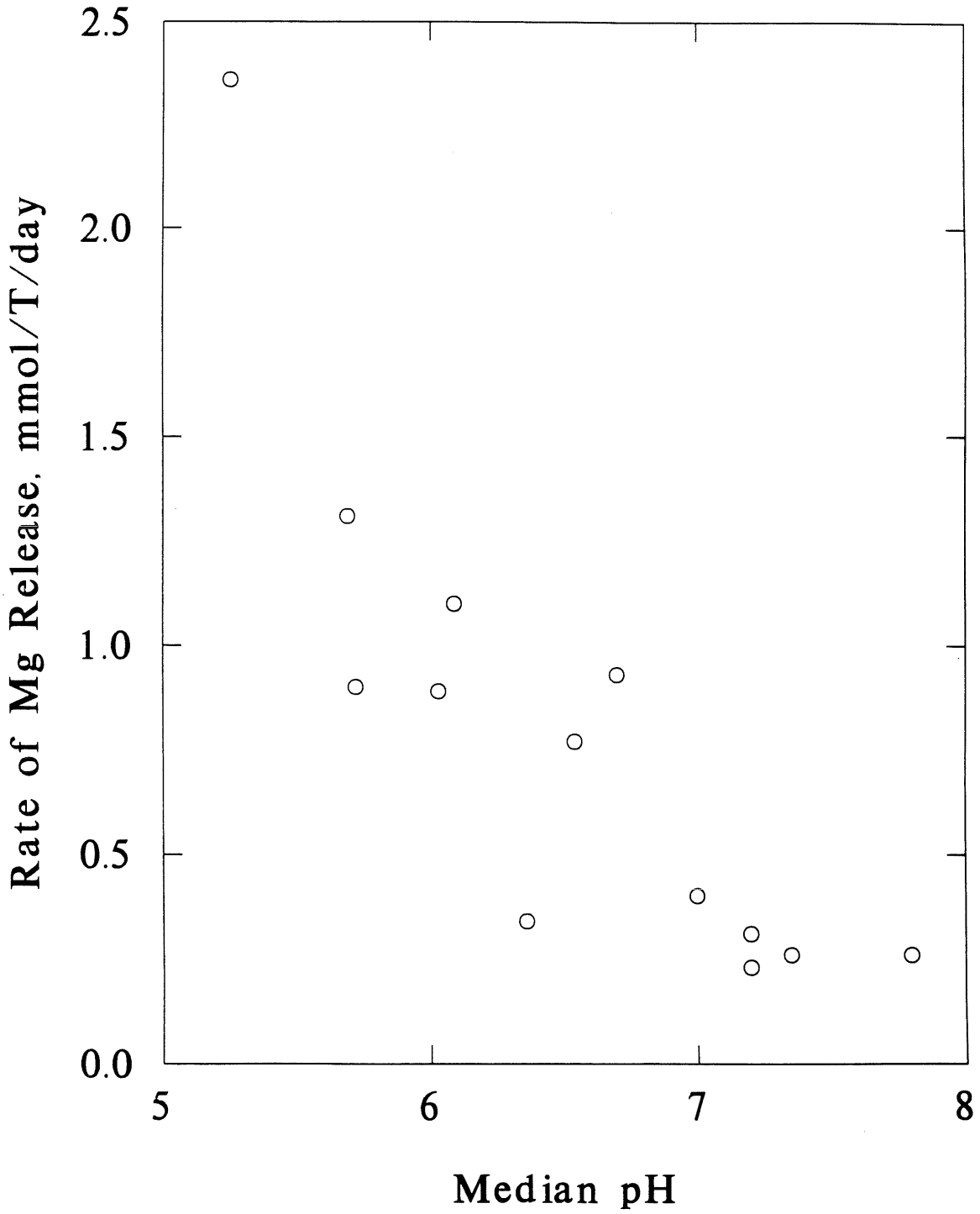

Figure A4.14. Annual magnesium release rate vs. annual median pH for Duluth Complex test pile FL2 (0.63% S).

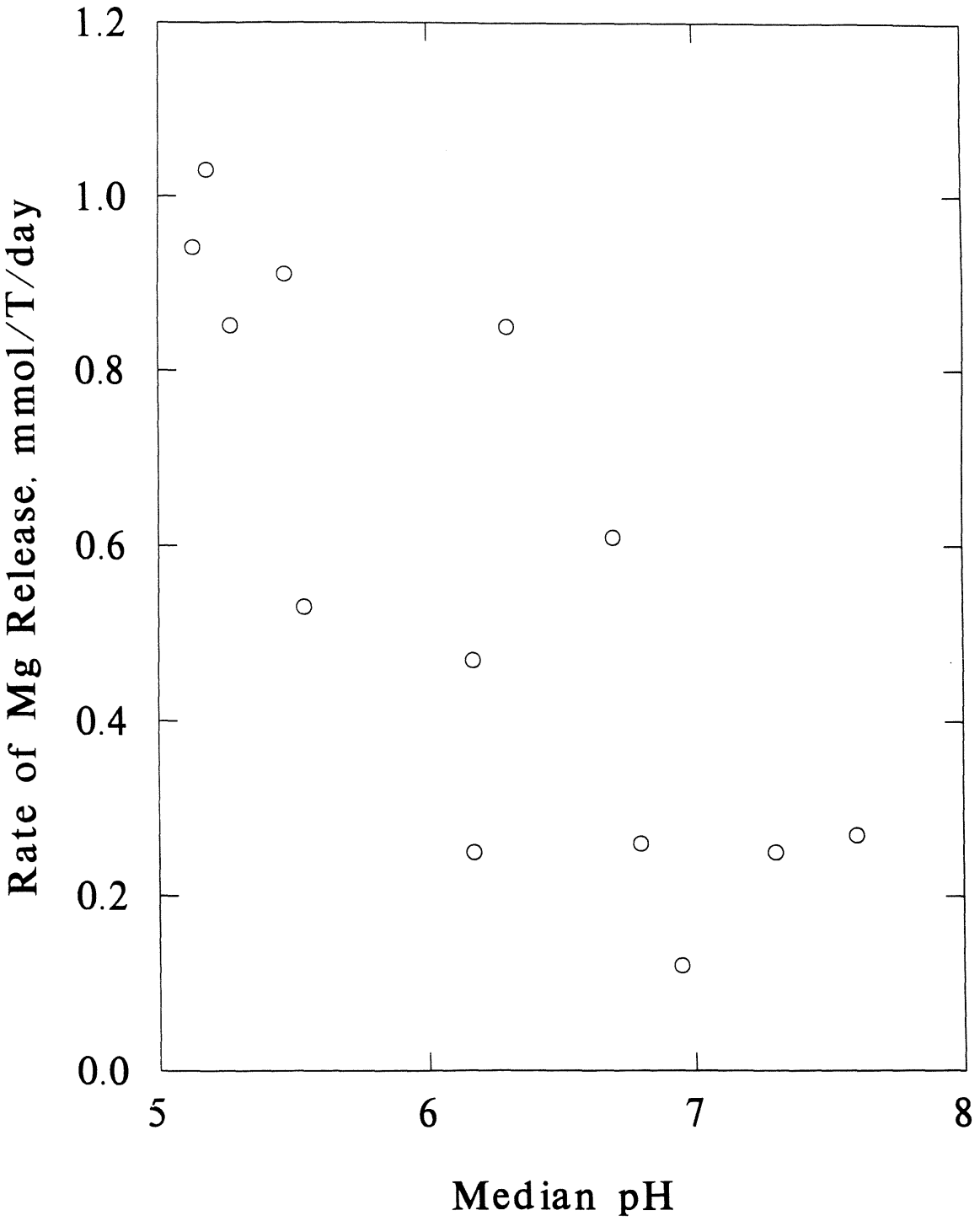

Figure A4.15. Annual magnesium release rate vs. annual median pH for Duluth Complex test pile FL3 (0.63% S).

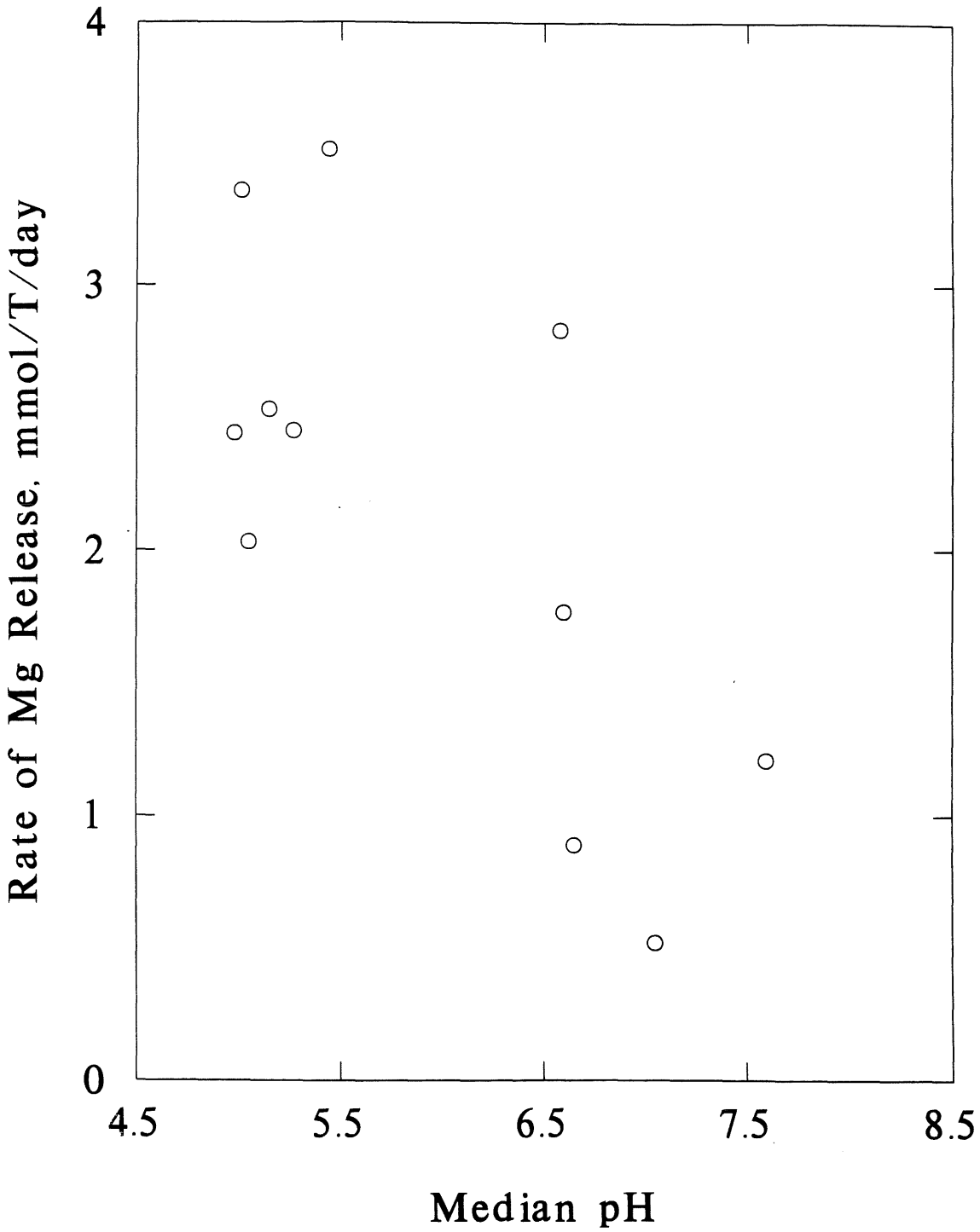

Figure A4.16. Annual magnesium release rate vs. annual median pH for Duluth Complex test pile FL6 (0.79% S).

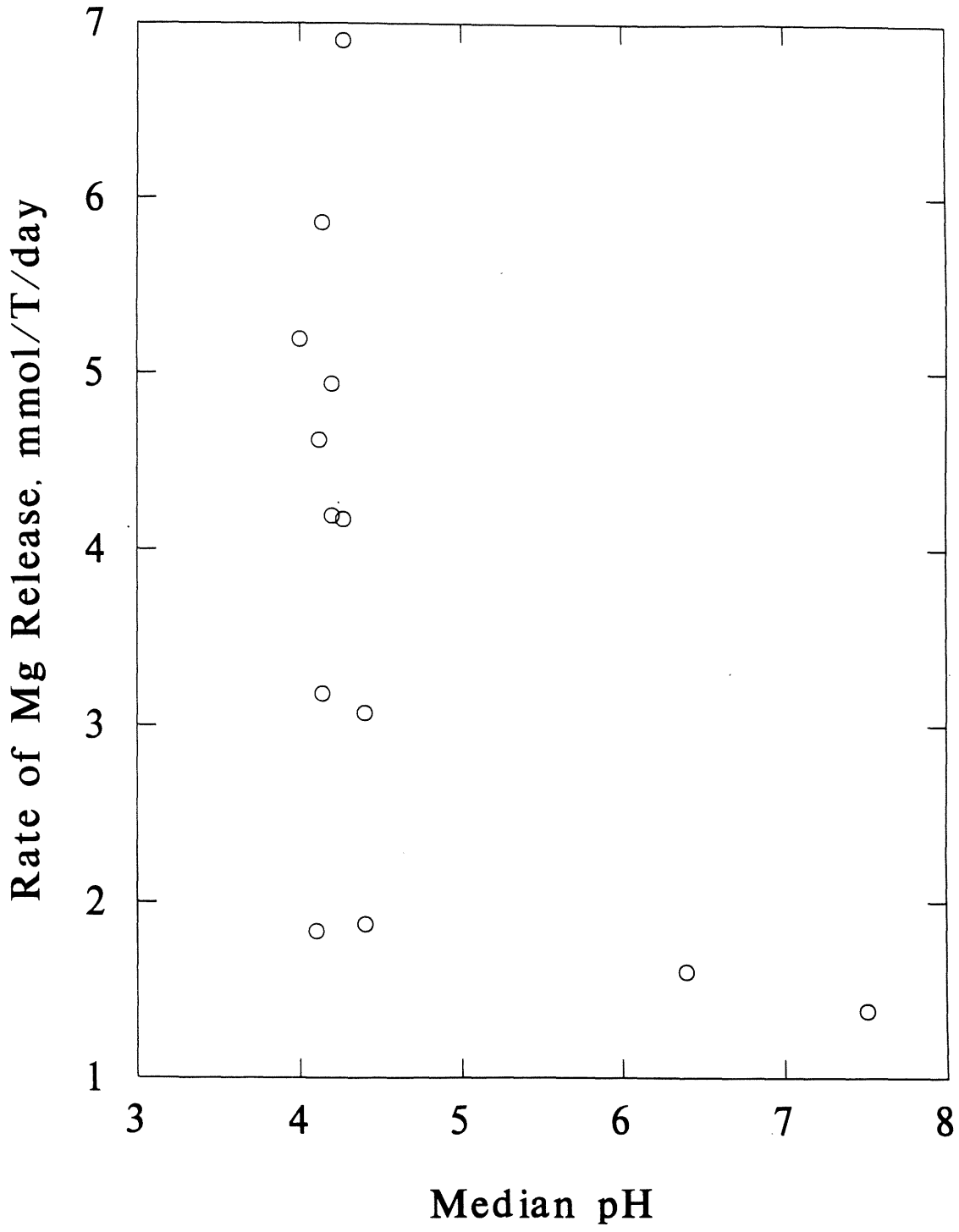

Figure A4.17. Annual magnesium release rate vs. annual median pH for Duluth Complex test pile FL5 (1.41% S).

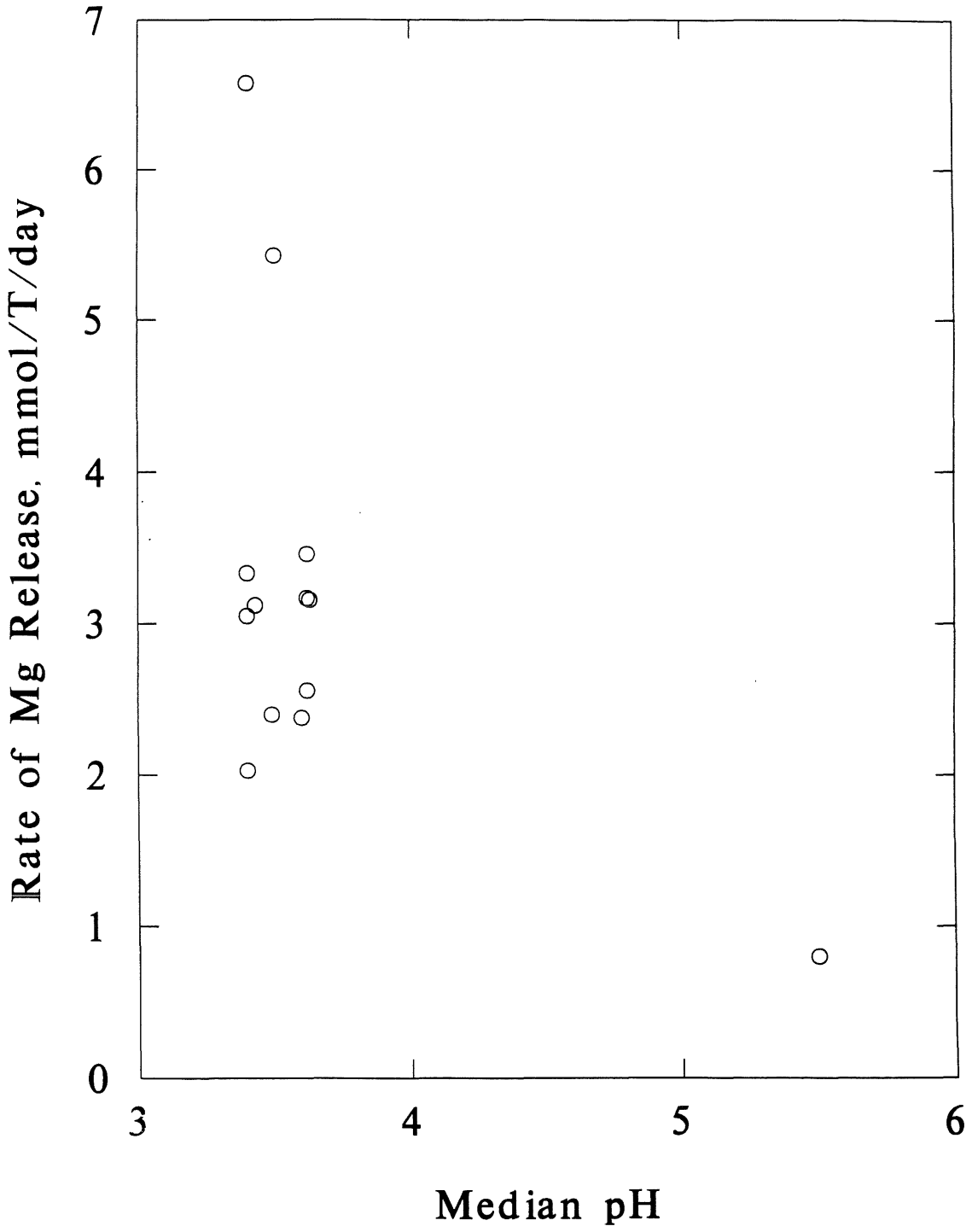

Figure A4.18. Annual magnesium release rate vs. annual median pH for Duluth Complex test piles FL1 (□), FL2 (*), and FL3 (◊).

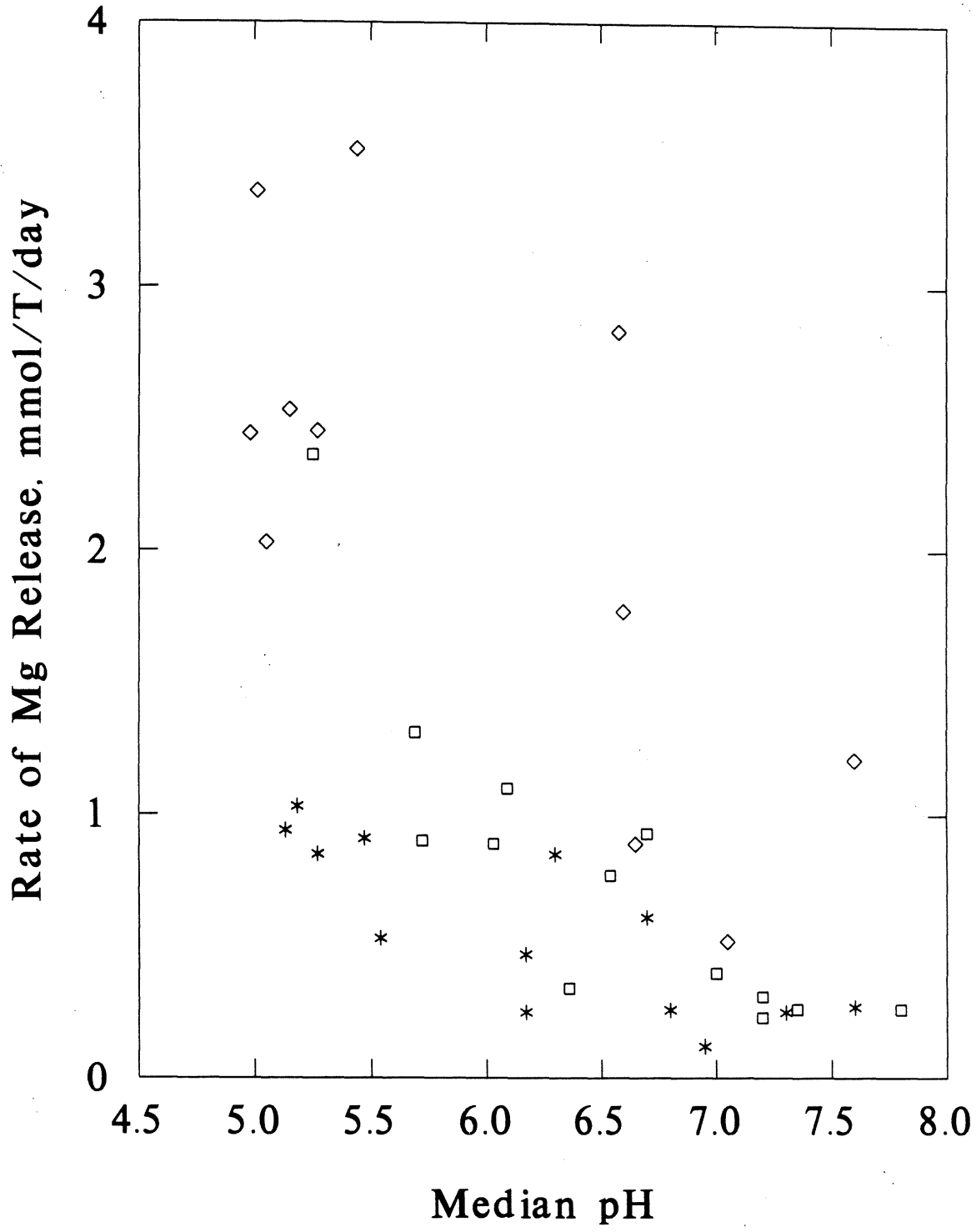

Figure A4.19. Annual magnesium release rate vs. annual median pH for Duluth Complex test piles FL1 (□), FL2 (*), FL3 (◊), FL6 (△), and FL5 (○).

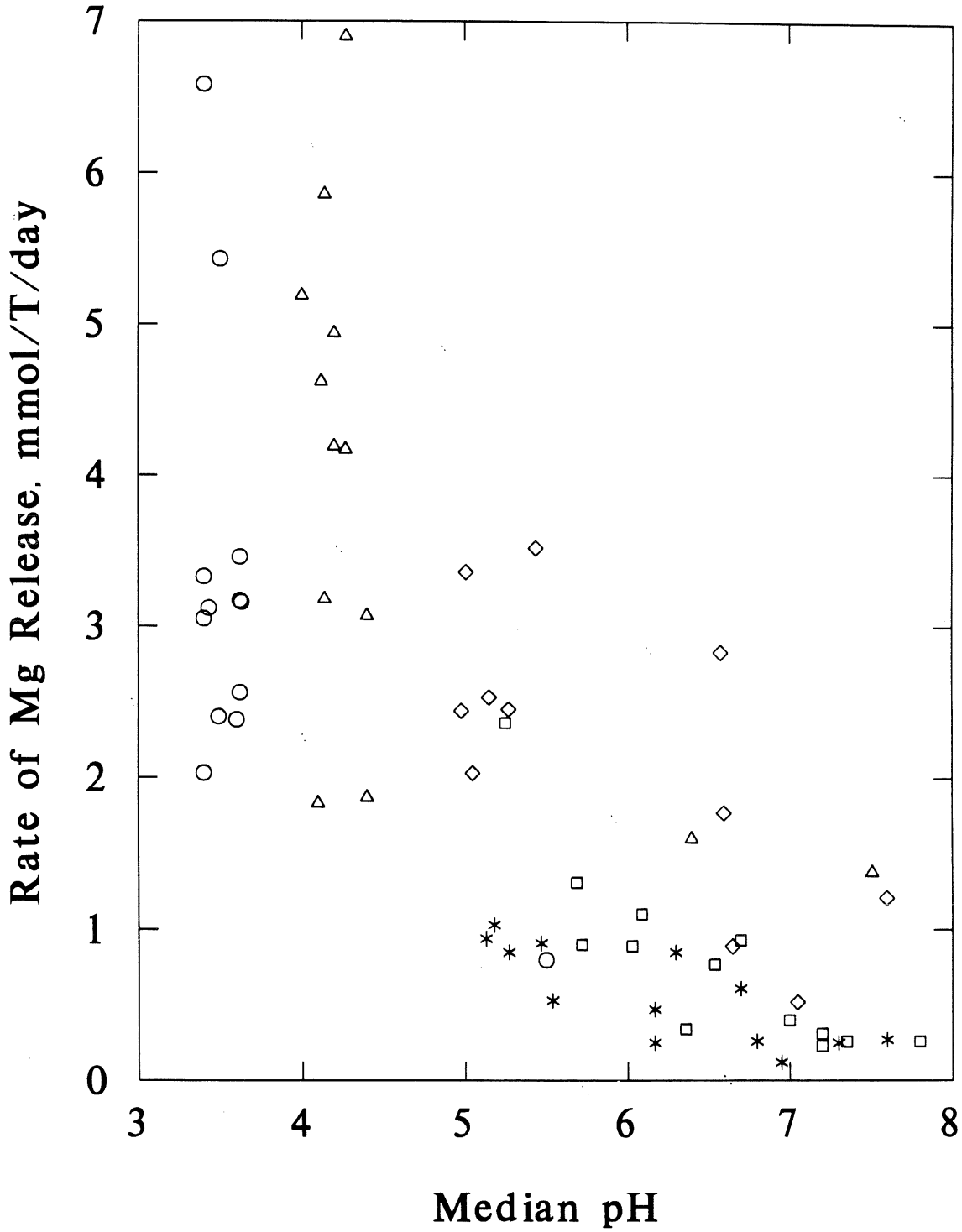

Table A4.1. Annual mass release rate vs. annual drainage volume regression statistics.

Sulfur %	Pile	Mass Release Rate (mmol/T/day) = a • volume (L) + b											
		Sulfate			Calcium			Magnesium			Calcium plus Magnesium		
		a x 10^5	r^2	n	a x 10^5	r^2	n	a x 10^5	r^2	n	a x 10^5	r^2	n
0.63	FL1	3.8	0.530	14	2.4	0.859	13	1.3	0.300	13	3.7	0.649	13
0.63	FL2	4.2	0.796	14	2.2	0.860	13	1.1	0.409	13	3.2	0.777	13
0.63	FL3	7.0	0.398	12	2.5	0.600	10[1]	2.9	0.245	11	5.4	0.403	11
0.79	FL6	5.5	0.364	14	2.0	0.868	13	7.7	0.250	13	4.7	0.479	13
1.41	FL5	7.6	0.240	14	3.6	0.928	13	0.9	0.027	13	4.5	0.424	13

[1] Regression excluded the 1978 calcium release rate, which was anomalously high.

APPENDIX 5

NEUTRALIZATION POTENTIAL

Appendix 5: Neutralization Potential

Table A5.1. Neutralization potentials as determined by drainage quality of Duluth Complex test piles.

Table A5.1. Neutralization potentials as determined by drainage quality of Duluth Complex test piles.

Sulfur %	Pile	Method	Neutralization Potential, mg $CaCO_3$/g rock					
			pH 7	pH 6	pH 5	pH 4.5	pH 4	pH 3.5
0.63	FL1	Ca+Mg[1]	0.346	0.781	>1.059	>1.059	>1.059	>1.059
		SO_4[2]	0.422	0.923	>1.259	>1.259	>1.259	>1.259
		avg.	0.384	0.852	>1.159	>1.159	>1.159	>1.159
0.63	FL2	Ca+Mg	0.179	0.393	>0.642	>0.642	>0.642	>0.642
		SO_4	0.228	0.498	>0.783	>0.783	>0.783	>0.783
		avg.	0.204	0.446	>0.712	>0.712	>0.712	>0.712
0.63	FL3	Ca+Mg	0.442	1.254	>1.340	>1.340	>1.340	>1.340
		SO_4	0.537	1.599	>1.721	>1.721	>1.721	>1.721
		avg.	0.490	1.426	>1.530	>1.530	>1.530	>1.530
0.79	FL6	Ca+Mg	0.157	0.172	0.226	1.702	>2.074	>2.074
		SO_4	0.175	0.191	0.246	2.102	>2.607	>2.607
		avg.	0.166	0.182	0.236	1.902	>2.340	>2.340
1.41	FL5	Ca+Mg	0.044	0.044	0.096	0.130[3]	0.136[3]	>1.889
		SO_4	0.080	0.080	0.135	0.189[3]	0.201[3]	>3.627
		avg.	0.062	0.062	0.116	0.160[3]	0.169[3]	>2.758

1 Neutralization potential (NP) was calculated using the cumulative calcium and magnesium release (see methods section of report).

2 Neutralization potential (NP) was calculated using the cumulative sulfate release (see methods section of report).

3 Neutralization potential was calculated as of 1978, although two pH values of 4.6 and 4.0 were observed in spring runoff in 1980 and 1989, respectively.