## Howardsville to Silverton – September 1997

### Study Area and Experimental Design

The tracer-injection study for Howardsville to Silverton, called the Howardsville tracer-injection study in this report, covered a 7,858 m section of the Upper Animas subbasin, starting upstream from Cunningham Gulch and the old tailings near Howardsville, and continuing to the A68 gaging station at Silverton (figs. 1 and 77). This study reach overlapped the Eureka Study reach and included several common sampling sites. This distance was divided into 40 stream segments, and there were 45 inflows sampled along the study reach (table 26). Site designations for this study reach include an H for Howardsville, followed by an S for stream sites, or an I for inflow sites and then the downstream distance at the end of each segment, or the distance of the inflow. For example, the segment that includes Cunningham Gulch is designated HS-1135 and the Cunningham Gulch inflow sample is HI-1075. Synoptic sampling sites are listed with their identifying information in table 26. Only 10 stream segments did not include inflow samples. Perhaps because of recent rains, there were many small seeps and springs along the study reach, as well as water running down from the county road along the right bank. The largest inflows included Cunningham Gulch (HI-1075), Arastra Gulch (HI-4186), an unnamed inflow at HI-1745, and Boulder Creek (HI-4951).

**Figure 77 near here.**



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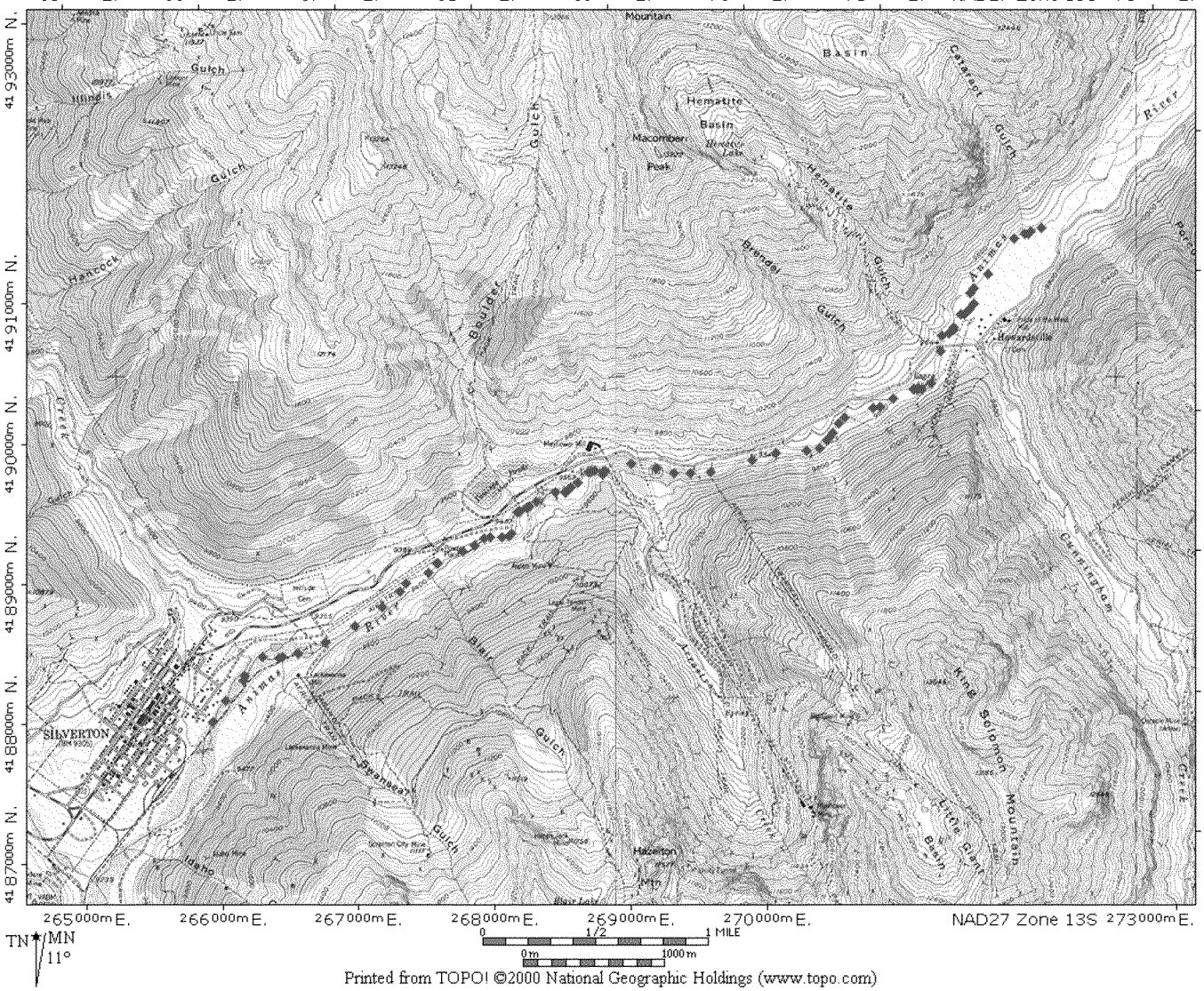


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**Table 27. Synoptic sampling sites, Upper Animas River, Eureka to Howardsville, Colorado, August 1998.**

[Distance, in meters along the study reach; Q, discharge, in cubic feet per second; pH, in standard units]

| Site Designation | Distance | Source | Site name | Q | pH |
|---|---|---|---|---|---|
| HS-160 | 160 | Stream | Below injection site--replicates | 39.10 | 7.55 |
| HI-181 | 181 | Inflow | Dredged ditch from Howardsville Ponds | 0.05 | 6.92 |
| HI-213 | 213 | Inflow | Stream from beaver ponds | 0.05 | 7.53 |
| HS-310 | 310 | Stream | Below RB ponds | 39.21 | 7.50 |
| HI-315 | 315 | Inflow | RB seep from talus | 0.00 | 7.59 |
| HS-595 | 595 | Stream | T1--near construction | 39.21 | 7.40 |
| HI-745 | 745 | Inflow | Drains beaver pond | 0.61 | 7.63 |
| HI-795 | 795 | Inflow | Outflow from cobble pond | 0.61 | 7.36 |
| HS-905 | 905 | Stream | Stream ab inflow RB | 40.43 | 7.46 |
| HI-910 | 910 | Inflow | From cobble road bank RB | 0.37 | 7.65 |
| HS-955 | 955 | Stream | Ab Howardsville Mill | 40.80 | 7.63 |
| HI-965 | 965 | Inflow | Mill Discharge (A46) | 0.51 | 6.88 |
| HS-1059 | 1059 | Stream | T2--Below Howardsville Mill - verticles | 41.31 | 7.65 |
| HI-1075 | 1075 | Inflow | Cunningham (A47) | 13.62 | 8.04 |
| HS-1135 | 1135 | Stream | Below Cunningham | 54.94 | 7.69 |
| HI-1150 | 1150 | Inflow | Hematite Guch (A48) | 2.00 | 8.12 |
| HS-1270 | 1270 | Stream | Below bridge | 56.94 | 7.64 |
| HS-1510 | 1510 | Stream | At State gage (A53) | 57.03 | 7.60 |
| HI-1605 | 1605 | Inflow | Draining LB adit--large inflow | 0.23 | 6.98 |
| HI-1648 | 1648 | Inflow | RB road bank seep (old mill site) | 0.23 | 6.74 |
| HI-1665 | 1665 | Inflow | RB seep beneth old road bank | 0.23 | 6.80 |
| HS-1725 | 1725 | Stream | Below clean and dirty inflows | 57.70 | 7.58 |
| HI-1745 | 1745 | Inflow | Water across road RB | 3.13 | 7.89 |
| HS-1925 | 1925 | Stream | At upper "campground" -- replicates | 60.83 | 7.61 |
| HI-2050 | 2050 | Inflow | LB spring inflow | 0.13 | 7.23 |
| HS-2110 | 2110 | Stream | Below campground | 60.96 | 7.68 |
| HI-2125 | 2125 | Inflow | Drains LB ponds w/ Fe pptn | 0.13 | 4.76 |
| HI-2355 | 2355 | Stream | Stream Below ponds | 61.00 | 7.74 |
| HI-2360 | 2360 | Inflow | LB inflow | 0.13 | 6.43 |
| HI-2361 | 2361 | Inflow | LB rapid inflow from marsh | 0.13 | 7.30 |
| HI-2425 | 2425 | Inflow | Swift inflow from marshy area | 0.13 | 7.15 |
| HS-2515 | 2515 | Stream | Above draining adit | 61.35 | 7.55 |
| HI-2522 | 2522 | Inflow | Drains old mining | 0.60 | 6.10 |
| HS-2572 | 2572 | Stream | Below adit | 61.94 | 7.53 |
| HI-2605 | 2605 | Inflow | RB inflow from willows | 0.01 | 7.92 |
| HI-2709 | 2709 | Inflow | RB inflow | 0.01 | 7.92 |
| HS-2800 | 2800 | Stream | T3--Truck park | 61.94 | 7.73 |
| HS-3040 | 3040 | Stream | Narrow chute within canyon | 63.12 | 7.78 |
| HI-3235 | 3235 | Inflow | RB cascade across road | 0.00 | 8.20 |
| HS-3295 | 3295 | Stream | Below first cableway | 63.12 | 7.84 |
| HS-3555 | 3555 | Stream | Mid canyon | 63.12 | 7.78 |
| HI-3682 | 3682 | Inflow | RB drainage off grassy hillside | 0.75 | 8.14 |
| HI-3820 | 3820 | Inflow | RB cascade from rocky bank | 0.75 | 7.93 |
| HS-4023 | 4023 | Stream | Between RB inflows in canyon | 64.62 | 7.73 |
| HI-4033 | 4033 | Inflow | RB cascade from rocky bank | 0.10 | 8.17 |
| HS-4166 | 4166 | Stream | T4 Above Arastra -- verticles | 64.72 | 7.75 |
| HI-4186 | 4186 | Inflow | Arastra Gulch | 7.68 | 7.92 |
| HI-4190 | 4190 | Inflow | Inflow from pipe RB | 0.10 | 7.77 |
| HS-4310 | 4310 | Stream | Below Arastra | 72.50 | 7.72 |
| HI-4334 | 4334 | Inflow | From "pipe bridge" | 0.11 | 7.75 |
| HI-4353 | 4353 | Inflow | Stream level spring RB | 0.11 | 4.17 |
| HS-4473 | 4473 | Stream | Below River Level Spring | 72.73 | 7.68 |



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| | | | | | |
|---|---|---|---|---|---|
| HI-4533 | 4533 | Inflow | Marsh area RB | 0.96 | 4.90 |
| HS-4581 | 4581 | Stream | Below LB Aban. Mill | 73.68 | 7.36 |
| HI-4586 | 4586 | Inflow | Ponded water RB | 0.42 | 4.89 |
| HS-4656 | 4656 | Stream | Above "Pinicle Gap" | 74.11 | 7.71 |
| HS-4816 | 4816 | Stream | Above Acid inflows | 74.11 | 7.70 |
| HI-4886 | 4886 | Inflow | Seep w/ acid algae | 0.10 | 5.92 |
| HS-4916 | 4916 | Stream | Below acid inflows | 74.21 | 7.61 |
| HI-4951 | 4951 | Inflow | Boulder Creek A62 | 1.38 | 7.53 |
| HI-4970 | 4970 | Inflow | RB inflow-substantial | 1.38 | 6.04 |
| HS-5131 | 5131 | Stream | Below Boulder Creek | 76.96 | 7.62 |
| HI-5161 | 5161 | Inflow | Pond to stream LB with fish | 0.50 | 7.47 |
| HI-5221 | 5221 | Inflow | Blair Gulch | 0.50 | 7.52 |
| HS-5306 | 5306 | Stream | Below Blair Gulch | 77.96 | 7.55 |
| HI-5355 | 5355 | Inflow | LB inflow from willow bog | 0.01 | 6.95 |
| HI-5356 | 5356 | Inflow | Small ponds RB in cobbles | 0.01 | 5.14 |
| HI-5446 | 5446 | Inflow | LB inflow near wells | 0.01 | 6.72 |
| HS-5536 | 5536 | Stream | Below first of capped tailings | 77.97 | 7.50 |
| HS-5756 | 5756 | Stream | Above drain from tails | 78.84 | 7.42 |
| HI-5766 | 5766 | Inflow | Drains tailings RB in "ditch" | 0.01 | 7.80 |
| HI-5858 | 5858 | Inflow | Seep along 60 m of grass | 0.01 | 5.67 |
| HS-6038 | 6038 | Stream | T5--Below capped tailings | 78.84 | 7.57 |
| HI-6105 | 6105 | Inflow | LB inflow from willows | 0.86 | 7.03 |
| HS-6288 | 6288 | Stream | Below toe of Mayflower | 79.70 | 7.49 |
| HS-6528 | 6528 | Stream | Above Lacawana Bridge | 79.70 | 7.66 |
| HS-6768 | 6768 | Stream | Below Lacawana Bridge | 79.70 | 7.65 |
| HS-7008 | 7008 | Stream | Above Lacawana Mill | 79.70 | 7.69 |
| HS-7103 | 7103 | Stream | Discharge from Lacawana | 79.70 | 7.61 |
| HI-7163 | 7163 | Inflow | Inflow LB | 0.01 | 7.66 |
| HS-7283 | 7283 | Stream | Below Lacawana Mill (A66) | 79.70 | 7.64 |
| HI-7483 | 7483 | Inflow | Inflow from LB | 0.10 | 7.64 |
| HS-7523 | 7523 | Stream | Among braids nr town | 79.70 | 7.63 |
| HI-7688 | 7688 | Inflow | RB drainage from Mayflower | 0.25 | 7.14 |
| HS-7858 | 7858 | Stream | T6--At bridge / gage A68 | 79.95 | 7.63 |

Abandoned mines and prospects exist along the study reach; the discharge from the old mill and tailings area at Howardsville (HI-965, which was EI-6438 for the Eureka tracer injection) was one of the most visually significant for its iron staining in the stream (see Martin and others, Chapter 4G this volume). In general, the rocks on both sides of the canyon have propylitic alteration, but there also are areas of quartz-sericite-pyrite alteration (Bove and others, this volume). Stream elevation ranged from approximately 9,670 ft at the injection site to 9,300 ft at the gage. Geology of the basin is described in Yager and Bove (this volume) and Bove and others (this volume).



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Results of this tracer-injection study have been reported in Paschke and others (in press). That report includes many load profiles for dissolved concentrations and also the results of solute-transport simulations. The summary here includes loading curves that are prepared using total-recoverable and dissolved concentrations. It also includes principal components analysis, which were not used in the previous study. The reader should consult Paschke and others (in press) for more details on this study.

Sodium chloride was used as the tracer for this study reach; the injectate solution had a chloride concentration of 77,760 mg/L (Paschke and others, in press). The salt was injected at a rate of 1.098 L/min, starting 1206 hours on 13 September 1997, and ran continuously until 0900 on 15 September 1997.

### Discharge

The majority of background chloride concentrations were low in comparison to the injected concentrations (fig. 78). However, six inflows had chloride concentrations that were unusually high. Because these inflow concentrations were quantified, it still was possible to use equations 3 and 4 to calculate discharge. High chloride concentrations likely resulted from inflows that contained magnesium chloride salt used for dust control on the county road along the right bank. During synoptic sampling, however, chloride concentrations decreased systematically downstream from the injection, but increased in segments downstream from these high inflow concentrations (fig. 78). Discharge increased by 40.8 cfs along the study reach, and stream segments that contained sampled inflows accounted for 95 percent of this increase.

**Figure 78 near here.**



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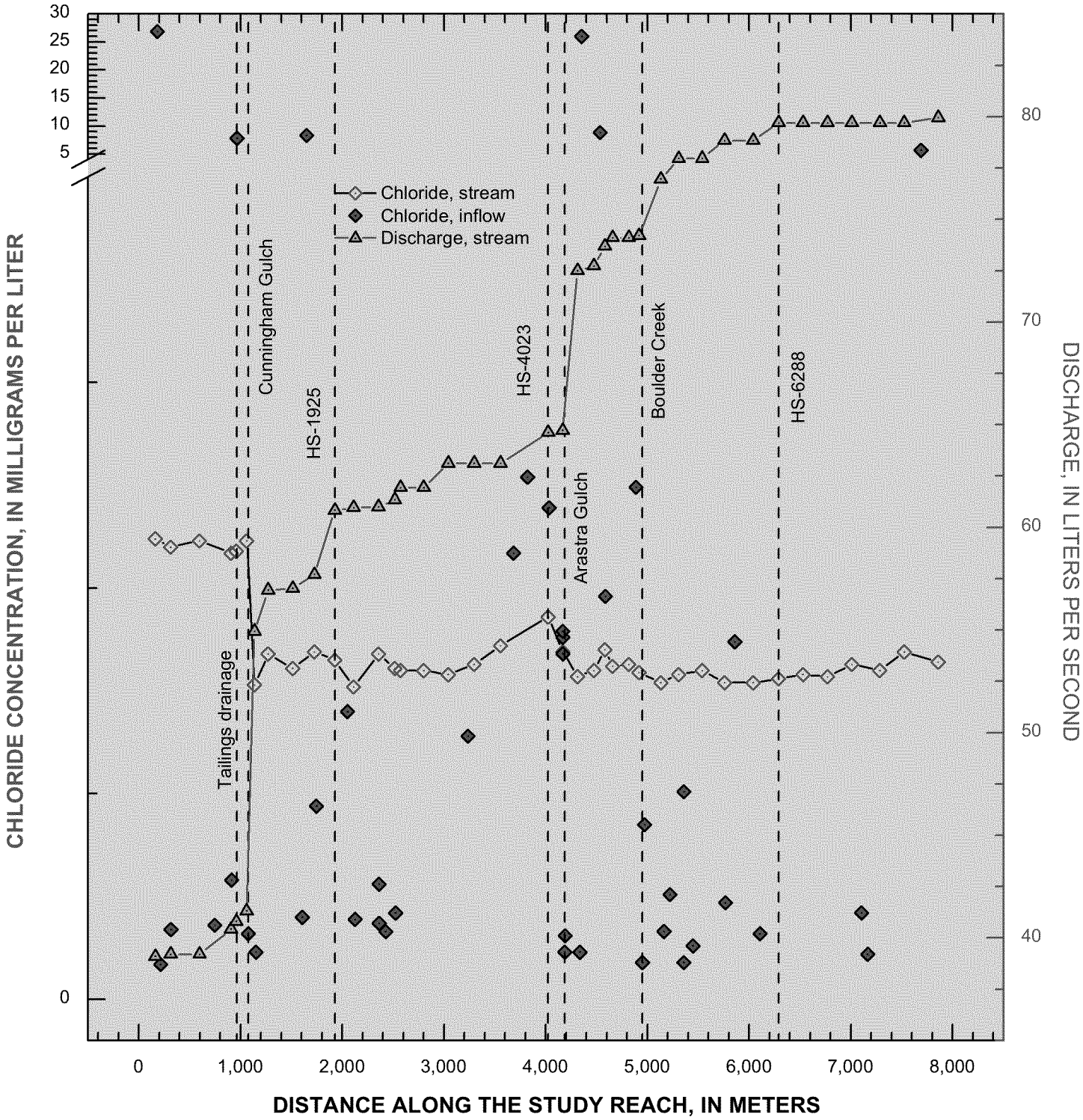


Figure 78. Variation of chloride and discharge with distance along the study reach, Upper Animas River, Howardsville to Silverton, September 1997.

Cunningham Gulch (segment HS-1135) was the largest tributary inflow, accounting for 13.6 cfs, or 33 percent of the flow. Arastra Gulch (HI-4186) accounted for 7.8 cfs, which was 19 percent of the total increase. Discharge increased at segment HS-1925, perhaps more than visual inspection of the inflow suggested it would. This increase was 8 percent of the total. Finally, there was a 7 percent increase in the segment that included Boulder Creek (HS-5131). This included more than just the discharge of Boulder Creek.

### Characterization of Synoptic Samples

Along the study reach, pH ranged from about 7.4 to 7.8; there was no systematic variation of pH (fig. 79a). Acidic inflows mostly occurred downstream from Arastra Gulch. Throughout the study reach, the dominant major ions were calcium and sulfate, and their concentrations were consistent, despite much variation among inflow concentrations (fig. 79b). Alkalinity was less than sulfate concentration.

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**Figure 79 near here.**

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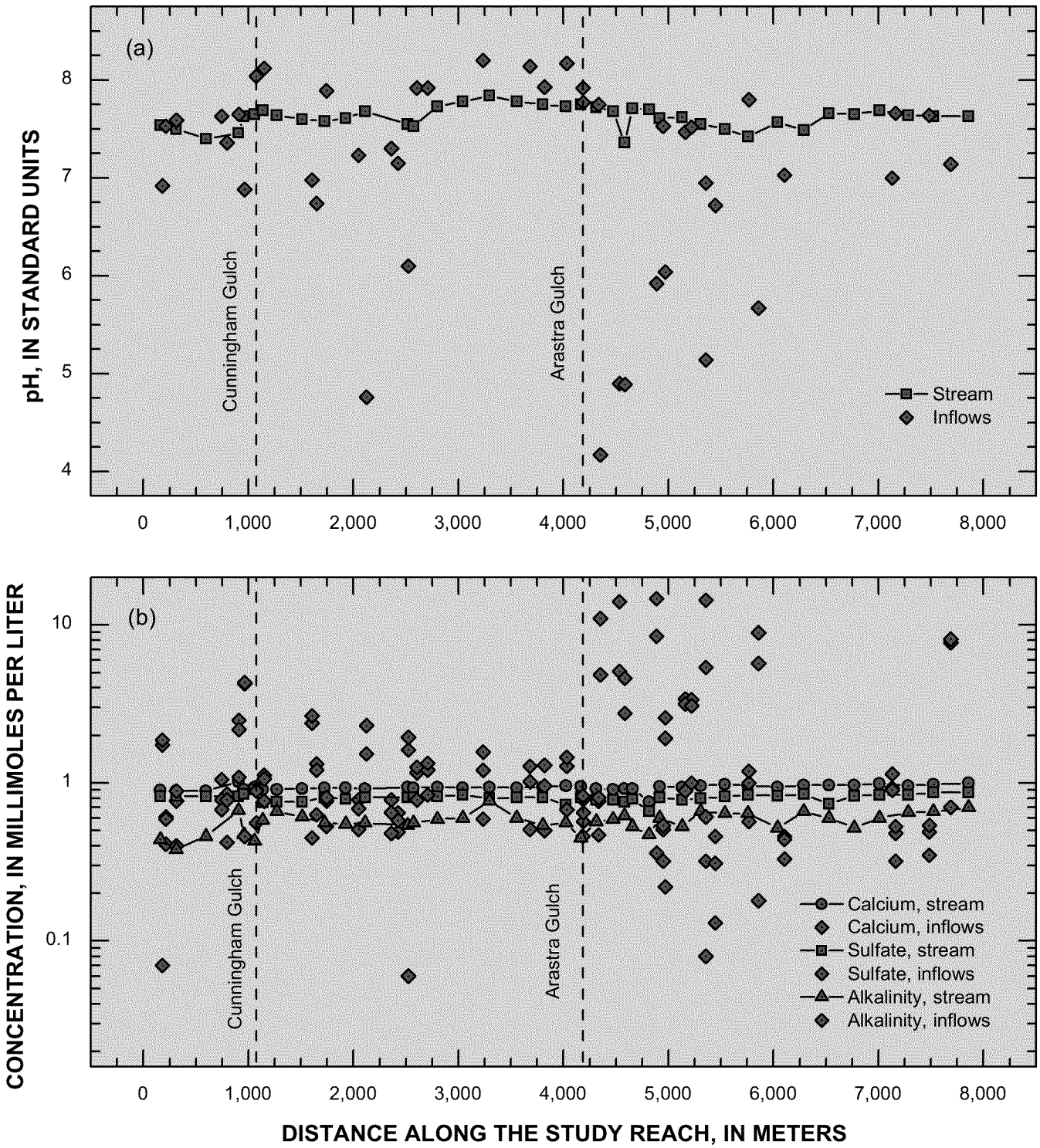


Figure 79. Variation of (a) pH and (b) calcium, sulfate, and alkalinty with distance along the study reach, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

Several metal concentrations were high (fig. 80). The highest dissolved concentrations were for manganese and zinc. Manganese concentrations ranged up to 1.10 mg/L and had a median of 0.45 mg/L. Median concentration of zinc was 0.28 mg/L (fig. 80). Colloidal concentrations of aluminum and iron also were relatively high. The colloidal concentrations were greater than dissolved concentrations, which was consistent with the relatively high pH along the study reach (figs. 79a and 80). The median concentration of colloidal iron was 0.42 mg/L; while the median dissolved concentration was 0.01 mg/L, indicating the dominance of the colloidal phase. Colloidal copper concentrations were greater than the dissolved concentration. The median concentration of colloidal zinc was 0.04 mg/L, but was lower than dissolved zinc. The majority of lead and nickel concentrations were less than detection, although colloidal lead concentrations occurred in a few samples.

**Figure 80 near here.**

There was a spatial pattern to the variation in concentrations manganese, zinc, colloidal aluminum, and colloidal iron. Generally, these concentrations increased downstream from the inflow at HI-965, which drains an area of old tailings, and also downstream from Arastra Gulch. There were 7 inflows downstream from Arastra Gulch that had manganese and zinc concentrations greater than 1 mg/L (figs. 81 and 82). For manganese the resulting increased concentrations in the Animas River were about 0.6 mg/L higher downstream from Arastra Gulch. The increase in zinc was only about 0.2 mg/L, but this also was substantial considering the amount of flow in the in the Animas at that point.

**Figures 81 and 82 near here.**



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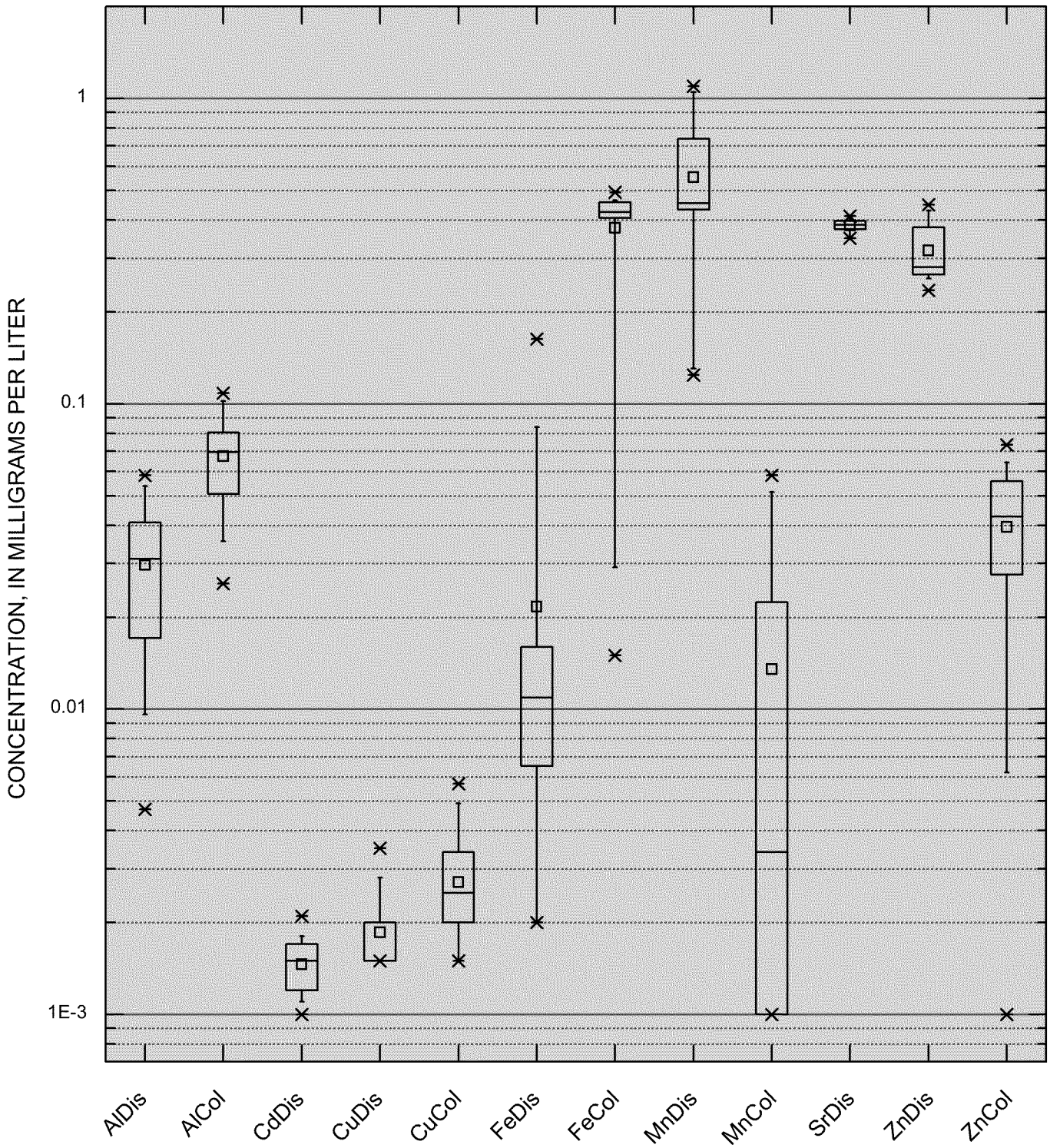


Figure 80. Box plot showing ranges of metal concentrations in synoptic stream samples, Upper Animas River, Howardsville to Silverton, September 1997.

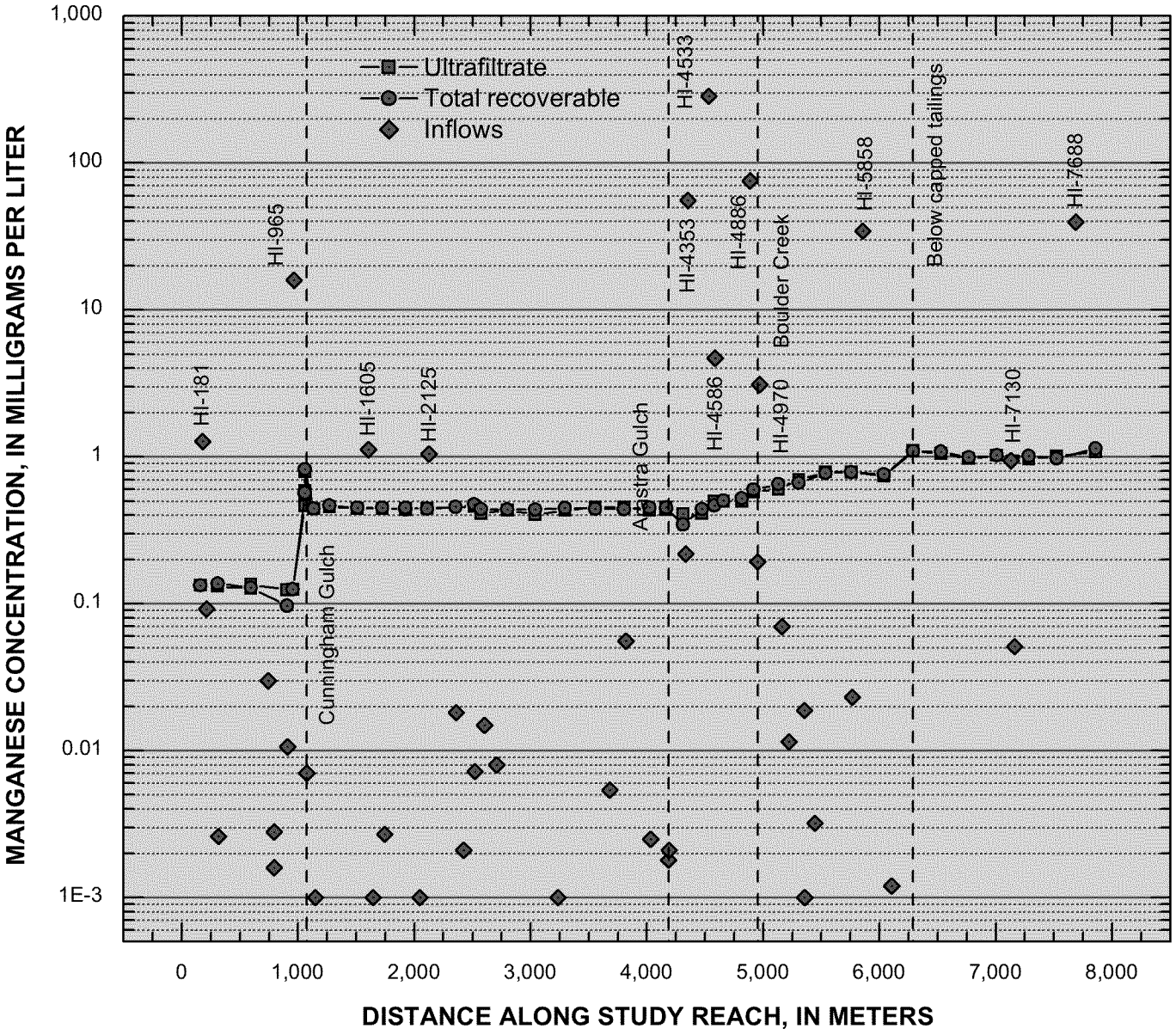


**Figure 84**. Variation of manganese concentration with distance in different filtrates, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

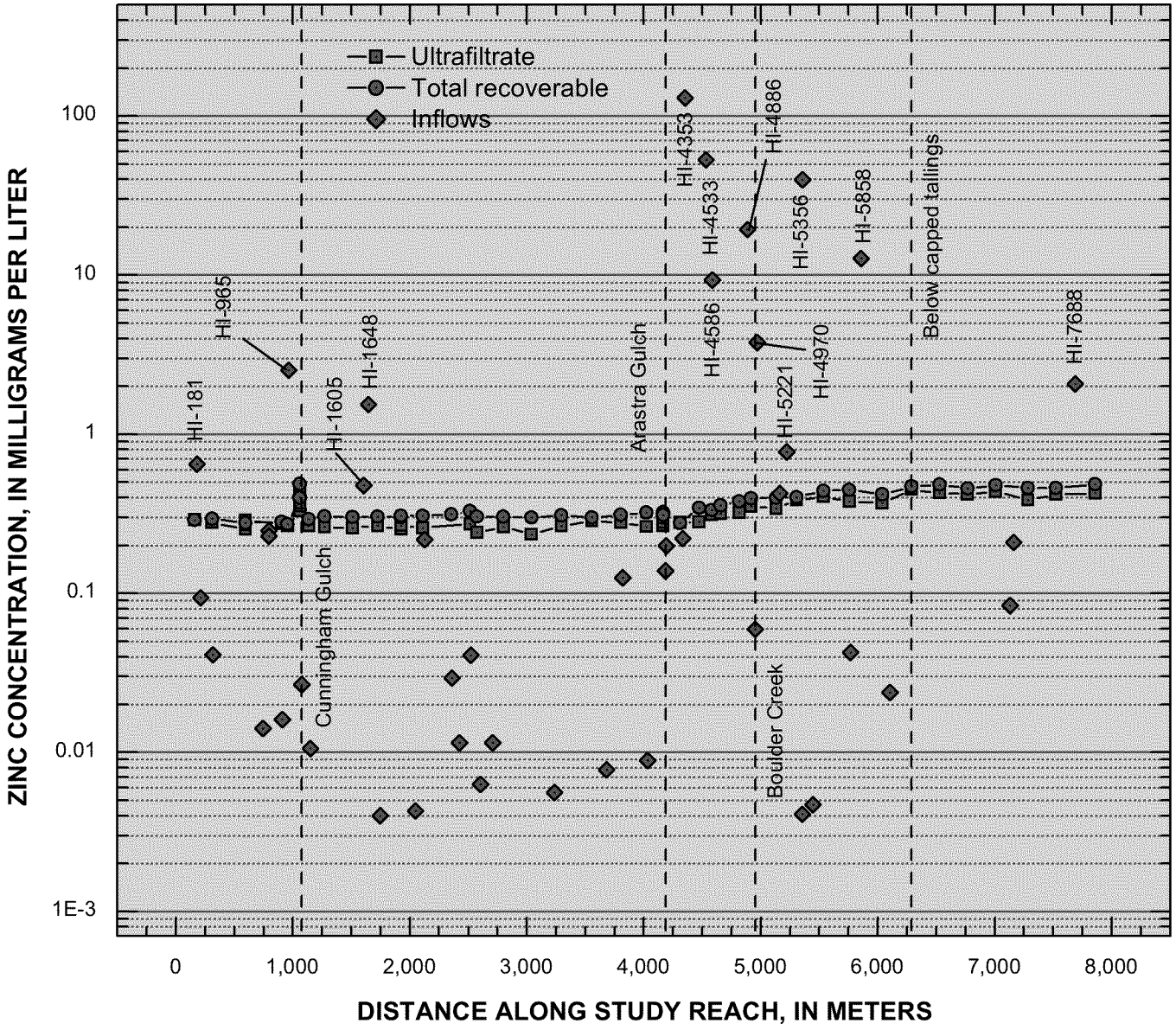


**Figure 82**. Variation of zinc concentration with distance in different filtrates, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

The highest inflow concentration of aluminum occurred in the discharge at HI-4353, which was a spring at stream level that was visible because of a pressure head that lifted the flow slightly above the stream level (fig. 83). Similar springs could have occurred, but were not seen during the sampling. Additional inflows downstream from Arastra Gulch also had high concentrations of aluminum, and caused the increase in total-recoverable aluminum concentration from near 0.1 mg/L to almost 0.2 mg/L. Again, this was not a large absolute increase in concentration, but was a significant change in a relatively large stream.

**Figure 83 near here.**

Downstream from HI-965 and Cunningham Gulch, the total-recoverable iron concentration increased and remained essentially constant, near 0.4 mg/L along the rest of the study reach (fig. 84). This inflow discharged from the area of tailings near Howardsville, and had the highest inflow concentration of iron. Other inflows that were downstream from Arastra Gulch had relatively high concentrations of iron, but these did not affect the instream concentrations. Only a small percentage of the total iron was transported as dissolved iron. The dissolved concentration of iron downstream from Cunningham Gulch progressively decreased (fig. 84). Such a decrease would be consistent with a transformation from dissolved to colloidal iron during transport.

**Figure 84 near here.**



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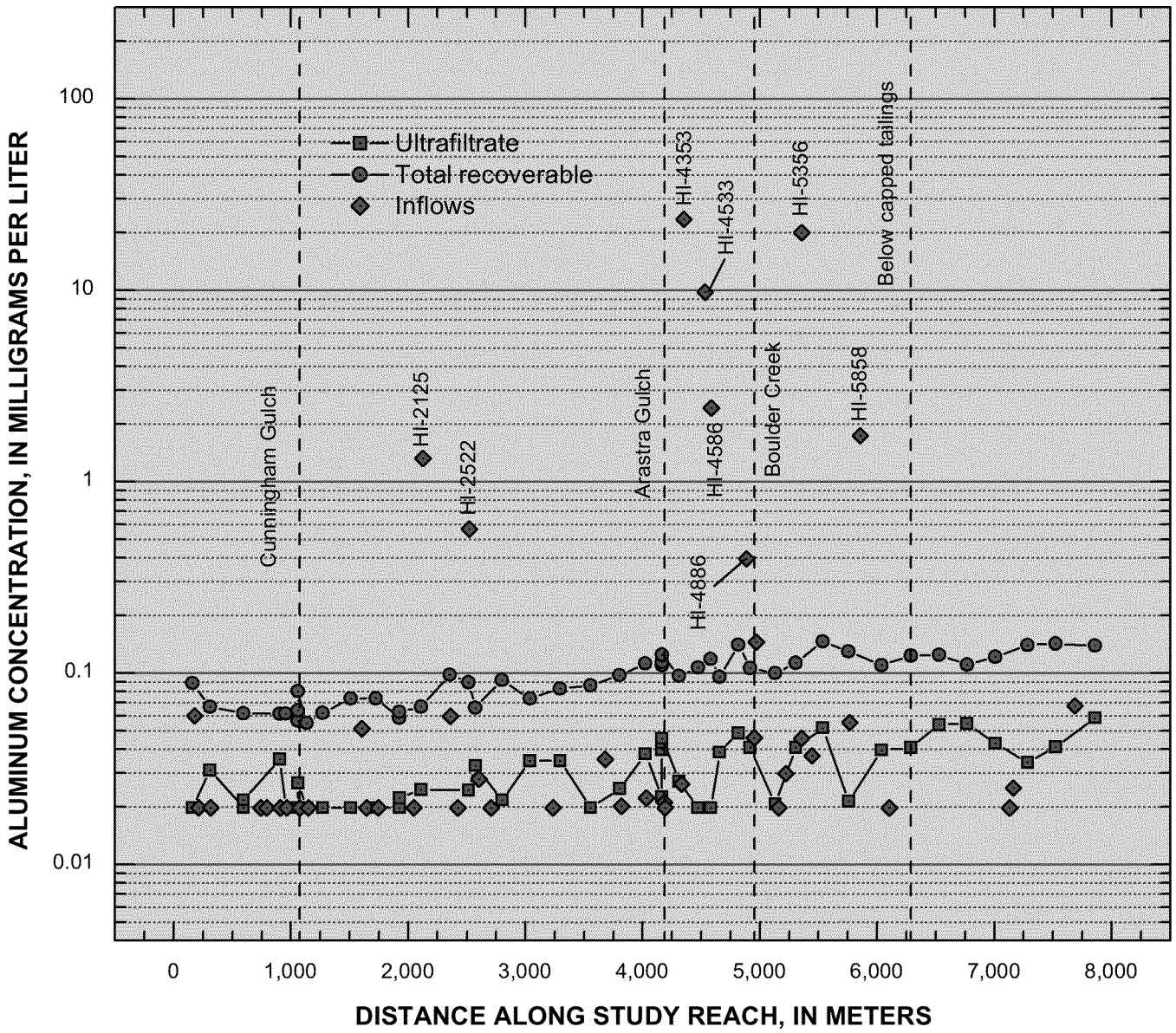


**Figure 83**. Variation of aluminum concentration with distance in different filtrates, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

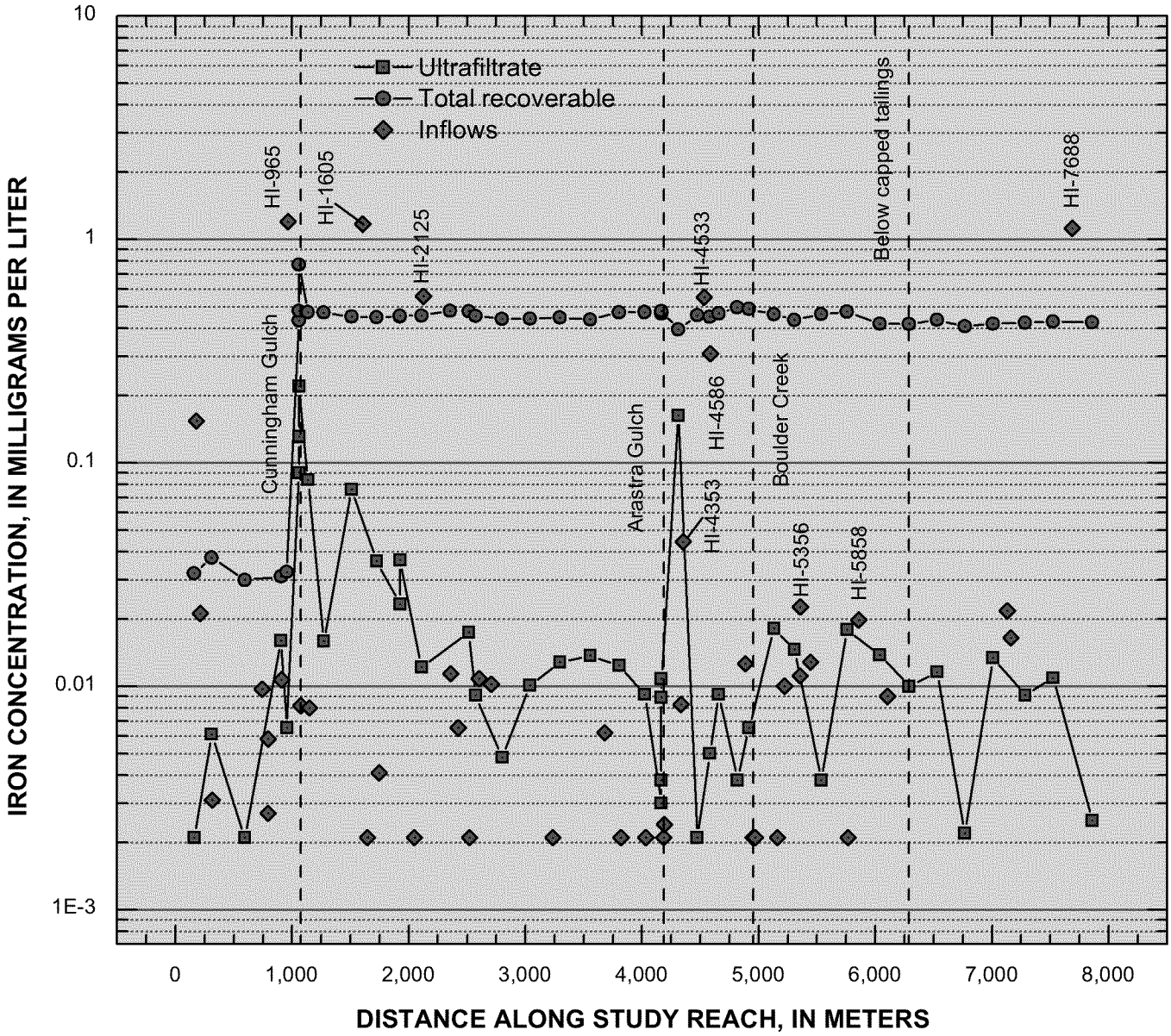


**Figure 84**. Variation of iron concentration with distance in different filtrates, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

When considering downstream changes among all the solutes, the PCA analysis classified all the stream samples into one group because of the large range among inflow concentrations (fig. 85). Focusing on stream sites only, however, there generally were four changes along the study reach that mostly correspond to downstream transport. The stream samples have been plotted in these four groups, labeled 1A through 1D (fig. 85). The samples upstream from the Howardsville inflow at HI-965 had the lowest concentrations (blue diamonds, fig. 85). Downstream from HI-965, iron and manganese increased substantially (green diamonds). Downstream from HS-2515, there was a shift in iron and in other metals (yellow diamonds). Finally, downstream from HS-4581 there was a continuous increase in manganese, zinc, and other metals (orange diamonds). This shift is in the direction of the inflows of group 5 that had the highest metal concentrations. The absolute change in concentration among these stream samples was not great, partly because the quantity of streamflow was substantial, but it was significant as loading profiles will indicate.

**Figure 85 near here.**

Inflow samples from groups 2 and 3 were are not similar to the water at the beginning of the study reach (fig. 85). Only sample HI-1648 was similar to group 1A, but generally, the chemical character of water in group 1A was a result of inflows upstream from the study reach. Changes among stream samples, from group 1A to 1C, are not in the direction of any groups of sampled inflows. This is consistent with the hypothesis that the chemistry of these upstream samples resulted from inflows that were upstream from the study reach. Other than the small shift toward inflow samples of group 5, the sampled groups of inflows did not appear to have a great affect on changes in stream chemistry.



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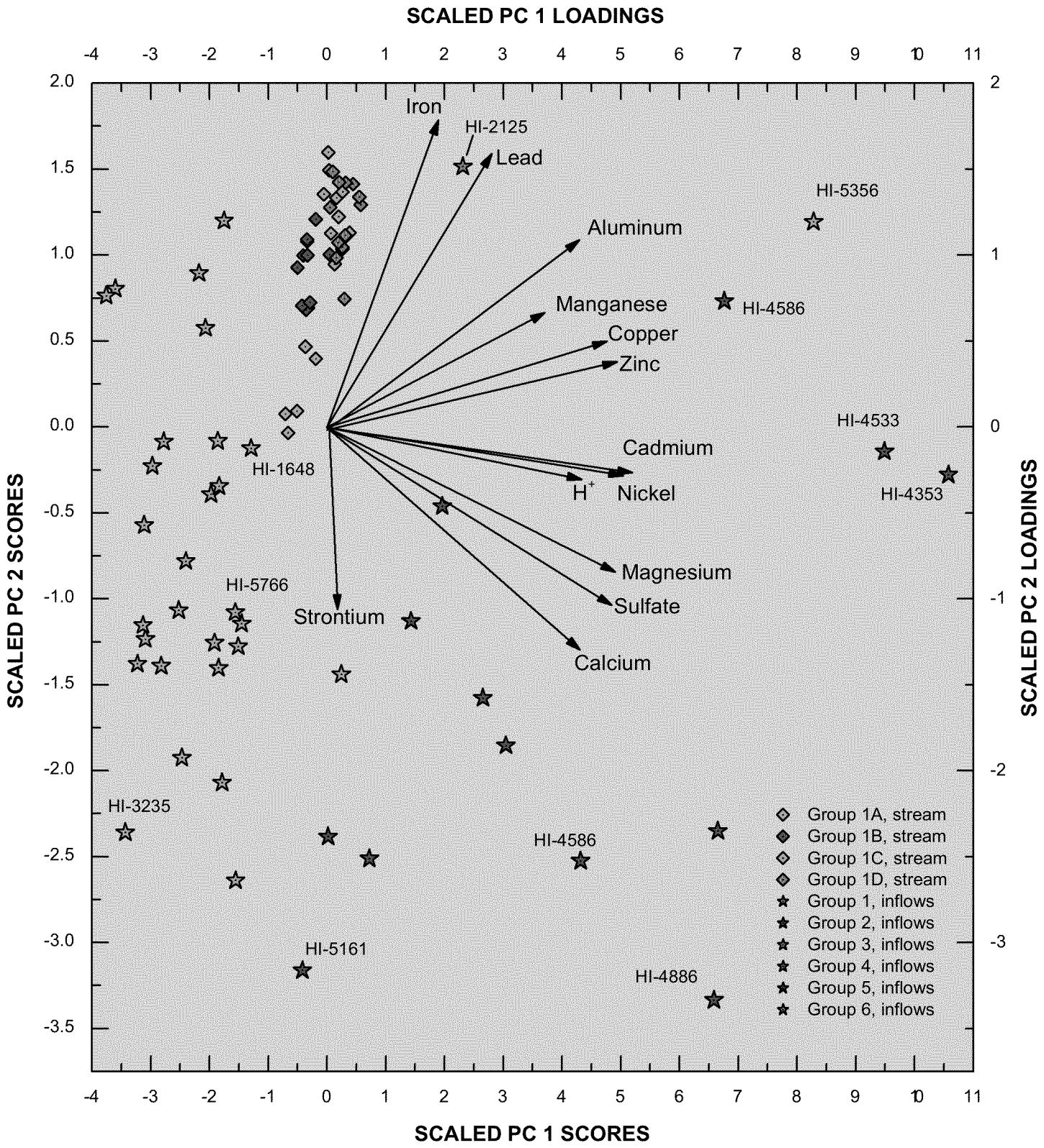


**Figure 85**. Biplot showing groups of inflows and stream sites, upper Animas River, from Howardsville to Silverton, Colorado, August 1997.

**Table 28. Median concentrations of stream and inflow samples classified by PCA groups, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.**

[Dis, dissolved; Col, colloidal; pH, in standard units; all concentrations in milligrams per liter; LD, less than detection]

| Solute | Phase | Group 1 All stream samples | Group 1 Mid-sulfate inflows | Group 2 High sulfate inflows | Group 3 Dilute inflows | Group 4 Acidic inflow at HI-2125 | Group 5 Acidic inflows downstream from Arastra Gulch | Group 6 Inflow at HI-5356 |
|---|---|---|---|---|---|---|---|---|
| Number of samples | | 39 | 2 | 8 | 26 | 1 | 5 | 1 |
| pH | Dis | 7.63 | 7.25 | 6.95 | 7.66 | 4.76 | 4.90 | 5.14 |
| Calcium | Dis | 37.6 | 41.9 | 115 | 34.1 | 61.5 | 204 | 216 |
| Magnesium | Dis | 2.55 | 2.14 | 6.51 | 2.12 | 5.80 | 24.4 | 18.0 |
| Sodium | Dis | 2.25 | 2.61 | 3.98 | 2.24 | 4.44 | 6.86 | 4.54 |
| Chloride | Dis | 1.61 | 4.27 | 0.680 | 0.340 | 0.390 | 2.49 | 1.01 |
| Sulfate | Dis | 78.1 | 80.5 | 308 | 48.7 | 222 | 1,050 | 1,380 |
| Aluminum | Dis | 0.031 | 0.014 | 0.056 | 0.016 | 1.32 | 2.43 | 20.0 |
| | Col | 0.069 | | | | | | |
| Cadmium | Dis | 0.002 | 0.007 | 0.004 | LD | LD | 0.056 | 0.124 |
| | Col | LD | | | | | | |
| Copper | Dis | 0.001 | 0.022 | 0.001 | LD | 0.011 | 0.248 | 2.42 |
| | Col | 0.003 | | | | | | |
| Iron | Dis | 0.011 | 0.005 | 0.082 | 0.007 | 0.556 | 0.044 | 0.023 |
| | Col | 0.424 | | | | | | |
| Manganese | Dis | 0.454 | 0.109 | 1.20 | 0.006 | 1.04 | 55.5 | LD |
| | Col | 0.003 | | | | | | |
| Nickel | Dis | LD | LD | 0.004 | LD | 0.005 | 0.045 | 0.095 |
| | Col | LD | | | | | | |
| Lead | Dis | LD | 0.004 | LD | LD | LD | 0.045 | 0.166 |
| | Col | 0.003 | | | | | | |
| Strontium | Dis | 0.385 | 0.547 | 0.848 | 0.358 | LD | 1.23 | LD |
| Zinc | Dis | 0.281 | 0.88 | 0.713 | 0.020 | 0.218 | 19.4 | 39.8 |
| | Col | 0.043 | | | | | | |



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### Load Profiles

Load profiles quantify physical and chemical changes along the study reach, and help to indicate whether changes result from dilution or chemical reaction. A summary of load calculations for the Howardsville study reach is listed in table 28. There were some special considerations for these calculations. First, at HS-4581, the calculated inflow load greatly exceeded the increase in sampled instream load for most all the metals. Considering this large inflow load, it is unlikely that the sampled inflow was representative of the water entering the Animas River in that stream segment. Because that sampled inflow did not appear to affect the instream load, the inflow load for that stream segment was assumed to be equal to the instream load.

Second, most of the aluminum concentrations along the study reach were in a poor analytical range for the ICP-AES analysis. It was possible to determine the trend of aluminum concentrations by smoothing the data after the method of Velleman and Hoaglin (1981). Greater analytical variability for all the metals required some smoothing, but not to the extent that was necessary for aluminum. The effect of smoothing is to eliminate small increases to the cumulative instream load that most likely do not represent real increases in load.



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**Table 29. Summary of load calculations for selected metals, upper Animas River, Howardsville to Silverton, Colorado, September 1997.**

[All loads are in kilograms per day; red text with parentheses indicates a negative net load for a stream segment; magnitude of loads are indicated by colors; red, greatest or first; orange, second; yellow, third; green, fourth; and blue, fifth]]

| Site Description | Distance | Aluminum | Cadmium | Copper | Iron | Manganese | Lead | Strontium | Zinc | Sulfate |
|---|---|---|---|---|---|---|---|---|---|---|
| Below injection site | 160 | 4.19 | 0.127 | 0.240 | 2.20 | 8.54 | 0.160 | 23.6 | 18.9 | 5260 |
| Stream at 310 m | 310 | 0.015 | 0.000 | 0.001 | 0.008 | 0.031 | 0.001 | 0.087 | 0.069 | 19.3 |
| T1--near construction | 595 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Stream Above inflow RB | 905 | 0.046 | 0.001 | 0.003 | 0.024 | 0.094 | 0.002 | 0.260 | 0.207 | 57.8 |
| Above Howardsville Mill | 955 | 0.046 | 0.001 | 0.023 | 0.024 | 0.094 | 0.002 | 1.07 | 0.207 | 245 |
| T2--Below Howardsville Mill | 1059 | 0.327 | 0.001 | 0.031 | 36.6 | 32.6 | 0.002 | 0.474 | 10.4 | 438 |
| Below Cunningham | 1135 | 1.09 | 0.067 | 0.131 | 10.6 | 6.43 | 0.085 | 13.3 | 2.03 | 1610 |
| Below bridge | 1270 | 0.752 | 0.000 | (0.073) | (0.219) | 0.000 | 0.000 | 0.282 | 0.000 | 0.000 |
| At State gage (A53) | 1510 | 0.676 | 0.000 | (0.020) | (1.96) | (0.866) | 0.001 | 0.259 | 0.074 | 17.9 |
| Below clean and dirty inflows | 1725 | 0.176 | 0.002 | 0.004 | 1.06 | 0.373 | 0.003 | 0.650 | 0.372 | 534 |
| At upper "campground" | 1925 | 0.477 | 0.011 | 0.018 | 2.48 | 2.40 | 0.013 | 2.20 | 1.71 | 435 |
| Below campground | 2110 | 0.109 | 0.000 | 0.023 | 0.056 | (0.043) | 0.001 | 0.093 | 0.074 | 18.9 |
| Stream at 2515 m | 2515 | 0.292 | 0.001 | 0.038 | 0.255 | 3.75 | 0.339 | 0.970 | 2.98 | 56.7 |
| Below adit | 2572 | 0.498 | 0.002 | 0.016 | 0.227 | (3.35) | 0.007 | 0.471 | (1.94) | 94.5 |
| T3--Truck park | 2800 | 0.283 | 0.001 | 0.012 | (0.284) | (0.013) | 0.003 | 0.188 | 0.151 | 178 |
| Narrow chute within canyon | 3040 | 0.287 | 0.003 | 0.010 | 0.426 | 0.481 | 0.008 | 0.565 | 0.452 | 326 |
| Below first cableway | 3295 | 0.326 | 0.000 | (0.017) | 0.224 | 1.20 | 0.000 | 0.000 | 0.000 | (295) |
| Mid canyon | 3555 | 0.693 | 0.000 | 0.000 | 0.000 | 0.867 | 0.000 | 0.000 | 0.000 | 0.000 |
| Stream at 3802 m | 3802 | 1.91 | 0.015 | (0.155) | 5.76 | 3.14 | 0.042 | 2.97 | 2.38 | 601 |
| Between RB inflows in canyon | 4023 | 1.89 | 0.015 | 0.018 | 4.25 | 3.43 | 0.043 | 3.05 | 2.44 | 616 |
| T4 Above Arastra | 4166 | 0.445 | 0.000 | 0.026 | (0.010) | (0.588) | 0.000 | 0.000 | 0.000 | 0.000 |
| Below Arastra Gulch | 4310 | 1.79 | 0.031 | 0.925 | (3.31) | 1.56 | 0.087 | 7.08 | 0.623 | 782 |
| Below River Level Spring | 4473 | 0.054 | 0.060 | (0.543) | 9.39 | 5.01 | 0.274 | (0.356) | 8.00 | 91.2 |
| Below LB Abandoned Mill | 4581 | 0.217 | 0.004 | (0.140) | 1.42 | 9.43 | 0.271 | 1.04 | 2.50 | 147 |
| Above "Pinicle Gap" | 4656 | 0.108 | 0.002 | 0.004 | 1.71 | 1.12 | 0.983 | 0.531 | 2.28 | 185 |
| Above Acid inflows | 4816 | 0.000 | 0.000 | 0.000 | 4.12 | 3.08 | (0.754) | 0.226 | 3.18 | 0.000 |
| Below acid inflows | 4916 | 0.000 | 0.000 | 0.000 | (1.25) | 11.5 | 0.000 | 0.483 | 2.59 | 0.000 |
| Below Boulder Creek | 5131 | 0.623 | 0.013 | 0.021 | (1.85) | 11.7 | (1.021) | 2.63 | 2.58 | 426 |
| Below Blair Gulch | 5306 | 0.956 | 0.003 | 0.005 | 0.562 | 7.51 | 0.004 | 2.43 | 1.10 | 323 |
| Below first of capped tailings | 5536 | 0.987 | 0.000 | 0.000 | 0.647 | 14.6 | 0.000 | 0.410 | 6.25 | 325 |
| Above drain from tails | 5756 | 2.29 | 0.036 | 0.272 | 9.23 | 12.3 | 0.055 | 5.53 | 7.98 | 1410 |
| T5--Below capped tailings | 6038 | 0.000 | 0.000 | 0.110 | (9.60) | 0.000 | 0.589 | 0.000 | 0.000 | 0.000 |
| Below toe of Mayflower | 6288 | 1.61 | 0.067 | 0.174 | 6.15 | 68.3 | 0.089 | 5.27 | 10.1 | 1340 |
| Above Lacawana Bridge | 6528 | 1.92 | 0.059 | 0.136 | 5.70 | 13.8 | 0.106 | 6.27 | 7.24 | 868 |
| Below Lacawana Bridge | 6768 | 0.000 | 0.020 | (0.163) | (0.001) | (18.4) | 0.000 | 0.000 | 0.000 | 0.000 |
| Above Lacawana Mill | 7008 | 0.061 | 0.022 | (0.137) | 0.492 | 6.67 | 0.003 | 0.199 | 0.230 | 168 |
| Below Lacawana Mill (A66) | 7283 | 1.90 | (0.081) | 0.000 | 0.449 | (1.86) | 0.000 | 0.303 | 0.000 | 26.3 |
| Among braids nr town | 7523 | 1.03 | (0.079) | 0.004 | 0.721 | 0.926 | 0.005 | 0.787 | 0.345 | 680 |
| T6--At bridge / gage A68 | 7858 | 0.212 | 0.000 | 0.101 | 0.155 | 25.2 | 0.000 | 2.01 | 0.000 | (114) |
| | | | | | | | | | | |
| Cumulative instream load | | 28.3 | 0.57 | 2.31 | 105 | 256 | 3.18 | 85.8 | 97.39 | 17300 |
| Cumulative inflow load | | 15.1 | 0.46 | 1.73 | 6.37 | 72.0 | 1.13 | 64.9 | 81.57 | 12900 |
| Percent inflow load | | 53% | 81% | 75% | 6% | 28% | 36% | 76% | 84% | 75% |
| Unsampled inflow | | 13.2 | 0.11 | 0.58 | 98.50 | 184.09 | 2.04 | 20.88 | 15.81 | 4400 |
| Percent unsampled inflow | | 47% | 19% | 25% | 94% | 72% | 64% | 24% | 16% | 25% |
| Attenuation | | 0.00 | 0.16 | 2.2 | 18.5 | 25.1 | 1.8 | 0.4 | 2.0 | 400 |
| Percent attenuation | | 0% | 28% | 95% | 18% | 10% | 56% | 0% | 2% | 2% |



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Load profiles for selected solutes indicate similarities and differences in patterns of loading and in the reactive nature of the solutes. Several solutes had substantial loads at the beginning of the study reach. Strontium (fig. 86) had 28 percent of its cumulative instream load, and sulfate (fig. 87) had 33 percent in the first stream segment. This indicates that there were sources upstream from the study reach. Cadmium (fig. 88), zinc (fig. 89), and aluminum (fig. 90) each had from 15 to 22 percent from upstream. Each of these solutes, except aluminum and cadmium, gained a substantial amount of load from the inflow at HI-965. Iron (fig. 91) gained 37 percent of its load from that inflow.

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**Figures 86-91 near here.**

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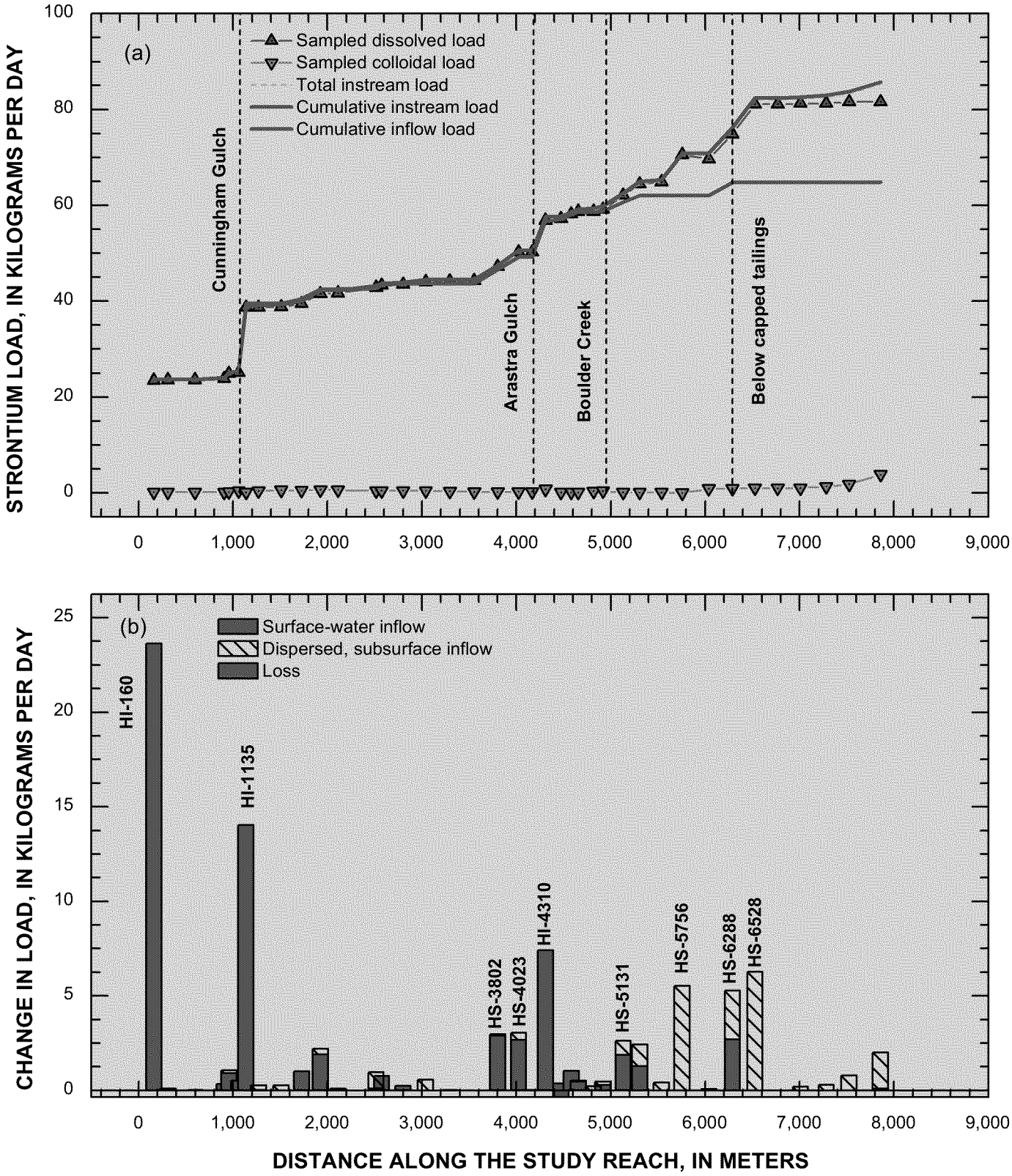


**Figure --**. Variation of (a) strontium load with distance along the study reach and (b) change in load for individual stream segments.

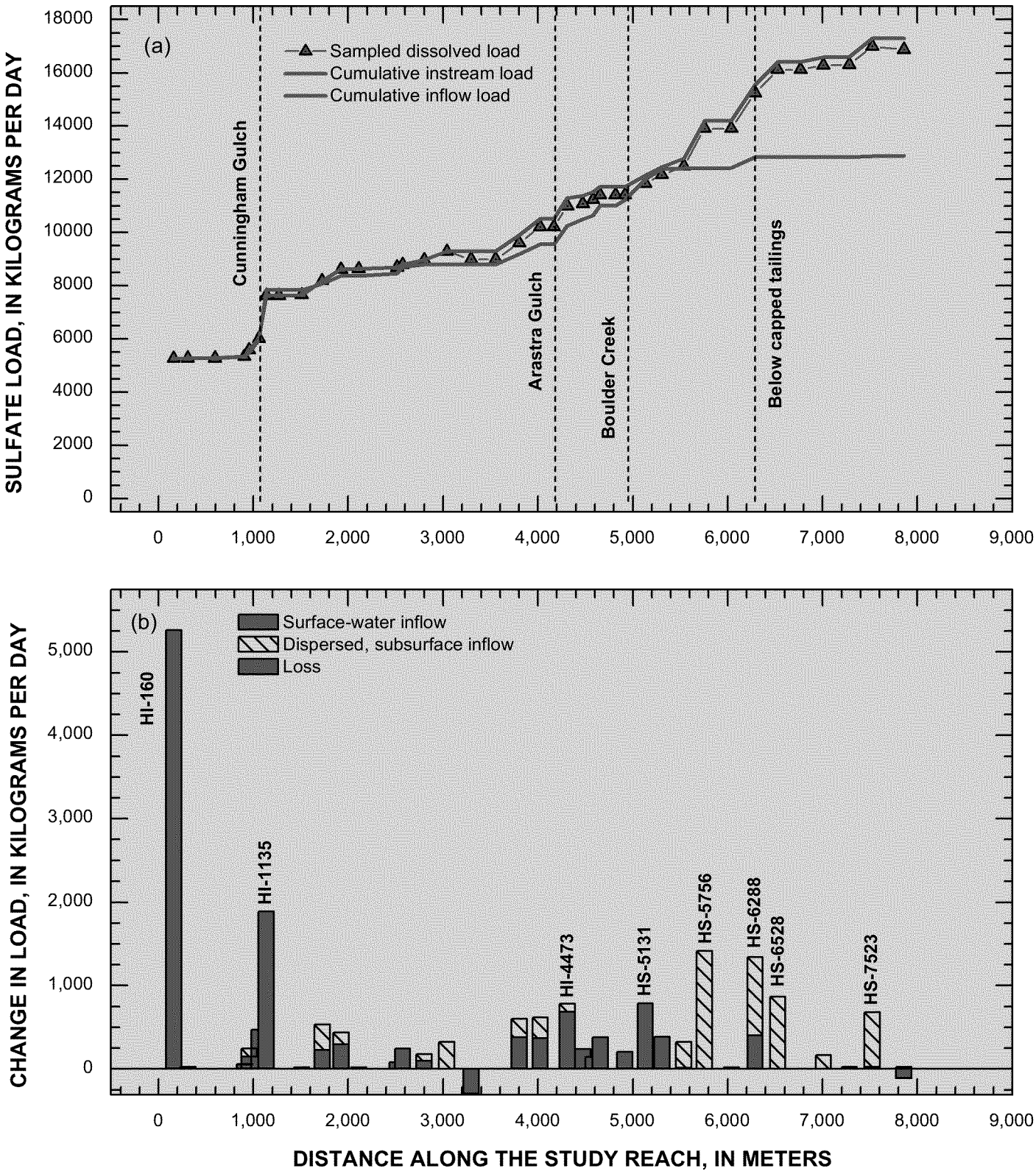


**Figure --**. Variation of (a) sulfate load with distance along the study reach and (b) change in load for individual stream segments.

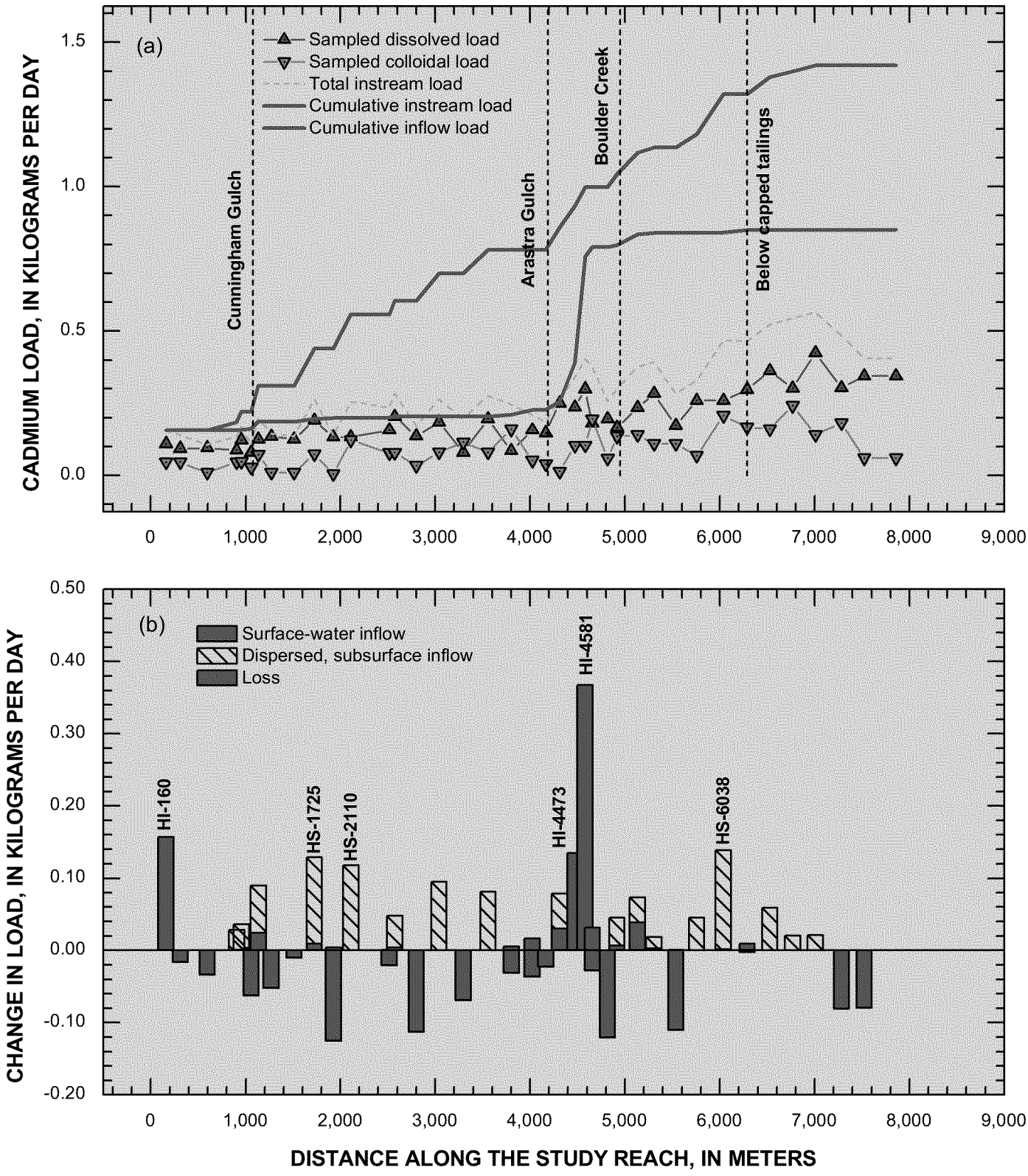


Figure --. Variation of (a) cadmium load with distance along the study reach and (b) change in load for individual stream segments.

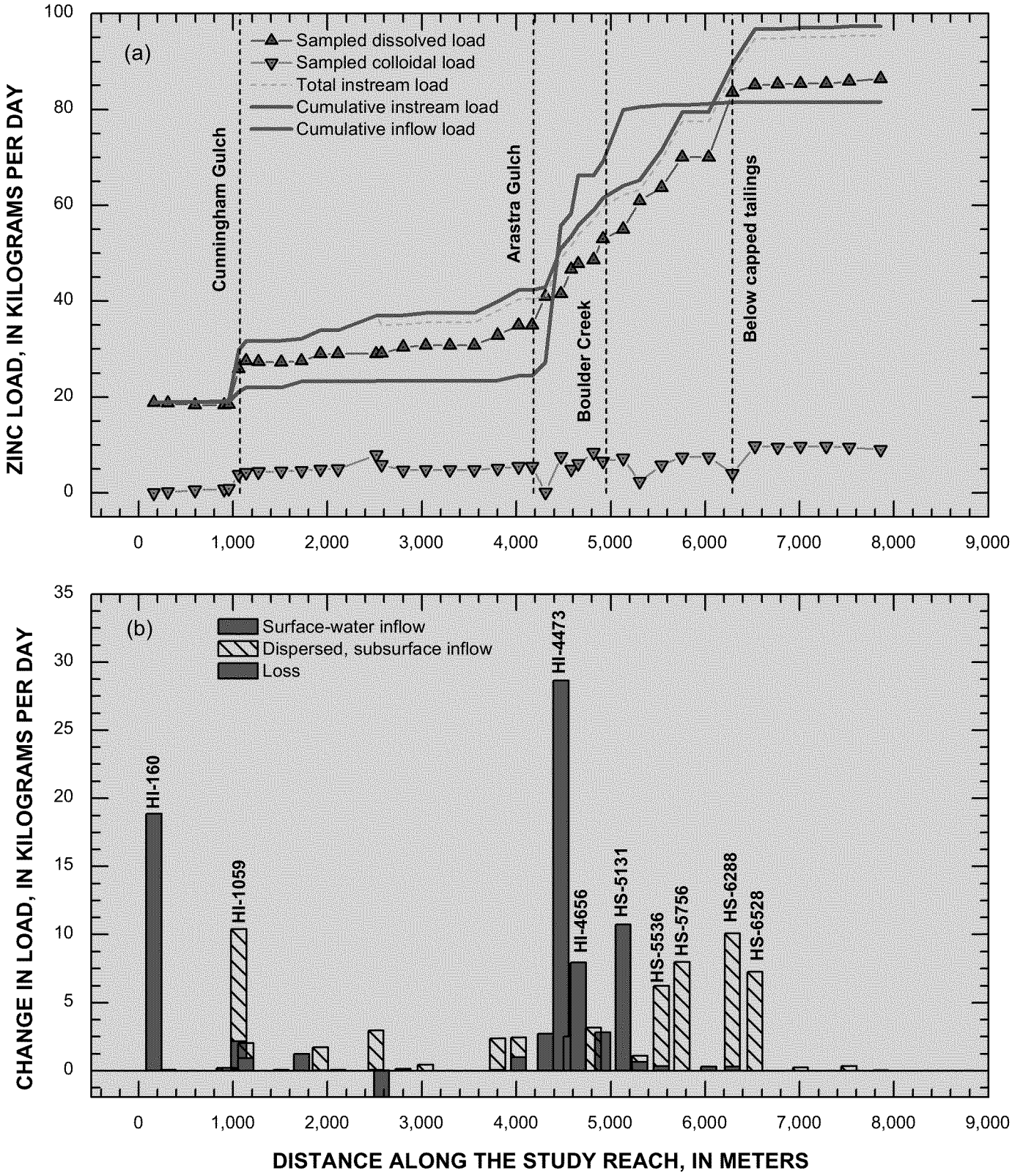


**Figure --**. Variation of (a) zinc load with distance along the study reach and (b) change in load for individual stream segments.

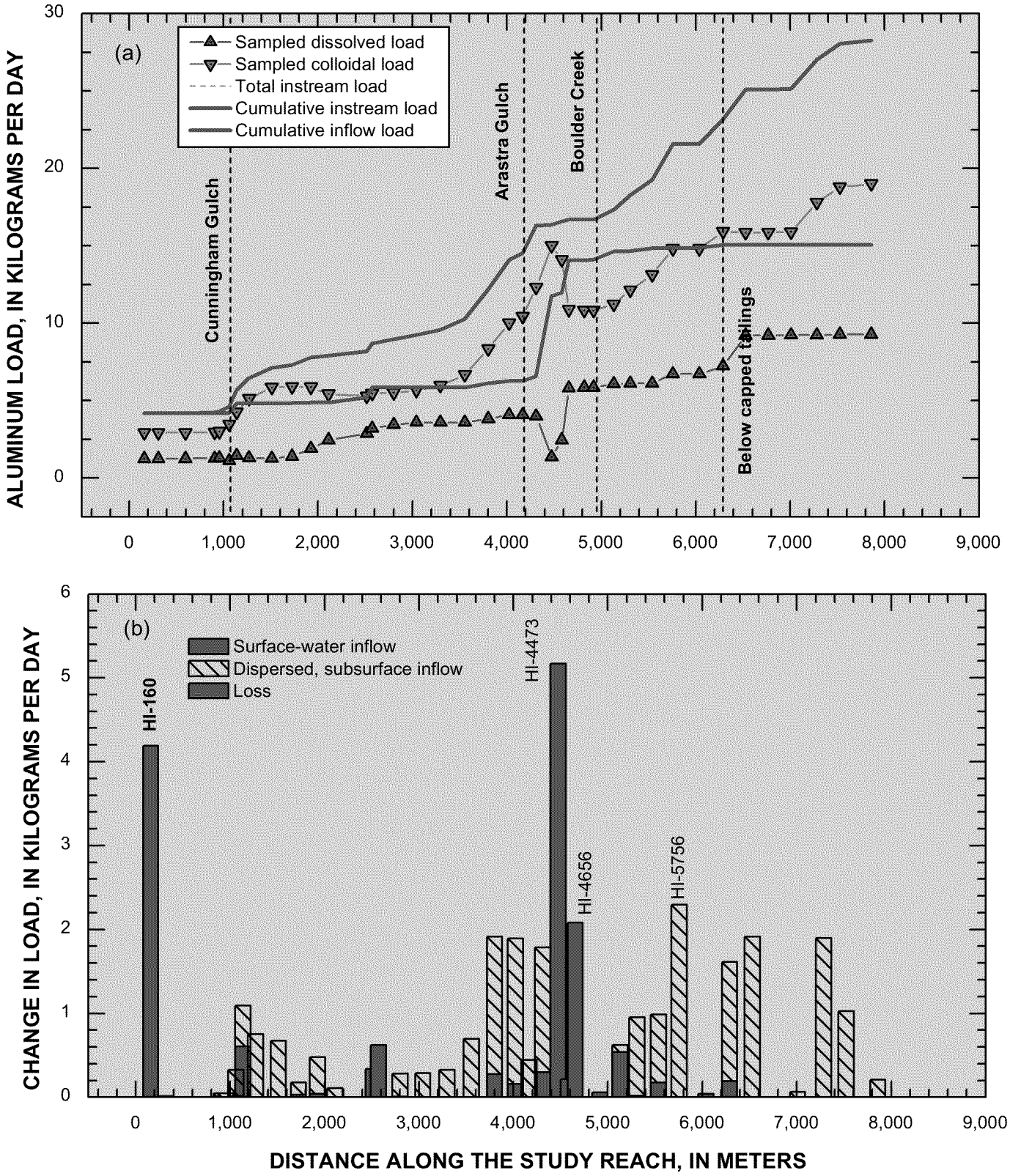


**Figure 86**. Variation of (a) aluminum load with distance along the study reach and (b) change in load for individual stream segments.

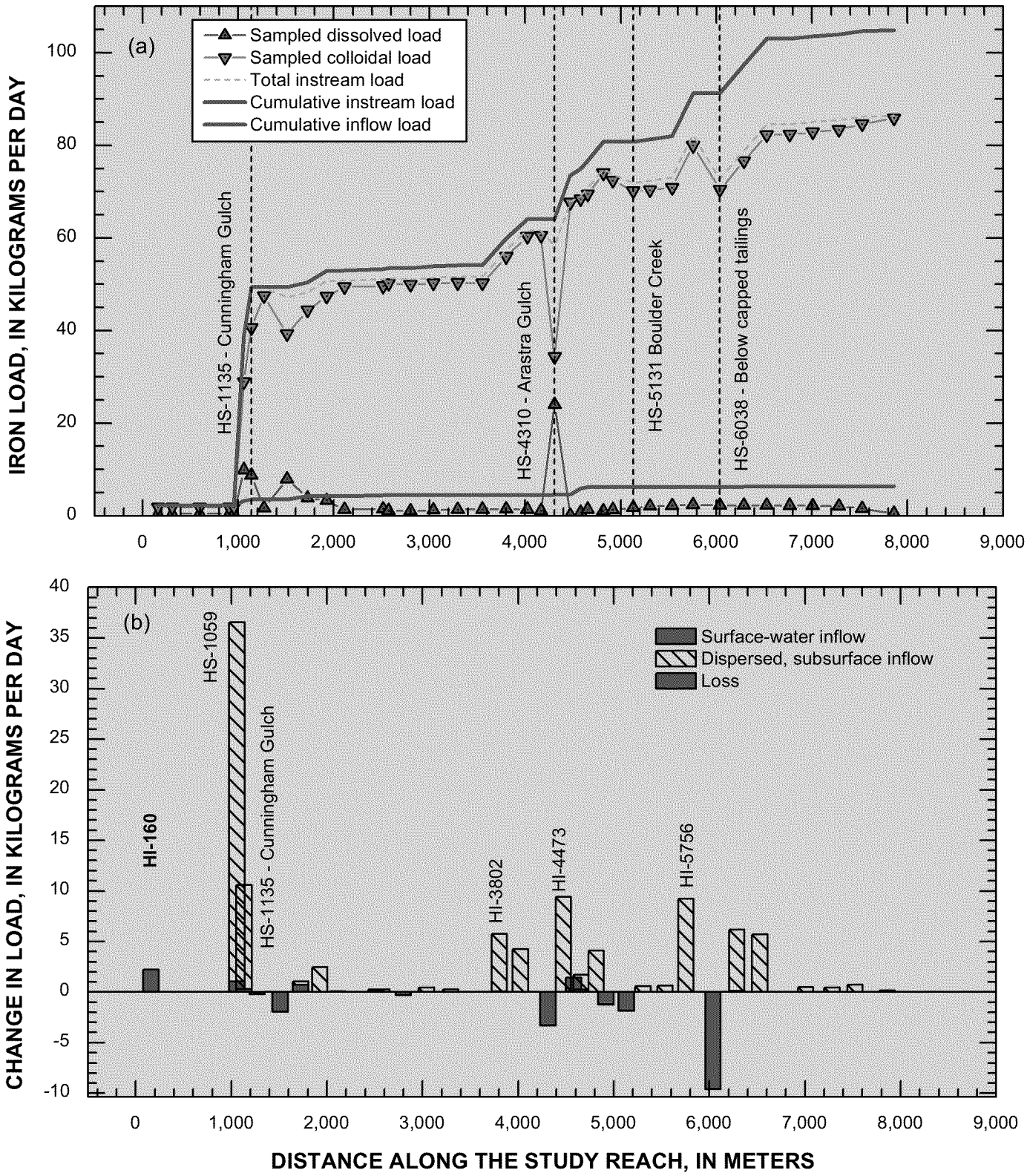


Figure --. Variation of (a) iron load with distance along the study reach and (b) change in load for individual stream segments.

Manganese (fig. 92) typically is very similar to zinc, but in this study reach, there were differences in their sources. As noted, loading of zinc was substantial upstream of the study reach and from HI-965 (fig. 89). There was a substantial load of manganese at HI-965, but the greatest load of manganese occurred downstream in segment HS-6288.

**Figure 92 near here.**

Patterns of copper (fig. 93) and lead (fig. 94) were different from all the others because these metals were very reactive. Both metals had their greatest load in the section of the study reach downstream from Arastra Gulch; copper in HS-4310, and lead in HS-4656.

**Figures 93 and 94 near here.**



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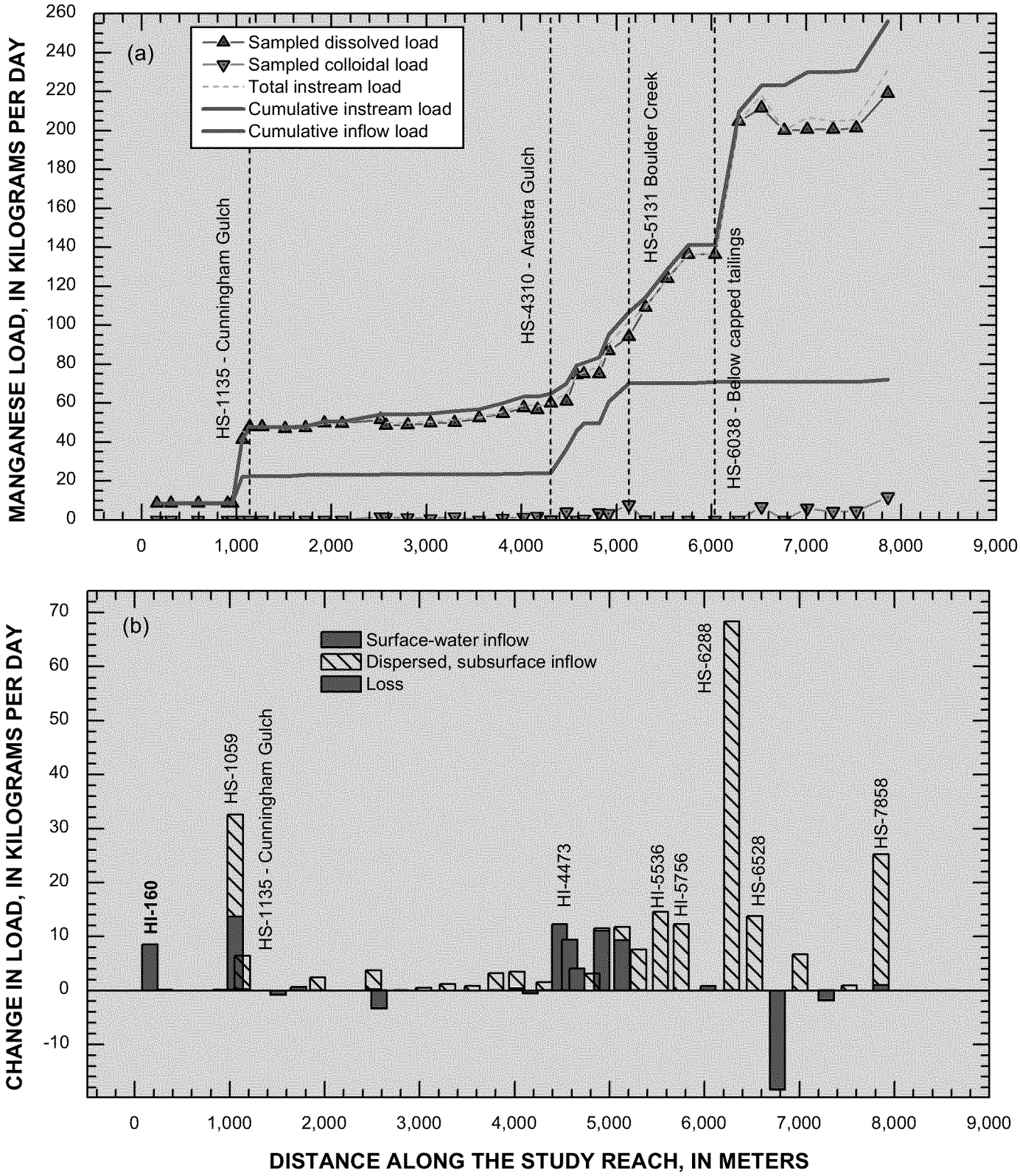


Figure --. Variation of (a) manganese load with distance along the study reach and (b) change in load for individual stream segments.

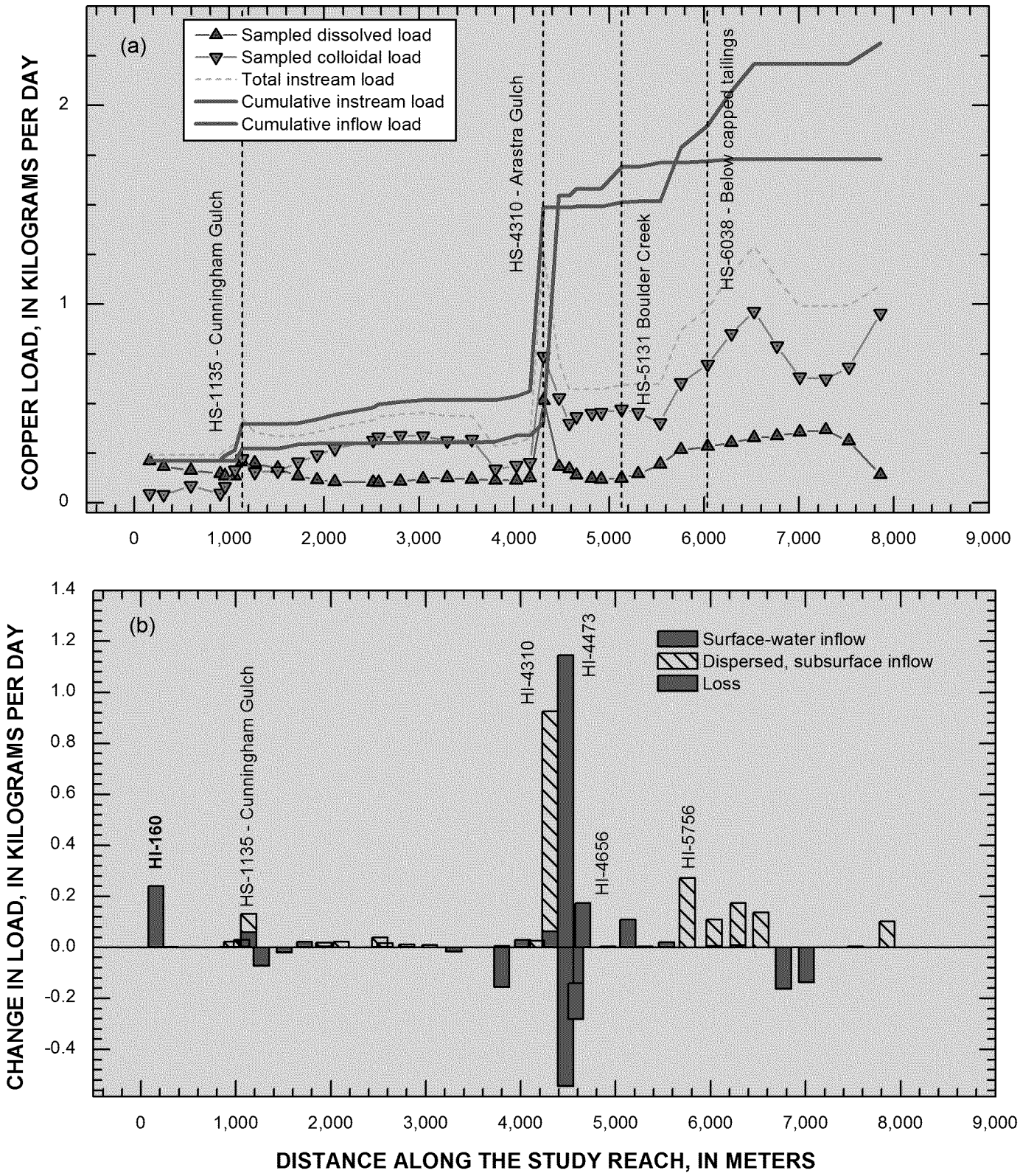


Figure --. Variation of (a) copper load with distance along the study reach and (b) change in load for individual stream segments.

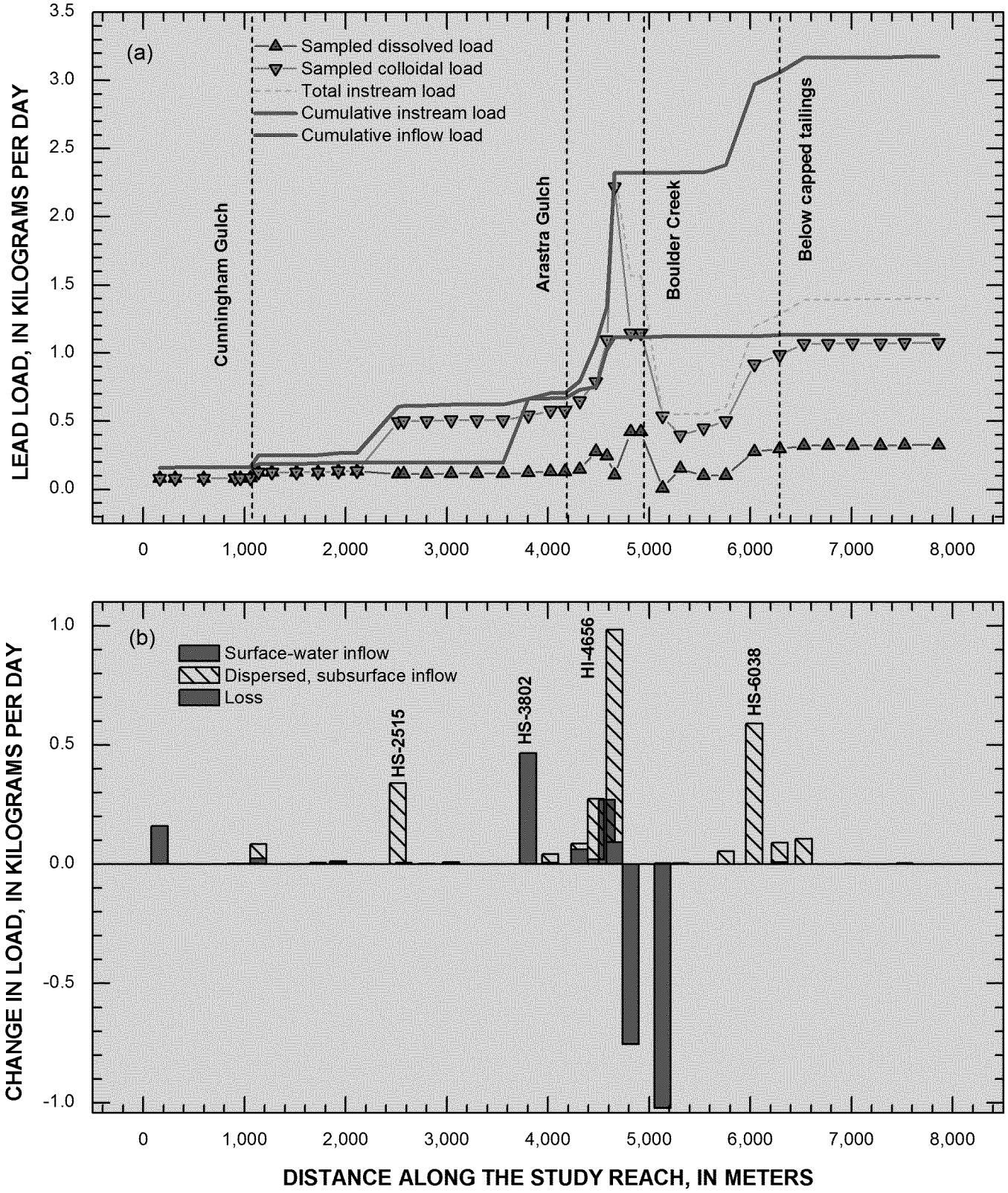


Figure --. Variation of (a) lead load with distance along the study reach and (b) change in load for individual stream segments.

## Principal sources of metal load

There greatest loads from individual stream segments are indicated in table 28. The colors give a visual pattern of those areas where the loading occurs. These areas include:

1. Upstream from the study reach (HS-160) -- Strontium, sulfate, cadmium, and zinc had substantial sources upstream from the study reach.
2. Area of old tailings near Howardsville (HI-965) – Iron, manganese and zinc were all added with this inflow. There was a prominent iron stain along the left bank of the stream downstream from the inflow, indicating the iron-rich water.
3. Cunningham Gulch (HI-1075)– Iron, strontium, and sulfate were added by the inflow of Cunningham Gulch. There are sources of metals upstream in Cunningham Gulch (Herron and others, xxxx), but this most likely represents weathering of non-sulfide minerals.
4. Downstream from Arastra Gulch (HS-4310 through HS-6528) – Copper and lead were the principal metals added in these segments. Iron and strontium also had loads in segments HS-4473 and HS-4310, respectively.
5. Downstream from Blair Gulch to Lacawana Bridge (HS-5536 through HS-6528) – Each of the metals had some loading in these segments. This was the location for the greatest loading of manganese.
6. Ditch draining right bank near Silverton (HS-7858) – Copper and manganese increased in the last stream segment where a ditch enters the stream. The source of metals to the ditch is not clear, but could include buried tailings or waste rock in the alluvium of the Animas River.



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### Unsampled inflow

There was a very noticeable change from sampled to unsampled inflow along the study reach. The change was downstream from Arastra Gulch, and mostly included inflows to stream segments between Arastra Gulch and Lacawana Bridge. The source of metals in this reach of the stream has not been determined. Possibilities include drainage of the Mayflower tailings piles and alluvial tailings. Seeps along the right bank that have iron and aluminum precipitates have been observed at a lower stage of the river than the time of the tracer study (T. Nash, 2001, U.S. Geological Survey, written communication). Considering the relatively high flow of the Upper Animas River compared to other streams in this study, the small increases in concentration represent a substantial increase in metal load.

### Attenuation

For most metals, there was not much attenuation along the study reach from Howardsville to Silverton. Only the decreases for cadmium, copper, and lead loads were substantial. Both copper and lead increased greatly in the area downstream from Arastra Gulch. After this increase, most of the load that had come into the stream was removed from the stream. There was some loss of iron load in segment HS-4310, and the largest decrease in copper load occurred in the next segment downstream, suggesting that the copper loss could be related to the loss of iron colloids. The attenuation of lead load was greatest in segment HS-5131, downstream from Boulder Creek, and this also corresponded to a loss of iron load.



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