A Preliminary Survey of Rainfall Catchment Systems for Impacts Associated with Halema'uma'u Gas Discharge

Final Results

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Introduction

In an effort to assess the impacts of the volcanic gas and fume emitted by the ongoing Halema'uma'u eruption, a collaborative study of domestic water catchment systems was undertaken by the UH CTAHR's Cooperative Extension Office and the UH Center for the Study of Active Volcanoes. Three broad areas of Hawaii Island were selected for sampling based on:

- their dominant use of rainfall catchment systems for domestic water supply;
- their locations near Halema'uma'u: Volcano Village and nearby subdivisions;
- downwind of Kilauea's summit plume: Hawaii Ocean View Estates and surrounding residential areas (for brevity, referred to as HOVE below); and
- upwind of Kilauea's summit (as a control): Lower Puna.

The study was intended as a general screening of the catchments for evidence of accumulation of compounds most likely to be derived from the volcanic plume as well as for their potential to have a public health or adverse environmental impact if the values were elevated.

Among the most abundant compounds present in the volcanic plume are sulfur dioxide and sulfur trioxide which are reportedly discharged at rates ranging from about 700 to 1100 metric tones per day. Both of these compounds convert first to sulfuric acid and then to one or more sulfate reaction products (e.g. ammonium sulfate, calcium sulfate, sodium sulfate) during their transport downwind in the plume. Sulfuric acid, as well as the sulfate salts, are present as aerosols (particulates) that will gradually settle out of the air column, often referred to as dry deposition, onto roofs and ground surfaces. During rainfall events these particulates also serve as condensation nuclei for raindrop formation. Dry deposition and condensation processes both serve as pathways for sulfate compounds to enter water catchment systems. Hence, the sulfate concentrations can provide a strong indication of the degree of influence of the plume on water catchment chemistry.

Hydrochloric and hydrofluoric acids are also present in the volcanic plume, albeit at lower concentrations, and both can form aerosols that will deposit along with the sulfate aerosols. Whereas the chloride and sulfate compounds are typically only a threat to human health at very high concentrations (>250 parts per million (ppm) in drinking water), fluoride salts are a recognized threat to health when their concentrations exceed a few (4 – 5) parts per million in drinking water.

Although not directly related to an acute public health threat, measurements were also made of the pH of the catchment water samples. As noted above, three strong acids are present in the downwind plume from Halema'uma'u: sulfuric acid (H_2SO_4), hydrochloric acid (HCl), and hydrofluoric acid (HF). The impacts of these acids on the catchment systems include corrosive reactions with the roof surfaces and metal components of the domestic water system (pumps, copper piping, fixtures). In addition to damage to the plumbing system, a secondary impact of the acidic water is the potential to leach heavy metals, principally lead, that may be present in the system. Dissolved lead is of greatest concern if lead containing roofing nails, paint, solder, or other plumbing components come in contact with the acidic water. The use of lead was prohibited in paints after about 1978 and lead-based solder, for copper "sweat" fittings, was removed from the market during the late 1980's and lead roofing-nail heads or washers have become less common as stable polymers have gradually replaced these components in roofing installations. In addition to the threat of heavy metal exposure resulting from low pH water, there has been increasing concern that consumption of acidic water may contribute to weakening of tooth enamel and an increasing incidence of dental carries in both children and adults.

As a result of these factors, we selected pH and the sulfate, chloride, and fluoride ions as our chemical tracers for plume impacts and as an indicator of the potential threat that the plume posed to public health. We should emphasize here that the presence of the dissolved ions at levels well below recognized standards – 250 ppm for chloride and sulfate, and 4-5 ppm for fluoride – should <u>not</u> be inferred to pose some lesser degree of adverse health impact. The standards cited above take into account any cumulative risks that these ions may pose if consumed in drinking water.

Procedures

Our procedure for collecting samples was to distribute notices to the area residents by a variety of media – direct mailing, email contacts, notices posted at local businesses, and posted in community newsletters – to offer them free testing of their catchment waters. The residents were advised to collect a sample of their catchment water (directly from the tank and upstream of any filters or treatment) in a clean plastic container and bring it to a designated location along with a filled-in form that provided us with some basic information about their catchment system (e.g. size, treatment system, elevation, etc.). A project team was stationed at that location on the date of the sample collection and each resident was provided with an immediate pH determination of their water along with: information and literature on managing their catchment to maintain their pH within an optimal range; treatment of biologic pathogens; and methods to minimize potential contaminant entry into their system. The samples provided to us were then returned to the laboratory and analyzed for their concentrations of fluoride, chloride, and sulfate ions by Ion Chromatography. The data from the forms were also collated and entered into a database that will allow us to do a more detailed assessment of the relationship among the ion concentrations and catchment parameters recorded on the forms.

Findings

The three targeted communities, HOVE, Volcano Village, and Lower Puna, Figure 1, have provided samples of their catchment water and analysis of those samples is complete. Overall, the response from all communities was very favorable: the HOVE community provided 153 individual samples from throughout the community and surrounding subdivisions; 205 catchment samples were provided by the Volcano Community and several subdivisions near Kilauea's summit; and 82 samples were collected for Lower Puna. The large number of samples obtained from each community allows us to draw some statistically reliable conclusions about the conditions of the catchment systems in these communities and the impact of Kilauea's plume on their chemical condition.

Catchment water pH distributions

The pH measurements made in all three communities spanned a broad range extending from a low (acid) pH of 2.9 to a high of 10.6. Although there are no health-based limits on water pH, the generally recommended levels are from 6.5 to 8.5. Figure 2 shows the distributions of pH values for the three communities: the horizontal axis is the pH (range) and the vertical axis is the number of samples measured within that range. Several things are evident from the data plot:

1) The median value (half the values are higher and half lower) for Volcano samples is considerably lower (pH is a logarithmic scale) than that for HOVE or Lower Puna.
2) The HOVE data are bimodal – there are two clusters of samples having an approximate median pH value near 4.3 and near 7 respectively.
3) All three suites of samples show a broad range of values with "tails" extending well above and below the median values.

We interpret the data as follows:
The naturally occurring pH of the rainfall in all three communities is likely to be fairly low – in the range of 4.4 to 5. Because of the high purity of the rainfall, it has very limited buffering capacity that is easily overcome by either atmospheric carbon dioxide, or even very small amounts of acid volatiles from Kilauea. There is, however, an additional influence on the catchment pH: some residents treat or "manage" their water catchment systems to control pH or biologic activity. We found that Lower Puna residents treated their water most frequently (59%), followed by HOVE residents (50%) whereas Volcano residents treated their water least frequently with only 37% using either sodium bicarbonate or chlorine bleach (or calcium hypochlorite tablets). Where the former will neutralize the acids present in the water, the latter is used as an anti-microbial that, due to its caustic pH, will also react with any acids present in the water. The cluster of near neutral values from Lower Puna and HOVE is believed to largely reflect those systems that are being managed by their owners whereas the cluster of low-pH values in HOVE are more likely representative of untreated water catchments that are being impacted by the acidic compounds in the volcanic plume. It is noteworthy that Lower Puna samples don't show the cluster of low pH values; we attribute this to the absence of a significant input from Kilauea's discharge.

The Volcano catchments were less frequently adjusted for pH by their owners and don't show as clearly bimodal values, although those with the higher pH levels are likely to be associated with a treatment program. We also note that there was a single "outlier" result with a pH of 10.6; when queried, the owner indicated that his catchment tank was constructed of ferrocement, which is quite caustic, and is consistent with maintaining a high pH level in the stored water.

Some general conclusions that can be drawn from the data distributions are that the Volcano community has a higher proportion of their catchment systems outside of the recommended range, but that the catchments in the HOVE community are more strongly affected by the volcanic emissions than are those of Volcano. This is likely the result of two factors: the HOVE community, even though it is more distant from the source of the acid gases, has a greater aggregate duration of exposure than do the Volcano communities; and, as a result of the markedly different rainfall rates in Volcano (120 in/yr) and HOVE (~50 in/yr) there is likely a great deal more dilution and flushing of the acid aerosols through the catchments in Volcano than in HOVE. The Lower Puna samples give us a good representation of the natural pH of catchment water when only (non-volcanic) natural inputs into the system are present.

As noted above, the pH values were determined at the sample receiving station and the results were immediately provided to the residents; this allowed us an opportunity to both alert the owners when their catchment systems' pH was outside of the recommended range and to encourage them to take an active role in managing their domestic water supply for the protection of their health and for protection of their plumbing systems from the corrosive conditions of their water.

Dissolved Ion Concentrations

The sulfate ion distribution is presented in Figure 3. Overall, the sulfate values were quite low in comparison to recommended drinking water limits of 250 parts per million (ppm). However, it is evident from the plot that the sulfate concentrations in the Lower Puna and Volcano communities were considerably lower than those found in the HOVE catchments: the median value for the latter was nearly fourteen times that of the Lower Puna catchments and seven times that in HOVE. The source of the sulfate in the Lower Puna catchments is likely to be dominantly sea-salt aerosols with negligible amounts coming from the rare instances when vog blankets this area. The Volcano data show that, even with the infrequent plume coverage of that community, there is some contribution of sulfate to the latter. The sulfate data for HOVE clearly indicate that the volcanic plume is a major contributor to the sulfate seen in the catchments there. It should be emphasized, though, that the median value seen is a factor of nearly twenty below recommended drinking water standards and, although some values ranged well above that median, the highest values were still about half the drinking water recommendations. Hence, the sulfate concentrations themselves are not considered to pose a serious threat to the residents in HOVE.

The distribution of fluoride values, Figure 4, for all three communities was consistent with that found for sulfate: the catchments in Lower Puna were extremely low with more than half the values at or below our minimum detection values of 0.01 ppm; the Volcano community values were also quite low, with a median value of 0.048 ppm, considerably higher than Lower Puna but much lower than HOVE; the HOVE catchments showed a median of 0.173 ppm that is at least 17 times higher than Lower Puna. These data convincingly demonstrate that the elevated fluoride concentrations in the HOVE and Volcano catchments are the result of fluoride salts contained in Kilauea's plume. Having the median value for the HOVE catchments well below the drinking water standard is reassuring in terms of the general public health risk. However, some of the values for the HOVE catchments did range as high as 20% of the (US) drinking water standard and one sample from Volcano was found to have a value of more than half the standard limit.

The fluoride values found don't pose an immediate or major threat to the those members of the HOVE community that consume catchment water as their major source of drinking water. However, these values don't entirely relieve the concern regarding the potential impacts of fluoride on the downwind communities. The observed levels of fluoride need to be recognized as reflecting fluoride impacts for a specific set of plume discharge and synoptic meteorological conditions that held sway during the time period leading up to the date of sampling. A substantial increase in the rate of gas emission from the Halema'uma'u crater, significant variations in monthly or annual rainfall, or significant changes in the average wind vectors can substantially increase (or decrease) the fluoride levels that each community is exposed to. At first blush, the much lower values in Volcano suggest a trivial risk arising from fluoride discharge to that community but this is countered by the close proximity of this community to the source. Should meteorological conditions develop where Volcano was frequently blanketed with heavy vog conditions, the fluoride concentrations could increase by substantial amounts. We believe that the one elevated fluoride value found for Volcano provides a basis for this concern.

The results of the chloride ion analyses for all three communities, Figure 5, were consistent with findings for sulfate and fluoride: Lower Puna and Volcano catchments had median values of about 60% and 40% of that for HOVE. The higher values in the HOVE and Puna communities relative to Volcano are likely the result of both higher volcanic fume contributions (HOVE) but also, and possibly a larger impact, from the owner's treatment of their water using chlorine as an antimicrobial. Consistent with the other ion data, the medians were well below the recommended drinking water standard and even the highest values were about half the standard.

We further analyzed the data distribution to determine whether the use of chlorine to treat the water had a demonstrable impact on ion concentrations in the catchment water. Whereas the median and mean chloride values for HOVE waters that were treated with chlorine were about 50% and 30% higher than the population median and mean, there was no statistically significant impact on the other ion values. Neither Volcano nor Lower Puna catchment samples showed a statistically significant difference for any ions between the chlorine treated waters from the population means and medians.

Final Summary

We believe that our screening exercise was a success for the three communities tested.

- The data gathered convincingly demonstrate that the emissions from Kilauea are having varying levels of impacts on the pH and dissolved ion concentrations present in domestic catchment systems in the Volcano and HOVE communities.
- The data show that the catchments in the Volcano community are experiencing a significantly smaller impact than those in HOVE even though Volcano is located closer to the source.
- Under the rainfall and gas emission conditions that have occurred during the last eight or so months, the levels of the (most abundant) acid volatiles produced by the volcano that eventually accumulate in the catchment systems do not reach EPA mandated or recommended water quality standards in either the Volcano or HOVE communities.
- The presence of some catchment concentrations that were substantially higher than the community median values suggests that, if emission conditions at Kilauea, or synoptic meteorological conditions change in a way that would substantially increase the exposure of the downwind communities to the plume constituents, the potential exists for some catchment fluoride concentrations to exceed the EPA MCL values.

In light of these findings, it may be prudent to conduct additional sampling in the HOVE and Volcano communities if discharge characteristics or weather conditions change in a way that would increase the impact of the vog plume on either of these communities.

Future Work

In the event that future sampling exercises are conducted to monitor fluoride and pH of the water catchments, it may be appropriate to conduct the sampling in a way that will allow analysis of heavy metals concentrations in the samples to determine whether the low pH catchment waters are leaching heavy metals from the domestic water systems.

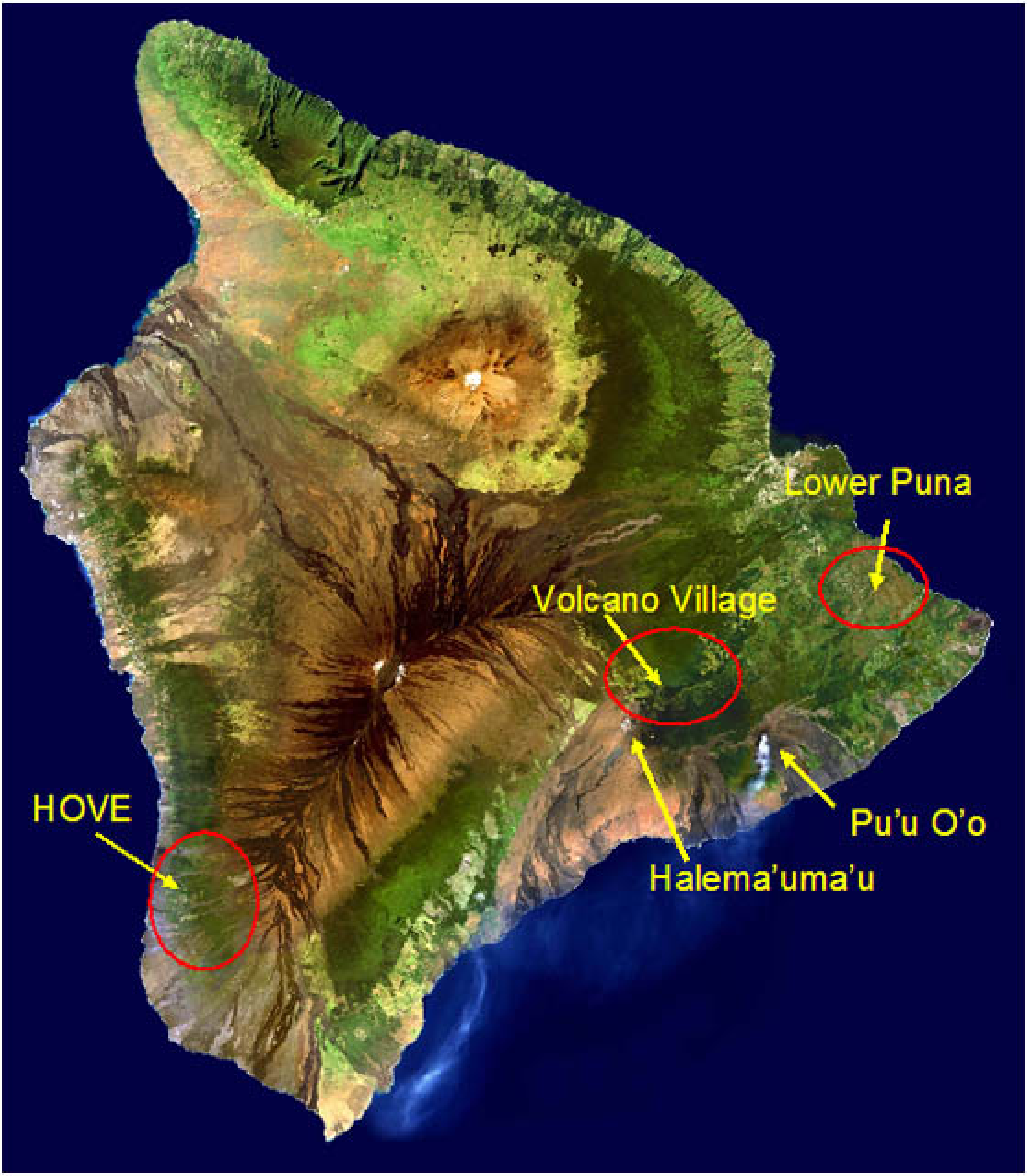

Figure 1. Island of Hawai'i showing locations of communities for which water water catchments were analyzed.

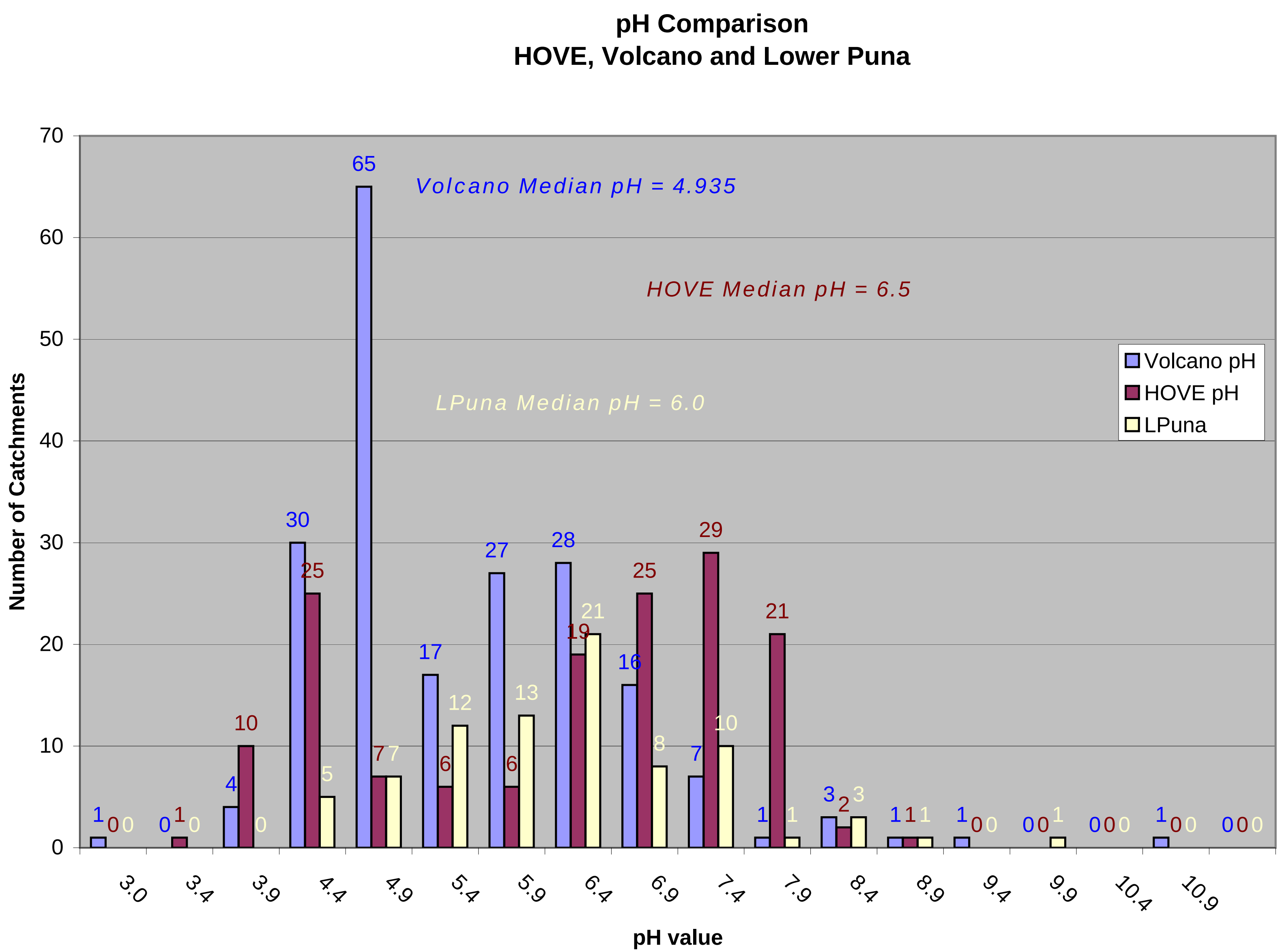

Figure 2. pH distribution for water catchment systems in Lower Puna, Volcano, and HOVE. pH values are shown on the lower axis and the number of catchments having values in the shown range, are shown near the top of each bar.

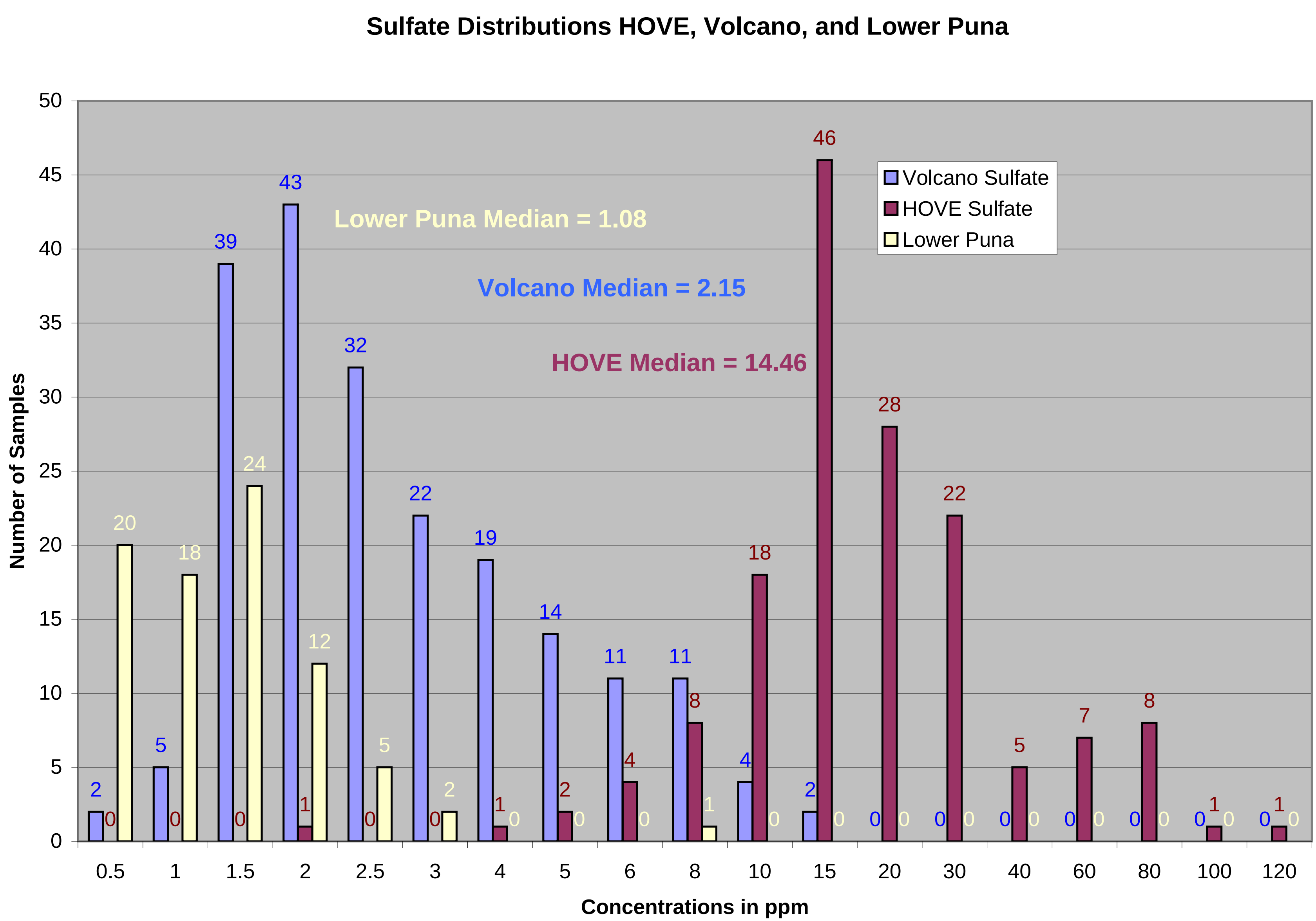

Figure 3. Sulfate concentrations found in the catchment systems sampled. The lower axis shows the concentration of sulfate ion and the number of catchments having values in the range shown are near the top of each bar.

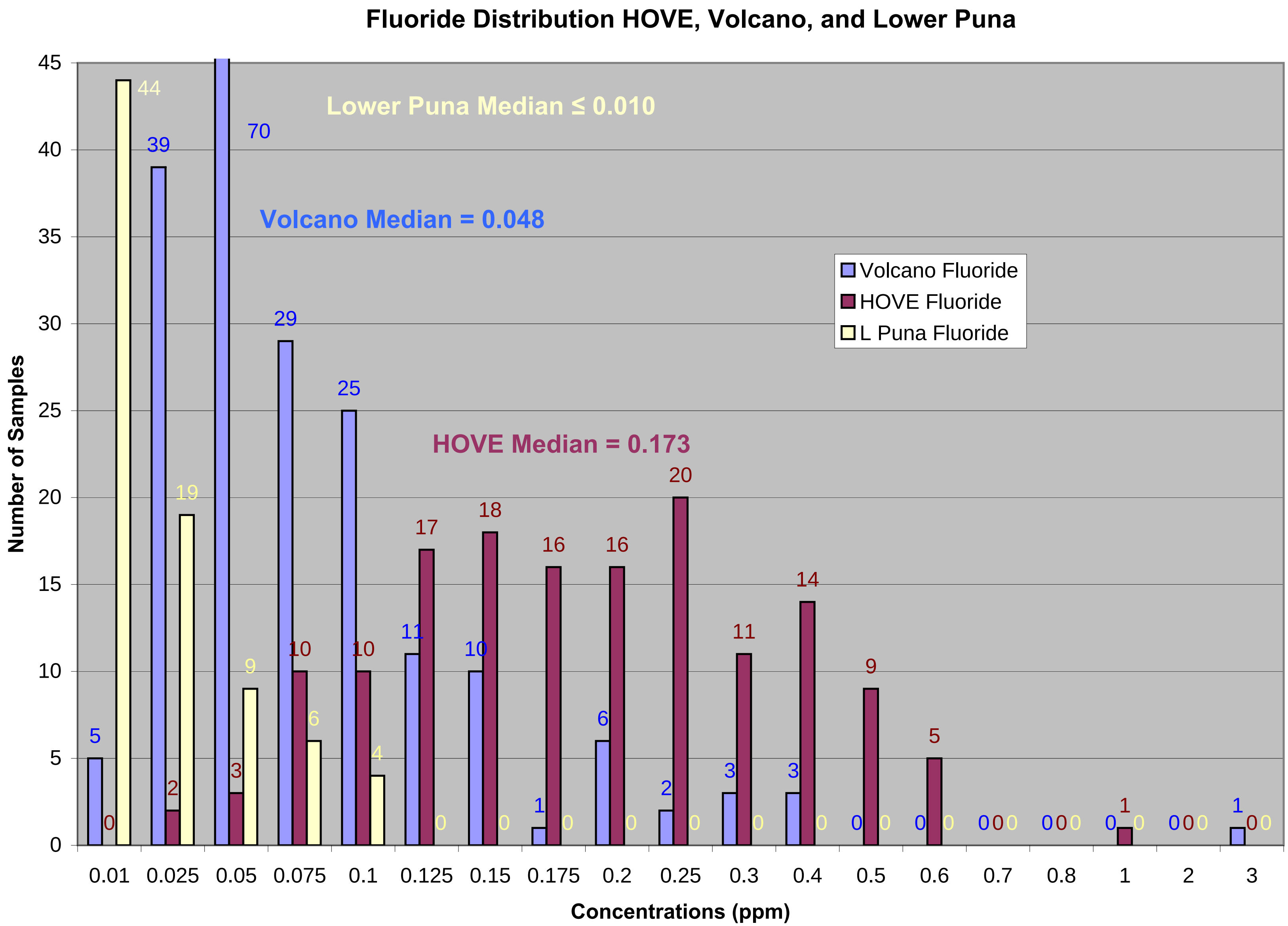

Figure 4. Fluoride concentrations found in the catchment systems sampled. The lower axis shows the concentration of fluoride ion and the number of catchments having values in the range shown are near the top of each bar.

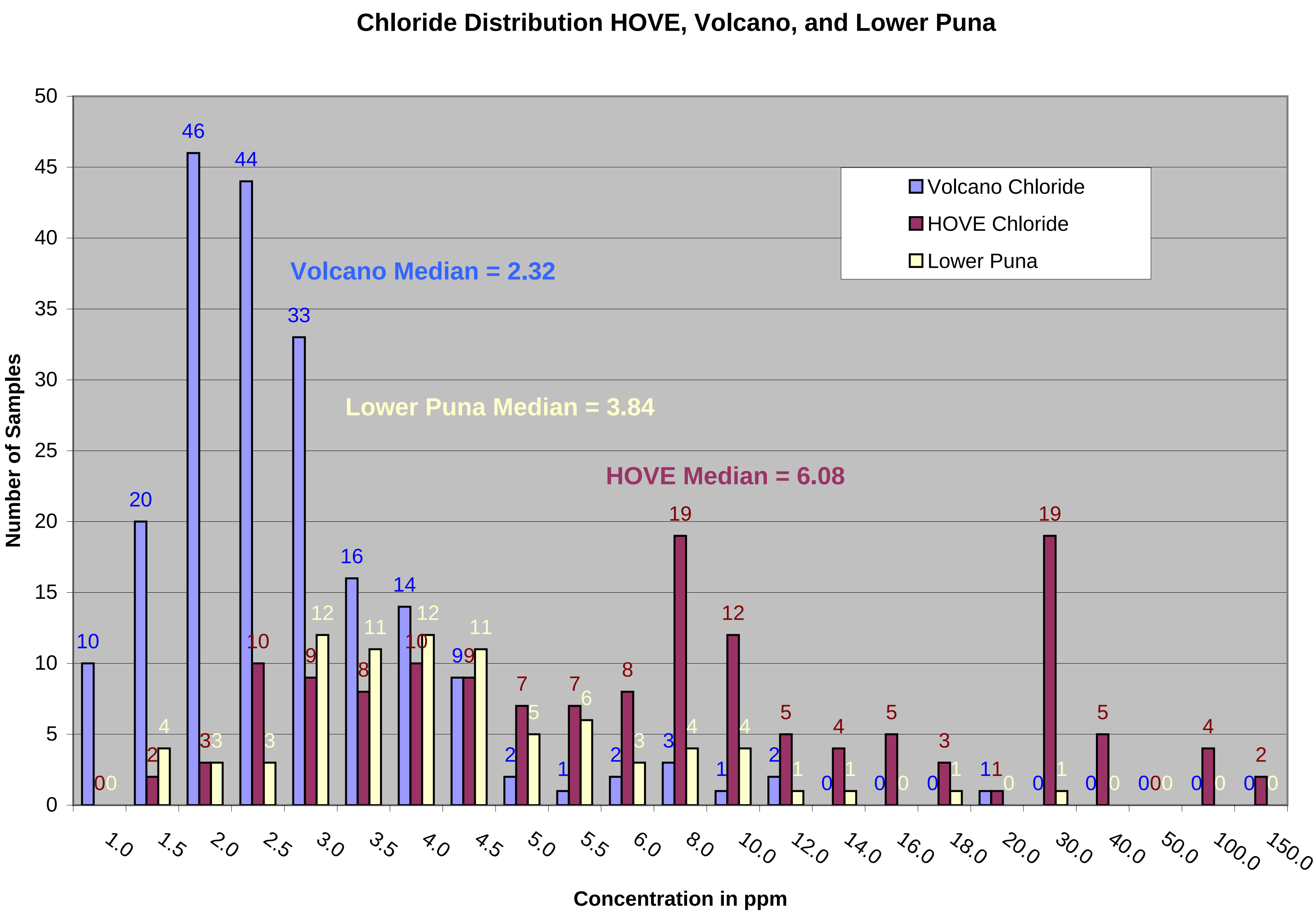

Figure 5. Chloride concentrations found in the catchment systems sampled. The lower axis shows the concentration of chloride ion and the number of catchments having values in the range shown are near the top of each bar.