Horsetooth Seepage Chemistry: Analysis of Seepage Water Chemistry before and during Safety of Dams Modification Construction at Horsetooth Dam, Colorado-Big Thompson Project, Ft. Collins, Colorado, 1999-2001

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by

Doug Craft[1] and Ron Pearson[2]

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[1]Fisheries Applications Research Group, D-8290
[2]Engineering Geology Group, D-8320
U.S. Department of the Interior - Bureau of Reclamation
Technical Service Center
PO Box 25007
Denver, Colorado 80225-0007

Abstract

This report compares seepage and well water chemistry for samples collected at Horsetooth Dam during 2001 with data collected in previous years. The purposes of this evaluation were to note any significant changes in seepage or groundwater chemistry that have occurred since the reservoir surface level was lowered to restricted elevation of approximately 5360 ft. for repair construction activities; and to assess historical seepage data with respect to mass loading and void formation from soluble mineral dissolution. Evaluation of all available chemistry data strongly suggest that mineral dissolution has been occurring in subsurface water flows beneath Horsetooth Dam from Horsetooth Reservoir, and that the dissolution of gypsum anhydrite and limestone (calcite and dolomite) contributed to increased seepage flows at Horsetooth Dam. The chemistry data strongly suggest that the decision to repair Horsetooth was timely. Four recent well samples show significant differences in chemistry associated with reservoir surface lowering. Three out of four of these wells show evidence of up-gradient and cross-strata communication and mixing of local groundwaters. Communication and mixing of water from the Lower Lykins - Blaine gypsum to the Middle Lykins - Forelle limestone unit may occur through natural fractures, progressive expansion of conduit flow paths, or from flow paths introduced during well installation. Flow-weighted mass loading data reveal that flows and loading can change dramatically and unexpectedly. While seepage is complex and detailed information of flow paths is unavailable, extrapolations of void formation rates for low and high loadings suggest that void formation from dissolution of calcite and gypsum was a significant contributor to seepage behavior observed at Horsetooth Dam.

Introduction

This report compares seepage and well water chemistry for samples collected during 2001 at Horsetooth Dam, Ft. Collins, Colorado, with data collected in previous years and provides historical data for flow-weighted mineral loadings and void space formation rates arising from mineral dissolution in seeps. The purpose of this evaluation was to note any significant changes in seepage chemistry that have occurred since the reservoir surface elevation was lowered to restricted elevation of approximately 5360 ft. (starting in April 2000) for repair construction activities, and to describe historical changes in seepage chemistry with emphasis on mass loading and void volume formation.

Chemical constituents pH, conductivity (EC), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate, (HCO_3^-), carbonate (CO_3^{2-}), hydroxide (OH^-), sulfate (SO_4^{2-}), chloride (Cl^-), and trace elements aluminum (Al), iron (Fe), manganese (Mn), and silicon (Si) have been analyzed for seepage, piezometer well, and reservoir water sampled at intervals since 1951. The chemistry of seepage and piezometer well water at Horsetooth Dam has consistently suggested that dissolution of limestone (as calcite, $CaCO_3$), dolomite ($CaMg(CO_3)_2$), gypsum ($CaSO_4 \cdot 2H_2O$) and/or anhydrite ($CaSO_4$), and silica (SiO_2) has been occurring in the foundation beneath this structure since first filling (Craft, 1999).

Geochemical evaluation of the chemistry data and seepage and piezometer network monitoring contributed to the decision to modernize and repair the 4 dams that contain Horsetooth Reservoir. After lowering of the reservoir, samples were collected from reservoir, seeps, weirs, and 2-inch piezometer wells on May 8-9, 2001 (reservoir surface elevation = 5358.1 ft.), and from seeps in a construction excavation on July 19, 2001 (reservoir surface elevation = 5353.5 ft.). These data were provided in draft form to Ron Pearson, D-8320, and reported previously by way of Denver Environmental Chemistry Laboratory memos.

Geology: Horsetooth Reservoir and Dam sit on a strike valley primarily composed of eroded and exposed strata of the Lykins Formation. The reservoir is generally bounded on the west by the Lyons Sandstone and on the east by the Dakota Sandstone. The Lykins Formation is composed of sedimentary claystone and siltstone layers with several subunits/members of limestone (notably the Forelle limestone) and gypsum/anhydrite evaporite deposits (the Blaine gypsum). All the sedimentary rock units of the Lykins Formation have been uplifted on the eastern flank of the Southern Rocky Mountains and now dip to the east 35° to 40° with a strike of N20°W that is nearly perpendicular to the axis of the dam.

The Forelle limestone is described as dolomite in some areas of the front range (Broin, 1957) and petrographic examination of samples from Horsetooth Dam showed evidence of dolomite and dolomitic limestone (Hurcomb, 1999). Evaporite deposits of gypsum and anhydrite are also known to occur locally within the Forelle limestone; however, they have not been observed in cores beneath the dam foundation. Dissolution of some of the evaporite deposits in the geologic past has resulted in extensive brecciation of the sedimentary layers. Vertical collapse structures (paleokarst sinkholes) caused by dissolution of underlying evaporite mineral deposits are believed responsible for formation of active sinkholes within and above the reservoir (Wright and Taucher, 1991). Investigations have shown that these collapse structures cross-cut all the units of the Lykins Formation and may allow for significant hydrologic cross-connections of seepage paths. For complete geologic descriptions and stratigraphic units, refer to Pearson (2002).

In this report, a simplified scheme is used for the geology associated with piezometer well screens or seepage samples. More complex strata from the Lykins Formation have been grouped into four classes:

alluvium (geologically recent deposits above the dipping Lykins units), upper Lykins (units above the Forelle limestone and below the alluvium), middle Lykins (Forelle limestone beds), and lower Lykins (primarily Blaine gypsum).

Methodology

Chemical Analyses and Modeling: Samples were analyzed by the Denver Environmental Chemistry Laboratory following established consensus methods (USEPA 1983, 1986, American Public Health Association, 1998). Saturation indices (SI) for carbonate- and sulfate-containing minerals were calculated using the MINTEQA2 model (Allison, et al., 1991) and have been included with the Horsetooth summary data Excel spreadsheet file. The SI's were calculated assuming a temperature of 10°C and that samples were in equilibrium with atmospheric O_2 and CO_2 at partial pressures for elevation 5,640 ft. Negative SI values suggest under saturation and that the water will dissolve the mineral. Positive SI values suggest over saturation and that the mineral will tend to precipitate. SI values near 0 suggest that the mineral is in equilibrium with the seepage water.

Flow-weighted mass loadings and void volume formation rates: Flow-weighted loadings and estimated dissolution void volume rates were calculated for seepage outfalls with flow data using procedures described by Bartholomew and Murray (1985). Example calculations may be found in Appendix 1. The following summarizes the assumptions applied for calculating Horsetooth Dam seepage loading and void volumes:

1. **Net increase in seepage:** For each analyzed constituent, same date reservoir mg/L is subtracted from seepage mg/L to calculate net difference mg/L. Overall net difference was calculated by subtracting reservoir mg/L sum of ions from seepage mg/L sum of ions.

   $mg/L_{\text{seepage}} - mg/L_{\text{reservoir}} = mg/L_{\text{net}}$

   Sum of ions, mg/L = $(Ca + Mg + Na + K + HCO_3^- + CO_3^{2-} + OH^- + SO_4^{2-} + Cl^- + Al + Fe + Mn + Si)$, mg/L

   Trace elements (Al, Fe, Mn, Si) reported below detection limits were re-coded as one-half the reported limit of detection before net mg/L were calculated.

2. **Simplified geochemical model:** The geology of the Lykins formation is complex and several simplifying assumptions about dissolution reactions were used to calculate seepage mass loadings and dissolution void space formation rates. These assumptions involve the expression of mass loadings and void volumes as gypsum or anhydrite, along with calcite. Other processes also act to increase net ions in seepage, however, these reactions lack the clear supportive evidence that is available for limestone, gypsum, and anhydrite.

   Increases observed in seepage SO_4^{2-} are likely caused by dissolution of both gypsum and anhydrite, but here net SO_4^{2-} was calculated assuming that all increased SO_4^{2-} was caused by only gypsum or only anhydrite. Gypsum (D = 2.30 to 2.37 g/cm^3) is less dense than anhydrite (D = 2.9 to 3.0 g/cm^3), so void volume rate estimates calculated assuming gypsum will be higher than those assuming anhydrite. These two density assumptions provide a range of void formation rates for soluble sulfate minerals.

The carbonate mineral units in the Lykins Formation are composed of both limestone and dolomite. Limestone (as calcite) will only produce Ca and CO_3^{2-} (as HCO_3^- below pH 8.3) upon dissolution, while dolomite will produce Ca, Mg, and CO_3^{2-}. The Ca:Mg ratio associated with dolomite deposits along specific flow paths is unknown, so a stoichiometric geochemical model for dolomite dissolution is unavailable. Since dolomite dissolution would be the cause of increased seepage Mg concentrations (along with Ca), net meq/L Mg was added to net meq/L Ca to calculate limestone mass loadings and void space formation rates *as calcite.* While this assumption will produce higher estimates for limestone mass loading, the comparable densities of calcite (2.72 to 2.94 g/cm^3) and dolomite (2.86 to 2.93 g/cm^3), will produce similar dissolution void formation rates. Net meq/L for limestone dissolution was calculated as follows:

$$(Ca_{\text{net meq/L}} - SO_{4\ \text{net meq/L}}^{2-}) + Mg_{\text{net meq/L}}$$

3. **Specific assumptions:**

    a. If same date seepage flow and reservoir elevations were unavailable, the closest available date was used.

    b. meq/L and mg/L data were averaged for 5/19/00 Reservoir, all SM-3 (average of 3N, 3S, and 3V), and all SM-FD98-3 (from field sample duplicates). July 1999 reservoir sample data was used for July 2001 SM-FD98-3 data.

    c. Seepage flow for EXSP-1 and EXSP-2 was not measured and was assumed to be 15 gpm (based on contractor pumping rates at the excavation).

    d. Net loadings expressed as a mineral were calculated based on meq/L data, which were converted to mass using the following factors:

        Gypsum = $CaSO_4 \cdot 2H_2O$ = 86.0861 mg/meq
        Anhydrite = $CaSO_4$ = 68.0708 mg/meq
        Limestone (Calcite) = $CaCO_3$ = 50.0047 mg/meq
        Silica = SiO_2 = 60.0843 mg/mmol, Si = 28.0855 mg/mmol

    e. Conversion factors for units of flow:

        1 cfs = 28.3169 L/s = 2.4466 X 10^6 L/d
        1 gpm = 3.7854 L/min = 5,451 L/d
        1 m^3 = 1,000 L = 1 X 10^6 cm^3 = 35.315 ft^3

    f. The higher reported density values (Deer, et al., 1992) were used to calculate void volume formation rates:

        Gypsum = 0.00230 to 0.00237 kg/cm^3
        Anhydrite = 0.00294 to 0.00300 kg/cm^3
        Calcite = 0.00272 to 0.00294 kg/cm^3
        Silica = 0.00262 to 0.00265 kg/cm^3

4. **Mass loading calculation, kg/day:**

(mg/L_{net}) X (seepage flow, ft^3/s) X (86,400 s/day) X (28.3169 L/f^3) X (1.0 X 10^{-6} kg/mg)

or

(mg/L_{net}) X (seepage flow, gal/min) X (1,440 min/day) X (3.7854 L/gal) X (1.0 X 10^{-6} kg/mg)

5. **Void volume formation calculation, m^3/day:**

m^3/day = ((mineral loading, kg/day)/(mineral density, kg/cm^3)) X 0.000001 m^3/cm^3

Precautions using mineral loading and void volume formation data: There are several important issues to consider before using or interpreting mass loading or void formation rate data. First, it would be inappropriate to extrapolate any observed daily loading or void formation rates to annual or multi-year periods without accounting for the changes in seepage flow observed throughout the year. Seepage flow varies throughout the year depending on the hydrostatic head at changing reservoir elevations and the flow path properties for a particular seep. Although reservoir elevation and seepage flow do not show a simple linear relationship at Horsetooth Dam, all seeps have responded to varying reservoir elevations with generally lower flows at lower reservoir elevations.

Second, a large proportion of the seepage increase in ions may be from biologically mediated processes (respiration and metabolism) and other unknown mineral weathering reactions. Depending on seepage transit time, bacterial respiration can produce pH changes and some of the increases observed for HCO_3^- and CO_3^{2-} ions in seepage. Well samples with elevated pH > 9 suggest contact with grout cement. Ion exchange on clays in the Lykins formation may also account for some the seepage net Na. Finally, incongruent mineral reactions where one mineral partially dissolves to release some ions and form another mineral, may account for a small portion of the net cations and Si (Drever, 1988).

Third, calculated seepage loadings need to be compared to the *contact volume* of the foundation or abutment along the seepage flow path (Bartholomew and Murray, 1985). At Horsetooth Dam, most seepage paths and contact volumes are poorly understood, and this issue represents the greatest uncertainty in assessing the engineering consequences of mineral dissolution. For example, seepage contact volume would be greater for SM-3, located 3,000 ft. downstream of the dam, compared to SM-2, the right toe drain. Seepage flow paths may change over time, forming new paths, and old paths may collapse. Flow paths though brecciated fracture zones are serpentine and "spread out" from the axis of flow in complex patterns. Seepage suggesting structural concern, such as the recent the left side seeps, increase over time for similar hydrostatic gradients.

A reasonable approach at Horsetooth Dam should seriously consider loadings and void volume formation rates calculated for gypsum, anhydrite, and limestone (calcite and dolomite). There is clear geological evidence for these simple congruent dissolution reactions.

Results and Discussion

Electronic data (Microsoft Excel, Microsoft Access, and SPSS® files) covering all water samples analyzed to date at Horsetooth Dam, including loading calculations and ancillary information about seeps and wells are available from the authors. Summaries of these data are presented here in the attached Appendix 2.

Chemistry of Drill Hole and Well Samples: Appendix 2 table 1 lists the chemical analysis results for all available piezometer hole and well samples collected to date, grouped by the general geological strata of the well screen. How has the chemistry in the well samples changed since the reservoir level was lowered for construction and repair activities? Figures 1 and 2 provide graphical comparisons that address this question. These figures contain Microsoft Excel radar diagrams that plot meq/L major ions data for piezometer well and drill hole samples collected on July 19-20, 1999 (reservoir elevation = 5426.8 ft.), and May 8-9, 2001 (reservoir elevation = 5358.1 ft.). These diagrams provide a visual way to compare water chemistry (expressed in meq/L) at higher (left) and lower (right) reservoir elevations after the lake was lowered for repairs. Left page facing figures 1a, 1c, 1e, and 1g are on log-scale diagrams, while right facing page figures 1b, 1d, 1f, and 1h show a the same wells and drill holes with linear scales. Four wells, DH-91-1, DH 98-7, DH99-11, and DH99-15, show differences in chemistry for higher and lower reservoir elevations. Embankment well DH91-1, with screen in the Lower Lykins - Blaine gypsum, shows evidence of sulfate mineral dissolution at both higher and lower reservoir elevations. However, the lower reservoir elevation 05/08/01 sample shows a significantly elevated pH with OH^- and CO_3^{2-} alkalinity not seen in the 7/20/99 sample. This sample, which also shows increased Na and a loss of Mg suggests some kind of contact with the cement used in grout.

The low reservoir elevation DH99-11 diagram, with screen in the Middle Lykins - Forelle Limestone, shows a clear increase in SO_4^{2-} compared to the higher reservoir diagram, which is typical of limestone contact. Figure 2 shows DH99-11 changes since the 12/09/98 sample. The lower linear scale diagrams in figure 2 clearly show the increase in SO_4^{2-} that suggests some kind of seepage movement and mixing from gypsum/anhydrite-influenced water in the Lower Lykins to the DH99-11 screen located in the Forelle Limestone.

Well DH98-7, with screen in the Upper Lykins, also shows evidence of communication from deeper Blaine gypsum units at higher reservoir elevation. Increased SO_4^{2-} is evident in figure 1h at higher reservoir elevation, but at lower reservoir, the water shows evidence of only calcite contact and a much lower total concentration. Figure 1h also shows a comparable change in total concentration between higher and lower reservoir elevations for DH99-15, another well with screen in the Upper Lykins. Unlike DH98-7, which shifts from a gypsum (or mixed) water to a calcite water, DH99-15 remains a calcite dominated water when reservoir level drops. Given White's (1988) observation that increases in seepage residence time for limestone karst groundwaters usually produce higher concentrations, the lower concentrations seen in DH99-15 at lower reservoir elevation was unexpected. This anomalous behavior may suggest expansion of the seepage flow path intersected by this well and warrants further investigation.

Three of the four well samples showed differences in chemistry between higher and lower reservoir elevations and all these wells suggest cross-strata and/or up-gradient transport and mixing of different groundwaters. Whether this communication and mixing of water occurs through natural fractures,

Figure 1a Log-scale radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from wells and piezometers during July 1999 (left) and May 2001 (right).

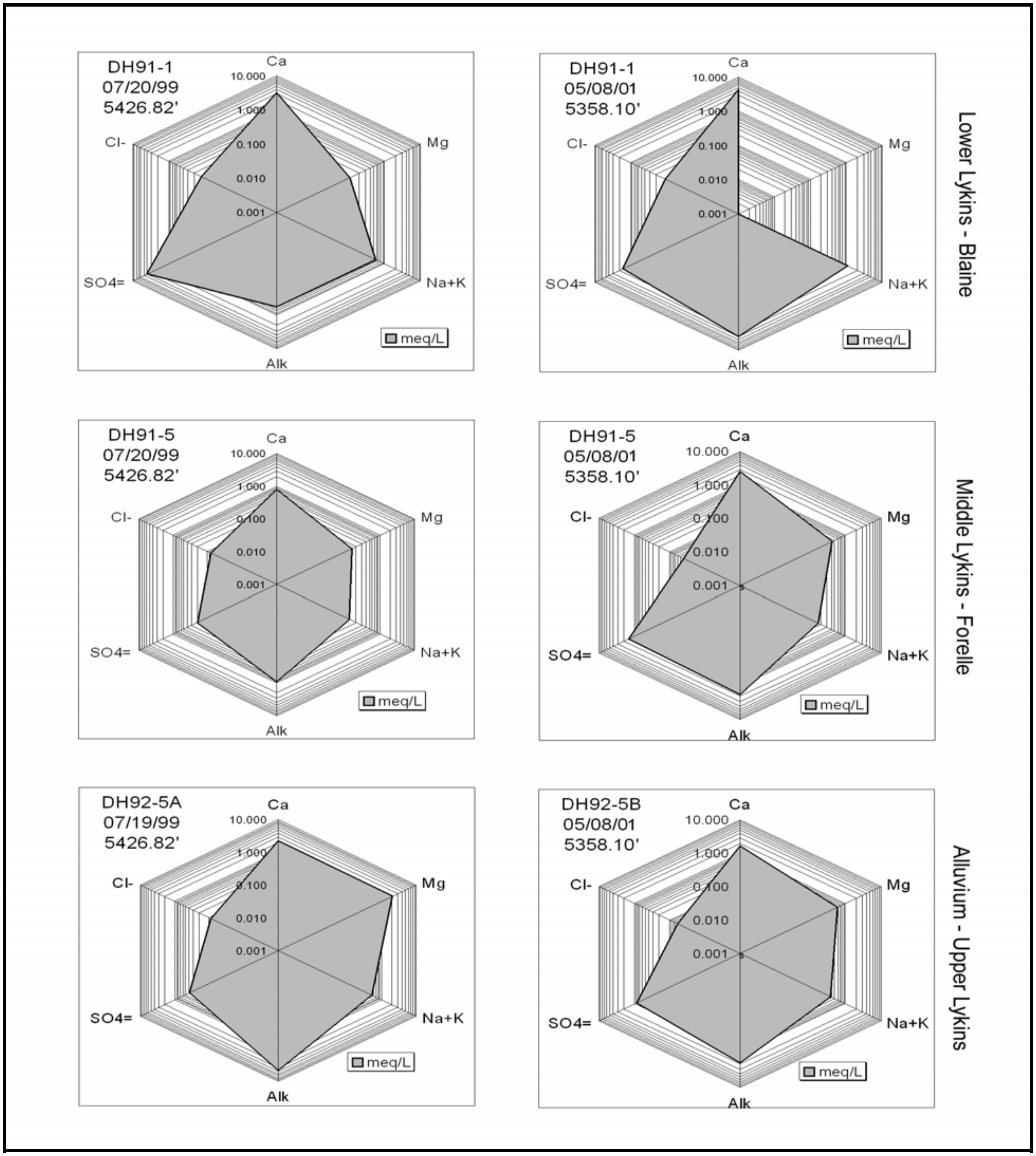


Figure 1b Linear-scale radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from wells and piezometers during July 1999 (left) and May 2001 (right).

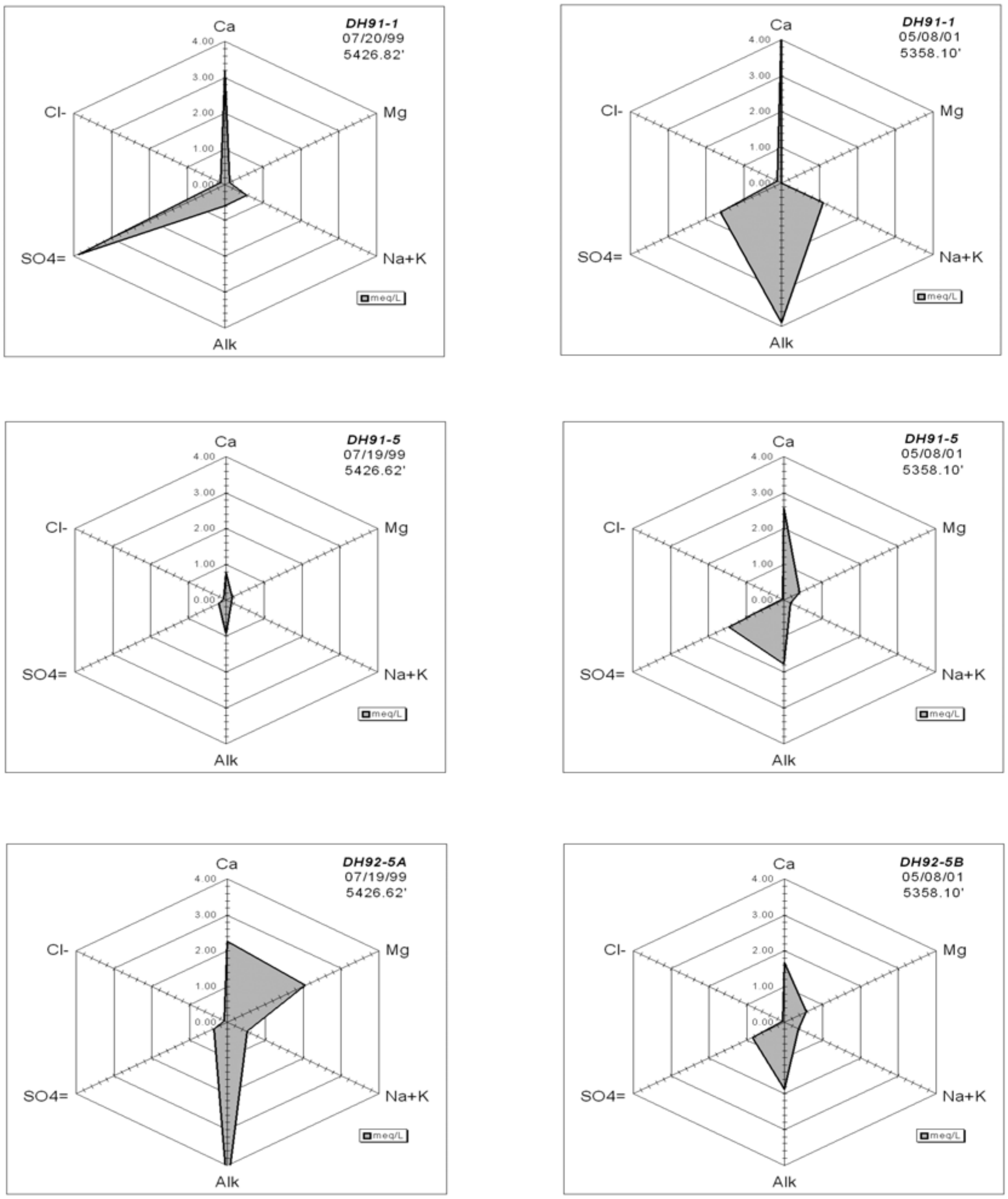


Figure 1c Log-scale radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from wells and piezometers during July 1999 (left) and May 2001 (right).

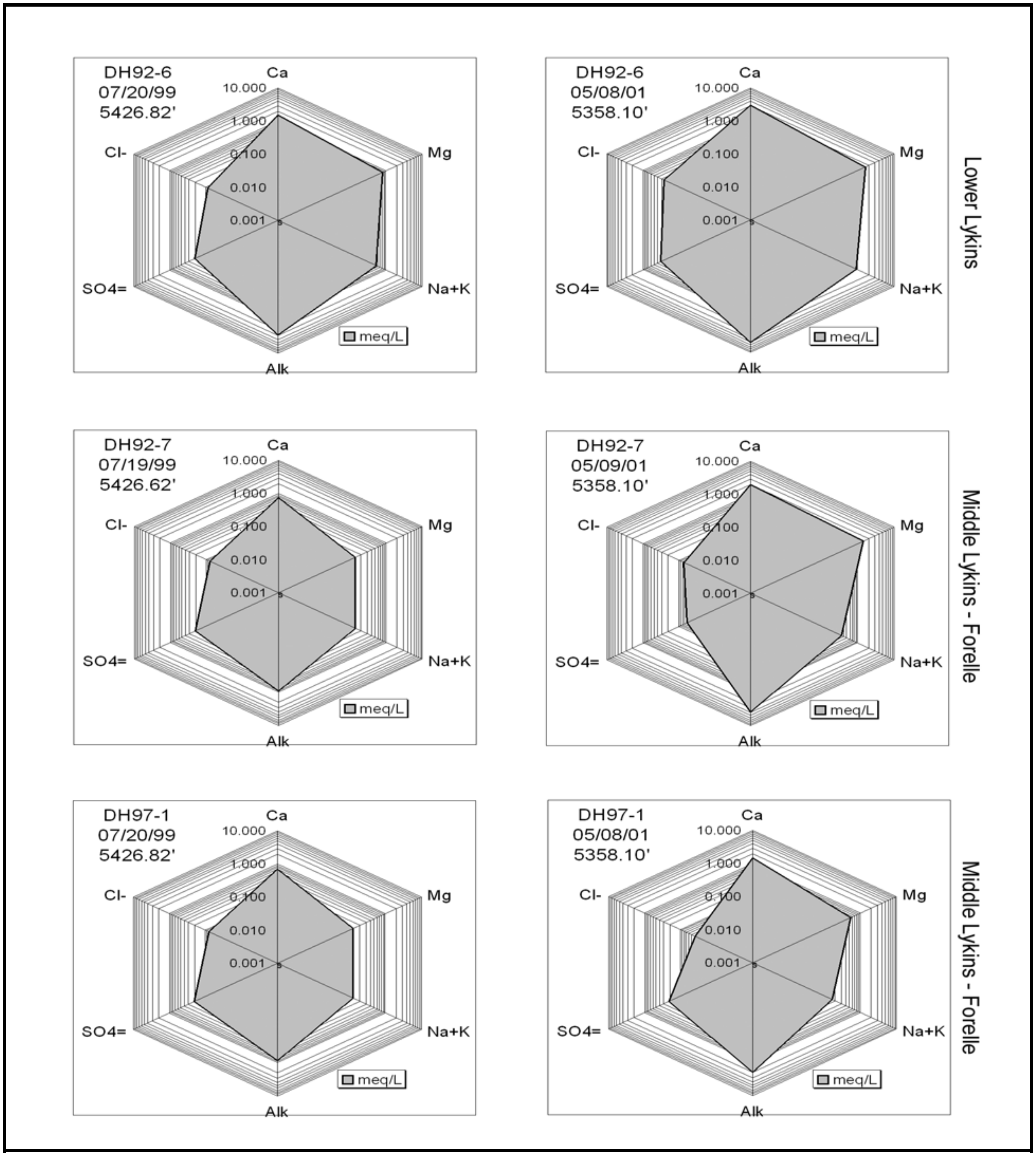


Figure 1d Linear-scale radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from wells and piezometers during July 1999 (left) and May 2001 (right).

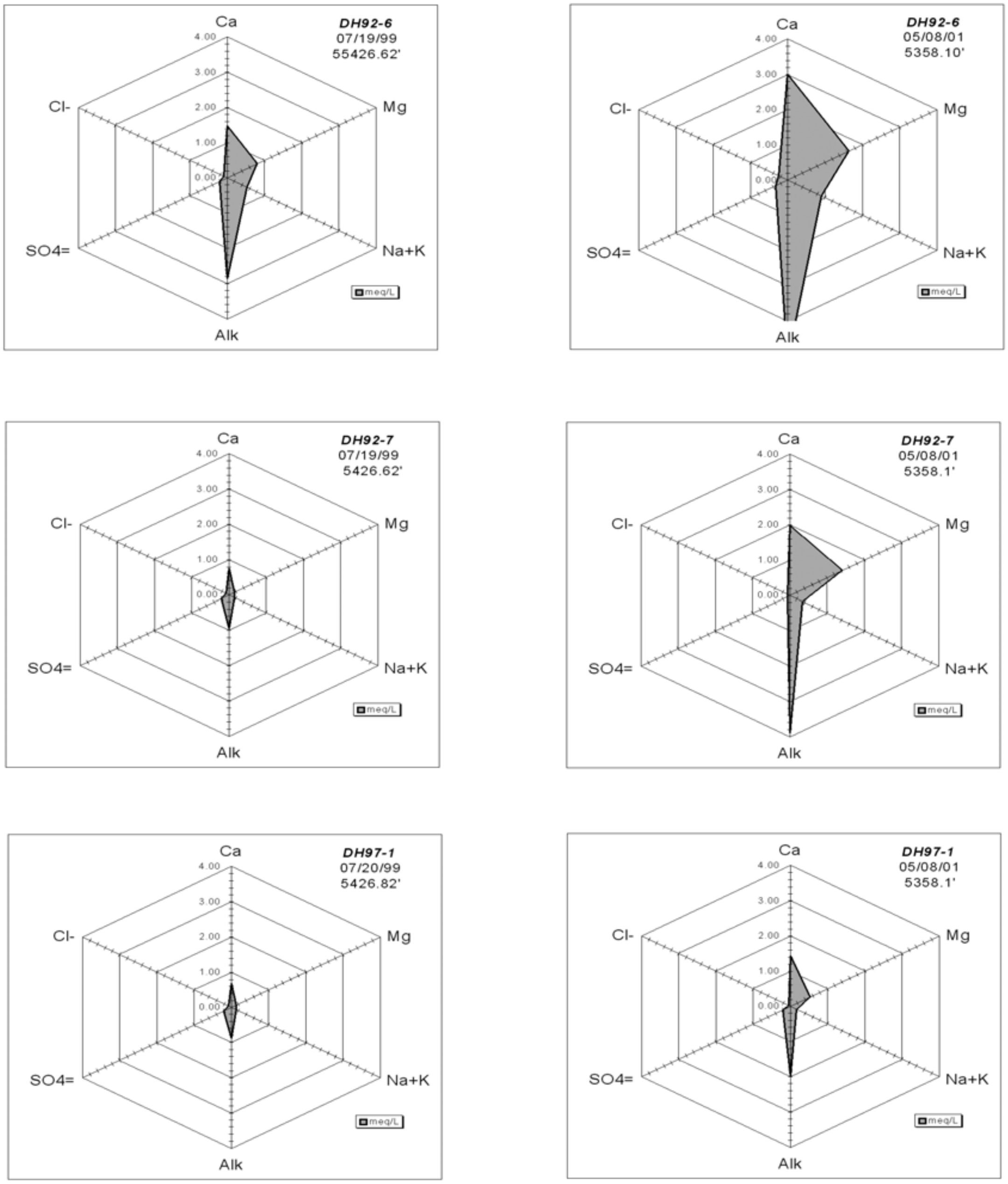


Figure 1e Log-scale radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from wells and piezometers during July 1999 (left) and May 2001 (right).

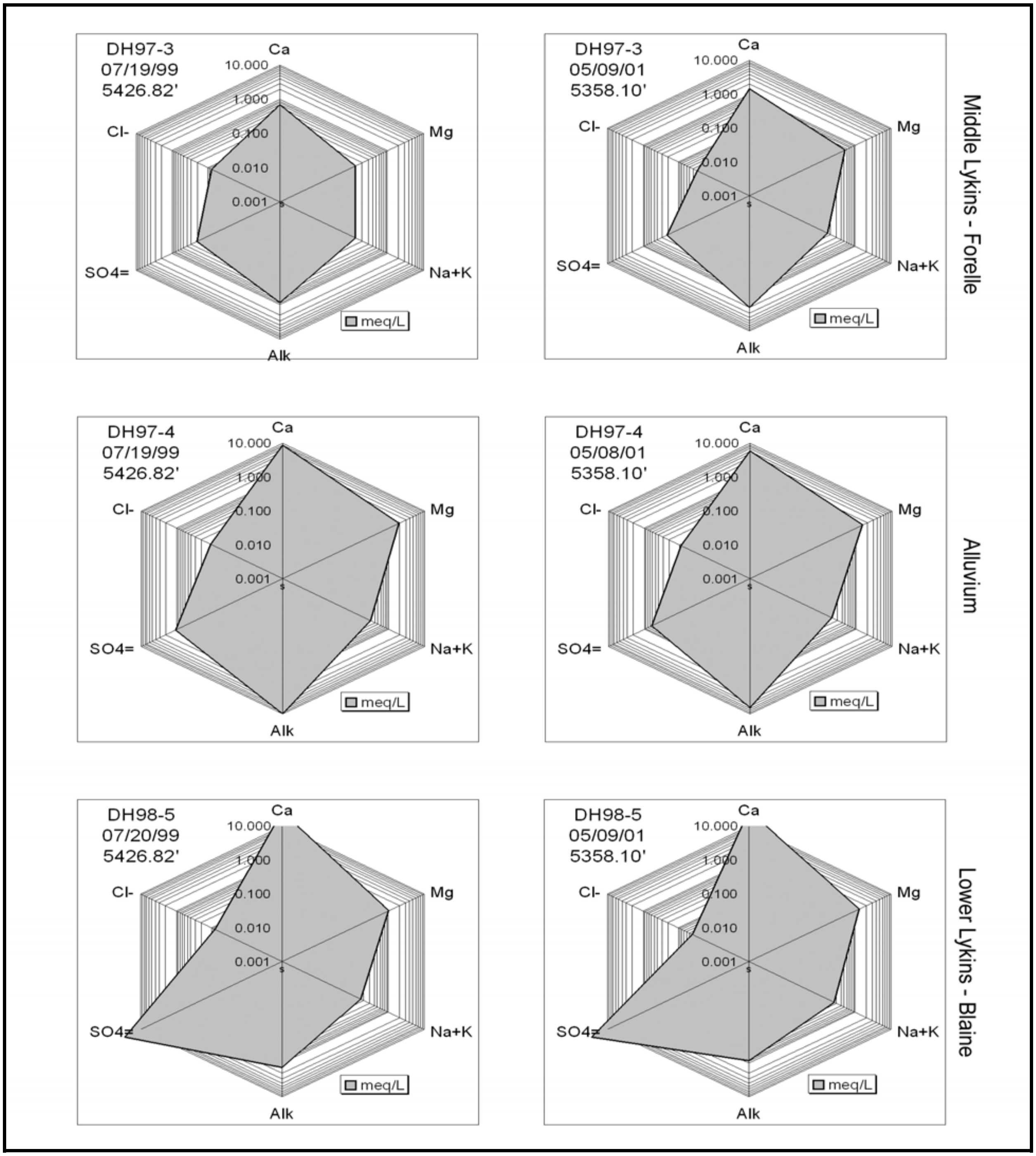


Figure 1f Linear-scale radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from wells and piezometers during July 1999 (left) and May 2001 (right).

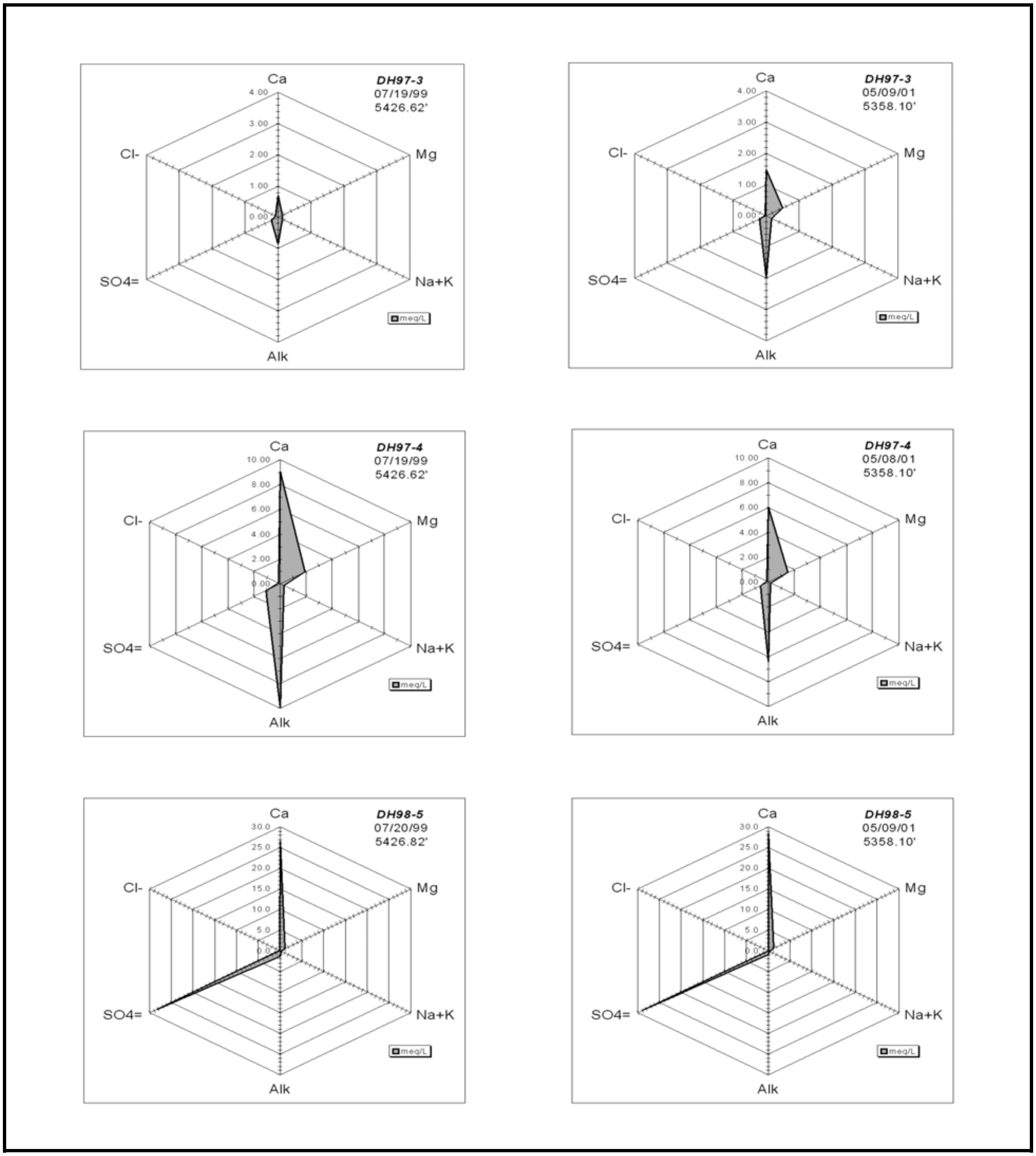


Figure 1g Log-scale radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from wells and piezometers during July 1999 (left) and May 2001 (right).

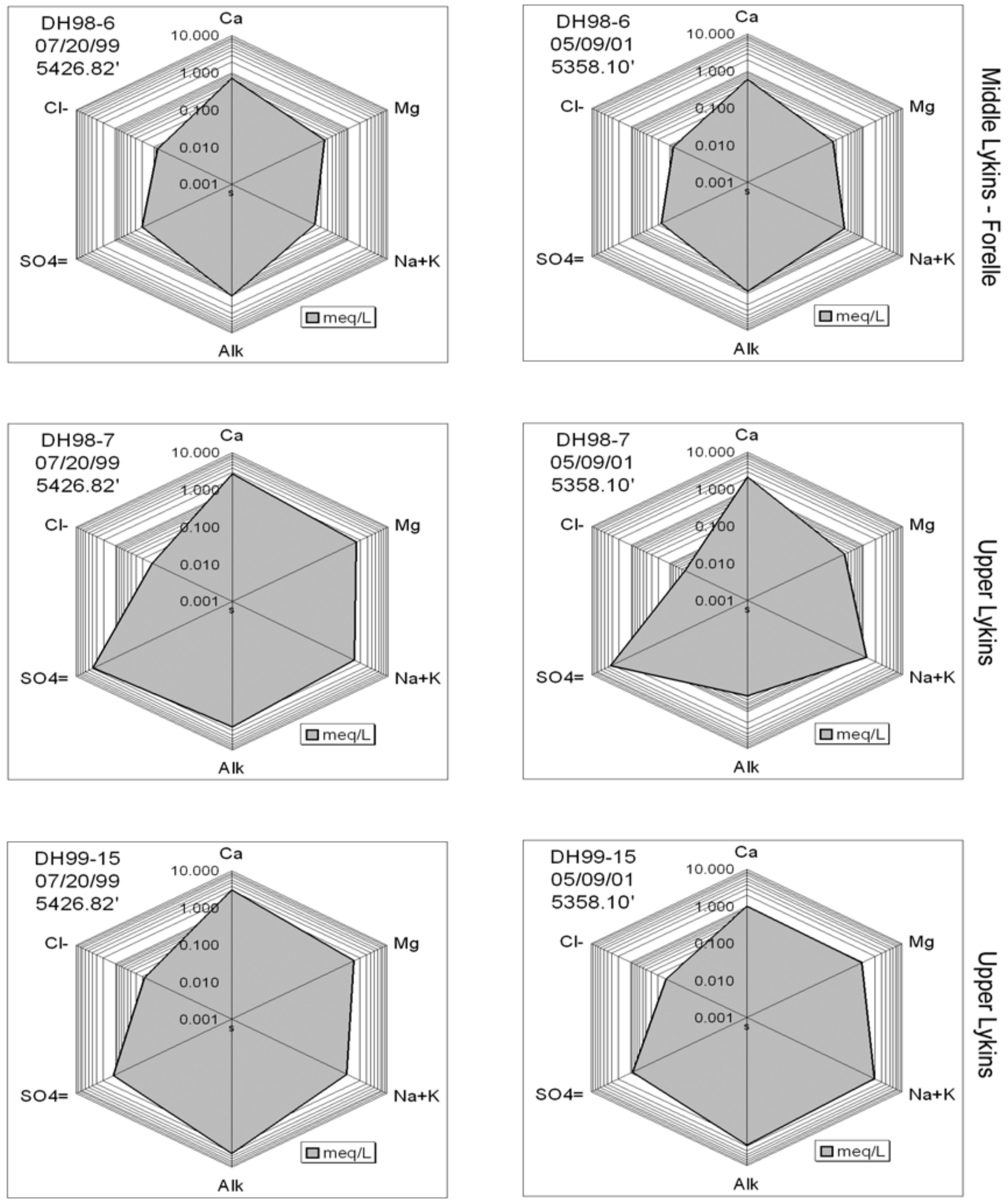


Figure 1h Linear-scale radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from wells and piezometers during July 1999 (left) and May 2001 (right).

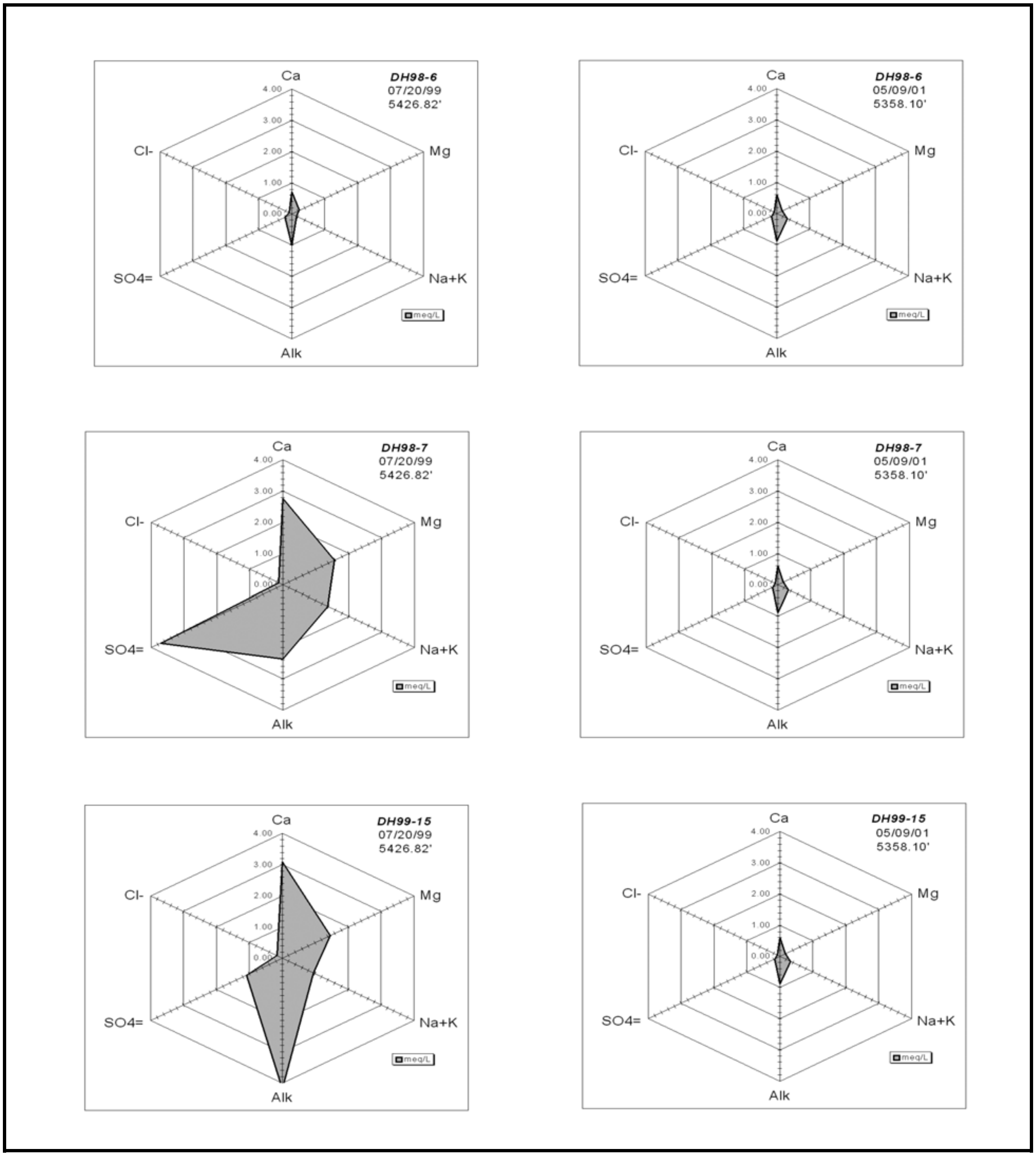


Figure 1i Log-scale (top) and linear-scale (bottom) radar diagrams comparing major ions concentrations (in meq/L) for water samples collected from the reservoir during July 1999 (left) and May 2001 (right).

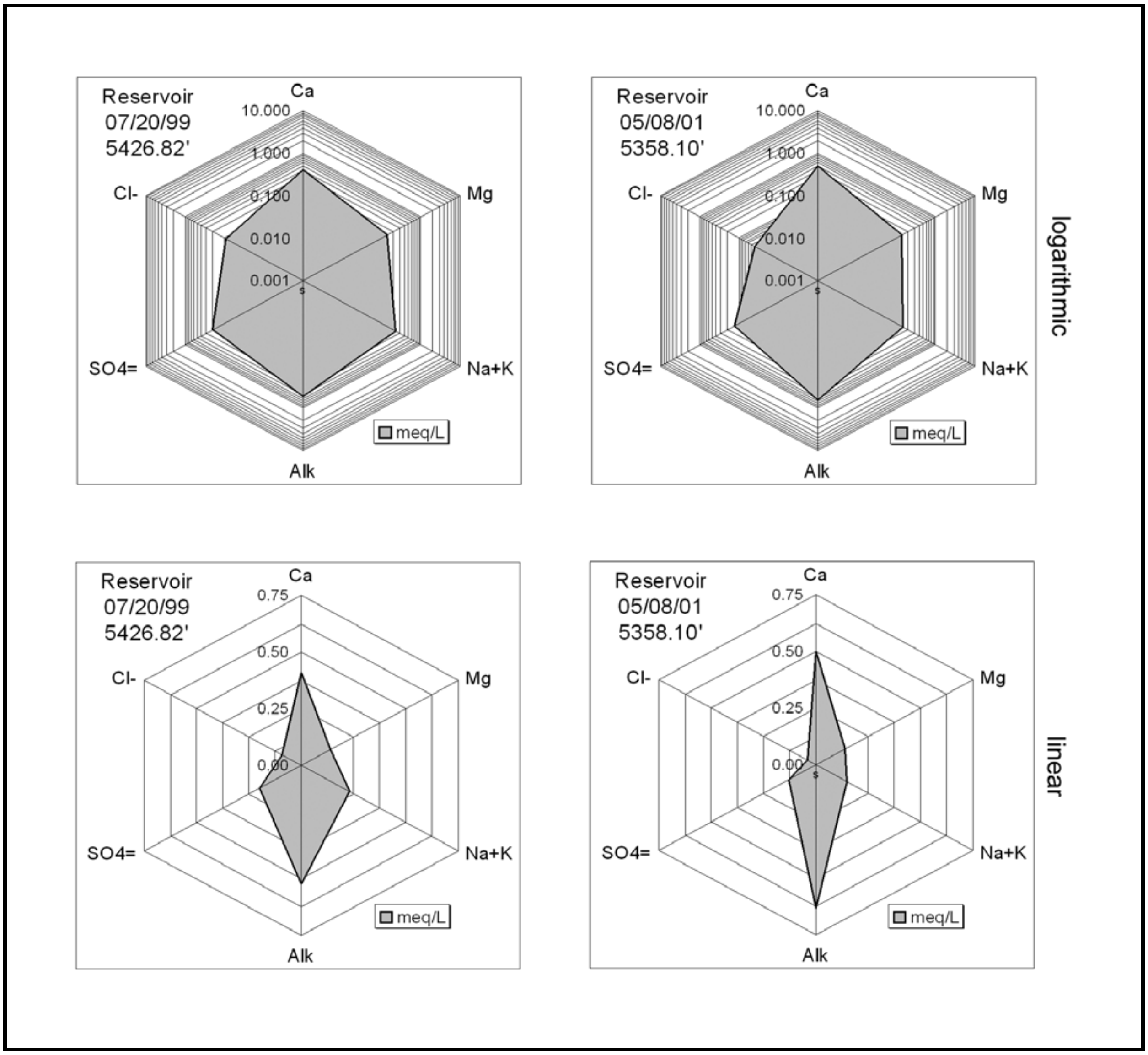
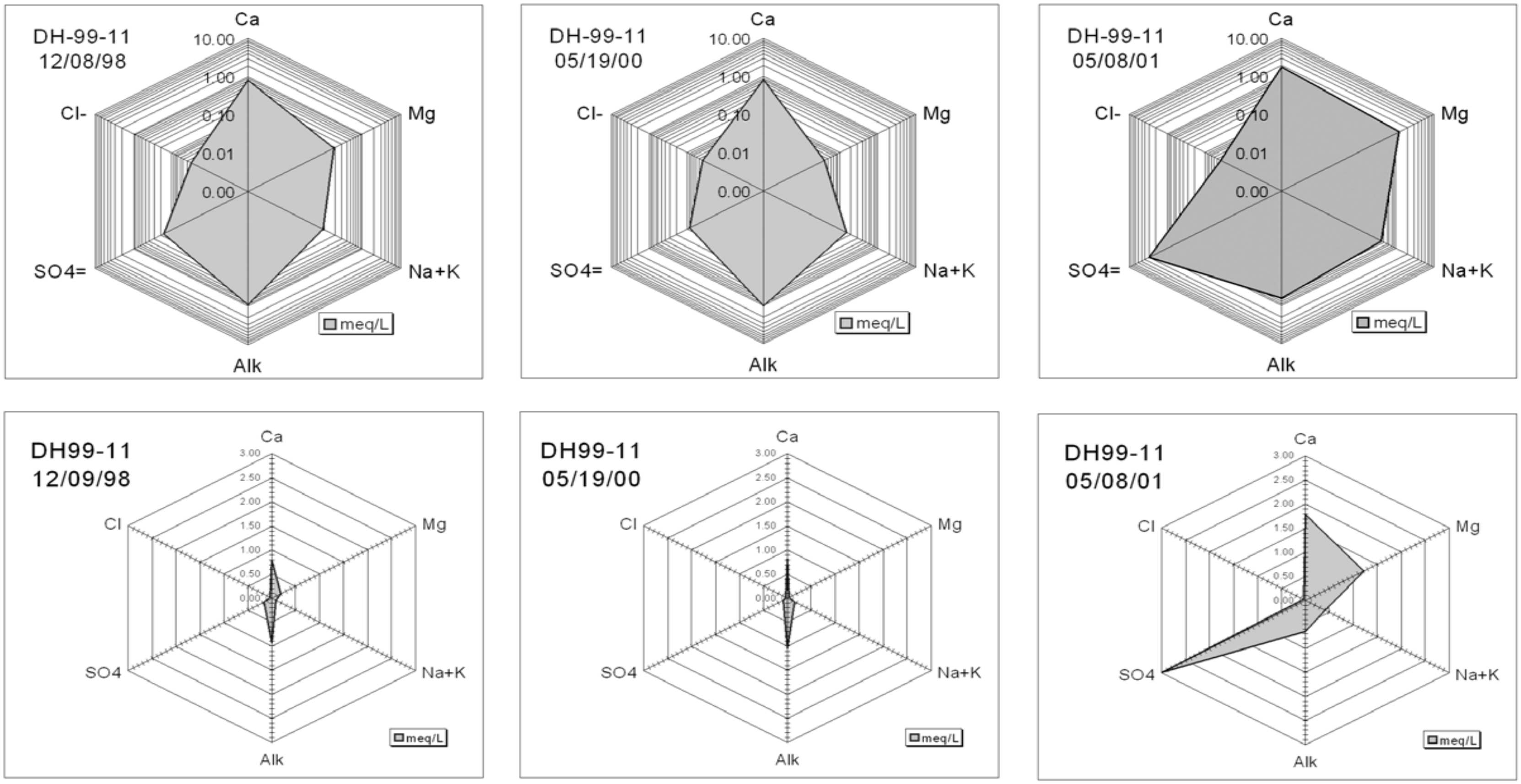


Figure 2 Radar diagrams comparing changes in chemistry from DH99-11 over time. The three upper diagrams use a log scale while the lower diagrams use a linear scale. Reservoir elevations were 5380.29 ft. on 12/09/98, 5389.83 ft. on 05/19/00, and 5358.10 ft. on 05/08/01. The screen for this well is in the Forelle limestone, so the presence of SO_4^{2-} (sulfate) in the 05/08/01 sample suggests communication from lower strata in the gypsum containing Lykins formation.



progressive expansion of conduit flow paths, flow through palaeokarst collapse structures, or is caused by the wells is not known. All four of these well samples suggest communication between gypsum layers in the Lower Lykins with flow paths in the Middle Lykins.

Seepage and Weir Water Chemistry Summaries: The notable difference between seepage at high and lower reservoir elevations is that most of the seeps do not flow at the restricted reservoir elevation. SM-3 and SM-7 continue to flow at the currently restricted elevation, but the pond at SM-4 is not flowing over the weir and the left side seepage in the French drain are no longer active. Appendix 2 table 2 lists the available water chemistry data for the seepage samples collected from weirs and drains at Horsetooth Dam. The electronic data file contains a spreadsheet that calculated the net increase in seepage ions concentrations compared to same date reservoir concentrations. These seepage net concentrations were then used with flow data to calculate mass loadings and potential void space formation rates.

Are there relationships between seepage flow and seepage net concentrations? Figures 3a and 3b plot the seepage net concentrations vs. seepage flow for the available seeps and weirs. Most seeps showed lower seepage net concentrations with higher flow, suggesting that seepage at higher flows did not dissolve as much soluble material. The implication is that the shorter subsurface residence times suggested by higher flows did not allow dissolution reactions to reach equilibrium.

SM-3 data at flows greater than 400 gpm suggest that there is very minor response in seepage net concentrations at higher flows. The 1951 data from initial filling response in SM-3 shows lower flows and much higher seepage net concentrations. Perhaps the readily available soluble minerals along this flow path were flushed out on first contact, and the current flow path has now stabilized. However, the figure 3b plots for the french drains, located in the Forelle limestone rifge near the dam (SM-FD98-2 and SM-FD98-3), show higher seepage net concentrations with increasing flow. These data, though limited to two data points, suggest that the flow path connecting the reservoir with the FD seeps may have been enlarging.

The Problem with Saturation Indices: White (1988) reported that SI values for calcite are suggestive of seepage residence time, because faster flowing seepage through conduits in karst formations does not have time to reach equilibrium with calcite. Since water flowing along conduit paths (as opposed to diffuse groundwater flow in semi-permeable formations) has less time for the water to reach saturation with calcite, White suggested that calcite SI values < -0.3 in karst terrains were indicative of under saturation, conduit flow, and residence times of less than 10 days. The calculation problem with SI values, however, is that calcite SI depends on the concentrations of Ca, HCO_3^-, as well as pH and the amount of CO_2 dissolved in the water. Only Ca and HCO_3 can be measured accurately after sample collection - assuming recommended holding time limits before analysis are met (28 days for Ca, 14 days for alkalinity). The pH and partial pressure of CO_2 (pCO_2) often change within hours (if not minutes) after sample collection. Flowing water at depth is under considerable pressure and biotic production of CO_2 means that pCO_2 is generally enriched compared to atmospheric values. White (1988) reported pCO_2 values up to 30 times atmospheric values in flowing groundwaters.

Figure 4 shows SI values calculated for several wells and seeps by the MINTEQA2 model at different values of pCO_2. The values plotted between $pCO_2 = 10^{-4}$ and 10^{-3} atm are based on the assumption that Horsetooth Reservoir water is in equilibrium with atmospheric CO_2 ($pCO_2 = 0.000270$ atm). Note that calcite SI increases with greater pCO_2, and the SI notably approaches the zero equilibrium benchmark

Figure 3a Net increase in seepage concentration vs. seepage flow.

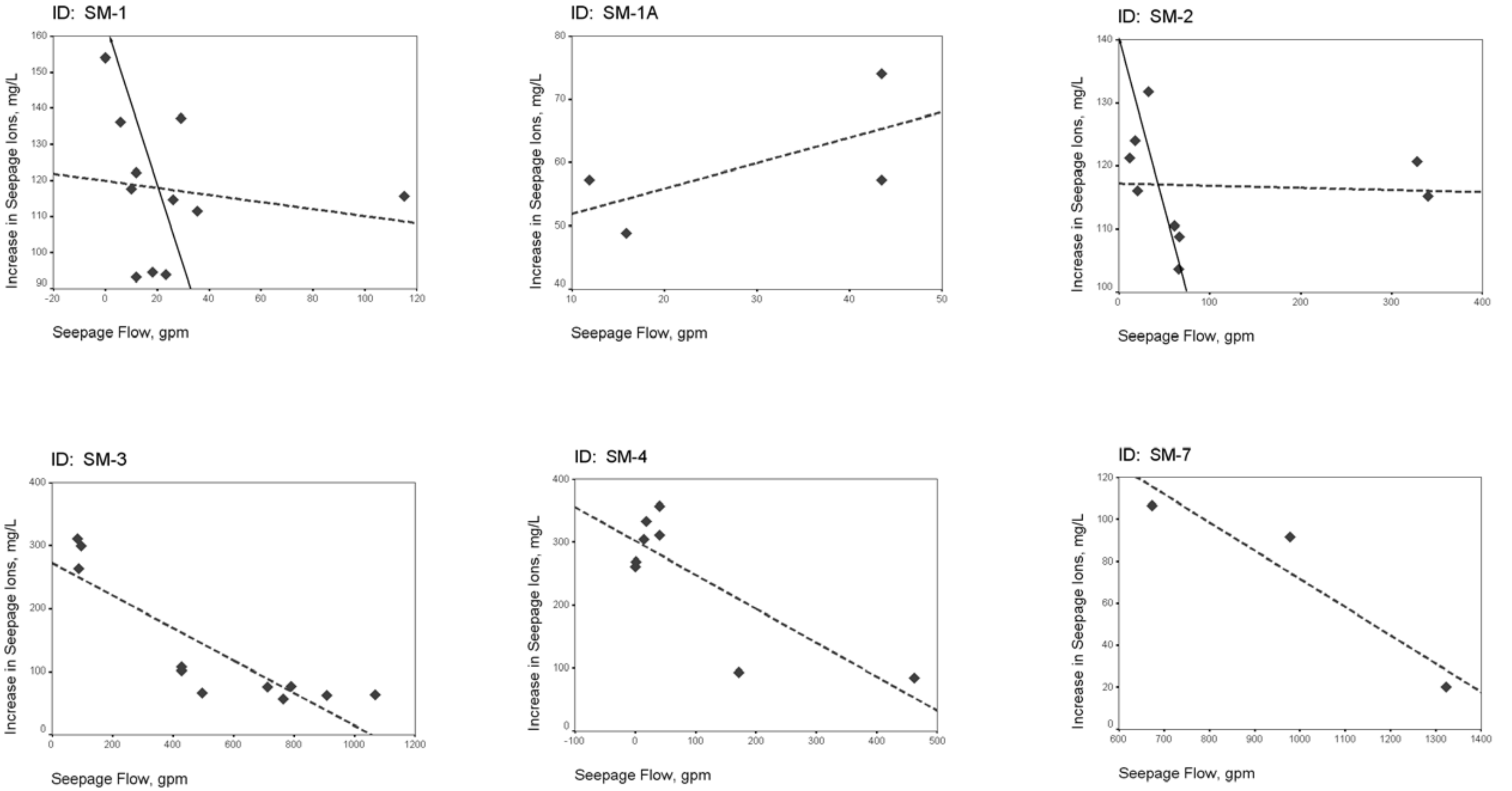


Figure 3b Net increase in seepage concentration vs. seepage flow.

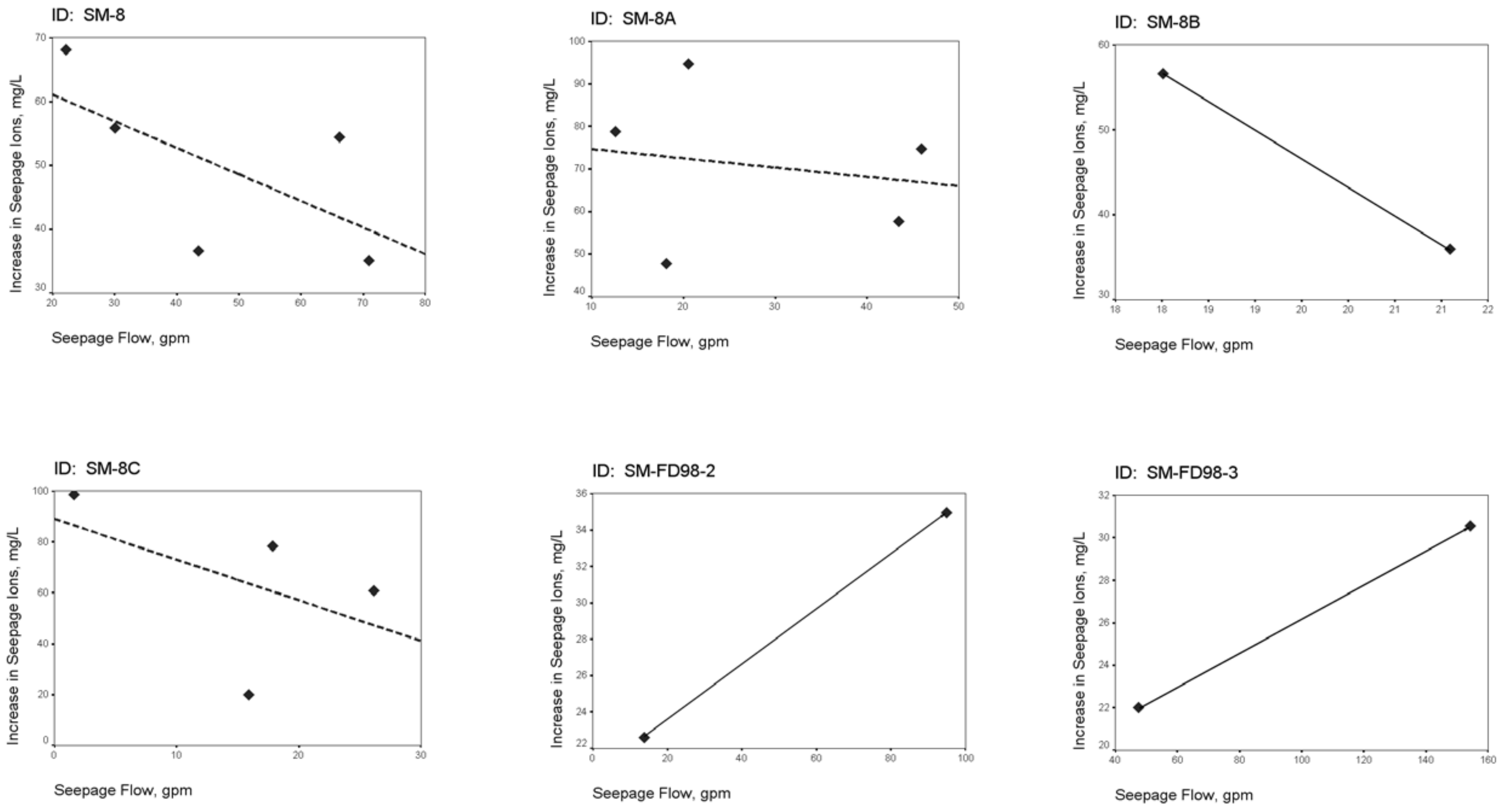
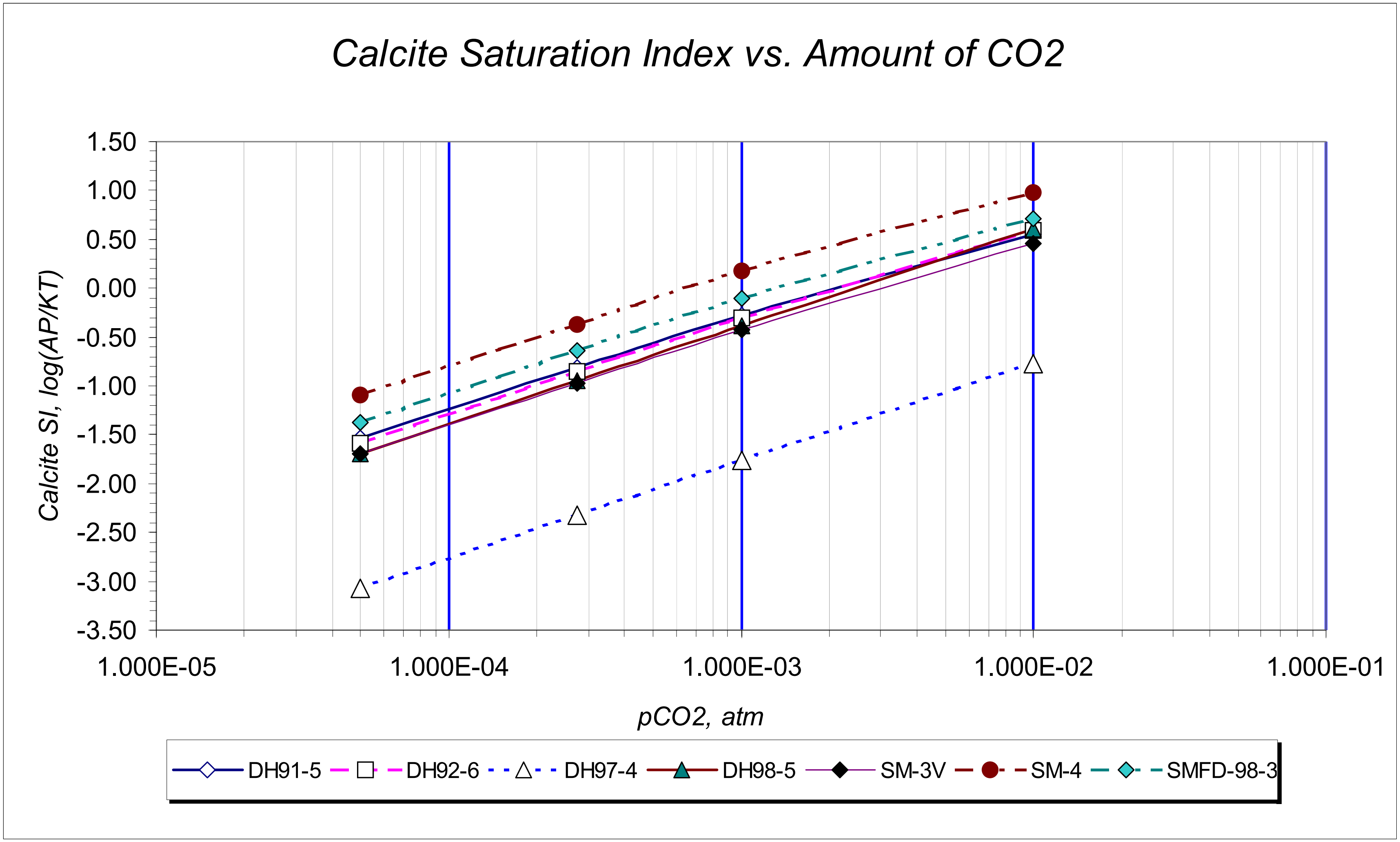


Figure 4 Chart showing relationship between partial pressure of CO_2 and the MINTEQA2 calculated mineral saturation index (SI) for calcite.



value at pCO_2 only 3-4 times the atmospheric equilibrium assumption for pCO_2. Previously reported SI values calculated by the MINTEQA2 model, all of which were negative, may have underestimated the actual pCO_2 in seepage. Langlier indices, which do not include pCO_2 in its calculation (American Public Health Association, 1998), were calculated in the Excel workbook, and these SI values are also higher compared to MINTEQA2 estimates with many samples showing near equilibrium and over saturated (positive) SI values.

If SI data are to be used to infer seepage transit time information as suggested by White (1988), then I recommend that field crews measure pCO_2 and pH *in situ* in wells and seeps at the time of sampling. Despite the interpretative issues with calcite SI data, the lack of observed hydrogen sulfide (rotten egg) odor at well heads (only well DH91-2 exhibited this indication of anaerobic biotic activity) suggests that seepage transit time is limited (eg. flows are more conduit than diffusional). The final answer on flow paths is currently moot given the repair progress at Horsetooth Dam, but future seepage and well monitoring should consider additional *in situ* well measurements and dye tracer investigations to measure actual seepage transit times.

Loading and Void Volume Formation Rates: Appendix 2 table 3 provides mass loading and void space formation associated with seepage at Horsetooth Dam, and these data are plotted as mass loadings vs. date on the graphs in figures 5a and 5b. These plots show kg/day loadings calculated for calcite, gypsum, and total seepage net concentrations. Note the 35-year gap in figure 5 dates, from 1951 until 1986, when renewed seepage concerns prompted sampling of seeps and wells.

As expected, all seepage mass loadings drop off as reservoir levels are lowered after April 2000. SM-1, SM-1A, SM-2, SM-4, SM-8, SM-8C all show calcite maxima around the 7/20/99 sampling, which was sampled before the reservoir lowering. SM-3 shows a gypsum maxima on 5/19/00, which may reflect time-lagged flows after reservoir lowering. Except for a gypsum maximum seen in the late 1980's in SM-4, and SM-3 on 5/19/00, no other seeps appear to show SO_4^{2-} dominated spikes in loading (though SM-7 shows a gypsum loading maxima in 1991). In general, the increased loadings leading up to the July 1999 sampling event seen in all seeps suggest a progressively worsening situation, rather than stable flow path/steady state seepage. Given these indications, the decision to lower the reservoir and proceed with repairs would appear to have been timely.

Figures 6a - 6c are pie diagrams for the available seepage data showing the average proportions of mass loadings attributed to gypsum, calcite, and silica dissolution, along with "other" mass loading from unspecified causes. Gypsum is a significant contributor to mass loading only for SM-3, SM-4, and SM-7, while calcite is dominant in the rest of the seeps. Of special interest is the close similarity in average loading proportions seen for the 2 construction excavation seepage samples, EXSP-1 and EXSP-2 (figure 6a, upper left), and the left side French drain seeps SM-FD98-2 and SM-FD98-3 (figure 6c). The loading proportions for these two seeps are essentially the same. Both sets of seepage loadings also have similar loading proportions attributable to silica, the maximum percentage of silica mass loading among all measured seeps at Horsetooth Dam.

Void volumes rates in m^3/day attributed to calcite, anhydrite, and gypsum, the two far right columns in appendix 2 table 3, generally follow the mass loading data. The greatest consistent void space formation rates occur for SM-7 (which collects seepage from all upstream seeps), located on the left side 3,300 ft (1,000 m) downstream of the toe, and SM-3, located on the right side 3000 ft (914 m) downstream of the

Figure 5a Flow-weighted loadings for seeps over time, including net increase in ions (total), as calcite, and as gypsum.

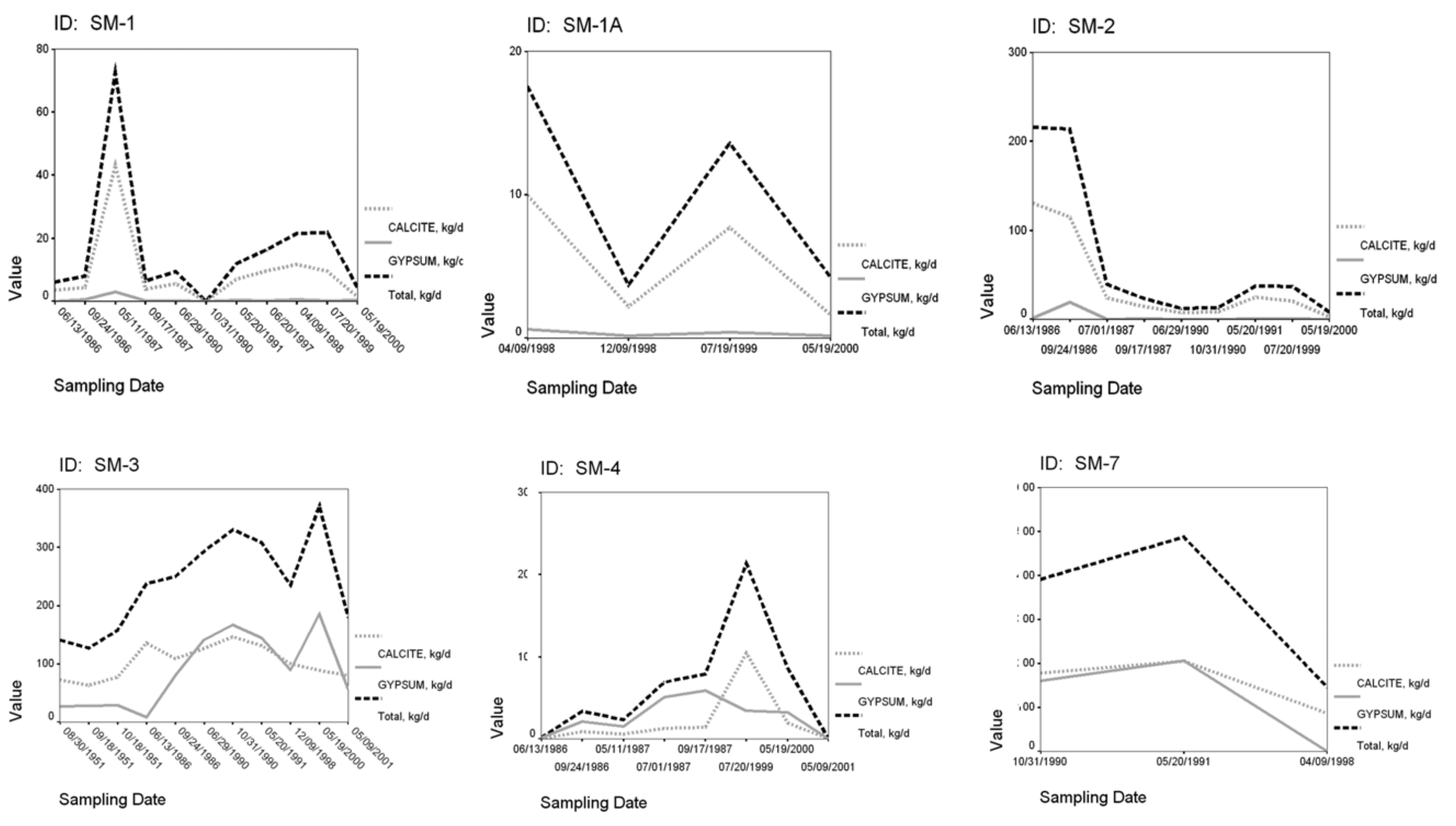


Figure 5b Flow-weighted loadings for seeps over time, including net increase in ions (total), as calcite, and as gypsum.

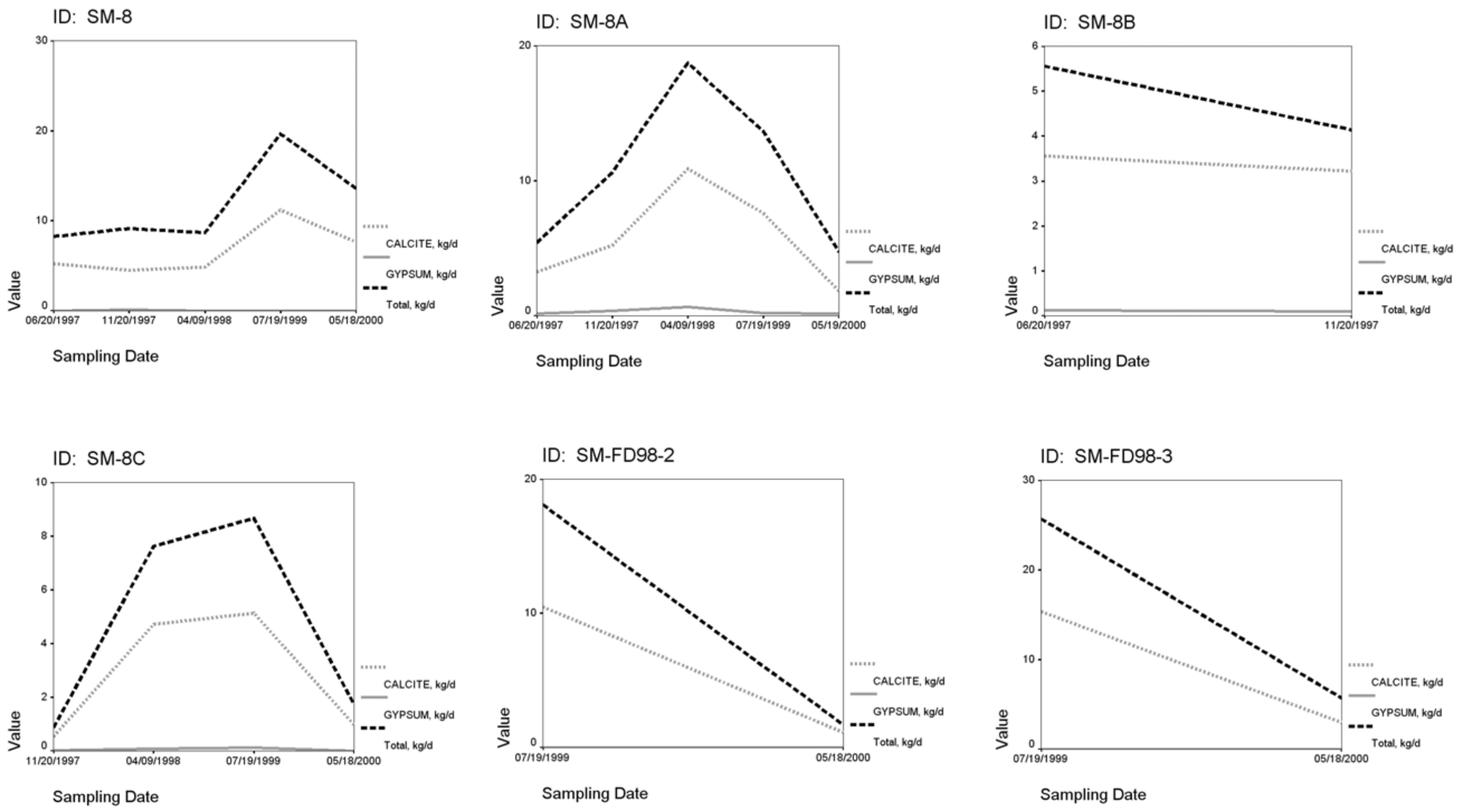


Figure 6a Pie diagrams showing average percentages of soluble mineral loading in seepage samples.

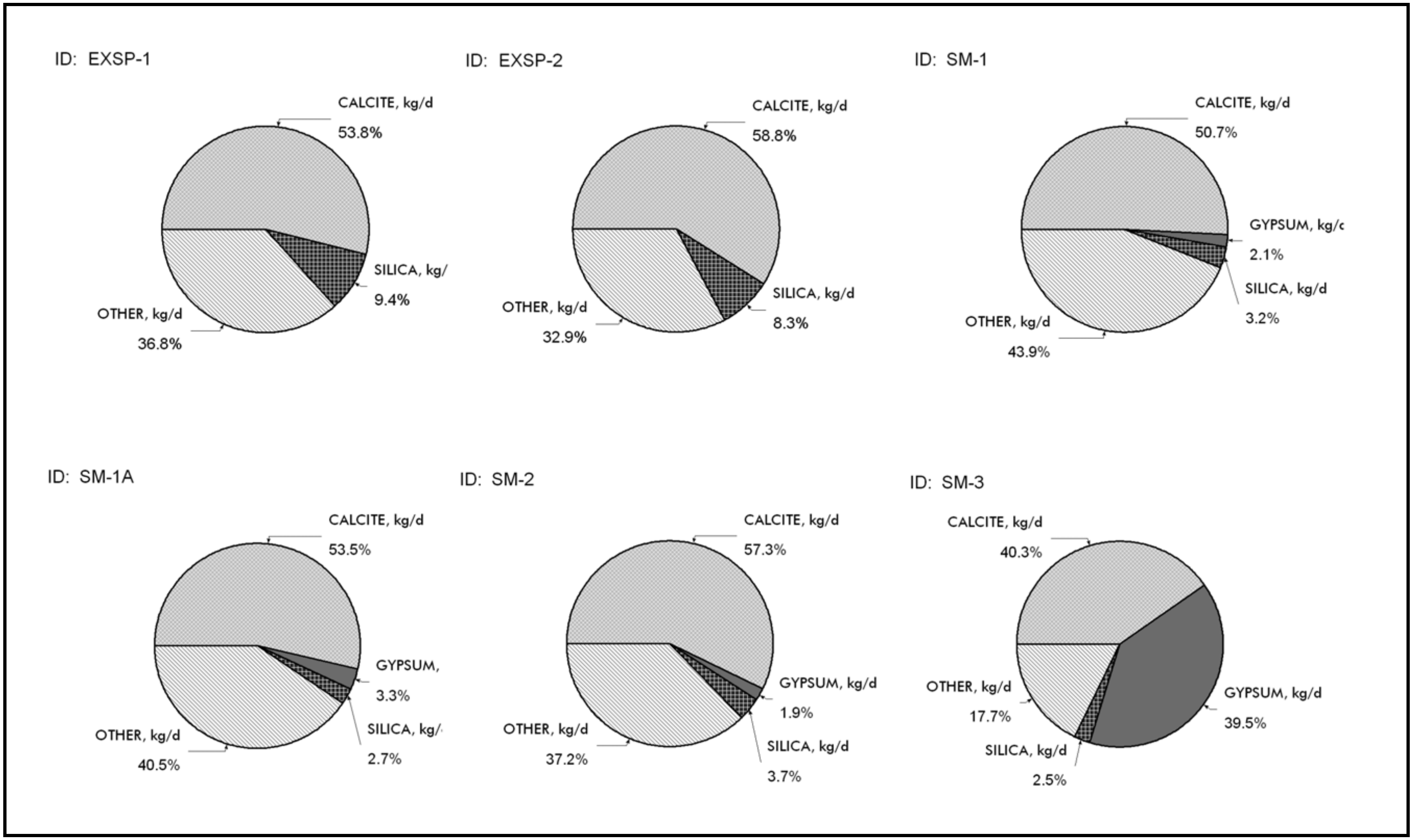


Figure 6b Pie diagrams showing average percentages of soluble mineral loading in seepage samples.

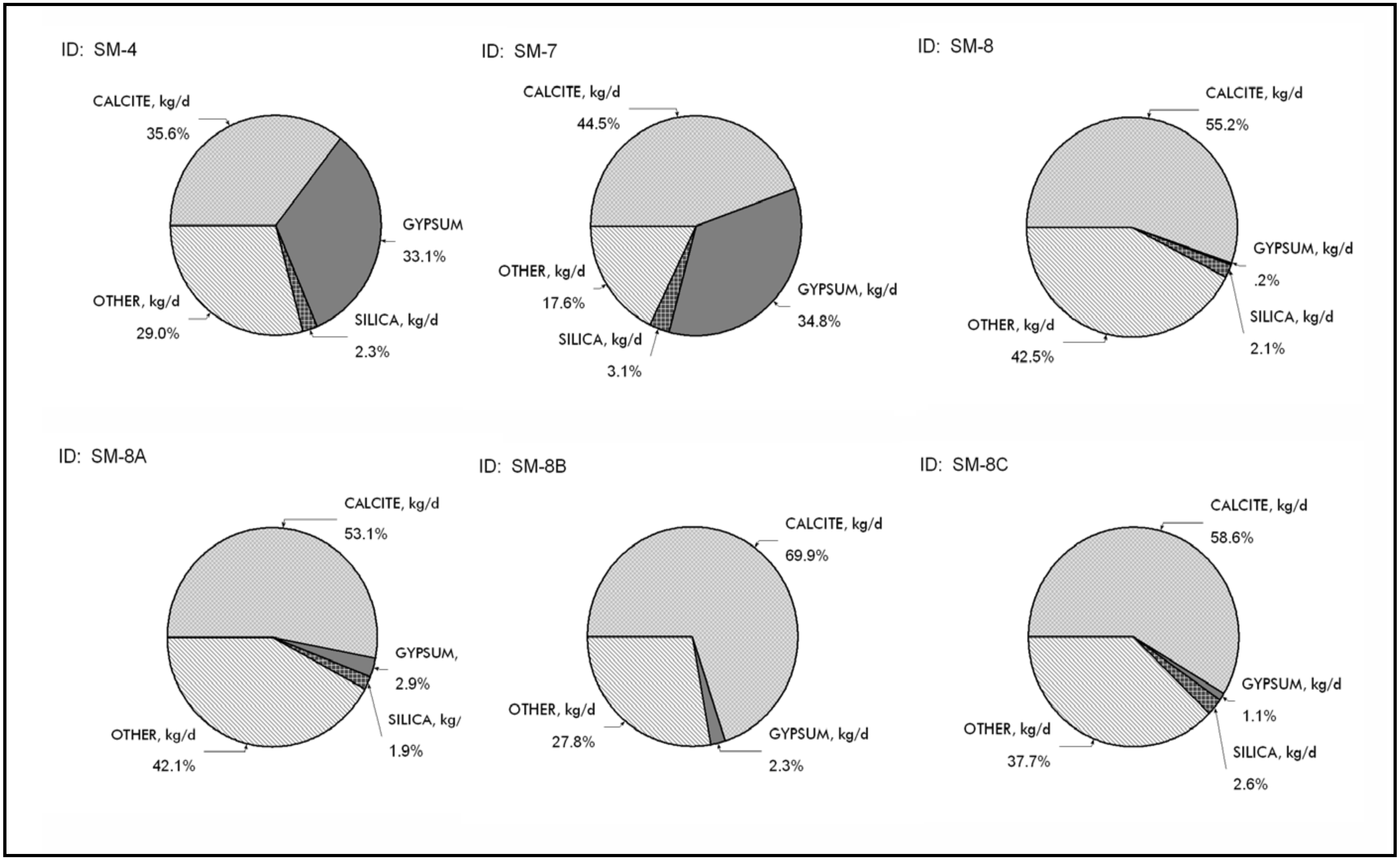
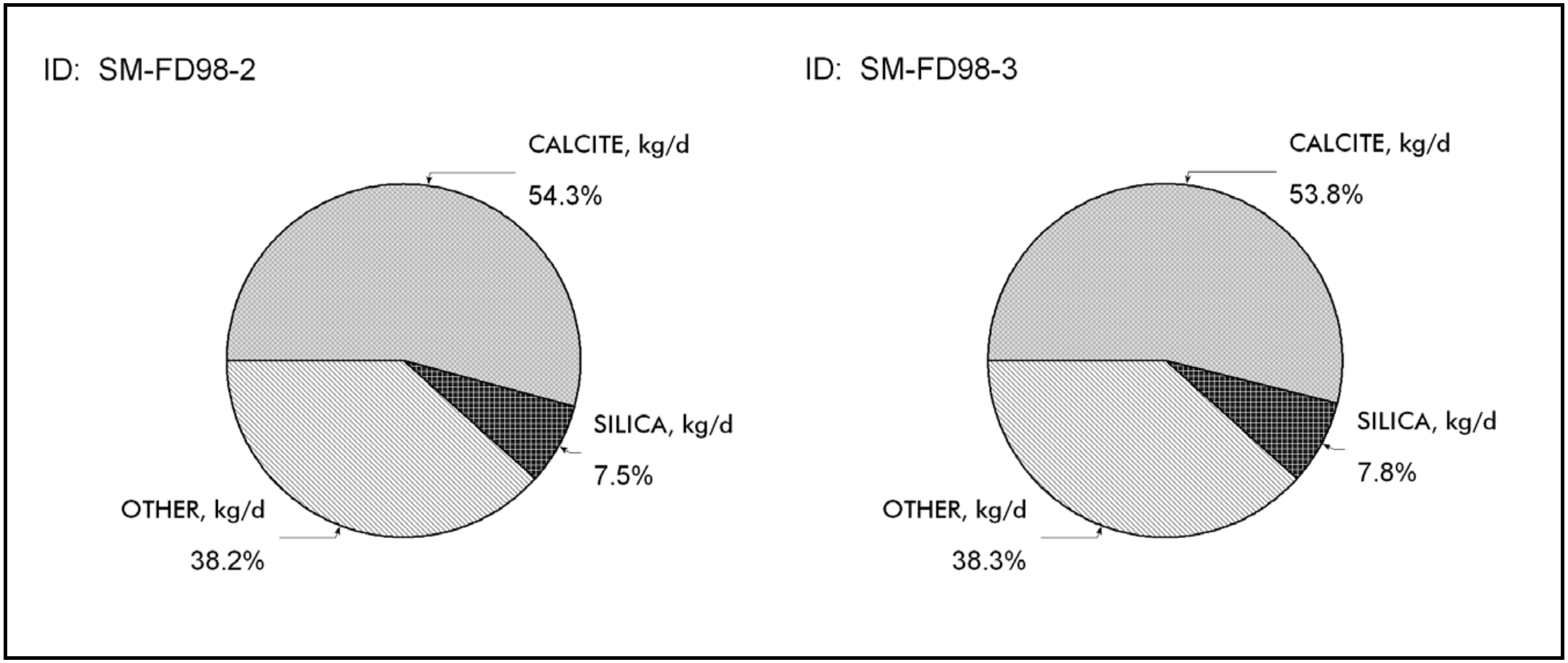


Figure 6c Pie diagrams showing average percentages of soluble mineral loading in the left side French drain seeps.



toe. Both of these seeps, with void formation rates ranging from 12 to 57 m^3/yr, show evidence of both gypsum and calcite loading and represent the longest sampled seepage paths at Horsetooth Dam. SM-3 showed a maximum calcite plus gypsum void formation rate of 43.9 m^3/yr in October 1990. SM-2, located on the right toe drainage ditch 825 ft (250 m) downstream of the toe, suggests fairly high void formation rates in the two 1986 samples, but these rates decrease the next year and have remained below 3.5 m^3/yr since 1987. The increasing seepage flow and loadings from SM-4, however, are more troubling. SM-4 loading and void formation did not decrease until reservoir levels were lowered in late April 2000 for construction.

Are these void formation rates significant? This question must first consider how seepage flow paths in karst formations proceed in dam failures (James and Lupton, 1978; James, 1992). First, flow through karst does not proceed as in a simple pipe - it is usually a network of cracks and fissures that combine conduit and diffuse flow behaviors. Conduits in a flow path may gradually enlarge, but flow paths can also diffusionally expand into a larger foundation contact volume so that the flow path enlarges over time. Loosely consolidated materials overlying the flow paths may also collapse and block flows. Mineral dissolution alone seldom accounts for structural failure, but may directly contribute to failure when enhanced flow from dissolution leads to *erosive* mass wasting and catastrophic piping. Piping and mass wasting usually directly precede failure. Considering the presence of erosive clays in the Lykins formation (Hurcomb, 1999), the potential for increased flows from mineral dissolution in strata contacting these clays could be very serious at Horsetooth Dam.

Table 1 provides a summary of both high and low seepage void formation rates (observed since 1986), assumed to be constant over the 50-year life of Horsetooth Dam. Note that only SM-3 and SM-7 have been consistently flowing since initial reservoir filling. SM-7, the collection weir for all upstream seeps, shows the greatest overall loading. These calculations assume the flow path length is equal to the lateral distance from the dam crest for the seep, which is likely a low estimate of actual flow path.

Table 1 Extrapolation of observed minimum and maximum calcite + gypsum dissolution void formation rates for selected seeps at Horsetooth Dam.

Seep	***Void Formation Scenario***	***Assumed Flow Path, m***	***Observed Seepage Flow, gpm***	***Calculated Daily Void Formation Rate, m^3/day***	***50-year Void Formation, m^3***	***Effective Flow Cross-Section, m^2***	***Simulated Conduit Diameter, m***
SM-3	low 06/13/86	914	427	0.0495	905	0.99	1.12
	high 5/19/00	914	1070	0.109	1980	2.17	1.66
SM-7	low 10/31/90	1000	673	0.129	2350	2.35	1.73
	high 5/20/91	1000	978	0.157	2860	2.86	1.91
SM-4	low 05/11/87	500	14.1	0.00836	153	0.305	0.623
	high 07/20/99	500	462	0.0501	914	1.83	1.53
SM-FD98-3	low 05/18/00	145	47.6	0.00100	18.3	0.126	0.400
	high 07/19/99	145	154	0.00520	94.9	0.654	0.913

The table 1 *effective* flow cross sections and *simulated* conduit diameters should not be misinterpreted to mean that a single open pipe of given diameter connecting reservoir and seepage outflow could have, or has formed. The fact that seepage flows have clearly been much lower than what would be expected are good indications that seepage paths through complex karst geology are considerably more serpentine and combine diffusional as well as conduit flows. We also do not know the dimensions of the actual flow paths beneath Horsetooth Dam, and assessment of structural risk depends largely on the flow path length and contact volume. What if the actual seepage path is 10 or 100 times the hypothetical lengths used above? Clearly, these issues make the assessment task difficult; however, the void formation calculations do show that mineral dissolution can potentially cause significant void formation over the lifetime of a structure.

Clearly, seepage has not been a constant or continuous process at Horsetooth Dam and seepage flow changes do not necessarily imply a similar change in dissolution loading. SM-2 shows a loading and flow spike that occurred in 1986, but by 1987, both flows and loadings had dropped to one-fifth of previous values. These data suggest that the flow path along SM-2 changed dramatically over a short period of time. Perhaps the 1986 SM-2 seepage represented the opening of a fresh flow path that "washed out" and then either collapsed or otherwise stabilized at much lower flow. Early 1990's SM-7 data clearly show lower flows, but much *higher* loadings. At SM-4, seepage flow was very low (1.20 gpm at reservoir elevation 5414.34 ft) in June 1986, yet had jumped to 18.6 gpm by August with a 38-ft lower reservoir elevation (perhaps suggesting a time-lagged hydraulic response). Between 1987 and 1999, SM-4 flows increase by an order of magnitude. Clearly, these examples demonstrate that seepage flow and dissolution loading are variable over time at Horsetooth Dam.

Recommendations

Given that repairs are currently in progress at Horsetooth Dam, now would be an opportune time to consider what monitoring should occur after the repair work is completed and reservoir levels are returned to normal operating elevations. The following should be considered:

1. All seepage flow should be monitored daily, and the data should be regularly posted on a secure Reclamation Intranet web page accessible by all project engineers and scientists. All past and future chemistry data should also be posted on this site. Additional structural and geology data should also be considered for inclusion and posting.

2. A comprehensive set of well, seepage, and at-depth reservoir samples should be collected for chemical analysis and interpretation after re-filling to establish and document post-construction baseline conditions. Additional samples should be collected from "benchmark" sites on a monthly schedule until the post-repair seepage system has stabilized. All benchmark samples should be consistently collected and labeled.

3. If feasible, *in situ* water quality conditions should be measured in all sampled wells using a well probe that can measure pH, temperature, conductivity, redox potential, and partial pressure of CO_2. This will require adequate bailing or pumping of the wells before measurement.

4. Past chemical data should be re-processed using the MINTEQA2 model to calculate calcite and other carbonate mineral saturation indices using better estimates of *in situ* pH, temperature, redox potential, and pCO_2 for subsurface seepage and groundwater.

5. Dye or other tracer studies should be performed to more accurately assess seepage residence time and general flow paths. Seepage flow rate coupled with the time for dye tracer to appear after injection could provide information on actual flow path length.

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Appendix 1: Example Loading and Void Volume Calculations for SM-4 on 7/20/99

Example loading and void volume calculations:

1 cfs = 28.3169 L/s = 2.4466 X 10^6 L/d
1 gpm = 3.7854 L/min = 5,451 L/d
1 m^3 = 1,000 L = 1 X 10^6 cm^3 = 35.315 ft^3

Gypsum	$CaSO_4 \cdot 2H_2O$ = 86.0861 mg/meq = 0.00230 to 0.00237 kg/cm^3
Anhydrite	$CaSO_4$ = 68.0708 mg/meq = 0.00294 to 0.00300 kg/cm^3
Limestone (Calcite)	$CaCO_3$ = 50.0047 mg/meq = 0.00272 to 0.00294 kg/cm^3
Silica	SiO_2 = 60.0843 mg/mmol, Si = 28.0855 mg/mmol = 0.00262 to 0.00265 kg/cm^3

Mass loading calculation, kg/day:

(mg/L_{net}) X (seepage flow, ft^3/s) X (86,400 s/day) X (28.3169 L/f^3) X (1.0 X 10^{-6} kg/mg)
or
(mg/L_{net}) X (seepage flow, gal/min) X (1,440 min/day) X (3.7854 L/gal) X (1.0 X 10^{-6} kg/mg)

Void volume formation calculation, m^3/day:

m^3/day = ((mineral loading, kg/day)/(mineral density, kg/cm^3)) X 0.000001 m^3/cm^3

SM-4 on 7/20/99

	seepage flow, gpm	*sum of ions mg/L*	*Ca meq/L*	*Mg meq/L*	*SO_4^{2-} meq/L*	*Si mg/L*
SM-4	461.45	144	1.15	0.39	0.36	2.13
Reservoir		59.5	0.41	0.14	0.20	0.880
NET CHANGE		84.8 mg/L	0.74 meq/L	0.25 meq/L	0.16 meq/L	1.25 mg/L

Gypsum Loading = $SO_4^{2-}{}_{\text{net meq/L}}$ X 86.0861 mg/meq = mg/L as gypsum
= 0.16 meq/L X 86.0861 mg/meq = ***13.77 mg/L as gypsum***
kg/day = 13.8 mg/L X 461.5 gpm X 3.7854 L/gal X 1,440 min/day
X (1.0 X 10^{-6} kg/mg)
= ***34.7 kg/day*** lost as gypsum

As Gypsum void volume = (34.7 kg/day ÷ 0.00237 kg/cm^3) X 0.000001 m^3/cm^3
= 0.01464 m^3/day = 0.517 ft^3/day

Anhydrite Loading = $SO_4^{2-}{}_{\text{net meq/L}}$ X 68.0708 mg/meq = mg/L as anhydrite
= 0.16 meq/L X 68.0708 mg/meq = ***10.89 mg/L as anhydrite***
kg/day = 10.9 mg/L X 461.5 gpm X 3.7854 L/gal X 1,440 min/day
X (1.0 X 10^{-6} kg/mg)
= ***27.4 kg/day*** lost as anhydrite

As Anhydrite void volume = (27.4 kg/day ÷ 0.00300 kg/cm^3) X 0.000001 m^3/cm^3
= 0.00913 m^3/day = 0.323 ft^3/day

Calcite Loading = (($Ca_{\text{net meq/L}}$ - $SO_4^{2-}{}_{\text{net meq/L}}$) + $Mg_{\text{net meq/L}}$) X 50.0047 mg/meq

= ((0.74 meq/L - 0.16 meq/L) + 0.25 meq/L) X 50.0047 mg/meq
= 0.83 meq/L X 50.0047 mg/meq = ***41.50 mg/L as calcite***
kg/day = 41.5 mg/L X 461.5 gpm X 3.7854 L/gal X 1,440 min/day
X (1.0 X 10^{-6} kg/mg)
= ***104 kg/day*** lost as calcite

As Calcite void volume = (104 kg/day ÷ 0.00294 kg/cm^3) X 0.000001 m^3/cm^3
= 0.0354 m^3/day = 1.25 ft^3/day

Silica Loading = $Si_{net\ mg/L\ as\ Si}$ X (molar weight SiO_2)/(molar weight Si)
= $Si_{net\ mg/L\ as\ Si}$ X 2.1393
= 1.25 mg/L X 2.1393 = ***2.674 mg/L as*** SiO_2
kg/day = 2.67 mg/L X 461.5 gpm X 3.7854 L/gal X 1,440 min/day
X (1.0 X 10^{-6} kg/mg)
= ***6.71 kg/day*** lost as silica

As Silica void volume = (6.71 kg/day ÷ 0.00265 kg/cm^3) X 0.000001 m^3/cm^3
= 0.00253 m^3/day = 0.0894 ft^3/day

Total Mass Loading = $Gions_{net\ mg/L}$ X 461.5 gpm X 3.7854 L/gal X 1,440 min/day
X (1.0 X 10^{-6} kg/mg)
kg/day = 84.8 mg/L X 461.5 gpm X 3.7854 L/gal X 1,440 min/day
X (1.0 X 10^{-6} kg/mg)
= ***213 kg/day*** total loading

Appendix 2: Tablular Summary of Seepage and Piezometer Well Chemistry at Horsetooth Dam, Colorado-Big Thompson Project, Ft. Collins, Colorado

Table 1 Chemistry data available to date on wells and piezometer holes sampled at Horsetooth Dam, grouped by general geological strata.

Sample	***Date***	***Elev.***	***pH***	***Sum***	***Ca***	***Mg***	***Na***	***K***	***HCO$_3$***	***CO$_3$***	***OH***	***SO$_4$***	***Cl***	***Fe***	***Mn***	***Al***	***Si***
	m/d/y	***ft.***	***s.u.***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***
Alluvium																	
DH00-625	5/18/00	5389.45	7.23	1441.40	136.00	2.73	60.70	139.00	949.00	0.00	0.00	85.52	68.40	0.008	3.040	<0.030	5.66
DH92-5A	6/20/97	5423.30	5.94	127.00	63.20	6.73	4.24	1.39	38.80	0.00	0.00	9.31	3.31	0.136	0.171	0.111	3.71
	11/20/97	5419.00	6.59	91.60	18.70	3.59	2.31	1.50	58.52	0.00	0.00	5.98	1.01	0.012	0.032	0.032	1.75
	4/9/98	5426.63	7.81	101.10	19.00	2.41	2.53	0.00	69.50	0.00	0.00	6.72	0.91	0.042	0.021	0.074	2.58
	12/9/98	5380.29	8.12	244.70	36.40	12.40	6.06	0.00	179.00	0.00	0.00	8.72	2.07	0.051	0.113	0.079	3.83
	7/19/99	5428.05	7.43	388.50	45.40	25.00	11.00	1.00	285.10	0.00	0.00	17.70	3.27	0.020	0.264	<0.030	3.41
	5/18/00	5389.45	8.03	432.40	45.90	0.50	21.30	29.20	315.00	0.00	0.00	17.77	2.72	0.006	0.218	0.031	2.74
Minimum		5380.29	5.94	91.60	18.70	0.50	2.31	0.00	38.80	0.00	0.00	5.98	0.91	0.006	0.021	<0.030	1.75
Maximum		5428.05	8.12	432.40	63.20	25.00	21.30	29.20	315.00	0.00	0.00	17.77	3.31	0.136	0.264	0.111	3.83
Mean			7.32	230.88	38.10	8.44	7.91	5.52	157.65	0.00	0.00	11.03	2.22	0.045	0.137	0.057	3.00
Median			7.62	185.85	40.90	5.16	5.15	1.20	124.25	.	.	9.02	2.40	0.031	0.142	0.053	3.08
S			0.88	150.12	17.25	9.12	7.29	11.62	120.98	0.00	0.00	5.33	1.07	0.048	0.099	0.037	0.80
DH97-4	11/20/97	5419.00	7.39	717.70	78.40	55.60	24.50	2.38	426.00	0.00	0.00	123.00	7.83	0.008	0.029	<0.030	6.30
	4/9/98	5426.63	6.95	883.90	183.00	30.40	8.18	1.76	597.00	0.00	0.00	59.40	4.20	0.010	0.008	<0.030	7.89
	12/9/98	5380.29	7.81	340.00	74.00	12.10	2.72	0.00	233.00	0.00	0.00	17.10	1.04	<0.004	<0.004	<0.030	4.48
	7/19/99	5428.05	7.23	872.50	181.00	23.10	5.55	2.53	605.30	0.00	0.00	51.20	3.78	0.005	<0.004	<0.030	8.88
	5/18/00	5389.45	6.88	586.50	105.00	0.50	17.10	5.53	439.00	0.00	0.00	16.57	2.76	0.008	<0.004	<0.030	5.23
	5/8/01	5358.34	7.21	566.40	121.00	18.30	3.88	0.10	391.00	0.00	0.00	28.80	3.28	<0.004	<0.004	<0.030	5.21
Minimum		5358.34	6.88	340.00	74.00	0.50	2.72	0.00	233.00	0.00	0.00	16.57	1.04	<0.004	<0.004	<0.030	4.48
Maximum		5428.05	7.81	883.90	183.00	55.60	24.50	5.53	605.30	0.00	0.00	123.00	7.83	0.010	0.029	<0.030	8.88
Mean			7.25	661.17	123.73	23.33	10.32	2.05	448.55	0.00	0.00	49.35	3.82	0.006	0.008	<0.030	6.33
Median			7.22	652.10	113.00	20.70	6.87	2.07	432.50	.	.	40.00	3.53	0.007	<0.004	.	5.77
S			0.34	207.45	48.33	18.78	8.64	2.03	139.27	0.00	0.00	40.16	2.25	0.003	0.011	0.000	1.72
All Alluvium	***Minimum***	5358.34	5.94	91.60	18.70	0.50	2.31	0.00	38.80	0.00	0.00	5.98	0.91	<0.004	<0.004	<0.030	1.75
	Maximum	5428.05	8.12	1441.40	183.00	55.60	60.70	139.00	949.00	0.00	0.00	123.00	68.40	0.136	3.040	0.111	8.88
	Mean		7.28	522.59	85.15	14.87	13.08	14.18	352.79	0.00	0.00	34.45	8.04	0.024	0.300	0.034	4.74
	Median		7.23	432.40	74.00	12.10	6.06	1.50	315.00	.	.	17.70	3.27	0.008	0.029	<0.030	4.48
	S		0.61	387.07	56.25	15.82	16.11	38.31	259.67	0.00	0.00	35.87	18.22	0.037	0.828	0.032	2.08

Table 1 - continued

Lower Lykins

Sample		Date m/d/y	Elev. ft.	pH s.u.	Sum mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	OH mg/L	SO_4 mg/L	Cl mg/L	Fe mg/L	Mn mg/L	Al mg/L	Si mg/L
DH91-2		6/20/97	5423.30	6.74	1583.00	269.00	116.00	12.60	0.00	183.00	0.00	0.00	1000.00	2.42	<0.004	0.465	<0.030	7.67
		11/20/97	5419.00	7.00	1563.50	253.00	110.00	11.40	1.81	186.11	0.00	0.00	1000.00	1.23	<0.004	0.389	<0.030	6.99
		4/9/98	5426.63	7.21	1507.70	252.00	111.00	11.90	1.62	187.00	0.00	0.00	943.00	1.16	0.008	0.381	<0.030	7.57
		12/9/98	5380.29	7.02	1515.20	242.00	105.00	11.80	0.00	190.23	0.00	0.00	965.00	1.15	0.011	0.401	<0.030	7.49
		7/20/99	5428.25	7.29	1360.40	183.00	77.70	11.70	1.00	187.90	0.00	0.00	896.00	3.10	0.020	0.391	<0.030	6.16
		5/18/00	5389.45	7.15	1493.30	246.00	0.50	106.00	11.40	187.00	0.00	0.00	940.70	1.67	0.005	0.310	<0.030	7.31
	Minimum		5380.29	6.74	1360.40	183.00	0.50	11.40	0.00	183.00	0.00	0.00	896.00	1.15	<0.004	0.310	<0.030	6.16
	Maximum		5428.25	7.29	1583.00	269.00	116.00	106.00	11.40	190.23	0.00	0.00	1000.00	3.10	0.020	0.465	<0.030	7.67
	Mean			7.07	1503.85	240.83	86.70	27.57	2.64	186.87	0.00	0.00	957.45	1.79	0.008	0.390	<0.030	7.20
	Median			7.09	1511.45	249.00	107.50	11.85	1.31	187.00	.	.	954.00	1.45	0.007	0.390	.	7.40
	S			0.20	78.30	29.80	44.36	38.43	4.36	2.36	0.00	0.00	39.86	0.81	0.007	0.049	0.000	0.56
DH92-6		6/20/97	5423.30	6.89	240.20	33.30	11.30	12.30	0.00	176.00	0.00	0.00	4.86	2.48	0.028	0.547	<0.030	3.94
		4/9/98	5426.63	7.42	235.50	32.30	10.60	12.60	0.00	172.00	0.00	0.00	6.62	1.33	0.028	0.334	0.048	3.91
		12/9/98	5380.29	7.35	252.20	34.80	11.80	11.50	0.00	188.44	0.00	0.00	4.00	1.64	0.019	0.550	<0.030	3.99
		7/20/99	5428.25	6.94	238.70	29.70	9.92	11.40	1.00	173.80	0.00	0.00	9.64	3.28	0.017	0.449	<0.030	3.74
		5/17/00	5389.06	7.86	239.90	30.60	0.50	10.80	12.40	177.00	0.00	0.00	4.13	4.46	0.016	0.435	0.032	4.10
		5/8/01	5358.34	7.40	436.80	60.40	19.90	19.70	0.10	312.00	0.00	0.00	15.40	9.31	0.176	0.426	<0.030	5.34
	Minimum		5358.34	6.89	235.50	29.70	0.50	10.80	0.00	172.00	0.00	0.00	4.00	1.33	0.016	0.334	<0.030	3.74
	Maximum		5428.25	7.86	436.80	60.40	19.90	19.70	12.40	312.00	0.00	0.00	15.40	9.31	0.176	0.550	0.048	5.34
	Mean			7.31	273.88	36.85	10.67	13.05	2.25	199.87	0.00	0.00	7.44	3.75	0.047	0.457	0.023	4.17
	Median			7.38	240.05	32.80	10.95	11.90	0.05	176.50	.	.	5.74	2.88	0.024	0.442	<0.030	3.97
	S			0.36	80.02	11.68	6.18	3.32	4.99	55.23	0.00	0.00	4.43	2.95	0.063	0.082	0.014	0.59
All Lower Lykins	**Minimum**		5358.34	6.74	235.50	29.70	0.50	10.80	0.00	172.00	0.00	0.00	4.00	1.15	<0.004	0.310	<0.030	3.74
	Maximum		5428.25	7.86	1583.00	269.00	116.00	106.00	12.40	312.00	0.00	0.00	1000.00	9.31	0.176	0.550	0.048	7.67
	Mean			7.19	888.87	138.84	48.69	20.31	2.44	193.37	0.00	0.00	482.45	2.77	0.028	0.423	0.019	5.68
	Median			7.18	898.60	121.70	15.85	11.85	0.55	186.56	.	.	455.70	2.05	0.017	0.414	<0.030	5.75
	S			0.30	646.75	108.69	49.88	27.09	4.47	37.88	0.00	0.00	496.86	2.30	0.048	0.073	0.010	1.67

Table 1 - continued

Sample	Date	Elev.	pH	Sum	Ca	Mg	Na	K	HCO_3	CO_3	OH	SO_4	Cl	Fe	Mn	Al	Si
	m/d/y	ft.	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lower Lykins - Blaine																	
DH91-1	6/20/97	5423.30	9.47	208.00	10.50	3.17	33.50	35.40	45.70	29.30	0.00	26.70	23.70	0.129	0.006	0.120	2.62
	11/20/97	5419.00	11.17	778.50	204.00	0.20	25.40	14.20	0.00	6.52	28.92	491.00	8.22	0.012	<0.004	0.054	1.58
	4/9/98	5426.63	10.70	651.40	174.00	0.81	19.60	9.54	0.00	12.40	12.60	417.00	5.43	<0.004	<0.004	<0.030	1.44
	12/9/98	5380.29	7.56	70.00	16.50	0.42	1.66	1.17	46.03	0.00	0.00	3.44	0.74	0.015	0.014	<0.030	0.45
	7/20/99	5428.25	8.10	306.90	63.70	1.35	10.10	5.15	35.30	0.00	0.00	187.00	4.28	0.006	<0.004	<0.030	1.43
	5/19/00	5389.83	9.59	300.80	67.60	4.53	2.07	10.50	14.50	12.10	0.00	186.18	3.31	0.013	<0.004	0.040	1.89
	5/8/01	5358.34	11.50	274.20	87.00	0.02	16.80	14.10	0.00	19.20	55.50	77.60	3.95	0.004	<0.004	0.015	3.75
Minimum		5358.34	7.56	70.00	10.50	0.02	1.66	1.17	0.00	0.00	0.00	3.44	0.74	<0.004	<0.004	<0.030	0.45
Maximum		5428.25	11.50	778.50	204.00	4.53	33.50	35.40	46.03	29.30	55.50	491.00	23.70	0.129	0.014	0.120	3.75
Mean			9.73	369.97	89.04	1.50	15.59	12.87	20.22	11.36	13.86	198.42	7.09	0.026	0.004	0.039	1.88
Median			9.59	300.80	67.60	0.81	16.80	10.50	14.50	12.10	0.00	186.18	4.28	0.012	<0.004	<0.030	1.58
S			1.51	251.74	74.13	1.71	11.84	10.99	21.61	10.54	21.33	189.63	7.66	0.046	0.005	0.039	1.05
DH98-5	7/20/99	5428.25	6.66	1987.40	532.00	12.40	3.06	1.00	83.10	0.00	0.00	1353.00	2.80	<0.004	0.007	<0.030	3.25
	5/17/00	5389.06	7.37	2017.40	534.00	0.50	12.00	2.97	79.30	0.00	0.00	1387.00	1.63	<0.004	0.008	<0.030	3.33
	5/9/01	5358.37	6.98	2029.50	571.00	15.40	5.15	0.10	52.50	0.00	0.00	1384.00	1.39	<0.004	<0.004	<0.030	3.47
Minimum		5358.37	6.66	1987.40	532.00	0.50	3.06	0.10	52.50	0.00	0.00	1353.00	1.39	<0.004	<0.004	<0.030	3.25
Maximum		5428.25	7.37	2029.50	571.00	15.40	12.00	2.97	83.10	0.00	0.00	1387.00	2.80	<0.004	0.008	<0.030	3.47
Mean			7.00	2011.43	545.67	9.43	6.74	1.36	71.63	0.00	0.00	1374.67	1.94	<0.004	0.006	<0.030	3.35
Median			6.98	2017.40	534.00	12.40	5.15	1.00	79.30	.	.	1384.00	1.63	.	0.007	.	3.33
S			0.36	21.67	21.96	7.88	4.68	1.47	16.68	0.00	0.00	18.82	0.75	0.000	0.003	0.000	0.11
All Lower Lykins-Blaine	**Minimum**	5358.34	6.66	70.00	10.50	0.02	1.66	0.10	0.00	0.00	0.00	3.44	0.74	<0.004	<0.004	<0.030	0.45
	Maximum	5428.25	11.50	2029.50	571.00	15.40	33.50	35.40	83.10	29.30	55.50	1387.00	23.70	0.129	0.014	0.120	3.75
	Mean		8.91	862.41	226.03	3.88	12.93	9.41	35.64	7.95	9.70	551.29	5.55	0.019	0.005	0.032	2.32
	Median		8.79	479.15	130.50	1.08	11.05	7.35	40.50	3.26	0.00	302.00	3.63	0.005	<0.004	<0.030	2.26
	S		1.81	819.17	228.96	5.52	10.80	10.58	31.46	10.21	18.66	588.97	6.74	0.039	0.004	0.034	1.11

Sample	**Date**	**Elev.**	**pH**	**Sum**	**Ca**	**Mg**	**Na**	**K**	**HCO_3**	**CO_3**	**OH**	**SO_4**	**Cl**	**Fe**	**Mn**	**Al**	**Si**
	m/d/y	**ft.**	**s.u.**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Middle Lykins - Forelle																	
DH91-3A	6/20/97	5423.30	6.68	84.70	15.10	2.22	2.20	0.00	56.00	0.00	0.00	7.18	2.04	0.014	<0.004	0.053	1.85
	11/20/97	5419.00	7.31	82.40	15.80	2.67	2.11	1.47	52.90	0.00	0.00	6.47	1.03	0.029	<0.004	0.083	2.04
	11/20/97	5419.00	6.89	78.90	14.20	2.01	2.01	1.47	51.69	0.00	0.00	6.47	1.03	0.027	<0.004	0.078	1.98
	4/9/98	5426.63	7.61	78.90	14.40	2.07	2.23	0.00	50.50	0.00	0.00	8.80	0.89	0.016	<0.004	0.032	2.10
	7/20/99	5428.25	8.61	100.90	20.30	2.40	2.29	1.00	43.00	19.00	0.00	10.10	2.83	0.011	0.008	0.036	3.42
Minimum		5419.00	6.68	78.90	14.20	2.01	2.01	0.00	43.00	0.00	0.00	6.47	0.89	0.011	<0.004	0.032	1.85
Maximum		5428.25	8.61	100.90	20.30	2.67	2.29	1.47	56.00	19.00	0.00	10.10	2.83	0.029	0.008	0.083	3.42
Mean			7.42	85.16	15.96	2.27	2.17	0.79	50.82	3.80	0.00	7.80	1.56	0.019	0.003	0.056	2.28
Median			7.31	82.40	15.10	2.22	2.20	1.00	51.69	0.00	.	7.18	1.03	0.016	<0.004	0.053	2.04
S			0.76	9.14	2.51	0.27	0.11	0.74	4.83	8.50	0.00	1.60	0.84	0.008	0.003	0.023	0.65
DH91-4	6/20/97	5423.30	6.65	70.60	13.10	1.58	2.25	0.00	46.90	0.00	0.00	4.60	2.13	0.049	0.006	0.075	1.61
	11/20/97	5419.00	7.03	64.40	12.70	1.40	2.02	1.31	43.12	0.00	0.00	2.76	1.04	0.065	<0.004	0.137	1.87
	4/9/98	5426.63	7.90	60.90	11.50	1.36	2.15	0.00	42.10	0.00	0.00	2.91	0.89	0.035	<0.004	0.039	1.89
	12/9/98	5380.29	7.11	71.30	13.20	1.55	1.97	0.00	50.16	0.00	0.00	3.51	0.94	0.012	<0.004	<0.030	1.28
	7/20/99	5428.25	6.51	84.20	13.90	1.66	2.32	1.00	52.90	0.00	0.00	9.55	2.86	0.058	<0.004	0.118	2.22
	5/19/00	5389.83	7.82	72.70	12.80	0.50	1.62	2.31	50.00	0.00	0.00	3.99	1.44	0.052	<0.004	0.086	1.80
Minimum		5380.29	6.51	60.90	11.50	0.50	1.62	0.00	42.10	0.00	0.00	2.76	0.89	0.012	<0.004	<0.030	1.28
Maximum		5428.25	7.90	84.20	13.90	1.66	2.32	2.31	52.90	0.00	0.00	9.55	2.86	0.065	0.006	0.137	2.22
Mean			7.17	70.68	12.87	1.34	2.06	0.77	47.53	0.00	0.00	4.55	1.55	0.045	0.003	0.078	1.78
Median			7.07	70.95	12.95	1.48	2.09	0.50	48.45	.	.	3.75	1.24	0.051	<0.004	0.081	1.84
S			0.58	8.03	0.79	0.43	0.25	0.95	4.27	0.00	0.00	2.54	0.79	0.019	<0.004	0.046	0.31
DH91-5	6/20/97	5423.30	6.68	77.50	14.90	1.73	2.17	0.00	49.70	0.00	0.00	6.94	2.06	0.020	<0.004	0.049	1.68
	4/9/98	5426.63	7.98	73.90	14.60	1.64	2.26	0.00	47.50	0.00	0.00	6.98	0.88	0.032	0.011	0.042	1.95
	7/19/99	5428.05	6.61	90.00	15.70	1.77	2.32	1.00	56.70	0.00	0.00	9.65	2.90	0.041	<0.004	0.091	2.07
	5/17/00	5389.06	8.04	76.60	13.60	0.50	1.65	2.93	52.20	0.00	0.00	4.23	1.45	0.042	<0.004	0.099	1.88
	5/8/01	5358.34	7.27	239.30	51.60	4.95	3.23	0.10	108.00	0.00	0.00	70.10	1.30	<0.004	0.005	0.114	3.03
Minimum		5358.34	6.61	73.90	13.60	0.50	1.65	0.00	47.50	0.00	0.00	4.23	0.88	<0.004	<0.004	0.042	1.68
Maximum		5428.05	8.04	239.30	51.60	4.95	3.23	2.93	108.00	0.00	0.00	70.10	2.90	0.042	0.011	0.114	3.03
Mean			7.32	111.46	22.08	2.12	2.33	0.81	62.82	0.00	0.00	19.58	1.72	0.027	0.004	0.079	2.12
Median			7.27	77.50	14.90	1.73	2.26	0.10	52.20	.	.	6.98	1.45	0.032	<0.004	0.091	1.95
S			0.68	71.73	16.52	1.67	0.57	1.26	25.49	0.00	0.00	28.31	0.78	0.017	0.004	0.032	0.53

Table 1 - continued

Sample	Date	Elev.	pH	Sum	Ca	Mg	Na	K	HCO_3	CO_3	OH	SO_4	Cl	Fe	Mn	Al	Si
	m/d/y	ft.	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
DH92-7	6/20/97	5423.30	7.43	97.90	16.40	2.98	3.76	0.00	67.30	0.00	0.00	5.21	2.26	0.014	0.015	0.040	1.83
	11/20/97	5419.00	7.44	102.00	16.00	3.16	4.19	0.00	73.74	0.00	0.00	3.76	1.16	0.009	0.007	0.037	1.89
	4/9/98	5426.63	8.11	90.20	14.90	2.59	4.13	0.00	64.10	0.00	0.00	3.51	0.99	0.009	0.006	<0.030	1.86
	12/9/98	5380.29	7.99	97.50	17.10	2.48	3.11	0.00	69.34	0.00	0.00	4.24	1.21	0.010	<0.004	<0.030	1.91
	7/19/99	5428.05	7.63	90.00	15.10	1.73	2.46	1.00	57.30	0.00	0.00	9.56	2.82	0.020	<0.004	<0.030	2.06
	5/18/00	5389.45	8.48	89.90	15.50	0.50	2.12	3.49	57.70	2.96	0.00	5.29	2.34	0.008	<0.004	0.032	1.86
	5/9/01	5358.37	7.45	306.90	39.70	17.20	7.46	0.10	237.00	0.00	0.00	3.10	2.34	0.007	0.067	<0.030	11.30
Minimum		5358.37	7.43	89.90	14.90	0.50	2.12	0.00	57.30	0.00	0.00	3.10	0.99	0.007	<0.004	<0.030	1.83
Maximum		5428.05	8.48	306.90	39.70	17.20	7.46	3.49	237.00	2.96	0.00	9.56	2.82	0.020	0.067	0.040	11.30
Mean			7.79	124.91	19.24	4.38	3.89	0.66	89.50	0.42	0.00	4.95	1.87	0.011	0.014	0.024	3.24
Median			7.63	97.50	16.00	2.59	3.76	0.00	67.30	0.00	.	4.24	2.26	0.009	0.006	<0.030	1.89
S			0.41	80.39	9.05	5.73	1.77	1.30	65.32	1.12	0.00	2.19	0.73	0.005	0.024	0.012	3.55
DH97-1	12/9/98	5380.29	6.88	68.40	12.70	1.42	1.99	0.50	47.35	0.00	0.00	3.51	0.96	0.029	<0.004	0.052	1.29
	7/20/99	5428.25	6.44	83.60	13.60	1.60	2.32	1.00	52.70	0.00	0.00	9.57	2.83	0.188	<0.004	0.392	2.75
	5/17/00	5389.06	7.95	70.10	12.40	0.50	1.57	2.51	47.10	0.00	0.00	4.31	1.69	0.089	<0.004	0.199	2.02
	5/8/01	5358.34	7.32	170.50	28.80	6.43	3.04	0.10	121.00	0.00	0.00	9.89	1.28	<0.004	<0.004	<0.030	3.75
Minimum		5358.34	6.44	68.40	12.40	0.50	1.57	0.10	47.10	0.00	0.00	3.51	0.96	<0.004	<0.004	<0.030	1.29
Maximum		5428.25	7.95	170.50	28.80	6.43	3.04	2.51	121.00	0.00	0.00	9.89	2.83	0.188	<0.004	0.392	3.75
Mean			7.15	98.15	16.88	2.49	2.23	1.03	67.04	0.00	0.00	6.82	1.69	0.077	<0.004	0.165	2.45
Median			7.10	76.85	13.15	1.51	2.16	0.75	50.03	.	.	6.94	1.49	0.059	.	0.126	2.39
S			0.64	48.71	7.97	2.67	0.62	1.05	36.07	0.00	0.00	3.38	0.82	0.082	0.000	0.171	1.05
DH97-3	7/19/99	5428.05	6.57	83.20	14.10	1.58	2.35	1.00	51.80	0.00	0.00	9.58	2.82	0.045	<0.004	0.101	2.22
	5/18/00	5389.45	7.76	71.30	12.90	0.50	1.56	2.84	48.10	0.00	0.00	3.98	1.40	0.056	<0.004	0.123	1.87
	5/9/01	5358.37	7.31	169.90	29.60	6.08	2.98	0.10	120.00	0.00	0.00	9.93	1.22	<0.004	<0.004	<0.030	3.69
Minimum		5358.37	6.57	71.30	12.90	0.50	1.56	0.10	48.10	0.00	0.00	3.98	1.22	<0.004	<0.004	<0.030	1.87
Maximum		5428.05	7.76	169.90	29.60	6.08	2.98	2.84	120.00	0.00	0.00	9.93	2.82	0.056	<0.004	0.123	3.69
Mean			7.21	108.13	18.87	2.72	2.30	1.31	73.30	0.00	0.00	7.83	1.81	0.034	<0.004	0.080	2.59
Median			7.31	83.20	14.10	1.58	2.35	1.00	51.80	.	.	9.58	1.40	0.045	.	0.101	2.22
S			0.60	53.82	9.31	2.96	0.71	1.40	40.49	0.00	0.00	3.34	0.88	0.029	0.000	0.057	0.97
DH98-10A	12/9/98	5380.29	8.47	100.00	7.93	2.44	16.90	0.00	38.00	12.00	0.00	21.10	1.64	0.192	<0.004	0.690	8.47
DH98-2A	7/20/99	5428.25	6.51	81.90	13.00	1.63	2.45	1.00	51.40	0.00	0.00	9.55	2.83	0.185	<0.004	0.380	2.68
	5/17/00	5389.06	8.01	70.70	12.30	0.50	1.64	3.23	46.80	0.00	0.00	4.29	1.94	0.056	<0.004	0.116	1.86
Minimum		5389.06	6.51	70.70	12.30	0.50	1.64	1.00	46.80	0.00	0.00	4.29	1.94	0.056	<0.004	0.116	1.86
Maximum			8.01	81.90	13.00	1.63	2.45	3.23	51.40	0.00	0.00	9.55	2.83	0.185	<0.004	0.380	2.68
Mean			7.26	76.30	12.65	1.07	2.05	2.12	49.10	0.00	0.00	6.92	2.39	0.121	<0.004	0.248	2.27
Median			7.26	76.30	12.65	1.07	2.05	2.12	49.10	.	.	6.92	2.39	0.121	.	0.248	2.27

Table 1 - continued

Sample	Date	Elev.	pH	Sum	Ca	Mg	Na	K	HCO$_3$	CO$_3$	OH	SO$_4$	Cl	Fe	Mn	Al	Si
	m/d/y	ft.	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
DH98-6	12/9/98	5380.29	9.46	174.60	8.67	7.63	48.90	6.10	52.80	41.80	0.00	7.70	1.04	12.100	0.036	38.400	0.11
	7/20/99	5428.25	8.35	73.20	14.20	2.95	2.54	1.00	19.00	21.00	0.00	9.69	2.78	0.028	<0.004	0.059	2.59
	5/18/00	5389.45	8.70	112.80	13.70	0.50	2.84	2.61	81.80	5.61	0.00	4.15	1.57	0.014	<0.004	0.064	2.74
	5/9/01	5358.37	7.21	86.00	12.20	1.91	6.72	0.10	54.20	0.00	0.00	7.91	2.94	0.049	<0.004	<0.030	5.33
Minimum		5358.37	7.21	73.20	8.67	0.50	2.54	0.10	19.00	0.00	0.00	4.15	1.04	0.014	<0.004	<0.030	0.11
Maximum		5428.25	9.46	174.60	14.20	7.63	48.90	6.10	81.80	41.80	0.00	9.69	2.94	12.100	0.036	38.400	5.33
Mean			8.43	111.65	12.19	3.25	15.25	2.45	51.95	17.10	0.00	7.36	2.08	3.048	0.011	9.635	2.69
Median			8.53	99.40	12.95	2.43	4.78	1.81	53.50	13.31	.	7.81	2.18	0.039	<0.004	0.062	2.67
S			0.94	45.09	2.50	3.09	22.51	2.64	25.71	18.71	0.00	2.32	0.93	6.035	0.017	19.177	2.13
DH99-11	12/9/98	5380.29	7.07	85.20	15.90	2.19	2.03	0.00	56.51	0.00	0.00	7.59	1.00	0.009	<0.004	0.033	1.72
	5/19/00	5389.83	7.87	90.60	16.20	0.50	2.11	2.27	63.70	0.00	0.00	4.33	1.45	0.016	0.005	0.048	2.02
	5/8/01	5358.34	6.99	245.50	35.60	15.00	6.67	4.51	39.30	0.00	0.00	143.00	1.38	<0.004	<0.004	0.072	4.67
Minimum		5358.34	6.99	85.20	15.90	0.50	2.03	0.00	39.30	0.00	0.00	4.33	1.00	<0.004	<0.004	0.033	1.72
Maximum		5389.83	7.87	245.50	35.60	15.00	6.67	4.51	63.70	0.00	0.00	143.00	1.45	0.016	0.005	0.072	4.67
Mean			7.31	140.43	22.57	5.90	3.60	2.26	53.17	0.00	0.00	51.64	1.28	0.009	0.003	0.051	2.80
Median			7.07	90.60	16.20	2.19	2.11	2.27	56.51	.	.	7.59	1.38	0.009	<0.004	0.048	2.02
S			0.49	91.03	11.29	7.93	2.66	2.26	12.54	0.00	0.00	79.14	0.24	0.007	<0.004	0.020	1.62
All Middle Lykins - Forelle	**Minimum**	5358.34	6.44	60.90	7.93	0.50	1.56	0.00	19.00	0.00	0.00	2.76	0.88	<0.004	<0.004	<0.030	0.11
	Maximum	5428.25	9.46	306.90	51.60	17.20	48.90	6.10	237.00	41.80	0.00	143.00	2.94	12.100	0.067	38.400	11.30
	Mean		7.50	102.98	16.90	2.85	4.27	1.15	61.79	2.56	0.00	11.72	1.74	0.341	0.006	1.052	2.63
	Median		7.44	84.45	14.30	1.75	2.31	1.00	52.45	0.00	.	6.71	1.45	0.028	<0.004	0.056	2.00
	S		0.71	53.91	8.53	3.48	7.70	1.45	34.74	7.96	0.00	23.77	0.73	1.908	0.012	6.058	1.94

Table 1 - continued

Sample	Date	Elev.	pH	Sum	Ca	Mg	Na	K	HCO$_3$	CO$_3$	OH	SO$_4$	Cl	Fe	Mn	Al	Si
	m/d/y	ft.	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Upper Lykins																	
DH92-5B	6/20/97	5423.30	10.00	163.00	30.70	4.07	10.30	2.56	23.60	40.30	0.00	48.70	2.80	0.028	<0.004	0.045	3.15
	11/20/97	5419.00	11.30	179.60	57.20	1.88	4.37	3.56	0.00	30.80	37.89	42.60	1.28	0.189	0.015	0.263	2.06
	4/9/98	5426.63	11.30	228.70	101.00	0.13	5.07	0.00	0.00	12.70	72.40	36.40	1.03	0.005	<0.004	0.041	2.74
	12/9/98	5380.29	8.77	180.60	35.30	5.24	5.76	0.00	68.00	15.10	0.00	49.80	1.41	0.006	0.005	<0.030	3.89
	5/19/00	5389.83	7.25	221.40	40.50	0.50	6.88	6.31	107.00	0.00	0.00	58.51	1.72	0.020	0.025	<0.030	3.42
	5/8/01	5358.34	7.03	206.90	33.50	6.97	7.38	1.86	114.00	0.00	0.00	41.00	2.18	0.006	0.024	0.125	3.95
	Minimum	5358.34	7.03	163.00	30.70	0.13	4.37	0.00	0.00	0.00	0.00	36.40	1.03	0.005	<0.004	<0.030	2.06
	Maximum	5426.63	11.30	228.70	101.00	6.97	10.30	6.31	114.00	40.30	72.40	58.51	2.80	0.189	0.025	0.263	3.95
	Mean		9.28	196.70	49.70	3.13	6.63	2.38	52.10	16.48	18.38	46.17	1.74	0.042	0.012	0.084	3.20
	Median		9.39	193.75	37.90	2.98	6.32	2.21	45.80	13.90	0.00	45.65	1.57	0.013	0.010	0.043	3.29
	S		1.90	26.17	26.85	2.74	2.12	2.39	51.65	16.32	30.50	7.83	0.65	0.072	0.011	0.097	0.72
DH98-7	12/9/98	5380.29	9.09	400.40	50.40	12.00	48.90	0.00	111.00	37.00	0.00	139.00	2.08	<0.004	<0.004	<0.030	6.21
	7/20/99	5428.25	8.16	438.00	55.60	19.10	24.00	12.70	144.80	0.00	0.00	178.00	3.81	<0.004	<0.004	<0.030	6.11
	5/19/00	5389.83	8.44	340.10	52.10	2.78	17.10	18.00	39.10	2.51	0.00	206.37	2.10	0.010	<0.004	<0.030	5.64
	5/8/01	5358.34	7.33	268.80	43.50	3.83	22.30	8.29	23.40	0.00	0.00	166.00	1.50	<0.004	<0.004	<0.030	1.59
	Minimum	5358.34	7.33	268.80	43.50	2.78	17.10	0.00	23.40	0.00	0.00	139.00	1.50	<0.004	<0.004	<0.030	1.59
	Maximum	5428.25	9.09	438.00	55.60	19.10	48.90	18.00	144.80	37.00	0.00	206.37	3.81	0.010	<0.004	<0.030	6.21
	Mean		8.26	361.83	50.40	9.43	28.08	9.75	79.58	9.88	0.00	172.34	2.37	0.004	<0.004	<0.030	4.89
	Median		8.30	370.25	51.25	7.92	23.15	10.50	75.05	1.26	.	172.00	2.09	<0.004	.	.	5.88
	S		0.73	73.97	5.08	7.65	14.19	7.61	57.84	18.12	0.00	27.94	1.00	0.004	0.000	0.000	2.21
DH99-15	7/20/99	5428.25	7.19	414.60	61.80	17.60	20.90	1.00	254.90	0.00	0.00	52.50	5.93	0.019	0.012	0.043	6.34
	5/18/00	5389.45	7.50	397.60	65.60	0.50	18.40	12.90	249.00	0.00	0.00	45.76	5.39	0.007	<0.004	<0.030	6.20
	5/9/01	5358.37	7.51	300.60	20.20	10.90	28.60	27.80	168.00	0.00	0.00	41.00	4.10	<0.004	<0.004	<0.030	4.61
	Minimum	5358.37	7.19	300.60	20.20	0.50	18.40	1.00	168.00	0.00	0.00	41.00	4.10	<0.004	<0.004	<0.030	4.61
	Maximum	5428.25	7.51	414.60	65.60	17.60	28.60	27.80	254.90	0.00	0.00	52.50	5.93	0.019	0.012	0.043	6.34
	Mean		7.40	370.93	49.20	9.67	22.63	13.90	223.97	0.00	0.00	46.42	5.14	0.009	0.005	0.024	5.72
	Median		7.50	397.60	61.80	10.90	20.90	12.90	249.00	.	.	45.76	5.39	0.007	<0.004	<0.030	6.20
	S		0.18	61.50	25.19	8.62	5.32	13.43	48.56	0.00	0.00	5.78	0.94	0.009	0.006	0.016	0.96
All Upper Lykins	**Minimum**	5358.34	7.03	163.00	20.20	0.13	4.37	0.00	0.00	0.00	0.00	36.40	1.03	<0.004	<0.004	<0.030	1.59
	Maximum	5428.25	11.30	438.00	101.00	19.10	48.90	27.80	254.90	40.30	72.40	206.37	5.93	0.189	0.025	0.263	6.34
	Mean		8.53	287.72	49.80	6.58	16.92	7.31	100.22	10.65	8.48	85.05	2.72	0.023	0.007	0.049	4.30
	Median		8.16	268.80	50.40	4.07	17.10	3.56	107.00	0.00	0.00	49.80	2.10	0.006	<0.004	<0.030	3.95
	S		1.51	99.94	20.31	6.42	12.63	8.48	86.42	15.45	21.87	62.41	1.60	0.051	0.009	0.071	1.68

Table 2 Chemistry of seepage collected at Horsetooth Dam.

Sample	***Date***	***Elev.***	***Flow***	***pH***	***Sum***	***Ca***	***Mg***	***Na***	***K***	***HCO_3***	***CO_3***	***OH***	***SO_4***	***Cl***	***Fe***	***Mn***	***Al***	***Si***
	m/d/y	***ft.***	***gpm***	***s.u.***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***
EXSP-2	7/11/01	5353.50	15.0	8.06	158	24.5	5.79	5.95	0.10	114	0.00	0.00	6.93	1.45	0.002	0.002	<0.030	6.08
	7/11/01	5353.50	15.0	8.21	155	23.4	7.37	4.57	0.10	111	0.00	0.00	7.45	1.60	0.015	0.036	<0.030	5.28
SM-1	6/13/86	5414.34	11.9	7.86	146	23.2	6.08	4.29	0.54	107	0.00	0.00	4.50	0.75	.	.	.	.
	6/13/86	5414.34	11.9	7.60	145	23.2	5.89	4.04	0.76	106	0.00	0.00	4.90	0.55	.	.	.	.
	9/24/86	5376.53	11.9	8.50	164	25.3	7.52	4.50	0.75	114	4.49	0.00	7.60	0.00	.	.	.	.
	5/11/87	5414.08	115.2	7.30	160	25.5	7.11	4.23	0.55	108	0.00	0.00	8.00	6.20	.	.	.	.
	5/11/87	5414.08	115.2	7.58	172	27.6	7.79	3.93	0.39	123	0.00	0.00	7.90	1.20	.	.	.	.
	9/17/87	5397.48	10.1	7.33	160	24.1	7.96	4.16	0.64	117	0.00	0.00	5.00	1.00	.	.	.	.
	9/17/87	5397.48	10.1	7.51	159	24.6	8.12	4.05	0.64	117	0.00	0.00	5.00	0.00	.	.	.	.
	6/29/90	5407.81	18.2	8.20	156	25.3	7.00	4.54	2.96	108	0.00	0.00	5.61	2.36	0.008	<0.004	0.078	3.50
	10/31/90	5390.37	0.0	5.86	219	34.7	7.90	4.78	1.52	161	0.00	0.00	6.75	1.86	0.005	0.009	<0.030	3.11
	5/20/91	5423.20	23.3	7.18	157	24.0	6.68	4.95	0.00	112	0.00	0.00	6.58	2.87	0.014	<0.004	0.062	2.97
	6/20/97	5423.30	26.2	6.70	162	25.6	6.79	4.93	0.00	116	0.00	0.00	5.47	3.38	<0.004	<0.004	<0.030	3.10
	11/20/97	5419.00	.	7.03	155	23.3	6.22	4.53	0.00	116	0.00	0.00	3.84	1.36	<0.004	<0.004	<0.030	2.88
	4/9/98	5426.63	35.4	7.60	157	24.2	6.36	4.84	0.00	114	0.00	0.00	4.21	3.09	<0.004	<0.004	<0.030	2.99
	7/20/99	5428.25	29.2	7.63	197	24.6	6.51	5.16	3.76	140	0.00	0.00	10.70	6.39	<0.004	<0.004	<0.030	2.77
	5/19/00	5389.83	5.8	8.09	189	27.8	0.50	8.18	3.80	135	0.00	0.00	11.68	1.59	0.023	0.010	<0.030	3.28
	Minimum	5376.53	0.0	5.86	145	23.2	0.50	3.93	0.00	106	0.00	0.00	3.84	0.00	<0.004	<0.004	<0.030	2.77
	Maximum	5428.25	115.2	8.50	219	34.7	8.12	8.18	3.80	161	4.49	0.00	11.68	6.39	0.023	0.010	0.078	3.50
	Mean		30.3	7.46	167	25.5	6.56	4.74	1.09	120	0.30	0.00	6.52	2.17	0.007	0.004	0.029	3.08
	Median		15.0	7.58	160	24.6	6.79	4.53	0.64	116	0.00	.	5.61	1.59	0.004	<0.004	<0.030	3.05
	S		37.2	0.64	20	2.9	1.83	1.02	1.33	15	1.16	0.00	2.32	1.97	0.008	0.003	0.026	0.23
SM-1A	4/9/98	5426.63	43.5	7.48	119	19.0	4.95	3.18	0.00	87	0.00	0.00	4.38	1.14	<0.004	<0.004	<0.030	2.17
	12/9/98	5380.29	11.9	6.98	107	17.6	4.24	2.43	0.00	77	0.00	0.00	4.59	1.16	0.006	<0.004	<0.030	2.27
	7/19/99	5428.05	43.5	6.60	117	17.6	4.13	2.81	1.00	78	0.00	0.00	10.40	2.94	0.009	0.007	<0.030	2.13
	5/19/00	5389.83	15.9	7.76	101	16.5	0.50	3.78	3.08	71	0.00	0.00	4.89	1.70	0.012	<0.004	0.033	2.01
	Minimum	5380.29	11.9	6.60	101	16.5	0.50	2.43	0.00	71	0.00	0.00	4.38	1.14	<0.004	<0.004	<0.030	2.01
	Maximum	5428.05	43.5	7.76	119	19.0	4.95	3.78	3.08	87	0.00	0.00	10.40	2.94	0.012	0.007	0.033	2.27
	Mean		28.7	7.21	111	17.7	3.46	3.05	1.02	78	0.00	0.00	6.07	1.74	0.007	0.003	0.020	2.15
	Median		29.7	7.23	112	17.6	4.19	3.00	0.50	77	.	.	4.74	1.43	0.008	<0.004	<0.030	2.15
	S		17.2	0.52	8	1.0	2.00	0.58	1.45	6	0.00	0.00	2.90	0.84	0.004	0.003	0.009	0.11
SM-1A-CON	5/17/83	27.0256		0.76	9	0.3	2.40	0.57	1.17	3	0.00	0.00	3.77	0.98	<0.004	0.000	0.018	0.06
	12/9/98	5380.29	.	6.92	108	18.1	4.35	2.47	0.00	77	0.00	0.00	4.67	1.17	0.005	<0.004	<0.030	2.29
	7/19/99	5428.05	.	6.49	110	16.0	3.90	2.74	1.00	74	0.00	0.00	9.81	2.93	0.009	<0.004	<0.030	2.02
	5/19/00	5389.83	.	7.66	96	15.6	0.50	3.57	2.68	68	0.00	0.00	4.57	1.63	0.010	<0.004	<0.030	1.93
	Minimum	5380.29		6.49	96	15.6	0.50	2.47	0.00	68	0.00	0.00	4.57	1.17	0.005	<0.004	<0.030	1.93
	Maximum	5428.05		7.66	110	18.1	4.35	3.57	2.68	77	0.00	0.00	9.81	2.93	0.010	<0.004	<0.030	2.29
SM-1A-COR	12/9/98	5380.29	.	7.23	433	73.8	16.30	5.20	0.00	320	0.00	0.00	13.50	3.85	<0.004	0.409	<0.030	6.04

Table 2 - continued

Sample	Date	Elev.	Flow	pH	Sum	Ca	Mg	Na	K	HCO_3	CO_3	OH	SO_4	Cl	Fe	Mn	Al	Si
	m/d/y	ft.	gpm	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SM-1A-black	7/19/99	5428.05	.	7.03	429	73.6	14.70	4.62	1.00	321	0.00	0.00	10.60	3.62	0.011	1.000	<0.030	7.17
	5/19/00	5389.83	.	7.50	436	76.1	0.50	16.10	4.45	324	0.00	0.00	11.98	2.59	0.020	0.216	<0.030	6.58
	5/9/01	5358.37	.	7.59	512	99.3	17.70	4.42	0.10	362	0.00	0.00	25.30	3.45	<0.004	0.006	0.044	5.35
	Minimum	5358.37		7.03	429	73.6	0.50	4.42	0.10	321	0.00	0.00	10.60	2.59	<0.004	0.006	<0.030	5.35
	Maximum	5428.05		7.59	512	99.3	17.70	16.10	4.45	362	0.00	0.00	25.30	3.62	0.020	1.000	0.044	7.17
	Mean			7.37	459	83.0	10.97	8.38	1.85	336	0.00	0.00	15.96	3.22	0.011	0.407	0.025	6.37
	Median			7.50	436	76.1	14.70	4.62	1.00	324	.	.	11.98	3.45	0.011	0.216	<0.030	6.58
	S			0.30	46	14.2	9.19	6.69	2.30	23	0.00	0.00	8.12	0.55	0.009	0.524	0.017	0.93
SM-1A-white	7/19/99	5428.05	.	6.58	109	15.9	3.90	2.77	1.00	72	0.00	0.00	9.87	2.95	0.015	<0.004	0.041	2.03
	5/19/00	5389.83	.	7.66	96	15.5	0.50	3.57	2.66	68	0.00	0.00	4.54	1.56	0.012	<0.004	<0.030	1.94
	Minimum	5389.83		6.58	96	15.5	0.50	2.77	1.00	68	0.00	0.00	4.54	1.56	0.012	<0.004	<0.030	1.94
	Maximum	5428.05		7.66	109	15.9	3.90	3.57	2.66	72	0.00	0.00	9.87	2.95	0.015	<0.004	0.041	2.03
				7.12	103	15.7	2.20	3.17	1.83	70	0.00	0.00	7.21	2.26	0.014	<0.004	0.028	1.99
				7.12	103	15.7	2.20	3.17	1.83	70	.	.	7.21	2.26	0.014	.	0.028	1.99
SM-2	6/13/86	5414.34	328.0	8.18	175	27.8	8.64	4.23	0.65	128	0.00	0.00	4.75	0.40	.	.	.	.
	6/13/86	5414.34	328.0	8.03	172	26.9	7.46	4.38	0.54	128	0.00	0.00	4.50	0.40	.	.	.	.
	9/24/86	5376.53	340.0	7.20	157	25.3	6.42	3.85	1.04	111	0.00	0.00	8.20	1.36	.	.	.	.
	7/1/87	5417.94	66.2	7.00	139	21.1	6.31	4.64	0.58	94	0.00	0.00	12.00	0.00	.	.	.	.
	7/1/87	5417.94	66.2	7.61	165	26.5	7.96	4.60	0.64	114	0.00	0.00	10.30	0.54	.	.	.	.
	9/17/87	5397.48	32.5	7.27	175	28.3	8.48	4.24	0.51	128	0.00	0.00	5.00	0.00	.	.	.	.
	9/17/87	5397.48	32.5	6.80	173	27.8	8.37	4.20	0.71	127	0.00	0.00	5.00	0.00	.	.	.	.
	6/29/90	5407.81	18.2	8.76	185	30.1	8.70	4.76	3.71	125	5.04	0.00	5.67	2.26	0.029	<0.004	0.097	4.16
	10/31/90	5390.37	20.6	6.99	181	28.6	9.12	4.40	0.00	130	0.00	0.00	6.84	1.78	<0.004	0.004	<0.030	3.39
	5/20/91	5423.20	66.0	8.59	167	27.5	8.05	5.05	0.00	105	11.80	0.00	6.77	2.70	0.012	<0.004	0.077	2.82
	7/20/99	5428.25	61.2	8.98	170	24.7	6.84	4.61	3.38	85	30.00	0.00	10.50	4.95	<0.004	<0.004	<0.030	2.56
	5/19/00	5389.83	11.9	8.48	174	26.4	0.50	7.89	3.96	123	5.19	0.00	5.38	1.31	0.020	<0.004	0.030	3.23
	Minimum	5376.53	11.9	6.80	139	21.1	0.50	3.85	0.00	85	0.00	0.00	4.50	0.00	<0.004	<0.004	<0.030	2.56
	Maximum	5428.25	340.0	8.98	185	30.1	9.12	7.89	3.96	130	30.00	0.00	12.00	4.95	0.029	0.004	0.097	4.16
	Mean		114.3	7.82	169	26.8	7.24	4.74	1.31	117	4.34	0.00	7.08	1.31	0.013	<0.004	0.047	3.23
	Median		63.6	7.82	173	27.2	8.01	4.50	0.65	124	0.00	.	6.22	0.93	0.012	<0.004	0.030	3.23
	S		132.8	0.77	12	2.3	2.31	1.04	1.46	15	8.87	0.00	2.58	1.47	0.012	0.001	0.038	0.61

Table 2 - continued

Sample	Date	Elev.	Flow	pH	Sum	Ca	Mg	Na	K	HCO_3	CO_3	OH	SO_4	Cl	Fe	Mn	Al	Si
	m/d/y	ft.	gpm	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SM-3	8/30/51	5353.23	83.1	7.80	367	56.6	19.50	13.10	2.30	230	0.00	0.00	38.40	7.10	.	.	.	.
	9/18/51	5355.28	88.2	8.20	335	54.6	15.80	11.70	2.00	204	0.00	0.00	37.40	9.90	.	.	.	.
	10/18/51	5358.62	96.6	7.60	370	55.6	19.00	13.80	2.30	238	0.00	0.00	33.60	7.80	.	.	.	.
	6/13/86	5414.34	427.0	7.60	155	23.7	7.03	4.04	0.43	113	0.00	0.00	6.25	0.30	.	.	.	.
	6/13/86	5414.34	427.0	7.54	155	23.7	7.08	4.04	0.43	113	0.00	0.00	6.00	0.30	.	.	.	.
	9/24/86	5376.53	427.0	6.88	159	24.3	7.48	3.81	0.75	112	0.00	0.00	9.10	1.29	.	.	.	.
	9/24/86	5376.53	427.0	6.60	140	27.7	3.87	2.22	0.66	70	0.00	0.00	34.20	1.41	.	.	.	.
	6/29/90	5407.81	713.0	8.38	137	28.4	4.20	3.22	3.63	69	0.96	0.00	25.10	2.24	0.013	<0.004	0.068	2.78
	10/31/90	5390.37	790.0	6.12	141	29.0	4.19	3.06	0.00	77	0.00	0.00	26.70	1.83	<0.004	<0.004	<0.030	2.58
	5/20/91	5423.20	907.0	7.31	126	24.1	3.47	3.09	0.00	71	0.00	0.00	21.60	2.60	0.006	<0.004	0.066	1.96
	12/9/98	5380.29	764.6	6.95	106	20.5	2.84	2.27	0.00	64	0.00	0.00	15.60	1.07	<0.004	<0.004	<0.030	2.12
	Minimum	5353.23	83.1	6.12	106	20.5	2.84	2.22	0.00	64	0.00	0.00	6.00	0.30	<0.004	<0.004	<0.030	1.96
	Maximum	5423.20	907.0	8.38	370	56.6	19.50	13.80	3.63	238	0.96	0.00	38.40	9.90	0.013	<0.004	0.068	2.78
	Mean		468.2	7.36	199	33.5	8.59	5.85	1.14	124	0.09	0.00	23.09	3.26	0.006	<0.004	0.041	2.36
	Median		427.0	7.54	155	27.7	7.03	3.81	0.66	112	0.00	.	25.10	1.83	0.004	.	0.041	2.35
	S		296.9	0.68	103	14.4	6.37	4.57	1.22	68	0.29	0.00	12.33	3.36	0.005	0.000	0.030	0.38
SM-3N	4/9/98	5426.63	925.6	7.82	91	16.0	2.87	3.16	0.00	64	0.00	0.00	3.83	0.99	0.008	<0.004	<0.030	1.98
	7/20/99	5428.25	1100.8	6.55	115	17.5	2.37	2.23	3.40	66	0.00	0.00	20.20	2.90	0.015	<0.004	<0.030	1.81
	5/19/00	5389.83	1068.6	7.80	103	18.5	0.50	2.76	2.71	66	0.00	0.00	10.55	1.50	0.022	<0.004	0.053	2.18
	5/9/01	5358.37	.	7.23	171	31.7	5.09	3.57	0.10	106	0.00	0.00	23.00	1.57	<0.004	<0.004	<0.030	2.96
	Minimum	5358.37	925.6	6.55	91	16.0	0.50	2.23	0.00	64	0.00	0.00	3.83	0.99	<0.004	<0.004	<0.030	1.81
	Maximum	5428.25	1100.8	7.82	171	31.7	5.09	3.57	3.40	106	0.00	0.00	23.00	2.90	0.022	<0.004	0.053	2.96
	Mean		1031.7	7.35	120	20.9	2.71	2.93	1.55	75	0.00	0.00	14.40	1.74	0.012	<0.004	0.025	2.23
	Median		1068.6	7.52	109	18.0	2.62	2.96	1.41	66	.	.	15.38	1.54	0.012	.	<0.030	2.08
	S		93.2	0.60	36	7.3	1.89	0.57	1.76	20	0.00	0.00	8.83	0.82	0.009	0.000	0.019	0.51
SM-3S	4/9/98	5426.63	925.6	7.50	205	37.6	7.54	4.41	0.00	136	0.00	0.00	17.40	1.52	<0.004	<0.004	<0.030	3.93
	7/20/99	5428.25	1100.8	6.50	84	11.0	1.83	2.11	3.34	53	0.00	0.00	9.71	2.89	0.127	<0.004	0.248	2.18
	5/19/00	5389.83	.	7.88	72	12.1	0.50	1.94	2.45	49	0.00	0.00	4.49	1.50	0.051	<0.004	0.106	1.90
	5/9/01	5358.37	.	6.86	68	11.7	1.74	2.30	0.10	45	0.00	0.00	5.64	0.91	0.016	<0.004	<0.030	2.25
	Minimum	5358.37	925.6	6.50	68	11.0	0.50	1.94	0.00	45	0.00	0.00	4.49	0.91	<0.004	<0.004	<0.030	1.90
	Maximum	5428.25	1100.8	7.88	205	37.6	7.54	4.41	3.34	136	0.00	0.00	17.40	2.89	0.127	<0.004	0.248	3.93
	Mean		1013.2	7.19	107	18.1	2.90	2.69	1.47	71	0.00	0.00	9.31	1.71	0.049	<0.004	0.096	2.57
	Median		1013.2	7.18	78	11.9	1.79	2.21	1.28	51	.	.	7.68	1.51	0.034	.	0.061	2.22
	S		123.9	0.62	65	13.0	3.15	1.16	1.68	43	0.00	0.00	5.84	0.84	0.056	0.000	0.110	0.92
SM-3V	5/19/00	5389.83	.	7.87	116	22.0	0.50	3.13	2.55	65	0.00	0.00	21.44	1.48	0.027	<0.004	0.065	2.13
	5/9/01	5358.37	496.6	7.14	127	23.5	3.61	2.92	0.10	78	0.00	0.00	17.60	1.24	<0.004	<0.004	<0.030	2.55
	Minimum	5358.37	496.6	7.14	116	22.0	0.50	2.92	0.10	65	0.00	0.00	17.60	1.24	<0.004	<0.004	<0.030	2.13
	Maximum	5389.83	496.6	7.87	127	23.5	3.61	3.13	2.55	78	0.00	0.00	21.44	1.48	0.027	<0.004	0.065	2.55

Sample	***Date***	***Elev.***	***Flow***	***pH***	***Sum***	***Ca***	***Mg***	***Na***	***K***	***HCO_3***	***CO_3***	***OH***	***SO_4***	***Cl***	***Fe***	***Mn***	***Al***	***Si***
	m/d/y	***ft.***	***gpm***	***s.u.***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***
SM-4	6/13/86	5414.34	1.2	10.10	321	36.7	24.30	17.40	0.22	120	25.50	0.00	96.00	0.70	.	.	.	.
	9/24/86	5376.53	18.6	7.68	375	57.4	20.90	15.60	0.57	162	0.00	0.00	118.00	0.62	.	.	.	.
	5/11/87	5414.08	14.1	8.56	354	51.7	21.20	13.70	0.31	142	8.57	0.00	115.00	1.20	.	.	.	.
	7/1/87	5417.94	40.7	8.98	354	48.6	22.30	16.00	0.23	116	11.60	0.00	139.00	0.00	.	.	.	.
	9/17/87	5397.48	40.7	6.96	399	57.0	23.70	17.60	0.90	148	0.00	0.00	150.00	1.50	.	.	.	.
	9/17/87	5397.48	40.7	6.88	399	57.0	23.60	17.40	0.96	148	0.00	0.00	150.00	1.50	.	.	.	.
	7/20/99	5428.25	461.5	8.13	144	23.1	4.75	3.55	1.00	91	0.00	0.00	17.40	3.13	0.022	<0.004	0.037	2.13
	5/19/00	5389.83	171.8	8.15	145	24.9	0.50	5.04	2.99	87	0.00	0.00	22.89	1.59	0.073	0.008	0.116	2.93
	5/9/01	5358.37	0.0	7.93	321	63.4	11.90	6.08	0.10	94	0.00	0.00	143.00	2.58	<0.004	<0.004	<0.030	2.98
	Minimum	5358.37	0.0	6.88	144	23.1	0.50	3.55	0.10	87	0.00	0.00	17.40	0.00	<0.004	<0.004	<0.030	2.13
	Maximum	5428.25	461.5	10.10	399	63.4	24.30	17.60	2.99	162	25.50	0.00	150.00	3.13	0.073	0.008	0.116	2.98
	Mean		87.7	8.15	312	46.6	17.02	12.49	0.81	123	5.07	0.00	105.70	1.42	0.032	0.004	0.056	2.68
	Median		40.7	8.13	354	51.7	21.20	15.60	0.57	120	0.00	.	118.00	1.50	0.022	<0.004	0.037	2.93
	S		149.5	1.00	99	14.9	9.02	5.86	0.89	28	8.85	0.00	51.73	0.97	0.037	0.003	0.053	0.48
SM-4N	6/29/90	5407.81	.	10.40	338	62.3	18.50	11.80	3.56	63	51.10	0.00	126.00	2.21	0.008	0.006	0.088	2.96
SM-4S	6/29/90	5407.81	.	10.30	334	57.2	18.90	12.00	3.45	64	48.50	0.00	128.00	2.16	.	.	.	.
SM-7	6/29/90	5407.81	.	8.72	151	32.5	5.20	3.78	3.77	76	3.12	0.00	24.30	2.19	0.039	<0.004	0.078	2.94
	10/31/90	5390.37	673.0	6.13	171	33.1	5.92	4.00	0.00	96	0.00	0.00	29.90	1.85	0.011	0.004	0.034	2.69
	5/20/91	5423.20	978.0	7.52	155	28.2	5.28	4.18	0.00	87	0.00	0.00	27.10	2.65	0.016	0.008	0.083	2.37
	4/9/98	5426.63	1323.2	7.99	62	11.6	1.38	2.07	0.00	44	0.00	0.00	2.71	0.88	0.019	<0.004	0.049	1.88
	4/9/98	5426.63	1323.2	7.90	69	12.9	1.57	2.17	0.00	48	0.00	0.00	2.86	0.87	0.060	<0.004	0.124	2.09
	Minimum	5390.37	673.0	6.13	62	11.6	1.38	2.07	0.00	44	0.00	0.00	2.71	0.87	0.011	<0.004	0.034	1.88
	Maximum	5426.63	1323.2	8.72	171	33.1	5.92	4.18	3.77	96	3.12	0.00	29.90	2.65	0.060	0.008	0.124	2.94
	Mean		1074.4	7.65	121	23.7	3.87	3.24	0.75	70	0.62	0.00	17.37	1.69	0.029	0.004	0.074	2.39
	Median		1150.6	7.90	151	28.2	5.20	3.78	0.00	76	0.00	.	24.30	1.85	0.019	<0.004	0.078	2.37
	S		313.2	0.96	52	10.6	2.21	1.03	1.69	23	1.40	0.00	13.46	0.79	0.020	0.003	0.035	0.43
SM-8	6/20/97	5423.30	22.2	6.54	116	22.6	2.43	2.16	0.00	82	0.00	0.00	4.40	1.90	0.027	0.004	0.053	1.47
	11/20/97	5419.00	30.1	7.23	91	16.4	1.85	2.99	0.00	66	0.00	0.00	2.93	1.06	0.031	<0.004	0.065	1.66
	4/9/98	5426.63	43.5	7.70	82	15.0	1.86	2.11	0.00	59	0.00	0.00	2.82	0.87	0.021	<0.004	0.040	1.52
	7/19/99	5428.05	66.2	6.38	114	19.4	2.49	2.76	1.00	75	0.00	0.00	9.60	3.67	0.040	<0.004	0.066	2.03
	5/18/00	5389.45	70.9	7.82	88	16.5	0.50	2.02	2.46	61	0.00	0.00	3.97	1.51	0.068	0.005	0.133	2.03
	Minimum	5389.45	22.2	6.38	82	15.0	0.50	2.02	0.00	59	0.00	0.00	2.82	0.87	0.021	<0.004	0.040	1.47
	Maximum	5428.05	70.9	7.82	116	22.6	2.49	2.99	2.46	82	0.00	0.00	9.60	3.67	0.068	0.005	0.133	2.03
	Mean		46.6	7.13	98	18.0	1.83	2.41	0.69	69	0.00	0.00	4.74	1.80	0.037	0.003	0.071	1.74
	Median		43.5	7.23	91	16.5	1.86	2.16	0.00	66	.	.	3.97	1.51	0.031	<0.004	0.065	1.66
	S		21.5	0.66	16	3.0	0.80	0.44	1.08	10	0.00	0.00	2.80	1.12	0.018	0.001	0.036	0.27
SM-8A	6/20/97	5423.30	12.6	6.56	126	19.9	5.50	3.54	0.00	89	0.00	0.00	5.70	2.59	0.004	<0.004	<0.030	2.15
	11/20/97	5419.00	20.6	7.27	130	19.3	5.06	9.80	4.54	86	0.00	0.00	4.37	1.22	0.009	<0.004	0.033	2.19
	4/9/98	5426.63	45.9	7.56	120	19.4	5.10	3.26	0.00	87	0.00	0.00	4.22	1.15	0.010	<0.004	<0.030	2.22
	7/19/99	5428.05	43.5	6.58	117	17.2	4.10	2.79	1.00	79	0.00	0.00	9.85	2.96	0.006	<0.004	<0.030	2.05
	5/19/00	5389.83	18.2	8.39	100	16.3	0.50	3.68	2.67	68	2.26	0.00	4.61	1.56	0.012	<0.004	0.031	1.89
	Minimum	5389.83	12.6	6.56	100	16.3	0.50	2.79	0.00	68	0.00	0.00	4.22	1.15	0.004	<0.004	<0.030	1.89
	Maximum	5428.05	45.9	8.39	130	19.9	5.50	9.80	4.54	89	2.26	0.00	9.85	2.96	0.012	<0.004	0.033	2.22
	Mean		28.1	7.27	119	18.4	4.05	4.61	1.64	82	0.45	0.00	5.75	1.90	0.008	<0.004	0.022	2.10
	Median		20.6	7.27	120	19.3	5.06	3.54	1.00	86	0.00	.	4.61	1.56	0.009	.	<0.030	2.15
	S		15.4	0.76	12	1.6	2.05	2.92	1.95	9	1.01	0.00	2.36	0.83	0.003	0.000	0.009	0.13

Table 2 - continued

Sample	Date	Elev.	Flow	pH	Sum	Ca	Mg	Na	K	HCO_3	CO_3	OH	SO_4	Cl	Fe	Mn	Al	Si
	m/d/y	ft.	gpm	s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SM-8B	6/20/97	5423.30	18.0	6.64	104	20.7	2.22	2.20	0.00	72	0.00	0.00	5.15	1.94	0.023	<0.004	0.048	1.27
	11/20/97	5419.00	21.1	8.85	72	16.7	1.86	2.00	0.00	31	16.53	0.00	2.87	1.08	<0.004	<0.004	0.061	1.53
	7/20/99	5428.25	.	7.23	121	18.3	2.59	6.89	1.00	74	0.00	0.00	11.40	7.69	0.044	0.006	0.064	1.96
	Minimum	5419.00	18.0	6.64	72	16.7	1.86	2.00	0.00	31	0.00	0.00	2.87	1.08	<0.004	<0.004	0.048	1.27
	Maximum	5428.25	21.1	8.85	121	20.7	2.59	6.89	1.00	74	16.53	0.00	11.40	7.69	0.044	0.006	0.064	1.96
	Mean		19.6	7.57	99	18.6	2.22	3.70	0.33	59	5.51	0.00	6.47	3.57	0.023	0.003	0.058	1.59
	Median		19.6	7.23	104	18.3	2.22	2.20	0.00	72	0.00	.	5.15	1.94	0.023	<0.004	0.061	1.53
	S		2.2	1.14	25	2.0	0.37	2.77	0.58	24	9.54	0.00	4.42	3.59	0.021	<0.004	0.009	0.35
SM-8C	6/20/97	5423.30	.	6.90	163	33.4	4.35	2.18	0.00	116	0.00	0.00	5.16	2.11	0.015	0.005	0.033	1.33
	11/20/97	5419.00	1.6	7.58	134	27.1	3.51	1.96	0.00	97	0.00	0.00	3.36	0.82	0.015	<0.004	0.033	1.06
	4/9/98	5426.63	17.8	8.11	124	24.7	2.89	2.08	0.00	90	0.00	0.00	3.22	0.84	0.022	<0.004	0.040	1.50
	7/19/99	5428.05	26.2	6.61	120	21.7	2.42	2.34	1.00	80	0.00	0.00	10.10	3.20	0.022	<0.004	0.037	2.37
	5/18/00	5389.45	15.9	8.57	72	13.1	0.50	1.56	2.30	47	2.91	0.00	3.93	1.44	0.050	<0.004	0.113	1.89
	Minimum	5389.45	1.6	6.61	72	13.1	0.50	1.56	0.00	47	0.00	0.00	3.22	0.82	0.015	<0.004	0.033	1.06
	Maximum	5428.05	26.2	8.57	163	33.4	4.35	2.34	2.30	116	2.91	0.00	10.10	3.20	0.050	0.005	0.113	2.37
	Mean		15.4	7.55	123	24.0	2.73	2.02	0.66	86	0.58	0.00	5.15	1.68	0.025	0.003	0.051	1.63
	Median		16.9	7.58	124	24.7	2.89	2.08	0.00	90	0.00	.	3.93	1.44	0.022	<0.004	0.037	1.50
	S		10.2	0.82	33	7.5	1.44	0.29	1.01	26	1.30	0.00	2.87	1.00	0.015	0.001	0.035	0.51
SM-FD98-0	7/19/99	5428.05	.	6.74	214	40.4	5.21	2.28	1.80	151	0.00	0.00	9.11	3.99	0.034	<0.004	0.033	3.49
SM-FD98-1	12/9/98	5380.29	.	6.84	80	15.7	1.87	2.04	0.00	56	0.00	0.00	3.84	1.03	0.009	<0.004	<0.030	1.65
	7/19/99	5428.05	.	6.44	91	15.7	1.70	2.34	1.00	56	0.00	0.00	11.60	2.81	0.070	<0.004	0.150	2.34
	5/18/00	5389.45	.	7.97	74	12.4	2.10	1.53	2.23	50	0.00	0.00	4.17	1.46	0.041	<0.004	0.088	1.79
	Minimum	5380.29		6.44	74	12.4	1.70	1.53	0.00	50	0.00	0.00	3.84	1.03	0.009	<0.004	<0.030	1.65
	Maximum	5428.05		7.97	91	15.7	2.10	2.34	2.23	56	0.00	0.00	11.60	2.81	0.070	<0.004	0.150	2.34
	Mean			7.08	82	14.6	1.89	1.97	1.08	54	0.00	0.00	6.54	1.77	0.040	<0.004	0.084	1.93
	Median			6.84	80	15.7	1.87	2.04	1.00	56	.	.	4.17	1.46	0.041	.	0.088	1.79
	S			0.79	8	1.9	0.20	0.41	1.12	3	0.00	0.00	4.39	0.93	0.031	0.000	0.068	0.36
SM-FD98-2	12/9/98	5380.29	.	6.86	77	14.8	1.80	2.02	0.00	54	0.00	0.00	3.67	0.97	0.008	<0.004	<0.030	1.58
	7/19/99	5428.05	94.9	6.41	87	14.6	1.76	2.34	1.00	55	0.00	0.00	9.64	2.83	0.086	<0.004	0.190	2.39
	7/19/99	5428.05	94.9	6.55	102	17.5	2.02	2.31	1.00	67	0.00	0.00	9.53	2.94	0.032	<0.004	0.039	2.20
	5/18/00	5389.45	13.8	8.19	76	12.2	2.70	1.55	2.20	52	0.00	0.00	4.06	1.42	0.043	<0.004	0.093	1.77
	5/18/00	5389.45	13.8	7.89	74	13.3	0.50	1.67	2.34	51	0.00	0.00	4.05	1.45	0.044	<0.004	0.100	1.90
	Minimum	5380.29	13.8	6.41	74	12.2	0.50	1.55	0.00	51	0.00	0.00	3.67	0.97	0.008	<0.004	<0.030	1.58
	Maximum	5428.05	94.9	8.19	102	17.5	2.70	2.34	2.34	67	0.00	0.00	9.64	2.94	0.086	<0.004	0.190	2.39
	Mean		54.4	7.18	83	14.5	1.76	1.98	1.31	56	0.00	0.00	6.19	1.92	0.043	<0.004	0.087	1.97
	Median		54.4	6.86	77	14.6	1.80	2.02	1.00	54	.	.	4.06	1.45	0.043	.	0.093	1.90
	S		46.8	0.81	12	2.0	0.80	0.36	0.97	6	0.00	0.00	3.10	0.90	0.028	0.000	0.068	0.33

Table 2 - continued

Sample	***Date***	***Elev.***	***Flow***	***pH***	***Sum***	***Ca***	***Mg***	***Na***	***K***	***HCO_3***	***CO_3***	***OH***	***SO_4***	***Cl***	***Fe***	***Mn***	***Al***	***Si***
	m/d/y	***ft.***	***gpm***	***s.u.***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***mg/L***
SM-FD98-3	12/9/98	5380.29	.	7.01	77	14.6	1.63	1.98	0.00	54	0.00	0.00	3.66	0.98	0.008	<0.004	<0.030	1.54
	7/19/99	5428.05	154.3	6.55	86	14.6	1.71	2.56	1.00	53	0.00	0.00	9.73	3.04	0.062	<0.004	0.136	2.32
	7/19/99	5428.05	154.3	6.52	94	16.1	1.89	2.33	1.00	60	0.00	0.00	9.58	2.90	0.046	<0.004	0.095	2.23
	5/18/00	5389.45	47.6	8.15	76	13.3	0.50	1.68	2.32	52	0.00	0.00	4.00	1.44	0.055	<0.004	0.122	1.91
	5/18/00	5389.45	47.6	7.88	73	13.1	0.50	1.63	2.33	50	0.00	0.00	4.00	1.43	0.057	<0.004	0.134	1.93
	Minimum	5380.29	47.6	6.52	73	13.1	0.50	1.63	0.00	50	0.00	0.00	3.66	0.98	0.008	<0.004	<0.030	1.54
	Maximum	5428.05	154.3	8.15	94	16.1	1.89	2.56	2.33	60	0.00	0.00	9.73	3.04	0.062	<0.004	0.136	2.32
	Mean		100.9	7.22	81	14.3	1.25	2.04	1.33	54	0.00	0.00	6.19	1.96	0.046	<0.004	0.100	1.99
	Median		100.9	7.01	77	14.6	1.63	1.98	1.00	53	.	.	4.00	1.44	0.055	.	0.122	1.93
	S		61.6	0.76	9	1.2	0.69	0.40	1.00	4	0.00	0.00	3.16	0.94	0.022	0.000	0.050	0.31
SM-FD98-4	7/20/99	5428.25	.	6.87	144	20.8	4.96	5.14	1.00	96	0.00	0.00	11.90	3.85	0.040	<0.004	0.085	2.59
	5/18/00	5389.45	.	7.95	77	13.7	0.50	1.84	2.37	53	0.00	0.00	3.96	1.44	0.042	<0.004	0.104	1.99
	Minimum	5389.45		6.87	77	13.7	0.50	1.84	1.00	53	0.00	0.00	3.96	1.44	0.040	<0.004	0.085	1.99
	Maximum	5428.25		7.95	144	20.8	4.96	5.14	2.37	96	0.00	0.00	11.90	3.85	0.042	<0.004	0.104	2.59
SM-FD98-4a	7/19/99	5428.05	.	6.91	223	30.5	9.32	10.30	1.00	150	0.00	0.00	15.60	6.59	0.010	<0.004	<0.030	3.37

Table 3 Soluble mineral loading and void formation calculated from seepage data.

Seep	**Sample Date**	**Flow, gpm**	**Reservoir Elevation, ft.**	**Net Loading as Calcite, kg/d**	**Net Loading as Gypsum, kg/d**	**Net Loading as Anhydrite, kg/d**	**Gypsum + Calcite Void, m^3/yr**	**Anhydrite + Calcite Void, m^3/yr**
EXSP-1	7/11/01	15.00	5353.5	5.21	-.49	-.39	5.71e-01	6.00e-01
EXSP-2	7/11/01	15.00	5353.5	5.46	-.35	-.28	6.23e-01	6.44e-01
SM-1	6/13/86	11.87	5414.3	3.51	.06	.04	4.44e-01	4.41e-01
	9/24/86	11.87	5376.5	4.34	.61	.48	6.33e-01	5.97e-01
	5/11/87	115.18	5414.1	43.17	2.97	2.35	5.82e+00	5.65e+00
	9/17/87	10.12	5397.5	3.86	.24	.19	5.16e-01	5.02e-01
	6/29/90	18.20	5407.8	5.56	.17	.14	7.16e-01	7.06e-01
	10/31/90	.00	5390.4	0.00	.00	.00	0.00e+00	0.00e+00
	5/20/91	23.30	5423.2	6.99	.33	.26	9.18e-01	8.99e-01
	6/20/97	26.15	5423.3	9.66	.18	.15	1.23e+00	1.22e+00
	4/9/98	35.42	5426.6	11.68	.50	.39	1.53e+00	1.50e+00
	7/20/99	29.20	5428.3	9.55	.27	.22	1.23e+00	1.21e+00
	5/19/00	5.82	5389.8	1.28	.44	.35	2.26e-01	2.01e-01
SM-1A	4/9/98	43.46	5426.6	9.95	.61	.48	1.33e+00	1.29e+00
	12/9/98	11.87	5380.3	2.20	.17	.13	2.99e-01	2.89e-01
	7/19/99	43.46	5428.1	7.70	.41	.32	1.02e+00	9.95e-01
	5/19/00	15.90	5389.8	1.63	.15	.12	2.25e-01	2.16e-01
SM-2	6/13/86	328.02	5414.3	130.54	1.54	1.22	1.64e+01	1.64e+01
	9/24/86	340.00	5376.5	114.92	19.15	15.14	1.72e+01	1.61e+01
	7/1/87	66.23	5417.9	23.92	.31	.25	3.02e+00	3.00e+00
	9/17/87	32.45	5397.5	14.28	.76	.60	1.89e+00	1.85e+00
	6/29/90	18.20	5407.8	7.44	.17	.14	9.50e-01	9.40e-01
	10/31/90	20.60	5390.4	8.37	.29	.23	1.08e+00	1.07e+00
	5/20/91	66.00	5423.2	24.83	.93	.73	3.23e+00	3.17e+00
	7/20/99	61.22	5428.3	20.36	.57	.45	2.62e+00	2.58e+00
	5/19/00	11.87	5389.8	2.80	.17	.13	3.73e-01	3.64e-01
SM-3	8/30/51	83.10	5353.2	72.48	27.30	21.58	1.32e+01	1.16e+01
	9/18/51	88.20	5355.3	63.23	28.14	22.25	1.22e+01	1.06e+01
	10/18/51	96.60	5358.6	77.15	29.01	22.94	1.40e+01	1.24e+01
	6/13/86	427.00	5414.3	135.59	8.01	6.34	1.81e+01	1.76e+01
	9/24/86	427.00	5376.5	108.82	80.15	63.38	2.59e+01	2.12e+01
	6/29/90	713.00	5407.8	126.33	140.52	111.12	3.73e+01	2.92e+01
	10/31/90	790.00	5390.4	146.43	166.82	131.91	4.39e+01	3.42e+01
	5/20/91	907.00	5423.2	131.03	144.71	114.43	3.86e+01	3.02e+01
	12/9/98	764.62	5380.3	100.04	89.70	70.93	2.62e+01	2.11e+01
	5/19/00	1,068.59	5389.8	88.84	185.53	146.71	3.96e+01	2.89e+01
	5/9/01	496.63	5358.4	79.87	55.93	44.23	1.85e+01	1.53e+01

Table 3 Continued

Seep	***Sample Date***	***Flow, gpm***	***Reservoir Elevation, ft.***	***Net Loading as Calcite, kg/d***	***Net Loading as Gypsum, kg/d***	***Net Loading as Anhydrite, kg/d***	***Gypsum + Calcite Void, m^3/yr***	***Anhydrite + Calcite Void, m^3/yr***
SM-4	6/13/86	1.20	5414.3	0.44	1.08	.85	2.21e-01	1.59e-01
	9/24/86	18.61	5376.5	8.83	21.05	16.64	4.34e+00	3.12e+00
	5/11/87	14.08	5414.1	5.87	15.06	11.91	3.05e+00	2.18e+00
	7/1/87	40.67	5417.9	12.86	50.96	40.29	9.44e+00	6.50e+00
	9/17/87	40.67	5397.5	14.25	58.59	46.33	1.08e+01	7.41e+00
	7/20/99	461.54	5428.3	104.42	34.65	27.40	1.83e+01	1.63e+01
	5/19/00	171.82	5389.8	19.67	32.25	25.50	7.41e+00	5.55e+00
	5/9/01	.00	5358.4	0.00	.00	.00	0.00e+00	0.00e+00
SM-7	10/31/90	673.00	5390.4	177.94	161.06	127.36	4.69e+01	3.76e+01
	5/20/91	978.00	5423.2	205.27	206.52	163.30	5.73e+01	4.54e+01
	4/9/98	1,323.20	5426.6	86.56	.00	.00	1.07e+01	1.07e+01
SM-8	6/20/97	22.20	5423.3	5.23	-.05	-.04	6.42e-01	6.45e-01
	11/20/97	30.07	5419.0	4.51	.14	.11	5.81e-01	5.73e-01
	4/9/98	43.46	5426.6	4.86	.00	.00	6.03e-01	6.03e-01
	7/19/99	66.23	5428.1	11.19	.00	.00	1.39e+00	1.39e+00
	5/18/00	70.92	5389.5	7.64	.00	.00	9.48e-01	9.48e-01
SM-8A	6/20/97	12.62	5423.3	3.25	.15	.12	4.26e-01	4.18e-01
	11/20/97	20.56	5419.0	5.21	.39	.31	7.06e-01	6.84e-01
	4/9/98	45.90	5426.6	10.88	.65	.51	1.45e+00	1.41e+00
	7/19/99	43.46	5428.1	7.58	.20	.16	9.73e-01	9.61e-01
	5/19/00	18.18	5389.8	1.83	.17	.13	2.54e-01	2.44e-01
SM-8B	6/20/97	18.01	5423.3	3.56	.13	.10	4.61e-01	4.54e-01
	11/20/97	21.09	5419.0	3.22	.10	.08	4.15e-01	4.09e-01
SM-8C	11/20/97	1.63	5419.0	0.54	.02	.01	6.90e-02	6.80e-02
	4/9/98	17.84	5426.6	4.72	.08	.07	5.98e-01	5.94e-01
	7/19/99	26.15	5428.1	5.13	.12	.10	6.56e-01	6.49e-01
	5/18/00	15.90	5389.5	0.98	.00	.00	1.21e-01	1.21e-01
SM-FD98-2	7/19/99	94.93	5428.1	10.48	.00	.00	1.30e+00	1.30e+00
	5/18/00	13.80	5389.5	1.13	.00	.00	1.40e-01	1.40e-01
SM-FD98-3	7/19/99	154.26	5428.1	15.35	.00	.00	1.91e+00	1.91e+00
	5/18/00	47.56	5389.5	2.98	.00	.00	3.70e-01	3.70e-01