Summary and Interpretation of Chemistry Data for Reservoir, Seeps, and Groundwater from Horsetooth Dam, Colorado-Big Thompson Project, Ft. Collins, Colorado

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by

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        SM-1A = **68.5 mg/L**, SM-8 = **44.8 mg/L**. . . . .

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EXECUTIVE SUMMARY

1951-1998 chemistry data from Horsetooth Reservoir, seepage weirs, and observation wells were compiled and analyzed to provide supporting information regarding the geochemistry of mineral dissolution for the current Horsetooth Dam safety investigation. The 138-sample data set combines the available water chemistry, geology, petrography, and hydrology data in a single data file.

Appendix 1 summarizes the sample inventory and selected physical data (Table A1-1), along with data quality information (Tables A1-2, A1-3 and Figure A1-1). The existing chemical data are of good to excellent quality; however, the available data are temporally limited, and the same sampling sites have not been consistently sampled over time. Therefore, the comments and observations reported here are not based on a data-rich environment amenable to statistical trend analysis, but rather on a series of chemical "snapshots."

Appendix 2 summarizes the chemical analysis data for major ions (Tables A2-1a, 2a, 3a), trace elements (Tables A2-1b, 2b, and 3b), and mineral saturation indices (SI's) calculated by the MINTEQA2 [*Allison, et.al., 1991*] chemical equilibrium model (Tables A2-1c, 2c, and 3c). SI's indicate whether the particular mineral is under saturated (negative SI) or over saturated (positive SI) with respect to the measured water chemistry concentrations. Sample major ions data are also plotted on Stiff [*Stiff, 1951*] and Piper [*Piper, 1944*] diagrams (Figures 1-3 in this report, and in Appendix 2, Figures A2-1 through A2-3).

The available chemistry data suggest that mineral dissolution occurs beneath and around Horsetooth Dam. Near-reservoir concentrations suggest more direct flows through the Middle Lykins - Forelle limestone, and inter-strata mixing of water from the Lower Lykins - Blaine gypsum with higher stratigraphic units waters in the Lykins and the Alluvium appears likely. More specific observations from this evaluation include the following:

1. **Reservoir water is under saturated and aggressive to all soluble minerals identified at Horsetooth Dam:** Horsetooth Reservoir water is relatively pure and shows chemistry consistent with the granitic - feldspar - sandstone exposures contacted during watershed transit. Mineral SI's suggest that the reservoir water is under saturated with respect to gypsum, anhydrite, calcite, and dolomite, and will thus tend to dissolve these minerals if contacted during subsurface transit.

2. **The Lykins formation contains a plentiful supply of soluble minerals that appear to account for the observed chemistry in seeps and wells.** The available geology and petrographic data indicate that the Lykins Formation, underlying Horsetooth Reservoir and Dam, contains large amounts of limestone

and gypsum in complexly inter-bedded strata. The available chemistry data strongly suggests that dissolution of these and several other minor minerals account for the observed chemistry of the seepage and groundwater downstream of the dam.

3.   **There are 4 different classes of water chemistry at Horsetooth Dam.** The chemistry data suggest that seepage, groundwaters, and Reservoir waters fall into 4 general categories at Horsetooth: ***calcite-dominant***, which is associated with the Reservoir, the well samples from the Middle Lykins - Forelle limestone, the left abutment Trenches, and the Toe Drains and near-structure seepage weirs; ***gypsum-dominant***, which is primarily seen in well screen samples in the Lower Lykins - Blaine gypsum; ***sodium-dominant***, seen only on limited occasions in Lower-Lykins wells and one Middle-Lykins - Forelle limestone sample; and ***mixture*** waters, seen most clearly in the artesian seepage Pond No. 1 and SM-4.

4.   **Seepage appears to flow directly through the Middle Lykins - Forelle limestone.** The similarity of waters from all Middle Lykins - Forelle limestone wells and the left abutment Trenches strongly suggests that the Forelle limestone represents a relatively open flow path from Reservoir infiltration points, with very little mineral dissolution occurring during seepage transit. These waters likely flow relatively unimpeded through dissolution voids, cracks, and open flow channels in the Forelle limestone. The 12/09/98 Trench samples show the lowest TDS concentrations and closest similarity to Reservoir water of any Middle Lykins - Forelle limestone source samples.

5.   **Mixing of seepage appears to occur between different stratigraphic layers in the Lykins Formation.** There is evidence that seepage is moving vertically and mixing between layers in the Lykins formation. The most likely path is along collapsed breccia chimneys and dissolution voids that interconnect surface Alluvium deposits with seepage from the Lower Lykins - Blaine gypsum strata. The mixing hypothesis is supported by the observed chemistry in SM-4 and the Sinkhole which bear a close resemblance to the average data for all available well samples.

6.   **There appears to be a decreasing seepage concentration gradient from the right Toe drain across the toe to the 3 recent Left Abutment Trenches.** Recent data from the Toe Drains, near-toe seepage weirs, and the left abutment trenches strongly suggest a right to left trend of decreasing seepage concentrations across the embankment toe. Samples from the trenches approach Reservoir concentrations, suggesting little interaction of seepage with soluble minerals. These observations contrast with the relatively unchanged chemistry seen on the Right Abutment weirs (except for the recent SM-7 samples). The relatively recent appearance of new seeps and wet spots along

the left downstream abutment, the chemistry data corroborate observed increasing seepage flows around the left abutment and strongly suggest that these new seepage paths are probably being formed in the Forelle limestone.

7. **Early SM-3 data suggests higher initial seepage concentrations.** Much higher seepage concentrations compared to recent samples were observed in the 1951 SM-3 samples, which emerge from a Forelle karst outcrop 3000 ft. downstream of the dam. Initial filling at Horsetooth Reservoir may have produced a new aquifer that contacted previously undissolved geologic strata and mobilized readily available soluble minerals.

8. **Several different water chemistry types were observed in some wells.** The highly variable chemistry observed in several wells suggests that the process of drilling and installation may have disturbed loosely-consolidated breccia located near the well casing and screen. Variable chemistry may be caused by pumping samples from disturbed deposits that result in enhanced mixing and dissolution hydrodynamics, or creation of enhanced surface area exposure of mineral assemblages to groundwater dissolution. Another possibility is that the sodium-dominant waters, only observed in initial samples pumped from new wells, may indicate calcium exchange with sodium-bentonite clay used to seal well casings during installation. Finally, well installation may also have created interconnection paths for mixing between previously separate layers and soluble mineral deposits.

9. **Grout contamination from well installation may be causing the high observed pH values.** Two wells intermittantly showed elevated pH and significant carbonate and hydroxide alkalinity. These wells are thought to have been contaminated with grout or an unidentified alkaline mineral.

These observations and the emergence of new seeps along Forelle limestone exposures should be considered a potentially serious dam safety concern that warrants implementation of additional structural monitoring, hydrologic and geophysical investigations, and enhanced frequency and inspection of all seepage flows in calibrated weirs. If additional chemistry samples are requested, I would recommend the following:

1. **Consistent sampling over time:** samples should be collected from the same consistent set of wells and weirs each sampling event, all new data should be archived with the current historical combined geochemistry file. Once a new sampling site is identified, continue to sample the new site at each scheduled event. Collect samples from SM-4, which was not recommended as a sampling site in a previous Horsetooth chemistry evaluation. Continue analyzing the samples for major ions, iron, manganese, aluminum, and silicon.

2.   **Pay attention to abrupt changes in chemistry:** The most recent samples from weir SM-7 and DH91-1 showed chemistry very similar to the Reservoir when previous samples were much higher in concentration. This suggests that available soluble minerals may have been solutioned and more direct paths to the reservoir have formed. Regardless of cause, these sampling locations need to be monitored over time for both chemistry and flow.

2.   **Pump wells longer before sampling:** Pump existing wells for longer periods of time before sampling, and not already performed, monitor conductivity and pH of pumped effluent to confirm stable readings. This will help assure that water from the surrounding formation is being collected and that any influence from local concentration gradients around the casing or screen is avoided.

3.   **Measure field chemistry variables:** Include field measurements of calibrated pH, temperature, dissolved oxygen, and conductivity with the sample chain of custody or analytical request. While this would be good practice for all future water samples, it is highly recommended for the well samples.

5.   **Perform additional petrographic analyses:** Collect additional geologic material samples for petrographic analysis that are tailored to mineral dissolution and geochemical purposes. Well cores need to be inspected by the project petrographer to identify any unusual rock or inter-bedded deposits worth further investigations. Collect and identify any suspended materials present in seepage or well water samples.

The following investigative work should also be considered as a way to better understand seepage processes at Horsetooth Dam and to improve the interpretation of existing or future chemistry data:

1.   **Include physical data on new wells:** Additional geologic information and well and screen depth on the more recently installed wells (DH92-6, DH92-7, DH97-1, DH98-6, DH98-7, DH98-10a) needs to be included with the combined chemistry data set. Location variables from precise GPS measurements should also be included in the chemistry data set.

2.   **Plot all data on 3-d projections:** Some additional information regarding seepage flow paths through the structures and chemical concentration changes at Horsetooth Dam might be obtained by plotting the existing chemical data on 3-dimensional Intergraph drawings that show the dam, geologic stratification, wells and screen depth locations, and flow data from downstream weirs. At the least, more informed decisions regarding placement and installation of new weirs and wells may be made.

3. **Consider dye and tracer tests:** Because hydrologic information regarding seepage residence times, flow velocities, and actual flow paths are unknown, dye or isotopic tracer studies are recommended and should be considered along with any appropriate geophysical void space detection measurements.

4. **Measure seepage flows frequently at all weirs:** The lack of seepage flow data for many existing previous chemistry data sets makes it unlikely to detect longer-term trends that might relate to worsening seepage problems. Future chemistry samples, however, combined with accurate seepage flow data, may enable that sort of analysis.

5. **Calculate flow-weighted dissolution masses:** Once the seepage hydrology is better defined and understood, it would be appropriate to calculate flow-weighted dissolution masses from the observed chemistry data to provide rough estimates of mass losses and potential void space formation over time. Other stochastic modeling of seepage flow could also be applied with more rigor and interpretative certainty.

INTRODUCTION

This report provides a historical overview and geochemical assessment of all available chemistry data collected from reservoir, seeps, and wells at Horsetooth Dam. A reference data set that combined chemical, geological, physiographic, and hydrologic data in one file was prepared and validated at the request of Al Kiene, D-8312, Principal Engineer for Horsetooth Dam.

At most dam sites, reservoir water will seep along flow paths through permeable strata in the foundation, abutments, and embankment. During underground seepage transit, the reservoir water will weather and dissolve minerals along the flow path and the concentrations of chemical constituents may change. When reservoir water initially contacts soluble minerals, higher initial concentrations indicative of the chemical components in the mineral are usually observed in seepage (as seen in the 1951 samples from SM-3). This initial high concentration suggests a "flushing out" of soluble materials along flow paths, and is accompanied by an increase in flow caused by enhanced permeability or formation of stable channels as dissolved minerals leave void space in the structure.

In a stable seepage flow scenario, seepage flows and concentrations should eventually approach a steady-state level. Void space formation may lead to creation of new flow channels and/or enlargement of existing flow channels, subsequently causing piping, physical erosion and loss of material along flow paths. Significant Increases from the steady state concentrations could indicate seepage contact with additional soluble minerals (that is, the seepage contact volume is expanding). A decrease in seepage

concentrations, especially if accompanied by increased flow or presence of suspended materials, could indicate piping and enlargement of seepage paths, a potentially dangerous scenario.

The dissolution of soluble minerals by subsurface flow of reservoir water beneath Horsetooth Dam and the potential effects of dissolution on seepage flows through the foundation and abutments has been an intermittent concern at Horsetooth Dam since first reservoir filling. The Engineering and Research Center, Engineering Laboratories Branch, analyzed seepage water collected from weir SM-3 and the reservoir in the late summer and fall of 1951.

Horsetooth Reservoir contains water that ranges between 20 and 90 mg/L total dissolved solids (TDS) with pH generally observed between 6 and 7, and is underlain by the continental sea sedimentary deposits of the Lykins formation. The Lykins Formation, which is tilted 40˚, contains layers of limestone and dolomite (the Forelle limestone), gypsum (the Blaine gypsum), and anhydrite. These deposits are stratigraphically complex with a high degree of interbedding and layering, and the gypsum, anhydrite, calcite, and dolomite are soluble in the slightly acidic pH and low TDS of Horsetooth Reservoir water.

Besides the 1951 sampling events, seepage and reservoir samples were collected during 1986-1987, and 1990-1991. A more detailed investigation involving installation and sampling of observation wells, along with reservoir and seepage samples, has been undertaken since 1997. Interpretative technical memorandums prepared for the individual 1986-87, and 1990-91 data sets which are included in Appendix 3 as background information.   The investigations since 1990 were started in response to the recent appearance of sink holes in the areas surrounding upper Horsetooth Reservoir and formation of additional seepage wet spots in the abutments and alluvium downstream of the dam toe. Given the long history of seepage and other water sampling at Horsetooth Dam, and the current concern regarding the potential engineering consequences of mineral dissolution, the collation and evaluation of all available chemistry data was deemed a necessary part of the overall dam safety evaluation.

GEOLOGY AND MINERALOGY AT HORSETOOTH DAM: Horsetooth Reservoir and Dam are underlain by several different strata exposed at the surface by tilting from the Rocky Mountain uplift. The strata are comprised of sedimentary rocks from the Lower Cretaceous to the Upper Permian systems including the Dakota and the Morrison (which forms the Hogback and the eastern side of the reservoir), the Lykins (exposed to reservoir water intrusion along the length of the impoundment), and the Lyons (which forms the left abutment and western side of the reservoir). At the dam, the beds dip approximately 40˚ to the east and the strata strike north, parallel to the reservoir axis and approximately perpendicular to the axis of Horsetooth Dam [*Wright and Taucher, 1991*]. A layer of weathered clay alluvium lies above the tilted Lykins, and the dam foundation rests directly on this layer.

For simplicity in this report, the Lykins was classified into 3 primary members or layers: The Upper, Middle, and Lower Lykins. Wells and their screens were installed to intersect these 3 general layers. The Upper Lykins formation, produced by shallow continental sea deposits, is a sequence of thin layers of siltstone and shale, and/or claystone, with some layers of friable sandstone interbedded with thin layers of limestone, gypsum, and anhydrite. The Middle Lykins - Forelle limestone member comprises a thicker layer of carbonate minerals in the approximate middle of the Lykins. The lower Lykins - Blaine gypsum member continues the pattern of interbedded carbonates in siltstone with a significant layer of sulfate minerals in the Blaine gypsum. Water from Horsetooth Reservoir potentially contacts all of these formations, all of which contain varying amounts of readily soluble minerals. Previous geological and mineralogical data document that the Lykins formation beneath Horsetooth Reservoir contains readily soluble materials, including gypsum, anhydrite, calcite, and dolomite.

Sinkholes, known to be formed by water dissolution of carbonates and evaporite beds in the Lower Lykins -Blaine gypsum, have been observed at the southern end of the reservoir approximately 5 miles from the dam. The available mineralogy data (Appendix 3) indicate that carbonate minerals (calcite and/or dolomite) are present in significant proportions in the available sinkhole samples. The mineralogy of suspended sediment collected from December 1998 piezometer samples at Horsetooth Dam is also summarized in this report.

DISSOLUTION AND OTHER GEOCHEMICAL REACTIONS IN SEEPAGE: When there is evidence of a soluble mineral existing along a seepage path, a comparison of seepage and reservoir chemistry data often suggests specific mineral dissolution reactions as the cause of observed chemical concentration changes. Seepage interactions, however, are often complex and difficult to definitively evaluate, especially if samples are only collected at infrequent intervals and/or minimal hydrologic and geologic information is available. Because of this uncertainty, it is best to consider seepage chemistry data as ancillary to observed physical changes in the structure, unexpected changes in seepage flow, or petrographic evidence of the presence of soluble or weatherable minerals.

The changes in chemical concentrations observed in seepage relative to the reservoir source water can be caused by several different processes and their interactions: 1) **mineral weathering** (congruent or incongruent dissolution or precipitation reactions); 2) **mixing** with another local groundwater or surface water source; 3) **ion exchange processes** on clays or cation substitution reactions; and 4) **biological processes** from underground bacterial metabolism and respiration. The net result of all possible reactions along a seepage flow path may show concentration changes relative to the reservoir source water. The following processes are thought to be active at Horsetooth Dam.

Congruent dissolution is the process where a relatively simple mineral such as gypsum (CaSO$_4$·2½H$_2$O), halite (NaCl), or calcite (CaCO$_3$) completely dissolves into its constituent ions. However, as seepage moves through a structure, concentrations may also increase to the point where the reverse reaction, mineral precipitation, occurs. Congruent dissolution will typically form void spaces in the geological formation as mineral deposits are dissolved, and the reactions are generally fast if the water is under saturated with respect to the mineral in question. Here are several congruent dissolution reactions [*Loughnan, 1969, Hem, 1985*; *Drever, 1982*] applicable at Horsetooth Dam and their effects on seepage concentrations:

Congruent dissolution of gypsum and anhydrite: Increased Ca, sulfate.

$$CaSO_4 \cdot nH_2O_{(s)} \rightleftarrows Ca^{2+}_{(aq)} + SO_4^{2-}_{(aq)} + nH_2O$$
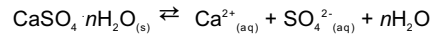
Congruent dissolution of calcite and dolomite: Increased Ca, Mg, bicarbonate

$$CaCO_3 + H_2O + CO_2 \rightleftarrows Ca^{2+}_{(aq)} + 2HCO_3^-_{(aq)}$$

$$Ca\text{-}Mg(CO_3)_2 + 2H_2O + 2CO_2 \rightleftarrows Ca^{2+}_{(aq)} + Mg^{2+}_{(aq)} + 4HCO_3^-_{(aq)}$$
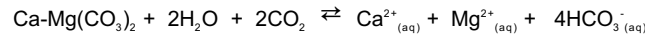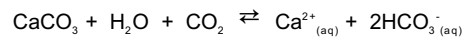
Congruent dissolution of halite: Increased Na and chloride

$$NaCl_{(s)} \rightleftarrows Na^+_{(aq)} + Cl^-_{(aq)}$$
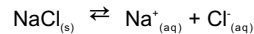
Congruent dissolution of quartz (minor) or amorphous silica: increased Si

Quartz or Silica

$$SiO_{2(s)} + 2H_2O \rightleftarrows H_4SiO_{4(aq)}$$

Incongruent dissolution takes place when a complex mineral, like a feldspar, reacts in the presence of seepage water to form a clay mineral along with some soluble ions. Incongruent processes are more complex chemical reactions and may cause increases or decreases in seepage concentrations. Void spaces may or may not form during these reactions depending on the relative densities of the original mineral and its weathered products. Most incongruent dissolution proceeds at slow reaction rates relative to seepage residence time, so these processes are generally responsible for only minor changes in ions concentrations. Here are some incongruent weathering reactions [*Loughnan, 1969; Clayton, 1986; Borchardt, 1977, Deer, et.al., 1977; Drever, 1982; and Stumm and Morgan, 1972*] that may apply to seepage at Horsetooth:

Incongruent dissolution of oligoclase feldspar to montmorillonite: increased Na, Ca, Si, and bicarbonate

Oligoclase   *Na-Montmorillonite*

$$Na_3CaAl_5Si_{11}O_{32} + 8.9H_2O + 2.58CO_2 + 1.6H^+ \rightleftarrows 1.29Na_{0.34}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 2.58Na^+ +$$

Ca-Montmorillonite

$$2.58HCO_3^- + 3.13H_4SiO_4 + 0.86Ca_{0.17}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 0.86Ca^{2+}$$
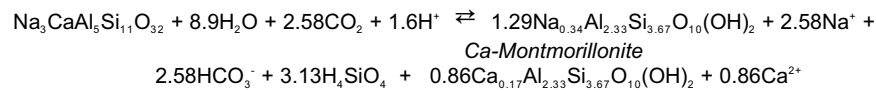
Incongruent dissolution of potassium feldspar to kaolinite: increased K, Si, and bicarbonate [*Drever, 1982*]

K-feldspar   *Kaolinite*

$$2KAlSi_3O_8 + 11H_2O + 2CO_2 \rightleftarrows Al_2Si_2O_5(OH)_4 + 2K^+ + 2HCO_3^- + 4H_4SiO_4$$
(orthoclase)
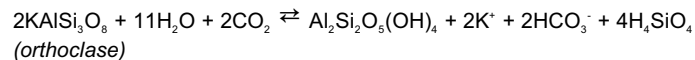
Ion Exchange Reactions: Another process affecting seepage concentration changes are exchange reactions such as cation exchange (primarily on illite clays) or cation substitution reactions. These reactions are usually responsible for minor concentration changes in seepage ions; however, with appropriate seepage concentrations, reaction rates are fast relative to incongruent processes. When obvious deposits of halite are not present or contacted by seepage, ion exchange may be the only reaction source causing increased Na. At Horsetooth Dam, bentonite clay used as a drilling mud in wells may produce Na^+ by exchanging Ca^{2+} from the ground water. Here are some ion exchange and ion substitution reactions [*Kelly, 1948; Garrels and Christ, 1965; Garrels and MacKenzie, 1967; Klimchouk, 1996*] suspected at Horsetooth dam:

Sodium (and/or potassium) exchange with calcium montmorillonite: decreased Na, increased Ca, mineral volume expansion

Ca-Montmorillonite   *Na-Montmorillonite*

$$Na^+ + Ca_{0.5}Al_{6.85}Si_{10.8}O_{29.4}(OH)_{5.88} \rightleftarrows NaAl_{6.85}Si_{10.8}O_{29.4}(OH)_{5.88} + 0.5Ca^{2+}$$
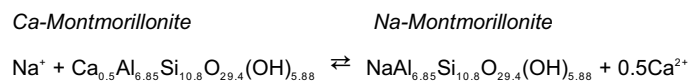
Calcium or Magnesium exchange with sodium montmorillonite: decreased Ca, increased Na, mineral volume shrinkage

Na-Montmorillonite   *Ca-Montmorillonite*

$$0.5Ca^{2+} + NaAl_{6.85}Si_{10.8}O_{29.4}(OH)_{5.88} \rightleftarrows Ca_{0.5}Al_{6.85}Si_{10.8}O_{29.4}(OH)_{5.88} + Na^+$$
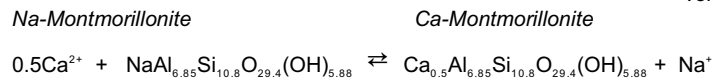
De-dolomomitization: increased Mg , mineral volume expansion

Dolomite

$$Ca^{2+} + Ca\text{-}Mg(CO_3)_2 \rightleftarrows 2CaCO_3 + Mg^{2+}$$
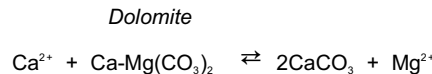
Biologically Mediated Changes: Seepage that contains dissolved or particulate organic carbon will provide a food source for bacterial communities present in subsurface formations. These bacterial populations will metabolize the organic carbon and respire (chemically reduce) oxygen by reducing available dissolved O_2, or other sources of oxygen, such as NO_3, iron and manganese oxyhydrates, $Fe_2(OH)_6$, $Mn(OH)_2)$,, as well as SO_4 and CO_2. These reactions [*Lindsay, 1978; Meyers and Nealson, 1988; Thurman, 1985; Redfield, et.al., 1963; Stumm and Morgan, 1972; Drever, 1982; and Hem, 1985*] depend on the native populations of bacteria along seepage flow paths and the availability of carbon and oxygen. These reactions are also kinetically limited and the contribution to seepage chemistry may vary with seasonal reservoir surface fluctuations and resulting seepage flow rates. The following bacterially-mediated reactions are also likely to affect reservoir water as it flows beneath, around and through the embankment:

Aerobic bacterial oxidation of organic carbon: if dissolved oxygen present, increased bicarbonate, nitrate, phosphate

$$CH_{2.48}O_{1.04}N_{0.151}P_{0.0094} + 1.3O_2 + H_2O \rightleftarrows HCO_3^- + 0.151NO_3^- + 0.0094HPO_4^{2-} + 1.15H_2O + 1.17H^+$$
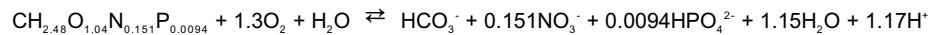
Anaerobic bacterial oxidation of organic carbon: reduction of nitrate, iron and manganese oxides provides oxygen

$$CH_{2.48}O_{1.04}N_{0.151}P_{0.0094} + 1.3O_2 + H_2O \rightleftarrows HCO_3^- + 0.151NO_3^- + 0.0094HPO_4^{2-} + 1.15H_2O + 1.17H^+$$
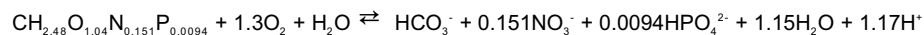
Anaerobic bacterial reduction of sulfate to sulfide: limited to slow flowing seepage

$$SO_4^{2-} + 2C_{organic} + 2H_2O \rightleftarrows H_2S + 2HCO_3^-$$
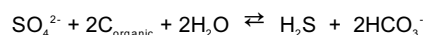
METHODOLOGY

WELL INSTALLATION and SAMPLE COLLECTION: Wells were drilled and installed by the Great Plains Regional Drill Crew following guidelines found in the Bureau of Reclamation *Ground Water Manual* and other standard references [*USBR, 1981, USEPA, 1975, Morrison, 1983*]. All samples after 1951 were collected by personnel from the TSC Engineering Geology Group A, D-8321, following procedures suggested by the EPA [*USEPA, 1981, Morrison, 1983*] and the Bureau of Reclamation [*USBR, 1981*]. Wells were pumped to remove a minimum of 3 well-volumes before collecting samples. Samples after 1951 were collected at high and low Reservoir surface elevations.

CHEMICAL ANALYSES: All chemical analyses were performed by the Bureau of Reclamation Denver Chemistry Laboratory, (under various organizational titles, hereafter referred to as the Lab) for the 48-year period samples have been collected at Horsetooth Dam.

For the 1951 sets of samples, information regarding analytical methods is unavailable; however, the following techniques were probably used: Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were likely determined using color-endpoint titrations with EDTA (ethylenediaminetetraacetic acid). Bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and hydroxide (OH^-) were determined using the same potentiometric-endpoint acid titration that is currently used for these analytes. Chloride (Cl^-) was likely determined with a color-endpoint titration with silver nitrate. Sodium (Na^+) and potassium (K^+) were probably determined using flame photometry, or perhaps an older colorimetric method. Sulfate (SO_4^{2-}) was likely determined using a gravimetric method employing precipitation of SO_4^{2-} with barium chloride.

Samples collected in the 1980's and later were analyzed using methods detailed in USEPA-approved methods [*U.S. Environmental Protection Agency, 1983, 1986*], and/or *Standard Methods for the Examination of Water and Wastewater*, [*American Public Health Association, 1985, 1989, and 1995*]. Conductivity was determined using a resistivity cell following EPA Method 120.1, and residues were determined gravimetrically: total suspended solids (TSS, or Non-filterable Residue) by EPA Method 160.2, and total dissolved solids (TDS, or Filterable residue) by EPA Method 160.1. A modified procedure for TSS that used 0.45-μm filter media to collect as much material as possible for petrographic analysis was used for the December 1998 samples. Inductively-coupled plasma emission spectroscopy (ICP-ES, EPA Method 200.7) was used to determine Ca^{2+}, Mg^{2+}, Na^+, K^+, and iron (Fe), manganese (Mn), aluminum (Al), and silicon (Si). Data for silicon is expressed as elemental silicon rather than as SiO_2 (silicon dioxide or silica). Automated potentiometric titration was used to determine carbonate and bicarbonate (EPA Method 160.1), and ion chromatography (IC, EPA Method 300) was used to determine sulfate and chloride.

PETROGRAPHIC METHODS: The mineralogy of soil and rock core samples collected from drill holes, surface soils, sinkholes, and suspended matter in water samples was determined using X-ray diffraction (XRD), megascopic inspection, and microscopic examination. Foundation sample descriptions and X-ray diffraction data, detailed in the previous technical memorandums are provided in appendix 3. Petrographic examinations were performed at the Bureau of Reclamation's Denver Technical Service Center (TSC).

The most recent petrographic evaluation was performed by Doug Hurcomb for suspended materials in seepage and well water collected on 12/09/98. The Appendix 1 Table A1-1 sample inventory details the 12/09/98 samples. The water samples were filtered through 0.45 µM pore-size polycarbonate filter membranes by the Lab, and the filter membranes with retained sediment were submitted to the Petrographic Laboratory for examination. Several of the samples contained insufficient suspended material for petrographic tests. Various sample preparation techniques were used to recover the very small amounts of suspended material on filter membranes; including rewetting the sample with deionized water and pipetting the suspended sediments onto glass slides, and preparation of grain mounts of sediments as well as filters containing sediment material. The submitted sediments were examined microscopically in grain mount, by X-ray diffraction (XRD), and physical techniques.

GENERAL COMPUTER METHODOLOGY: The available chemical and other related geologic and hydrologic data were manually entered into a data file in SPSS™ (*Statistical Package for the Social Sciences*, SPSS, Inc.) for Windows, version 8.0. SPSS™ was used to perform all statistical analyses and summary output tables and graphs. Stiff diagrams [*Stiff, 1951*] were plotted using the Stiff program, version 2.0,included in the Rockware Utilities suite (Rockware, Inc.). Output tables and copies of the SPSS™were exported to Microsoft Excel™ 97, version SR-1, spreadsheets as an archival and transfer medium for plotting data using the Intergraph system.

DATA CODING FOR "BELOW DETECTION LIMIT" DATA: "Non-detects", data reported as "below detection limit" or "<detection limit" were coded for simplicity of data entry. For major ions analyses, K^+ and Cl^- data reported as "below detection limit" or reported as zero, were entered as zeros. Alkalinity species not present below pH 8.3, such as CO_3^{2-} and OH^-, were also entered as zeros. While the assumption of zero concentration is reasonable for alkalinity, some biasing of parametric statistical estimates will occur for K and Cl unless data are recoded (see next paragraph).

Non-detect trace element data were coded as the negative value of the reported limit of detection (LOD), a precision based detection limit based on the standard deviation calculated from 15 replicate instrumental determinations of a laboratory control sample [*Taylor, 1987*]. This approach was selected to simplify data entry and to preserve information regarding the LOD at the time of analysis. Unless several different detection limits are reported, the negative coding of below-detection limit does not

significantly affect rank-based population estimates, such as histogram plots, median or percentiles. However, these data must be re-coded as suggested by Nehls [*Nehls and Akland, 1973*] and others [*Keith, et.al., 1983; Gilliom, et.al., 1984, or Gilbert, 1987*] if less biased statistical estimators are to be calculated.

Data entered into MINTEQA2 were coded differently. Potassium and chloride zeros or non-detects were entered as 0.1 mg/L, and trace element non-detects were entered as 0.1 times the LOD. This was done to preserve calculation of all possible mineral saturation indices. All alkalinity species were converted to meq/L concentrations, summed and then converted to carbonate - as required by the MINTEQA2 model.

MINTEQA2 Modeling and Saturation Index (SI) Calculations: Mineral SI's (see expanded description in Appendix 2, p. 1) were calculated using MS-DOS microcomputer versions of the EPA MINTEQ (*min-tech*) chemical equilibrium model, MINTEQA2, Version 3.11, and the accompanying data entry software, PRODEFA2, version 3.11 [*Allison, et.al., 1991*]. Copies of all input and output files are archived in loose-leaf notebooks kept in the Lab project files.

The MINTEQA2 model was run for all samples using the Lab-measured pH, temperature entered as 10° C, and assuming that the water samples were in equilibrium with atmospheric CO_2 and O_2 at partial pressures associated with the sample elevation above mean sea level . Atmospheric CO_2 will affect the equilibrium alkalinity species concentrations, and entering O_2 partial pressure allows the model to estimate equilibrium dissolved oxygen concentration and redox potential, Eh in mV. The partial pressures, in atmospheres, of O_2 (called pO_2) and CO_2 (pCO_2) for reservoir and surface seepage samples were calculated based on the elevation of the reservoir surface (for reservoir samples) or the downstream foundation elevation (for seeps and weirs) using the following regression expressions calculated from pressure vs. elevation data found in *U.S Standard Atmosphere* [*National Oceanic and Atmospheric Administration, et.al. 1976*]:

$$pCO_2, atm = 0.0003262 - (9.8297E-09 \times Elevation, ft)$$

$$pO_2, atm = 0.20704 - (6.239E-06 \times Elevation, ft)$$

Groundwater samples pumped from observation wells used the values for pO_2 and pCO_2 calculated at the elevation of the well head, multiplied by 0.10. An initial guess for the redox potential, or Eh in mV, was entered into the model as +300 mV. This estimate allowed MINTEQA2 to calculate the equilibrium Eh based on the dissolved oxygen (DO) resulting from the entered pO_2.

Appendix 2 provides a more detailed description of mineral SI's and the assumptions and data limitations of the MINTEQA2 model. SI's may be generally interpreted as follows:

Negative SI means UNDER SATURATED: *potential Dissolution*
Positive SI means OVER SATURATED: *potential Precipitation*

Increasing (less negative) SI between Reservoir and seepage samples suggests possible mineral dissolution, or mixing with a higher concentration water along the flow path. **Decreasing** (more negative) SI between Reservoir and seepage samples suggests possible mineral precipitation, or dilution mixing with a lower concentration source of water.

DATA QUALITY EVALUATION: The overall quality of the major ions data sets was evaluated using the ion balance calculation [*American Public Health Association, 1985, 1989, 1995*]. This calculation is based on the observed electrical neutrality of dissolved ions in water. Theoretically, negatively-charged ions (anions) should be equal to positively-charged ions (cations) on a charge-equivalent basis. Ion balance percentages were re-calculated and summarized for all 138 samples collated and evaluated for this report in Appendix 1, Table A1-2. Figure A1-1 shows the histogram of ion balance percentages for the Horsetooth Dam chemistry data set.

Field sampling repeatability was evaluated by calculating the relative percent difference (RPD) for duplicate field samples, which were collected on 3 separate sampling events. These data are summarized in Table A1-3.

Manually-entered data for this report were visually checked after entry and peer-reviewed to identify and correct coding errors. Samples with ion balances > ± 5.0% were double-checked for obvious coding or transcription errors by comparison with the original Lab data reports. Similarly, geology, hydrology, physiographic, and petrographic data were checked and validated as part of the peer review process in place at the TSC.

PETROGRAPHIC DATA AND MINERALOGY

HISTORICAL PETROGRAPHIC DATA: Appendix 3 provides copies of past petrographic memoranda describing the mineralogy of soil and rocks rock samples collected near the south end of Horsetooth Reservoir. These samples were collected from the west wall of an exposed sinkhole and road cut (Petrographic memo 90-2, dated January 26, 1990), and rock core DH-1, 85.5 - 86.0 ft. (memo 90-9, dated April 13, 1990). Calcite and/or dolomite are present in significant proportions in all samples. The samples also contain minor amounts of quartz and feldspar, which are potential sources of dissolved silica. While sulfate containing minerals, such as gypsum and anhydrite, were not detected in these particular samples, gypsiferous layers have been observed in the Lykins Formation during drilling operations at the site [*Wright and Taucher, 1991*].

MINERALOGY OF SUSPENDED MATERIALS IN WATER SAMPLES: The 12/09/98 suspended materials samples were collected from seepage and well water samples using filtration. The sediments, present in a limited number of samples, are thought to represent erosion of joint in-fillings, soft erodible strata of the Permian-Triassic Lykins Formation, and/or failed bentonite well casing seals.

Table 1 lists the mineralogical composition of the 12/09/98 suspended material samples. Table cells labeled "Qual ID" indicate the qualitative identification of the mineral and blank spaces indicate a mineral was absent or not detected. Numeric values indicate semiquantitative volume percent data estimated from XRD analyses. The percentages were estimated from the intensity of XRD peaks and may not be accurate quantity indicators, especially for the clay minerals.

The mineralogy of the suspended sediments was very simple in most cases. Varying amounts of calcite, dolomite, and quartz with the clay minerals smectite, illite/mica, and kaolinite were typically present in the seepage water. These minerals are apparently ubiquitous in the foundation rock of Horsetooth Dam. Only occasional evidence of feldspars and mica grains were observed. Hematite was not detected in the seepage sediments but is certainly an important mineral locally because it stains the damsite sediments red. Previous work on Horsetooth Dam foundation rock indicates gypsum is also present [*Wright and Taucher, 1991*]. Several of the samples contained insufficient material for petrographic analysis.

Suspended material samples DH98-6 (K5271-7), with screen in the Alluvium, and DH98-10a (K5271-11), with screen in the Middle Lykins/Forelle, appear to be bentonite, probably from well construction activities. The clay Mineral smectite detected in these samples was nearly pure and the diffraction peaks were very intense with a rational series of reflections not normally detected in smectites found in complex soil Mineral mixtures. Bentonite is a commercial term for hydrated sodium aluminum silicate clay Mineral used to thicken drilling muds or seal well casings. While these data are suggestive of drilling bentonite, the local Lykins formations may also contain laminations and beds of pure clay minerals. Comparison of the actual material used to construct the wells with the material from the well screens and outcrops may be the best way to identify natural or human source for the clay.

Table 1 Mineralogy of the 12/09/98 suspended material samples from seeps and wells. Numbers represent approximate volume percentages. "Qual ID" indicates that the mineral was observed but in unknown trace amounts.

ID	Calcite	Dolomite	Quartz	Feldspar	Smectite	Illite-Mica	Kaolin	Comment
1A-CON								insufficient sample
1A-COR								insufficient sample
DH91-1		qual ID	qual ID			qual ID		Clay size minerals and mica flakes present
DH91-2								insufficient sample
DH91-3A		qual ID	qual ID			qual ID		Clay size minerals and mica flakes present
DH91-4	qual ID	qual ID	qual ID					many opaline plants fragments
DH92-5A	10	1	30		60			XRD scan
DH92-5B	qual ID	qual ID	qual ID	qual ID	qual ID	qual ID	qual ID	XRD scan
DH92-6	qual ID		qual ID			qual		Clay size minerals and mica flakes present
DH92-7	qual ID	qual ID	qual ID		qual ID	qual ID	qual ID	XRD scan
DH97-1								insufficient sample
DH97-4	10	10	30		50	1	1	XRD scan
DH98-10A	1	1	1		100	1		Intense XRD smectite peaks
DH98-6			5		90	5		Intense XRD smectite peaks
DH98-7	qual ID	qual ID	qual ID		qual ID	qual ID	qual ID	XRD scan
Reservoir								insufficient sample
SM-1A								insufficient sample
SM-3								insufficient sample
TRENCH 1								insufficient sample
TRENCH 2								insufficient sample
TRENCH 3								insufficient sample
V-5								insufficient sample
V-6								insufficient sample

CHEMISTRY OF RESERVOIR AND SEEPAGE

Appendix 1 summarizes the inventory of all available water samples analyzed from Horsetooth Dam along with selected geologic and physiographic data (Table A1-1), and calculations relating to data quality checks performed for this report. Ion balance percentage calculations for major ions data sets are summarized in Table A1-2, and sampling repeatability is summarized for duplicate samples in Table A1-3.

Appendix 2 contains a more detailed explanation describing MINTEQA2-calculated mineral saturation indices, along with a discussion of the model's thermodynamic assumptions. Also included in Appendix 2 are the chemical analysis data and mineral saturation indices for all available water samples collected to date at Horsetooth Dam. Reservoir samples are summarized in Tables A2-1a to1c, and Stiff diagrams of the average reservoir water are plotted with seepage and well waters in other Appendix 2

figures. Seepage weir samples are summarized in Tables A2-2a to 2c, and Figures A2-1a through A2-1h. Chemistry from wells are found in Tables A2-3a to 3c, and Figures A2-2 through A2-3. Within each Appendix 2 table, the chemistry data are organized by major ions ("a" tables) first, followed by trace elements ("b" tables) and then MINTEQA2 mineral saturation indices ("c" tables).

CHEMICAL ANALYSIS DATA QUALITY: Information regarding chemical analysis data quality is summarized in Appendix 1, Tables A1-2, A1-3 and Figure A1-1. While all samples have been analyzed by the Bureau of Reclamation Denver Lab, the data collated for this report cover a period of 48 years, during which time both analytical methods and quality assurance - quality control (QA/QC) practices have varied.

The nature of Lab QA/QC practices in place for the 1951 samples is unknown. Starting in the mid-1980's, the Lab adopted a QA Plan that specified analytical procedures, daily calibration of instruments, and checks of precision and accuracy for chemical analysis instrument runs. Instrument calibration for these samples was checked using interlaboratory performance evaluation samples from USGS or EPA. After the 1951 samples, ion balance calculations were used by the Lab as an additional quality check and cause for repeated analyses or other corrective action.

After the 1991 samples, the Lab operated with a more formal QA Plan based on the continuous improvement system found in *Quality Management and Quality System Elements for Laboratory - Guidelines*, American National Standard ANSI/ASQC Q2-1991 [*American Society for Quality Control, 1991*] and the quality control approaches suggested by Taylor [*Taylor, 1987*]. This more rigorous QA Plan involved increased procedural documentation, definition of a corrective action loop, and additional instrument QC check samples run along with samples. These QC checks included blanks, initial and continuing calibration verification (ICV-CCV) with certified and traceable standards, analyte spike recovery, autosampler duplicates, and natural water laboratory control samples (LCS). Raw data and QC records for post-1991 samples are archived in the Lab files.

Recalculated ion balance percentage values are summarized in Appendix 1, Table A1-1 and a histogram of ion balance percentages found in Figure A1-1. Based on the Lab QC guideline that ion balances should be < ±5%, the re-calculated values suggest that the overall quality of the available data are good. Only 12.0% (16 out of 138) of samples showed ion balances > ±5%, and 11 of these samples showed values > ±7% (see Table 2). Of the 16 suspect > ±5% samples, 11 showed acceptable QC checks for all individual tests run by the Lab. For the remaining 5 samples (3.62%), the likely test results that should be qualified are alkalinity (carbonate, bicarbonate, and hydroxide ions) and calcium. Samples with high observed pH and carbonate and hydroxide alkalinity may show biases due to rapid changes in alkalinity equilibria prior to analysis. Calcium and magnesium may be biased high due to fine suspended particles of calcite and dolomite as seen for DH92-5A on 06/20/97. The low-TDS Reservoir samples with

out of range values are probably a result of normal random variation for low analyte concentrations near method detection limits observed in these samples.

Table 2   Summary of water chemistry samples where ion balance percentages exceeded ± 7%.

ID	Date	pH	Sum of Ions, mg/L	Sum of Cations, meq/L	Sum of Anions, meq/L	Ion Balance Percent	Comments
DH92-5A	06/20/97	5.94	126.980	3.928	0.923	61.940	high TSS and Ca probably from suspended particles
DH92-5A	11/20/97	6.59	91.607	1.367	1.112	10.301	cation bias high, but test QC ok
DH92-5B	06/20/97	10	163.030	2.380	2.823	-8.502	high pH, but test QC ok
DH92-5B	11/20/97	11.3	179.577	3.290	4.177	-11.877	high pH, but test QC ok
DH98-6	12/09/98	9.46	174.640	3.344	2.448	15.461	high pH
Reservoir	08/30/51	6.6	56.300	0.639	0.782	-10.007	1951 data - low TDS - minor problem
Reservoir	09/18/51	7.4	71.300	0.834	0.972	-7.649	1951 data - low TDS - minor problem
Reservoir	06/29/90	8.38	61.200	0.892	0.749	8.723	carbonate alkalinity? Holding times?
Reservoir	06/20/97	6.26	48.420	0.573	0.659	-7.035	anion high bias, but test QC ok
SM-7	06/29/90	8.72	150.760	2.311	1.916	9.346	pH 8.72 - low alkalinity bias?
SM-8A	11/20/97	7.27	130.314	1.922	1.535	11.185	high K and Na relative to 8B and 8C

SAMPLE REPEATABILITY: The error associated with field collection of duplicate samples is summarized in Appendix 1, Table A1-3. Repeatability is represented as relative percent difference, RPD, and was calculated for each of the samples collected in duplicate during 1986, 1987, and 1997. For each analyte measured, the RPD is calculated by dividing the absolute value of the difference between duplicates by the mean of the duplicates, and then multiplying by 100. For analytes measured near the limits of detection, the RPD exaggerates duplicate repeatability, so higher RPD values observed for K^+, Cl^-, SO_4^{2-}, CO_3^{2-}, and OH^-, are not necessarily indicative of questionable repeatability. RPDs were summarized for grouped reservoir and seepage samples and ranged from a low value of 2.1% for Reservoir Ca^{2+}, up to 35% for seepage Cl^-.

Average RPD for all major ions analytes, an indication of overall sampling repeatability, was best for the Reservoir samples at 6.2%, with seepage samples showing 12% average RPD. These data suggest that seepage samples, despite higher analyte concentrations well above the LOD for these tests, show more sampling error. Perhaps the seepage samples are less homogeneous and vary more with close sampling locations compared to Reservoir samples, as suggested by the variable results from 2 SM-3 samples collected from slightly different locations near the weir on 04/09/98. The overall average for all major ions samples and analytes was around 10% as RPD.

RESERVOIR CHEMISTRY: The major ions and trace element chemistry of Horsetooth Reservoir is summarized in Appendix 2, Tables A2-1a and A2-1b. This water, which is the principal end-member, or source water, for drainage, seepage, and groundwater, originates from high elevation granitic watersheds in the Rocky Mountains, and undergoes only minor increases in ions concentrations during trans-mountain diversion and transport to Horsetooth Reservoir.

Horsetooth Reservoir is a calcium-bicarbonate dominated water with low TDS (25-80 mg/L), slightly acidic pH (pH 5-6), and is suggestive of some interaction with calcite or limestone in the exposure watershed. Saturation indices for calcite, dolomite, and gypsum, found in Table A2-1c, are all consistently negative, suggesting that the source water will tend to dissolve these particular minerals if contact occurs during underground seepage.

Trace elements (Table A2-1b), measured only starting in 1990, suggest that the reservoir water has interacted with and weathered alumino-silicate minerals, probably feldspars, during watershed exposure. Al ranges from below detection (LOD = 30 µg/L) to 197 µg/L with an average of 89.0 µg/L. Si ranges from 0.970 to 1.96 mg/L with an average of 1.33 mg/L (std. deviation = 0.371, n = 8). Silicon and iron may also be suggestive of watershed interaction with reddish sandstones such as the Dakota or Lyons formation (which are stained with hematite). Fe, probably present as very fine suspended particulates below the 0.45-µM pore size from filtration, ranges from 10.0 to 86.0 µg/L, with an average of 45.0 µg/L.

GENERAL SEEPAGE AND GROUND WATER TYPES: All seepage and well samples show indications of increased ions concentrations compared to the Reservoir, suggesting that dissolution of soluble minerals is an ongoing process at Horsetooth Dam. MINTEQA2 calculated SI's also suggest that, despite changes in pH and increased ion concentrations, all groundwaters and seepage remain under-saturated (negative SI, though consistently less negative than the Reservoir) with respect to anhydrite, calcite, dolomite, gypsum, and amorphous silica. These results indicate that the local ground waters and seepage are not at equilibrium and retain the capacity to dissolve soluble minerals even after subsurface transit.

Except for the 1951 SM-3 samples which were higher in concentration compared to later SM-3 samples, the seepage weirs show only minor variability between sampling events, and little indication of trends in concentrations. However, the well samples are more complicated. Several well samples (**DH91-1** with screen in the Lower Lykins, **DH92-5a**, **DH92-5b**, and **DH97-4** with screens in the Upper Lykins - Alluvium) have shown a significant amount of variability between relatively recent sampling events, both in concentrations as well as general chemistry and water type (see Appendix 2, Figures A2-2a to A2-2d). It is not known whether this variability could be caused by coincidental contamination of the wells with grout and bentonite clay, inadequate pumping of wells prior to sample collection, or the deterioration and exposure of soluble

mineral deposits in loosely-consolidated breccia near the screen. These wells are also in an up-dip:down-dip relationship in the Lykins and Alluvium.

In order to simplify the complexity of the Lykins Formation for this report, wells were classified according to the general geologic strata at the location of the well screens (variable name = genform). Seepage weirs were classified into 3 groups based on proximity to the toe of the dam. Grouped average chemical data were then examined using Stiff and Piper [*Piper, 1944*] diagrams found in Figures 1a and 1b.

The grouped Stiff diagrams in Figure 1a and the clustering seen in the Figure 1b Piper diagrams suggest several generalized water chemistry types, or classes, observed at Horsetooth Dam, and provide some interesting clues regarding possible causes for and relationships between the different water types. Average Reservoir chemistry is plotted on the top Stiff diagram, RES-AVG, and provides a source water reference for comparison to the seepage and wells. Well data that were grouped by the general geologic classification at the depth of the installed well screen. ALLUV represents the average chemistry of wells with screens in the Upper Lykins - Alluvium layer (DH92-5A, DH92-5B, DH92-6, DH97-4). M-LYKINS is the average for wells with screens in the MIddle Lykins - Forelle limestone (DH91-3A, DH91-4, DH91-5, DH92-7, DH97-1, excluding the anomalous DH98-10a), along with the 3 12/09/98 Trench samples that are very similar to other Middle Lykins - Forelle limestone well samples.

TOE-WEIRS represents the average of all toe drains and weirs located near the dam (SM-1, SM-2, SM-1A. SM-8, SM-8A, SM-8B, and SM8C). L-LYKINS is the average for wells with screens in the Lower Lykins - Blaine gypsum (DH91-1, DH91-2, DH98-6, and DH98-7), and WELL-AVG represents the average for all well samples from all screen strata. Note that the well average is weighted based on the available samples, which are biased towards Upper and Middle Lykins samples, so it is coincidental that the Stiff diagrams are so similar in overall concentrations. SM4-AVG represents the average chemistry for the SM-4 weir located directly downstream of the artesian Pond No. 1, which is dissimilar to other weir samples located near the dam. NA-LYKINS is the average of 2 anomalous well samples (DH98-6, DH98-10a) that are included because of their elevated sodium and unique Stiff diagram shape.

> ***Calcite-dominant Waters:*** This water type is suggested by similarity in average Stiff diagram shape by diagrams with a prominent Middle bulge and converging tops and bottoms. The Reservoir, Middle Lykins - Forelle limestone wells, and the 12/09/98 Trench samples, are very similar both in diagram shape and total concentrations, suggesting that very little dissolution is occurring for water flowing through the Forelle limestone of the Middle Lykins. These data strongly suggest that the Middle Lykins - Forelle limestone layer represents a free-flowing path from the Reservoir to downstream emergence points, and that source water experiences only minimal contact with soluble Mineral deposits along these flow paths.

The Upper Lykins - Alluvium wells (ALLUV) and the Toe Drain Weirs (TOW-WEIRS) near the dam are also calcite-dominant waters, but show significantly elevated total concentrations compared to Reservoir or Middle Lykins waters. The Toe Drain Weirs show elevated magnesium (Mg^{2+}) and Alluvium Wells show increased Mg^{2+}, sulfate (SO_4^{2-}) and some sodium (Na^+). These samples are suggestive of interaction with similar minerals as the Middle Lykins wells, but perhaps at longer seepage residence times and greater cross-sectional exposure to dispersed Mineral deposits. These is also a suggestion of

Figure 1a Stiff diagrams of averaged ions concentrations for different subsets of well and seepage samples. Diagrams represent averages of: well samples with screens in the Upper Lykins-Alluvium (ALLUV), the Middle Lykins - Forelle limestone (M-LYKINS), Lower Lykins - Blaine gypsum (L-LYKINS), 2 unique sodium-containing well samples from the Lower and Middle Lykins (NA-LYKINS), seep SM-4 (SM4-AVG), all weirs close to and including the toe drains (TOE-WEIRS), and the average of all wells (WELL-AVG), and the Reservoir average (RES-AVG).
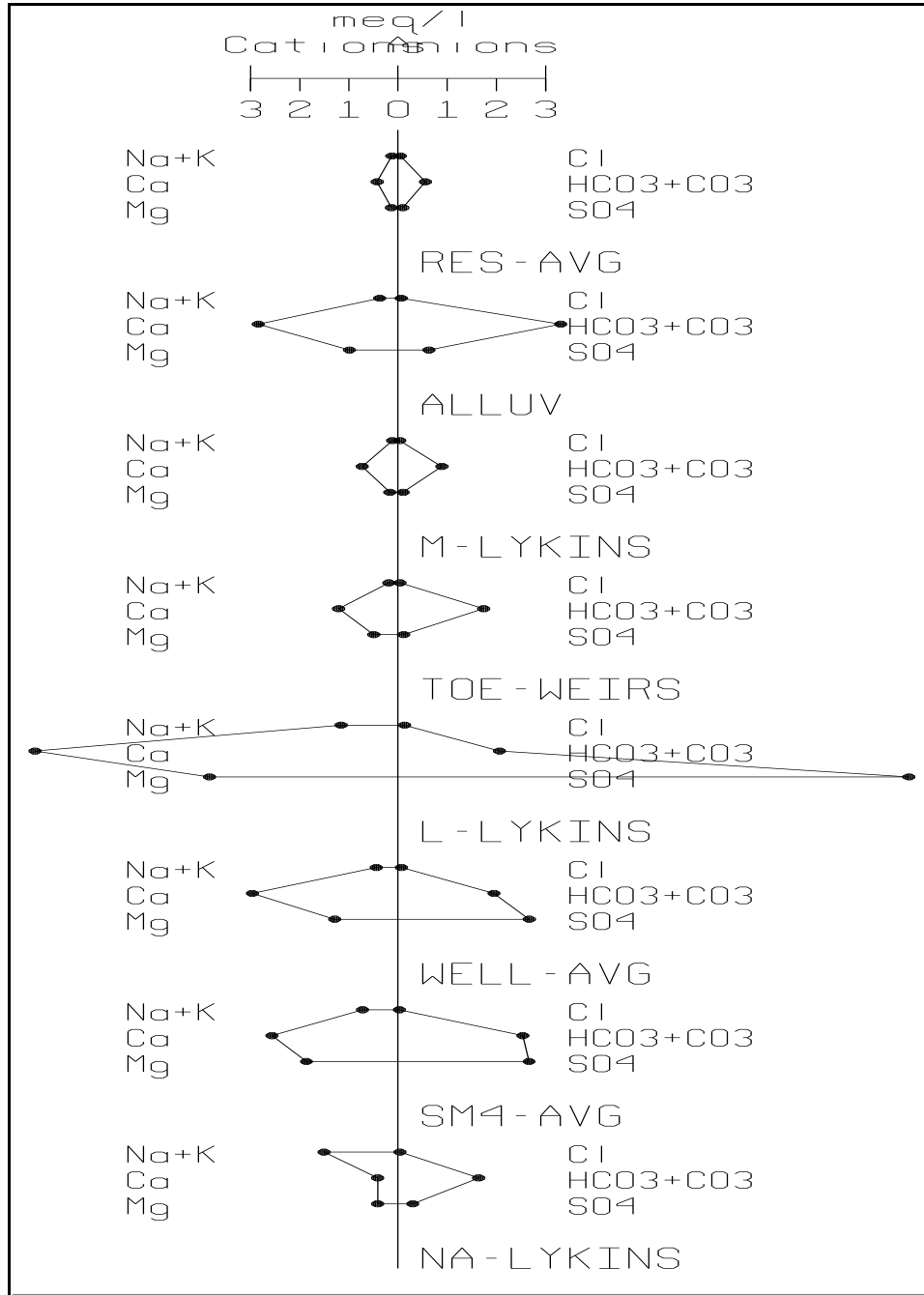
Figure 1b   Piper diagrams [*Piper, 1944*] showing the same averaged sample groups as in Figure 1b. This plot shows clustering of the different waters at Horsetooth: the calcite-dominated, the gypsum-dominated, mixture waters, and the sodium-dominated waters.
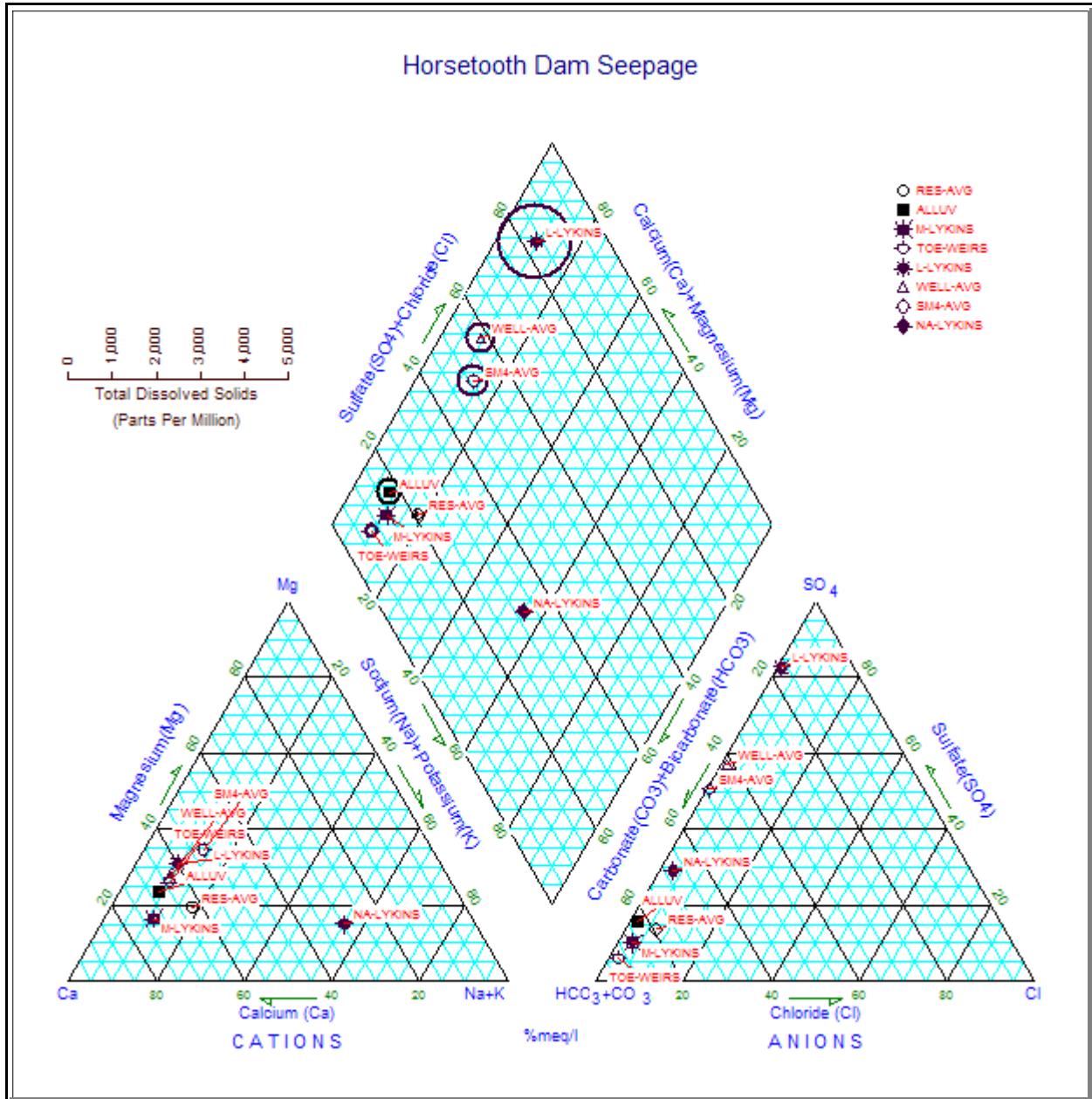
dissolution of near surface dolomite and gypsum, or possible mixing with waters from the Lower Lykins - Blaine gypsum layer, seen in the larger calcium-bicarbonate dominant Stiff diagrams, and in the downstream seeps SM-3, and SM-7.

Gypsum-dominant Waters: The second general water type observed at Horsetooth Dam is the *gypsum-dominant*, seen in the Figure 1 Stiff diagram of the Lower Lykins - Blaine gypsum wells (L-LYKINS). These samples show the greatest overall concentrations observed at Horsetooth Dam, and are indicative of the greater solubility of gypsum and anhydrite (around 2 g/L) compared to calcite (around 0.02 g/L) systems seen in the Alluvium and Toe Weirs. This broad-based and wide Stiff diagram suggests a chemistry with large increases in calcium (Ca^{2+}), SO_4^{2-}, Mg^{2+}, as well as the highest observed Na^+ concentrations. Besides sulfate minerals, these data suggest interactions with dolomites, and, because very little chloride (Cl-) was observed, perhaps some previously unidentified sodium-containing high-temperature marine evaporite Mineral. Consistently uniform evidence of gypsum and dolomite dissolution was not observed for any of the Toe Weirs or Middle Lykins samples.

Sodium-Dominant Waters: The third general water type was observed only on a limited number of occasions (DH91-1 on 06/20/97 - pH = 9.47, and DH98-6 - pH = 9.46, and DH98-10a - pH = 8.47,on 12/09/98), and is seen in the bottom Stiff diagram in Figure 1 (NA-LYKINS). These waters appear to originate from the Lower Lykins; however DH98-10a has a Middle Lykins well screen. *This water type has only been observed in the initial samples pumped from these wells, and the pH is consistently elevated.* As mentioned in the previous paragraph, this water may be formed by interaction with an as-yet unidentified sodium-carbonate or sulfate Mineral, or by ion exchange with the bentonite used to seal the wells. Finally, there is some indication in the other Lower Lykins well Stiff diagrams, that the increased Na^+ may represent some mixing of the sodium-dominant water with the gypsum-dominant type.

Mixture Waters: The last general water type is seen in weir **SM-4** samples, and the Figure 1 SM4-AVG plot, which has elevated Na^+, Mg^{2+}, and SO_4^{2-}. SM-4, located downstream of the artesian seepage Pond No. 1, is unlike other near-toe weirs and drains which show very little elevated SO_4^{2-}. A comparison of the SM-4 plot with the average of all well samples (WELL-AVG) reveals a striking similarity that strongly suggests that SM-4 water is the result of mixing of the three previous water types observed at Horsetooth Dam. Given this apparent groundwater mixing effect, it is likely that there are interconnections and mixing between different layer waters in the Lykins Formation, at least in the vicinity of Pond No. 1. The presence of in-filling breccia chimneys that cause sinkhole formation and connect different layers in the Lykins has been previously observed [*Wright and Taucher, 1991*], and the chemical similarity to SM-4 seen

in the **Sinkhole** water sample collected on 08/14/89 (see Figure A2-1h) support the interconnection and mixing hypothesis.

Chemistry similar to the SM-4 and Sinkhole samples has also been observed in subsurface samples collected from wells (See Figure A2-2d of alluvium screen well DH97-4 on 11/20/97), suggesting that mixing similar to the proportions seen in SM-4 also occurs at depth beneath the Dam.

DETAILED CHEMISTRY OF SEEPS AND WEIRS: Major ions data for seepage samples, defined here to include toe drains, and other near-surface seepage collected in structural drains and having installed weirs, are detailed in Appendix 2, Tables A2-2a to 2c. These tables are organized based on a grouping of the seepage weirs based on their general proximity to the embankment toe, as follows:

Toe Drain Seepage:	These are the samples directly draining the dam and/or near surface alluvium, and located at the toe or very near the toe. Includes the following weirs and drains: the Right Toe Drain, **SM-1**; the Left Toe Drain, **SM-1A**; abandoned Left toe drains, **SM-1A-CON** and **SM-1A-COR**; The Left Toe **SM-8** weir on Ditch #1; and the 2 Gatehouse outlet works overflow drains, **V-5** and **V-6**.
Weirs Downstream of and near Toe:	These are samples from weirs located just downstream of the toe, including: **SM-8A**, downstream of the Left Toe Drain (SM-1A) on Ditch #2; **SM-8B,** downstream of SM-8 on Ditch #1; **SM-8C** on the left on Ditch #3; **SM-4**, located downstream of the seepage pond; and the left abutment **TRENCH 1**, **2**, and **3** waters sampled on 12/09/98.
Weirs Farther Downstream:	These weirs collect seepage and drainage downstream, on the right abutment, and away from the structure, including: **SM-2**, **SM-3**, and **SM-7**.

Individual samples in chronological order are plotted on Stiff diagrams for SM-1, SM-2, SM-3, SM-4 and SM-7 in Figures A2-1a through A2-1e. Each figure contain a plot of average Reservoir chemistry concentrations for comparison. Stiff diagrams for Left toe weirs SM-8, SM-8A SM-8B and SM-8C are shown in Figure A2-1f. Figure A2-1g compares left and right toe drains by plotting average concentrations from SM1 and

SM-1A.   The single Sinkhole sample, collected from the campground at the south end of Horsetooth Reservoir, is plotted along with other seepage weir average data in Figure A2-1h.

With the exception of SM-4, chemistry of seepage weirs is very similar with Stiff diagrams showing calcite-dominated chemistry.

> ***Toe Drain Seepage:*** The Right toe drain, **SM-1**, seen in Figure A2-1a, shows the calcite-dominant Stiff diagram shape with higher concentrations of Mg compared to the reservoir water. Note that SM-1 shows very little variation in flow or concentrations. **SM-2** (Figure A2-1b)**,** downstream of the Right Toe Drain, shows chemistry very similar to SM-1, suggesting that little mixing with other subsurface seepage occurs and this weir contains primarily toe drain water. The Left Toe Drain, **SM-1A**, (sampled only during 1998) shows a similar shape to SM-1, but appears to be less concentrated than SM-1 by a factor of about one-half, perhaps indicative of shorter structural residence times.

> **SM-8**, located on Ditch #1 at the far left toe, shows similar chemistry to SM-1A and an even lower total concentration (the 11-20-97 TDS of 390 mg/L is believed to be anomalous). While the available data set is not conclusive, the apparent right to left trend seen in Figure 2 Stiff diagrams, and in TDS data from the 04/09/98 sampling suggests decreasing seepage concentration towards the left. This observation is supported by the chemistry observed in the 3 left abutment **TRENCH** seepage samples collected on 12/09/98, which are on the near-dam downstream left abutment (see Figure A2-3b), and also drain the Middle Lykins - Forelle limestone. These samples are similar in proportions to the Reservoir water and are only slightly elevated in total dissolved concentration. Seepage closer in concentration and chemistry to the Reservoir water implies less interaction and dissolution of soluble minerals along transit paths, and possibly greater flows or shorter underground residence times towards the left.

> ***Weirs Downstream of and Near Toe:*** Refer to Figure A2-1f for Stiff diagrams comparing the left-side seeps. **SM-2** (Figure A2-1b) is very similar to the Right Toe Drain SM-1 water. **SM-8A**, located immediately downstream of the Left Toe Drain, SM-1A, nevertheless shows similar to slightly higher total concentrations along with the most elevated Mg (Figure A2-1f) observed for left-side seeps (besides SM-4). These data are suggestive of possible dissolution of subsurface dolomite. **SM-8B** appears to be almost identical to the SM-8 samples collected on the same dates.

> The notable observation for the "near toe" samples is the chemistry found in the central seepage pond and weir **SM-4**. Note that the data summarized here are from the 1980's and were collected prior to the appearance of new seeps along the left toe that currently drain and mix with the Pond No. 1 water. These

Figure 2   Stiff diagrams showing the Right to Left decreasing concentration gradient for Toe Drains and SM-8 for the 04/09/98 sampling event. TDS for these samples: SM-1 = **124 mg/L**, SM-1A = **68.5 mg/L**, SM-8 = **44.8 mg/L**.
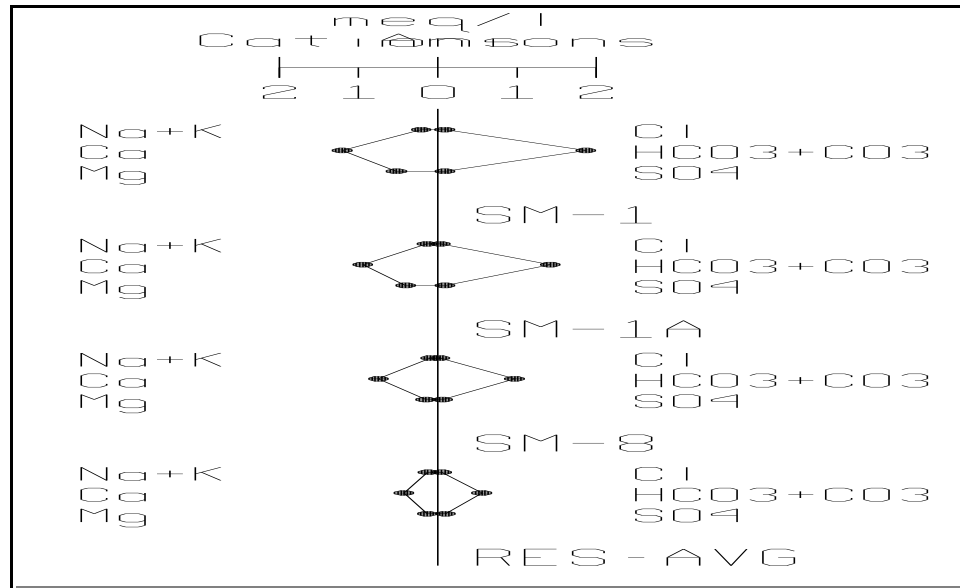
samples, seen in Figure 1 and Appendix 2, Figure A2-1d, show a chemistry very different from the other weirs and have elevated concentrations of sulfate, indicative of possible gypsum dissolution; along with elevated Mg, suggestive of dolomite dissolution. Since the seepage pond is artesian and probably intercepts seepage similar to the other toe drains and weirs draining the dam and alluvium in the immediate vicinity, there is a strong suggestion that the SM-4 pond represents a mixing of structural-alluvium contact groundwater with seepage in contact with the Lower (stratigraphically) Lykins and the Blaine gypsum.   This would imply either communication to upper alluvium strata from deeper deposits, or a near surface exposure of the Lower Lykins strata.

Another possibility accounting for SM-4 is suggested by consistently elevated and alkaline pH values (pH = 10.4 on 06/29/90, pH = 10.1 on 06/13/86, mean pH = 9.67).   Wells with chemistry and pH similar to SM-4 include **DH98-7** (with screen in the Lower Lykins - Blaine gypsum, pH = 9.09 - see Figure A2-3c), **DH97-4** (with screen in the Upper Lykins - Alluvium), but only on the 11/20/97 sample, with pH = 7.39 (see Figure A2-3a). There is also some similarity to SM-4 seen in **DH92-5b**, Figure A2-3a, (with screen in the Upper Lykins - Alluvium) on 06/20/97 (pH = 10.0) and 12/09/98 (pH = 8.77). These well samples may indicate possible up-dip flow paths and flow contact from grout-contaminated wells, or possible cross-connection in a collapsed chimney structure that mixes water from alkaline deposits from the Lower Lykins - Blaine gypsum.

Weirs Farther Downstream: There are several notable observations based on examination of the seepage weir samples located father downstream. The first is the large observed difference in concentration between the 1951 **SM-3** samples (see Figure 3 below and Appendix 2, Figure A2-1c), shortly after first filling of the reservoir and seepage contact with the structural geology, and later SM-3 samples. The 1951 samples are between 1.6 and 4.1 times more concentrated compared to samples collected from 1986 onward.   Since the pre-impoundment water table was approximately 100 ft below the dam, these data may suggest an initial dissolution of available soluble mineral deposits located along initial seepage flow paths, a process that has now settled into a lower-

concentration, steady-state seepage interaction. SM-3 also shows elevated Mg^{2+} and SO_4^{2-}, suggesting that seepage in downstream weirs is either contacting Lower Lykins - Blaine gypsum and dolomite deposits, or that the surface drainage is mixing with seepage groundwater in contact with the Lower Lykins.

There is a complication worth noting for the 04/09/98 SM-3 "duplicate" samples collected at SM-3, which suggests that duplicate samples collected from slightly different locations may show water having very different concentrations. One of the 04/09/98 samples, SM-3B, collected 40 ft. away from SM-3A at the south spring, is around twice as concentrated as the SM-3A, collected at the north side of spring.

SM-7 (which collects seepage from all surface weirs) is generally very similar to SM-3 except for samples collected on 04/09/98. These recent samples (Figure A2-1e), collected in duplicate, exhibit water chemistry (sum of ions = 62-68 mg/L) very similar to the Reservoir. There is no clear explanation for this anomalous observation. Since SM-3 is directly upstream and showed higher (though very different for duplicates) concentrations on the same date, there are suggestions of some fairly direct dilution - either from the Reservoir via a Middle Lykins - Forelle limestone flow path, or recent storm or snowmelt runoff. Clearly, abrupt and unexpected changes in historical concentrations such as observed on 04/09/98 suggest that the downstream weirs should be more consistently sampled in the future.

Figure 3 Stiff diagrams showing a comparison of average concentrations for the 1951 SM-3 samples, the post-1951 SM-3 samples (SM3-NEW), and SM-7.
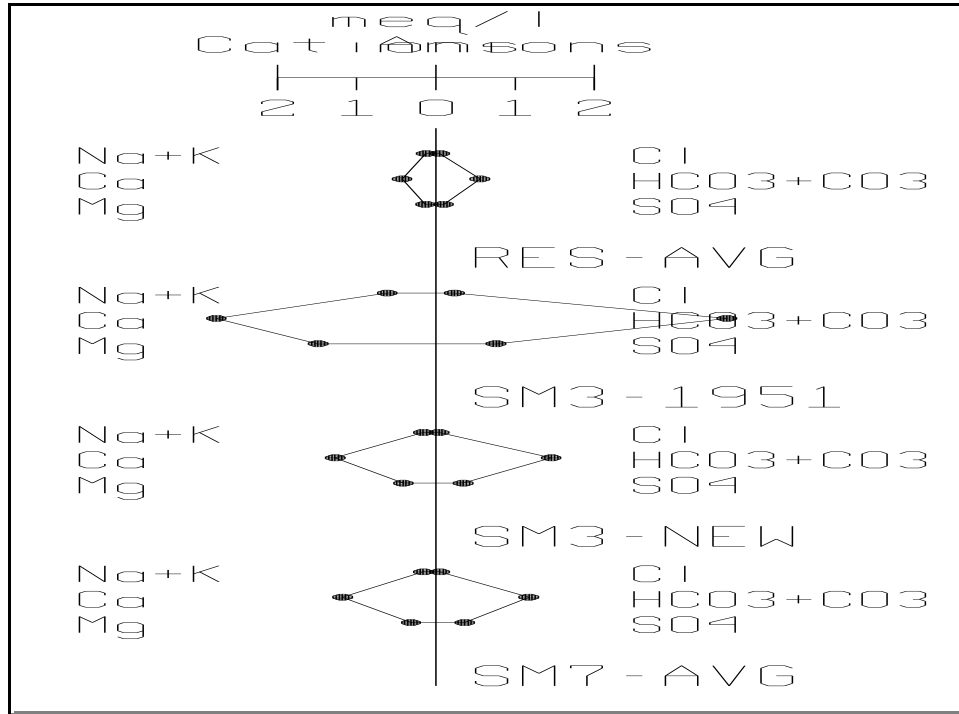
DETAILED CHEMISTRY OF THE WELL SAMPLES: In this report, well chemistry samples are grouped based on the general Lykins Formation strata where the well screen is located. The three general strata are defined as the ***Upper Lykins - Alluvium***, the ***Middle Lykins - Forelle limestone***, and the ***Lower Lykins - Blaine gypsum***, and grouped well samples are plotted as average concentration Stiff diagrams in Appendix 2, Figures A2-3a through A2-3c. Note that the Alluvium is dominated by clay and is geologically different from the Upper Lykins.

>***Unusual Variability and Alkaline Chemistry in Several Wells:*** Some of the Upper Lykins - Alluvium and Lower Lykins - Blaine gypsum well samples exhibited unusual variability between sampling events. Figures A2-2a - A2-2d, show individual Stiff diagrams for the variable chemistry wells. For DH91-1, DH92-5a, DH92-5b, and DH97-4, not only do the total concentrations vary significantly between sampling episodes, the pH and the actual type of water may be different. Elevated alkaline pH values (> 9) are observed only in well samples except for the mixture water seen in **SM-4**. Several of the variable chemistry wells also indicated alkaline pH, but no well was observed with alkaline pH in every sample. Two wells vary in concentration and water type with consistently neutral pH (DH92-5a and DH97-4). The chemistry data suggest that conditions arising from drilling, casing installation, finishing, and pumping of wells may be responsible for both the observed variability and alkaline pH at

Horsetooth Dam. There is also a suggestion that the relative changes in chemistry observed in the variable wells represents a possible up-dip flow path connecting these screens.

General chemistry variability may be due to the well casing and screen intercepting and/or connecting loosely consolidated breccia, limestone dissolution void spaces, and other inter-bedded soluble deposits. The physical void complexity and the variable distribution of the different soluble materials in the Lykins may have contributed to mixing of groundwaters from different (but connected) layers when the wells were pumped.

Since naturally-occurring alkaline salt deposits have not been petrographically identified at Horsetooth Dam, the most likely cause for elevated pH may be that these samples have been contaminated with alkaline compounds present in grout (oxides NaO, KO, CaO, MgO, which form soluble alkaline hydroxides on wetting), and/or bentonite clay used to seal well casings. Grout contamination would account for elevated pH and alkalinity, and perhaps the elevated sodium observed in well samples.

The pH influence from grout may also be supported by the observed chemistry of the Sinkhole sample collected from the south end of Horsetooth Reservoir in 1989. There are no wells or other sources of grout in the vicinity of the sinkhole, which has a mixture chemistry similar to SM-4, but neutral pH, and no elevated K^+. The presence of wells and grout, both from well installation and original construction, are associated with the dam, perhaps suggesting why the mixture water in SM-4 is sometimes alkaline.

The cation exchange properties of the sodium bentonite used in well installation may account for some of the elevated Na^+ and pH observed in the sodium-dominant waters. These particular water types were only observed for the initial samples collected from new wells. For example, DH91-1, (Figure A2-2a) with screen in the Lower Lykins - Blaine gypsum, shows an initial pH = 9.47, sodium-dominant water, followed by gypsum-dominated and alkaline pH on 11/20/97 (pH = 11.2) and 04/09/98 (pH = 10.7), and then neutral pH and low TDS on 12/09/98. The most recent data suggest an almost direct flow path to the Reservoir. DH91-1 also shows elevated potassium (K^+) and Na^+ which decline over time, suggesting a gradual dissolving of the alkaline oxide/hydroxide components in grout.

DH97-4 (screen in the Upper Lykins - Alluvium) initially shows a neutral pH mixture water similar to SM-4, followed by calcite-dominated waters, and an apparent downward trend in Na^+, Mg^{2+}, and SO_4^{2-}, but not Ca^{2+} and HCO_3^-. Wells like DH91-2 (Lower Lykins - Figure A2-2d) that have gypsum-dominated water at neutral pH, can be contrasted with Lower Lykins - Blaine gypsum DH91-1 (Figure A2-2a) that also show gypsum-dominant water, but at alkaline pH values. There

appears to be a similar trend in relative total concentration changes on the same sampling dates among the variable wells, but the data set is too limited to draw any meaningful conclusions.

Wells in Upper Lykins - Alluvium: (See Figures 1 and A2-4a). Despite some observed variability in well samples between recent sampling events, averaged concentrations suggest that these samples are all calcite-dominant - very similar to the Toe Drains except for elevated total concentrations and Mg^{2+} and SO_4^{2-}, suggesting additional interaction with gypsum and dolomite. Overall concentrations in Alluvium screen wells are higher that the near-toe weirs, suggesting that the wells are contacting additional soluble minerals and/or experience longer seepage transit times at depths slightly deeper than the embankment.

DH92-5a (Figure A2-2b) is a calcite-dominant water with screen in the Alluvium that exhibits variable concentrations over time and near-neutral pH that appears to show a trend toward higher pH over time. Located approximately 77 ft. downstream of the left toe, these waters are similar in shape to **SM-3**, and there is a suggestion of a more direct flow path from the Reservoir on 11/20/97 and 04/09/98 as evidenced by the lower total concentrations.

DH92-5b (Figure A2-2c), with screen in the Upper Lykins, is another calcite-dominant water located close to DH92-5a and about 80 ft. downstream of the toe, shows increased SO_4^{2-} , similar in shape to **SM-3** but with greater TDS, and indicates probable gypsum dissolution. The concentrations are variable and the average pH is 10.3, very alkaline.

DH92-6 is an *artesian* well with screen in the shallow Middle Lykins - Forelle limestone, located at the left tow of the embankment. This sample shows calcite-dominant chemistry with some elevated Na^+ and Mg^{2+}.   The pH is consistently neutral and TDS (median = 162 mg/L) fairly uniform for the 3 samples collected since 06/20/97. The minor increases in Na^+ may suggest some mixing with lower strata in the Lykins containing sodium-dominant water; however, the chemistry otherwise appears to be common to the alluvial/structural interactions seen in the Toe Drains (SM-8 median TDS = 62.1 mg/L) and nearby weirs.

DH97-4 (Figure A2-2d) has a shallow screen in the Alluvium and is located approximately 180 ft. downstream of the toe and has showed variable concentrations and consistently neutral pH for the 3 samples collected since 11/20/97. The initial sample on 11/20/97 shows a Stiff diagram similar to SM-4, suggesting that this well is intercepting mixed waters. Na^+, Mg^{2+}, and SO_4^{2-}, initially elevated on 11/20/97, appear to

decrease steadily over time and later samples resemble calcite-dominant waters found in **SM-3** and **SM-7**.

Wells in the Middle Lykins - Forelle limestone: (Fig A2-4b) These wells show one of the important observations from this study: that almost all MIddle Lykins - Forelle limestone screen wells show consistently neutral pH, calcite-dominant chemistry, and much more uniform total concentrations over time, only slightly elevated compared to Reservoir samples. The suggestion is that these groundwaters (except for DH98-10a) are not appreciably dissolving minerals during seepage transit and are *likely indicative of a more direct flow path from the Reservoir through limestone dissolution fissures and pipes.*

The 3 **Trench** samples collected on 12/09/98 are also very similar to the Middle Lykins - Forelle limestone well screen samples. The trenches are located at the far left side of the near downstream abutment and were cut to intersect the Forelle limestone. The Trench samples show the lowest TDS concentrations and closest similarity to Reservoir water of any Middle Lykins - Forelle limestone source samples.

The only anomalous chemistry well in the Middle Lykins is **DH98-10a**, (collected on 12/09/98, pH = 8.47) which shows sodium-dominated chemistry that is similar to the Lower Lykins wells **DH91-1** sampled on 06/20/97 (pH = 9.47), and **DH98-6** sampled on 12/09/98 (pH = 9.46). This alkaline pH and chemistry is probably indicative of influences from well installation, likely cation exchange with bentonite clay.

Wells in the Lower Lykins - Blaine gypsum: (Fig A2-4c) These wells show a variety of elevated TDS waters, and all except DH98-6 (another initial well sample showing sodium-dominant chemistry) show the greatest concentrations of SO_4^{2-}. The preponderance of significantly elevated Ca^{2+} and SO_4^{2-} samples is thought to be indicative of contact with the Blaine gypsum, a concentrated deposit associated with the Lower Lykins.

DH91-1 (Figure A2-2a), located on the Dam axis, shows variable water types and concentrations over time. The first 3 samples show elevated pH, with very alkaline pH on 11/20/97 and 04/09/98. The initial 06/20/97 sample exhibits the sodium-dominant chemistry (also observed in DH98-10a, and DH98-6), but the subsequent 11/20/97 and 04/09/98 samples show a gypsum-dominant water with TDS approximately 4-times greater than the 06/20/97 sample. However, the important observation from this well is the near Reservoir chemistry and neutral pH observed on 12/09/98. *The implication is that this low concentration groundwater represents a nearly direct flow path to the Reservoir.*

DH91-2 (Figure A2-2d) is an **artesian** well located approximately 285 ft downstream of the toe and containing gypsum-dominant water. These samples consistently show neutral pH and almost uniform concentrations - the highest sum of ions (1510-1580 mg/L) and concentrations of SO_4^{2-} and Mg^{2+} observed so far at Horsetooth Dam.

DH98-6 shows another sodium-dominant water with elevated Na^+, but no SO_4^{2-}, suggesting that the Lower Lykins strata contains some kind of sodium carbonate mineral deposit, or that perhaps, the well has been contaminated by grout.

DH98-7 is similar to the SM-4 mixed chemistry with less Mg^{2+}. This sample suggests that mixing of the different water types at Horsetooth Dam may also be occurring at depth in subsurface seepage.

SUMMARY CONCLUSIONS

The available chemistry data suggest that Mineral dissolution occurs beneath and around Horsetooth Dam. Near-reservoir concentrations suggest more direct flows through the Middle Lykins - Forelle limestone, and inter-strata mixing of water from the Lower Lykins - Blaine gypsum with higher stratigraphic units waters in the Lykins and the Alluvium appears likely. More specific observations from this evaluation include the following:

1. **Reservoir water is under-saturated and aggressive to all soluble minerals identified at Horsetooth Dam:** Horsetooth Reservoir water is relatively pure and shows chemistry consistent with the granitic - feldspar - sandstone exposures contacted during watershed transit. Mineral SI's suggest that the reservoir water is under-saturated with respect to gypsum, anhydrite, calcite, and dolomite, and will thus tend to dissolve these minerals if contacted during subsurface transit.

2. **The Lykins formation contains a plentiful supply of soluble minerals that appear to account for the observed chemistry in seeps and wells.** The available geology and petrographic data indicate that the Lykins Formation, underlying Horsetooth Reservoir and Dam, contains large amounts of limestone and gypsum in complexly inter-bedded strata. Seepage flows through the Lykins, which is tilted, along both permeable/uniform gypsum and other sedimentary deposits in a gradual manner, as well as more rapidly through open flow paths in the Forelle limestone. The available chemistry data strongly suggests that dissolution of these and several other minor minerals account for the observed chemistry of the seepage and groundwater downstream of the dam.

3.   **There are 4 different classes of water chemistry at Horsetooth Dam.** The chemistry data suggest that seepage, groundwaters, and Reservoir waters fall into 4 general categories at Horsetooth: *calcite-dominant*, which are associated with the Reservoir, the well samples from the Middle Lykins - Forelle limestone, the left abutment Trenches, and the Toe Drains and near-structure seepage weirs; *gypsum-dominant*, which are primarily seen in well screen samples in the Lower Lykins - Blaine gypsum; *sodium-dominant*, seen only on limited occasions in Lower-Lykins wells and one Middle-Lykins - Forelle limestone sample; and *mixture* waters, seen most clearly in the artesian seepage Pond No. 1, SM-4, and the Sinkhole sample.

4.   **Seepage appears to flow directly through the Middle Lykins - Forelle limestone.** The similarity of waters from all Middle Lykins - Forelle limestone wells and the left abutment trenches strongly suggests that the Forelle limestone represents a relatively open flow path from Reservoir infiltration points, with very little Mineral dissolution occurring during seepage transit. These waters likely flow relatively unimpeded through dissolution voids, cracks, and open flow channels in the Forelle limestone. The 12/09/98 Trench samples show the lowest TDS concentrations and closest similarity to Reservoir water of any Middle Lykins - Forelle limestone source samples.

5.   **Mixing of seepage appears to occur between different stratigraphic layers in the Lykins Formation.** There is evidence that seepage is moving vertically and mixing between layers in the Lykins formation. The most likely path is along collapsed breccia chimneys and dissolution voids that interconnect surface Alluvium deposits with seepage from the Lower Lykins - Blaine gypsum strata. The mixing hypothesis is supported by the observed chemistry in SM-4 and the Sinkhole which bear a close resemblance to the average data for all available well samples. Similar mixed chemistry samples were observed in Upper Lykins - Alluvium wells, and one Lower Lykins - Blaine gypsum well; however, only one well sample in the Middle Lykins - Forelle limestone showed evidence of cross-strata mixing or communication.

6.   **There appears to be a decreasing seepage concentration gradient from the right Toe drain across the toe to the 3 recent Left Abutment Trenches.** Recent data from the Toe Drains, near-toe seepage weirs, and the left abutment trenches strongly suggest a right to left trend of decreasing seepage concentrations across the embankment toe. Samples from the trenches approach Reservoir concentrations, suggesting little interaction of seepage with soluble minerals. These observations contrast with the relatively unchanged chemistry seen on the Right Abutment weirs (except for the recent SM-7 samples). The relatively recent appearance of new seeps and wet spots along the left downstream abutment, the chemistry data corroborate observed

increasing seepage flows around the left abutment and strongly suggest that these new seepage paths are probably being formed in the Forelle limestone.

7. **Early SM-3 data suggests much higher initial seepage concentrations.** Much higher seepage concentrations compared to recent samples were observed in the 1951 SM-3 samples, which emerge from a Forelle karst outcrop 3000 ft. downstream of the dam. Initial filling at Horsetooth Reservoir produced a new aquifer that may have contacted previously undissolved geologic strata and mobilized readily available soluble minerals.

8. **Several different water chemistry types were observed in some wells.** The highly variable chemistry observed in several wells suggests that the process of drilling and installation may have disturbed loosely-consolidated breccia located near the well casing and screen. Elevated chemical concentrations may be caused by pumping samples from disturbed deposits that result in enhanced mixing and dissolution hydrodynamics, or creation of enhanced surface area exposure of Mineral assemblages to groundwater dissolution. Another possibility is that the sodium-dominant waters, only observed in initial samples pumped from new wells, may indicate calcium exchange with sodium-bentonite clay used to seal well casings during installation. Finally, well installation may also have created interconnection paths for mixing between previously separate layers and soluble Mineral deposits.

9. **Grout contamination from well installation may be causing the high observed pH values.** Two wells intermittantly showed elevated pH and significant carbonate and hydroxide alkalinity. These wells are thought to have been contaminated with grout or an unidentified alkaline Mineral. Additional evidence supporting the grout hypothesis is the neutral pH and lack of elevated potassium seen in the 1989 Sinkhole sample. This sample was collected from the campground at the southern end of the Reservoir where there were no recently installed nearby wells.

RECOMMENDATIONS

These observations and the emergence of new seeps along Forelle limestone exposures should be considered a potentially serious dam safety concern that warrants implementation of additional structural monitoring, hydrologic and geophysical investigations, and enhanced frequency and inspection of all seepage flows in calibrated weirs. If additional chemistry samples are requested, I would recommend the following:

1. **Consistent sampling over time:** samples should be collected from the same consistent set of wells and weirs each sampling event, all new data should be archived with the current historical combined geochemistry file. Once a new

sampling site is identified, continue to sample the new site at each scheduled event. Collect samples from SM-4, which was not recommended as a sampling site in a previous Horsetooth chemistry evaluation. Continue analyzing the samples for major ions, iron, manganese, aluminum, and silicon.

2. **Pay attention to abrupt changes in chemistry:** The most recent samples from weir SM-7 and DH91-1 showed chemistry very similar to the Reservoir when previous samples were much higher in concentration. This suggests that readily available soluble minerals may have been dissolved and more direct paths to the reservoir have formed. Regardless of cause, these sampling locations need to monitored over time for both chemistry and flow.

2. **Pump wells longer before sampling:** Pump existing wells for longer periods of time before sampling, and if not already performed, monitor conductivity and pH of pumped effluent to confirm stable readings. This will help assure that water from the surrounding formation is being collected and that any influence from local concentration gradients around the casing or screen is avoided.

3. **Measure field chemistry variables:** Include field measurements of calibrated pH, temperature, dissolved oxygen, and conductivity with the sample chain of custody or analytical request. While this would be good practice for all future water samples, it is highly recommended for the well samples.

5. **Perform additional petrographic analyses:** Collect additional geologic material samples for petrographic analysis that are tailored to Mineral dissolution and geochemical purposes. Well cores need to be inspected by the project petrographer to identify any unusual rock or inter-bedded deposits worth further investigations. Collect and identify any suspended materials present in seepage or well water samples.

The following investigative work should also be considered as a way to better understand seepage processes at Horsetooth Dam and to improve the interpretation of existing or future chemistry data:.

1. **Include physical data on new wells:** Additional geologic information and well and screen depth on the more recently installed wells (DH92-6, DH92-7, DH97-1, DH98-6, DH98-7, DH98-10a) needs to be included with the combined chemistry data set. Location variables from precise GPS measurements should also be included in the chemistry data set.

2. **Plot all data on 3-d projections:** Some additional information regarding seepage flow paths through the structures and chemical concentration changes at Horsetooth Dam might be obtained by plotting the existing chemical data on 3-dimensional Intergraph drawings that show the dam, geologic stratification, wells

and screen depth locations, and flow data from downstream weirs. At the least, more informed decisions regarding placement and installation of new weirs and wells may be made.

3. **Consider dye and tracer tests:** Because hydrologic information regarding seepage residence times, flow velocities, and actual flow paths are unknown, dye or isotopic tracer studies are recommended and should be considered along with any appropriate geophysical void space detection measurements.

4. **Measure seepage flows frequently at all weirs:** The lack of seepage flow data for many existing previous chemistry data sets make it unlikely to detect longer-term trends that might relate to worsening seepage problems. Future chemistry samples, however, combined with accurate seepage flow data, may enable that sort of analysis.

5. **Calculate flow-weighted dissolution masses:** Once the seepage hydrology is better defined and understood, it would be appropriate to calculate flow-weighted dissolution masses from the observed chemistry data to provide rough estimates of mass losses and potential void space formation over time. Other stochastic modeling of seepage flow could also be applied with more rigor and interpretative certainty.

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APPENDIX 1

Inventory of Samples, Background Information, and Data Quality

Checks for Samples Collected at Horsetooth Dam, 1951-1998

Table A1-1   Inventory of water samples collected from Reservoir, seeps, drains, and wells at Horsetooth Dam.

Sample Type	Sample ID	Sample Date	Sample Location	Axis Offset	Lateral Distance from Axis, ft	Lateral Distance from Toe, ft	Sample Depth, ft	General Geologic Formation	Reservoir Elevation, ft
SOURCE	Reservoir	08/30/51	behind dam		.	.	.	None	.
n=19	n=19	09/18/51	behind dam		.	.	.	None	.
		10/18/51	behind dam		.	.	.	None	.
		06/13/86	behind dam		.	.	.	None	5414.34
		06/13/86	behind dam		.	.	.	None	5414.34
		05/11/87	behind dam		.	.	.	None	5414.08
		07/01/87	behind dam		.	.	.	None	5417.94
		09/17/87	behind dam		.	.	.	None	5397.48
		09/17/87	behind dam		.	.	.	None	5397.48
		08/14/89	behind dam		.	.	.	None	5381.43
		08/14/89	behind dam		.	.	.	None	5381.43
		06/29/90	behind dam		.	.	.	None	5407.81
		10/31/90	behind dam		.	.	.	None	5390.37
		05/20/91	behind dam		.	.	.	None	5423.20
		06/20/97	behind dam		.	.	.	None	5423.30
		06/20/97	behind dam		.	.	.	None	5423.30
		10/02/97	behind dam		.	.	.	None	5415.50
		04/09/98	behind dam		.	.	.	None	5426.63
		12/09/98	behind dam		.	.	.	None	5380.29
DRAIN	SM-1	06/13/86	right toe drain	8+00	475	50	.	Structure - Alluvium	5414.34
n=26	n=13	06/13/86	right toe drain	8+00	475	50	.	Structure - Alluvium	5414.34
		09/24/86	right toe drain	8+00	475	50	.	Structure - Alluvium	5376.53
		05/11/87	right toe drain	8+00	475	50	.	Structure - Alluvium	5414.08
		05/11/87	right toe drain	8+00	475	50	.	Structure - Alluvium	5414.08
		09/17/87	right toe drain	8+00	475	50	.	Structure - Alluvium	5397.48
		09/17/87	right toe drain	8+00	475	50	.	Structure - Alluvium	5397.48
		06/29/90	right toe drain	8+00	475	50	.	Structure - Alluvium	5407.81

Sample Type	Sample ID	Sample Date	Sample Location	Axis Offset	Lateral Distance from Axis, ft	Lateral Distance from Toe, ft	Sample Depth, ft	General Geologic Formation	Reservoir Elevation, ft
DRAIN (cont)		10/31/90	right toe drain	8+00	475	50	.	Structure - Alluvium	5390.37
		05/20/91	right toe drain	8+00	475	50	.	Structure - Alluvium	5423.20
		06/20/97	right toe drain	8+00	475	50	.	Structure - Alluvium	5423.30
		11/20/97	right toe drain	8+00	475	50	.	Structure - Alluvium	5419.00
		04/09/98	right toe drain	8+00	475	50	.	Structure - Alluvium	5426.63
	SM-1A	04/09/98	Left toe drain	10+00	475	35	.	Structure - Alluvium	5426.63
	n=2	12/09/98	Left toe drain	10+00	475	35	.	Structure - Alluvium	5380.29
DRAIN	SM-1A-CON n=1	12/09/98	Abandoned toe drain pipe	8+00	475	35	.	Structure - Alluvium	5380.29
DRAIN	SM-1A-COR n=1	12/09/98	Abandoned toe drain pipe	8+00	475	35	.	Structure - Alluvium	5380.29
DRAIN	V-5	09/24/86	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5376.53
	n=5	06/20/97	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5423.30
		11/20/97	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5419.00
		04/09/98	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5426.63
		12/09/98	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5380.29
DRAIN	V-6	06/20/97	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5423.30
	n=4	11/20/97	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5419.00
		04/09/98	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5426.63
		12/09/98	gatehouse around outlet works	9+00	475	30	.	Structure - Alluvium	5380.29
SEEP n=3	TRENCH 1 n=1	12/09/98	L-abutment Ditch #3 nearest	15+00	700	375	.	Lyons SS	5380.29
SEEP	TRENCH 2 n=1	12/09/98	L abutment Ditch #3 50' ds 1	15+00	750	425	.	Lyons SS	5380.29
SEEP	TRENCH 3 n=1	12/09/98	L abutment Ditch #3 50' ds 2	15+00	800	475	.	Lyons SS	5380.29

Sample Type	Sample ID	Sample Date	Sample Location	Axis Offset	Lateral Distance from Axis, ft	Lateral Distance from Toe, ft	Sample Depth, ft	General Geologic Formation	Reservoir Elevation, ft
WEIR n=47	SM-2 n=10	06/13/86	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5414.34
		06/13/86	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5414.34
		09/24/86	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5376.53
		07/01/87	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5417.94
		07/01/87	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5417.94
		09/17/87	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5397.48
		09/17/87	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5397.48
		06/29/90	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5407.81
		10/31/90	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5390.37
		05/20/91	R-toe drain ditch 825' ds	8+00	1260	825	.	Struct - Alluvium - Mix	5423.20
WEIR	SM-3 n=13	08/30/51	R-2500' ds of toe	12+00	2850	2400	.	Struct - Alluvium - Mix	.
		09/18/51	R-2500' ds of toe	12+00	2850	2400	.	Struct - Alluvium - Mix	.
		10/18/51	R-2500' ds of toe	12+00	2850	2400	.	Struct - Alluvium - Mix	.
		06/13/86	R-2500' ds of toe - "spring"	12+00	2850	2400	.	Struct - Alluvium - Mix	5414.34
		06/13/86	R-2500' ds of toe - "spring"	12+00	2850	2400	.	Struct - Alluvium - Mix	5414.34
		09/24/86	R-2500' ds of toe	12+00	2850	2400	.	Struct - Alluvium - Mix	5376.53
		09/24/86	R-2500' ds of toe - "spring"	12+00	2850	2400	.	Struct - Alluvium - Mix	5376.53
		06/29/90	R-2500' ds of toe	12+00	2850	2400	.	Struct - Alluvium - Mix	5407.81
		10/31/90	R-2500' ds of toe	12+00	2850	2400	.	Struct - Alluvium - Mix	5390.37
		05/20/91	R-2500' ds of toe	12+00	2850	2400	.	Struct - Alluvium - Mix	5423.20
		04/09/98	R-2500' ds of toe - sample A	12+00	2850	2400	.	Struct - Alluvium - Mix	5426.63
		04/09/98	R-2500' ds of toe - sample B	12+00	2850	2400	.	Struct - Alluvium - Mix	5426.63
		12/09/98	R-2500' ds of toe	12+00	2850	2400	.	Struct - Alluvium - Mix	5380.29
WEIR	SM-4 n=8	06/13/86	ds of seepage pond	11+00	1225	1800	.	Unknown Gypsum Mix	5414.34
		09/24/86	ds of seepage pond	11+00	1225	1800	.	Unknown Gypsum Mix	5376.53
		05/11/87	ds of seepage pond	11+00	1225	1800	.	Unknown Gypsum Mix	5414.08
		07/01/87	ds of seepage pond	11+00	1225	1800	.	Unknown Gypsum Mix	5417.94
		09/17/87	ds of seepage pond	11+00	1225	1800	.	Unknown Gypsum Mix	5397.48
		09/17/87	ds of seepage pond	11+00	1225	1800	.	Unknown Gypsum Mix	5397.48
		06/29/90	Seepage Pond North	12+00	1200	1775	.	Unknown Gypsum Mix	5407.81
		06/29/90	Seepage Pond South	12+00	1000	1575	.	Unknown Gypsum Mix	5407.81

Sample Type	Sample ID	Sample Date	Sample Location	Axis Offset	Lateral Distance from Axis, ft	Lateral Distance from Toe, ft	Sample Depth, ft	General Geologic Formation	Reservoir Elevation, ft
WEIR	SM-7	06/29/90	R abutment 3000' ds of toe	6+00	3670	3300	.	Struct - Alluvium - Mix	5407.81
	n=5	10/31/90	R abutment 3000' ds of toe	6+00	3670	3300	.	Struct - Alluvium - Mix	5390.37
		05/20/91	R abutment 3000' ds of toe	6+00	3670	3300	.	Struct - Alluvium - Mix	5423.20
		04/09/98	7A R abutment 3000' ds of toe	6+00	3670	3300	.	Struct - Alluvium - Mix	5426.63
		04/09/98	7B R abutment 3000' ds of toe	6+00	3670	3300	.	Struct - Alluvium - Mix	5426.63
WEIR	SM-8	06/20/97	Ditch #1 at L-toe	13+00	355	0	.	Structure - Alluvium	5423.30
	n=3	11/20/97	Ditch #1 at L-toe	13+00	355	0	.	Structure - Alluvium	5419.00
		04/09/98	Ditch #1 at L-toe	13+00	355	0	.	Structure - Alluvium	5426.63
WEIR	SM-8A	06/20/97	Ditch #2 - 100' ds of toe	10+00	500	100	.	Structure - Alluvium	5423.30
	n=3	11/20/97	Ditch #2 - 100' ds of toe	10+00	500	100	.	Structure - Alluvium	5419.00
		04/09/98	Ditch #2 - 100' ds of toe	10+00	500	100	.	Structure - Alluvium	5426.63
WEIR	SM-8B	06/20/97	Ditch #1 - 110' ds of toe	11+00	530	110	.	Structure - Alluvium	5423.30
	n=2	11/20/97	Ditch #1 - 110' ds of toe	11+00	530	110	.	Structure - Alluvium	5419.00
WEIR	SM-8C	06/20/97	Ditch #3 wet spot 4	14+00	725	400	.	Struct - Alluvium - Mix	5423.30
	n=3	11/20/97	Ditch #3 wet spot 4	14+00	725	400	.	Struct - Alluvium - Mix	5419.00
		04/09/98	Ditch #3 wet spot 4	14+00	725	400	.	Struct - Alluvium - Mix	5426.63
WELL n=41	DH91-1 n=4	06/20/97	dam axis	10+00	30	-405	473.56	Lower Lykins - Blaine	5423.30
		11/20/97	dam axis	10+00	30	-405	473.56	Lower Lykins - Blaine	5419.00
		04/09/98	dam axis	10+00	30	-405	473.56	Lower Lykins - Blaine	5426.63
		12/09/98	dam axis	10+00	30	-405	473.56	Lower Lykins - Blaine	5380.29
WELL	DH91-2 n=4	06/20/97	285' ds of toe	12+00	695	285	260.60	Lower Lykins - Blaine	5423.30
		11/20/97	285' ds of toe	12+00	695	285	260.60	Lower Lykins - Blaine	5419.00
		04/09/98	285' ds of toe	12+00	695	285	260.60	Lower Lykins - Blaine	5426.63
		12/09/98	285' ds of toe	12+00	695	285	260.60	Lower Lykins - Blaine	5380.29

Sample Type	Sample ID	Sample Date	Sample Location	Axis Offset	Lateral Distance from Axis, ft	Lateral Distance from Toe, ft	Sample Depth, ft	General Geologic Formation	Reservoir Elevation, ft
WELL	DH91-3A	11/20/97	dam axis	12+00	30	-370	326.81	Middle Lykins - Forelle	5419.00
	n=5	11/20/97	dam axis	12+00	30	-370	326.81	Middle Lykins - Forelle	5419.00
		06/20/97	dam axis	12+00	30	-370	326.81	Middle Lykins - Forelle	5423.30
		04/09/98	dam axis	12+00	30	-370	326.81	Middle Lykins - Forelle	5426.63
		12/09/98	dam axis	12+00	30	-370	326.81	Middle Lykins - Forelle	5380.29
WELL	DH91-4	06/20/97	dam axis	14+00	30	-290	134.78	Middle Lykins - Forelle	5423.30
	n=4	11/20/97	dam axis	14+00	30	-290	134.78	Middle Lykins - Forelle	5419.00
		04/09/98	dam axis	14+00	30	-290	134.78	Middle Lykins - Forelle	5426.63
		12/09/98	dam axis	14+00	30	-290	134.78	Middle Lykins - Forelle	5380.29
WELL	DH91-5	06/20/97	75' ds of toe	12+00	485	75	209.30	Middle Lykins - Forelle	5423.30
	n=2	04/09/98	75' ds of toe	12+00	485	75	209.30	Middle Lykins - Forelle	5426.63
WELL	DH92-5A	06/20/97	80' ds of toe	12+00	485	77	36.00	Upper Lykins - Alluvium	5423.30
	n=4	11/20/97	80' ds of toe	12+00	485	77	36.00	Upper Lykins - Alluvium	5419.00
		04/09/98	80' ds of toe	12+00	485	77	36.00	Upper Lykins - Alluvium	5426.63
		12/09/98	80' ds of toe	12+00	485	77	36.00	Upper Lykins - Alluvium	5380.29
WELL	DH92-5B	06/20/97	80' ds of toe	12+00	485	80	86.00	Upper Lykins - Alluvium	5423.30
	n=4	11/20/97	80' ds of toe	12+00	485	80	86.00	Upper Lykins - Alluvium	5419.00
		04/09/98	80' ds of toe	12+00	485	80	86.00	Upper Lykins - Alluvium	5426.63
		12/09/98	80' ds of toe	12+00	485	80	86.00	Upper Lykins - Alluvium	5380.29
WELL	DH92-6	06/20/97	left embankment toe	15+00	250	-15	.	Upper Lykins - Alluvium	5423.30
	n=3	04/09/98	left embankment toe	15+00	250	-15	.	Upper Lykins - Alluvium	5426.63
		12/09/98	left embankment toe	15+00	250	-15	.	Upper Lykins - Alluvium	5380.29
WELL	DH92-7	06/20/97	left Ditch #3 250' ds of toe	14+00	545	255	.	Middle Lykins - Forelle	5423.30
	n=4	11/20/97	left Ditch #3 250' ds of toe	14+00	545	255	.	Middle Lykins - Forelle	5419.00
		04/09/98	left Ditch #3 250' ds of toe	14+00	545	255	.	Middle Lykins - Forelle	5426.63
		12/09/98	left Ditch #3 250' ds of toe	14+00	545	255	.	Middle Lykins - Forelle	5380.29
WELL	DH97-1	12/09/98	40' ds of toe	13+00	400	35	.	Middle Lykins - Forelle	5380.29

Sample Type	Sample ID	Sample Date	Sample Location	Axis Offset	Lateral Distance from Axis, ft	Lateral Distance from Toe, ft	Sample Depth, ft	General Geologic Formation	Reservoir Elevation, ft
WELL	DH97-4	11/20/97	40' ds of toe	13+00	430	45	21.00	Upper Lykins - Alluvium	5419.00
	n=3	04/09/98	40' ds of toe	13+00	430	45	21.00	Upper Lykins - Alluvium	5426.63
		12/09/98	40' ds of toe	13+00	430	45	21.00	Upper Lykins - Alluvium	5380.29
WELL	DH98-10A	12/09/98	50' ds of toe	14+00	355	50	.	Middle Lykins - Forelle	5380.29
WELL	DH98-6	12/09/98	Ditch #2 430' ds of toe	10+00	700	430	.	Lower Lykins - Blaine	5380.29
WELL	DH98-7	12/09/98	55' ds of toe	11+00	480	55	.	Lower Lykins - Blaine	5380.29
MISC n=2	Sink Hole n=1	08/14/89	south end of reservoir		.	.	.	None	5381.43
MISC	Sample A n=1	05/20/91	unknown		.	.	.	None	5423.20

Table A1-2   Summary of ion balance percentages for samples collected from Horsetooth Dam, 1951-1998.

Sample Type	Sample ID	Sampling Date	pH	TDS, mg/L	Ion Sum, mg/L	Anion Sum, meq/L	Cation Sum, meq/L	Ion Balance Percent
drain	SM-1	06/13/86	7.86	130.00	146.36	1.87	1.86	-.27
		06/13/86	7.60	133.00	145.34	1.85	1.84	-.46
		09/24/86	8.50	131.00	164.16	2.18	2.10	-1.87
		05/11/87	7.30	128.00	159.59	2.11	2.06	-1.34
		05/11/87	7.58	141.00	171.81	2.21	2.20	-.34
		09/17/87	7.33	104.00	159.86	2.05	2.06	.13
		09/17/87	7.51	106.00	159.41	2.02	2.09	1.62
		06/29/90	8.20	.	155.77	1.95	2.11	3.90
		10/31/90	5.86	147.00	218.51	2.83	2.63	-3.72
		05/20/91	7.18	117.00	157.08	2.05	1.96	-2.26
		06/20/97	6.70	93.30	162.17	2.11	2.05	-1.43
		11/20/97	7.03	177.06	155.25	2.02	1.87	-3.80
		04/09/98	7.60	124.00	156.70	2.04	1.94	-2.55
drain	SM-1A-CON	12/09/98	6.92	67.04	107.71	1.39	1.37	-.83
drain	SM-1A-COR	12/09/98	7.23	293.13	432.91	5.64	5.25	-3.56
drain	SM-1A	04/09/98	7.48	68.50	119.25	1.54	1.49	-1.61
		12/09/98	6.98	63.71	107.08	1.39	1.33	-2.14
drain	V-5	09/24/86	8.46	.55	573.63	6.97	7.58	4.21
		06/20/97	7.46	154.00	222.34	2.81	2.95	2.39
		11/20/97	7.80	110.91	194.45	2.48	2.38	-2.11
		04/09/98	8.13	51.40	168.12	2.16	2.08	-1.74
		12/09/98	9.19	145.36	192.29	2.58	2.58	.05
drain	V-6	06/20/97	8.10	117.00	174.13	2.09	2.14	1.22
		11/20/97	9.44	2720.00	3283.04	42.39	40.34	-2.48
		04/09/98	6.91	7.43	52.40	.68	.65	-1.66
		12/09/98	7.21	79.48	120.82	1.56	1.50	-2.03
seep	TRENCH 1	12/09/98	6.84	49.23	80.36	1.02	1.03	.06
seep	TRENCH 2	12/09/98	6.86	51.35	77.16	.99	.97	-.65
seep	TRENCH 3	12/09/98	7.01	37.83	76.71	.99	.95	-1.95
sink hole	Sink Hole	08/14/89	7.24	204.00	235.18	3.00	3.09	1.39
source	Reservoir	08/30/51	6.60	74.00	56.30	.78	.64	-10.01
		09/18/51	7.40	52.00	71.30	.97	.83	-7.65
		10/18/51	6.90	78.00	71.00	.93	.91	-.93
		06/13/86	6.90	85.80	55.44	.70	.71	.90
		06/13/86	6.78	70.90	49.88	.63	.65	1.64
		05/11/87	6.18	55.50	50.05	.66	.64	-2.05
		07/01/87	6.30	41.90	42.71	.57	.56	-.19
		09/17/87	6.39	40.10	42.18	.53	.56	3.13
		09/17/87	6.33	24.20	41.84	.53	.54	1.16
		08/14/89	6.16	63.80	63.04	.81	.83	1.41
		08/14/89	6.15	64.40	63.02	.81	.83	1.37
		06/29/90	8.38	.	61.20	.75	.89	8.72
		10/31/90	5.32	69.30	64.55	.84	.81	-1.58
		05/20/91	6.75	58.50	63.26	.84	.79	-3.04
		06/20/97	6.26	36.60	48.42	.66	.57	-7.04
		06/20/97	6.32	34.80	46.57	.63	.57	-5.29
		10/02/97	6.55	44.80	35.64	.46	.49	3.22
		04/09/98	6.68	69.80	45.17	.58	.59	.47
		12/09/98	6.49	26.63	49.79	.66	.60	-4.08
unknown	Sample A	05/20/91	8.59	129.00	166.87	2.32	2.30	-.36

Table A1-2 Ion Balance Percentages (cont.)

Sample Type	Sample ID	Sampling Date	pH	TDS, mg/L	Ion Sum, mg/L	Anion Sum, meq/L	Cation Sum, meq/L	Ion Balance Percent
weir	**SM-2**	06/13/86	8.18	162.00	174.47	2.21	2.30	2.02
		06/13/86	8.03	128.00	172.18	2.20	2.16	-.97
		09/24/86	7.20	110.00	157.17	2.03	1.98	-1.08
		07/01/87	7.00	104.00	138.63	1.79	1.79	-.04
		07/01/87	7.61	130.00	164.54	2.10	2.19	2.23
		09/17/87	7.27	118.00	174.53	2.20	2.31	2.34
		09/17/87	6.80	123.00	173.08	2.19	2.28	2.05
		06/29/90	8.76	.	185.24	2.40	2.52	2.47
		10/31/90	6.99	115.00	180.74	2.32	2.37	.98
		05/20/91	8.59	133.00	166.87	2.33	2.25	-1.67
weir	**SM-3**	08/30/51	7.80	300.00	367.00	4.77	5.06	2.94
		09/18/51	8.20	272.00	335.40	4.40	4.58	2.04
		10/18/51	7.60	286.00	370.10	4.82	5.00	1.80
		06/13/86	7.60	136.00	154.75	1.99	1.95	-1.08
		06/13/86	7.54	118.00	154.55	1.99	1.95	-.85
		09/24/86	6.60	103.00	139.66	1.89	1.81	-2.11
		09/24/86	6.88	102.00	158.73	2.06	2.01	-1.19
		06/29/90	8.38	.	136.55	1.75	2.00	6.69
		10/31/90	6.12	165.00	141.28	1.86	1.93	1.69
		05/20/91	7.31	129.00	125.56	1.68	1.62	-1.79
		04/09/98	7.82	73.50	90.55	1.15	1.17	.88
		04/09/98	7.50	158.00	204.47	2.63	2.69	1.03
		12/09/98	6.95	79.58	106.24	1.40	1.36	-1.73
weir	**SM-4**	06/13/86	10.10	310.00	320.82	4.83	4.59	-2.56
		09/24/86	7.68	343.00	375.09	5.13	5.28	1.42
		05/11/87	8.56	354.00	353.68	5.04	4.93	-1.13
		07/01/87	8.98	314.00	353.73	5.18	4.96	-2.16
		09/17/87	6.96	368.00	398.70	5.59	5.58	-.07
		09/17/87	6.88	382.00	398.46	5.59	5.57	-.21
weir	**SM-7**	06/29/90	8.72	.	150.76	1.92	2.31	9.35
		10/31/90	6.13	130.00	171.17	2.25	2.31	1.28
		05/20/91	7.52	130.00	154.71	2.07	2.02	-1.13
		04/09/98	7.99	34.10	62.24	.80	.78	-.84
		04/09/98	7.90	61.70	68.47	.87	.87	-.29
weir	**SM-8**	06/20/97	6.54	62.10	115.59	1.49	1.42	-2.37
		11/20/97	7.23	390.03	91.43	1.18	1.10	-3.30
		04/09/98	7.70	44.80	81.76	1.05	.99	-2.86
weir	**SM-8A**	06/20/97	6.56	34.40	126.33	1.65	1.60	-1.61
		11/20/97	7.27	87.51	130.31	1.54	1.92	11.18
		04/09/98	7.56	71.40	120.03	1.54	1.53	-.48
weir	**SM-8B**	06/20/97	6.64	63.40	104.11	1.34	1.31	-1.09
		11/20/97	8.85	179.56	71.62	1.14	1.07	-3.10
weir	**SM-8C**	06/20/97	6.90	87.20	163.20	2.07	2.12	1.23
		11/20/97	7.58	325.88	134.18	1.69	1.73	1.07
		04/09/98	8.11	70.20	123.63	1.56	1.56	-.10
weir/pond	**SM-4**	06/29/90	10.40	.	338.17	5.42	5.24	-1.70
		06/29/90	10.30	.	334.11	5.39	5.02	-3.55
well	**DH91-1**	06/20/97	9.47	196.00	207.97	2.95	3.15	3.24
		11/20/97	11.17	770.21	778.45	12.37	11.66	-2.94
		04/09/98	10.70	720.80	651.38	9.99	9.85	-.72
		12/09/98	7.56	59.41	69.95	.85	.96	6.25
well	**DH91-2**	06/20/97	6.74	1550.00	1583.02	23.89	23.52	-.78
		11/20/97	7.00	1770.00	1563.55	23.90	22.22	-3.65
		04/09/98	7.21	1600.00	1507.68	22.73	22.27	-1.03

Table A1-2 Ion Balance Percentages (cont.)

Sample Type	Sample ID	Sampling Date	pH	TDS, mg/L	Ion Sum, mg/L	Anion Sum, meq/L	Cation Sum, meq/L	Ion Balance Percent
	DH91-2	12/09/98	7.02	1570.00	1515.18	23.24	21.23	-4.52
well	**DH91-3A**	11/20/97	7.31	325.23	82.45	1.03	1.14	4.93
		11/20/97	6.89	169.30	78.88	1.01	1.00	-.59
		06/20/97	6.68	46.80	84.74	1.12	1.03	-4.31
		04/09/98	7.61	61.80	78.89	1.04	.99	-2.47
		12/09/98	7.07	44.49	85.22	1.11	1.06	-2.32
well	**DH91-4**	06/20/97	6.65	60.40	70.56	.92	.88	-2.37
		11/20/97	7.03	294.80	64.35	.79	.87	4.62
		04/09/98	7.90	53.20	60.91	.78	.78	.23
		12/09/98	7.11	28.40	71.33	.92	.87	-2.77
well	**DH91-5**	06/20/97	6.68	62.20	77.50	1.02	.98	-1.84
		04/09/98	7.98	66.00	73.86	.95	.96	.69
well	**DH92-5A**	06/20/97	5.94	346.00	126.98	.92	3.93	61.94
		11/20/97	6.59	403.58	91.61	1.11	1.37	10.30
		04/09/98	7.81	81.80	101.07	1.30	1.26	-1.88
		12/09/98	8.12	170.88	244.65	3.17	3.10	-1.17
well	**DH92-5B**	06/20/97	10.00	190.00	163.03	2.82	2.38	-8.50
		11/20/97	11.30	387.18	179.58	4.18	3.29	-11.88
		04/09/98	11.30	295.00	228.73	5.47	5.27	-1.82
		12/09/98	8.77	159.78	180.61	2.69	2.44	-4.89
well	**DH92-6**	06/20/97	6.89	156.00	240.24	3.06	3.13	1.15
		04/09/98	7.42	163.00	235.45	2.99	3.03	.63
		12/09/98	7.35	162.25	252.18	3.22	3.21	-.16
well	**DH92-7**	06/20/97	7.43	62.10	97.91	1.28	1.23	-1.92
		11/20/97	7.44	281.78	102.01	1.32	1.24	-3.08
		04/09/98	8.11	57.10	90.22	1.15	1.14	-.66
		12/09/98	7.99	56.68	97.48	1.26	1.19	-2.70
well	**DH97-1**	12/09/98	6.88	30.77	68.43	.88	.85	-1.52
well	**DH97-4**	11/20/97	7.39	583.58	717.71	9.76	9.61	-.77
		04/09/98	6.95	684.00	883.94	11.14	12.03	3.86
		12/09/98	7.81	271.13	339.96	4.20	4.81	6.69
well	**DH98-10A**	12/09/98	8.47	86.32	100.01	1.51	1.33	-6.22
well	**DH98-6**	12/09/98	9.46	518.00	174.64	2.45	3.34	15.46
well	**DH98-7**	12/09/98	9.09	386.89	400.38	6.00	5.63	-3.23

Figure A1-1   Histogram showing distribution of ion balance percentages for Horsetooth Dam seepage analyzed for major ions.
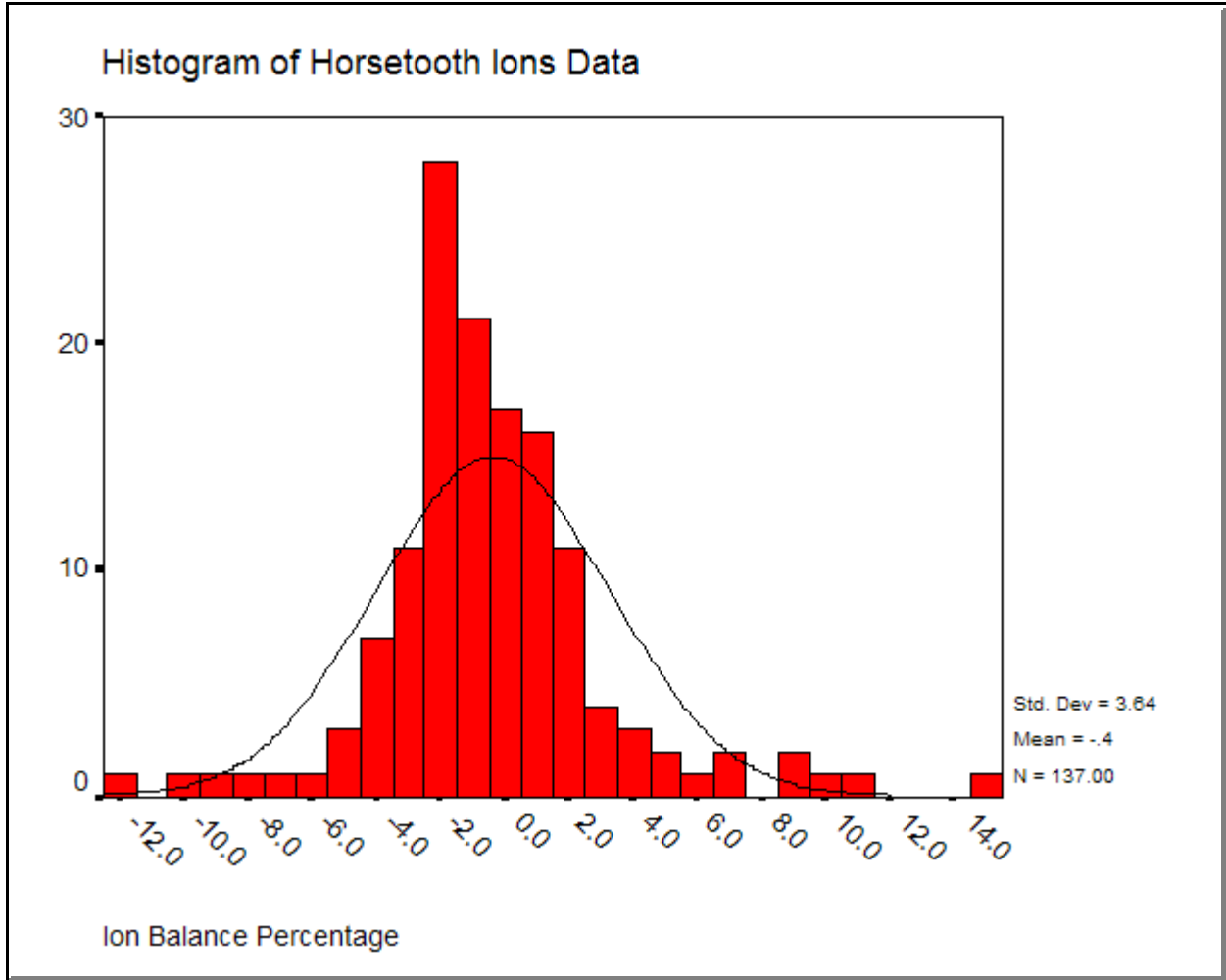
Table A1-3   Summary of repeatability of duplicate samples from the 1986 and 1987 sampling events. The Relative Percent Difference (RPD) values are indicative of sampling error. High RPD values are only indicative of a quality issue if the analyte concentration is above the limit of quantitation (LOQ), which is 3.3-times the limit of detection (LOD).

Analyte	Reservoir	Reservoir	Reservoir	SM1	SM1	SM1	SM2	SM2	SM2	SM3	SM3	SM4
Date	6/13/86	9/17/87	6/20/97	6/13/86	5/11/87	9/17/87	6/13/86	7/1/87	9/17/87	6/13/86	9/24/86	9/17/87
EC	7.74%	15.96%	0.00%	1.09%	10.68%	0.00%	0.94%	13.00%	1.87%	0.51%	0.00%	0.00%
PH	1.75%	0.94%	0.95%	3.36%	3.76%	2.43%	1.85%	8.35%	6.68%	0.79%	4.15%	1.16%
TDS	19.02%	49.46%	5.04%	2.28%	9.67%	1.90%	23.45%	22.22%	4.15%	14.17%	0.98%	3.73%
SUM	10.56%	0.81%	3.90%	0.70%	7.37%	0.28%	1.32%	17.09%	0.83%	0.13%	12.78%	0.06%
CA	6.05%	0.00%	0.27%	0.00%	7.91%	2.05%	3.29%	22.69%	1.78%	0.00%	13.08%	0.00%
MG	0.00%	4.92%	2.43%	3.17%	9.13%	1.99%	14.66%	23.13%	1.31%	0.71%	63.61%	0.42%
NA	2.26%	14.25%	3.20%	6.00%	7.35%	2.68%	3.48%	0.87%	0.95%	0.00%	52.74%	1.14%
K	84.62%	8.09%	0.00%	33.85%	34.04%	0.00%	18.49%	9.84%	32.79%	0.00%	12.77%	6.45%
HCO3	10.25%	0.36%	6.71%	0.94%	12.99%	0.00%	0.00%	19.23%	0.78%	0.00%	46.70%	0.00%
CO3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
OH	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SO4	7.23%	0.00%	4.10%	8.51%	1.26%	0.00%	5.41%	15.25%	0.00%	4.08%	115.94%	0.00%
CL	11.02%	0.00%	1.86%	30.77%	135.14%	66.67%	0.00%	73.42%	0.00%	0.00%	8.89%	0.00%
SUM_AN	10.53%	0.00%	4.65%	1.08%	4.63%	1.47%	0.45%	15.94%	0.46%	0.00%	8.61%	0.00%
SUM_CAT	8.82%	3.64%	0.00%	1.08%	6.57%	1.45%	6.28%	20.10%	1.31%	0.00%	10.47%	0.18%
				mg/L								
FE			13.71%	0.057	mg/L	DL = 0.004	GOOD			AVG RES	AV SM	ALL AVG
MN			66.67%	0.003	mg/L	DL = 0.002	at LOD			6.21%	11.58%	10.24%
AL			19.76%	0.108	mg/L	DL = 0.030	at LOQ					
SI			5.76%	1.390	mg/L	DL = 0.020	GOOD					

Analyte	RES AVG	SM AVG	ALL AVG	COMMENT
EC	7.90%	3.12%	4.32%	
PH	1.22%	3.62%	3.02%	
TDS	24.50%	9.17%	13.01%	
SUM	5.09%	4.51%	4.65%	
CA	2.11%	5.64%	4.76%	
MG	2.45%	13.13%	10.46%	
NA	6.57%	8.36%	7.91%	
K	30.90%	16.47%	20.08%	LOD = 1.00
HCO3	5.77%	8.96%	8.16%	
CO3	0.00%	0.00%	0.00%	LOW CONC
OH	0.00%	0.00%	0.00%	LOW CONC
SO4	3.78%	16.72%	13.48%	
CL	4.29%	34.99%	27.31%	LOD = 0.500
SUM_AN	5.06%	3.63%	3.98%	
SUM_CAT	4.15%	5.27%	4.99%	

APPENDIX 2

Tables and Figures Summarizing Chemistry Data from

Seeps, Wells, and Reservoir at Horsetooth Dam

Table A2-1a Major ions chemistry data for samples collected from Horsetooth Reservoir behind the dam. Data should be rounded to 3 significant figures.

Date	EC µS/cm	pH su	Ca²⁺ mg/L	Mg²⁺ mg/L	Na⁺ mg/L	K⁺ mg/L	HCO₃⁻ mg/L	CO₃²⁻ mg/L	OH- mg/L	SO₄²⁻ mg/L	Cl⁻ mg/L
08/30/51	64.0	6.60	7.40	1.80	2.10	1.20	35.40	0.00	0.00	4.80	3.60
09/18/51	84.0	7.40	9.00	3.10	1.80	2.00	47.00	0.00	0.00	4.80	3.60
10/18/51	74.0	6.90	9.20	3.70	2.30	1.90	48.20	0.00	0.00	2.90	2.80
06/13/86	71.1	6.90	9.19	1.29	2.24	1.85	35.90	0.00	0.00	4.30	0.67
06/13/86	65.8	6.78	8.65	1.29	2.19	0.75	32.40	0.00	0.00	4.00	0.60
05/11/87	73.9	6.18	7.82	1.42	2.52	0.79	30.10	0.00	0.00	5.20	2.20
07/01/87	54.7	6.30	6.42	1.47	2.36	0.76	21.30	0.00	0.00	10.40	0.00
09/17/87	72.4	6.39	6.70	1.25	2.33	0.90	27.80	0.00	0.00	2.50	0.70
09/17/87	61.7	6.33	6.70	1.19	2.02	0.83	27.90	0.00	0.00	2.50	0.70
08/14/89	78.3	6.16	11.20	1.67	2.73	0.73	38.80	0.00	0.00	6.55	1.36
08/14/89	77.6	6.15	11.20	1.75	2.58	0.73	38.90	0.00	0.00	6.50	1.36
06/29/90	80.0	8.38	11.00	1.80	2.67	3.08	35.40	0.00	0.00	4.85	2.40
10/31/90	53.2	5.32	10.50	1.70	2.85	1.03	41.20	0.00	0.00	5.40	1.87
05/20/91	74.7	6.75	9.81	1.62	2.91	1.52	38.90	0.00	0.00	5.35	3.15
06/20/97	60.0	6.26	7.48	1.25	2.22	0.00	30.80	0.00	0.00	4.54	2.13
06/20/97	60.0	6.32	7.50	1.22	2.15	0.00	28.80	0.00	0.00	4.73	2.17
10/02/97	54.7	6.55	6.36	1.09	1.90	0.00	22.40	0.00	0.00	2.39	1.50
04/09/98	69.6	6.68	7.86	1.20	2.17	0.00	30.20	0.00	0.00	2.78	0.96
12/09/98	63.0	6.49	8.17	1.33	2.00	0.00	33.69	0.00	0.00	3.57	1.03
Total	19	19.0	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Minimum		53.2	5.32	6.36	1.09	1.80	0.00	21.30	0.00	0.00	2.39	0.00
Maximum		84.0	8.38	11.20	3.70	2.91	3.08	48.20	0.00	0.00	10.40	3.60
Mean		**68.0**	**6.57**	**8.53**	**1.64**	**2.32**	**0.95**	**33.95**	**0.00**	**0.00**	**4.63**	**1.73**
Median		**69.6**	**6.49**	**8.17**	**1.42**	**2.24**	**0.79**	**33.69**	**.**	**.**	**4.73**	**1.50**
Std. Deviation		9.2	0.61	1.62	0.67	0.32	0.83	7.23	0.00	0.00	1.89	1.06

Note: Total row has an extra count value (19) in the Date column.

Table A2-1b   Trace element chemistry data for samples collected from Horsetooth Reservoir behind the dam.

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
	08/30/51	6.60	74.0	.	.	.	.
	09/18/51	7.40	52.0	.	.	.	.
	10/18/51	6.90	78.0	.	.	.	.
	06/13/86	6.90	85.8	.	.	.	.
	06/13/86	6.78	70.9	.	.	.	.
	05/11/87	6.18	55.5	.	.	.	.
	07/01/87	6.30	41.9	.	.	.	.
	09/17/87	6.39	40.1	.	.	.	.
	09/17/87	6.33	24.2	.	.	.	.
	08/14/89	6.16	63.8	.	.	.	.
	08/14/89	6.15	64.4	.	.	.	.
	06/29/90	8.38	.	0.054	-0.004	0.126	1.080
	10/31/90	5.32	69.3	0.022	-0.004	0.068	1.010
	05/20/91	6.75	58.5	0.010	-0.004	-0.030	0.970
	06/20/97	6.26	36.6	0.053	-0.004	0.098	1.350
	06/20/97	6.32	34.8	0.061	0.004	0.119	1.430
	10/02/97	6.55	44.8	0.086	0.007	0.197	1.960
	04/09/98	6.68	69.8	0.021	-0.004	0.032	1.780
	12/09/98	6.49	26.6	0.052	0.006	0.104	1.090
Minimum		5.32	24.2	0.010	-0.004	-0.030	0.970
Maximum		8.38	85.8	0.086	0.007	0.197	1.960
Mean		**6.57**	**55.1**	**0.045**	**0.000**	**0.089**	**1.334**
Median		**6.49**	**57.0**	**0.052**	**-0.004**	**0.101**	**1.220**
Std. Deviation		0.61	18.3	0.025	0.005	0.068	0.371

Table A2-1c   Mineral saturation indices - log(AP/KT) - for representative minerals at Horsetooth Dam as calculated \by the MINTEQA2 chemical equilibrium model. Negative numbers suggest under saturation with respect to the given mineral, positive numbers suggest over saturation with respect to the given mineral.

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
	08/30/51	6.60	74.0	-3.670	-3.930	-8.390	-3.300	-4.940	.
	09/18/51	7.40	52.0	-3.600	-3.850	-8.080	-3.230	-4.710	.
	10/18/51	6.90	78.0	-3.810	-3.840	-7.990	-3.440	-4.633	.
	06/13/86	6.90	85.8	-3.620	-3.830	-8.440	-3.260	-5.090	.
	06/13/86	6.78	70.9	-3.620	-3.830	-8.440	-3.260	-5.090	.
	05/11/87	6.18	55.5	-3.610	-3.900	-8.460	-3.240	-5.043	.
	07/01/87	6.30	41.9	-3.390	-3.990	-8.540	-3.030	-5.030	.
	09/17/87	6.39	40.1	-3.980	-3.960	-8.570	-3.610	-5.090	.
	09/17/87	6.33	24.2	-3.980	-3.960	-8.570	-3.610	-5.090	.
	08/14/89	6.16	63.8	-3.370	-3.750	-8.250	-3.000	-4.980	.
	08/14/89	6.15	64.4	-3.370	-3.750	-8.250	-3.000	-4.980	.
	06/29/90	8.38	.	-3.530	-0.574	-1.860	-3.410	-1.760	-0.574
	10/31/90	5.32	69.3	-3.460	-3.540	-7.750	-3.380	-4.690	-3.540
	05/20/91	6.75	58.5	-3.470	-2.130	-4.880	-3.410	-3.240	-2.130
	06/20/97	6.26	36.6	-3.680	-3.920	-8.530	-3.310	-5.100	-1.130
	06/20/97	6.32	34.8	-3.680	-3.920	-8.530	-3.310	-5.100	-1.130
	10/02/97	6.55	44.8	-4.020	-3.980	-8.650	-3.650	-5.150	-0.966
	04/09/98	6.68	69.8	-3.870	-3.900	-8.520	-3.500	-5.110	-1.010
	12/09/98	6.49	26.6	-3.750	-3.880	-8.470	-3.380	-5.070	-1.221
Minimum		5.32	24.2	-4.020	-3.990	-8.650	-3.650	-5.150	-3.540
Maximum		8.38	85.8	-3.370	-0.574	-1.860	-3.000	-1.760	-0.574
Mean		**6.5705**	**55.1**	**-3.657**	**-3.602**	**-7.851**	**-3.333**	**-4.731**	**-1.463**
Median		**6.4900**	**57.0**	**-3.620**	**-3.880**	**-8.440**	**-3.310**	**-5.043**	**-1.130**
Std. Deviation		.6083	18.3	0.205	0.841	1.673	0.191	0.838	0.947

Table A2-2a   Major ions chemistry data for seepage samples collected from toe drains and weirs at Horsetooth Dam.

Toe Drain Seepage Samples influenced by Dam Structure and/or Alluvium Contact

	Date	EC µS/cm	pH su	Ca²⁺ mg/L	Mg²⁺ mg/L	Na⁺ mg/L	K⁺ mg/L	HCO₃⁻ mg/L	CO₃²⁻ mg/L	OH- mg/L	SO₄²⁻ mg/L	Cl⁻ mg/L
SM-1	06/13/86	183	7.86	23.20	6.08	4.29	0.54	107.00	0.00	0.00	4.50	0.75
	06/13/86	185	7.60	23.20	5.89	4.04	0.76	106.00	0.00	0.00	4.90	0.55
	09/24/86	210	8.50	25.30	7.52	4.50	0.75	114.00	4.49	0.00	7.60	0.00
	05/11/87	195	7.30	25.50	7.11	4.23	0.55	108.00	0.00	0.00	8.00	6.20
	05/11/87	217	7.58	27.60	7.79	3.93	0.39	123.00	0.00	0.00	7.90	1.20
	09/17/87	195	7.33	24.10	7.96	4.16	0.64	117.00	0.00	0.00	5.00	1.00
	09/17/87	195	7.51	24.60	8.12	4.05	0.64	117.00	0.00	0.00	5.00	0.00
	06/29/90	201	8.20	25.30	7.00	4.54	2.96	108.00	0.00	0.00	5.61	2.36
	10/31/90	216	5.86	34.70	7.90	4.78	1.52	161.00	0.00	0.00	6.75	1.86
	05/20/91	195	7.18	24.00	6.68	4.95	0.00	112.00	0.00	0.00	6.58	2.87
	06/20/97	197	6.70	25.60	6.79	4.93	0.00	116.00	0.00	0.00	5.47	3.38
	11/20/97	195	7.03	23.30	6.22	4.53	0.00	116.00	0.00	0.00	3.84	1.36
	04/09/98	195	7.60	24.20	6.36	4.84	0.00	114.00	0.00	0.00	4.21	3.09
Minimum		183	5.86	23.20	5.89	3.93	0.00	106.00	0.00	0.00	3.84	0.00
Maximum		217	8.50	34.70	8.12	4.95	2.96	161.00	4.49	0.00	8.00	6.20
Mean		**198**	**7.40**	**25.43**	**7.03**	**4.44**	**0.67**	**116.85**	**0.35**	**0.00**	**5.80**	**1.89**
Median		**195**	**7.51**	**24.60**	**7.00**	**4.50**	**0.55**	**114.00**	**0.00**	**.**	**5.47**	**1.36**
Std. Deviation		10	0.66	3.04	0.77	0.36	0.81	14.14	1.25	0.00	1.42	1.71
SM-1A	04/09/98	151	7.48	19.00	4.95	3.18	0.00	86.60	0.00	0.00	4.38	1.14
	12/09/98	133	6.98	17.60	4.24	2.43	0.00	77.06	0.00	0.00	4.59	1.16
Mean		**142**	**7.23**	**18.30**	**4.60**	**2.81**	**0.00**	**81.83**	**0.00**	**0.00**	**4.49**	**1.15**
SM-1A-CON	12/09/98	134	6.92	18.10	4.35	2.47	0.00	76.95	0.00	0.00	4.67	1.17
SM-1A-COR	12/09/98	506	7.23	73.80	16.30	5.20	0.00	320.26	0.00	0.00	13.50	3.85
SM-8	06/20/97	137	6.54	22.60	2.43	2.16	0.00	82.10	0.00	0.00	4.40	1.90
	11/20/97	112	7.23	16.40	1.85	2.99	0.00	66.20	0.00	0.00	2.93	1.06
	04/09/98	102	7.70	15.00	1.86	2.11	0.00	59.10	0.00	0.00	2.82	0.87
Minimum		102	6.54	15.00	1.85	2.11	0.00	59.10	0.00	0.00	2.82	0.87
Maximum		137	7.70	22.60	2.43	2.99	0.00	82.10	0.00	0.00	4.40	1.90
Mean		**117**	**7.16**	**18.00**	**2.05**	**2.42**	**0.00**	**69.13**	**0.00**	**0.00**	**3.38**	**1.28**
Median		**112**	**7.23**	**16.40**	**1.86**	**2.16**	**.**	**66.20**	**.**	**.**	**2.93**	**1.06**
Std. Deviation		18	0.58	4.04	0.33	0.49	0.00	11.78	0.00	0.00	0.88	0.55

Table A2-2a - Samples Influenced by Dam Structure and/or Alluvium Contact (cont)

	Date	EC µS/cm	pH su	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^+ mg/L	K^+ mg/L	HCO_3^- mg/L	CO_3^{2-} mg/L	OH- mg/L	SO_4^{2-} mg/L	Cl^- mg/L
V-5	09/24/86	833	8.46	25.30	3.92	123.00	25.40	331.00	5.41	0.00	42.50	17.10
	06/20/97	269	7.46	32.10	10.60	9.65	2.26	157.00	0.00	0.00	8.40	2.33
	11/20/97	234	7.80	25.40	8.40	7.27	3.92	144.98	0.00	0.00	3.33	1.15
	04/09/98	202	8.13	24.40	7.45	5.20	1.01	126.00	0.00	0.00	3.11	0.95
	12/09/98	262	9.19	8.32	1.33	36.00	19.30	90.70	25.90	0.00	9.64	1.10
Minimum		202	7.46	8.32	1.33	5.20	1.01	90.70	0.00	0.00	3.11	0.95
Maximum		833	9.19	32.10	10.60	123.00	25.40	331.00	25.90	0.00	42.50	17.10
Mean		**360**	**8.21**	**23.10**	**6.34**	**36.22**	**10.38**	**169.94**	**6.26**	**0.00**	**13.40**	**4.53**
Median		**262**	**8.13**	**25.30**	**7.45**	**9.65**	**3.92**	**144.98**	**0.00**	**.**	**8.40**	**1.15**
Std. Deviation		266	0.66	8.82	3.69	50.09	11.19	93.46	11.23	0.00	16.53	7.05
V-6	06/20/97	207	8.10	18.00	2.00	16.90	13.40	114.00	0.00	0.00	7.68	2.15
	11/20/97	3960	9.44	8.40	3.12	639.00	464.00	1580.00	337.38	0.00	248.00	3.14
	04/09/98	72	6.91	9.01	1.18	2.45	0.00	36.00	0.00	0.00	2.80	0.96
	12/09/98	148	7.21	18.00	5.11	4.14	0.00	89.10	0.00	0.00	3.45	1.02
Minimum		72	6.91	8.40	1.18	2.45	0.00	36.00	0.00	0.00	2.80	0.96
Maximum		3960	9.44	18.00	5.11	639.00	464.00	1580.00	337.38	0.00	248.00	3.14
Mean		**1097**	**7.92**	**13.35**	**2.85**	**165.62**	**119.35**	**454.78**	**84.35**	**0.00**	**65.48**	**1.82**
Median		**178**	**7.66**	**13.51**	**2.56**	**10.52**	**6.70**	**101.55**	**0.00**	**.**	**5.57**	**1.59**
Std. Deviation		1910	1.14	5.37	1.70	315.65	229.85	750.85	168.69	0.00	121.70	1.04

Seepage Weirs and Samples Located Downstream of and Near the Toe

	Date	EC µS/cm	pH su	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^+ mg/L	K^+ mg/L	HCO_3^- mg/L	CO_3^{2-} mg/L	OH- mg/L	SO_4^{2-} mg/L	Cl^- mg/L
SM-8A	06/20/97	157	6.56	19.90	5.50	3.54	0.00	89.10	0.00	0.00	5.70	2.59
	11/20/97	155	7.27	19.30	5.06	9.80	4.54	86.02	0.00	0.00	4.37	1.22
	04/09/98	150	7.56	19.40	5.10	3.26	0.00	86.90	0.00	0.00	4.22	1.15
Minimum		150	6.56	19.30	5.06	3.26	0.00	86.02	0.00	0.00	4.22	1.15
Maximum		157	7.56	19.90	5.50	9.80	4.54	89.10	0.00	0.00	5.70	2.59
Mean		**154**	**7.13**	**19.53**	**5.22**	**5.53**	**1.51**	**87.34**	**0.00**	**0.00**	**4.76**	**1.65**
Median		**155**	**7.27**	**19.40**	**5.10**	**3.54**	**0.00**	**86.90**	**.**	**.**	**4.37**	**1.22**
Std. Deviation		4	0.51	0.32	0.24	3.70	2.62	1.58	0.00	0.00	0.81	0.81
SM-8B	06/20/97	128	6.64	20.70	2.22	2.20	0.00	71.90	0.00	0.00	5.15	1.94
	11/20/97	110	8.85	16.70	1.86	2.00	0.00	30.58	16.53	0.00	2.87	1.08
Mean		**119**	**7.75**	**18.70**	**2.04**	**2.10**	**0.00**	**51.24**	**8.26**	**0.00**	**4.01**	**1.51**

Table A2-2a - Seepage Weirs and Samples Located Downstream of and Near the Toe

	Date	EC µS/cm	pH su	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^+ mg/L	K^+ mg/L	HCO_3^- mg/L	CO_3^{2-} mg/L	OH- mg/L	SO_4^{2-} mg/L	Cl^- mg/L
SM-8C	06/20/97	200	6.90	33.40	4.35	2.18	0.00	116.00	0.00	0.00	5.16	2.11
	11/20/97	170	7.58	27.10	3.51	1.96	0.00	97.43	0.00	0.00	3.36	0.82
	04/09/98	155	8.11	24.70	2.89	2.08	0.00	89.90	0.00	0.00	3.22	0.84
Minimum		155	6.90	24.70	2.89	1.96	0.00	89.90	0.00	0.00	3.22	0.82
Maximum		200	8.11	33.40	4.35	2.18	0.00	116.00	0.00	0.00	5.16	2.11
Mean		**175**	**7.53**	**28.40**	**3.58**	**2.07**	**0.00**	**101.11**	**0.00**	**0.00**	**3.91**	**1.26**
Median		**170**	**7.58**	**27.10**	**3.51**	**2.08**	**.**	**97.43**	**.**	**.**	**3.36**	**0.84**
Std. Deviation		23	0.61	4.49	0.73	0.11	0.00	13.43	0.00	0.00	1.08	0.74
SM-4	06/13/86	387	10.10	36.70	24.30	17.40	0.22	120.00	25.50	0.00	96.00	0.70
	09/24/86	496	7.68	57.40	20.90	15.60	0.57	162.00	0.00	0.00	118.00	0.62
	05/11/87	528	8.56	51.70	21.20	13.70	0.31	142.00	8.57	0.00	115.00	1.20
	07/01/87	450	8.98	48.60	22.30	16.00	0.23	116.00	11.60	0.00	139.00	0.00
	09/17/87	541	6.96	57.00	23.70	17.60	0.90	148.00	0.00	0.00	150.00	1.50
	09/17/87	541	6.88	57.00	23.60	17.40	0.96	148.00	0.00	0.00	150.00	1.50
	06/29/90	462	10.40	62.30	18.50	11.80	3.56	62.70	51.10	0.00	126.00	2.21
	06/29/90	442	10.30	57.20	18.90	12.00	3.45	63.90	48.50	0.00	128.00	2.16
Minimum	05/11/87	387	6.88	36.70	18.50	11.80	0.22	62.70	0.00	0.00	96.00	0.00
Maximum	09/24/86	541	10.40	62.30	24.30	17.60	3.56	162.00	51.10	0.00	150.00	2.21
Mean		**481**	**8.73**	**53.49**	**21.68**	**15.19**	**1.27**	**120.33**	**18.16**	**0.00**	**127.75**	**1.24**
Median		**479**	**8.77**	**57.00**	**21.75**	**15.80**	**0.73**	**131.00**	**10.09**	**.**	**127.00**	**1.35**
Std. Deviation		55	1.46	7.93	2.19	2.40	1.41	38.29	21.33	0.00	18.46	0.77
Trench 1	12/09/98	104	6.84	15.70	1.87	2.04	0.00	55.88	0.00	0.00	3.84	1.03
Trench 2	12/09/98	98	6.86	14.80	1.80	2.02	0.00	53.90	0.00	0.00	3.67	0.97
Trench 3	12/09/98	96	7.01	14.60	1.63	1.98	0.00	53.86	0.00	0.00	3.66	0.98

Table A2-2a - Seepage Weirs Located Farther Downstream

	Date	EC μS/cm	pH su	Ca²⁺ mg/L	Mg²⁺ mg/L	Na⁺ mg/L	K⁺ mg/L	HCO₃⁻ mg/L	CO₃²⁻ mg/L	OH- mg/L	SO₄²⁻ mg/L	Cl⁻ mg/L
SM-2	06/13/86	211	8.18	27.80	8.64	4.23	0.65	128.00	0.00	0.00	4.75	0.40
	06/13/86	213	8.03	26.90	7.46	4.38	0.54	128.00	0.00	0.00	4.50	0.40
	09/24/86	206	7.20	25.30	6.42	3.85	1.04	111.00	0.00	0.00	8.20	1.36
	07/01/87	187	7.00	21.10	6.31	4.64	0.58	94.00	0.00	0.00	12.00	0.00
	07/01/87	213	7.61	26.50	7.96	4.60	0.64	114.00	0.00	0.00	10.30	0.54
	09/17/87	212	7.27	28.30	8.48	4.24	0.51	128.00	0.00	0.00	5.00	0.00
	09/17/87	216	6.80	27.80	8.37	4.20	0.71	127.00	0.00	0.00	5.00	0.00
	06/29/90	216	8.76	30.10	8.70	4.76	3.71	125.00	5.04	0.00	5.67	2.26
	10/31/90	177	6.99	28.60	9.12	4.40	0.00	130.00	0.00	0.00	6.84	1.78
	05/20/91	207	8.59	27.50	8.05	5.05	0.00	105.00	11.80	0.00	6.77	2.70
Minimum		177	6.80	21.10	6.31	3.85	0.00	94.00	0.00	0.00	4.50	0.00
Maximum		216	8.76	30.10	9.12	5.05	3.71	130.00	11.80	0.00	12.00	2.70
Mean		**206**	**7.64**	**26.99**	**7.95**	**4.44**	**0.84**	**119.00**	**1.68**	**0.00**	**6.90**	**0.94**
Median		**212**	**7.44**	**27.65**	**8.21**	**4.39**	**0.61**	**126.00**	**0.00**	.	**6.22**	**0.47**
Std. Deviation		13	0.70	2.43	0.95	0.34	1.06	12.36	3.89	0.00	2.55	1.01
SM-3	08/30/51	474	7.80	56.60	19.50	13.10	2.30	230.00	0.00	0.00	38.40	7.10
	09/18/51	455	8.20	54.60	15.80	11.70	2.00	204.00	0.00	0.00	37.40	9.90
	10/18/51	471	7.60	55.60	19.00	13.80	2.30	238.00	0.00	0.00	33.60	7.80
	06/13/86	196	7.60	23.70	7.03	4.04	0.43	113.00	0.00	0.00	6.25	0.30
	06/13/86	195	7.54	23.70	7.08	4.04	0.43	113.00	0.00	0.00	6.00	0.30
	09/24/86	203	6.60	27.70	3.87	2.22	0.66	69.60	0.00	0.00	34.20	1.41
	09/24/86	203	6.88	24.30	7.48	3.81	0.75	112.00	0.00	0.00	9.10	1.29
	06/29/90	195	8.38	28.40	4.20	3.22	3.63	68.80	0.96	0.00	25.10	2.24
	10/31/90	165	6.12	29.00	4.19	3.06	0.00	76.50	0.00	0.00	26.70	1.83
	05/20/91	161	7.31	24.10	3.47	3.09	0.00	70.70	0.00	0.00	21.60	2.60
	04/09/98	114	7.82	16.00	2.87	3.16	0.00	63.70	0.00	0.00	3.83	0.99
Minimum		114	6.12	16.00	2.87	2.22	0.00	63.70	0.00	0.00	3.83	0.30
Maximum		474	8.38	56.60	19.50	13.80	3.63	238.00	0.96	0.00	38.40	9.90
Mean		**257**	**7.44**	**33.06**	**8.59**	**5.93**	**1.14**	**123.57**	**0.09**	**0.00**	**22.02**	**3.25**
Median		**196**	**7.60**	**27.70**	**7.03**	**3.81**	**0.66**	**112.00**	**0.00**	.	**25.10**	**1.83**
Std. Deviation		137	0.68	14.89	6.37	4.51	1.22	67.64	0.29	0.00	13.50	3.36
SM-7	06/29/90	210	8.72	32.50	5.20	3.78	3.77	75.90	3.12	0.00	24.30	2.19
	10/31/90	194	6.13	33.10	5.92	4.00	0.00	96.40	0.00	0.00	29.90	1.85
	05/20/91	190	7.52	28.20	5.28	4.18	0.00	87.30	0.00	0.00	27.10	2.65
	04/09/98	83	7.99	11.60	1.38	2.07	0.00	43.60	0.00	0.00	2.71	0.88
	04/09/98	88	7.90	12.90	1.57	2.17	0.00	48.10	0.00	0.00	2.86	0.87
Minimum		83	6.13	11.60	1.38	2.07	0.00	43.60	0.00	0.00	2.71	0.87
Maximum		210	8.72	33.10	5.92	4.18	3.77	96.40	3.12	0.00	29.90	2.65
Mean		**153**	**7.65**	**23.66**	**3.87**	**3.24**	**0.75**	**70.26**	**0.62**	**0.00**	**17.37**	**1.69**
Median		**190**	**7.90**	**28.20**	**5.20**	**3.78**	**0.00**	**75.90**	**0.00**	.	**24.30**	**1.85**
Std.Deviation		62	0.96	10.60	2.21	1.03	1.69	23.49	1.40	0.00	13.46	0.79

Table A2-2b   Trace element chemistry data for seepage samples collected from toe drains and weirs at Horsetooth Dam.

Seepage Samples influenced by Dam Structure and/or Alluvium Contact

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
SM-1	06/13/86	7.86	130.0	.	.	.	.
	06/13/86	7.60	133.0	.	.	.	.
	09/24/86	8.50	131.0	.	.	.	.
	05/11/87	7.30	128.0	.	.	.	.
	05/11/87	7.58	141.0	.	.	.	.
	09/17/87	7.33	104.0	.	.	.	.
	09/17/87	7.51	106.0	.	.	.	.
	06/29/90	8.20	.	0.008	-0.004	0.078	3.500
	10/31/90	5.86	147.0	0.005	0.009	-0.030	3.110
	05/20/91	7.18	117.0	0.014	-0.004	0.062	2.970
	06/20/97	6.70	93.3	-0.004	-0.004	-0.030	3.100
	11/20/97	7.03	177.1	-0.004	-0.004	-0.030	2.880
	04/09/98	7.60	124.0	-0.004	-0.004	-0.030	2.990
Minimum	04/09/98	5.86	93.3	-0.004	-0.004	-0.030	2.880
Maximum	11/20/97	8.50	177.1	0.014	0.009	0.078	3.500
Mean		**7.40**	**127.6**	**0.002**	**-0.002**	**0.003**	**3.092**
Median		**7.51**	**129.0**	**0.000**	**-0.004**	**-0.030**	**3.045**
Std. Deviation		0.66	22.1	0.008	0.005	0.052	0.218
SM-1A	04/09/98	7.48	68.5	-0.004	-0.004	-0.030	2.170
	12/09/98	6.98	63.7	0.006	-0.004	-0.030	2.270
Mean		**7.23**	**66.1**	**0.001**	**-0.004**	**-0.030**	**2.220**
SM-1A-CON	12/09/98	6.92	67.0	0.005	-0.004	-0.030	2.290
SM-1A-COR	12/09/98	7.23	293.1	-0.004	0.409	-0.030	6.040
SM-8	06/20/97	6.54	62.1	0.027	0.004	0.053	1.470
	11/20/97	7.23	390.0	0.031	-0.004	0.065	1.660
	04/09/98	7.70	44.8	0.021	-0.004	0.040	1.520
Minimum	04/09/98	6.54	44.8	0.021	-0.004	0.040	1.470
Maximum	11/20/97	7.70	390.0	0.031	0.004	0.065	1.660
Mean		**7.16**	**165.6**	**0.026**	**-0.001**	**0.053**	**1.550**
Median		**7.23**	**62.1**	**0.027**	**-0.004**	**0.053**	**1.520**
Std. Deviation		0.58	194.5	0.005	0.005	0.012	0.098

Table A2-2b - ... influenced by Dam Structure and/or Alluvium Contact (cont)

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
V-5	09/24/86	8.46	0.6	.	.	.	.
	06/20/97	7.46	154.0	-0.004	-0.004	-0.030	5.610
	11/20/97	7.80	110.9	-0.004	-0.004	-0.030	5.070
	04/09/98	8.13	51.4	0.017	-0.004	-0.030	4.870
	12/09/98	9.19	145.4	0.064	-0.004	0.107	1.790
Minimum	04/09/98	7.46	0.6	-0.004	-0.004	-0.030	1.790
Maximum	12/09/98	9.19	154.0	0.064	-0.004	0.107	5.610
Mean		**8.21**	**92.4**	**0.018**	**-0.004**	**0.004**	**4.335**
Median		**8.13**	**110.9**	**0.006**	**.**	**-0.030**	**4.970**
Std. Deviation		0.66	65.3	0.032	0.000	0.069	1.725
V-6	06/20/97	8.10	117.0	0.024	-0.004	0.050	2.300
	11/20/97	9.44	2720.0	0.030	-0.004	-0.030	3.060
	04/09/98	6.91	7.4	0.027	-0.004	0.037	1.910
	12/09/98	7.21	79.5	0.018	-0.004	0.037	3.560
Minimum	04/09/98	6.91	7.4	0.018	-0.004	-0.030	1.910
Maximum	12/09/98	9.44	2720.0	0.030	-0.004	0.050	3.560
Mean		**7.92**	**731.0**	**0.025**	**-0.004**	**0.023**	**2.708**
Median		**7.66**	**98.2**	**0.026**	**.**	**0.037**	**2.680**
Std. Deviation		1.14	1326.8	0.005	0.000	0.036	0.742

Samples Located Downstream of and Near the Toe

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
SM-8A	06/20/97	6.56	34.4	0.004	-0.004	-0.030	2.150
	11/20/97	7.27	87.5	0.009	-0.004	0.033	2.190
	04/09/98	7.56	71.4	0.010	-0.004	-0.030	2.220
Minimum	04/09/98	6.56	34.4	0.004	-0.004	-0.030	2.150
Maximum	11/20/97	7.56	87.5	0.010	-0.004	0.033	2.220
Mean		**7.13**	**64.4**	**0.008**	**-0.004**	**-0.009**	**2.187**
Median		**7.27**	**71.4**	**0.009**	**.**	**-0.030**	**2.190**
Std. Deviation		0.51	27.2	0.003	0.000	0.036	0.035
SM-8B	06/20/97	6.64	63.4	0.023	-0.004	0.048	1.270
	11/20/97	8.85	179.6	0.002	-0.004	0.061	1.530
Mean		**7.75**	**121.5**	**0.013**	**-0.004**	**0.055**	**1.400**

Table A2-2b - Samples Located Downstream of and Near the Toe (cont)

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
SM-8C	06/20/97	6.90	87.2	0.015	0.005	0.033	1.330
	11/20/97	7.58	325.9	0.015	-0.004	0.033	1.060
	04/09/98	8.11	70.2	0.022	-0.004	0.040	1.500
Minimum	04/09/98	6.90	70.2	0.015	-0.004	0.033	1.060
Maximum	11/20/97	8.11	325.9	0.022	0.005	0.040	1.500
Mean		**7.53**	**161.1**	**0.017**	**-0.001**	**0.035**	**1.297**
Median		**7.58**	**87.2**	**0.015**	**-0.004**	**0.033**	**1.330**
Std. Deviation		0.61	143.0	0.004	0.005	0.004	0.222
SM-4	06/13/86	10.10	310.0	.	.	.	.
	09/24/86	7.68	343.0	.	.	.	.
	05/11/87	8.56	354.0	.	.	.	.
	07/01/87	8.98	314.0	.	.	.	.
	09/17/87	6.96	368.0	.	.	.	.
	09/17/87	6.88	382.0	.	.	.	.
	06/29/90	10.40	.	0.008	0.006	0.088	2.960
	06/29/90	10.30	.	.	.	.	.
Minimum	05/11/87	6.88	310.0	0.008	0.006	0.088	2.960
Maximum	09/24/86	10.40	382.0	0.008	0.006	0.088	2.960
Mean		**8.73**	**345.2**	**0.008**	**0.006**	**0.088**	**2.960**
Median		**8.77**	**348.5**	.	.	.	.
Std. Deviation		1.46	28.9	.	.	.	.
TRENCH 1	12/09/98	6.84	49.2	0.009	-0.004	-0.030	1.650
TRENCH 2	12/09/98	6.86	51.4	0.008	-0.004	-0.030	1.580
TRENCH 3	12/09/98	7.01	37.8	0.008	-0.004	-0.030	1.540

Table A2-2b - Seepage Weirs Located Farther Downstream

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
SM-2	06/13/86	8.18	162.0	.	.	.	.
	06/13/86	8.03	128.0	.	.	.	.
	09/24/86	7.20	110.0	.	.	.	.
	07/01/87	7.00	104.0	.	.	.	.
	07/01/87	7.61	130.0	.	.	.	.
	09/17/87	7.27	118.0	.	.	.	.
	09/17/87	6.80	123.0	.	.	.	.
	06/29/90	8.76	.	0.029	-0.004	0.097	4.160
	10/31/90	6.99	115.0	-0.004	0.004	-0.030	3.390
	05/20/91	8.59	133.0	0.012	-0.004	0.077	2.820
Minimum	05/20/91	6.80	104.0	-0.004	-0.004	-0.030	2.820
Maximum	10/31/90	8.76	162.0	0.029	0.004	0.097	4.160
Mean		**7.64**	**124.8**	**0.012**	**-0.001**	**0.048**	**3.457**
Median		**7.44**	**123.0**	**0.012**	**-0.004**	**0.077**	**3.390**
Std. Deviation		0.70	16.9	0.017	0.005	0.068	0.673
SM-3	08/30/51	7.80	300.0	.	.	.	.
	09/18/51	8.20	272.0	.	.	.	.
	10/18/51	7.60	286.0	.	.	.	.
	06/13/86	7.60	136.0	.	.	.	.
	06/13/86	7.54	118.0	.	.	.	.
	09/24/86	6.60	103.0	.	.	.	.
	09/24/86	6.88	102.0	.	.	.	.
	06/29/90	8.38	.	0.013	-0.004	0.068	2.780
	10/31/90	6.12	165.0	-0.004	-0.004	-0.030	2.580
	05/20/91	7.31	129.0	0.006	-0.004	0.066	1.960
	04/09/98	7.82	73.5	0.008	-0.004	-0.030	1.980
	04/09/98	7.50	158.0	-0.004	-0.004	-0.030	3.930
	12/09/98	6.95	79.6	-0.004	-0.004	-0.030	2.120
Minimum	04/09/98	6.12	73.5	-0.004	-0.004	-0.030	1.960
Maximum	12/09/98	8.38	300.0	0.013	-0.004	0.068	3.930
Mean		**7.41**	**160.2**	**0.003**	**-0.004**	**0.002**	**2.558**
Median		**7.54**	**132.5**	**0.001**	.	**-0.030**	**2.350**
Std. Deviation		0.63	80.9	0.008	0.000	0.050	0.750
SM-7	06/29/90	8.72	.	0.039	-0.004	0.078	2.940
	10/31/90	6.13	130.0	0.011	0.004	0.034	2.690
	05/20/91	7.52	130.0	0.016	0.008	0.083	2.370
	04/09/98	7.99	34.1	0.019	-0.004	0.049	1.880
	04/09/98	7.90	61.7	0.060	-0.004	0.124	2.090
Minimum	04/09/98	6.13	34.1	0.011	-0.004	0.034	1.880
Maximum	10/31/90	8.72	130.0	0.060	0.008	0.124	2.940
Mean		**7.65**	**89.0**	**0.029**	**0.000**	**0.073**	**2.394**
Median		**7.90**	**95.9**	**0.019**	**-0.004**	**0.078**	**2.370**
Std. Deviation		0.96	48.7	0.020	0.006	0.035	0.431

Table A2-2c Mineral saturation indices - log(AP/KT) - for representative minerals at Horsetooth Dam as calculated \by the MINTEQA2 chemical equilibrium model. Negative numbers suggest under saturation with respect to the given mineral, positive numbers suggest over saturation with respect to the given mineral. These data are grouped according to proximity to the dam toe.

Drain Samples Influenced by Dam Structure and/or Alluvium Contac

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
SM-1	06/13/86	7.86	130.0	-3.281	-3.458	-7.414	-2.914	-4.439	.
	06/13/86	7.60	133.0	-3.281	-3.458	-7.414	-2.914	-4.439	.
	09/24/86	8.50	131.0	-3.033	-3.427	-7.298	-2.666	-4.353	.
	05/11/87	7.30	128.0	-3.007	-3.423	-7.319	-2.639	-4.378	.
	05/11/87	7.58	141.0	-3.007	-3.423	-7.319	-2.639	-4.378	.
	09/17/87	7.33	104.0	-3.232	-6.446	-7.290	-2.865	-4.326	.
	09/17/87	7.51	106.0	-3.232	-6.446	-7.290	-2.865	-4.326	.
	06/29/90	8.20	.	-3.163	-3.426	-7.327	-3.070	-4.383	-0.714
	10/31/90	5.86	147.0	-2.975	-3.298	-7.157	-2.607	-4.341	-0.765
	05/20/91	7.18	117.0	-3.111	-3.447	-7.367	-2.744	-4.402	-0.785
	06/20/97	6.70	93.3	-3.168	-3.420	-7.334	-2.800	-4.396	-0.689
	11/20/97	7.03	177.1	-3.350	-3.456	-7.402	-2.982	-4.429	-0.799
	04/09/98	7.60	124.0	-3.298	-3.441	-7.380	-2.931	-4.421	-0.782
Minimum		5.86	93.3	-3.350	-6.446	-7.414	-3.070	-4.439	-0.799
Maximum		8.50	177.1	-2.975	-3.298	-7.157	-2.607	-4.326	-0.689
Mean		**7.40**	**127.6**	**-3.164**	**-3.890**	**-7.332**	**-2.818**	**-4.385**	**-0.756**
Median		**7.51**	**129.0**	**-3.168**	**-3.441**	**-7.327**	**-2.865**	**-4.383**	**-0.774**
Std. Deviation		0.66	22.1	0.127	1.135	0.069	0.148	0.040	0.044
SM-1A	04/09/98	7.48	68.5	-3.360	-3.537	-7.576	-2.993	-4.521	-0.922
	12/09/98	6.98	63.7	-3.364	-3.567	-7.670	-2.997	-4.585	-0.902
Mean		**7.23**	**66.1**	**-3.362**	**-3.552**	**-7.623**	**-2.995**	**-4.553**	**-0.912**
SM-1A-CON	12/09/98	6.92	67.0	-3.347	-3.556	-7.649	-2.979	-4.575	-0.898
SM-1A-COR	12/09/98	7.23	293.1	-2.460	-3.010	-6.593	-2.092	-4.065	-0.476
V-5	09/24/86	8.46	0.6	-2.390	-3.489	-7.703	-2.022	-4.696	.
	06/20/97	7.46	154.0	-2.923	-3.337	-7.072	-2.556	-4.218	-0.509
	11/20/97	7.80	110.9	-3.394	-3.425	-7.249	-3.026	-4.306	-0.553
	04/09/98	8.13	51.4	-3.430	-3.439	-7.310	-3.063	-4.354	-0.570
	12/09/98	9.19	145.4	-2.546	-2.957	-7.628	-2.178	-5.153	-1.005
Minimum		7.46	0.6	-3.430	-3.489	-7.703	-3.063	-5.153	-1.005
Maximum		9.19	154.0	-2.390	-2.957	-7.072	-2.022	-4.218	-0.509
Mean		**8.21**	**92.4**	**-2.937**	**-3.329**	**-7.392**	**-2.569**	**-4.545**	**-0.659**
Median		**8.13**	**110.9**	**-2.923**	**-3.425**	**-7.310**	**-2.556**	**-4.354**	**-0.562**
Std. Deviation		0.66	65.3	0.475	0.215	0.266	0.476	0.385	0.232

Table A2-2c - Drain Samples Influenced by Dam Structure and/or Alluvium Contact

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
V-6	06/20/97	8.10	117.0	-3.147	-3.568	-8.008	-2.779	-4.922	-0.896
	11/20/97	9.44	2720.0	-2.396	-4.126	-8.594	-2.029	-4.950	-0.768
	04/09/98	6.91	7.4	-3.812	-3.837	-8.474	-3.444	-5.119	-0.977
	12/09/98	7.21	79.5	-3.484	-4.559	-9.583	-3.117	-5.506	-0.707
Total	4	4.00	4.0	4.000	4.000	4.000	4.000	4.000	4.000
Minimum		6.91	7.4	-3.812	-4.559	-9.583	-3.444	-5.506	-0.977
Maximum		9.44	2720.0	-2.396	-3.568	-8.008	-2.029	-4.922	-0.707
Mean		**7.92**	**731.0**	**-3.210**	**-4.023**	**-8.665**	**-2.842**	**-5.124**	**-0.837**
Median		**7.66**	**98.2**	**-3.316**	**-3.982**	**-8.534**	**-2.948**	**-5.035**	**-0.832**
Std. Deviation		1.14	1326.8	0.607	0.424	0.662	0.606	0.269	0.122

Seepage Weirs and Samples Located Downstream of and Near the Toe

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
SM-8	06/20/97	6.54	62.1	-3.281	-3.461	-7.808	-2.914	-4.829	-1.091
	11/20/97	7.23	390.0	-3.653	-3.619	-7.104	-3.285	-3.967	-1.038
	04/09/98	7.70	44.8	-3.618	-3.626	-8.076	-3.251	-4.932	-1.076
Minimum		6.54	44.8	-3.653	-3.626	-8.076	-3.285	-4.932	-1.091
Maximum		7.70	390.0	-3.281	-3.461	-7.104	-2.914	-3.967	-1.038
Mean		**7.16**	**165.6**	**-3.517**	**-3.569**	**-7.663**	**-3.150**	**-4.576**	**-1.068**
Median		**7.23**	**62.1**	**-3.618**	**-3.619**	**-7.808**	**-3.251**	**-4.829**	**-1.076**
Std. Deviation		0.58	194.5	0.205	0.093	0.502	0.205	0.530	0.027
SM-8A	06/20/97	6.56	34.4	-3.234	-3.521	-7.518	-2.867	-4.479	-0.925
	11/20/97	7.27	87.5	-3.365	-3.535	-7.570	-2.997	-4.516	-0.917
	04/09/98	7.56	71.4	-3.370	-3.529	-7.549	-3.002	-4.502	-0.912
Minimum		6.56	34.4	-3.370	-3.535	-7.570	-3.002	-4.516	-0.925
Maximum		7.56	87.5	-3.234	-3.521	-7.518	-2.867	-4.479	-0.912
Mean		**7.13**	**64.4**	**-3.323**	**-3.528**	**-7.546**	**-2.955**	**-4.499**	**-0.918**
Median		**7.27**	**71.4**	**-3.365**	**-3.529**	**-7.549**	**-2.997**	**-4.502**	**-0.917**
Std. Deviation		0.51	27.2	0.077	0.007	0.026	0.077	0.019	0.007
SM-8B	06/20/97	6.64	63.4	-3.243	-3.497	-7.880	-2.876	-4.866	-1.154
	11/20/97	8.85	179.6	-3.571	-3.582	-8.035	-3.203	-4.935	-1.073
Mean		**7.75**	**121.5**	**-3.407**	**-3.540**	**-7.958**	**-3.040**	**-4.901**	**-1.114**

Table A2-2c - Seepage Weirs and Samples Located Downstream of and Near the Toe

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
SM-8C	06/20/97	6.90	87.2	-3.086	-3.306	-7.415	-2.718	-4.591	-1.134
	11/20/97	7.58	325.9	-3.338	-3.388	-7.580	-2.970	-4.675	-1.233
	04/09/98	8.11	70.2	-3.385	-3.424	-7.698	-3.018	-4.756	-1.082
Minimum		6.90	70.2	-3.385	-3.424	-7.698	-3.018	-4.756	-1.233
Maximum		8.11	325.9	-3.086	-3.306	-7.415	-2.718	-4.591	-1.082
Mean		**7.53**	**161.1**	**-3.270**	**-3.373**	**-7.564**	**-2.902**	**-4.674**	**-1.150**
Median		**7.58**	**87.2**	**-3.338**	**-3.388**	**-7.580**	**-2.970**	**-4.675**	**-1.134**
Std. Deviation		0.61	143.0	0.161	0.060	0.142	0.161	0.083	0.077
TRENCH 1	12/09/98	6.84	49.2	-3.496	-3.609	-8.059	-3.101	-4.932	-1.041
TRENCH 2	12/09/98	6.86	51.4	-3.509	-3.633	-8.097	-3.142	-4.947	-1.071
TRENCH 3	12/09/98	7.01	37.8	-3.515	-3.638	-8.145	-3.147	-4.990	-1.071
SM-4	06/13/86	10.10	310.0	-1.921	-3.346	-6.784	-1.553	-3.921	.
	09/24/86	7.68	343.0	-1.671	-3.167	-6.685	-1.303	-4.001	.
	05/11/87	8.56	354.0	-1.718	-3.209	-6.718	-1.350	-3.991	.
	07/01/87	8.98	314.0	-1.674	-3.246	-6.744	-1.306	-3.979	.
	09/17/87	6.96	368.0	-1.540	-3.173	-7.638	-1.173	-4.948	.
	09/17/87	6.88	382.0	-1.540	-3.173	-7.638	-1.173	-4.948	.
	06/29/90	10.40	.	-1.612	-3.135	-6.709	-1.244	-4.057	-0.786
	06/29/90	10.30	.	-1.637	-3.171	-6.736	-1.270	-4.047	-0.786
Minimum		6.88	310.0	-1.921	-3.346	-7.638	-1.553	-4.948	-0.786
Maximum		10.40	382.0	-1.540	-3.135	-6.685	-1.173	-3.921	-0.786
Mean		**8.73**	**345.2**	**-1.664**	**-3.203**	**-6.957**	**-1.297**	**-4.237**	**-0.786**
Median		**8.77**	**348.5**	**-1.654**	**-3.173**	**-6.740**	**-1.287**	**-4.024**	**.**
Std. Deviation		1.46	28.9	0.121	0.067	0.422	0.121	0.441	0.000

Table A2-2c - Seepage Weirs Located Farther Downstream

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
SM-2	06/13/86	8.18	162.0	-3.205	-3.388	-7.200	-2.838	-4.295	.
	06/13/86	8.03	128.0	-3.205	-3.388	-7.200	-2.838	-4.295	.
	09/24/86	7.20	110.0	-2.996	-3.426	-7.364	-2.629	-4.421	.
	07/01/87	7.00	104.0	-2.889	-3.411	-7.261	-2.522	-4.332	.
	07/01/87	7.61	130.0	-2.889	-3.411	-7.261	-2.522	-4.332	.
	09/17/87	7.27	118.0	-3.176	-3.380	-7.201	-2.808	-4.303	.
	09/17/87	6.80	123.0	-3.176	-3.380	-7.201	-2.808	-4.303	.
	06/29/90	8.76	.	-3.104	-3.357	-7.171	-2.736	-4.296	-0.639
	10/31/90	6.99	115.0	-3.041	-3.379	-7.170	-2.674	-4.274	-0.728
	05/20/91	8.59	133.0	-3.056	-3.394	-7.238	-2.689	-4.327	-0.808
Minimum		6.80	104.0	-3.205	-3.426	-7.364	-2.838	-4.421	-0.808
Maximum		8.76	162.0	-2.889	-3.357	-7.170	-2.522	-4.274	-0.639
Mean		**7.64**	**124.8**	**-3.074**	**-3.391**	**-7.227**	**-2.706**	**-4.318**	**-0.725**
Median		**7.44**	**123.0**	**-3.080**	**-3.388**	**-7.201**	**-2.713**	**-4.303**	**-0.728**
Std. Deviation		0.70	16.9	0.121	0.020	0.058	0.121	0.041	0.085
SM-3	08/30/51	7.80	300.0	-2.118	-3.134	-6.647	-1.751	-3.995	.
	09/18/51	8.20	272.0	-2.131	-3.145	-6.745	-1.764	-4.082	.
	10/18/51	7.60	286.0	-2.179	-3.139	-6.660	-1.811	-4.003	.
	06/13/86	7.60	136.0	-3.138	-3.452	-7.348	-2.770	-4.379	.
	06/13/86	7.54	118.0	-3.138	-3.452	-7.348	-2.770	-4.379	.
	09/24/86	6.60	103.0	-3.138	-3.452	-7.348	-2.770	-4.379	.
	09/24/86	6.88	102.0	-2.971	-3.445	-7.318	-2.603	-4.356	.
	06/29/90	8.38	.	-2.477	-3.389	-7.517	-2.110	-4.610	-0.814
	10/31/90	6.12	165.0	-2.440	-3.381	-7.518	-2.075	-4.619	-0.846
	05/20/91	7.31	129.0	-3.571	-3.435	-7.630	-3.204	-4.677	-0.966
	04/09/98	7.82	73.5	-3.470	-3.604	-7.871	-3.103	-4.749	-0.961
	04/09/98	7.50	158.0	-2.543	-3.272	-7.159	-2.175	-4.369	-0.663
	12/09/98	6.95	79.6	-3.765	-3.499	-7.773	-3.397	-4.757	-0.932
Minimum		6.12	73.5	-3.765	-3.604	-7.871	-3.397	-4.757	-0.966
Maximum		8.38	300.0	-2.118	-3.134	-6.647	-1.751	-3.995	-0.663
Mean		**7.41**	**160.2**	**-2.852**	**-3.369**	**-7.299**	**-2.485**	**-4.412**	**-0.864**
Median		**7.54**	**132.5**	**-2.971**	**-3.435**	**-7.348**	**-2.603**	**-4.379**	**-0.889**
Std. Deviation		0.63	80.9	0.571	0.150	0.400	0.571	0.265	0.116
SM-7	06/29/90	8.72	.	-2.447	-3.335	-7.381	-2.079	-4.529	-0.790
	10/31/90	6.13	130.0	-2.357	-3.331	-7.326	-1.989	-4.477	-0.828
	05/20/91	7.52	130.0	-2.452	-3.395	-7.433	-2.085	-4.521	-0.883
	04/09/98	7.99	34.1	-3.729	-3.731	-8.305	-3.361	-5.056	-0.984
	04/09/98	7.90	61.7	-3.677	-3.688	-8.208	-3.299	-5.002	-0.938
Minimum		6.13	34.1	-3.729	-3.731	-8.305	-3.361	-5.056	-0.984
Maximum		8.72	130.0	-2.357	-3.331	-7.326	-1.989	-4.477	-0.790
Mean		**7.65**	**89.0**	**-2.932**	**-3.496**	**-7.731**	**-2.563**	**-4.717**	**-0.885**
Median		**7.90**	**95.9**	**-2.452**	**-3.395**	**-7.433**	**-2.085**	**-4.529**	**-0.883**
Std. Deviation		0.96	48.7	0.705	0.197	0.483	0.702	0.286	0.079

Table A2-3a - Summary of major ions chemistry data for groundwater wells grouped by the general geologic formation where the well screen is located. All values should be rounded to 3 significant figures.

Wells with Screens in the Lower Lykins - Blaine gypsum

	Date	EC µS/cm	pH su	Ca²⁺ mg/L	Mg²⁺ mg/L	Na⁺ mg/L	K⁺ mg/L	HCO₃⁻ mg/L	CO₃²⁻ mg/L	OH- mg/L	SO₄²⁻ mg/L	Cl mg/L
DH91-1	6/20/97	346	9.47	10.50	3.17	33.50	35.40	45.70	29.30	0.00	26.70	23.70
	11/20/97	1275	11.17	204.00	0.20	25.40	14.20	0.00	6.52	28.92	491.00	8.22
	4/9/98	1009	10.70	174.00	0.81	19.60	9.54	0.00	12.40	12.60	417.00	5.43
	12/9/98	103	7.56	16.50	0.42	1.66	1.17	46.03	0.00	0.00	3.44	0.74
Minimum		103	7.56	10.50	0.20	1.66	1.17	0.00	0.00	0.00	3.44	0.74
Maximum		1275	11.17	204.00	3.17	33.50	35.40	46.03	29.30	28.92	491.00	23.70
Mean		**683**	**9.73**	**101.25**	**1.15**	**20.04**	**15.08**	**22.93**	**12.05**	**10.38**	**234.54**	**9.52**
Median		**678**	**10.09**	**95.25**	**0.61**	**22.50**	**11.87**	**22.85**	**9.46**	**6.30**	**221.85**	**6.83**
Std. Deviation		550	1.61	102.09	1.37	13.51	14.58	26.48	12.56	13.71	255.39	9.94
DH91-2	6/20/97	1760	6.74	269.00	116.00	12.60	0.00	183.00	0.00	0.00	1000.00	2.42
	11/20/97	1278	7.00	253.00	110.00	11.40	1.81	186.11	0.00	0.00	1000.00	1.23
	4/9/98	1759	7.21	252.00	111.00	11.90	1.62	187.00	0.00	0.00	943.00	1.16
	12/9/98	1790	7.02	242.00	105.00	11.80	0.00	190.23	0.00	0.00	965.00	1.15
Minimum		1278	6.74	242.00	105.00	11.40	0.00	183.00	0.00	0.00	943.00	1.15
Maximum		1790	7.21	269.00	116.00	12.60	1.81	190.23	0.00	0.00	1000.00	2.42
Mean		**1647**	**6.99**	**254.00**	**110.50**	**11.93**	**0.86**	**186.58**	**0.00**	**0.00**	**977.00**	**1.49**
Median		**1760**	**7.01**	**252.50**	**110.50**	**11.85**	**0.81**	**186.56**	.	.	**982.50**	**1.19**
Std. Deviation		246	0.19	11.17	4.51	0.50	0.99	2.97	0.00	0.00	28.04	0.62
DH98-6	12/9/98	267	9.46	8.67	7.63	48.90	6.10	52.80	41.80	0.00	7.70	1.04
DH98-7	12/9/98	572	9.09	50.40	12.00	48.90	0.00	111.00	37.00	0.00	139.00	2.08

Wells with Screens in the Middle Lykins - Forelle limestone

	Date	EC µS/cm	pH su	Ca²⁺ mg/L	Mg²⁺ mg/L	Na⁺ mg/L	K⁺ mg/L	HCO₃⁻ mg/L	CO₃²⁻ mg/L	OH- mg/L	SO₄²⁻ mg/L	Cl mg/L
DH91-3A	11/20/97	105	7.31	15.80	2.67	2.11	1.47	52.90	0.00	0.00	6.47	1.03
	11/20/97	105	6.89	14.20	2.01	2.01	1.47	51.69	0.00	0.00	6.47	1.03
	6/20/97	104	6.68	15.10	2.22	2.20	0.00	56.00	0.00	0.00	7.18	2.04
	4/9/98	158	7.61	14.40	2.07	2.23	0.00	50.50	0.00	0.00	8.80	0.89
	12/9/98	110	7.07	15.90	2.19	2.03	0.00	56.51	0.00	0.00	7.59	1.00
Minimum		104	6.68	14.20	2.01	2.01	0.00	50.50	0.00	0.00	6.47	0.89
Maximum		158	7.61	15.90	2.67	2.23	1.47	56.51	0.00	0.00	8.80	2.04
Mean		**116**	**7.11**	**15.08**	**2.23**	**2.12**	**0.59**	**53.52**	**0.00**	**0.00**	**7.30**	**1.20**
Median		**105**	**7.07**	**15.10**	**2.19**	**2.11**	**0.00**	**52.90**	.	.	**7.18**	**1.03**
Std. Deviation		23	0.36	0.78	0.26	0.10	0.81	2.64	0.00	0.00	0.97	0.47

Table A2-3a - Wells with Screens in the Middle Lykins - Forelle limestone (cont)

	Date	EC µS/cm	pH su	Ca²⁺ mg/L	Mg²⁺ mg/L	Na⁺ mg/L	K⁺ mg/L	HCO₃⁻ mg/L	CO₃²⁻ mg/L	OH- mg/L	SO₄²⁻ mg/L	Cl mg/L
DH91-4	6/20/97	88	6.65	13.10	1.58	2.25	0.00	46.90	0.00	0.00	4.60	2.13
	11/20/97	83	7.03	12.70	1.40	2.02	1.31	43.12	0.00	0.00	2.76	1.04
	4/9/98	80	7.90	11.50	1.36	2.15	0.00	42.10	0.00	0.00	2.91	0.89
	12/9/98	97	7.11	13.20	1.55	1.97	0.00	50.16	0.00	0.00	3.51	0.94
Minimum		80	6.65	11.50	1.36	1.97	0.00	42.10	0.00	0.00	2.76	0.89
Maximum		97	7.90	13.20	1.58	2.25	1.31	50.16	0.00	0.00	4.60	2.13
Mean		**87**	**7.17**	**12.63**	**1.47**	**2.10**	**0.33**	**45.57**	**0.00**	**0.00**	**3.45**	**1.25**
Median		**86**	**7.07**	**12.90**	**1.48**	**2.09**	**0.00**	**45.01**	**.**	**.**	**3.21**	**0.99**
Std. Deviation		7	0.52	0.78	0.11	0.13	0.66	3.69	0.00	0.00	0.84	0.59
DH91-5	6/20/97	100	6.68	14.90	1.73	2.17	0.00	49.70	0.00	0.00	6.94	2.06
	4/9/98	96	7.98	14.60	1.64	2.26	0.00	47.50	0.00	0.00	6.98	0.88
Mean		**98**	**7.33**	**14.75**	**1.69**	**2.22**	**0.00**	**48.60**	**0.00**	**0.00**	**6.96**	**1.47**
DH92-7	6/20/97	121	7.43	16.40	2.98	3.76	0.00	67.30	0.00	0.00	5.21	2.26
	11/20/97	133	7.44	16.00	3.16	4.19	0.00	73.74	0.00	0.00	3.76	1.16
	4/9/98	115	8.11	14.90	2.59	4.13	0.00	64.10	0.00	0.00	3.51	0.99
	12/9/98	121	7.99	17.10	2.48	3.11	0.00	69.34	0.00	0.00	4.24	1.21
Minimum		**115**	**7.43**	**14.90**	**2.48**	**3.11**	**0.00**	**64.10**	**0.00**	**0.00**	**3.51**	**0.99**
Maximum		**133**	**8.11**	**17.10**	**3.16**	**4.19**	**0.00**	**73.74**	**0.00**	**0.00**	**5.21**	**2.26**
Mean		123	7.74	16.10	2.80	3.80	0.00	68.62	0.00	0.00	4.18	1.41
Median		121	7.72	16.20	2.79	3.95	.	68.32	.	.	4.00	1.19
Std. Deviation		8	0.36	0.92	0.32	0.50	0.00	4.04	0.00	0.00	0.75	0.58
DH97-1	12/9/98	87	6.88	12.70	1.42	1.99	0.50	47.35	0.00	0.00	3.51	0.96
DH98-10A	12/9/98	143	8.47	7.93	2.44	16.90	0.00	38.00	12.00	0.00	21.10	1.64

Table A2-3a - Wells with Screens in the Upper Lykins - Alluvium

	Date	EC μS/cm	pH su	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^+ mg/L	K^+ mg/L	HCO_3^- mg/L	CO_3^{2-} mg/L	OH- mg/L	SO_4^{2-} mg/L	Cl mg/L
DH92-5A	6/20/97	446	5.94	63.20	6.73	4.24	1.39	38.80	0.00	0.00	9.31	3.31
	11/20/97	145	6.59	18.70	3.59	2.31	1.50	58.52	0.00	0.00	5.98	1.01
	4/9/98	129	7.81	19.00	2.41	2.53	0.00	69.50	0.00	0.00	6.72	0.91
	12/9/98	292	8.12	36.40	12.40	6.06	0.00	179.00	0.00	0.00	8.72	2.07
Minimum		129	5.94	18.70	2.41	2.31	0.00	38.80	0.00	0.00	5.98	0.91
Maximum		446	8.12	63.20	12.40	6.06	1.50	179.00	0.00	0.00	9.31	3.31
Mean		**253**	**7.12**	**34.33**	**6.28**	**3.79**	**0.72**	**86.45**	**0.00**	**0.00**	**7.68**	**1.83**
Median		**219**	**7.20**	**27.70**	**5.16**	**3.39**	**0.70**	**64.01**	.	.	**7.72**	**1.54**
Std. Deviation		148	1.02	20.95	4.47	1.74	0.84	62.99	0.00	0.00	1.59	1.12
DH92-5B	6/20/97	224	10.00	30.70	4.07	10.30	2.56	23.60	40.30	0.00	48.70	2.80
	11/20/97	708	11.30	57.20	1.88	4.37	3.56	0.00	30.80	37.89	42.60	1.28
	4/9/98	1150	11.30	101.00	0.13	5.07	0.00	0.00	12.70	72.40	36.40	1.03
	12/9/98	247	8.77	35.30	5.24	5.76	0.00	68.00	15.10	0.00	49.80	1.41
Minimum		224	8.77	30.70	0.13	4.37	0.00	0.00	12.70	0.00	36.40	1.03
Maximum		1150	11.30	101.00	5.24	10.30	3.56	68.00	40.30	72.40	49.80	2.80
Mean		**582**	**10.34**	**56.05**	**2.83**	**6.38**	**1.53**	**22.90**	**24.73**	**27.57**	**44.38**	**1.63**
Median		**478**	**10.65**	**46.25**	**2.98**	**5.42**	**1.28**	**11.80**	**22.95**	**18.94**	**45.65**	**1.35**
Std. Deviation		439	1.21	32.12	2.28	2.68	1.81	32.06	13.12	34.82	6.19	0.80
DH92-6	6/20/97	287	6.89	33.30	11.30	12.30	0.00	176.00	0.00	0.00	4.86	2.48
	4/9/98	287	7.42	32.30	10.60	12.60	0.00	172.00	0.00	0.00	6.62	1.33
	12/9/98	300	7.35	34.80	11.80	11.50	0.00	188.44	0.00	0.00	4.00	1.64
Minimum		287	6.89	32.30	10.60	11.50	0.00	172.00	0.00	0.00	4.00	1.33
Maximum		300	7.42	34.80	11.80	12.60	0.00	188.44	0.00	0.00	6.62	2.48
Mean		**291**	**7.22**	**33.47**	**11.23**	**12.13**	**0.00**	**178.81**	**0.00**	**0.00**	**5.16**	**1.82**
Median		**287**	**7.35**	**33.30**	**11.30**	**12.30**	.	**176.00**	.	.	**4.86**	**1.64**
Std. Deviation		8	0.29	1.26	0.60	0.57	0.00	8.57	0.00	0.00	1.34	0.60
DH97-4	11/20/97	871	7.39	78.40	55.60	24.50	2.38	426.00	0.00	0.00	123.00	7.83
	4/9/98	1100	6.95	183.00	30.40	8.18	1.76	597.00	0.00	0.00	59.40	4.20
	12/9/98	510	7.81	74.00	12.10	2.72	0.00	233.00	0.00	0.00	17.10	1.04
Minimum		510	6.95	74.00	12.10	2.72	0.00	233.00	0.00	0.00	17.10	1.04
Maximum		1100	7.81	183.00	55.60	24.50	2.38	597.00	0.00	0.00	123.00	7.83
Mean		**827**	**7.38**	**111.80**	**32.70**	**11.80**	**1.38**	**418.67**	**0.00**	**0.00**	**66.50**	**4.36**
Median		**871**	**7.39**	**78.40**	**30.40**	**8.18**	**1.76**	**426.00**	.	.	**59.40**	**4.20**
Std. Deviation		297	0.43	61.70	21.84	11.33	1.23	182.11	0.00	0.00	53.31	3.40

Table A2-3b - Summary of available trace element chemistry data for groundwater wells grouped by the general geologic formation where the well screen is located.

Wells with Screens in the Lower Lykins - Blaine gypsum

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
DH91-1	6/20/97	9.47	196	0.129	0.006	0.120	2.620
	11/20/97	11.17	770	0.012	-0.004	0.054	1.580
	4/9/98	10.70	721	-0.004	-0.004	-0.030	1.440
	12/9/98	7.56	59	0.015	0.014	-0.030	0.450
Minimum		7.56	59	-0.004	-0.004	-0.030	0.450
Maximum		11.17	770	0.129	0.014	0.120	2.620
Mean		**9.73**	**437**	**0.038**	**0.003**	**0.029**	**1.523**
Median		**10.09**	**458**	**0.014**	**0.001**	**0.012**	**1.510**
Std. Deviation		1.61	362	0.061	0.009	0.073	0.887
DH91-2	6/20/97	6.74	1550	-0.004	0.465	-0.030	7.670
	11/20/97	7.00	1770	-0.004	0.389	-0.030	6.990
	4/9/98	7.21	1600	0.008	0.381	-0.030	7.570
	12/9/98	7.02	1570	0.011	0.401	-0.030	7.490
Minimum		6.74	1550	-0.004	0.381	-0.030	6.990
Maximum		7.21	1770	0.011	0.465	-0.030	7.670
Mean		**6.99**	**1623**	**0.003**	**0.409**	**-0.030**	**7.430**
Median		**7.01**	**1585**	**0.002**	**0.395**	**.**	**7.530**
Std. Deviation		0.19	100	0.008	0.038	0.000	0.302
DH98-6	12/9/98	9.46	518	12.100	0.036	38.400	113.000
DH98-7	12/9/98	9.09	387	-0.004	-0.004	-0.030	6.210

Wells with Screens in the Middle Lykins - Forelle limestone

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
DH91-3A	11/20/97	7.31	325	0.029	-0.004	0.083	2.040
	11/20/97	6.89	169	0.027	-0.004	0.078	1.980
	6/20/97	6.68	47	0.014	-0.004	0.053	1.850
	4/9/98	7.61	62	0.016	-0.004	0.032	2.100
	12/9/98	7.07	44	0.009	-0.004	0.033	1.720
Minimum		6.68	44	0.009	-0.004	0.032	1.720
Maximum		7.61	325	0.029	-0.004	0.083	2.100
Mean		**7.11**	**130**	**0.019**	**-0.004**	**0.056**	**1.938**
Median		**7.07**	**62**	**0.016**	**.**	**0.053**	**1.980**
Std. Deviation		0.36	121	0.009	0.000	0.024	0.153

Table A2-3b - Middle Lykins/Forelle limestone (cont)

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
DH91-4	6/20/97	6.65	60	0.049	0.006	0.075	1.610
	11/20/97	7.03	295	0.065	-0.004	0.137	1.870
	4/9/98	7.90	53	0.035	-0.004	0.039	1.890
	12/9/98	7.11	28	0.012	-0.004	-0.030	1.280
Minimum		6.65	28	0.012	-0.004	-0.030	1.280
Maximum		7.90	295	0.065	0.006	0.137	1.890
Mean		**7.17**	**109**	**0.040**	**-0.002**	**0.055**	**1.663**
Median		**7.07**	**57**	**0.042**	**-0.004**	**0.057**	**1.740**
Std. Deviation		0.52	124	0.022	0.005	0.070	0.285
DH91-5	6/20/97	6.68	62	0.020	-0.004	0.049	1.680
	4/9/98	7.98	66	0.032	0.011	0.042	1.950
Mean		**7.33**	**64**	**0.026**	**0.003**	**0.045**	**1.815**
DH92-7	6/20/97	7.43	62	0.014	0.015	0.040	1.830
	11/20/97	7.44	282	0.009	0.008	0.037	1.890
	4/9/98	8.11	57	0.009	0.006	-0.030	1.860
	12/9/98	7.99	57	0.010	-0.004	-0.030	1.910
Minimum		7.43	57	0.009	-0.004	-0.030	1.830
Maximum		8.11	282	0.014	0.015	0.040	1.910
Mean		**7.74**	**114**	**0.010**	**0.006**	**0.004**	**1.873**
Median		**7.72**	**60**	**0.010**	**0.007**	**0.004**	**1.875**
Std. Deviation		0.36	112	0.002	0.008	0.040	0.035
DH97-1	12/9/98	6.88	31	0.029	-0.004	0.052	1.290
DH98-10A	12/9/98	8.47	86	0.192	-0.004	0.690	8.470

Wells with Screens in the Upper Lykins - Alluvium

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
DH92-5A	6/20/97	5.94	346	0.136	0.171	0.111	3.710
	11/20/97	6.59	404	0.012	0.032	0.032	1.750
	4/9/98	7.81	82	0.042	0.021	0.074	2.580
	12/9/98	8.12	171	0.051	0.113	0.079	3.830
Minimum		5.94	82	0.012	0.021	0.032	1.750
Maximum		8.12	404	0.136	0.171	0.111	3.830
Mean		**7.12**	**251**	**0.060**	**0.084**	**0.074**	**2.968**
Median		**7.20**	**258**	**0.046**	**0.072**	**0.077**	**3.145**
Std. Deviation		1.02	150	0.053	0.071	0.032	0.988

Table A2-3b - Wells with Screens in the Upper Lykins - Alluvium (cont)

	Date	pH	TDS, mg/L	Fe, mg/L	Mn, mg/L	AL, mg/L	Si, mg/L
DH92-5B	6/20/97	10.00	190	0.028	-0.004	0.045	3.150
	11/20/97	11.30	387	0.189	0.015	0.263	2.060
	4/9/98	11.30	295	0.005	-0.004	0.041	2.740
	12/9/98	8.77	160	0.006	0.005	-0.030	3.890
Minimum		8.77	160	0.005	-0.004	-0.030	2.060
Maximum		11.30	387	0.189	0.015	0.263	3.890
Mean		**10.34**	**258**	**0.057**	**0.003**	**0.080**	**2.960**
Median		**10.65**	**243**	**0.017**	**0.000**	**0.043**	**2.945**
Std. Deviation		1.21	104	0.089	0.009	0.127	0.766
DH92-6	6/20/97	6.89	156	0.028	0.547	-0.030	3.940
	4/9/98	7.42	163	0.028	0.334	0.048	3.910
	12/9/98	7.35	162	0.019	0.550	-0.030	3.990
Minimum		6.89	156	0.019	0.334	-0.030	3.910
Maximum		7.42	163	0.028	0.550	0.048	3.990
Mean		**7.22**	**160**	**0.025**	**0.477**	**-0.004**	**3.947**
Median		**7.35**	**162**	**0.028**	**0.547**	**-0.030**	**3.940**
Std. Deviation		0.29	4	0.005	0.124	0.045	0.040
DH97-4	11/20/97	7.39	584	0.008	0.029	-0.030	6.300
	4/9/98	6.95	684	0.010	0.008	-0.030	7.890
	12/9/98	7.81	271	-0.004	-0.004	-0.030	4.480
Minimum		6.95	271	-0.004	-0.004	-0.030	4.480
Maximum		7.81	684	0.010	0.029	-0.030	7.890
Mean		**7.38**	**513**	**0.005**	**0.011**	**-0.030**	**6.223**
Median		**7.39**	**584**	**0.008**	**0.008**	**.**	**6.300**
Std. Deviation		0.43	215	0.008	0.017	0.000	1.706

Table A2-3c Mineral saturation indices - log(AP/KT) - for representative minerals at Horsetooth Dam as calculated \by the MINTEQA2 chemical equilibrium model. Negative numbers suggest under saturation with respect to the given mineral, positive numbers suggest over saturation with respect to the given mineral. These data are grouped according to the general geologic formation at the well screen depth.

Wells with Screens in the Lower Lykins - Blaine gypsum

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
DH91-1	06/20/97	9.47	196	-2.880	-4.830	-10.096	-2.510	-5.750	-0.839
	11/20/97	11.17	770	-0.739	-3.752	-10.427	-0.372	-7.158	-1.057
	04/09/98	10.70	721	-0.838	-3.800	-9.840	-0.471	-6.520	-1.098
	12/09/98	7.56	59	-3.488	-4.584	-10.684	-3.120	-6.582	-1.603
Minimum		7.56	59	-3.488	-4.830	-10.684	-3.120	-7.158	-1.603
Maximum		11.17	770	-0.739	-3.752	-9.840	-0.372	-5.750	-0.839
Mean		**9.73**	**437**	**-1.986**	**-4.242**	**-10.262**	**-1.618**	**-6.503**	**-1.149**
Median		**10.09**	**458**	**-1.859**	**-4.192**	**-10.262**	**-1.491**	**-6.551**	**-1.078**
Std. Deviation		1.61	362	1.406	0.547	0.370	1.405	0.578	0.323
DH91-2	06/20/97	6.74	1550	-0.515	-3.730	-7.728	-0.148	-4.481	-0.369
	11/20/97	7.00	1770	-0.533	-3.756	-7.778	-0.165	-4.504	-0.410
	04/09/98	7.21	1600	-0.492	-3.751	-8.760	-0.125	-5.491	-0.376
	12/09/98	7.02	1570	-0.555	-3.770	-7.807	-0.188	-4.519	-0.380
Minimum		6.74	1550	-0.555	-3.770	-8.760	-0.188	-5.491	-0.410
Maximum		7.21	1770	-0.492	-3.730	-7.728	-0.125	-4.481	-0.369
Mean		**6.99**	**1623**	**-0.524**	**-3.752**	**-8.018**	**-0.157**	**-4.749**	**-0.384**
Median		**7.01**	**1585**	**-0.524**	**-3.754**	**-7.793**	**-0.157**	**-4.512**	**-0.378**
Std. Deviation		0.19	100	0.027	0.017	0.496	0.027	0.495	0.018
DH98-6	12/09/98	9.46	518	-3.492	-4.900	-9.774	-3.125	-5.355	-0.800
DH98-7	12/09/98	9.09	387	-1.651	-4.232	-9.000	-1.284	-5.250	-0.464

Table A2-3c - Wells with Screens in the Middle Lykins - Forelle limestone

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
DH91-3A	11/20/97	7.31	325	-3.249	-4.611	-9.911	-2.881	-5.782	-0.948
	11/20/97	6.89	169	-3.249	-4.611	-9.911	-2.881	-5.782	-0.948
	06/20/97	6.68	47	-3.219	-4.629	-10.008	-2.841	-5.861	-0.991
	04/09/98	7.61	62	-3.640	-4.643	-10.046	-3.273	-5.885	-0.936
	12/09/98	7.07	44	-3.175	-4.608	-9.993	-2.807	-5.868	-1.023
Minimum		6.68	44	-3.640	-4.643	-10.046	-3.273	-5.885	-1.023
Maximum		7.61	325	-3.175	-4.608	-9.911	-2.807	-5.782	-0.936
Mean		**7.11**	**130**	**-3.306**	**-4.620**	**-9.974**	**-2.937**	**-5.836**	**-0.969**
Median		**7.07**	**62**	**-3.249**	**-4.611**	**-9.993**	**-2.881**	**-5.861**	**-0.948**
Std. Deviation		0.36	121	0.189	0.015	0.061	0.191	0.050	0.037
DH91-4	06/20/97	6.65	60	-3.458	-4.684	-10.204	-3.091	-6.002	-1.051
	11/20/97	7.03	295	-3.687	-4.694	-10.263	-3.320	-6.051	-0.986
	04/09/98	7.90	53	-3.701	-4.735	-10.314	-3.334	-6.062	-0.982
	12/09/98	7.11	28	-3.569	-4.679	-10.205	-3.202	-6.009	-1.151
Minimum		6.65	28	-3.701	-4.735	-10.314	-3.334	-6.062	-1.151
Maximum		7.90	295	-3.458	-4.679	-10.204	-3.091	-6.002	-0.982
Mean		**7.17**	**109**	**-3.604**	**-4.698**	**-10.247**	**-3.237**	**-6.031**	**-1.043**
Median		**7.07**	**57**	**-3.628**	**-4.689**	**-10.234**	**-3.261**	**-6.030**	**-1.019**
Std. Deviation		0.52	124	0.114	0.025	0.053	0.114	0.030	0.079
DH91-5	06/20/97	6.68	62	-3.235	-4.633	-10.119	-2.868	-5.968	-1.033
	04/09/98	7.98	66	-3.239	-4.641	-10.149	-2.872	-5.990	-0.968
Mean		**7.33**	**64**	**-3.237**	**-4.637**	**-10.134**	**-2.870**	**-5.979**	**-1.001**
DH92-7	06/20/97	7.43	62	-3.331	-4.595	-9.849	-2.963	-5.736	-0.996
	11/20/97	7.44	282	-3.480	-4.604	-9.831	-3.113	-5.708	-0.982
	04/09/98	8.11	57	-3.533	-4.632	-9.942	-3.166	-5.792	-0.989
	12/09/98	7.99	57	-3.399	-4.575	-9.907	-3.031	-5.814	-0.977
Minimum		7.43	57	-3.533	-4.632	-9.942	-3.166	-5.814	-0.996
Maximum		8.11	282	-3.331	-4.575	-9.831	-2.963	-5.708	-0.977
Mean		**7.74**	**114**	**-3.436**	**-4.602**	**-9.882**	**-3.068**	**-5.763**	**-0.986**
Median		**7.72**	**60**	**-3.440**	**-4.600**	**-9.878**	**-3.072**	**-5.764**	**-0.986**
Std. Deviation		0.36	112	0.089	0.024	0.051	0.089	0.049	0.008

Table A2-3c - Wells with Screens in the Middle Lykins - Forelle limestone (cont)

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
DH97-1	12/09/98	6.88	31	-3.583	-4.694	-10.258	-3.216	-6.046	-1.148
DH98-10A	12/09/98	8.47	86	-2.215	-3.975	-9.379	-1.847	-5.886	-0.330

Wells with Screens in the Upper Lykins - Alluvium

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
DH92-5A	06/20/97	5.94	346	-2.638	-4.059	-9.008	-2.270	-5.431	-0.689
	11/20/97	6.59	404	-3.225	-4.542	-9.719	-2.858	-5.659	-1.015
	04/09/98	7.81	82	-3.162	-4.534	-9.882	-2.795	-5.830	-0.846
	12/09/98	8.12	171	-2.866	-4.286	-8.957	-2.499	-5.153	-0.674
Minimum		5.94	82	-3.225	-4.542	-9.882	-2.858	-5.830	-1.015
Maximum		8.12	404	-2.638	-4.059	-8.957	-2.270	-5.153	-0.674
Mean		**7.12**	**251**	**-2.973**	**-4.355**	**-9.392**	**-2.606**	**-5.518**	**-0.806**
Median		**7.20**	**258**	**-3.014**	**-4.410**	**-9.364**	**-2.647**	**-5.545**	**-0.768**
Std. Deviation		1.02	150	0.273	0.231	0.477	0.273	0.293	0.160
DH92-5B	06/20/97	10.00	190	-2.187	-4.376	-9.545	-1.820	-5.651	-0.759
	11/20/97	11.30	387	-2.016	-4.113	-9.626	-1.648	-5.995	-0.944
	04/09/98	11.30	295	-1.906	-3.884	-10.572	-1.539	-7.170	-0.820
	12/09/98	8.77	160	-2.128	-4.318	-9.379	-1.760	-5.544	-0.668
Minimum		8.77	160	-2.187	-4.376	-10.572	-1.820	-7.170	-0.944
Maximum		11.30	387	-1.906	-3.884	-9.379	-1.539	-5.544	-0.668
Mean		**10.34**	**258**	**-2.059**	**-4.173**	**-9.781**	**-1.692**	**-6.090**	**-0.798**
Median		**10.65**	**243**	**-2.072**	**-4.216**	**-9.586**	**-1.704**	**-5.823**	**-0.790**
Std. Deviation		1.21	104	0.124	0.223	0.538	0.124	0.745	0.116
DH92-6	06/20/97	6.89	156	-3.149	-4.321	-9.029	-2.782	-5.190	-0.662
	04/09/98	7.42	163	-3.024	-4.334	-9.068	-2.656	-5.217	-0.666
	12/09/98	7.35	162	-3.218	-4.303	-8.992	-2.851	-5.172	-0.657
Minimum		6.89	156	-3.218	-4.334	-9.068	-2.851	-5.217	-0.666
Maximum		7.42	163	-3.024	-4.303	-8.992	-2.656	-5.172	-0.657
Mean		**7.22**	**160**	**-3.130**	**-4.319**	**-9.030**	**-2.763**	**-5.193**	**-0.662**
Median		**7.35**	**162**	**-3.149**	**-4.321**	**-9.029**	**-2.782**	**-5.190**	**-0.662**
Std. Deviation		0.29	4	0.098	0.016	0.038	0.099	0.023	0.005

Table A2-3c - Wells with Screens in the Upper Lykins - Alluvium (cont)

	Date	pH	TDS, mg/L	Anhydrite	Calcite	Dolomite	Gypsum	Magnesite	Amorphous Silica
DH97-4	11/20/97	7.39	584	-1.615	-4.058	-8.179	-1.248	-4.603	-0.457
	04/09/98	6.95	684	-1.607	-3.685	-8.065	-1.239	-4.862	-0.359
	12/09/98	7.81	271	-2.344	-4.005	-8.714	-1.977	-5.191	-0.606
Minimum		6.95	271	-2.344	-4.058	-8.714	-1.977	-5.191	-0.606
Maximum		7.81	684	-1.607	-3.685	-8.065	-1.239	-4.603	-0.359
Mean		**7.38**	**513**	**-1.855**	**-3.916**	**-8.319**	**-1.488**	**-4.885**	**-0.474**
Median		**7.39**	**584**	**-1.615**	**-4.005**	**-8.179**	**-1.248**	**-4.862**	**-0.457**
Std. Deviation		0.43	215	0.423	0.202	0.347	0.424	0.295	0.124

Figure A2-1a **Weir SM-1.** Stiff diagrams showing the ion chemistry of seepage water observed at the Right Toe Drain in weir **SM-1**. Average Reservoir data are plotted for comparison
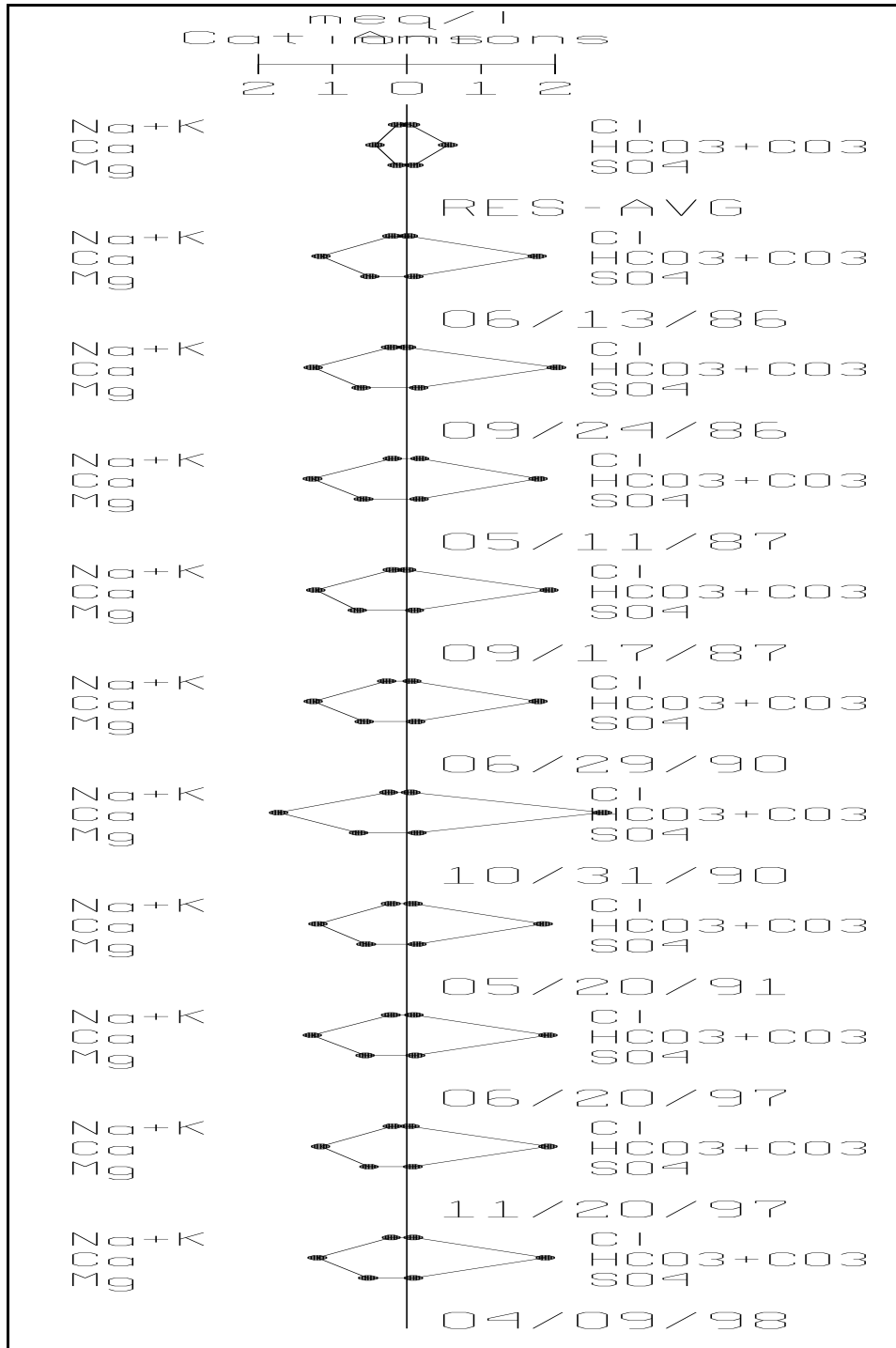
Figure A2-1b   Weir SM-2. Stiff diagrams showing the ion chemistry of seepage water from **SM-2**. This weir is located approximately 1200 ft downstream from the dam axis and 900 ft downstream of SM-1. Average Reservoir data are plotted for comparison.

Figure A2-1c   **Weir SM-3.** Stiff diagrams showing the ion chemistry of seepage water from **SM-3**. This weir is located approximately 2500 ft downstream from the Right Toe. Note the higher 1951 concentrations. Average Reservoir data are plotted for comparison.
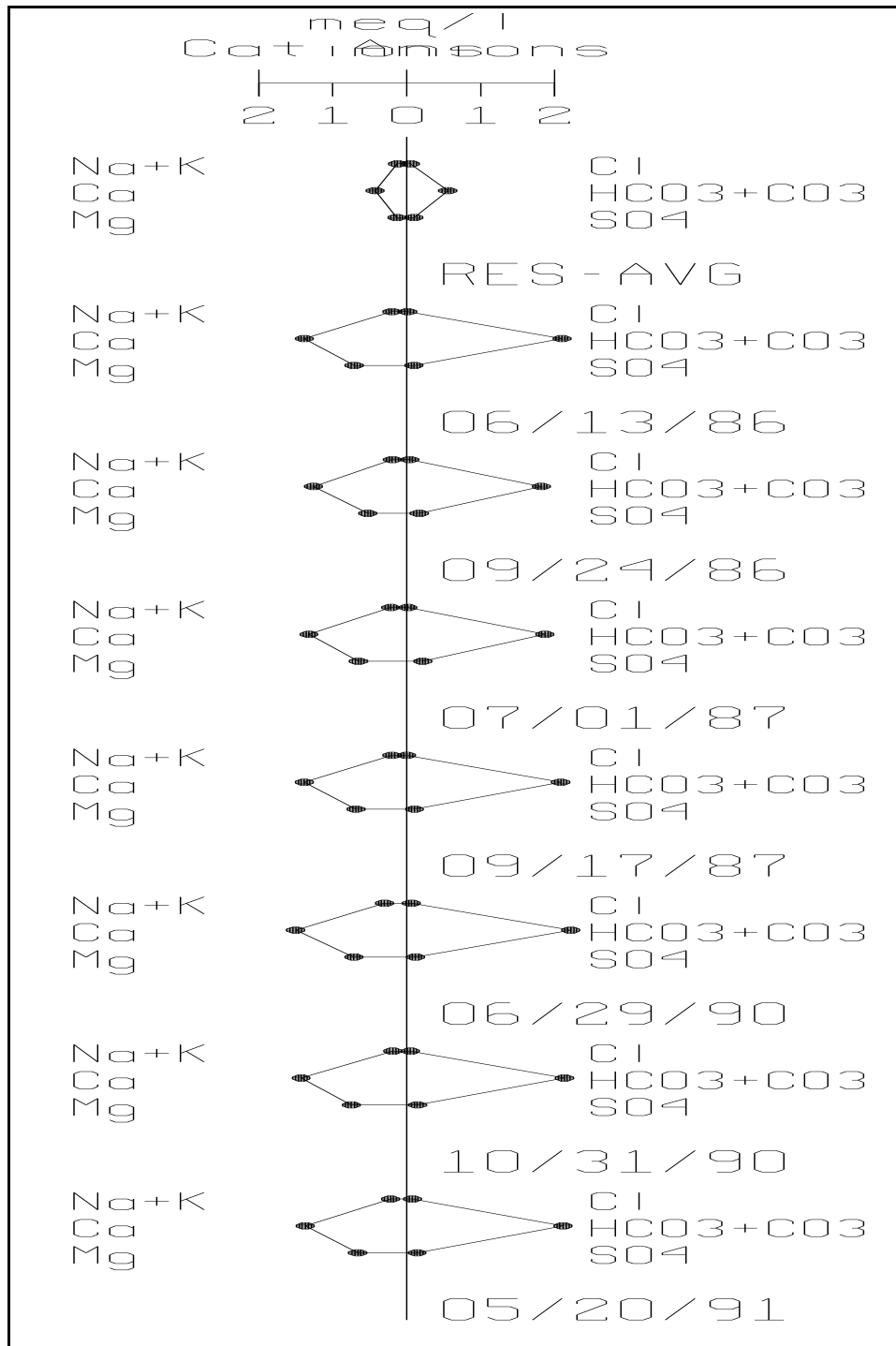
Figure A2-1d **Weir SM-4 and Pond.** Stiff diagrams showing the ion chemistry of seepage water from **SM-4**. This weir is located downstream from the seepage pond on the left. Average Reservoir data are plotted for comparison

Figure A2-1e   **Weir SM-7.** Stiff diagrams showing the ion chemistry of seepage water from **SM-7**. This weir is located approximately 3000 ft downstream from the Right Toe.   Average Reservoir data are plotted for comparison.
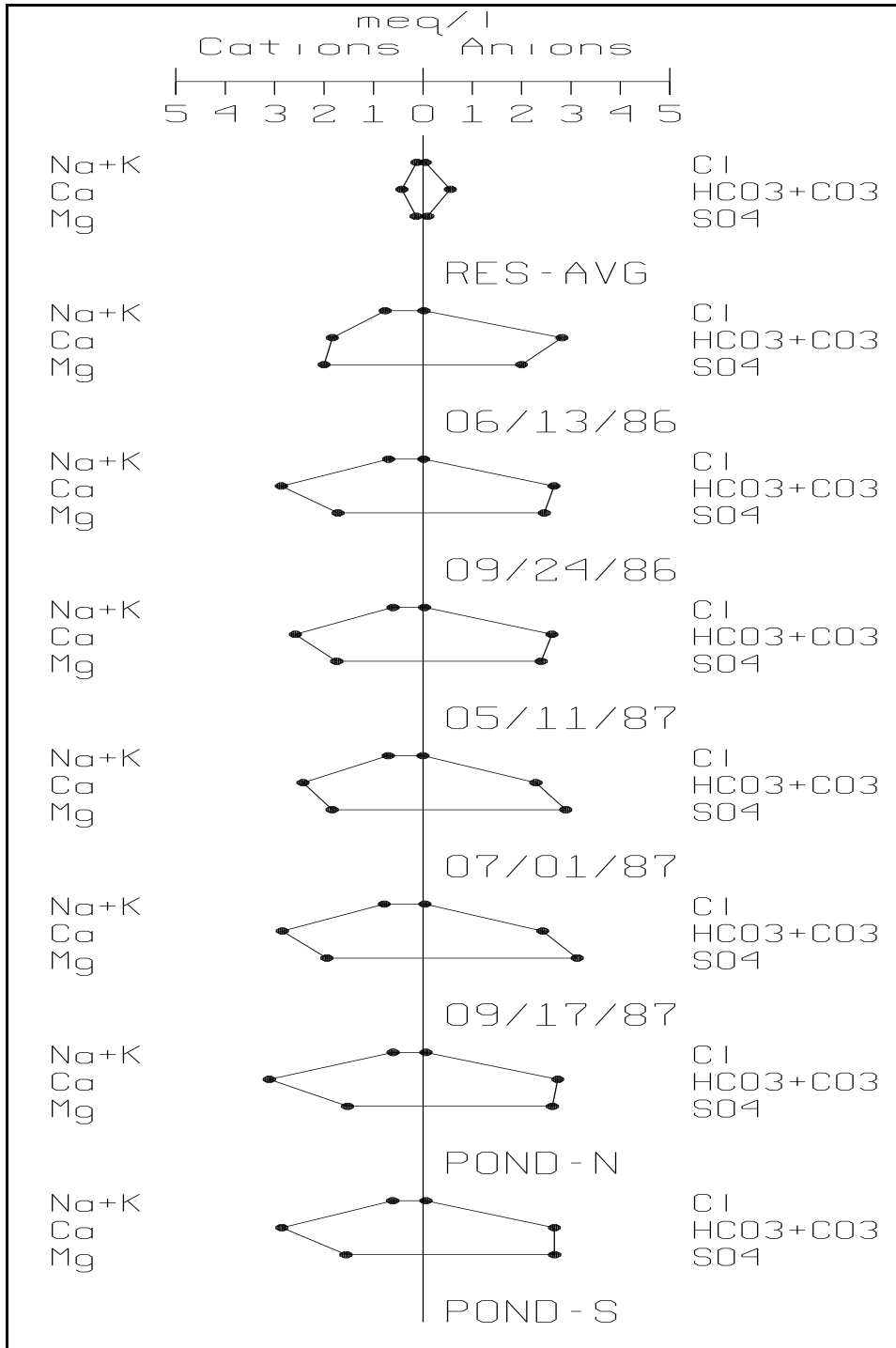
Figure A2-1f **Left Toe Weirs.** Stiff diagrams showing the ion chemistry of seepage water from **SM-8, SM-8A, SM-8B,** and SM-8C, located along and near the left toe of the dam. Average Reservoir data are plotted for comparison.
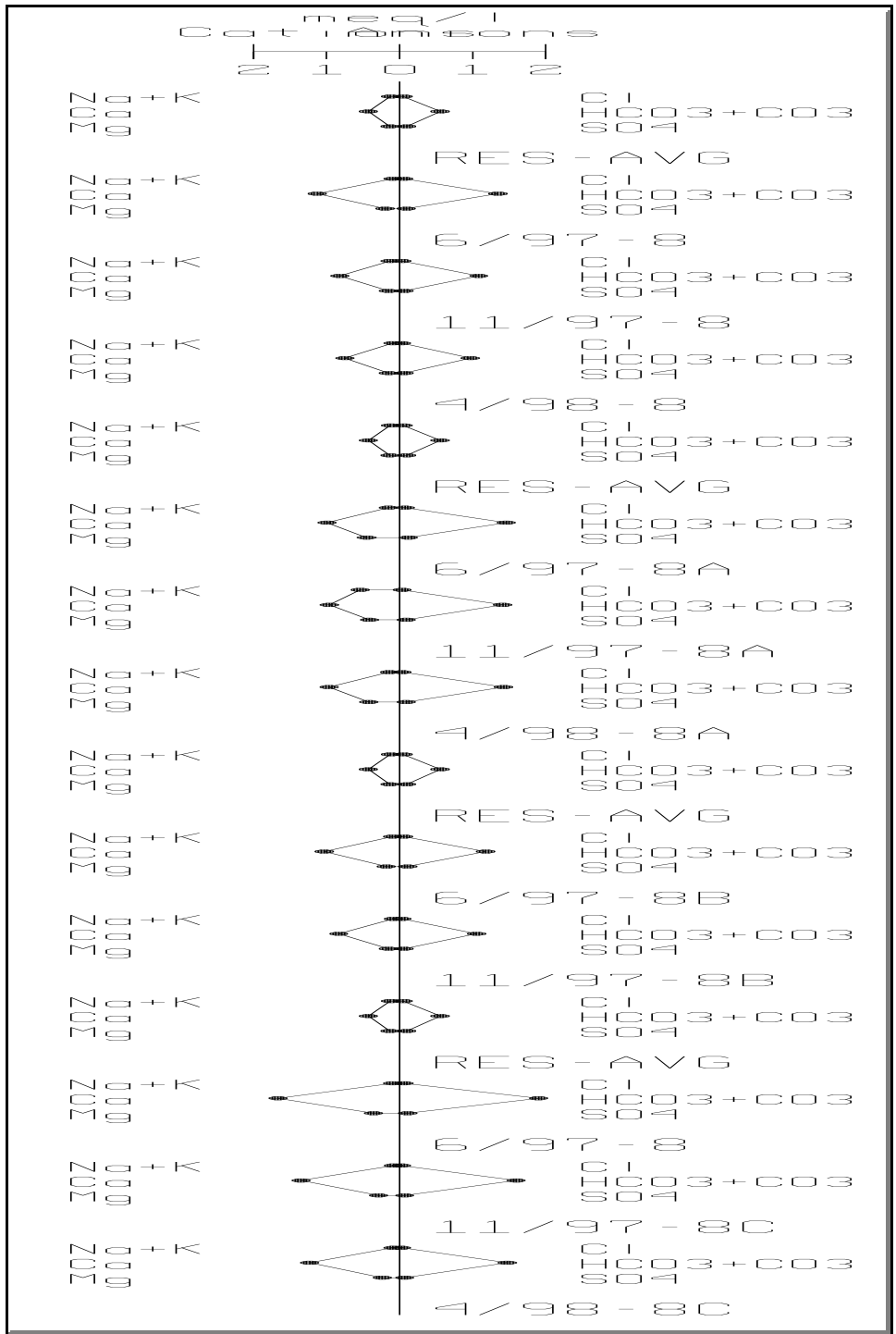
Figure A2-1g **Toe Drain Comparison.** Stiff diagrams of average concentrations (single available samples for 1A-CON) that compare the **Right Toe Drain** (SM-1), the **Left Toe Drain** (SM-1A), and the **Former Left Toe Drain** (1A-CON). Average Reservoir data are plotted for comparison.
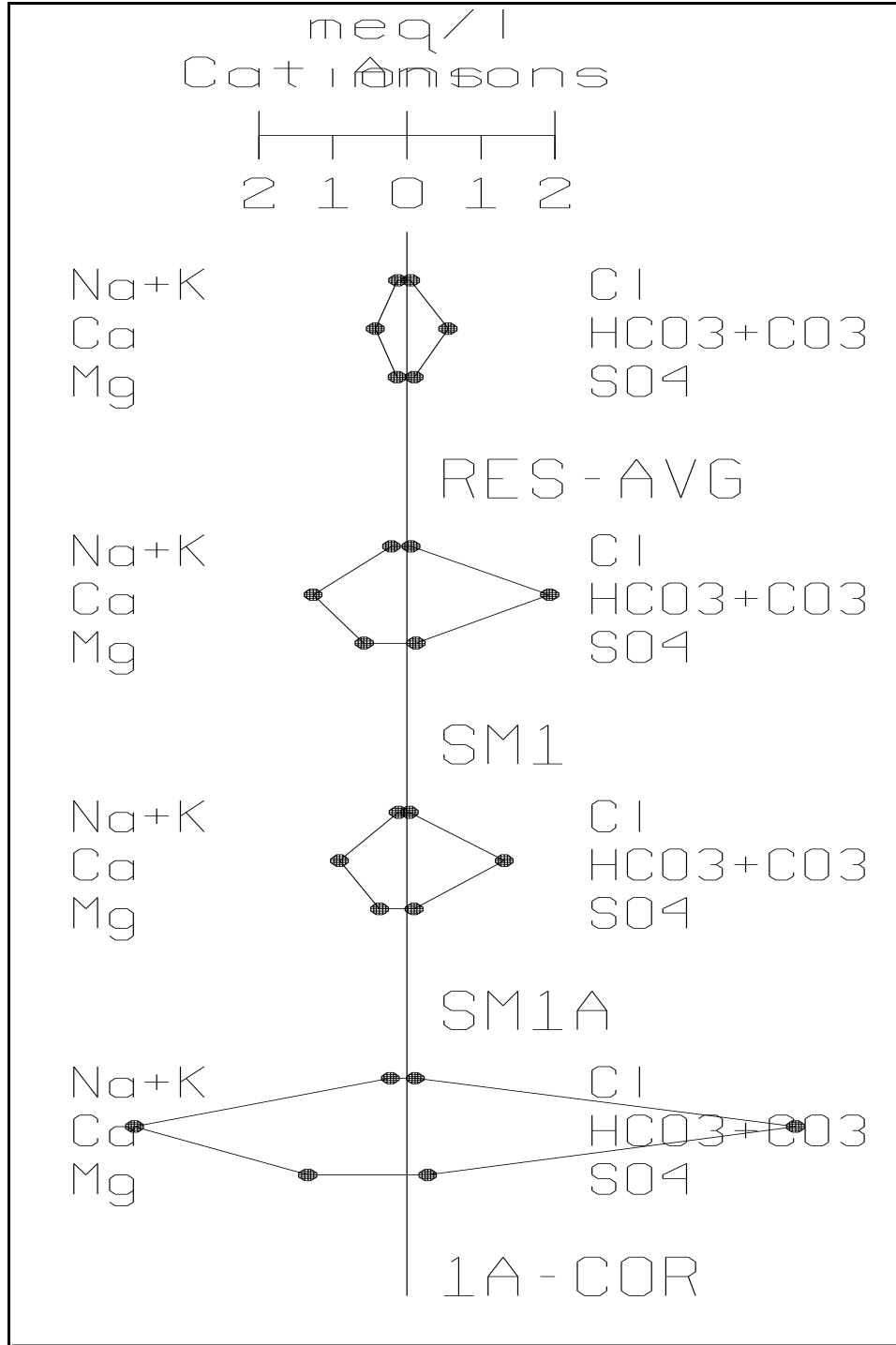
Figure A2-1h   Sinkhole Comparison to Seepage in Weirs. Stiff diagrams of average concentrations (single available sample for Sinkhole from the campground at the south end of the Reservoir). Average Reservoir data are plotted for comparison.
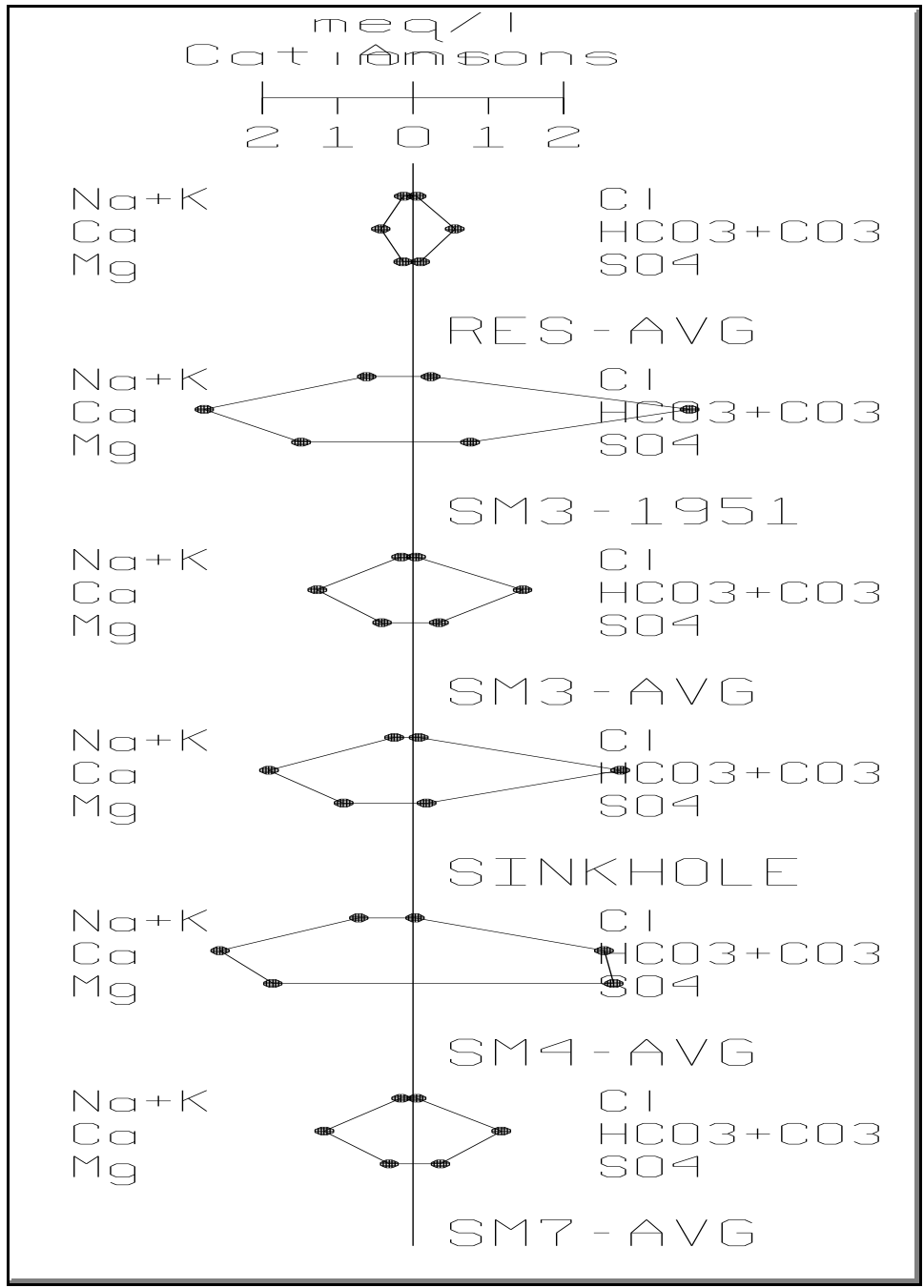
Figure A2-2a   Stiff diagrams showing the variable chemistry observed in groundwater collected from well **DH91-1**.   This well is located on the dam axis and the deep screen contacts the Lower Lykins - Blaine gypsum. Very alkaline pH has been observed for some samples.
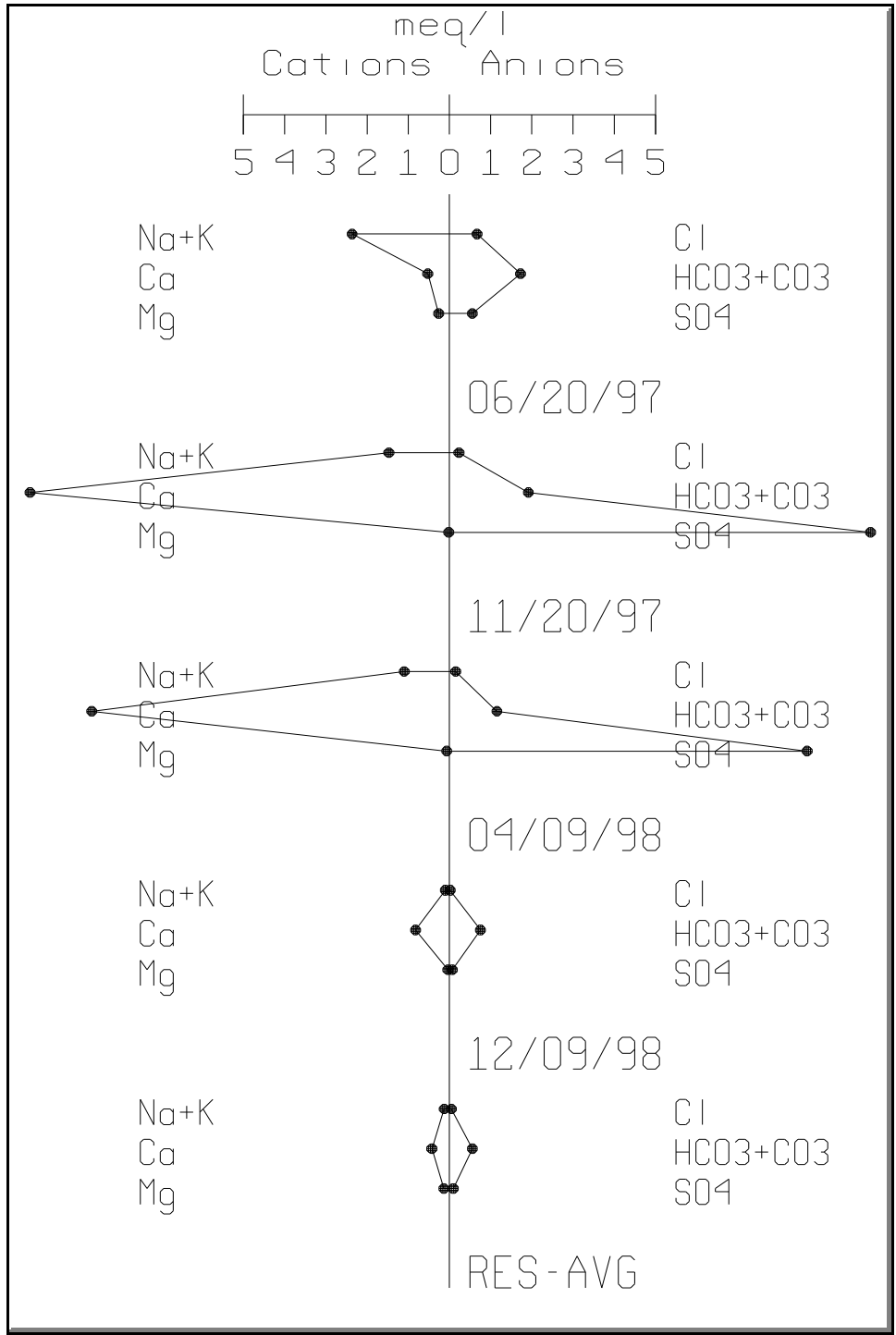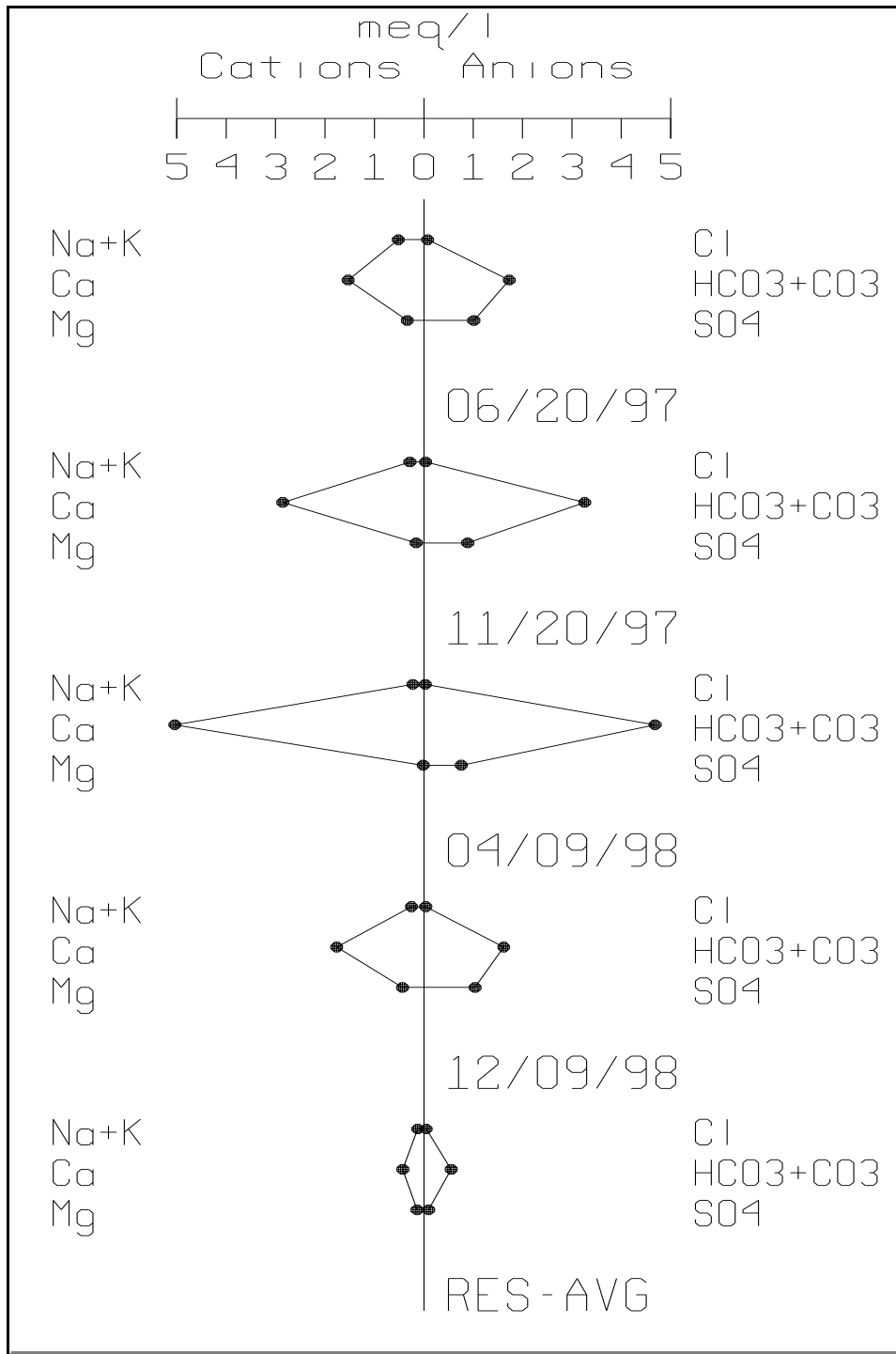
Figure A2-2b Stiff diagrams showing the variable chemistry observed in groundwater collected from well **DH92-5a**. This well is located approximately 200 ft downstream of the dam axis and the shallow screen contacts the Alluvium and Clay layers. The pH is not alkaline.
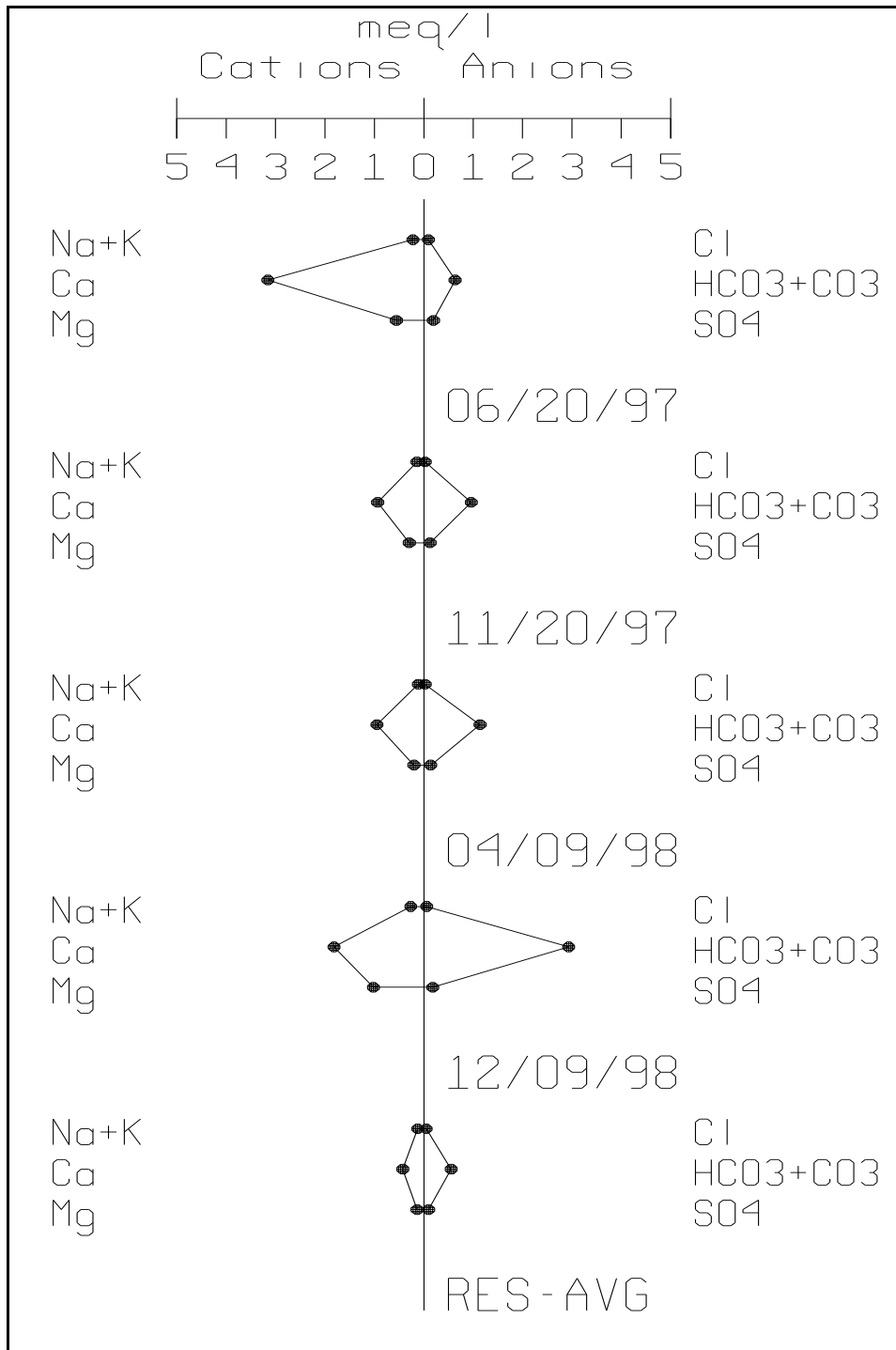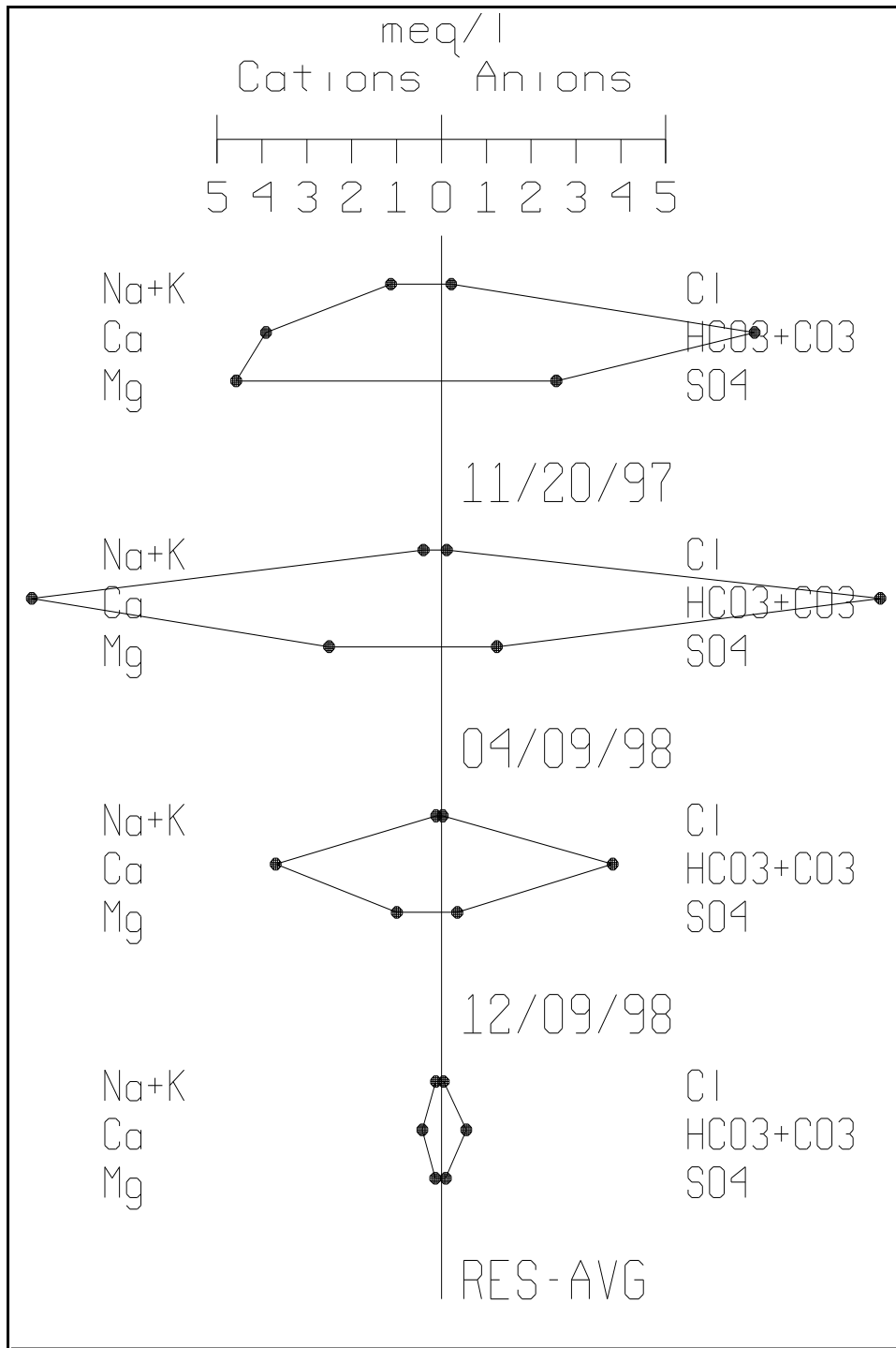
Figure A2-2c Stiff diagrams showing the variable chemistry observed in groundwater collected from well **DH92-5b**. This well is located approximately 160 ft downstream of the dam axis and the shallow screen contacts the Upper Lykins. Very alkaline pH has been observed for some samples.

Figure A2-2d Stiff diagrams showing the variable chemistry observed in groundwater collected from well **DH97-4**. This well is located approximately 180 ft downstream of the dam axis and the shallow screen contacts the Alluvium - Clay layer. Neutral pH has been observed.

Figure 4e   **DH91-2 - Consistently Elevated Concentrations.**   Here are Stiff diagrams showing the consistent and elevated concentrations observed in DH91-2. This well is located approximately 285 ft downstream of the toe and 695 ft downstream of the dam axis with a middle-depth screen in the **Lower Lykins** formation. These data suggest that the screen contacts groundwater that has dissolved gypsum deposits. pH was observed to be consistently neutral.
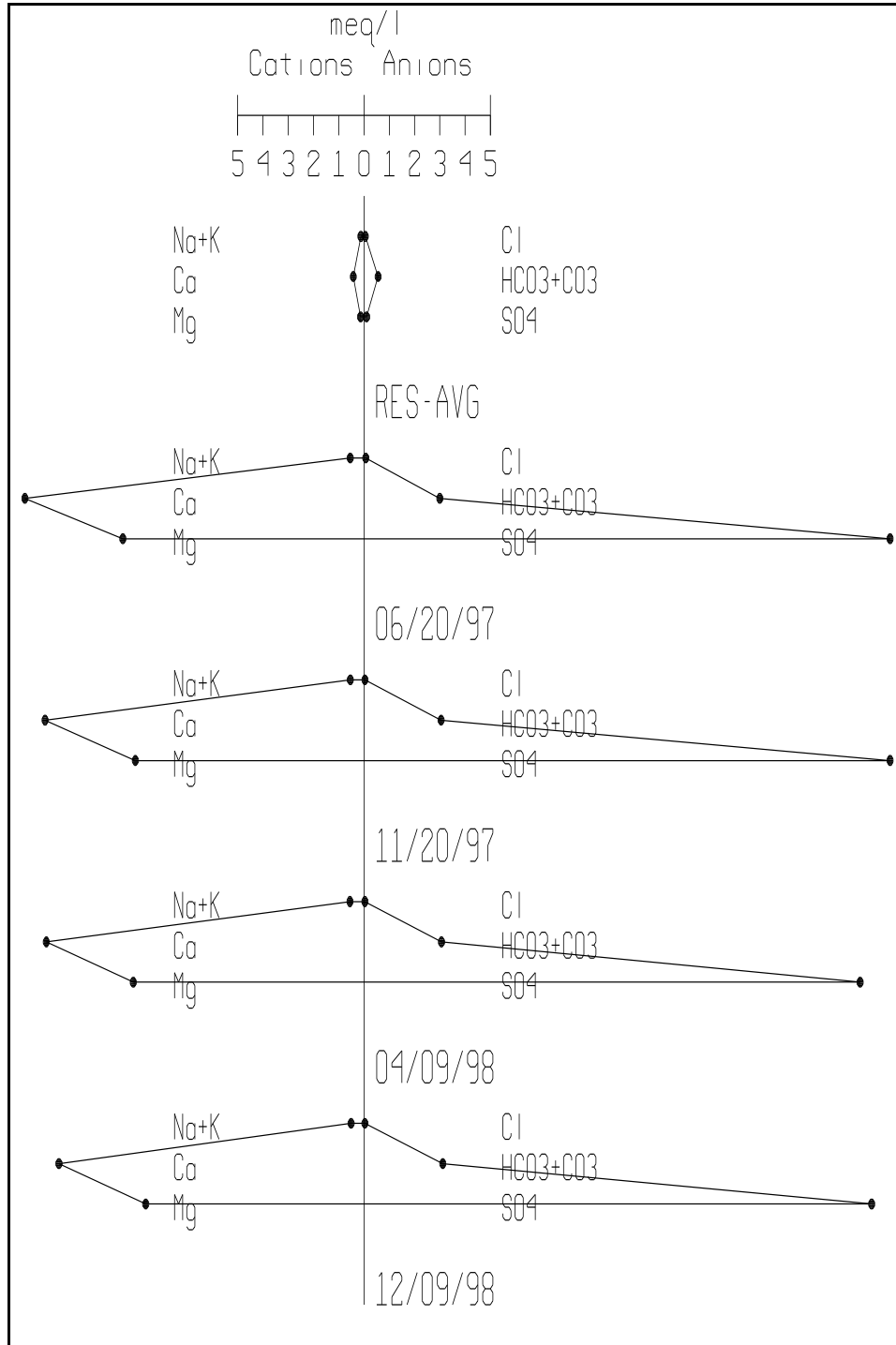
Figure A2-3a Stiff diagrams showing the average ion chemistry of wells with screens that contact the **Alluvium - Clay** or **Upper Lykins** strata. The average reservoir data are plotted for comparison.
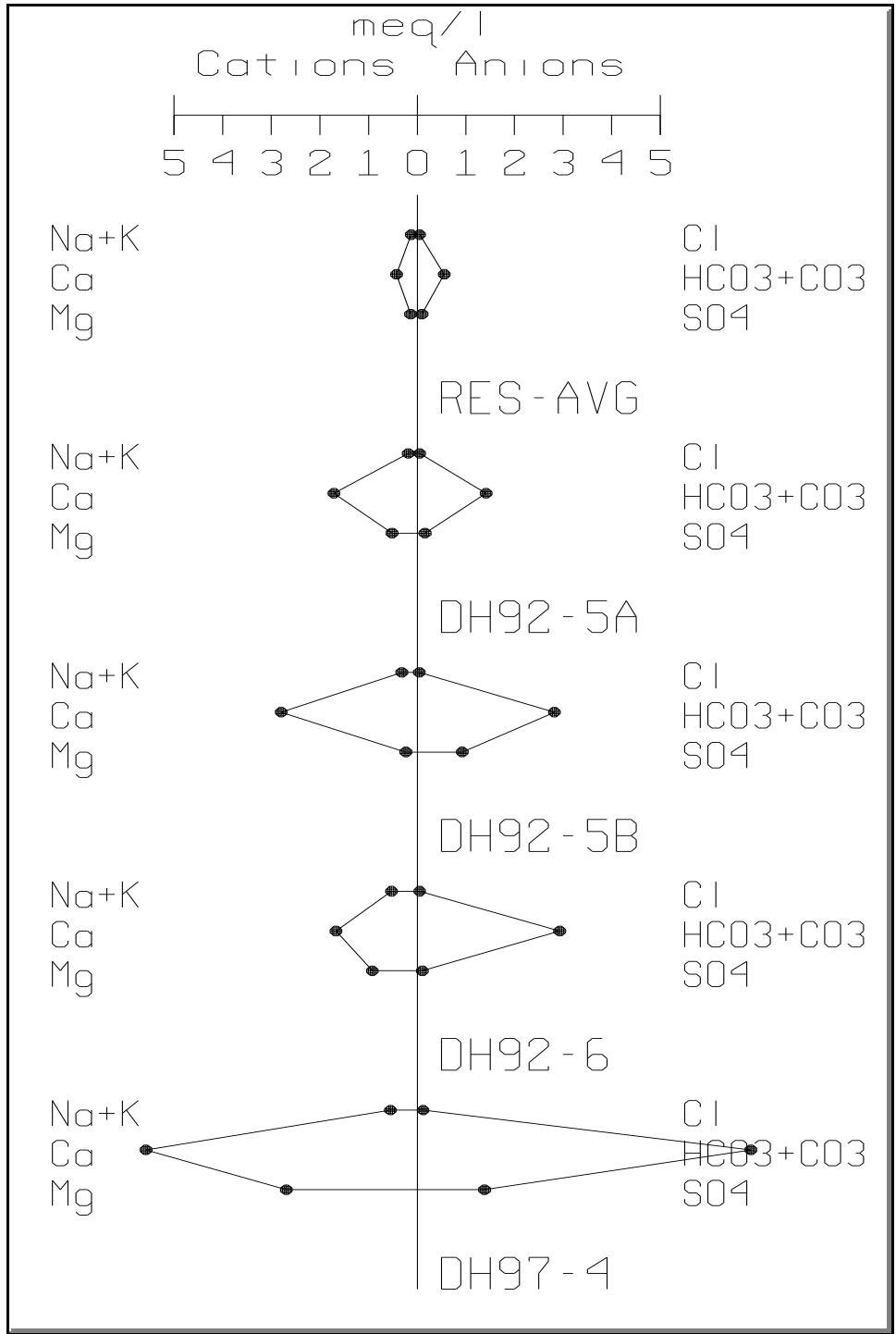
Figure A2-3b   Stiff diagrams showing the average ion chemistry of wells with screens that contact the **Middle Lykins** or **Forelle limestone** strata. The average reservoir data and average data for the 12/09/98 Left Abutment Trench samples are included for comparison.
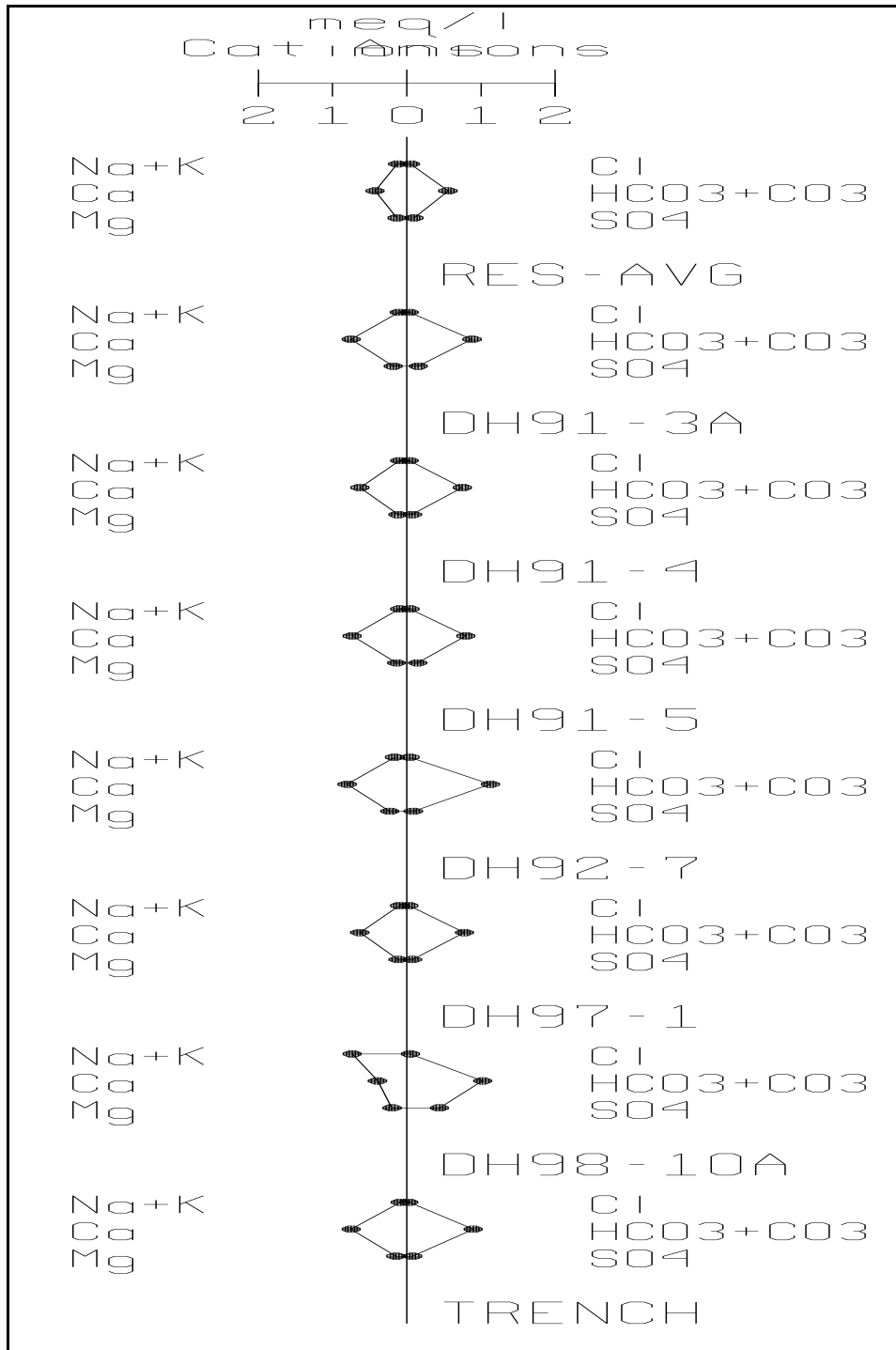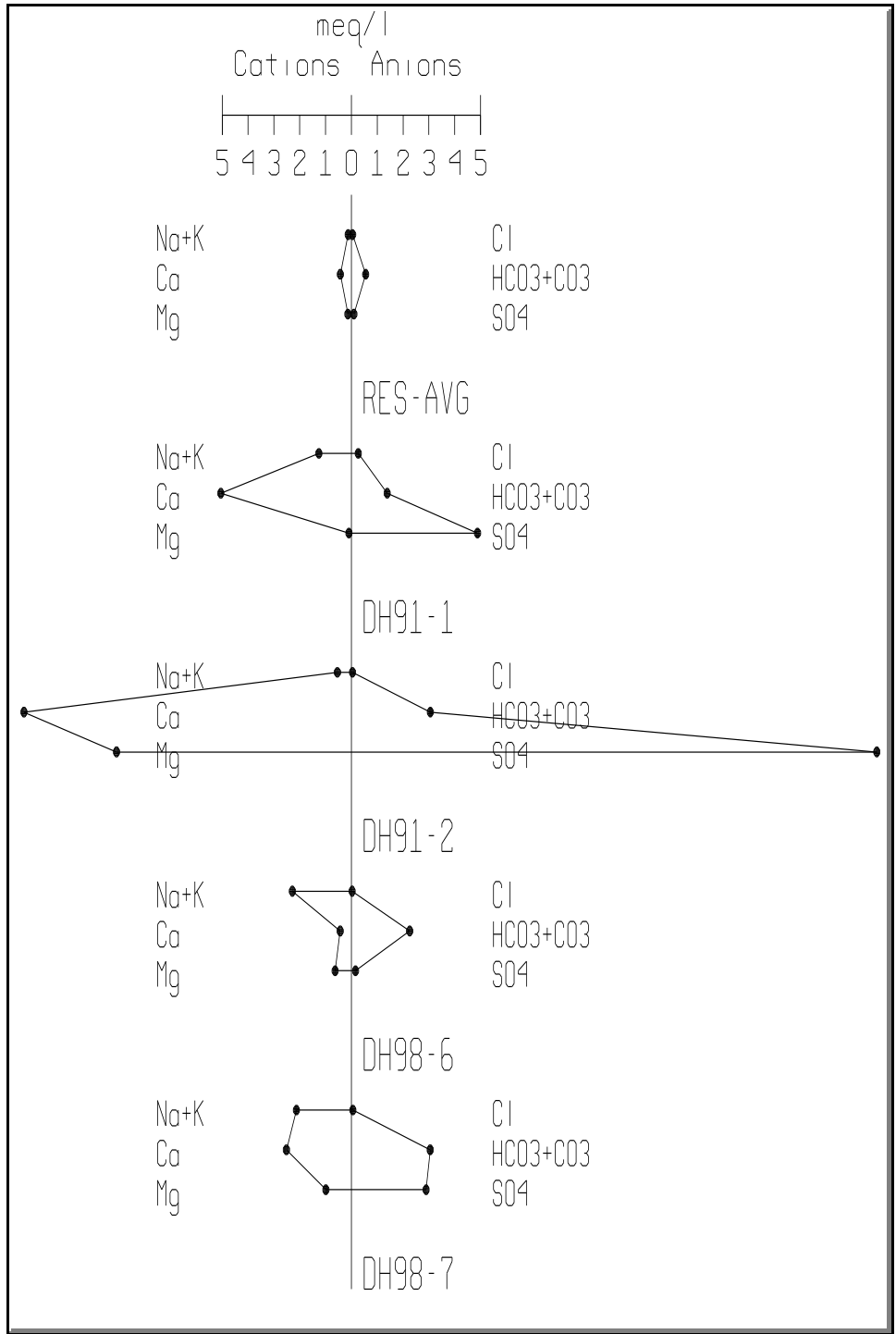
Figure A2-3c Stiff diagrams showing the average ion chemistry of wells with screens that contact the **Lower Lykins** or **Blaine gypsum** strata. The average reservoir data are plotted for comparison.

meq/l

Cations Anions

5 4 3 2 1 0 1 2 3 4 5

Na+K   Cl
Ca   HCO3+CO3
Mg   SO4

RES-AVG

Na+K   Cl
Ca   HCO3+CO3
Mg   SO4

DH91-1

Na+K   Cl
Ca   HCO3+CO3
Mg   SO4

DH91-2

Na+K   Cl
Ca   HCO3+CO3
Mg   SO4

DH98-6

Na+K   Cl
Ca   HCO3+CO3
Mg   SO4

DH98-7

APPENDIX 3

Petrographic Memorandums for Materials from Horsetooth Dam

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