Interpretation of Chemistry Data from Seepage, Observation Well, and Reservoir Water Samples collected at Horsetooth Dam during June 2005

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by

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INTRODUCTION

This technical memorandum summarizes chemistry data from reservoir, seepage, and observation well water samples collected at Horsetooth Dam on June 6-7, 2005. These samples are the second set of seepage water samples to be collected at maximum seasonal reservoir elevation after completion of modifications to Horsetooth Dam and re-filling of the reservoir in 2003.

Seepage, well, and reservoir water were analyzed for the chemical constituents pH, calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), bicarbonate, (HCO_3^-), carbonate (CO_3^{2-}), hydroxide (OH^-), sulfate (SO_4^{2-}), chloride (Cl^-), and trace elements aluminum (Al), iron (Fe), and manganese (Mn), following U.S. Environmental Protection Agency (EPA) consensus analytical methods.

Seepage, well, and reservoir water have been sampled and analyzed at intervals since 1951 in response to concerns about seepage at Horsetooth Dam, Ft. Collins, Colorado. Chemical data from seepage and well water at Horsetooth Dam has consistently suggested that mineral dissolution of calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), gypsum ($CaSO_4 \cdot 2H_2O$), anhydrite ($CaSO_4$), and silica (SiO_2), has been occurring in the foundation and abutments since first filling. The tilted geology of the foundation is composed of brecciated sedimentary claystone deposits with layered beds of limestone (notably the Forelle Limestone) and gypsum (the Blaine gypsum) associated with the Lykins formation. Samples were initially collected from the downstream seep at SM-3 shortly after reservoir filling in 1951, and indications of soluble mineral dissolution have been evaluated in technical memos for water samples collected since 1987.

SAMPLES AND LOCATIONS

Samples were collected from several wells and seepage locations. Information about these samples, obtained from Chuck Sullivan (in his travel report dated August 30, 2005), are summarized in Table 1. Static water levels in wells were measured using a portable M-Scope meter, and other hydrologic data were obtained from the DAMS (Data Acquisition and Management System) client program, v. 5.04_01. Samples are identified in table 1 and organized by abutment and distance from dam axis. Refer to the map in figure 1 for sampling locations.

METHODOLOGY

Samples were received by the Pacific Northwest Regional Water Quality Laboratory, Boise, Idaho, on June 9, 2005, and the final data were reported to me on June 26, 2004. Samples were analyzed using the EPA methods summarized in Table 2. Samples for Fe, Mn, and Al, were filtered through a 0.45-μm pore-size membrane by the laboratory. Analyses for silicon as SiO_2 were requested but were not analyzed.

In this report, concentrations for major ions are reported in units of milligrams per liter (mg/L) and milliequivalents per liter (meq/L), and trace elements are reported in micrograms per liter (µg/L). For each analyzed constituent, same date reservoir mg/L concentrations were subtracted from seepage mg/L concentrations to calculate net difference mg/L.

Saturation indices (SI's) are reported for carbonate-containing minerals (calcite, dolomite, magnesite), and sulfate minerals anhydrite and gypsum. SI's were calculated using the MINTEQA2 model and have been included with the Horsetooth summary data spreadsheet file (transmitted by email on 09-14-05). This spreadsheet also contains data analyzed for the July 2004 sampling and worksheets comparing the two post-repair sampling events. The SI's were calculated assuming temperature = 10˚C, and that samples were in equilibrium with atmospheric O_2 and CO_2 at partial pressures calculated for elevation 5,640 ft. Trace elements (Al, Fe, Mn) reported below detection limits were re-coded as one-tenth the reported limit of detection for input into the MINTEQA2 model.

Negative SI values suggest under saturation and that the water will tend to dissolve the mineral. Positive SI values suggest over saturation and that the mineral will tend to precipitate out of solution. SI values near 0 suggest that the mineral is in equilibrium with the seepage water, and that the particular mineral dissolution reaction may control the constituent ion concentrations in seepage.

RESULTS AND DISCUSSION

Static Water Levels in Wells and Seepage Flows:

Table 3 provides a summary of available static water levels and reservoir elevations for the 2004 and 2005 sampling events. Static water levels from field sampling log sheets are reported for piezometer wells, and flow is reported for weirs and seeps. The table 3 data show that the reservoir elevation this year (5422.94 ft) was only 3.6 ft higher compared to the previous sampling event July 13-14, 2004. In order to compare flows and static water levels, both of these variables were divided by reservoir elevation and these ratios (called adjusted static water levels and adjusted flows) were used to compare 2004 and 2005 data.

However, comparisons presented here are based on two snapshots of flow and static water levels observed during two slightly different seepage water sampling events. Changing time lags in hydraulic response of seepage to changes in reservoir surface elevation, and timing of sampling relative to reservoir peak elevation (10-12 weeks after maximum in 2004, near peak in 2005) also complicates comparison of 2004 and 2005 data. Variability associated with measuring static water levels at the time of well sampling also introduces an unknown level of uncertainty to any evaluation of observed trends based on static water levels. Therefore, any indications or concerns expressed here based on static levels should be confirmed or denied by a more detailed analysis of piezometer elevation data.

Static Levels Trends in Piezometer Wells: Adjusted static water levels in 2005 were lower in all wells but DH91-4, on the crest, and DH92-7, downstream from the left toe. Both wells intercept the Middle Lykins - Forelle Limestone and are located perpendicular to axis at 14+00. Discrete piezometer elevations for these wells near the sampling dates, however, do not suggest increasing water levels. Calcite particulates were identified in suspended materials collected from DH91-4 in the 2004 sampling that suggests breccia disturbance that could lead to increased permeability over time.

Seepage Trends in Weirs and Drains: 2005 seepage flows were lower at a higher reservoir elevation for most right abutment seeps, downstream seeps SM-3 and SM-7, and left abutment seep SM-9, which drains below Satanka Dike. SM-2, which collects near-embankment right side seepage, showed adjusted flow reduction around 10.9 percent. Further downstream, SM-3, draining a Forelle outcrop, showed an adjusted flow reduction of 4.08 percent. SM-7, which measures all upstream seepage not lost to groundwater, showed decreased adjusted flows of 17.2 percent between 2004 and 2005.

However, adjusted flows increased in IW-3R, the Manhole Weir to the west of the outlet works building that collects the right toe drain flows and SM-4, the Seepage Pond Outlet. A potentially new seepage flow with unknown origin, SM-LF5, was also observed flowing along the center left toe between 12+00 and 14+00; however, no flow was observed in the nearby left abutment Forelle Drain, SM-FOR.

SM-4 increased 14.3 gallons per minute (gpm) from 2004 to 2005, and this represents a 77.8 percent increase in adjusted flow. IW-3R, which discharges to the Seepage Pond and SM-4, showed an absolute increase of 12.4 gal/min from 2004 to 2005, representing a 289-percent increase in adjusted flow. These results suggest that around 87 percent of increased discharges seen at SM-4 are from the right toe drain, rather than from increased upwelling flow or surface seeps on the left side of the dam (accounting for around 1.9 gpm). Flows in SM-4 may also be influenced by reservoir releases flowing in the Charles Hansen Canal.

The large percentage change calculations for IW-3R and SM-4 should be considered in light of the actual changes in flows, which are modest. The low 2004 flows in IW3R (4.29 gpm) may have also been the result of sampling (July 14-15) the weir well after maximum reservoir elevation was reached (a broad peak from mid-March to mid-April). We are seeing an increase of around 14 gpm, up to 32.5 gpm at SM-4, compared to flows of around 460 gpm observed during July 1999 prior to repairs. For comparison, consider that SM-4 flows in July 1987 were 40.7 gpm at reservoir elevation 5397.48 ft.

Chemistry of Piezometer Wells and Seeps:

2005 major ions and trace element results are summarized in table 4. Figures 2a - 2e plot seepage chemistry data in meq/L for both 2004 and 2005 sampling events, with the reservoir average sample reproduced on each Stiff diagram in the inner blue-green polygon. 2004 data are plotted on the left side of each figure, and 2005 data are plotted to the right. Sum of ions (a proxy for total dissolved solids, and labeled as TDS, mg/L), and pH data are annotated on the Stiff diagrams. Figures 2a - 2b show the chemistry of piezometer well samples, and figures 2c - 2e show the chemistry of surface seeps and drains. Differences in mg/L between reservoir and downstream samples are summarized in table 5, and MINTEQA2-calculated mineral saturation indices are presented in table 6.

The first general comparison between the chemistry of 2004 and 2005 is that lab pH values were consistently lower and more acidic in 2004 compared to 2005. These data are suggestive of overall greater equilibration with calcite and perhaps longer seepage residence times. In general, the mineral saturation indices for calcite, dolomite, and magnesite suggest a trend toward greater saturation with respect to carbonate minerals since the repair. Less negative saturation indices suggest longer residence time for seepage, confirmed by generally lower seepage flows and static water levels in piezometers. These results, with the exception of new flows observed in SM-LF5, and the lack of flow observed in the left toe drain, suggest that the overall flows in the left embankment and abutments are stable and not progressing.

Piezometer Wells Intercepting the Middle Lykins-Forelle Limestone: Figure 2a shows Stiff diagrams for wells DH91-4 (crest @ 14+00), DH91-5 (left toe @ 12+00), DH92-7 (foundation @ 14+00), DH97-3 (foundation @ 13+00), and DH99-11 (crest @ 12+00).

Middle Lykins-Forelle wells generally showed increases in overall concentrations between 2004 and 2005 except for DH91-4 and DH97-3, which saw a 3.5- to 8.4-percent *decrease* in sum of ions TDS between 2004 and 2005. Decreasing concentrations are usually suggestive of faster seepage flows and greater permeabiliy along a flow path. While piezometric data do not suggest any clear change in permeability for these wells, adjusted static water levels increased by 1.3 percent for DH91-4. No change in static water level was observed for DH97-3.

All of these wells show Stiff diagrams consistent with calcite dissolution (the bulges at Ca and HCO_3 on the Stiff polygons); however, DH91-5 and DH99-11 (directly downstream from DH91-1) also show increases in SO_4^{2-} not seen in other Middle Lykins wells. These embankment wells located between 10+00 and 12+00 suggest dissolution of gypsum and /or anhydrite in the Middle Lykins, or inter-bed mixing of Lower Lykins seepage in contact with sulfate minerals. The presence of SO_4^{2-} warrants future monitoring and scrutiny of DH91-5 and DH99-11.

Piezometer Wells Intercepting the Lower Lykins-Blaine Gypsum: Figure 2b shows piezometer wells intercepting the Lower Lykins. DH98-5 (and the duplicate sample DH98-5C) suggest gypsum or anhydrite dissolution dominating the chemistry. This well showed the highest observed TDS of all samples. While the adjusted static water levels suggest a 15.4 percent decrease between 2004 and 2005, the decrease of 3 - 7 percent in TDS is contradictory and suggests a shorter seepage residence time and possibly increased permeability along this flow path.

DH91-1 is a crest piezometer upstream of DH98-5, and showed a very alkaline pH of 11.7, suggesting contact with and dissolution of grout cement. As noted in Sullivan's travel report, this well has a bend or constriction in the casing that may prevent pump sampling deep enough to purge the well properly. DH92-6, located on the left of the embankment at 15+00, intercepts the Lower Lykins, but in strata much closer to the foundation containing shale and limestone. The chemistry of this sample suggests dissolution of gypsum or anhydrite, and perhaps some influence from grout (in the elevated Na).

Seeps and Drains Near the Dam: Figure 2c shows near-dam seeps that are primarily representing near embankment right side toe drainage. SO_4^{2-} is only slightly elevated in all of these weirs, and the overall chemistry suggests a calcite-dominated water chemistry. All of these seeps except IW-3R showed decreases in 2005 measured flow.

Figure 2d shows the chemistry of left abutment seeps near the dam. SM-4, below the Seepage Pond, increased in flow from 2004 by 14.7 gpm, though only a small amount of this increase (around 1.9 gpm) is not due to increases observed at IW-3R. The chemistry this year also shows significantly higher concentrations of SO_4^{2-}, not seen in upstream seepage at SM-9 or IW-3R. These chemistry results suggest that the higher SO_4^{2-} is likely from upwelling of seepage at depth intersecting the Lower Lykins - Blaine formation. SM-4 is the only 2005 sample suggesting over saturated carbonate mineral conditions, and the table 6 carbonate mineral SI's are all positive. A pH of 9.2 is also unexpectedly high, suggesting a possible influence from grout-dominated chemistry seen in DH91-1, upstream of SM-4.

On the far left abutment below Satanka Dike, SM-9 (figure 2d) shows very encouraging trends from 2004. Adjusted flows are around 50.0 percent lower this year, and no indication of sulfate mineral dissolution is currently seen. The greater concentrations seen in SM-9 in 2004 were perhaps indicative of a first-flush dissolution concentration spike.

SO_4^{2-} also is present in the new left toe flow, SM-LF5 (figure 2d), suggesting gypsum and/or anhydrite dissolution. SM-LF5 shows a chemistry similar to that seen in well DH92-6 (intercepting the Lower Lykins-Falcon Limestone/Glendo Shale) but at elevated overall concentrations (TDS = 401 mg/L compared to 362 mg/L for DH92-6). Significant 2005 rain events on May 30 (1.1") and June 2-4 (1.4") may have contributed to flows observed at SM-LF5, perhaps by promoting percolation though the stability berm Zone 3 material placed along the left toe during the repair work. However the presence of SO_4^{2-} and much higher concentrations in SM-LF5 are unlike other near dam toe drain and seepage samples. Because the strata in the foundation are tilted, the Lykins is fairly shallow along this axis. Therefore, the chemistry of SM-LF5 may suggest a possible new near-foundation seepage path - an issue that deserves closer scrutiny.

Downstream Seepage: SM-3 and SM-3S, which drain a Forelle outcrop, show chemistry influenced by calcite with some gypsum dissolution (figure 2e). SM-7, which collects all upstream seepage not re-entering groundwater, suggests greater proportions of gypsum influence. Both of these downstream seeps showed decreased adjusted flows between 2004 and 2005. These decreased flows have been accompanied by *increases* in TDS and higher pH, suggestive of longer underground residence time, and an overall decrease in total seepage.

SUMMARY AND RECOMMENDATIONS

Observed increases in concentrations between 2004 and 2005 for most wells and seeps suggest generally lower flows and a general seepage stability on the margins of Horsetooth Dam. There are conflicting and ambiguous data; however, associated with wells and seeps located in the central part of the dam axis. Some of the observed changes in chemistry, static level, and flow may be the result of differences in the timing of the 2004 and 2005 sampling events relative to reservoir maximum. Some of observed differences may be the result of measurement variability. The overall changes observed between 2004 and 2005 appear subtle at this point; however, even small increases in seepage flow and subtle indications in chemistry warrant appropriate scrutiny. For example, SM-4 flows in July 1987 were around 40 gpm at reservoir elevation 5397.48 ft - only 8 gmp greater than the 2005 SM-4 flow.

Seepage in Karst formations usually begins with modest or ambiguous increases in permeability or flow. Despite the potential uncertainties in comparative data noted here, the findings that warrant consideration include the following:

1. **Decreased TDS in DH91-4 and DH97-3 -** Decreased TDS compared to 2004, and erratic and variable recent piezometer data in DH91-4 suggest that these 14+00 Middle Lykins-Forelle Limestone wells should be evaluated carefully as more hydraulic data are collected.

2. **SO_4^{2-} in DH99-11 and DH91-5 -** The presence of SO_4^{2-} in two wells intercepting the Middle Lykins - Forelle Limestone perpendicular to 12+00, DH99-11 on the crest, and DH91-5 at the toe, suggest that seepage from the Lower Lykins is up welling and that inter-bed flow paths may exist along this axis.

3. **Decreased TDS in DH98-5 -** A decrease in TDS between 2004 and 2005 contradicts the observed 15.4 percent drop in static level.

4. **SO_4^{2-} in SM-4** - Significantly increased SO_4^{2-} in 2005 SM-4 water also suggests possible vertical mixing and connection to Lower Lykins flow paths.

5. **SO_4^{2-} in SM-LF5 -** The origins of this seepage and hydraulic response to reservoir elevation or rain are unknown, but the chemical resemblance to the nearby Lower Lykins well DH92-6 should be of concern because of the suggestion of possible flows from near foundation Lower Lykins flow paths emerging near the toe.

In light of these findings, I recommend the following actions be considered by the Eastern Colorado Area Office:

1. Because of the chemistry issues noted above and differences in time lag between maximum reservoir elevations and sampling in 2004 and 2005, I recommend one additional seepage sampling event next year, timed to duplicate the 2005 time lag between reservoir maximum and sampling. Coordination and field crew scheduling should be initiated no later than March 2006 to ensure sample timing is comparable to the 2005 time lag. This will complete the baseline post-repair seepage water quality monitoring and establish more firmly whether seepage is stable or showing any indications of progressive dissolution.

2. A reduced set of stations may be sampled for the 2006; however, the following samples should be collected:

   - Reservoir
   - Wells in Middle Lykins-Forelle Limestone showing sulfate: DH91-5, DH99-11, and DH91-4 and DH92-7 (no observed sulfate) for comparison
   - Wells in Lower Lykins-Blaine Gypsum: DH92-6, DH98-5 (DH91-1, if repaired)
   - Seeps and Drains: IW-3R, SM-2, SM-4, SM-7
   - Any current surface drainage: SM-LF5
   - Any wells or seeps showing erratic or unexplained response to reservoir elevation identified prior to the 2006 sampling.

3. Piezometer data from DH99-11, DH91-1, DH91-5, DH92-6, DH98-5, and DH97-3 should be regularly monitored during and after spring filling and releases. Piezometric data for wells with apparent decreasing TDS should be carefully examined.

4. Seepage flows at IW-3R and SM-4 should also be monitored more frequently during reservoir filling and some attempt should be made to determine seepage flow measurement variability. SM-4 flows > 50 gpm should prompt greater scrutiny and perhaps opportunistic grab samples for chemical analysis. The influence of reservoir releases on SM-4 discharges should also be evaluated.

5. Any future flows at SM-LF5 should be measured or estimated as soon as feasible when flows are observed. If flows return at high reservoir elevation next year *without* significant recent rainfall, a weir should be installed and included with the other regular seepage monitoring stations. Any new flowing water should be sampled as soon as practicable.

6. Consider repair or replacement of casing for DH91-1. This is a crest well in the Lower Lykins that is in-line with DH98-5, and may be intercepting a flow path through the Lower Lykins that up wells in the Seepage Pond. With the current casing, the pump cannot be lowered to the depth of the screen to correctly draw water from the Lower Lykins. If the casing is fixed, then DH91-1 should be included in next year's sampling event.

TABLES

Interpretation of Chemistry Data from Seepage, Observation Well, and Reservoir Water Samples collected at Horsetooth Dam during June 2005

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Table 1 - Seepage and well samples collected June 6-7, 2005 from Horsetooth Dam.

Station ID	Abutment L or R	Lateral Distance from Dam Axis		Pump* Depth, ft	Screen Depth, ft	Notes
		ft	m			
SM-9	L	965	294.1	0	na	@ 17+10, Satanka Dike seepage
SM-4	L	1,245	379.5	0	na	@ 10+75, Seepage Pond, collects all left side seepage
SM-LF5	L			0	na	@ 15+00 - new surface seep on left toe near DH92-6
DH91-1	L	30	9.14	126.2	474	@ 10+00, static level 126.2 ft., crest of dam, intercepts Blaine, sampled frequently before repairs, NOT sampled in 2004, hand bailed
DH91-4	L	32	9.75	140	126-145	@ 14+00, static level 127.1', Middle Lykins - Glendo Shale
DH99-11	L	32	9.75	150	310-392	@ 11+89, static level 135.5', Lower Lykins (Forelle - Blaine)
DH91-5	L	485	148.8	34.5	184-234	@ 11+97, static level 28.2', Middle Lykins - Forelle Limestone
DH92-7	L	570	173.7	54.6	51-61	@ 14+32, static level 51.9', hand-bailed sample, Middle- Lykins - Harriman shale, cloudy + organic smell
DH98-5**	L	615	187.5	75	341-375	@ 10+56, static level 8.2', pump 210 cycles, Blaine Gypsum, clear with organic smell, previously hand-bailed
DH98-5C**	L	615	187.5	75	375-341	duplicate of DH98-5
DH92-6	L	250	76.2	22	22	@ 15+00, not sampled in 2004, hand-bailed sample, cloudy + organic smell - Lower Lykins shale and limestone
DH97-3	L	620	189.0	100	120-101	@ 13+00, static level 24.8', intercepts Middle Lykins - Forelle in shale
SM-1	R	470	143.3	0	na	@ 08+50 right side of outlet - sampled from pipe
IW-3R	R	525	160.0	0	na	@ 09+08, Right toe drain - inspection well on left (west) side of outlet building
SM-11	R	490	149.4	0	na	@ 08+20, right side of outlet
SM-11B	R	940	286.5	0	na	@ 06+40, new right side seepage measurement site
SM-2	R	1,272	387.7	0	na	@ 08+95, right (east) of Hansen Canal - collects all right-side seepage except IW-3R
SM-3	L + R	2,920	890.0	0	na	@ 13+10, downstream left of center seep - deeper seepage - Forelle outcrop
SM-7	L + R	3,750	1,143	0	na	@ 05+50, all seepage collection point

* Hand bailed samples use static water level for pump depth

** Samples DH98-5 and DH98-5C are duplicates

Table 2 - Summary of analytical methods used by the Pacific Northwest Regional Water Quality Laboratory.

Test	*EPA Method*	*Technique*
Laboratory pH	150.1	electrometric
CO_3^{2-}	310.1	titrimetric
HCO_3^-	310.1	titrimetric
OH^-	310.1	titrimetric
Total Alkalinity as $CaCO_3$	310.1	calculation
SO_4^{2-}	300	ion chromatography
Cl^-	300	ion chromatography
Ca	215.1	flame atomic absorption
Mg	242.1	flame atomic absorption
Na	273.1	flame atomic absorption
K	258.1	flame atomic absorption
Al, dissolved	202.2	furnace atomic absorption
Fe, dissolved	236.1	flame atomic absorption
Mn, dissolved	243.1	flame atomic absorption

Table 3 - Hydrologic conditions during the two post-repair seepage sampling events at Horsetooth Dam, 2004 and 2005. Measured static water levels are provided for wells, and flow in gallons per minute (gal/min) for seeps. These values are divided by reservoir elevation to provide a uniform ratio adjusted (or scaled) for reservoir elevation. Changes suggesting an increase in static level or flow are denoted in gray.

Sample	*2004 July 13-14, 2004*		*2005 June 6-7, 2005*		*Change from 2004 to 2005*	
Reservoir Elevation, ft	5419.38		5422.94		+3.56	
	Static Water Level, ft	*Adjusted Static Water Level**	*Static Water Level, ft*	*Adjusted Static Water Level**	*Absolute Change, ft*	*Adjusted Percentage Change*
DH91-1	-126.0	-0.0232	-126.2	-0.0233	-0.1	-0.43
DH91-4	-128.3	-0.0237	-127.1	-0.0234	+1.2	**+1.27**
DH91-5	-26.6	-0.0049	-27.2	-0.0050	-0.6	-2.04
DH92-6	-	-	-18.0	-0.0033	-	-
DH92-7	-54.6	-0.0101	-51.9	-0.0096	+2.7	**+4.95**
DH97-3	-24.8	-0.0046	-25.1	-0.0046	-0.3	0.00
DH98-5	-7.1	-0.0013	-8.2	-0.0015	-1.1	-15.4
DH99-11	-135.1	-0.0249	-135.5	-0.0250	-0.4	-0.40
	Seepage Flow, gal/min	*Adjusted Flow***	*Seepage Flow, gal/min*	*Adjusted Flow***	*Absolute Change, gal/min*	*Adjusted Percentage Change*
SM-2	29.20	0.0054	26.15	0.0048	-3.05	-10.9
SM-3	680.23	0.1255	652.84	0.1204	-27.49	-4.08
SM-4	18.18	0.0034	32.45	0.0060	+14.27	**+77.8**
SM-7	898.80	0.1658	744.95	0.1374	-153.85	-17.2
SM-9	51.88	0.0096	26.15	0.0048	-25.73	-50.0
SM-LF5	-	-	new - no weir	-	-	-
IW-3R	4.29	0.0008	16.65	0.0031	+12.36	**+289**

* Calculated to provide a reservoir elevation-corrected value, unitless ratio

** Calculated to provide a reservoir elevation-corrected value, in gal/min-ft

Table 4 - Seepage chemistry data for water samples collected from piezometer wells, seeps, and reservoir at Horsetooth Dam, June 2005.

Sample	*Sample Date*	*Fe, µg/L*	*Mn, µg/L*	*Al, µg/L*	*Lab pH*	*Ca, mg/L*	*Mg, 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*	*Sum mg/L*
Reservoir	6/ 7/05	50	<10	70	7.9	10.4	1.8	2.6	0.700	38.0	0	0	5.4	1.4	60.3
DH91-1	6/ 7/05	40	<10	1050	11.7	2.40	0.01	42.3	49.7	0	103	159	13.2	8.7	378
DH91-4	6/ 7/05	<20	<10	<10	8.2	44.1	10.6	3.4	0.800	180	0	0	10.5	1.2	251
DH91-5	6/ 6/05	<20	70	<10	8.2	66.1	8.10	3.2	0.800	119	0	0	107	3.9	308
DH92-6	6/ 6/05	<20	40	<10	8.1	52.1	14.8	19.9	0.600	242	0	0	26.9	5.2	362
DH92-7	6/ 6/05	<20	140	<10	8.1	61.5	21.0	5.5	2.60	315	0	0	4.1	2.4	412
DH97-3	6/ 6/05	<20	<10	<10	8.2	28.3	6.60	3	0.500	116	0	0	7.4	1.6	163
DH98-5	6/ 6/05	30	70	<10	8.0	561	43.0	5.3	1.40	117	0	0	1514	3.8	2250
DH98-5C	6/ 6/05	40	70	<10	8.0	582	41.2	5.2	1.40	116	0	0	1505	3.8	2260
DH99-11	6/ 7/05	<20	30	30	8.5	63.5	18.5	4.7	1.50	119	4.78	0	142.2	1.2	355
SM-1	6/ 6/05	<20	10	<10	8.3	42.2	12.3	5.7	0.900	184	0	0	13.4	7.3	266
SM-2	6/ 6/05	<20	<10	<10	8.5	44.1	11.7	5.2	0.600	171	4.3	0	10.9	6.2	254
SM-3	6/ 6/05	<20	<10	<10	8.3	38.7	6.90	3.3	0.700	117	0	0	29.3	4.8	201
SM-3S	6/ 6/05	<20	<10	<10	8.3	43.3	7.90	3.5	0.700	135	0	0	30.6	4.4	225
SM-4	6/ 6/05	<20	20	<10	9.2	51.1	16.0	6.4	0.900	129	21.5	0	63.2	4.8	293
SM-7	6/ 7/05	<20	<10	<10	8.3	42.5	8.50	4.2	0.700	136	0	0	31.3	5	228
SM-9	6/ 7/05	<20	<10	<10	8.4	32.9	9.60	6.5	0.500	142	1.43	0	8.7	2.7	204
SM-11	6/ 6/05	<20	20	<10	8.3	38.1	11.5	5.1	0.600	163	0	0	12.5	6.8	238
SM-11B	6/ 6/05	<20	<10	<10	8.4	46.5	10.8	4.8	0.500	187	1.91	0	7.2	1.8	261
SM-LF5	6/ 6/05	<20	<10	<10	8.3	63.5	16.8	13.5	2.90	268	0	0	27.6	9.1	401
IW-3R	6/ 6/05	<20	<10	<10	8.0	44.9	9.80	6.8	1.60	171	0	0	13.5	7.8	255

Table 5 - Changes in seepage concentration compared to reservoir chemistry at Horsetooth Dam, June, 2005.

Difference Data: Reservoir Chemistry Subtracted from Seepage														
Sample	*ΔFe, µg/L*	*ΔMn, µg/L*	*ΔAl, µg/L*	*ΔpH*	*ΔCa, mg/L*	*ΔMg, mg/L*	*ΔNa, mg/L*	*ΔK, mg/L*	*ΔHCO_3^-, mg/L*	*ΔCO_3^{2-}, mg/L*	*ΔOH^-, mg/L*	*ΔSO_4^{2-}, mg/L*	*ΔCl^-, mg/L*	*ΔSum, mg/L*
DH91-1	-10	0	+980	+3.8	-8.00	-1.79	+39.7	+49.0	-38.0	+103	+159	+7.80	+7.30	+318
DH91-4	-48	0	-69	+0.3	+33.7	+8.80	+0.800	+0.100	+142	0	0	+5.10	-0.200	+190
DH91-5	-48	+69	-69	+0.3	+55.7	+6.30	+0.600	+0.100	+81.0	0	0	+102	+2.50	+248
DH92-6	-48	+39	-69	+0.2	+41.7	+13.0	+17.3	-0.100	+204	0	0	+21.5	+3.80	+301
DH92-7	-48	+140	-69	+0.2	+51.1	+19.2	+2.90	+1.90	+277	0	0	-1.30	+1.00	+352
DH97-3	-48	0	-69	+0.3	+17.9	+4.80	+0.400	-0.200	+78.0	0	0	+2.00	+0.200	+103
DH98-5	-20	+69	-69	+0.1	+551	+41.2	+2.70	+0.700	+79.0	0	0	+1509	+2.40	+2190
DH98-5C	-10	+69	-69	+0.1	+572	+39.4	+2.60	+0.700	+78.0	0	0	+1500	+2.40	+2190
DH99-11	-48	+29	-40	+0.6	+53.1	+16.7	+2.10	+0.800	+81.0	+4.78	0	+136.8	-0.200	+295
SM-1	-48	+9.0	-69	+0.4	+31.8	+10.5	+3.10	+0.200	+146	0	0	+8.00	+5.90	+206
SM-2	-48	0	-69	+0.6	+33.7	+9.90	+2.60	-0.100	+133	+4.30	0	+5.50	+4.80	+194
SM-3	-48	0	-69	+0.4	+28.3	+5.10	+0.700	0	+79.0	0	0	+23.9	+3.40	+140
SM-3S	-48	0	-69	+0.4	+32.9	+6.10	+0.900	0	+97.0	0	0	+25.2	+3.00	+165
SM-4	-48	+19	-69	+1.3	+40.7	+14.2	+3.80	+0.200	+91.0	+21.5	0	+57.8	+3.40	+233
SM-7	-48	0	-69	+0.4	+32.1	+6.70	+1.60	0	+98	0	0	+25.9	+3.60	+168
SM-9	-48	0	-69	+0.5	+22.5	+7.80	+3.90	-0.200	+104	+1.43	0	+3.30	+1.30	+144
SM-11	-48	+19	-69	+0.4	+27.7	+9.70	+2.50	-0.100	+125	0	0	+7.10	+5.40	+177
SM-11B	-48	0	-69	+0.5	+36.1	+9.00	+2.20	-0.200	+149	+1.91	0	+1.80	+0.400	+200
SM-LF5	-48	0	-69	+0.4	+53.1	+15.0	+10.9	+2.20	+230	0	0	+22.2	+7.70	+341
IW-3R	-48	0	-69	+0.1	+34.5	+8.00	+4.20	+0.900	+133	0	0	+8.10	+6.40	+195

Table 6 Mineral saturation indices and differences between reservoir and seeps calculated using the MINTEQA2 model for samples from reservoir, wells, and surface seeps at Horsetooth Dam, June 6-7, 2005.

Horsetooth Piezometer Wells, June 2005 - MINTEQ Saturation Indices

Minerals	*Reservoir*	*DH91-1*	*DH91-4*	*DH91-5*	*DH92-6*	*DH92-7*	*DH97-3*	*DH98-5*	*DH98-5C*	*DH99-11*
Calcite	-2.18	1.14	-1.01	-0.90	-1.16	-1.08	-1.18	-0.67	-0.66	-0.33
Dolomite	-5.04	0.15	-2.55	-2.61	-2.78	-2.55	-2.91	-2.36	-2.36	-1.12
Magnesite	-3.34	-1.48	-2.03	-2.20	-2.11	-1.95	-2.21	-2.17	-2.19	-1.26
Gypsum	-3.11	-7.14	-2.35	-1.26	-1.92	-2.68	-2.63	0.24	0.25	-1.19
Anhydrite	-3.48	-7.50	-2.71	-1.63	-2.28	-3.04	-3.00	-0.13	-0.12	-1.56
Net Change in SI Between Reservoir and Well										
Calcite	0	3.33	1.18	1.29	1.02	1.10	1.00	1.51	1.53	1.85
Dolomite	0	5.20	2.49	2.43	2.26	2.50	2.13	2.68	2.68	3.93
Magnesite	0	1.87	1.32	1.14	1.24	1.40	1.13	1.17	1.16	2.08
Gypsum	0	-4.02	0.77	1.86	1.20	0.44	0.48	3.35	3.36	1.92
Anhydrite	0	-4.02	0.77	1.86	1.20	0.44	0.48	3.35	3.36	1.92

Horsetooth Surface Seeps, June 2005 - MINTEQ Saturation Indices

Minerals	*Reservoir*	*SM-1*	*SM-2*	*SM-3*	*SM-4*	*SM-7*	*SM-9*	*SM-11*	*SM-11B*	*IW-3R*	*SM-LF5*
Calcite	-2.18	-0.83	-0.41	-0.87	***0.99***	-0.84	-0.73	-0.87	-0.59	-1.40	-1.28
Dolomite	-5.04	-2.11	-1.32	-2.40	***1.57***	-2.29	-1.91	-2.18	-1.72	-3.39	-3.06
Magnesite	-3.34	-1.76	-1.39	-2.02	***0.10***	-1.93	-1.66	-1.79	-1.62	-2.46	-2.26
Gypsum	-3.11	-2.26	-2.34	-1.95	-1.59	-1.90	-2.53	-2.33	-2.49	-2.24	-1.84
Anhydrite	-3.48	-2.63	-2.71	-2.32	-1.96	-2.26	-2.90	-2.70	-2.86	-2.60	-2.21
Net Change in SI between Reservoir and Seep											
Calcite	0	1.35	1.77	1.31	3.18	1.35	1.46	1.31	1.60	0.78	0.90
Dolomite	0	2.93	3.73	2.64	6.62	2.76	3.14	2.86	3.32	1.66	1.99
Magnesite	0	1.58	1.96	1.33	3.44	1.41	1.68	1.55	1.73	0.88	1.09
Gypsum	0	0.85	0.78	1.17	1.52	1.22	0.59	0.79	0.62	0.88	1.27
Anhydrite	0	0.85	0.78	1.17	1.52	1.22	0.59	0.79	0.62	0.88	1.27

FIGURES

Interpretation of Chemistry Data from Seepage, Observation Well, and Reservoir Water Samples collected at Horsetooth Dam during June 2005

TSC Technical Memorandum No. 8290-2005-02

by

Doug Craft, Research Chemist

Figure 1 - Map of Horsetooth Dam showing piezometer and seepage locations for the June 2005 sampling event.

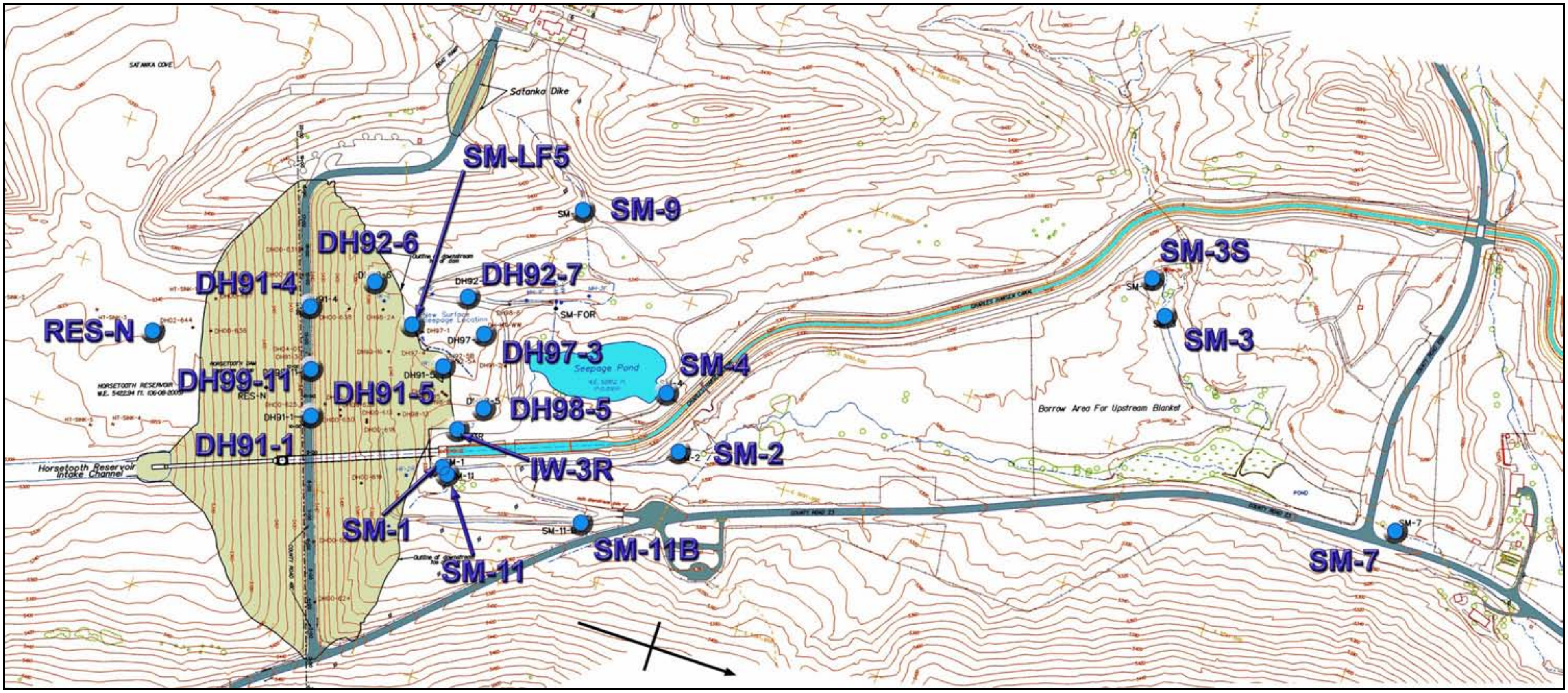

Figure 2a - Stiff diagrams comparing 2004 and 2005 piezometer wells whose screens intercept the Middle Lykins formation and the Forelle Limestone.

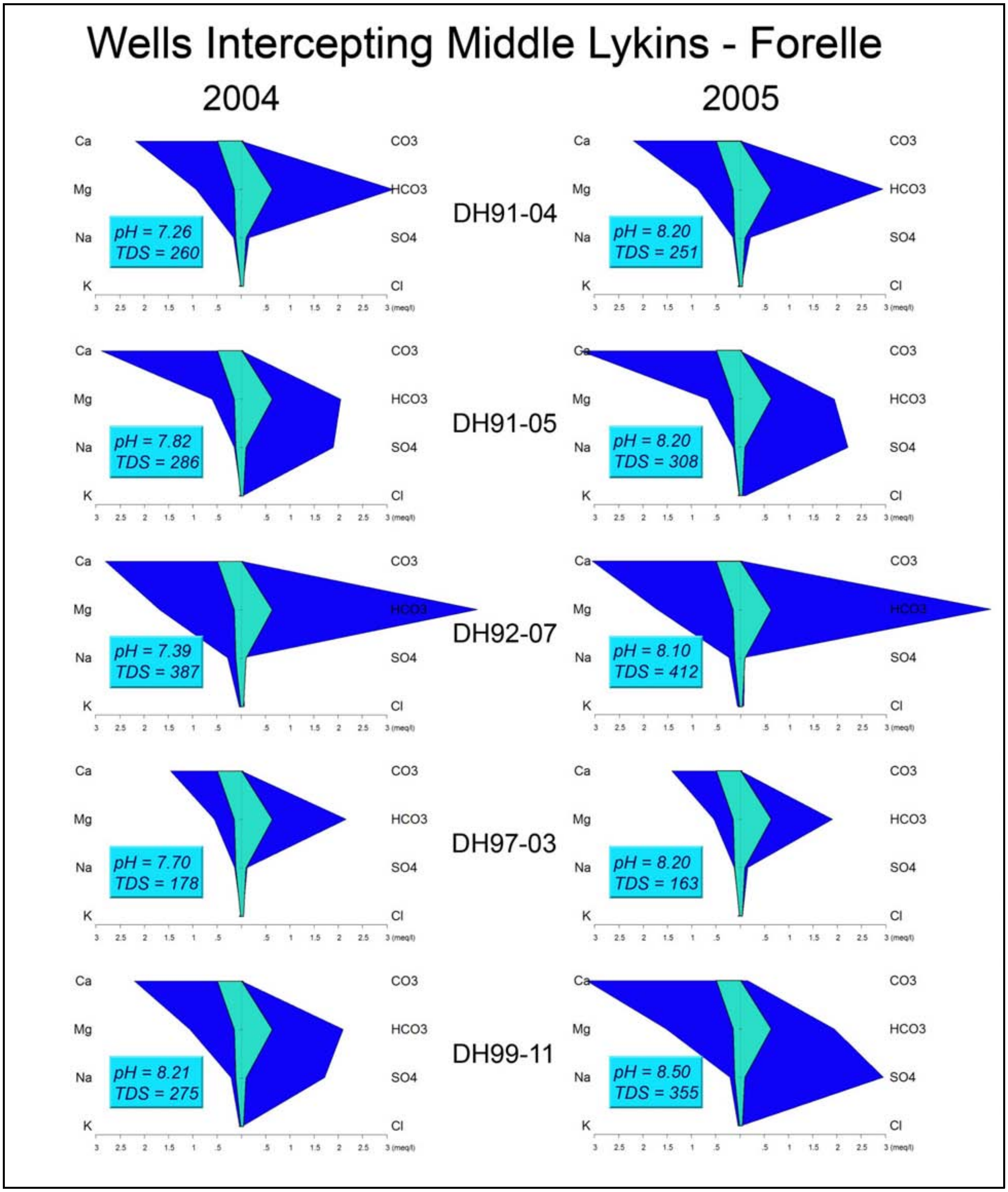

Figure 2b - Stiff diagrams comparing 2004 and 2005 piezometer wells whose screens intercept the Lower Lykins formation and the Blaine Gypsum. Note the 30 meq/L scale for DH98-05 Stiff diagrams.

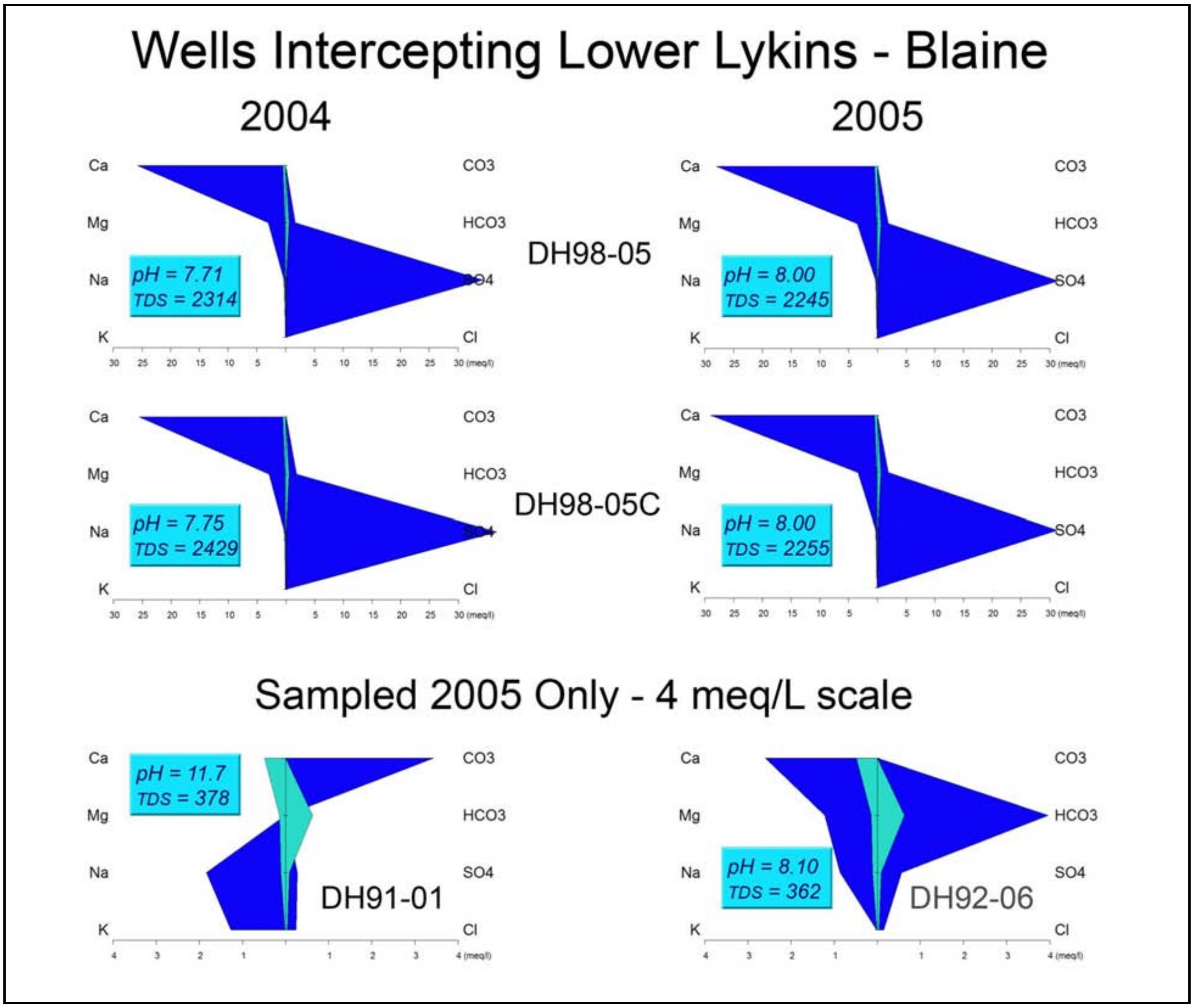

Figure 2c - Stiff diagrams comparing 2004 and 2005 seepage samples collected from weirs located near the dam. These weirs are primarily draining the right abutment and embankment and collecting water from the left and right toe drains.

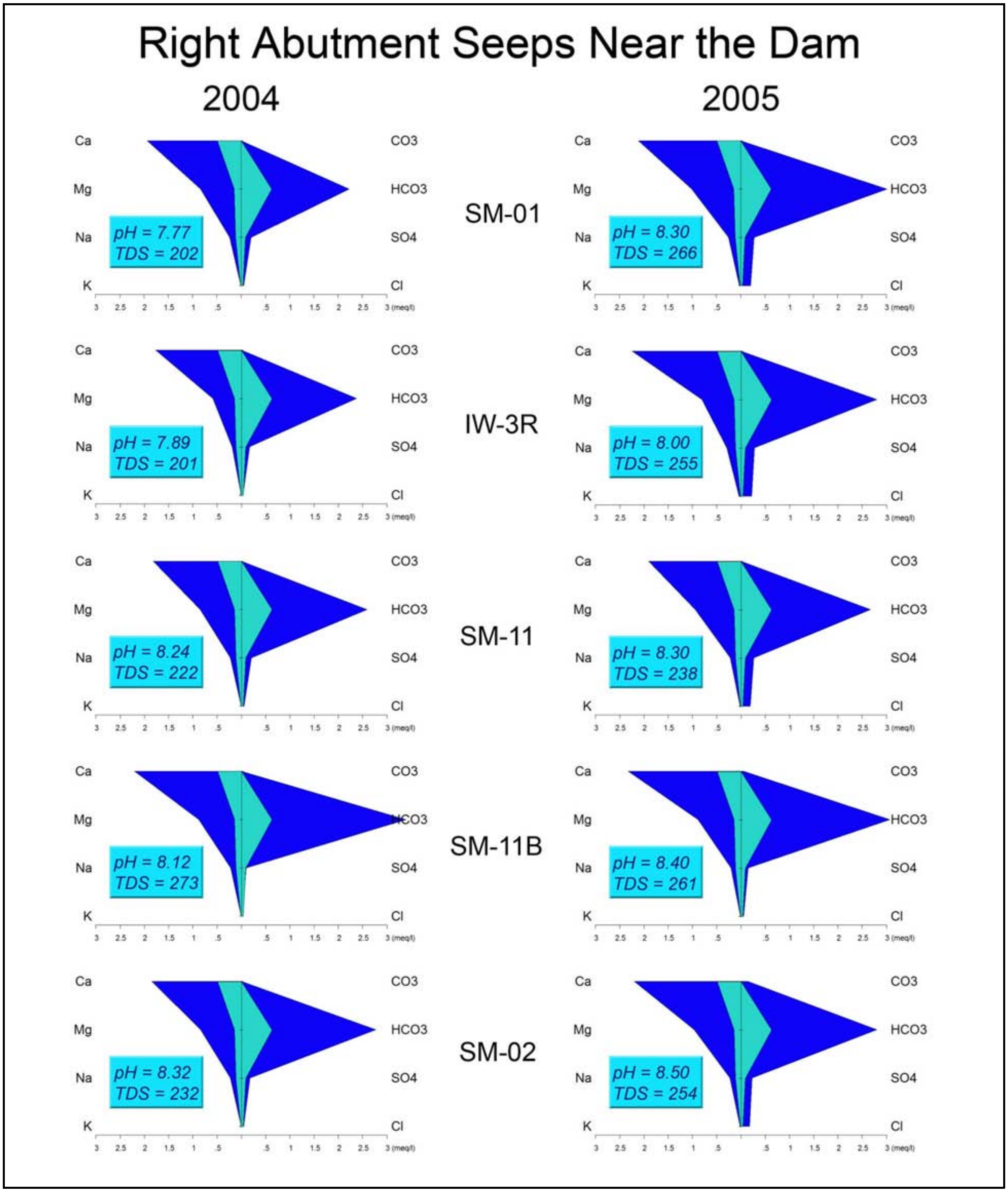

Figure 2d - Stiff diagrams comparing 2004 and 2005 seeps on the left abutment. SM-09 is draining Satanka Dike, and SM-LF5 is a new seep running along the left toe between DH92-6 and DH91-5. SM-4 drains the seepage pond.

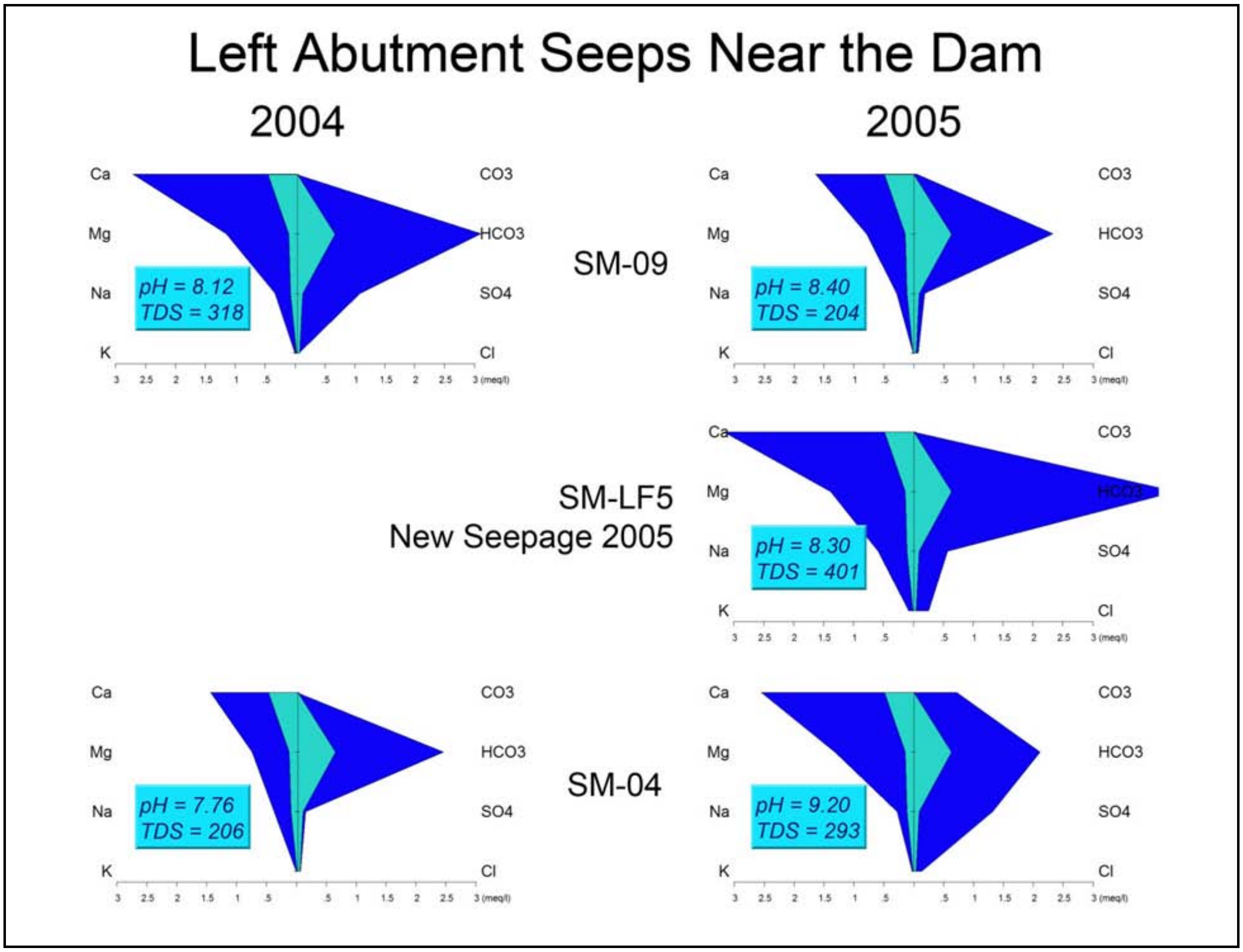

Figure 2e - Stiff diagrams comparing 2004 and 2005 seepage for weirs downstream of Horsetooth Dam that collect all upstream seepage and drain Forelle limestone outcrops.