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DEPTH PROFILE STUDY OF PHOSPHORUS CONCENTRATIONS IN THE CHERRY CREEK ALLUVIAL AQUIFER

PREPARED FOR: Cherry Creek Basin Water Quality Authority, Greenwood Village, Colorado

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DEPTH PROFILE STUDY OF PHOSPHORUS CONCENTRATIONS IN THE CHERRY CREEK ALLUVIAL AQUIFER

INTRODUCTION

The Cherry Creek Basin Water Quality Authority (Authority) is charged with managing the water quality of the upper Cherry Creek Basin, with a focus on nutrients such as nitrogen and phosphorus entering Cherry Creek Reservoir that could adversely impact the quality of the reservoir and the aquatic resources. Toward that end, the Authority has regularly sampled and measured nutrient concentrations in the surface waters and ground waters of the basin since 1994. The results of this sampling are used in the quantitative assessment of the distribution and movement of nitrogen and phosphorus in the surface water and through the alluvial sediments. Historically, the Authority has sampled phosphorus in the alluvial ground water through monitoring wells that are open to the full saturated thickness of the alluvium. Samples obtained in this manner are taken as representing the composite concentration for the full alluvial thickness. Similarly, the vertical distribution of aquifer hydraulic conductivity, a measure of the ease with which water moves through the alluvial sediments, is treated as uniform through the full saturated thickness. It is also treated as uniform through the entire cross-sectional area of flow at each monitoring point.

The Cherry Creek alluvial aquifer is not a homogeneous aquifer with continuous, unstratified sediments. Instead, the Cherry Creek alluvium generally exhibits varying degrees of vertical stratification, with interbedded, unconsolidated sands, gravels, silts, and clays. The presence of laterally-continuous silts and clays in the alluvial aquifer create the potential for there to be preferential flow paths through the alluvium, i.e., flow through the more highly-permeable sands and gravels, with little, or no, flow through the silts and clays. There are a number of implications for the case in which the alluvial aquifer is highly stratified. For example, isolated zones having high hydraulic conductivity may serve as preferential pathways for the transport of phosphorus. Composite samples obtained from wells that are completed through the full saturated thickness may not provide an accurate measure of the concentrations within specific zones. In addition, analyses of phosphorus concentrations and loads being transported through the alluvial aquifer may not be reliable if these analyses rely on averaged concentrations or averaged hydraulic conductivities.

Lytle Water Solutions, LLC (LWS) was retained by the Authority in 2005 to assist it in investigating variability in hydrogeologic and water quality conditions within the alluvial aquifer. The purpose of this special study was to evaluate the heterogeneity of the Cherry Creek alluvial aquifer at four separate locations within the basin. Specifically, the study was designed to investigate the degree of stratification within the alluvial sediments and, where separate and distinct zones could be identified, to evaluate the variability in water chemistry between these separate zones. The study was done in response to specific studies that were identified in the Cherry Creek Control Regulation No. 72 relative to achieving the phased total maximum annual load (TMAL) for phosphorus at Cherry Creek Reservoir.

STUDY METHODOLOGY

Four sites were identified for detailed investigations in concert with the Authority's Technical Advisory Committee (TAC). The sites were generally selected to coincide with existing ground water monitoring wells that are sampled as part of the Authority's ground water monitoring program to allow for a comparison between the existing sites where composite sampling has been done historically and a one-time depth-specific sampling that was authorized as part of this study. The following identifies the Authority monitoring well site by number and the corresponding depth profile test hole:

Authority Monitoring Well Site	Depth Profile Test Hole
MW2	DP2
MW4	DP4
MW5	DP5
MW9	DP9

The locations of the monitoring wells and depth profile test holes are shown in Figure 1.

Test drilling was accomplished with an AP-1000 drilling rig through a subcontract with Layne Christensen, Inc.. This drilling equipment was chosen specifically because of its unique capabilities for sampling and testing of unconsolidated sediments such as the alluvium of Cherry Creek. Drilling is accomplished by advancing a drill bit connected to dual-wall drill pipe. The drill bit and drill pipe are advanced by percussion hammer, while the drill "cuttings" are carried to the surface using high-velocity compressed air. The dual-wall configuration of the drill pipe allows for injection of compressed air down the annular space formed between the concentric pieces of pipe, while cuttings are ejected through the center piece of pipe. The principal benefits of this method of drilling are that (a) since the hole is supported by drill pipe, samples are virtually uncontaminated (unlike those recovered using augers, rotary drilling, etc.) and (b) the hole is cased as it is advanced, which virtually eliminates the risk of collapse and provides a means for installing well screen and casing. This approach allows for the drilling and sampling of the full thickness of the alluvial aquifer at discrete intervals.

Once the subsurface geology was determined from drill cuttings, specific intervals were identified for testing and sampling. Intervals were tested and sampled, beginning with the lowest interval and working upward in the hole. In general, once the borehole reached total depth a temporary string of 4-inch (in) diameter polyvinyl chloride (PVC) casing and screen was lowered through the center of the drill pipe. The drill pipe was then lifted into a low-permeability layer (where present) to expose the screen and the hole was allowed to collapse around the screen, which resulted in naturally gravel-packing the screen. If this did not occur, gravel pack was placed around the screen. A layer of bentonite, typically 6 to 12 in. deep, was placed above the screen to isolate the interval for testing. A submersible pump was then lowered into the 4-in. casing/screen assembly and pumped for periods lasting from 15 to 45 minutes, depending on the time required for water chemistry to stabilize. LWS field personnel used the same sampling protocols as developed for the Authority's baseline ground water monitoring program (JCHA, 1994b).

Water levels were monitored prior to, and during, pumping to provide information on the hydrologic properties of the interval being tested. Pumping was continued until water discharged from the pump was relatively clear and field water quality parameters (pH, temperature, specific conductance) stabilized. Water quality samples were collected at this point in time. Following sampling, the casing and screen assembly were retracted to the next interval slated for testing and the entire process was repeated.

The initial process for identifying specific zones for sampling was to delineate zones that were generally uniform in geologic character and separated from other zones by distinct and moderately thick (several feet (ft) in thickness) clays or silts. The rationale was that thicker clays were more likely to persist laterally, thereby forming a distinct hydrogeologic zone, whereas relatively thin clay beds might not extend very far from the drilling site and would be less likely to form a distinct hydrogeologic zone.

The first site drilled, DP4, was completed using this strategy. As may be seen on the log for DP4, two distinct zones can be identified, one extending from a depth of 19 to 47 ft, and the second extending from a depth of 52 to 66 ft. Accordingly, two intervals were sampled and tested. Both zones appeared to be homogeneous. It was apparent from the drilling at this site that there might not be a significant amount of layering within the alluvial sediments. In light of this, sampling strategy was modified somewhat, such that at subsequent test holes at least three intervals would be tested, whether or not there was evidence of significant layering. This was accomplished at test holes DP5 and DP9. At test hole DP2, the static water level was deep (likely the result of nearby pumping) and only one interval could be tested and sampled. At this particular location, a 2-ft thick sand layer was encountered immediately above bedrock. This sand layer is considered to be weathered bedrock (sometimes referred to as *saprolite*) and is not a part of the alluvial aquifer.

Field measurements were obtained during pumping of each interval and included specific conductance, pH, and temperature. Water quality samples were obtained from each of the intervals tested once these parameters had stabilized in accordance with the Authority's Quality Assurance/Quality Control (QA/QC) procedures (JCHA, 1994b). As identified in the Authority's Request for Proposal (RFP), each sample was analyzed for the following parameters:

Total Phosphorus (TP)
Soluble Reactive Phosphorus (SRP)
Nitrate-Nitrogen
Calcium
Magnesium
Potassium
Sodium
Bicarbonate
Sulfate
Chloride

Samples were also obtained from the adjacent Authority monitoring wells within 7 days of the day on which the corresponding interval samples were obtained. Sampling protocols for the Authority's monitoring wells were also consistent with the Authority's QA/QC procedures (JCHA, June 1994b). Samples were obtained using a temporary submersible pump, pumping at a rate of between 7 and 8 gallons per minute (gpm). The monitoring wells were each pumped for a period of not less than 15 minutes. The equivalent of not less than three casing volumes was removed from each well prior to sampling. As with the depth profile test holes, sampling did not begin until water quality parameters had stabilized.

STUDY RESULTS

Depth Profile Sampling

Based on the Authority's RFP, four sites were selected for one-time depth profile sampling. A summary of the depth profile sampling at the four specific sites chosen is presented in the following sections.

<u>Depth Profile Test Hole DP2:</u> The total depth drilled at DP2 was 69 ft. The static water level at DP2 was measured at a depth of 40 ft, significantly below the static water level encountered at the other depth profile sites and significantly below the bed elevation of Cherry Creek. It is likely that the water level at this site was influenced by nearby pumping. As a result, the saturated thickness of alluvial sediments at this location was only 11 ft. A single interval test was completed at this location in the interval from 41 to 51 ft (Figure 2). A comparison of the water obtained from DP2 with the water obtained from the adjacent monitoring well MW2 indicates very different water chemistries in virtually all measurements, including specific conductance, basic cations and anions, total and soluble reactive phosphorus, and nitrate. These differences may be related in part to the fact that the wells are separated by almost one mile. This large intentional separation was due to (a) the anomalous results that have been obtained historically from MW2 for phosphorus and (b) access to a suitable site. It may also be related to the fact that the aquifer is partially dewatered at DP2. Water quality at DP2 is of the calcium bicarbonate type, whereas the water obtained from MW2 is of the sodium chloride type. As may be seen from Figure 6, the water chemistry at MW2 is unlike the chemistry at any of the other sampling locations.

Depth Profile Test Hole DP4: The total depth drilled at DP4 was 66.5 ft. The static water level before testing was 17 ft. Interval testing and sampling was completed at two depths in DP4 (40-45 ft and 53-58 ft). These intervals are separated by a 5-ft thick clay (Figure 3). Concentrations of total phosphorus, soluble reactive phosphorus, and nitrate were all significantly higher in the shallower interval (40-45 ft). Major cations and anions were similar between the two zones. Stiff diagrams indicate water from the interval samples at DP4 is of the calcium bicarbonate type. Similarly, water obtained from MW4 is of the calcium bicarbonate type.

Depth Profile Test Hole DP5: The total depth drilled at DP5 was 52 ft. The static water level before testing was 14 ft. Three intervals were tested and sampled in DP5 (24-29 ft, 35-40 ft, and 45-50 ft). The upper two intervals lie within the same vertically-continuous layer. The bottom interval is separated from the upper two intervals by a 4-ft thick clay (Figure 4). At this location, the highest concentrations of total phosphorus, soluble reactive phosphorus, and nitrate occur in the deepest interval, and are significantly greater than concentrations occurring in the two shallower intervals. Between the two shallow intervals, concentrations of total phosphorus, soluble reactive phosphorus and nitrate are higher in the deeper of the two intervals. There do not appear to be significant differences in concentrations of major cations and anions among the three tested intervals. This is confirmed by comparing the stiff diagrams for the three intervals, as shown in Figure 6. Water type is virtually identical for all three intervals and is classified as calcium bicarbonate type. Water obtained from MW4 is also of the calcium bicarbonate type.

Depth Profile Test Hole DP9: The total depth drilled at DP9 was 54 ft. The static water level before testing was 3 ft. Three intervals were tested and sampled in DP9 (5-10 ft, 23-28 ft, and 43-48 ft). The upper two intervals are separated by a 9-ft thick clay (Figure 5). The bottom two intervals lie within the same vertically-continuous layer. At this location, the highest concentrations of total phosphorus, soluble reactive phosphorus, and nitrate occur in the deeper intervals. The differences in concentrations of total phosphorus and soluble reactive phosphorus are not large (approximately 50 micrograms per liter (µg/L)). The concentration of nitrate in the shallowest interval was anomalously low in comparison with other intervals at this location and also at other locations (less than 2 µg/L, compared to over 2,200 µg/L). There do not appear to be significant differences in concentrations of major cations and anions among the three tested intervals. This is confirmed by comparing the stiff diagrams for the three intervals, as shown in Figure 6. Water type is virtually identical for all three intervals and is classified as calcium bicarbonate type. Water obtained from MW9 is also of the calcium bicarbonate type.

Geologic Stratification

Alluvial sediments at the four test sites consist of varying amounts of gravel, sand, silt, and clay, with coarse sand and fine gravel predominating. Bedrock was encountered between the depths of about 50 and 60 ft. Bedrock in three of the test holes (DP4, DP5, and DP9) was a dark gray to brown, fissile shale. Bedrock in the fourth hole (DP2) was a buff-colored, moderately well-cemented sandstone. There was some layering evident in each of the four test holes. Although the vertical occurrence of clay is not consistent among the holes, clay, or silt and clay, was encountered in all four test holes at a depth of between about 15 and 20 ft. However, this low-permeability zone is generally at, or above, the local water table and, therefore, has a minimal impact on ground water flow in the alluvial aquifer. It may serve to limit vertical infiltration of precipitation. Once into the alluvial aquifer sediments, there is only minimal stratification evident in the form of silt and clay layers. However, there are distinct variations in hydraulic conductivity in the various water-bearing intervals. Geologic logs for the depth profile test holes are shown in Figures 2 through 5 (test holes DP2, DP4, DP5, and DP9, respectively).

Water Quality

Distinct differences in water quality were apparent within each of the test holes, and also between test holes, although there was no consistent relationship between water quality and depth. The results of water quality testing at the depth profile test holes and at the corresponding monitoring wells are summarized in Table A-1 in Appendix A. Stiff diagrams are useful in determining water "type" based on the relative proportions of major ions (Hem, 1970). Chemical typing is often useful in differentiating waters originating from different sources or hosted within differing environments. Stiff diagrams were prepared for all water quality samples obtained during the investigation. These diagrams are shown in Figure 6. The individual analyses used to generate these diagrams are reproduced in Appendix A.

The one water sample that had a distinctly different type from all others was at MW2. This anomalous water quality was identified in the fate and transport modeling that is currently being conducted by the Authority. With the DP2 depth profile indicating a water chemistry consistent with all of the other sampling locations, we believe this provides justification for the modification of use of MW2 water chemistry in the fate and transport model.

Hydrogeologic Properties and Estimates of Underflow

Hydrogeologic properties, in particular hydraulic conductivity and transmissivity, were inferred based on water level response to pumping from each of the intervals. Specific capacity (the ratio of pump discharge to water level drawdown in response to pumping) can be used to estimate transmissivity. The relationship between these is derived from the Theis equation, describing non-steady, radial flow to a well (Driscoll, 1986). Transmissivity can then be inferred for the full saturated thickness of the alluvial aquifer. The estimated transmissivity for the full saturated thickness is shown in Table A-1 in Appendix A. Values of transmissivity are generally consistent (same order of magnitude) among DP2, DP4, and DP9, ranging from about 22,000 gallons per day per foot (gpd/ft) to about 49,000 gpd/ft. Transmissivity at DP5 is extraordinarily low, approximately 1,800 gpd/ft. This location had far more fine-grained sediments than did the other boreholes. At DP5, silt and clay extend from the surface to a depth of 24 ft. and a second clay layer, about 4 ft thick, was encountered at a depth of 41 ft (Figure 4). However, measurements of specific capacity of the sand and gravel sediments at DP5 were also lower than estimates for similar sediments at the other test sites (Figures 2, 3, and 5).

The aquifer hydraulic properties obtained from this study indicate that the water-bearing sediments of the Cherry Creek alluvial aquifer are neither homogenous in a vertical direction or at spatial locations along the alluvial flow cross-section. This has some bearing on the estimates of hydraulic conductivity that have been used historically to estimate alluvial underflows and, therefore, ground water loads of nutrients.

Comparison of Interval-Based Water Chemistry with Results of Composite Sampling

Table A-2 in Appendix A provides a comparison of water chemistry observed at the depth profile sites with that observed for the corresponding monitoring wells. In general, the water chemistry measured for specific intervals in a depth profile hole should, when combined, resemble the water chemistry observed for a composite sample obtained from the corresponding monitoring well. Two comparisons are shown in Table A-2. The first method simply compares the arithmetic mean for the interval samples with the corresponding concentration reported at the monitoring well. The second method accounts for the heterogeneity in the alluvial system by comparing the weighted average of the specific intervals in the depth profile hole with the composite concentration at the monitoring well. In this case, individual concentrations are weighted according to the estimated transmissivity of the interval they are assumed to represent. In the case of DP2, only one interval was tested. Accordingly, the values for arithmetic mean and weighted mean are identical.

With the exception of DP2, concentrations of major cations and anions are relatively consistent and relatively unaffected by the weighting process. In the case of DP2, water obtained from MW2 is substantially different in most respects from that in DP2 and substantially different from the other sites. In the case of total phosphorus, there appears to be fair agreement between concentrations observed in the depth profile holes with those observed in the composite sampling. Weighting of concentrations does not produce consistently better agreement. In the case of soluble reactive phosphorus and nitrate, concentrations in samples from the depth profile holes and the composite samples are not well correlated.

In a heterogeneous aquifer, water samples obtained from monitoring wells that are completed through the entire saturated thickness represent a composite of water over the length of the vertical interval. If there is significant stratification of water quality combined with large differences in hydraulic conductivity over the vertical interval, composite samples may not be representative of the actual quality of the water traveling through the aquifer and may suggest either higher or lower concentrations of parameters of interest than actually exist. If water having comparatively high concentrations of dissolved chemicals occurs in an interval that has a high hydraulic conductivity, the composite sample will likely consist of a larger fraction of high-concentration water and a smaller fraction of the lower-concentration water. If this higher-permeability zone is not laterally continuous within the aquifer, the composite sample will not be representative of the overall concentrations of dissolved chemicals within the aquifer and, in this case, may overestimate the dissolved load. The converse of this condition is also true. That is, if water which is low in dissolved chemicals resides within the high-permeability sediments, the composite sample may underestimate the dissolved load that may actually be moving through the aquifer.

Estimates of the phosphorus load being transported through the alluvium have historically been based on concentrations measured in composite samples. These have been combined with estimates of underflow through the alluvial aquifer to obtain the total chemical load moving through the alluvial aquifer (JCHA, 1994a). Chemical loads being transported into Cherry Creek

Reservoir have been based on composite sample concentrations obtained at monitoring well MW9.

The results of this study provide a means to compare the chemical loading at the reservoir which has been historically predicted using composite sample results with samples obtained through the depth profile testing and sampling. In the case of the composite sampling, the chemical concentration is taken from the composite sample at MW9. In the case based on depth profile test results, the concentration is taken as the weighted average for depth profile site DP9, weighted according to transmissivity of the interval represented by the sample. In both cases, flow through the aquifer (underflow) is based on earlier estimates of underflow through a cross-section of the alluvial aquifer at MW9 (4.88 cubic feet per second, JCHA, 1994a). The following table compares the MW9 site results for total phosphorus, soluble reactive phosphorus and nitrate as nitrogen:

Constituent	**Transport Based on Composite Sample Concentration (pounds/year)**	**Transport Based on Weighted Sample Concentration (pounds/year)**	**Difference (pounds/year)**
Total Phosphorus	2,690	2,500	190
Soluble Reactive Phosphorus	2,320	1,920	400
Nitrate as Nitrogen	510	320	190

As this table shows, while there are a number of variables related to the heterogeneities in the Cherry Creek alluvial aquifer, the resulting difference in phosphorus loading to Cherry Creek Reservoir is relatively small (approximately 7 percent).

Similar comparisons can be made for estimates of chemical transport at cross-sections corresponding to the other depth profile test sites. For MW2, the results of these comparisons are shown in the following table:

Constituent	**Transport Based on Composite Sample Concentration (pounds/year)**	**Transport Based on Weighted Sample Concentration (pounds/year)**	**Difference (pound/year)**
Total Phosphorus	4,730	1,470	3,260
Soluble Reactive Phosphorus	1,630	1,160	470
Nitrate as Nitrogen	150	4,600	-4,450

It can be seen that there are substantial differences in estimates of transport at this location. Estimates for both total and soluble reactive phosphorus concentrations are lower when based on weighted sample concentrations, whereas the estimate for nitrate concentration is higher for the weighted sample concentration. However, there are several factors that may contribute to these differences: the depth profile test sites DP2 and MW2 are separated by a distance of almost one mile, the water type at MW2 is different than the water types encountered at any of the other test locations, and the aquifer at DP2 was partially dewatered at the time of sampling, whereas the aquifer at MW2 appeared to be unaffected by nearby pumping. The anomalous water type observed at MW2 may indicate a unique source for this water or a unique set of influences on the water chemistry. Given the unique aspects of the water found at MW2, it is likely that the chemistry as reflected by DP2 (weighted sample in above table) provides a more accurate reflection of alluvial aquifer transport in the area of MW2 and DP2. This provides justification for modification of water chemistry data at MW2 in the fate and transport model.

Similar comparative results are presented below for MW4:

Constituent	**Transport Based on Composite Sample Concentration (pounds/year)**	**Transport Based on Weighted Sample Concentration (pounds/year)**	**Difference (pound/year)**
Total Phosphorus	1,420	1,700	-280
Soluble Reactive Phosphorus	220	1,290	-1,070
Nitrate as Nitrogen	290	13,750	-13,460

Consistently higher concentrations are predicted using weighted sample concentrations at the MW4 cross-section than are predicted by the composite sampling. In the case of both soluble reactive phosphorus and nitrate, these differences are significant. For total phosphorus, the variation is approximately 20 percent.

The comparative analysis for MW5 is presented below:

Constituent	**Transport Based on Composite Sample Concentration (pounds/year)**	**Transport Based on Weighted Sample Concentration (pounds/year)**	**Difference (pound/year)**
Total Phosphorus	1,470	1,290	180
Soluble Reactive Phosphorus	1,320	840	480
Nitrate as Nitrogen	13,410	8,980	4,430

Consistently lower concentrations are predicted using weighted sample concentrations at the MW5 cross-section than are predicted by the composite sampling. In the case of both soluble reactive phosphorus and nitrate, these differences are significant. For total phosphorus, the variation is approximately 12 percent.

These results (MW2, MW4, MW5, and MW9) suggest that stratification in the alluvial aquifer properties combined with stratification in water chemistry yield different estimates of chemical transport than predictions based on composite sample concentrations. In light of this, the CCBWQA's ongoing modeling of chemical transport through the alluvial sediments could be modified to reflect estimates based on site-specific aquifer properties and depth-specific sampling, where this information is available. However, at the present time, with only limited additional data, we would not recommend modifying the model parameters.

CONCLUSIONS

Based on the field studies completed and water quality analyses obtained, we offer the following conclusions related to the depth profiling study:

(1) Subsurface geologic conditions vary between the test sites; however, the sediments are predominantly sand and gravel. There was evidence of stratification (layering) in each of the test holes formed by intermittent layers of silt and clay. Layers of silt and clay do not appear to be laterally continuous.

(2) There is a great deal of vertical and spatial variability in aquifer hydraulic conductivities in the water-bearing sediments.

(3) Bedrock was encountered between the depth of 50 and 60 ft at the four locations.

(4) Concentrations of total phosphorus, soluble reactive phosphorus, and nitrate vary both vertically at individual depth profile test sites and between sites. The variations do not appear to be systematic. In some cases, the highest concentrations occur in the deepest parts of the aquifer, while at others, the highest concentrations occur at shallower depths. However, the highest concentrations generally occur in the deeper half of the aquifer.

(5) Concentrations of major cations and anions are more consistent vertically and between test sites. Water at all test sites (DP2, DP4, DP5, and DP9) is classified as calcium bicarbonate water for all the intervals sampled. This is also the case

for monitoring wells MW4, MW5, and MW9. Water at MW2 is notably different than at all other locations. Water at MW2 is classified as sodium chloride type.

(6) Water quality data at DP2 is distinctly different from water quality at MW2. DP2 water quality is consistent with the other depth profile boreholes and the monitoring wells. This provides justification for the modification of MW2 water quality in the fate and transport model.

(7) Hydraulic properties are relatively consistent at test holes DP2, DP4, and DP9. Transmissivity of the full saturated aquifer thickness ranges from about 22,000 gpd/ft to 49,000 gpd/ft. Transmissivity at test hole DP5 is extraordinarily low, at about 1,800 gpd/ft. This may be due in part to the fact there is a greater thickness of finer grained sediments (silts and clays) at this site than at the other test sites.

(8) The average concentrations of total phosphorus, soluble reactive phosphorus, and nitrate obtained from the combined intervals for a given depth profile hole are not well correlated with concentrations measured for composite samples obtained from adjacent monitoring wells. This is true whether the comparison is made on the basis of simple arithmetic averages or averages weighted according to hydrologic properties.

(9) Phosphorus loading at the reservoir is reasonably well represented by the composite monitoring well sampling. One-time depth profile sampling indicates that the results of weighted sampling and composite sampling differed by 7 percent.

(10) Differences between estimates of channel transport based on weighted sample concentration and those based on composite sample concentrations are significant at other locations further upstream in the basin (DP2, DP4, and DP5) for some chemical constituents, although these differences are not systematic. Total phosphorus variations ranged from 12 to 20 percent at DP4 and DP5. Well DP2, due to the anomalous data at MW2, had a total phosphorus variation between the depth profile borehole and MW2 data of 69 percent. These results suggest that

estimates of chemical transport should, wherever possible, be based on site-specific aquifer properties and depth-specific sampling.

RECOMMENDATIONS FOR FURTHER STUDY

At the July 2006 TAC meeting, it was requested that LWS provide recommendations on follow-on studies that could be conducted related to the drill cuttings obtained from the depth profile boreholes and/or refinement of loading estimates. In response, LWS believes that there are several investigations which could be conducted to better define the occurrence, possible sources, and transport of phosphorus in the Cherry Creek alluvium. These include:

- **Column leach testing and chemical loading of sediment samples.** At this time, it is unclear to what extent the sediments themselves are contributing to observed phosphorus concentrations. Also unclear is the degree to which sediments may differ in their adsorption capacity. For example, the different concentrations of phosphorus may be the result of different rates of loading, or they may be related to differences in sediment types. Sediment type may influence dissolved concentrations in two ways, (a) the sediment may itself be a partial source for the observed concentrations or (b) different sediments may have different capacities to adsorb phosphorus. Samples have been retained from the test drilling at each of the depth profile holes and are available for use in such testing. Testing of samples would be designed to ascertain whether their capacity for adsorbing specific chemicals and their capacity to release these same chemicals to water as it moves through the sediment (*desorption*). This testing is estimated to cost approximately $500 per test.

- **Supplemental investigations to improve definition of the alluvial aquifer subsurface geometry.** Calculations of underflow through the alluvial sediments depend in part on the subsurface cross-sectional area through which flow takes place. This geometry has been estimated from published geologic maps, but is not well defined locally. Test drilling would provide supplemental information of the depth to bedrock and thickness of the alluvial aquifer. However, given the difficulty of accessing sites for test drilling, the need to minimize site impacts and the cost for drilling, geophysical profiling would provide a relatively inexpensive, non-invasive means to better define aquifer geometry.

If geophysical profiling was just completed at MW9 to better define ground water loads to the reservoir, the cost is estimated to be approximately $15,000.

- **Supplemental investigations to improve definition of aquifer hydrologic properties.** Calculations of underflow through the alluvial sediments also depend in part on the hydraulic properties (specifically hydraulic conductivity) of the alluvial aquifer. Limited data have been compiled at each site, based on existing pump test information. The depth profile study has shown that aquifer hydraulic properties can vary significantly spatially and with depth. Therefore, a better spatial understanding of aquifer characteristics would be helpful. There are a number of wells throughout the basin for which aquifer tests have been completed. These tests normally yield an estimate of hydraulic conductivity. These results could be compiled and merged as a way to improve information on the absolute values and distribution of hydraulic conductivity within the basin. We estimate the costs to compile aquifer hydraulic characteristic data and map these values to define spatial variations would be $3,000. LWS is currently in the process of collecting these data for a ground water modeling project in the upper Cherry Creek Basin, so the cost for this effort is minimized due to an economy of scale.

These proposed additional studies should be viewed in light of the need for, and the value of, such additional investigations versus the significance of the changes in predicted chemical loading in the upper basin and at Cherry Creek Reservoir that would result from refined information on geochemical and hydrogeologic conditions affecting the occurrence and movement of phosphorus within the Cherry Creek alluvial aquifer. We would be happy to discuss these results with the TAC to assess the cost/benefit ratio of such additional studies.

LWS appreciates the opportunity to work with the Authority on this special study and provide the results of the depth profile study for your use as you go forward with the basin fate and transport model and the phased TMAL for Cherry Creek Reservoir.

William F. Hahn, P.G.
Principal Hydrogeologist

Bruce A. Lytle, P.E.
President

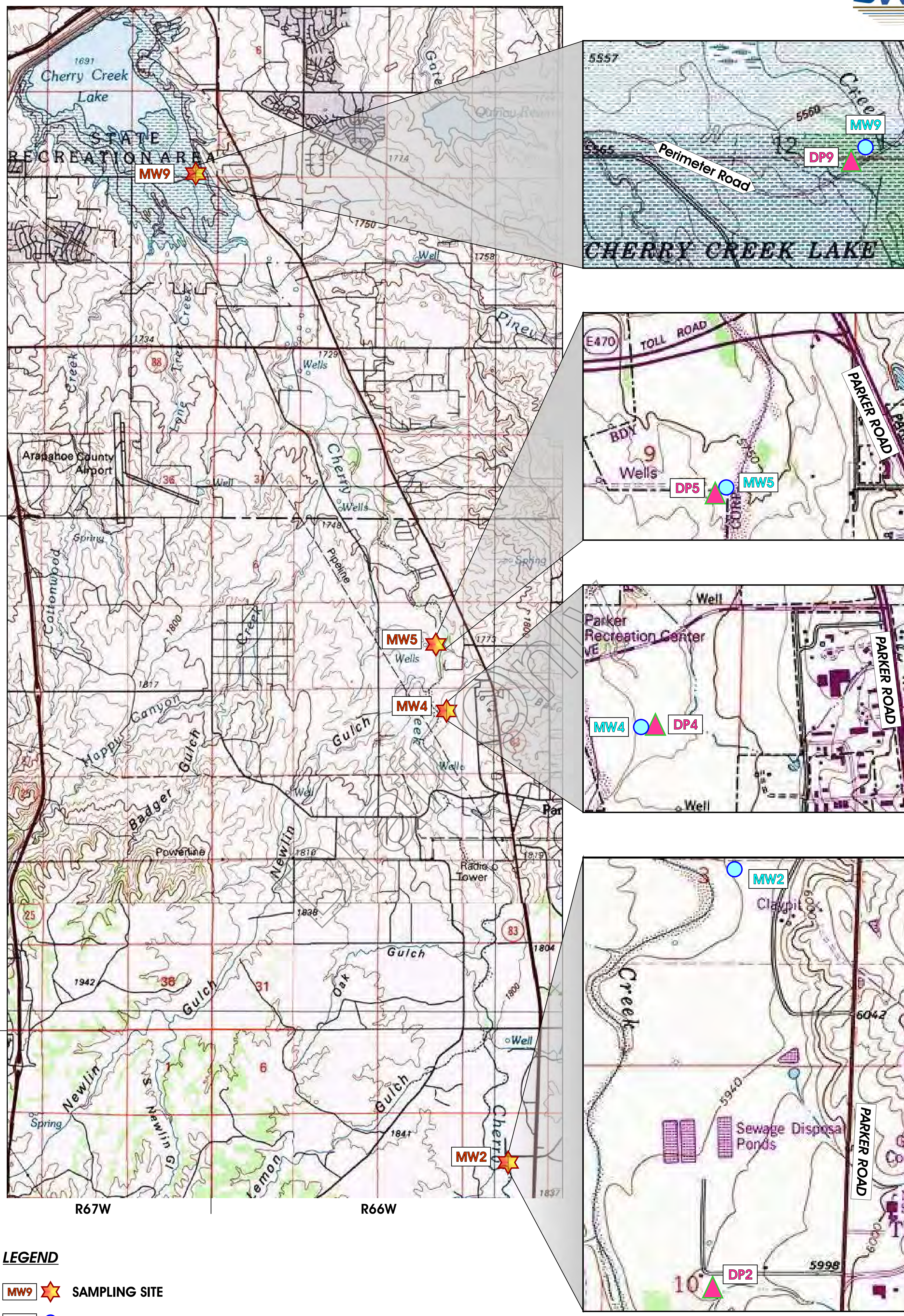
REFERENCES

Driscoll, Fletcher G., 1986. Groundwater and Wells, Second Edition. Johnson Division, St. Paul, Minnesota.

Hem, John D., 1970. Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey Water-Supply Paper 1473.

John C. Halepaska and Associates, Inc., 1994a. Phase I Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin, Ground Water Flow Calculation Sheet.

John C. Halepaska and Associates, Inc., 1994b. Quality Assurance/Quality Control Protocols for Collection of Surface and Ground Water Samples, Phase I Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin.



LEGEND

MW9 SAMPLING SITE

MW9 EXISTING MONITORING WELL

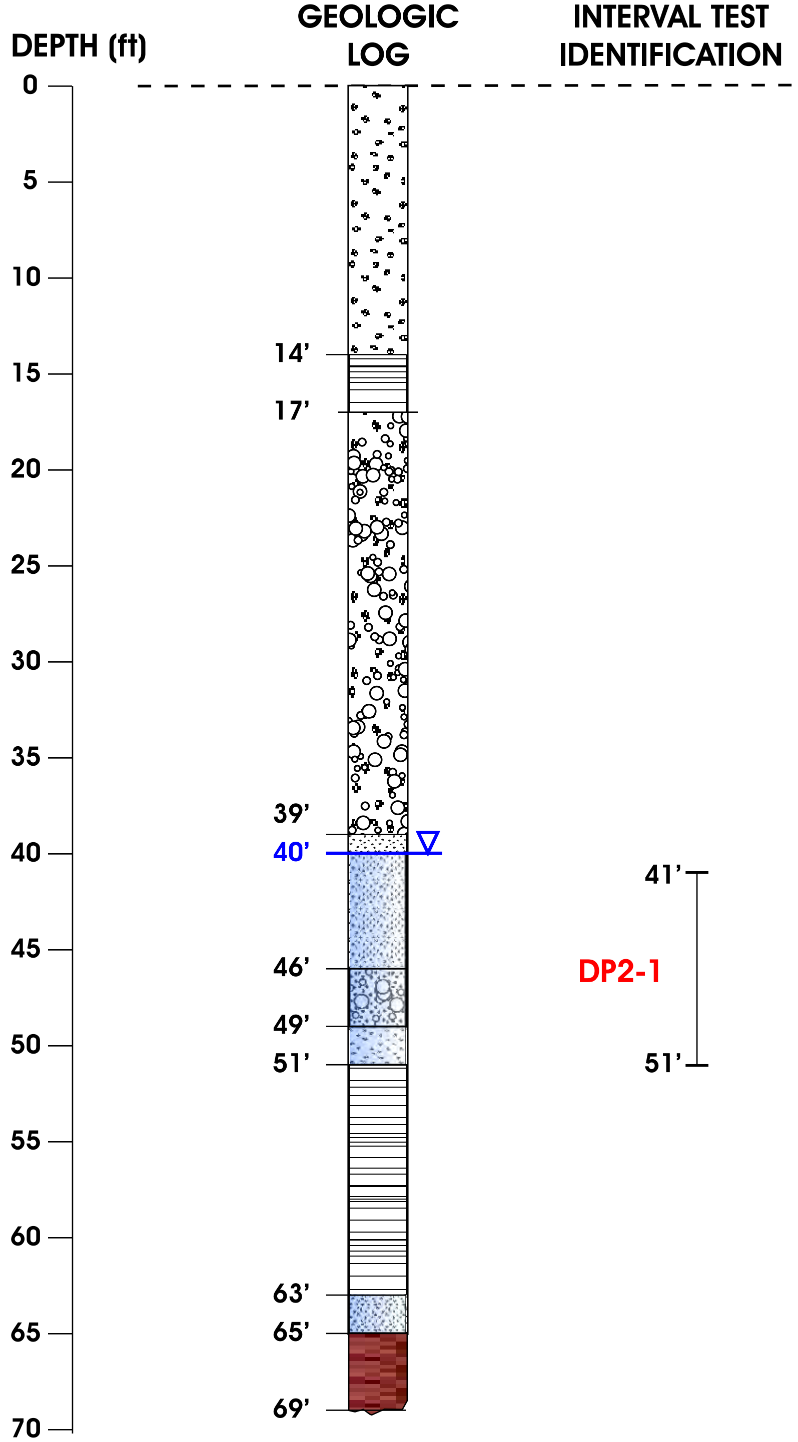
DP9 DEPTH PROFILE TEST HOLE

N

Notes:
1) Overview map scale is 1 inch = 6500 feet
2) Enlargement map scale is 1 inch = 1320 feet.

CHERRY CREEK BASIN WATER QUALITY AUTHORITY		
DEPTH PROFILE TEST HOLE LOCATIONS		
File Name: TestHoleLoc.cdr		Date: 08/06/2006
Project No.: 1051-05	Drawn By: VAL	Fig. No.: 1

LYTLE WATER SOLUTIONS, LLC



RESULTS OF INTERVAL TESTING

Interval Test	Q/s (gpm/ft)	SC (µmhos/cm)	TP (mg/L)	SRP (mg/L)	NO_3-N (mg/L)
DP2-1 (41'–51')	28.5	465	0.236	0.186	0.737

Note: Geologic log shows dominant lithology only, for illustration purposes.

LEGEND

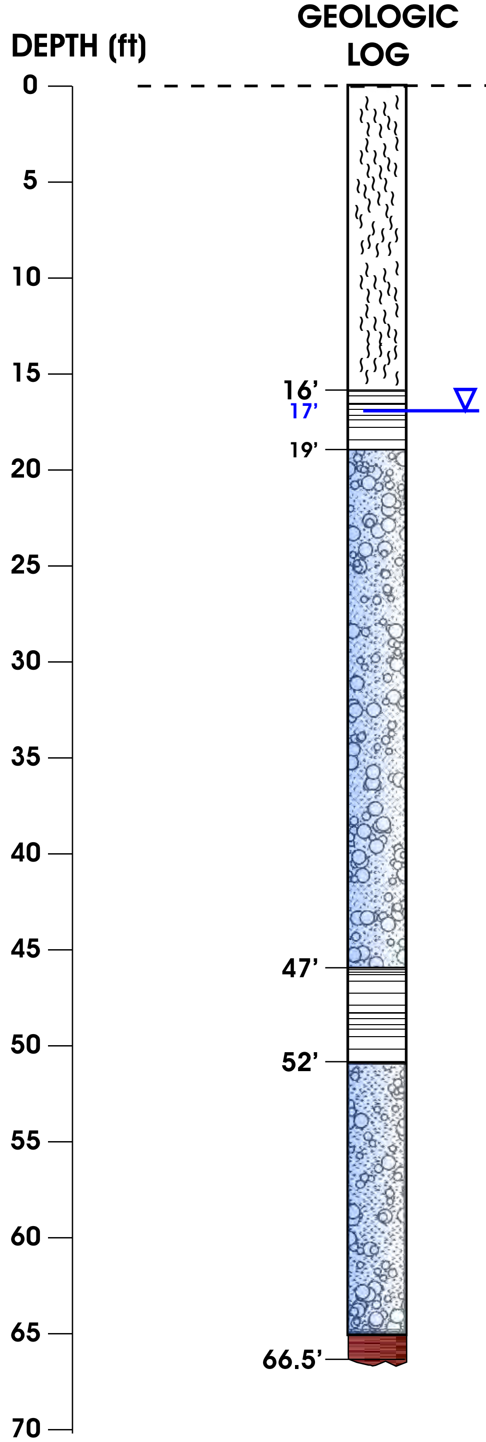
- BEDROCK (Sandstone)
- CLAY
- GRAVEL
- SAND
- SAND & GRAVEL
- SILT
- SATURATED, WATER-BEARING ZONE
- STATIC WATER LEVEL
- 10' – 20': INTERVAL TEST SHOWING TOP AND BOTTOM OF SCREEN
- Q/s: WELL SPECIFIC CAPACITY (gallons per minute per foot)
- SC: SPECIFIC CONDUCTANCE (microsiemens per centimeter)
- TP: TOTAL PHOSPHORUS (milligrams per liter)
- SRP: SOLUBLE REACTIVE PHOSPHORUS (milligrams per liter)
- NO_3-N: NITRATE AS NITROGEN (milligrams per liter)

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

DEPTH PROFILE
TEST HOLE DP2

File Name: DP-2.cdr		Date: 07/31/2006
Project No.: 1051-05	Drawn By: VAL	Fig. No.: 2

LYTLE WATER SOLUTIONS, LLC



RESULTS OF INTERVAL TESTING

INTERVAL TEST IDENTIFICATION	Screen interval	Q/s (gpm/ft)	SC (µmhos/cm)	TP (mg/L)	SRP (mg/L)	NO_3-N (mg/L)
DP4-1	40'–45'	3.2	868	0.261	0.201	2.062
DP4-2	53'–58'	1.0	840	0.135	0.078	1.423

LEGEND

- BEDROCK (Shale)
- CLAY
- GRAVEL
- SAND
- SAND & GRAVEL
- SILT
- SATURATED, WATER-BEARING ZONE
- STATIC WATER LEVEL
- 10'–20': INTERVAL TEST SHOWING TOP AND BOTTOM OF SCREEN
- Q/s: WELL SPECIFIC CAPACITY (gallons per minute per foot)
- SC: SPECIFIC CONDUCTANCE (microsiemens per centimeter)
- TP: TOTAL PHOSPHORUS (milligrams per liter)
- SRP: SOLUBLE REACTIVE PHOSPHORUS (milligrams per liter)
- NO_3-N: NITRATE AS NITROGEN (milligrams per liter)

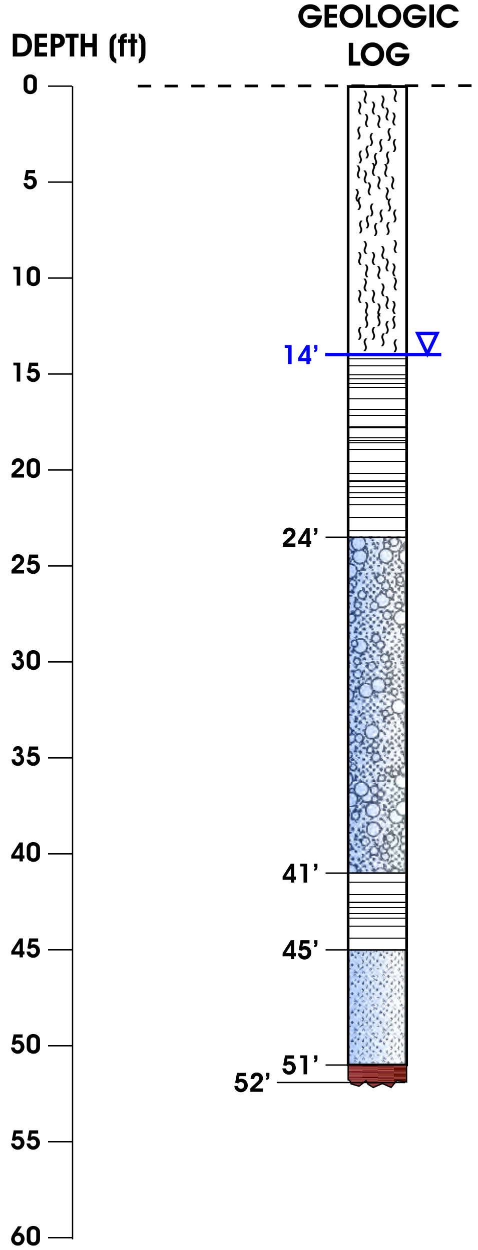
Note: Geologic log shows dominant lithology only, for illustration purposes.

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

DEPTH PROFILE
TEST HOLE DP4

File Name: DP-4.cdr		Date: 07/31/2006
Project No.: 1051-05	Drawn By: VAL	Fig. No.: 3

Lytle Water Solutions, LLC



RESULTS OF INTERVAL TESTING

INTERVAL TEST IDENTIFICATION	Screen (top–bottom)	Q/s (gpm/ft)	SC (µmhos/cm)	TP (mg/L)	SRP (mg/L)	NO_3-N (mg/L)
DP5-1	24'–29'	0.1	744	0.046	0.011	0.034
DP5-2	35'–40'	0.7	755	0.168	0.119	1.002
DP5-3	45'–50'	0.4	765	0.262	0.155	2.259

LEGEND

- BEDROCK (Shale)
- CLAY
- GRAVEL
- SAND
- SAND & GRAVEL
- SILT
- SATURATED, WATER-BEARING ZONE
- STATIC WATER LEVEL
- 10' / 20' — INTERVAL TEST SHOWING TOP AND BOTTOM OF SCREEN
- Q/s — WELL SPECIFIC CAPACITY (gallons per minute per foot)
- SC — SPECIFIC CONDUCTANCE (microsiemens per centimeter)
- TP — TOTAL PHOSPHORUS (milligrams per liter)
- SRP — SOLUBLE REACTIVE PHOSPHORUS (milligrams per liter)
- NO_3-N — NITRATE AS NITROGEN (milligrams per liter)

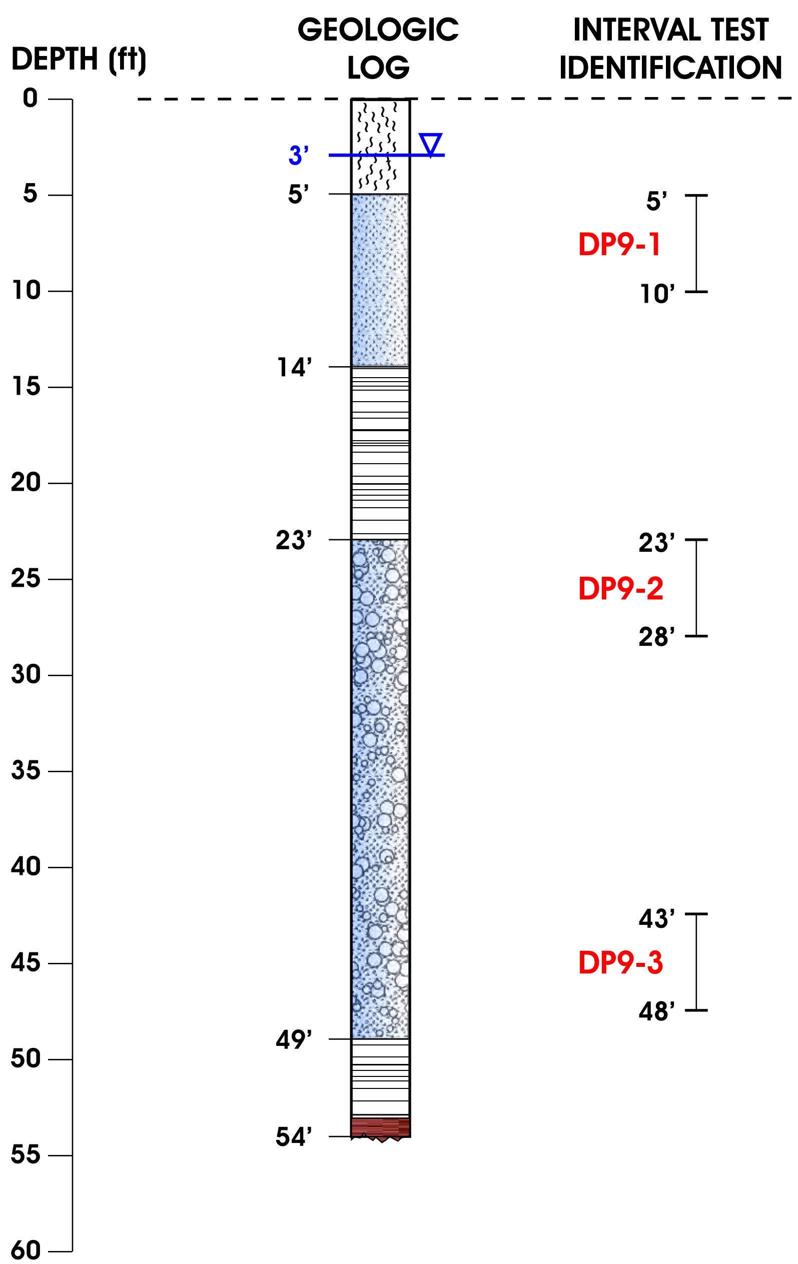
Note: Geologic log shows dominant lithology only, for illustration purposes.

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

DEPTH PROFILE
TEST HOLE DP5

File Name: DP-5.cdr		Date: 07/31/2006
Project No.: 1051-05	Drawn By: VAL	Fig. No.: 4

Lytle Water Solutions, LLC



RESULTS OF INTERVAL TESTING

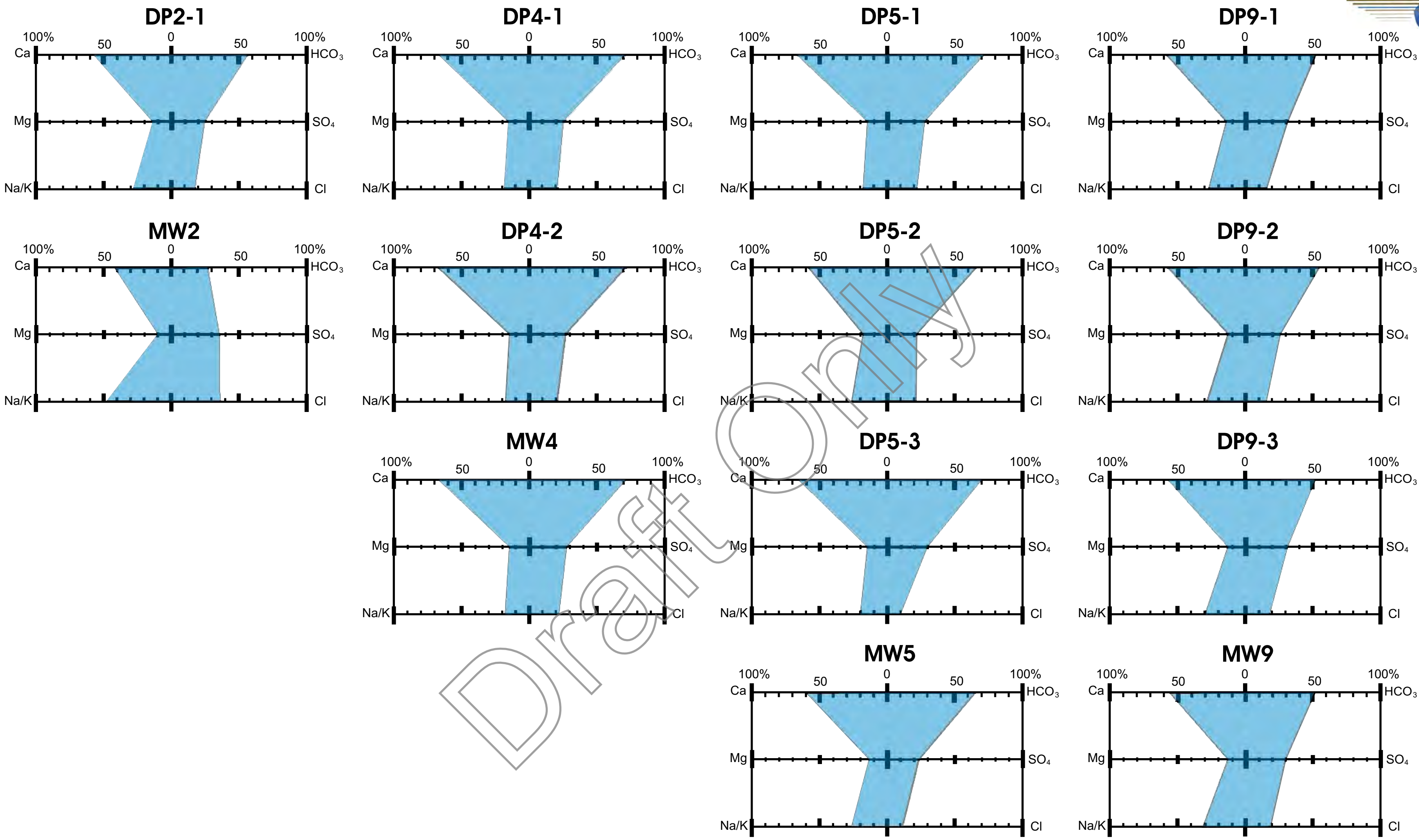
Interval Test	Q/s (gpm/ft)	SC (µmhos/cm)	TP (mg/L)	SRP (mg/L)	NO_3-N (mg/L)
DP9-1 (5'–10')	7.4	991	0.250	0.192	<0.002
DP9-2 (23'–28')	2.0	793	0.303	0.169	0.013
DP9-3 (43'–48')	10.4	794	0.257	0.209	0.053

LEGEND

- BEDROCK (Shale)
- CLAY
- GRAVEL
- SAND
- SAND & GRAVEL
- SILT
- SATURATED, WATER-BEARING ZONE
- STATIC WATER LEVEL
- 10' / 20' — INTERVAL TEST SHOWING TOP AND BOTTOM OF SCREEN
- Q/s — WELL SPECIFIC CAPACITY (gallons per minute per foot)
- SC — SPECIFIC CONDUCTANCE (microsiemens per centimeter)
- TP — TOTAL PHOSPHORUS (milligrams per liter)
- SRP — SOLUBLE REACTIVE PHOSPHORUS (milligrams per liter)
- NO_3-N — NITRATE AS NITROGEN (milligrams per liter)

Note: Geologic log shows dominant lithology only, for illustration purposes.

CHERRY CREEK BASIN WATER QUALITY AUTHORITY		
DEPTH PROFILE TEST HOLE DP9		
File Name: DP-9.cdr		Date: 07/31/2006
Project No.: 1051-05	Drawn By: VAL	Fig. No.: 5



Note:
Values in milligram-equivalents per liter, expressed as a percentage of total, for major cations and anions.
See Appendix B for details of analysis.

CHERRY CREEK BASIN WATER QUALITY AUTHORITY		
STIFF DIAGRAMS SHOWING WATER TYPES		
File Name: CCBWQA_STIFFs.cdr		Date: 08/11/2006
Project No.: 1051-05	Drawn By: VAL	Fig. No.: 6

APPENDIX A
WATER QUALITY SUMMARY TABLES

Table A-1
Results of Depth Profile Testing and Sampling
Cherry Creek Basin Water Quality Authority

	Well and Interval Represented													
Well Number>	**DP2**	**MW2**	**DP4**		**MW4**	**DP5**			**MW5**	**DP9**			**MW9**
Interval Number>	**1**	**composite**	**1**	**2**	**composite**	**1**	**2**	**3**	**composite**	**1**	**2**	**3**	**composite**
Field Results (see notes for explanation)													
Interval Top (depth in ft)	41		40	53		24	35	45		5	23	43	
Interval Bottom (depth in ft)	51		45	58		29	40	50		10	28	48	
Interval Tested (ft)	10		5	5		5	5	5		5	5	5	
Discharge (gpm)	25.9		10	28		1	9.3	10.3		5.9	6.4	33.3	
Drawdown (ft)	0.91		3.1	29.2		11.7	14	26.6		0.8	3.25	3.21	
Specific Capacity (gpm/ft)	28.5		3.2	1.0		0.1	0.7	0.4		7.4	2.0	10.4	
Est. Transmissivity (gpd/ft)	30738		3484	1036		92	717	418		7965	2127	11204	
Est. Hydraulic Conductivity (gpd/ft^2)	3074		697	207		18	143	84		1593	425	2241	
Interval Represented (ft)	10		28	14		6	8	6		9	13	13	
Est. Transmissivity for Representative Interval (gpd/ft)	30738		19510	2900		111	1148	502		14337	5530	29130	
Est. Transmissivity for Full Saturated Thickness (gpd/ft)	30738	n/a	22409		n/a		1760		n/a		48996		n/a
Calculated Hydraulic Conductivity for Full Saturated Thickness (ft/d)	411	n/a	71		n/a		12		n/a		187		n/a
Field Specific Conductance (umhos/cm)	465	1035	868	840	842	744	755	765	805	991	793	794	818
Field pH	6.98	6.75	7.04	6.99	7.11	7.71	7.26	7.12	7.18	7.05	7.28	7.21	7.17
Laboratory Results													
Total Phosphorus (TP) (ug/L)	236	758	261	135	204	46	168	262	213	250	303	257	280
Soluble Reactive Phosphorus (SRP) (ug/L)	186	261	201	78	31	11	119	155	191	192	169	209	241
Nitrate-Nitrogen (ug/L)	737	24	2062	1423	42	34	1002	2259	1940	<2	13	53	53
Calcium (mg/L)	58	85	130	130	130	90	100	110	110	130	100	100	99
Magnesium (mg/L)	8.5	12	19	18	18	12	14	15	15	20	14	14	14
Potassium (mg/L)	3.7	4.3	4.9	5.3	4.8	6.8	5.1	4.2	5	3.8	4.9	4.5	4.5
Sodium (mg/L)	30	110	36	34	37	56	49	37	52	67	53	57	62
Bicarbonate (mg/L)	158	145	369	360	366	274	289	315	319	291	250	230	241
Sulfate (mg/L)	55.2	187	85.7	84.4	87.8	91.9	93.6	84.2	105	172	118	136	137
Chloride (mg/L)	29.6	142	42.9	38.7	43.6	41.4	38.1	31.7	40.4	62.2	55.4	58.5	63.4

Notes:
- Interval Top: Top of temporary screen section
- Interval Bottom: bottom of temporary screen section
- Interval Length: Length of screen used in testing
- Discharge: rate of pumping during testing
- Drawdown: amount of water level lowering during pumping (static water level - pumping water level)
- Specific Capacity: ratio of discharge to drawdown
- Est. Transmissivity: estimated transmissivity calculated as Q/s*1080 (based on Theis solution)
- Est. Hydraulic Conductivity: transmissivity/interval tested
- Interval Represented: estimated thickness of saturated water-bearing interval from geologic log
- Est. Transmissivity for Representative Interval: Estimated hyraulic conductivity x interval represented
- Est. Transmissivity for Full Saturated Thickness: sum of transmissivities for separate intervals
- Calculated Hydraulic Conductivity for Full Saturated Thickness: transmissivity for full saturated thickness/sum of intervals represented

Table A-2
Comparison of Water Quality at Depth Profile Sites with Monitoring Well Sites
Cherry Creek Basin Water Quality Authority

	Sampling Location												
	DP2		MW2	DP4		MW4	DP5		MW5	DP9		MW9
Water Quality Parameter	Average	Wtd. Avg.	composite	Average	Wtd. Avg.	composite	Average	Wtd. Avg.	composite	Average	Wtd. Avg.	composite
Total Phosphorus (TP) (ug/L)	236	236	758	198	245	204	159	187	213	270	260	280
Soluble Reactive Phosphorus (SRP) (ug/L)	186	186	261	140	185	31	95	122	191	190	200	241
Nitrate-Nitrogen (ug/L)	737	737	24	1743	1979	42	1098	1299	1940	33	33	53
Calcium (mg/L)	58	58	85	130	130	130	100	102	110	110	109	99
Magnesium (mg/L)	8.5	8.5	12	19	19	18	14	14	15	16	16	14
Potassium (mg/L)	3.7	3.7	4.3	5	5	4.8	5	5	5	4.4	4	4.5
Sodium (mg/L)	30	30	110	35	36	37	47	46	52	59	59	62
Bicarbonate (mg/L)	158	158	145	365	368	366	293	295	319	257	250	241
Sulfate (mg/L)	55.2	55.2	187	85	86	87.8	90	91	105	142	145	137
Chloride (mg/L)	29.6	29.6	142	41	42	43.6	37	36	40.4	58.7	59	63.4

APPENDIX B
WATER QUALITY ANALYSIS REPORTS

LYTLE WATER SOLUTIONS, LLC

WATER QUALITY ANALYSIS REPORT

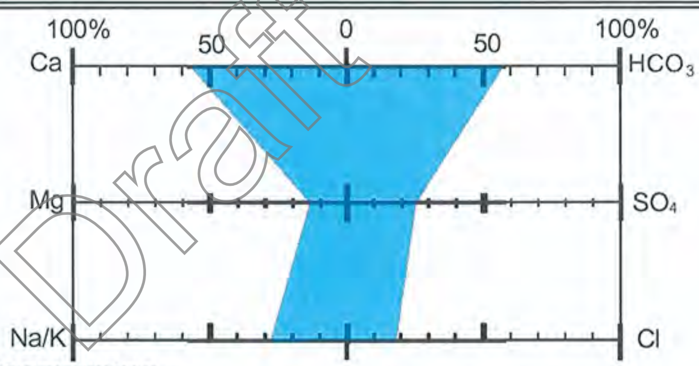
Well No. DP2-1

Date Collected : 6/27/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	58.00	20.04		2.89
Magnesium (Mg)	8.50	12.16		0.70
Sodium (Na)	30.00	22.99		1.30
Potassium (K)	3.70	39.10		0.09
			TOTAL CATION:	4.99
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	160.85	61.02		2.64
Sulfate (SO_4)	55.20	48.03		1.15
Chloride (Cl)	29.60	35.45		0.83
Nitrate (NO_3N)	0.74			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	4.62
TOTAL ION:	346.59			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	1.08	.96 to 1.04
TDS (calculated)	266	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)	CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01	Thallium (Th)		0.002
Barium (Ba)		2	Uranium (U)		0.03
Cadmium (Cd)		0.005	Zinc (Zn)		5
Chromium (Cr)		0.1			
Copper (Cu)		1.3	Radium 226 *(1)*		} 5
Iron (Fe)		0.3	Radium 228 *(1)*		(Combined)
Lead (Pb)		0.015	Gross Alpha *(1)*		15
Manganese (Mn)		0.05	Gross Beta *(1)*		50
Mercury (Hg)		0.002	Total Coliforms *(2)*		<1
Nickel (Ni)		--			
Selenium (Se)		0.05			
Silver (Ag)		0.1			

(1) pCi/L

(2) counts/100mL

(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

Well No. MW2

Date Collected : 6/29/2006

MAJOR CATIONS AND ANIONS

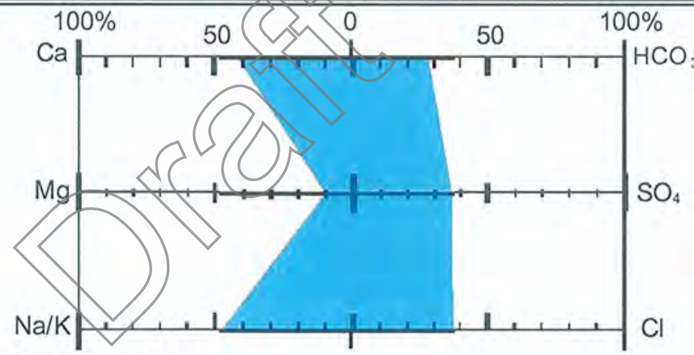
CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	85.00	20.04		4.24
Magnesium (Mg)	12.00	12.16		0.99
Sodium (Na)	110.00	22.99		4.78
Potassium (K)	4.30	39.10		0.11
			TOTAL CATION:	10.12
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	176.96	61.02		2.90
Sulfate (SO_4)	187.00	48.03		3.89
Chloride (Cl)	142.00	35.45		4.01
Nitrate (NO_3N)	0.02			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	10.80
TOTAL ION:	717.28			

TOTAL ION CHECK

TDS (180°C)	
TDS (calculated)	629

ACCURACY CHECK

		Range
Ion Balance	0.94	.96 to 1.04
TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)	CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01	Thallium (Th)		0.002
Barium (Ba)		2	Uranium (U)		0.03
Cadmium (Cd)		0.005	Zinc (Zn)		5
Chromium (Cr)		0.1			
Copper (Cu)		1.3	Radium 226 *(1)*		5
Iron (Fe)		0.3	Radium 228 *(1)*		(Combined)
Lead (Pb)		0.015	Gross Alpha *(1)*		15
Manganese (Mn)		0.05	Gross Beta *(1)*		50
Mercury (Hg)		0.002	Total Coliforms *(2)*		<1
Nickel (Ni)		--			
Selenium (Se)		0.05			
Silver (Ag)		0.1			

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

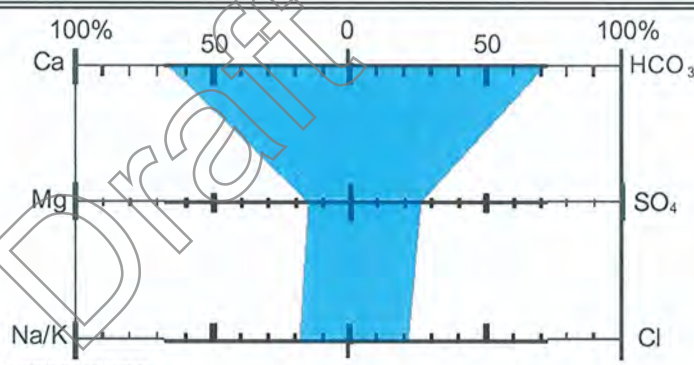
Well No. DP4-1

Date Collected : 6/22/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	130.00	20.04		6.49
Magnesium (Mg)	19.00	12.16		1.56
Sodium (Na)	36.00	22.99		1.57
Potassium (K)	4.90	39.10		0.13
			TOTAL CATION:	9.74
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	450.33	61.02		7.38
Sulfate (SO_4)	85.70	48.03		1.78
Chloride (Cl)	42.90	35.45		1.21
Nitrate (NO_3N)	2.06			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	10.37
TOTAL ION:	770.89			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	0.94	.96 to 1.04
TDS (calculated)	546	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01
Barium (Ba)		2
Cadmium (Cd)		0.005
Chromium (Cr)		0.1
Copper (Cu)		1.3
Iron (Fe)		0.3
Lead (Pb)		0.015
Manganese (Mn)		0.05
Mercury (Hg)		0.002
Nickel (Ni)		--
Selenium (Se)		0.05
Silver (Ag)		0.1

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Thallium (Th)		0.002
Uranium (U)		0.03
Zinc (Zn)		5
Radium 226 *(1)*		5 (Combined)
Radium 228 *(1)*		
Gross Alpha *(1)*		15
Gross Beta *(1)*		50
Total Coliforms *(2)*		<1

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

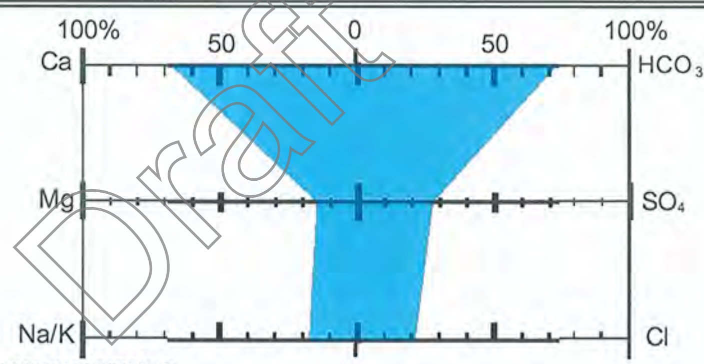
Well No. DP4-2

Date Collected : 6/22/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	130.00	20.04		6.49
Magnesium (Mg)	18.00	12.16		1.48
Sodium (Na)	34.00	22.99		1.48
Potassium (K)	5.30	39.10		0.14
			TOTAL CATION:	9.58
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	439.34	61.02		7.20
Sulfate (SO_4)	84.40	48.03		1.76
Chloride (Cl)	38.70	35.45		1.09
Nitrate (NO_3N)	1.42			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	10.05
TOTAL ION:	751.17			

TOTAL ION CHECK		ACCURACY CHECK		Range
TDS (180°C)		Ion Balance	0.95	.96 to 1.04
TDS (calculated)	531	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01
Barium (Ba)		2
Cadmium (Cd)		0.005
Chromium (Cr)		0.1
Copper (Cu)		1.3
Iron (Fe)		0.3
Lead (Pb)		0.015
Manganese (Mn)		0.05
Mercury (Hg)		0.002
Nickel (Ni)		--
Selenium (Se)		0.05
Silver (Ag)		0.1

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Thallium (Th)		0.002
Uranium (U)		0.03
Zinc (Zn)		5
Radium 226 *(1)*		5 (Combined)
Radium 228 *(1)*		
Gross Alpha *(1)*		15
Gross Beta *(1)*		50
Total Coliforms *(2)*		<1

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

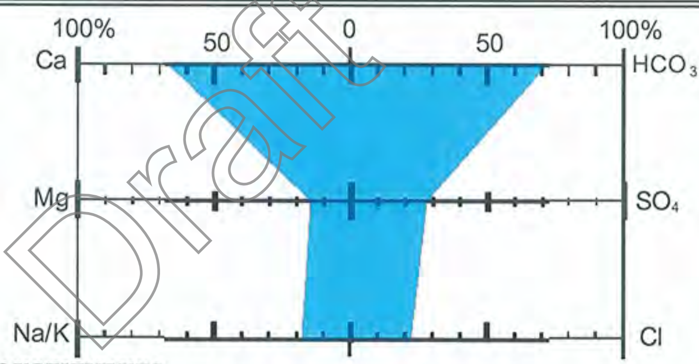
Well No. MW4

Date Collected : 6/29/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	130.00	20.04		6.49
Magnesium (Mg)	18.00	12.16		1.48
Sodium (Na)	37.00	22.99		1.61
Potassium (K)	4.80	39.10		0.12
			TOTAL CATION:	9.70
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	446.67	61.02		7.32
Sulfate (SO_4)	87.80	48.03		1.83
Chloride (Cl)	43.60	35.45		1.23
Nitrate (NO_3N)	0.04			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	10.38
TOTAL ION:	767.91			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	0.93	.96 to 1.04
TDS (calculated)	545	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01
Barium (Ba)		2
Cadmium (Cd)		0.005
Chromium (Cr)		0.1
Copper (Cu)		1.3
Iron (Fe)		0.3
Lead (Pb)		0.015
Manganese (Mn)		0.05
Mercury (Hg)		0.002
Nickel (Ni)		--
Selenium (Se)		0.05
Silver (Ag)		0.1

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Thallium (Th)		0.002
Uranium (U)		0.03
Zinc (Zn)		5
Radium 226 *(1)*		} 5 (Combined)
Radium 228 *(1)*		
Gross Alpha *(1)*		15
Gross Beta *(1)*		50
Total Coliforms *(2)*		<1

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

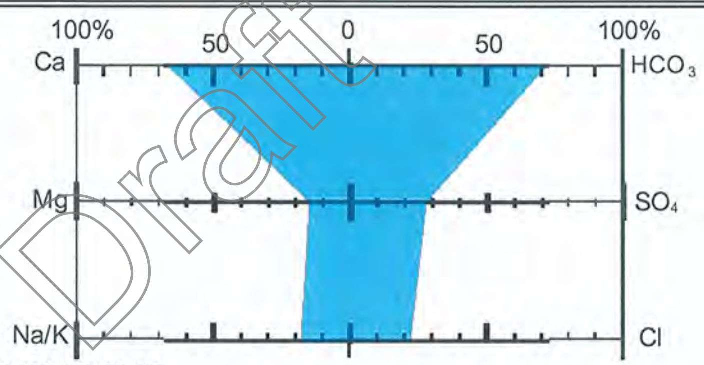
Well No. DP5-1

Date Collected : 6/24/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	90.00	20.04		4.49
Magnesium (Mg)	12.00	12.16		0.99
Sodium (Na)	56.00	22.99		2.44
Potassium (K)	6.80	39.10		0.17
			TOTAL CATION:	8.09
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	334.39	61.02		5.48
Sulfate (SO_4)	91.90	48.03		1.91
Chloride (Cl)	41.40	35.45		1.17
Nitrate (NO_3N)	0.03			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	8.56
TOTAL ION:	632.52			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	0.94	.96 to 1.04
TDS (calculated)	465	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)	CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01	Thallium (Th)		0.002
Barium (Ba)		2	Uranium (U)		0.03
Cadmium (Cd)		0.005	Zinc (Zn)		5
Chromium (Cr)		0.1			
Copper (Cu)		1.3	Radium 226 *(1)*		5
Iron (Fe)		0.3	Radium 228 *(1)*		(Combined)
Lead (Pb)		0.015	Gross Alpha *(1)*		15
Manganese (Mn)		0.05	Gross Beta *(1)*		50
Mercury (Hg)		0.002	Total Coliforms *(2)*		<1
Nickel (Ni)		--			
Selenium (Se)		0.05			
Silver (Ag)		0.1			

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC
Water Quality Analysis Report

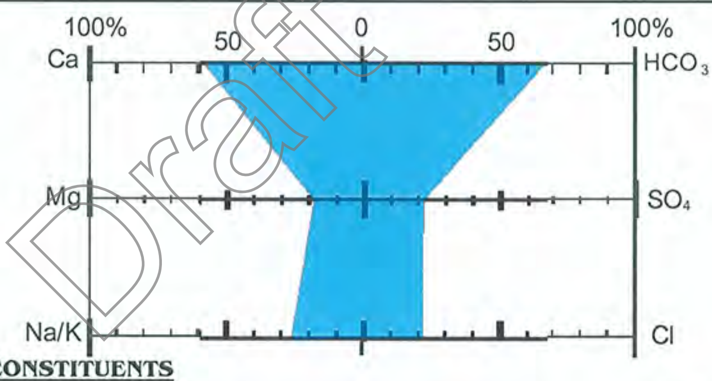
Well No. DP5-2

Date Collected : 6/24/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	100.00	20.04		4.99
Magnesium (Mg)	14.00	12.16		1.15
Sodium (Na)	49.00	22.99		2.13
Potassium (K)	5.10	39.10		0.13
			TOTAL CATION:	8.40
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	352.70	61.02		5.78
Sulfate (SO_4)	93.60	48.03		1.95
Chloride (Cl)	38.10	35.45		1.07
Nitrate (NO_3N)	1.00			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	8.80
TOTAL ION:	653.50			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	0.95	.96 to 1.04
TDS (calculated)	477	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01
Barium (Ba)		2
Cadmium (Cd)		0.005
Chromium (Cr)		0.1
Copper (Cu)		1.3
Iron (Fe)		0.3
Lead (Pb)		0.015
Manganese (Mn)		0.05
Mercury (Hg)		0.002
Nickel (Ni)		--
Selenium (Se)		0.05
Silver (Ag)		0.1

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Thallium (Th)		0.002
Uranium (U)		0.03
Zinc (Zn)		5
Radium 226 *(1)*		5 (Combined)
Radium 228 *(1)*		
Gross Alpha *(1)*		15
Gross Beta *(1)*		50
Total Coliforms *(2)*		<1

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

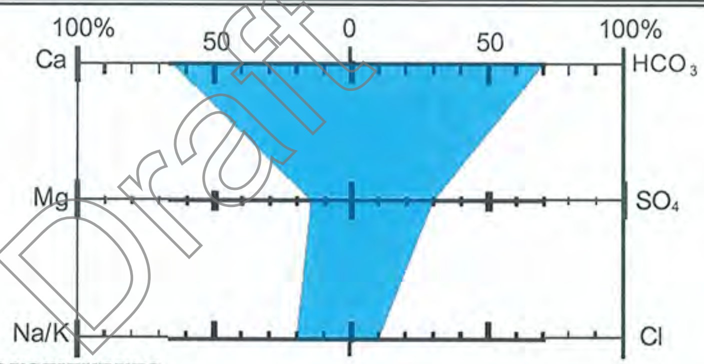
Well No. DP5-3

Date Collected : 6/24/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	110.00	20.04		5.49
Magnesium (Mg)	15.00	12.16		1.23
Sodium (Na)	37.00	22.99		1.61
Potassium (K)	4.20	39.10		0.11
			TOTAL CATION:	8.44
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	384.43	61.02		6.30
Sulfate (SO_4)	84.20	48.03		1.75
Chloride (Cl)	31.70	35.45		0.89
Nitrate (NO_3N)	2.26			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	8.95
TOTAL ION:	668.79			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	0.94	.96 to 1.04
TDS (calculated)	477	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01
Barium (Ba)		2
Cadmium (Cd)		0.005
Chromium (Cr)		0.1
Copper (Cu)		1.3
Iron (Fe)		0.3
Lead (Pb)		0.015
Manganese (Mn)		0.05
Mercury (Hg)		0.002
Nickel (Ni)		--
Selenium (Se)		0.05
Silver (Ag)		0.1

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Thallium (Th)		0.002
Uranium (U)		0.03
Zinc (Zn)		5
Radium 226 *(1)*	}	5 (Combined)
Radium 228 *(1)*		
Gross Alpha *(1)*		15
Gross Beta *(1)*		50
Total Coliforms *(2)*		<1

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC
Water Quality Analysis Report

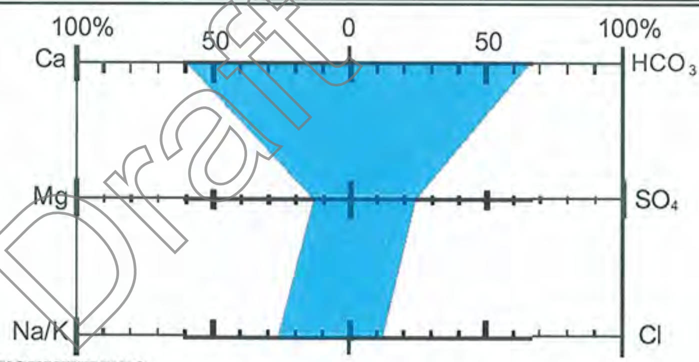
Well No. MW5

Date Collected : 6/29/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	110.00	20.04		5.49
Magnesium (Mg)	15.00	12.16		1.23
Sodium (Na)	52.00	22.99		2.26
Potassium (K)	5.00	39.10		0.13
			TOTAL CATION:	9.11
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	389.31	61.02		6.38
Sulfate (SO_4)	105.00	48.03		2.19
Chloride (Cl)	40.40	35.45		1.14
Nitrate (NO_3N)	1.94			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	9.71
TOTAL ION:	718.65			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	0.94	.96 to 1.04
TDS (calculated)	524	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)	CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01	Thallium (Th)		0.002
Barium (Ba)		2	Uranium (U)		0.03
Cadmium (Cd)		0.005	Zinc (Zn)		5
Chromium (Cr)		0.1			
Copper (Cu)		1.3	Radium 226 *(1)*	}	5 (Combined)
Iron (Fe)		0.3	Radium 228 *(1)*		
Lead (Pb)		0.015	Gross Alpha *(1)*		15
Manganese (Mn)		0.05	Gross Beta *(1)*		50
Mercury (Hg)		0.002	Total Coliforms *(2)*		<1
Nickel (Ni)		--			
Selenium (Se)		0.05			
Silver (Ag)		0.1			

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

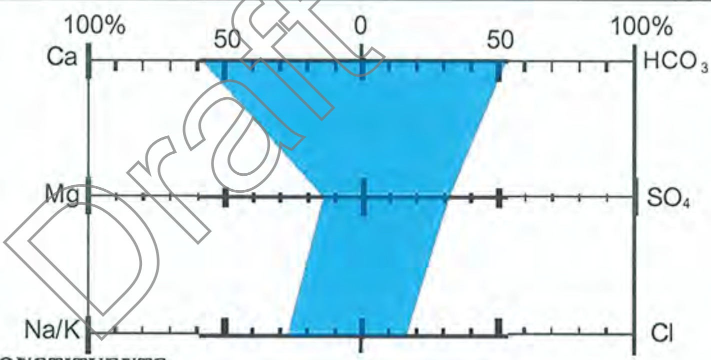
Well No. DP9-1

Date Collected : 6/26/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	130.00	20.04		6.49
Magnesium (Mg)	20.00	12.16		1.64
Sodium (Na)	67.00	22.99		2.91
Potassium (K)	3.80	39.10		0.10
			TOTAL CATION:	11.14
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	355.14	61.02		5.82
Sulfate (SO_4)	172.00	48.03		3.58
Chloride (Cl)	62.20	35.45		1.75
Nitrate (NO_3N)	<0.002			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	11.16
TOTAL ION:	810.14			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	1.00	.96 to 1.04
TDS (calculated)	633	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)	CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01	Thallium (Th)		0.002
Barium (Ba)		2	Uranium (U)		0.03
Cadmium (Cd)		0.005	Zinc (Zn)		5
Chromium (Cr)		0.1			
Copper (Cu)		1.3	Radium 226 *(1)*		5 (Combined)
Iron (Fe)		0.3	Radium 228 *(1)*		
Lead (Pb)		0.015	Gross Alpha *(1)*		15
Manganese (Mn)		0.05	Gross Beta *(1)*		50
Mercury (Hg)		0.002	Total Coliforms *(2)*		<1
Nickel (Ni)		--			
Selenium (Se)		0.05			
Silver (Ag)		0.1			

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

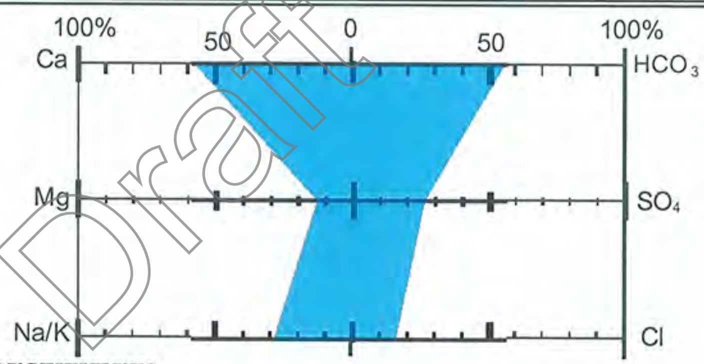
Well No. DP9-2

Date Collected : 6/26/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	100.00	20.04		4.99
Magnesium (Mg)	14.00	12.16		1.15
Sodium (Na)	53.00	22.99		2.31
Potassium (K)	4.90	39.10		0.13
			TOTAL CATION:	8.57
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	305.10	61.02		5.00
Sulfate (SO_4)	118.00	48.03		2.46
Chloride (Cl)	55.40	35.45		1.56
Nitrate (NO_3N)	0.01			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	9.02
TOTAL ION:	650.41			

TOTAL ION CHECK		**ACCURACY CHECK**		Range
TDS (180°C)		Ion Balance	0.95	.96 to 1.04
TDS (calculated)	498	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01
Barium (Ba)		2
Cadmium (Cd)		0.005
Chromium (Cr)		0.1
Copper (Cu)		1.3
Iron (Fe)		0.3
Lead (Pb)		0.015
Manganese (Mn)		0.05
Mercury (Hg)		0.002
Nickel (Ni)		--
Selenium (Se)		0.05
Silver (Ag)		0.1

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Thallium (Th)		0.002
Uranium (U)		0.03
Zinc (Zn)		5
Radium 226 *(1)*		5 (Combined)
Radium 228 *(1)*		
Gross Alpha *(1)*		15
Gross Beta *(1)*		50
Total Coliforms *(2)*		<1

(1) pCi/L

(2) counts/100mL

(3) Analysis not required.

Lytle Water Solutions, LLC

Water Quality Analysis Report

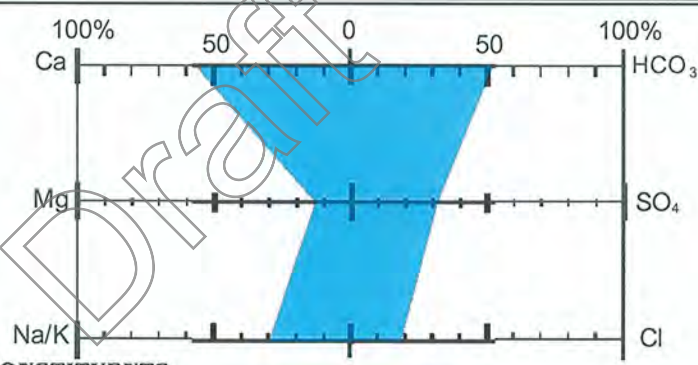
Well No. DP9-3

Date Collected : 6/26/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	100.00	20.04		4.99
Magnesium (Mg)	14.00	12.16		1.15
Sodium (Na)	57.00	22.99		2.48
Potassium (K)	4.50	39.10		0.12
			TOTAL CATION:	8.74
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	280.69	61.02		4.60
Sulfate (SO_4)	136.00	48.03		2.83
Chloride (Cl)	58.50	35.45		1.65
Nitrate (NO_3N)	0.05			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	9.08
TOTAL ION:	650.75			

TOTAL ION CHECK		**ACCURACY CHECK**		
				Range
TDS (180°C)		Ion Balance	0.96	.96 to 1.04
TDS (calculated)	510	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01
Barium (Ba)		2
Cadmium (Cd)		0.005
Chromium (Cr)		0.1
Copper (Cu)		1.3
Iron (Fe)		0.3
Lead (Pb)		0.015
Manganese (Mn)		0.05
Mercury (Hg)		0.002
Nickel (Ni)		--
Selenium (Se)		0.05
Silver (Ag)		0.1

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Thallium (Th)		0.002
Uranium (U)		0.03
Zinc (Zn)		5
Radium 226 *(1)*		5 (Combined)
Radium 228 *(1)*		
Gross Alpha *(1)*		15
Gross Beta *(1)*		50
Total Coliforms *(2)*		<1

(1) pCi/L

(2) counts/100mL

(3) Analysis not required.

Lytle Water Solutions, LLC
Water Quality Analysis Report

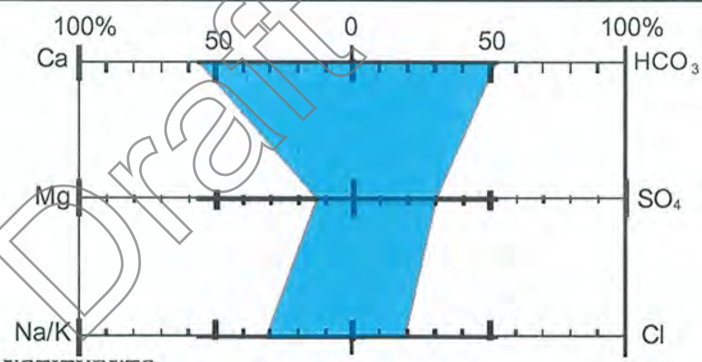
Well No. MW9

Date Collected : 6/29/2006

MAJOR CATIONS AND ANIONS

CONSTITUENT	Concentration (mg/l)	Equivalent Weight		meq/L
Calcium (Ca)	99.00	20.04		4.94
Magnesium (Mg)	14.00	12.16		1.15
Sodium (Na)	62.00	22.99		2.70
Potassium (K)	4.50	39.10		0.12
			TOTAL CATION:	8.90
Carbonate (CO_3)		30.00		0.00
Bicarbonate (HCO_3)	294.12	61.02		4.82
Sulfate (SO_4)	137.00	48.03		2.85
Chloride (Cl)	63.40	35.45		1.79
Nitrate (NO_3N)	0.05			
Fluoride (F)				
Silica (SiO_2)			**TOTAL ANION:**	9.46
TOTAL ION:	674.07			

TOTAL ION CHECK		ACCURACY CHECK		Range
TDS (180°C)		Ion Balance	0.94	.96 to 1.04
TDS (calculated)	527	TDS Balance	0.00	.90 to 1.10



PRIMARY/SECONDARY CONSTITUENTS

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Arsenic (As)		0.01
Barium (Ba)		2
Cadmium (Cd)		0.005
Chromium (Cr)		0.1
Copper (Cu)		1.3
Iron (Fe)		0.3
Lead (Pb)		0.015
Manganese (Mn)		0.05
Mercury (Hg)		0.002
Nickel (Ni)		--
Selenium (Se)		0.05
Silver (Ag)		0.1

CONSTITUENT	Sample Concentration (mg/L)	MCL (mg/L)
Thallium (Th)		0.002
Uranium (U)		0.03
Zinc (Zn)		5
Radium 226 *(1)*		5 (Combined)
Radium 228 *(1)*		
Gross Alpha *(1)*		15
Gross Beta *(1)*		50
Total Coliforms *(2)*		<1

(1) pCi/L
(2) counts/100mL
(3) Analysis not required.