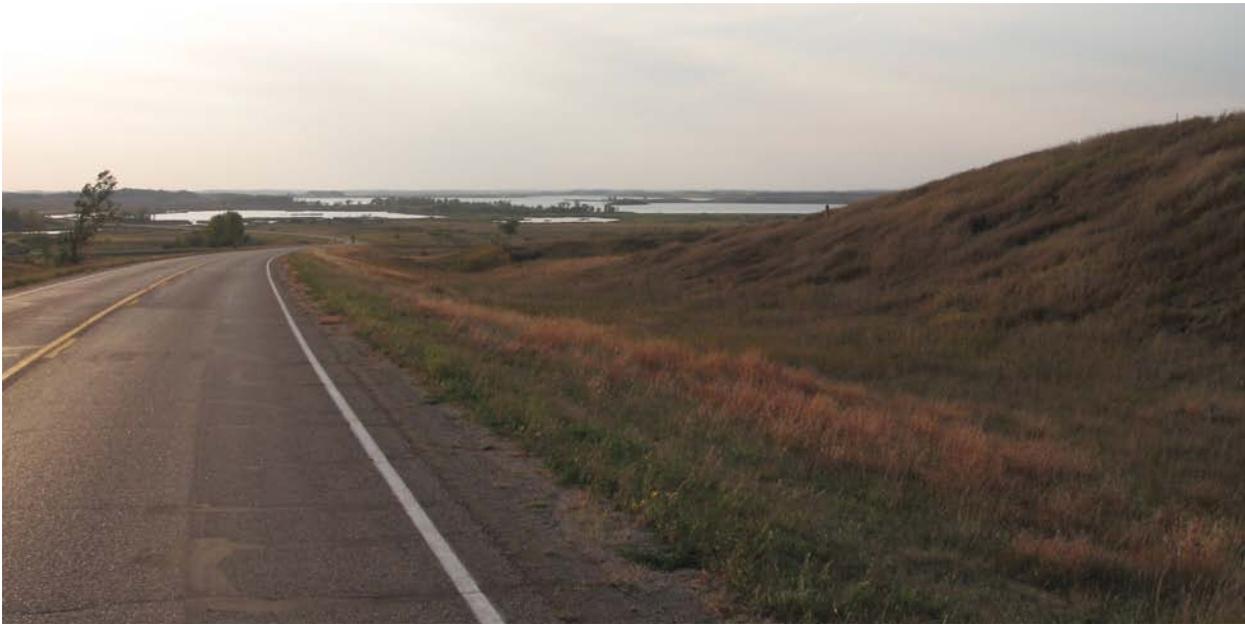
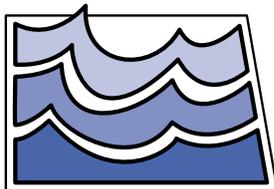


Review of Water Quality Assessments for the North Dakota National Guard Camp Grafton (South Unit), Eddy County, North Dakota: 1986 through 2006



By
W. M. Schuh

Water Resources Investigation No. 40
North Dakota State Water Commission
Dale L. Frink, State Engineer



Prepared by the
North Dakota State Water Commission
in cooperation with the
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LIST OF COMMONLY USED ABBREVIATIONS AND ACRONYMS

bls	Below land surface
CGS	Camp Grafton South Unit facility
CPQL	Combat Pistol Qualification Range
DNT	Dinitrotoluene; an explosive chemical
DOD	U.S. Department of Defense
DRO	Diesel-range organics
DWEL	"protective of adverse, non-cancer health effects, that assumes all of the contaminant is from a drinking water source"
EPA-MCL	The U.S. Environmental Agency Maximum Contaminant Level. Maximum permissible level of contaminant in water which is delivered to any user of a public water system
EPA-MCL ^N	The proposed new EPA-MCL for arsenic (10 mg/L), compared with the previous standard of 50 mg/L
GCEM	General C. Emerson Murray Ranges
GRO/BTEX	Gasoline-range organics / benzene, toluene, ethyl-benzene, xylene
HAL	Health Advisory Level
HMX	Cyclotetramethylene-tetranitramine; an explosive chemical
MDL	Laboratory minimum detection level
MICLIC	Mine Clearing Line Charge
MPMG	Multiple Purpose Machine-Gun range
MRF	Modified Record Fire range
RDX	Cyclotrimethylenetrinitramine; an explosive chemical
RID	"Reference Dose:" an estimate of daily exposure to the human population that is likely to be non-deleterious to human health over a lifetime

LIST OF ACRONYMS (Continued)

SAR	Sodium-adsorption ratio
SI	Screened interval for well screen
TDS	Total Dissolved Solids
TNT	Trinitrotoluene; an explosive chemical
TPH	Total petroleum hydrocarbons
USEPA	U.S. Environmental Protection Agency
ZERO	Sighting range



Photo 1. North Spring



Photo 2. Purging a well by compressed air lift.



Photo 3. Purging a well by suction lift using a screw pump.



Photo 4. Purging a well using a gas squeeze pump.

EXECUTIVE SUMMARY

Ground water of the Cherry Lake aquifer and surface water (Lake Coe, South Washington Lake, two springs and a reservoir) on the CGS reservation have been monitored for general chemistry and trace elements since 1986, and for munitions and explosives residues, petroleum residues, and pesticide residues since 1993. Sample analytes have been targeted to specific use areas of CGS. Comprehensive sampling is conducted at five-year intervals.

Shallow ground water and springs within the CGS reservation are characterized by a low TDS, calcium bicarbonate type chemical composition. Deeper ground water and lakes are characterized by higher concentrations of sodium sulfate and TDS, likely through the proximity and influence of the underlying Pierre Shale, and some evaporative concentration in the lakes. There is no indication of increasing salinity or other signs of ground-water quality degradation with respect to general chemistry, that could be attributed to CGS use and management.

Nitrate concentrations on the CGS reservation are highest in shallow ground water (less than 100 feet below land surface), and negligible below that depth. Of all ground-water samples analyzed during the period of measurement, more than 95% of each well set are below concentrations common to "natural" conditions without anthropogenic influence, and all but one sample are below the EPA-MCL. The one high-concentration detection was in a very shallow well, screened at the water table, in a pasture with a lot of cattle and considerable manure on the surface, and near a wetland. A deeper well on the same site had low nitrate, so nitrate was concentrated and stratified near the surface. These data indicate that there is no evidence of ground-water or surface-water deterioration with respect to nitrate at CGS due to management practices, and that measured ground-water concentrations conform to very high standards with respect to nitrate management.

Trace elements, other than arsenic, have been consistently low in ground water and surface water of the CGS reservation. There was one detection of lead at 2 µg/L in the reservoir west of the GCEM ranges in 2001. No concentration of lead is acceptable for tap water. However, action levels of 15 µg/L have been set for remediation. In 2001 lead concentrations briefly reached 2 µg/L. But as of 2006 lead was non detectable in the reservoir. There have been no confirmed indications of ground-water or surface-water degradation with respect to trace elements at CGS. It is cautioned that many trace metals can be mobilized more effectively at lower pH values, and that any management practice

that might cause acidification of the soil might enhance mobilization of trace metals. Acidification processes might include addition of large quantities of elemental sulfur, ammonium or urea. It is difficult to conceive of a reason for applying such chemicals, but the caution is given for the sake of awareness.

Arsenic is common in CGS ground water and surface water. More than 20% of CGS ground-water samples have arsenic concentrations above the EPA-MCL. These percentages are approximately double those of the Northwest Provenance glacial drift from which CGS lands are formed. Arsenic sources are natural, and are likely derived from oxidation of arseno-pyrite in the underlying shale, and in the shale-derived glacial materials. Arsenic tends to be higher in deeper wells, and elevated concentrations appear to be associated with reducing conditions and the mobilization of iron, which removes sorption surfaces that normally sequester arsenic. Highest ground-water arsenic concentrations are in the Colvin Creek subbasin, east of the GCEM ranges.

Arsenic in the two lakes (Lake Coe, and South Washington Lake) is high, and generally above the EPA-MCL. High arsenic concentrations in both lakes appear to be affected to a great degree by high pH, which results from algal photosynthesis. Concentrations in Lake Coe fluctuate within a range of 10 to 26 $\mu\text{g/L}$, and usually above 16 $\mu\text{g/L}$, and may be governed by fluctuating pH. Highest concentrations of all water sources were in South Washington Lake, which peaked at 71 $\mu\text{g/L}$ in 1993 (7 times the EPA-MCL), but which declined to as low as 16.7 $\mu\text{g/L}$ in 2006. The decreasing concentrations are systematic and appear to be affected somewhat by pH changes, and also by dilution from ground water following large rains in the 1990s. They may be expected to rise again during drier climatic periods.

High arsenic in CGS reservation waters are all of natural origin, and precede military use of the reservation. High arsenic concentrations are also found in similar settings near, but off of, the reservation. There are no indications of degradation of surface or ground waters with respect to arsenic, caused by management or use of the reservation. Two management measures have been undertaken in relation to elevated arsenic: (1) CGS has contracted for treated drinking water rather than use of local wells; and (2) CGS has developed procedures, acceptable to the North Dakota Health Department, for disposal of filtrate (containing concentrated arsenic) following water purification training.

Munitions and explosives residues have been detected in small quantities in ground water used to monitor the demolitions and munitions ranges. Acetone, methylene chloride and toluene were detected in several water samples in 2001, but it seemed likely that they were introduced by sample contamination, possibly in the laboratory. In 2006

toluene was again detected in one shallow well, indicating its probable occasional presence in shallow ground water. In 2001 carbon disulfide was detected in several ground-water and surface-water samples and seemed authentic. Benzoic acid was detected in the reservoir and in Lake Coe. Di-n-butylphthalate was detected in one ground-water sample (Site 2 in the Colvin Creek subbasin) and in Lake Coe. Except for benzene and toluene, none of these were detected in the 2006 sampling. In 2006 benzene and toluene were detected in one shallow well south of the demolitions range. Detections were below levels of toxicological concern, and were not present in the deeper well at the same site. Because of repeated detections (2001 and 2006), benzene and toluene are likely authentic and periodically present at trace concentrations. The repeated presence of benzene and toluene, and the single detection of other explosives residues, indicate that small amounts are reaching ground water. However, all detections were below EPA-MCL, and most were lower by several orders of magnitude. Most were also detected only once. None were detected more than once in the same source location. There is, therefore, evidence of munitions and explosives residues reaching ground water and surface waters sporadically and in very small quantities. There is no evidence of a persistent or growing problem that would likely reach levels of toxicological concern.

Petroleum residues as DRO (diesel-range organics) were first detected in 2001 in ground water at the Engineering Training Site (Site 9), in buck hollow (Site 8), and in wells northeast of South Washington Lake. Detections were below lab MDL (minimum detection levels) and were therefore considered "qualitative." They were also several thousand times below levels of toxicological concern. DRO were not sampled in 2006. GRO (gasoline-range organics)/BTEX (benzene, toluene, ethylbenzene, xylene) samples indicated no detections in all sample events before 2006. In 2006 there were low-level detections of benzene and toluene in one shallow well. These were attributed to demolitions residues rather than to petroleum spills. There have been no indications in any of the sample assays that management and use of the CGS reservation is causing deterioration of ground water or surface water through contamination with petroleum products.

Since 1993 pesticide analyses have been performed for various herbicides and insecticides. Picloram, 2,4-D and malathion have been assayed in all years. Dimethoate was assayed only in 1993. Chlorpyrifos was assayed in 2001, and bromoxynil and prometone were assayed in 2001 and 2006. There have been no detections of any of the insecticides (malathion, dimethoate, chlorpyrifos) in any of the sample sets. There have been no detections of 2,4-D and prometone in any of the sample sets. Picloram was detected consistently in South Washington Lake and in Lake Coe at barely detectable

concentrations (0.1 to 0.2 µg/L) during the 1993, 1996 and other supplemental assays during the 1990s. Beginning in 2001 picloram was no longer detectable in the lakes. Again, in 2006 there were no detections. All concentrations were several orders of magnitude below EPA-MCLs. It was concluded that wet conditions during the 1990s contributed to runoff of picloram into the lakes during that time, and that contemporary influx seems to have decreased. There was one low-level (2.3 µg/L) detection of picloram in the North Spring water sample collected in 2006. This was likely caused by local spraying for leafy spurge. In general, as of 2006 there is no indication of degradation of CGS ground water or surface water due to use or management of pesticides.

There is no evidence to indicate that CGS land use and management have caused any substantial degradation of local water resources during the period of operation to date.

RECOMMENDATIONS

There are no indications of significant degradation of the CGS facility from management and use. The following summary recommendations are made.

1. Be aware of high arsenic concentrations, and continue to practice cautionary measures in reverse-osmosis water purification exercises on the CGS facility. Follow Health Department guidelines. Return purified water with the filtrate to the original source to maintain net concentration.
2. Continue the current grazing management plan. It is successful with respect to ground-water contamination with nitrate and other nutrients.
3. Avoid any practices that could enhance acidification of firing range areas where heavy metals might be present. These practices would include the addition of any acidifying materials, like anhydrous ammonia, urea, or elemental sulfur.
4. Be aware of sporadic traces of organic solvents in ground water in the demolitions range areas. While all current indications are non-threatening, these should be resampled every five years to assure that accumulations are not occurring.
5. Pesticide residues are rare and of negligible concern. Trace detections of picloram have decreased in area lakes over the last six years, and have been non-detectable. Continue the same management practices with respect to herbicide and insecticide use.

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APPENDIX A: LETTERS OF CORRESPONDENCE (INCLUDING E-MAIL)

Includes correspondence with LTC (2001) David Anderson on composition and use of munitions and explosives on the CGS facility; e-mail correspondence with Louise Parker on interpretation of residue detections; e-mail correspondence with Bob Benson on the toxicology of carbon disulfide; correspondence with DATACHEM laboratories over 2006 sample holding times.

APPENDIX B: MUNITIONS AND EXPLOSIVES RESIDUES

Includes 2006 laboratory results, case narratives, method descriptions, and QA/QC for munitions and explosives residues assays (EPA Methods 8260B, 8270C, 8330 and 8332).

APPENDIX C: MUNITIONS AND EXPLOSIVES RESIDUES

Includes 2006 laboratory results, chain of custody, case narratives, method descriptions, and QA/QC for residues of herbicides, insecticides and petroleum.

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INTRODUCTION

In 1992 a water quality monitoring plan for the North Dakota National Guard Camp Grafton South (CGS) facility in Eddy County, North Dakota, was submitted to the North Dakota National Guard (Schuh 1992). The plan was designed to consider existing geologic and hydrologic information, current and future use patterns of the facility, objectives and goals for protection - including the sensitivity of resources to be protected, and the limitations of funding and resources available for implementing the plan. An attempt was also made to consider training objectives and resource conservation in a balanced manner, and to maximize the information obtainable from limited field data.

The initial sampling plan was laid out in two phases. Phase I consisted of the selection of appropriate surface-water sites and the construction of appropriate observation wells for monitoring munitions and explosives residues, petroleum residues, and pesticide contamination. Phase I also included baseline water samples for appropriate contaminants and for basic water quality and trace elements on each of the selected sites. Phase I was implemented in 1992 and 1993. In 1994 a report was published describing the monitoring well network, the water sample collection plan, and results of the baseline samples collected for each of the potential contaminant groups sampled at CGS (Schuh 1994). Included in the 1994 publication were:

1. Well and sampling locations;
2. Well completion information, including lithologies, materials, construction methods, development, and cleaning procedures;
3. Sampling procedures, including well purging methods, sampling methods, and sample-handling methods and procedures;
4. Baseline data for basic water chemistry and trace elements from each newly constructed sample well;
5. Data for water quality and trace elements measured in wells constructed before Phase I; and
6. A brief analysis and interpretation of results.

Phase II consisted of a plan for ongoing periodic assessment of water quality at CGS. The provisions of the initial Phase II plan were designed to be flexible and to allow for modification as understanding of area hydrology and its effect on water quality increases. Ongoing assessments of CGS water quality were to be accomplished through periodic (three- to six-year interval) reevaluation of use of CGS and potential water contamination resulting from use patterns. We have since adopted a five-year interval for targeted sampling, and a 10-year interval for full comprehensive sampling of all wells.

CLIMATE, GEOLOGY, AND HYDROLOGY

CGS is located in Eddy County in east central North Dakota (Figure 2). The facility occupies portions of four townships, Lake Washington (149-063), Colvin (149-062), Paradise (148-062), and Cherry Lake (148-062). CGS lands are approximately bisected by State Highway 15, which runs east-west.

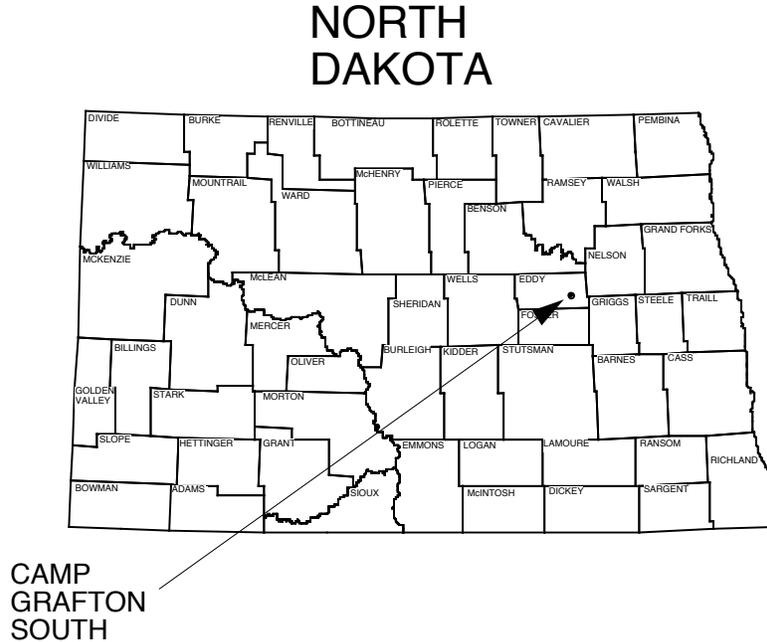


Figure 2. Location of Camp Grafton (South Unit) training reservation.

Climate

The climate of Eddy County North Dakota is continental, having cold winters and hot summers. The onset of cold weather usually begins in early November. The frost usually leaves the soil in mid April. The moisture regime is borderline between semi-arid and sub-humid, with a long-term average precipitation of about 48 cm (19 inches).

Geologic and Hydrologic Setting

The general geological setting of Camp Grafton South has been described by Bluemle (1965), and by Comeskey (1989). Local geology and its relation to water resources on the CGS facility and the sampling plan were discussed in detail by Schuh (1994). In general, the surficial geology of the CGS facility consists of uplands which are composed of glacial drift which comprise subunits of the McHenry End Moraine, and

lowlands, or drainage basins, which drain toward the Sheyenne River about five miles north of CGS. A simple schematic of the relationship between moraine uplands and lowland basins is shown on Figure 3.

There are three distinct subunits of the McHenry End Moraine on the CGS facility (called moraine units 1, 2, and 3 in this report). The largest subunit (moraine unit 1) extends from the southern through the northern boundary on the east side of the facility, and separates the drainage into two principal basins. On the east side, all drainage flows northeastward toward the Sheyenne River through the Colvin Creek basin. On the west side of moraine unit 1, all drainage flows toward the Sheyenne River through the Lake Coe and South Washington Lake basin. The other two subunits of the McHenry End Moraine on the CGS facility (moraine units 2 and 3) are oriented north to south, and are located entirely in the southern half of the facility. Neither extends north of Hwy 15. These two moraine subunits serve to divide the southern portion of the Lake Coe and South Washington Lake basin into three subbasins. Most drainage through the Lake Coe and South Washington Lake basin originates from the eastern two of these subbasins. Between moraine unit 1 and moraine unit 2 water flows northward to Lake Coe through a series of small lakes and littoral areas. Between moraine unit 2 and moraine unit 3, water flows northward to Lake Coe through North and South Twin Lakes. Drainage from uplands to lowlands occurs through a series of coulees.

The principal ground-water resource underlying the CGS facility is the Cherry Lake aquifer. Trapp (1966B) and Comeskey (1989) described Cherry Lake aquifer system as composed of two confined units, separated by 20 to 40 feet of glacial till. The surface of the deepest (and least areally extensive) unit is located approximately between 126 and 182 feet below land surface. In addition to the two confined units of the Cherry Lake aquifer, Comeskey (1989) identified a surficial unconfined unit. The surficial unit consists of a sand mantle overlying the glacial till confining the lower units. In many areas, however, this mantle is not saturated. Comeskey also described the presence of some coarse deposits within the glacial drift that are apparently locally isolated and not connected with the larger aquifer units.

The lake system has been described as an exposure of the water table, and has been used to describe a general regional flow system northward to the Sheyenne River. Water-table maps (Trapp 1966A), which may or may not be related to piezometric levels in the underlying aquifers, indicate that overall regional ground-water flow at the water table is toward the Sheyenne River through the Washington lakes chain, and through the Colvin Creek lowland.

There is a very slight water table gradient southeastward toward the Johnson Lake aquifer, and some water movement may occur in that direction. Flow from Cherry Lake is indicated to be southward toward the Juanita Lake aquifer and the James River.

Generally, however, CGS land is too far north to affect the southward drainage system. Also water-table gradients toward the Johnson Lake aquifer are small. All indications from current information are that most ground water and surface water moves on a regional scale northward to the Sheyenne River through the Lake Coe /South Washington Lake chain (and subunits), and through the Colvin Creek basin.

Readers are also referred to Comeskey (1989) and Trapp (1966B) for in-depth studies of the Cherry Lake aquifer. In addition, Schuh (1994) described the relationship between local geology and hydrology and land use practices and potential risk of ground-water contamination.

SAMPLE PLAN DESIGN

Objectives And Priorities

Objectives and priorities for the CGS water quality sampling plan were discussed in detail by Schuh (1994). In brief, priorities in designing the plan were:

Priority 1 - protection of ground-water and surface-water exterior to CGS. The primary focus is on detection of contaminants migrating to regional, rather than local, flow systems, before they can substantially effect the regional resource.

Priority 2 - protection of the wildlife, such as migratory waterfowl, that inhabit the lakes and wetlands of CGS.

Priority 3 - protection of the local fresh-water supply.

Monitoring Plan Criteria

Factors considered in the water quality monitoring plan included: (1) The nature of local and regional surface drainage; (2) The nature of local and regional ground-water flow; (3) The disposition and use of water by others near the military reservation; (4) The sensitivity of specific water uses on and near the reservation to specific contaminants; and (5) Land use patterns on the military reservation. Consideration was also given to the desirability of having all major use areas of the reserve given sample representation

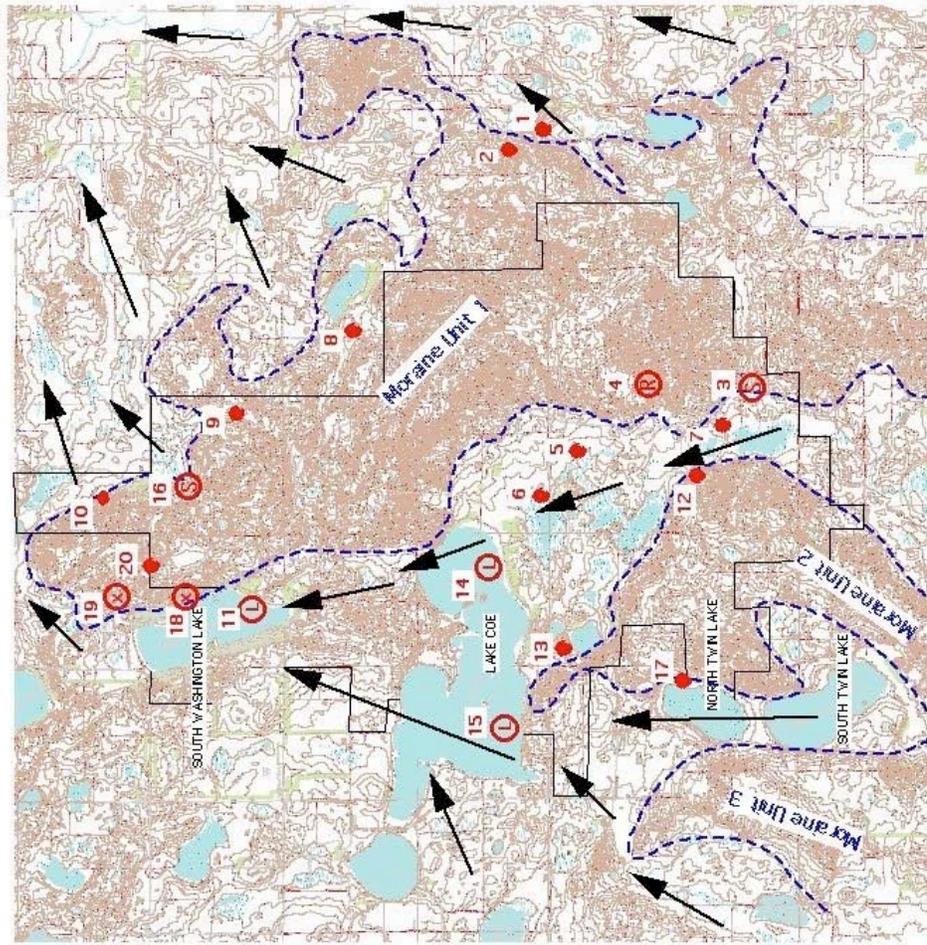


Figure 3. Location of WS-2 sample-well sites and surface-water sampling sites in relation to moraine subunits, and direction of ground-water flow at the water table.

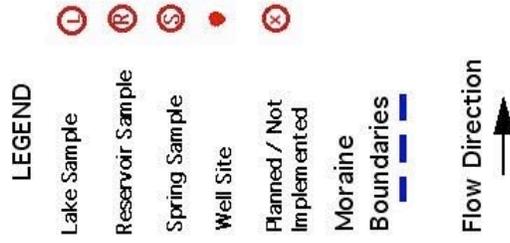


Figure 3. Location of WS-2 sample-well sites and surface-water sampling sites in relation to moraine subunits, and direction of ground-water flow.

Water samples are collected from three basic sources on CGS. The three sample sources include two sets of sampling and monitoring wells, and a number of surface water sources that include two lakes, two springs, and one reservoir (Fig. 3).

Well Set 1 (WS-1)

The first well set (labeled Well Set 1, or WS-1) was constructed by driller Gary Calheim under direction of Comeskey (1989), in mapping the Cherry Lake aquifer on CGS. This well set consists of 25 wells placed in nests of one to four wells at a total of 12 sites. Well placement was non biased with respect to CGS use patterns, geology, and topography. Wells were placed at approximately evenly spaced intervals along two transects, one north to south, and the other east to west. Well construction was of 2-inch and 1.25-inch diameter polyvinyl chloride (PVC) casing, and joints were bonded using solvent-weld cement containing methyl-ethyl ketone. WS-1 wells are protected from cattle by barbed wire fences, but they do not have a protective cover (PC), nor are they locked and secured. Placement of these wells limits their usefulness for sampling contaminants from targeted land uses. Construction methods and security limitations also limit their usefulness for sampling organic contaminants (Parker et al. 1990, Sykes et al. 1986). However, both construction and placement methods render the WS-1 wells suited for sampling background inorganic water chemistry. In addition, these wells have the longest sampling record for basic water chemistry (dating to 1987). WS-1 wells are used for ongoing sampling of basic water chemistry and for piezometric readings. They may also be used for supplemental sampling of organic contaminants if needed for investigation of specific problems. Locations of WS-1 wells are summarized on Table 1, and illustrated on Figure 4. A description of the hydrologic setting of well nests, lithologic logs for WS-1 wells, and initial water chemistry data from samples collected in 1987 are in Comeskey (1989). A list of locations and wells for the 1996 sampling is shown on Table 2.

Well Set 2 (WS-2)

The second well set (labeled Well Set 2, or WS-2) was constructed by driller Gary Calheim, under direction of Schuh (1994). This set consists of 23 wells placed in nests of one to three, at 12 sites. WS-2 sites were selected for coverage of drainage areas from areas of specific use within the CGS facility.

The WS-2 wells were placed primarily in the lower reaches of coulees feeding into the Colvin Creek and Lake Coe and South Washington Lake basins and their tributaries. The mouths of coulees were selected for two reasons: (1) The coulees are the major conduits of surface water runoff. For this reason, they are the logical points of

Table 1. List and locations of 1993 proposed sampling sites for the CGS training facility as presented in the initial plan proposal. L indicates a lake sampling site, R indicates a reservoir sampling site, S indicates a natural spring sampling site, and W indicates a well sampling site. WS-1 designates wells placed by Comeskey (1989). WS-2 designates wells placed by Schuh (1994). All WS well nests were to be sampled only in the shallowest well.

Well Set	Site	SWC Well No.	Township N	Range W	Section	Location	water source	Mun.	TPH	picloram	chlor-pyrifos	Basic	Trace
WS-1		12024A	148	63	1	CBBC1	W					x	x
WS-1		12024B	148	63	1	CBBC2	W					x	x
WS-1		12024C	148	63	1	CBBC3	W					x	x
WS-1		12020A	149	63	14	DACD1	W					x	x
WS-1		12020B	148	63	14	DACD2	W					x	x
WS-1		12020C	148	63	14	DACD3	W					x	x
WS-1		12019A	149	63	23	ADBB1	W					x	x
WS-1		12019B	149	63	23	ADBB2	W					x	x
WS-1		12019C	149	63	23	ADBB3	W					x	x
WS-1		12017A	149	63	25	DBBC1	W					x	x
WS-1		12017B	149	63	25	DBBC2	W					x	x
WS-1		12017C	149	63	25	DBBC3	W					x	x
WS-1		12017D	149	63	25	DBBB4	W					x	x
WS-1		12025	149	63	26	DCA	W					x	x
WS-1		12012	149	63	27	DDDC1	W					x	x
WS-1		12015B	149	63	31	ABBC2	W					x	x
WS-1		12015C	149	63	31	ABBC3	W					x	x
WS-1		12026A	149	63	34	BBB1	W					x	x
WS-1		12026B	149	63	34	BBB2	W					x	x
WS-1		12011B	149	63	35	ABBD2	W					x	x
WS-1		12014A	149	63	36	AACB1	W					x	x
WS-1		12014B	149	63	36	AACB2	W					x	x
WS-1		12014C	149	63	36	AACB3	W					x	x
WS-1		12014D	149	63	36	AACB4	W					x	x
WS-1		12023A	149	63	36	DDBBC1	W					x	x
WS-1		12023B	149	63	36	DDBBC2	W					x	x
WS-1		12023C	149	63	36	DDBC3	W					x	x
WS-1		12021A	149	63	13	BAAB1	W					x	x
WS-2	1	13104	149	62	28	CCC2	W	x				x	x
WS-2	2	13105	149	62	29	DAD	W	x		x		x	x
WS-2	3	Spring	148	63	2	DA	S	x				x	x
WS-2	4	Reservoir	149	62	31	C	R	x				x	x
WS-2	5	13098	149	63	36	ACA2	W	x				x	x
WS-2	6	13102	149	63	25	CDC2	W	x		x		x	x
WS-2	7	13087	148	63	2	ACA2	W	x				x	x
WS-2	8	13091	149	62	19	DBD2	W		x	x		x	x
WS-2	9	13089	149	63	13	DAA2	W		x	x		x	x
WS-2	10	13093	149	63	12	CAC2	W		x	x		x	x
WS-2	11	S W Lake	149	63	14	CAC	L		x	x		x	x
WS-2	12	13085	148	63	2	BABC2	W		x	x		x	x
WS-2	13	13100	149	63	35	BCBA2	W		x	x		x	x
WS-2	14	Lake Coe	149	63	26	ADD	L		x	x		x	x
WS-2	15	Lake Coe	149	63	27	DDB	L		x	x		x	x
WS-2	16	Spring	149	63	13	BDA	S			x		x	x
WS-2	17	13096	148	63	4	ABA2	W			x		x	x
WS-2	18a		149	63	14	BAA	S			x		x	x
WS-2	18b)		149	63	14	BAA	S			x		x	x
WS-2	18c		149	63	14	BAA	S			x		x	x
WS-2	19		148	63	11	DDC	W			x		x	x
WS-2	20	13094	149	63	14	AAB	W			x		x	x

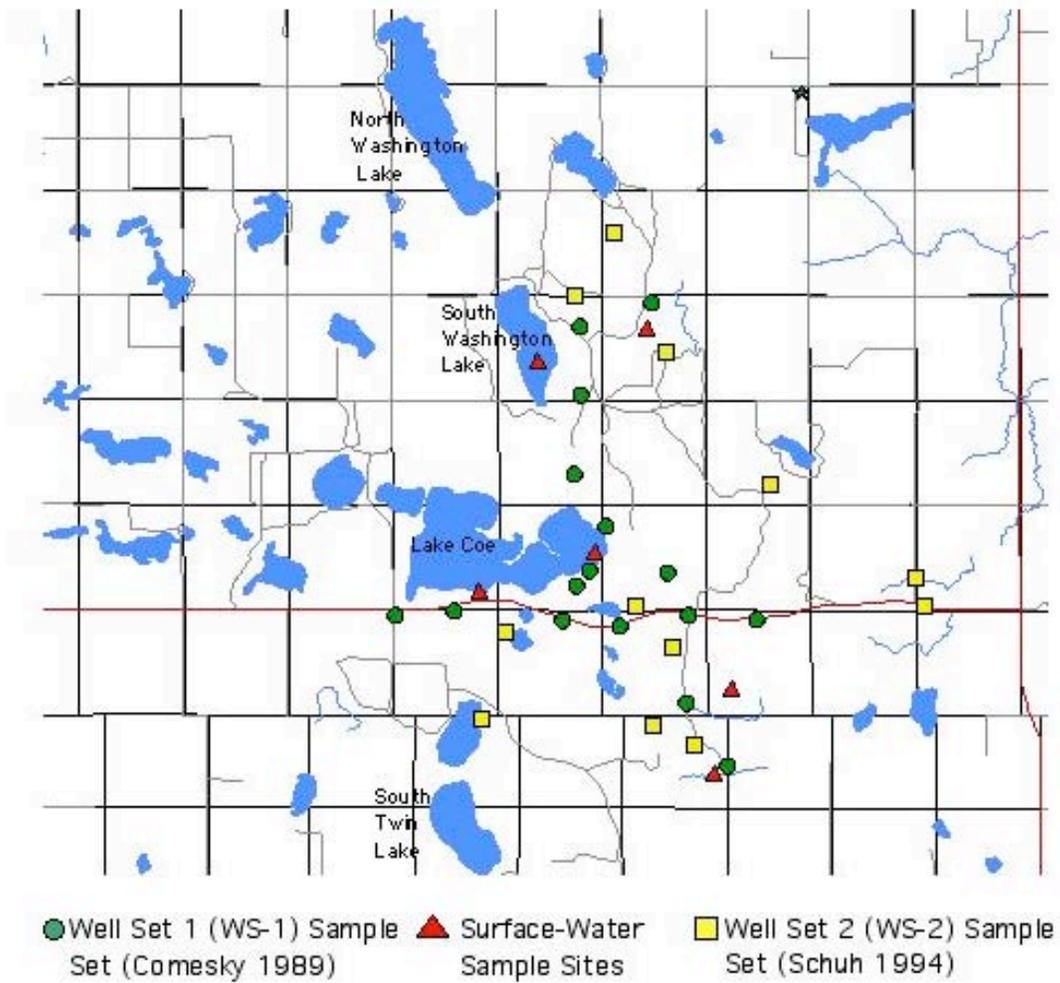


Figure 4. Location of ground-water and surface-water sampling sites used for monitoring water quality on Camp Grafton (South Unit) lands.

concentration for contaminants draining from higher elevations. (2) Coulees are frequently the locations of springs, where till and overlying coarse units outcrop along the cuts or walls of the coulees. In some cases, seepage faces are extensive and relatively permanent. In others, they may flow only some of the time during wet years, or sporadically following particularly large rainfall events. When such springs are flowing, or when ground water is nearer the surface so that higher evaporation occurs, ground water discharges into the coulees. This means that local ground water in the vicinity of springs should tend to preferentially receive both surface-water and ground-water contaminant plumes from the upland recharge sites. Such advanced monitoring points should provide the highest probability of early detection and protection for both the regional ground-water flow system and the lake and littoral areas.

Well placement was also based on specific land use within the watershed. Specific targeted uses included weapons and demolitions ranges, vehicle staging areas, bivouac areas, and pest control areas. To accommodate sampling for organic contaminants, well construction consisted of 2-inch PVC casing, with joints fastened using stainless steel screws, rather than solvent weld cement (Parker et al. 1990, Schuh et al. 1997, Sykes et al. 1986). Well annuli above the well-screen were sealed with high solids bentonite. Each well was secured by a 6-inch PVC protective cover (PC) with concrete at the base, and by a locking aluminum cap.

Placement, construction, and security make WS-2 wells most appropriate for sampling organic contaminants, and site-specific contaminants from munitions, pesticides, and petroleum spills on weapons and demolitions ranges, vehicular staging areas, bivouac sites, and pest control areas. Specific uses and locations for each well set were described in detail by Schuh (1994). A summary of samples collected from each well site in 1996 is shown on Table 2. A summary of samples collected from each well site in 2001 is shown on Table 3. Water-level measurements were not made in these wells because of the desirability of avoiding surface contamination. WS-2 wells were sampled after their construction to provide baseline data in basic water chemistry and trace elements. The deeper WS-2 wells are not routinely sampled for general chemistry and trace elements. These samples are routinely collected from WS-1 wells. WS-2 wells may be used for supplementary samples for basic water chemistry if needed for a specific investigative purpose. They are also sampled at all depths in periodic comprehensive sample sets. Locations of WS-2 wells are summarized on Table 2, and illustrated on Figure 4. Detailed hydrologic setting of well nests, lithologic logs for WS-2 wells, and initial water chemistry data from samples collected in 1992 and 1993 are described in Schuh (1994).

Table 2. List and locations of 1996 proposed sampling sites for the CGS training facility as presented in the initial plan proposal. L indicates a lake sampling site, R indicates a reservoir sampling site, S indicates a natural spring sampling site, and W indicates a well sampling site. WS-1 designates wells placed by Comeskey (1989). WS-2 designates wells placed by Schuh (1994). All WS well nests were to be sampled only in the shallowest well.

Well Set	Site	SWC Well No.	Township	Range W	Section	Location	Water	Mun.	Petrol	picolram	chlor-pyrifos	Basic	Trace
			N				Source						
WS-1		12024A	148	63	1	CBBC1	W					x	x
WS-1		12024B	148	63	1	CBBC2	W					x	x
WS-1		12024C	148	63	1	CBBC3	W					x	x
WS-1		12020A	149	63	14	DACD1	W					x	x
WS-1		12020B	148	63	14	DACD2	W					x	x
WS-1		12020C	148	63	14	DACD3	W					x	x
WS-1		12019A	149	63	23	ADBB1	W					x	x
WS-1		12019B	149	63	23	ADBB2	W					x	x
WS-1		12019C	149	63	23	ADBB3	W					x	x
WS-1		12017A	149	63	25	DBBC1	W					x	x
WS-1		12017B	149	63	25	DBBC2	W					x	x
WS-1		12017C	149	63	25	DBBC3	W					x	x
WS-1		12017D	149	63	25	DBBB4	W					x	x
WS-1		12025	149	63	26	DCA	W					x	x
WS-1		12012	149	63	27	DDDC1	W					x	x
WS-1		12015B	149	63	31	ABBC2	W					x	x
WS-1		12015C	149	63	31	ABBC3	W					x	x
WS-1		12026A	149	63	34	BBB1	W					x	x
WS-1		12026B	149	63	34	BBB2	W					x	x
WS-1		12011B	149	63	35	ABBD2	W					x	x
WS-1		12014A	149	63	36	AACB1	W					x	x
WS-1		12014B	149	63	36	AACB2	W					x	x
WS-1		12014C	149	63	36	AACB3	W					x	x
WS-1		12014D	149	63	36	AACB4	W					x	x
WS-1		12023A	149	63	36	DDBBC1	W					x	x
WS-1		12023B	149	63	36	DDBBC2	W					x	x
WS-1		12023C	149	63	36	DDBC3	W					x	x
WS-1		12021A	149	63	13	BAAB1	W					x	x
WS-2	1	13103	149	62	28	CCC1	W	x				x	x
WS-2	1	13104	149	62	28	CCC2	W	x				x	x
WS-2	2	13105	149	62	29	DAD	W	x				x	x
	3	Spring	148	63	2	DA	S	x				x	x
	4	Reservoir	149	62	31	C	R	x				x	x
WS-2	5	13097	149	63	36	ACA1	W	x				x	x
WS-2	5	13098	149	63	36	ACA2	W	x				x	x
WS-2	6	13101	149	63	25	CDC1	W	x				x	x
WS-2	6	13102	149	63	25	CDC2	W	x				x	x
WS-2	7	13086	148	63	2	ACA1	W	x				x	x
WS-2	7	13087	148	63	2	ACA2	W	x				x	x
WS-2	8	13090	149	62	19	DBD1	W		x	x	x		
WS-2	8	13091	149	62	19	DBD2	W						
WS-2	8	13106	149	62	19	DBD3	W		x	x	x		
WS-2	9	13088	149	63	13	DAA1	W		x	x	x		
WS-2	9	13089	149	63	13	DAA2	W		x	x	x		
WS-2	10	13092	149	63	12	CAC1	W		x	x	x		
WS-2	10	13093	149	63	12	CAC2	W		x	x	x		
	11	S W Lake	149	63	14	CAC	L		x	x	x		
WS-2	12	13084	148	63	2	BABC1	W						
WS-2	12	13085	148	63	2	BABC2	W						
WS-2	13)	13099	149	63	35	BCBA1	W			x			
WS-2	13	13100	149	63	35	BCBA2	W			x			
	14	Lake Coe	149	63	26	ADD	L		x	x	x		
	15	Lake Coe	149	63	27	DDB	L		x	x	x		
	16	Spring	149	63	13	BDA	S			x	x		
WS-2	17	13095	148	63	4	ABA1	W			x			
WS-2	17	13096	148	63	4	ABA2	W			x			
WS-2	20	13094	149	63	14	AAB	W						

Table 3. List and locations of 2001 proposed sampling sites for the CGS training facility as presented in the initial plan proposal. L indicates a lake sampling site, R indicates a reservoir sampling site, S indicates a natural spring sampling site, and W indicates a well sampling site. WS-1 designates wells placed by Comeskey (1989). WS-2 designates wells placed by Schuh (1994). All WS well nests were to be sampled only in the shallowest well.

Well Set	Site	SWC Well No.	Township N	Range W	Section	Location	Water Source	Mun. + Expl.	Petrol (GRO / DRO)	prometon	picloram + 2,4-D	malathion	Basic	Trace
WS-1		12024A	148	63	1	CBBC1	W							
WS-1		12024B	148	63	1	CBBC2	W							
WS-1		12024C	148	63	1	CBBC3	W						x	x
WS-1		12020A	149	63	14	DACD1	W							
WS-1		12020B	149	63	14	DACD2	W							
WS-1		12020C	149	63	14	DACD3	W						x	x
WS-1		12019A	149	63	23	ADBB1	W							
WS-1		12019B	149	63	23	ADBB2	W							
WS-1		12019C	149	63	23	ADBB3	W						x	x
WS-1		12017A	149	63	25	DBBC1	W							
WS-1		12017B	149	63	25	DBBC2	W							
WS-1		12017C	149	63	25	DBBC3	W							
WS-1		12017D	149	63	25	DBBB4	W						x	x
WS-1		12025	149	63	26	DCA	W						x	x
WS-1		12012	149	63	27	DDDC1	W							
WS-1		12015B	149	62	31	ABBC2	W							
WS-1		12015C	149	62	31	ABBC3	W						x	x
WS-1		12026A	149	63	34	BBB1	W							
WS-1		12026B	149	63	34	BBB2	W							
WS-1		12011B	149	63	35	ABBD2	W						x	x
WS-1		12014A	149	63	36	AACB1	W							
WS-1		12014B	149	63	36	AACB2	W							
WS-1		12014C	149	63	36	AACB3	W							
WS-1		12014D	149	63	36	AACB4	W						x	x
WS-1		12023A	149	63	36	DDBBC	W							
						1								
WS-1		12023B	149	63	36	DDBBC	W							
						2								
WS-1		12023C	149	63	36	DDBC3	W						x	x
WS-1		12021A	149	63	13	BAAB1	W						x	x
WS-2	1	13103	149	62	28	CCC1	W	x	x	x			x	x
WS-2	1	13104	149	62	28	CCC2	W	x	x	x			x	x
WS-2	2	13105	149	62	29	DAD	W	x					x	x
WS-2	3	Spring	148	63	2	DA	S	x					x	x
WS-2	4	Reservoir	149	62	31	C	R	x	x	x			x	x
WS-2	5	13097	149	63	36	ACA1	W	x		x			x	x
WS-2	5	13098	149	63	36	ACA2	W	x	x	x			x	x
WS-2	6	13101	149	63	25	CDC1	W	x					x	x
WS-2	6	13102	149	63	25	CDC2	W	x			x		x	x
WS-2	7	13086	148	63	2	ACA1	W	x					x	x
WS-2	7	13087	148	63	2	ACA2	W	x	x		x		x	x
WS-2	8	13090	149	62	19	DBD1	W							
WS-2	8	13091	149	62	19	DBD2	W							
WS-2	8	13106	149	62	19	DBD3	W		x		x	x		
WS-2	9	13088	149	63	13	DAA1	W							
WS-2	9	13089	149	63	13	DAA2	W		x		x	x		
WS-2	10	13092	149	63	12	CAC1	W							
WS-2	10	13093	149	63	12	CAC2	W		x		x	x		
WS-2	11	SW Lake	149	63	14	CA	L		x		x	x	x	x
WS-2	12	13084	148	63	2	BABC1	W							
WS-2	12	13085	148	63	2	BABC2	W				x			
WS-2	13)	13099	149	63	35	BCBA1	W							
WS-2	13	13100	149	63	35	BCBA2	W			x				
WS-2	14	Lake Coe	149	63	26	ADD	L	x	x		x	x	x	x
WS-2	15	Lake Coe	149	63	27	DDB	L							
WS-2	16	Spring	149	63	13	BDA	S		x		x	x	x	x
WS-2	17	13095	148	63	4	ABA1	W							
WS-2	17	13096	148	63	4	ABA2	W				x			
WS-2	20	13094	149	63	14	AAB	W				x	x		

Surface-Water Sampling Sites

There are five surface-water sampling sites. These include two springs, two sampling sites on Lake Coe, one sampling site on South Washington Lake, and one sampling site on a small reservoir located west of the General C. Emerson Murray (GCEM) weapons ranges. The two spring sites, and the three lake sites were sampled with the WS-1 well set in 1986. The reservoir was added with the 1993 sampling because of its position for collecting runoff from the firing range complex (Area Descriptions R-1-3 through R-1-8 on Fig. 5). Surface-water sampling locations are summarized on Table 2, and shown on Figures 3 and 4.

CAMP GRAFTON SOUTH USE PATTERNS

Overview of CGS Chemical Use

In 2001 only the shallow WS-1 wells were sampled. Deeper wells in nests were not sampled. Sampling from the WS-2 wells was designed to monitor potential contamination based on CGS use patterns. In 2006 all WS-1 and WS-2 wells, and all surface-water sites were sampled for general chemistry and trace elements. Sample results in this report will be discussed under categories: 1. General chemistry; 2. Trace elements; 3. Munitions and explosives residues; 4. Petroleum residues; and 5. Pesticides. CGS use patterns affecting water quality can be summarized as follows.

1. Agricultural use: Most of the CGS facility is used for grazing during part of the year. The primary chemical parameter of concern would be nitrate. Nitrate is assayed with general chemistry for water samples from the WS-1 wells and selected WS-2 wells. Weed control (primarily leafy spurge) is practiced throughout CGS. Herbicides used are bromoxynil, picloram and 2,4-D. In addition, prometon is used for weed control around buildings and other infrastructure. In 2006 water samples were collected and analyzed for picloram, 2,4-d, bromoxynil and prometon.

2. Bivouac sites: Common bivouac site locations are shown on Figure 5. Potential contaminants on bivouac sites include gasoline and diesel fuel (from vehicles staged on site), and insecticides used for mosquito control (usually malathion or chlorpyrifos). In 2006 water samples were collected and analyzed for malathion. Previously, potential nitrate and bacterial contamination from latrines was possible. Current CGS practice (since about 1990) is to use portable lavatories, which should minimize future contamination. Tests for bivouac areas previously included TPH as gasoline and TPH as fuel oil (which includes diesel fuel). This has been replaced by GRO (gasoline range organics) and DRO (diesel range organics). In 2006 water samples were collected and analyzed only for GRO. Nitrates were assayed in samples on bivouac sites. Some trace metals were also assayed as possible indicators of contamination from spills of used motor oils. Locations of planned pesticide, petroleum, basic water chemistry, and trace element samples are on Table 4.

3. Munitions and explosives use sites: Most of these are located south of Hwy 15. The demolitions range, located at 149-063-36DC has been in operation since 1993. The M60 range located at 149-062-32B was completed in 1993. The M203 range was completed in 1992; and the pistol range was completed in 1995. The combined system of weapons ranges was completed in 1997, and has been named the General C. Emerson Murray range. A wide range of munitions and explosives residues were assayed in 2001, and again in 2006.

CAMP GRAFTON SOUTH

BIVOUAC SITES, TRAINING AREAS & RANGES

AREA NO.	AREA DESCRIPTION	GRID LOCATION
B-1-1	BIVOUAC SITE	NH 226558585
B-1-2	BIVOUAC SITE	NH 23108489
B-1-3	BIVOUAC SITE	NH 23308503
B-1-4	BIVOUAC SITE	NH 25556490
B-1-5	BIVOUAC SITE	NH 24958630
B-1-6	BIVOUAC SITE	NH 23368054
B-1-7	BIVOUAC SITE	NH 22908090
B-1-8	BIVOUAC SITE	NH 24148175
B-1-9	BIVOUAC SITE	NH 23758175
B-1-10	BIVOUAC SITE	NH 22908160
B-1-11	BIVOUAC SITE	NH 22158155
B-1-12	BIVOUAC SITE	NH 26558268
B-1-13	BIVOUAC SITE	NH 25057945
B-1-14	BIVOUAC SITE	NH 2535280
T-1-1	INDIRECT WEAPONS EMP.	VIC NH 245845
T-1-2	DIRECT FIRE ENPLACEMENT	VIC NH 257825
T-1-3	FANK DITCH/BARRIER AREA	NH 251825 TO 257817
T-1-4	TIMBER FRESTLE BRIDGE SITE	VIC NH 247827
T-1-5	BAILEY BRIDGE SITE	VIC NH 246824
T-1-6	ENGINEER EQUIP. TRNG. SITE	VIC NH 252858
T-1-7	M416 BRIDGE SITE, DRY (NORTH)	VIC NH 256845
T-1-8	M416 BRIDGE SITE, DRY (SOUTH)	VIC NH 146826
R-1-1	M203, AT 4, MK 19 RANGE	NH 25757995
R-1-2	DEMOLITION RANGE	NH 2568025
R-1-3	MULTIPURPOSE MG RANGE	NH 28308130
R-1-4	MODIFIED RECORD FIRE RANGE	NH 28308020
R-1-5	KD RANGE (NOT CONSTRUCTED)	
R-1-6	25 METER ZERO RANGE	NH 28308055
R-1-7	COMBAT PSYOL RANGE	NH 28308060
R-1-8	MICLIC RANGE	NH 28308085

 Pesticide and TPH Samples
 Explosive Residue Samples

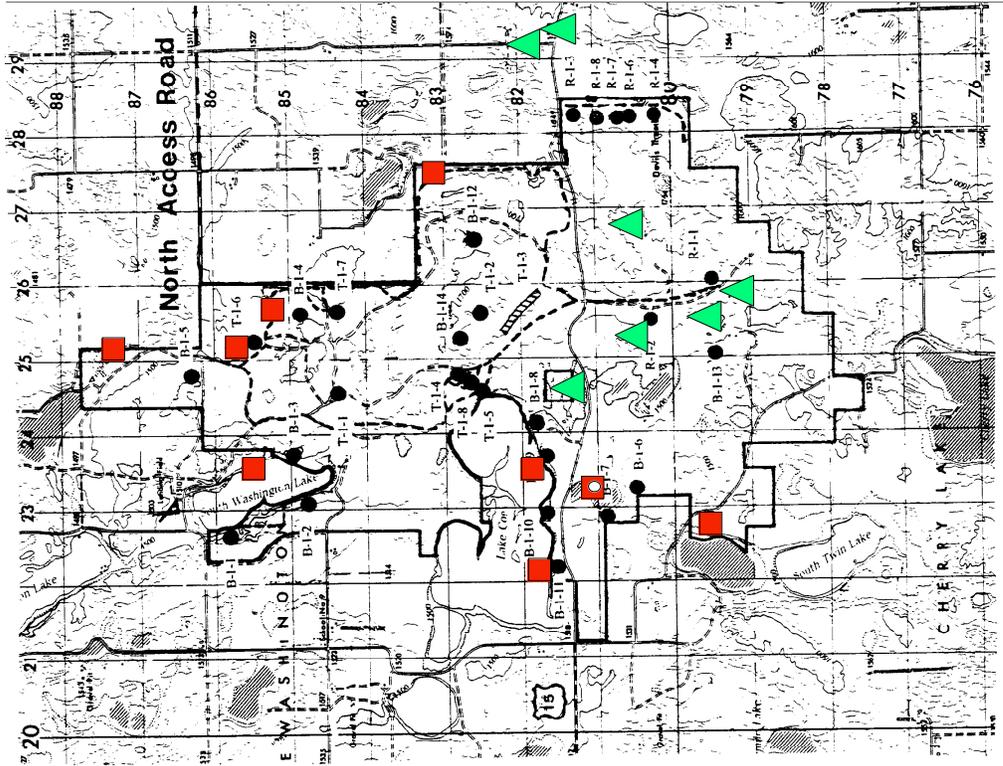


Figure 5. Sample sites for pesticide samples in relation to bivouac sites, and sample sites for explosives residue samples in relation to training areas involving demolitions and munitions training.  Indicates sites with no TPH sample.

Table 4. List and locations of 2006 proposed sampling sites for the CGS training facility as presented in the initial plan proposal. L indicates a lake sampling site, R indicates a reservoir sampling site, S indicates a natural spring sampling site, and W indicates a well sampling site. WS-1 designates wells placed by Comeskey (1989). WS-2 designates wells placed by Schuh (1994). All WS well nests were to be sampled only in the shallowest well.

Well Set	Site	SWC Well No.	Township	Range W	Section	Location	Water Source	Mun.	Petrol	Prome	pic +2,4-D	malath	Basic	Trace
			N											
WS-1		12024A	148	63	1	CBBC1	W						x	x
WS-1		12024B	148	63	1	CBBC2	W						x	x
WS-1		12024C	148	63	1	CBBC3	W						x	x
WS-1		12020A	149	63	14	DACD1	W						x	x
WS-1		12020B	149	63	14	DACD2	W						x	x
WS-1		12020C	149	63	14	DACD3	W						x	x
WS-1		12019A	149	63	23	ADBB1	W						x	x
WS-1		12019B	149	63	23	ADBB2	W						x	x
WS-1		12019C	149	63	23	ADBB3	W						x	x
WS-1		12017A	149	63	25	DBBC1	W						x	x
WS-1		12017B	149	63	25	DBBC2	W						x	x
WS-1		12017C	149	63	25	DBBC3	W						x	x
WS-1		12017D	149	63	25	DBBC4	W						x	x
WS-1		12025	149	63	26	DCA	W						x	x
WS-1		12012	149	63	27	DDDC1	W						x	x
WS-1		12015B	149	62	31	ABBC2	W						x	x
WS-1		12015C	149	62	31	ABBC3	W						x	x
WS-1		12026A	149	63	34	BBB1	W						x	x
WS-1		12026B	149	63	34	BBB2	W						x	x
WS-1		12011B	149	63	35	ABBD2	W						x	x
WS-1		12014A	149	63	36	AACB1	W						x	x
WS-1		12014B	149	63	36	AACB2	W						x	x
WS-1		12014C	149	63	36	AACB3	W						x	x
WS-1		12014D	149	63	36	AACB4	W						x	x
WS-1		12023A	149	63	36	DDBBC1	W						x	x
WS-1		12023B	149	63	36	DDBBC2	W						x	x
WS-1		12023C	149	63	36	DDBBC3	W						x	x
WS-1		12021A	149	63	13	BAAB1	W						x	x
WS-2	1	13103	149	62	28	CCC1	W	x	x	x			x	x
WS-2	1	13104	149	62	28	CCC2	W	x	x	x			x	x
WS-2	2	13105	149	62	29	DAD	W	x					x	x
	3	Spring	148	63	2	DA	S	x					x	x
	4	Res.	148	62	31	C	R	x	x	x			x	x
WS-2	5	13097	149	63	36	ACA1	W	x		x			x	x
WS-2	5	13098	149	63	36	ACA2	W	x	x	x			x	x
WS-2	6	13101	149	63	25	CDC1	W	x					x	x
WS-2	6	13102	149	63	25	CDC2	W	x			x		x	x
WS-2	7	13086	148	63	2	ACA1	W	x					x	x
WS-2	7	13087	148	63	2	ACA2	W	x	x		x		x	x
WS-2	8	13090	149	62	19	DBD1	W						x	x
WS-2	8	13091	149	62	19	DBD2	W						x	x
WS-2	8	13106	149	62	19	DBD3	W		x		x	x	x	x
WS-2	9	13088	149	63	13	DAA1	W						x	x
WS-2	9	13089	149	63	13	DAA2	W		x		x	x	x	x
WS-2	10	13092	149	63	12	CAC1	W						x	x
WS-2	10	13093	149	63	12	CAC2	W		x		x	x	x	x
	11	S W Lake	149	63	14	CAC	L		x		x	x	x	x
WS-2	12	13084	148	63	2	BABC1	W						x	x
WS-2	12	13085	148	63	2	BABC2	W				x		x	x
WS-2	13)	13099	149	63	35	BCBA1	W						x	x
WS-2	13	13100	149	63	35	BCBA2	W			x			x	x
	14	Lake Coe	149	63	26	ADD	L	x	x		x	x	x	x
	15	Lake Coe	149	63	27	DDB	L						x	x
	16	Spring	149	63	13	BDA	S		x		x	x	x	x
WS-2	17	13095	148	63	4	ABA1	W						x	x
WS-2	17	13096	148	63	4	ABA2	W				x		x	x
WS-2	20	13094	149	63	14	AAB	W				x	x		

Munitions and Explosives Use, Residues and Sampling Strategy

In 2001 sample plans for munitions and explosives residues were revised and intensified to: (1) Identify well and surface-water sample sites associated with each operational area; (2) Identify as many known compounds as possible for each use and operational area; (3) Identify sampling procedures and laboratory methods required to evaluate those compounds; and (4) Sample each well and surface-water site for the required compounds and methods.

Use areas of influence were:

(1) The M203 range, located in the northwest quarter of 148-063-02. Both ground water and surface runoff from this area flows westward toward the wetlands in the center of 148-063-02, and from there northward through the Lake Coe and South Washington Lake basins toward the Sheyenne River. Ground water from the M203 range may also discharge from the spring located at 148-063-02DA.

(2) The western half of 149-062-32 is occupied by several training sites, including an M-60/ 50-caliber machine gun training site (MPMG), a pistol range, an M-16 zero range, and a modified record fire range (MRF), which are collectively identified as the General Emerson Murray (GCEM) ranges. Depending on time, conditions and specific locations of use, both surface-water and ground-water flow could carry contaminants in either direction. A reservoir located in the southwest quarter of 149-062-31 collects water from the training area and would be expected to trap contaminants.

(3) A demolitions range is located in the south half of 149-063-36. Surface water and ground water draining from this area likely flows northwestward to the Lake Coe and South Washington Lake basins, and from there toward the Sheyenne River. In addition, possible contamination of the Reservoir between the demolitions range and the firing ranges (Site 4, Figures 3, 4, 5) and the South Spring (Site 3, Figure 3, 4, 5) could occur through atmospheric deposit following demolitions exercises.

Table 5. List of analytes for EPA Methods 8260B, 8270C, 8330, and 8332 used for 2001 samples at CGS. * indicates partial list of specific target analytes known to be in use.

Method / Analyte	MDL / mg/L	Method / Analyte	MDL / mg/L	Method / Analyte	MDL / mg/L
EPA Method 8260B		EPA Method 8270C (cont.)		EPA Method 8270C (cont.)	
1,1,1-Trichloroethane	0.0971	Benzyl Alcohol	0.0699	Carbazole	0.0726
1,1,2,2-Tetrachloroethane	0.182	1,2-Dichlorobenzene	0.0638	Di-n-butylphthalate *	0.347
1,1,2-Trichloroethane	0.116	2-Methylphenol	0.113	Fluoranthene	0.0723
1,1-Dichloroethane	0.0585	Bis (2-chloroisopropyl)ether	0.0967	Pyrene	0.0836
1,1-Dichloroethene	0.0507	2-Methylphenol	0.0552	Butylphenylphthalate	0.204
1,2-Dichloroethane	0.0395	2-Nitrosodi-n-propyl amine	0.109	3,3'-Dichlorobenzidine	0.372
1,2-Dichloropropane	0.0752	Hexachloroethane	0.0773	Benzo (a) anthracene	0.075
2-Butanone	1.4	Nitrobenzene	0.0924	Chrysene	0.076
2-Hexanone	2.06	Isophorone	0.114	Bis (2-ethylhexyl) phthalate	2.49
2-methol-2-Pentanone	0.774	2-Nitrophenol	0.0830	Di-n-octylphthalate	0.126
Acetone	2.16	2,4-Dimethylphenol	0.285	Benzo (b) fluoranthene	0.105
Benzene	0.0357	Benzoic Acid	4.35	Benzo (k) fluoranthene	0.132
Bromodichloromethane	0.0544	bis (2-Chloroethoxy) methane	0.0508	Benzo (a) pyrene	0.0772
Bromoform	0.0868	2,4-Dichlorophenol	0.144	Ideno (1,2,3-c,d) pyrene	0.318
Bromoethane	0.0629	1,2,4-Trichlorobenzene	0.0492	Dibenz (a,h) Anthracene	0.287
Carbon Disulfide	0.0573	Naphthalene	0.0532	Benzo (g,h,i)perylene	0.276
Carbon Tetrachloride	0.0888	4--Chloroaniline	0.155		
Chlorobenzene	0.0706	Hexachlorobutadiene	0.112		
Chloroethane	0.127	4-Chloro-3-methylphenol	0.0794	EPA Method 8330	
Chloroform	0.0405	2-Methylnaphthalene	0.0687	1,3,5-Trinitrobenzene	0.0758
Chloromethane	0.0955	Hexachlorocyclopentadiene	0.0864	1,3-Dinitrobenzene	0.0256
Dibromochloromethane	0.0562	2,4,6-Trichlorophenol	0.0925	2,4,6-Trinitrotoluene *	0.0769
Ethylbenzene *	0.0551	2,4,5-Trichlorophenol	0.112	2,4-Dinitrotoluene *	0.0681
Methylene Chloride	0.0491	2-Chloronaphthalene	0.0769	2,6-Dinitrotoluene *	0.0154
Styrene	0.0928	2-Nitroaniline	0.14	2-Amino-4,6-Dinitrotoluene	0.0582
Tetrachloroethene	0.0696	Dimethylphthalate	0.0766	2-Nitrotoluene	0.0129
Toluene *	0.0483	2,6-Dinitrotoluene	0.152	3-Nitrotoluene	0.196
Trichloroethene	0.0548	Acenaphthylene	0.0467	2-Amino-2,6-Dinitrotoluene	0.153
Vinyl Chloride	0.114	3-Nitroaniline	0.313	4-Nitrotoluene	0.123
cis-1,3-Dichloropropene	0.0618	Acenaphthene	0.0680	HMX *	0.0445
trans-1,3-Dichloropropene	0.128	2,4-Dinitrophenol	1.24	nitrobenzene	0.0696
cis-1,2-Dichloroethene	0.0667	4-Nitrophenol	0.7415	RDX *	0.0539
trans-1,2-Dichloroethene	0.0791	Dibenzofuran	0.0519	Tetryl *	0.0853
o-Xylene *	0.0451	2,4-Dinitrotoluene	0.0981		
m,p-Xylene *	0.136	Diethylphthalata	0.140		
		4-Chlorophenyl Phenyl Ether	0.0478		
		Fluroene	0.0737	EPA Method 8332	
		4-Nitroaniline	0.341	PETN *	0.354
		2,4-Dinitro-2-Methylphenol	1.48	Nitroglycerin *	0.376
		N-nitrosodiphenylamine *	0.0865		
		4-Bromophenyl Phenyl Ether	0.108		
		Hexachlorobenzene	0.151		
		Pentachlorophenol	1.03		
		Phenanthrene	0.0582		
		Anthracene	0.088		
EPA Method 8270C					
Pyridine	0.315				
Phenol	0.0525				
Bis (2-chloroethyl) ether	0.262				
2-Chlorophenol	0.0851				
1,3-Dichlorobenzene	0.0369				
1,4-Dichlorobenzene	0.0622				

An inventory of known compounds for uses on each location was compiled by LTC David Anderson (Letter of 3/23/2000); Personal Communication, Appendix A-1). Most common uses of munitions and explosives are located at the Demolition Range and the assembly of ranges (GCEM) located in the northeast corner of the camp, south of Hwy 29. Of the listed chemicals, there are standard EPA screening methods for Pentaerythritol Tetranitrate (PETN), 2,4,6-trinitrooluene (TNT), Styrene, Nitroglycerin, Dipubylphthalate, and Toluene. Cadmium, magnesium, lead, nickel, and zinc components can also be tested using standard trace element methods. A general list of all analytes determined for each of the four method is in Table 5. Table 6 matches the targeted analytes for specific EPA methods with CGS use areas. Table 7 lists the water sample sites targeted for each of the use areas.

Table 6. EPA laboratory method procedures for known compounds from each designated use area, based on munitions and explosives use inventory (Appendix A).

Demo Range	GCEM ranges	M203
8260B	-	-
-	8270C	-
8330	-	-
8332	8332	-
Zn, Pb, Ni, Cu, Ba	Zn, Pb	Zn, Pb

Table 7 Water sample sites associated with ranges. Demo=Demolition range, (R) = Reservoir, (S) = South Spring, GCEM = General C. Emerson Murray combined ranges. Site Locations are shown on Table 5.

Munitions and Explosives Use Site	Water Sample Site
Demo	3(S), 4(R), 5,6,7, 15 (Lake Coe)
M203	5,7
GCEM ranges	1,2,3*S), 4(R),5,6

FIELD SAMPLING AND LABORATORY METHODS

Field Methods

Sampling methods were designed for specific contaminants. Sampling procedures for low level detection of organic compounds, such as petroleum products, explosives residues, and pesticides, require "clean-clean" procedures, which involve high assurance against spurious contamination caused by field procedures (U.S. EPA 1992). Because of their low concentrations, trace elements also require greater cleanliness in sampling. Basic water chemistry can usually be sampled using less stringent procedures, although even for these elements reasonable care is necessary to avoid contamination.

In the CGS monitoring plan, general water chemistry and trace elements were sampled using PVC bailers. They were collected from wells from which at least three well volumes had been purged using either air lift (Photo 2, front), or suction lift (Photo 3, front) methods. Air-lift purging was used for WS-1 wells having piezometric surface too deep for suction lift. A rubber compressor hose was field-cleaned by coiling it in a polyethylene tub, and scrubbing it with non-phosphate soap, and rinsing with distilled water. The tip was inserted in the well to a level at least 20 feet above the well screen. An air compressor was used to air lift the water. Suction lift was used on both WS-1 and WS-2 wells having piezometric surface near enough to the surface to support a water column (generally less than 20 feet). A 1-inch rigid polyethylene hose was washed with non-phosphate soap and stored in a polyethylene bag. The hose was inserted in the well, and water was pumped using a screw pump.

For organic contaminants, five well volumes were evacuated from the well to be sampled. Air lift was not used for these samples, because of concern over possible introduction of petroleum residues on a compressor hose. Clean-clean procedures were used. A polyethylene apron was placed on the soil around each well to be sampled, and weeds and brush were cut or flattened. The well-cap was removed, and the inside and outside of the well were cleaned using non phosphate soap and a clean-white disposable laboratory tissue. Shallow wells were purged using the suction-lift procedure described above. Deeper wells were purged using a gas-squeeze pump (Photo 4, front). For petroleum samples, the engine used for operating the gas-squeeze pump was moved as far downwind as possible from the sample well. Both the polyethylene hose of the suction pump and the gas squeeze pump were thoroughly cleaned with non phosphate detergent and distilled water before placement in the well.

After purging, water samples were collected using a disposable polyethylene bailer. Before sampling the assistant washed his hands with soap and distilled water, and put on clean latex gloves from a container held by the clean worker. Throughout the sampling process the assistant would periodically rinse his gloves with distilled water.

The assistant washed the hands of the clean worker with non-phosphate soap and distilled water and then presented an opened package of disposable latex gloves to the clean worker, who removed them without touching the container and put them on his hands. The assistant opened the end of the disposable bailer package, without touching the bailer, and placed the still-covered body of the bailer under the arm of the clean worker. The assistant then removed a spool of nylon rope from a polyethylene bag, and without touching the rope presented the spool to the clean worker. The clean worker tied the rope to the bailer with gloved hand, and then placed the bailer down the well for sampling. About one additional well volume was bailed using the disposable bailer, and the well was then sampled. The assistant opened caps of the bottles. Replicate bottles were partially filled from each bailer sample. Bottles were filled to the top before capping. After completion the samples were placed in coolers with frozen "blue-ice". All samples were placed in a refrigerator in a utility building at the CGS facility within two hours of sampling. Cold samples (approx. 3° C) were packed on ice in insulated coolers and transported for arrival at the laboratory within 24 hours of packing. All samples arrived on ice. Chain of custody and evaluations of sample condition on arrival are provided with laboratory data in Appendices C and D.

General Water Chemistry and Trace Elements

Water samples for general water chemistry [pH, total dissolved solids (TDS), hardness, specific conductivity (EC), temperature, sodium adsorption ration (SAR), bicarbonate (HCO_3^-), potassium (K^+), sodium (Na^+), sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), fluoride (F^-), boron (B), silicate (SiO_2), iron (Fe^{2+}), manganese (Mn^{2+}), calcium (Ca^{2+}), and magnesium (Mg^{2+})] were collected from each well and surface-water site. In 1996 samplings water samples for determination of trace elements [arsenic (As), mercury (Hg), lead (Pb), and selenium (Se)] were collected. Previous samples collected in 1993 included cadmium (Cd) and zinc (Zn) as well. In 2006 trace elements determined included aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), lithium (Li), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), strontium (Sr), thallium (Tl), and zinc (Zn).

All samples were collected after purging of at least three well volumes of water from the well. Samples were stored in 500 ml polyethylene bottles. All basic chemistry bottles were washed with well water before collecting the sample. Bottles used for water samples for trace metal analysis were washed with concentrated nitric acid, two distilled water washes, and one deionized water wash before use. Samples for trace metal analysis were acidified in the field with 2 ml of concentrated nitric acid per 500 ml sample. Lab methods for general chemistry and trace elements were described previously by Shaver

(1991). Nitrate measurements were made using an Orion ion-specific electrode, using an Orion conductivity meter.

Organic Compounds

GRO (gasoline range organics), DRO (diesel range organics), malathion, prometon, and picloram were analyzed by Minnesota Valley Testing Laboratory (New Ulm, MN). For DRO and GRO the laboratory used Method 8015B (EPA-SW-846, Rev. 2, 1996). Prometon and malathion were extracted using Method 3510, and measured using Method 8270, while picloram and 2,4-D were extracted and measured using Method 8151 (EPA-SW-846, Rev. 2, 1996). Methods for determining TPH and pesticides in previous sampling (1992 and 1993) were described by Schuh (1994, 1997). Water samples collected in 1996 for determination of munitions and explosives residues were analyzed by Data Chem Laboratories (Salt Lake City, Utah). Laboratory procedures used were Methods 8260B, 8270C, and 8332 (U.S. EPA-SW-846, Rev. 2, 1996); and Method 8330 (U.S. EPA-SW-846, Rev. 0, 1994). Methods for initial munitions and explosives samples collected prior to 1996 are described in Schuh (1994).

SUMMARY OF 1993 THROUGH 2001 SAMPLING AND ASSESSMENT

Summary of 1993 Sampling and Assessment

The following conclusions were reached in a previous ground-water quality study at CGS (Schuh 1994). Basic water quality of the Cherry Lake aquifer is of low to average total dissolved solids (TDS < 800), near-neutral pH, and low to slightly high sodium adsorption ratio (SAR). Shallow ground water is usually of the calcium bicarbonate type, while deeper aquifer units are frequently of the sodium sulfate type. There was no significant lead, mercury, selenium, or cadmium in any of the wells sampled. However, arsenic was present in most samples, and in some of the deeper aquifer units approached and even exceed EPA-MCL (then 50 µg/L, now 10 µg/L). Natural lakes were very high in TDS, sulfate, chloride, and sodium, with pH above 9 and very high SAR. There was no significant lead, mercury, selenium, or cadmium in any of the samples. However, arsenic approached or exceeded the recent EPA-MCL of 10 µg/L in many samples. Nitrates were low in both surface and ground water. There were no indications of anthropogenic degradation of basic water quality on the reserve.

Of the wells sampled in 1992 and 1993 there was only one pesticide detection. Dimethoate was detected at a level just below the EPA Lifetime Health Advisory Level (HAL) in one well near Lake Coe. However, dimethoate was never deliberately sprayed on CGS land. The well site of the detection was within the spray drift zone of aerially sprayed picloram during drilling and construction of the well. Dimethoate residual in the picloram spray is a likely source. The dimethoate detection does not indicate a likely case of environmental contamination from routine facility use and care. There were no detections of picloram, malathion, chlorpyrifos, or any other pesticides used on the reserve in any of the well or spring samples.

There were detections of picloram at low levels (0.1 to 0.2 µg/L) in Lake Coe and South Washington Lake in August of 1993. Because picloram was not detected in 1986, and because of the exceptionally heavy rainfall in 1993, it was suspected that these detections were a result of exceptional runoff. It is unlikely that contaminants entered Lake Coe or South Washington Lake through ground water.

There were no indications of total petroleum hydrocarbons (gasoline or fuel oil) in any of the samples collected from ground water in August of 1993.

There were no detections of munitions and explosives residues (HMX, RDX, Nitrobenzene, tetryl, 1,3-dinitrobenzene, 2,4,6-TNT, 2,4-DNT, and 2,6-DNT) in any of the water samples collected in the fall of 1992.

Summary of 1996 Sampling and Assessment

In 1996 the use of the CGS facility was again evaluated, and a water-quality sampling plan was designed to monitor potential contamination from current land use practices. In September of 1996 water samples were collected from wells and surface waters at CGS. The 1996 sample report (Schuh, 1997) evaluated progress in accomplishing previous recommendations resulting from the 1994 assessment, apparent water quality status of CGS water resources based on the most recent (1996) sample results, and trends in the chemical composition of water samples collected over the ten-year period from 1986 through 1996.

Results indicated that there was no evidence of significant anthropogenic impact on the basic water chemistry or trace elements in the Cherry Lake aquifer, or in surface waters. Background water chemistry in the Cherry Lake aquifer varied from low TDS (total dissolved solids) of less than 200 mg/L to brackish water having TDS as high as 5,000 mg/L. Principal dissolved salts varied from calcium and bicarbonate, to predominantly sodium and sulfate. In some cases, chloride concentrations were as high as 1,000 mg/L. Shallower water was usually freshest, having lowest TDS and sulfate concentrations. Deeply buried aquifer subunits had higher dissolved solids, sodium, and sulfate. Highest sodium and sulfate appeared to be related to proximity the underlying Pierre shale bedrock.

Nitrate concentrations in surface waters and ground-water at CGS were below levels of toxicological concern, based on an EPA Maximum Contaminant Level (EPA-MCL) of 44 mg/L (U.S. EPA 1996a). Of all water samples collected in 1996, the median nitrate concentration was 1 mg/L. The maximum concentration was 7 mg/L. Most of the higher nitrate concentrations were in shallower wells. Since fertilizer is not used on the CGS Reservation, the most probable nitrate source was manure from cattle grazed on the land. Trends in nitrate concentration since 1987 are variable, but from 1991 through 1996 the overall trend is toward lower nitrate concentrations. South Washington Lake has low nitrate concentrations. However, presence of manure along the lake border and strong algal blooms indicate that substantial nitrate influx is likely, and that nitrate is biologically consumed.

As in previous samplings (1986, 1991) non-arsenic trace elements, including barium, lead, selenium, and mercury were not detected in significant quantities in 1996. Arsenic concentrations were relatively high in waters sampled on CGS. In some wells and in some surface water samples, arsenic concentrations exceed levels of toxicological concern (EPA-MCL was 50 mg/L). Arsenic concentrations have been relatively consistent over time, but varied over the area of the facility. Concentrations were at levels of toxicological concern in South Washington Lake. They were high in Lake Coe, and in the area of the CGS supply wells. Concentrations were also high in the area of the

GCEM ranges. Arsenic concentrations were almost certainly natural in origin, and have not been introduced by human use. However, certain uses that concentrate salts, such as use of reverse osmosis systems or boiling the water, were noted to cause concentration of arsenic. Care was suggested in disposal of reverse osmosis filtrate waters, or in consumptive use of boiled water.

Eleven water samples were collected from nine sites, including five well sites, one spring (148-063-02DA) and one reservoir (149-062-02DA) for 14 organic compounds used in munitions and explosives. Samples were collected from watersheds fed by the major munitions and demolitions training areas. Results indicated no detections of any of the compounds tested.

Nine water samples were collected from nine sites, including one from South Washington Lake, two from Lake Coe, and six from two wells on each of three sites, for measurement of total petroleum hydrocarbon (TPH) as gasoline and as fuel oil (including diesel fuel). Chosen sites were in watersheds near, or fed by areas used for vehicle staging, such as the Engineering Training Site, or common bivouac areas. Results indicated no detections of TPH as gasoline or fuel oil in any of the water samples.

Fourteen water samples were collected from eight sites for determination of pesticide concentrations. Samples included one from South Washington Lake, two from Lake Coe, one from a spring (149-063-13BDA), and ten samples from two wells on each of five well sites in appropriate target areas. Samples were tested for chlorpyrifos and picloram. Results indicated no detections of chlorpyrifos in any of the water samples. Picloram was not detected in any of the well samples or in the spring sample. Picloram was detected at low concentration (about 0.1 µg/L) in Lake Coe and South Washington Lake. Annual samples from 1993 through 1996 have indicated that trace concentrations of picloram are consistently present in South Washington Lake and Lake Coe. Detected presence is several orders of magnitude below EPA-MCL (500 µg/L).

Summary of 2001 Sampling and Assessment

In 2001 the use of the CGS facility was again evaluated, and a water-quality sampling plan was designed to monitor potential contamination from current land use practices. A summary of the water-sample plan is shown on Table 3.

General Chemistry in 2001

In September of 2001 water samples were collected from CGS wells and surface waters. Results were substantially the same as in 1996.

TDS varied from as low as 200 mg/L to as much as 2,000 mg/L in ground-water samples. Water from most shallow wells was determined to be of good quality for drinking. Shallow ground water was mainly a calcium bicarbonate type with low EC

and TDS. The pH of most shallow wells was described as slightly acid to neutral (6.5 to 7.5).

Anionic composition of many deep ground-water samples was a mixture of chloride, sulfate, and bicarbonate. Deeper wells are, in general, more sulfatic and chloridic than shallower wells. Sodium was elevated in some of the deeper wells, and sulfate concentrations were mainly correlated with sodium. Several of the deep wells had SAR values greater than ten, and some were as large as 35. Highest SAR and specific conductance values are in the deep wells of nests placed in the uplands east of South Washington Lake.

Effects of hydrologic connections between the three aquifer subunits described by Comeskey (1989) were examined in 2001. In some areas, aquifer subunits were identified as interconnected, while others occurred as isolated pockets within the glacial till. Temporal changes in water chemistry of some deep wells indicated that they are connected to other aquifer units, and could be freshened. For example, the deep well on Site 6 located in the littoral area southeast of Lake Coe changed from an EC of 1,041 $\mu\text{S}/\text{cm}$ in October of 1992, to 471 $\mu\text{S}/\text{cm}$ in September of 1996. Following large rains in 1993 this well was flowing, indicating a large change in piezometric pressure caused by recharge in the uplands. Thus, both changing piezometric pressure and water chemistry data indicated a deep well connected to the surface, and freshened by rainfall in the uplands at some distance (more than one mile) from the well. Similar, but less marked decreases in specific conductance occurred in several deep wells. Differences in water chemistry between deep wells were determined to be strongly related to their levels of isolation from other fresher bodies of water.

Surface waters, and particularly Lake Coe and South Washington Lake, were described as "windows" on the water tables. They were described to function as evaporative sinks for waters moving slowly toward the Sheyenne River. Water in the lakes was brackish, having specific conductance ranging from 3,720 to 6,430 $\mu\text{S}/\text{cm}$. Lake waters were high in sodium, having very large SAR values, and also in sulfate and bicarbonate. Higher sodium was likely related to their proximity to the underlying Pierre Shale. Water from springs were found to be of good quality, and similar in chemistry to water samples collected from shallow wells.

Nitrate in 2001

Nitrate has an EPA-MCL of 10 mg/L nitrate as N, or 44 mg/L nitrate. In general, nitrate concentrations in samples were variable, but low, having a median concentration near 1 mg/L for all three sample years in the WS-1 wells (1987, 1992, and 1993). Concentrations appeared to increase slightly in 1993, likely due to heavy rains in that year, and then decreased by 1996 for most wells. Concentrations were highest for wells

screened at less than 100 feet bls. Occasional nitrate concentrations above 1 - 3 mg/L likely originated in manure from cattle pastured on the CGS Reservation. However, all detections were below levels of toxicological concern, and appeared to be ephemeral. In surface-water samples, including South Washington Lake and Lake Coe, nitrate concentrations were low and were likely limited by algae growth.

Trace Elements and Arsenic in 2001

Results for trace elements barium (Ba), cadmium (Cd), mercury (Hg), lithium (Li), molybdenum (Mo), lead (Pb), selenium (Se), strontium (Sr), and zinc (Zn) indicated no concentrations above levels of toxicological concern, and no increasing trends.

A review of arsenic (As) concentrations for both well sets indicated similar median concentrations (4.5 µg/L for WS-1, 5.5 for WS-2) and similar coefficients of variation (120% on WS-1, and 130% on WS-2). Concentrations approaching the EPA-MCL (then 50 µg/L) were detected in South Washington Lake. Elevated concentrations were observed in several wells, including the following:

- (1) In 1988 two 5-inch diameter supply wells were drilled at a site just south of Hwy 15 (149-063-35A). Well-screens were placed at intervals (SI) of 26 to 34 feet bls, and 28 to 36 feet bls. Measured pumping capacities were 51 and 55 gpm. About 200 feet west of the supply wells (at 149-063-35ABBD2) a sample well (WS-1 set) was placed with screen at about 45 to 50 feet. Arsenic concentrations in this well varied from 16 to 22 mg/L (one third to half of the EPA-MCL of 50 µg/L, but 1.6 to 2.2 times the new EPA-MCL of 10 µg/L).
- (2) One well having a particularly high arsenic concentration is located at 149-062-31ABBC2, which is located just south of Hwy 15, west of the GCEM range, with a screened interval from 162 to 167 feet bls.
- (3) The deep well (Site 1, 149-062-28CCC2) is located about one-half mile east of the previously described (149-062-31ABBC2). This well had high arsenic concentration, varying between 47 and 52 mg/L. This exceeded EPA-MCL. The well placed at Site 2 (149-062-29DAD) also had a high arsenic concentration.
- (4) Arsenic concentrations were high in the sections bordering the south side of Hwy 15. These include 149-063-35, 149-063-36, 149-063-29, 149-063-31, and 149-063-32. The area having potentially high arsenic concentrations would include the GCEM range, the equipment storage site located in 149-063-36, and the main well site 149-63-35.

The analysis in 2001 indicated no detectable trends of increasing arsenic or arsenic-related degradation of ground-water caused by CGS use. Because of impending changes in the EPA-MCL (from 50 µg/L to 10 µg/L), however, CGS managers converted from local wells to treated water imported from a rural water system in November of 2004. It was further recommended that use of ground water or surface water on the CGS facility for water purification training using reverse osmosis return purified water as well as filtrate to the natural system to avoid depositing a water stream containing concentrated arsenic which would be classified as toxic waste.

Munitions and Explosives Residues in 2001

In the 2001 sampling, four of the Method 8260B compounds were detected in water samples from several sites. Detected volatile compounds were acetone, carbon disulfide, methylene chloride, and toluene. Of these, all except carbon disulfide were detected in the trip blank in concentrations comparable to, or greater than those in the environmental samples. One, methylene chloride was also detected in the laboratory method blank. Only carbon disulfide was detected in field samples alone.

Louise Parker of the U.S. Army ERDC-CRREL, New Hampshire, assisted in identifying some potential sources of detected compounds through a search of the Department of Defense (DOD) data base and additional sources in response to specific queries. In e-mail queries (cited previously in Schuh 2002, Appendix A-2) she identified the following potential sources:

1. Di-n-butylphthalate: Parker (cited in Appendix A-2a, Schuh 2002) cited the Encyclopedia of Explosives and Related Items (U.S. Army Armanent Research, Development, and Engineering Center, 1999) in identifying its use as a solvent for nitroaromatic compounds such as DNT and Dinitroethylbenzene, and as a coat for nitrocellulose and nitroguanidine propellants. She found it associated with 24 pages of munitions (20 munitions per page) in "one of the DOD data bases" queried.
2. Acetone: Parker (cited in Appendix A-2a, Schuh 2002) found, in a DOD database query, 60 munitions listed, including "flares, fuses, hand grenades (smoke and riot types), anti-personnel mines, signals, and smoke pots."
3. Toluene: Citing the Encyclopedia of Explosives and Related Items, Parker (cited in Appendix A-2a, Schuh 2002) found toluene to be one of the major components of explosives, including DNT and TNT. Citing Hawley's Condensed Chemical Dictionary (Sax and Lewis, 1987), "it is also a diluent and thinner for nitrocellulose and explosives

such as TNT." In the DOD database, she found "78 munitions listed including fuses, fuse bombs, and several sizes of projectiles and ... rockets."

4. Methylene Chloride: In a search of the DOD database Parker (cited in Appendix A-2a, Schuh 2002) found 15 matches of methylene chloride, including "several signals and smoke grenade launchers and a personnel signal kit."

5. Carbon disulfide: Parker (cited in Appendix A-2a, Schuh 2002) found carbon disulfide listed in the Encyclopedia of Explosives and Related Items as a compound that "had been tested as a developmental component for munitions," but was unable to find details of specific uses (there were no matches in the DOD database).

Conclusions of 2001 findings were: (1) Acetone, methylene chloride and toluene were detected in several samples, but seem likely to have had sources other than the well and surface waters sampled. (2) Carbon disulfide was detected in several ground-water and surface-water samples, and detections seemed to be authentic. All concentrations were at least 30 times lower than levels of potential toxicological concern. (3) Benzoic acid was detected in the Reservoir (Site 4) and in Lake Coe (Site 15). Detections were qualitative, indicating a likely presence, but at concentrations below that of the laboratory minimum detection level (MDL). (4) Di-n-butylphthalate was detected in one well-water sample (Site 2 in the Colvin Creek subbasin) and in Lake Coe (Site 15). Detections were qualitative, indicating a likely presence, but at concentrations below that of the laboratory minimum detection level (MDL). All detections were below levels of toxicological concern by a large margin. These are discussed in detail in Schuh (2002).

Pesticide Residues

Water samples were collected for herbicide and insecticide residues in 2001. The primary pesticides used at CGS included a mixture of picloram (Tordon) and 2,4-D, which is used for leafy spurge control, and malathion and chlorpyrifos (Lorsban) which is used for mosquito control in bivouac areas. Prometon is also used to control vegetation around buildings and operational facilities.

There were no detections of Prometon, 2,4-D or picloram in any of the well- or surface-water samples collected. Absence of picloram was significant in that the 2001 sample set was the first in which there were no detections of picloram in Lake Coe and South Washington Lake at the 0.1 to 0.2 µg/L concentration level. Picloram had been detected in all previous samplings.

Of the insecticides, only malathion was sampled in 2001. There were no detections of malathion in any of the well or surface-water samples collected.

Petroleum Residues

Petroleum residues [gasoline range organics (GRO) and diesel range organics (DRO)] were sampled in 15 wells and surface-water locations located on 12 sites. There were no detections of GRO. DRO were detected in the range of 0.041 to 0.07 $\mu\text{g/L}$ on Site 8 (Buck Hollow), Site 9 (Engineering Training Site) and Site 10 (northeast of South Washington Lake). These detections were less than the MDL (0.3 $\mu\text{g/L}$) and were considered qualitative. The State of North Dakota as represented by the State Health Department uses a value of 0.5 mg/L as a threshold of "concern" for DRO. This is not a regulatory limit, but value at which further investigation is considered warranted. All detections on environmental samples were 10,000 times below this threshold. It was concluded that if the DRO detections truly represent field conditions and not incidental sample contamination (which is a real possibility at such low concentrations), they are far below levels of toxicological concern and warrant no further action.

PREVIOUS SAMPLING RECOMMENDATIONS

Following water sampling and analysis in 1992 and 1993, six recommendations were made:

Recommendation #1994-1, that Lake Coe and South Washington Lake be sampled at least once per year to determine if picloram contamination is an ephemeral or long-term condition. This recommendation has been implemented. Samples for picloram were collected in 1994, 1995, and 1996 from each lake. Results indicated that trace levels of picloram were consistently present, and that background picloram is therefore a consistent outcome of current weed-control management on the CGS facility. Recommendation #1994-2, that dimethoate be resampled in WS-2 Well 13102 (Site 6) in early 1994 to determine whether the well was contaminated was implemented in June of 1994. Results indicated no further detections of dimethoate. The initial (fall 1993) detection was therefore either spurious or ephemeral. Recommendation #1994-3, that sampling for each potential contaminant group be selectively repeated in 1996 was implemented. Recommendation #1994-4, that all wells drilled in 1992 be surveyed for measuring point elevation (MP) has not yet been implemented. Recommendation #1994-5, that all wells drilled in 1992 be fitted with locking caps, was completed by the North Dakota National Guard in 1995. However, WS-2 Well 13103 (Site 6, 149-062-28CCC1) was too long for the outside protective case, and the aluminum cap could not be closed without removing the inside cap, risking contamination of the well. This PC was repaired to accommodate the cap. Recommendation #1994-6, that a comparative analysis of water chemistry data trends be considered following the 1996 sampling was implemented in Schuh (1997), and will be updated in this report.

Following water sampling and analysis in 1996, seven recommendations were made (Schuh 1997):

Recommendation #1997-1, that samples for picloram in Lake Coe and South Washington Lake be collected every other year instead of every year. The lakes were sampled in 2001. Recommendation #1997-2, stated that water supply wells located south of Hwy 15 (149-063-35A) should be sampled for water chemistry and for trace elements, and sampled annually to determine arsenic concentration. These wells were sampled and reported in a memorandum from W.M. Schuh to Mr. Neal Jacobson, titled Water Quality and Arsenic Concentrations in the Camp Grafton South Supply Wells, dated 5/20/98. Recommendation #1997-3, stated that appropriate procedures for disposal of high arsenic filtrate should be established following use or training in water purification using reverse osmosis. Appropriate procedures have been worked out with the North Dakota Department of Health. Recommendation #1997-4, stated that the well-house area (149-063-35A) as a staging area for storage of herbicide and for mixing herbicides should be

reviewed for well-protection safety, and that pesticides be stored away from the well site. A separate storage and staging facility was constructed in 2005. Recommendation #1997-5, that CGS wells should be sampled again for water quality in 2001, has been implemented was completed and reported in Schuh (2002). Recommendation #1997-6, that the PVC protective cover for WS-2 well 13103 (Site 1, 149-062-28CCC1) should be extended three or four inches, has been remedied by the SWC. Recommendation #1997-7, stated that elevations of the measuring points (tops) of all wells should be surveyed. Surveys of WS-1 well set elevations were conducted in 1989 and 1994.

Following water sampling and analysis in 2001, ten recommendations were made (Schuh 2002):

Recommendation #2001-1, that annual sampling for picloram be discontinued and that sampling be implemented only at times of major sampling, was implemented. Recommendation #2001-2, that ramifications of the new arsenic standard of 10 µg/L be considered for drinking water supplies on the CGS Reservation, were implemented in the 2004 with the change to contract rural water. Recommendation #2001-3, that procedures for handling high-arsenic filtrate during reverse osmosis operational training be approved by the North Dakota Health Department, were implemented. Implementation status of Recommendation #2001-4, that the well-house area at 149-063-35A not be used for storage of pesticides, was implemented in 2005 with establishment of a separate storage and staging facility. Recommendation #2001-5, that camp waters be resampled in 2006 has been implemented, and is presented in this report. Recommendation #2001-7, that the protective cover for well 13103 (Site 1, 149-062-28CCC1) be extended, has been implemented. Recommendation #2001-8, that elevations of measuring points (tops) of all wells be surveyed to the nearest 0.1 foot, was implemented in 1989 and 1994. Recommendation #2001-9, that South Washington Lake should be resampled for lead and zinc to test the validity of 2001 detections, was implemented in 2006 and is presented in this report. Recommendation #2001-10, that storage and handling procedures for volatile organic compounds should be reviewed before the next major sampling to assure non-contamination of samples, was implemented in the 2006 sampling set.

Table 8. Water chemistry parameters for the WS-1 monitoring well set, CGS.

Well No.	Location	Top_Screen		Bottom_Screen	Feet	Longitude	Latitude	Date_Sampled	Water_Level_Feetbls	Field_Cond.	Lab_Cond.	Field_pH	Lab_pH	Field_Temp °C	TDS_Det. mg/L	TDS_Calc. mg/L	Hardness mg/L	NCH mg/L	SAR
		Feet	Feet																
12011B	14906335ABBD2	45	50	-98.68326785	47.68561295	9/1/87	16.04	880	864	8.80	7.82	10	505	564	270	0	2.5		
12011B	14906335ABBD2	45	50	-98.68326785	47.68561295	10/24/91	21.54	869	893	8.02	7.47	7	565	585	280	0	2.4		
12011B	14906335ABBD2	45	50	-98.68326785	47.68561295	9/10/96		835	984		7.6	7.7	647	627	320	0	2.4		
12011B	14906335ABBD2	45	50	-98.68326785	47.68561295	9/6/01	15.45	887	994		7.95		622	609	320	0	2.4		
12011B	14906335ABBD2	45	50	-98.68326785	47.68561295	9/6/06	16.12	842	887	8.45	7.45			550	260	0	2.38		
12012	14906327DDDC1	164	169	-98.70573941	47.68694066	9/6/06	58.85	653	688	8.41	7.96			427	181	0	2.2		
12013B	14906336BBD2	22	27	-98.67150962	47.68462529	9/1/87	3.7	620	627		7.87	14	377	395	240	0	1.3		
12013B	14906336BBD2	22	27	-98.67150962	47.68462529	10/24/91	7.01	620	628	7.96	7.33	9	377	394	230	0	1.4		
12013B	14906336BBD2	22	27	-98.67150962	47.68462529	9/11/96		536	634		7.67	8.7	401	376	240	0	1.3		
12013B	14906336BBD2	22	27	-98.67150962	47.68462529	9/6/06	4.89	744	786	7.57	7.56			487	275	0	1.41		
12014B	14906336AACB2	181	186	-98.65790652	47.6861436	9/2/87	49.15	950	958		7.94	10	523	626	210	0	4.2		
12014B	14906336AACB2	181	186	-98.65790652	47.6861436	10/22/91	53.91	929	984	7.75	7.45	7	578	619	210	0	4.2		
12014B	14906336AACB2	181	186	-98.65790652	47.6861436	9/11/96		804	960		7.74	8.4	608	601	210	0	4.2		
12014B	14906336AACB2	181	186	-98.65790652	47.6861436	9/5/06	45.09	935	999	6.36	8.02			619	187	0	4.64		
12014C	14906336AACB3	64	69	-98.65790652	47.6861436	9/2/87	11.36	740	685		7.73	10	348	450	400	70	0.2		
12014C	14906336AACB3	64	69	-98.65790652	47.6861436	10/22/91	15.53	763	807	7.41	7.28	8	416	499	430	33	0.2		
12014C	14906336AACB3	64	69	-98.65790652	47.6861436	9/11/96		627	744		7.61	8.4	464	444	390	7	0.2		
12014C	14906336AACB3	64	69	-98.65790652	47.6861436	9/5/06	11.88	705	745	6.26	7.7			462	347	0	0.22		
12014D	14906336AACB4	24	29	-98.65790652	47.6861436	9/2/87	12.31	540	510		7.87	12	286	325	290	42	0.1		
12014D	14906336AACB4	24	29	-98.65790652	47.6861436	10/22/91	16.14	597	568	7.59	7.48	8	359	353	290	20	0.2		
12014D	14906336AACB4	24	29	-98.65790652	47.6861436	9/10/96		481	563		7.54	7.6	334	323	300	19	0.1		
12014D	14906336AACB4	24	29	-98.65790652	47.6861436	9/6/01	12.18	577	600		7.89		319	346	330	46	0.1		
12014D	14906336AACB4	24	29	-98.65790652	47.6861436	9/5/06	13.25	613	643	7.02	7.8			399	302	3	0.14		
12015B	14906231ABBC2	162	167	-98.64374799	47.68552364	9/1/87	94.68	570	575		7.9	13	358	370	160	0	2.2		
12015B	14906231ABBC2	162	167	-98.64374799	47.68552364	10/23/91	98.97	563	580	8.44	7.48	5	378	358	150	0	2.3		
12015B	14906231ABBC2	162	167	-98.64374799	47.68552364	9/11/96		493	565		7.83	7.9	348	329	150	0	2.2		
12015B	14906231ABBC2	162	167	-98.64374799	47.68552364	9/5/06	92.07	558	582	6.97	8.06			361	140	0	2.51		

Table 8 (cont.). Water chemistry parameters for the WS-1 monitoring well set, CGS.

Well No.	Location	Top_Screen		Bottom_Screen		Date_Sampled	Latitude	Longitude	Water_Level_Feet_bls	Field_Cond.		Lab_Cond.		Field_Temp °C	TDS_Det. mg/L	TDS_Calc. mg/L	Hardness mg/L	NCH mg/L	SAR
		Feet	Feet	µS/cm	µS/cm					µS/cm	µS/cm	pH	pH						
12015C	14906231ABBC3	78	83	-98.64374799	47.68552364	10/23/91	64.75	455	471	7.97	7.22	6	287	295	230	0	0.2		
12015C	14906231ABBC3	78	83	-98.64374799	47.68552364	9/11/96	410	475	491	7.48	7.6	7.6	299	269	250	0	0.1		
12015C	14906231ABBC3	78	83	-98.64374799	47.68552364	9/16/01	58.35	470	491	8.3	8.3	292	266	240	0	0.2			
12015C	14906231ABBC3	78	83	-98.64374799	47.68552364	9/5/06	57.3	456	480	7.07	7.49	298	298	207	0	0.19			
12017A	14906325DBBC1	263	268	-98.66232991	47.69220213	9/1/87	39.48	1200	1190	8.21	8.21	12	743	721	66	0	1.3		
12017A	14906325DBBC1	263	268	-98.66232991	47.69220213	10/24/91	44.23	1144	1210	8.15	7.92	5	722	729	64	0	1.4		
12017A	14906325DBBC1	263	268	-98.66232991	47.69220213	9/11/96	1008	1180	1008	7.98	8.8	8.8	733	715	64	0	1.4		
12017A	14906325DBBC1	263	268	-98.66232991	47.69220213	9/5/06	35.05	1150	1230	7.24	8.02	7.24	763	763	54	0	1.6		
12017B	14906325DBBC2	78	83	-98.66232991	47.69220213	9/2/87	5.17	860	877	7.99	7.99	11	567	573	96	0	7.1		
12017B	14906325DBBC2	78	83	-98.66232991	47.69220213	10/24/91	7.29	706	719	8.16	7.96	7	467	460	94	0	5.8		
12017B	14906325DBBC2	78	83	-98.66232991	47.69220213	9/11/96	632	702	632	7.89	7.9	7.9	471	435	110	0	5		
12017B	14906325DBBC2	78	83	-98.66232991	47.69220213	9/5/06	4.22	646	668	7.21	8.17	4.22	414	414	105	0	5.02		
12017C	14906325DBBC3	51	56	-98.66232991	47.69220213	9/2/87	3.04	490	505	7.99	7.99	11	303	316	260	5	0.2		
12017C	14906325DBBC3	51	56	-98.66232991	47.69220213	10/24/91	9.45	457	449	7.84	7.62	9	275	274	220	8	0.2		
12017C	14906325DBBC3	51	56	-98.66232991	47.69220213	9/10/96	411	473	411	7.62	7.62	9.4	274	269	240	3	0.1		
12017C	14906325DBBC3	51	56	-98.66232991	47.69220213	9/5/06	5.92	506	532	6.98	7.8	5.92	330	330	237	0	0.18		
12017D	14906325DBBC4	23	28	-98.66232991	47.69220213	9/2/87	6.13	500	504	7.98	7.98	9	316	314	260	0	0.1		
12017D	14906325DBBC4	23	28	-98.66232991	47.69220213	10/24/91	9.39	500	506	7.32	7.11	9	298	317	250	0	0.2		
12017D	14906325DBBC4	23	28	-98.66232991	47.69220213	9/10/96	442	508	442	7.44	7.5	7.5	301	289	260	0	0.2		
12017D	14906325DBBC4	23	28	-98.66232991	47.69220213	9/6/01	7.55	504	531	7.84	7.84	284	289	270	2	0.2			
12017D	14906325DBBC4	23	28	-98.66232991	47.69220213	9/5/06	8.2	509	526	6.8	7.19	8.2	326	326	234	0	0.22		
12019A	14906323ADBB1	218	223	-98.68074564	47.70575185	9/1/87	7.99	590	579	7.82	7.82	12	347	367	140	0	2.8		
12019A	14906323ADBB1	218	223	-98.68074564	47.70575185	10/23/91	13.87	569	592	8.3	7.4	6	368	363	160	0	2.3		
12019A	14906323ADBB1	218	223	-98.68074564	47.70575185	9/11/96	491	572	491	7.52	7.52	8.5	362	335	140	0	2.6		
12019A	14906323ADBB1	218	223	-98.68074564	47.70575185	9/6/06	3.9	601	612	9.23	7.44	3.9	379	379	135	0	2.9		
12019B	14906323ADBB2	32	37	-98.68074564	47.70575185	9/1/87	4.23	515	511	8.03	8.03	11	294	323	270	27	0.2		
12019B	14906323ADBB2	32	37	-98.68074564	47.70575185	10/23/91	7.88	524	538	8.08	7.25	9	325	331	270	17	0.2		
12019B	14906323ADBB2	32	37	-98.68074564	47.70575185	9/10/96	471	541	471	7.57	7.9	7.9	334	317	280	29	0.2		
12019B	14906323ADBB2	32	37	-98.68074564	47.70575185	9/6/06	2.21	499	521	8.6	7.4	2.21	323	323	239	2	0.16		

Table 8 (cont.). Water chemistry parameters for the WS-1 monitoring well set, CGS.

Well No.	Location	Top_Screen		Bottom_Screen		Water											
		Feet	Feet	Feet	Feet	Date_Sampled	Feet	Field_Cond.	Lab_Cond.	Field_pH	Lab_pH	Field_Temp	TDS_Det.	TDS_Calc.	Hardness	NCH	
12019C	14906323ADBB3	7	12	-98.68074564	47.70575185	9/1/87	4.29	585	461	7.87	8.08	14	272	301	270	31	0.1
12019C	14906323ADBB3	7	12	-98.68074564	47.70575185	10/23/91	7.53	537	558	7.24	8.08	10	303	334	290	16	0.1
12019C	14906323ADBB3	7	12	-98.68074564	47.70575185	9/10/96		462	518	7.47	8.08	10.9	321	297	270	16	0.1
12019C	14906323ADBB3	7	12	-98.68074564	47.70575185	9/6/01	1.3	525	542	7.85	8.08		333	294	280	49	0.1
12019C	14906323ADBB3	7	12	-98.68074564	47.70575185	9/6/06	2.11	477	499	7.4	8.43		309	309	228	6	0.1
12020A	14906314DACD1	212	217	-98.67972132	47.71653647	9/1/87	41.57	3070	2990	8.13	8.13	12	1910	1870	75	0	32
12020A	14906314DACD1	212	217	-98.67972132	47.71653647	10/23/91	45.36	2310	2270	8.62	8.19	6	1430	1450	49	0	32
12020A	14906314DACD1	212	217	-98.67972132	47.71653647	9/11/96		1858	2230	8.01	8.01	8.3	1410	1370	40	0	34
12020A	14906314DACD1	212	217	-98.67972132	47.71653647	9/5/06	35.37	2100	2270	7.1	8.22		1410	1410	40	0	37.3
12020B	14906314DACD2	151	156	-98.67972132	47.71653647	9/1/87	34.94	1460	1400	8.21	8.21	12	903	915	52	0	19
12020B	14906314DACD2	151	156	-98.67972132	47.71653647	10/23/91	39.35	1384	1420	8.41	8.41	6	924	923	50	0	20
12020B	14906314DACD2	151	156	-98.67972132	47.71653647	9/11/96		1173	1430	7.94	7.94	8.4	904	885	44	0	20
12020B	14906314DACD2	151	156	-98.67972132	47.71653647	9/5/06	31.04	1383	1460	7.29	8.14		905	905	42	0	23.7
12020C	14906314DACD3	38	43	-98.6796115	47.71665814	9/1/87	23.53	580	572	8.09	8.09	12	323	362	280	0	0.5
12020C	14906314DACD3	38	43	-98.6796115	47.71665814	10/23/91	29.58	567	569	7.5	8.04	6	357	350	270	0	0.4
12020C	14906314DACD3	38	43	-98.6796115	47.71665814	9/10/96		499	572	7.56	7.56	7.7	343	328	270	0	0.4
12020C	14906314DACD3	38	43	-98.6796115	47.71665814	9/6/01	23.15	585	596	7.89	7.89		349	330	280	2	0.4
12020C	14906314DACD3	38	43	-98.6796115	47.71665814	9/5/06	24.32	550	579	7.05	7.77		359	359	252	0	0.33
12021A	14906313BAA1	96	101	-98.66521977	47.73016393	9/1/87	10.14	3710	3450	8	8	12	1510	1540	230	0	13
12021A	14906313BAA1	96	101	-98.66521977	47.73016393	10/23/91	11.04	4440	4520	7.68	8.03	6	2440	2560	400	0	18
12021A	14906313BAA1	96	101	-98.66521977	47.73016393	9/11/96		3060	4680	7.66	7.66	7.9	2580	2580	400	0	18
12021A	14906313BAA1	96	101	-98.66521977	47.73016393	9/6/01	6.22	3980	4940	7.79	7.79		2560	2620	440	0	19
12021A	14906313BAA1	96	101	-98.66521977	47.73016393	9/6/06	6.25	4260	4560	8.66	8.66		2830	2830	378	0	21.8
12022	14906327DDDC2	158	163	-98.70573941	47.68694066	9/1/87	22.52	241	385	6.8	6.8	13	150	207	110	0.1	4
12022	14906327DDDC2	158	163	-98.70573941	47.68694066	11/19/91	102.53	638	674	7.53	7.53	7	423	423	190	2	40
12022	14906327DDDC2	158	163	-98.70573941	47.68694066	9/11/96		725	676	7.83	7.83	7.7	482	434	200	2	40

Table 8 (cont.). Water chemistry parameters for the WS-1 monitoring well set, CGS.

Well No.	Location	Top_Screen		Bottom_Screen	Longitude	Latitude	Date_Sampled	Water_Level_Feet	Field_Cond._µS/cm	Lab_Cond._µS/cm	Field_pH	Lab_pH	Field_Temp_°C	TDS_Det_mg/L	TDS_Calc_mg/L	Hardness_mg/L	SAR
		Feet	Feet														
12023A	14906336DDBC1	131	136	-98.65819588	47.67442052	9/2/87	10.36	720	742	8.06	8.06	11	456	474	110	5.4	
12023A	14906336DDBC1	131	136	-98.65819588	47.67442052	10/22/91	15.84	748	766	8.18	8.18	6	483	482	99	6.1	
12023A	14906336DDBC1	131	136	-98.65819588	47.67442052	9/11/96	6.13	724	758	7.69	7.69	7.7	457	439	100	5.7	
12023A	14906336DDBC1	131	136	-98.65819588	47.67442052	9/5/06	12.9	723	758	6.78	8.01	8.01	470	470	94	6.19	
12023B	14906336DDBC2	83	88	-98.65819588	47.67442052	9/2/87	10.63	620	617	8.12	8.12	10	382	394	200	1.9	
12023B	14906336DDBC2	83	88	-98.65819588	47.67442052	10/22/91	14.28	598	622	7.83	7.34	6	371	381	210	1.6	
12023B	14906336DDBC2	83	88	-98.65819588	47.67442052	9/11/96	6.12	509	612	7.61	7.61	7.4	390	364	210	1.6	
12023B	14906336DDBC2	83	88	-98.65819588	47.67442052	9/5/06	11.4	596	632	6.58	7.82	7.82	392	392	195	1.66	
12023C	14906336DDBC3	46	51	-98.65819588	47.67442052	9/2/87	14.84	540	540	7.86	7.86	10	342	336	280	0.2	
12023C	14906336DDBC3	46	51	-98.65819588	47.67442052	10/22/91	18.41	548	572	2	7.34	7	346	349	270	0.4	
12023C	14906336DDBC3	46	51	-98.65819588	47.67442052	9/10/96	4.65	465	541	7.39	7.39	7.9	318	316	280	0.3	
12023C	14906336DDBC3	46	51	-98.65819588	47.67442052	9/6/01	14.85	531	578	7.94	7.94	7.94	324	313	290	0.2	
12023C	14906336DDBC3	46	51	-98.65819588	47.67442052	9/5/06	15.87	549	582	6.97	7.37	7.37	361	361	261	0.24	
12024B	14806301CBBC2	151	156	-98.65030232	47.6653726	9/2/87	43.81	590	607	8.11	8.11	11	357	379	150	2.7	
12024B	14806301CBBC2	151	156	-98.65030232	47.6653726	10/23/91	47.58	583	614	8.03	7.54	6	375	386	140	2.9	
12024B	14806301CBBC2	151	156	-98.65030232	47.6653726	9/11/96	44.21	509	594	7.72	7.72	8.1	383	359	140	3	
12024B	14806301CBBC2	151	156	-98.65030232	47.6653726	9/5/06	44.21	587	619	7.18	7.99	7.99	384	384	125	3.35	
12025	14906326DCA	38	43	-98.68057616	47.69021308	9/1/87	16.32	975	973	7.86	7.86	11	610	647	370	2	
12025	14906326DCA	38	43	-98.68057616	47.69021308	10/24/91	20.12	996	1050	7.87	7.41	7	671	688	400	1.8	
12025	14906326DCA	38	43	-98.68057616	47.69021308	9/12/96	8.80	880	1140	7.65	7.65	7.9	748	740	460	4.6	
12025	14906326DCA	38	43	-98.68057616	47.69021308	9/6/01	13.57	992	1150	7.63	7.63	7.63	703	698	420	3	
12025	14906326DCA	38	43	-98.68057616	47.69021308	9/6/06	13.28	1087	1160	7.21	7.54	7.54	719	719	393	0	
12026A	1490634BBB1	251	256	-98.71776161	47.6863879	9/1/87	25	913	913	7.77	7.77	7.77	578	577	210	0	
12026A	1490634BBB1	251	256	-98.71776161	47.6863879	11/19/91	28.4	595	632	7.05	7.26	7	384	384	180	0	
12026A	1490634BBB1	251	256	-98.71776161	47.6863879	9/12/96	491	581	581	7.66	7.66	8	372	340	190	0	
12026A	1490634BBB1	251	256	-98.71776161	47.6863879	9/6/06	20.12	557	580	8.06	8.17	8.17	360	360	169	0	
12026B	1490634BBB2	27	32	-98.71776161	47.6863879	9/1/87	21.46	670	635	8.06	8.06	11	380	405	290	4.4	
12026B	1490634BBB2	27	32	-98.71776161	47.6863879	10/24/91	25.95	566	584	7.95	7.32	6	372	368	270	3.5	
12026B	1490634BBB2	27	32	-98.71776161	47.6863879	10/22/92	486	597	565	6.68	6.68	7.4	380	354	270	3.9	
12026B	1490634BBB2	27	32	-98.71776161	47.6863879	9/12/96	18.33	486	597	7.74	7.74	7.4	373	357	290	3.6	
12026B	1490634BBB2	27	32	-98.71776161	47.6863879	9/6/06	18.33	596	630	7.89	7.53	7.53	391	391	282	2.2	

Table 9. General cations and anions for water samples from the WS-1 well set, CGS.

Well No.	Date_Sampled	Location	Top_Screen		Silica	Calcium	Magnesium	Potassium	Sodium	Fluoride	Bicarbonate	Carbonate	Sulfate	Chloride	Nitrate
			Feet	Bottom_Screen											
12011B	9/1/87	14906335ABBD2	45	50	29	68	25	9.6	93	0.2	422	0	120	8.5	1.8
12011B	10/24/91	14906335ABBD2	45	50	27	68	26	9.9	94	0.3	432	0	130	10	5.5
12011B	9/10/96	14906335ABBD2	45	50	80	29	29	10	99	0.2	459	0	170	11	0.1
12011B	9/6/01	14906335ABBD2	45	50	79	29	29	9.3	97	0.2	455	0	160	9.4	0.1
12011B	9/6/06	14906335ABBD2	45	50	62.9	24.9	8.16	88.1	0.182	0.182	413	<1	129	7.18	<0.09
12012	9/6/06	14906327DDDC1	164	169	49	14.2	7.45	68	0.233	0.233	305	<1	92.7	12.6	<0.09
12013B	9/1/87	14906336BDDA2	22	27	31	59	22	7.5	47	0.3	358	0	43	8	1
12013B	10/24/91	14906336BDDA2	22	27	30	60	19	7.7	49	0.3	358	0	42	8.9	0.2
12013B	9/11/96	14906336BDDA2	22	27	66	19	19	7.6	45	0.3	370	0	47	8.2	0.4
12013B	9/6/06	14906336BDDA2	22	27	72.9	22.6	7.47	53.8	0.211	0.211	390	<1	93.1	7.66	<0.09
12014B	9/2/87	14906336AACB2	181	186	31	63	13	9.8	140	0.2	452	0	110	32	2.7
12014B	10/22/91	14906336AACB2	181	186	28	62	13	9	140	0.1	457	0	110	30	0.8
12014B	9/11/96	14906336AACB2	181	186	64	64	13	9.5	140	0.2	467	0	110	33	0.2
12014B	9/5/06	14906336AACB2	181	186	54.8	12.2	7.89	146	0.099	0.099	461	<1	107	31.6	0.09
12014C	9/2/87	14906336AACB3	64	69	32	110	30	7.4	11	0.2	401	0	57	3	0.4
12014C	10/22/91	14906336AACB3	64	69	29	120	32	7.4	11	0.1	486	0	55	5	0
12014C	9/11/96	14906336AACB3	64	69	110	110	29	6.5	9	0.2	472	0	50	5.2	0.1
12014C	9/5/06	14906336AACB3	64	69	92.2	28.2	6.27	9.3	0.13	0.13	441	<1	44.9	5.5	<0.09
12014D	9/2/87	14906336AACB4	24	29	29	79	23	3.5	5.5	0.2	305	0	29	2.9	3.2
12014D	10/22/91	14906336AACB4	24	29	26	78	23	5.6	6	0.1	329	0	36	6	10
12014D	9/10/96	14906336AACB4	24	29	82	82	23	2.8	4	0.2	342	0	27	4.1	12
12014D	9/6/01	14906336AACB4	24	29	91	91	26	3	5.5	0.1	352	0	29	2.8	15
12014D	9/5/06	14906336AACB4	24	29	79.2	25.3	3.49	5.4	0.1	0.1	364	<1	33.2	3.8	14.2
12015B	9/1/87	14906231ABBC2	162	167	31	45	12	9.1	64	0.3	321	0	43	4	2.8
12015B	10/23/91	14906231ABBC2	162	167	29	42	12	9	65	0.3	325	0	36	4.4	0
12015B	9/11/96	14906231ABBC2	162	167	42	42	11	8.9	61	0.3	332	0	37	4.2	0.1
12015B	9/5/06	14906231ABBC2	162	167	37.1	11.6	8.53	68.4	0.27	0.27	323	<1	38.1	2.72	<0.09

Table 9 (cont.). General cations and anions for water samples from the WS-1 well set, CGS.

Well No.	Date_Sampled	Location	Top_Screen		Silica	Calcium	Magnesium	Potassium	Sodium	Fluoride	Bicarbonate	Carbonate	Sulfate	Chloride	Nitrate
			Feet	Bottom_Screen											
12015C	10/23/91	14906231ABBC3	78	83	32	63	18	6.2	5.5	0.2	290	0	19	3	3.6
12015C	9/11/96	14906231ABBC3	78	83	69	69	18	5.2	4.5	0.2	300	0	21	2.5	0.1
12015C	9/6/01	14906231ABBC3	78	83	68	68	18	5.5	6.5	0.2	300	0	19	0	0.6
12015C	9/5/06	14906231ABBC3	78	83	54.7	54.7	17	5.53	6.2	0.14	286	<1	18.1	1.31	0.49
12017A	9/1/87	14906325DBBC1	263	268	30	19	4.5	7.5	240	0.4	444	0	100	99	0.6
12017A	10/24/91	14906325DBBC1	263	268	27	18	4.5	8	250	0.4	454	0	100	96	0
12017A	9/11/96	14906325DBBC1	263	268	18	18	4.5	7.4	250	0.4	458	0	110	97	1.2
12017A	9/5/06	14906325DBBC1	263	268	15	15	4.1	6.24	272	0.358	447	<1	106	98.5	0.13
12017B	9/2/87	14906325DBBC2	78	83	22	26	7.5	14	160	0.5	376	0	150	4.1	3.1
12017B	10/24/91	14906325DBBC2	78	83	26	25	7.5	7.9	130	0.5	416	0	45	7.5	5.6
12017B	9/11/96	14906325DBBC2	78	83	29	29	8.5	8.3	120	0.5	418	0	53	8.4	0.9
12017B	9/5/06	14906325DBBC2	78	83	27.2	27.2	8.9	7.31	118	0.359	380	<1	39.9	2.4	0.09
12017C	9/2/87	14906325DBBC3	51	56	31	72	20	5.1	6	0.3	314	0	25	1	0.4
12017C	10/24/91	14906325DBBC3	51	56	24	62	17	3.9	6.5	0.2	264	0	23	4.8	2.4
12017C	9/10/96	14906325DBBC3	51	56	66	66	19	4.3	5	0.2	293	0	26	3.7	0.6
12017C	9/5/06	14906325DBBC3	51	56	63.3	63.3	19.1	5.08	6.3	0.13	309	<1	28.6	1.6	<0.09
12017D	9/2/87	14906325DBBC4	23	28	32	72	19	5.2	5.5	0.2	319	0	19	1.3	1
12017D	10/24/91	14906325DBBC4	23	28	32	70	19	4.9	7	0.2	316	0	18	4	3
12017D	9/10/96	14906325DBBC4	23	28	74	74	19	4.3	6	0.2	325	0	20	2.9	0.1
12017D	9/6/01	14906325DBBC4	23	28	74	74	20	2	8	0.2	324	0	22	0	0.1
12017D	9/5/06	14906325DBBC4	23	28	63.2	63.2	18.4	4.69	7.8	0.202	309	<1	22.9	1.58	<0.09
12019A	9/1/87	14906323ADBB1	218	223	30	41	10	6.9	76	0.2	322	0	19	21	2.9
12019A	10/23/91	14906323ADBB1	218	223	28	44	11	6.3	67	0.2	331	0	23	16	4.3
12019A	9/11/96	14906323ADBB1	218	223	41	41	9.5	6.5	70	0.2	337	0	23	18	0.2
12019A	9/6/06	14906323ADBB1	218	223	38	38	9.6	5.9	77.3	0.17	331	<1	22.2	21.2	0.44
12019B	9/1/87	14906323ADBB2	32	37	28	74	21	3.6	6.5	0.2	298	0	40	1.6	0.4
12019B	10/23/91	14906323ADBB2	32	37	26	72	21	3.3	8	0.2	304	0	45	3.9	0.7
12019B	9/10/96	14906323ADBB2	32	37	77	77	22	3.1	6	0.1	310	0	53	1.7	0.4
12019B	9/6/06	14906323ADBB2	32	37	64.1	64.1	19.2	3.11	5.8	0.148	288	<1	39.1	1.76	0.13

Table 9 (cont.). General cations and anions for water samples from the WS-1 well set, CGS.

Well No.	Date_Sampled	Location	Top_Screen		Bottom_Screen	Silica	Calcium	Magnesium	Potassium	Sodium	Fluoride	Bicarbonate	Carbonate	Sulfate	Chloride	Nitrate
			Feet	Feet												
12019C	9/1/87	I4906323ADBB3	7	12	38	77	18	2.3	4	0.2	287	0	16	1	3.4	
12019C	10/23/91	I4906323ADBB3	7	12	27	82	20	1.2	3.5	0.2	331	0	9.9	3.4	24	
12019C	9/10/96	I4906323ADBB3	7	12	80	80	18	1.4	3.5	0.1	315	0	19	2.7	14	
12019C	9/6/01	I4906323ADBB3	7	12	78	78	21	1.3	5	0.2	284	0	37	0	10	
12019C	9/6/06	I4906323ADBB3	7	12	62.2	62.2	17.7	1.62	3.5	0.139	269	<1	21.9	1.64	14.7	
12020A	9/1/87	I4906314DACD1	212	217	31	20	6	12	640	0.5	752	0	430	360	0.6	
12020A	10/23/91	I4906314DACD1	212	217	30	13	4	9.5	510	0.6	772	0	340	160	3.7	
12020A	9/11/96	I4906314DACD1	212	217	9.3	9.3	4	10	490	0.7	782	0	330	140	2.3	
12020A	9/5/06	I4906314DACD1	212	217	10	10	3.6	7.95	542	0.66	761	<1	331	145	<0.09	
12020B	9/1/87	I4906314DACD2	151	156	31	14	4	8.4	310	0.7	659	0	200	20	0.5	
12020B	10/23/91	I4906314DACD2	151	156	29	15	3	7.9	320	0.6	671	0	190	23	1.8	
12020B	9/11/96	I4906314DACD2	151	156	11	11	4	9	310	0.6	693	0	190	19	0.2	
12020B	9/5/06	I4906314DACD2	151	156	11.6	11.6	3.1	7.01	352	0.649	664	<1	190	18.2	<0.09	
12020C	9/1/87	I4906314DACD3	38	43	32	73	23	6.8	18	0.2	341	0	35	3.9	2.4	
12020C	10/23/91	I4906314DACD3	38	43	29	70	23	5.8	15	0.2	335	0	35	5.6	1.4	
12020C	9/10/96	I4906314DACD3	38	43	73	73	23	5.5	15	0.2	353	0	31	4.5	1.8	
12020C	9/6/01	I4906314DACD3	38	43	74	74	23	4.9	16	0.3	338	0	32	9.7	2.7	
12020C	9/5/06	I4906314DACD3	38	43	64.4	64.4	22	5.21	12.1	0.19	318	<1	22.6	1.4	3.14	
12021A	9/1/87	I4906313BAABI	96	101	25	64	18	17	470	0.4	633	0	140	490	5.5	
12021A	10/23/91	I4906313BAABI	96	101	26	110	30	20	820	0.3	755	0	79	1100	0.1	
12021A	9/11/96	I4906313BAABI	96	101	110	110	30	25	830	0.3	782	0	77	1100	17	
12021A	9/6/01	I4906313BAABI	96	101	120	120	33	25	900	0.3	765	0	67	1100	0.2	
12021A	9/6/06	I4906313BAABI	96	101	104	104	28.6	21.8	974	0.32	730	<1	88.5	1070	0.09	
12022	9/1/87	I4906327DDDC2	158	163	10	29	8.5	14	2.5	0.1	161	0	61	1.8	1	
12022	11/19/91	I4906327DDDC2	158	163	28	53	15	9.2	64	0.3	299	0	89	15	1.2	
12022	9/11/96	I4906327DDDC2	158	163	57	57	15	8.6	65	0.3	308	0	94	41	0.2	

Table 9 (cont.). General cations and anions for water samples from the WS-1 well set, CGS.

Well No.	Date_Sampled	Location	Top_Screen		Silica	Calcium	Magnesium	Potassium	Sodium	Fluoride	Bicarbonate	Carbonate	Sulfate	Chloride	Nitrate
			Feet	Bottom_Screen											
12023A	9/2/87	14906336DDBC1	131	136	31	30	8	7.5	130	0.5	399	0	49	18	2
12023A	10/22/91	14906336DDBC1	131	136	27	28	7	6.9	140	0.3	413	0	48	20	0
12023A	9/11/96	14906336DDBC1	131	136		29	7	6.9	130	0.3	403	0	47	18	0.6
12023A	9/5/06	14906336DDBC1	131	136		26.1	7	5.94	138	0.3	408	<1	44.5	17.5	<0.09
12023B	9/2/87	14906336DDBC2	83	88	32	55	15	7.6	61	0.3	353	0	38	9.4	0.4
12023B	10/22/91	14906336DDBC2	83	88	29	56	16	7.6	52	0.2	353	0	35	9.2	0.4
12023B	9/11/96	14906336DDBC2	83	88		59	16	7.3	52	0.2	360	0	41	9.9	0.1
12023B	9/5/06	14906336DDBC2	83	88		52.5	15.5	6.56	53.2	0.196	347	<1	37.1	8.3	<0.09
12023C	9/2/87	14906336DDBC3	46	51	30	77	22	4.4	8	0.2	329	0	28	3.3	0.5
12023C	10/22/91	14906336DDBC3	46	51	27	72	21	5.6	16	0.2	339	0	30	5.5	3.7
12023C	9/10/96	14906336DDBC3	46	51		75	22	4.1	11	0.2	345	0	27	5.3	0.1
12023C	9/6/01	14906336DDBC3	46	51		78	23	2.9	8.5	0.2	355	0	20	4.5	0.1
12023C	9/5/06	14906336DDBC3	46	51		68.1	22.1	4.39	8.9	0.15	347	<1	25.5	3.9	<0.09
12024B	9/2/87	14806301CBBC2	151	156	30	40	11	7.9	75	0.3	339	0	40	4.8	1.7
12024B	10/23/91	14806301CBBC2	151	156	30	37	11	9.1	80	0.3	341	0	42	7.3	0
12024B	9/11/96	14806301CBBC2	151	156		38	11	7.5	82	0.2	344	0	44	6.7	0.1
12024B	9/5/06	14806301CBBC2	151	156		32.7	10.6	7.03	86.4	0.22	339	<1	41.9	5.4	<0.09
12025	9/1/87	14906326DCA	38	43	28	71	46	12	83	0.3	444	0	170	14	2
12025	10/24/91	14906326DCA	38	43	27	73	53	14	82	0.3	476	0	190	14	0
12025	9/12/96	14906326DCA	38	43		87	58	14	83	0.2	500	0	230	20	0.4
12025	9/6/01	14906326DCA	38	43		80	54	13	90	0.2	511	0	190	17	0.2
12025	9/6/06	14906326DCA	38	43		71.6	52.1	12.8	103	0.176	567	<1	154	16.3	0.09
12026A	9/1/87	14906334BBB1	251	256	27	47	23	14	120	0.5	428	0	110	23	1
12026A	11/19/91	14906334BBB1	251	256	30	49	15	7.7	59	0.5	328	0	47	13	0
12026A	9/12/96	14906334BBB1	251	256		52	14	7.2	50	0.5	318	0	48	10	0.3
12026A	9/6/06	14906334BBB1	251	256		45.6	13.4	6.14	52.7	0.451	305	<1	44.7	8	<0.09
12026B	9/1/87	14906334BBB2	27	32	27	74	25	4.7	28	0.2	298	0	89	8.5	1
12026B	10/24/91	14906334BBB2	27	32	25	71	23	3.6	18	0.2	289	0	72	8	5.1
12026B	10/22/92	14906334BBB2	27	32	25	70	23	3.1	16	0.1	281	0	66	5.6	7.6
12026B	9/12/96	14906334BBB2	27	32		75	24	3.5	18	0.2	305	0	63	5.5	17
12026B	9/6/06	14906334BBB2	27	32		71.9	24.9	2.94	11	0.089	316	<1	43	4.44	30.3

Table 10. Water Chemical Parameters for water samples from the WS-2 well set, CGS.

Well No.	Site No.	Location	Top Screen		Bottom Screen		Longitude	Latitude	Date Sampled	Field Cond. $\mu\text{S}/\text{cm}$	Lab Cond. $\mu\text{S}/\text{cm}$	Field pH	Lab pH	Field Temp $^{\circ}\text{C}$	TDS Det. mg/L	TDS Calc. mg/L	Hardness mg/L	NCH mg/L	%	
			Feet	Feet	Feet	Feet													SAR	NA
13084	12	14806302BABC1	69	74	-98.66510688	47.67110223	8/26/93	653	645	7.8	7.54	7	408	421	100	0	4.8	68		
13084	12	14806302BABC1	69	74	-98.66510688	47.67110223	9/6/06	655	686	7.5	8.28			425	107	0	4.55	68.7		
13085	12	14806302BABC2	12	17	-98.66510688	47.67110223	8/26/93	746	744	7.56	7.59	8	461	484	420	50	0.2	5		
13085	12	14806302BABC2	12	17	-98.66510688	47.67110223	9/6/06	831	878	8.17	7.58			544	442	114	0.27	5.9		
13086	7	14806302ACA1	97	102	-98.65665915	47.66852272	10/22/92	623	614	6.42	7.03	8	369	384	290	0	0.6	14		
13086	7	14806302ACA1	97	102	-98.65665915	47.66852272	9/3/96	524	586	7.52	7.52	8.5	377	348	280	0	0.6	15		
13086	7	14806302ACA1	97	102	-98.65665915	47.66852272	9/5/01	547	626	7.36	7.36		366	350	280	0	0.6	15		
13086	7	14806302ACA1	97	102	-98.65665915	47.66852272	9/11/06	367	377	7.9	7.42			234	196	0	0.09	3.2		
13087	7	14806302ACA2	18	23	-98.65665915	47.66852272	10/22/92	464	360	6.6	6.86	10	214	222	190	1	0.1	3		
13087	7	14806302ACA2	18	23	-98.65665915	47.66852272	9/3/96	337	363	7.58	7.58	7.7	235	201	200	0	0.1	2		
13087	7	14806302ACA2	18	23	-98.65665915	47.66852272	9/5/01	347	362	7.65	7.65		219	194	180	2	0.1	4		
13087	7	14806302ACA2	18	23	-98.65665915	47.66852272	9/11/06	593	617	8.01	7.4			383	276	0	0.58	14.8		
13088	9	14906313DAA1	95	100	-98.66220371	47.72232642	8/25/93	1299	1330	8.13	8.07	9	855	904	49	0	19	92		
13088	9	14906313DAA1	95	100	-98.66220371	47.72232642	9/13/06	1006	1060	8.49	7.93			657	74	0	10.3	85.6		
13089	9	14906313DAA2	30	35	-98.66220371	47.72232642	8/25/93	776	618	7.69	7.69	11	392	387	330	21	0.2	5		
13089	9	14906313DAA2	30	35	-98.66220371	47.72232642	9/13/06	555	581	9.02	7.3			360	302	23	0.13	3.6		
13090	8	14906219DBD1	95	100	-98.64120628	47.70405205	8/25/93	673	648	7.55	7.51	10	416	410	310	1	0.4	10		
13090	8	14906219DBD1	95	100	-98.64120628	47.70405205	9/13/06	682	510	8.32	7.55			316	258	10	0.12	3.7		
13106	8	14906219DBD3	43	48	-98.64120628	47.70405205	8/25/93	1109	494	6.87	7.66	10	310	326	250	0	0.2	6		
13106	8	14906219DBD3	43	48	-98.64120628	47.70405205	9/13/06	595	624	9.65	7.42			387	289	0	0.38	9.9		
13092	10	14906312CAC1	105	110	-98.66985835	47.73482973	8/25/93	867	898	7.23	7.8	11	573	575	140	0	5.5	68		
13092	10	14906312CAC1	105	110	-98.66985835	47.73482973	9/13/06	753	788	8.93	7.78			489	125	0	4.79	68.1		

Table 10 (cont.). Water Chemical Parameters for water samples from the WS-2 well set, CGS.

Well No.	Site No.	Location	Top Screen		Bottom Screen Feet	Longitude	Latitude	Date Sampled	Field Cond. $\mu\text{S}/\text{cm}$	Lab Cond. $\mu\text{S}/\text{cm}$	Field pH	Lab pH	Field Temp $^{\circ}\text{C}$	TDS Det. mg/L	TDS Calc. mg/L	Hardness mg/L	NCH mg/L	%	
			Feet	Feet														SAR	NA
13093	10	14906312CAC2	45	50	-98.66985835	47.73482973	8/25/93	581	572	6.35	7.6	12	354	348	290	6	0.3	9	
13093	10	14906312CAC2	45	50	-98.66985835	47.73482973	9/13/06	563	586	8.1	7.17			363	283	4	0.3	8.2	
13094	20	14906314AAB	17	22	-98.680243	47.730444	8/25/93	633	646	7.06	7.5	11	387	401	340	8	0.3	7	
13094	20	14906314AAB	17	22	-98.680243	47.730444	9/6/06	647	680	7.63	7.5			422	351	33	0.17	4.4	
13095	17	14806304ABA1	39.67	44.67	-98.70000214	47.67220701	8/24/93	656	551	7.35	7.56	10	357	353	210	0	1.2	28	
13096	17	14806304ABA2	25	30	-98.70000214	47.67220701	8/26/93	718	735	7.47	7.62	11	469	472	310	3	1.1	24	
13097	5	14906336ACA1	41	48	-98.66113372	47.68172516	10/22/92	543	501	6.65	7.02	10	297	307	210	0	0.7	18	
13097	5	14906336ACA1	41	48	-98.66113372	47.68172516	9/3/96	427	483	7.46	7.46	7.6	311	280	210	0	0.7	18	
13097	5	14906336ACA1	41	48	-98.66113372	47.68172516	9/4/01	472	519	7.52	7.52		300	291	210	0	0.8	22	
13097	5	14906336ACA1	41	48	-98.66113372	47.68172516	9/12/06	491	505	8.02	7.24			313	195	0	0.87	23.6	
13098	5	14906336ACA2	21	27	-98.66113372	47.68172516	10/22/92	491	469	6.63	6.89	10	276	284	230	0	0.2	7	
13098	5	14906336ACA2	21	27	-98.66113372	47.68172516	9/3/96	425	457	7.5	7.5	7.2	288	258	230	0	0.2	6	
13098	5	14906336ACA2	21	27	-98.66113372	47.68172516	9/4/01	455	499	7.49	7.49		286	263	240	0	0.2	7	
13098	5	14906336ACA2	21	27	-98.66113372	47.68172516	9/12/06	485	500	8.9	7.29			310	248	0	0.18	5.4	
13098	5	14906336ACA2	21	27	-98.66113372	47.68172516	9/12/06	485	501	8.9	7.32			311	251	0	0.18	5.3	
13099	13	14906335BCBA1	39.5	43.5	-98.69500484	47.68365693	8/24/93	728	748	7.08	7.42	13	477	468	330	15	1	20	
13099	13	14906335BCBA1	39.5	43.5	-98.69500484	47.68365693	9/6/06	701	741	6.94	7.59			459	354	44	0.47	11.1	
13100	13	14906335BCBA2	23	28	-98.69500484	47.68365693	8/24/93	629	634	7	7.32	14	392	410	320	22	0.5	11	
13100	13	14906335BCBA2	23	28	-98.69500484	47.68365693	9/6/06	660	699	7.57	7.38			433	337	35	0.39	9.5	
13101	6	14906325CDC1	110	115	-98.66851649	47.68746005	10/22/92	1041	1110	6.92	6.92	10	733	745	310	110	3	44	
13101	6	14906325CDC1	110	115	-98.66851649	47.68746005	9/5/96	890	1080	7.57	7.57	14.6	756	722	310	100	3	45	
13101	6	14906325CDC1	110	115	-98.66851649	47.68746005	9/5/01	1072	1160	7.36	7.36		740	716	310	110	3	44	
13101	6	14906325CDC2	110	115	-98.66851649	47.68746005	9/11/06	1117	1180	7.66	7.19			732	318	118	2.83	44.1	

Table 10 (cont.). Water Chemical Parameters for water samples from the WS-2 well set, CGS.

Well No.	Site No.	Location	Top_Screen		Bottom_Screen	Longitude	Latitude	Date_Sampled	Field_Cond.	Lab_Cond.	Field_pH	Lab_pH	Field_Temp	TDS_Det.	TDS_Calc.	Hardness	NCH	SAR	% NA
			Feet	Feet															
13102	6	14906325CDC2	25	30	30	-98.66851649	47.68746005	10/22/92	579	574	6.58	6.98	10	349	345	300	2	0.3	7
13102	6	14906325CDC2	25	30	30	-98.66851649	47.68746005	9/5/96	471	555	7.66	7.66	12.4	347	318	290	0	0.3	7
13102	6	14906325CDC2	25	30	30	-98.66851649	47.68746005	9/5/01	614	642	7.39	7.39		363	357	320	0	0.3	7
13102	6	14906325CDC1	25	30	30	-98.66851649	47.68746005	9/11/06	608	628	7.64	7.35			389	320	5	0.25	6.5
13103	1	14906228CCC1	139	144	144	-98.60948722	47.68746434	10/21/92	958	959	7.26	7.24	8	629	631	110	0	7.5	76
13103	1	14906228CCC1	139	144	144	-98.60948722	47.68746434	9/5/96	794	924	7.58	7.58	9.4	629	599	120	0	7.1	75
13103	1	14906228CCC1	139	144	144	-98.60948722	47.68746434	9/4/01	916	996	7.59	7.59		622	602	120	0	7.1	75
13103	1	14906228CCC1	139	144	144	-98.60948722	47.68746434	9/12/06	922	973	7.75	7.23			603	128	0	6.3	73.5
13104	1	14906228CCC2	56	61	61	-98.60948722	47.68746434	10/21/92	661	636	7.07	7.05	8	386	406	280	0	0.7	17
13104	1	14906228CCC2	56	61	61	-98.60948722	47.68746434	9/4/96	515	611	7.51	7.51	9.1	394	361	270	0	0.7	16
13104	1	14906228CCC2	56	61	61	-98.60948722	47.68746434	9/4/01	619	653	7.26	7.26		390	370	280	0	0.7	17
13104	1	14906228CCC2	56	61	61	-98.60948722	47.68746434	9/12/06	596	619	8.14	7.24			384	269	0	0.59	15.2
13105	2	14906229DAD	50	55	55	-98.61142796	47.69146637	10/21/92	608	628	7	6.78	10	395	403	320	20	0.3	7
13105	2	14906229DAD	50	55	55	-98.61142796	47.69146637	9/4/96	527	605	7.48	7.48	8.5	393	356	300	0	0.3	7
13105	2	14906229DAD	50	55	55	-98.61142796	47.69146637	9/4/01	600	656	7.41	7.41		400	365	310	11	0.3	7
13105	2	14906229DAD	50	55	55	-98.61142796	47.69146637	9/11/06	628	640	7.4	7.23			397	316	18	0.26	6.8

Table 11. General cations and anions for water samples from the WS-2 well set, CGS.

Well No.	Site No.	Date Sampled	Location	Top Screen		Bottom Screen		Silica	Calcium	Magnesium	Potassium	Sodium	Fluoride	Bicarbonate	Carbonate	Sulfate	Chloride	Nitrate
				Feet	Feet	Feet	Feet											
13084	12	8/26/93	14806302BABC1	69	74	29	27	8.5	6.2	110	0.3	399	0	26	12	4.5		
13084	12	9/6/06	14806302BABC1	69	74	29	29	8.3	5.58	108	0.286	396	2	27.1	9.28	<0.09		
13085	12	8/26/93	14806302BABC2	12	17	26	110	35	3.2	9.5	0.1	450	0	65	7.1	5.7		
13085	12	9/6/06	14806302BABC2	12	17	26	117	36.3	3.46	12.9	0.054	399	<1	61.5	14.1	73.9		
13086	7	10/22/92	14806302ACA1	97	102	25	83	21	5.1	23	0.2	371	0	37	3.8	1.1		
13086	7	9/3/96	14806302ACA1	97	102	25	78	20	5.4	23	0.2	369	0	37	0.5	0.4		
13086	7	9/5/01	14806302ACA1	97	102	25	78	20	5.3	24	0.2	370	0	37	2	0.2		
13086	7	9/11/06	14806302ACA1	97	102	25	55.5	13.8	1.82	<3	0.091	240	<1	1.98	0.97	0.97		
13087	7	10/22/92	14806302ACA2	18	23	26	53	15	1.6	2.5	0.1	236	0	4.5	2.2	0.8		
13087	7	9/3/96	14806302ACA2	18	23	26	55	15	1.6	2	0.1	246	0	4.5	0.2	0.5		
13087	7	9/5/01	14806302ACA2	18	23	26	51	14	1.7	3.5	0	223	0	9.1	4.3	0.3		
13087	7	9/11/06	14806302ACA2	18	23	26	78.5	19.4	5.42	22.2	0.165	359	<1	37	2.69	0.27		
13088	9	8/25/93	14906313DAA1	95	100	59	13	4	8.9	300	0.7	716	0	150	8.4	5		
13088	9	9/13/06	14906313DAA1	95	100	59	19.6	6.1	5.98	203	0.58	563	<1	92.4	5.17	1.64		
13089	9	8/25/93	14906313DAA2	30	35	28	83	31	4.5	9	0.2	383	0	35	6.2	1.2		
13089	9	9/13/06	14906313DAA2	30	35	28	77	26.7	3.95	5.2	0.153	339	<1	27.1	4.28	3.45		
13090	8	8/25/93	14906219DBD1	95	100	31	89	21	13	16	0.2	375	0	45	3.7	5.6		
13090	8	9/13/06	14906219DBD1	95	100	31	74	17.7	5.87	4.6	0.201	301	<1	19.4	1.49	1.99		
13106	8	10/21/92	14906219DBD3	43	48	40	69	18	7.8	8	0.2	311	0	23	4.7	1.1		
13106	8	9/4/96	14906219DBD3	43	48	40	85.3	18.3	11.2	14.7	0.223	353	<1	41.5	1.7	0.93		
13092	10	8/25/93	14906312CAC1	105	110	28	38	11	9.9	150	0.4	453	0	79	30	5.4		
13092	10	9/13/06	14906312CAC1	105	110	28	34.6	9.3	6.91	123	0.38	412	<1	58.9	12.6	1.77		

Table 11 (cont.). General cations and anions for water samples from the WS-2 well set, CGS.

Well No.	Site No.	Date Sampled	Location	Top_ Screen		Silica mg/L	Calcium mg/L	Magnesium mg/L	Potassium mg/L	Sodium mg/L	Fluoride mg/L	Bicarbonate mg/L	Carbonate mg/L	Sulfate mg/L	Chloride mg/L	Nitrate mg/L
				Feet	Bottom_ Screen Feet											
13093	10	8/25/93	14906312CAC2	45	50	26	78	23	5.1	13	0.2	346	0	27	2.7	1.3
13093	10	9/13/06	14906312CAC2	45	50	50	77.7	21.6	5.51	11.7	0.212	339	<1	36.5	2.21	1.24
13094	20	8/25/93	14906314AAB	17	22	29	88	30	3.9	12	0.2	409	0	24	7.6	2.3
13094	20	9/6/06	14906314AAB	17	22	22	93.1	28.8	3.8	7.4	0.223	387	<1	34.7	8.98	<0.09
13095	17	8/24/93	14806304ABA1	39.67	44.67	28	57	16	7	39	0.2	311	0	41	6.7	4
13096	17	8/26/93	14806304ABA2	25	30	26	81	25	4.6	46	0.1	369	0	94	11	1
13097	5	10/22/92	14906336ACA1	41	48	25	60	15	6.7	23	0.2	302	0	23	2.6	1.8
13097	5	9/3/96	14906336ACA1	41	48	48	60	15	6.4	22	0.2	305	0	26	0.2	0.1
13097	5	9/4/01	14906336ACA1	41	48	48	58	15	6.4	28	0.2	311	0	30	0	0.3
13097	5	9/12/06	14906336ACA1	41	48	48	56.2	13.2	6.63	27.8	0.228	296	<1	25.5	2.22	<0.09
13098	5	10/22/92	14906336ACA2	21	27	24	67	16	5.3	8	0.2	288	0	17	3.5	0
13098	5	9/3/96	14906336ACA2	21	27	27	65	16	3.8	7	0.2	300	0	16	0	0.2
13098	5	9/4/01	14906336ACA2	21	27	27	69	17	4	8.5	0.2	296	0	17	0	0.1
13098	5	9/12/06	14906336ACA2	21	27	27	71.6	16.7	4.47	6.5	0.179	307	<1	12.8	1.72	<0.09
13098	5	9/12/06	14906336ACA2	21	27	27	72	17.3	4.22	6.5	0.176	306	<1	12.7	1.76	<0.09
13099	13	8/24/93	14906335BCBA1	39.5	43.5	6.5	83	30	5.7	40	0.1	385	0	100	7.8	1.5
13099	13	9/6/06	14906335BCBA1	39.5	43.5	28	90.8	30.8	3.93	20.4	0.127	376	<1	81.1	5.59	<0.09
13100	13	8/24/93	14906335BCBA2	23	28	26	84	27	4.7	19	0.2	364	0	60	7.7	0.9
13100	13	9/6/06	14906335BCBA2	23	28	28	88.7	27.9	4.1	16.4	0.126	367	<1	68.6	5.6	<0.09
13101	6	10/22/92	14906325CDC1	110	115	25	94	19	13	120	0.4	250	0	300	46	2.2
13101	6	9/5/96	14906325CDC1	110	115	115	91	19	11	120	0.4	246	0	310	43	5
13101	6	9/5/01	14906325CDC1	110	115	115	94	19	12	120	0.3	245	0	300	48	0.2
13101	6	9/11/06	14906325CDC2	110	115	115	96.6	18.5	10.3	116	0.354	242	<1	321	54.7	

Table 11 (cont.). General cations and anions for water samples from the WS-2 well set, CGS.

Well No.	Site No.	Location	Top Screen		Bottom Screen Feet	Silica mg/L	Calcium mg/L	Magnesium mg/L	Potassium mg/L	Sodium mg/L	Fluoride mg/L	Bicarbonate mg/L	Carbonate mg/L	Sulfate mg/L	Chloride mg/L	Nitrate mg/L
			Feet	mg/L												
13102	6	10/22/92 14906325CDC2	25	30	25	77	25	4.3	11	0.2	359	0	22	3.1	0.1	
13102	6	9/5/96 14906325CDC2	25	30	24	75	24	4.3	10	0.2	366	0	23	1.2	0.1	
13102	6	9/5/01 14906325CDC2	25	30	27	84	27	4.5	12	0.2	398	0	28	4.5	0.1	
13102	6	9/11/06 14906325CDC1	25	30	25.4	86.1	25.4	4.59	10.3	0.187	383	<1	24.3	3.44	0.09	
13103	1	10/21/92 14906228CCC1	139	144	32	32	8	8.8	180	0.3	482	0	130	6.1	2.9	
13103	1	9/5/96 14906228CCC1	139	144	34	34	8	7.4	180	0.3	481	0	130	1.4	0.3	
13103	1	9/4/01 14906228CCC1	139	144	35	35	8	7.1	180	0.4	480	0	130	4.2	0.2	
13103	1	9/12/06 14906228CCC1	139	144	37.6	37.6	8.3	6.87	164	0.316	464	<1	128	3.49	0.09	
13104	1	10/21/92 14906228CCC2	56	61	78	78	20	10	27	0.2	372	0	49	3.5	4.3	
13104	1	9/5/96 14906228CCC2	56	61	76	76	19	9.7	25	0.2	376	0	45	0.3	0.2	
13104	1	9/4/01 14906228CCC2	56	61	78	78	20	10	27	0.2	380	0	47	0	0.3	
13104	1	9/12/06 14906228CCC2	56	61	77.5	77.5	18.3	9.53	22.3	0.212	348	<1	42.2	1.66	0.35	
13105	2	10/21/92 14906229DAD	50	55	88	88	24	7.3	12	0.2	365	0	54	1.7	2	
13105	2	9/4/96 14906229DAD	50	55	84	84	22	7.8	11	0.2	368	0	49	0.2	0.2	
13105	2	9/4/01 14906229DAD	50	55	88	88	23	8	12	0.2	370	0	51	0	0.1	
13105	2	9/12/06 14906229DAD	50	55	90	90	22.2	8.23	10.6	0.221	362	<1	47.8	1.73	<0.09	

RESULTS FOR 2006 SAMPLING AND ASSESSMENT

General Chemistry and Trace Elements in CGS Ground Water

Two well sets were constructed on the CGS facility. The first well set, labeled WS-1, was constructed using solvent-weld glue, and suitable for water samples used to determine general chemistry and some trace elements. The second well set, labeled WS-2, was designed specifically to target CGS land uses, including munitions and explosives residues, herbicides, insecticides, and petroleum product residues. Both well sets are described in the METHODS section of this report.

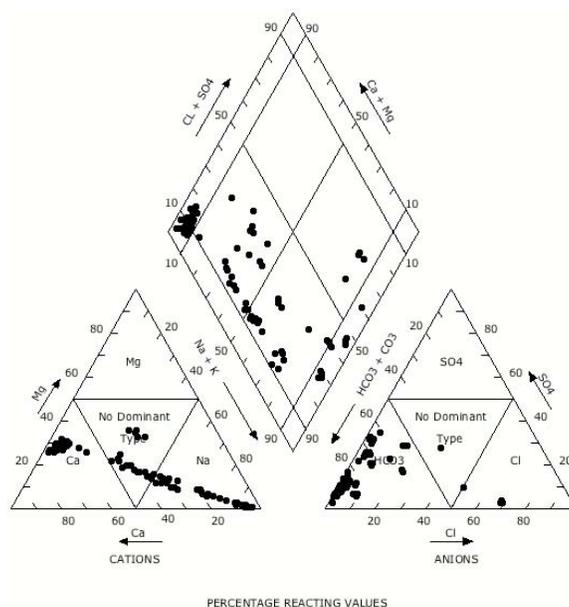


Figure 6. Piper diagram showing cation and anion distributions of the WS-1 wells.

General Chemistry in WS-1 and WS-2 Wells

Well parameters and general chemistry for the WS-1 wells are on Tables 8 and 9, respectively. Well parameters and general chemistry for the WS-2 wells are on Tables 10 and 11, respectively. Water from all wells of both the WS-1 (Fig. 6) and WS-2 (Fig. 7) well sets is predominantly of calcium and sodium bicarbonate types, with some percentage gradation between the two dominant cations. There are a few exceptions with respect to anion chemistry. Well 12021A of the WS-1 set is chloridic. It is located near a

wetland near the northern border of the CGS lands and is screened at 96 to 101 feet bls. This well contains the only predominantly chloridic water identified in CGS wells. Well 12021A is screened only 23 feet above the Pierre shale (at 124 feet). Its chemistry is likely controlled by diffusion from the pore-water of the shale, enhanced somewhat by evaporative draw from the overlying wetland. Another exceptional water source is Well 13101 of the WS-2 well set. This well is the deepest (110 to 115 feet screened interval) of the well nest placed at Site 6, in a wetland near the southeast shore of Lake Coe. Its chemistry is predominantly of the calcium-sodium sulfate type.

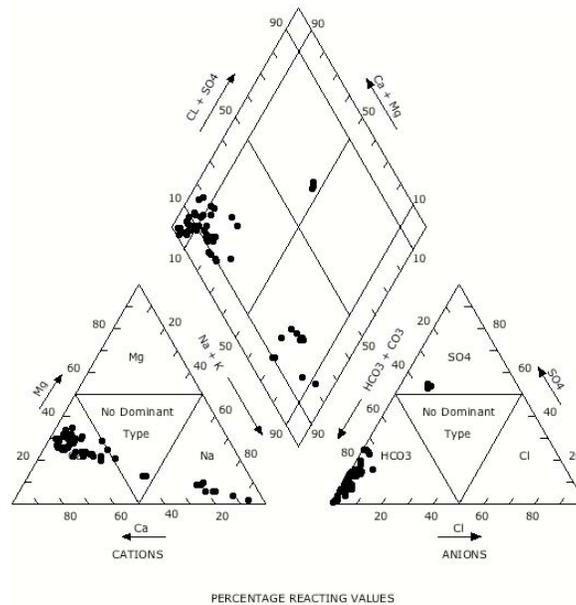


Figure 7. Piper diagram showing cation and anion distributions of the WS-2 wells.

Nitrate in WS-1 and WS-2 Wells

The EPA-MCL for nitrate (as NO_3^-) is 44 mg/L (or 10 mg/L for nitrate as N). One survey (Burkhardt and Kolpin, 1993) has indicated that ground-water unaffected by human activities usually has concentrations less than 13 mg/L (3 mg/L as N). For this report all concentrations will be reported as nitrate (NO_3^-) rather than nitrate-N.

Nitrate-N above the EPA-MCL has been reported to vary from 0 to 25% of reported drinking-water wells in surveys conducted in the Northern Great Plains of the United States and Canada (Harker and others, 1997). These percentages have been

confirmed in annual reports of the North Dakota Department of Health during the 1990s (Bartelson, 1993-2006). Nitrate is frequently found to be stratified in North Dakota aquifers, with high concentrations near the surface and low concentrations within a few feet of the surface (Mayer 1992, Korom and others 2005, Casey and others 2002, Schuh and others 1997, Schuh and others 2006). This has been found to occur under numerous agricultural systems, including numerous irrigated crops, dryland hay, wheat and soybeans, and hay and pasture systems (which have little applied N, but often leguminous plants which fix nitrogen, and, in the case of pastures, animal manure.) Summer fallow has also found to be a common source of nitrate-N (Bauder and others,1993).

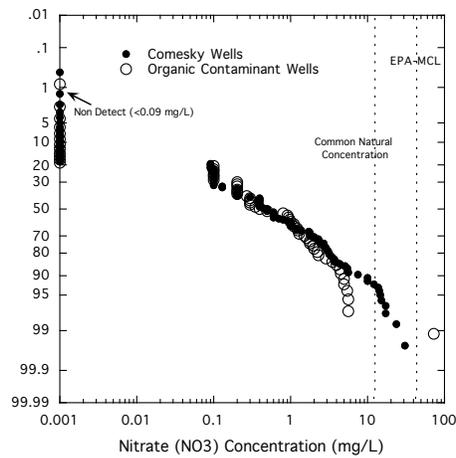


Figure 8. Probability distribution of nitrate concentrations in WS-1 and WS-2 wells from 1987 through 2006.

By contrast, nitrate concentrations for both the WS-1 (Table 9) and the WS-2 (Table 11) wells are low. The distribution of nitrate-N in well-water samples is shown on Figure 8. Results are for all samples collected from 1987 through 2006. Thirty (30) % of the samples are non detects, 70% are less than 1 mg/L, all of the WS-2 and 95% of the WS-1 well samples are below the common natural background concentration of 13 mg/L, and all but one measurement are below the EPA-MCL.

The single sample above the EPA-MCL (73.9 mg/L. Table 11) is for the shallow well (SI 7 to 12 feet) at the Pinkerton Farm site (Site 12 of WS-1). This site is located in a pasture near a wetland. During almost all sampling events the pasture was being actively grazed and manure deposits were common near the wells. The source of the nitrate was most likely cattle manure and urine, although nitrate could also be released from soil organic matter during periods of wetland recession, which would increase local

aeration and cause mineralization of the carbon-nitrogen pool. The deeper well in the same nest indicated no nitrate detections in 2006.

Although the measured concentration was almost double the EPA-MCL, similar stratified concentrations in shallow wells are common under almost all agricultural uses including pasture and summer fallow. A shallow stratified concentration does not indicate that the aquifer is contaminated, and should not in itself be of concern from the standpoint of land management.

Wells of the WS-1 set having highest nitrate concentrations (Table 9) include 12019C (SI 7 to 12 feet bls) which initially was 3.4 mg/L, increased to 24 mg/L, and then declined to 14.7 mg/L. Similar to the Site 12 well discussed above, these detections were in a shallow well in a pasture near a wetland. Well 12014D had a maximum concentration of 15 mg/L. This well was screened near the water table (SI 24 to 29 feet bls) near a cattle loading dock, and adjacent to a wetland. Finally, slightly elevated nitrate concentrations were measured at Well 12026B. The well was screened near the water table (SI 24 to 29 feet bls) in a pasture.

The temporal distribution of nitrate concentrations is also important. Most wells, including deep wells, began with low but detectable concentrations shortly after drilling and then gradually declined. The cause of early detections was most likely the introduction of nitrate and organic matter during the process of drilling, which requires the circulation of drilling fluid, and therefore tends to carry with it organic materials from near the surface. The gradual decline in nitrate would occur through dilution, and frequently through denitrification, either using introduced organic matter or reduced iron or sulfide as an electron donor (Korom and others 2005). The detectable concentrations in the distribution shown on Figure 8 are disproportionately higher for early sample times than they are for the most recent samplings (Tables 9 and 11). More recent nitrate concentrations tend to be lower than initial measured values.

In conclusion, nitrate concentrations in ground water of the CGS facility are generally low. Where they are slightly elevated, it is almost always under active pasture, and it is usually near a wetland. Sources are most likely cattle manure and urine. While comparatively high locally, these detections are all below levels of toxicological concern and within levels common to good management, and should not be of concern from a management or regulatory standpoint. Overall nitrate concentrations are lower now than they were at early times following the drilling of the wells. Nitrate from topsoil was likely introduced during drilling, and is gradually being cleared from the deeper wells through denitrification and diffusion. There is no evidence of a ground-water nitrate problem caused by CGS use or land management practices.

Minor and Trace Element Concentrations in WS-1 and WS-2 Wells

Results for minor and trace elements for WS-1 and WS-2 wells are shown on Tables 12 and 13 (pp 55 to 61). Minor and trace elements measured include aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), Lithium (Li), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), Selenium (Se), silver (Ag), strontium (Sr), thallium (Tl), and zinc (Zn). Of these, barium and lead might be expected to affect ground water as residues of munitions and explosives training on the firing and demolition ranges. Other metals, used as alloys, might be detected from microscopic shavings of metals in lubricating oils improperly disposed of, or through accidents.

For both well sets, none of the trace elements, with the exception of arsenic (discussed separately) were detected at concentrations of toxicological concern, or displayed trends of increasing concentrations. Lead and mercury concentrations, specifically, were below detection levels in almost all samples.

These data indicate that current CGS management practices are adequately protecting ground and surface waters. There are management factors, however, that could change this. Because of the sensitivity of many trace elements to pH with respect to mobilization, particular care should be taken to avoid practices that radically increase or decrease pH. Lead, for example, would tend to become more mobile at a lower pH. Acidification of soil in the firing range areas could be caused by additions of large quantities of ammonium fertilizer or urea, or through addition of elemental sulfur. While there is no reason to believe that these materials would be added, there should be a general awareness of the importance of maintaining the soil and geo-chemical stability of the environment in which potentially toxic trace elements are heavily used.

Arsenic Concentrations in CGS Waters

Camp Grafton (South Unit) is located within what Erickson and Barnes (2005a,b) call the "footprint" of the Northwest Provenance of the late Wisconsinan glacial drift. Erickson and Barnes (2005a) have shown that public water supplies within this "footprint" have a higher (greater than 12%) incidence of arsenic concentrations above the U.S. Environmental Protection Agency (USEPA) Maximum allowable Contaminant Level (MCL) of 10 µg/L, compared with about 2.5% for public water supplies tested outside of the footprint. Arsenic concentrations are highly variable in CGS ground water and surface waters, and range from about 2 µg/L to as high as 70 µg/L. They vary spatially (both depth and location) and temporally, decreasing or increasing on some measurements sites. Highest concentrations have been in Lake Coe (exceeding 20 µg/L), South Washington Lake (as high as 70 µg/L), and in the wells of Sites 1 and 2 (well set WS-2) east of the east of the GCEM ranges, in the Colvin Creek watershed.

Arsenic is near sulfur on the periodic table, and is among the oxyanion forming elements (including As, Se, Sb, Mo, V, Cr, U, and Re) (Smedley and Kinniburgh 2002). It is reduced at an oxidation-reduction state slightly above sulfur, but below iron and manganese. Reduced arsenic is present in many of the high-organic Cretaceous shales common to the northern Great Plains, particularly those containing pyrite, where it is found in arseno-pyrite. Background arsenic concentrations in glacial soils formed through weathering and oxidation of shale detritus from Wisconsinan till have been reviewed by Erickson and Barnes (2005a), and have been found to be in the range of about 2 to 10 µg/L.

Several environmental and geochemical factors control, and ultimately, affect the mobility of arsenic. These include (1) pH, (2) oxidation state, (3) the presence of iron, manganese, and other metal-oxide minerals, and (4) the presence of carbonate, phosphate, and silicate anions. When reduced arsenic-containing minerals are exposed and oxidized they release arsenic into solution as oxides of As(III) (reduced) and As(V) (oxidized). As(V) is most common in field oxidation states, and its most common oxyanion (arsenate) strongly adsorbs on the surface of iron oxides. Thus, although oxidation may release arsenic from its mineral reservoir in weathered shales and glacial drift, it also tends to release and oxidize iron. This, in turn, removes arsenic from solution. When reducing conditions occur (reducing environments are common in buried sediments or till containing organic matter or minerals containing reduced sulfur) iron and manganese oxides reduce and mobilize, removing adsorption surfaces and releasing arsenic into solution.

At high pH values (greater than 8.5) arsenic desorbs from iron-oxide surfaces. Smedley and Kinniburgh (2002) have stated that "Desorption at high pH is the most likely mechanism for the development of groundwater-As problems under oxidizing conditions and would account for the observed positive correlation of As concentrations with increasing pH." Competition for sorption surfaces from other strongly sorbed anions, including carbonate, phosphate and silicate ions, can also enhance the release of arsenate into solution.

Conditions cited for high-arsenic environments include ground-water sources formed in fluvial deltaic environments which have substantial organic matter, contributing to reducing conditions, and/or high pH conditions, and/or competing anions, and slow ground-water movement which delays flushing of mobilized arsenic from pore-water.

The Cherry Lake aquifer is a glacio-fluvial deposit, and the littoral areas of CGS would tend to have substantial organic matter. It also directly overlies a high-organic Cretaceous shale of the Pierre Formation. Some members of the Pierre Formation have reduced sulfur in the form of pyrite (Schuh and others 2006), and have been shown to

contain arsenic as well. While reducing conditions likely occur within the some strata of the Cherry-Lake aquifer, the relatively short time of deposition and weathering (less than 15 thousand years since deposition) and the rate of movement of water through the aquifer are likely sufficient to prevent the dangerously large concentrations found in some parts of the world. Concentrations are, nonetheless, substantial in some parts of the aquifer.

Table 12. Dissolved minor and trace element concentrations in the WS-1 well set.

Well No.	Location	Top_Screen	Bottom_Screen	Date_Sampled	B	Fe	Mn	Se	Pb	Hg	As	Li	Mo	Sr	Cd	Al	Be	Cr	Ni	Cu	Ba	Zn	Cd	Ag	Sb	Tl
					mg/L	mg/L	mg/L	µg/L																		
12011B	14906335ABBD2	45	50	9/1/87	0.3	0.76	0.29	0	0	0	22	79	5	410	<1	<50	<1	<1	4.15	1.35	42.9	13	<1	<1	<1	
12011B	14906335ABBD2	45	50	10/24/91	0.24	0.37	0.34	0	0	0.1	16	80	4	450	47	9	0.1									
12011B	14906335ABBD2	45	50	9/10/96		1.2	0.29	0	0	0	20	80	3	460	44											
12011B	14906335ABBD2	45	50	9/6/01		1	0.27	3	2	0	24	100	4	470	100											
12011B	14906335ABBD2	45	50	9/6/06	0.299	1.03	0.241	<1	<1	25.9					<1	<50	<1	<1	4.15	1.35	42.9	13	<1	<1	<1	
12012	14906327DDDC1	164	169	9/6/06	0.396	<0.01	1.09	<1	<1	<1					<1	<50	<1	<1	4.45	1.28	26.6	19.8	<1	<1	<1	
12013B	14906336BDDA2	22	27	9/1/87	0.23	0.01	0.11	0	0	0	20	48	13	380												
12013B	14906336BDDA2	22	27	10/24/91	0.19	0.01	0.34	0	0	0.1	12	50	11	400	62	9	0.1									
12013B	14906336BDDA2	22	27	9/11/96		0.03	0.36	0	0	0	22	40	10	360	46											
12013B	14906336BDDA2	22	27	9/6/06	0.25	0.051	0.392	<1	<1	22.6					<1	<50	<1	<1	6.01	1.2	72.5	7.17	<1	<1	<1	
12014B	14906336AACB2	181	186	9/2/87	0.5	0.03	1.1	1	0	0	1	120	9	480												
12014B	14906336AACB2	181	186	10/22/91	0.48	0.03	1	0	0	0	1	100	5	500	62	7	0									
12014B	14906336AACB2	181	186	9/11/96		0.02	1.1	0	0	0	0	110	8	430	77											
12014B	14906336AACB2	181	186	9/5/06	0.577	<0.01	0.94	<1	1.58	2.01					<1	<50	<1	1.23	5.2	2.53	57.5	31.1	<1	<1	1.57	
12014C	14906336AACB3	64	69	9/2/87	0.06	0.18	0.81	1	0	0.1	13	30	2	420												
12014C	14906336AACB3	64	69	10/22/91	0.04	0.23	0.61	0	0	0	11	30	2	460												
12014C	14906336AACB3	64	69	9/11/96		0.37	0.6	0	0	0	8	30	4	370	21	13	0									
12014C	14906336AACB3	64	69	9/5/06	0.084	0.358	0.548	<1	1.52	12.4					<1	<50	<1	1.26	5.72	1.46	180	46.2	<1	<1	1.55	
12014D	14906336AACB4	24	29	9/2/87	0.03	0.02	0.03	1	0	0	0	14	3	220												
12014D	14906336AACB4	24	29	10/22/91	0.03	0.01	0.02	0	0	0	0	10	1	250												
12014D	14906336AACB4	24	29	9/10/96		0.01	0.02	0	0	0	0	20	0	220												
12014D	14906336AACB4	24	29	9/6/01		0.08	0.04	3	2	0	2	100	2	220												
12014D	14906336AACB4	24	29	9/5/06	0.061	0.013	0.034	<1	1.53	<1					<1	<50	<1	1.08	5.72	1.96	92.3	15.8	<1	<1	1.55	
12015B	14906231ABBC2	162	167	9/1/87	0.28	0.04	0.27	0	1	0	42	79	26	330												
12015B	14906231ABBC2	162	167	10/23/91	0.26	0.02	0.2	0	0	0	1	80	18	390												
12015B	14906231ABBC2	162	167	9/11/96		0.15	0.21	0	0	0	47	70	19	320												
12015B	14906231ABBC2	162	167	9/5/06	0.326	0.169	0.22	<1	<1	54					<1	<50	<1	<1	2.55	1.16	47.9	12.7	<1	<1	<1	

Table 12 (cont.). Dissolved minor and trace element concentrations in the WS-1 well set.

Well No.	Location	Top_ Screen	Bottom_ Screen	Date_ Sampled	B	Fe	Mn	Se	Pb	Hg	As	Li	Mo	Sr	Cd	Al	Be	Cr	Ni	Cu	Ba	Zn	Cd	Ag	Sb	Tl
					mg/L	mg/L	mg/L	μg/L																		
12015C	14906231ABBC3	78	83	10/23/91	0.01	0.02	1.1	0	0	0	10	20	4	350	<1	<50	<1	<1	<1	<1	160	6	0	<1	<1	
12015C	14906231ABBC3	78	83	9/11/96	0.3	0.64	0	0	0	0	10	20	1	290	<1	<50	<1	<1	<1	<1	120	6	0	<1	<1	
12015C	14906231ABBC3	78	83	9/6/01	0.08	0.46	0.46	3	2	0	11	100	3	300	<1	<50	<1	<1	<1	<1	120	15.1	<1	<1	<1	
12015C	14906231ABBC3	78	83	9/5/06	0.052	0.068	0.435	<1	<1	<1	11.2	<1	<1	<1	<1	<50	<1	3.81	<1	<1	121	15.1	<1	<1	<1	
12017A	14906325DBBC1	263	268	9/1/87	0.65	0.01	0.24	0	0	0	5	99	200	170	<1	<50	<1	1.03	1.82	3.45	25.7	7.35	<1	<1	<1	
12017A	14906325DBBC1	263	268	10/24/91	0.71	0	0.24	0	1	0.1	2	100	4	200	<1	<50	<1	<1	<1	<1	26	14	0	<1	<1	
12017A	14906325DBBC1	263	268	9/11/96	0.02	0.28	0	0	0	0	4	100	20	190	<1	<50	<1	<1	<1	<1	24	11	0.4	<1	<1	
12017A	14906325DBBC1	263	268	9/5/06	0.826	<0.01	0.253	1.83	<1	<1	4.7	<1	<1	<1	<1	<50	<1	1.5	1.63	<1	44.6	7.46	<1	<1	<1	
12017B	14906325DBBC2	78	83	9/2/87	0.55	0.01	0.15	0	0	0	13	87	300	270	<1	<50	<1	<1	<1	<1	38	11	0.4	<1	<1	
12017B	14906325DBBC2	78	83	10/24/91	0.47	0.01	0.11	0	0	0.1	19	80	12	260	<1	<50	<1	<1	<1	<1	35	11	0.4	<1	<1	
12017B	14906325DBBC2	78	83	9/11/96	0.15	0.13	0	0	0	0	25	70	15	270	<1	<50	<1	<1	<1	<1	35	11	0.4	<1	<1	
12017B	14906325DBBC2	78	83	9/5/06	0.465	0.152	0.137	<1	<1	<1	45.5	<1	<1	<1	<1	<50	<1	2.78	<1	105	7.71	<1	<1	<1		
12017C	14906325DBBC3	51	56	9/2/87	0.06	0.09	0.5	0	0	0.3	6	21	4	270	<1	<50	<1	<1	<1	<1	85	9	0	<1	<1	
12017C	14906325DBBC3	51	56	10/24/91	0.03	0	0.03	0	0	0.1	3	20	2	260	<1	<50	<1	<1	<1	<1	120	6	0	<1	<1	
12017C	14906325DBBC3	51	56	9/10/96	0.08	0.25	0	0	0	0	3	20	2	260	<1	<50	<1	<1	<1	<1	120	6	0	<1	<1	
12017C	14906325DBBC3	51	56	9/5/06	0.065	0.077	0.423	<1	<1	<1	6.23	<1	<1	<1	<1	<50	<1	3.28	<1	105	7.71	<1	<1	<1		
12017D	14906325DBBC4	23	28	9/2/87	0.07	1.1	0.93	0	0	0	8	21	4	290	<1	<50	<1	<1	<1	<1	150	6	0	<1	<1	
12017D	14906325DBBC4	23	28	10/24/91	0.04	1.8	0.74	0	0	0.1	2	20	1	320	<1	<50	<1	<1	<1	<1	150	6	0	<1	<1	
12017D	14906325DBBC4	23	28	9/10/96	1.8	0.69	0	0	0	0	3	20	0	300	<1	<50	<1	<1	<1	<1	190	6	0	<1	<1	
12017D	14906325DBBC4	23	28	9/6/01	2	0.61	0.61	3	2	0	6	100	3	280	<1	<50	<1	<1	<1	<1	130	11.6	<1	<1	<1	
12017D	14906325DBBC4	23	28	9/5/06	0.069	1.25	0.543	<1	<1	<1	5.26	<1	<1	<1	<1	<50	<1	3.28	<1	127	11.6	<1	<1	<1		
12019A	14906323ADBB1	218	223	9/1/87	0.15	0.09	0.43	1	1	5	45	9	400	<1	<50	<1	<1	<1	<1	<1	170	5	0.1	<1	<1	
12019A	14906323ADBB1	218	223	10/23/91	0.14	0.11	0.41	0	0	0	3	50	7	450	<1	<50	<1	<1	<1	<1	120	7	0	<1	<1	
12019A	14906323ADBB1	218	223	9/11/96	0.12	0.42	0	0	0	0	3	40	4	380	<1	<50	<1	<1	<1	<1	165	129	<1	<1	<1	
12019A	14906323ADBB1	218	223	9/6/06	0.214	0.039	0.392	<1	<1	<1	3.77	<1	<1	<1	<1	<50	<1	4.28	5.04	<1	165	129	<1	<1	<1	
12019B	14906323ADBB2	32	37	9/1/87	0.04	0.21	0.44	1	1	0.1	3	17	1	230	<1	<50	<1	<1	<1	<1	170	7	0	<1	<1	
12019B	14906323ADBB2	32	37	10/23/91	0.05	0.05	0.35	1	1	0.1	2	20	1	260	<1	<50	<1	<1	<1	<1	170	7	0	<1	<1	
12019B	14906323ADBB2	32	37	9/10/96	0.25	0.4	0	0	0	0	0	20	0	250	<1	<50	<1	<1	<1	<1	180	7	0	<1	<1	

Table 12 (cont.). Dissolved minor and trace element concentrations in the WS-1 well set.

Well No.	Location	Top_ Screen	Bottom_ Screen	Date_ Sampled	B	Fe	Mn	Se	Pb	Hg	As	Li	Mo	Sr	Cd	Al	Be	Cr	Ni	Cu	Ba	Zn	Cd	Ag	Sb	Tl
					mg/L	mg/L	mg/L	µg/L																		
12019C	14906323ADBB3	7	12	9/1/87	0.05	0.11	0.33	2	0.1	1	8	170														
12019C	14906323ADBB3	7	12	10/23/91	0.03	0	0.05	3	1	0.1	7	190										50	6	0		
12019C	14906323ADBB3	7	12	9/10/96		1.7	1.3	1	0	0	10	0	200									160				
12019C	14906323ADBB3	7	12	9/6/01		0.84	0.45	3	2	0	2	100	3	180								130				
12019C	14906323ADBB3	7	12	9/6/06	0.061	0.268	0.289	1.54	<1	<1	<1	<50	<1	118	10.1	<1	4.38	<1	<1	<1	<1	118	10.1	<1	<1	<1
12020A	14906314DADC1	212	217	9/1/87	3.4	0.03	0.39	1	1	4	180	8	280													
12020A	14906314DADC1	212	217	10/23/91	2	0.02	0.16	0	0	0	6	140	6	230								13	8	0		
12020A	14906314DADC1	212	217	9/11/96		0.01	0.17	0	0	0	6	130	47	190								12				
12020A	14906314DADC1	212	217	9/5/06	2.22	<0.01	0.172	2.52	<1	9.33	<1	<50	<1	18.2	2.21	7.06	13.8	34.5	<1	<1	<1	<1	<1	<1	<1	<1
12020B	14906314DADC2	151	156	9/1/87	1.1	0.01	0.22	1	1	4	120	200	160													
12020B	14906314DADC2	151	156	10/23/91	1.3	0.02	0.17	0	0	0	4	110	10	190								21	29	0		
12020B	14906314DADC2	151	156	9/11/96		0.05	0.18	0	0	0	4	110	69	170								20				
12020B	14906314DADC2	151	156	9/5/06	1.47	0.011	0.174	<1	<1	4.89	<1	<50	<1	1.38	2.46	4.45	19.7	13.4	<1	<1	<1	<1	<1	<1	<1	<1
12020C	14906314DADC3	38	43	9/1/87	0.06	0.01	0.06	0	0	14	29	5	290													
12020C	14906314DADC3	38	43	10/23/91	0.05	0.08	0.07	0	0	0	8	30	4	330								86	12	0		
12020C	14906314DADC3	38	43	9/10/96		0.09	0.07	2	0	0	6	30	2	280								91				
12020C	14906314DADC3	38	43	9/6/01		0.02	0.02	6	2	0	11	100	4	280								100				
12020C	14906314DADC3	38	43	9/5/06	0.079	<0.01	0.041	3.79	<1	9.84	<1	<50	<1	73.8	3.49	<1	<1	<1	<1	<1	<1	73.8	3.49	<1	<1	<1
12021A	14906313BAAB1	96	101	9/1/87	1.2	0.02	0.22	0	0	0.1	24	160	16	510												
12021A	14906313BAAB1	96	101	10/23/91	2.4	0.03	0.44	4	0	0	25	250	18	980								230	15	0.1		
12021A	14906313BAAB1	96	101	9/11/96		0.43	0.42	0	0	0	36	240	19	890								160				
12021A	14906313BAAB1	96	101	9/6/01		0.05	0.39	16	2	0	38	240	15	960								170				
12021A	14906313BAAB1	96	101	9/6/06	3.2	0.705	0.348	24.7	<1	49.5	<1	<50	<1	1.47	5.39	13.7	241	22.2	<1	<1	<1	<1	<1	<1	<1	<1
12022	14906327DDDC2	158	163	9/1/87	0.07	0.15	0.24	2	0	0.1	7	5	0	140												
12022	14906327DDDC2	158	163	11/19/91	0.31	0.01	1.1	1	0	0	1	80	9	390								30	43	0.4		
12022	14906327DDDC2	158	163	9/11/96		0.02	1.1	0	0	0	1	80	13	320								16				

Table 12 (cont.). Dissolved minor and trace element concentrations in the WS-1 well set.

Well No.	Location	Top_Screen	Bottom_Screen	Date_Sampled	B	Fe	Mn	Se	Pb	Hg	As	Li	Mo	Sr	Cd	Al	Be	Cr	Ni	Cu	Ba	Zn	Cd	Ag	Sb	Tl
					ng/L	ng/L	mg/L	µg/L																		
12023B	14906336DDBC2	83	88	9/2/87	0.22	0.01	1.4	0	0	0	1	68	20	340	<1	<50	<1	1.17	6.03	1.2	62.9	13.7	<1	<1	<1	1.55
12023B	14906336DDBC2	83	88	10/22/91	0.16	0.02	1.3	0	0	0	1	60	14	400	<1	<50	<1	1.17	6.03	1.2	62.9	13.7	<1	<1	<1	1.55
12023B	14906336DDBC2	83	88	9/11/96	0.01	0.01	1.3	0	0	0	1	60	14	350	<1	<50	<1	1.17	6.03	1.2	62.9	13.7	<1	<1	<1	1.55
12023B	14906336DDBC2	83	88	9/5/06	0.22	<0.01	1.19	<1	1.53	1.71	1.71	60	14	350	<1	<50	<1	1.17	6.03	1.2	62.9	13.7	<1	<1	<1	1.55
12023C	14906336DDBC3	46	51	9/2/87	0.08	0.4	0.32	0	0	0	5	23	2	240	<1	<50	<1	1.05	4.07	<1	1.33	6.71	<1	<1	<1	1.55
12023C	14906336DDBC3	46	51	10/22/91	0.05	0.31	0.3	0	0	0	9	30	4	340	<1	<50	<1	1.05	4.07	<1	1.33	6.71	<1	<1	<1	1.55
12023C	14906336DDBC3	46	51	9/10/96	0.55	0.31	0	0	0	0	5	20	1	260	<1	<50	<1	1.05	4.07	<1	1.33	6.71	<1	<1	<1	1.55
12023C	14906336DDBC3	46	51	9/6/01	0.62	0.27	3	2	0	4	100	2	240	<1	<50	<1	1.05	4.07	<1	1.33	6.71	<1	<1	<1	1.55	
12023C	14906336DDBC3	46	51	9/5/06	0.077	0.531	0.265	<1	1.53	5.78	5.78	100	2	240	<1	<50	<1	1.05	4.07	<1	1.33	6.71	<1	<1	<1	1.55
12024B	14806301CBBC2	151	156	9/2/87	0.27	0.01	0.79	0	0	0	1	84	10	330	<1	<50	<1	3.09	1.25	<1	53.9	11	<1	<1	<1	<1
12024B	14806301CBBC2	151	156	10/23/91	0.3	0.02	0.68	0	0	0	0	90	6	380	<1	<50	<1	3.09	1.25	<1	53.9	11	<1	<1	<1	<1
12024B	14806301CBBC2	151	156	9/11/96	0.04	0.04	0.79	0	0	0	0	80	10	300	<1	<50	<1	3.09	1.25	<1	53.9	11	<1	<1	<1	<1
12024B	14806301CBBC2	151	156	9/5/06	0.348	<0.01	0.677	<1	<1	1.24	1.24	80	10	300	<1	<50	<1	3.09	1.25	<1	53.9	11	<1	<1	<1	<1
12025	14906326DCA	38	43	9/1/87	0.26	0.61	0.34	0	0	0.1	1.5	82	6	460	<1	<50	<1	5.82	2.02	<1	52.9	25.4	<1	<1	<1	<1
12025	14906326DCA	38	43	10/24/91	0.21	0.49	0.28	0	0	0.1	1.3	80	3	510	<1	<50	<1	5.82	2.02	<1	52.9	25.4	<1	<1	<1	<1
12025	14906326DCA	38	43	9/12/96	1.4	0.31	0	0	0.1	1.9	19	80	2	510	<1	<50	<1	5.82	2.02	<1	52.9	25.4	<1	<1	<1	<1
12025	14906326DCA	38	43	9/6/01	1.1	0.3	3	2	0	19	100	5	500	<1	<50	<1	5.82	2.02	<1	52.9	25.4	<1	<1	<1	<1	<1
12025	14906326DCA	38	43	9/6/06	0.313	1.06	0.291	1.54	<1	1.9	1.9	100	5	500	<1	<50	<1	5.82	2.02	<1	52.9	25.4	<1	<1	<1	<1
12026A	14906334BBB1	251	256	9/1/87	0.28	0.03	0.68	0	0	0	2	94	12	320	<1	<50	<1	4.05	1.31	<1	51.1	30.5	<1	<1	<1	<1
12026A	14906334BBB1	251	256	11/19/91	0.2	0.01	0.73	1	0	0	4	60	10	390	<1	<50	<1	4.05	1.31	<1	51.1	30.5	<1	<1	<1	<1
12026A	14906334BBB1	251	256	9/12/96	0.07	0.07	0.72	0	0	0.1	3	50	9	310	<1	<50	<1	4.05	1.31	<1	51.1	30.5	<1	<1	<1	<1
12026A	14906334BBB1	251	256	9/6/06	0.25	0.039	0.707	<1	<1	2.9	2.9	50	9	310	<1	<50	<1	4.05	1.31	<1	51.1	30.5	<1	<1	<1	<1
12026B	14906334BBB2	27	32	9/1/87	0.1	0.01	0.34	0	0	0	1	30	0	170	<1	<50	<1	6.34	<1	<1	35.8	7.57	<1	<1	<1	<1
12026B	14906334BBB2	27	32	10/24/91	0.05	0.01	0.04	2	0	0.1	1	20	0	170	<1	<50	<1	6.34	<1	<1	35.8	7.57	<1	<1	<1	<1
12026B	14906334BBB2	27	32	10/22/92	0	0.02	0.01	0	0	0	0	20	0	170	<1	<50	<1	6.34	<1	<1	35.8	7.57	<1	<1	<1	<1
12026B	14906334BBB2	27	32	9/12/96	0.01	0.01	0.33	1	0	0	1	20	0	160	<1	<50	<1	6.34	<1	<1	35.8	7.57	<1	<1	<1	<1
12026B	14906334BBB2	27	32	9/6/06	0.086	<0.01	0.028	2.48	<1	1.55	1.55	20	0	160	<1	<50	<1	6.34	<1	<1	35.8	7.57	<1	<1	<1	<1

Table 13. Dissolved minor and trace element concentrations in the WS-2 well set.

Well No.	Site	Location	Top_Screen	Bottom_Screen	Date_Sampled	B	Fe	Mn	Se	Pb	Hg	As	Li	Mo	Sr	Cd	Al	Be	Cr	Ni	Cu	Ba	Zn	Cd	Ag	Sb	Tl	
						mg/L	mg/L	mg/L	µg/L																			
13084	12	14806302BABC1	69	74	8/26/93	0.22	0.12	0.39	0	0	0	1	70	6	250	0	<50	<1	<1	1.83	1.85	60.4	5.81	<1	<1	<1	<1	
13084	12	14806302BABC1	69	74	9/6/06	0.266	0.103	0.45	<1	<1	<1	1.25				<1	<50	<1	<1	1.83	1.85	60.4	5.81	<1	<1	<1	<1	
13085	12	14806302BABC2	12	17	8/26/93	0.04	0.02	0.04	0	1	0	2	20	0	200	0	<50	<1	<1	6.22	1.32	86.6	3.98	<1	<1	<1	<1	
13085	12	14806302BABC2	12	17	9/6/06	<0.050	<0.01	0.011	1.09	<1	<1	3.95				<1	<50	<1	<1	6.22	1.32	86.6	3.98	<1	<1	<1	<1	
13086	7	14806302ACAI	97	102	10/22/92	0.12	0.02	1.3	0	0	0	2	40	5	430	0							0					
13086	7	14806302ACAI	97	102	9/3/96		0.03	1.3	0	0	0	0	40	4	350							150						
13086	7	14806302ACAI	97	102	9/5/01		0.09	1.3	3	2	0.1	2	100	6	350							160						
13086	7	14806302ACAI	97	102	9/11/06	<0.050	0.197	0.362	<1	<1	<1	<1				<1	<50	<1	<1	3.59	<1	66.2	2.28	<1	<1	<1	<1	
13087	7	14806302ACA2	18	23	10/22/92	0.03	0.23	0.37	0	0	0	2	0	0	160	0							0					
13087	7	14806302ACA2	18	23	9/3/96		0.47	0.28	0	0	0	1	3	0	110							170						
13087	7	14806302ACA2	18	23	9/5/01		0.26	0.28	3	2	0	2	100	2	68							100						
13087	7	14806302ACA2	18	23	9/11/06	0.126	0.047	1.06	<1	<1	<1	<1				<1	<50	<1	<1	7.45	1.8	131	4.72	<1	<1	<1	<1	
13088	9	14906313DAA1	95	100	8/25/93	1.7	0.04	0.07	0	0	0	10	120	28	170	0							0					
13088	9	14906313DAA1	95	100	9/13/06	1.1	0.043	0.052	<1	<1	<1	21.9				<1	<50	<1	<1	2.28	4.59	30	22.6	<1	<1	<1	<1	
13089	9	14906313DAA2	30	35	8/25/93	0.05	0.02	0.02	0	0	0	2	10	2	280	0							0					
13089	9	14906313DAA2	30	35	9/13/06	0.062	0.032	<0.01	1.71	<1	<1	1.33				<1	<50	<1	<1	5.67	3.02	94.1	5.5	<1	<1	<1	<1	
13090	8	14906219DBD1	95	100	8/25/93	0.04	0.18	0.56	0	0	0	51	50	6	500	0							0					
13090	8	14906219DBD1	95	100	9/13/06	<0.050	0.07	0.42	<1	<1	<1	11.9				<1	<50	<1	<1	5.81	<1	102	8.51	<1	<1	<1	<1	
13106	8	14906219DBD3	43	48	8/25/93	0.09	0.04	0.71	0	0	0	6	20	4	360	0							0					
13106	8	14906219DBD3	43	48	9/13/06	0.106	0.069	0.492	<1	<1	<1	65.5				<1	<50	<1	<1	6.87	1.07	93.3	25.4	<1	<1	<1	<1	
13092	10	14906312CAC1	105	110	8/25/93	0.05	0.18	0.28	0	0	0	14	110	17	340	0							0					
13092	10	14906312CAC1	105	110	9/13/06	0.775	0.04	0.051	<1	<1	<1	21.1				<1	<50	<1	<1	2.59	3.71	27.3	3.22	<1	<1	<1	<1	

Table 13 (cont.). Dissolved minor and trace element concentrations in the WS-2 well set.

Well No.	Site	Location	Top Screen	Bottom Screen	Date Sampled	B	Fe	Mn	Se	Pb	Hg	As	Li	Mo	Sr	Cd	Al	Be	Cr	Ni	Cu	Ba	Zn	Cd	Ag	Sb	Tl
						mg/L	mg/L	mg/L	µg/L																		
13093	10	14906312CAC2	45	50	8/25/93	0.73	0.14	0.48	0	0	0	5	30	1	320	0	<50	<1	<1	6.93	1.96	59	51.4	<1	<1	<1	<1
13093	10	14906312CAC2	45	50	9/13/06	0.091	0.23	0.388	1.4	<1	<1	6.94															
13094	20	14906314AAB	17	22	8/25/93	0.06	1.9	0.58	0	0	0	3	20	2	280	0	<50	<1	<1	5.41	<1	173	4.76	<1	<1	<1	<1
13094	20	14906314AAB	17	22	9/6/06	<0.050	1.82	0.502	<1	<1	<1	2.5															
13095	17	14806304ABA1	39.67	44.67	8/24/93	0.13	0.41	0.19	0	0	0	20	60	6	430	0	<50	<1	<1	3.99	3.02	63	3.24	<1	<1	<1	<1
13096	17	14806304ABA2	25	30	8/26/93	0.09	0.43	0.68	0	0	0	4	30	4	250	0											
13097	5	14906336ACA1	41	48	10/22/92	0.13	0.12	0.34	0	0	0	26	40	3	410	0							0				
13097	5	14906336ACA1	41	48	9/3/96		0.19	0.34	0	0	0	20	40	4	350	130											
13097	5	14906336ACA1	41	48	9/4/01		0.24	0.3	3	2	0	22	100	5	370	100											
13097	5	14906336ACA1	41	48	9/12/06	0.223	0.101	0.299	1.02	<1	<1	19.5															
13098	5	14906336ACA2	21	27	10/22/92	0.05	0.61	0.66	0	0	0	13	20	2	320	0							0				
13098	5	14906336ACA2	21	27	9/3/96		0.92	0.61	0	0	0	11	20	2	260	270											
13098	5	14906336ACA2	21	27	9/4/01		0.49	0.71	3	2	0	11	100	4	260	120											
13098	5	14906336ACA2	21	27	9/12/06	0.051	0.592	0.754	<1	<1	<1	11.3															
13098	5	14906336ACA2	21	27	9/12/06	<0.050	0.997	0.648	<1	<1	<1	11.5															
13099	13	14906335BCBA1	39.5	43.5	8/24/93	2.3	0.18	0.5	0	0	0	2	40	1	280	0	<50	<1	<1	5.2	1.1	118	4.6	<1	<1	<1	<1
13099	13	14906335BCBA1	39.5	43.5	9/6/06	0.062	0.595	0.481	<1	<1	<1	4.94															
13100	13	14906335BCBA2	23	28	8/24/93	0.08	0.71	0.79	0	0	0	10	20	3	330	0	<50	<1	<1	4.82	<1	104	4.65	<1	<1	<1	<1
13100	13	14906335BCBA2	23	28	9/6/06	0.065	0.834	0.57	<1	<1	<1	11.3															
13101	6	14906325CDC1	110	115	10/22/92	0.47	0.04	1.5	0	0	0	4	130	14	580	0											
13101	6	14906325CDC1	110	115	9/5/96		0.02	1.8	0	0	0	1	120	2	470												
13101	6	14906325CDC1	110	115	9/5/01		0.07	1.8	3	2	0	3	120	48	540	100											
13101	6	14906325CDC2	110	115	9/11/06	0.622	0.033	1.89	4.27	<1	<1	2.55															

Table 13 (cont.). Dissolved minor and trace element concentrations in the WS-2 well set.

WellNo.	Site	Location	Top_Screen	Bottom_Screen	Date_Sampled	B	Fe	Mn	Se	Pb	Hg	As	Li	Mo	Sr	Cd	Al	Be	Cr	Ni	Cu	Ba	Zn	Cd	Ag	Sb	Tl
						mg/L	mg/L	mg/L	ug/L																		
13102	6	14906325CDC2	25	30	10/22/92	0.06	0.27	0.46	0	0	0	7	20	5	380								0				
13102	6	14906325CDC2	25	30	9/5/96		0.23	0.42	0	0	0	6	20	0	300							100					
13102	6	14906325CDC2	25	30	9/5/01		0.31	0.49	3	2	0.1	7	100	4	350							110					
13102	6	14906325CDC1	25	30	9/11/06	0.07	0.351	0.49	<1	<1		6.2				<1	<50	<1	<1	5.94	<1	124	5.2		<1	<1	
13103	1	14906228CCC1	139	144	10/21/92	0.58	0.06	0.55	0	0	0	4	90	21	300								0				
13103	1	14906228CCC1	139	144	9/5/96		0.06	0.61	0	0	0	4	90	19	220							13					
13103	1	14906228CCC1	139	144	9/4/01		0.21	0.59	3	2	0	6	100	26	210							100					
13103	1	14906228CCC1	139	144	9/12/06	0.695	0.178	0.618	3.86	<1		3.69				<1	<50	<1	<1	3.45	9.57	28.8	4.21		<1	<1	
13104	1	14906228CCC2	56	61	10/21/92	0.15	0.3	0.4	0	0	0	52	70	8	550								0				
13104	1	14906228CCC2	56	61	9/4/96		0.47	0.37	0	0	0	47	60	6	440							53					
13104	1	14906228CCC2	56	61	9/4/01		0.38	0.37	3	2	0	62	100	9	470							100					
13104	1	14906228CCC2	56	61	9/12/06	0.139	0.321	0.352	<1	<1		58.7				<1	<50	<1	<1	5.3	1.07	56.4	3.48		<1	<1	
13105	2	14906229DAD	50	55	10/21/92	0.11	0.1	0.52	0	0	0	25	40	3	500								0				
13105	2	14906229DAD	50	55	9/4/96		0.13	0.52	0	0	0	26	40	3	410							97					
13105	2	14906229DAD	50	55	9/4/01		0.18	0.5	3	2	0.1	28	100	5	430							110					
13105	2	14906229DAD	50	55	9/11/06	0.063	0.17	0.538	<1	<1		30.3				<1	<50	<1	<1	4.79	1.01	104	4.42		<1	<1	

Arsenic Concentration in WS-1 Wells

Arsenic concentrations are predominantly above 10 mg/L in seven out of 26 wells (27%), and seven sites (one well per site) out of 14 well nest sites (50%). These exceed the average of 12% cited by Erickson and Barnes (2005a) for the Northern Provenance of the Wisconsin glacial drift. Arsenic concentrations for 1987 through 2006 are shown on Table 12.

Table 14, below, summarizes some of the properties characterizing high-arsenic wells on CGS lands. Generally, they tend to be screened at greater depths which may be an indicator of lower oxidation state, or alternately proximity to the shale. They tend to have a high SAR, which may indicate local acidification from pyrite weathering, or conversely may be caused by proximity to the underlying shale. All but one of the wells had elevated iron concentrations. Soluble iron is usually reduced iron, thus indicating conditions conducive to dissolution of iron oxides. Usually iron concentrations are in the range of hundredths of a part per million. High arsenic ground-water tends to have an order of magnitude higher iron concentration. In some of the cases, temporal trends of increasing arsenic follow trends of increasing iron, further indicating likely loss of sorption surfaces caused by reduction of iron oxides. Dissolved arsenic vs. dissolved ferrous iron trends for five wells are shown on Fig. 9. Arsenic is strongly correlated with iron on four of the five wells, although significance cannot be reasonably ascertained with only three degrees of freedom.

Table 14. Summary of selected well construction and chemical parameters in high arsenic wells of the WS-1 well set. (-) not present; (+) present and moderately expressed; (++) present and strongly expressed.

Well	SI	>Fe	pH	SAR>1
	Feet			
12011B	45-50	++	8.02-8.45	+
12013B	22-27	-	7.96-7.57	+
12014C	64-69	++	7.41-6.26	-
12015B	162-167	+	6.97-8.44	+
12017B	78-83	+	7.21-8.16	++
12020C	96-101	+	8.03-8.66	++
12025	38-43	++	7.22-7.87	+

Well Site 12025, located at 149-063-26DCA, (SI 38 to 43 feet) exhibits temporal trends indicating possible initial pyrite oxidation; including decreasing pH (7.87 to 7.21), increasing sulfate, rising bicarbonate indicating mobilization of carbonates through acid weathering, and increasing calcium and magnesium - followed by a decrease. The later decrease corresponds to increasing sodium, indicative of possible calcium and magnesium adsorption and release of sodium through cation exchange following oxidation and acid weathering. The increasing EC and TDS are likely caused by the acid weathering processes and cation exchange, as described. Increasing arsenic and iron indicate later reducing conditions, with mobilization of iron (loss of iron oxide surfaces) and release of arsenic from those surfaces. There is a corresponding increase in selenium. The arsenic is above EPA-MCL throughout the measured period. The combined evidence indicates that an initial oxidizing event may have occurred, possibly during drilling, followed by a gradual resumption of reducing conditions.

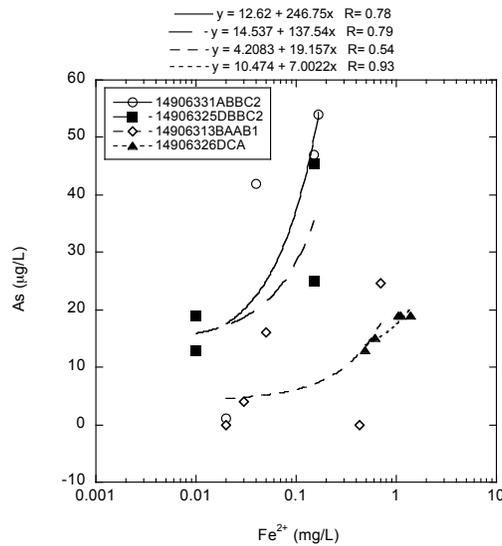


Figure 9. Dissolved arsenic concentration vs. dissolved ferrous iron for selected WS-1 wells.

Well-Site 12017B, located at 149-063-25DBBC, (SI 78 to 83 feet), exhibited increases of both iron and arsenic. While pH decreased, EC, TDS, calcium, sulfate, and sodium also decreased, indicating that local oxidation of pyrite and acid weathering are unlikely causes for arsenic mobilization. Chloride increased slightly, indicating possible influx of solute from the underlying Pierre shale. Nitrate was initially high and then decreased, indicating likely dispersion or denitrification of nitrate contaminants from drilling. While iron reduction requires slightly more reducing conditions than nitrate,

denitrification still supports the likelihood of an oxidation state conducive to the reduction of iron and the subsequent release of sorbed arsenic.

Well Site 12021A, located at 149-063-13BAAB, (SI 96 to 101 feet) exhibited substantial increases in both arsenic and iron. There were large accompanying increases in EC and TDS, but no increased sulfate or bicarbonate. Chloride was the main increasing anion, indicating likely influx from the underlying shale. pH increased to 8.66, high enough to promote arsenic mobilization. Arsenic concentrations are also strongly correlated with dissolved iron, indicating release from iron sorption surfaces as reducing conditions reoccurred after the disturbance of drilling.

Well Site 12011B, located at 149-063-35ABB, (SI 45 to 50 feet) exhibited an initial decrease in arsenic followed by an increase. This was accompanied by a small increase and then decrease in calcium; a small increase, and then decrease in bicarbonate; a decrease in pH, and no change in chloride. These trends indicate arsenic trends were likely caused by initial disturbance and oxidation caused by well drilling, followed by eventual resumption of reducing conditions. There is no evidence of bedrock water influence.

Well Site 12013B, located at 149-063-36BBDA, (SI 22 to 27 feet) indicates arsenic and other chemical trends similar to 12011B.

Arsenic Concentrations in WS-2 Wells

Arsenic concentrations from WS-2 wells for 1991 through 2006 are shown on Table 13. Of 22 wells on 12 sites, ten wells (on seven sites) have arsenic concentrations most frequently above 10 µg/L. Eight of the wells have concentrations above 20 µg/L at least part of the time. Three of the wells exceeded 50 µg/L. Highest arsenic concentrations were in both of the wells in Buck Hollow (Site 8), the deep well of the engineering training site (Site 9), the deepest wells at North Twin Lake (Site 17, now non-functional), and north of the Demolitions Range (Site 5). East of CGS, in the Colvin Creek subbasin, wells screened at about 50 to 60 feet depths on both Sites 1 and 2 had very high (2 to 5 times the EPA-MCL) arsenic concentrations. Of these wells, six had elevated iron and two had elevated manganese. Several well samples had very high field pH values in 2006. These, however, are suspicious. They were all measured on September 12 and 13; they differ by a large margin from previous measurements; there are no measured carbonates at pH values approaching 9; and they differ by a large margin from lab pH values. Field pH measurements made on these days should be interpreted with care. Overall the strongest correlations appear to be with reduced iron and manganese.

Summary of General and Trace Elements in CGS Wells

In Summary, about 35% of the wells have predominant historical arsenic concentrations above the EPA-MCL. These are high in comparison with predominant concentrations in the Northwest Provenance of the Wisconsin glacial drift. Sources and processes affecting arsenic appear to vary. The most consistent causes for increasing arsenic appear to be reducing conditions and the mobilization of iron with subsequent loss of sorption sites. In others, elevated arsenic appears to be related to close proximity of the shale. The Colvin Creek subbasin appears to have common high arsenic concentrations in ground water at about 50 to 60 feet bls. Arsenic concentrations in ground-water on CGS are natural, and there is no evidence of increasing arsenic caused by use or management.

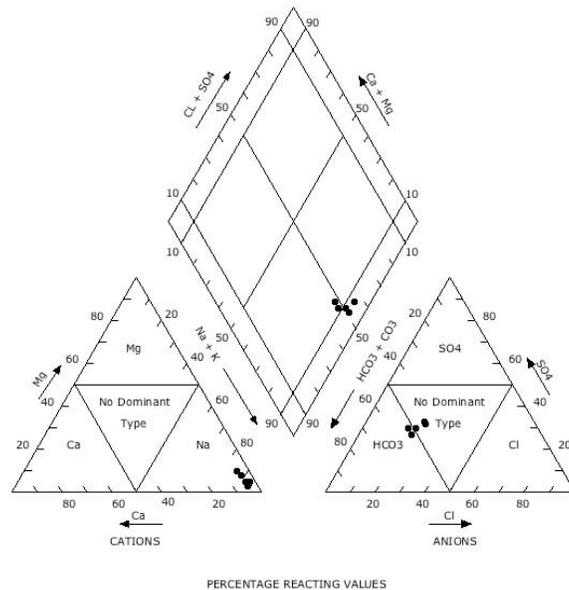


Figure 10. Piper diagram showing cation and anion distributions of Lake Coe.

General Chemistry and Trace Elements in Surface Waters

Five surface water sources have been sampled since 1987. These are: 1. Lake Coe, 2. South Washington Lake, 3. A reservoir west of the Emerson Murray Range, 4. A spring northwest of the Engineering Training Site, and (5) A spring near the livestock loading site south of Hwy 15.

Table 15. Chemical parameters for water samples from surface water at CGS.

S I T E	Location Mg/L	Water Body	Longitude	Latitude	Date Sampled	MP EI, ft. amsl	Field EC µS/cm	Lab EC µS/cm	Field pH	Lab pH	Field T., °C	TDS Det. mg/L	TDS Calc. mg/L	Hardness mg/L	NCH	ALK	SAR	% Sodium
4	14806231C(CBA)	Reservoir	-98.62314	47.59089	10/22/92	0	331	293	7.25	6.73	10	175	164	130	0	0	0.1	5
4	14806231C	Reservoir	-98.62314	47.59089	9/4/96	0	224	222	7.32	7.32	20.2	155	120	100	0	0	0.1	4
4	14806231C	Reservoir	-98.62314	47.59089	9/5/01	0	303	315	7.44	7.44		190	163	140	0	0	0.2	7
4	14806231C	Reservoir	-98.62314	47.59089	9/12/06	0	290	299	8.16	7.62		185	131	131	0	152	0.19	7.5
3	14806302DA	S. Spring	-98.65239	47.66452	9/11/86	0	540	517	8.19	8.19	13	344	316	270	12	0	0.1	4
3	14806302DA	S. Spring	-98.65239	47.66452	10/22/92	0	502	501	6.8	7.21	9	313	309	260	23	0	0.2	5
3	14806302DA	S. Spring	-98.65239	47.66452	9/4/96	0	424	499	7.93	7.93	13.3	332	287	270	0	0	0.1	4
3	14806302DA	S. Spring	-98.65239	47.66452	9/5/01	0	469	515	7.8	7.8		301	281	270	4	0	0.2	5
3	14806302DA	S. Spring	-98.65239	47.66452	9/12/06	0	483	503	8.13	7.72		312	263	263	13	250	0.11	3.2
16	14906313BD	N. Spring	-98.66742	47.72489	9/11/86	0	620	607	8.14	8.14	14	397	374	300	1	0	0.4	11
16	14906313BDA	N. Spring	-98.666	47.72583	8/25/93	0	660	643	7.22	7.01	18	404	411	350	0	0	0.3	8
16	14906313BDA	N. Spring	-98.666	47.72583	9/5/96	0	483	567	7.84	7.84	16.3	366	334	290	0	0	0.3	9
16	14906313BDA	N. Spring	-98.666	47.72583	9/11/01	0	400	393	7.23	7.23		213	221	200	0	0	0.2	8
16	14906313BDA	N. Spring	-98.666	47.72583	9/13/06	0	616	668	8.88	8.02		414	414	332	0	353	0.43	10.4
11	14906314CA	SW Lake	-98.68882	47.72128	9/11/86	1472	5400	5160	9.71	9.71	15	3660	3410	280	0	0	26	77
11	14906314DBB	SW Lake	-98.68479	47.72215	8/24/93	1472	3720	3430	9.05	9.28	26	2340	2370	190	0	0	20	75
11	14906314CA	SW Lake	-98.68882	47.72128	9/12/01	1472	1730	1780	9	8.91		953	1020	260	0	0	6.2	59
11	14906314CA	SW Lake	-98.68882	47.72128	9/12/06	1472	1809	1860	9	9.05		1150	1150	303	0	637	6.64	65.5
14	14906326DA	Lake Coe	-98.67792	47.69234	9/11/86	1492	6000	5860	9.19	9.19	15	4120	3850	200	0	0	40	87
15	14906327CA	Lake Coe	-98.71004	47.69241	9/11/86	1492	6400	6260	9.31	9.31	14	4440	4220	200	0	0	43	88
14	14906326ADD	Lake Coe	-98.67663	47.69492	8/24/93	1492	3950	4250	9.2	9.33	27	2820	2910	190	0	0	28	85
15	14906327DDB	Lake Coe	-98.70069	47.68959	8/24/93	1492	6430	6570	9.46	9.48	26	4570	4740	190	0	0	47	88
14	14906326ADD	Lake Coe	-98.67663	47.69492	9/5/01	1492	2700	3160	8.32	9.2		1930	1910	180	0	0	20	83
14	14906326ADD	Lake Coe	-98.67663	47.69492	9/12/06	1492	3050	3170	8.32	9.03		1970	1970	217	0	852	17.8	85.7

Table 16. General cations and anions for water samples from surface water at CGS.

S I T E	Location	Water Body	Date Sampled	Calcium mg/L	Magnesium mg/L	Potassium mg/L	Sodium mg/L	Fluoride mg/L	Bicarbonate mg/L	Carbonate mg/L	Sulfate mg/L	Chloride mg/L	Nitrate mg/L	Silica mg/L
4	14806231C	Reservoir	10/22/92	36	9.5	18	3.5	0.1	182	0	0.8	2.8	0.6	3
4	14806231C	Reservoir	9/4/96	26	8.5	8.8	2	0.1	145	0	2.9	0	0.8	
4	14806231C	Reservoir	9/5/01	33	14	11	5	0.1	193	0	4.1	0	0.5	
4	14806231C	Reservoir	9/12/06	25.3	16.4	10.8	4.9	0.172	186	<1	0.89	2.07	<0.09	
3	14806302DA	S. Spring	9/11/86	72	21	2.2	5.5	0.1	310	0	27	2.6	0	33
3	14806302DA	S. Spring	10/22/92	71	21	4	6	0.2	294	0	34	2.7	0	25
3	14806302DA	S. Spring	9/4/96	74	21	3.5	5.5	0.2	337	0	16	0.3	0.3	
3	14806302DA	S. Spring	9/5/01	73	21	3	6	0.2	323	0	18	0	0.1	
3	14806302DA	S. Spring	9/12/06	73.4	19.4	2.61	4	0.166	304	<1	18.5	0.88	<0.09	
16	14906313BD	N. Spring	9/11/86	79	25	7	17	0.2	365	0	31	4.3	0.3	30
16	14906313BDA	N. Spring	8/25/93	90	30	4.8	15	0.2	428	0	22	2.9	0	34
16	14906313BDA	N. Spring	9/5/96	76	25	6.4	13	0.3	366	0	32	0.9	0.2	
16	14906313BDA	N. Spring	9/11/01	50	17	8.3	8	0.1	271	0	3.3	0	0.2	
16	14906313BDA	N. Spring	9/13/06	86.2	28.2	6.54	17.8	0.264	430	<1	24.1	0.61	<0.09	
11	14906314CA	SW Lake	9/11/86	15	60	280	1000	0.1	737	400	930	360	1	1.4
11	14906314DBB	SW Lake	8/24/93	20	35	200	630	0.1	778	100	710	260	1.1	32
11	14906314CA	SW Lake	9/12/01	30	45	68	230	0.1	582	50	220	91		
11	14906314CA	SW Lake	9/12/06	24.2	59	87.8	266	0.117	574	100	222	103	<0.09	
14	14906326DA	Lake Coe	9/11/86	15	40	160	1300	0.1	1230	200	980	540	1	7.9
15	14906327CA	Lake Coe	9/11/86	15	40	180	1400	0.2	1210	300	1100	580	0.1	2.2
14	14906326ADD	Lake Coe	8/24/93	20	33	120	900	0.1	1060	200	730	370	2	9.7
15	14906327DDB	Lake Coe	8/24/93	20	35	200	1500	0.1	1510	400	1200	630	0	9.4
14	14906326ADD	Lake Coe	9/5/01	17	33	81	620	0.2	773	100	470	210	0.1	
14	14906326ADD	Lake Coe	9/12/06	21.4	39.8	72.8	604	0.2	793	121	454	258	<0.09	

Table 17. Trace elements for water samples from surface water at CGS.

S T E	Location	Water Body	Date Sampled	B mg/L	Fe mg/L	Mn mg/L	Se µg/L	Pb µg/L	Hg µg/L	As µg/L	Li µg/L	Mo µg/L	Sr µg/L	Cd µg/L	Al µg/L	Be µg/L	Cr µg/L	Ni µg/L	Cu µg/L	Ba µg/L	Zn µg/L	Ag µg/L	Sb µg/L	Pb µg/L	
4	14806231C	Reservoir	10/22/92	0.02	0.12	0.01	0	0	0	2	10	0	170	0											0.02
4	14806231C	Reservoir	9/4/96		0.09	0.14	0	0	0	4	5	0	110							93					
4	14806231C	Reservoir	9/5/01		0.12	0.25	3	2	0	5	100	2	94												
4	14806231C	Reservoir	9/12/06	<0.050	0.043	0.017	<1	<1		3.91				<1	<50	<1	<1	4.26	<1	51	<1	<1	<1	<1	<0.050
3	14806302DA	S. Spring	9/11/86	0.03	0.02	0.04	1	1	0.1	1	21	1	200												0.03
3	14806302DA	S. Spring	10/22/92	0.03	0.06	0.03	0	0	0	2	20	0	260	0											0.03
3	14806302DA	S. Spring	9/4/96		0.05	0.29	0	0	0	1	20	0	200							82					
3	14806302DA	S. Spring	9/5/01		0.1	0.17	3	2	0.1	2	100	2	190												
3	14806302DA	S. Spring	9/12/06	<0.050	0.063	0.151	<1	<1		1.6				<1	<50	<1	<1	5.05	<1	71.1	1.41	<1	<1	<1	<0.050
16	14906313BD	N. Spring	9/11/86	0.06	0.03	0.13	0	1	0.1	2	39	1	320												0.06
16	14906313BDA	N. Spring	8/25/93	0.07	0.09	1	0	0	0	2	40	0	360	0											0.07
16	14906313BDA	N. Spring	9/5/96		0.04	0.17	0	0	0	3	30	0	280							91					
16	14906313BDA	N. Spring	9/11/01		0.3	0.43	3	2	0	4	100	2	120												
16	14906313BDA	N. Spring	9/13/06	0.109	0.065	0.154	<1	<1		3.66				<1	<50	<1	<1	6.68	<1	97.5	1.78	<1	<1	<1	0.109
11	14906314CA	SW Lake	9/11/86	2.7	0.04		2	2	0.2	52	410	1	100												2.7
11	14906314DBB	SW Lake	8/24/93	0.06	0.03	0.01	0	0	0	71	240	4	140	0											0.06
11	14906314CA	SW Lake	9/12/01		2	0.45	3	320	0	30	120	3	130												
11	14906314CA	SW Lake	9/12/06	0.882	0.049	<0.01	6.31	<1		16.7				<1	<50	<1	<1	2.09	4.33	42.1	1.46	<1	<1	<1	0.882
14	14906326DA	Lake Coe	9/11/86	3.7	0.14	0.01	2	2	0	17	290	2	200												3.7
15	14906327CA	Lake Coe	9/11/86	4.8	0.18	0.01	2	2	0.2	19	310	2	200												4.8
14	14906326ADD	Lake Coe	8/24/93	3.8	0.05	0.01	0	0	0	10	230	4	180	0											3.8
15	14906327DDB	Lake Coe	8/24/93	1.5	0.13	0.01	0	1	0.1	24	320	8	140	0											1.5
14	14906326ADD	Lake Coe	9/5/01		0.15	0.03	8	2	0	16	150	5	150												
14	14906326ADD	Lake Coe	9/12/06	2.05	0.074	0.015	11.2	<1		19.3				<1	<50	<1	<1	2.12	8.26	62.3	1.54	<1	<1	<1	2.05

Lake Coe

Lake Coe General Chemistry

The water of Lake Coe is saline (Tables 15 and 16, pp. 65 to 68), having an EC varying from 2,000 uS/cm to 6,400 μ S/cm. The water chemistry of Lake Coe is predominantly of the sodium bicarbonate type (Figure 10, p. 65). Predominant bicarbonate anionic composition is augmented with dissolved sulfate and chloride. Predominant chloride sources in eastern North Dakota groundwater are in the underlying Cretaceous shales, and concentrations generally increase with depth and proximity to shale bedrock. Chloride concentrations in CGS wells are generally low, but increase with depth. Wells near Lake Coe (See Site 6, Table 11) increase in chloride with depth. Chloride sodium from underlying shale are likely concentrated in the lake through evaporation. Sodium adsorption ratios (SAR) are very high.

The pH, usually greater than 9, is high enough to mobilize the carbonate ion. High pH in the lake is likely caused by photosynthesis, which consumes bicarbonate and releases oxygen (Bouwer and Rice 1989, Schuh 1990). The high pH would cause precipitation of calcium and magnesium carbonates. Precipitation would cause cloudy water and sedimentation of carbonates on the lake bottom. In the presence of excess carbonate and bicarbonate ion, this likely accounts for the very low calcium and magnesium concentrations in solution, and their difference from nearby ground waters. All samples and data were collected in summer, and some changes in lake chemistry occur because of seasonal effects on photosynthetic activities. It is possible that some calcium and magnesium carbonate dissolution may occur during winter.

Trends in Lake Coe since 1987 have been toward lower EC and fresher water. EC values have decreased from approx. 6,000 μ S/cm in 1987 to about half in 2006. These have been caused by dilution from increasing runoff and shallow ground-water seepage which resulted from large rains and the generally wet climate period in the 1990s. While sodium concentration has decreased, calcium and magnesium have remained approximately the same. This has caused a decrease in sodium adsorption ratio (SAR) from 47 to approx. 18. SAR can decrease due to dilution alone, since the formula:

$$SAR = \frac{[Na^+]}{\sqrt{\frac{([Ca^{2+}] + [Mg^{2+}])}{2}}} \quad (1)$$

causes smaller decreases in the denominator than in the numerator, for a proportional decrease in concentration.

Nitrate Concentrations in Lake Coe

Nitrate concentrations (Table 16) in Lake Coe are low, all below EPA-MCL. Neighboring wells indicate that ground-water sources have little nitrate. Surface-water sources (runoff from manure) are present, but nitrate is likely consumed quickly by aquatic plants and algae.

Trace Elements in Lake Coe

All trace elements, with the exception of arsenic, are low, and below levels of toxicological concern (Table 17). There is no evidence of significant or increasing lead, barium or mercury concentrations from upstream training activities on the munitions and explosives ranges.

Arsenic in Lake Coe

Arsenic concentrations in Lake Coe (Table 17) are relatively high, ranging from 10 to 26 $\mu\text{g/L}$, and usually above 16 $\mu\text{g/L}$. Two potential causes are discernible. First, ferrous iron concentrations are relatively high (about an order of magnitude higher than in most ground-water samples). This may indicate that iron oxides are being reduced in the lake bottom sediments. This would release adsorbed arsenic. In addition, arsenic is commonly released from iron oxide surfaces at pH values above 8.5 (Smedly and Kinniburgh, 2002). Thus, it is speculated that high organic matter on the lake bottom and high pH resulting from algal photosynthesis may be causing conditions conducive to arsenic release. It may also explain why arsenic is higher in lake water than in surrounding wells. If photosynthetic controls on pH are important factors, then there may be some seasonal variation in arsenic concentrations; i.e. arsenic concentrations may be lower in winter. This, however, has not been tested. Arsenic concentrations in Lake Coe are entirely controlled by natural sources and processes and are not related to camp activities.

Summary of General and Trace Elements in Lake Coe

There is no evidence of degradation in Lake Coe caused by CGS management and activities.

South Washington Lake

South Washington Lake General Chemistry

The water of South Washington Lake is similar to Lake Coe in many respects. It is saline and a sodium bicarbonate type (Figure 11). Electrical conductivities in 1987 were about 5,400 $\mu\text{S/cm}$, but freshened considerably to about 1,800 $\mu\text{S/cm}$ over the next 20 years (Table 15). This was caused by runoff and ground-water seepage during a wet-

climate period which began in 1993. A decrease in SAR, similar to Lake Coe, also occurs. However, a slight increase in calcium and magnesium concentrations may indicate an increased contribution from ground-water seepage from higher ground-water levels. As with Lake Coe, relatively high sodium and chloride are likely caused by proximity to the underlying shale sources, and to evaporative concentration.

pH is high, usually above 9. The pH is high enough to mobilize the carbonate ion. High pH was likely caused by algae through consumption of bicarbonate and release of oxygen during photosynthesis. Precipitation of calcium and magnesium with the carbonate ion likely accounts for the overall relatively low calcium and magnesium concentrations. As with Lake Coe, pH effects would tend to be seasonal and would depend on other factors, such as nutrients, affecting algae. Fluctuations in calcium and magnesium may be influenced by these factors.

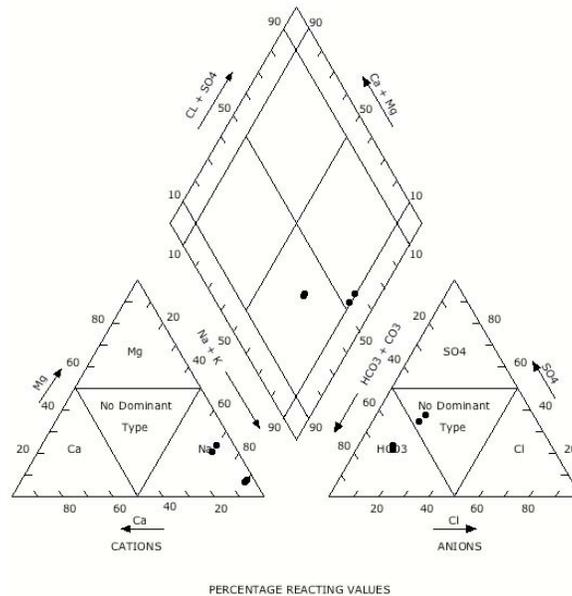


Figure 11. Piper diagram showing cation and anion distributions of South Washington Lake.

Nitrate Concentrations in South Washington Lake

As with Lake Coe, nitrate was low for all measurements (Table 16). This despite evidence of ample cattle manure along the shoreline during the early (1987 to 1993) measurement period. South Washington Lake has much visible algae in mid summer, which likely assimilates nitrogen entering the lake. The algae effect is further indicated by high pH (usually above 9) discussed above.

Trace elements in South Washington Lake

All measured trace elements (Table 17, with the exception of arsenic, are below levels of toxicological concern, and exhibit no indications of changes induced by management.

Arsenic in South Washington Lake

Arsenic concentrations in South Washington Lake were initially among the highest on the CGS facility, measured at 52 µg/L in 1986 and 71 µg/L in 1993. They declined throughout the 1990s and were as low as 16.7 µg/L in 2006 (Table 17). There is no apparent correlation with the iron concentrations or trends. There is some fluctuation, and a general decrease in pH, beginning at 9.71 and ending with 8.91 and 9.05 measurements. The most probable cause of decreasing arsenic is simply dilution with fresher waters during the wet period of the 1990s, with some possible synergistic effect from decreasing pH. Arsenic concentrations appear to fluctuate, and may be expected to increase again during drier climatic periods with evaporative concentration of salts in the lake water.

Summary of General and Trace Elements in South Washington Lake

There is no evidence of degradation in South Washington Lake caused by CGS management and activities.

North and South Springs

North and South Springs General Chemistry

The North Spring is located northwest of the Engineering Training Site. The South Spring is located south of the livestock loading station approx. 1.5 miles south of Hwy 15, near WS-1 Well No. 12024. Exact sample locations varied somewhat, with the first and last being sampled at the stone structure through which the spring flows, and other samples collected in the littoral area around the spring. All water samples are a calcium-bicarbonate type (Table 15, 16). TDS and EC within the range common for well samples, which would be expected (Table 15).

North and South Springs Nitrate Concentrations

Nitrate concentrations are barely detectable (Table 16).

North and South Springs Trace Elements

Trace element concentrations are all below levels of toxicological concern, and exhibit no discernable upward trends (Table 17).

North and South Springs Arsenic

Arsenic concentrations are all below 4 µg/L, and below EPA-MCL (Table 17).

Summary of General and Trace Elements in North and South Springs

There is no evidence of degradation of the general or trace element chemistry of spring water from natural causes of use and management of the CGS facility.

Reservoir

A reservoir is located west of the GCEM ranges and serves as a cattle watering station.

Reservoir General Chemistry

Water chemistry indicates that it is a mixture of ground water and surface runoff. It is calcium bicarbonate type, but has about half the conductivity and TDS of nearby ground water (Tables 15 and 16). SAR is very low (Table 15).

Reservoir Nitrate Concentrations

Nitrate, chloride and sulfate are very low (Table 16). There is ample cattle manure around the reservoir, which would serve as a nitrate and sulfate source. Concentrations in the reservoir are likely limited and controlled by aquatic plants and algae.

Reservoir Trace Elements

Trace element concentrations in the reservoir are low (Table 17). The reservoir would be expected to collect runoff from the GCEM ranges, and might serve as a collection basin for trace metals, including lead. No concentration of lead is acceptable for tap water. However, action levels of 15 µg/L have been set for remediation. In 2001 lead concentrations briefly reached 2 µg/L. But as of 2006 lead was non-detectable in the reservoir. There are no indications of trace elements at concentrations of concern in the reservoir.

Reservoir Arsenic

Arsenic concentrations have varied from 2 to 5 µg/L in the reservoir. These are all below EPA-MCL.

Summary of General and Trace Elements in the Reservoir

There is no evidence of degradation of the general or trace element chemistry of reservoir water from natural causes of use and management of the CGS facility.

Munitions and Explosives Residues

In 2006 munitions and explosives residue analyses were determined for eight wells and two surface-water sources on six sites (Table 18). The wells included: Site 1, west of the GEM ranges; Site 5, in the lowland area west of the GEM ranges and north of the demolitions range; Site 6, in the lowland area between the demolitions range and on the southern edge of Lake Coe, down-gradient of Site 5; and Site 7, in the lowland area due west of the MRF range and south of the demolitions range (Fig. 5). Surface-water sites sampled included: Site 4, the reservoir west of and downslope from the GCEM ranges; and Site 3, the spring southwest of the MRF range and south of the cattle loading station (Fig.5).

There were no detections of any of the target analytes in any of the samples or sample duplicates in the munitions and explosives groups. There was insufficient sample for all determinations on the shallow well of Site 7 (Well 13087), and Method 8260B was not performed on this well. Benzene and toluene, determined using Method 8260B, was duplicated in the speciation of GRO (gasoline range organics). Benzene was detected at 3.3 µg/L and toluene was detected at 6.6 µg/L.

Table 18. Sample sites, and well and surface-water identifiers for munitions and explosives residue samples. FB = field blank, R = Reservoir, SS = South Spring, SSD = South Spring Duplicate.

Site No.	7	7	5	5	6	6	6	1	1	1	4	3	3
Well No.	13086	13087	13097	13098	13101	13102	13102D	13103	13104	FB	R	SS	SSD
EPA METHOD #													
8260B	+	-	+	+	+	+	-	-	-	+	+	+	+
8270C	+	+	+	+	+	+	+	+	+	+	+	+	+
8330	+	+	+	+	+	+	+	-	-	+	+	+	+
8332	+	+	+	+	+	+	+	-	-	+	+	+	+

The EPA- Maximum Contaminant Level (MCL) for benzene is 5 µg/L and the MCL for toluene is 1 mg/L (1,000 µg/L). Benzene is a part of the ring structure of a wide range of organic compounds. Toluene is a major component of many explosives, including DNT and TNT. The detection of these two species in shallow ground-water in proximity to the demolitions range indicates that some small portions of explosives residues are reaching local ground water. The benzene concentration is only slightly below the MCL, which indicates that concentrations are reaching levels of concern. On the other hand, there were no detections of benzene or toluene deeper on the same site,

which indicates that contamination is shallow. Follow-up samples should be collected at this site to see if detections are consistent, or if they were only temporary.

As previously discussed under "trace elements," there is no evidence of elevated lead (from munitions), barium (from barium nitrate), or zinc and cadmium (from flares and other pyrotechnical devices).

Sample results should be sufficiently reliable to ascertain that there is no evidence of substantial concentrations of munitions and explosives residues in ground water of the CGS facility.

Munitions and Explosives Data Quality Control

Munitions and explosives residue samples for all four listed procedures were obtained using "clean-clean" procedures described, were stored in coolers in the field, and were refrigerated at 4° C within two hours of sampling. They were transported overnight on ice, and were refrigerated at 4° C immediately upon being received. Data Chem Laboratory quality control assessment (Appendix C), however, indicated that some of the samples were extracted one to two days after the 7-day holding time. A detailed evaluation of sample handling from receiving to extraction was requested on February 23 (Appendix A-4), and received on March 1 (Appendix A-5). According to Kevin Griffiths of DataChem affected samples were as follows:

"The samples being analyzed for Volatiles by method 8260 were all analyzed within their holding time. The effected methods were SVOC's by 8270, Explosives by 8330 and PETN/NG by 8332. All of the samples were stored in a cooler at 4[°]C and never exceeded the temperature requirement."

In comment, Mr. Griffiths offered that any bias from late extraction would be toward lower concentrations rather than higher, but would not likely be significant for one to two additional days.

I agree with Mr. Griffith's assessment for the following reasons. The primary elements affecting breakdown in a subsurface environment are: (1) the microbial pool, which is generally associated with grain matrix and organic matter or, in the case of autotrophs, mineral species; (2) temperature, which governs rates of chemical and microbial reaction; and (3) the chemical environment, including pH and dissolved nutrients. Removal from the field context should decrease microbial contact. Ambient ground-water temperatures are normally between 10° and 11° C, so that storage at 4° C should slow degradation of organic solute compared with field conditions. Conversely, exposure to light can enhance degradation of some chemicals, but the water is contained in dark (amber) bottles.

Field processes causing contamination would also possibly influence storage effects. Contamination from a previous discrete incident would be dependent on the rate of breakdown and would be more dependent on temperature than on storage time. For reasons explained in the previous paragraph, I would not expect degradation rates in storage to exceed those in the field. Rate controlled contamination caused by ongoing influx exceeding rates of degradation would be affected by time of non replenishment following sampling, as well as the rate of breakdown. The summer of 2006 was dry, and there were no precipitation events in the two weeks preceding sampling. It is unlikely that detections in samples in this environment would result from ongoing replenishment of contaminants.

Table 19. Results of water sample analysis for gasoline-range organics (GRO) and BTEX.

Well No.	Site No.	SI	GRO (mg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl (µg/L)	Xylenes (µg/L)
13087	7	18-23	<0.2	3.3	6.8	<1	<3
13088	9	95-100	<0.2	<1	<1	<1	<3
13089	9	30-35	<0.2	<1	<1	<1	<3
13089-D	9	30-35	<0.2	<1	<1	<1	<3
13092	10	105-110	<0.2	<1	<1	<1	<3
13093	10	45-50	<0.2	<1	<1	<1	<3
13098	5	21-27	<0.2	<1	<1	<1	<3
FB	5	21-27	<0.2	<1	<1	<1	<3
13100	13	23-28	<0.2	<1	<1	<1	<3
13103	1	139-144	<0.2	<1	<1	<1	<3
13104	1	56-61	<0.2	<1	<1	<1	<3
13106	8	43-48	<0.2	<1	<1	<1	<3
North Spring	16	0	<0.2	<1	<1	<1	<3
S. Wash. L.	11	0	<0.2	<1	<1	<1	<3
S. Wash. L. -D	11	0	<0.2	<1	<1	<1	<3
Reservoir	4	0	<0.2	<1	<1	<1	<3
L. Coe	14	0	<0.2	<1	<1	<1	<3
TB		0	<0.2	<1	<1	<1	<3

Petroleum Residues

Gasoline-range organics (GRO) and BTEX were analyzed for 12 wells on eight well sites, and for three surface-water sites. Use areas selected were the Engineering Training Site (Site 9 and the North Spring), the demolitions range area (Sites 5 and 7), and potential bivouac sites (Sites 8, 10 and 13 and the border of Lake Coe). The reservoir west of the EMR and wells east of the EMR were also sampled. Results are shown on Table 19.

The only detections were the solvents benzene and toluene in the shallow well of Site 7, located near to, and south of, the demolitions range. These solvents were most

likely derived from explosives rather than from vehicle petroleum use. They were discussed above under the Munitions and Explosives section.

Table 20. Results of water sample analysis for herbicides and insecticides used on CGS.

Well No.	Site No.	SI	2,4-D (µg/L)	Picloram (µg/L)	Bromoxynil (µg/L)	Malathion (µg/L)	Prometone (µg/L)
13085	12	12-17	<0.3	<0.3	<0.1	-	-
13087	7	18-23	<0.3	<0.3	<0.1	-	-
13089	9	30-35	<0.3	<0.3	<0.1	<0.5	-
13089-D	9	30-35	-	-	-	<0.5	-
13093	10	45-50	<0.3	<0.3	<0.1	<0.5	-
13094	5	21-27	<0.3	<0.3	<0.1	<0.5	-
13098	5	21-27	-	-	-	-	<0.5
FB			<0.3	<0.3	<0.1	<0.5	-
13100	13	23-28	<0.3	<0.3	<0.1	-	<0.5
13103	1	139-144	-	-	-	-	<0.5
13104	1	56-61	-	-	-	-	<0.5
13106	8	43-48	<0.3	<0.3	<0.1	<0.5	-
North Spring	16	0	<0.3	2.3	<0.1	<0.5	<0.5
S. Wash. L.	11	0	<0.3	<0.3	<0.1	<0.5	<0.5
S. Wash. L. -D	11	0	<0.3	<0.3	<0.1	<0.5	-
Reservoir	4	0	-	-	-	-	<0.5
L. Coe	14	0	<0.3	<0.3	<0.1	-	-

Pesticide Residues

Pesticides used on the CGS facility include:

- (1) Malathion, an insecticide used for mosquito control in bivouac areas;
- (2) Bromoxynil, 2,4-D and picloram, herbicides used for broadleaf weed control, and particularly leafy-spurge control; and
- (3) Prometone, a broad spectrum herbicide used for killing weeds near buildings and stationary equipment.

Results for the 2006 sampling are on Table 20.

In past samples, the only detections were of picloram, which was detected consistently at concentrations of 0.1 to 0.2 µg/L in Lake Coe and South Washington Lake during the 1990s. Beginning in the 2001 picloram was no longer detected in either of the Lakes.

In the 2006 sampling picloram was detected in the North Spring sample. There were no detections in Lake Coe or South Washington Lake, or in any of the other surface waters or wells sampled. It is considered likely that the picloram contacted the spring water directly after discharge above ground rather than through infiltration to ground water before discharge. The picloram concentration in the North Spring sample was 1/2,000 of the EPA-MCL of 500 µg/L, and represents no health or regulatory concern.

In 2006 there were no detections of bromoxynil, 2,4-D, malathion or prometone in any of the ground water or surface water samples.

SUMMARY AND CONCLUSIONS

Ground water of the Cherry Lake aquifer and surface water (Lake Coe, South Washington Lake, two springs and a reservoir) on the CGS reservation have been monitored for general chemistry and trace elements since 1986, and for munitions and explosives residues, petroleum residues, and pesticide residues since 1993. Sample analytes have been targeted to specific use areas of CGS. Comprehensive sampling is conducted at five-year intervals.

General chemistry of the CGS reservation is a calcium bicarbonate type with low TDS in shallow well-water and springs. Deeper ground water and lakes are characterized by higher sodium and sulfate and high TDS, likely through the proximity and influence of the underlying Pierre Shale. There is no indication of increasing salinity or other signs of ground-water quality degradation with respect to general chemistry, that could be attributed to CGS use and management.

Nitrate concentrations on the CGS reservation are highest in shallow ground water (less than 100 feet below land surface), and negligible below that depth. Of all ground-water samples tested during the period of measurement, more than 95% of each well set are below concentrations common to "natural" conditions without anthropogenic influence, and all but one sample are below the EPA-MCL. The one high-concentration detection was in a very shallow well, screened at the water table, in a pasture with a lot of cattle and considerable manure on the surface, and near a wetland. A deeper well on the same site had low nitrate, so nitrate was concentrated and stratified near the surface. These data indicate that there is no evidence of ground-water or surface-water deterioration with respect to nitrate at CGS due to management practices, and that measured ground-water concentrations conform to very high standards with respect to nitrate management.

Trace elements, other than arsenic, have been consistently low in ground water and surface water of the CGS reservation. There was one detection of lead at 2 µg/L in the reservoir west of the GCEM ranges in 2001. No concentration of lead is acceptable for tap water. However, action levels of 15 µg/L have been set for remediation. In 2001 lead concentrations briefly reached 2 µg/L. But as of 2006 lead was non detectable in the reservoir. There are no indications of trace elements at concentrations of concern in the reservoir. There have been no indications of ground-water or surface-water degradation with respect to trace elements at CGS. It is cautioned that many trace metals can be mobilized more effectively at lower pH values, and that any management practice that might cause acidification of the soil might enhance mobilization of trace metals. Acidification processes might include addition of large quantities of elemental sulfur,

ammonium or urea. It is difficult to conceive of a reason for applying such chemicals, but the caution is given for the sake of awareness.

Arsenic is common in CGS ground water and surface water. More than 20% of CGS ground-water assays have arsenic concentrations above the EPA-MCL. These percentages are approximately double those of the Northwest Provenance glacial drift of which CGS lands are formed. Arsenic sources are natural, and are likely derived from oxidation of arseno-pyrite in the underlying shale, and in the shale-derived glacial materials. Arsenic tends to be higher in deeper wells, and elevated concentrations appear to be associated with reducing conditions and the mobilization of iron, which removes sorption surfaces that normally sequester arsenic. Highest ground-water arsenic concentrations are in the Colvin Creek subbasin, east of the GCEM ranges.

Arsenic in the two lakes (Lake Coe, and South Washington Lake) are high, and generally above the EPA-MCL. High arsenic concentrations in both lakes appear to be affected to a great degree by high pH, which results from algal photosynthesis. Concentrations in Lake Coe fluctuate within a range of 10 to 26 $\mu\text{g/L}$, and usually above 16 $\mu\text{g/L}$, and may be governed by fluctuating pH. Highest concentrations of all water sources were in South Washington Lake, which peaked at 71 $\mu\text{g/L}$ in 1993 (7 times the EPA-MCL), but which declined to as low as 16.7 $\mu\text{g/L}$ in 2006. The decreasing concentrations are systematic and appear to be affected somewhat by pH changes, and also by dilution from ground water following large rains in the 1990s. They may be expected to rise again during drier climatic periods.

High arsenic in CGS reservation waters are all of natural origin, and precede military use of the reservation. High arsenic concentrations are also found in similar settings near, but off of, the reservation. There are no indications of degradation of surface or ground waters with respect to arsenic, caused by management or use of the reservation.

Two management measures have been undertaken in relation to elevated arsenic: (1) CGS has contracted for treated drinking water rather than use of local wells; and (2) CGS has developed procedures, acceptable to the North Dakota Health Department, for disposal of filtrate (containing concentrated arsenic) following water purification training.

Munitions and explosives residues have been detected in small quantities in well water used to monitor the demolitions and munitions ranges. Acetone, methylene chloride and toluene were detected in several water samples in 2001, but it seemed likely that they were introduced by sample contamination, possibly in the laboratory. In 2006 toluene was again detected in one shallow well, indicating its probable occasional presence in shallow ground water. In 2001 carbon disulfide was detected in several ground-water and surface-water samples and seemed authentic. Benzoic acid was detected in the reservoir and in Lake Coe. Di-n-butylphthalate was detected in one well-

water sample (Site 2 in the Colvin Creek subbasin) and in Lake Coe. Except for benzene and toluene, none of these were detected in the 2006 sampling. In 2006 benzene and toluene were detected in one shallow well south of the demolitions range. Detections were below levels of toxicological concern, and were not present in the deeper well at the same site. Because of repeated detections (2001 and 2006), benzene and toluene are likely authentically periodically present at trace concentrations. The repeated presence of benzene and toluene, and the single detection of other explosives residues, indicate that small amounts are reaching ground water. However, all detections were below EPA-MCL, and most were lower by several orders of magnitude. Most were also detected only once. There is, therefore, evidence of munitions and explosives residues reaching ground water and surface waters sporadically and in very small quantities. There is no evidence of a persistent or growing problem that would likely reach levels of toxicological concern.

Petroleum residues as DRO (diesel-range organics) were first detected in 2001 in ground water at the Engineering Training Site (Site 9), in Buck Hollow (Site 8), and in wells northeast of South Washington Lake. Detections were below lab MDL (minimum detection levels) and were therefore considered "qualitative." They were also several thousand times below levels of toxicological concern. DRO were not sampled in 2006. GRO/BTEX samples indicated no detections in all sample events before 2006. In 2006 there were low-level detections of benzene and toluene in one shallow well. These were attributed to demolitions residues rather than to petroleum spills. There have been indications in any of the sample assays that management and use of the CGS reservation is causing deterioration of ground water or surface water through contamination with petroleum products.

Since 1993 pesticide assays have been performed for various herbicides and insecticides. Picloram, 2,4-D and malathion have been assayed in all years. Dimethoate was assayed only in 1993. Chlorpyrifos was assayed in 2001, and bromoxynil and prometone were assayed in 2001 and 2006. There have been no detections of any of the insecticides (malathion, dimethoate, chlorpyrifos) in any of the sample sets. There have been no detections of 2,4-D and prometone in any of the sample sets. Picloram was detected consistently in South Washington Lake and in Lake Coe at barely detectable concentrations (0.1 to 0.2 $\mu\text{g/L}$) during the 1993, 1996 and other supplemental samplings during the 1990s. Beginning in 2001 picloram was no longer detectable in the lakes. Again, in 2006 there were no detections. All concentrations were several orders of magnitude below EPA-MCLs. It was concluded that wet conditions during the 1990s contributed to runoff of picloram into the lakes during that time, and that contemporary influx seems to have decreased. There was one low-level (2.3 $\mu\text{g/L}$) detection of picloram in the North Spring water sample, collected in 2006. This was likely caused by

local spraying for leafy spurge. In general, as of 2006 there is no indication of degradation of CGS ground water or surface water due to use or management.

CGS land use and management have not caused any substantial degradation of local water resources during the period of operation to date.

CITATIONS

Bartelson, Norene. 1993-2006. North Dakota Groundwater Monitoring Program (series of annual reports.) North Dakota Department of Health, Division of Water Quality. Bismarck, ND.

Bauder, J.W., K.N. Sinclair, and R.F. Lund. 1993. Physiographic and land use characteristics associated with nitrate nitrogen in Montana groundwater. *J. Environ. Qual.* 22:255-262.

Benson, Robert. 2002 (6/24/02). Subject: Citation. E-mail correspondence from: Benson.Bob@epamail.epa.gov. to: William Schuh <bschuh@state.nd.us.

Bluemle, J.P. 1965. Geology and ground water resources of Eddy and Foster counties, North Dakota: part I. geology. *Ground Water Studies # 5.* North Dakota State Water Commission. Bismarck, ND.

Bouwer, H. and R.C. Rice. 1989. Effect of water depth in groundwater recharge basins on infiltration rate. *Irrig. Drain. Eng. Am. Soc. Civ. Eng.* 115(4):566-568.

Burkart, M.R. and D.W. Kolpin. 1993. Hydrologic and land-use factors associated with herbicides and nitrate in near-surface aquifers. *J. Environ. Qual.* 33:646-656.

Casey, F.X.M., N. Derby, R.E. Knighton, D.D. Steele and E.C. Stegman. 2002. Initiation of irrigation effects on temporal nitrate leaching. *Vadose Zone J.* 1:300-309.

Comeskey, A.E. 1989. Hydrogeology of Camp Grafton South, Eddy county, North Dakota. *North Dakota Ground-Water Studies #8.* North Dakota State Water Commission. Bismarck, ND.

Erickson, M.L, Randal J. Barnes. 2005a. Glacial sediment causing regional-scale elevated arsenic in drinking water. *Ground Water* 43:6:795-805

Erickson, M.L, Randal J. Barnes. 2005b. Well characteristics influencing arsenic concentrations in ground water. *Water Research* 39:4029-4039.

Harker, D. B., K. Bolton, L. Townley-Smith, and B. Bristol. 1997. Nonpoint agricultural effects on water quality: a review of documented evidence and expert opinion. PFRA, Prairie Resources Division, Sustainable Development Service, Regina, SK, CA.

Korom, S.F., A.J. Schlag, W.M. Schuh and A.K. Schlag. 2005. In situ mesocosms: denitrification in the Elk Valley aquifer. *Ground Water Monitoring and Remediation*. 25:1:787-89.

Mayer, G.G. 1992. Denitrification in the Elk Valley aquifer, northeastern North Dakota: Ph.D. Dissertation. Department of Geology and Geological Engineering. University of North Dakota. Grand Forks, ND.

Parker, L.V., A.D. Hewitt, and T.F. Jenkins. 1990. Influence of casing materials on trace-level chemicals in well water. *Ground Water Monitoring Review*. Spring:146-156.

Parker, Louise. 2001a (10/ 31/ 01). Subject: Munitions contaminants. E-mail correspondence from: Louise.V.Parker@erdc.usace.army.mil; to: bschuh@swc.state.nd.us.

Parker, Louise. 2001b (11/ 1/ 01). Subject: Munitions contaminants. E-mail correspondence from: Louise.V.Parker@erdc.usace.army.mil; to: bschuh@swc.state.nd.us.

Sax, N.I. and R.J. Lewis, Sr. (Revised by). 1987. "Hawley's condensed chemical dictionary, Eleventh edition, Van Nostrand Reinhold Company, New York.

Schuh, W.M. 1990. Seasonal variation of clogging of an artificial recharge basin in a northern climate. *J. Hydrol.* 121:193-215.

Schuh, W.M. 1992. Initial proposal for a water quality monitoring program for the North Dakota National Guard Camp Grafton South facility. Unpublished proposal, submitted 4/26 to Captain David Anderson.

Schuh, W.M. 1994. Planning, construction, and initial sampling results for a water quality monitoring program: Camp Grafton South Military Reservation, Eddy County, North Dakota. Water Resource Investigation No. 27. North Dakota State Water Commission. Bismarck, ND.

- Schuh, W.M., D.L. Klinkebiel, J.C. Gardner, and R.F. Meyer. 1997. Tracer and Nitrate movement to groundwater in the Northern Great Plains. *J. Environ. Qual.* 26:1335-1347.
- Schuh, W.M. 1997. Water quality evaluation for the North Dakota National Guard Camp Grafton (South Unit), Eddy County, North Dakota: 1996 sampling. Water Resource Investigation No. 33. North Dakota State Water Commission. Bismarck, ND.
- Schuh, W.M. 2002. Water quality evaluation for the North Dakota National Guard Camp Grafton (South Unit), Eddy County, North Dakota: 2001 sampling. Water Resources Investigation No. 37. North Dakota State Water Commission. Bismarck, ND.
- Schuh, William M., Bottrell, Simon H., and Scott F. Korom. 2006. Sources and Processes Affecting the Distribution of Dissolved Sulfate in the Elk Valley Aquifer in Grand Forks County, Eastern North Dakota. Water Resources Investigation No. 38. North Dakota State Water Commission. Bismarck, ND. 132 pp.
- Shaver, Robert B. 1991. Sample bias in a hydrochemical investigation of the Oakes aquifer, southeastern North Dakota. Water Resources Investigation No. 16. North Dakota State Water Commission. Bismarck, ND.
- Smedley, P.L., and D.G. Kinniburgh. 2002. A review of the source, behavior and distribution of arsenic in natural waters. *Applied Geochemistry.* 27:517-568.
- Sykes, A.L., R.A.S. McAllister, and J.B. Homolya. 1986. Sorption of organics by monitoring well construction materials. *Ground Water Monitoring Review.* Fall:44-47.
- Trapp, Henry Jr. 1966a. Geology and ground water resources of Eddy and Foster counties, North Dakota: part II. ground water basic data. *Ground Water Studies # 5.* North Dakota State Water Commission. Bismarck, ND.
- Trapp, Henry Jr. 1966b. Geology and ground water resources of Eddy and Foster counties, North Dakota: part III. ground water resources. *Ground Water Studies # 5.* North Dakota State Water Commission. Bismarck, ND.
- U.S. Army Armament Research, Development, and Engineering Center. 1999. "Encyclopedia of Explosives and Related Items;" U.S. Army Armament Research, Development, and Engineering Center; U.S. Army Research and Development

Command; U.S. Army Tank and Automotive Command; Picatinny Arsenal; Dover, New Jersey

U.S. EPA. 1992. RCRA ground-water monitoring: draft technical guidance. G-93-00016 EPA/530-R-93-001 Pb93-139 350.

U.S. EPA. 1994. Methods for evaluating soil and water. EPA-SW-846. Revision 0.

U.S. EPA. 1996a. Drinking water regulations and health advisories. EPA-822-R-96-001.

U.S. EPA. 1996b. Methods for evaluating soil and water. EPA-SW-846. Revision 2.