In cooperation with Grand County

Ground-Water-Quality Assessment of Selected Wells in the Fraser River Watershed, Colorado, August 1998

INTRODUCTION

The Fraser River watershed is located in the southeastern part of Grand County, Colorado. The Fraser River flows about 28 river miles from its headwaters along the Continental Divide in the Arapaho National Forest through the towns of Winter Park, Fraser, Tabernash, and Granby and into the Colorado River (fig. 1). Grand County covers 1,869 square miles; the Fraser River watershed comprises about 16 percent of the county (about 302 square miles).The annual precipitation in the watershed ranges from 20 inches per year north and west of Fraser to more than 40 inches per year in the higher peaks near the Continental Divide. Land use/land cover in the watershed is 71 percent forested land; 14 percent agriculture and rangeland; 11 percent tundra, bare ground, or exposed rock; 2 percent urban; and 2 percent other land-use classifications (fig. 1; Fegeas and others, 1983).

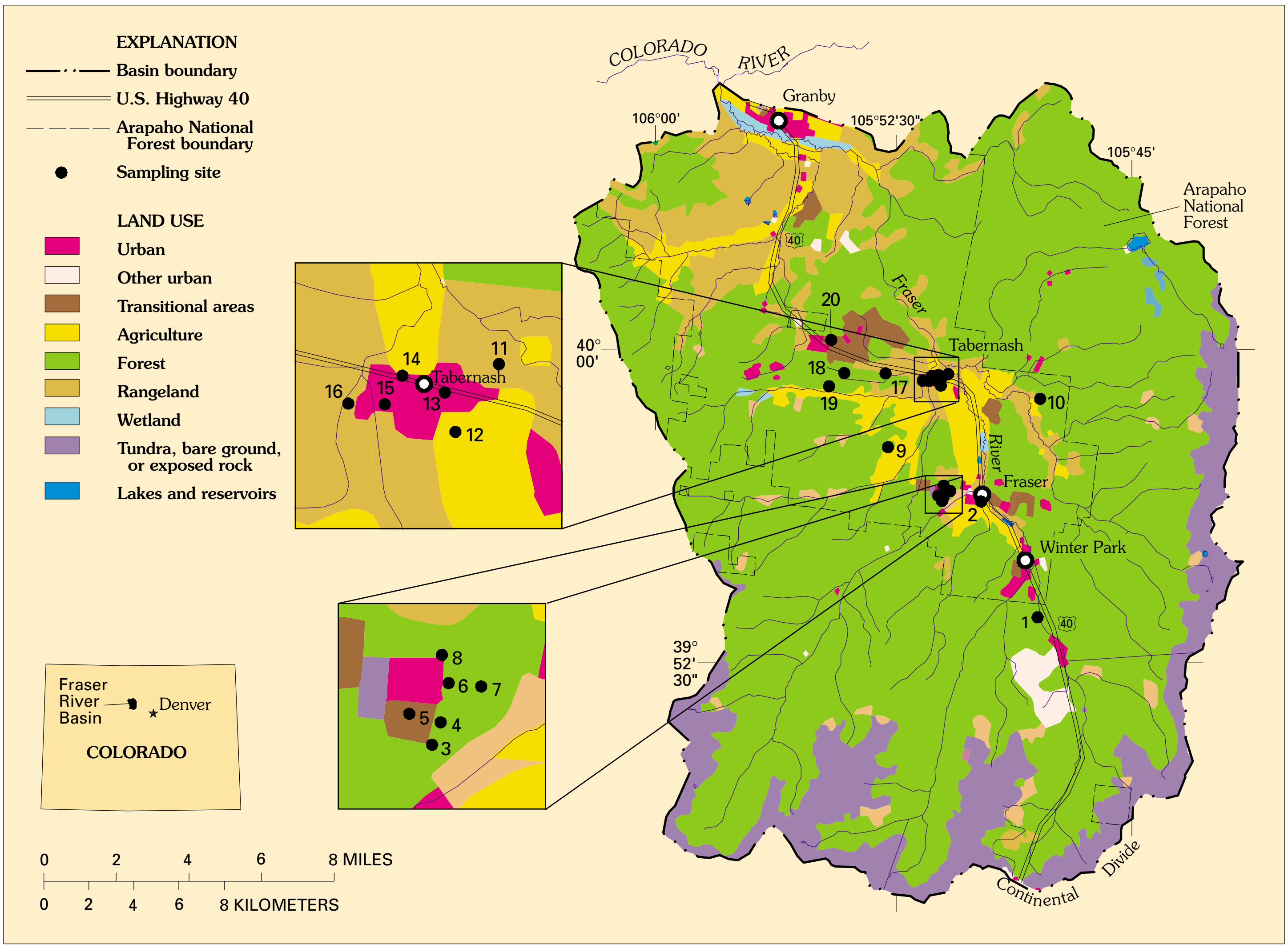

Figure 1. Location of the study area, ground-water sampling sites, and land use/land cover. All land-use/land-cover classifications were determined during the late 1970's (Fegeas and others, 1983) and refined with 1990 population data (Hitt, 1995).

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Ground-water quality in the Fraser River watershed is generally suitable for domestic and municipal uses.

The population of Grand County (estimated 1997 population of 9,879) has increased 138 percent between 1970 and 1997 (U.S. Bureau of the Census, 1970, 1997). In the upper part of the watershed upgradient from Tabernash, there are three wastewater-treatment facilities and public water supplies that serve the larger urban centers. Homes located outside the urban centers rely on well water and individual septic disposal systems (ISDS's). With the increase in population, local agencies are concerned about a high density of ISDS's and their potential effects on the future water quality in the watershed. In addition, the increased use (withdrawal) of ground water in the study area also is a factor that may affect the water quality. The U.S. Geological Survey (USGS), in cooperation with Grand County, began a 5-year study in 1998 to evaluate the ground-water quality in the Fraser River watershed. Twenty wells (18 domestic, 1 municipal, and 1 monitoring) were randomly selected in the watershed upgradient from Tabernash to determine baseline ground-water-quality conditions in this part of the watershed. The majority of the sites were randomly selected by using a stratified random selection computer program (Scott, 1990). The results from this study and the continued monitoring of 10 wells are intended to aid land-use planners in preserving water quality of the Fraser River watershed for Grand County residents and visitors.

Urban development

DATA COLLECTION

The 20 wells used in this study were sampled in August 1998. In addition to the samples collected to determine ground-water quality, eight quality-assurance samples were collected and analyzed to determine bias and variability in the data. The 20 wells were selected to represent water-quality characteristics associated with overlying land use/land cover, lithology, and well depth. The major land-use classifications within a radius of 1,640 feet (ft) from the wells are forested and urban (primarily residential) lands. Wells in this study ranged in depth from 25 to 295 ft and were completed in the alluvium of Quaternary age, in the Troublesome Formation sedimentary rocks of Tertiary age, and in fractured rocks of Precambrian age. Water samples were analyzed for major ions, iron, manganese, nutrients, dissolved organic carbon (DOC), bacteria (total coliform and *Escherichia coli* [*E. coli*]), methylene blue active substances (MBAS), radon, chlorofluorocarbons (CFC's), and oxygen and hydrogen isotopes. The results from these samples were compared to U.S. Environmental Protection Agency (USEPA) drinking-water standards.

The USEPA drinking-water standards are defined as the permissible level of a contaminant in water as delivered to users of a public water system. The drinking-water standards consist of a maximum contaminant level (MCL) that is health related and legally enforceable, a secondary maximum contaminant level (SMCL) that applies to the esthetic qualities of water and is a recommended level, and a proposed maximum contaminant level (PMCL) that is not currently (2000) enforceable. A maximum contaminant level goal (MCLG) is a nonenforceable level of a drinking-water contaminant and is intended for protection against adverse human health effects. A USEPA health advisory (HA) used in this report is defined as the concentration of a contaminant in drinking water that is expected to cause adverse, but noncarcinogenic, effects over a lifetime of typical exposure. The typical exposure assumes that a 154-pound adult drinks about 0.5 gallon of such contaminated water per day for 70 years (U.S. Environmental Protection Agency, 1996).

The water-quality samples were analyzed at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. The year the ground water was recharged was determined by measuring CFC's (manmade compounds used mainly as refrigerants) present in the water using the method of Busenberg and Plummer (1992). The source of the ground water was evaluated by analyzing oxygen and hydrogen stable isotopes. The CFC's and stable isotopes were analyzed at a USGS laboratory in Reston, Virginia. The field properties measured at each site were water temperature, specific conductance, dissolved oxygen, pH, alkalinity, and turbidity. Sampling protocols and procedures used in this study are described in Koterba and others (1995).

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance of water-quality samples is needed to assess bias and variability in the analytical results. The quality-assurance samples included four field blanks and four replicate samples. Field blanks are obtained by using a blank solution that is subjected to all aspects of sample collection, field processing, preservation, transportation, and laboratory handling to test for high bias in the data, which may result from the introduction of contaminants into the water-quality sample. Source water for the field blanks is documented by the NWQL to be essentially free of constituents of concern; if constituents are present in the source water, they are generally near the reporting limit. Results from field blanks indicate that a high bias on the water-quality data is unlikely. The few constituents detected were near the reporting limit and were at concentrations of less than 10 percent of the water-quality sample.

Sequential replicate samples were collected to assess the variability in chemical constituents as a result of sampling and analytical procedures. Relative percent differences were calculated for all replicate samples. Results indicate that differences between the water-quality samples and the replicate samples were less than 10 percent for approximately 90 percent of the constituents analyzed. A relative percent difference of greater than 10 percent occurred when the sample and the replicate concentrations were at or near the reporting limit. Results from the quality-assurance samples indicated that the water-quality sample data show low variability and that a high bias is unlikely.

The major-ion data were quality assured by examining the differences between the total-cation and total-anion charge balance. Differences between the charge balance for all samples were less than 5 percent, which was acceptable for this study.

GEOLOGIC AND HYDROLOGIC CHARACTERISTICS

The geology of the Fraser River watershed varies from rocks of Precambrian age to unconsolidated alluvial deposits of Quaternary age (fig. 2). The oldest rocks are of Precambrian age and are exposed in the eastern and southern parts of the watershed. Fractured Precambrian rocks generally yield small quantities of water that are adequate only for domestic supplies. Sedimentary rocks of Triassic, Jurassic, and Cretaceous age in the northwestern part of the watershed generally yield little water; however, well yields from these sedimentary rocks probably are sufficient for most domestic uses. The geologic units in the watershed that yield the most water are Tertiary or younger in age (Voegeli, 1965). These units include the Troublesome Formation and alluvial deposits in the lower altitudes of the watershed, which provide water for residential and municipal use. The Troublesome Formation is predominantly siltstone with some interbedded sandstones and conglomerates and is as much as 1,000 ft thick. The alluvial deposits, which can be 200 ft thick, consist of unconsolidated sands and gravels and older glacial drift.

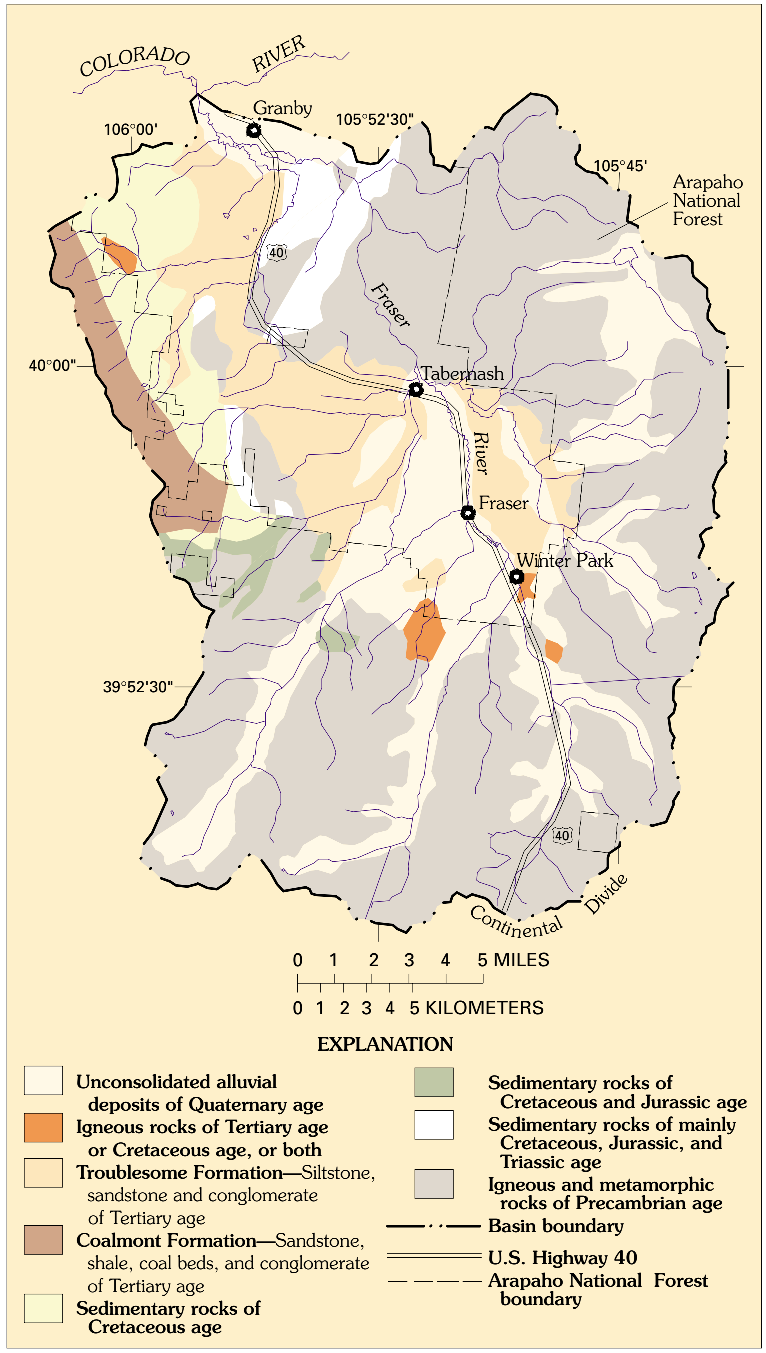

Figure 2. *Generalized geology of the Fraser River watershed (Tweto, 1979; Green, 1992).*

GROUND-WATER QUALITY

The quality of the ground water in the Fraser River watershed is important because many individuals rely on ground water for drinking water. The ground-water-quality conditions in the Fraser River watershed can be characterized by assessing the dissolved constituents and other physical properties (table 1).

Some measured properties that are significant in assessing water-quality conditions and that also may indicate effects by ISDS's are specific conductance, dissolved oxygen, and pH.

Table 1. Summary of measured properties and analyzed constituents for water samples from 20 wells in the Fraser River watershed, August 1998

[USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 mL; pCi/L, picocuries per liter; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; PMCL, proposed maximum contaminant level; MCLG, maximum contaminant level goal; HA, health-advisory level; <, less than; ---, no standard]

Properties, constituents, and reporting units	Minimum	Median	Maximum	USEPA drinking-water standards or health advisories[a]
Field properties				
Water temperature (°C)	6.0	7.8	14	---
Specific conductance (µS/cm)	106	236	436	---
Oxygen, dissolved (mg/L)	0.1	4.5	7.6	---
pH, field (standard units)	6.1	7.4	8.1	6.5–8.5 (SMCL)
Alkalinity (mg/L as $CaCO_3$)	39	109	206	---
Turbidity (NTU)	0.06	0.42	3.17	5.0
Major ions				
Bromide, dissolved (mg/L)	<0.01	0.02	0.06	---
Calcium, dissolved (mg/L)	14.2	33.7	71.1	---
Chloride, dissolved (mg/L)	0.33	1.78	16.4	250 (SMCL)
Fluoride, dissolved (mg/L)	<0.10	0.19	1.40	4.0 (MCL)
Magnesium, dissolved (mg/L)	1.26	2.55	5.84	---
Potassium, dissolved (mg/L)	1.03	2.00	6.30	---
Silica, dissolved (mg/L)	11.1	28.1	46.6	---
Sodium, dissolved (mg/L)	4.02	7.07	19.1	---
Sulfate, dissolved (mg/L)	1.62	3.14	10.9	250 (SMCL)
Dissolved solids (mg/L)	82	129	281	500 (SMCL)
Trace elements				
Iron, dissolved (µg/L)	<10	<10	244	300 (SMCL)
Manganese, dissolved (µg/L)	<4	<4	436	50 (SMCL)
Nutrients				
Ammonia, dissolved as N (mg/L)	<0.002	<0.002	0.010	30 (HA)
Ammonia plus organic, dissolved as N (mg/L)	<0.10	<0.10	0.13	---
Nitrite, dissolved as N (mg/L)	<0.001	<0.001	0.002	1.0 (MCL)
Nitrate plus nitrite, dissolved as N (mg/L)	<0.005	0.256	4.678	10 (MCL)
Orthophosphate, dissolved as P (mg/L)	0.003	0.035	0.131	---
Phosphorus, dissolved as P (mg/L)	0.001	0.036	0.126	---
Other constituents				
Carbon, organic, dissolved as C (mg/L)	0.2	0.6	2.3	---
Coliform bacteria, total, m-ENDO agar (col/100 mL)	<1.0	<1.0	2.0	0 (MCLG)
Methylene blue active substances (mg/L)	<0.02	<0.02	0.03	0.5 (SMCL)
Radon-222, total (pCi/L)	365	867	6,378	300 (PMCL)

[a] U.S. Environmental Protection Agency (1996).

Of the 20 wells sampled:

- *water samples from 3 wells exceeded the U.S. Environmental Protection Agency secondary maximum contaminant level drinking-water standard of 50 micrograms per liter for manganese;*
- *nitrate concentrations were elevated in 2 wells;*
- *total coliform bacteria were detected in 2 wells;*
- *methylene blue active substances were detected in 4 wells;*
- *all wells had radon concentrations greater than the U.S. Environmental Protection Agency proposed maximum contaminant level drinking-water standard of 300 picocuries per liter.*

Specific conductance ranged from 106 to 436 microsiemens per centimeter at 25 degrees Celsius (µS/cm). Dissolved oxygen ranged from 0.1 to 7.6 milligrams per liter (mg/L). Dissolved-oxygen concentrations of less than 1.0 mg/L can be considered low for the Fraser River watershed (Apodaca and Bails, 1999). Low dissolved oxygen in the ground water may be a result of the presence of organic material in the water, which allows microorganisms to grow and consume oxygen. The pH values measured at 19 of the 20 wells (6.1 to 8.1) were in the range of the USEPA SMCL drinking-water standard of 6.5 to 8.5 for pH.

Major ions, which compose the bulk of dissolved constituents in ground water, generally occur naturally. Major ions in ground water most commonly result from interactions between the water and soil and rock. All major ions were less than the USEPA drinking-water standards. On the basis of the major ions present in the water, ground water in the Fraser River watershed is predominantly a calcium bicarbonate type water.

Dissolved-solids concentrations for all 20 wells were less than the USEPA SMCL of 500 mg/L in drinking water. Water containing amounts of dissolved solids above the USEPA SMCL is usually hard. High concentrations of dissolved constituents in the ground water can result from natural sources or ISDS contamination.

A major ion that may be associated with ISDS's is chloride (Canter and Knox, 1985). Chloride is present in all natural waters, usually in relatively small amounts; however, chloride also can be derived from human sources. Chloride is not effectively removed by the septic systems and, therefore, remains in their effluent. Chloride concentrations detected in the ground water of the Fraser River watershed did not exceed the USEPA SMCL standard of 250 mg/L. The chloride concentrations detected cannot be related to ISDS's in the study area.

Manganese, which is a trace element, exceeded the USEPA SMCL drinking-water standard of 50 micrograms per liter (µg/L) at three wells near the Tabernash area. The presence of elevated manganese concentrations in drinking water can cause a brown discoloration of the water and can affect the taste of the water (Hem, 1992).

Nitrogen and phosphorus are nutrients in ground water that can occur naturally. However, elevated nutrient concentrations may result from human activity, such as lawn fertilizer and animal and human waste. In areas containing ISDS's, the infiltration of septic system effluent can cause elevated nutrient levels in the ground water. For the 20 wells sampled, nutrient concentrations were less than USEPA drinking-water standards. However, nitrate was detected at two wells at concentrations greater than 2.0 mg/L. Nitrate concentrations greater than 2.0 mg/L may indicate that the concentrations are affected by human activities (U.S. Geological Survey, 1999). The concentrations of nitrate were generally higher in the urban setting (median = 0.40 mg/L) than in the forested setting (median = 0.14 mg/L) (fig. 3). Both of these factors suggest the effects of human activities.

Although no USEPA drinking-water standards or health advisories apply to phosphorus, the amount of phosphorus in ground water is important. Ground water that has elevated phosphorus concentrations can discharge into surface water and accelerate the process of eutrophication in rivers and lakes. Eutrophication is the process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen. Concentrations greater than 0.1 mg/L were present at 10 wells for orthophosphate.

Most of the DOC in ground water results from biological processes. The source of the DOC may be organic matter in the aquifer or may be related to human activities such as the use of fertilizers and ISDS's. Dissolved organic carbon was detected at all wells and ranged in concentration from 0.2 to 2.3 mg/L (table 1). The presence of DOC in water can affect the dissolved-oxygen concentration, which in turn can affect the nutrients and trace elements present in the ground water.

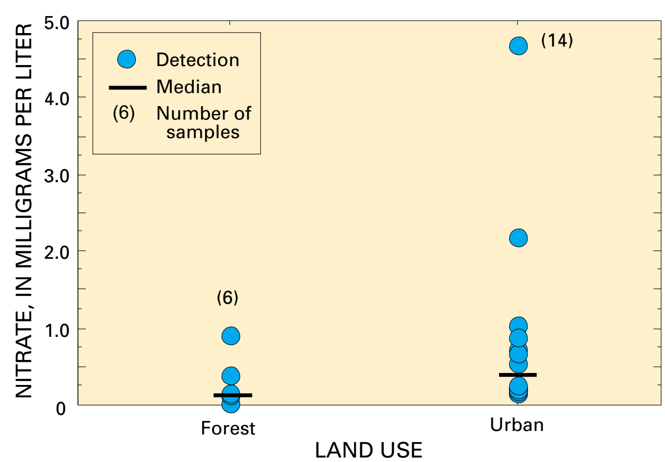

Figure 3. *Nitrate concentrations by land-use classifications.*

Total coliform bacteria are used to assess the sanitary quality of the drinking water because they can be correlated with water-borne diseases. Total coliform bacteria were detected at two wells in this study area at concentrations of 1 and 2 colonies per 100 milliliters (col/100 mL). The USEPA MCLG in drinking water for bacteria is 0 col/100 mL (U.S. Environmental Protection Agency, 1996). Total coliform bacteria may occur naturally in the soils or may be related to human or animal waste. The bacteria detected in this study probably are related to the soils because *E. coli*, which originates from warm-blooded animals, was not detected.

Methylene blue active substances are natural or synthetic anionic surfactants; the synthetic surfactants are found in many types of laundry detergents as optical brighteners. Methylene blue active substances are water soluble and may be transported from septic system effluent into the ground water (Thurman and others, 1986).The surfactants were detected at four wells at a concentration greater than the reporting limit of 0.02 mg/L. The USEPA SMCL for MBAS is 0.5 mg/L, and none of the wells exceeded this concentration. The presence of detergents in drinking water may cause an unpleasant taste and may create foaming.

Radon-222 is a natural decay product of uranium and occurs in soils and rocks. Radon can enter a home from seepage of air through dirt floors, cracks in concrete floors or walls, floor drains, or from the use of water from wells. All of the wells sampled exceeded the USEPA PMCL of 300 picocuries per liter (pCi/L) (table 1), which is currently under review (U.S. Environmental Protection Agency, 1996). The higher radon concentrations generally occurred in the samples from wells west of Fraser. Radon is a concern because it has been identified as a human carcinogen. Radon concentrations in ground water for the Fraser River watershed are comparable to concentrations from selected wells sampled in other parts of the Upper Colorado River Basin, Colorado, which ranged in concentration from 305 to 4,030 pCi/L (L.E. Apodaca, U.S. Geological Survey, unpub. data, 1997).

Table 2. Well information, estimated ground-water recharge date, and stable-isotope data for the 20 wells sampled in the Fraser River watershed, August 1998

[USGS, U.S. Geological Survey; ft, feet; F, forest; U, urban (primarily residential); CFC, chlorofluorocarbons; $\delta^{18}O$, oxygen isotopes; δD, hydrogen isotopes; Fm, formation; N/A, not available; data in bold type indicated sites with continued monitoring]

Site number (figure 1)	USGS station identification	Altitude (ft)	Aquifer [a]	Well depth (ft)	Land use [b]	CFC estimated recharge date	$\delta^{18}O$ per mil	δD per mil
1	395411105464500	8,920	Granite	185	F	1981	–18.3	–138
2	**395658105485400**	**8,568**	**Troublesome Fm**	**110**	**U**	**1983 or younger**	**–17.8**	**–135**
3	**395642105500700**	**8,685**	**Troublesome Fm**	**145**	**U**	**1968**	**–18.5**	**–141**
4	395647105500500	8,680	Alluvium	100	U	1990’s	–18.2	–138
5	395649105501500	8,680	Alluvium	120	U	1990’s	–18.3	–142
6	395657105500300	8,640	Alluvium	120	U	1961	–18.5	–140
7	**395657105495300**	**8,610**	**Alluvium**	**85**	**U**	**1980**	**–18.0**	**–137**
8	395704105500700	8,660	Alluvium	91	U	1990’s	–18.1	–139
9	**395750105515800**	**8,665**	**Troublesome Fm**	**120**	**F**	**1979**	**–18.3**	**–139**
10	**395921105472300**	**8,531**	**Alluvium**	**75**	**F**	**1991**	**–17.7**	**–134**
11	**395942105502000**	**8,332**	**Alluvium**	**65**	**U**	**1969 or younger**	**–17.8**	**–135**
12	395925105503100	8,377	Alluvium	45	U	1981	–18.2	–138
13	395934105503600	8,345	Troublesome Fm	N/A	U	1968	–17.4	–132
14	**395937105500500**	**8,342**	**Alluvium**	**25**	**U**	**1990’s**	**–18.0**	**–138**
15	395930105505500	8,348	Alluvium	25	U	1974	–17.9	–137
16	**395929105510300**	**8,320**	**Alluvium**	**28**	**U**	**1976**	**–17.7**	**–134**
17	395934105521700	8,410	Alluvium	200	F	1973	–18.6	–143
18	**395928105533500**	**8,592**	**Troublesome Fm**	**295**	**F**	**1968**	**–18.6**	**–143**
19	**395907105540100**	**8,582**	**Granite**	**105**	**F**	**1955**	**–18.7**	**–143**
20	400013105540600	8,670	Alluvium	80	U	1989	–18.3	–142

[a] Tweto (1979) and Green (1992).

[b] Fegeas and others (1983).

GROUND-WATER AGE AND SOURCE

Measurement of CFC's in the ground water has been useful in dating ground water recharged within the last 50 years. Chlorofluorocarbons are manmade organic compounds used as refrigerants, aerosol propellants, cleaning agents, solvents, and blowing agents used in the production of foam rubber and plastics. Concentrations of CFC's in the atmosphere have steadily increased from the 1940's through the early 1990's (Busenberg and Plummer, 1992). Ground water acquires CFC's through recharge; on the basis of knowledge of the temporal variations in the CFC concentrations in the atmosphere, the date of the ground-water recharge can be estimated.

On average, ground-water recharge takes 18 to 38 years. The recharge age of the ground water is an important factor when devising land-management practices.

Ground-water ages in the Fraser River watershed ranged from the mid-1950's to 1990's (table 2). Water samples that were dated in the 1990's were collected from the alluvial aquifers. Most of the ground water sampled ranged in age from the late 1960's to early 1980's, indicating that the interval from the time the water recharged the aquifer to the time it was withdrawn from the aquifer was about 18 to 38 years. The two wells that had nitrate concentrations greater than 2.0 mg/L had water of 1990's age (fig. 4).

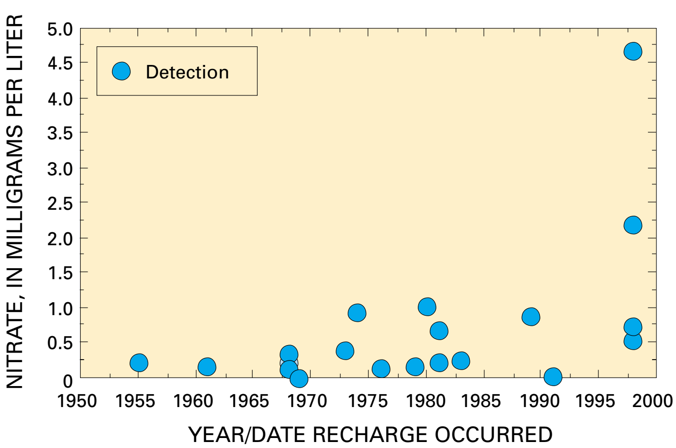

Figure 4. *Nitrate concentrations as related to the age of the ground water.*

These dates indicate that changes in the land use in recharge areas may not affect the ground-water quality in the Fraser River watershed for 20 to 40 years; correspondingly, land-management practices may take 20–40 years to cause changes in ground-water quality. Supplementing water-quality data with the age of the ground water helps provide a better understanding of the link between current land use and water quality in the underlying aquifers.

Recharge of the ground water is most likely from snowmelt.

Analyses of $\delta^{18}O$ (oxygen isotopes) and δD (hydrogen isotopes) can be useful in identifying the probable source of the ground water. If the ground-water isotopic compositions plot close to the local meteoric water line, then the source of the ground water is likely from local precipitation (Drever, 1988). If the data plot to the right of the meteoric water line, then the precipitation may have undergone evaporation. Also, the precipitation may have infiltrated through the land surface and chemically interacted with the surrounding soils and sediment, as it moved through the aquifer. Ground water in the Fraser River watershed had $\delta^{18}O$ values ranging from –17.4 to –18.7 per mil and δD concentrations ranging from –132 to –143 per mil (fig. 5). An alpine basin northeast of the Fraser River watershed had $\delta^{18}O$ values of the snowpack ranging from –25.9 to –16.5 per mil and had an average $\delta^{18}O$ value of the snowmelt of –18.6 per mil (Mast and others, 1995). The comparable $\delta^{18}O$ values indicate that the Fraser River watershed ground water is probably derived from snowmelt.

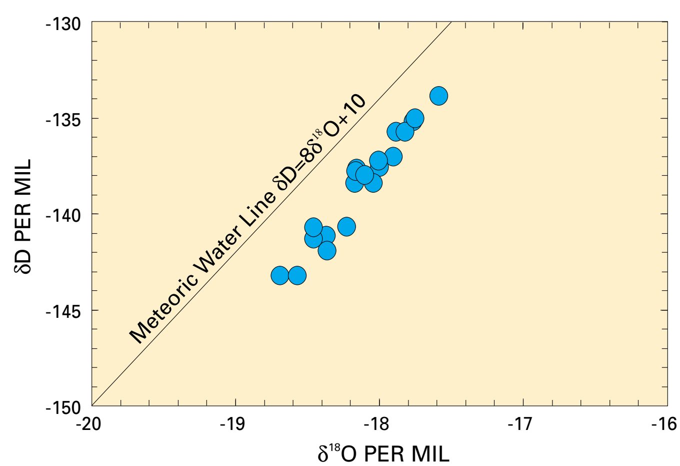

Figure 5. *Hydrogen (deuterium) and oxygen (^{18}O) isotopic compositions of selected ground-water wells sampled in the Fraser River watershed.*

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey, in cooperation with Grand County, began a 5-year study in 1998 to evaluate the ground-water quality in the Fraser River watershed. Because of the increase in population, the county is concerned about a high density of ISDS's and their potential effects on the future water quality in the watershed. In addition, the increased use (withdrawal) of ground water in the study area also may affect water quality. In August 1998, 20 randomly selected wells in the Fraser River watershed were sampled upgradient from Tabernash as part of the 5-year study. The results indicated that the ground water is of suitable quality for a drinking-water resource. The ground water in the Fraser River watershed is probably derived from snowmelt. The presence of nitrate and methylene blue active substances in modern waters may indicate that current (1998) land-use practices are affecting the water quality. The age of most of the ground water sampled is between 18 to 38 years, indicating that present-day land use may not affect the ground-water quality for many years. Therefore, the development and implementation of land-use planning strategies are important for maintaining the ground-water quality for future use.

The effects of individual septic disposal systems on the ground-water quality are not definitive or substantial; but with current and future urban growth of the watershed, ongoing monitoring would be beneficial to evaluate human effects.

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