

**Environmental Isotope Studies
of Wastewater and Ground Water
at Wastewater Land Treatment Sites in Idaho**



**Department of Environmental Quality
Technical Services Division
Revised June 2004**

The cover photograph shows a potato processing wastewater land treatment field in eastern Idaho. A wastewater clarifier can be seen in the foreground.

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Technical Services Division
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June 2004 Revision

The sole significant change is the corrected scatter plot in Figure 3, Scatter plot of chloride versus sulfate concentrations for ground water and wastewater samples.

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Abstract

Ground water contamination, whether from land-treatment or other adjacent land uses, exists in proximity to several wastewater land-treatment sites in Idaho. Contaminant sources are often difficult to discern. This reconnaissance study utilized environmental (stable) isotope analyses (^{15}N , ^{18}O , ^{34}S , and ^2H) of wastewaters and ground water to determine the feasibility of utilizing such analyses to help determine contaminant sources. Ground water and wastewater were sampled at 24 land-treatment facility sites. Ground water mixing zone modeling was conducted to determine whether predicted differences in isotopic signatures of up-gradient and down-gradient ground water are great enough to discern wastewater land-treatment as a contaminant source. Results indicated that isotopic enrichment generally takes place as ground (source) water is transformed to wastewater and as wastewater is stored. Modeling predicted that, for certain facilities, sufficient difference in up- and down-gradient ground water isotopic signatures may exist to discern contaminant sources. Site-specific follow-up studies are recommended.

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Introduction

There are approximately 130 permitted wastewater land application facilities that generate and treat wastewater in the state of Idaho. Wastewater volumes generated by permittees in Idaho range from a few million gallons per year to over a billion gallons per year for the largest industrial processors. Slow rate land application has been recognized as an effective method to treat wastewater generated by a variety of industrial processes as well as municipalities. However, wastewater land application poses a risk to ground water if wastewater is applied at rates exceeding the treatment capacity of the site and/or is applied utilizing poor management practices. The Department of Environmental Quality (DEQ) is responsible for determining if ground water impacts from slow rate land application are occurring, and if so, to adjust permit conditions accordingly. Therefore, DEQ is seeking to develop additional methods for evaluation of land application treatment sites.

To protect ground waters of the state, Idaho's Wastewater-Land Application Permit Rules (IDAPA 58.01.17) were promulgated in 1988. The companion Guidelines for Land Application of Municipal and Industrial Wastewater, were issued by DEQ in March 1988 (DEQ, 1988). The guidelines were updated in 1994 and issued as part of the Handbook for Land Application of Municipal and Industrial Wastewater (DEQ, 1996).

Idaho's Wastewater Land Application Permit (WLAP) program has undergone considerable development and improvement since its inception. One issue that remains at the forefront is how to evaluate ground water impacts from the operation of a land application facility. Ground water impacts can result from historical or current site operations, changes in site operation, and surrounding land use activities that are beyond the control of the facility.

Various analytical methods are employed to evaluate ground water impacts to and from facilities including evaluation of both ground water geochemistry and aquifer properties; analysis of nutrient, salt, and hydraulic balances; evaluation of vadose zone processes; use of statistical methods to evaluate constituent concentration trends; and simplified modeling of ground water capture zones and mixing zones. In many cases, there is insufficient information to make determinations of the causes of ground water impacts, and analytical results are often inconclusive. Additional lines of evidence are needed to develop more definitive conclusions. Utilization of naturally occurring isotopes in wastewater and/or ground water may help establish or clarify cause and effect relationships with respect to ground water contamination, which would be valuable to DEQ programs.

The use of environmental isotopes (i.e., isotopes which are stable in the environment and do not decay) as tracers has proven useful in many hydrogeological settings in Idaho. In particular:

- Stable isotopes of nitrogen have been used to differentiate between naturally occurring and anthropogenic sources of nitrogen in ground water in many nonpoint source settings. In one example, nitrogen isotopes were used to differentiate sources of nitrogen in ground water from municipal wastewater treatment, a large confined animal feeding operation, and general nonpoint source agriculture in northern Ada County, Idaho (Howarth, 1999).

- The Idaho State Department of Agriculture routinely uses nitrogen isotope analysis to investigate sources of nitrate found in ground water in agricultural areas.
- Oxygen and deuterium isotopes have been successfully used to provide information about ground water recharge conditions in the western end of the eastern Snake River Plain (Clark and Ott, 1996) and to determine sources of ground water found in municipal wells in the Fruitland area (Wicherski, 2000).

A review of the principles involved with oxygen, deuterium, sulfur, and nitrogen isotopes indicates that environmental isotopes can be useful tracers of contaminants. However, a recent literature review conducted by DEQ staff did not yield any published information or site-specific data relevant in this regard to wastewater land treatment facilities.

Purpose and Objectives

The purpose of this study was to investigate the feasibility of using environmental isotopes as tracers to determine contaminant sources, if any, at permitted wastewater land application facilities.

The objective of the study was to analyze environmental isotope concentrations in ground water sources and in wastewater generated using those ground water sources, at a variety of facilities that land apply wastewater. These facilities include sugar beet, meat, cheese, and potato processing facilities, and municipal wastewater treatment facilities. Wastewater and ground water samples were analyzed for the stable isotopes of nitrogen (^{14}N and ^{15}N), oxygen (^{16}O and ^{18}O), sulfur (^{34}S and ^{32}S) and hydrogen (^1H and ^2H). Samples also were collected for analysis of common anions and field parameters, which provide additional information about water chemistry at the facilities and help interpret the stable isotope data. Ground water mixing zone modeling was also conducted to determine whether predicted differences in isotopic signatures of up-gradient and down-gradient ground water are great enough to warrant further field studies using environmental isotopes.

Background

A brief overview of the chemistry of environmental isotopes used in this study is provided below, including applications of isotopic analysis for characterization of sources of environmental contamination. The genesis and characteristics of wastewater, along with the types of wastewater facilities studied, are also discussed.

Environmental Isotopes

The summary of environmental isotope occurrence and structure in this section is drawn largely from Clark and Fritz (1997) and Cook and Herczeg (2000). Isotopes are atoms of the same element that differ in mass because of a difference in the number of neutrons in the nucleus. The number of neutrons plus the number of protons equals the atomic mass of an element. An element is identified by writing the atomic mass in the upper left corner of the symbol of the element (e.g., ^1H is common hydrogen with one proton and zero neutrons, ^2H is deuterium with one proton and one neutron, ^3H is tritium with one proton and two neutrons).

Environmental or stable isotopes do not spontaneously decay to other atoms, in contrast to unstable isotopes (radionuclides) that decay and do so at predictable rates. The naturally occurring stable isotopes of the elements hydrogen (H), carbon (C), nitrogen (N), oxygen (O), and sulfur (S) are found in abundance in hydrological and geological systems and serve as tracers of water, carbon, nutrient, and solute cycling.

A stable isotope is measured as the ratio of the two most abundant isotopes of a given element. For instance, the $^{18}\text{O}/^{16}\text{O}$ ratio is about 0.00204 (^{18}O abundance is 0.204% and ^{16}O abundance is 99.796% of terrestrial oxygen). Small variations in this ratio are only apparent to the fifth or sixth decimal place. Rather than measure the absolute isotope ratio, laboratories measure an apparent ratio of a sample and a known reference on the same instrument (a mass spectrometer) at the same time. This method allows for the expression of variations in stable isotope concentrations rather than an actual abundance. An isotope concentration is then expressed as the difference between the measured ratios of the sample and the reference divided by the measured ratio of the reference. For oxygen, this is expressed using the delta (δ) notation:

$$\delta^{18}\text{O}_{\text{sample}} = \left[\left(\frac{^{18}\text{O}}{^{16}\text{O}} \right)_{\text{sample}} \div \left(\frac{^{18}\text{O}}{^{16}\text{O}} \right)_{\text{reference}} - 1 \right] \cdot 1000$$

Environmental isotopes combine with other atoms to form molecules that have slightly different weights than molecules with the more common form of the element, and these heavier molecules have different physical and chemical reaction rates. This results in partitioning or fractionation. Fractionation only imparts small variations in isotope concentrations so the results are expressed as parts per thousand or permil (‰). As an example, a δ -‰ value of + 10 ‰ has 10 parts per thousand (one percent) more ^{18}O than the reference. A positive δ -‰ value is said to be “enriched” or “heavy” relative to the standard, while a negative δ -‰ value indicates the sample is “depleted” or “light” relative to the standard. Standard mean ocean water (SMOW) is the reference used for the analysis of isotopic concentrations of $^{18}\text{O}/^{16}\text{O}$ and deuterium-hydrogen ($^2\text{H}/^1\text{H}$) for this study. The international standard for ^{34}S values is the troilite (iron sulfide - FeS) phase of the Cañon Diablo Troilite (CDT) meteorite which has a $^{34}\text{S}/^{32}\text{S}$ ratio of 0.0450.

The analytical precision for $\delta^{18}\text{O}$ values is usually better than ± 0.2 ‰, the analytical error for deuterium is usually ± 1.0 ‰, and the analytical error for sulfur is usually about ± 0.3 ‰ (Clark and Fritz, 1997).

Oxygen and Deuterium (^{18}O and ^2H)

Stable oxygen and hydrogen isotopes (^{16}O , ^{18}O , ^1H and ^2H) are present in certain proportions in the water molecule. Most ground water originates as precipitation. The isotopic content of oxygen and hydrogen in precipitation is affected by meteorological processes such as evaporation from oceans, rainout, re-evaporation from terrestrial basins, and snow and ice accumulation and runoff. As water evaporates from an open reservoir, the lighter isotopes, ^{16}O and ^1H , are preferentially removed and the remaining reservoir becomes enriched in the heavier isotopes ^{18}O and ^2H . This phenomenon has particular application at facilities studied that have large wastewater storage structures and long wastewater detention times (see Tables 3 and 4, pages 8 and 9). The spatial and temporal variations in oxygen and hydrogen isotopes

in precipitation and ground water can also be used to investigate sources of recharge (Coplen, 1993).

Condensation of water vapor causes the reverse effect, whereby the heavier molecules condense more efficiently, leaving the residual water vapor depleted in ^{18}O and ^2H (Clark and Fritz, 1997). Craig (1961) determined that $\delta^{18}\text{O}$ and $\delta^2\text{H}$ in fresh waters correlate on a global scale, and developed a “global meteoric water line” (GMWL) that defines the relationship between ^{18}O and ^2H in worldwide fresh waters:

$$\delta^2\text{H} = 8 \delta^{18}\text{O} + 10 \text{‰} \quad \text{SMOW} \quad (\text{where SMOW is Standard Mean Ocean Water})$$

The GMWL represents an empirical relationship between $\delta^{18}\text{O}$ and $\delta^2\text{H}$ from worldwide precipitation measurements at numerous global locations. Data that depart significantly from this line are often interpreted to have undergone some type of fractionation process subsequent to deposition, such as evaporation. Meteoric water lines that may depart from this global relationship, termed local meteoric water lines (LMWLs), have been developed for specific regions.

Craig’s GMWL has only global application because it is an average of many local or regional meteoric water lines, each differing from the global line due to varying climatic and geographic parameters. Wood and Low (1988) developed a local surface water meteoric line (LSWML) for southern Idaho from surface water samples collected at rivers in the eastern and western Snake River basin:

$$\delta^2\text{H} = 6.4 \delta^{18}\text{O} - 21\text{‰} \quad \text{V-SMOW}$$

where Vienna Standard Mean Ocean Water V-SMOW is a more recent meteoric water line used as a standard in the determination.

The LSWML is an integration of fractionation effects on water in the east and west Snake River basin that occurs during precipitation and residence time in lakes, reservoirs, and rivers. Another factor that probably affects ^{18}O and ^2H results are the evaporative processes that occur during irrigation of agricultural lands in the Snake River and tributary basins. Figure 4 in the Results and Discussion section shows plots of both GMWL and LSWML in relation to data collected in this study.

Sulfur (^{34}S)

Sulfur has several stable isotopes, of which ^{32}S and ^{34}S were employed in this study. About 95% of sulfur is ^{32}S , while only 4.2% is ^{34}S . The $^{34}\text{S}/^{32}\text{S}$ abundance ratio of the troilite standard is 1/22.22 (H. G. Thode *in* Krouse and Grinenko, 1991). Sulfur from different sources can have different isotopic signatures. Sulfur sources include atmospheric sulfur compounds, soil sulfur compounds, sulfur minerals in rocks, and sulfur in fertilizers such as ammonium sulfate (Krouse and Grinenko, 1991). Industrial processes can contribute sulfur to the atmosphere, soils, and ground water. If the isotopic signature of the source sulfur can be identified, that information can be utilized along with the isotopic signatures of the source

water and wastewater at a land application facility to more definitively determine any effects of the wastewater on the ground water.

Oxygen associated with the sulfate ion can also be analyzed for its $^{18}\text{O}/^{16}\text{O}$ ratio. The oxygen atoms in aqueous sulfate exchange with oxygen atoms in water only over very long time periods, with half-times estimated to be on the order of 10^7 years (Krouse and Grinenko, 1991). The age of ground water at sites sampled for this study is on the order of 10^3 to 10^4 years, so the oxygen atoms in the aqueous sulfate were not in equilibrium with the oxygen atoms in the water. Bacterial reduction of sulfate causes isotopic enrichment of ^{18}O and ^{34}S . Comparison of oxygen and sulfur isotope data from ground water and wastewater samples can give an indication of the redox history of the water and sulfur.

Nitrogen (^{15}N)

Much of the following discussion about the use of nitrogen isotopes to identify contaminant sources is excerpted from Seiler (1996). The nitrogen isotopes ^{15}N and ^{14}N constitute an isotope pair. The lighter isotope ^{14}N is significantly more abundant in the environment than ^{15}N . In the atmosphere there is one atom of ^{15}N per 273 atoms of ^{14}N (Drever, 1997). The reference standard for the stable isotopes of nitrogen ($^{15}\text{N}/^{14}\text{N}$) is atmospheric nitrogen (Clark and Fritz, 1997).

Several steps in the nitrogen cycle can modify the stable isotope composition of a nitrogen-containing chemical. Denitrification, for example, causes the nitrate of the starting material to become isotopically heavier. Volatilization of ammonia results in the lighter isotope preferentially being lost to the atmosphere and the ammonia that remains becoming isotopically heavier.

For stable isotopes to provide a useful tool in identifying sources of nitrogen contamination, the isotopic composition of the potential source materials must be distinguishable. The major potential sources of nitrogen contamination in the hydrosphere commonly have characteristic $^{15}\text{N}/^{14}\text{N}$ ratios. Typical $\delta^{15}\text{N}$ values for important sources of nitrogen contamination (Seiler, 1996) are presented in Table 1.

Table 1. Typical $\delta^{15}\text{N}$ Values for Different Nitrogen Sources

Potential Nitrogen Contaminant Source	$\delta^{15}\text{N}$ (‰)
Precipitation	- 3
Commercial Fertilizer	- 4 to + 4
Organic Nitrogen in Soil	+ 4 to + 9
Animal or Human Waste	> + 10

Wastewater Generation and Characteristics

Each wastewater land treatment facility is unique in terms of hydrogeology, soils, climate, season of application, and other factors. They are also unique with respect to wastewater streams. Wastewater quality and quantity can vary significantly among different types of facilities represented in this study and even among similar facilities. Wastewater

characteristics can vary with industrial process, particularly with the product being made (e.g. potato flakes versus diced potatoes), type and extent of treatment, storage and detention times, and physical state, age, and quantity of vegetative material being processed, among other factors.

Tables 2 through 5 contain information about the facilities included in this study. Table 2 has general information such as the type, location, and elevation of the each facility; Table 3 summarizes the wastewater treatment unit processes; and Table 4 shows wastewater sampling information including approximate detention times of wastewater streams sampled (as discussed in this paper, longer detention times may influence the isotopic signature of the wastewater). Table 5 gives generalized wastewater chemical characteristics of facilities participating in this study. The remainder of this section describes wastewater generation processes and characteristics of facilities in this study.

Potato Processing Wastewater

The most represented facility type in this study is dehydration potato processing (nine facilities). For these facilities, wastewater is a combination of wastewater from potato washing and fluming (silt wastewater) and potato processing (process wastewater). The silt wastewater is clarified to remove silt in a conventional clarifier, Delta Stak[®], settling pit, or other equivalent process. Potato process wastewater is generally a combination of cooker water, blancher water, general plant sewer water (non-septic), and other flows. This wastewater receives primary screening, after which it generally goes to a clarifier to remove suspended solids. Solids from clarifier underflow are removed with a vacuum filter drum, centrifuge, hydroclone, or equivalent process. Filtrate or concentrate from clarifier underflow is routed either back to the clarifier or on to land treatment, depending on how the system is plumbed. Figure 1 shows potato processing wastewater being flood-applied to land treatment acreage.

Two of these facilities (ID-032 and ID-039) have advanced treatment where high strength blancher and cooker wastewater is diverted and differentially treated through reverse osmosis, ultra-filtration, and evaporative processes to remove organic and inorganic constituents from the wastewater. Both the silt and process wastewater is generally combined after clarification and conveyed to land treatment fields. None of the dehydration potato processing facilities in this study has storage facilities.

Table 2. Wastewater Land Application Permitted Facility Information

Site ID	Facility Type	County	Latitude Degree, Minute, Second	Longitude Degree, Minute, Second	Elevation at Facility Feet Above Mean Sea Level
ID-005	Potato Processing (French Fry)	Power	42 45 57.20	-112 54 47.02	4390
ID-007	Potato Processing (Dehydration)	Elmore	42 57 15.34	-115 17 24.54	2550
ID-008	Potato Processing (French Fry)	Canyon	43 40 1.97	-116 43 39.72	2335
ID-010	Potato Processing (Dehydration)	Bonneville	43 33 1.77	-112 3 23.65	4730
ID-011	Potato Processing (Dehydration)	Jefferson	43 42 12.09	-112 00 12.49	4795
ID-031	Potato Processing (French Fry)	Bingham	42 56 50.15	-112 49 44.29	4395
ID-032	Potato Processing (Dehydration)	Bingham	43 22 43.61	-112 7 22.55	4625
ID-033	Potato Processing (Dehydration)	Bingham	43 18 46.03	-112 10 25.21	4570
ID-035	Municipal Wastewater Treatment	Bannock	42 54 52.20	-112 30 59.08	4400
ID-036	Potato Processing (Dehydration)	Bingham	43 12 6.18	-112 22 33.38	4470
ID-039	Potato Processing (Dehydration)	Bingham	43 12 9.87	-112 22 50.38	4475
ID-040	Potato Processing (Dehydration)	Madison	43 50 23.29	-111 46 50.59	4865
ID-042	Cheese Processing	Madison	43 50 52.21	-111 44 16.37	4880
ID-049	Sugar Beet Processing	Twin Falls	42 32 0.83	-114 25 55.02	3810
ID-050	Sugar Beet Processing	Minidoka	42 36 45.23	-113 45 28.15	4150
ID-055	Meat Processing (Slaughter)	Ada	43 26 8.89	-116 16 15.74	2860
ID-060	Municipal Wastewater Treatment	Ada	43 27 25.46	-116 24 52.74	2820
ID-063	Sugar Beet Processing	Canyon	43 36 20.65	-116 34 24.35	2470
ID-075	Potato Processing (Dehydration)	Clark	44 5 4.62	-112 13 11.64	4910
ID-079	Municipal Wastewater Treatment	Twin Falls	42 34 59.52	-114 36 36.58	3710
ID-084	Cheese Processing	Bingham	43 11 26.49	-112 20 43.48	4495
ID-091	Cheese Processing	Canyon	43 36 19.52	-116 29 31.63	2510
ID-095	Meat Processing (Product Processing)	Canyon	43 41 46.93	-116 54 41.83	2420
ID-104	Fertilizer Production (Phosphorus)	Bannock	42 54 33.92	-112 31 24.49	4440

Table 3. Wastewater Treatment Processes at Wastewater Land Application Facilities

Site ID	Primary Screening Y/N	Clarifier Y/N	FOG (1) Removal Y/N	Silt Settling/ Removal Y/N	Advanced Treatment Y/N	Wastewater Storage Y/N	Aerated Lagoon(s) Y/N	Anaerobic Lagoon(s) Y/N	Facultative Lagoon(s) Y/N
ID-005	Y	Y	Y (2)	Y	N	Y	N	N	Y
ID-007	Y	N	NA (3)	Y	N	N	NA	NA	NA
ID-008	Y	Y	Y (4)	Y	N	Y	N	N	Y
ID-010	Y	Y (5)	NA	Y	N	N	NA	NA	NA
ID-011	Y	Y	NA	Y	N	N	NA	NA	NA
ID-031	Y	Y	N	Y	N	N	NA	NA	NA
ID-032	Y	Y	NA	Y	Y	N	NA	NA	NA
ID-033	Y	Y	NA	Y	N	N	NA	NA	NA
ID-035	Y	Y	NA	NA	N	Y	Y	N	Y
ID-036	Y	Y	NA	Y	N	N	NA	NA	NA
ID-039	Y	Y	NA	Y	Y	N	NA	NA	NA
ID-040	Y	Y	NA	Y	N	N	NA	NA	NA
ID-042	Y	N	NA	NA	N	Y	Y	N	Y
ID-049	Y	Y (6)	NA	Y	N	Y	Y	N	Y
ID-050	Y	Y (6)	NA	Y	N	Y	Y	N	Y
ID-055	Y	N	Y (4)	NA	N	Y	Y	Y	Y
ID-060	Y	N	NA	NA	N	Y	Y	N	Y
ID-063	Y	Y (6)	NA	Y	N	Y	Y	N	Y
ID-075	Y	N	NA	N	N	N	NA	NA	NA
ID-079	Y	N	NA	NA	N	Y	Y	N	Y
ID-084	Y	N	NA	NA	N	N	NA	NA	NA
ID-091	Y	N	NA	NA	N	Y	Y	Y	Y
ID-095	Y	N	Y (4)	NA	N	Y	Y	N	Y
ID-104	Y	N	NA	NA	N	Y	N	N	N

- (1) Fat, oil, and grease (FOG)
- (2) Clarifier skimmer
- (3) Not applicable (NA)
- (4) Dissolved air flotation (DAF)
- (5) Hydroclones used instead of clarifier
- (6) Clarifier for silt stream only

Table 4. Wastewater Sampling Point Descriptions

Site ID	Sample ID (1)	Sample Date	Wastewater Sampling Point	Wastewater Detention Time (Days)
ID-005	F-005-WW01	11/9/2001	Concrete Ditch Near Clarifier and Sanitary Inflow Pipe	< 1
ID-005	F-005-WW02	11/8/2001	Pond 16	170
ID-007	D-007-WW01	11/6/2001	Holding Tank at West Farm	< 1
ID-008	F-008-WW01	11/2/2001	Effluent Storage Pond	15
ID-010	D-010-WW01	11/8/2001	Farm Pump Pit	< 1
ID-011	D-011-WW01	10/25/2001	Farm Pumphouse	< 1
ID-031	F-031-WW01	11/9/2001	Land Pumps	< 1
ID-032	D-032-WW01	11/8/2001	Farm Pumping Station	< 1
ID-033	D-033-WW01	10/25/2001	Effluent Pump Station	< 1
ID-035	M-035-WW01	10/23/2001	NPDES (2) Outfall Sampling Point	< 1
ID-036	D-036-WW01	10/24/2001	Clarifier Pump Station	< 1
ID-039	D-039-WW01	10/24/2001	Irrigation Distribution Ditch in Flood Field	< 1
ID-040	D-040-WW01	10/25/2001	Pumphouse	< 1
ID-042	C-042-WW01	10/25/2001	Secondary Lagoon	95
ID-049	S-049-WW01	11/7/2001	Condensate Pond	120
ID-049	S-049-WW02	11/7/2001	7-Acre Pond	55
ID-050	S-050-WW01	10/23/2001	Flume Excess Pond, West Side	260
ID-050	S-050-WW02	10/23/2001	East Lagoon (Condensate Wastewater)	50
ID-050	S-050-WW03	10/23/2001	Offsite Surge Pond (Condensate Wastewater)	5
ID-055	B-055-WW01	11/2/2001	Large Storage Lagoon	215
ID-060	M-060-WW01	11/2/2001	Cell No. 6 (Lagoon), North Side	275
ID-063	S-063-WW01	11/5/2001	No. 1 Sewer	3
ID-075	D-075-WW01	10/25/2001	Spigot in Waste Room	< 1
ID-079	M-079-WW01	11/7/2001	Mixing Chamber Effluent	65
ID-084	C-084-WW01	10/25/2001	Spigot at the Wastewater Silo	< 1
ID-091	C-091-WW01	11/5/2001	Pond No. 2	< 1
ID-095	B-095-WW01	11/5/2001	Process Water Pump Station	10
ID-104	E-104-WW01	11/28/2001	Final Equilization Pond at Pump Overflow	25

(1) F = French Fry Plant, D = Potato Dehydration Plant, M = Municipal Wastewater Treatment Plant, C = Cheese Processing Plant, S = Sugar Beet Processing Plant, B = Meat Processing Plant, E = Fertilizer (Phosphorus) Production Plant

(2) NPDES = National Pollution Discharge Elimination System

Table 5. Wastewater Quality at Wastewater Land Application Facilities – Generalized Description by Wastewater Type

Sample ID	Site ID	pH	TKN (1)	NH ₃ -N (2)	NO ₃ -N (3)	COD (4)	TDS (5)	NVDS (6)	P (7)	K (8)	Ca (9)	Mg (10)	Na (11)	CO ₃ /HCO ₃ (12)	SO ₄ (13)	Cl (14)
B-055-WW01	ID-055	7.8	140	130	0.1	200	1300 (15)	ND (16)	ND	ND	ND	ND	190	ND	ND	170
B-095-WW01	ID-095	ND	60	10	1	2500	1300 (15)	ND	20	40	20	3	300	ND	350	100
C-042-WW01	ID-042	ND	60	ND	ND	400	700	600	30	40	ND	ND	ND	ND	ND	ND
C-084-WW01	ID-084	ND	470	90	1	55600	4400 (15)	ND	440	ND	360	70	640	ND	ND	1450
C-091-WW01	ID-091	ND	140	ND	0.3	5600	3600	1400	50	120	ND	ND	ND	ND	ND	540
D-007-WW01	ID-007	ND	140	ND	5	4300	2000	1100	30	230	ND	ND	150	ND	90	110
D-010-WW01	ID-010	ND	80	ND	0.7	1800	1200	600	20	160	60	20	40	ND	ND	30
D-011-WW01	ID-011	ND	100	ND	0.2	3300	1600	800	20	220	60	20	30	ND	ND	50
D-032-WW01	ID-032	5.5	160	40	1	3600	1000	ND	10	340	60	50	30	290	90	70
D-033-WW01	ID-033	3.9	100	20	0.3	4300	ND	700 (17)	20	270	50	30	30	200	100 (18)	70
D-036-WW01	ID-036	5	110	ND	1	2700	ND	600	10	190	60	20	30	ND	ND	50
D-039-WW01	ID-039	ND	60	ND	ND	1400	ND	ND	10	160	50	ND	50	ND	50	100
D-040-WW01	ID-040	ND	100	ND	ND	2500	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D-075-WW01	ID-075	ND	130	10	ND	4300	2100	900	20	140	70	20	40	ND	50	60
E-104-WW01	ID-104	ND	ND	160	64	ND	1900	ND	40	10	90	30	340	210	1120	120
F-005-WW01	ID-005	5.5	140	ND	0.5 (19)	2800	ND	900	40	300	ND	ND	80	ND	ND	ND
F-005-WW02	ID-005	7.7	20	2	0.5	300	1500	1400	10	350	ND	ND	150	ND	ND	140
F-008-WW01	ID-008	7.1	180	ND	ND	600	1600	1100	60	400	ND	ND	ND	ND	20 (18)	140
F-031-WW01	ID-031	5.6	110	50	ND	2800	1300	700	20	220	ND	ND	ND	ND	60	110
M-035-WW01	ID-035	ND	60	50	10	ND	1600	ND	10	ND	100	ND	300	ND	670	ND
M-060-WW01	ID-060	ND	20	ND	2	60	500	300	5	ND	ND	ND	ND	ND	ND	ND
M-079-WW01	ID-079	ND	20 (20)	ND	ND	ND	ND	ND	3	ND	ND	ND	ND	ND	ND	ND
S-049-WW01	ID-049	9.2	90	80	2	200	40	30	0.1	0.3	2	0.2	0.2	270	1	1
S-049-WW02	ID-049	ND	100	80	1	2300	3000	1700	2	210	300	40	280	ND	90	180
S-050-WW01	ID-050	ND	60	30	1	1100	1700	1200	2	ND	ND	ND	ND	ND	ND	150
S-050-WW02	ID-050	9.2	907	80	2	200	40	30	0	0.3	2	0.2	0.2	270	1	1
S-050-WW03	ID-050	9.2	90	80	2	200	40	30	0	0.3	2	0.2	0.2	270	1	1
S-063-WW01	ID-063	7.5	50	20	0.5	1300	2600	ND	2	130	180	30	380	ND	ND	410

Column Heading Notes:

(1) total Kjeldahl nitrogen, (2) ammonia nitrogen, (3) nitrate nitrogen, (4) chemical oxygen demand, (5) total dissolved solids, (6) non-volatile dissolved solids, (7) phosphorous, (8) potassium, (9) calcium, (10) magnesium, (11) sodium, (12) carbonate/bicarbonate, (13) sulfate, (14) chloride

Data Notes:

(15) calculated from EC * 0.64, (16) ND = no data, (17) TDIS = Total Dissolved Inorganic Solids, (18) sulfur as SO₄-S, (19) Analysis was done and results were below detection limit—the value presented is the detection limit, (20) total nitrogen

Sample ID Notes:

B = Meat Processing Plant, C = Cheese Processing Plant, D = Potato Dehydration Plant, E = Fertilizer (Phosphorus) Production Plant, F = French Fry Plant, M = Municipal Wastewater Treatment Plant, S = Sugar Beet Processing Plant,



Three french fry potato processing facilities were sampled in this study. The wastewater treatment train for french fry processing is similar to that for dehydration potato processing, the exception being the need for fat, oil, and grease (FOG) removal in french fry processing. Only one facility (ID-008) has a dissolved air flotation unit process for FOG removal. The other two (ID-005 and ID-031) rely on clarifier skimming. Two of these facilities (ID-005 and ID-008) have storage to which post clarifier water is routed; ID-005 has an extensive system of natural ponds that allows for long detention times during which significant evaporation and facultative treatment takes place.

Figure 1. Potato processing wastewater being land applied to flood irrigation field.

Sugar Beet Processing Wastewater

Three sugar beet processing facilities were part of this study. These plants are rather complex with respect to wastewater generation and respective treatment processes, and there are significant differences among them in certain aspects of wastewater treatment. There are several wastewater streams generated by these facilities, each having a unique origin and characteristics. The flume system generates wastewater from flume transport of beets into the plant. The lime water system generates wastewater from the sugar purification process. The scrubber water system generates wastewater from pulp drying and coal-fired boiler scrubber systems. The fly ash system generates wastewater from slurring coal-fired boiler bottom ash to ash ponds. The condenser system generates condensate from the sugar crystallization process. And finally, a sanitary wastewater flow is generated from the plant, but does not generally mix with wastewater for land treatment. These wastewaters are typically stored in separate storage structures, but can be wasted to other storage structures at specific times during, and at the close of, campaign.

Wastewater quality from sugar beet processing varies considerably depending upon the types of processes taking place. The major processing phases at these sugar facilities are the beet slice campaign, in which beets are sliced and processed to sugar juice and sugar, and the juice run, which takes place after the beet slice and only processes sugar from sugar juice made and stored during the beet slice. These two processing phases generate different proportions and types of wastewater. Wastewater quality also depends upon the stage of the particular campaign and the age of the vegetative materials being processed. Biological degenerative

processes affect older beets and thus they generate more waste during processing than fresh beets. Sources of coal for coal-fired boilers may influence the amount of sulfur in waste streams as well as the sulfur's isotopic signature. As mentioned above, wastewater from certain closed systems is wasted into wastewater storage ponds periodically and at the close of campaign. These events can significantly change wastewater quality over time. At ID-049 and ID-050, condensate wastewater generated is separated from other wastewater and is either re-used for boiler feed water (ID-049) or both re-used and land applied (ID-050). Facility ID-063 does not isolate or re-use its condensate wastewater stream, nor does this facility land apply wastewater at this time.

Wastewater samples were taken from ID-049 and ID-050 about two months into the beet slice campaign. The wastewater samples were from wastewater storage ponds that receive wastewater from several systems and are large enough to have significant detention times (see Table 4). Longer detention times may influence the isotopic signature of these wastewaters. Since these two facilities are coal-powered, their wastewater isotopic signatures of sulfur may be influenced by sulfur from the coal. Sulfur can influence wastewater through the wasting of both scrubber pond wastewater and fly and bottom ash pond wastewater to wastewater storage ponds. It should be noted that the facilities obtain coal from more than one source, and coal from these sources is known to vary in its sulfur content. Wastewater sampled at ID-063 consisted of plant sewer water prior to it entering the oxidation pond and prior to it combining with flume, mud pond, and condenser wastewaters. Thus, this sample would not represent wastewater as would typically be land applied.

Condensate wastewater samples were taken from ID-049 and ID-050. The ID-049 sample was taken from a large condensate storage pond with long detention times. Condensate is not generally land applied at ID-049. One of the ID-050 condensate samples was taken from a small surge pond receiving condensate as it was being generated from the plant. After a short detention time, condensate was land applied from this surge pond. The other ID-050 condensate sample was taken from a large (20 million gallon) storage pond.

Municipal Wastewater

Three municipal wastewater treatment plants were sampled as part of this study. There are a number of different unit processes that may be utilized in the treatment of municipal wastewater. Wastewater from municipal collection systems typically undergoes primary treatment (solids removal through screening and primary clarification), then secondary (biological) treatment and clarification. After this, wastewater can be disinfected and discharged to surface water immediately or stored in lagoons for either discharge to surface water or land treatment (land application) at a later time. All three municipal systems in this study have storage lagoons. All three facilities land apply wastewater during the growing season only; facility ID-035 also discharges to surface water year-round. Facility ID-079 discharges to surface water during the non-growing season only. Facility ID-060 does not discharge to surface water at all.

Wastewater samples from ID-079 were taken from a point near the surface water discharge outfall, but underwent moderate detention times in storage structures prior to discharge. Wastewater samples from ID-035 were taken from a point near the surface water discharge outfall. At the time of sampling, wastewater entered this plant and was treated and discharged, undergoing negligible detention, as shown in Table 4. The wastewater sample from ID-060 was taken from the polishing lagoon, where the wastewater had undergone a long detention time.

Meat Processing Wastewater

Two meat processing facilities were included in this study. Facility ID-055 is a cattle slaughter facility. The wastewater sample was taken from a large storage lagoon that has a long wastewater detention time. Facility ID-095 is a food processor utilizing bulk prepared meats to manufacture meat-based food products. At the time of sampling, the smaller treatment and storage ponds at the ID-095 facility site had been by-passed and were no longer in use. Wastewater is now piped offsite and goes directly to both an irrigation mixing pond and a storage pond at the land treatment site. The wastewater sample from ID-095 was taken from the storage pond at the land treatment site.

Cheese Processing Wastewater

Three cheese processing plants were represented in this study. The disposition of wastewater from these plants is varied. It is either discharged to a waste silo, trucked offsite, and immediately land applied (ID-084); discharged to small anaerobic lagoons and then land applied (ID-091); or discharged into a highly aerated cell, then into a large facultative lagoon with long detention times, then land applied (ID-042). Samples were taken from the waste silo, a small anaerobic lagoon, and a large facultative lagoon respectively.

Fertilizer Production Wastewater

One fertilizer production facility was sampled as part of this study (ID-104). Wastewater from this phosphorus plant undergoes primary treatment, then pre-treatment (pH adjustment) if needed, before it enters a surge pond. After a moderately short detention time, wastewater either combines with municipal wastewater flows from ID-035 or is routed to a wastewater land treatment site. The sample was taken from a point just beyond the surge pond (after pre-treatment), and prior to combining with municipal flows.

Materials and Methods

The geographic area of the study and procedures used are described in this section.

Study Area

Facilities participating in the study generally were located within the arcuate-trending east and west Snake River Plain aquifers of southern Idaho (Figure 2). The distance between the western-most and eastern-most sample locations is approximately 270 miles.

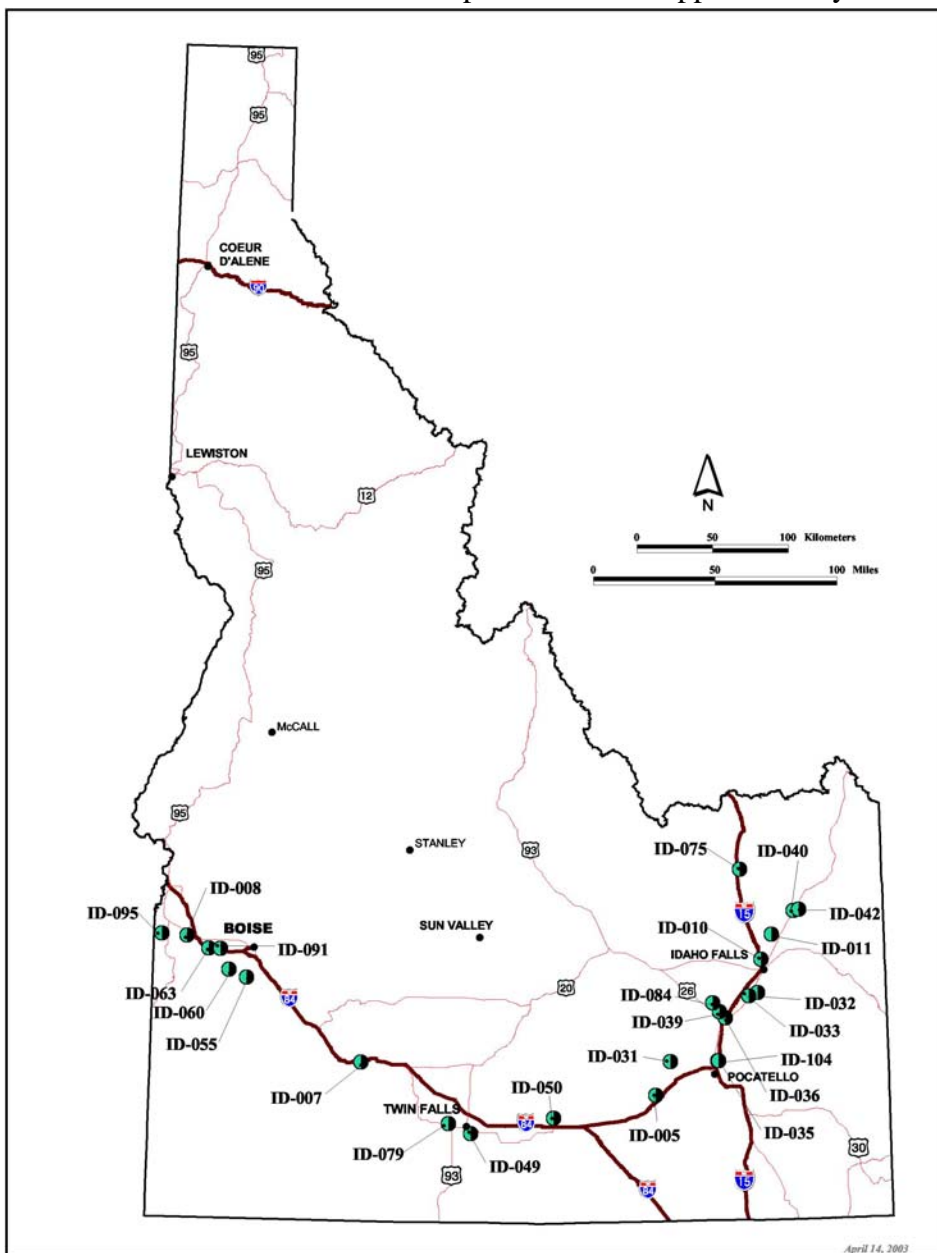


Figure 2. Study area and facility locations.

Sampling Procedures

Twenty-four ground water source samples and 28 corresponding wastewater samples were collected in October and November of 2001 (see Table 4 or 10 for exact sampling dates). All samples were analyzed for inorganic analytes and environmental isotopes. Sampling points for ground water sources (source water) were production water wells for the facilities and represented ground water used in processes that generate wastewater at those facilities. The difference in isotopic signature between source water and wastewater generated from source water is examined in this report.

Following are the types of wastewater facilities sampled in each geographic area.

1. Southwestern Idaho: two meat processing facilities, two potato processing facilities (one french fry plant and one dehydration plant), a sugar beet processing plant, a cheese processing plant, and a municipal wastewater treatment plant.
2. South Central Idaho: two sugar beet processing facilities and a municipal wastewater treatment facility.
3. Eastern Idaho: ten potato processing facilities (two french fry plants and eight dehydration plants), two cheese processing plants, a municipal wastewater treatment facility, and a fertilizer production facility.

At some facilities more than one wastewater stream was sampled to characterize the isotopic signature of different wastewater effluent streams. For each wastewater sample, the sampling point selected was expected to be the point during current operation that represented the furthest endpoint in the treatment train and longest detention period. Wastewater from these points generally is representative of wastewater that is being land applied to treatment acreage, but not always. An exception to this is condensate wastewater from site ID-050 (sample S-050-WW03), which is often routed to a small surge pond and immediately land applied. Another exception is at site ID-005, where samples were obtained from different points in the wastewater treatment train, both raw wastewater (F-005-WW01) and highly treated wastewater (F-005-WW02), to evaluate isotopic differences. The latter wastewater is not land applied. Table 4 lists wastewater sampling points and estimated detention times that wastewater from these points might reside in the treatment system.

For ground water sources, well logs were obtained where available. Well construction information and location are summarized in Table 6. Prior to taking ground water samples, field parameters (pH, electrical conductivity, dissolved oxygen, and temperature) were monitored until levels stabilized and variation in reading was less than 10 %. A Horiba model U-10 probe was utilized for field parameter measurement and was calibrated daily according to operating instructions. See Table 7 for recorded field parameter values.

Field staff recorded sampling conditions on field sampling forms. Sample size for both wastewater and ground water was 2 liters for isotope analyses and 2 liters for inorganic analyses for a total of 4 liters. One-liter cubitainers were used to collect samples. Samples were immediately iced and cooled to 4 °C. One 2-liter portion of each sample was analyzed at the

Idaho Bureau of Laboratories for chloride, sulfate, and nitrate-nitrogen, the latter being a measure of $\text{NO}_2\text{-N} + \text{NO}_3\text{-N}$ (hereafter referred to as nitrate-N or $\text{NO}_3\text{-N}$). See Tables 7 and 8, respectively, for ground water and wastewater inorganic analytical results. Two-liter portions of all samples were frozen immediately upon return from sampling events, and within 30 days were mailed to the University of Waterloo Environmental Isotope Laboratory for isotopic ratio analysis. Environmental isotopes analyzed included ^{15}N (in NO_3), ^{18}O (in NO_3), ^{18}O (in SO_4), ^{18}O , ^2H , and ^{34}S . See Tables 9 and 10 for isotope ratio analysis results for ground water and wastewater, respectively.

Results and Discussion

An evaluation of chloride, sulfate, and nitrate-N data from ground water and wastewater is presented below, followed by discussion of isotope data and results of ground water mixing zone modeling.

Chloride, Sulfate and Nitrate-N Results

Results of chloride, sulfate and nitrate-N data for ground water and wastewater, respectively, are found in Tables 6 and 7. A plot of chloride versus sulfate for ground water and wastewater is presented in Figure 3.

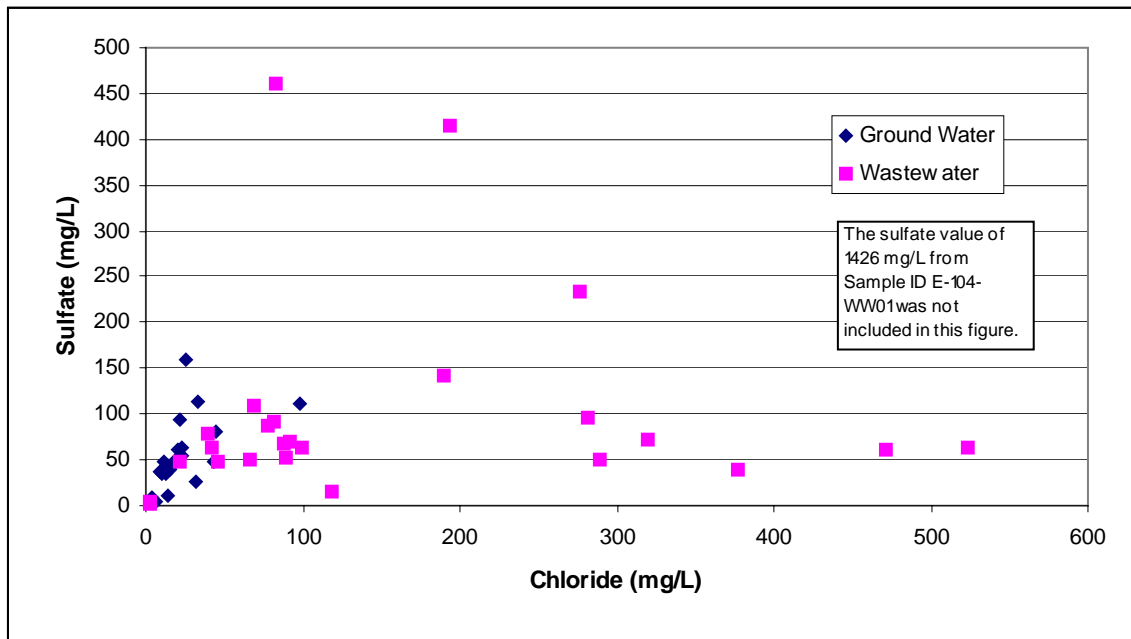


Figure 3. Scatter plot of chloride versus sulfate concentrations for ground water and wastewater samples.

Table 6. Ground Water Sampling Point Descriptions

Sample ID	Site ID	Sample Date	Ground Water Sampling Point	Well Log? Y or N	Screened or Open Interval Feet	Latitude Degree, Minute, Second	Longitude Degree, Minute, Second	Aquifer Materials
B-055-GW01	ID-055	11/2/2001	West Well	Y	360 - 370 (1)	43 26 10.54	-116 16 25.28	Gravel/Sand
B-095-GW01	ID-095	11/5/2001	Well No. 1-A	Y	411-443	43 41 46.93 (2)	-116 54 41.83 (2)	Sand
C-042-GW01	ID-042	10/25/2001	Well Nos. 1 and 2	Y	124.5 - 125	43 50 54.71	-111 44 22.92	Gravel/Boulders
C-084-GW01	ID-084	10/24/2001	Blackfoot Municipal Well No. 3	Y	? - 99.6	43 11 8.45	-112 20 26.59	Basalt (3)
C-091-GW01	ID-091	11/5/2001	Fresh Water Well House	Y (4)	265 - 290	43 36 19.48	-116 29 30.30	Sand
D-007-GW01	ID-007	11/6/2001	Plant Well (before chlorination)	Y	198 - ?	42 57 8.17 (2)	-115 17 55.10 (2)	Clay/Sandstone
D-010-GW01	ID-010	11/8/2001	Main Well	N	unknown	43 33 2.84	-112 3 27.29	Basalt
D-011-GW01	ID-011	10/25/2001	Boiler Room Well (Plant Well)	N	unknown	43 42 9.54	-112 0 19.08	Gravel (3)
D-032-GW01	ID-032	11/9/2001	Plant Well No. 2	N	unknown	43 22 26.69	-112 7 37.60	Basalt (3)
D-033-GW01	ID-033	10/24/2001	Main Well	Y	108 - 190	43 18 47.20	-112 10 26.94	Basalt/Gravel
D-036-GW01	ID-036	10/24/2001	Processing Well	Y (4)	20 - 60	43 12 9.50	-112 22 29.96	Cinders/Basalt
D-039-GW01	ID-039	10/24/2001	Plant Well No. 3 (before chlorination)	Y	128-155	43 12 47.92	-112 22 31.73	Basalt/Cinders
D-040-GW01	ID-040	10/25/2001	Main Well	Y	112-286	43 50 23.42	-111 46 58.84	Basalt (5)
D-075-GW01	ID-075	10/25/2001	North Well	Y	56-160	44 5 6.65 (2)	-112 13 13.44 (2)	Basalt/Crevices
E-104-GW01	ID-104	11/9/2001	Pocatello Municipal Well No. 35	Y	221 - 265	42 54 38.56	-112 34 39.22	Basalt
F-005-GW01	ID-005	11/8/2001	Plant Well	Y	208 - 220	42 45 56.45	-112 54 50.83	Basalt
F-008-GW01	ID-008	11/2/2001	Plant Well	N	unknown	43 39 58.36	-116 43 33.02	Sand (5)
F-031-GW01	ID-031	11/9/2001	Plant Well	Y (4)	274 - 317 (6)	42 53 24.07	-112 49 32.48	Basalt
M-035-GW01	ID-035	10/23/2001	Pocatello Municipal Well No. 32	Y	153 - 190	42 54 19.98	-112 28 38.17	Basalt
M-060-GW01	ID-060	11/2/2001	Cedar Well No. 4	N	unknown	43 29 25.51	-116 25 45.88	Sand (3)
M-079-GW01	ID-079	11/7/2001	Filer Municipal Well	N	unknown	42 33 34.88	-114 36 44.35	Basalt (3)
S-049-GW01	ID-049	11/7/2001	Spring Water at Main Sump	NA (7)	NA	42 31 13.19 (2)	-114 26 8.45 (2)	Discharge from Basalt
S-050-GW01	ID-050	10/23/2001	Production Well No. 2	Y	115-150(8)	42 36 46.01 (2)	-113 45 32.33 (2)	Basalt/Cinders/ Sand
S-063-GW01	ID-063	11/5/2001	Well No. 9	Y	462 - 477 (9)	43 36 19.51 (2)	-116 34 26.62 (2)	Sand

Sample ID Notes:

- B = Meat Processing Plant
- C = Cheese Processing Plant
- D = Potato Dehydration Plant
- E = Fertilizer (Phosphorus) Production Plant
- F = French Fry Plant
- M = Municipal Wastewater Treatment Plant
- S = Sugar Beet Processing Plant

- (1) Also 380 - 390 ft; 407 - 438 feet
- (2) Approximate location
- (3) Presumed based on surrounding well logs
- (4) Available log is most likely the log in question
- (5) Aquifer materials most likely in screened/open interval
- (6) Also 377 - 397 feet (gravel)
- (7) Not applicable (NA)
- (8) Also 60 - 195 ft
- (9) Also 484 - 489 feet; 499 - 524 feet

Table 7. Ground Water Analytical Data – Field Parameters and Inorganic Analyses

Sample ID	Site ID	Field pH SU (1)	Field Sp. Cond. (2) $\mu\text{m/cm}$ (3)	Field Temperature Degrees C	Field D.O. (4) mg/L (5)	Lab Cl mg/L	Lab SO ₄ mg/L	Lab NO ₂ +NO ₃ mg/L
B-055-GW01	ID-055	7.72	482	23.8	6.86	23.5	63.6	1.86
B-095-GW01	ID-095	8.24	453	23.9	5.43	6.19	4.17	0.005 (6)
C-042-GW01	ID-042	8.00	379	8.0	1.86	3.46	8.6	0.433
C-084-GW01	ID-084	7.88	617	12.1	6.76	13.7	43.2	1.57
C-091-GW01	ID-091	7.69	590	18.3	4.85	21.3	92.8	1.33
D-007-GW01	ID-007	9.25	625	36.3	4.62	14.1	12.0	0.005 (6)
D-010-GW01	ID-010	7.86	508	11.1	7.01	9.01	36.7	1.46
D-011-GW01	ID-011	7.94	522	9.0	3.50	11.1	47.0	0.533
D-032-GW01	ID-032	7.84	596	12.8	6.01	15.2	40.0	2.29
D-033-GW01	ID-033	7.60	529	12.9	4.76	10.0	34.8	1.21
D-036-GW01	ID-036	7.86	509	10.1	7.85	13.2	37.4	1.76
D-039-GW01	ID-039	7.68	449	12.4	3.82	12.2	35.1	0.431
D-040-GW01	ID-040	8.07	408	10.6	3.73	4.3	9.07	0.959
D-075-GW01	ID-075	7.86	494	12.1	7.02	32.3	25.7	0.986
E-104-GW01	ID-104	8.22	479	11.5	7.25	18	46.0	0.973
F-005-GW01	ID-005	8.01	709	13.2	5.35	44.9	80.3	1.52
F-008-GW01	ID-008	7.93	493	19.1	2.21	22.4	55.5	1.19
F-031-GW01	ID-031	8.39	490	10.7	9.70	19.2	50.1	0.86
M-035-GW01	ID-035	7.49	791	12.6	7.11	43.8	48.6	1.73
M-060-GW01	ID-060	8.61	241	24.9	4.68	3.89	7.05	0.12
M-079-GW01	ID-079	6.98	900	15.3	7.22	26.1	159	2.09
S-049-GW01	ID-049	ND (7)	ND	ND	ND	33.3	114	3.16
S-050-GW01	ID-050	7.71	990	14.5	4.50	98	111	0.005 (6)
S-063-GW01	ID-063	8.32	433	19.9	5.80	19.8	60.6	0.77

(1) standard units

(2) specific conductivity

(3) micromhos per centimeter

(4) dissolved oxygen

(5) milligrams per liter

(6) Analysis was done and results were below detection limit. The value presented is the detection limit.

(7) No data (ND)

Table 8. Wastewater Analytical Data – Inorganic Analyses

Sample ID	Site ID	Cl mg/L (1)	SO₄ mg/L	NO₂+NO₃ mg/L
B-055-WW01	ID-055	289	49.2	14.7
B-095-WW01	ID-095	82.2	460	0.04
C-042-WW01	ID-042	118	14.5	0.368
C-084-WW01	ID-084	471	62.0	0.073
C-091-WW01	ID-091	524	62.5	0.03
D-007-WW01	ID-007	91.8	68.8	0.03
D-010-WW01	ID-010	21.7	48.8	0.018
D-011-WW01	ID-011	81.1	90.9	0.056
D-032-WW01	ID-032	42.2	64.1	5.37
D-033-WW01	ID-033	87.9	66.8	0.428
D-036-WW01	ID-036	78.0	87.0	1.37
D-039-WW01	ID-039	98.9	63.6	0.008
D-040-WW01	ID-040	377	39.0	0.138
D-075-WW01	ID-075	46.1	47.1	0.916
E-104-WW01	ID-104	72.6	1426	4.54
F-005-WW01	ID-005	68.7	110	0.049
F-005-WW02	ID-005	ND (2)	ND	ND
F-008-WW01	ID-008	89.7	51.7	0.005 (3)
F-031-WW01	ID-031	320	71.7	0.225
M-035-WW01	ID-035	282	97.0	3.23
M-060-WW01	ID-060	40.1	77.6	0.23
M-079-WW01	ID-079	190	141	1.90
S-049-WW01	ID-049	2 (3)	4.2	0.029
S-049-WW02	ID-049	276	234	0.022
S-050-WW01	ID-050	193	414	0.051
S-050-WW02	ID-050	2 (3)	2.15	0.005 (3)
S-050-WW03	ID-050	2 (3)	2 (3)	0.005 (3)
S-063-WW01	ID-063	66.8	49.4	0.06

(1) Milligrams per liter

(2) No data (ND)

(3) Analysis was done and results were below detection limit.
The value presented is the detection limit.

Table 9. Ground Water Analytical Data – Isotopic Analyses

Sample ID	Site ID	$\delta^{18}\text{O}$ (‰) (1)	$\delta^2\text{H}$ (‰)	$\delta^{34}\text{S}$ (‰)	$\delta^{18}\text{O}$ in SO_4 (‰)	$\delta^{15}\text{N}$ in NO_3 (‰)	$\delta^{18}\text{O}$ in NO_3 (‰)
B-055-GW01	ID-055	-16.75	-136.75	8.35	-0.93	9.81	1.58
B-095-GW01	ID-095	-17.09	-140.14	11.45	2.33	ND	ND
C-042-GW01	ID-042	-17.82	-134.8	14.29	4.96	ND	ND
C-084-GW01	ID-084	-16.00	-128.1	14.68	7.12	7.48	ND
C-091-GW01	ID-091	-16.24	-130.82	7.73	2.68	10.62	-2.85
D-007-GW01	ID-007	-18.08	-143.55	19.54	4.28	ND	ND
D-010-GW01	ID-010	-17.10	-132.37	16.01	8.29	5.17	-0.03
D-011-GW01	ID-011	-17.15	-136.2	17.99	10.99	6.33	ND
D-032-GW01	ID-032	-17.35	-127.04	15.99	7.66	6.93	-1.83
D-033-GW01	ID-033	-16.48	-132.2	16.63	9.56	7.90	ND
D-036-GW01	ID-036	-16.52	-131.3	16.58	8.44	7.39	ND
D-039-GW01	ID-039	-16.69	-129.7	17.29	7.98	ND	ND
D-040-GW01	ID-040	-17.35	-134.6	12.30	3.75	6.21	ND
D-075-GW01	ID-075	ND	-134.2	7.46	-1.61	8.92	ND
E-104-GW01	ID-104	-17.55	-133.44	15.45	9.36	ND	ND
F-005-GW01	ID-005	-17.17	-135.96	12.41	1.77	7.09	1.02
F-008-GW01	ID-008	-17.19	-132.24	6.40	-0.68	11.84	1.12
F-031-GW01	ID-031	-17.59	-136.01	15.68	9.73	ND	ND
M-035-GW01	ID-035	-15.50	-125.8	12.86	3.59	8.46	ND
M-060-GW01	ID-060	-16.53	-133.04	8.90	4.54	ND	ND
M-079-GW01	ID-079	-15.37	-125.01	10.33	3.34	6.27	1.26
S-049-GW01	ID-049	-15.84	-125.96	11.05	4.16	6.87	-0.38
S-050-GW01	ID-050	-16.70	-127.6	5.51	0.49	ND	ND
S-063-GW01	ID-063	-16.23	-133.37	8.22	1.42	ND	ND

(1) No data (ND)

Table 10. Wastewater Analytical Data – Isotopic Analyses

Sample ID	Site ID	$\delta^{18}\text{O}$	$\delta^2\text{H}$	$\delta^{34}\text{S}$	$\delta^{18}\text{O}$ in	$\delta^{15}\text{N}$ in	$\delta^{18}\text{O}$ in
		(‰) (1)	(‰)	(‰)	SO_4 (‰)	NO_3 (‰)	NO_3 (‰)
B-055-WW01	ID-055	-6.29	-82.13	7.54	-0.87	ND (1)	5.44
B-095-WW01	ID-095	-17.02	-135.83	15.07	8.31	ND	ND
C-042-WW01	ID-042	-14.79	-121.6	12.62	-0.25	ND	ND
C-084-WW01	ID-084	-15.51	-128.0	13.09	-0.29	ND	ND
C-091-WW01	ID-091	-15.34	-123.53	14.52	ND	ND	ND
D-007-WW01	ID-007	-16.09	-132.66	12.44	ND	ND	ND
D-010-WW01	ID-010	-16.60	-130.19	14.11	3.90	ND	ND
D-011-WW01	ID-011	-16.78	-129.9	14.32	3.01	ND	ND
D-032-WW01	ID-032	-15.92	-127.08	ND	ND	6.89	ND
D-033-WW01	ID-033	-16.33	-130.4	13.73	4.64	ND	ND
D-036-WW01	ID-036	-15.58	-128.8	11.42	ND	-4.53	ND
D-039-WW01	ID-039	-15.90	-131.8	14.09	4.77	ND	ND
D-040-WW01	ID-040	-15.06	-133.8	10.47	1.3	ND	ND
D-075-WW01	ID-075	-16.22	-133.7	8.42	-1.01	6.00	ND
E-104-WW01	ID-104	-15.84	-126.43	10.93	8.36	ND	ND
F-005-WW01	ID-005	-16.67	-129.42	ND	5.38	ND	ND
F-005-WW02	ID-005	1.61	-44.09	13.74	7.40	ND	ND
F-008-WW01	ID-008	-14.81	-125.29	6.61	-5.39	ND	ND
F-031-WW01	ID-031	-16.21	-124.83	ND	ND	ND	ND
M-035-WW01	ID-035	-16.04	-128.3	9.28	0.29	3.26	ND
M-060-WW01	ID-060	-14.31	-122.76	7.30	-0.44	ND	ND
M-079-WW01	ID-079	-13.89	-116.99	9.43	ND	29.67	4.85
S-049-WW01	ID-049	-10.64	-95.29	10.83	-1.00	ND	ND
S-049-WW02	ID-049	-11.03	-102.95	12.88	7.63	ND	ND
S-050-WW01	ID-050	-10.87	-97.78	11.01	ND	ND	ND
S-050-WW02	ID-050	-12.66	-108.9	12.35	ND	ND	ND
S-050-WW03	ID-050	-5.71	-83.49	13.87	2.64	ND	ND
S-063-WW01	ID-063	-9.06	-101.36	10.41	5.02	ND	ND

(1) No data (ND)

Chloride concentrations in 24 ground water samples ranged from 3 to 98 milligrams per liter (mg/L), with all but one ranging from 3 to 45 mg/L. The well with a chloride concentration of 98 mg/L supplies water to a sugar beet processing plant; the reason for this elevated chloride value is unknown. Sulfate concentrations in the ground water at the wells ranged from 4 to about 160 mg/L, with most concentrations in the range of 4 to 65 mg/L. The five wells with sulfate concentrations from about 80 to 160 mg/L included a potato french fry plant, two sugar beet processing plants, a municipal wastewater treatment facility, and a cheese processing plant.

Chloride concentrations in 27 wastewater samples ranged from below the detection limit of 2 mg/L to 524 mg/L. Most chloride concentrations in wastewater ranged from 2 to 100 mg/L, but 10 wastewater samples had chloride concentrations greater than 100 mg/L. The elevated chloride concentrations may have resulted from 1) the addition of brine from water softening processes to the wastewater stream, 2) the use of salt in the cheese making process, or 3) other inputs of chloride to the waste stream. Sulfate concentrations in wastewater ranged from below the detection limit of 2 mg/L to 1426 mg/L. The elevated value of 1,426 mg/L was from a fertilizer production facility where sulfuric acid is used in processing the ore material. Absent this value, sulfate concentrations ranged from 2 mg/L to 460 mg/L. There appears to be little correlation between chloride and sulfate levels in the wastewater analyzed.

Nitrate-N concentrations from ground water samples ranged from below the laboratory detection limit of 0.005 mg/L to 3.16 mg/L. Twenty-one of 24 ground water nitrate samples had concentrations of 2.0 mg/L or less, even though nine of the 24 sites fall within nitrate priority areas (see Parlman [2002] for descriptions and locations of nitrate priority areas in the state). Nitrate-N concentrations from wastewater samples were generally low, with values ranging from less than detection (0.005 mg/L) to 14.7 mg/L. Twenty-two out of 27 samples were less than 1 mg/L.

Oxygen and Deuterium Isotope Results

Oxygen and deuterium data were compared to meteoric water lines and also reviewed for the potential for enrichment of the heavier isotopes.

Relative to Meteoric Water Lines

Results of ^{18}O isotope analyses are plotted against those of ^2H in Figure 4, in relation to the GMWL of Craig (1961) and an LSXML for the Snake River basin area (Wood and Low, 1988).

Ground water data are grouped fairly tightly in the lower left, indicating that 1) there is not much variability in isotopic signatures in ground water among the sites sampled, even though they are from various areas of the state, and 2) little isotopic enrichment of deuterium and oxygen has taken place in these waters. An enrichment of both isotopes is indicated as data trend from the lower left to the upper right of the plot field. It can be noted that for both

ground water and wastewater, all data points but one lie below the LSWML and conform more closely to the LSWML than to the GMWL, which is as expected.

Enrichment in Wastewater Relative to Ground Water

Enrichment of both $\delta^2\text{H}$ and $\delta^{18}\text{O}$ in wastewater is observed compared to corresponding ground water in the comparison of wastewater and ground water isotope analyses when analyses are paired by facility. The shift in $\delta^2\text{H}$ and $\delta^{18}\text{O}$ between each wastewater and ground water pair was evaluated quantitatively. This was done by subtracting wastewater $\delta^2\text{H}$ and $\delta^{18}\text{O}$ data from ground water $\delta^2\text{H}$ and $\delta^{18}\text{O}$. If the result was positive, this indicated a shift towards enrichment of heavier isotopic composition. Out of 27 wastewater/ground water data pairs, 89% show positive shifts for both $\delta^2\text{H}$ and $\delta^{18}\text{O}$, 7% show a positive shift in $\delta^{18}\text{O}$ and a negative shift in $\delta^2\text{H}$, and 4% (one pair) show negative shifts in both $\delta^2\text{H}$ and $\delta^{18}\text{O}$. Overall, this suggests that ground water used for municipal and food processing tends to become enriched in heavier isotopes.

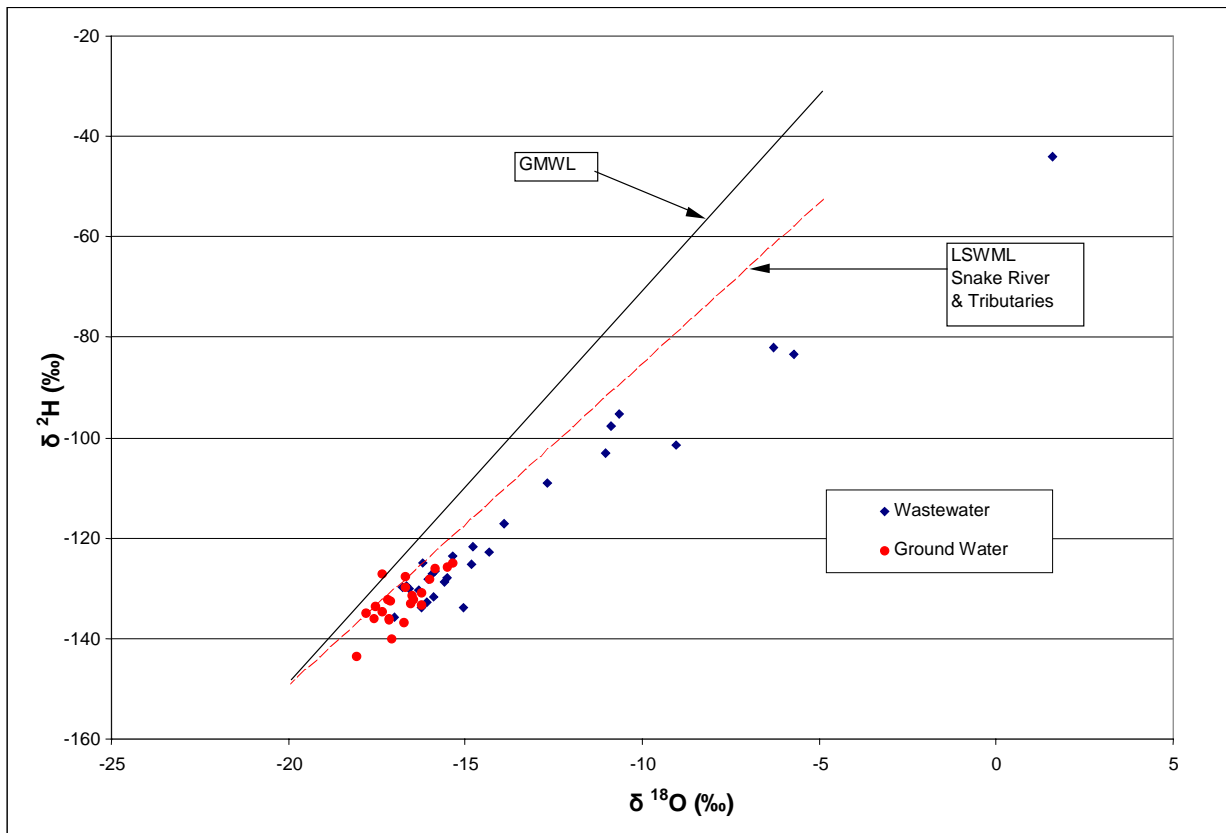


Figure 4. Wastewater and ground water stable isotope ratio analyses. Plot of $\delta^2\text{H}$ (‰) versus $\delta^{18}\text{O}$ (‰) with global and local meteoric water lines.

Enrichment in Wastewater Relative to Detention Times

Figure 5 shows $\delta^2\text{H}$ plotted against $\delta^{18}\text{O}$ for wastewater samples only, with wastewater sample results differentiated based on detention times. Evidence of isotopic enrichment of wastewater is seen as a function of wastewater detention time. Site ID-005 wastewater

samples F-005-WW01 and F-005-WW02 represent two contrasting wastewaters. Sample F-005-WW01 represents primary treated (solids screening and primary clarification) potato processing wastewater (“raw wastewater”) obtained as it leaves the clarifier and before it experiences further facultative treatment. It plots in the lower left. In contrast, F-005-WW02 represents wastewater from Pond 16, the terminal wastewater treatment structure in the extensive pond system at this facility. Wastewater in Pond 16 undergoes significant detention times. This wastewater has been routed through several ponds, experiencing approximately 170 days of detention time and significant evaporative effects. These conditions would be expected to enrich environmental isotopes. The Pond 16 wastewater plots in the far upper right of the plot field indicating substantial alteration of the wastewater isotopic signature as expected. See Table 4 for estimated detention times of all samples.

Other wastewater samples plotted in Figure 5 also reflect enrichment as data points denoting longer detention times generally trend towards the upper right of the plot field. It can be seen from Figure 5 that not all data points denoting higher detention times show enrichment, however.

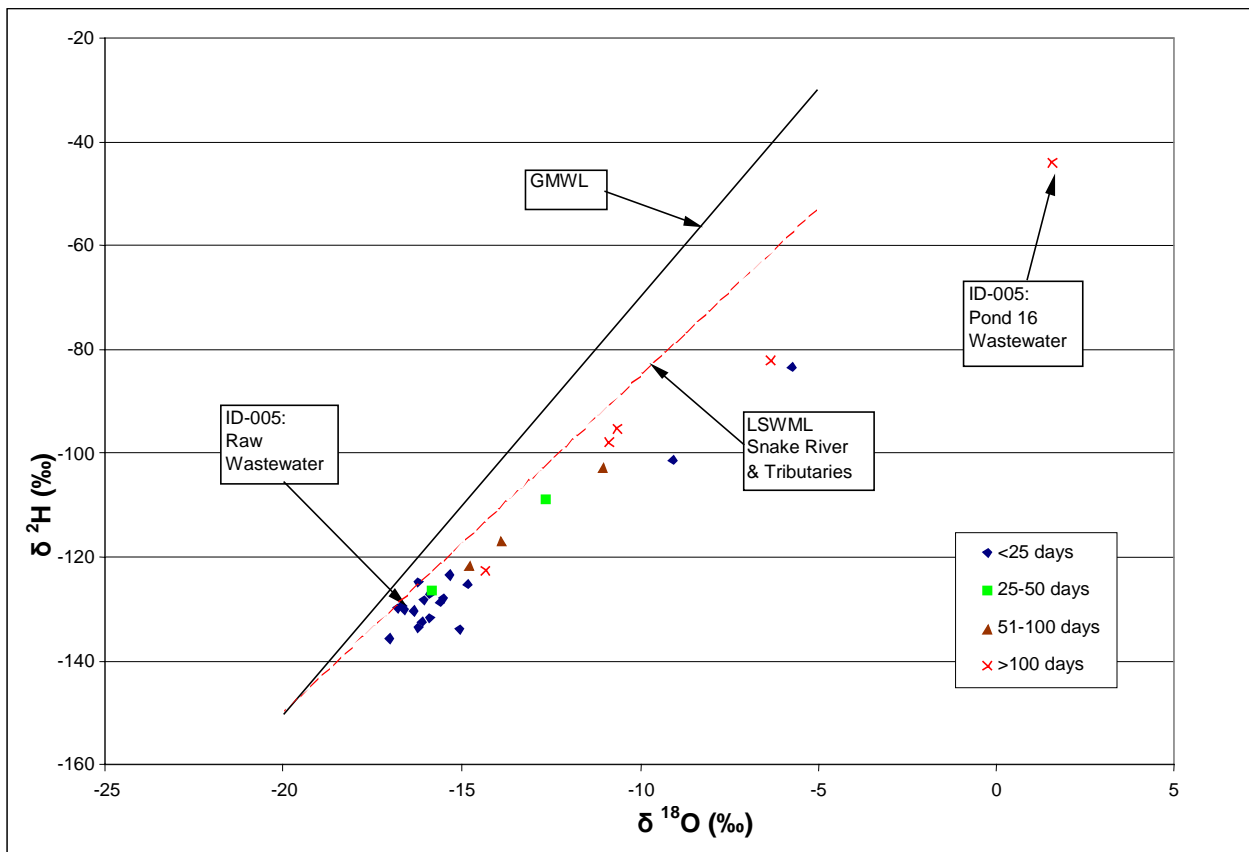


Figure 5. Wastewater stable isotope ratio analyses. Plot of $\delta^2\text{H}$ (‰) versus $\delta^{18}\text{O}$ (‰). Data marked in detention time categories.

In particular, while the 20 wastewater samples clustered to the lower left of the plot field of Figure 5 are predominantly those with detention times less than 25 days, three represent samples from treatment systems having detention times greater than 50 days. These represent

two municipal wastewater treatment plants (ID-060 and ID-079) and one cheese processor (ID-042). Conversely, two wastewater samples having detention times less than 25 days plot in the middle and upper right of the plot field: ID-063 (sugar beet wastewater) and ID-050 (sugar beet condensate wastewater) respectively.

Figure 6 shows $\delta^2\text{H}$ data plotted against $\delta^{18}\text{O}$ data for wastewater samples identified by facility/wastewater type. Most of the potato processing wastewater samples appear in the lower left of the plot field. With one exception discussed above, potato processing facilities participating in the study do not have storage ponds as part of their wastewater treatment trains and therefore their wastewaters undergo negligible detention times. See Table 3 for a summary of wastewater treatment unit processes at each facility.

The three cheese processing facility wastewater samples plot in the same area. While two have detention times of less than one day (ID-084 and ID-091), the third has a detention time of 95 days (ID-042), and might have been expected to have a different isotopic signature. Wastewater (non-condensate) samples from the sugar beet facilities plot towards the middle of Figure 6 in an unexpectedly close cluster, having varied detention times of 3, 55, and 260 days. Condensate wastewater data from sugar beet facilities, although reflecting isotopic enrichment, have a greater spread along the plot field. Detention times for the three cheese facilities, from the lower left data point to the upper right data point, are 50, 120, and 5 days respectively. A pattern of 5, 50, and 120 days from lower left to upper right would be more according to expectations. Contrasting the two meat processors, ID-095 and ID-055, the former has a wastewater detention time of 10 days and the latter 215 days. Relative to each other, they occupy positions in Figure 6 that would be expected: ID-095 to the lower left and ID-055 toward the upper right.

$^{15}\text{N-NO}_3$ and $^{18}\text{O-NO}_3$ Isotope Results

Tables 9 and 10 show data for $\delta^{15}\text{N}$ in NO_3 ($^{15}\text{N-NO}_3$) and $\delta^{18}\text{O}$ in NO_3 ($^{18}\text{O-NO}_3$) for ground water and wastewater, respectively. There were 15 and five ^{15}N isotope results from ground water and wastewater samples, respectively. The limited data set is due to the generally low concentrations of $\text{NO}_3\text{-N}$ in both ground water and wastewater samples. Inadequate masses of nitrogen in the samples made isotopic analysis infeasible to perform in many cases. There were eight and two $^{18}\text{O-NO}_3$ isotope results for ground water and wastewater, respectively. As with $^{15}\text{N-NO}_3$, limited data sets were due to generally low concentrations of NO_3 in samples.

Twelve of the 15 ground water $\delta^{15}\text{N-NO}_3$ sample results were in the range of 6 to 10 ‰, indicative of a soil organic nitrogen source (see Table 1). Two $\delta^{15}\text{N-NO}_3$ sample results were greater than 10 ‰, indicative of an animal or human waste source and one sample result was less than 4 ‰, indicative of a commercial fertilizer source. Five $\delta^{15}\text{N}$ results from wastewater samples ranged from - 4.53 to 29.67 ‰. The $\delta^{15}\text{N-NO}_3$ value of 29.67 ‰, from a municipal wastewater treatment plant (ID-079), is typical of nitrogen from a human waste source.

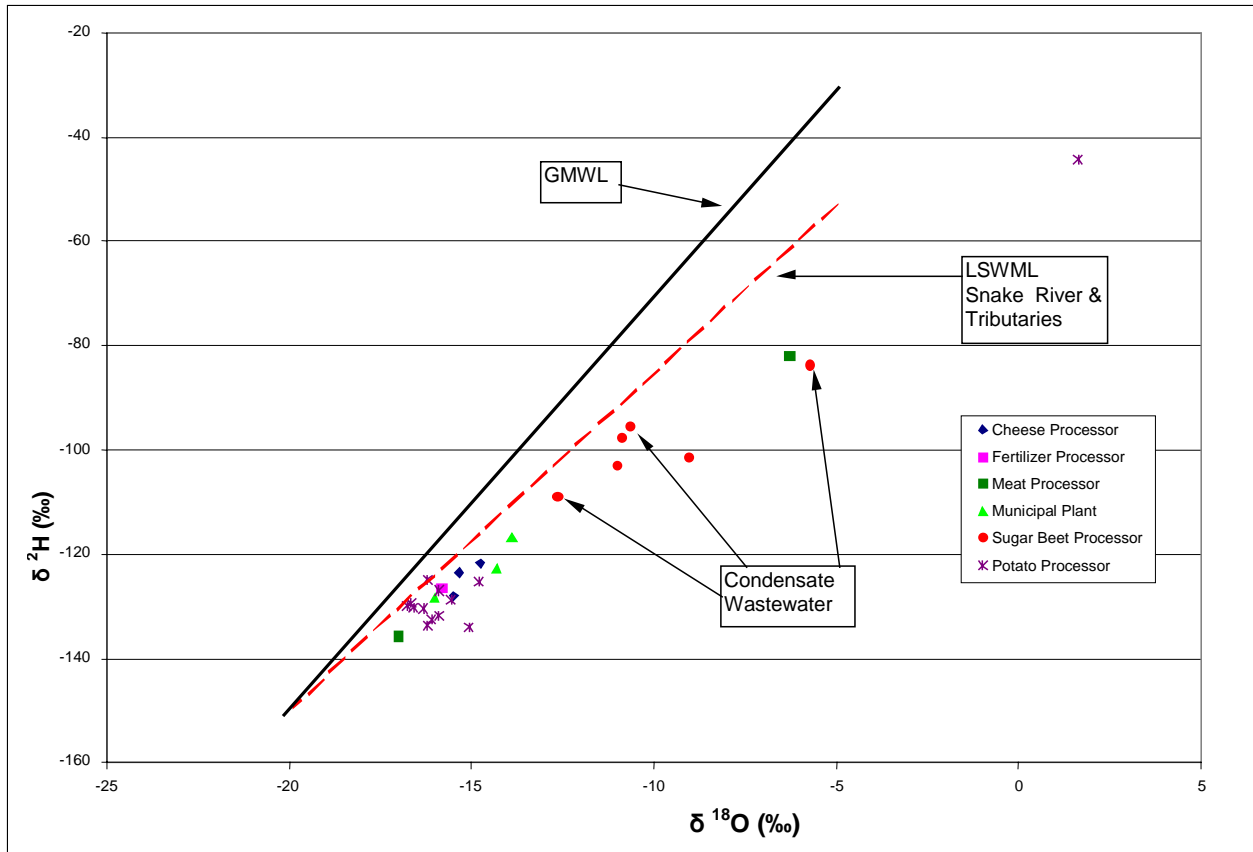


Figure 6. Wastewater stable isotope ratio analyses. Plot of $\delta^2\text{H}$ (‰) versus $\delta^{18}\text{O}$ (‰). Data marked by wastewater/facility type.

^{34}S Isotope Results

Depletion of ^{34}S in wastewater compared to corresponding ground water samples occurs in 88% (seven out of eight) of the potato processing dehydration facilities sampled. All three municipal facilities showed slight ^{34}S depletion of wastewater as well. Pronounced $\delta^{34}\text{S}$ enrichment of wastewater and condensate wastewater was seen in all three sugar beet wastewater samples compared to ground water at site ID-050. This pronounced enrichment was not seen in other sugar beet wastewaters.

Potential problems with interpretation of sulfur isotope results include lack of knowledge about chemical, biological, and kinetic fractionation effects; the concentrations of sulfate end members in ground water; and the final concentrations after end member mixing. No interpretation is made of ^{34}S results.

Longitudinal Isotopic Changes in Ground Water

There is often a relationship between isotope composition of natural waters and distance from an ocean. As a precipitation-bearing weather front moves from a point of origin off the coast

and travels inland, distillation and precipitation of heavier isotopes occurs first. As the front moves inland, precipitation becomes depleted of heavier isotopes and reflects a correspondingly lighter isotopic signature. Such a pattern of varying isotopic signatures of precipitation may influence natural waters to be heavier isotopically closer to the coast and lighter with distance inland.

Trends of ground water isotopic data for $\delta^{18}\text{O}$ and $\delta^2\text{H}$ (see Table 6) were examined as a function of varying longitudes. Longitudinal location of facilities in this study varied across southern Idaho from -111.7397 to -116.9116 decimal degrees, spanning approximately 270 miles. No trends were observed.

Predicting Isotopic Signature in Down-Gradient Ground Water Using Mixing Zone Analysis

For isotope sample results to provide useable information to determine contaminant sources from a wastewater land application facility, there must be a discernable difference between the isotopic signature of the ground water source, from either a deep aquifer or first-encountered up-gradient ground water (often shallow), and the final isotopic signature of down-gradient ground water after having mixed with leachate derived from wastewater application. If the isotopic signatures are sufficiently different, impacts from wastewater land treatment may be discernable. Mixing zone analyses were conducted to make preliminary determinations whether discernable differences might exist.

General Considerations

The final isotopic signature of down-gradient ground water, which represents mixing of up-gradient ground water with leachate from a land treatment field, is dependent upon many factors besides respective isotopic signatures of up-gradient ground water and wastewater. Critical factors affecting the final isotopic signature of down-gradient ground water include the respective volumes of: 1) ground water subject to mixing; and 2) wastewater and irrigation water applied, and the resulting volume and chemical characteristics of leachate that is generated and subsequently mixed with ground water. Ground water volume is dependent on aquifer properties. Wastewater, irrigation water, and subsequent leachate volumes are dependent on many factors including 1) regulatory limitations and allowances specified in wastewater land application permits, 2) facility operation and management, 3) soil and crop type, and 4) type of irrigation. Wastewater may have a widely differing isotopic signature than corresponding source ground water, but depending on the volume and signature of irrigation water utilized, wastewater may or may not have influence on the down-gradient ground water.

Another critical factor affecting the final isotopic signature of down-gradient ground water is the concentration of sulfur and $\text{NO}_3\text{-N}$ in ground water and wastewater when conducting a mixing zone analysis for ^{34}S or ^{15}N . For example, a wastewater may have a significantly different isotopic signature for ^{34}S than up-gradient ground water, yet if the sulfur concentration in the wastewater is low, the isotopic signature after mixing with groundwater

may show little influence from the wastewater. For example, it can be seen from Table 11 (page 31) that the $\delta^{34}\text{S}$ level in condensate wastewater sample S-050-WW02 differs widely from the level in the associated ground water. But because of the low concentration of sulfur in the condensate, resulting mixing zone modeling shows little difference between calculated down-gradient levels and up-gradient ground water levels (see Figure 7, page 32).

Methods

To make a preliminary determination of which facilities might benefit from environmental isotopic analyses in contaminant source characterization, ground water mixing zone modeling was conducted. The object of this modeling was to determine whether there might be 1) sufficient difference in isotopic signature between up-gradient ground water and predicted steady-state down-gradient ground water, the latter representing up-gradient ground water mixing with leachate generated from a wastewater land treatment site, and 2) sufficient similarity between down-gradient ground water and wastewater isotopic signatures to observe impacts from wastewater land treatment on ground water. The mixing equation used (EPA, 1981) is given below.

$$C_{\text{mix}} = \frac{(C_p * Q_p) + (C_{\text{gw}} * Q_{\text{gw}})}{Q_p + Q_{\text{gw}}}$$

Where:

- C_{mix} is the predicted steady-state down-gradient ground water concentration after mixing with up-gradient ground water and leachate.
- C_p is percolate (leachate) constituent concentration (mass/volume).
- Q_p is percolate flow (volume/time). Time period is one year.
- C_{gw} is up-gradient ground water constituent concentration (mass/volume).
- Q_{gw} is flow of ground water mixing with percolate flow (volume/time). The time period is one year. For purposes of this study, $Q_{\text{gw}} = KiA$, where:
 - K is aquifer saturated hydraulic conductivity (length/time),
 - i is the hydraulic gradient (unitless), and
 - A is the cross sectional area of up-gradient ground water discharge onto the site for mixing with leachate. This area is perpendicular to ground water flow (length²).

Assumptions

Assumptions made in the course of modeling are listed below.

- 1) Isotopic signatures of ground water source wells sampled were assumed to be the same as both first-encountered ground water up-gradient of the treatment sites and irrigation water utilized on the treatment acreage.

- 2) Management and loading scenarios utilized for each facility were chosen based upon the likelihood of seeing effects of those scenarios in additional field studies if any are conducted in the near future. For sites with slower moving ground water, historical scenarios were utilized. For sites having rapid displacement of ground water, current management scenarios were utilized.
- 3) Hydraulic conductivity and gradient are aquifer properties that were chosen based upon the best information available. It should especially be noted that hydraulic conductivity values can vary widely and mixing zone modeling output can be very sensitive to this parameter.
- 4) Mixing zone depth, used to calculate cross-sectional area, was assumed to be 10 feet for all scenarios. Mixing zone modeling output can be sensitive to this parameter. Since this is a reconnaissance level evaluation, more complex assessments of probable mixing zone depths were not conducted.
- 5) Crop uptake of sulfur was not taken into account in these mixing zone modeling calculations, and it was assumed that no change in the sulfur isotopic signature of wastewater took place in the crop/soil system other than that of mixing irrigation water with applied wastewater.
- 6) It was assumed that no change in the oxygen or hydrogen isotopic signatures of wastewater or irrigation water took place in the crop/soil system other than that of mixing irrigation water with applied wastewater.

Results

Results of mixing zone modeling are shown in Table 11. There are three major columns for $\delta^{18}\text{O}$, $\delta^2\text{H}$, and $\delta^{34}\text{S}$. Values of $\delta^{18}\text{O}$, $\delta^2\text{H}$, and $\delta^{34}\text{S}$ for ground water and wastewater (the end-members) are given on the left and right respectively in each major column, while the results of mixing zone modeling (Cmix) are shown in the center of each major column. Note that the results of mixing zone modeling always lie between the end-member levels of the volumes being mixed. An important indicator is whether there is a sufficient difference between the up-gradient ground water signature and the down-gradient mix signature to discern wastewater impacts. These differences have been calculated for each wastewater sample by taking the absolute value of the difference between the up-gradient ground water isotope ratio analysis and that predicted for the final down-gradient ground water/leachate mix (hereafter ABS(GW - Cmix)). The greater the ABS(GW - Cmix) value, the greater the difference between up- and down-gradient ground water isotopic signatures, and thus a potentially greater utility for the use of environmental isotopes in the determination of contaminant sources. Figure 7 shows ABS(GW - Cmix) for $\delta^{18}\text{O}$, $\delta^2\text{H}$, and $\delta^{34}\text{S}$.

Figure 7 shows that different isotopes have different magnitudes of ABS(GW - Cmix) and that one isotope may be better suited than another for use at a particular facility. For example, the magnitudes of $\delta^{34}\text{S}$ ABS(GW - Cmix) for wastewater samples D-033-WW01, B-095-WW01, and E-104-WW01 are high relative to others calculated, while the magnitudes of $\delta^2\text{H}$ ABS(GW - Cmix) and $\delta^{18}\text{O}$ ABS(GW - Cmix) for the same wastewater samples are relatively low.

Setting magnitudes of ABS(GW - Cmix) that would be sufficient to see, in reproducible ground water sampling events, isotopic differences between up-gradient and down-gradient ground water, remains speculative until further studies are done. For the purposes of this study, the relative magnitudes of the $\delta^{18}\text{O}$ ABS(GW - Cmix) (see Figure 7) suggest that sufficient isotopic differences may exist at sites ID-050 and ID-063. The relative magnitudes of the $\delta^2\text{H}$ ABS(GW - Cmix) suggest that sufficient isotopic differences may exist at sites ID-005, ID-008, ID-011, ID-042, ID-050, ID-055, ID-060, ID-063, ID-079, and ID-091. And finally, the relative magnitudes of the $\delta^{34}\text{S}$ ABS(GW - Cmix) suggest that sufficient isotopic differences may exist at sites ID-007, ID-011, ID-033, ID-040, ID-050, ID-060, ID-063, ID-091, ID-95 and ID-104. Sites with sufficient isotopic differences might benefit from environmental isotopic analyses in contaminant source characterization.

Mixing zone analysis was not conducted for ^{15}N isotope results. Ground water and wastewater isotope results were compared. There were five pairs of ground water/wastewater $\delta^{15}\text{N}$ isotope results (see Tables 9 and 10). Three of the five (ID036, ID-075, and ID-035) showed a depletion in nitrogen isotopes for wastewater compared to ground water and one (ID-079) showed an enrichment in wastewater compared to ground water. At the fifth site (ID-032), there was no change in the $\delta^{15}\text{N}$ result. At site ID-079 the enriched $\delta^{15}\text{N}$ value of 29.67 permil in wastewater would provide a useful tracer for nitrate in ground water monitoring wells. At site ID-035, another municipal wastewater treatment facility where a $\delta^{15}\text{N}$ result is available, enrichment of $\delta^{15}\text{N}$ was not seen. The reason for this is unknown.

Wastewater Isotope Study Design Limitations

There are two study design limitations which are due to the limited reconnaissance nature of the study. These limitations have been taken into account in the interpretation of the data.

- The isotope results represent a one-time sample analysis at each facility and it is not known whether or how much seasonal or annual variability occurs at these facilities. For facilities with a uniform stream entering the plant such as a municipal wastewater treatment facility or a milk processing plant, there may not be significant seasonal or annual isotopic variation. At other facilities, the product entering the plant can “age” as the processing season progresses, or the nature of the waste stream can change as wastewater is released to storage ponds from different areas of the plant.
- Also, ground water source isotope analysis results generally represent deep regional aquifers, while monitoring wells at wastewater land application sites often are completed in shallow aquifers. It is unknown how isotope signatures vary between shallow and regional aquifers at the facilities investigated.

Table 11. Ground Water Mixing Zone Modeling Results for ^{18}O , ^2H , and ^{34}S

Sample ID	Site ID	GW (1) $\delta^{18}\text{O}$ (‰)	Cmix (2) $\delta^{18}\text{O}$ (‰)	WW (3) $\delta^{18}\text{O}$ (‰)	GW $\delta^2\text{H}$ (‰)	Cmix $\delta^2\text{H}$ (‰)	WW $\delta^2\text{H}$ (‰)	GW $\delta^{34}\text{S}$ (‰)	Cmix $\delta^{34}\text{S}$ (‰)	WW $\delta^{34}\text{S}$ (‰)
B-055-WW01	ID-055	-16.75	-15.66	-6.29	-136.75	-131.07	-82.13	8.35	8.16	7.54
B-095-WW01	ID-095	-17.09	-17.08	-17.02	-140.14	-139.34	-135.83	11.45	14.18	15.07
C-042-WW01	ID-042	-17.82	-17.07	-14.79	-134.8	-131.54	-121.6	14.29	13.93	12.62
C-084-WW01	ID-084	-16.00	-15.99	-15.51	-128.1	-128.1	-128.0	14.68	14.61	13.09
C-091-WW01	ID-091	-16.24	-15.98	-15.34	-130.82	-128.68	-123.53	7.73	11.44	14.52
D-007-WW01	ID-007	-18.08	-17.79	-16.09	-143.55	-141.98	-132.66	19.54	17.03	12.44
D-010-WW01	ID-010	-17.10	-17.05	-16.60	-132.37	-132.17	-130.19	16.01	15.65	14.11
D-011-WW01	ID-011	-17.15	-17.02	-16.78	-136.2	-133.93	-129.9	17.99	16.25	14.32
D-032-WW01	ID-032	-17.35	-17.20	-15.92	-127.04	-127.37	-127.08	15.99	ND	ND
D-033-WW01	ID-033	-16.48	-16.44	-16.33	-132.2	-131.71	-130.4	16.63	14.47	13.73
D-036-WW01	ID-036	-16.52	-16.51	-15.58	-131.3	-131.28	-128.8	16.58	16.33	11.42
D-039-WW01	ID-039	-16.69	-16.21	-15.90	-129.7	-130.98	-131.8	17.29	16.78	14.09
D-040-WW01	ID-040	-17.35	-15.80	-15.06	-134.6	-134.06	-133.8	12.30	10.97	10.47
D-075-WW01	ID-075	ND	ND	-16.22	-134.2	-134.09	-133.7	7.46	7.89	8.42
E-104-WW01	ID-104	-17.55	-17.46	-15.84	-133.44	-133.08	-126.43	15.45	12.21	10.93
F-005-WW01	ID-005	-17.17	-17.14	-16.67	-135.96	-135.53	-129.42	12.41	ND	ND
F-005-WW02	ID-005	-17.17	-15.75	1.61	-135.96	-129.00	-44.09	12.41	12.65	13.74
F-008-WW01	ID-008	-17.19	-15.86	-14.81	-132.24	-128.35	-125.29	6.40	6.54	6.61
F-031-WW01	ID-031	-17.59	-17.57	-16.21	-136.01	-135.81	-124.83	15.68	ND	ND
M-035-WW01	ID-035	-15.50	-15.50	-16.04	-125.8	-125.8	-128.3	12.86	12.30	9.28
M-060-WW01	ID-060	-16.53	-15.35	-14.31	-133.04	-127.60	-122.76	8.90	7.41	7.30
M-079-WW01	ID-079	-15.37	-14.36	-13.89	-125.01	-119.55	-116.99	10.33	9.67	9.43
S-049-WW01	ID-049	-15.84	-15.66	-10.64	-125.96	-124.89	-95.29	11.05	11.05	10.83
S-049-WW02	ID-049	-15.84	-15.79	-11.03	-125.96	-125.71	-102.95	11.05	11.11	12.88
S-050-WW01	ID-050	-16.70	-14.31	-10.87	-127.6	-115.39	-97.78	5.51	10.32	11.01
S-050-WW02	ID-050	-16.70	-15.99	-12.66	-127.6	-124.35	-108.9	5.51	5.55	12.35
S-050-WW03	ID-050	-16.70	-14.55	-5.71	-127.6	-118.98	-83.49	5.51	5.56	13.87
S-063-WW01	ID-063	-16.23	-13.12	-9.06	-133.37	-119.49	-101.36	8.22	9.63	10.41

(1) GW = Assumed Up-gradient Ground Water

(2) Cmix = Down Gradient Steady State Ground Water Concentration (Up-Gradient Ground Water and Leachate Mix)

(3) WW = Wastewater

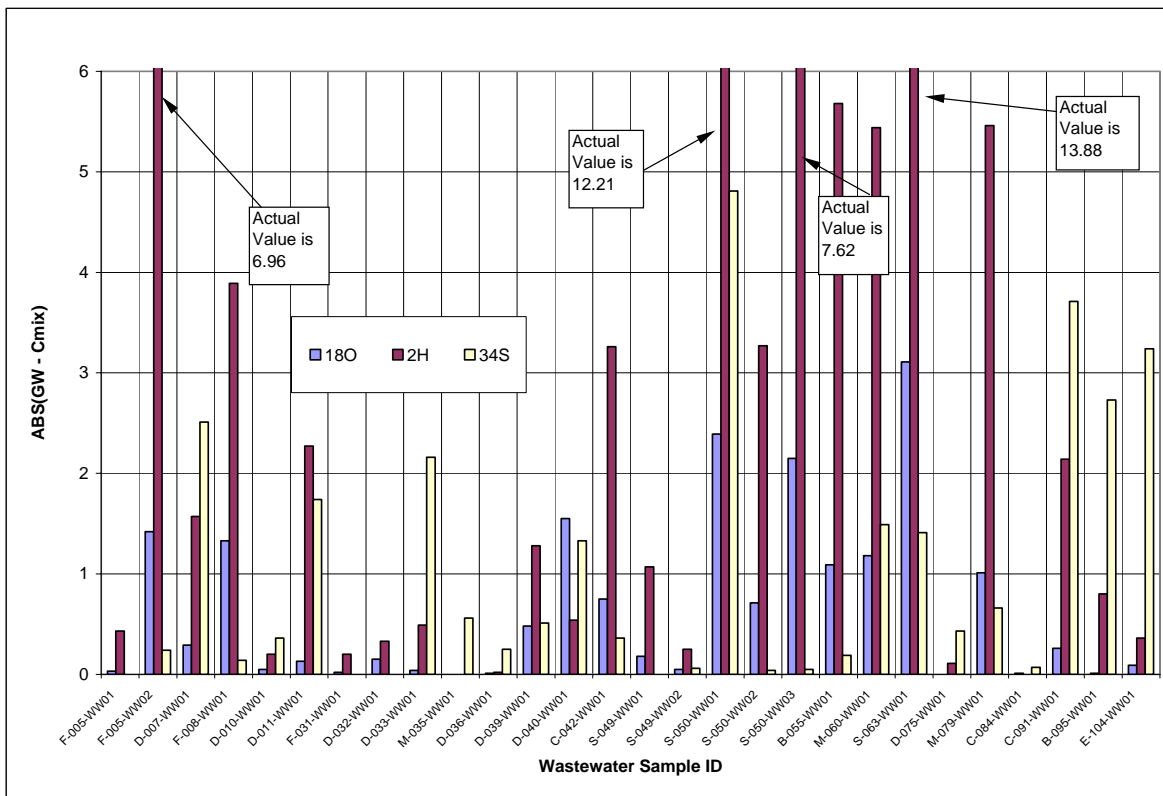


Figure 7. Differences between up-gradient ground water isotope ratio analysis and that predicted for final down-gradient ground water/leachate mix ($ABS(GW - C_{mix})$).

Conclusions

Twenty-four facilities that generate wastewater in the state of Idaho were sampled for stable isotopes of oxygen, hydrogen, nitrogen, and sulfate. The following conclusions are made as a result of this study:

- In almost all cases, isotopic enrichment is seen in wastewater after source ground water is utilized for food or industrial processing or for municipal purposes.
- Detention time in wastewater ponds generally affects the isotopic signature of wastewaters. Longer detention times often cause wastewater to become enriched in heavier isotopes (2H and ^{18}O).
- As seen in Figure 7, certain facility wastewaters have significantly different isotopic signatures than their ground water sources. Ground water mixing zone modeling shows there may be significantly different isotopic signatures between ground water sources (assumed to represent up-gradient ground water) and down-gradient ground water (which represents a mathematically calculated mix of wastewater, irrigation water and ground water). Facilities with such contrasting isotopic signatures may be good candidates for isotopic tracer studies of the effects of wastewater on ground water.
- Oxygen and deuterium isotope variability in regional or deep ground water is expected to show little seasonal and/or annual variation since the amount of water that is recharged is small compared to the amount in storage. Oxygen and deuterium values in shallow ground water would be expected to be more variable since this water is more impacted by seasonal

precipitation events. However, since only a single sample was collected, the seasonal and/or annual variability of isotopes in wastewater was not evaluated. Wastewater is expected to show greater variability than ground water. Additional samples would be required to adequately characterize variability.

Recommendations

This study demonstrated that certain wastewaters, which are land applied, have substantially contrasting isotopic signatures compared to corresponding ground water sources. As mentioned in the Conclusions section, facilities with such contrasting isotopic signatures may be good candidates for isotopic tracer studies of the effects of wastewater upon ground water. It is recommended that one or two facilities be studied in detail, to 1) characterize source ground water, ambient and down-gradient first-encountered ground water, and wastewater; and 2) study mixing effects of wastewater leachate on ground water through isotopic analysis. Such a study would establish the usefulness of environmental isotopes as tracers in ground water at wastewater land treatment sites.

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