GroundWater Quality Technical Report No. 17

Groundwater Quality Investigation
And
Wellhead Protection Study
City of Fruitland, Idaho

Idaho Department of
Environmental Quality
Technical Services Division
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Acknowledgments

This report, evaluating potential sources of nitrate found in public and domestic wells in the Fruitland area and delineating the source areas for the Fruitland public drinking water system, was a cooperative effort of the Idaho Department of Environmental Quality, the City of Fruitland, and local residents. The support of the Fruitland City Council, public water system operator Mr. Jerry Campbell, and Holladay Engineers was essential in conducting the project. The cooperation and assistance of local well owners who allowed IDEQ access to sample their wells was crucial to completion of the study.

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Abstract

A groundwater investigation and wellhead protection study was performed for the City of Fruitland, Idaho during late 1998 and 1999 to evaluate the viability of the Idaho Wellhead Protection Plan to fulfill Source Water Assessment requirements mandated in the 1996 Safe Drinking Water Act. This work was funded through a э319 Grant from the U.S. Environmental Protection Agency. The City of Fruitland was selected because of elevated nitrate concentrations in their municipal wells as well as their commitment to protecting and managing their groundwater resource.

The City of Fruitland is a community of 3300 located in Southwestern Idaho in the lower Payette River Valley. The dominant land use in the vicinity of Fruitland is gravity irrigated agriculture with the primary agricultural crops being small grains, sugarbeets, corn, onions, mint, and alfalfa hay. The municipal drinking water system consists of a well field of ten to twelve wells. Water pumped from these wells is derived primarily from a shallow unconfined sand and gravel aquifer, though several wells also pump from a deeper confined aquifer. Historical water quality data for these wells show increasing trends for nitrate-nitrogen in many wells and several wells have been taken off line due to exceedance of the nitrate drinking water maximum contaminant level of 10 mg/l. In addition to problems with nitrate arsenic concentrations are elevated. These arsenic concentrations are below current regulatory levels but exceed recently proposed new standards.

Ten year time of travel capture zones were developed for the Fruitland municipal wells using both Basic II and Refined Methods as defined in the Idaho Wellhead Protection Plan. The size of the resulting Basic II and Refined capture zones was 146 and 1.5 square miles, respectively. This great reduction in size easily justified the significantly greater effort required to develop the refined delineation. Potential contaminant sources within the zones for the two methods were tabulated and the number of sources in the refined delineation was less than half that found in the basic delineation. A valid comparison was not possible due to the large size of the Basic II capture zone and it's extension into the State of Oregon.

A groundwater investigation was conducted, using stable and radioactive isotopes as well as other traditional water quality parameters, to attempt to identify the potential sources of recharge and nitrate in the Fruitland municipal well groundwater. Fruitland municipal wells, local wells completed in both the shallow and deeper aquifer systems, surface water, and local canal water were sampled.

Recharge to the shallow unconfined aquifer was found to be primarily from surface water associated with agricultural activities. Sources of recharge to the deeper, semi-confined aquifer are indeterminate but are likely much older and at much greater distance from the Fruitland municipal wells.

Nitrogen isotope data indicate that the source of high nitrate in municipal wells and in the shallow aquifer in general is primarily due to agricultural activities, such as the use of commercial fertilizer, as well as the release of mineralized nitrogen from soil organic matter.

Introduction

During May of 1998, the Idaho Division of Environmental Quality (IDEQ) selected numerous communities within the state to be included in the *Wellhead Protection Viability Demonstration Project*. The project was designed to assist community water systems (CWSs) serving populations less than 10,000 impacted by nonpoint source contaminants. CWSs with regulated contaminants within plus or minus 25 percent of the drinking water maximum contaminant level (MCL) were selected for the project. Fruitland, Idaho was one of the communities selected because of elevated nitrate concentrations in their municipal wells as well as their commitment to protecting and managing their groundwater resource.

Purpose and Objectives

The primary purpose of this demonstration project was to evaluate the viability of the Idaho Wellhead Protection Plan to fulfill Source Water Assessment requirements mandated in the 1996 Safe Drinking Water Act. Secondary purposes include 1) comparing different wellhead delineation methods to determine if collecting site specific hydrogeologic information is scientifically and economically feasible and 2) evaluating whether groundwater monitoring within a wellhead protection area increases the effectiveness of wellhead protection.

The objectives of this project, with respect to the City of Fruitland, were:

- Delineate the time-of-travel capture zones supplying water to the City's municipal wells.
- Perform an inventory of potential contaminant sources present in the vicinity of these capture zones delineations.
- Perform groundwater monitoring to help identify the source of nitrate impacting the drinking water supply of the city and surrounding domestic wells.
- Provide this information to the City of Fruitland to form the basis for a Source Water Assessment of the drinking water system and to assist in developing Wellhead Protection strategies.

Background

The City of Fruitland is located in Southwestern Idaho in the lower Payette Valley. Fruitland has a population of 3300 and has historically been an agricultural community while in recent years light manufacturing has increased in importance to the local economy. Land use within Fruitland consists of residential homes, small businesses, and light manufacturing.The dominant land use outside Fruitland is gravity-irrigated agriculture. Historically, the growth of orchard crops dominated the study area. In recent years the primary agricultural crops grown have shifted to small grains (barley, oats, wheat), sugarbeets, corn, onions, mint, and alfalfa hay. Most water for irrigation is supplied from surface water derived from the Payette River.

Homes within Fruitland are connected to a sewer system, while homes outside of town operate with on-site wastewater treatment systems. The City of Fruitland has two wastewater lagoons located to the northeast and west of the City adjacent to the Payette and Snake Rivers.

The City of Fruitland municipal drinking water system is supplied from groundwater pumped from a well field of ten to twelve wells located within the city limits of Fruitland (Figure 1). Outside the Fruitland city limits residents depend on private wells for drinking water.

Water Quality Problems

Nitrate contamination and the problems associated with managing this contamination represents the primary drinking water quality issue currently facing the City of Fruitland today. Historical water quality data for the City of Fruitland wells, compiled to evaluate trends, show increasing trends (some quite dramatic) in many wells (Figure 2). Several wells in the drinking water system have been taken off line recently because nitrate concentrations in the well water exceeded the MCL. A new well recently brought on line (Well 19) has an initial nitrate concentration of 6 mg/l. While this does not exceed the MCL it does represent significant overall nitrate contamination. As wells have been taken out of service industrial and residential demands for water have continued to grow. This growth, combined with a potential decrease in the supply of high quality water, may soon limit the City's ability to provide water of adequate quantity and quality.

In addition to problems with nitrate contamination many of the wells in the system also show elevated levels of arsenic. Currently, the arsenic concentrations in these wells are below the current drinking water standard of 0.050 mg/l. However, the U.S. Environmental Protection Agency recently proposed a new drinking water standard for arsenic of 0.005 mg/l. Most of the wells in Fruitland's drinking water system exceed this proposed standard and treatment may be the only option for achieving compliance.

Previous Studies

The hydrology and water quality of the Lower Payette area have been extensively studied over the last fifteen years. Agencies which have conducted investigations include the University of Idaho (Dieck and Ralston, 1986), United States Geological Survey (Parliman, 1986), Idaho Division of Environmental Quality (IDEQ, 1994, 1996), Idaho Department of Agriculture (IDA, 1998) and the Natural Resources Conservation Service (NRCS, 1991). While these studies have documented areas of water quality problems a complete understanding of the hydrogeological system of the area is still lacking.

The study area was included in the Snake-Payette Hydrologic Unit Assessment conducted by the NRCS (1991). The goal of the NRCS assessment was to accelerate the transfer of technology necessary to protect groundwater and surface water while maintaining farm profitability.

Study Area

The study area, located in the western portion of Payette County near the confluence of the Snake and Payette rivers, encompasses the community of Fruitland, Idaho (Figure 1).

Climate

Mean annual precipitation in the study area is approximately 11 inches based on precipitation records for the City of Payette (Idaho State Climate Services, 1999).

The mean annual temperature is approximately 52 degrees Fahrenheit (Idaho State Climate Services, 1999). The average annual number of frost-free days is 147 (Rasmussen, 1976).

Soils

The Greenleaf-Nyssaton Association is the dominant soil association in the Fruitland area. As described in the Payette County, Idaho soil survey (Rasmussen, 1976) the general soil characteristics of this unit are as follows:

- nearly level to moderately steep, well drained silt loam soils found on intermediate terraces.

Greenleaf soils have the following characteristics:

- deep and well drained;
- surface layer is light brownish gray silt loam approximately 10 inches thick;
- upper portion of the subsoil is light brownish gray heavy silt loam approximately 16 inches thick;
- lower portion of the subsoil is light gray silty clay loam approximately 7 inches thick; and
- substratum to a depth of 60 inches is light-gray silt.

Nyssaton soils have the following characteristics:

- deep and well drained;
- surface layer is light gray silt loam approximately 15 inches thick; and
- very pale brown and white silt loam to a depth of 60 inches.

Geology and Hydrogeology

The Payette Valley forms a somewhat crescent-shaped, flat-floored valley bounded by the uplands of Squaw Butte to the north, the foothills to the Boise Front Mountains to the east, the ASouth Slope≅ foothills to the south, and the Snake River to the west. The valley floor slopes gently to the west-northwest and is drained by the Payette River except for the westernmost portion of the basin which is also drained by the Snake River. Elevations in the valley range from about 2,380 feet above mean sea level east of Emmett, to about 2,010 feet at the Snake River at the town of Payette.

The foothills and uplands are composed of basalt, granite, and both sedimentary rocks and unconsolidated sedimentary deposits. The valley is filled with erosional remnants derived primarily from these rocks and deposits. The alluvial fill of the Payette Valley can be divided into two major units: the younger fluvial deposits, and the older lacustrine deposits. The younger fluvial deposits consist of clay, silt, sand, and gravel. The older lacustrine deposits represent the majority of the basin-fill material and consist of interfingering beds and lenses of clay, silt, and sand.

There are two major aquifers in the valley that are found in the alluvial fill: a shallow water table aquifer and a deeper Ablue clay≅ aquifer. Each aquifer possesses differing physical and chemical characteristics. The shallow Payette Valley water table aquifer is contained within the fluvial deposits. In the Fruitland area, these deposits are clay- and silt-dominated. Lithologic drill logs in the area show an average of 70 percent clay/silt, 17 percent gravel, and 13 percent sand. Cross-sections constructed from lithologic drill logs suggest that the depositional environment consists of stacked channel deposits of moderate sinuosity, with abrupt lateral variations. Water wells typically yield less than 500 gallons per minute (GPM) from the gravel and sand deposits. Recharge is primarily from infiltration of diverted irrigation water and leakage from the Payette River and its tributaries.

The deeper Payette Valley Ablue clay≅ aquifer is contained within lacustrine deposits. Lithologic drill logs in the area show an average of 75 to 96 percent blue clay, with the remainder being intervals of sand that vary in thickness from inches to feet. Analysis of lithologic drill logs in the area suggest that the sand intervals are lens-shaped, with moderate to poor lateral and vertical interconnectedness. This interconnectedness decreases with depth. Yields typically average less than 50 GPM from the sand lenses. The primary source of recharge to this aquifer is assumed to be historic runoff from the surrounding mountains. Only a small potential for recharge can be attributed to leakage from the Payette River and its tributaries, and infiltration of diverted irrigation water. Groundwater from the blue clay aquifer may have a long residence time.

The wells within the vicinity of Fruitland are completed in both fluvial and lacustrine deposits.
The degree and nature of any hydraulic connection between the shallow and the deeper water-bearing units is not well understood. Groundwater flow in the study area for both the shallow and deeper aquifers is generally in a north-northwesterly direction.

City of Fruitland Drinking Water System

The city of Fruitland drinking water system consists of ten to twelve wells which extract groundwater for domestic and industrial use (Figure 1). Water extraction from individual wells is monitored and managed from a central location using a sophisticated computer system. Water from individual wells is blended prior to entering the distribution system. A large ground tank and water tower are used for storage and blending of water.

The wells in the City of Fruitland system range in total depth from 46 to 204 feet below ground surface with most being shallower than 70 feet (Table 1). The shallower wells (Wells 1, 5 12, 14, 15, 16, and 19) are completed in the unconfined sand and gravel aquifer above the blue clay noted above. The deeper wells (Wells 6, 9, 10, and 11) are typically completed with a gravel pack that crosses the blue clay and with multiple screened sections both above and below the blue clay. The amount of aquifer screened in the City wells ranges from 10 to 50 feet and is typically about 20 feet.

Table 1. Selected Construction Characteristics of City of Fruitland Wells.

Well #	Total Depth (ft.)	Screened Interval (ft. below ground surface)	Screen Below Blue Clay?	Gravel Pack Interval (ft.)
1	115	46-90	N	No data
5	72	60-72	N	0-72
6	204	44-54, 58-68, 109-119, 179-189	Y	No data
9	145	35-45, 70-90, 93-113	Y	20-145
10	175	30-40, 76-81, 98-113, 127-132	Y	28-175
11	95	30-50, 54-64, 65-75	Y	0-95
12	46	25-46	N	No data
14	65	40-55	N	18-60
15	68	42-52	N	0-52
16	75	30-40	N	0-75
19	88	40-67.5	N	40-88

The wells in the system are typically pumped at relatively constant rates ranging from 60 to 240 gallons per minute but are cycled on and off for variable amounts of time depending on the demand. Water demand varies seasonally with highest pumping discharge occurring in July and August and minimum discharge in December and January. During peak demand periods most wells are pumping for fifteen to twenty hours per day.

Source Water Area Delineation

Factors such as the well construction, well pumping rate, hydrogeological characteristics of the aquifer, and sources of recharge to the aquifer influence which areas surrounding a well will supply water to that well while it is pumping. These source water areas can be subdivided into zones, time-of-travel zones, based on the estimated time it will take water from a given distance from the wellhead to reach the well.

There are four designated time-of-travel capture zones (IA, IB, II, and III). Zone IA corresponds to the sanitary setback , a circle with a 50 foot radius centered on each wellhead. Contaminant sources within this zone would have a high probability of impacting groundwater quality if not properly managed and particularly if well construction practices are poor. Contaminant sources outside of this zone also represent a potential groundwater impact, but the magnitude and intensity of that impact depend on the speed and direction of groundwater movement in relation to the wellhead. Contamination in groundwater coming from far away will take a long time and may be substantially diluted by the time it reaches the wellhead. Zones IB, II, and III attempt to identify specific “time of travel” based impact areas for each wellhead. Zone IB represents the estimated zero to three year time of travel zone. Zone II designates the three to six year time of travel zone, and Zone III designates the six to ten year time-of-travel.

The zones are designed so that appropriate levels of management can be applied to contaminant sources within those zones and assist with management of contaminant sources so as to prevent chemical or microbial contamination from reaching the water supply well.

Two methods were evaluated to delineate the time-of-travel capture zones for the City of Fruitland drinking water system, the Basic II method and the Refined method, as described in the State of Idaho Wellhead Protection Plan (IDEQ, 1997).The Basic II method uses simple analytical expressions to calculate a fixed radius capture zone around each wellhead based on limited site-specific data and the assumption of a zero gradient for groundwater flow direction. The Refined method uses more complex analytical or numerical modeling and requires significantly more information regarding the hydrogeological setting , and input parameter values.

The Refined method time-of-travel capture zones were delineated by the IDEQ using the MODFLOW groundwater flow model (McDonald and Harbaugh, 1988) and the MODPATH particle-tracking model (Pollock, 1994), developed by the United States Geological Survey, as implemented in the Groundwater Modeling System (BOSS International, Inc. et al., 1999) interface.

Basic II Method Delineation

The calculated fixed-radius for the ten year time-of-travel capture zone for the Fruitland drinking water system, based on pumping rates derived from information supplied by the City of Fruitland, hydraulic conductivity and transmissivity values estimated from production well tests and well logs, and porosity estimated from knowledge of the grain size characteristics, was 34,300 feet or approximately 6.5 miles. This delineated area encompasses approximately 146 square miles, some of it extending to the west across the Snake River into Oregon. This delineation is shown in Figure 3.

Refined Method Delineation

Conceptual Model

The hydrogeologic conceptual model assumed for the Refined method delineation process was that of a one-layer system corresponding to the shallow unconfined sand and gravel aquifer. The total well yield from the deeper confined system was assumed to be small. The base of the shallow aquifer was assumed to be the top of the blue clay layer which is found consistently throughout the study area. Sources of recharge to the model were assumed to be from areal recharge due to precipitation and irrigation deep percolation, leakage from canals, and groundwater inflow from outside the study. Sources of discharge from the model domain were primarily from well pumping from City of Fruitland wells, drainage to Sand Hollow and discharge to the Payette and Snake rivers. Model domain boundary conditions included designating the Snake and Payette rivers and the southern border as constant head boundaries and the eastern and southwestern borders as no-flow bounderies. The model domain cell size was 155 feet. wide by 249 feet. high and the grid was oriented in a north-south direction.

Model Parameters

Aquifer hydraulic properties initially used in the model are based primarily on information derived from well logs in the area and pump test information available for the City of Fruitland wells. Hydraulic conductivity was estimated using specific capacity data, estimates of aquifer saturated thickness from well logs and estimation equation 5.16 from Walton (1970). For the wells with adequate data the range of estimated hydraulic conductivity was 25 to 250 ft/day. The aquifer bottom elevation configuration and values were derived from interpolation of estimated elevations of the top of the blue clay obtained from well logs.

Areal recharge estimates of 1.5 feet/year were based on information developed for the surface irrigated lands for the Treasure Valley Hydrologic Project by Scott Urban (1999). These estimates were applied to the entire model domain. Leakage/recharge from the Farmer's Ditch canal was estimated based on flow measurements of the canal between NW 2nd Ave and Gayway Junction and diversions from the canal on the sampling date (September 2, 1999). Infiltration conditions between the bottom of the canal and groundwater at the end of the irrigation season could be assumed to be at steady-state and probably represent lower rates than that which might be measured at the beginning of the season. The Farmer's Ditch was treated using the River package and Sand Hollow was modeled using the Drain package in MODFLOW.

Pumping rates for the City of Fruitland wells were derived from individual well pumping records for the year 1997. This was the most recent year for which complete data were available. The trend in total annual water pumpage is up. During any given year the pumping rate for any given well may vary due to maintainance and other associated activities. Total annual pumping volumes for each well were converted to a daily discharge rate for input into the model. The pumping rate for new well 19 was estimated based on an assumed daily pumping duration of 6 hours at a rate of 360 gpm. The final calibrated values of model parameters are presented in Table 2 and Figures 4 and 5.

Table 2. Final Calibrated Model Input Parameter Values.

Model Parameter	Units	Value
Recharge	feet/day	0.004
Porosity	dimensionless	0.3
Well Pumping Rates	Gallons/day	
1		69,273
5		122,166
6		216,063
9		40,317
10		52,259
11		98,256
12		139,735
14		17,252
15		69,722
16		24,729
19		129,669

Model Calibration

The model was run under steady-state conditions. Initial calibration of the model was undertaken under non-pumping conditions. Measured water level elevations from wells in the study area that were sampled by IDEQ (1994) as well as estimated elevations from static water levels taken from well logs were used as observation wells for calibration. The spatial distribution and value of model input parameters (hydraulic conductivity, bottom elevation, canal and drain conductance) were adjusted until the best match between computed and observed water elevations were obtained, the computed recharge due to canal leakage from the Farmer's Ditch corresponded with that measured, and an acceptable water balance was obtained (Table 3 and Figures 6a and 6b). A criteria of ± 5 feet was set as a calibration goal for correspondence between computed and observed water elevations.

Table 3. Volumetric Water Budget for Pumping Well Simulation for City of Fruitland Model. (units in gallons/day)

Category	In		Out
Storage	0.0		0.0
Constant Head	1.74e6		8.25e6
Wells	0.0		0.98e6
Drains	0.0		1.03e6
Recharge	7.73e6		0.0
River Leakage	0.80e6		0.0
Total In/Out	10.27e6		10.26e6
In-Out		0.004e6	
Percent Discrepancy		0.04	

Figure 7 illustrates the groundwater elevation contours obtained from the calibrated non-pumping flow simulation. Once the initial non-pumping calibration was completed a simulation which included pumping of the City of Fruitland wells was run. Only minor modifications to the aquifer bottom elevation and hydraulic conductivity distribution were made during the pumping simulations in order to eliminate dry cells which appeared upon the initiation of pumping.

Particle Tracking

The output of the steady-state flow model simulation with pumping wells served as input for the particle tracking program and delineation of the source water areas for the pumping wells. Particles were seeded in the lateral cell faces for the cells containing each well and, based on the velocity distribution developed from the flow simulation, tracked backward in time. Delineations were developed for zero to three, three to six, and six to ten year time-of-travel from the wellhead (Figures 3 and 12). The approximate area represented by the Refined method delineations was about 1.5 square miles.

Inventory

A two-phased contaminant inventory of the study area was conducted during December of 1998. The first phase involved identifying and documenting potential contaminant sources through the use of databases and Geographic Information System (GIS) coverages developed by IDEQ. A potential contaminant source is simply a location where there is an activity having the potential to release contaminants into the environment at a level of concern. The activity may be associated with a business, industry, or operation involving the use, transport, storage, or manufacture of the potential contaminants. The second, enhanced phase of the contaminant inventory involved conducting an on-the-ground identification of additional potential sources not found through phase one and validation of sources identified in the first phase. This task was undertaken with the assistance of Jerry Campbell, City of Fruitland Public Works Department.

Identification of a business, industry, or operation as a potential contaminant source does not mean that the business, industry, or operation is out of compliance with any local, state, or federal regulation, and it does not necessarily mean that the business, industry, or operation has or will cause contamination. What it does mean is that the potential for contamination exists due to the nature of the business, industry, or operation.

The contaminant inventory provides 1) information on the locations of potential sources, especially those that present the greatest risks to the water supply, and 2) a reliable basis for developing a wellhead protection plan to reduce the risks to the water supply.

A total of 44 potential contaminant sources were identified within the study area. Ten of these potential sources were identified using on-the-ground surveys and the remainder were identified through searches of IDEQ databases. The study area represented only a portion of the extremely large time-of-travel capture zone delineated using the Basic II method and all of the potential sources present within the Basic II delineation were not identified. Due to the extremely large size and the extension of the Basic II delineation into Oregon a valid comparison of the number of sources in the Basic II vs. Refined method time-of-travel capture zones was not possible.

Of the potential sources identified within the study area only nineteen are located within or directly adjacent to the Refined method time-of-travel capture zones. Table 4 lists the general characteristics of all of the identified potential sources. Figure 12 shows the location of only the sources identified within or in proximity to the Refined method delineations.

Irrigated agricultural operations that use fertilizer and pesticides were the primary potential contaminant sources within delineated source water areas located outside Fruitland city limits.

Residences with on-site sewage treatment were identified using 1997 aerial photography and the density of systems within time-of-travel delineations was analyzed using GIS. Only 24 systems were identified inside of or within 250 feet of all delineations. The calculated densities within all delineations were less than 1 system/acre. For this reason on-site treatment systems outside the service area of the City's wastewater treatment facilities were not considered to constitute a significant potential source. There was one confined animal feeding operation identified.

Potential contaminant sources located in the delineated source water areas within Fruitland include underground and above ground storage tank facilities, small businesses which may use and store chemicals and organic materials, historical businesses such as old gas stations, auto repair and sales facilities, and food processing facilities, and several larger manufacturing facilities.

Contaminants of concern are primarily business chemicals such as petroleum products, solvents and degreasers. Several large manufacturing or processing facilities are located within delineated source areas that appear to have significant potential sources of contamination with respect to the quantity of chemicals used and/or stored on site. These chemicals include solvents, hydrocarbons, acids, bases, and anhydrous ammonia. A petroleum pipeline presents another significant potential source of volatile organic compounds (VOC) and semivolatile organic compounds (SOC) for selected wells.

Table 4. Fruitland Potential Contaminant Inventory

SITE #	In Refined Delineation Source Area?	Source Description	TOT Zone (years)	Source of Information	Potential Contaminants
P-1	Y	UST	3-6	Database Search	VOC, SOC
P-2	Y	Former Auto Sales	0-3	Database Search	VOC, SOC
P-3	Y	Food Storage and Processing	3-6	Enhanced Inventory	IOC
P-4	Y	Food Processor	3-6	Database Search	IOC, VOC
P-5	Y	AST	0-3	Database Search	VOC, SOC
P-6	Y	Irrigation Supplies	0-3	Database Search	IOC
P-7	Y	Light Food Processing	3-6	Database Search	IOC
P-9		UST		Database Search	VOC, SOC
P-10		UST		Database Search	VOC, SOC
P-11	Y	Light Food Processing	0-3	Database Search	IOC
P-12		Motorcycle Repair		Database Search	VOC, SOC
P-13	Y	UST	0-3	Enhanced Inventory	VOC, SOC
P-14		UST		Database Search	VOC, SOC
P-15		Auto Service		Database Search	VOC, SOC
P-16		Former AST		Database Search	VOC, SOC
P-17	Y	Millwork	0-3	Database Search	VOC, SOC
P-18		Nursery		Database Search	IOC
P-19		Boat Service		Database Search	VOC, SOC
P-20		Sanitation Services		Database Search	IOV, VOC, SOC
P-21		Auto Service		Database Search	VOC, SOC
P-22	Y	Auto Service	0-3	Database Search	VOC, SOC
P-23	Y	Old Gas Station	0-3	Enhanced Inventory	VOC, SOC
P-24		Old Wrecking Yard		Enhanced Inventory	VOC, SOC
P-25		Auto Sales		Database Search	VOC, SOC
P-26		Auto Service		Database Search	VOC, SOC
P-27	Y	Small Feedlot	0-3	Enhanced Inventory	IOC
P-28		Food Processor		Database Search	IOC
P-29		Trucking		Database Search	VOC, SOC
P-30		Car Wash		Database Search	IOC, VOC, SOC
P-31		Auto Parts		Database Search	VOC, SOC
P-32		Outdoor Power Products		Database Search	IOC,VOC,SOC
P-33		Auto Service		Database Search	VOC, SOC

Table 4. Fruitland Potential Contaminant Inventory (cont.)

SITE #	Refined Delineation Source Area?	Source Description	TOT Zone (years)	Source of Information	Potential Contaminants
P-34	Y	Former Food Processor	0-3	Database Search	IOC
P-35		UST		Database Search	VOC, SOC
P-36		Auto Service		Enhanced Inventory	VOC, SOC
P-37		Auto Service		Database Search	VOC, SOC
P-38		Auto Service		Database Search	VOC, SOC
P-39	Y	Warehouse	3-6	Enhanced Inventory	IOC, VOC
P-40		Auto Service		Enhanced Inventory	VOC, SOC
P-41	Y	Pipeline	0-3	Enhanced Inventory	VOC, SOC
P-42	Y	Building Contractor	0-3	Database Search	IOC, VOC
P-43	Y	Road Maintainance	0-3	Database Search	VOC, SOC
P-44	Y	Irrigation Canal	0-3	Enhanced Inventory	IOC, SOC

Water Sampling Materials and Methods

In addition to data obtained from the City of Fruitland drinking water monitoring program, data from two rounds of water quality sampling, conducted in December 1998 and September 1999, were utilized during this investigation. During the December 1998 sampling event groundwater samples were collected from 13 wells. These wells included three domestic wells, nine city wells, and one city test well. In addition surface water samples were taken from two locations. During the September 1999 sampling event surface water samples were collected from five canal locations in proximity to Fruitland (see Figure 1).

All of the wells, surface water, and canal water were sampled for common ions (bicarbonate alkalinity, calcium, chloride, magnesium, potassium, sodium and sulfate), silica, nitrate (NO_2 + NO_3 as N), ammonia, Total Kjeldahl nitrogen, orthophosphate, alkalinity, total iron and arsenic (Table 6). Samples were also collected from selected wells and surface water for stable isotope ratio analysis ($*^{15}N$, $*^{18}O$, $*^{2}H$, and $*^{13}C$) and radioactive isotope analysis (^{14}C) . Field parameters measured during sample collection included dissolved oxygen, specific conductivity, temperature, and pH.

Stable Isotopes

Nitrogen

The nitrogen stable isotope ratio analysis (SIRA) was conducted on the samples to identify the source of nitrate in the groundwater. The nitrogen SIRA test provides a measurement of the ratio of the two most abundant isotopes of nitrogen ^{14}N and ^{15}N. Much of the following discussion about the use of nitrogen isotopes to identify contaminant sources is excerpted from Seiler (1996).

Isotopes of an element have the same number of protons but a different number of neutrons. Elements have a predominant isotope and less abundant isotopes. The standard notation for identifying difference isotopes is to write the sum of the number of protons and neutrons in the upper corner of the symbol of the element (e.g., ^{1}H = common hydrogen with one proton and zero neutrons; ^{3}H = tritium with one proton and two neutrons). The term “stable isotope” simply refers to isotopes that are nonradioactive forms of an element.

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 ratio of the heavier isotope to that of the lighter isotope in a substance can provide useful information because the slight differences in the mass of the isotopes cause slight differences in their behavior. Stable isotopes are measured as the ratio of the two most abundant isotopes of a given element. Isotope values for nitrogen and other elements are presented in the delta notation:

$$\delta^{15}N = \{[(^{15}N/^{14}N)_{sample}\,)\;(^{15}N/^{14}N)_{air}\,] - 1\} \text{ x } 1000$$

The δ-value is expressed as parts per thousand or per mil ($^{0}/_{00}$) difference from the reference.

For example, a δ^{15}N value of +10 per mil has 10 parts per thousand (one percent) more ^{15}N than the reference. A positive δ-value is said to be “enriched” or “heavy”, while a negative δ-value is said to be “depleted” or “light”. The reference standard for the stable isotopes of nitrogen (^{15}N/^{14}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. These changes, called fractionation, occur as a result of physical and chemical reactions. Isotopic effects, caused by slight differences in the mass of two isotopes, tend to cause the heavier isotope to remain in the starting material of a chemical reaction. 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 behind becomes isotopically heavier.

These isotopic effects mean that, depending on its origin, the same compound may have different isotopic compositions. 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}N/^{14}N ratios. Typical δ^{15}N values for important sources of nitrogen contamination are presented in Table 5.

Table 5. Typical d ^{15}N Values

Contaminant Source	**d ^{15}N (permil)**
Precipitation	-3
Commercial Fertilizer	-4 to +4
Organic Nitrogen in Soil	+4 to +9
Animal or Human Waste	> +10

Oxygen/Deuterium

Stable oxygen and hydrogen isotopes are intimately associated in the water molecule. Most groundwater originates as precipitation. The isotopic content of precipitation varies with altitude, temperature, distance inland from the coast, and amount. Upon deposition processes such as evaporation can further modify the isotopic content. The spatial and temporal variations in these isotopes in precipitation and groundwater can be used to investigate sources of recharge (Coplen, 1993). The oxygen and hydrogen stable isotope analysis was undertaken in an attempt to clarify the sources of recharge to the shallow and deeper aquifers from which the City of Fruitland wells derive their drinking water.

Carbon

Carbon stable isotope analysis are gathered primarily as part of the evaluation for radioactive isotopes described below. However, because this analysis provides information on the origins of dissolved inorganic carbon in the groundwater it can also be used to aid in discriminating the sources of recharge to a groundwater system.

Radioactive Isotopes

Carbon-14 (^{14}C) is an unstable or radioactive isotope of carbon. Because of the consistent rate of decay of ^{14}C it can be used to estimate the relative age of carbon containing materials compared to some assumed standard material. Carbon-14 analyses were conducted on three wells which, based on their documented construction, were assumed to be completed in and drawing their water exclusively from the deeper aquifer zone. This analysis was done to estimate the residence time of groundwater in the deeper water-bearing zones and to attempt to document that the deep aquifer in the Fruitland study area has origins and properties distinct and separate from the shallow aquifer.

RESULTS AND DISCUSSION

The analytical results for Fruitland are presented in Table 6. Figure 1 illustrates the location of wells and surface water sampled for this study. The Payette River at Black Canyon Dam is not shown.

General Groundwater Chemistry

The relationship of common geochemical constituents in each water sample were plotted using standard water chemistry techniques in an attempt to distinguish differences in water type between various groups of samples. Figure 8 is a Piper Diagram for the water samples taken in the study area. Major cation relationships are shown in the lower left triangle and anions are shown in lower right. The combined cation-anion composition is reflected in the large diamond-shaped portion of the diagram. The results of these analyses do not indicate dramatic differences in water type between the City of Fruitland wells and the other private domestic wells or the surface water that were sampled. Waters in the study area are generally of the calcium-sodium-magnesium bicarbonate type. While recharge waters increase in concentration of cations and anions as they move through the vadose zone to groundwater their composition does not change dramatically. Two deep wells (S and 18M), one private and one city test well, show a composition that reflects a greater component of sulfate and chloride but there are no common features of these wells that would suggest a reason for the differences. The other deep private well sampled as well as the deepest interval of the city test well did not show this water composition.

Dramatic differences in selected individual constituents (nitrate, iron, and dissolved oxygen) clearly indicate however that the shallow and deeper water-bearing units are distinct.

Table 6. Fruitland Geochemical Results

Common Ion Summary
(mg/l except as noted)

Sample Type	Sample ID	Calcium	Magnesium	Sodium	Potassium	Silica	Chloride	Sulfate
City Wells	**1**	28.2	17	64	3.4	52.8	5.52	38.3
	6	60.3	21.5	92	5	60.8	14.6	79.3
	9	35.3	21.4	30	5.1	59.9	7.65	16.6
	10	31.4	17.9	25	4.1	55.7	6.36	15.6
	11	79.5	40.8	54	7.6	62.7	12.9	53
	12	22.4	13.1	32	2.8	58.3	3.96	12.7
	14	34.5	15.9	81	3.7	49.7	13	43.2
	15	40.6	29.3	32	6.4	65.4	4.57	13.4
City Test Wells	**18 Shallow**	90.6	35.8	156	12.5	82.4	13.3	79.3
	18 Medium	93.5	21.1	55	7.9	55.5	52.8	153
	18 Deep	21.6	5	30	5	56.2	3.41	24.4
	19	39.3	16.4	64	4	58.9	9.08	39.5
Surface Water	**Sand Hollow at 2nd Ave.**	47.8	17.7	67	3.5	51.1	10.1	34.3
	Payette River at Black Canyon Dam	9	1.4	5.2	0.9	17	1	2.5
Deep Private Wells	**S**	65.7	13.9	42	5.1	58.4	40.2	94
	B	26.7	5.9	36	4.7	54.4	6.24	12.3
Shallow Private Wells	**D**	38.8	21.2	43	5.2	53.4	4.28	26.1
Canals	**C-1 (West Ditch at NW 2nd Ave)**	11.4	1.8	9.2	1	13.4	1	3.82
	C-2 (East Ditch at NW 2nd Ave)	13.2	3.3	11	1.3	16.3	2.2	6.63
	C-3 (N. Pennsylvania Ave)	13.2	3.2	11	1.3	16.3	1	6.4
	C-4 (Gayway Junction)	13.6	3.2	11	1.2	15.8	2.2	6.97
	C-5 (Elmore & SW 1st)	6.8	0.9	3.5	0.6	11.3	1	1

Table 6. Fruitland Geochemical Results (continued)

(mg/l except as noted)

			(as N)					**(as HCO3)**
Sample Type	**Sample ID**	**O-PO4**	**NO3+NO2**	**Ammonia**	**TKN**	**Iron**	**Arsenic**	**Alkalinity**
City Wells	**1**	0.149	7.76	0.0025	0.10	0.014	0.032	262
	6	0.112	9.3	0.007	0.12	2.6	0.033	388
	9	0.111	9.04	0.005	0.05	0.024	0.03	238
	10	0.09	5.06	0.0025	0.07	0.012	0.021	218
	11	0.139	8.95	0.0025	0.22	0.014	0.018	494
	12	0.117	3.45	0.0025	0.13	0.01	0.022	180
	14	0.088	13.1	0.017	0.05	2.8	0.027	299
	15	0.119	2.54	0.0025	0.06	0.012	0.028	332
City Test Wells	**18 Shallow**	0.225	19.3	0.234	1.07	66.1	0.056	442
	18 Medium	0.085	0.16	0.878	1.10	6.7	0.036	257
	18 Deep	0.105	0.07	2.32	2.43	1.9	0.018	135
	19	0.159	5.87	0.034	0.15	0.81	0.046	289
Surface Water	**Sand Hollow at 2nd Ave.**	0.125	3.67	0.097	0.43	0.9	0.018	316
	Payette River at Black Canyon Dam	0.017	0.063	0.021	0.22	0.49	0.005	45
Deep Private Wells	**S**	0.053	0.0025	0.242	0.33	0.35	0.025	205
	B	0.079	0.0025	3.09	3.28	0.27	0.005	210
Shallow Private Wells	**D**	0.133	8.58	0.006	0.08	0.22	0.022	278
Canals	**C-1 (West Ditch at NW 2nd Ave)**	0.027	0.023	0.007	0.25	0.1	0.005	62.2
	C-2 (East Ditch at NW 2nd Ave)	0.06	0.447	0.015	0.27	0.72	0.005	72
	C-3 (N. Pennsylvania Ave)	0.054	0.386	0.011	0.27	0.71	0.005	70.8
	C-4 (Gayway Junction)	0.058	0.378	0.011	0.21	0.61	0.005	70.8
	C-5 (Elmore & SW 1st)	0.018	0.017	0.01	0.19	0.39	0.005	31.7

Table 6. Fruitland Geochemical Results (continued)

(mg/l except as noted)						Stable and Radioactive Isotope Summary (per mil except as noted)				
Sample Type	**Sample ID**	**Dissolved O2**	**pH**	**Conductivity (umhos)**	**Temp (degrees C)**	**15N**	**2H**	**18O**	**13C**	**14C (years BP)**
City Wells	**1**	1.7	7.77	593	14.1	+3.5	-114	-15.9		
	6	1.0	7.71	797	14.6	+4.7	-116	-15.9		
	9	4.3	7.76	520	14.1	+2.8	-118	-15.9		
	10	2.0	7.74	454	14.7	+6.4	-115	-15.9		
	11	4.1	7.57	982	13.1	+2.8	-116	-15.7		
	12	1.4	7.83	382	14.5	+4.8	-121	-16.1		
	14	0.5	8.15	624	16.3	+7.5	-118	-15.9		
	15	6.2	8.01	518	14.3	+0.7	-116	-15.9		
City Test Wells	**18 Shallow**		8.11	930	13.1					
	18 Medium	0.9	7.82	804	14.6	+1.6	-136	-17.6	-13.1	2700
	18 Deep	0.7	8.34	267	14.9	-2.4	-140	-18.7	-10.2	7220
	19	8.7	8.02	551	15.2	+3.3	-121	-16.1		
Surface Water	**Sand Hollow at 2nd Ave.**	12.8	8.48	669	7.2	+4.8	-117	-15.8		
	Payette River at Black Canyon Dam	13.0	7.27	1	2.0		-118	-16.1		
Deep Private Wells	**S**	0.2	7.27	672	13.5		-133	-17.6		
	B	0.1	7.76	395	13.4	+0.4	-137	-18.6	-10.8	14830
Shallow Private Wells	**D**	4.5	7.74	588	13.7	+2.3	-119	-15.8		
Canals	**C-1 (West Ditch at NW 2nd Ave)**		8.17	101	16.6					
	C-2 (East Ditch at NW 2nd Ave)		7.93	126	15.5					
	C-3 (N. Pennsylvania Ave)		8.38	134	16.3					
	C-4 (Gayway Junction)									
	C-5 (Elmore & SW 1st)		8.15	55	18.5					

Nitrogen Results

Nitrogen results are presented in Table 6 for the nitrate, ammonia, and Total Kjeldahl Nitrogen (TKN) fractions.

Nitrate concentrations (as N) ranged from less than 0.0025 to 19.3 mg/l. Several trends are apparent in the results. The four deep wells sampled contained little nitrate (average 0.059 mg/l) but significant amounts of ammonia (average 1.63 mg/l). By contrast the nine City Wells, and two shallow private and City test wells sampled averaged 8.45 mg/l nitrate and 0.029 mg/l ammonia.

Except for the Sand Hollow water sample, which reflects water draining agricultural fields in the study area, surface water samples from the Payette River and the Farmer's Ditch contained very low levels of both nitrate and ammonia. Nitrate in the Farmer's Ditch water was elevated compared to Payette River water (0.250 mg/l vs. 0.063 mg/l).

Stable Isotope Results

Nitrogen

The nitrogen isotope analyses were conducted to evaluate the causes of the elevated nitrate levels in the groundwater. The nitrogen isotope $\delta^{15}N$ values varied from –2.4 $^{0}/_{00}$ to +7.6 $^{0}/_{00}$. Two of the samples (Payette River and Deep Well S) were determined by the laboratory to contain insufficient nitrate to conduct the nitrogen isotope analysis. The mean value for City of Fruitland wells was + 4.1 $^{0}/_{00.}$ This mean value likely represents a combination of commercial inorganic fertilizer and decomposition of naturally occurring organic nitrogen. Field studies of mineralization of nitrogen in soil organic matter on commercial sugar beet fields in Idaho and Oregon by Oregon State University (OSU, 1997) found that an average of 163 lb N/acre were mineralized, compared to the 30-50 lb N/acre commonly assumed in fertilizer guides. Another possibility is enrichment of $\delta^{15}N$ in commercial fertilizer due to denitrification in the fine-textured silt loam soils found in the study area following leaching below the root zone.

City well 14, immediately downgradient from a small feedlot, produced the highest $\delta^{15}N$ value, +7.6 $^{0}/_{00}$. The two deep wells which had sufficient nitrogen for analysis (wells 18 Deep and B) produced the lowest $\delta^{15}N$ values, -2.4 and + 0.4 $^{0}/_{00,}$ respectively.

Oxygen/Deuterium

Results of stable isotope analysis for $\ast^{18}O$ and $\ast^{2}H$ are presented in Table 6 and are plotted in Figure 9. The plot presents data in relation to the Global Meteoric Water Line (GMWL) of Craig (1961). This line represents an empirical relationship developed that represents the results of worldwide precipitation measurements of $\ast^{18}O$ and $\ast^{2}H$. Data which depart significantly from this line are often interpreted to have undergone some type of fractionation process subsequent to deposition, such as evaporation has a occurred. Lines are also developed for individual regions which may depart from this global relationship.

All of the data from the study area fall on or near the GMWL indicating that very little evaporative fractionation has occurred. The grouping of the data into two groups along the GMWL is significant. One group with enriched values of $*^{18}$O and $*^{2}$H (less negative values) correspond to the Fruitland city wells and surface water samples which represent current recharge sources. The other group, with depleted values (which plot on the lower portion of the line, consists of samples from the deeper water-bearing units. The large separation of $*^{18}$O and $*^{2}$H between these two groups indicates significantly different recharge conditions for these two groups of water samples. The specific nature of the differences in those conditions is not clear, though recharge to the deeper groundwater under cooler, more humid conditions perhaps associated with pleistocene glaciation is one possibility. The close correspondence in values between samples of surface water and the City of Fruitland wells indicates that the primary source of recharge to these wells is modern surface water. These groupings of wells for $*^{2}$H and $*^{18}$O also corresponds to wells with high and low nitrates, as Figures 10 and 11 illustrates.

Carbon

$*^{13}$C results for three deep wells gave results of -10.2, -10.8, and -13.1 $^{0}/_{00.}$ These results are similar to those measured in groundwater in the Treasure Valley and do not provide any additional information regarding the source of recharge of the deep groundwater.

Radioactive Isotope Results

The three deep wells sampled for ^{14}C produced dissolved inorganic carbon (DIC) ages of 2700, 7220, and 14830 years Before Present (BP). These ages should be viewed as semi-quantitative results for several reasons. While the results were corrected for ^{13}C other factors which may cause the results to vary from the “true” age were not taken into account. Factors which could result in an overestimate of age include exchange and dilution of dissolved inorganic carbon along the groundwater travel path with other sources of older, “dead” carbon such as in methanogenic aquifers with organic deposits or carbonates and diffusion of DIC into low permeability aquitards. If mixing occurs with younger groundwater measured ages may be underestimated. Tritium measurements were not taken on these samples which would indicate the presence of a “young” component to the groundwater. Notwithstanding these limitations the ages measured indicate that the deeper water-bearing units have very long residence times due to very long flow paths from recharge areas, slow velocities or a combination of the two.

Arsenic Results

Arsenic concentrations in the study area ranged from less than 0.01 to 0.056 mg/l. The average arsenic concentration for the nine Fruitland city wells was 0.029 mg/l. Two shallow wells (Well 18 Shallow and D) had average arsenic concentrations of 0.039 mg/l. Three deep wells had an average arsenic concentration of 0.016 mg/l. The lower concentrations of arsenic in deep wells compared to shallow wells, the lack of detectable arsenic in Payette River and canal water and it’s presence in Sand Hollow (0.018 mg/l), which drains agricultural land east of Fruitland indicates that arsenic in groundwater in the Fruitland wells may be acquired as irrigation water percolates through the vadose zone prior to recharging groundwater. The source of this arsenic may be the result of past orchard pesticide application practices or area soils may be naturally high in arsenic.

Susceptability Evaluation

The final phase of the Source Water Assesment process, the susceptability evaluation, builds upon the source water delineation and contaminant inventory portions and evaluates the potential, based on well construction criteria, the hydrogeologic setting, and the contaminant inventory, for contaminant impacts to the source water at the wellhead. Susceptability evaluations for all the wells in the City of Fruitland drinking water system can be found in the Source Water Assessment Report for the City of Fruitland (DEQ, 2000).

Conclusions

- The City of Fruitland drinking water system is currently threatened by levels of nitrate contamination that approach or exceed the drinking water Maximum Contaminant Level (MCL) for nitrate (10 mg/l) in several wells. The nitrate trend in most wells is toward increasing concentrations. Several wells have been either shut down or are currently being blended with water from other wells due to high nitrate concentrations. Arsenic concentrations in city wells, while currently meeting drinking water standards, may pose future problems if the MCL is reduced to projected concentrations.
- Most wells in the City of Fruitland system take their water in whole or in large part from the shallow, unconfined alluvial aquifer, although several wells are also completed in the deeper, semi-confined lacustrine aquifer.
- Time-of-travel capture zones were delineated for the City of Fruitland drinking water wells using basic and refined methodology. The additional effort required to develop delineations using the refined method is more than justified by the significant reduction in delination size (from greater than 100 square miles to less than 2 square miles).
- A potential contaminant source inventory was performed for both the basic method and the refined method time-of-travel capture zone delineations. The number of sources identified was reduced by over half using the refined method delineations. This reduction is considered conservative, given the large size and extent of the basic method delineation (> 100 square miles).
- The shallow aquifer has been demonstrated to be a distinct water-bearing unit in terms of water quality, water yield, and the sources of recharge. The shallow aquifer contains much higher levels of nitrate, lower levels of iron, and higher levels of arsenic than the deeper aquifer. Water yields from the shallow aquifer are significantly higher than those of the deeper aquifer. Groundwater in the shallow aquifer is recharged primarily from surface water irrigation, direct precipitation, and canal leakage while the sources of recharge to the deeper aquifer are indeterminate but are very likely much older.
- The use of specific types of groundwater monitoring, particularly the use of stable and radioactive isotope analyses, provided valuable information to completing the potential contaminant source inventory and for the development of future source water protection activities.
- Nitrogen isotope data indicate that the source of high nitrate in the city wells and the shallow aquifer in general is primarily due to agricultural activities such as the use of commercial fertilizer on crops with moderate to low nitrogen use efficiency. Detections of selected pesticides (atrazine and dacthal) in City of Fruitland wells and other shallow wells in the area further supports the likelihood of impacts from agricultural activities. The deeper aquifer does not appear to have been similarly impacted.

Recommendations

- Source water protection activities should focus on implementation of practices aimed at reducing the leaching of agricultural chemicals from agricultural land within the delineated source water areas. Most of these lands are outside the direct jurisdiction of the City of Fruitland. Partnerships with state and local agricultural agencies and industry groups are critical to reducing threats outside the City limits and should be actively pursued. Transit times of water and chemicals from agricultural application sites to the point of extraction at the wellhead are of significant duration (greater than 3 years for much of the agricultural land outside City jurisdiction). It should be recognized that protection activities aimed at agricultural land will be a long-term mitigation strategy which will probably not yield results in the near term.
- While the deeper aquifer possesses adequate quality, yield limitations, construction difficulties, and uncertainty as to the sustainability of production in the long-term (as a result of uncertainty as to sources of recharge) prevent the use of this water-bearing unit as a long-term solution.
- An investigation of the feasability of a shift to potential surface water sources to augment or replace the current groundwater system should be considered.

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Figure 2. Historical Trend of Nitrate-Nitrogen in Fruitland Drinking Water Supply Wells

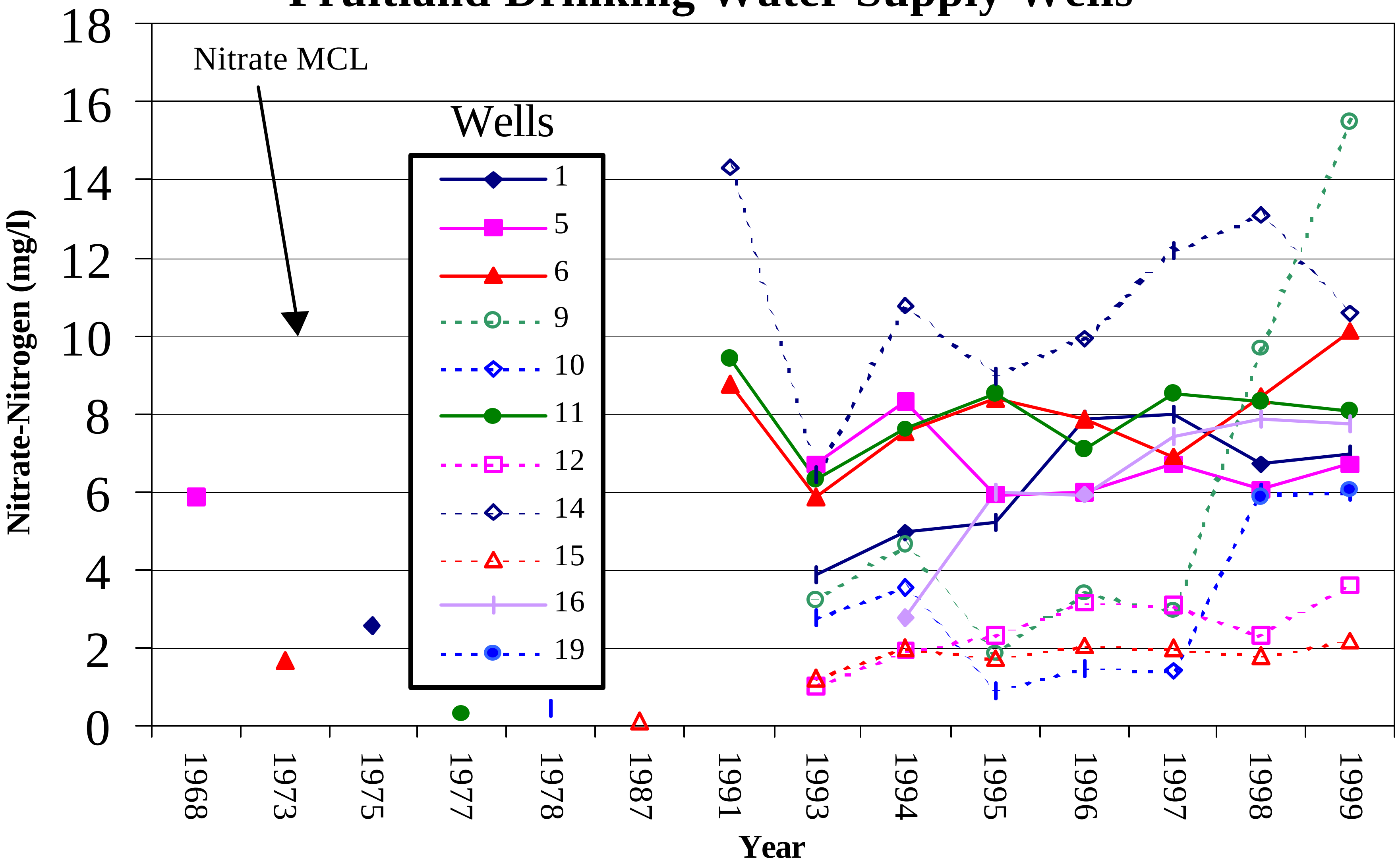

Figure 6a. Computed vs. Observed Groundwater Elevation at Selected Observation Points for the Fruitland Non-Pumping Flow Simulations

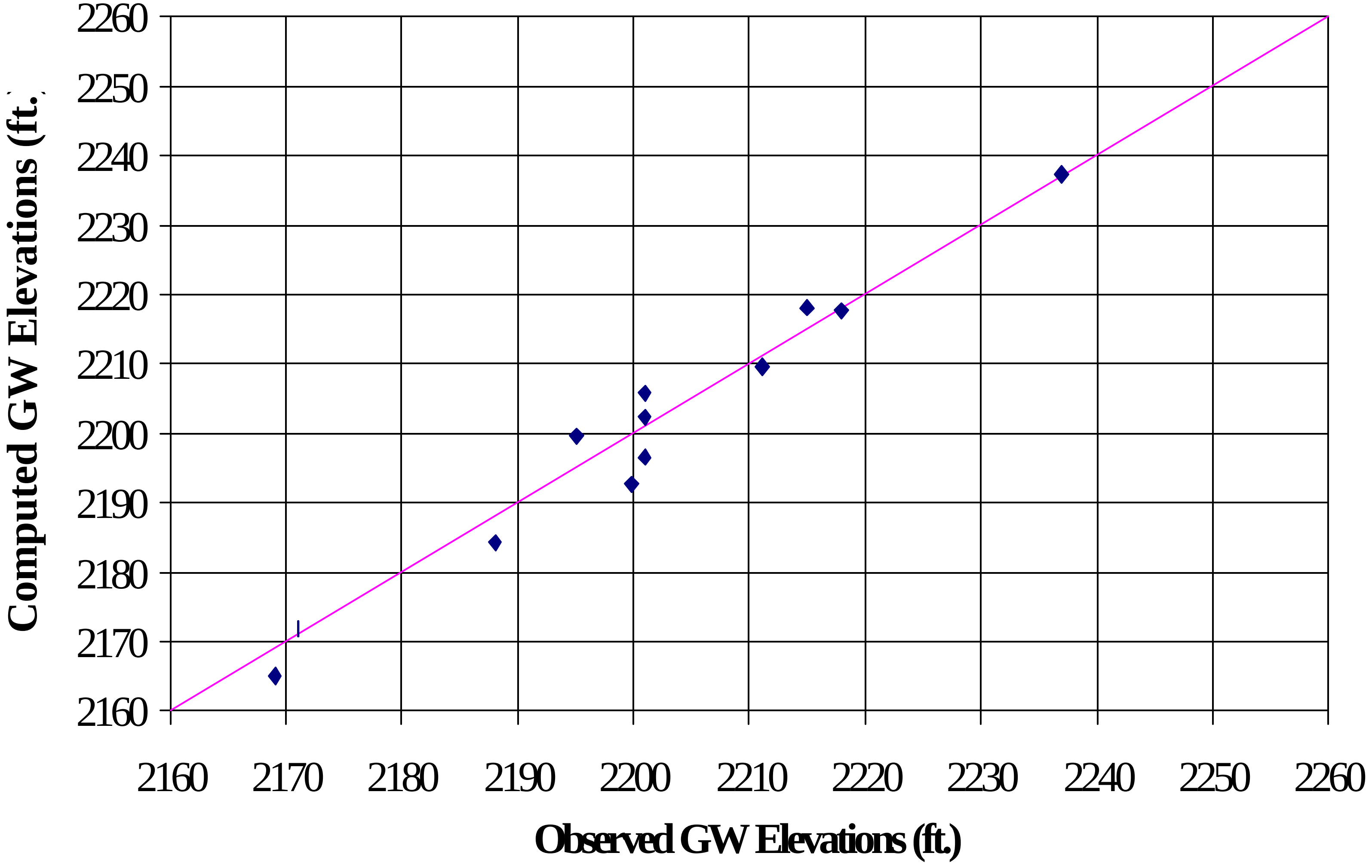

Figure 6b. Residual vs. Observed Groundwater Elevation at Selected Observation Points for the Fruitland Non-Pumping Flow Simulations

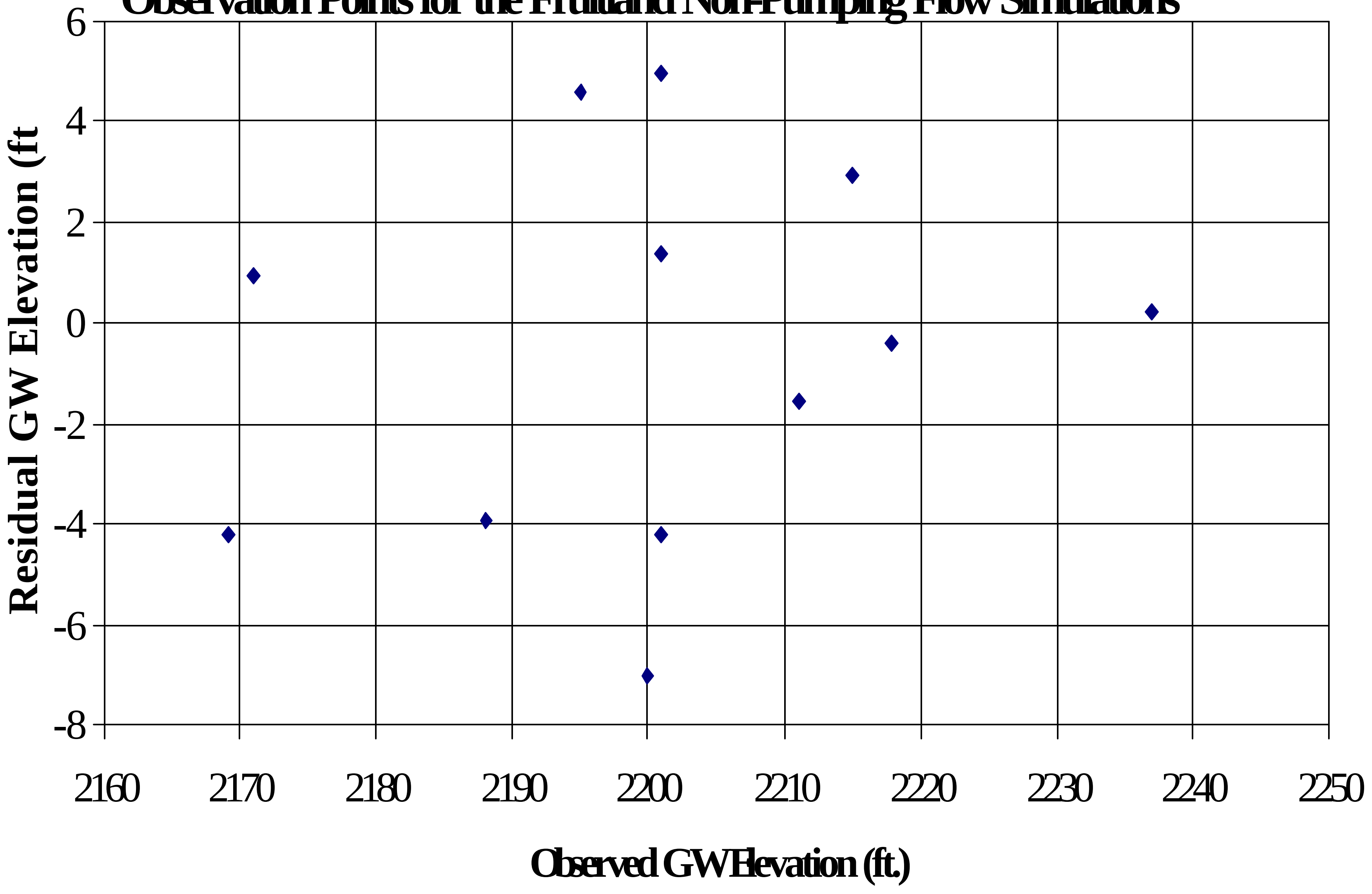

Figure 8. Piper Diagram of Fruitland Water Sample Results

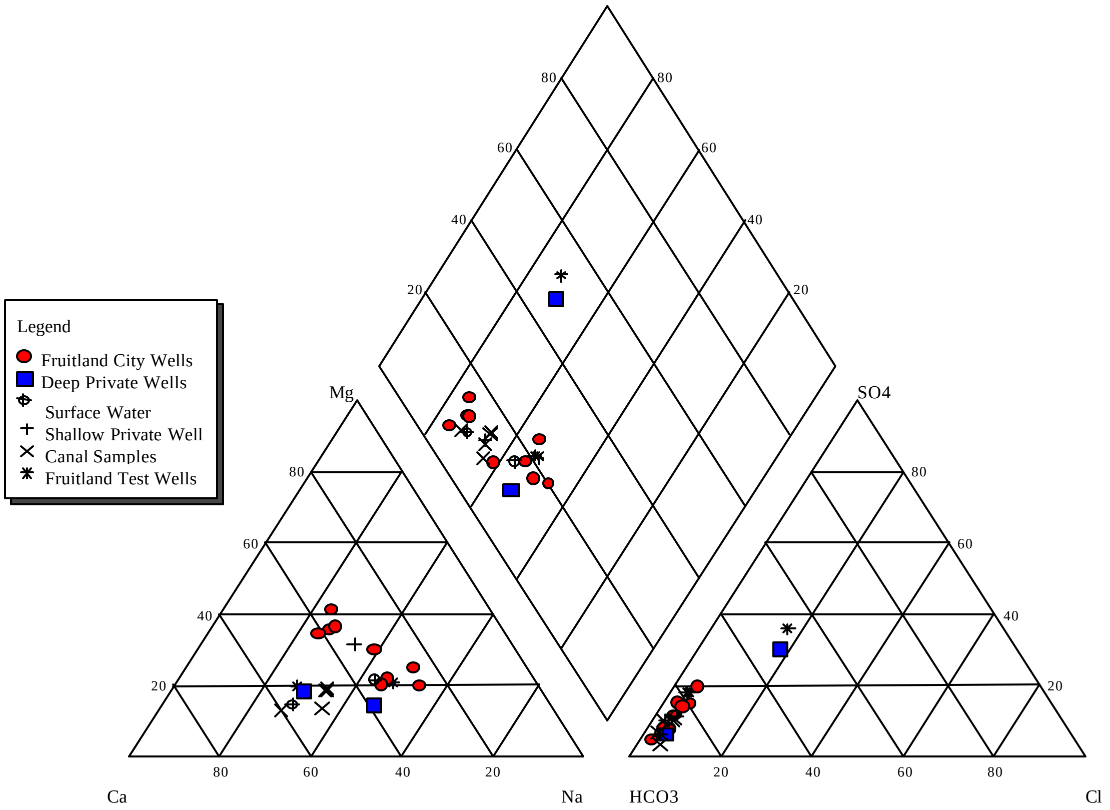

Figure 9. d^{18}O and d^{2}H Results for Selected Fruitland Samples Compared to the Global Meteoric Water Line (GMWL) of Craig (1961).

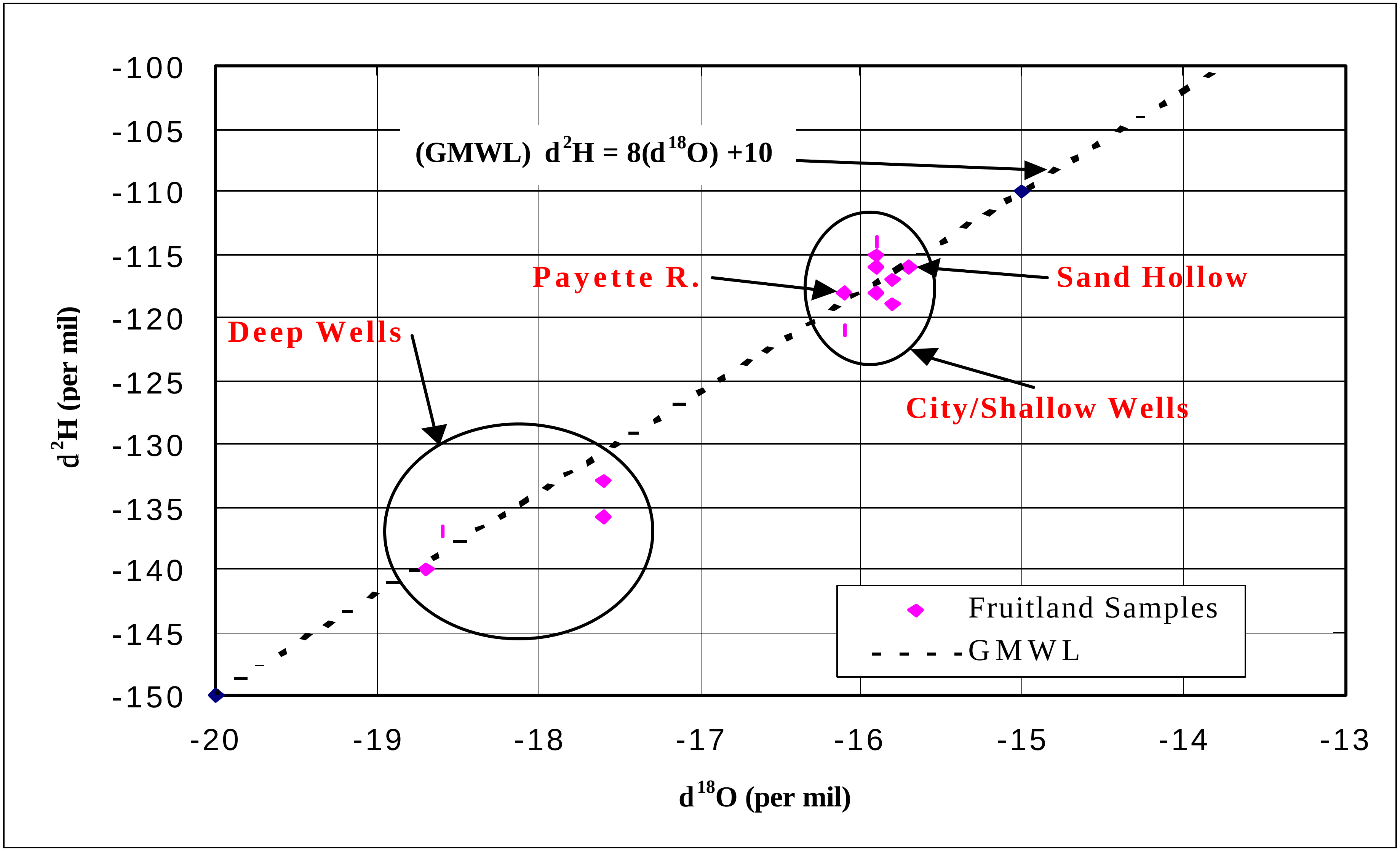

Figure 10. d^2H vs. Nitrate for Selected Fruitland Water Samples.

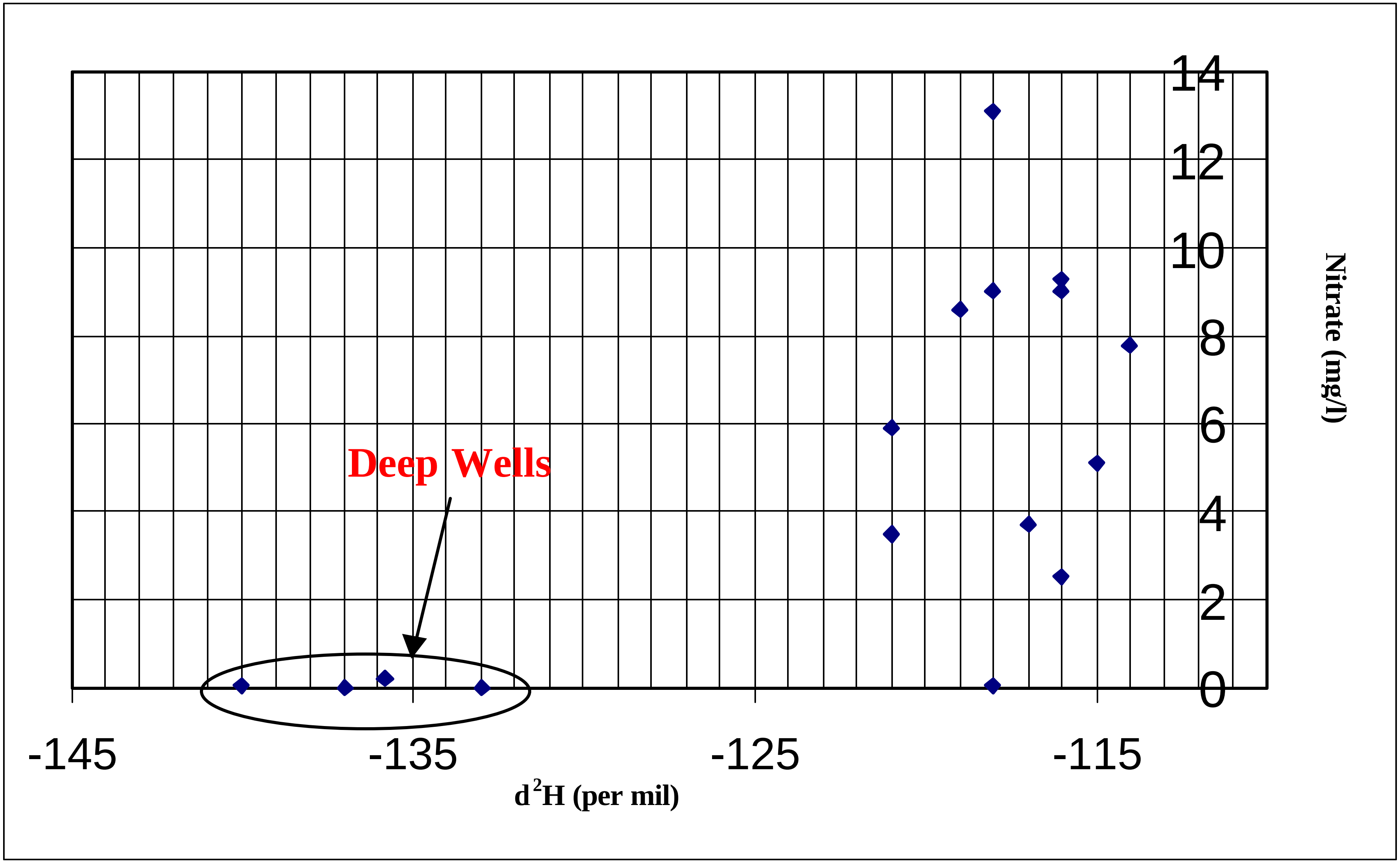

Figure 11. d^{18}O vs. Nitrate for Selected Fruitland Water Samples