Hydrogeologic Analysis of the Water Supply for Bloomington and Paris, Bear Lake County, Idaho

Allan H. Wylie
Bruce R. Otto
Michael J. Martin

Idaho Geological Survey
University of Idaho
Moscow, Idaho

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Allan H. Wylie,[1] Bruce R. Otto,[1] and Michael J. Martin[1]

SUMMARY

The communities of Bloomington and Paris, located along the west side of Bear Lake, derive their water from limestone cave-hosted springs. Scientists with the Idaho Water Resources Research Institute's "Technical Assistance for Rural Ground Water Development Within Idaho" project have met with the town councils of both communities and agreed to (1) evaluate the hydrology of the springs that supply their water, (2) delineate recharge areas for these springs, (3) identify alternative ground-water targets, and (4) locate recharge zones for the new targets.

The dominant rock types in the Bear River Range consist of limestones and sandstones deposited in an ancient sea. Later in geologic time, the rocks were exposed at land surface, folded, and then faulted, resulting in a north-south oriented valley. Weathering and erosion deposited additional sediment on the older rocks. The geologic formations of hydrogeologic interest here include the Bloomington Formation, the Lead Bell Shale, the Brigham Quartzite, and the Salt Lake Formation, an assortment of shales, silts, silty limestones, sands, and gravels.

Our ground-water conceptual model involves precipitation in the mountains recharging the regional aquifer's ground-water flow along more permeable zones in the faulted and folded rock with discharge from fracture-controlled springs in the Bloomington Formation that sits just above the Lead Bell Shale. We think the shale acts as a barrier to ground-water flow, thereby forcing most of the ground water out of the limestone aquifer. The Brigham Quartzite, which lies below the shale and sits on a thrust fault, hosts numerous springs of limited discharge. We think the ground-up rock in the thrust fault acts as a barrier to ground-water flow, forcing the precipitation falling on the Brigham Quartzite to discharge in springs within the same formation. The Salt Lake Formation is particularly interesting as an aquifer because its gravels host most of the high-yielding wells in the valley.

Our study evaluated three exploration targets and ranked them on the basis of ease-of-discovery versus risk-of-failure. These are listed in descending order of preference: (1) Salt Lake Formation, (2) Bloomington Formation, and (3) Brigham Quartzite. The gravels within the Salt Lake Formation are close to both Bloomington and Paris and host high-yielding wells, but may be isolated from potential recharge areas. The Bloomington Formation contains high-volume springs and is in direct connection with a recharge area. However, because fracture distribution controls ground-water flow, a well needs to intersect fractures to yield much water. We suspect a shale unit limits the amount of water available in the Brigham Quartzite. We recommend drilling a test well to determine the suitability of a target aquifer and establishing routine water-level monitoring.

INTRODUCTION

Bloomington and Paris, located along the west side of Bear Lake, derive municipal water from limestone cave-hosted springs sited several miles to the west (Figure 1). The springs serve 251 people in Bloomington and 576 in Paris (Idaho Department of Commerce, 2001). Water is fed by gravity through pipelines to the towns.

STATEMENT OF PROBLEM

Though the springs have historically produced adequate volumes of water, population growth and the need for an alternate source mean that the towns must seek additional sources. The towns will need an alternate source if their primary water source ever fails.

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[1] Formerly with the Idaho Water Resources Research Institute, University of Idaho, Moscow, ID 83844

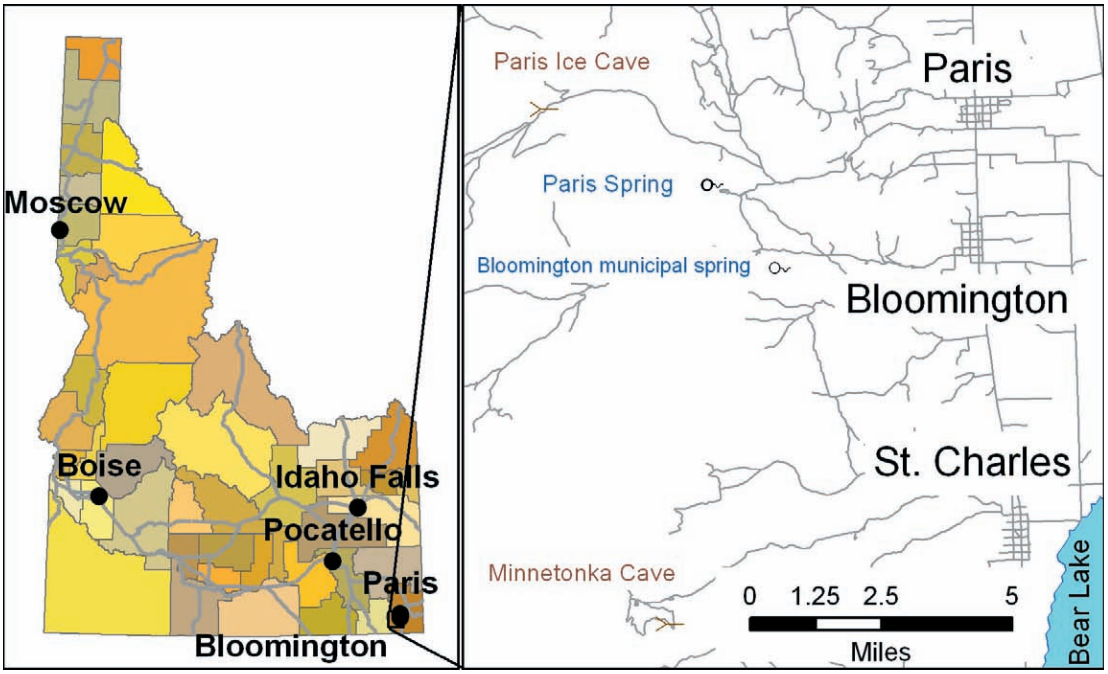

Figure 1. Map showing the locations of Bloomington and Paris, Idaho.

Our report describes the geologic controls for the springs supplying Bloomington and Paris, the ground-water system that feeds the springs, and alternatives for ground-water development in the area. It does not address regulatory requirements or establish regulatory policy.

OBJECTIVES

Scientists with the Idaho Water Resources Research Institute's "Technical Assistance for Rural Ground Water Development Within Idaho" project met with the town councils of Bloomington and Paris to offer hydrogeologic services. Subsequently, we agreed to provide them with the following data and interpretations:

1. Evaluate the hydrology of the towns' springs.
2. Delineate the recharge areas for these springs.
3. Identify alternative ground-water targets.
4. Locate the recharge zones for these targets.
5. Deliver a report on the results to the town counsels, the towns' engineers, and the Idaho Department of Environmental Quality.

GENERAL GROUND-WATER CONCEPTS

The main points in understanding the ground-water system for Bloomington and Paris are the composition of the subsurface rocks that make up the water source or aquifer, the locations of recharge and discharge areas for the aquifer, and the long-term sustainability of the aquifer.

Ground water occurs and moves through interconnected fractures and intergranular pore spaces in an aquifer. It moves under the force of gravity from higher elevation recharge areas to lower elevation discharge areas. Most recharge comes from precipitation infiltrating the soil and rock, though some infiltration occurs from streams and lakes at elevations higher than the water table. Typical discharge areas include springs, streams, and lakes. Ground water moves slowly, generally less than 10 feet a day.

Subsurface geology controls water movement within an aquifer. By determining the extent and physical properties of sediment, rocks, and faults in the subsurface, we can better understand the capacity of ground-water flow systems. Mapping rock outcrops and reviewing drillers' logs of wells help interpret these features.

Sustainable well development means that less ground water is withdrawn from the aquifer than is recharged to it. To achieve a sustained yield, water users must first delineate the discharge and recharge areas and determine the rates of discharge and recharge. Also critical to proper well development is maintaining potable water quality. Human activities on the land may potentially damage the recharge area. Contaminants from residential, industrial, and agricultural uses most likely will infiltrate the land surface and mix with the ground water. To protect the aquifer, communities may have to restrict the extent and type of activities near and over the recharge area.

REGIONAL GEOLOGY

Bear Lake County lies within the Idaho-Wyoming-Montana overthrust belt and also in the northern part of the Basin and Range Province. The county includes the structural characteristics of both provinces. Limestone and sandstone, the dominant rock types in the Bear River Mountain Range, were originally formed by sedimentation in shallow seas during Paleozoic time. In Cretaceous time, compressional forces folded and faulted these rocks into the Idaho-Wyoming-Montana overthrust belt. Valleys in the county were formed primarily during Tertiary-age Basin and Range extensional faulting. As a result of this activity, rocks identical to those in the adjacent mountains occur at depth in Bear Lake Valley. Because Bear Lake has occupied much of the valley throughout the last several thousand years, these older rocks lie buried under lacustrine sediments.

PROJECT AREA GEOLOGY

The discussion of the project area geology is divided into two parts, stratigraphy and structure. The stratigraphy section provides an overview of the hydrogeologically significant units exposed in this part of the Bear River Range. The structure section discusses the hydrogeologically significant folds and faults.

Strata exposed in the Bear River Range include a several thousand-foot thick section of upper Proterozoic, Paleozoic, and Tertiary age sedimentary rocks (Oriel and Platt, 1980). The Proterozoic and Paleozoic strata represent continuous deposition through time with only a few minor erosional interruptions. Oldest to youngest, the hydrogeologically significant strata are as follows:

STRATIGRAPHY

Brigham Quartzite

The lowest strata exposed make up the Brigham Quartzite (Plate 1, unit *CpCb*). The Brigham Quartzite consists primarily of silicified sand and occasional small lenses of pebble conglomerate.

The lithology contains little primary porosity and permeability (porosity and permeability present when the rock formed), two qualities necessary to form a good aquifer. However, the rock fractures readily during faulting, and this characteristic provides secondary porosity and permeability (porosity and permeability developed after formation of the rock).

Lead Bell Shale

The Middle Cambrian age Lead Bell Shale (Plate 1, unit *Clb*) lies above the Brigham Quartzite. The Lead Bell Shale consists primarily of green mudstone with some gray limestone and mudstone.

The Lead Bell Shale does not contain the characteristics required to make it a worthwhile aquifer. However, its location, between the Brigham Quartzite and the rest of the Bear River Mountain Range, makes the Lead Bell Shale a hydrogeologically significant confining unit.

Paleozoic Carbonate Strata

Strata above the Lead Bell Shale include a thick section of limestone, dolostone, and interbedded quartzite (Plate 1). This sequence hosts some locally well-known caves, such as Minnetonka Cave, within the Mississippian age Madison Limestone (Plate 1, unit *Ml*), and Paris Ice Cave, within the Ordovician Garden City Limestone (Plate 1, unit *Og*). Figures 1 and 2 locate these caves.

Limestone and dolostone host some of the most robust aquifers in the world, for example, the Floridian Aquifer in Florida and the Edwards Aquifer in Texas. However, carbonate rocks originally lack significant primary porosity and permeability. With dissolution along fractures due to water movement, they develop significant secondary porosity and permeability. Continued water movement through the fractures modifies them into caverns and caves by a gradual dissolution of the rock matrix. The Bloomington Formation (Plate 1, unit *Cbo*), located near the base of this carbonate sequence, hosts interconnected caves and channels that provide pathways for water movement. These caves supply the avenue through which ground water easily passes, and they form the plumbing system for most of the large volume springs in the area. Bloomington gets water from a cave-hosted spring in the Bloomington Formation. Paris acquires it from a cave-hosted spring in the upper part of the Bloomington Formation or in the overlying Nounan Formation (Plate 1, unit *Cn*).

Salt Lake Formation

The Salt Lake Formation (Plate 1, unit *Tsl*) overlies the older limestone and sandstone sequence. The Salt Lake Formation consists of mostly fine-grained claystone and silty limestone with interspersed sand and gravel lenses. A laterally extensive gravel lies at the base of the formation.

The claystone and silty limestone in the Salt Lake Formation generally act as confining layers that inhibit ground-water movement. However, when the sand and gravel lenses are large enough, they form aquifers. Additionally, the extensive gravel unit at the base of the formation acts as a particularly robust aquifer.

Unconsolidated Sediments

In the Bear Lake area, the unconsolidated material filling the valleys consists of sands and gravels deposited from flowing streams and fine-grained mud deposited from lakes (Plate 1, unit *Qal*). The sands and gravels lie in canyons incised into the mountains. Clay beds deposited from an ancient lake fill much of the central part of the Bear Lake Valley.

Unconsolidated sand and gravel deposits form good aquifers and the river or stream that deposited them represents a good source of recharge. Unfortunately, this intimate contact with a surface water body also tends to render these aquifers vulnerable to contamination.

STRUCTURE

Rocks in the Bear Lake area have structures created during at least two tectonic events. Cretaceous tectonism includes folds and associated thrust faults caused from compression. The younger, Tertiary-age event consists primarily of normal faults that formed in response to extension during development of the Basin and Range Province.

Cretaceous-Age Features

Cretaceous-age tectonism produced the syncline that forms the core of the Bear River Range. Cross section at UTM 4,672,181 m N in Plate 1 shows our interpretation of this structure. Roadcuts along Idaho Highway 36 between Ovid and Preston expose the same rocks in this section. The other major Cretaceous-age tectonic feature exposed in the Bear River Range is the Bloomington thrust fault. The cross section shows the Bloomington thrust placing the Precambrian-age Brigham Quartzite above Paleozoic strata.

The folding that produced the syncline and movement along the Bloomington thrust fault fractured the adjacent overlying and underlying rocks, thus greatly enhancing their hydraulic conductivity. Movement along the Bloomington thrust also likely produced fault gouge. Fault gouge may inhibit ground-water flow.

Tertiary-Age Features

Basin and Range faulting further modified the landscape, displacing the valleys downward and the mountain ranges upward, and thereby produced the Bear Lake Valley. The normal faults on the east side of the Bear River Range all trend north and generally displace strata down to the east.

We mapped several normal faults along the east front of the Bear River Range. These steeply dipping faults cause concern because they can offset aquifers. Occasionally either the upthrown or the downthrown segment of an aquifer becomes isolated from any source of recharge. Without recharge, the aquifer simply dries up with use.

REGIONAL HYDROGEOLOGY

All water in the Bear River drainage basin originated as precipitation. Most of it within this high elevation valley comes as snow during the winter months. Thus, the entire hydrogeologic system is sensitive to snowpack accumulations. Figure 2 contains an average annual precipitation map for the area (modified from Daly and Taylor, 2001). The color scale alongside the map assigns precipitation values to the different colors. The contour lines in the figure indicate ground-water elevation. Notice that most of the precipitation falls on the mountains.

The hydrogeologic conceptual model consists of precipitation accumulating in the mountains, primarily during the winter months as snow. The plants use most of any precipitation occurring during the summer months. In the spring, some snowmelt flows across the

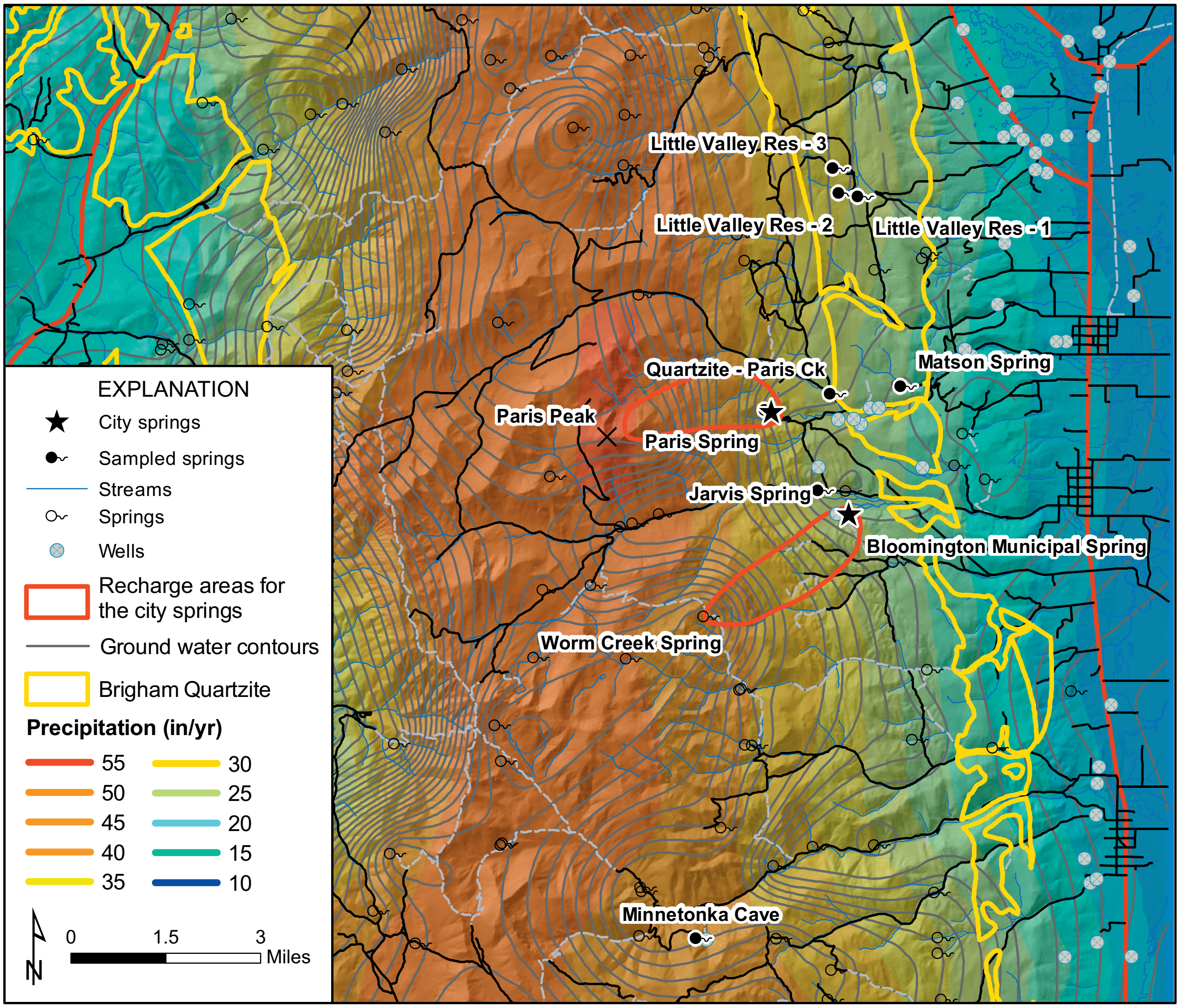

Figure 2. Ground-water flow and precipitation map for the area around Bloomington and Paris, Idaho.

land and into streams and rivers; some evaporates; some infiltrates the soil and is used by plants; and some infiltrates the soil and recharges the ground-water system.

The cross section in Plate 1 illustrates our conceptual model for the hydrological system. Precipitation enters the system primarily in the mountains, flows through the largely carbonate rocks, and discharges in springs primarily in the Bloomington Formation and Brigham Quartzite. The Lead Bell Shale probably acts as a barrier to ground-water flow and forces most of the ground water out of the limestone aquifers in springs such as Jarvis Spring, Paris Spring, and the Bloomington municipal spring. Some water seeps through the shale into the Brigham Quartzite. The Brigham lies above the Bloomington thrust fault, which we think contains fault gouge and acts as a barrier to ground-water flow. This barrier forces ground water out into the surface water system through springs in the formation.

PROJECT AREA HYDROGEOLOGY

In this section, we discuss the flow systems for the municipal springs and for potential new sources. Figure 2 contains an average annual precipitation map for the Bear River Range near Bloomington and Paris. We inferred the ground-water elevations from well logs on file with the Idaho Department of Water Resources, spring elevations, and elevations of hydraulically connected rivers and streams. Because ground water, like surface water, flows downhill, hydrogeologists prepare maps like this to infer ground-water flow directions. Our analysis indicates that the ground water flows eastward from the mountainous recharge area to the municipal springs.

GROUND-WATER FLOW SYSTEM IN THE BRIGHAM QUARTZITE

The Brigham Quartzite hosts several springs and some wells indicating that it stores and transmits water (Plate 1). However, our conceptual model of the ground-water flow system suggests the Lead Bell Shale acts as a barrier that limits the volume of water leaking into the Brigham Quartzite. The Brigham Quartzite in turn rests on the Bloomington thrust fault. Fault gouge within the Bloomington thrust fault forms another hydrologic barrier that forces ground water to discharge in the Brigham Quartzite.

The extent to which the Lead Bell Shale isolates the Brigham aquifer from the carbonate flow system is critical when estimating Brigham aquifer recharge. The Brigham Quartzite outcrops at a low elevation, so without flow from the carbonate aquifer system, the Brigham probably will not receive much recharge. We decided to use ground-water chemistry to evaluate the extent of mixing between the Brigham Quartzite and the carbonate aquifer system. As ground water flows through an aquifer, it acquires a chemical signature from the host rock. Thus, ground water that originates in the carbonate aquifer system and flows into the Brigham aquifer will carry some chemical hints of its original host aquifer. To conduct this analysis, we collected samples from several springs in both aquifers (Figure 3). Figure 2 shows the sampling locations, and Table 1 contains the analytical results. We collected a sample, Little Valley Res 1, from a stagnant spring that we decided not to use after locating several more active Brigham Quartzite springs. We present our interpretation of these analyses later in the Results section.

Figure 3. Sampling for common ions in springs near Bloomington and Paris, Idaho.

Table 1. Water analysis of springs in the Bloomington and Paris area, Idaho.

Location (aquifer system)	Date sampled	Alkalinity ($CaCO_3$) (mg/L)	Ca (mg/L)	Mg (mg/L)	Si (mg/L)	K (mg/L)	Na (mg/L)	Sulfate (mg/L)
Little Valley Res 2 (Brigham Qtz.)	8/21/02	14	5.3	1.2	6.68	0.7	2.2	2.52
Little Valley Res 3 (Brigham Qtz.)	8/21/02	16	6.1	1.2	6.71	0.7	2.3	2.46
Quartzite-Paris Creek (Brigham Qtz.)	8/21/02	18	4.8	1	6.17	0.6	1.9	<2.00
Matson Spring (Brigham Qtz.)	8/22/02	37	9.9	2.4	10.8	0.7	3	3.09
Paris Spring (Carbonate)	8/21/02	161	43.9	11.3	5.15	0.5	1.8	2.31
Jarvis Spring (Carbonate)	8/21/02	175	44.1	15.5	5.13	0.6	1.9	2.92
Minnetonka Cave (Carbonate)	8/21/02	215	54.4	19.4	5.12	0.5	2	5.23

GROUND-WATER FLOW SYSTEMS IN CARBONATE ROCKS

Paris Spring and Bloomington municipal spring discharge within or near the Bloomington Formation. As mentioned above, we suspect the many springs at this geologic horizon exist because the Lead Bell Shale restricts ground-water flow and forces water out of the aquifer and into the surface water system.

Paris Spring

Precipitation enters the system on or near Paris Peak, flows through the carbonate rocks, and discharges at Paris Spring. Figure 2 and Plate 1 show the inferred recharge area. We suspect that the Lead Bell Shale acts as a barrier, forcing most of the ground water out of the aquifer at Paris Spring. Figure 2 also shows the average annual precipitation. We do not know the flow rate from Paris Spring and how it varies with time because of numerous small diversions near its head; however, local residents claim the flow is quite steady. We decided to gauge Jarvis Spring as a proxy because it has a similar source area. We measured two flow rates for Jarvis Spring: one on May 21, 2002, during spring runoff, at 11.87 cfs, and the other on August 20, 2002, near base flow, at 11.24 cfs. From the negligible difference in these two rates, we conclude that the annual flow for Paris Spring must also be steady because the recharge area for both springs includes Paris Peak. Paris Peak is the highest point in the Bear River Range and receives the highest average annual precipitation in the Bear River Range, and hence, more recharge. More elevation also provides a thicker aquifer and therefore more storage. We think these factors explain why Paris Spring maintains a more consistent discharge than many other springs in the area.

Bloomington Municipal Spring

Precipitation enters the system east of Horse Flat, flows through the carbonate rocks and discharges at the Bloomington municipal spring. Figure 2 and Plate 1 show the inferred recharge area. We suspect that the Lead Bell Shale acts as a barrier to ground-water flow and forces most of the ground water out of the aquifer at Bloomington municipal spring. Bloomington uses all of the flow from the spring during the dry portions of the year. In 2002, this included most of the year. Most years the spring provides ample water until late in the summer. The Horse Flat area is much lower in elevation than Paris Peak: less elevation means a thinner aquifer and less storage. Lower elevation also translates into less precipitation and therefore less recharge. Consequently, Bloomington municipal spring has less consistent discharge than Paris Spring.

GROUND-WATER FLOW SYSTEMS IN THE SALT LAKE FORMATION

The Salt Lake Formation lies beneath both Bloomington and Paris (see cross-section at UTM 4,672,181 m N in Plate 1) and hosts high-yielding wells. We examined well logs and consulted with a driller who had installed several wells in the area. This evidence suggests that laterally extensive gravels lie at the bottom of the formation.

We were unable to locate a source of recharge for these gravels. Not enough wells penetrate these gravels in the vicinity of Bloomington and Paris to create a structure contour map on the top of the Salt Lake gravels. Such a map would allow us to locate possible outcrops and, hence, recharge areas. The number of faults between Bloomington and Paris and potential recharge areas, i.e., Bear River Range and Bear Lake, may indicate that the gravels do not connect to a source of recharge. If these gravels lack recharge, they will eventually run out of water.

RESULTS

We identified three potential targets to explore for additional sources of water: (1) the Brigham Quartzite, (2) the Bloomington Formation, and (3) gravels within the Salt Lake Formation. The hydrogeologic advantages and disadvantages are discussed below.

BRIGHAM QUARTZITE

The advantages of the Brigham Quartzite are that it contains water, that no commercial development has occurred in its recharge area, and that wells may not require an engineered well screen. Several springs and some wells exist in the Brigham Quartzite indicating that it stores and transmits water. No hazardous material handling or storage takes place or is ever likely to take place in the recharge area; therefore, little risk exists of aquifer contamination from human activity. Because the sand grains in the Brigham Quartzite are cemented together, wells drilled in it may not need an engineered well screen to keep the aquifer material out of the well while allowing ground water in.

The disadvantages of the Brigham Quartzite are that it will likely be a difficult drilling environment, that none of the springs or wells we found in this formation yield significant quantities of water, and that the available evidence indicates the recharge may be limited. Quartzite is a hard rock to drill, and fractured rock poses its own drilling problems. We expect any drilling in this formation to face both hard rock and fractured rock problems. A more significant disadvantage is that none of the wells or springs we located in the Brigham yields more than 20 gpm.

Our conceptual model suggests that the Lead Bell Shale limits recharge to the Brigham Quartzite. We sampled springs in both flow systems to evaluate the extent of mixing between the carbonate aquifer flow system and the flow system in the Brigham Quartzite. Figure 2 shows the sampling locations, and Figure 4 contains a trilinear diagram of the results. Note the two clusters on the trilinear diagram. The samples from within the carbonate aquifer system plot on the calcium-rich side of the diagram, and the samples from within the Brigham Quartzite plot on the silica-rich side. If the flow systems mixed, the data points would scatter along a line indicating a transitional zone between the two systems. We interpret the lack of a transitional zone to mean that most of the water in the Brigham Quartzite originates from precipitation falling directly on formation outcrops. This would not be a problem if the Brigham Quartzite outcrops received significant recharge. However, the Brigham Quartzite receives little annual precipitation (Figure 2), rendering the available supply inadequate for either Bloomington or Paris.

BLOOMINGTON FORMATION

The advantages of the Bloomington Formation are that it contains several high volume springs, that it is directly connected to a recharge area, that no commercial development has occurred in its recharge area, and that it may not require an engineered well screen. The number of high-volume springs indicates that the formation yields large volumes of water. Equally important, our conceptual model suggests that the aquifer has a direct

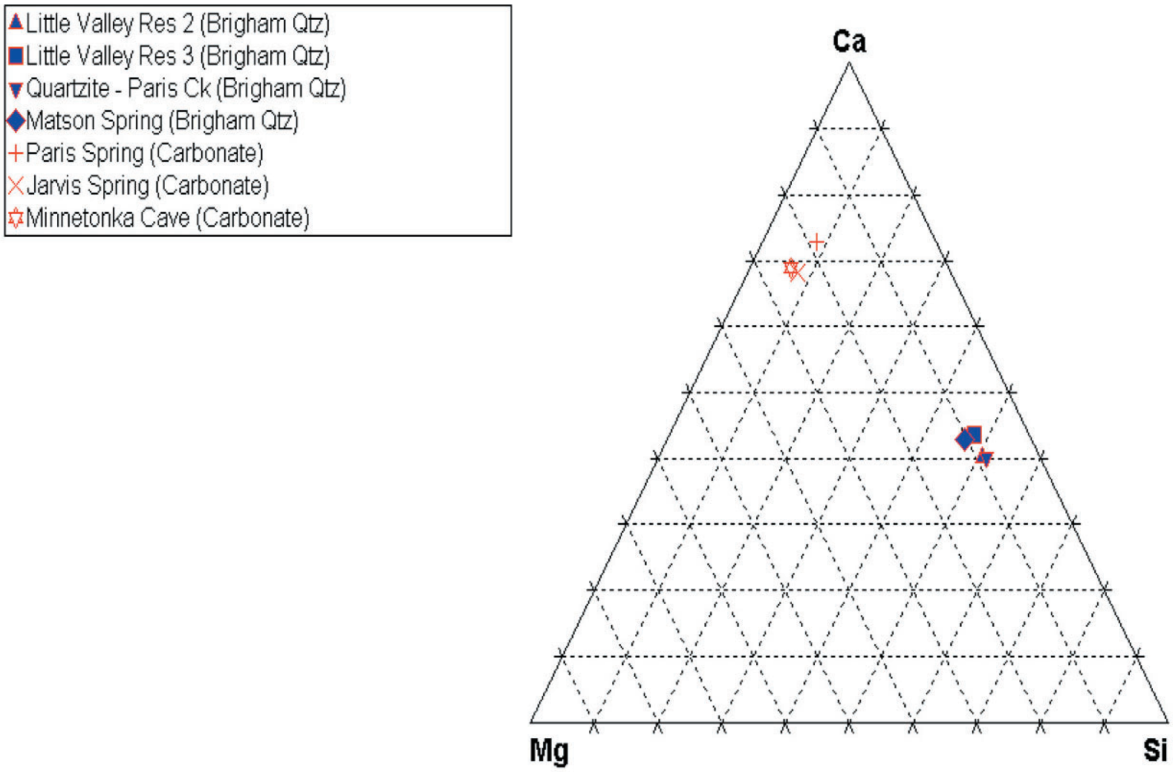

Figure 4. Plot illustrating the chemical composition of water from springs in the carbonate flow system and springs in the Brigham Quartzite flow system.

connection to a recharge area. No hazardous material handling or storage takes place or is ever likely to take place in the recharge area; therefore, little risk of aquifer contamination exists. Because the Bloomington Formation consists of solid rock, wells in it may not require an engineered well screen.

The disadvantage of the Bloomington Formation is aquifer complexity. The aquifer rock matrix consists of small interlocking crystals, nearly eliminating primary porosity and hydraulic conductivity; therefore, most water movement and storage takes place in fractures, in caves, and along bedding planes. Because these features are not equally distributed, successful drilling will depend largely on luck or hours of detailed geologic mapping and air photo analysis, and probably both.

GRAVELS WITHIN SALT LAKE FORMATION

The advantages of the gravels within the Sale Lake Formation are that they lie beneath both Bloomington and Paris, that they host high-yielding wells in the Ovid area north of Bloomington and Paris, and that a thick sequence of shale and marl insulates the gravels from surface activities. We located high-yielding wells in the Salt Lake Formation in the Ovid area and consulted with a driller on some of the wells. This evidence suggests that the gravels are at the bottom of the formation and are laterally extensive. Since the gravels lie below a thick sequence of shale and marl, there is little risk of contaminants making their way into the gravel aquifer.

A disadvantage of the gravels within the Salt Lake Formation is that they may lack a direct connection to a source of aquifer recharge. The lack of wells deep enough to map the gravels in the Bloomington and Paris area and the number of faults between the towns and potential recharge areas, i.e., Bear River Range and Bear Lake, leave us concerned that some of the gravels may not be connected to a source of recharge. We mapped several faults within the Salt Lake Formation and suspect they could limit ground-water movement. We have no way of knowing how effectively (if at all) recharge reaches the gravels. This could mean that a new well might produce from an aquifer receiving no recharge. Therefore, if either Bloomington or Paris accepts the Salt Lake Formation as a target, the town should plan to routinely monitor water levels in the new well. Because we could not locate wells in the Bloomington and Paris area completed in this aquifer, we cannot estimate either well yield or well depth. Another disadvantage is that the gravels within the Salt Lake Formation do not appear to be cemented; therefore, a well will need an engineered screen to allow water into the well while keeping fine-grained material out.

RECOMMENDATIONS

Before attempting a new production well, we recommend drilling test wells, conducting hydraulic tests, and collecting water samples to determine the suitability of the target aquifer. The town should implement routine water-level monitoring once a ground-water well is on line. Monitoring establishes seasonal and long-term trends that can be applied to water-supply planning.

We ranked the possible targets for additional ground-water sources on the basis of ease-of-discovery versus risk-of-failure. These geologic formations are listed in descending order of preference: (1) Salt Lake Formation, (2) Bloomington Formation, and (3) Brigham Quartzite. Community planners must understand that any exploration project like this has risks and may fail. Developing an adequate source also assumes that it will provide an acceptable water quality. Our report does not address requirements that may be imposed by regulatory or administrative agencies.

ACKNOWLEDGMENTS

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The authors are alone responsible for the interpretations expressed in this document. These do not necessarily reflect those of the University of Idaho and IWRRI, the U.S. Environmental Protection Agency, or any other institution. Rather, they are observations shaped by our experiences in the field, study of the scientific and technical literature, and discussions with colleagues and the representatives of Bloomington and Paris.

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