Hydrogeologic Analysis of the Water Supply for Victor, Teton County, Idaho

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

Idaho Geological Survey
University of Idaho
Moscow, Idaho

Information Circular 59
ISBN 1-55765-113-2
2005

Contents

Illustrations

Hydrogeologic Analysis of the Water Supply for Victor, Teton County, Idaho

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

SUMMARY

Victor, located in the upper Teton River drainage of southeast Idaho, acquires its drinking water from two sources: springs in the Game Creek drainage, and the supplemental Willow Creek ground-water well located west of town. This town of 840 uses springs and a supplemental well to meet its current water demand, though the town will soon need an additional source because of growth. Scientists with the Idaho Water Resources Research Institute's "Technical Assistance for Rural Ground Water Development Within Idaho" project provided the following data and interpretations to the town of Victor: (1) evaluated the hydrology of the municipal springs, (2) delineated recharge areas for these springs, (3) defined potential alternate ground-water sources, (4) delineated the recharge zones for the alternate water supplies, and (5) supplied results to the consulting engineers responsible for implementing the water system upgrade.

The most common rocks in the upper Teton River drainage consist of limestones and sandstones deposited in an ancient sea. Later, during Cretaceous time, the rocks were folded, faulted, and then exposed at the surface. During Tertiary time, eruptions from the Yellowstone caldera deposited an ash-flow tuff, and extensional faulting produced the north-south oriented Teton Valley. Weathering and erosion then deposited additional sediment on the older rocks.

Regionally, the ground-water flow system consists of a series of alluvial gravel aquifers feeding successively larger alluvial gravel aquifers until the system reaches the alluvial fan upon which Victor resides. Clay-rich sediments deposited by an ancient lake lie downgradient of the fan, forcing most of the ground water to discharge in springs near the tail of the fan.

Victor springs, located in the lower Game Creek drainage, represent the primary source of water for the town. The springs probably tap into a local flow system fed entirely from the unconsolidated gravels within the Game Creek drainage.

Recharge to the Victor alluvial fan comes from the fluvial gravel aquifer in the Trail Creek valley and its tributaries. The Willow Creek well, which penetrates the Victor fan, is perforated between 200 and 300 feet below land surface. Although inexpensive, this style of well construction is inefficient.

We identified three potential targets: (1) a more efficient well on the Victor alluvial fan, (2) Game Creek fluvial gravels, and (3) the fractured Huckleberry Ridge Tuff aquifer. The Victor alluvial fan is the most promising target because it stores more water and receives more recharge than the other choices.

We recommend further research on the chemical character of ground water in the Victor area. This would involve analyzing water samples from existing wells completed in the target or analogous aquifers.

Before drilling a new production well, we recommend drilling test wells, conducting hydraulic tests, and collecting water samples to determine the suitability of the target aquifer or aquifers. The exploration targets for additional ground-water sources are listed in descending order of preference: (1) redevelop the Victor municipal springs, (2) drill a new well on the Victor alluvial fan, (3) drill the lower Game Creek gravels, and (4) drill the

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

fractured volcanic target. The order is determined by the hydrogeologic merits of the targets. It does not address requirements that may be imposed by regulatory or administrative agencies.

INTRODUCTION

Victor, a town of 840 residents, lies in the southern part of Teton County (Figure 1). It gets municipal drinking water from two sources: springs in the Game Creek drainage, and the supplemental Willow Creek ground-water well located west of town (Plate 1). Water derived from the springs flows by gravity into a chlorination tank, and thence also by gravity into the municipal system. The town pumps water from the Willow Creek well; hence, water from this source costs more than water from the springs.

STATEMENT OF PROBLEM

The springs and supplemental well meet current demand, though because of growth, Victor will soon require an additional source of water. If possible, the town would like to locate this alternate ground-water source closer to the existing infrastructure near the mouth of the Game Creek drainage in order to maximize gravity flow.

OBJECTIVES

Scientists with the Idaho Water Resources Research Institute's "Technical Assistance for Rural Ground Water Development Within Idaho" project agreed to provide the following data and interpretations to Victor:

1. Evaluate the hydrology of the municipal springs.
2. Delineate recharge areas for these springs.
3. Identify potential alternate ground-water sources.
4. Locate the recharge zones for the alternate water supplies.
5. Deliver a report on the results to the town councils, the town's engineers, and the Idaho Department of Environmental Quality.

GENERAL GROUND-WATER CONCEPTS

The main points in understanding the ground-water system for Victor are the composition of the subsurface

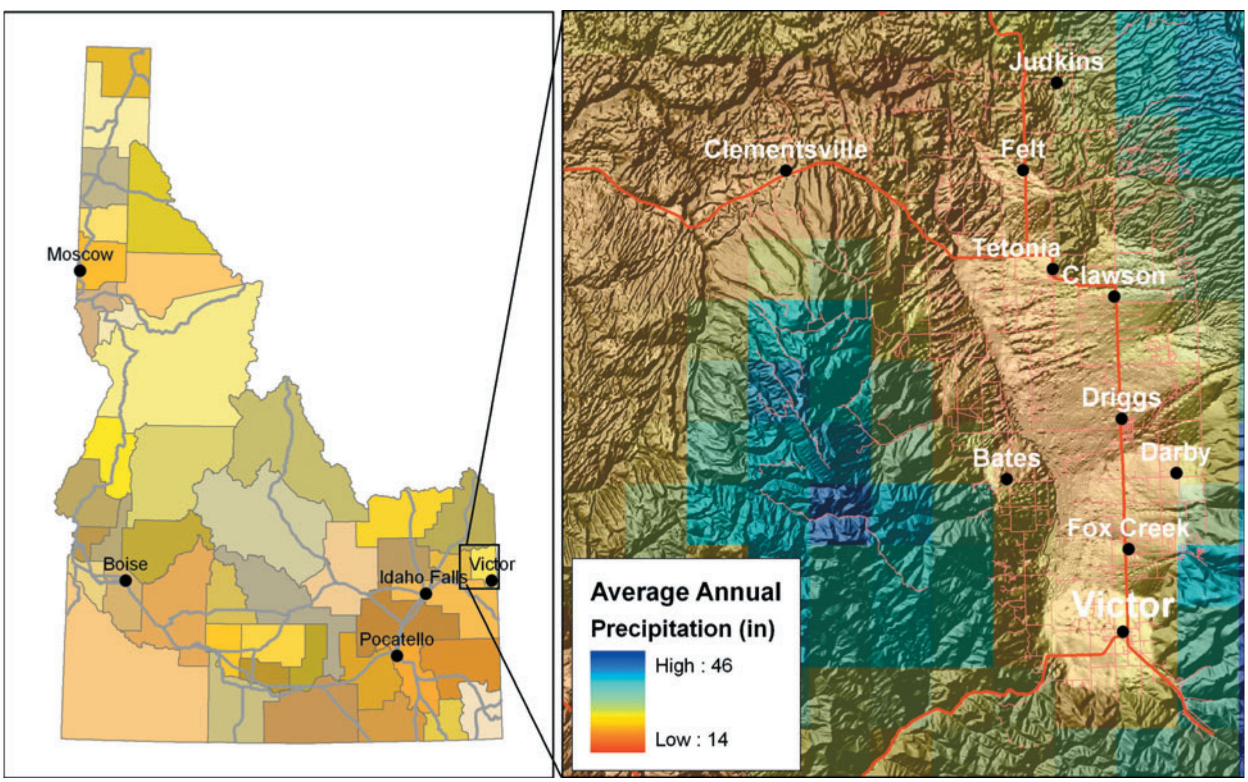

Figure 1. Location map of Victor, Teton County, Idaho.

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 collects and moves between individual grains of sand and gravel in an aquifer and through cracks and fractures in solid rocks. One of the keys to exploiting a ground-water resource is locating a zone where the holes between grains or fractures are large and interconnected. In such a saturated zone, called an aquifer, water in the subsurface moves under the force of gravity from higher elevations (recharge areas) to lower elevations (discharge areas). Typical discharge areas include springs, streams, and lakes. Most recharge comes from precipitation (rain and snow) that infiltrates the ground. Some recharge occurs from streams and lakes at elevations higher than the ground-water table. Generally, ground water moves downgradient less than 10 feet per day.

Understanding subsurface geology improves our knowledge of ground-water systems. Aquifers occur where ancient streams deposited sand or gravel or where an extensive network of fractures cut solid rock. Geologists study aquifers and ground-water flow patterns by mapping surface rock outcrops and reviewing well-drillers' logs of material penetrated by wells. This leads to identifying the potential areas for well construction and the recharge areas critical for good water quality and sustainability.

Sustainable development requires that ground-water use be less than aquifer recharge. Removing water from wells results in some water level decline in the ground and an associated reduction in natural discharge. Characterizing natural ground-water discharge from springs and seeps, estimating the discharge of interconnected streams, and defining the quantity and location of annual aquifer recharge provide the fundamental data for sustainable ground-water exploitation.

REGIONAL GEOLOGY

Teton County lies within two geologic provinces: the Idaho-Wyoming-Montana overthrust belt and the northern part of the Basin and Range. Limestones and sandstones, the dominant types of sedimentary rock exposed in Teton County, originally formed in shallow seas during Paleozoic time. Later, during the Cretaceous, compressional forces folded and faulted these rocks, forming the Idaho-Wyoming-Montana overthrust belt. During the Late Tertiary, volcanic activity produced strata that included the Huckleberry Ridge Tuff. The Huckleberry Ridge Tuff erupted from a large caldera in what is now Yellowstone National Park (Newhall and Dzurisin, 1988). The tuff lies unconformably on many ridges along the Teton River valley, and drill logs indicate it also lies buried in the valley. The valleys in Teton County formed primarily during Tertiary age basin-and-range extensional faulting. As a result of this activity, rocks identical to those exposed in the adjacent mountains occur at depth in the Teton River valley. Younger unconsolidated sediments that accumulated as the valleys formed cover the older rocks in low-lying areas. Throughout much of the last several thousand years, an ancient lake occupied parts of the Teton valley and deposited clay-rich sediments. Clay-rich sediments generally do not form quality aquifers, so wells drilled closer to the central part of the valley tend to show lower yields than those near the mountain range.

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 Teton County. The structure section discusses the hydrogeologically significant folds and faults.

STRATIGRAPHY

Strata exposed in Teton County include a several thousand-foot-thick section of upper Proterozoic, Paleozoic, and Tertiary age sedimentary and volcanic rocks (Pampeyan and others, 1967). The Proterozoic and Paleozoic strata represent continuous deposition through time, with only a few minor erosional interruptions.

Sedimentary Rocks

The oldest sedimentary strata exposed in the Victor area include limestone, calcareous sandstone, siltstone, and shale (Plate 1). The strata that underlie the Game Creek drainage consist of calcite-cemented quartz sandstone of the Tensleep Formation, and the Madison Limestone. The calcite-cement fills the space between sand grains in the Tensleep Formation, reducing its porosity and hydraulic conductivity; therefore, we do not consider the Tensleep Formation a worthwhile target.

Limestone, as found in the Madison Limestone, hosts some of the most robust aquifers in the world, e.g., the Floridian Aquifer in Florida and the Edwards Aquifer in Texas. However, limestone originally lacks significant porosity and permeability. With fracturing and water movement limestone can develop into an aquifer. We found no evidence of limestone-hosted springs or high-yielding wells completed in limestone in the Victor area and do not regard the Madison as a potential aquifer in this area.

Volcanic Rocks

Tertiary-age volcanic strata (Plates 1 and 2, unit *Tk*) overlie the sedimentary rocks in the Victor area. The most prominent is the Huckleberry Ridge Tuff, an ash-flow tuff erupted 2 million years ago from a large caldera north of Victor (Newhall and Dzurisin, 1988). The caldera extended over 80 km northeastward from Island Park past the northern Teton Range to the center of Yellowstone Park. The Huckleberry Ridge Tuff forms the lowest of three regionally extensive units and has an estimated volume of 2,500 cubic km. Additional information regarding the Yellowstone and adjacent calderas exists on the U.S. Geological Survey's Web site listed in the References.

Ash-flow tuffs lack significant porosity and permeability. However, the rock fractures readily when folded or faulted, providing avenues for water movement.

Unconsolidated Sediments

The unconsolidated material filling the Teton valley consists of sands and gravels deposited from flowing streams (Plates 1 and 2, unit *Qal*) and fine-grained mud deposited from lakes. The sands and gravels lie in canyons incised into the mountains (Game Creek and Trail Creek in Plate 1). Alluvial fans generally form where these streams issue from the canyons into valleys (Plates 1 and 2, unit *Qf*). Clay beds deposited from an ancient lake fill much of the central part of the Teton valley near Victor.

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

STRUCTURE

Rocks in the Teton valley display 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 most of the folding and thrust faulting observable in roadcuts along Idaho Highway 33 between Victor and Teton Pass. We found no evidence indicating that the Cretaceous folding and thrust faulting directly improves the capacity of any unit to store and transmit water in the Victor area. This activity, however, contributed to the present topography that controls the locations of recharge areas (uplands) and discharge areas (lowlands).

Tertiary-Age Features

Basin-and-range faulting modified the landscape, displacing the valleys downward and the mountain ranges upward, and thereby produced the Teton valley. The normal faults on the east side of the Teton valley all trend north and generally displace strata down to the west.

Normal faults play an important role in the distribution of ground water in the area. Geologic mapping completed during this project provides a detailed understanding of the nature and geometry of the normal faults in the Trail Creek-Game Creek area. Plate 1 portrays our mapping in combination with more general mapping published by Pampeyan and others, (1967).

Our work indicates that the Huckleberry Ridge Tuff generally rests on low- to moderate-angle normal faults. This relationship provides a critical ingredient to the local hydrogeology. Fault movement tends to fracture the volcanic rocks, providing an avenue for fluid migration in the otherwise low hydraulic conductivity rhyolite tuff. One fault of particular interest to Victor occurs immediately north of the Trail Creek drainage (Game Creek fault; Plate 1). The surface trace of the fault originates near the chlorination tank, continues southeastward along the hill slope to Game Creek and

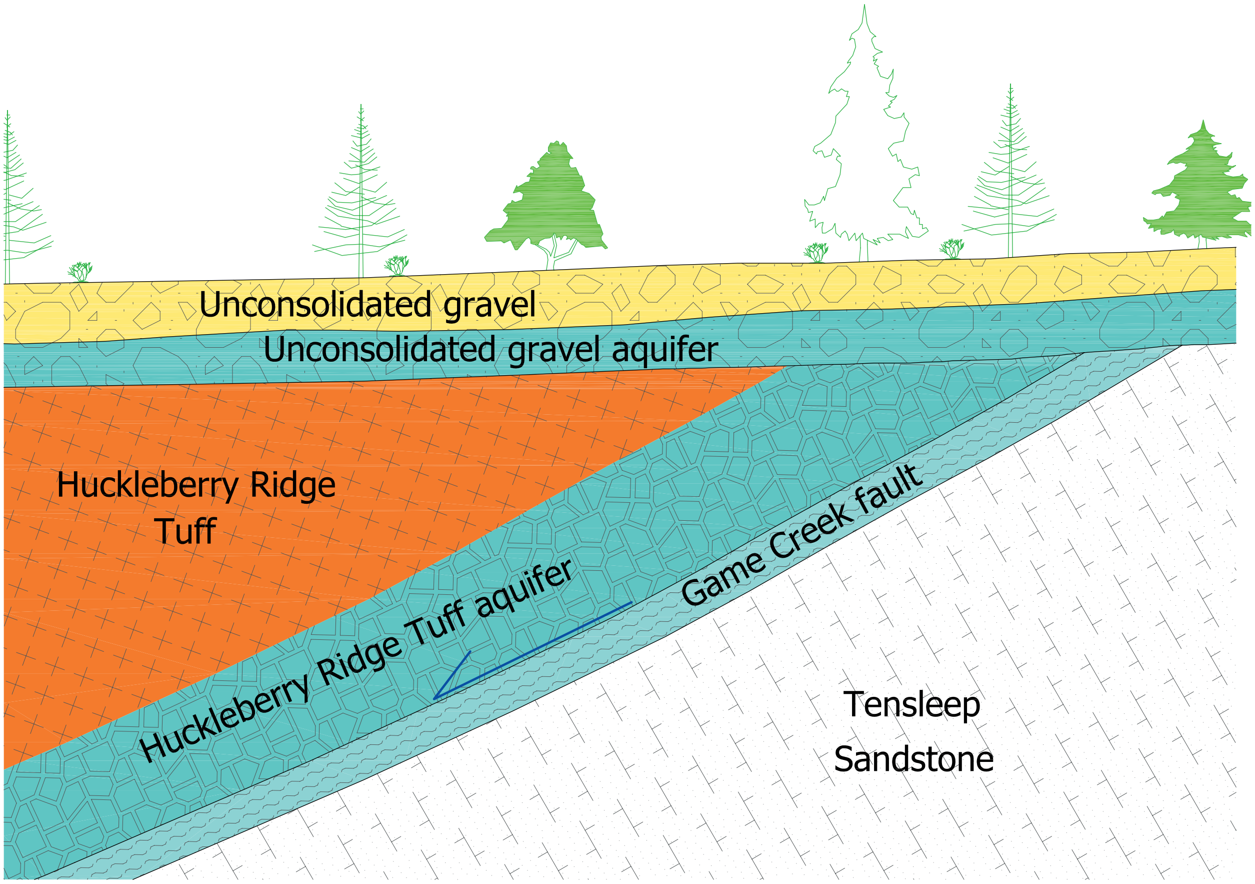

Figure 2. Schematic long section along Game Creek fault illustrating interaction between the unconsolidated gravel aquifer and the Huckleberry Ridge Tuff aquifer.

thence to Moose Creek. The plane of the fault dips about 25 degrees from horizontal in a southwesterly direction. The structure contour lines in Plate 1 estimate the elevation of the fault in the subsurface. Figure 2 illustrates the fault in a schematic section down Game Creek (line A-A' in Plate 1).

REGIONAL HYDROGEOLOGY

All water in the Teton River drainage 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 snow-pack accumulations. Figure 1 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. Notice that most of the precipitation falls on the mountains.

The hydrogeologic conceptual model starts with 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 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.

Regionally, the ground-water system consists of a series of fluvial gravel aquifers feeding successively larger fluvial gravel aquifers until the system reaches the

Victor alluvial fan. Low-hydraulic conductivity, clay-rich sediments deposited by an ancient lake lie downgradient of the fan, forcing most of the ground water to discharge in springs along the distal edge of the fan.

PROJECT AREA HYDROGEOLOGY

Ground water flows from recharge areas via aquifers to discharge areas. Delineating ground-water flow systems, from recharge area to discharge area, is important to understanding the potential for ground-water development. Understanding this path allows the developer or user to estimate the amount of water available from the volume of water in the recharge area. The risk of contamination can also be estimated from the land use and the geology along the path from recharge area to discharge area.

GROUND-WATER FLOW SYSTEMS IN CONSOLIDATED ROCK

We consider the Huckleberry Ridge Tuff in the Game Creek drainage the only viable consolidated rock aquifer for Victor. We found no high yielding wells completed in limestone or sandstone but did find some in the Huckleberry Ridge Tuff. This leads us to suspect that lithostatic pressure and calcareous cement reduced the porosity and hydraulic conductivity of the sedimentary rocks to the point that they do not form adequate aquifers.

The recharge area for the Huckleberry Ridge Tuff aquifer in the Game Creek valley lies upstream from where the fault crosses the Game Creek valley. Water then enters the fluvial gravel aquifer in the Game Creek valley and enters the Huckleberry Ridge Tuff where the fault crosses Game Creek (Plate 2B). At this point, the fractured rock communicates with the saturated gravel in the drainage bottom, providing an avenue for recharge (Figure 2). The most likely discharge point for this aquifer is the fluvial gravel aquifer within the Trail Creek valley.

Plate 2A shows the outline of the area in Game Creek that provides water to the aquifer in which the springs reside. We chose to terminate the recharge zone at the Idaho-Wyoming state border because the area upgradient from that point lies within the Grand Teton National Park and is protected from possible sources of contaminants by the National Park Service.

GROUND-WATER FLOW SYSTEMS IN UNCONSOLIDATED ROCK

The ground-water flow system in unconsolidated sediment consists of tributary aquifers that recharge larger aquifers. Thus, a hierarchy of aquifers exists with smaller aquifers in smaller valleys feeding larger aquifers in larger valleys. Focusing on the Game Creek valley-Trail Creek valley-Victor alluvial fan aquifer system, the recharge area for the fluvial gravel aquifer in the Game Creek valley encompasses the outline of the drainage basin (Plate 2A). The Game Creek fluvial gravel aquifer recharges the Trail Creek fluvial gravel aquifer; the Trail Creek fluvial gravel aquifer discharges into the Victor alluvial fan. The Victor alluvial fan discharges as springs along the distal edge of the fan where it comes into contact with the clay sediments filling the central part of the valley.

ANALYSIS OF SPRINGS AND WELL DEVELOPMENT

This section presents the hydrogeology of Victor's water supply system. Two hydrogeologic items exist in Victor's supply system: springs within the Game Creek fluvial gravel aquifer and a well completed in the Victor alluvial fan.

Victor Springs

Victor springs, located in the lower Game Creek drainage, represent the primary source of water for Victor (Figure 3, Plate 2A). There are six springs in the Game Creek drainage. The spring box for each extends about 3-4 feet deep with one drain tile extending horizontally from it. This configuration allows the system to skim shallow ground water moving downgradient within the Game Creek fluvial gravels. Victor realizes 300 to 375 gallons per minute yield from these springs.

The location of the springs with respect to exposed bedrock in the drainage basin and the cold temperature of the water (37°-40°F) suggest that the springs tap a local flow system fed entirely from the unconsolidated gravels within the Game Creek drainage rather than a system emanating from a bedrock source. The springs lie near the north-facing slope of the valley just below a Bull Lake-age gravel terrace. We think a significant component of flow captured by the springs comes from the north-facing slope and terrace gravels. This material

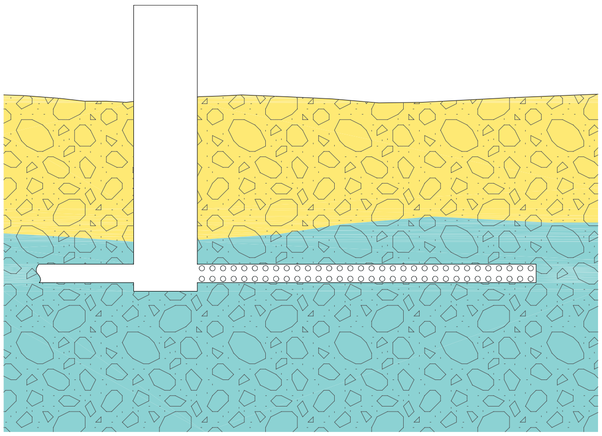

Figure 3. Typical municipal spring box for Victor springs.

holds its snow until late in the spring, and the terrace gravels help store the water as it runs off the slope.

Willow Creek Well

The Willow Creek well, located on the Victor alluvial fan, provides a secondary source of water for the town. This well was drilled in 1993 to a depth of 300 feet with knife-cut perforations between 200 and 300 feet below surface. The town uses this well sparingly to supplement water supplied by the springs. Recharge to the Victor alluvial fan comes from the fluvial gravel aquifer in the Trail Creek valley and its tributaries.

Although cutting perforations in casing is inexpensive, this style of construction produces more drawdown in the well per gallon of water pumped than a well with an engineered well screen. The resulting well inefficiency contributes to the cost of production by increasing the lifting head, and it generally shortens the well's useful life.

RESULTS

We identified three potential targets to explore for additional sources of water: (1) a more efficient well on the Victor alluvial fan (Plate 2D), (2) Game Creek fluvial gravels (Plate 2B), and (3) fractured Huckleberry Ridge Tuff aquifer (Plate 2C). The hydrogeologic advantages and disadvantages are discussed below.

VICTOR ALLUVIAL FAN AQUIFER

The advantages of the Victor alluvial fan aquifer are that it is known to produce sufficient water, that it receives sufficient recharge, and that it stores large volumes of water. The existing municipal well (the Willow Creek well) produces adequate water from the alluvial fan. The tributary valleys feeding this aquifer receive recharge from tall mountains that capture large amounts of precipitation and discharge into the alluvial fan. Also, this is probably a large aquifer and therefore stores a large volume of water. Aquifer storage provides a huge advantage during a sustained drought.

The disadvantages of the Victor alluvial fan aquifer are that water will have to be pumped from the well up to the current distribution system, that the well will require an engineered well screen, that the aquifer is heterogeneous, and that the aquifer is vulnerable to human-caused contamination. Designing an efficient well and distribution system could minimize the lifting head, but not eliminate it. Since the host aquifer is unconsolidated (loose sand and gravel not consolidated rock), the most efficient well design uses a wire wrapped screen to maximize the ease with which water enters the well while still keeping the aquifer material out. Usually the costs involved in carefully designing these types of wells pays dividends in longer well life as well as in lower pumping and pump maintenance costs. The design and construction costs for this system would probably be substantial; however, the town could expect to reap benefits from the improved efficiency for 20 to 30 years. This alluvial fan consists of poorly sorted alluvium and well-sorted stream gravels. The higher producing wells will intersect thick sequences of stream gravels. We expect a higher concentration of stream gravels along Trail Creek because this is the shortest path between the mouth of the Trail Creek valley and the Teton River. A more serious disadvantage is the lack of a laterally extensive low permeability layer between the aquifer and land surface. Any upgradient chemical spill can potentially make its way into the well, thereby contaminating the town's water supply.

GAME CREEK FLUVIAL GRAVEL AQUIFER

The advantages of the Game Creek fluvial gravel aquifer are that it will require a low lifting head, that this is likely to be the shallowest well, and that only moderate potential for contamination exists. Since the well lies uphill from the chlorination tank, pumped water will flow into the chlorination tank under the influence of gravity, thus the lifting head consists of only the lift required to get the water out of the well. Another potential cost savings is that this is probably the shallowest of the three proposed wells. Perhaps the most significant advantage over the Victor alluvial fan aquifer is that most of the upgradient land is public, lowering the risk of human-caused contamination.

The disadvantages of the Game Creek fluvial aquifer are that a well will require an engineered well screen, that the aquifer yield remains unknown, that it lacks an extensive low permeability protective layer, and that there may not be much unappropriated water left in this drainage. This target is an unconsolidated aquifer, like the Victor alluvial fan, and the most efficient well design for such an aquifer is an engineered well screen. We are more concerned that there are no high yield wells in this aquifer, so this target is a calculated risk. The aquifer lacks a shallow low permeability layer protecting the aquifer from human-caused contamination. Although large portions of the aquifer lie on public land, such a layer provides added insurance. Potentially, the most serious disadvantage is the limited recharge area. We are concerned that the drainage basin may not receive enough recharge to supply much more unappropriated water for Victor.

The springs, if redeveloped, could provide more water than the town presently enjoys. This would entail adding additional drain tiles to the existing spring boxes. We believe this presents a viable option because of the quality of water, and because of the protection that the watershed above the spring system maintains.

HUCKLEBERRY RIDGE TUFF AQUIFER

The advantages for the Huckleberry Ridge Tuff aquifer are that it will require a low lifting head, that the well will probably not require an engineered well screen, and that it has the lowest potential for contamination. We will look at the cost saving advantages first. Like the Game Creek fluvial gravel aquifer, this prospect sits uphill from the chlorination tank so pumped water can flow downhill into the chlorination tank. Another potential cost savings is that the Huckleberry Ridge Tuff aquifer is a bedrock aquifer so it will probably not require a well screen. Hydrogeologically, we think most of the water enters the aquifer near the boundary between public and private land in the Game Creek valley, so there are no upgradient residences and little vehicle traffic, which significantly reduce the risk of human-derived contamination.

The disadvantages of the Huckleberry Ridge Tuff aquifer are that well yield remains uncertain, that this well may prove the most costly to drill, that it presents an increased potential to yield water containing natural undesired contaminants, and that this aquifer has a low recharge potential. The Teton Springs well, completed in the Huckleberry Ridge Tuff but in a totally different ground-water flow system, provides anecdotal evidence that this aquifer may yield significant quantities of water. However, yield in fractured rock aquifers tends to be more variable than in sand and gravel aquifers. Fractured-rock aquifers commonly present some of the more challenging drilling environments. Rhyolitic aquifers, like the Huckleberry Ridge Tuff, occasionally produce water containing undesirable dissolved constituents such as arsenic and fluorine. As with the Game Creek fluvial gravel aquifer, potentially the most serious disadvantage is the limited recharge area. We are concerned that there may not be enough recharge in the Game Creek valley to supply much unappropriated water.

RECOMMENDATIONS

We recommend obtaining additional information on the chemical character of ground water in the Victor area by analyzing water samples from existing wells completed in the target aquifers or aquifers analogous to the target aquifers.

Before drilling 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 exploration targets are listed in descending order on their relative merits based on an ease-of-discovery versus a risk-of-failure. Of course, failure is always a possibility in any exploration program. The list assumes the chemical quality of all target aquifers is acceptable. It does not address requirements that may be imposed by regulatory or administrative agencies.

1. Redevelop the Victor municipal springs (this does not address the need to maintain the present IDEQ ground-water status).
2. Drill a new well on the Victor alluvial fan.
3. Drill the lower Game Creek gravels.
4. Drill the fractured volcanic target.

ACKNOWLEDGMENTS

This work was funded through grant number X97008601 from the U.S. Environmental Protection Agency (Region 10) to the Idaho Water Resources Research Institute at the University of Idaho. We thank the representatives of Victor for their contributions and the Idaho Geological Survey for providing peer reviews and publishing this work. The representatives from Victor include the mayor, Don Tompson, and the town administrator, Craig Sherman.

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 Victor.

REFERENCES

Daly, C., and G. Taylor, 2001, PRISM Precipitation Maps: Oregon State University Spatial Climate Analysis Service and State of Oregon Climate Service, <http://www.ocs.orst.edu/ prism/prism_new.html>.

Pampeyan, E.H., M.L. Schroeder, E.M. Schell, and E.R. Cressman, 1967, Geologic map of the Driggs quadrangle, Bonneville and Teton counties, Idaho and Teton County, Wyoming: U.S. Geological Survey Map MF-300.

Newhall, C.G., and D. Dzurisin, 1988, Historical unrest at large calderas of the World: U.S. Geological Survey Bulletin 1855, 1108 p.

U.S. Geological Survey, 2002, Web information on the Yellowstone Caldera: http://vulcan.wr.usgs.gov/Volcanoes/Yellowstone/description_yellowstone.html>.