The Spokane Valley-Rathdrum Prairie Aquifer Atlas

2004 Update

Contents

Welcome!

The Spokane Valley-Rathdrum Prairie Aquifer Atlas presents a comprehensive summary of the region's most precious groundwater resource and is a basic reference of the geographic, geologic and hydrologic characteristics of this aquifer.

The Atlas is designed in a narrative format supported by graphs, maps and images. It is intended for broad community use in education, planning, and general technical information. The preparation and publication of the original Atlas were partially funded by a United States Environmental Protection Agency grant for aquifer wellhead protection.

The information was collected and obtained from a variety of sources, including: United States Environmental Protection Agency, Idaho Department of Environmental Quality, Washington Department of Ecology, Panhandle Health District, Kootenai County Planning Department (Idaho), Spokane County (Washington), United States Geologic Survey and Eastern Washington University.

The Spokane Valley-Rathdrum Prairie Aquifer spans two states (Washington and Idaho) and lies within three counties (Kootenai, Bonner and Spokane). Natural resources, such as the Aquifer, that cross political boundaries are often subject to different, and sometimes conflicting, standards, protections and uses. This Atlas is a joint effort by agencies in both states to create a holistic representation of the Aquifer as both geologic feature and a natural resource used daily by more than 500,000 people.

Political boundaries are absent on the front cover map. The authors intend the reader first view the Aquifer as a continuous natural feature, then investigate the various aquifer elements presented in this Atlas. The authors believe that factual information about the Aquifer will generate greater public understanding of the region's groundwater and lead to continued protection and wise use of this precious and finite resource.

What's New?

The original Aquifer Atlas was published in 2000. This document is an update of the original publication that includes a few new topics and more recent information. Major revisions were made to several pages based on comments received from Aquifer Atlas users. Individuals and organizations responsible for the 2000 Edition and the 2004 Edition are listed on page 26.

The pages in this document are color coded (see right) by category to assist the atlas user. The original page order has been changed slightly to better group similar topics. Other changes from the original Atlas include:

Page 3: New! "Historic Aquifer" presents a 1860 painting of the Aquifer.

Page 5: The satellite image is based on 2003 data.

Page 6: New! "Digital Mapping"

Page 12: The geologic map has been generalized.

Page 15: New! "Aquifer-River Interchange"

Pages 17-18: Computer modeling information is combined on two pages.

Page 20: "Regional Trends" replaces the original "Climate & Population" page.

Page 21: Two original pages have been combined into one page, "Aquifer Issues."

Navigating the Atlas

The pages in the Aquifer Atlas are organized into six categories, and each category is color coded in the title and outside margin to assist the reader in locating a specific page.

The Aquifer

The sole source of water for most of the people in Spokane County, Washington and Kootenai County, Idaho, is a high quality underground water body called the Spokane Valley-Rathdrum Prairie Aquifer (Aquifer), and it is also commonly known as the "Rathdrum-Spokane Aquifer." Discovered in 1895, this Aquifer has become one of the most important resources in the region, supplying drinking water to more than 500,000 people. The Aquifer has been studied in considerable detail since 1977, and the results of these investigations have produced programs and regulations designed to ensure this aquifer will remain a valued and protected resource for future generations.

The Spokane Valley and Rathdrum Prairie are ancient geologic features that have, for millions of years, been formed by water flowing downhill from the western slopes of the Rocky Mountains to the Pacific Ocean. During the last Glacial Age (18,000 to 12,000 years ago), and possibly in multiple previous Ice Ages, cataclysmic floods inundated North Idaho and approximately one-third of Washington as a result of the rapid draining of ancient Lake Missoula when ice dams broke (see pages 9 and 10). These floods deposited thick layers of coarse sediments (gravels, cobbles, and boulders) in this area. The saturated portion of these sediments, where void spaces are filled with water, comprises the Aquifer. Water from adjacent lakes, mountain streams, the Spokane River, and precipitation flows through the flood sediments replenishing the Aquifer.

In the 1970s area residents began to recognize that the Aquifer could easily become contaminated. The highly permeable aquifer boulders, gravel and sands, together with permeable overlying soils, make the Aquifer highly susceptible to contamination from the surface. One of the first important steps to protect the Aquifer was taken by the Environmental Protection Agency when it designated the Spokane Valley-Rathdrum Prairie a "Sole Source Aquifer" in 1978. It was the second aquifer in the nation to receive this special designation. This step further increased public awareness for Aquifer protection and supported the development of special management practices by local agencies. Presently, aquifer protection efforts are managed by Spokane County's Water Resource Program in Washington and by the Department of Environmental Quality and the Panhandle Health District in Idaho.

Aquifer Facts

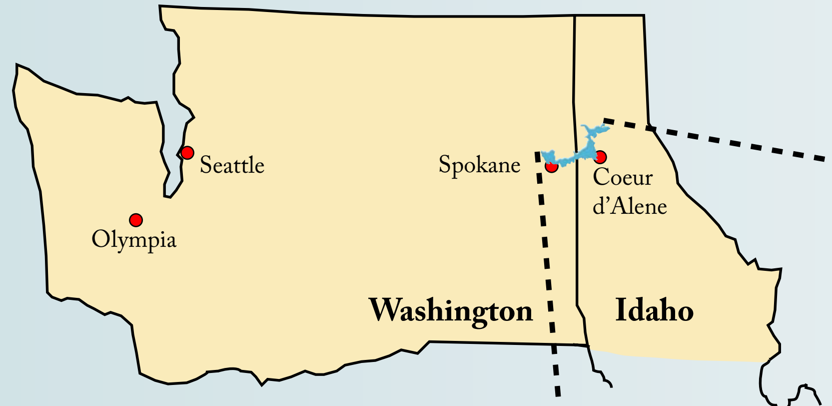
The Aquifer has one of the fastest flow rates in the United States, flowing as much as 50 feet per day in some areas. In comparison, a typical aquifer has a flow rate between 1/4-inch and five feet per day.

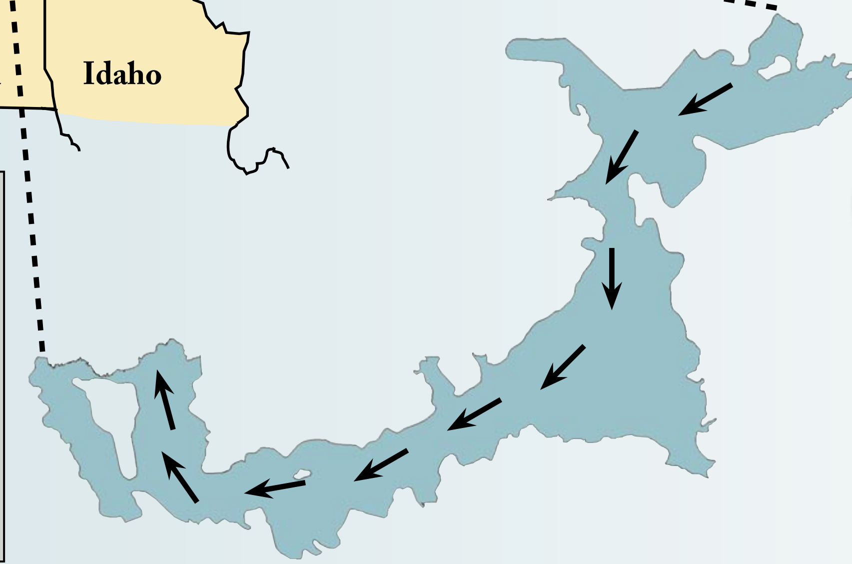
The Aquifer sediments range from about 150 feet to 600 feet thick.

The Aquifer covers 322 square miles in two states.

The average daily water withdrawal is about 146 million gallons.

The volume of the entire Aquifer is about 10 trillion gallons, making it one of the most productive aquifers in the United States.





The Aquifer begins in Idaho between Spirit Lake and the south end of Lake Pend Oreille. The Aquifer water flows south until it reaches the middle of the Rathdrum Prairie, where it turns west and flows into Washington under the Spokane Valley. When the Aquifer water reaches downtown Spokane, most of it turns north, flows under the city and discharges into the Little Spokane River through springs.

Water Quality

The first monitoring of the Aquifer water began in October, 1908 in the City of Spokane (see side bar article), but detailed water quality testing in the Aquifer began much later. Since 1977, every three months Spokane County obtains water samples from about 50 wells in Washington. The Panhandle Health District has taken samples from about 28 wells in Idaho since 1974. Testing of these quarterly water samples has shown that:

- contaminant levels show a direct relationship to human activity,
- contaminants are mostly located in the top few feet in the Aquifer, and,
- overall contaminant levels have increased since 1977.

This monitoring suggests that human activities on the land surface over the Aquifer are deteriorating the Aquifer water quality. Contaminants carried to the Aquifer originate as stormwater, septic tank leachate, fertilizer leachate, leaking underground storage tanks and other sources that percolate downward from the surface. Even though contamination has reached the Aquifer, the Aquifer water quality remains very good.

Water Supply

Newspaper articles from the 1890s and 1910s relate that area residents believed the Aquifer was an "inexhaustible supply of pure water." The belief that the Aquifer was unlimited continued until the early 1980s when the U. S. Geological Survey presented the results of a flow model for the Aquifer. The model found that:

- the daily Aquifer flow at the Washington-Idaho border was about 258 million gallons,
- total Aquifer recharge was about 650 million gallons per day,
- the Aquifer is a reservoir with storage capacity of 10 trillion gallons,
- the average daily water withdrawal is about 146 million gallons, and
- the peak summer daily withdrawal is 450 million gallons.

Some studies and models suggest that during periods of high water demand we may be using a large percentage of the Aquifer flow. Currently the available supply is adequate to support area growth for some time, but the supply is not inexhaustible. In 2004 the U.S. Geological Survey began collecting data in Idaho and Washington as part of a new multi-year Rathdrum-Spokane Aquifer study.

SPOKANE'S WATER PUREST IN WORLD

City Bacteriologist Frank Rose Reports Results No Colon Bacilli Found

Showing the Spokane water supply purer than the average of American cities, Frank Rose, city bacteriologist, has made a report of tests from the city well made monthly since last October. The tests are simply counts of the number of bacteria found in a cubic centimeter of water.

The average count shows only seven or eight germs in that amount of water. The test was made from water taken from the drinking fountain at Howard street and Riverside avenue or from water from a faucet in the Rookery building. Speaking of his tests, Dr. Rose said:

"It can be said that there is no city in the world that has a better water supply than Spokane. Water which shows 100 germs in a cubic centimeter is considered comparatively pure and drinkable. I made from four to eight counts monthly since last October, and the counts in any one month was 17 bacteria, while the tests last month showed 15 bacteria in eight tests, less than two each.

"In April, 1908, I made tests of the river water from which Spokane got its drinking supply at that time. I took water from the place where the Coeur d'Alene sewer emptied into it and another sample from a place about 500 feet below the outlet of the sewer. In both cases the number of bacteria was so great as to be practically uncountable.

"In contrast to this is the practical purity of the water since last October. Special care was taken to make tests for colon bacilli, which show the presence of sewage, and in no case was there a single trace."

Spokesman-Review
Thursday, May 6, 1909

In 1860, James Madison Alden was a member of the International Boundary Survey team traveling through the Washington Territory. He painted this watercolor of the Spokane Valley from a location near the present-day Arbor Crest Winery. In the foreground is Plante's Ferry, a popular ferry crossing of the Spokane River operated by Antoine Plante from 1852 to 1864. The inset photograph of the Spokane Valley was taken from the Arbor Crest Winery property in 2004. *Watercolor courtesy of the National Archives, College Park, Maryland (thanks to Jack Nisbet.)*

Aquifer Timeline

This timeline highlights important Aquifer milestones relating to its discovery, initial investigations and use. EXPO '74 represented a change in the community's relationship to the Aquifer from exploitation of an "unlimited" resource to understanding how best to ensure continued wise use of the Aquifer water. Recent efforts to understand and protect the Aquifer are presented on page 22.

1860
James Madison Alden paints "Plante's Crossing" shown on page 3.

1881
Northern Pacific Railroad arrives and provides an economic boost to the region.

1884
Spokane purchases a private waterworks located in the old Echo Mill on Havermale Island as the beginning of a city water system using the Spokane River as a water source.

1888
For the next few years, Spokane investigates potential water sources for its expanding water system. Under consideration are: springs near the Little Spokane River, Hayden Lake, and a dam east of the City.

1889
Washington becomes the 42nd state.

1890
Idaho becomes the 43nd state.

1894
Upriver Dam and a pump station are built to provide 10 million gallons of water river daily to the City. While constructing the pump station foundation, so much water is encountered that the foundation is built six feet higher than designed. Although unrecognized at the time, the contractor had discovered the Aquifer.

1905
Between 1898 and 1905 Spokane upgrades the pumping capacity at the Upriver Dam several times. In 1905 while excavating for a new pump station foundation, workers encounter the same high water conditions found near the site in 1894. This time, city engineers deduce the existence of the Aquifer.

1906
Post Falls Dam begins operation.

1908
Spokane's health officer issues a boil water notice for all river water in early 1908. After testing the Aquifer water, City officials authorize construction of a well near the Upriver Dam site. By the fall of 1908, the Aquifer becomes the City's primary drinking water source.

1923
Dr. J. Harlan Bretz makes two presentations to the Geological Society of America proposing that the Channeled Scablands of eastern Washington were formed by catastrophic flooding. He had discovered the geologic process that created the Aquifer. His idea was not generally accepted for another 20 to 30 years.

1929-1934
Grand Coulee Dam is constructed.

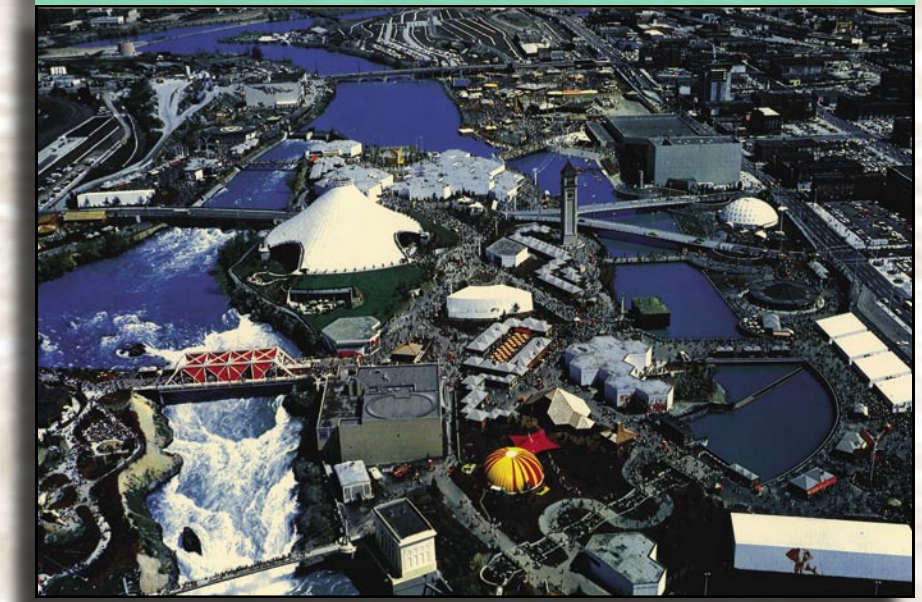
1931
Under contract to the Washington Water Power Company, E. R. Fosdick prepares the first comprehensive study of groundwater in the Spokane Valley and Rathdrum Prairie.

1938
A survey of all major rivers and waterways found the Spokane River the foulest water body in the state of Washington.

1940
Joesph T. Pardee, a USGS geologist, presents a paper to the American Association for the Advancement of Science proposing that an Ice Age glacial lake (Lake Missoula) in present day Montana had drained rapidly. Pardee had discovered the source of Bretz's catastrophic floods.

1972
Federal Clean Water Act: Section 208 provided authority and funding for Aquifer protection planning efforts.

1974
EXPO '74 opens in Spokane, Washington, with the theme: "Celebrating Tomorrow's Fresh New Environment." EXPO's headquarters are located on Havermale Island, the site of the City's first water system.

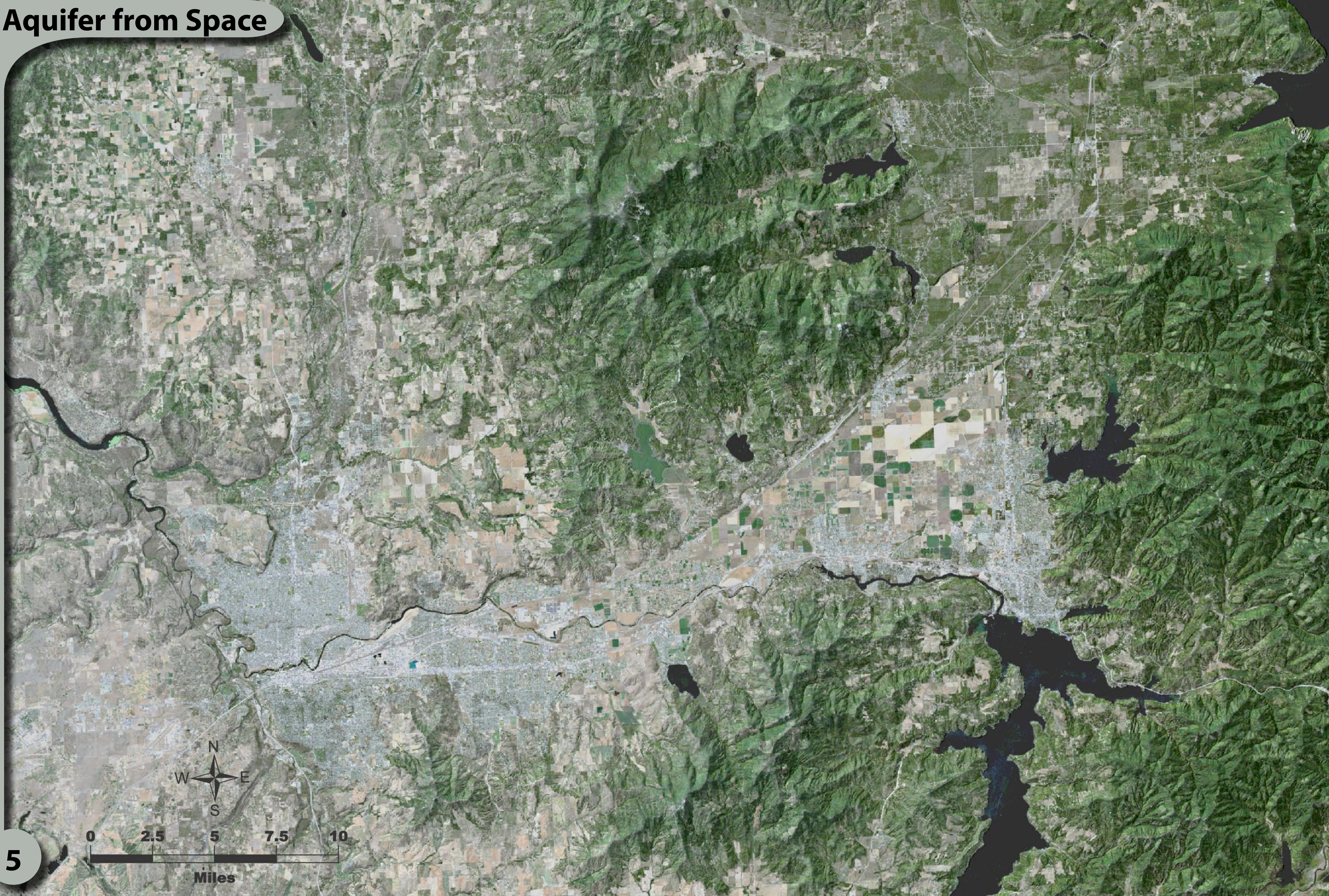


1860 | 1870 | 1880 | 1890 | 1900 | 1910 | 1920 | 1930 | 1940 | 1950 | 1960 | 1970

Page 22

Background is a photograph of the Upriver Dam constructed of timber on the Spokane River in 1895.

Aquifer from Space



Land Mapping Satellites (Landsat)

The National Aeronautics & Space Administration (NASA) launched the first satellite designed to provide repetitive global coverage of the Earth's land masses in July, 1972. Since the Landsat1 launch, other Landsats have been placed into orbit and have provided nearly continual land mapping coverage of the Earth from 1982 to the present.

The source of the image on the opposite page is Landsat5. This NASA satellite was launched from Point Arguello, California on March 4, 1984, and it flies in a repetitive orbit that takes 16 days to return to the same location. The satellite orbits at 423 miles above the Earth, and each somewhat over-lapping image covers an area, 106 miles by 115 miles (12,190 square miles).

The United States Geological Survey (USGS) manages the Landsat data archive. This archive contains a detailed collection of information about the land surface of our planet. Major changes to the land surface can be detected and analyzed with Landsat data. Governments, businesses and educational institutions world-wide have employed Landsat data for a variety of applications including mapping, geography, geology, oceanography, agriculture and forestry.

The image at left is a section of the 2003 satellite image on the opposite page at the Idaho-Washington border where Interstate 90 crosses the Spokane River that has been enlarged 10 times. As you can see the image is comprised of colored squares, called "pixels." A pixel represents a data point 30 meters (98 feet) square collected by Landsat5, and each pixel is about 0.22 acres. The entire image is 16 pixels (1,575 feet) wide and 14 pixels (1,378 feet) high with an area of about 50 acres.

Image or Photograph?

Satellite imagery can LOOK like photography, but satellite imagery is actually one or a combination of the seven data sets (called spectral bands) collected by the satellite's data collector, a thematic mapper multispectral scanning radiometer. The spectral bands are Band 1, red; Band 2, green; Band 3, blue; Band 4, mid infra-red; Band 5, near infra-red; Band 6, thermal; and, Band 7, far infra-red. Each data point, or "pixel," of the spectral imagery represents 30 square meters.

Images are created by using one or more of the spectral bands collected by the satellite's thematic mapper. The data (pixels) from the spectral bands are organized in a digital grid, and colors are assigned to value ranges in each pixel. By carefully constructing a color palette for the pixel values, a satellite image can be made that looks very much like a photograph.

The image at right contains multi-band data with emphasis on the infra-red spectrum. The data set used to create this image was collected at the same time (2003) as the data used to make the aquifer image on the opposite page.

1986

2003

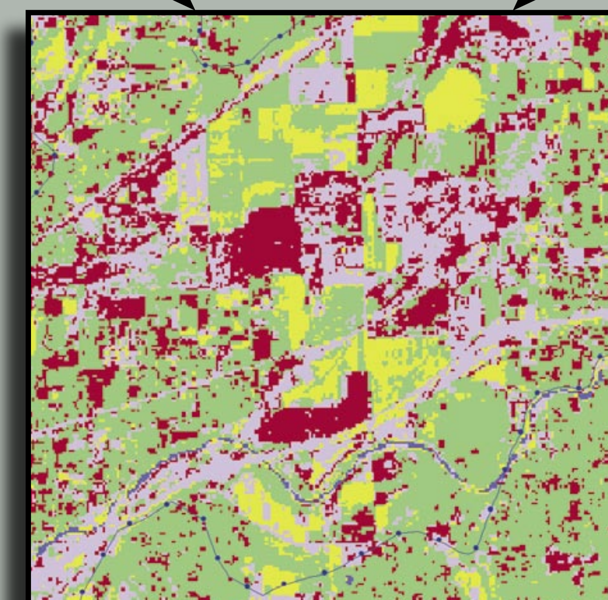
Change Mapping

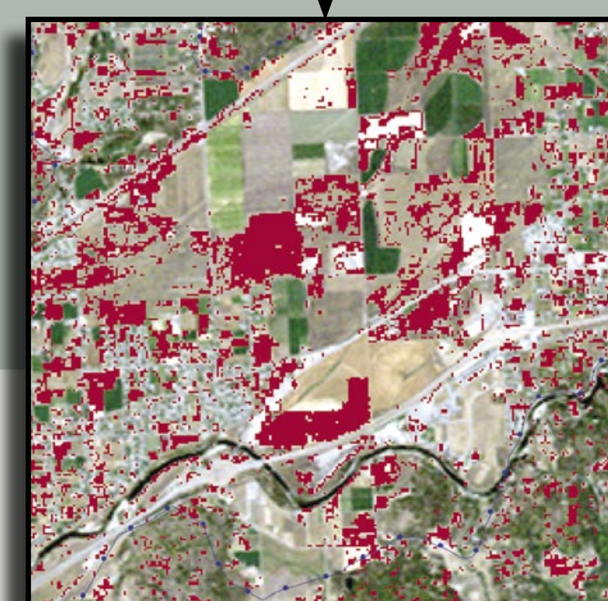
Since each pixel in a digital image has a numeric value, images collected at different times can be compared, pixel by pixel. At the top right are two Landsat images over the Aquifer at the Idaho-Washington border collected in 1986 and 2003. The 2003 image is the same data set as the image on the opposite page.

These two images were compared, pixel by pixel, using a sophisticated computer program to assess the change in vegetation on the land surface over seventeen years, and a four color comparison map was produced. If the 2003 pixel had a spectral value that indicated significantly LESS VEGETATION than the comparable 1986 pixel, then that pixel was assigned a red color on the comparison map. If the 2003 pixel had a spectral value that indicated significantly MORE VEGETATION than the comparable 1986 pixel, then that pixel was assigned a yellow color on the comparison map. If the 2003 pixel and the 1986 pixel had about the same value, then that pixel was assigned a green color. Impervious surfaces present on both images were assigned a gray color.

While the change map is interesting, it is not possible to generalize the results without field verification: the red pixels do not in all cases represent vegetation lost to development, and the green pixels do not in all cases represent vegetation "gained." For example, if a field was green with vegetation in the 1986 image, and in 2003 contained a subdivision, most of the field area would be red in the change map. However, if the field was fallow with no vegetation in the 1986 image, and in 2003 contained a subdivision, most of the field area would be green in the change map due to the subdivision landscaping.

The final image is a composite of the red pixels from the change map with the 2003 image. This image shows where the pixel comparison program indicates less vegetation in 2003 when compared to 1986.



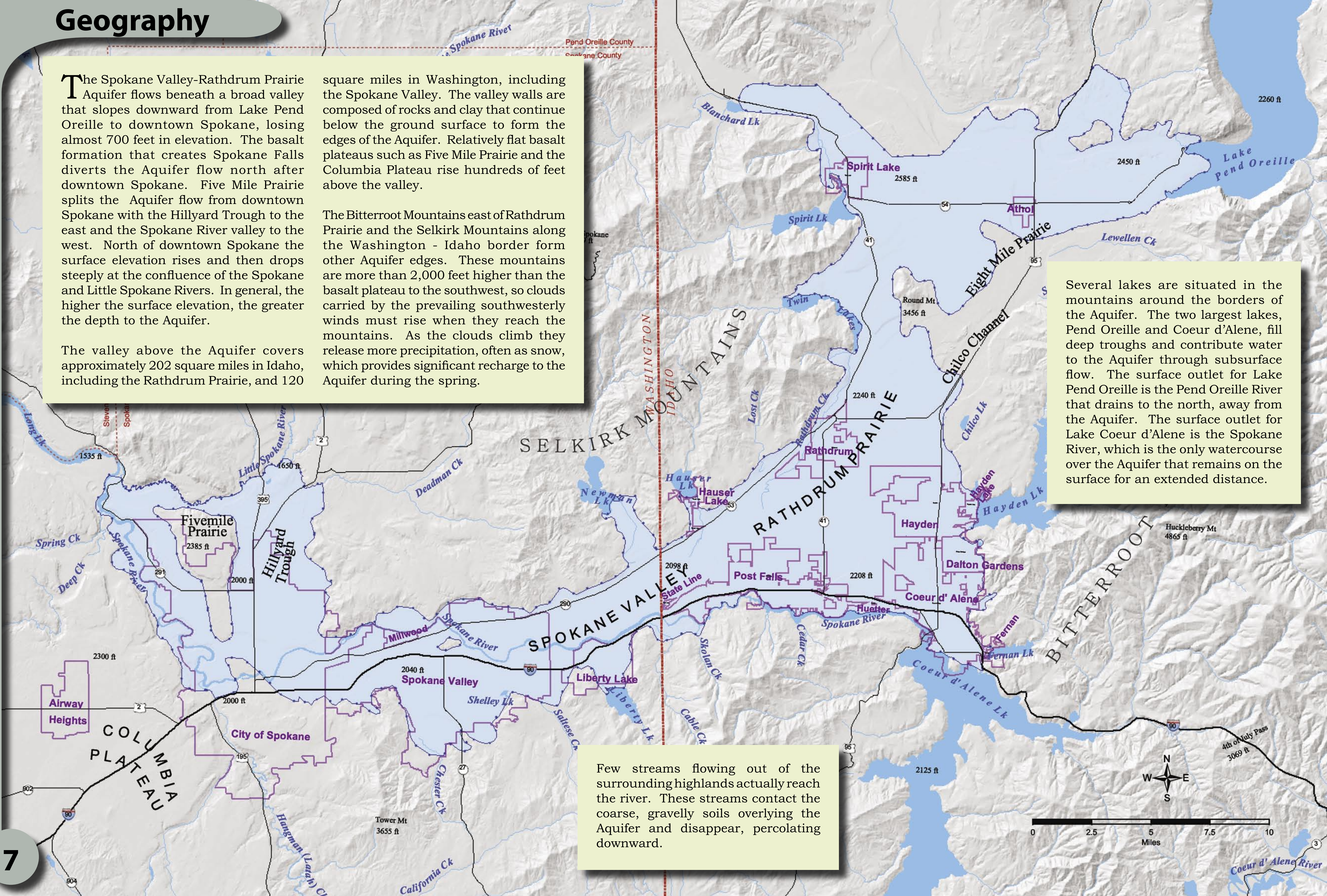


Geography

The Spokane Valley-Rathdrum Prairie Aquifer flows beneath a broad valley that slopes downward from Lake Pend Oreille to downtown Spokane, losing almost 700 feet in elevation. The basalt formation that creates Spokane Falls diverts the Aquifer flow north after downtown Spokane. Five Mile Prairie splits the Aquifer flow from downtown Spokane with the Hillyard Trough to the east and the Spokane River valley to the west. North of downtown Spokane the surface elevation rises and then drops steeply at the confluence of the Spokane and Little Spokane Rivers. In general, the higher the surface elevation, the greater the depth to the Aquifer.

The valley above the Aquifer covers approximately 202 square miles in Idaho, including the Rathdrum Prairie, and 120 square miles in Washington, including the Spokane Valley. The valley walls are composed of rocks and clay that continue below the ground surface to form the edges of the Aquifer. Relatively flat basalt plateaus such as Five Mile Prairie and the Columbia Plateau rise hundreds of feet above the valley.

The Bitterroot Mountains east of Rathdrum Prairie and the Selkirk Mountains along the Washington - Idaho border form other Aquifer edges. These mountains are more than 2,000 feet higher than the basalt plateau to the southwest, so clouds carried by the prevailing southwesterly winds must rise when they reach the mountains. As the clouds climb they release more precipitation, often as snow, which provides significant recharge to the Aquifer during the spring.

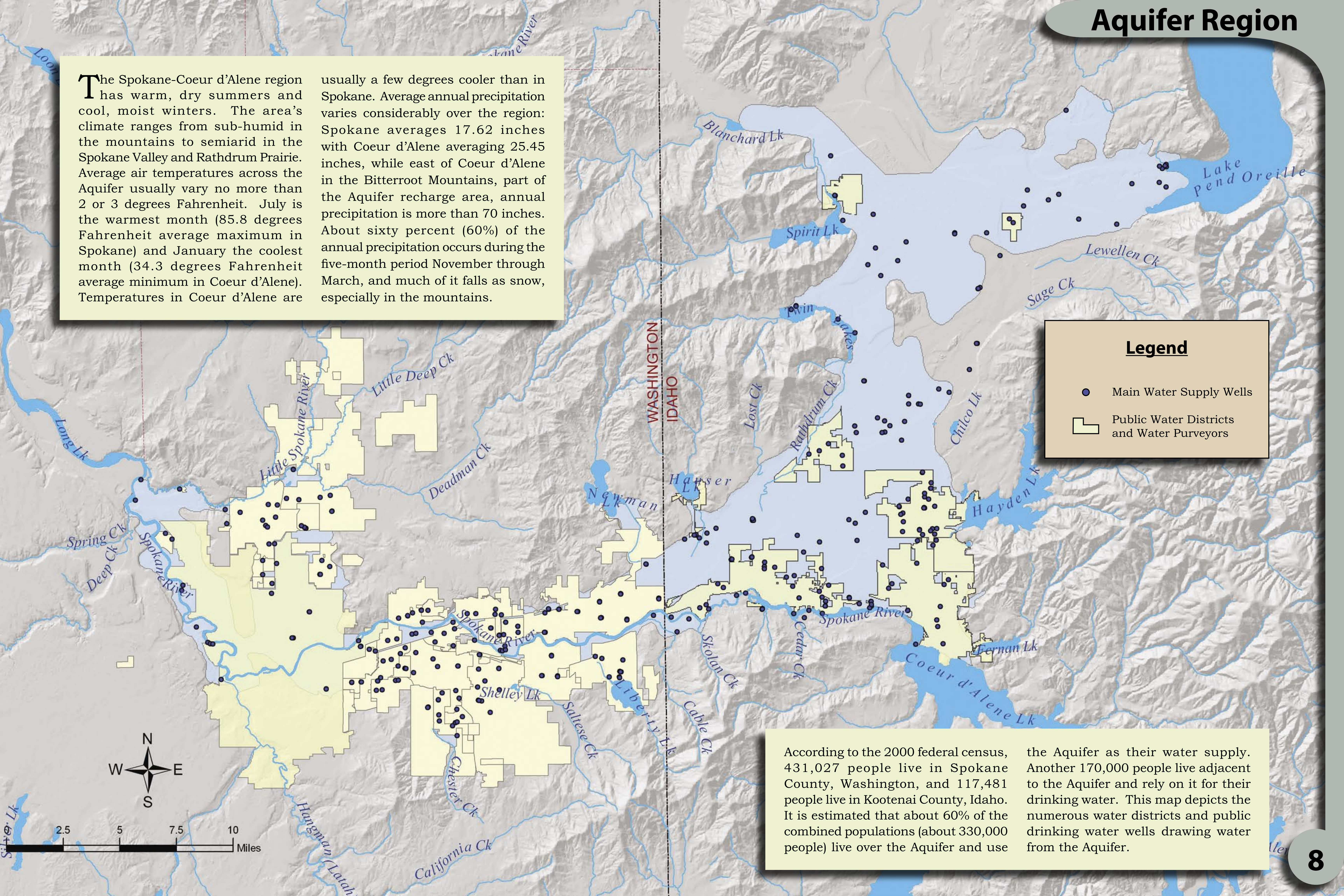


Several lakes are situated in the mountains around the borders of the Aquifer. The two largest lakes, Pend Oreille and Coeur d'Alene, fill deep troughs and contribute water to the Aquifer through subsurface flow. The surface outlet for Lake Pend Oreille is the Pend Oreille River that drains to the north, away from the Aquifer. The surface outlet for Lake Coeur d'Alene is the Spokane River, which is the only watercourse over the Aquifer that remains on the surface for an extended distance.

Few streams flowing out of the surrounding highlands actually reach the river. These streams contact the coarse, gravelly soils overlying the Aquifer and disappear, percolating downward.

Aquifer Region

The Spokane-Coeur d'Alene region has warm, dry summers and cool, moist winters. The area's climate ranges from sub-humid in the mountains to semiarid in the Spokane Valley and Rathdrum Prairie. Average air temperatures across the Aquifer usually vary no more than 2 or 3 degrees Fahrenheit. July is the warmest month (85.8 degrees Fahrenheit average maximum in Spokane) and January the coolest month (34.3 degrees Fahrenheit average minimum in Coeur d'Alene). Temperatures in Coeur d'Alene are usually a few degrees cooler than in Spokane. Average annual precipitation varies considerably over the region: Spokane averages 17.62 inches with Coeur d'Alene averaging 25.45 inches, while east of Coeur d'Alene in the Bitterroot Mountains, part of the Aquifer recharge area, annual precipitation is more than 70 inches. About sixty percent (60%) of the annual precipitation occurs during the five-month period November through March, and much of it falls as snow, especially in the mountains.



According to the 2000 federal census, 431,027 people live in Spokane County, Washington, and 117,481 people live in Kootenai County, Idaho. It is estimated that about 60% of the combined populations (about 330,000 people) live over the Aquifer and use the Aquifer as their water supply. Another 170,000 people live adjacent to the Aquifer and rely on it for their drinking water. This map depicts the numerous water districts and public drinking water wells drawing water from the Aquifer.

Ice Age

Between about 10,000 and 1.6 million years ago, during the Pleistocene Epoch (or Ice Age), the Earth's climate underwent periods of alternate cooling and warming. During the periods of cooling, with an average annual temperature probably between 5 and 10 degrees Fahrenheit cooler than present, vast continental ice sheets grew in size and extended far beyond the polar regions. In addition, alpine glaciers developed locally in the higher mountains. In southern Canada, the ice sheets periodically thickened and advanced southward, some reaching the northern parts of the United States before retreating and melting back to the north as the climate again became warmer. Evidence indicates that at least four, and perhaps six or more, major glaciations affected the Spokane–Coeur d'Alene area. The last of these occurred between 10,000 and 22,000 years ago and had the most significant effect on the present landscape. The map on the back cover provides a representation of the Pacific Northwest during this most recent part of the Ice Age.

The Cordilleran Ice Sheet was that part of the southward-moving continental ice mass that covered much of the Rocky Mountains in Canada and eventually extended into the northern part of the United States. In western Washington State, it covered parts of the northern Cascade Range and the northern margins of the Olympic Mountains. A thick ice lobe (a separate tongue of the glacier mass) extended down the Puget lowland. In eastern Washington, ice lobes extended down the principal valleys and onto the margins of the Columbia Plateau. During the last Ice Age, the advancing glaciers stopped short of the Spokane–Coeur d'Alene area. Meltwater streams draining these lobes carried large quantities of sand, gravel, silt, and clay and deposited them in and along the lower valleys. The deeply entrenched Spokane Valley was partially filled with these glacial materials.

Eventually, the Purcell ice lobe moved into the valley of the north-flowing Clark Fork River near Sandpoint, Idaho and formed a massive ice dam across the valley. At the maximum glacial advance, the dam was between 2,150 and 2,500 feet high, about four times the height of Grand Coulee Dam. As a result, melt water from other ice lobes far up the Clark Fork River drainage became ponded behind the ice dam and eventually formed a vast lake, Glacial Lake Missoula, which occupied the intricate system of valleys in western Montana.

At its highest level, the lake covered an area of about 2,900 square miles and contained an estimated 500 cubic miles of water, one-half of the volume of present-day Lake Michigan. Traces of the ancient shorelines of Glacial Lake Missoula in western Montana indicate that, at its maximum elevation, the lake was about 950 feet deep at present-day Missoula and more than 1,100 feet deep at the south end of Flathead Lake. The lake's wave-cut shorelines are faint, however, suggesting that the lake kept changing.

At the same time, other lakes were formed by the melt water from local mountain glaciers and snow fields elsewhere in the valleys and basins of the Northwest interior. The back cover depicts the Pacific Northwest during the last Ice Age. The location and likely extent of Glacial Lake Missoula and Glacial Lake Columbia are shown on this map.

Ultimately, as the water deepened behind the ice dam, the glacial lobe floated off its foundation, allowing the water in Glacial Lake Missoula to escape in an enormous "outburst" flood. The flood wave swept down the Rathdrum Prairie, through the Spokane Valley and eventually flowed across the Columbia plateau through a braided series of channels as shown on the image on this page. This flood initially eroded, then deposited sediments in the Rathdrum Prairie and Spokane Valley. The flood also created the coulees and pothole topography called the "Channeled Scablands" in eastern Washington. In 1923 J. Harlan Bretz was the first scientist to recognize the flood origin of the Channeled Scablands. He called them the Spokane Floods because he was unaware of the origin of flood. Joseph T. Pardee discovered the origins of the floods and published the evidence in 1942.

Glacial Lake Missoula Facts

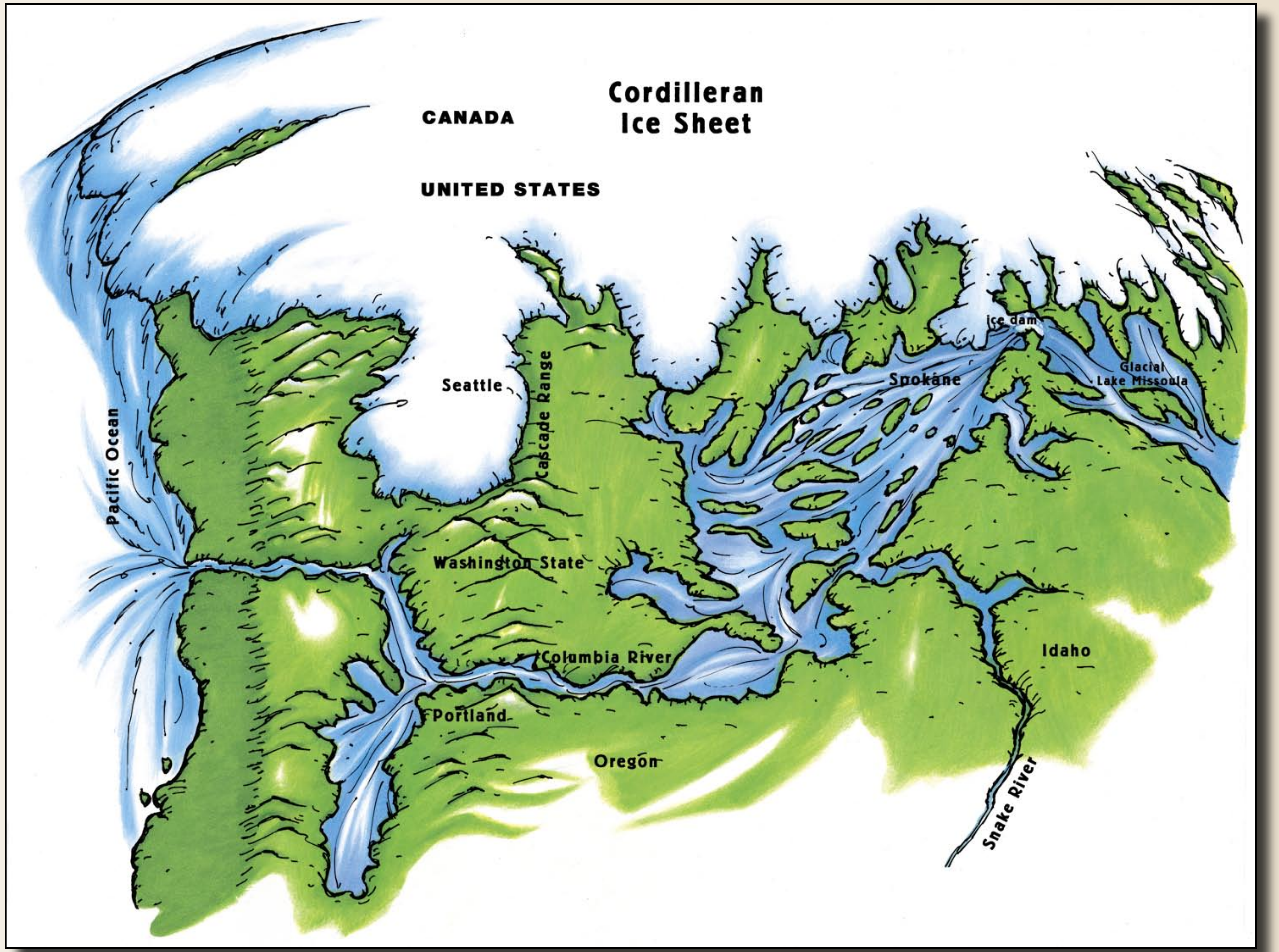
The ice dam that created the lake was between 2,150 and 2,500 feet high.

At its greatest extent, the lake covered more than 2,900 square miles, an area greater than the state of Delaware.

The lake contained about 500 cubic miles of water, about one half the volume of present Lake Michigan.

At its full extent, the lake was 950 feet deep at present day Missoula, Montana.

After most flood events, the ice dam was reformed allowing Glacial Lake Missoula to refill.



The rapid draining of 500 cubic-mile Glacial Lake Missoula, probably in only a few days, resulted in a maximum discharge across the Columbia Plateau 10 times the combined flow of all the rivers of the world today. The floodwaters of the lake rapidly shot south-westward down the length of the present sites of Pend Oreille and Coeur d'Alene Lakes and the Rathdrum Prairie - Spokane Valley area and out across the Columbia Plateau and beyond. Attaining speeds estimated to be as great as 45 miles per hour, the water swept across the Columbia Plateau, through the Pasco and Umatilla Basins, down the Columbia River Gorge, and eventually into the Pacific Ocean beyond the Coast Range. The floods occured repeatedly at least 40 times.

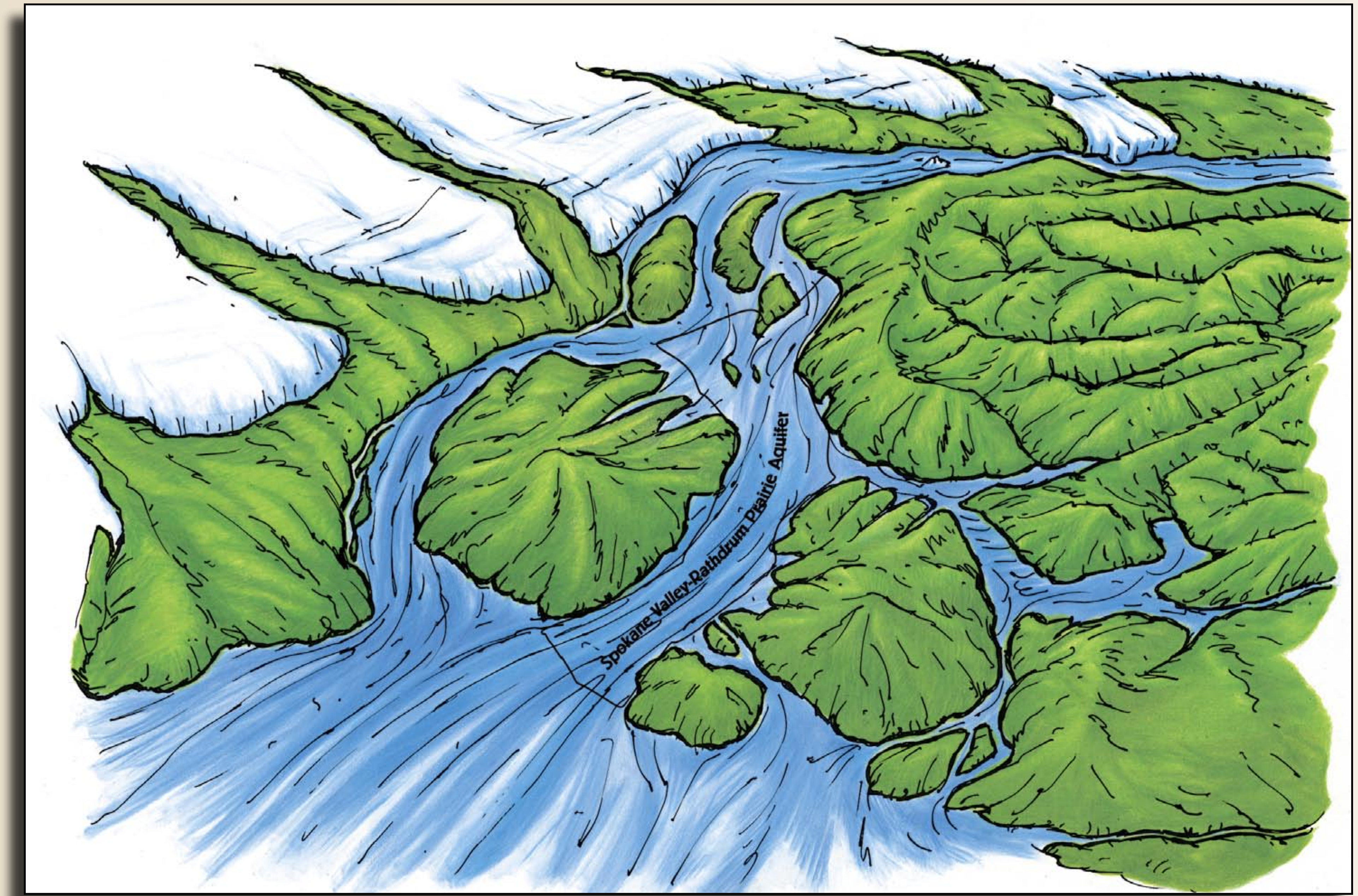
The most prominent testimony to the cutting power of the floodwaters is observed clearly today in the numerous coulees carved into the basalt surface of the Columbia Plateau, forming an area of unique topographic relief known as the Channeled Scablands. Other features that indicate the magnitude of the flood event and the amount of rock debris carried and dumped along the flood's pathway include giant current ripples and gravel bars. Some gravel bars are more than 50 feet high and 500 feet between crests, and they are found today along much of the flood's course, from the valleys of western Montana to the lowlands along the Columbia River beyond the Cascade Range. Along its journey to the ocean, at various reaches where the river valley narrows, the floodwater was impounded temporarily by restrictions and formed several large temporary lakes.

In passing through the Rathdrum Prairie-Spokane Valley area, the floodwaters carried large volumes of rock debris in the masses of ice broken from the glacier's terminus, which included large boulders that came from the mountains farther north. The flood carried great quantities of sediment of all sizes, from clay particles to large cobbles and boulders, picked up from the flood channels. The heavier, large materials, such as boulders, cobbles, and coarse gravel, dropped out of the water first. These coarse materials were deposited along the main valley in the line of greatest flow and velocity; much of this sediment was deposited on top of the previously accumulated normal glacial outwash silts, sands, and gravels. Some of the smaller particles in these earlier outwash materials were washed out and carried in suspension; then eventually either deposited in side eddy valleys, such as the Hillyard Trough, or carried out onto the Columbia Plateau and beyond. The coarse materials today underlie the Rathdrum Prairie-Spokane Valley lowland. Some isolated localities contain boulders as much as 8 or 10 feet across.

The subsidence of the floodwaters following the final emptying of Glacial Lake Missoula was followed by a gradual northward retreat of the Cordilleran Ice Sheet, and, eventually, during recent time, the region acquired its present aspect and drainage system. After the disappearance of the ice from the Pend Oreille Valley, the Clark Fork River drained through Pend Oreille Lake and then west and north to the Columbia River. To the east, the Coeur d'Alene, St. Joe, and St. Maries Rivers drained to Coeur d'Alene Lake, the source of the Spokane River. The broad, flat, gravel filled flood pathway between Lake Pend Oreille and the Spokane Valley became virtually devoid of a surface drainage system, with streams from side valleys flowing only short distances before sinking into the coarse materials. The Spokane River resumed its course westward to Spokane; then, instead of flowing north through the Hillyard Trough, which now had a higher surface created by flood deposits, the river followed a new, lower course along the margin of the Columbia Plateau lava to its confluence with the Columbia River.

A few small lakes were created in the lower parts of tributary mountain valleys. These lakes are held in their basins by the finer-grained deposits laid down along the edges of the valley where flood velocities were low. They include Spirit, Twin, Hauser, and Newman Lakes on the lower east and south flanks of the Spokane Mountain area, Hayden Lake at the base of the Coeur d'Alene Mountains, and Liberty Lake below Mica Peak. Discharges from the lakes percolate rapidly into the main valley gravels, and only a few short stream channels exist.

As the climate became warmer, vegetation developed over the area. Eventually coniferous forests covered parts of the adjacent uplands and mountains, and cottonwoods and other deciduous trees, along with small groups of conifers, lined the river channel. The valley floor and nearby slopes became covered by grasses and other small plants. This was the Spokane Valley–Rathdrum Prairie area as inhabited by Native Americans when first visited by the early white explorers, fur trappers, and traders (see page 3).



Ice Age Flood Facts

Most of Lake Missoula, about 500 cubic miles, drained in a few days.

The maximum flood discharge was estimated as ten times the combined flow of all the rivers in the world today.

The floods occurred at least 40 times.

The flood velocity over the Columbia Plateau is estimated at 45 miles per hour.

The flood carried boulders as large as 8 to 10 feet across to the Spokane Valley – Rathdrum Prairie region.

Geology

The Spokane Valley-Rathdrum Prairie Aquifer area contains richly varied and interesting geology. The geologic history of this area includes ancient mountain building, spectacular basalt lava flows, and some of the largest known glacial outburst floods. The map on the opposite page provides a visual description of the surface geology of the Aquifer area.

Throughout the Idaho Panhandle and the mountains around the Spokane Valley of Washington, the Belt Formations of Proterozoic sedimentary rocks dominate the geologic landscape. These rock formations were named after the Belt Mountains of central Montana, where they were first studied. The Belt Formations of Idaho and Washington consist mostly of mudstones and sandstones in somber shades of gray and brown, along with some pale gray limestone. Ripple marks are preserved in many of the mudstone and sandstone layers of the Belt Formation rocks, indicating these rocks were likely deposited in a shallow marine environment. Throughout northern Idaho the Belt Formations contain intruded layers (or sills) composed of diabase, a black igneous rock with the composition of ordinary basalt. These sills were formed as molten magma squirts between layers of sedimentary Belt rock forming a layer of igneous rock. The Precambrian Belt Formation also contains metal minerals (of silver, lead, and gold) in hydrothermal vein deposits, a valuable resource for the region. The placement of these valuable mineral deposits is associated with the mountain building continental plate collisions that created the Rocky Mountains.

Spokane and Coeur d'Alene are situated on the eastern edge of the Columbia Plateau. Many of the largest lava flows in the Columbia Plateau erupted about 135 miles southwest of the Aquifer. Extraordinarily fluid lava flows extended northward past the present location of Spokane and into Idaho. The remnants of these flows are found in and around the Spokane Valley. Basalt is a dense dark rock with very fine crystals, and it sometimes has a unique hexagonal (six-sided) column-like appearance. The Columbia basalts in the Spokane-Rathdrum valley were eroded prior to the formation of the Aquifer, and now only the western portion of the Aquifer lies on Columbia basalts.

This cross section of a local gravel pit illustrates the ice age flood episodes that deposited various layers of sands, gravels and cobbles, which presently comprise and contain the Aquifer water.

Geologic Time

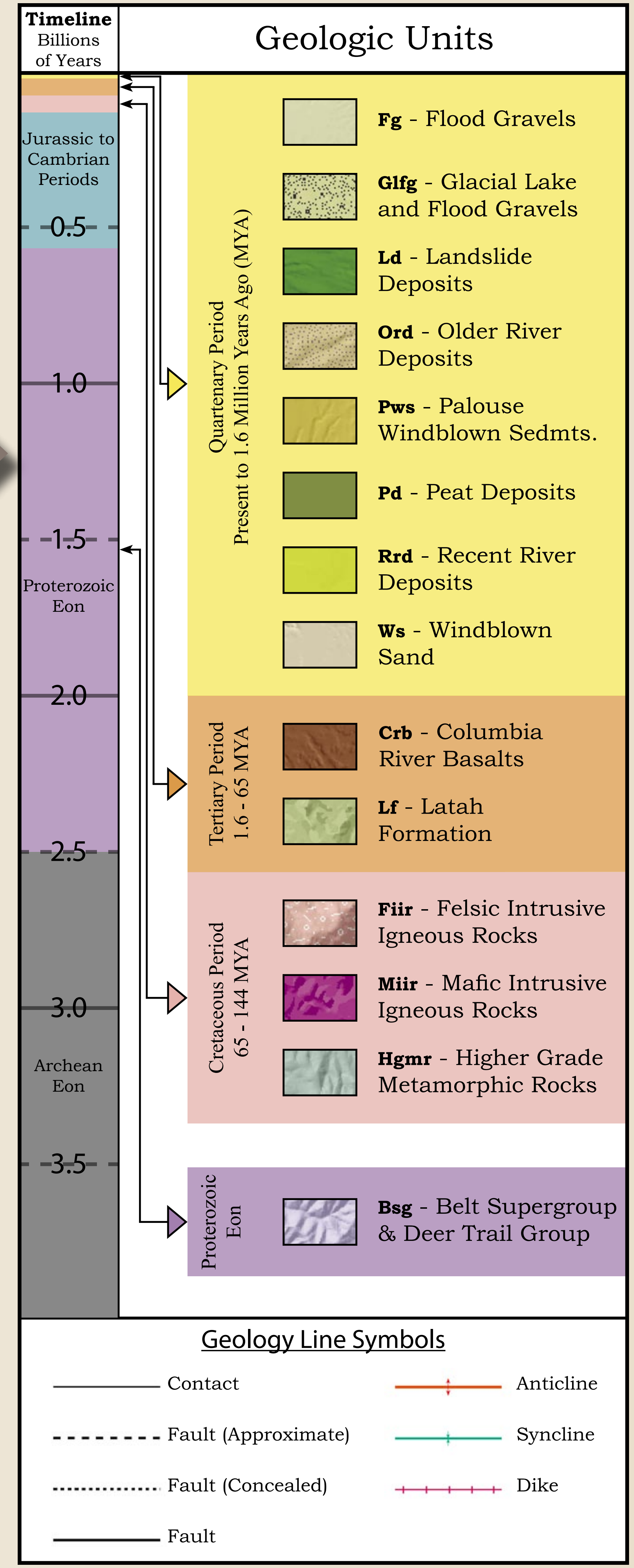
Geologists use the geologic time scale to place events in geologic history. This time scale was developed through age dating and fossil correlation. Geologic time is organized into two "Eons" and numerous "Periods," as shown on the Geologic Unit key on this page. Three major geologic events define the creation of the Spokane Valley-Rathdrum Prairie Aquifer. The first event was the emplacement, metamorphism, and erosion of the Precambrian basement rock (Proterozoic Eon); the second event was the eruption of Tertiary (Miocene) flood basalts that created the Columbia Plateau; and, the third event was the glaciation in the Quaternary Period that first eroded, then filled the Spokane Valley-Rathdrum Prairie area with coarse sediments and gravel to create the Aquifer.

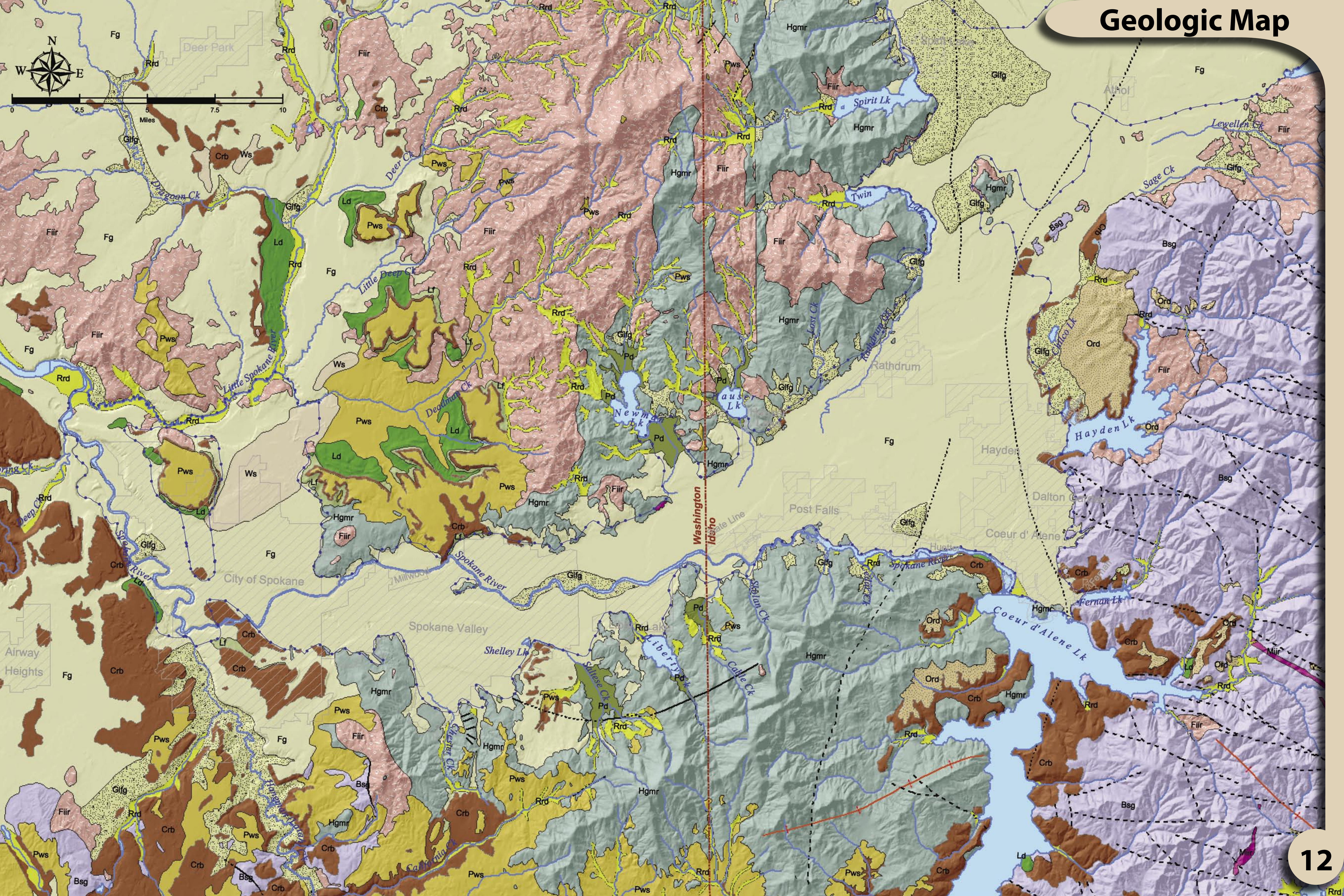
Recent Glaciation

Much of the geologic landscape we have inherited today in the northern Rocky Mountains was finally sculpted by processes related to glaciation. Four major glacial advances and recessions occurred in the last 1.6 million years of Earth history. The most recent of these Ice Age episodes climaxed about 15,000 years ago and ended about 10,000 years before present, leaving behind an eroded and modified landscape covered by various sedimentary deposits. Many of these relatively young and unconsolidated deposits cover the bedrock in the local area and show up on the Geologic Map on the adjacent page.

Large glaciers advanced as far south as Sandpoint in Idaho, and to near Deer Park in Washington. There is no evidence of glacial ice entering the Rathdrum Prairie or the Spokane Valley (see Back Cover) during the last Ice Age. The close proximity of these glaciers allowed sediments to be deposited that provide an important framework for the Aquifer we have today. Enormous outburst floods (see Ice Age Floods, page 10) were the primary agent for the distribution and deposition of coarse sands and gravels that eventually filled the Rathdrum Prairie and Spokane Valley. Also, blustery winds moving southward off of earlier glaciers picked up some of the finer-grained silt-sized sediments and distributed them across eastern Washington in the form of the rolling and fertile Palouse hills. In addition, the erosive action of the energetic glacial floods caused some steep slopes to be undermined, allowing large landslides to slip off of unsupported hill sides, particularly in the area north of Spokane.

Since the last Ice Age, subsequent on-going river erosion has caused the Spokane River to entrench into the glacial flood deposits and leave small terraces adjacent to the present day river course. A visit to the Spokane River in the valley shows the large boulders transported and deposited by the Ice Age floods, now exposed in the ancient benches along the modern stream.




N
W
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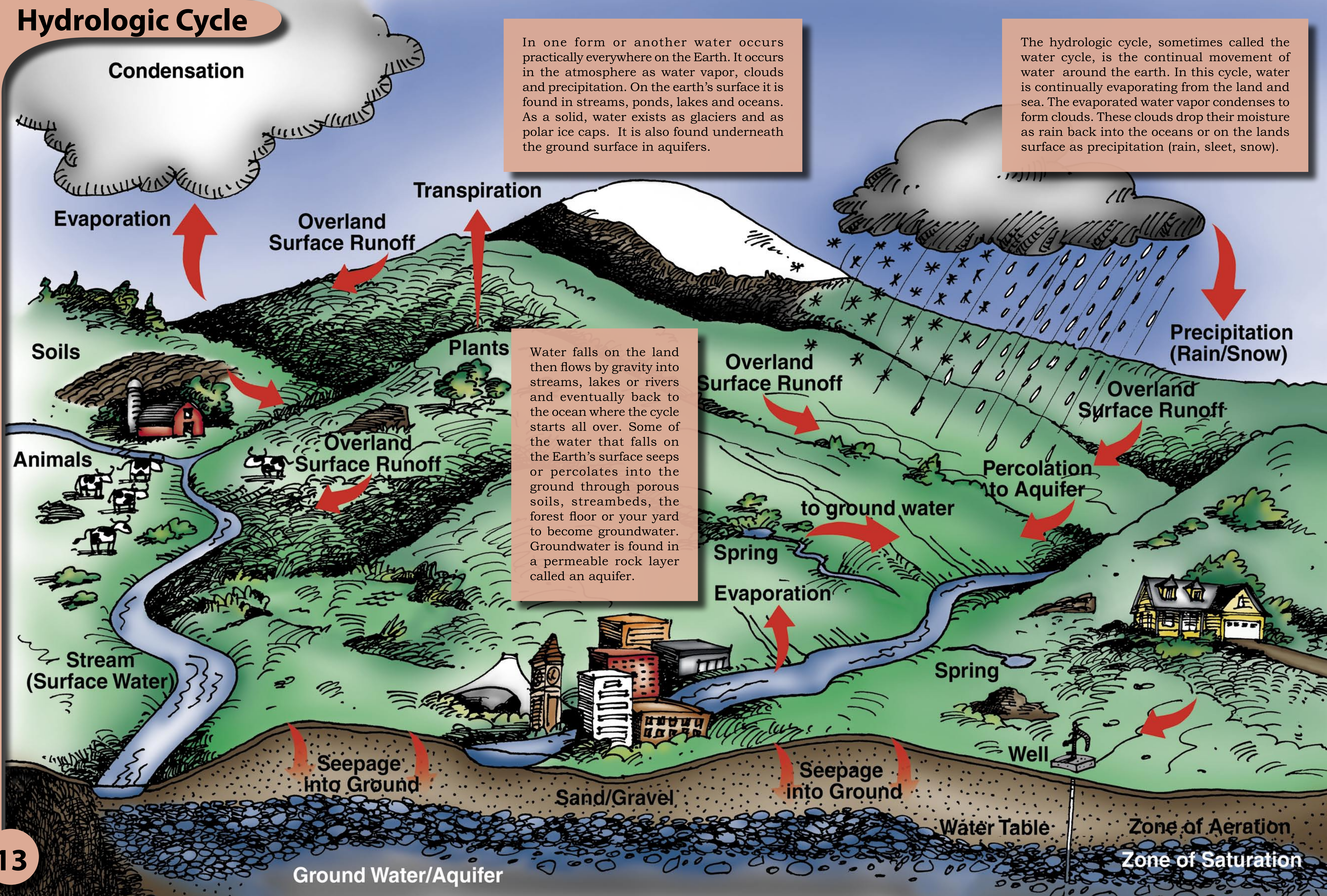
10
Miles
Deer Park
Spirit Lk
Athol
Lewellen Ck
Sage Ck
Twin Lakes
Dragoon Ck
Deer Ck
Little Deep Ck
Little Spokane River
Deadman Ck
Newman Lk
Hauser Lk
Lost Ck
Rathdrum Ck
Rathdrum
Chilco Lk
Hayden Lk
Hayden
Dalton Gardens
Coeur d' Alene
Post Falls
Washington
Idaho
State Line
Spring Ck
Deep Ck
Spokane River
City of Spokane
Millwood
Spokane Valley
Shelley Lk
Liberty Lk
Saltese Ck
Chester Ck
Hangman Ck
California Ck
Airway Heights
Huetter
Fernan Lk
Coeur d'Alene Lk
Fg
Rrd
Fiir
Crb
Ws
Glfg
Ld
Pws
Lf
Hgmr
Pd
Bsg
Ord
Miir

Hydrologic Cycle

In one form or another water occurs practically everywhere on the Earth. It occurs in the atmosphere as water vapor, clouds and precipitation. On the earth's surface it is found in streams, ponds, lakes and oceans. As a solid, water exists as glaciers and as polar ice caps. It is also found underneath the ground surface in aquifers.

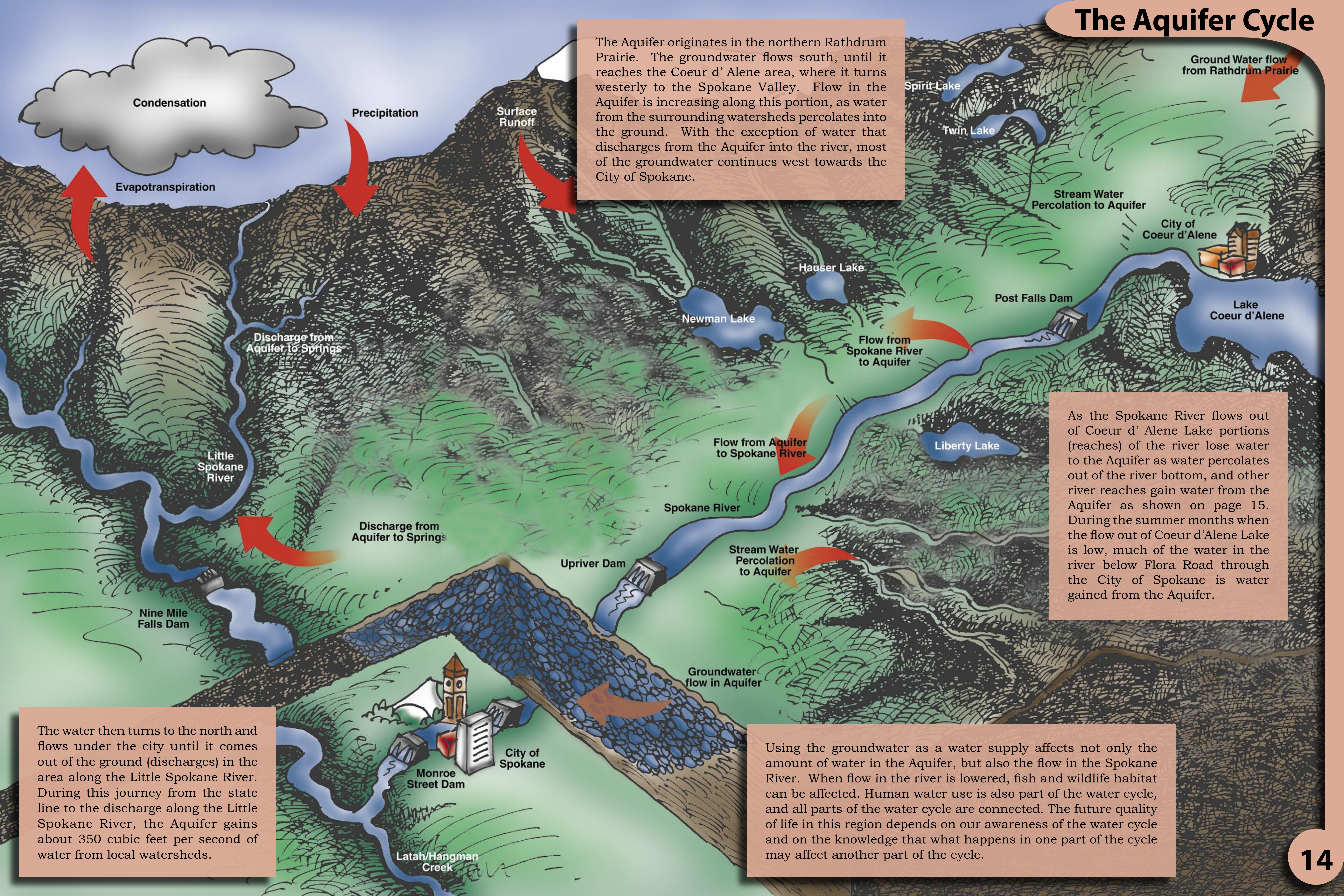
The hydrologic cycle, sometimes called the water cycle, is the continual movement of water around the earth. In this cycle, water is continually evaporating from the land and sea. The evaporated water vapor condenses to form clouds. These clouds drop their moisture as rain back into the oceans or on the lands surface as precipitation (rain, sleet, snow).

Water falls on the land then flows by gravity into streams, lakes or rivers and eventually back to the ocean where the cycle starts all over. Some of the water that falls on the Earth's surface seeps or percolates into the ground through porous soils, streambeds, the forest floor or your yard to become groundwater. Groundwater is found in a permeable rock layer called an aquifer.



The Aquifer Cycle

The Aquifer originates in the northern Rathdrum Prairie. The groundwater flows south, until it reaches the Coeur d' Alene area, where it turns westerly to the Spokane Valley. Flow in the Aquifer is increasing along this portion, as water from the surrounding watersheds percolates into the ground. With the exception of water that discharges from the Aquifer into the river, most of the groundwater continues west towards the City of Spokane.



As the Spokane River flows out of Coeur d' Alene Lake portions (reaches) of the river lose water to the Aquifer as water percolates out of the river bottom, and other river reaches gain water from the Aquifer as shown on page 15. During the summer months when the flow out of Coeur d'Alene Lake is low, much of the water in the river below Flora Road through the City of Spokane is water gained from the Aquifer.

The water then turns to the north and flows under the city until it comes out of the ground (discharges) in the area along the Little Spokane River. During this journey from the state line to the discharge along the Little Spokane River, the Aquifer gains about 350 cubic feet per second of water from local watersheds.

Using the groundwater as a water supply affects not only the amount of water in the Aquifer, but also the flow in the Spokane River. When flow in the river is lowered, fish and wildlife habitat can be affected. Human water use is also part of the water cycle, and all parts of the water cycle are connected. The future quality of life in this region depends on our awareness of the water cycle and on the knowledge that what happens in one part of the cycle may affect another part of the cycle.

Aquifer-River Interchange

A strong relationship between the Aquifer and the Spokane River is present throughout the river's length, from Lake Coeur d'Alene to the confluence with the Little Spokane River. Although the Aquifer-River interchange is complex, studies of the river have identified four types of interaction: gaining, losing, transitional and minimal.

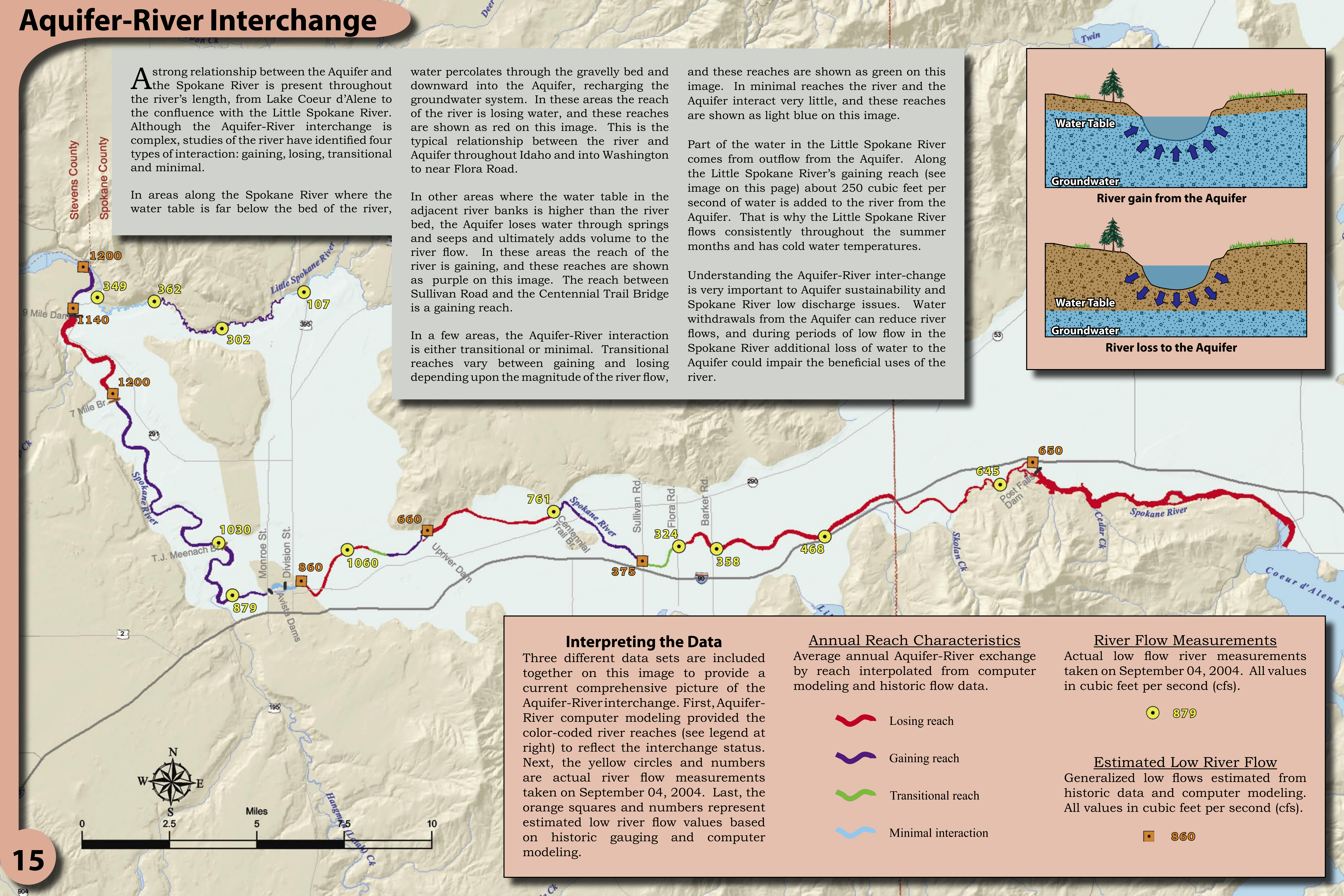
In areas along the Spokane River where the water table is far below the bed of the river, water percolates through the gravelly bed and downward into the Aquifer, recharging the groundwater system. In these areas the reach of the river is losing water, and these reaches are shown as red on this image. This is the typical relationship between the river and Aquifer throughout Idaho and into Washington to near Flora Road.

In other areas where the water table in the adjacent river banks is higher than the river bed, the Aquifer loses water through springs and seeps and ultimately adds volume to the river flow. In these areas the reach of the river is gaining, and these reaches are shown as purple on this image. The reach between Sullivan Road and the Centennial Trail Bridge is a gaining reach.

In a few areas, the Aquifer-River interaction is either transitional or minimal. Transitional reaches vary between gaining and losing depending upon the magnitude of the river flow, and these reaches are shown as green on this image. In minimal reaches the river and the Aquifer interact very little, and these reaches are shown as light blue on this image.

Part of the water in the Little Spokane River comes from outflow from the Aquifer. Along the Little Spokane River's gaining reach (see image on this page) about 250 cubic feet per second of water is added to the river from the Aquifer. That is why the Little Spokane River flows consistently throughout the summer months and has cold water temperatures.

Understanding the Aquifer-River inter-change is very important to Aquifer sustainability and Spokane River low discharge issues. Water withdrawals from the Aquifer can reduce river flows, and during periods of low flow in the Spokane River additional loss of water to the Aquifer could impair the beneficial uses of the river.



Interpreting the Data

Three different data sets are included together on this image to provide a current comprehensive picture of the Aquifer-River interchange. First, Aquifer-River computer modeling provided the color-coded river reaches (see legend at right) to reflect the interchange status. Next, the yellow circles and numbers are actual river flow measurements taken on September 04, 2004. Last, the orange squares and numbers represent estimated low river flow values based on historic gauging and computer modeling.

Annual Reach Characteristics

Average annual Aquifer-River exchange by reach interpolated from computer modeling and historic flow data.

- Losing reach
- Gaining reach
- Transitional reach
- Minimal interaction

River Flow Measurements

Actual low flow river measurements taken on September 04, 2004. All values in cubic feet per second (cfs).

879

Estimated Low River Flow

Generalized low flows estimated from historic data and computer modeling. All values in cubic feet per second (cfs).

860

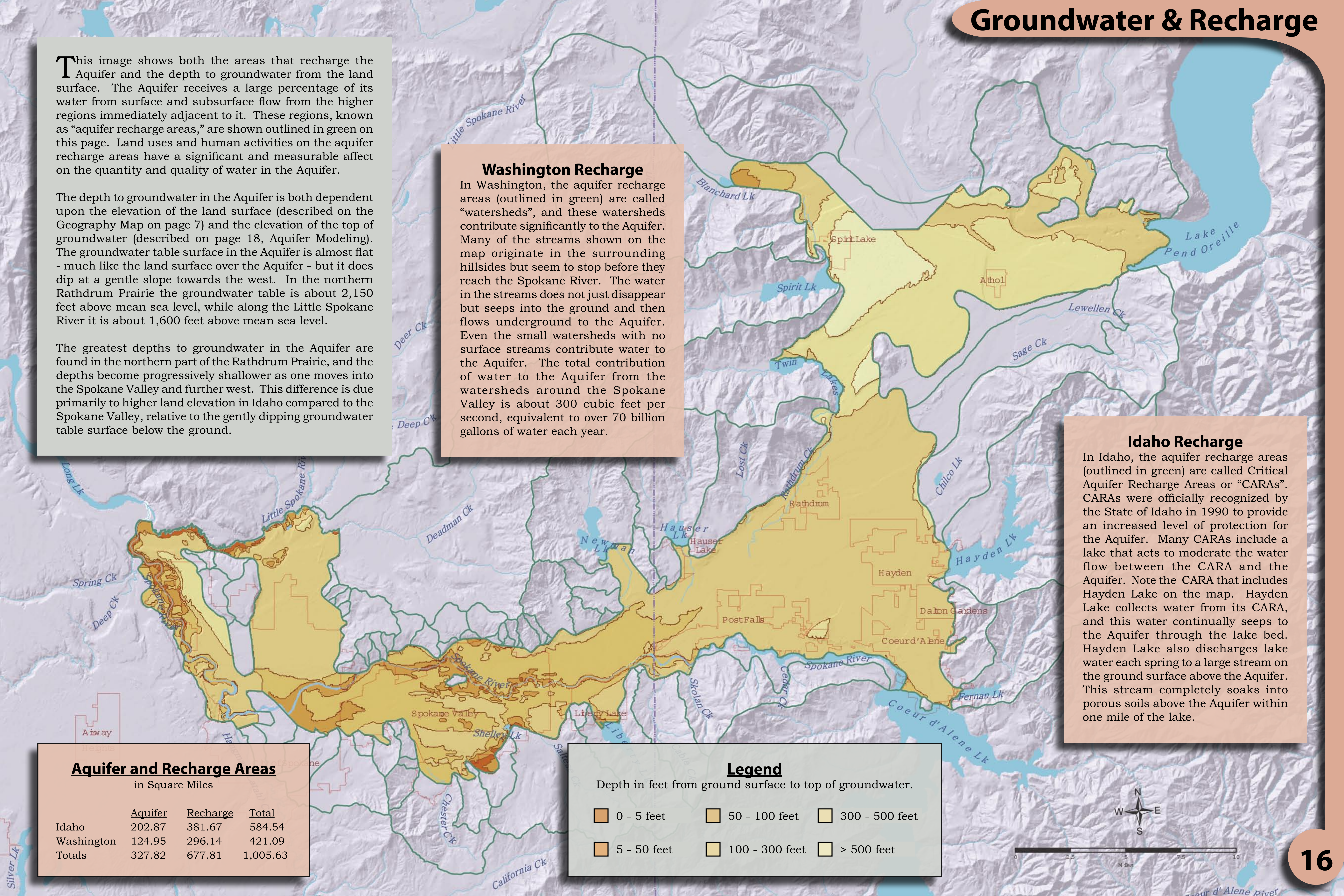
This image shows both the areas that recharge the Aquifer and the depth to groundwater from the land surface. The Aquifer receives a large percentage of its water from surface and subsurface flow from the higher regions immediately adjacent to it. These regions, known as "aquifer recharge areas," are shown outlined in green on this page. Land uses and human activities on the aquifer recharge areas have a significant and measurable affect on the quantity and quality of water in the Aquifer.

The depth to groundwater in the Aquifer is both dependent upon the elevation of the land surface (described on the Geography Map on page 7) and the elevation of the top of groundwater (described on page 18, Aquifer Modeling). The groundwater table surface in the Aquifer is almost flat - much like the land surface over the Aquifer - but it does dip at a gentle slope towards the west. In the northern Rathdrum Prairie the groundwater table is about 2,150 feet above mean sea level, while along the Little Spokane River it is about 1,600 feet above mean sea level.

The greatest depths to groundwater in the Aquifer are found in the northern part of the Rathdrum Prairie, and the depths become progressively shallower as one moves into the Spokane Valley and further west. This difference is due primarily to higher land elevation in Idaho compared to the Spokane Valley, relative to the gently dipping groundwater table surface below the ground.

Washington Recharge

In Washington, the aquifer recharge areas (outlined in green) are called "watersheds", and these watersheds contribute significantly to the Aquifer. Many of the streams shown on the map originate in the surrounding hillsides but seem to stop before they reach the Spokane River. The water in the streams does not just disappear but seeps into the ground and then flows underground to the Aquifer. Even the small watersheds with no surface streams contribute water to the Aquifer. The total contribution of water to the Aquifer from the watersheds around the Spokane Valley is about 300 cubic feet per second, equivalent to over 70 billion gallons of water each year.



Idaho Recharge

In Idaho, the aquifer recharge areas (outlined in green) are called Critical Aquifer Recharge Areas or "CARAs". CARAs were officially recognized by the State of Idaho in 1990 to provide an increased level of protection for the Aquifer. Many CARAs include a lake that acts to moderate the water flow between the CARA and the Aquifer. Note the CARA that includes Hayden Lake on the map. Hayden Lake collects water from its CARA, and this water continually seeps to the Aquifer through the lake bed. Hayden Lake also discharges lake water each spring to a large stream on the ground surface above the Aquifer. This stream completely soaks into porous soils above the Aquifer within one mile of the lake.

Aquifer and Recharge Areas

in Square Miles

	Aquifer	Recharge	Total
Idaho	202.87	381.67	584.54
Washington	124.95	296.14	421.09
Totals	327.82	677.81	1,005.63

Legend

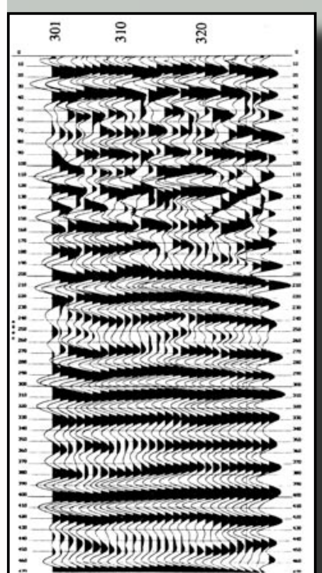
Depth in feet from ground surface to top of groundwater.

- 0 - 5 feet
- 5 - 50 feet
- 50 - 100 feet
- 100 - 300 feet
- 300 - 500 feet
- > 500 feet

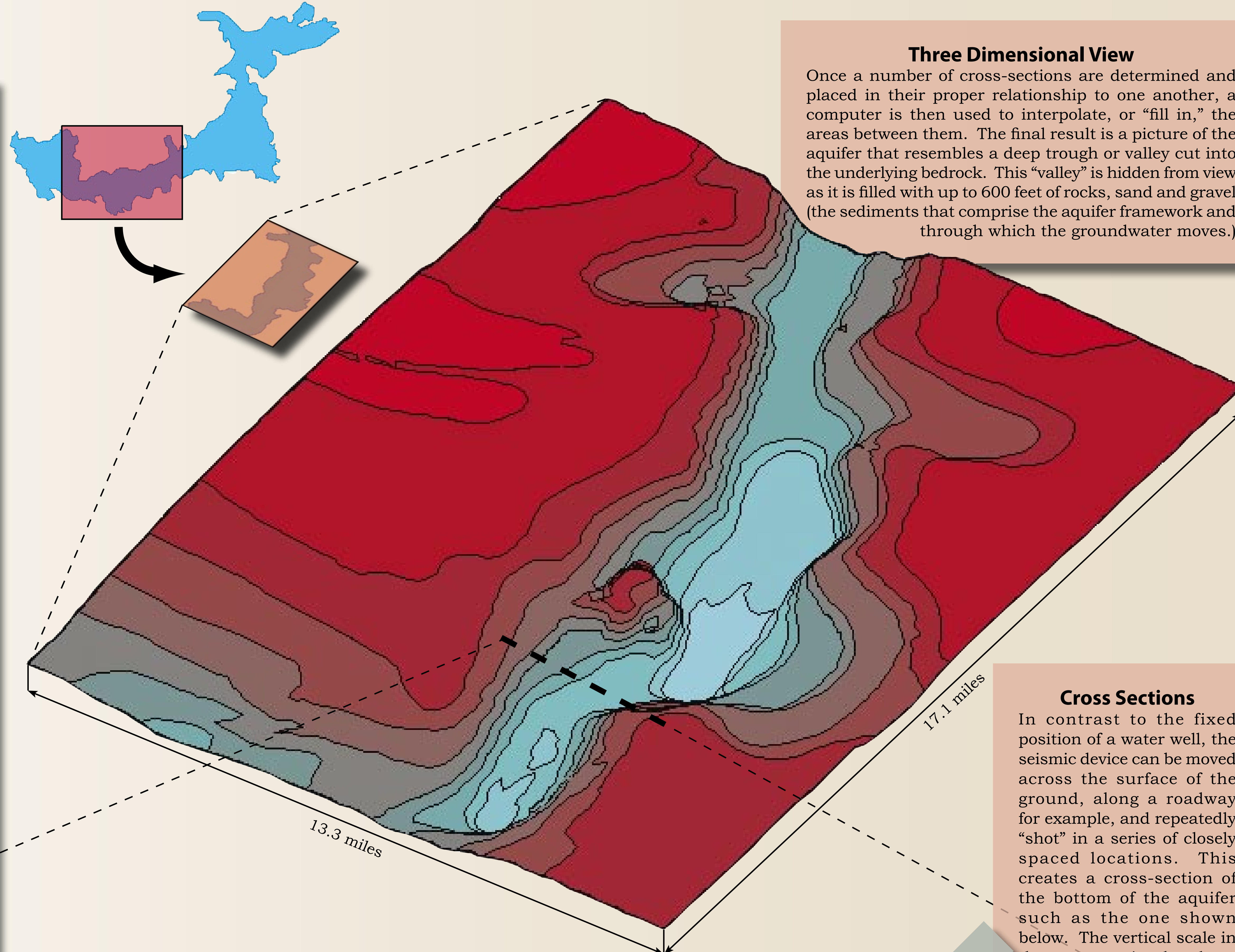
Exploring the Aquifer

Unlike a river where you can easily see the water flowing down the channel, it is difficult - if not impossible - to actually see the water moving beneath the ground in an aquifer. Therefore, geologists use a variety of tools to visualize the shape and extent of an aquifer, to map the groundwater table surface, and to better understand the flow of groundwater within this subterranean reservoir. These tools include something as simple as drilling a well into the ground to the high tech use of seismic energy.

Drilling a water well provides information at a single point in the aquifer, such as depth to the water table and maybe the thickness of the aquifer. It is also useful to periodically take water level measurements to see how the water table moves up and down with the seasonal changes in recharge and discharge of the aquifer. Water wells also provide a point where water samples can be taken for purposes of monitoring water quality through time. However, wells are very expensive to drill and provide information at only one point in the aquifer - they can't provide much information about the other parts of an aquifer system.



To visualize the shape of the aquifer across a larger area a SeisPulse™ device was used to map out the bottom of the Aquifer so that scientists could better determine the volume of water underground. This device uses seismic energy - actually sound waves created by small, contained explosions directed downward at the Earth - much like ultra-sound technology is used to look inside the human body. A geophone set nearby listens for the reflected return vibrations from deep underground. The geophone records the reflected sound waves on a chart (an example is shown at left). By knowing the velocity of sound in sand and gravel one can estimate the thickness of the aquifer by carefully measuring the time the sound energy takes to travel down and back.

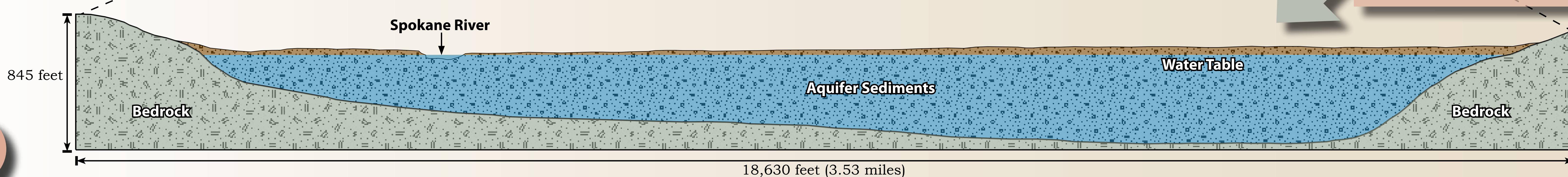


Three Dimensional View

Once a number of cross-sections are determined and placed in their proper relationship to one another, a computer is then used to interpolate, or "fill in," the areas between them. The final result is a picture of the aquifer that resembles a deep trough or valley cut into the underlying bedrock. This "valley" is hidden from view as it is filled with up to 600 feet of rocks, sand and gravel (the sediments that comprise the aquifer framework and through which the groundwater moves.)

Cross Sections

In contrast to the fixed position of a water well, the seismic device can be moved across the surface of the ground, along a roadway for example, and repeatedly "shot" in a series of closely spaced locations. This creates a cross-section of the bottom of the aquifer such as the one shown below. The vertical scale in the cross section has been exaggerated two times (2X).



Aquifer Computer Models

Since we can't directly see or measure the direction and rate of groundwater flow underground, hydrogeologists (scientists who study groundwater) use computer models to simulate this process. A computer model is a mathematical representation of the physical aspects of the Aquifer, such as its thickness, porosity, hydraulic conductivity (permeability), and other parameters. It is necessary to have good field data on a wide variety of aquifer properties in order to develop a good working model of an aquifer system.

Several groundwater flow models have been constructed for the Aquifer during the last 20 years. The U.S. Geological Survey, Eastern Washington University, and engineering consultants have all created models of the Aquifer for specific purposes. Models have been used to focus the research efforts on the Aquifer, to help determine the overall water budget of the system, to delineate wellhead capture zones for large municipal wells, to predict potential pathways that contaminants might follow, and to better understand the interaction between the Spokane River and the Aquifer. A new computer model is currently being developed as part of a study of the Aquifer.

An important application of models is prediction of contamination movement in the Aquifer. These models can identify wells that are down-gradient (downstream) from a contamination source. A model was constructed to track a trichloroethylene (TCE) contamination plume near Coeur d'Alene in the early 1990s. The model assisted local water managers in preventing harmful levels of TCE from entering the drinking water supply.

Computer models can be used to delineate capture zones around important water supply wells (see the text box below.) Capture zone information is useful in determining where appropriate land use activities should be located. Activities that include handling of hazardous and dangerous substances should not be located over the Aquifer in the capture zone for a large well.

Perhaps the most comprehensive use of flow models is estimating the Aquifer water budget. Since we depend on the Aquifer as our sole source of water, models can help us manage Aquifer water use wisely.

Computer Models Can . . .

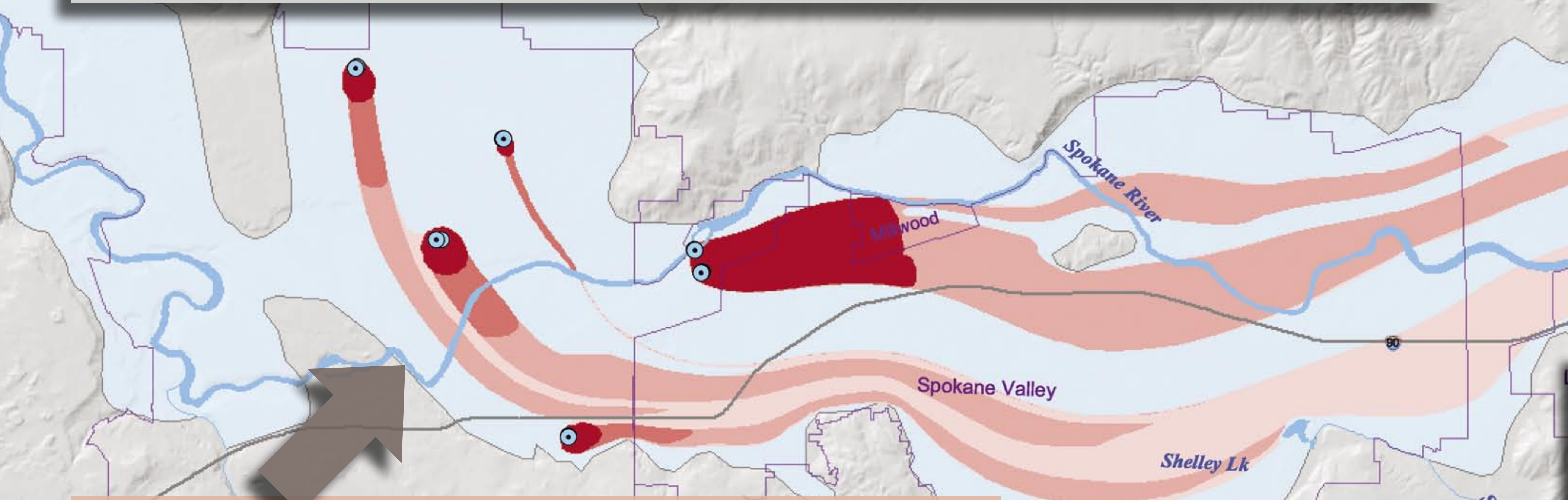
. . . predict the rate and direction of groundwater flow in the Aquifer.

. . . calculate a water budget (recharge and discharge) for the Aquifer.

. . . predict where contamination may travel in the Aquifer.

. . . define capture zones around important pumping wells.

. . . be a guide to future research needed for understanding the Aquifer.



Spokane Wells Capture Zone

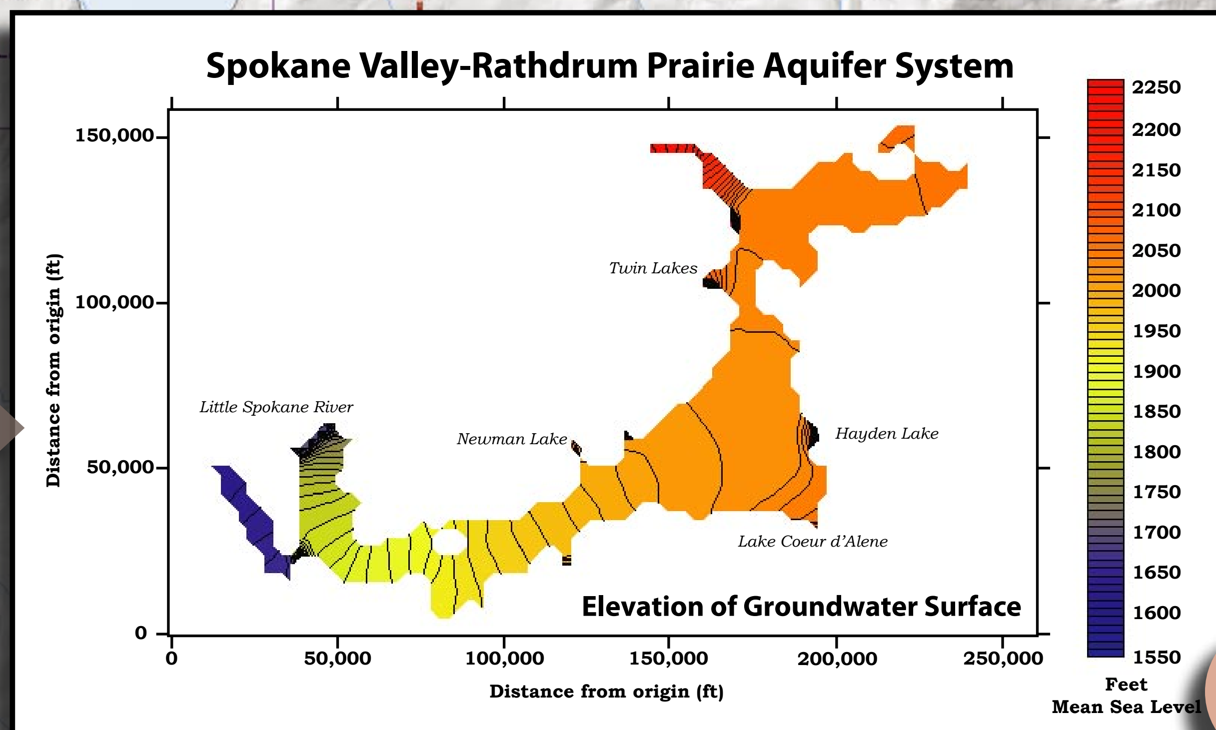
The main image on this page shows the computer model generated capture zones for the primary City of Spokane wells. A capture zone is the area of the Aquifer up-gradient (upstream) from the well that provides water to the well during a defined period of time (see legend at right.) The 10 year capture zones for some of these wells extend to the east 15 to 20 miles through the Spokane Valley and into Idaho.

Legend

- City of Spokane well
- Special Capture Zone
- 1 Year Capture Zone
- 5 Year Capture Zone
- 10 Year Capture Zone

Model Output

The image at right is an example of an Aquifer computer model output. This output shows water levels in the Aquifer as elevations above mean sea level.



Nitrate Concentrations

Legend

Colors represent nitrate levels in parts per million (ppm).

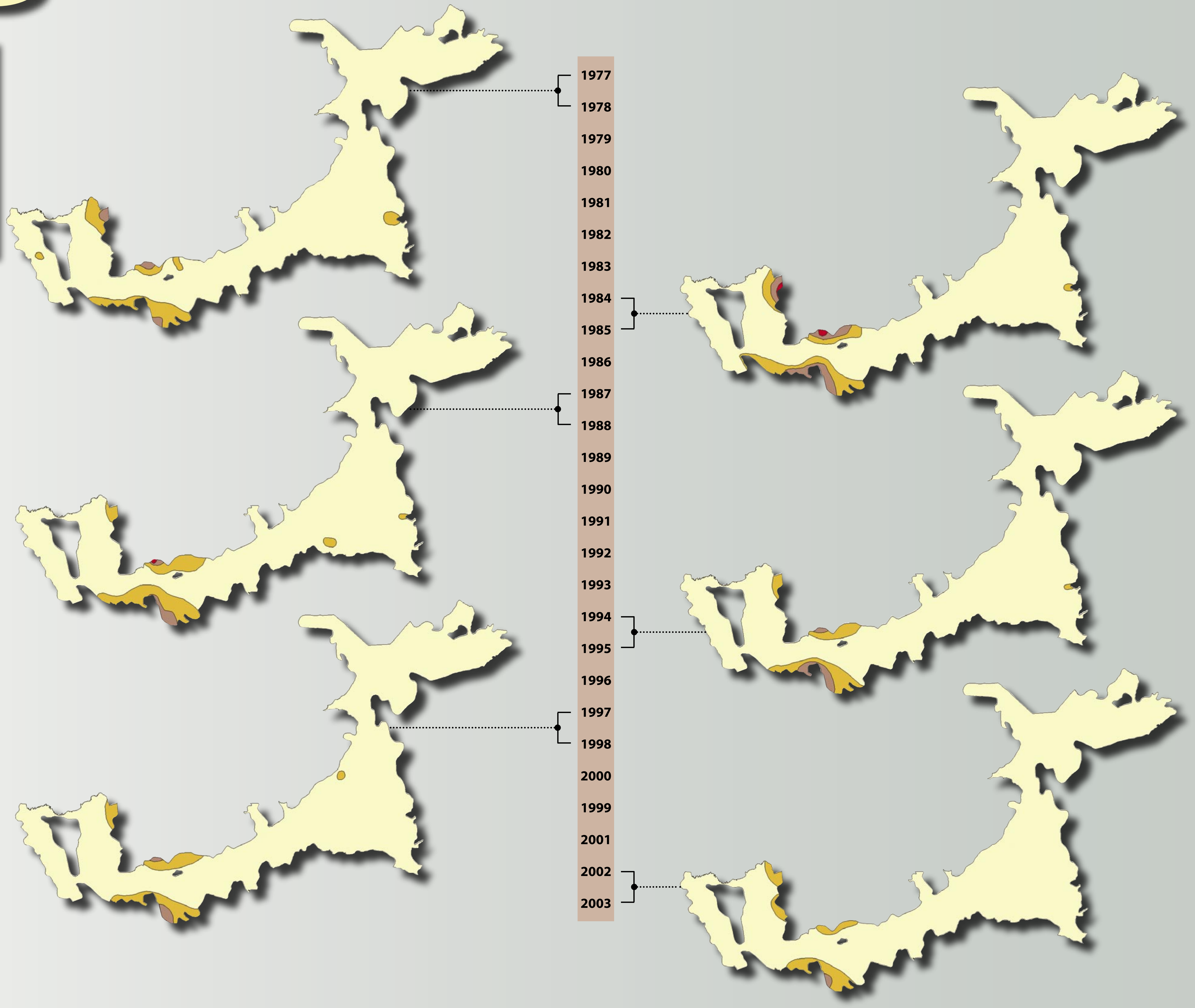
- 0 - 3 ppm
- 5 - 10 ppm
- 3 - 5 ppm
- > 10 ppm

The illustrations in this section show concentrations of nitrate in the Aquifer through time. Nitrate is a form of nitrogen that is highly stable under conditions commonly found in the topsoil and aquifer sediments. Under natural conditions, nitrate occurs in very low concentrations, typically less than 0.1 part per million (ppm). Sources of elevated nitrate levels in the Aquifer include septic systems, fertilizer and stormwater (see page 21).

The earliest nitrate concentration map is from 1977-78, which represents the earlier stages of Aquifer protection activities in Washington and Idaho. The peak of observed nitrate degradation in the entire Aquifer was 1984-85. In 1985 a major effort on both sides of the state line was initiated to reduce septic system contamination of the Aquifer through installation of piped sewer collection systems. On all the maps, certain areas near the edge of the Aquifer show high levels of nitrate. These locations represent "eddy" areas where incoming contaminants from side hill development are not easily or quickly mixed with the better quality water recharging from the east.

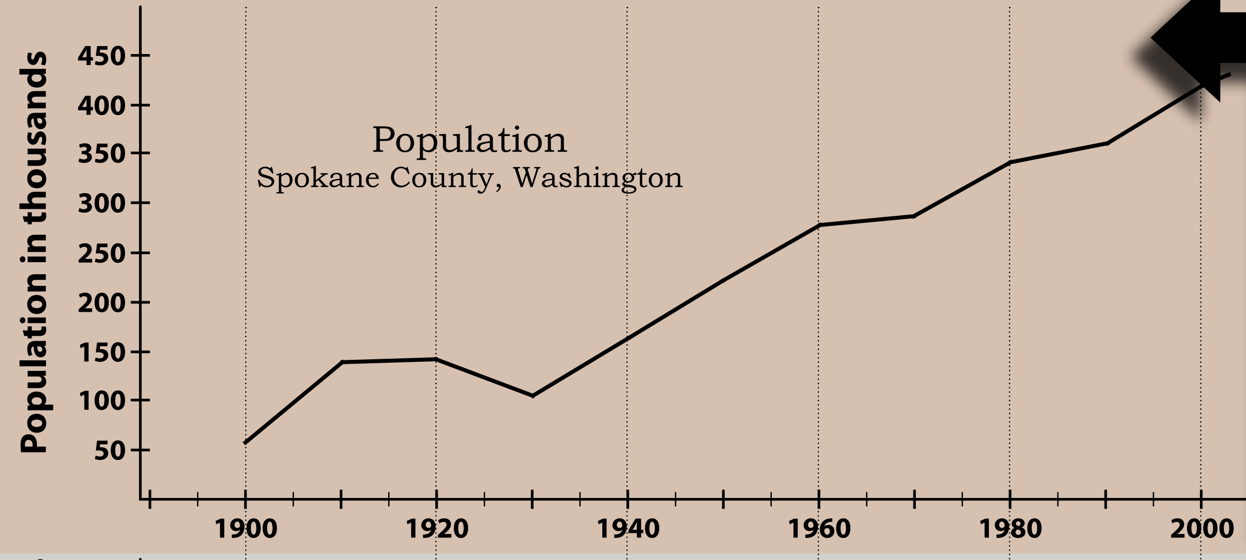
Nitrate in drinking water above 10 ppm may cause illness. Nitrate is one by-product of human activities, and the presence of high levels of nitrate in groundwater is an indicator that other harmful, but less easily detectable, by-products of human activity may also be present. As an indicator chemical, nitrate is often used as a measure of overall aquifer water quality.

The good news about nitrate and other contaminants in the Aquifer is that ongoing protection programs have decreased the rate of contamination. Current trend analysis shows nitrate concentrations are decreasing despite significant population increases. The groundwater in the Aquifer remains some of the best quality water available anywhere.



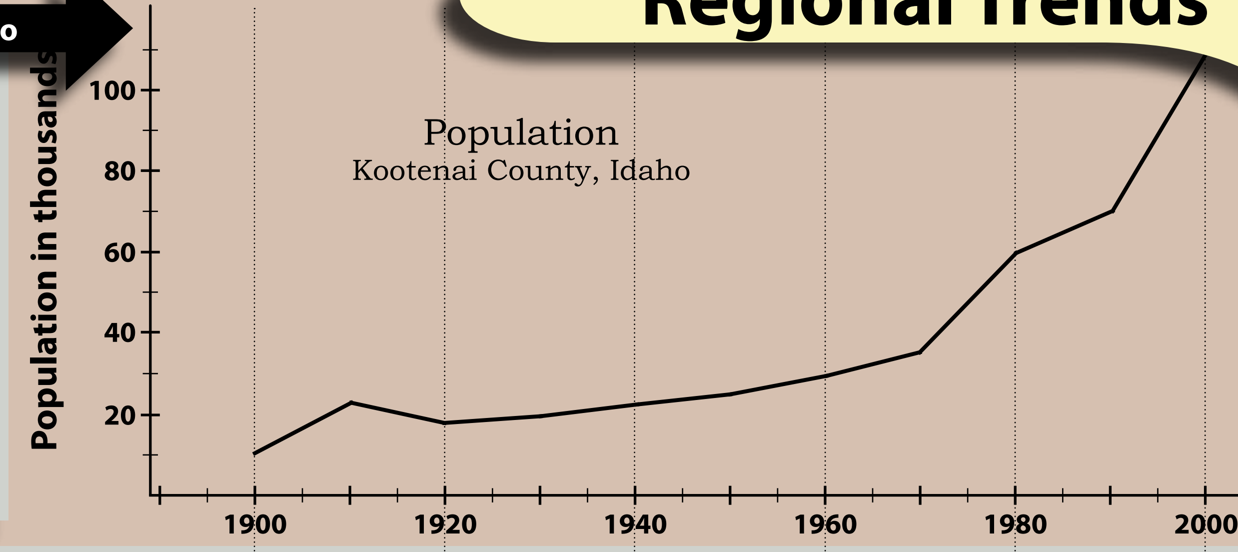
Washington

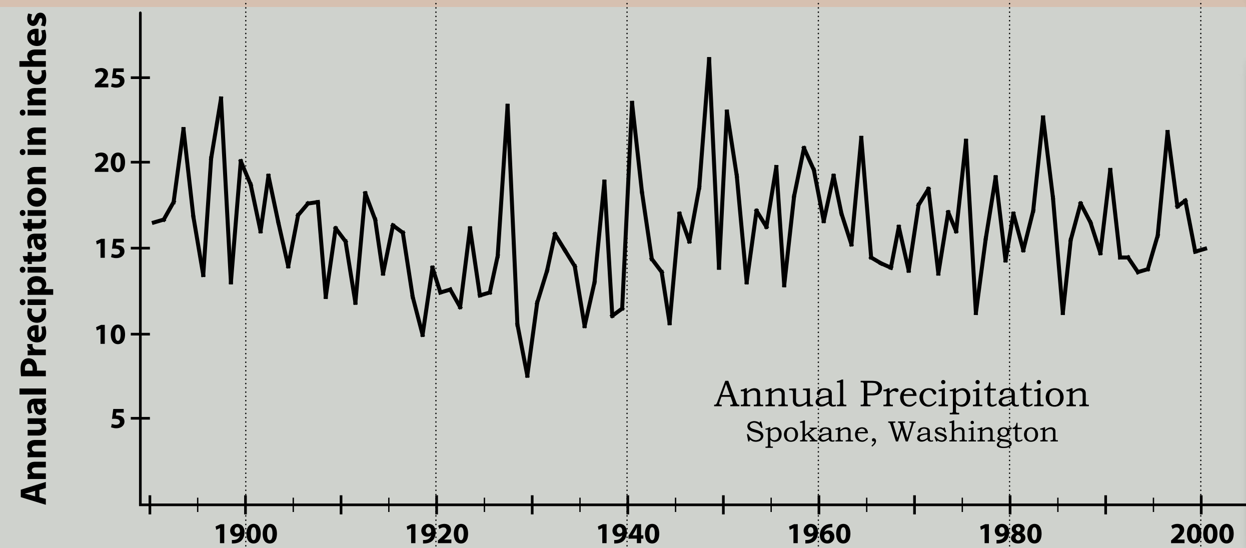
Idaho



Population

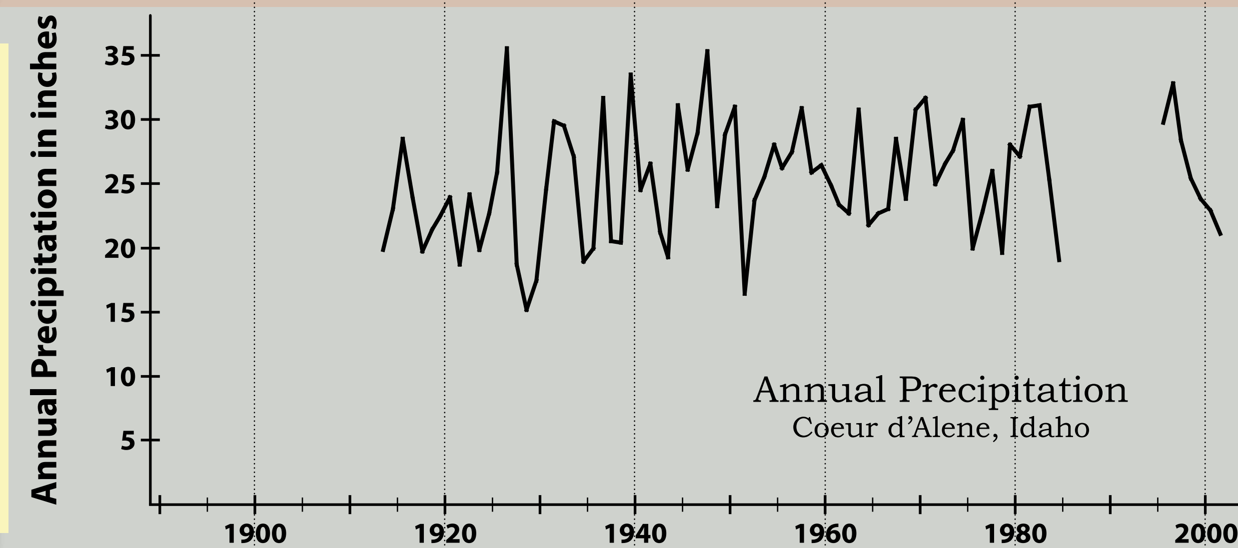
The region's population has grown in the past 100 years with the exception of a dip in 1920-1930. While the growth rate in Spokane County has remained stable since 1930, Kootenai County expereinced a sharp population increase in 1990. A growing population requires an increasing amount of potable water, and the demand for Aquifer water continues to grow.

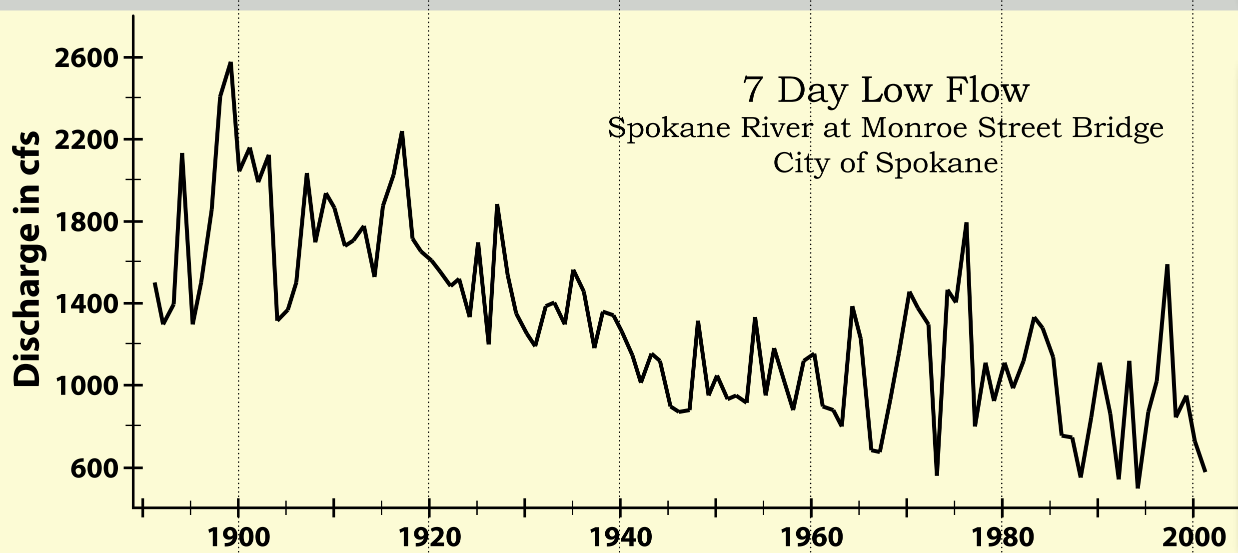




Annual Precipitation

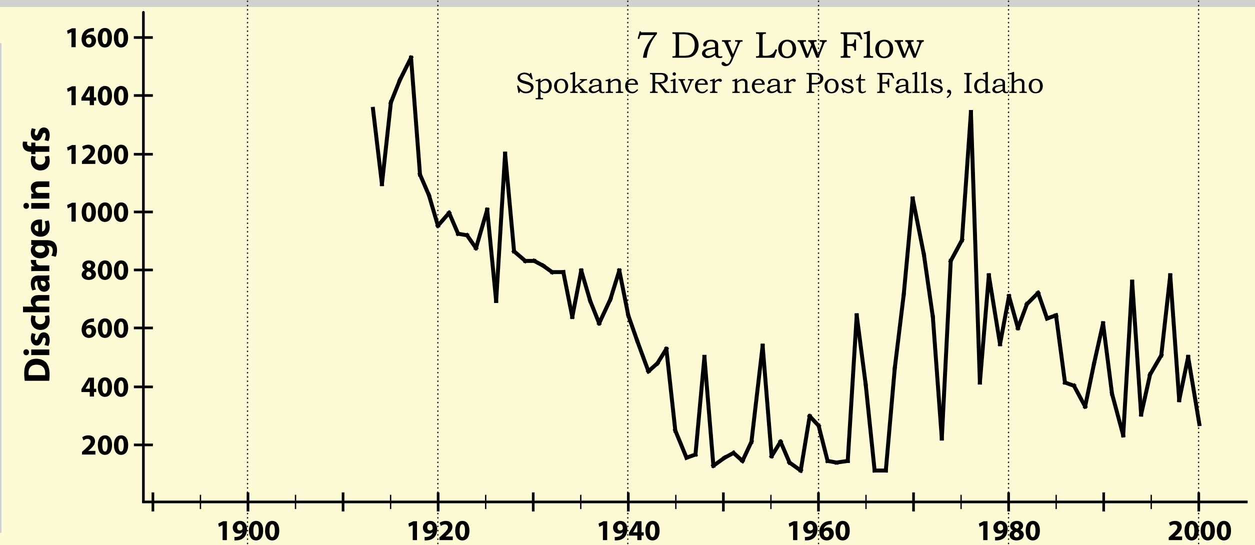
The annual precipitation varies across the Aquifer, increasing from west to east. The average annual precipitation in Spokane is about 16 inches, while it is over 25 inches in Coeur d'Alene. Precipitation is the primary Aquifer recharge source, and annual variation in precipitation is reflected in the Aquifer monitoring wells maintained by the USGS.

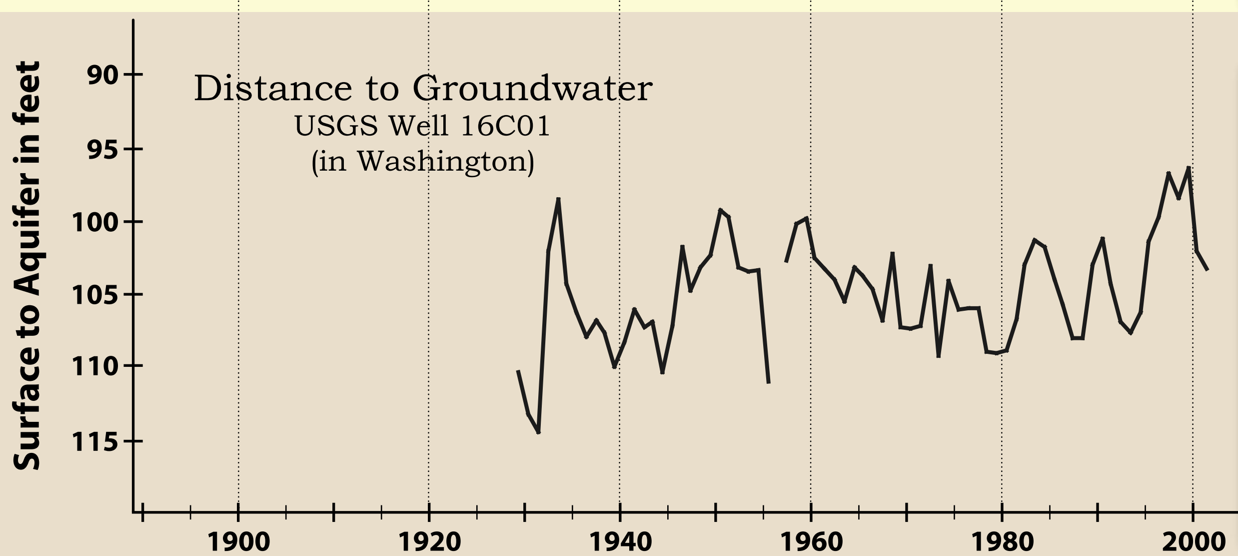




7 Day Low Flow

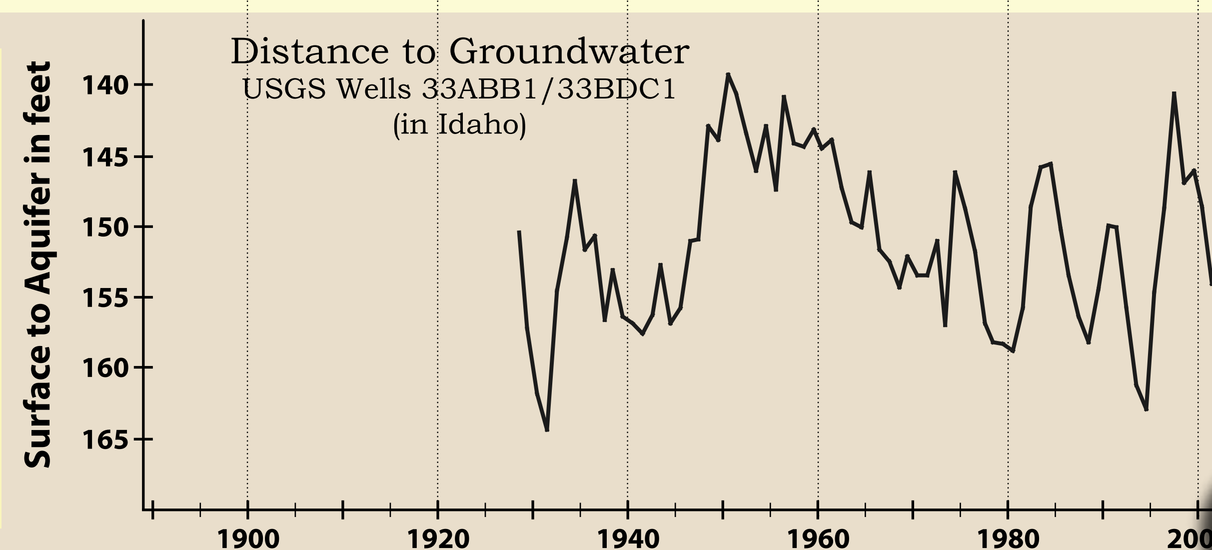
The 7 day low flow of the Spokane River shows a continuous downward trend both in the City of Spokane (left) and in Post Falls (right). In Post Falls, the river 7 day low flow has decreased 600 cfs between 1910 and 2000. For the same period in Spokane, the 7 day low flow has decreased about 700 cfs. This decrease is not fully understood, and it may have several causes.





Ground Surface to Aquifer

Variations in the depth from ground surface to Aquifer are related to several factors, including precipitation, water withdrawals, and river flow. Compare the Spokane River 7 day low flow and precipitation graphs with the depth to Aquifer graphs, and you may see similarities in general fluctuations and trends.



Aquifer Issues

Vulnerability

The Spokane Valley-Rathdrum Prairie Aquifer is highly vulnerable to contamination. Unlike many other aquifers, the Aquifer does not have protective layers of clay or rock to deter infiltration of surface contaminants. The soil layer above the Aquifer is relatively thin in most areas, and fluids readily infiltrate into the porous sands and gravel that comprise the Aquifer materials. Potential contamination is the most important Aquifer issue that must be addressed to preserve and maintain the Aquifer as a regional drinking water resource. A contaminant on the surface may reach the Aquifer water table in a matter of hours or days, particularly contaminants that are dissolved in water that is recharging the Aquifer. Once a contaminant enters the Aquifer it spreads into a plume. Different chemicals mixed with the water in the Aquifer create different plume behavior, and remedial actions must be customized to the specific contaminant. Contamination in the Aquifer may be cleaned-up, or remediated, but the clean-up process is costly and does not eliminate 100% of the contamination. Contamination prevention is the best strategy for protecting Aquifer water quality.

Contamination

Sources of contamination over the Aquifer are varied and abundant. Almost any activity that generates or stores waste material has the potential to contaminate an aquifer. Human-generated surface contamination has already reached the Aquifer, including: landfill leachate, industrial process wastewater, vehicle and tanker spills, and contaminated water from industrial and residential activities. Contamination incidents are costly and technically difficult to cleanup, and local agencies have learned that prevention efforts are much more cost effective than clean up. The most common contaminants found in the Aquifer are inorganic chemicals generated by normal everyday activities: nitrates, chlorides, sulfates and other chemicals that mix readily with Aquifer water. Industrial chemicals from past poor disposal practices and from landfill leachate have also created plumes in the Aquifer. These industrial chemicals (such as trichloroethylene, and gasoline components such as benzene) often create greater concern because their toxicity is generally much greater than inorganic chemicals.

Water Quality

The Aquifer is the most economical supply of drinking water for approximately 500,000 people in our region. The quality of the Aquifer water is high, yet water quality trends have shown a gradual increase of contaminants reaching the Aquifer. Our Aquifer is highly susceptible to pollution because of the porosity of the glacial gravels, shallow soils, and shallow water table. Pollutants such as coliform bacteria, nitrates, and volatile organic compounds have been detected in Aquifer water samples. These contaminants are seldom in concentrations high enough to exceed water quality standards and only occur in limited areas for short periods of time, since the high flow rate of the Aquifer tends to dilute pollution comparatively quickly. The trend of increased contamination indicates that we must protect the Aquifer from further contamination. Local governments, citizen groups and water purveyors have begun to reverse this trend by supporting and developing Aquifer protection programs and regulations.

Water Quantity

From its discovery over 100 years ago through the 1960s, the Aquifer was considered an "inexhaustible supply" of water. Approximately 219 million gallons were withdrawn from the Aquifer to supply the domestic needs of the area's residents on an average day in 1999. However, on hot summer days the added water use for irrigation increases the daily Aquifer water withdrawal to over 680 million gallons. In our region daily household use can be as high as 600 gallons per day, while the national average is about 350 gallons per day. Future Aquifer water withdrawal must be carefully managed to prevent a draw down or depletion of the Aquifer reservoir. Maintaining the Aquifer reservoir is essential to maintain the health of the Spokane River during periods of seasonal low river flow.

Water Quality Testing

Both Spokane County and Panhandle Health District have ongoing monitoring programs to sample and test the Aquifer for contamination. About 60-70 wells scattered throughout the Aquifer are tested quarterly in Washington and three times a year in Idaho. The purpose of this testing is to monitor the overall quality of the Aquifer and to examine water quality trends. Very few contaminants have been detected in the water supply and those that are found are usually detected at levels far below drinking water standards. Nearly two hundred water supply wells at 100 locations are regularly tested to ensure the water supply meets heath standards established by the federal government and state agencies.

Septic Systems

Studies from the 1980s indicated that about sixty percent of the pollution reaching the Aquifer originates from septic systems. The most common pollutant from septic systems is nitrogen, usually in the form of nitrate. Household chemicals dumped down the drain are not adequately treated in the septic tank and constitute another source of pollution from septic systems. Ongoing efforts in Spokane County and communities in north Idaho have connected many households and businesses to sewer collection systems, thereby reducing pollutants reaching the Aquifer and improving water quality. However in rural areas, septic systems will continue to be the only method of sewage treatment and disposal. These rural systems must be properly maintained to protect the Aquifer from further pollution.

Stormwater

Stormwater accounts for about thirty percent of the pollution reaching the Aquifer. Stormwater can collect a large variety of contaminants as it flows across roads, parking lots, roofs and other impervious surfaces. Some of this water goes into dry wells without treatment. Both Spokane County and north Idaho now have regulations that require the use of grassed infiltration basins, also called grassy swales, that use natural processes to clean up the stormwater as it percolates through a grass and soil layer before making its way to the Aquifer.

Wastewater

Wastewater production is related to water usage, as most domestic and commercial water contributes to the wastewater stream. The Spokane River receives treated wastewater from several area wastewater treatment plants, and the river has reached its capacity for certain wastewater pollutants during the low flow summer months. An alternate wastewater treatment system is currently employed in north Idaho. During the growing season, a portion of the treated wastewater from the Hayden treatment plant is applied to crops on the Rathdrum Prairie. This method of wastewater treatment and disposal prevents further degradation of the Spokane River, and wastewater, rather than Aquifer water, is used to grow crops.

Little Spokane River

At the western edge of the Aquifer, groundwater discharges into the Little Spokane River. The flow in the Little Spokane River is frequently below its desired minimum flow during the summer months, and the recharge from the Aquifer is an important contribution to this river. Similar to the Spokane River, the Little Spokane River supports a diverse plant and wildlife population, and Aquifer water is critical to maintaining this population.

Spokane River

In certain reaches, the Spokane River discharges to the Aquifer, and in other reaches the Aquifer adds water to the river (see page 15). The flow in the Spokane River during late summer is very low. During these low flow periods, much of the water in the Spokane River originates from the Aquifer, and this Aquifer water flowing into the river is very important for several reasons. First, the Spokane River supports a diverse plant and wildlife population, and the Aquifer water helps maintain the necessary habitat for these populations. Next, minimum river flows are necessary to dilute the treated effluent discharging from wastewater treatment plants at Coeur d'Alene, Hayden, Post Falls, Liberty Lake and the City of Spokane. Finally, water from the Aquifer helps the Spokane River meet State and Federal water quality standards.

Protecting the Aquifer

Protecting the Aquifer is a joint effort by agencies and organizations in Washington and Idaho including: Spokane County, the Idaho Department of Environmental Quality (DEQ), Panhandle Health District (PHD), the City of Spokane, the Spokane Aquifer Joint Board and the Washington Department of Ecology. The federal Environmental Protection Agency (EPA) has greatly assisted the Aquifer protection efforts by first declaring the Spokane Valley – Rathdrum Prairie Aquifer a "Sole Source Aquifer," then providing annual funding from 1988 through 1995 for aquifer protection projects. This page illustrates many past Aquifer protection activities.

1976
Local citizens and environmental groups petition the EPA to designate the Aquifer as a "Sole Source Aquifer".

1977
Panhandle Health District (PHD) begins to actively manage wastewater over the Aquifer: New development over the Aquifer is limited to one septic system for every five acres. PHD enters into Sewage Management Agreements with cities to encourage growth near urban centers where sewer lines would eventually be installed.

1977
Local "208" studies are completed, and the sources of Aquifer pollution are identified.

1978
EPA designates the Aquifer as a "Sole Source Aquifer" under Section 1424(e) of the Safe Drinking Water Act.

1979
Spokane County and City of Spokane adopt a Water Quality Management Plan.

1980
Spokane County and Panhandle Health District initiate a Ground Water Monitoring Program for the Aquifer.

1980
DEQ designates the Aquifer as a "special resource water" in Idaho, thereby granting the Aquifer the highest level of state protection.

1981
Spokane County writes a Comprehensive Wastewater Management Plan.

1983
Spokane County creates an Aquifer Sensitive Area Overlay Zone.

1986
Spokane County Health District creates a Renewable On-Site Sewage Permit Program that requires regular inspection of septic tanks.

1986
City of Spokane passes a Critical Materials Ordinance to protect the Aquifer from hazardous materials.

1988
City of Spokane adopts Hazardous Waste Treatment and Storage Zoning. Spokane County adopts an Existing Underground Storage Tank Ordinance.

1988
U.S. Congress provides Aquifer Protection Funding through the EPA.

1990
PHD adopts a Critical Materials Regulation.

1991
PHD prohibits new commercial septic tanks over Aquifer.

1992
Kootenai County builds a permanent Household Hazardous Waste Collection Facility, partially funded by DEQ.

1993
Spokane County, DEQ, and PHD host a National Conference on Wellhead Protection in Coeur d'Alene, Idaho.

1995
DEQ adopts guidelines for land applying wastewater over the Aquifer.

1996
Rathdrum Prairie Aquifer Policy Committee evaluates Idaho Aquifer Program and recommends its continuation.

1997
DEQ designates Aquifer as a "Sensitive Resource Aquifer" in the state Ground Water Quality Rule.

1998
City of Spokane and the Spokane Aquifer Joint Board publish a wellhead protection plan.

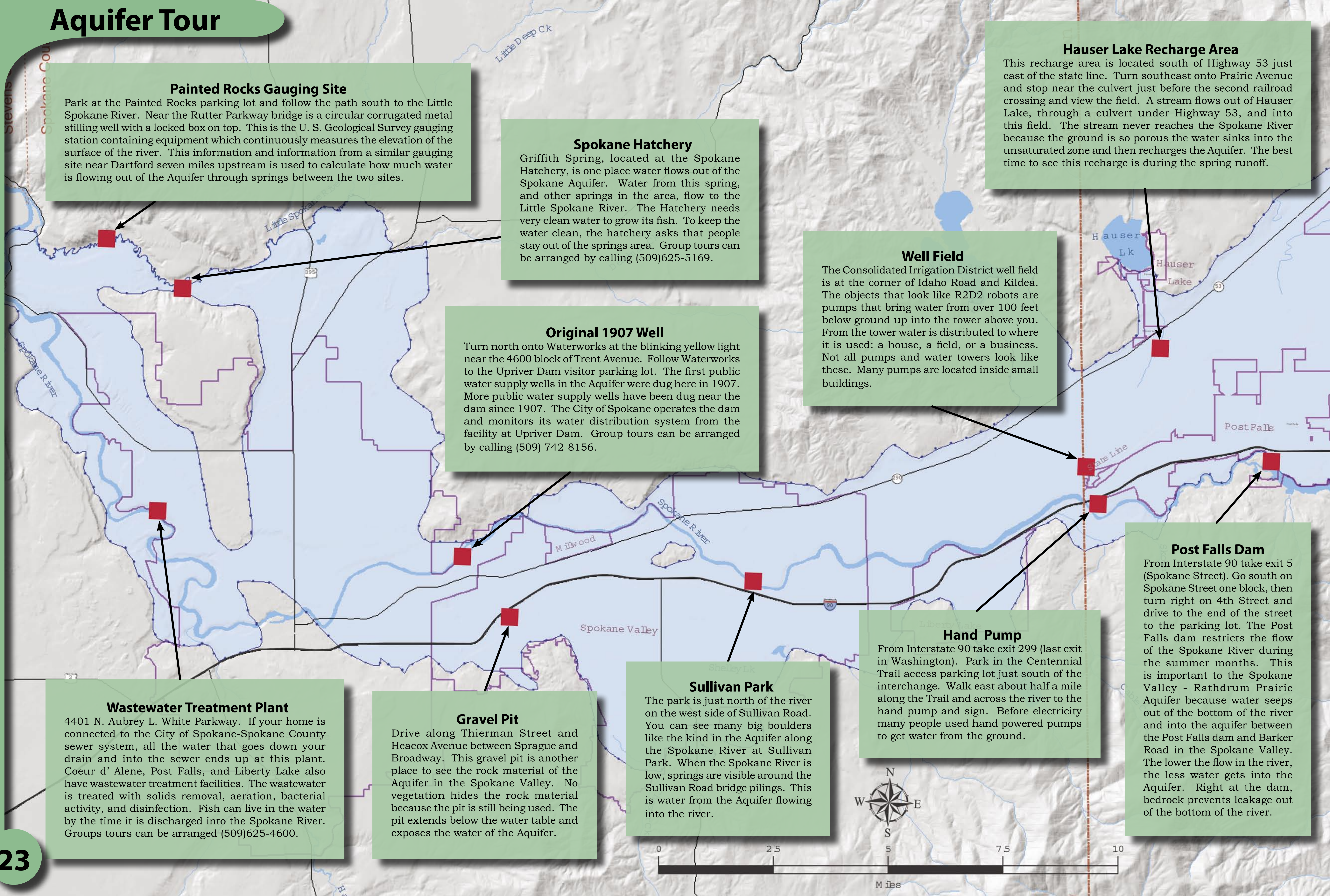
1999
Local efforts to halt a new train refueling depot evolves into a grassroots group, "Friends of the Aquifer."

2004
USGS begins data collection for a new multi-year study of the Aquifer.

Page 4

1975 | 1980 | 1985 | 1990 | 1995 | 2000

Aquifer Tour



Painted Rocks Gauging Site

Park at the Painted Rocks parking lot and follow the path south to the Little Spokane River. Near the Rutter Parkway bridge is a circular corrugated metal stilling well with a locked box on top. This is the U. S. Geological Survey gauging station containing equipment which continuously measures the elevation of the surface of the river. This information and information from a similar gauging site near Dartford seven miles upstream is used to calculate how much water is flowing out of the Aquifer through springs between the two sites.

Spokane Hatchery

Griffith Spring, located at the Spokane Hatchery, is one place water flows out of the Spokane Aquifer. Water from this spring, and other springs in the area, flow to the Little Spokane River. The Hatchery needs very clean water to grow its fish. To keep the water clean, the hatchery asks that people stay out of the springs area. Group tours can be arranged by calling (509)625-5169.

Original 1907 Well

Turn north onto Waterworks at the blinking yellow light near the 4600 block of Trent Avenue. Follow Waterworks to the Upriver Dam visitor parking lot. The first public water supply wells in the Aquifer were dug here in 1907. More public water supply wells have been dug near the dam since 1907. The City of Spokane operates the dam and monitors its water distribution system from the facility at Upriver Dam. Group tours can be arranged by calling (509) 742-8156.

Well Field

The Consolidated Irrigation District well field is at the corner of Idaho Road and Kildea. The objects that look like R2D2 robots are pumps that bring water from over 100 feet below ground up into the tower above you. From the tower water is distributed to where it is used: a house, a field, or a business. Not all pumps and water towers look like these. Many pumps are located inside small buildings.

Hauser Lake Recharge Area

This recharge area is located south of Highway 53 just east of the state line. Turn southeast onto Prairie Avenue and stop near the culvert just before the second railroad crossing and view the field. A stream flows out of Hauser Lake, through a culvert under Highway 53, and into this field. The stream never reaches the Spokane River because the ground is so porous the water sinks into the unsaturated zone and then recharges the Aquifer. The best time to see this recharge is during the spring runoff.

Wastewater Treatment Plant

4401 N. Aubrey L. White Parkway. If your home is connected to the City of Spokane-Spokane County sewer system, all the water that goes down your drain and into the sewer ends up at this plant. Coeur d' Alene, Post Falls, and Liberty Lake also have wastewater treatment facilities. The wastewater is treated with solids removal, aeration, bacterial activity, and disinfection. Fish can live in the water by the time it is discharged into the Spokane River. Groups tours can be arranged (509)625-4600.

Gravel Pit

Drive along Thierman Street and Heacox Avenue between Sprague and Broadway. This gravel pit is another place to see the rock material of the Aquifer in the Spokane Valley. No vegetation hides the rock material because the pit is still being used. The pit extends below the water table and exposes the water of the Aquifer.

Sullivan Park

The park is just north of the river on the west side of Sullivan Road. You can see many big boulders like the kind in the Aquifer along the Spokane River at Sullivan Park. When the Spokane River is low, springs are visible around the Sullivan Road bridge pilings. This is water from the Aquifer flowing into the river.

Hand Pump

From Interstate 90 take exit 299 (last exit in Washington). Park in the Centennial Trail access parking lot just south of the interchange. Walk east about half a mile along the Trail and across the river to the hand pump and sign. Before electricity many people used hand powered pumps to get water from the ground.

Post Falls Dam

From Interstate 90 take exit 5 (Spokane Street). Go south on Spokane Street one block, then turn right on 4th Street and drive to the end of the street to the parking lot. The Post Falls dam restricts the flow of the Spokane River during the summer months. This is important to the Spokane Valley - Rathdrum Prairie Aquifer because water seeps out of the bottom of the river and into the aquifer between the Post Falls dam and Barker Road in the Spokane Valley. The lower the flow in the river, the less water gets into the Aquifer. Right at the dam, bedrock prevents leakage out of the bottom of the river.

A

Alluvium: A general term for all materials deposited by rivers or streams, including the sediments laid down in riverbeds, and floodplains.

Alpine: A mountainous or mountain-like environment or region.

Aquifer: Any underground permeable layer of rock or sediment that holds water and allows water to easily pass through.

Artesian Water: Groundwater that has sufficient pressure to rise above the aquifer containing it when penetrated by a well. It does not necessarily have to rise to the surface.

B

Basalt: A fine-grained and usually dark-colored igneous rock that originates as surface flow of lava.

Batholith: A body of intrusive rock at least 40 square miles in area.

C

Capillary Action: The movement of water within the spaces of a porous material (such as soil) due to the forces of adhesion, cohesion, and surface tension.

Capillary Water: Underground water that is held above the water table by capillary action.

Chlorination: The application of chlorine to water for the purpose of disinfection.

Cobbles: Rocks that are larger than pebbles and smaller than boulders, usually rounded while being carried by water, wind, or glaciers.

Coliform Bacteria: A type of bacteria that live in the digestive tracts of animals and humans but are also found in soils and water. The presence of coliform bacteria in certain quantities in water is used as an indicator of pollution.

Cone of Depression: A cone shaped area in the water table around a pumping well due to the well's influence on the flow of water in the aquifer.

Conifer: A tree that reproduces by means of cones and has needles instead of leaves.

Confined Aquifer: An aquifer with an overlying layer of impermeable or semi-impermeable material.

Consumptive Use (of water): The water used for any purpose that does not return to its source, such as irrigation water lost to the atmosphere by evapotranspiration.

Cordillera: A group of mountain ranges including the valleys, plains, rivers, and lakes between the mountains.

Correlation (geologic): The determination of the equivalence in geologic age and stratigraphic position of two formations or other stratigraphic units in separated areas. This can be based on paleontologic or physical evidence.

Coulee: A steep-sided gulch or water channel.

Cubic Feet Per Second: A unit of measurement for expressing the flow rate (discharge) of a moving body of water. One cubic foot per second is equal to a stream one foot deep, one foot wide and flowing at a velocity of one foot per second. One cubic foot of water is equal to 7.48 U.S. gallons.

D

Discharge: The volume of water that passes through a given cross section of a stream, pipe, or even an entire drainage basin.

Domestic Consumption (use): The quantity of water used for household use including drinking, washing, bathing and cooking.

E

Effluent: Something that flows out, such as a liquid discharged as a waste; for example, the liquid waste that comes out of a sewage treatment plant.

Effluent Stream: A stream that receives all or part of its water from groundwater; also called a "gaining stream".

Emplacement: Development of rocks in a particular place.

Evaporation: The process by which water is changed from a liquid to a vapor. In hydrology, evaporation is vaporization that occurs at a temperature below the boiling point.

Evapotranspiration: Evaporation plus transpiration.

F

Fluvial: Of or pertaining to rivers; produced by a rivers action, such as a fluvial plain. Also used to denote an organism that grows or lives in streams.

G

Gallons Per Minute: A unit for expressing the rate of discharge, typically for the discharge of a well.

Geophone: A detector, placed on or in the ground in seismic work, which responds to the ground motion at its location.

Glacier: A mass of ice that is moving on land in a definite direction, originating from accumulated snow.

Glaciofluvial: Pertaining to streams flowing from glaciers or the deposits made by those streams.

Grass Percolation Area (grassy swale): An area covered with grass or other vegetation used to catch and treat stormwater runoff by allowing the water to slowly percolate through the grass and soils.

Groundwater: Subsurface water found in the zone of saturation.

H

Hardness: A measure of the amount of calcium, magnesium, and iron dissolved in the water.

Hydraulic Conductivity: A measurement of permeability.

Hydrogeology: The science of the interaction between geologic materials and water, especially groundwater.

Hydrologic Cycle: The endless interchange of water between sea, air, and land: includes evaporation from oceans, movement of water vapor, condensation, precipitation, surface runoff, and groundwater flow.

Hydrology: The science of the behavior of water in the atmosphere, on the earth's surface, and underground.

Hydrothermal vein deposits: A mineral deposit formed in cracks in rocks by the injection and cooling of hot liquid containing dissolved minerals.

I

Ice Age: A geological period of widespread glacial activity when ice sheets covered large parts of the continents.

Ice Dam: A blockage of a river by ice.

Igneous Rock: A rock formed by the cooling of molten magma; for example, granite or basalt.

Impervious: Incapable of being penetrated by water.

Impermeable Rock: A rock layer made of materials such as clay or shale that does not allow water to pass through it.

Infiltration: In hydrology it is the movement of water into soil or porous rock.

Influent Stream: A stream contributing water to the zone of saturation thereby sustaining or increasing the water table; also called a "losing stream".

Isoconcentration: A line on a chart or map connecting places with the same concentration.

L

Lava: Molten rock erupted on the surface of the earth by volcanic processes.

Leachate: A solution created by water dissolving chemicals while flowing through the soil or a landfill.

M

Metamorphism: Transformation in the character of igneous or sedimentary rock, resulting in more compact metamorphic rock.

Moraine: Glacial drift deposited chiefly by direct glacial action, and having constructional topography independent of control by the surface on which the drift lies.

N

Nonpoint Source Pollution: Pollution discharged over a wide area of land, not from one specific location.

O

Observation Well: A well used to monitor ground water for water quality and/or changes in water levels.

Outwash: Neat layers of clay, sand, and gravel deposited by glacial meltwater.

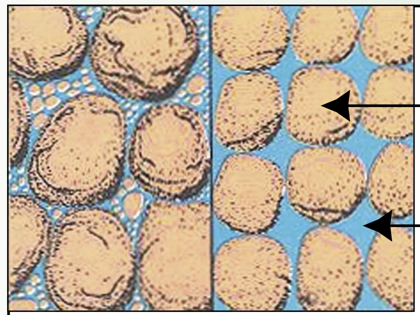
P

Parts Per Million (ppm): The number of "parts" of a substance by weight per million parts. A commonly used unit used to express a pollutant's concentration in water. Equivalent to milligrams per liter (mg/L).

Perched Water Table: Groundwater separated from the underlying water table by an impermeable rock layer.

Percolation: The downward movement of water through the pores or spaces of a rock or soil.

Permeability: The ability of rock or sediment to permit water to pass through it. It is dependent on the volume of the pores and openings and their interconnectedness.



The sample on the right has higher permeability because of better interconnections between pores

Point Source Pollution: Pollution discharged from a single source or point such as a pipe, ditch or sewers.

Porosity: In rock or soil, it is the ratio of the volume of openings in the material to the total volume of the material. In hydrology it is used to express the capacity of rock or soil to contain water and is expressed as a percentage.

Precipitation: In hydrology, any form of water that falls to the ground from the atmosphere, including rain, snow, ice, hail, drizzle, etc.

R

Recharge, groundwater: The addition of water to the zone of saturation. Precipitation and its movement to the water table is an example.

Recharge Area: An area in which an aquifer receives water by the force of gravity moving water down from the surface.

Remedial Action: Actions for the purpose of repairing or remedying a condition or situation.

Runoff: That portion of precipitation or irrigation water that drains from an area as surface flow.

S

Sanitary Landfill: A method of disposing of solid waste on land by spreading it into thin layers, compacting it and then covering it with soil.

Sanitary Sewers: A sewer system that carries domestic waste water as opposed to a sewer system that carries stormwater, or both domestic waste and stormwater.

Saturated: In hydrology, the condition in which all the pore spaces in a rock or soil layer are filled with water.

Saturated Zone: The top of the zone of saturation is the water table. A subsurface zone below which all rock pore space is filled with water.

Sediment: 1) any material carried in suspension by flowing water that ultimately will settle to the bottom of a body of water; 2) waterborne material deposited or accumulated on the bottom of waterways.

Seepage: Water that passes slowly through porous material.

Seismic Energy: Energy similar in character to that produced by an earthquake.

Septic Tank: Underground tanks that receive household wastewater. Bacterial action breaks down the organic matter in the tank. The effluent then flows out of the tank into the ground through drains.

Sewage: The total of organic waste and wastewater generated by residential and commercial establishments.

Sewer, Combined: A sewer that carries both wastewater and stormwater.

Sole Source Aquifer: An aquifer which is the sole or principal drinking water source for the area and which, if contaminated, would create a significant hazard to public health.

Solid Waste: Unwanted or discarded material produced from agricultural, residential, commercial, municipal, and industrial sources.

Spectral bands: samples of the electromagnetic spectrum, the entire range of wavelengths or frequencies of electromagnetic radiation extending from gamma rays to the longest radio waves and including visible light.

Static Water Level: The level of water in a non-pumping or non-flowing well.

Storm Drain (Storm Sewer): A drain (sewer) that carries storm waters and drainage, but excludes domestic and industrial wastewater.

Surface Water: All water on the land surface exposed to the atmosphere, includes oceans, lakes, streams, glaciers and snow.

T

TCE (Trichloroethylene): A solvent used in dry cleaning and metal degreasing that can contaminate groundwater when disposed of improperly.

Till: Unsorted and unlayered mixture of all sizes of sediment carried or deposited by glaciers.

Toxicity: The degree that something is poisonous.

Transmissivity (groundwater): The capacity of an aquifer to transmit water through its entire saturated thickness.

Transpiration: The process by which water from a plant is evaporated to the atmosphere, usually through the leaf surface.

U

Unconfined Aquifer: An aquifer without an impermeable layer on its upper surface; also called a "water table aquifer".

Underground Storage Tanks: Tanks used to store fuels and other liquids underground. There are usually two or more such tanks at every gas station.

V

Vadose Zone: The area above the zone of saturation that holds moisture; also called the "unsaturated zone".

W

Wastewater: Water discarded after use by human activities so that it must be treated before being returned to the environment.

Water Budget: A numeric evaluation of all sources of supply to and discharge from an aquifer or a drainage basin.

Water Cycle: The complete cycle of water from its evaporation from bodies of water, movement through the atmosphere, falling back to earth as precipitation, then movement over the earth's surface, and under the earth's surface as ground water, to its eventual discharge and evaporation again from bodies of water.

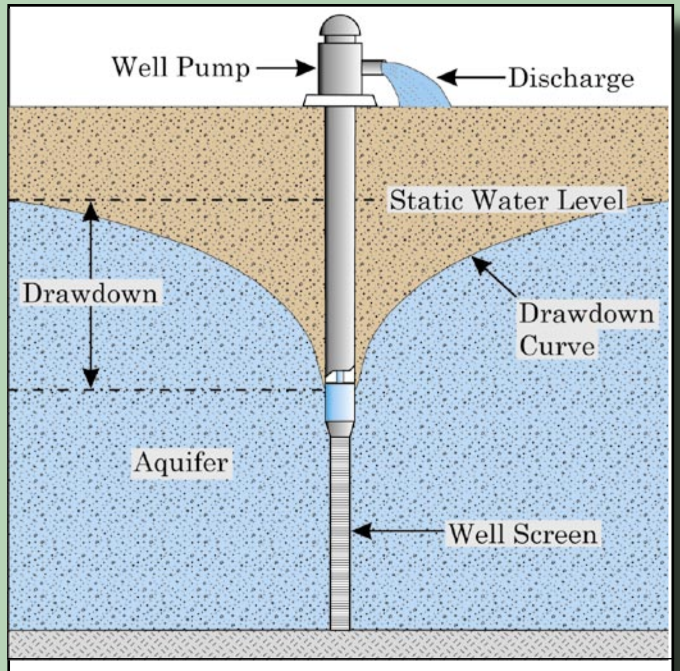
Water Pollution: The addition of sewage, industrial waste, or other harmful or objectionable material to water in concentrations or in sufficient quantities to result in measurable decline of water quality.

Water Quality: A term used to describe the characteristics of water with respect to its suitability for certain uses. This can include chemical, biological, and physical characteristics.

Water Quality Standards: The lawful limit of a pollutant in water that is established by a governmental authority as part of a program for water pollution prevention.

Watershed: An area of land from which water drains to a single point; in a natural basin, the area contributing flow to a given point on a stream.

Water Table: The upper limit of the part of soil or underlying rock material that is completely saturated with water; the top of the zone of saturation.



Well Cross Section

Well: A connection to an underground source of water made accessible by drilling or digging to below the water table.

Wetlands: An area of land in which the soils are saturated with water during a portion of the year, and that have vegetation that live in water, or need saturated soils at least for a portion of the year. They include bogs, swamps, marshes, and the shorelines of lakes, rivers and streams.

Z

Zone of Aeration: The unsaturated zone between the land surface and the groundwater table; pores are filled with air and water.

Zone of Saturation: A subsurface zone in which all pore spaces are filled with ground water; below the groundwater table.

Acknowledgements

Atlas Update Acknowledgements

In early fall 2000 seven thousand Aquifer Atlases were printed and allocated to the participating agencies in Washington and Idaho. The Atlases were very popular, and within eighteen months most had been distributed to the public and to local schools. In 2003 the Spokane Aquifer Joint Board (SAJB) began efforts to reprint the Atlas. The SAJB is comprised of twenty-two water purveyors throughout the Spokane area, and it has an active Aquifer Education and Awareness Program. Although the original printing plates were not available, the computer files had been archived, and four of the original six Aquifer Atlas team members were available to contribute to an Atlas update. Beginning in fall 2003, a new Aquifer Atlas team, comprised of original and new members, began work began on updating the 2000 Atlas with current information in preparation for a new printing. And you hold the results of their work in your hands.

Special Acknowledgements: The SAJB spearheaded the Atlas Update. Bea Lackaff (SC) created or revised Atlas maps and provided other graphics. Jim MacInnis (CoS) was responsible for project management, text writing, editing and layout. Special thanks to Spokane County and the City of Spokane for generously supporting Bea's and Jim's efforts on the Atlas Update.

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From The Original 2000 Atlas

"Creation and publication of this Atlas was the result of faith, hard work and sweat by a small number of people, the Aquifer Atlas Team, whose names appear in the Preface. (see below) However, many other people assisted the Team's efforts, and everyone's contribution added measurably to the quality and content of this document. The Aquifer Atlas Team acknowledges the following people for their contributions: Calvin Terada (EPA), Stan Miller (SC), Connie Grove (SC), Ken Lustig (PHD), John Sutherland (IDEQ), and Glen Pettit (IDEQ)."

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EWU	Eastern Washington Univ.
SC	Spokane County
CoS	City of Spokane
IDEQ	Idaho Depart. of Environmental Quality
EPA	U.S. Environmental Protection Agency
PHD	Panhandle Health District
SAJB	Spokane Aquifer Joint Board

Front Cover: Spokane County Water Quality Management Program GIS, 2000.

Page 1: Atlas Team.

Page 2: Atlas Team. Sidebar article from the Spokesman-Review, May 6, 1909.

Page 3: "Plante's Ferry" painting by James Madison Alden, International Boundary Survey, 1860. Courtesy of the National Archives, College Park, Maryland (thanks to Jack Nisbet.) Photo credit: Jim MacInnis from Arbor Crest Winery, 2004.

Page 4: Photo credits: Upriver Timber Dam, 1895, City of Spokane Water Department. Expo photo: Mike Roberts, 1974, Northwest Room, Spokane Public Library. Timeline data: Archives of the Spokesman Review and the Spokane Chronicle.

Pages 5 & 6: Landsat Data: National Aeronautics & Space Administration (NASA), Washington Remote Sensing Consortium (WARSC). Change mapping: Dr. Kerry Brooks, GIS & Simulation Laboratory, Washington State University Interdisciplinary Design Institute.

Page 7: Map data: Spokane County GIS, Kootenai County GIS.

Page 8: Map data: Spokane County GIS, Kootenai County GIS, IDEQ.

Pages 9 & 10: Graphics by Klundt & Hosmer Design, Inc.

Page 11: Photo credit: Dr. John P. Buchanan.

Page 12: Geologic map data: USGS, M.L. Zientek and others, unpublished data, 2004.

Pages 13 & 14: Graphics by Klundt & Hosmer Design, Inc.

Page 15: Measured flow data: USGS. Interpolated flow data: Golder & Associates, MIKE-SHE integrated groundwater model; Stan A. Miller.

Page 16: Depth to Aquifer data: Spokane County Water Quality Management Program, Derived from USGS land surface elevation data, and USGS Aquifer water-table elevation data (1991). Drainage basin data: Idaho Panhandle Health District, Spokane County Water Resources Department.

Page 17: Text and graphics: Dr. John P. Buchanan (Eastern Washington University).

Page 18: Text and water table elevation graphic, Dr. John P. Buchanan. Capture zone data: CH2M-Hill, modeled for the City of Spokane.

Page 19: Nitrate concentration data: Spokane County Water Quality Management Program, Idaho Panhandle Health District.

Page 20: Population data: U.S. Census Bureau. Climate data: National Weather Service. Hydrologic data: USGS.

Page 21: Photo credit: Dr. John P. Buchanan.

Page 22: Photo credit: Robert Higdem (IDEQ).

Page 23: Tour information and text: Reanette Boese (Spokane County).

Pages 24, 25 & 26: Atlas Team.

Back Cover: Image Jeff Silkwood's U.S. Forrest Service poster, "Glacial Lake Missoula and the Channeled Scabland" Adapted for Atlas by Spokane County WQMP - GIS.

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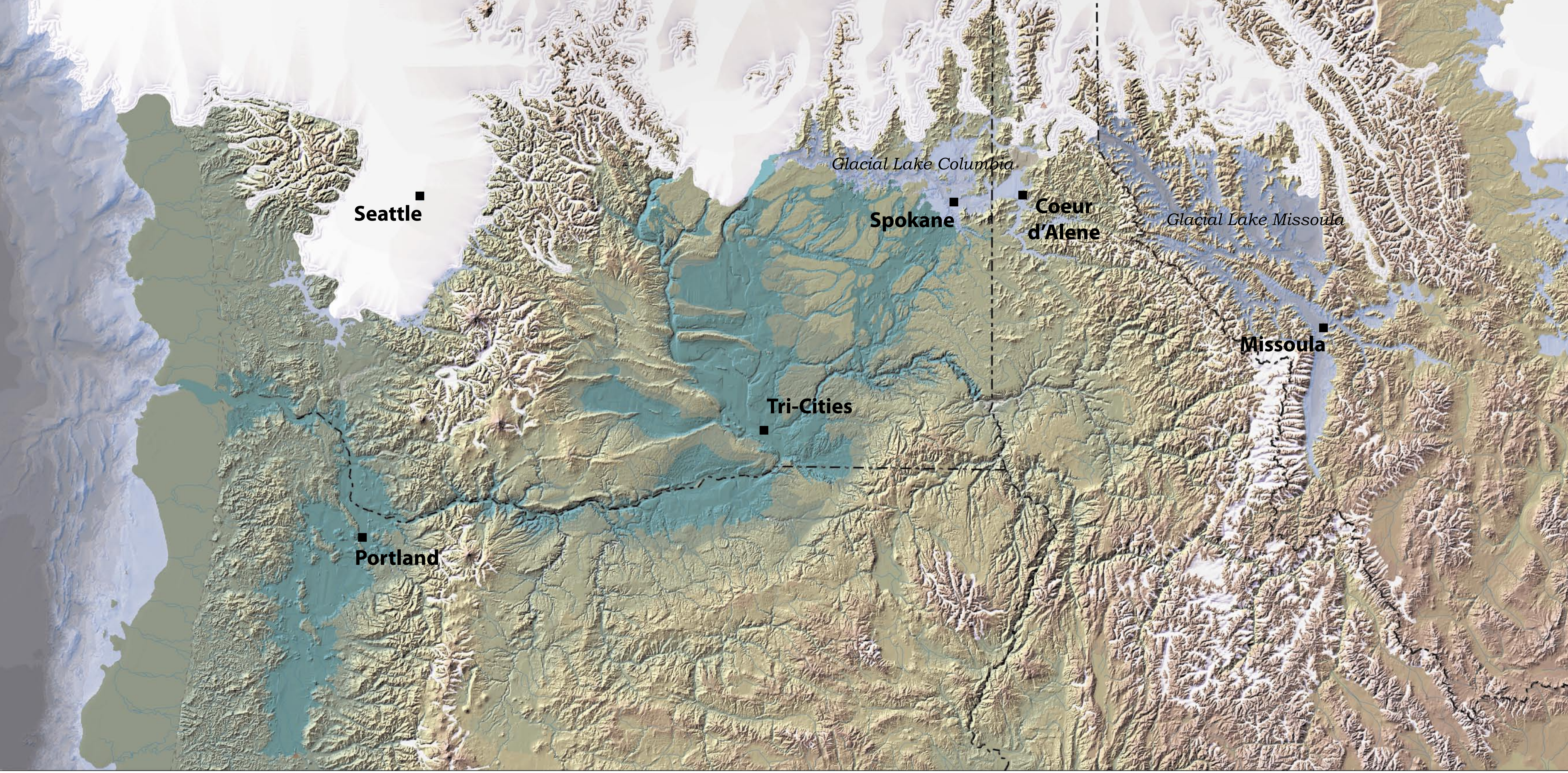

The Pacific Northwest During the Last Ice Age: 15,000 to 12,000 Years Ago

This map depicts the Pacific Northwest during the late Pleistocene Epoch based on available scientific evidence. Several interesting conditions relative to modern times are evident. The present city of Missoula, Montana was under Glacial Lake Missoula, the lake responsible for generating the floods that created the Aquifer sediments. Present day Spokane and Coeur d'Alene were also under water from Glacial Lake Columbia that was created when glacial ice blocked the Columbia River. The present location of Seattle, Washington was under a lobe of the glacial ice sheet. The vast amounts of water trapped in the ice sheet caused the Pacific Ocean level to drop about 300 feet, and the ocean shore retreated several miles from its present location. A full-size map developed by Jeff Silkwood, "Glacial Lake Missoula and the Channeled Scabland" is available from the United States Forest Service.