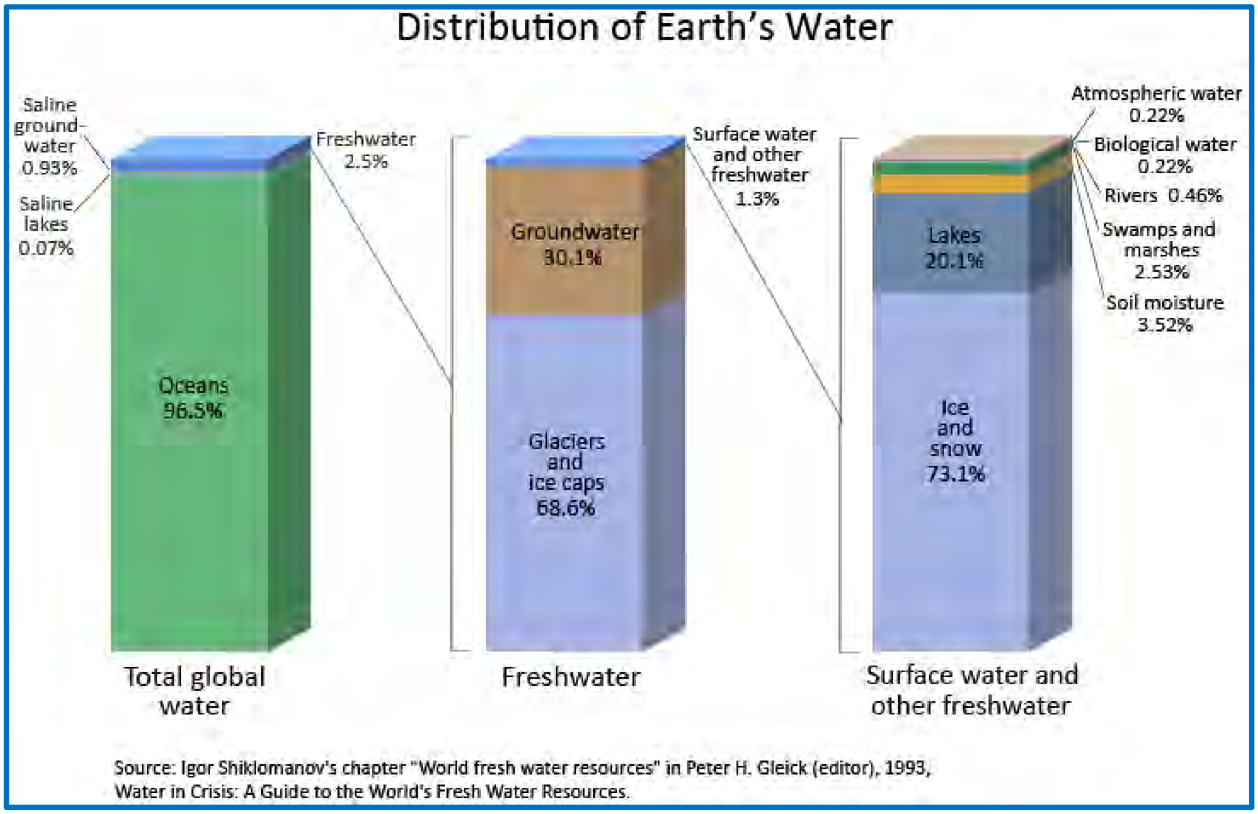
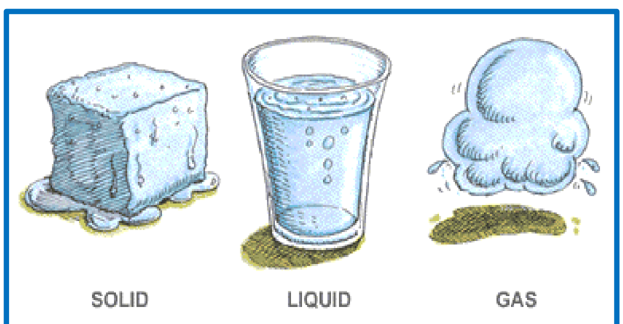
Chapter 1 - Rochester's Water Cycle

Water is the basis for life. Water is a limited resource that recycles both locally and globally. Most of the water on earth is salt water, with less than 3% being fresh. About two thirds of fresh water (about 2% of all water) is stored as a solid in ice and glaciers. That leaves only about 1% of the total water on earth as fresh, liquid water. Contamination of fresh water impacts human and aquatic life. Pollution prevention and water conservation are needed to protect our limited freshwater resources.



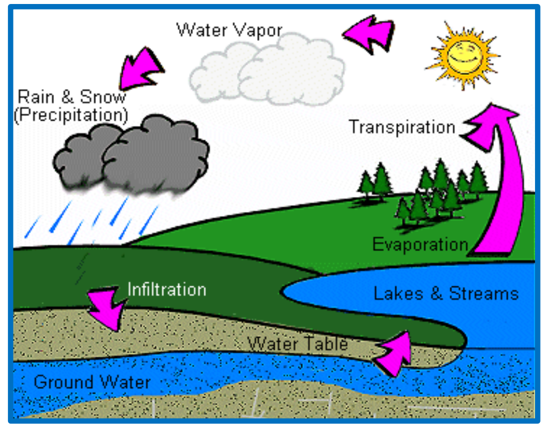
Water is found in three phases, or states, of matter: solid, liquid, or gas. Water may change from state to state depending on seasonal temperatures and where water is found within the water cycle. Another name for the water cycle is the hydrologic cycle. Hydro refers to the Greek word for water. Hydro also relates to the two hydrogen atoms that bond with a single oxygen atom to create a molecule of water. Cycle refers to a series of reoccurring events.



Source: Fairfax, VA

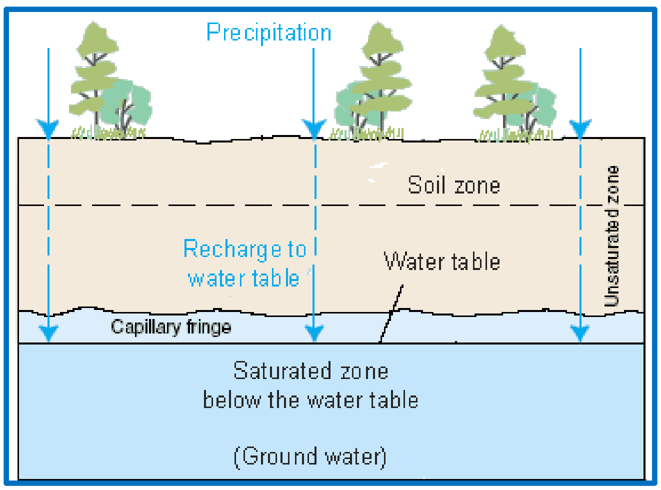
In general, the hydrologic cycle involves water moving through a series of events:

- liquid water evaporating to water vapor(in winter, snow and lake ice can change to water vapor by a process called sublimation)
- liquid water being converted to water vapor by plants and released, or transpired, to the air
- water vapor condensing to form liquid rain or solid snow or ice
- rain, snow or ice falling as precipitation
- rain or snowmelt running across the land to join water bodies, like lakes and streams runoff or lake and stream water infiltrating into the soil to become groundwater



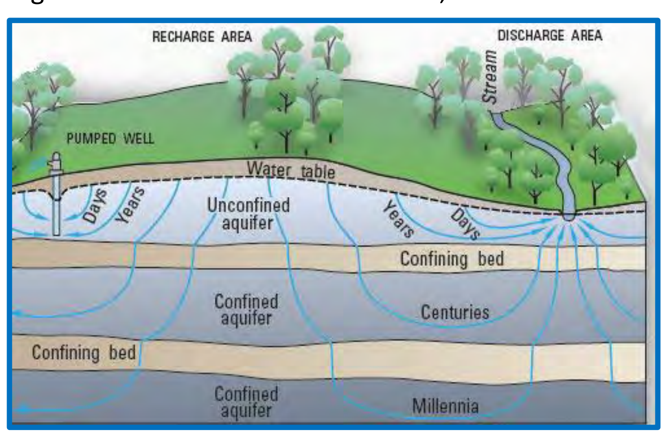
Source: Environmental Education for Kids

Water may not flow through the water cycle in the order listed above. Think of the variable routes water can take in the cycle. Water that falls to the ground may evaporate quickly to return to the atmosphere before infiltrating or reaching a lake. The water vapor may condense on small particles to form clouds and travel long distances before falling back to the Earth as precipitation. Some water will filter into the ground and cling to particles of soil where plant roots may capture it through osmosis and use it for photosynthesis and growth. Some water may travel deeper through the cracks and spaces of the soil and rock. The water-filled zone is called the zone of saturation, or groundwater. The water table is the name given to the top of this zone, with the unsaturated zone lying above it. The water table is not fixed, but rises as water fills the spaces between rock particles or lowers as water leaves the rock to fill a stream or lake or when it is pumped out at a well. Sometimes the surface of a lake or stream is also the top of the groundwater table. In these cases, the water table is at the land surface, not underground!



Source: US Geological Survey

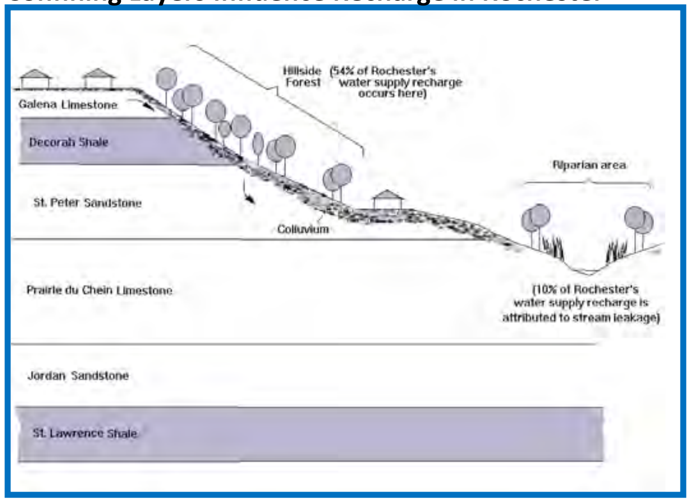
Water can move through the fractures and pores of bedrock, like the limestone and sandstone formations found underneath Rochester. Rock formations that hold water are called aquifers. If a rock type does not allow water to pass easily through it, it is said to be impermeable and is called a confining bed.



Source: US Geological Survey

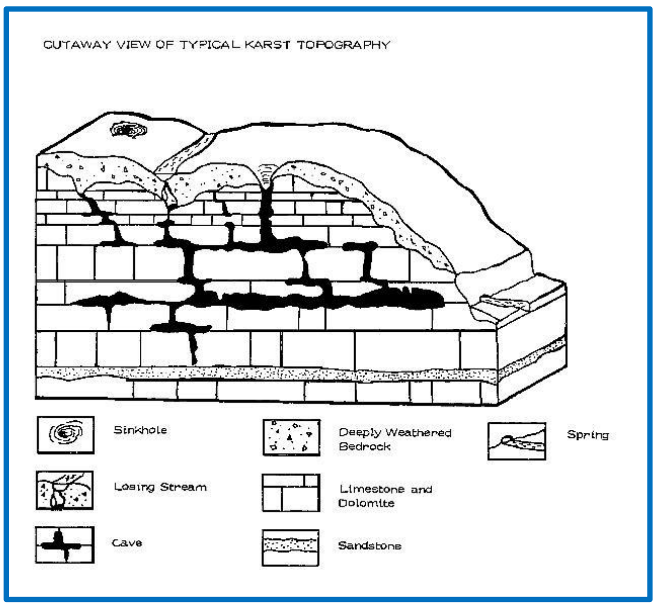
In Rochester, the uppermost confining bed is the Decorah shale. Water can sometimes leak very slowly down through a confining layer, but will be more likely to move along its top until it can seep out at a hillside edge or road cut. The process of water infiltrating from the land surface to form groundwater is known as recharge. Groundwater can be recharged from rain, snowmelt, or surface water features like streams and lakes. When groundwater returns to the land surface to supply rivers, streams, lakes and wetlands, the process is called discharge. A spring is an example of a discharge focused in one area and a seep is groundwater oozing out over a larger area.

Confining Layers Influence Recharge in Rochester



Source: Hydrogeology adapted from Delin, USGS, 1991

Rochester's geology is known as "karst", which has distinctive landforms and hydrology. It is characterized by disappearing streams, springs, caves, and sinkholes that form in limestone bedrock.



Source: Missouri Speleological Survey

These karst features form because limestone, a carbonate rock, is easily dissolved by rainwater that mixes with carbon dioxide in the air to form a weak carbonic acid. Although the limestone rock itself is fairly impermeable, water can pass through it quickly via interconnected fissures, fractures, and joints. These spaces are great for water storage and movement, which makes limestone a highly productive aquifer. But those spaces are also conduits for contaminants to travel quickly between the land surface and groundwater. Topsoil that might otherwise filter surface impurities is thin in karst areas, thus compounding the vulnerability of groundwater contamination.

Recharge - Water moving from the surface to groundwater

Discharge - Water moving from the groundwater to the surface

KEY TERMS:

- **Evapotranspiration or Transpiration** – Water turns into a gas as it returns to the atmosphere as a result of evaporation from plants. This process requires energy.
- **Evaporation** – Water changes from a liquid into a solid. This process requires energy.
- **Condensation** – Water changes from a gas to a solid. This process releases energy.
- **Precipitation** – Water falls to the Earth, most commonly as rain or snow.
- **Infiltration** – Water soaks into the underlying soil and bedrock.
- **Groundwater** – Water below the Earth's surface, where all the spaces are filled with water.
- **Run-Off** – Water that travels on the land surface.
- **Surface Water** – Water that is not underground. It includes run-off and water bodies like rivers, wetlands, and lakes.

Water travels all around planet Earth as part of the water cycle. Some water moves quickly and other water can get stuck somewhere for thousands of years. Think about how long water may be trapped in the polar ice caps. If the climate warms and the ice caps melt, that water will be released back into the water cycle for the first time in thousands of centuries.

Rochester has tested the age of its ground water and found that some wells extract young water that is only a few decades old, while others pump out ancient water that was probably left here by the glaciers over 10,000 years ago. To age date water, scientists analyze water to see how much tritium (^3H or hydrogen-3) is in it. Tritium is a radioactive isotope of hydrogen that forms during the nuclear decay process. Naturally occurring tritium is very rare on Earth. Atmospheric level of tritium started rising in 1945 when the United States began testing nuclear bombs. Nuclear testing peaked in 1963. Tritium from the atmosphere can replace H_2 in water, joining the water cycle as precipitation. Higher tritium levels in water are an indication of younger water. Rochester's young water is recharged within about a 20 mile radius. Ancient water recharges from much farther distances.

While the process is generally the same, the water cycle may look different at other places on the globe. For example, rain forests receive a lot of precipitation and deserts hardly get any. The amount of transpiration from plants will differ depending on temperature and humidity.

The water cycle in Rochester has its own unique characteristics. According to the National Oceanic and Atmospheric Administration, Rochester's average monthly precipitation is almost 32 inches of rain and nearly 53 inches of snow.

NORMALS, MEANS, AND EXTREMES

ROCHESTER, MN (RST)

LATITUDE: 43° 54′ 15″ N LONGITUDE: 92° 29′ 30″ W ELEVATION (FT): GRND: 1323 BARO: 1326 TIME ZONE: CENTRAL (UTC + 6) WBAN: 14925

	ELEMENT	POR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
PRECIPITATION	NORMAL (IN)	30	0.94	0.75	1.88	3.01	3.53	4.00	4.61	4.33	3.12	2.20	2.01	1.02	31.40
	MAXIMUM MONTHLY (IN)	46	2.53	2.21	3.58	7.30	8.41	12.51	12.33	9.52	10.50	6.08	5.90	2.83	12.51
	YEAR OF OCCURRENCE		1967	1971	1990	2001	1982	2000	1978	1979	1986	1970	1991	1982	JUN 2000
	MINIMUM MONTHLY (IN)	46	0.07	0.04	0.32	0.94	1.17	0.94	1.02	0.34	0.38	0.27	0.06	0.22	0.04
	YEAR OF OCCURRENCE		1961	1964	1994	2000	1963	1985	1975	2003	1975	1965	1967	1967	FEB 1964
	MAXIMUM IN 24 HOURS (IN)	46	1.42	1.05	2.04	3.97	5.23	4.80	7.47	3.89	6.01	2.81	2.64	1.35	7.47
	YEAR OF OCCURRENCE		1967	1984	1966	1990	2000	2000	1981	1991	1978	1966	1991	1982	JUL 1981
	NORMAL NO. DAYS WITH:														
	PRECIPITATION ≥ 0.01	30	9.6	7.8	10.7	11.7	11.6	11.4	10.7	10.1	9.8	8.6	9.6	9.3	120.9
	PRECIPITATION ≥ 1.00	30	*	0.0	0.2	0.5	0.8	0.8	1.3	1.0	0.8	0.3	0.4	*	6.1
SNOWFALL	NORMAL (IN)	30	11.9	7.8	9.0	4.3	0.*	0.0	0.0	0.0	0.*	1.0	7.1	11.6	52.7
	MAXIMUM MONTHLY (IN)	42	30.2	19.1	25.2	16.4	0.3	T	T	T	0.8	5.4	22.5	35.3	35.3
	YEAR OF OCCURRENCE		1996	1962	1985	1983	1967	1993	1994	1989	1961	1979	1985	2000	DEC 2000
	MAXIMUM IN 24 HOURS (IN)	42	15.4	9.3	19.8	13.7	0.3	T	T	T	0.8	5.4	9.2	9.0	19.8
	YEAR OF OCCURRENCE		1982	1983	2005	1988	1967	1993	1994	1989	1961	1979	1991	1985	MAR 2005
	MAXIMUM SNOW DEPTH (IN)	53	29	21	20	11	1	0	0	0	0	4	11	20	29
	YEAR OF OCCURRENCE		1982	1979	1951	1988	1954					1979	1983	1969	JAN 1982
	NORMAL NO. DAYS WITH:														
	SNOWFALL ≥ 1.0	30	3.1	2.5	3.0	1.1	0.0	0.0	0.0	0.0	0.0	0.2	2.4	3.3	15.6

published by: NCDC Asheville, NC 3 30 yr Normals (1971-2000)

Of course, averages only tell part of the story. NOAA tracks weather extremes too, like theses shown below.

Highest One-Day Amount of Moisture for Rochester

1.	7.47"	July 11, 1981
2.	6.22"	July 5, 1978
3.	5.98"	September 12, 1978
4.	5.24"	July 26, 1949
5.	5.16"	August 18th, 2007
6.	4.80"	June 1, 2000
7.	4.34"	September 23, 2010
8.	4.18"	June 25, 1993
9.	4.10"	June 23, 1908
10.	4.06"	June 9, 2004

http://www.crh.noaa.gov/arx/?n=pcpn.rst

Highest Snowfall for One Month			Record One-Day Snowfall		
1.	41.3"	December 2010	1.	19.8"	March 18, 2005
2.	35.3"	December 2000	2.	15.4"	January 22, 1982
3.	35.1"	March 1951	3.	15.0"	December 11, 2010
4.	30.6"	December 1969	4.	14.0"	March 30, 1934
5.	30.2"	January 1996	5.	(NA)	April 20, 1893
6.	29.4"	January 1999	6.	13.5"	February 27, 1893
7.	28.6"	December 2008	7.	13.0"	April 26, 1988
8.	27.3"	January 1982	8.	12.0"	November 30, 1934
9.	27.0"	January 1932	9.	10.8"	March 10, 1956
10.	26.3"	December 2009	10.	10.6"	November 25, 1952

Source: http://www.crh.noaa.gov/arx/?n=snow.rst

Seasonal Snowfall for Rochester
(Measured from July through June)

Highest			Lowest		
1.	84.7"	1996-97	1.	9.1"	1967-68
2.	77.5"	1950-51	2.	10.5"	1913-14
3.	74.5"	1961-62	3.	17.5"	1924-25
4.	73.6"	1951-52	4.	19.4"	1930-31
5.	73.3"	1978-79	5.	20.5"	1910-11
6.	70.5"	2010-11	6.	21.2"	1919-20
7.	68.6"	1984-85	7.	21.6"	1957-58
8.	68.0"	1881-82	8.	24.4"	1956-57
9.	66.3"	1887-88	9.	24.6"	1937-38
10.	66.0"	1983-84	10.	24.8"	1953-54

Source: http://www.crh.noaa.gov/arx/?n=snow.rst

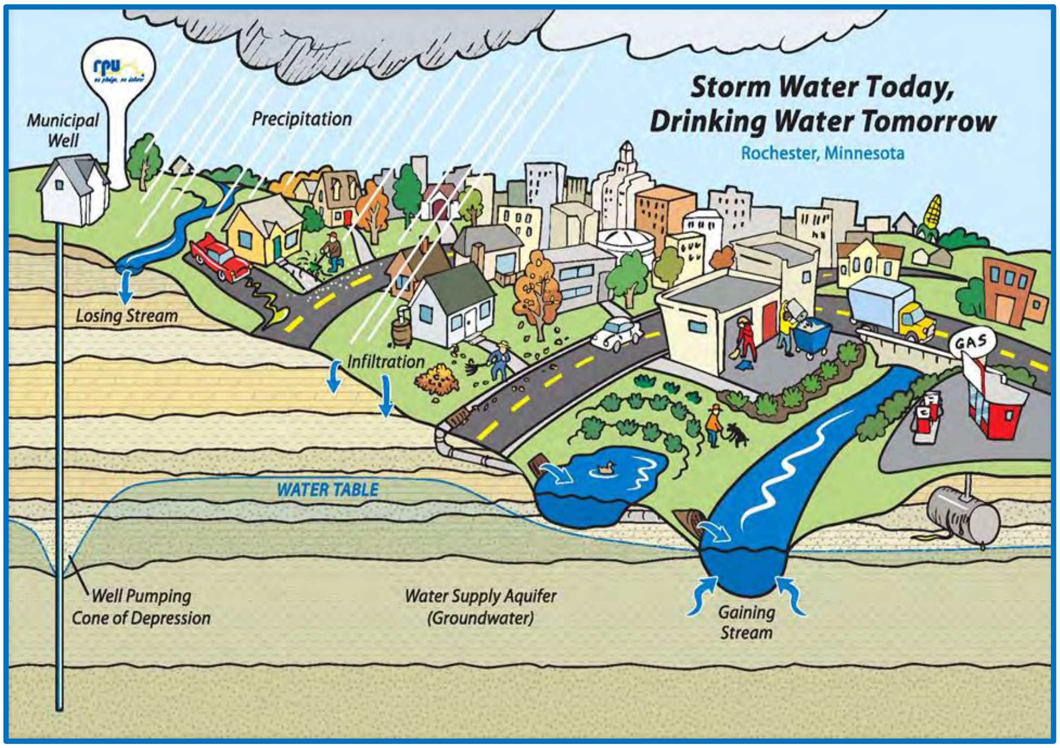
The US Geological Survey has an interactive website about water resources of Minnesota. It includes current stream flow data for Rochester and water-quality and groundwater data for other parts of Minnesota. Check it out at: http://mn.water.usgs.gov/

In Minnesota, snowmelt is an important part of the water cycle!

The Advanced Hydrologic Prediction Service of the National Weather Service has an interactive website that displays Rochester's river levels in comparison to flood stage. Check it out at: http://water.weather.gov/ahps2/index.php?wfo=arx

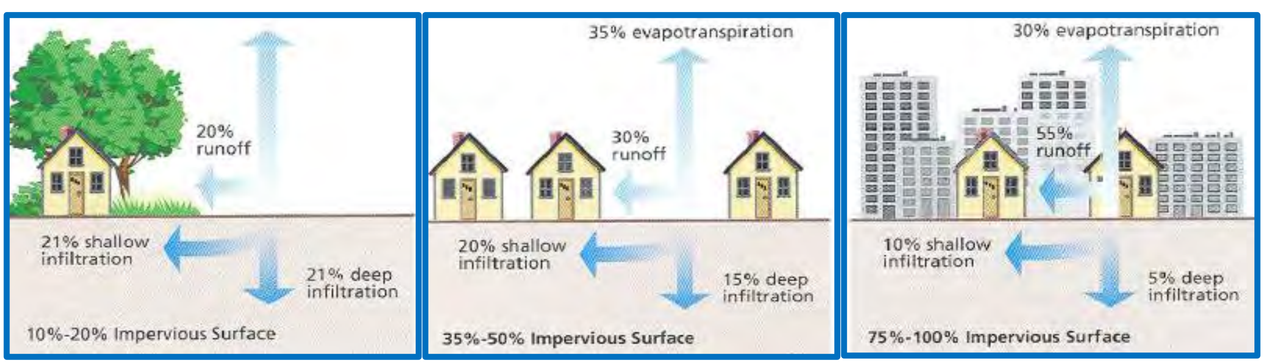
As an urban area, Rochester interrupts the natural water cycle. The groundwater is pumped out of the ground so we can use it at our businesses and homes. At this time, the amount of groundwater used in Rochester is about equal to one inch of precipitation. When we are done using it, it flows down drains and into sanitary sewers as wastewater. After it is treated at the Water Reclamation Plant, it is discharged back to the river. Plus, precipitation and snowmelt travel across a lot of constructed surfaces like: roofs, sidewalks, driveways, roads and parking lots. This storm water is directed into storm sewers that eventually discharge back into our lakes and rivers. Can you see how closely groundwater and surface water are connected in Rochester's water cycle?

Rochester's Urban Water Cycle



Source: Rochester Public Works

It is obvious that urbanization has affected water flow, but how much have hard surfaces changed the water cycle? Before settlement, about 50% of rainwater and snowmelt could soak into the ground because it moved slowly across the landscape. The remainder moves back into the air or runs off the land to fill lakes and rivers. As cities grow, more hard surfaces and compacted soils are added and they prevent water from infiltrating below. They are impervious surfaces. It is estimated that as impervious surface area increases to 20%, infiltration is reduced by 8%. As it reaches 50%, 15% of infiltration has been lost. If a City's entire landscape is nothing but buildings, roads and parking lots, then 35% of the infiltration is gone. If the water can't soak into the ground, where does it go? It runs off the surface, so the more pavement, the more storm water, the faster it flows, and the more urban pollution it collects.



Source: Center for Watershed Protection

Even agriculture has changed the water cycle. Farmers have drained wetlands that used to hold water on the landscape. They have installed field tile to quickly move water away from their fields. Most of their crops cover the soil only for a part of the year, exposing loosened soil to wind and water erosion. If plants do not take up all the fertilizers and pesticides, then the excess can run off as pollution.

The Minnesota State Climatology Office, a DNR Division of Ecological and Water Resources, maintains the "Wetland Delineation Precipitation Data Retrieval Gridded Database". This tool was created to help people delineate wetlands, but it is also useful for other research. Highlight a specific location in Rochester and click on the button to create a precipitation data table for that site. Check it out here: http://climate.umn.edu/gridded_data/precip/wetland/wetland.asp

Case Study: Water and Rocks

Hydrology and geology interact with each other. We extract our water supply from bedrock aquifers. In karst regions, water affects rock by dissolving limestone to form fractures, joints, caves, and sinkholes. In Rochester, shale is exposed by the river valley to form the Decorah Edge, releasing water from the upper aquifer so it can flow into, or recharge, the lower aquifer. Much can be inferred about the interaction of water and rocks by comparing data.

By looking at each of the following pictures of the Century High School area, make inferences about how hydrology and geology relate to each other.

Picture A

1. Find Century High School. What do you already know about the area around Century?
2. Make an inference about the relationship between springs and the area known as the Decorah Edge, which is comprised of the Decorah, Plattville, and Glewood shale formations.

Picture B

1. What color represents the highest elevation?
2. What color represents the lowest elevation?
3. Make an inference about the relationship between springs and elevation.

Picture C

1. What color represents the highest vulnerability to pollution?
2. What color represents the lowest vulnerability to pollution?
3. Make an inference about the relationship between springs and vulnerability to pollution.

Picture D

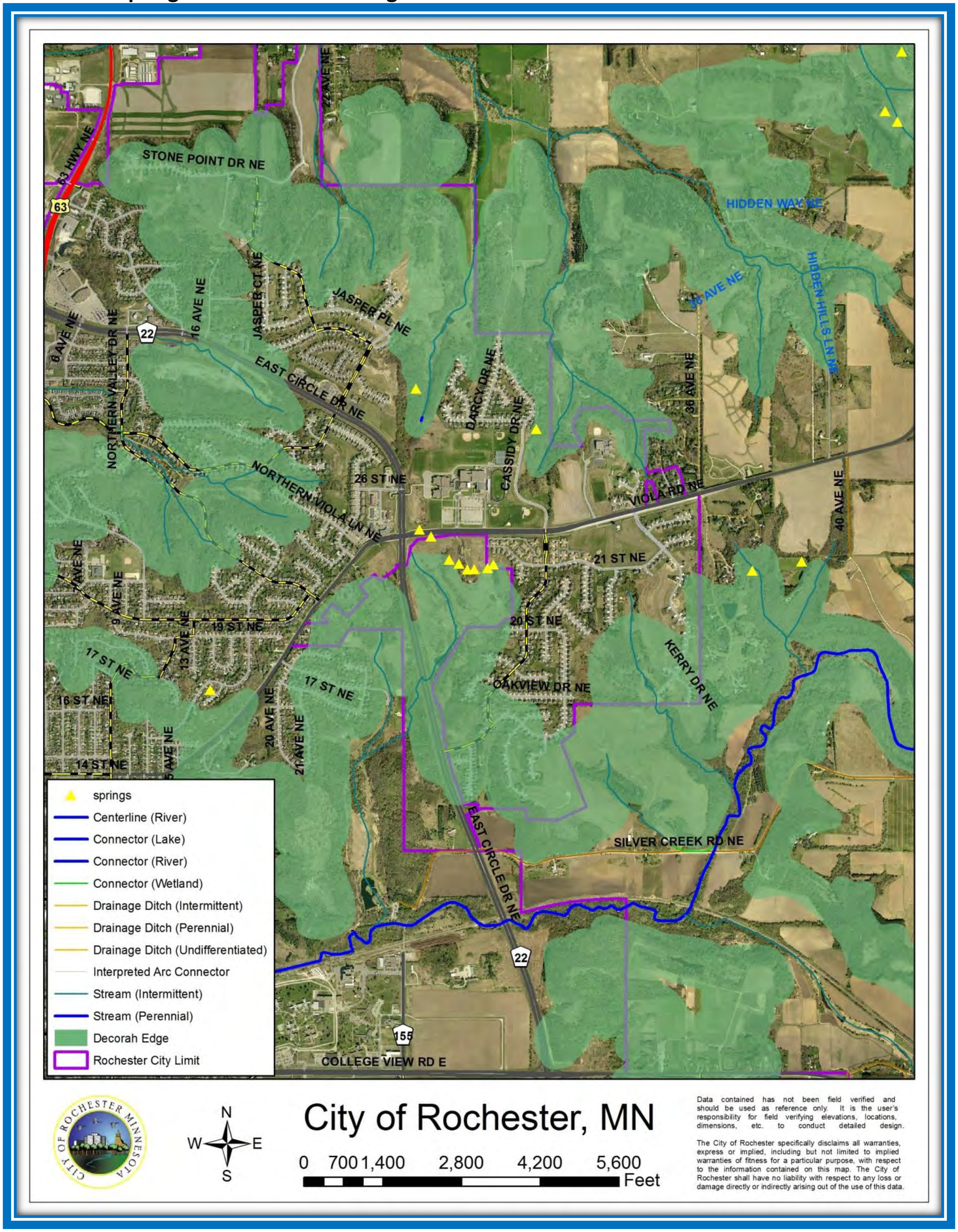
1. Which rock layer has the highest elevation?
2. Which rock layer has the lowest elevation?
3. Make an inference about the relationship between springs and rock layers.

Putting It Together

1. Write a short paragraph that summarizes the relationship between the geology and hydrology shown in these pictures.
2. How do you think this area would compare to the rest of Rochester?

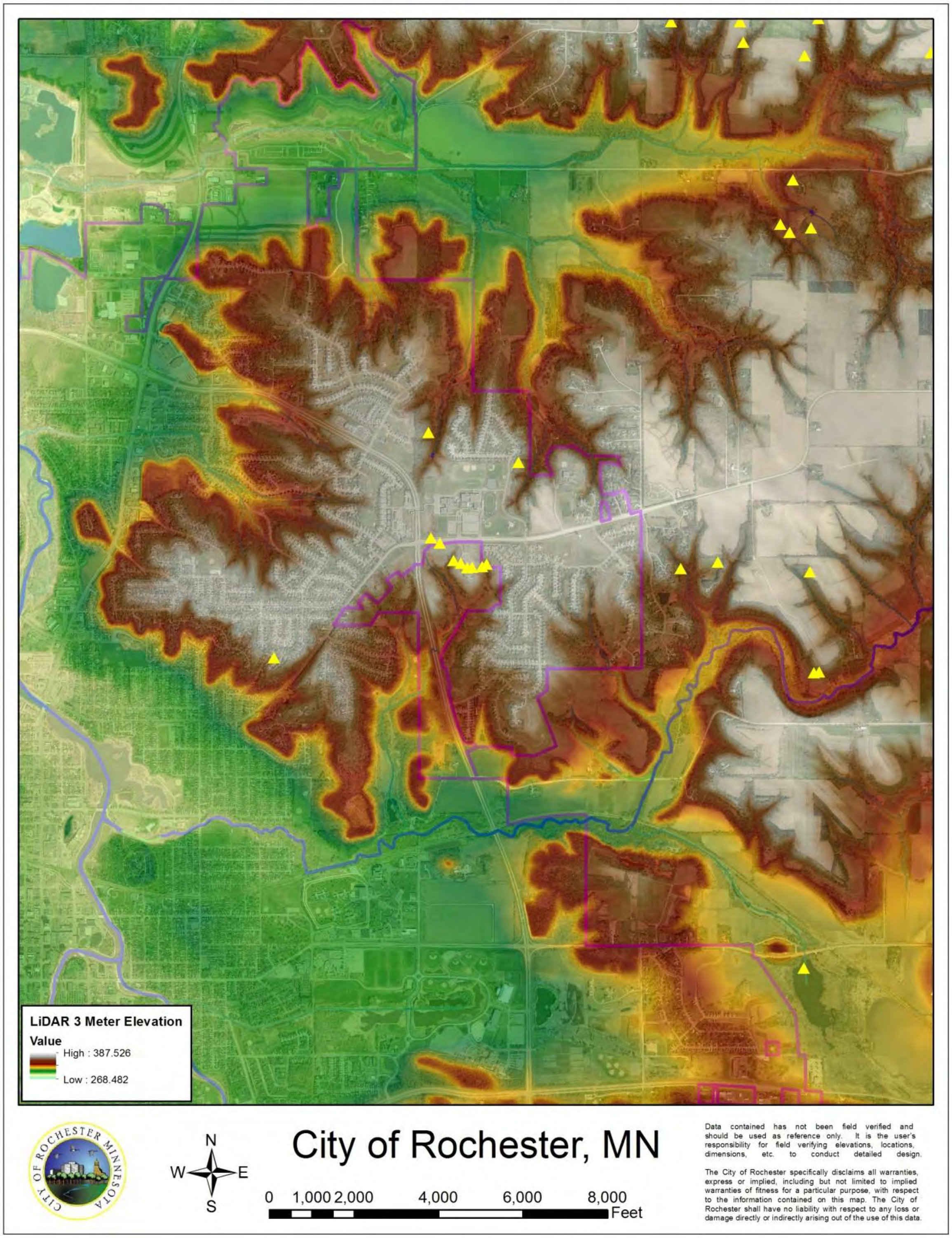
To find out more about the relationship between springs and rocks, check out USGS's website at http://ga.water.usgs.gov/edu/watercyclesprings.html.

Picture A – Springs and the Decorah Edge



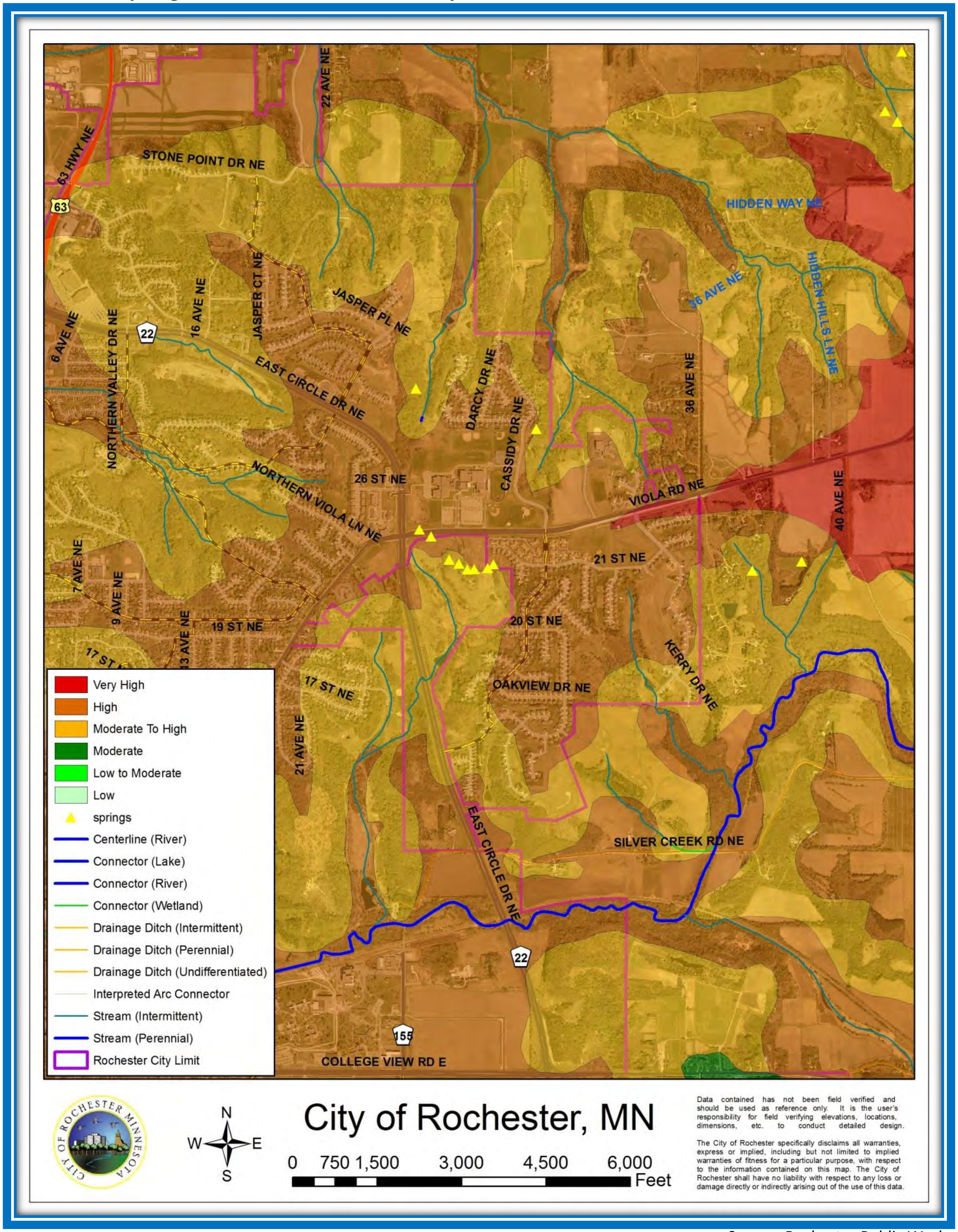
Source: Rochester Public Works

Picture B – Springs and Elevation



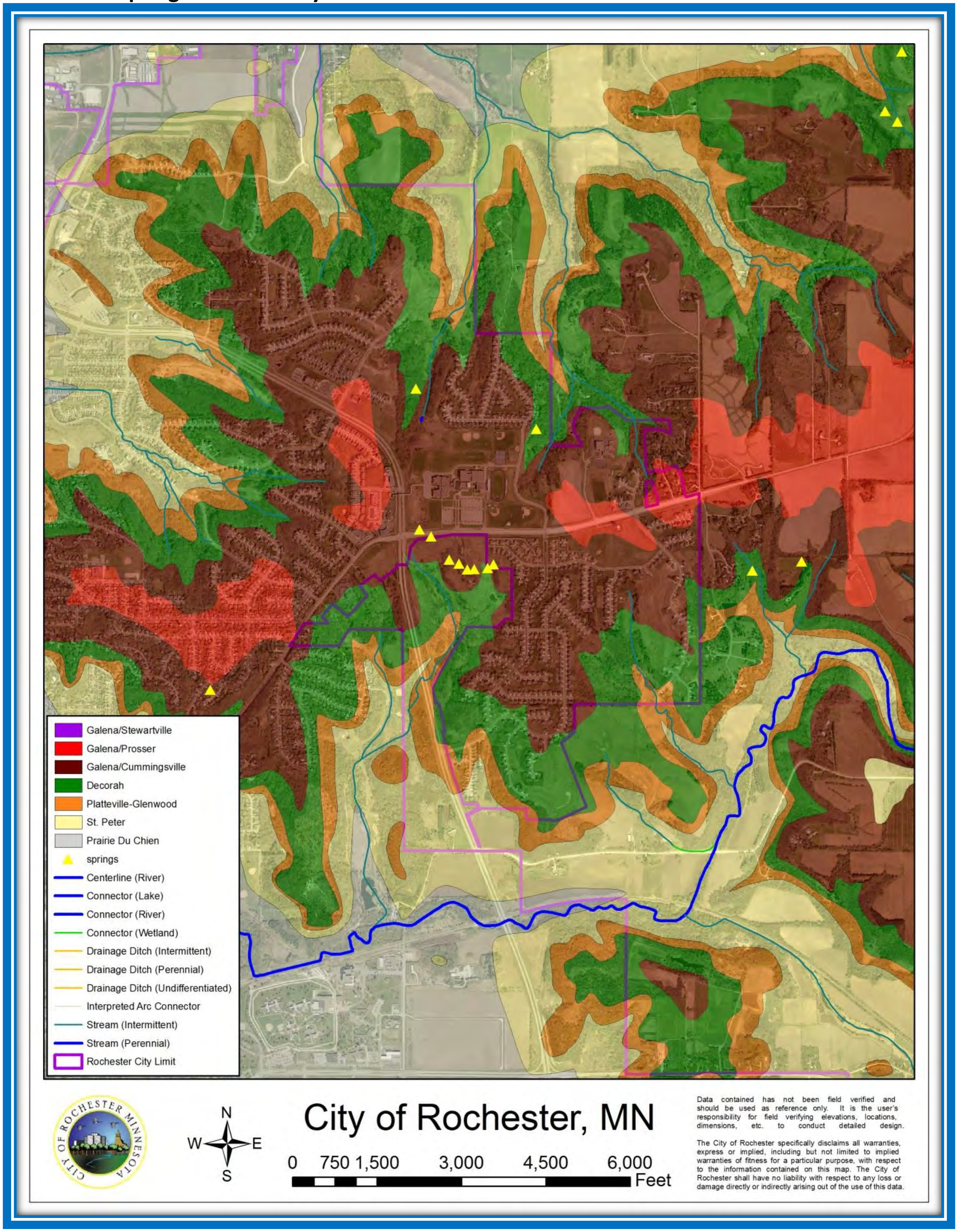
Source: Rochester Public Works

Picture C – Springs and Pollution Vulnerability



Source: Rochester Public Works

Picture D – Springs and Rock Layers



Source: Rochester Public Works