Chapter 4 - Rochester's Constructed Water Bodies

In lake rich Minnesota, Rochester is lake poor. In fact, Rochester is located in Olmsted County, one of only four counties in Minnesota that does not have a natural lake. (The others are Mower, Pipestone and Rock counties.) In the 1930's, Rochester citizens wouldn't accept what nature gave them, however, so they created the City's first lake for a park. Both public and private landowners have continued the practice of modifying natural waterways for many reasons: for recreation, to protect the City from flooding, to provide storm water management, to create an aesthetic feature for a development, to extract sand and gravel, and to produce power.

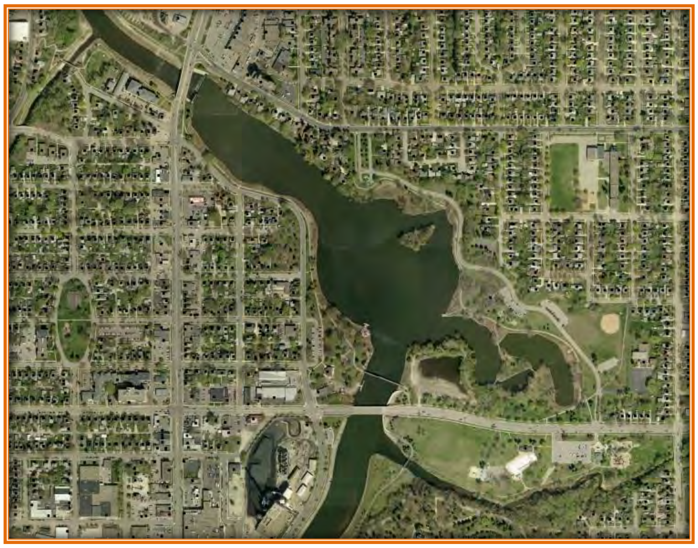
Silver Lake Reservoir

Silver Lake is actually a reservoir that was created by first, hand-digging a basin to hold water and then constructing a dam from 1935-1936 to back-up river water. It was built for half a million dollars during the 1930's Great Depression as a work relief project, providing work for over 400 unemployed men. Various New Deal programs supported the effort. The project was started by the Civil Works Administration (formed as part of the Federal Emergency Relief Act in 1933), then joined by the State Emergency Relief Administration in 1934, and later transitioned to a Works Project Administration project in 1935. Today, the water surface area of the Lake is nearly 40 acres. The land on which the Lake now lies was once a combination of small gravel and sand pits, poor pasture land, and "unimproved" marshy land.

Silver Lake 2013

Source: Rochester Public Works

Aerial Photo of Silver Lake 2012

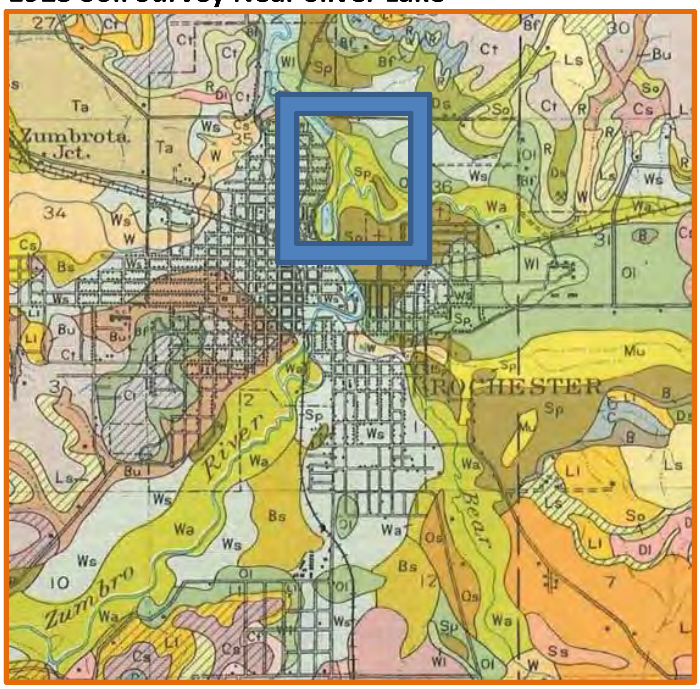


Source: Rochester Public Works Department

It is interesting to note that the sand from one of the pits that formed Silver Lake was known to be of such high quality that it did not need to be washed and it was used to build the original Kahler Hotel and other buildings in the area. Architect Hugh Vincent Feehan was hired by the City to design the layout of the lake and park surrounding it so it could be a recreational feature for the City. The original lake created was 17 acres, with a lagoon and small island to the east. Three arched bridges spanned to the island. Silver Lake Park was dedicated June 25, 1937.

Compare the aerial photograph of Silver Lake today with this 1923 soil survey map of Rochester. Can you see that today's east lagoons were once the Silver Creek channel? A new confluence of Silver Creek with the Zumbro River was another result of the Silver Lake project.

1923 Soil Survey Near Silver Lake



Source: Soil Survey of Olmsted County, Minnesota by J. Ambrose Elwell, G. B. Shivery. B.H.Hendrickson, Mark Baldwin, and A. T. Sweet

Silver Lake Characteristics:

Lake Area (acres): 40
Maximum Depth (ft): 11
Water Clarity range (ft): 0.5 – 4.5

Source: Deb Las

Silver Lake

Source: Deb Las

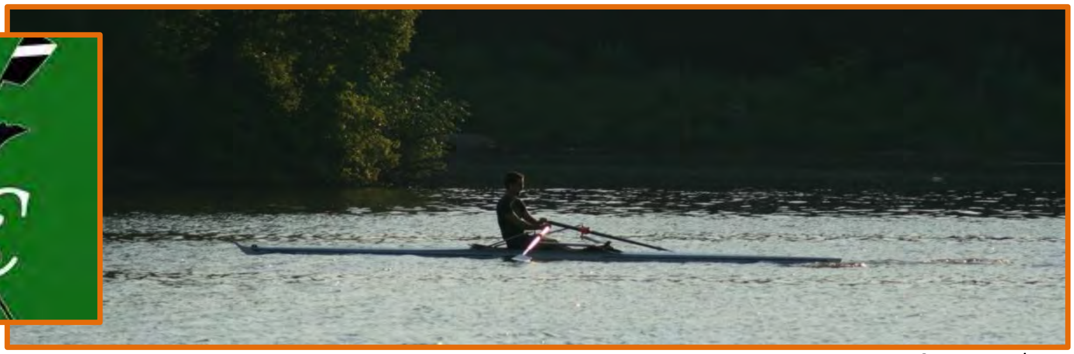
Today, the Silver Lake dam is managed by Rochester Public Utilities (RPU). It holds back the waters of the Zumbro River, forming the Lake and controlling water levels. The Lake acts as a stilling basin for the river, causing the water to slow down. With a decrease in velocity, the river cannot carry heavier materials, so sediment collects on the lake bottom. Over time, as sediment collected in the Lake, the Lake depth and volume decreased. Dredging the Lake to restore depth and recreational capacity was found to be necessary as early as 1945. The City purchased a floating dredge so it could operate seasonally from 1947 to 1962, until a flood destroyed the equipment. Dredging resumed in 1964 when equipment was replaced and continued in 1967, 1969, 1975, 1976, 1980, and also during the construction of the City's Flood Control Project between 1986 and 1995. Dredged material was used to fill the Old Mill Pond (where the Silver Lake Power Plant is currently located), old sand pits, and a swampy area south of 7th Ave NE and the Izaak Walton League cabin. When the sediment level reaches the threshold set by the Army Corps of Engineers for the flood control channel, a channel dredging project within the Lake will be planned.

The stretch of the Zumbro River most frequently dredged was designed as a wider channel by Army Corps engineers to slow the flow of water so sediments would settle out. That particular stretch was chosen because the bottom of the river channel is bedrock. That makes it less desirable habitat for fish and an easier location to collect sediment so flood storage capacity can be restored.

Dredging is the removal of bottom sediments. Watch a YouTube video of a Zumbro River dredging project here:

http://www.youtube.com/watch?v=eaVGtc5sG9Y

Silver Lake Park was originally created for recreation (See Chapter 2: Rochester's Water History) and it is still heavily used for that purpose today. Trails with benches encircle the lake. Tables and shelters are available for picnics. It is the site for the annual 4th of July concert and fireworks show. A private business rents paddleboats on the west bank. Silver Lake has been the home for the Rochester Rowing Club since 1992.



Source: Deb Las

A fishing pier and several limestone pathways make fishing access easy. The following table identifies the types of fish that are present in Silver Lake.

Source: David Leske

Fish Sampled in Silver Lake by DNR (2007)

Species	Gear Used	Number of fish per net		Average Fish	Normal Range
		Caught	Normal Range		
Black Bullhead	Trap net	0.29	2.5 - 70.2	0.57	0.1 - 0.5
Black Crappie	Trap net	15	1.3 - 27.7	0.25	0.1 - 0.4
	Gill net	1.5	2.0 - 19.0	0.42	0.1 - 0.2
Bluegill	Trap net	21.14	2.8 - 43.3	0.13	0.1 - 0.3
Common Carp	Trap net	0.14	0.4 - 2.9	2.98	1.4 - 4.5
Common Shiner	Gill net	2	N/A	0.1	N/A
Golden Redhorse	Trap net	2.29	N/A	0.71	N/A
	Gill net	9	N/A	0.67	N/A
Green Sunfish	Trap net	1.71	0.4 - 3.8	0.07	0.1 - 0.2
Hybrid Sunfish	Trap net	0.29	N/A	0.11	N/A
Largemouth Bass	Gill net	0.5	1.0 - 3.8	1.04	0.2 - 0.7
Northern Pike	Gill net	1	1.5 - 9.0	4.02	1.8 - 3.7
White Crappie	Trap net	1.14	0.3 - 8.2	0.36	0.1 - 0.5
White Sucker	Trap net	5.14	0.2 - 2.2	0.86	1.0 - 2.0
	Gill net	30	1.0 - 6.6	0.83	1.0 - 2.2
Yellow Bullhead	Trap net	0.43	0.3 - 4.2	0.5	0.5 - 0.8
	Gill net	0.5	1.0 - 4.1	0.4	0.5 - 0.7
Yellow Perch	Trap net	0.29	0.4 - 3.5	0.19	0.1 - 0.2
	Gill net	6.5	2.5 - 25.8	0.15	0.1 - 0.2

Source: www.dnr.state.mn.us/lakefind/showreport.html?downum=55000300

In the above table, Normal Range represents averages of typical catches for lakes with similar physical and chemical characteristics. The number of fish caught per net doesn't appear as a whole number because it is an average number based on the number of fish caught in all the nets. Click on the hyperlinks to go to the DNR web site to learn more about the linked fish species and the inventory techniques.

While fishing is allowed in Silver Lake and the Zumbro River, the Department of Natural Resources encourages moderation in the consumption of some fish species to limit exposure to mercury. Contaminants listed in the table below were measured at levels that trigger the stated advice to limit consumption. Pregnant women, women who may become pregnant, and children under age 15 have a lower consumption advisory.

Silver Lake Fish Consumption Limitations for the General Population

	Species	Meal Advice				Contaminants
		Unrestricted	1 meal/week	1 meal/month	Do not eat	
SILVER LAKE	Carp	All sizes				
Olmsted Co.	Channel Catfish		All sizes			Mercury
55000300	Crappie	All sizes				
	Redhorse Sucker	All sizes				
	White Sucker		All sizes			Mercury
	Yellow Perch		All sizes			Mercury

Source: www.dnr.state.mn.us/lakefind/fca/report.html?downum=55000300

Aquatic plants also live in Silver Lake and they are important in providing food and habitat for many animals such as fish, frogs, birds, muskrats, turtles, insects, and snails. The area within a lake or pond where aquatic plants grow is called the littoral zone. It is a shallow transition zone between dry land and the open water area of the lake. In Minnesota waters, the littoral zone extends from the shore to a depth of about 15 feet, depending on water clarity. The shallow water, abundant light, and nutrient-rich sediment provide ideal conditions for plant growth. Protecting the littoral zone is important for the health of a lake's fish and other animal populations.

As can be seen below, there are four categories of plants that typically grow in a littoral zone: emergent plants, floating plants, submerged plants and suspended algae. For many years, Silver Lake had an artificial shoreline made from pillowed concrete to control shoreline erosion. In 2007, native prairie and wetland plants were planted to create an upland shoreline buffer, but attempts to grow emergent plants on top of the concrete bank and in the lake were thwarted by the 2007 flood event (see Ch. 7 Rochester's Storm Water Management System).

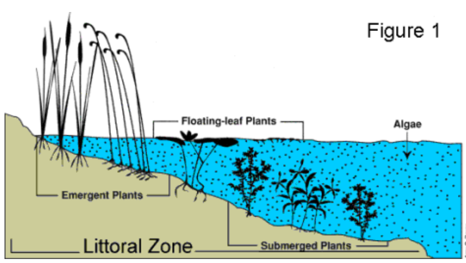


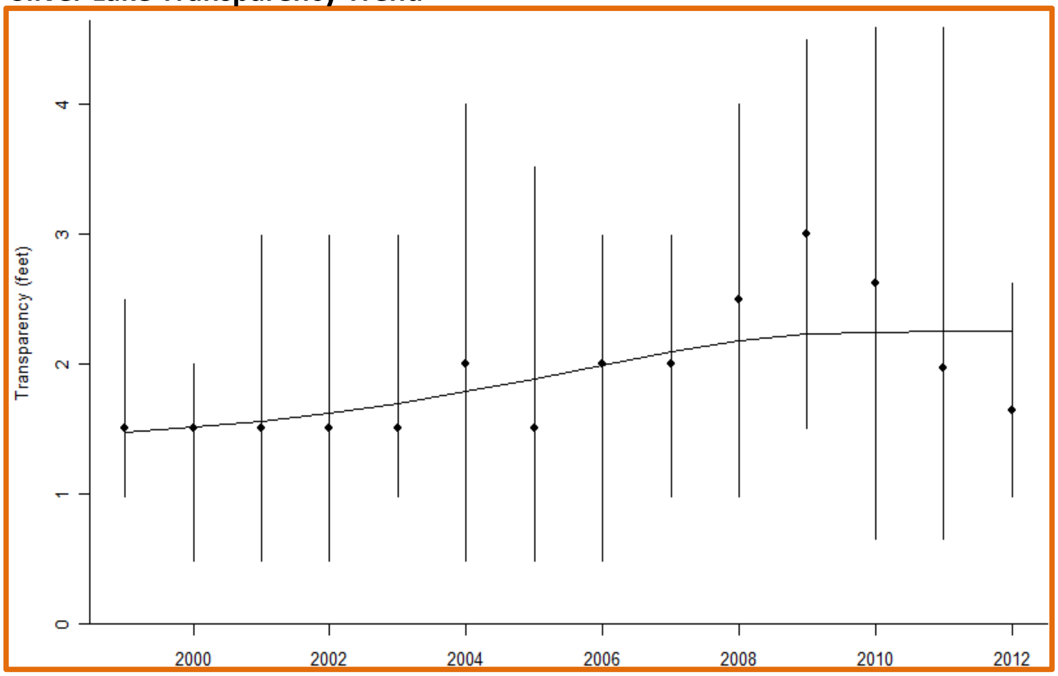
Figure 1

Littoral refers to the lake shore area where aquatic plants grow.

Water transparency is an excellent indicator of water quality. It is measured in lakes using an instrument called a Secchi disk, which is a circular, 8 inch diameter metal plate painted with alternating white and black colors. It is connected to a rope with distance measurements on it. The disk is lowered into the water until it disappears from view. The depth at which the disk can no longer be seen is the water clarity depth. The deeper the disk can be seen, the higher the number, the clearer the water. The clearest water generally occurs in the spring, shortly after ice-out. (A different device, called a transparency tube, is used to measure clarity in streams.)

Trend analysis of transparency results are presented in the chart below. It shows that the median transparency at Silver Lake increased by about 0.75 feet from 1999 to 2012. Although the annual trend is toward clearer water, the annual variability in clarity is still high (0.5 ft to 4.5 ft) and the lowest clarity readings are not improving significantly. This effect is probably due to the fact that the Zumbro River flows through Silver Lake. The river drains a large watershed, so sediment is transported into the river and through the Lake after each snowmelt and rain event.

Silver Lake Transparency Trend



Source: http://cf.pca.state.mn.us/water/watershedweb/datasearch/waterUnit.cfm?WID=55-0003-00

● Median for each year | Data range for each year — Trend line

Foster Arend Lake

Converting private sand and gravel mining pits to small lakes is common in Rochester. Foster Arend Lake is one example of an artificial lake created from a mine pit after all its sand and gravel was removed. The lake was originally the site of commercial mining by Rochester Sand and Gravel. The acreage was purchased by the City from Edward Foster and Raymond Arend on June 1, 1981, so that it could become part of the park system, offering swimming, fishing, and picnicking. Beach grading started in 1983 and continued into 1984. In 1985, a fishing pier was constructed and the beach opened. A rip-rap bank was installed for stabilization. The fishing pier was expanded to 150' in 1991. Trout are stocked annually by the Minnesota Department of Natural Resources. The pond has hosted events such as triathlons, lumberjack competitions, and polar plunges through the ice.

Foster Arend Fishing Pier and Beach

Source: Deb Las

Lake Characteristics

Lake Area (acres): around 17.7
Maximum Depth (ft): 42

Foster Arend -2012 Fish Stocking *55001900*

Brook Trout - 920 adults weighing 400.2 lbs.
Rainbow Trout - 7,800 yearlings weighing 5,283.5 lbs.

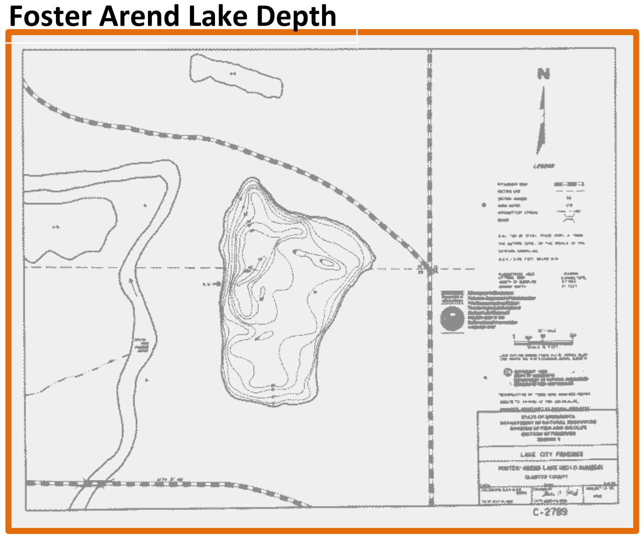
Foster Arend Aerial View 2012

Source: Rochester Public Works

Unfortunately, the 15 acre Lake was the site of eight drowning deaths between its opening in 1985 and 2007. In 2008, the City posted new signage, added chain link fencing around the water area, and installed gates to each entrance. The Park Board adopted new hours and rules for the Park. A security service was also added. Since these measures were added, no further incidents have occurred.

Like all mine pits in Rochester, if the sand and gravel is excavated at a depth below the water table, when mining is over, the pit will fill with cold, clear groundwater. That is why trout like it. The depth of Foster Arend Lake is determined by completing a bathymetric survey. This is a technique to measure the distance from the surface of the water to the bottom of the lake, either using marked cables or an echosounder (i.e., sonar) mounted on the side of a boat. A beam of sound or light is sent downward and the amount of time it takes to bounce off the bottom and return to the surface informs the equipment of the distance. Depth contours like those shown above can then be mapped.

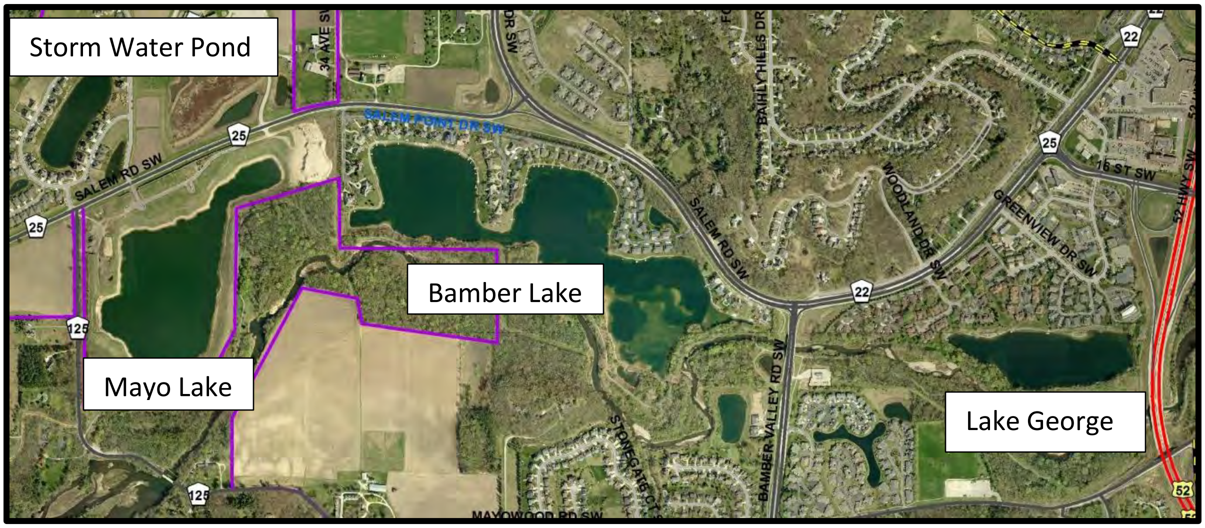
Foster Arend Lake Depth



Source: MnDNR

Other mining pits have also been converted to private water bodies that are used for recreation, for aesthetics, or to treat storm water. Bamber Valley Lake, for example, is a small, private lake owned by the Salem Sound and Salem Point housing developments.

Lakes and Ponds Along Salem Road SW, Rochester



Source: Rochester Public Works

Lakes and Ponds South of Hwy 14 NW, Rochester

Source: Rochester Public Works

Flood Control Project Reservoirs

Rochester has seven reservoirs specifically designed and constructed as part of the City's Flood Control Project to store rainfall in the upper, or headwater, portions of the South Zumbro Watershed. Once captured, the water can then be released slowly downstream over a longer period of time, significantly reducing flooding. As can be seen in the following table, the outflow rate for each reservoir is reduced from between 2% to 10% of the inflow rate. Inflow rates are based on peak inflow modeled for the contributing areas for the 500 year storm event.

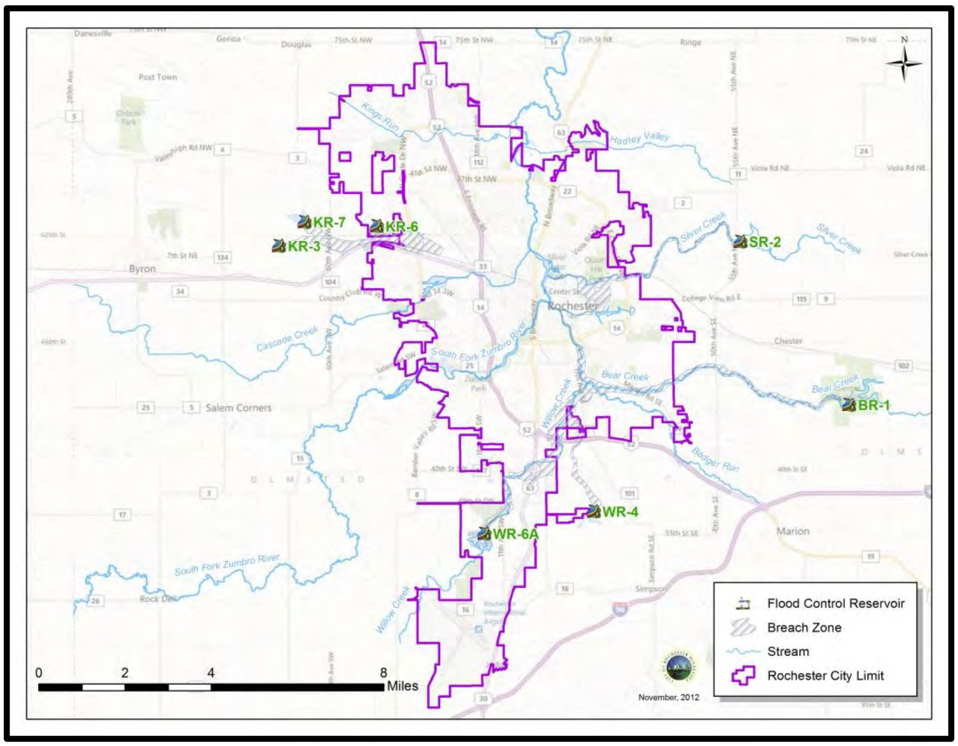
Predicted Inflow & Outflow Rates for a 500 Year Storm Event

(in cubic feet per second)

Reservoir	Inflow	Outflow
WR-4 (Willow Creek by Gamehaven)	2912 cfs	143 cfs
WR-6A (Willow Creek west of TH 63)	2824 cfs	275 cfs
BR-1 (Chester Lake)	5019 cfs	410 cfs
SR-2 (Silver Creek)	6944 cfs	113 cfs
KR-3 (Kalmar Twp, south of landfill)	1513 cfs	115 cfs
KR-6 (Kalmar Twp; dry)	2810 cfs	96 cfs
Kalmar KR-7 (Kalmar Twp, east of landfill)	2584 cfs	95 cfs

Source: U.S. Army Corps of Engineers

Reservoirs in Rochester



Source: Rochester Public Works

While the reservoirs' primary value is for flood control, they are also used for recreation. An example is the KR-7 Reservoir in Kalmar Township, east of the County's Kalmar Landfill. KR-7 was constructed in the early 1990 to store waters in the North Branch Cascade Creek Watershed, northwest of Rochester. An earthen dam holds back the waters collected in the reservoir after each rainfall event. The surface area of the reservoir covers about 20 acres and its maximum depth is about 8 feet.

In 2009, the DNR stocked 113 largemouth bass in KR-7 to try and increase the size of the bluegills, black crappies, and yellow perch. Even though the reservoir is considered “highly productive”, both summer and winter fish kills have occurred due to a seasonal lack of oxygen.

Kalmar Reservoir and Dam

Source: Deb Las

North Branch Cascade Creek

Source: Deb Las

The North Branch of Cascade Creek discharges from KR-7 to the channel below the dam. The water flow is regulated through an engineered control structure.

A dam is an artificial barrier (together with any associated spillways and other related structures) that is placed across a watercourse or natural drainage area that impounds or diverts water.

Check out DNR’s lake finder tool to learn about local lakes: www.dnr.state.mn.us/lakefind/index.html

Quarry Hill Pond & Other Water Features

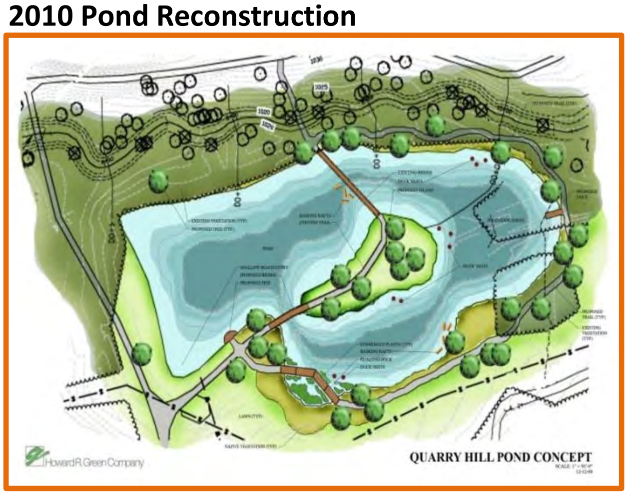
Quarry Hill Park and Nature Center are located near Silver Creek in SE Rochester. An artificial pond was constructed in the Park in 1978 as an environmental education feature. That pond was built using a plastic liner that was covered with soil. The million gallon pond was initially filled with water pumped from nearby Silver Creek. It was completed on October 12, 1979. Thereafter, water from the Nature Center was pumped into the pond to offset evaporation and to add oxygen to the pond. Unfortunately, the liner was ripped at the time of construction and burrowing animals caused other leaks that added to the problem of keeping water in the pond.

1978 Pond

Source: Quarry Hill Nature Center, Harry Buck

In 2010, the City got a grant to reconstruct and expand the pond. This time, clay excavated on site was compacted to form the pond liner. Additionally, when Quarry Hill Creek was returned to its original alignment west of the pond, an infiltration system was installed that allowed water to flow from the creek into the pond. An overflow structure was built in the pond to allow high water to flow from the pond into the creek so a more constant water level could be maintained in the pond. In addition to offsetting evaporation, the periodic influxes of creek water also add oxygen to the pond so that well water no longer needs to be used to maintain the pond's water level. By using creek water instead of well water, the Nature Center is also saving money on their water and electrical bills. The DNR stocked the pond with 324 adult bluegill sunfish in 2012.

2010 Pond Reconstruction



Source: Howard Green

Quarry Hill Pond Today

Source: Deb Las

Storm Water Pond

Source: Rochester Public Works

There are other types of constructed water bodies in Rochester, too. Some developments build a pond solely as a feature to beautify their landscape. There are hundreds of ponds built to manage storm water (see Ch. 7 Rochester's Storm Water Management System). Rochester was responsible for building the dam that created Lake Zumbro (another reservoir) to produce hydroelectric power. To meet floodplain regulations, some ponds are built to provide flood storage when it is lost because of construction in the floodplain. On golf courses, ponds are built to provide a challenge to golfers. It is difficult to know by looking at it why a water body was built, so the City keeps records of the intended functions of these artificial water bodies.

Throughout Rochester, there are many acres of constructed wetlands built to offset wetlands that are lost when new residential and commercial areas are constructed. Constructed wetlands must be created to meet the requirements of the Minnesota's Wetland Conservation Act (see Ch. 4 Rochester's Natural Water Features). A new technique being tried in Rochester today is the installation of floating wetlands to help absorb nutrients in storm water ponds.

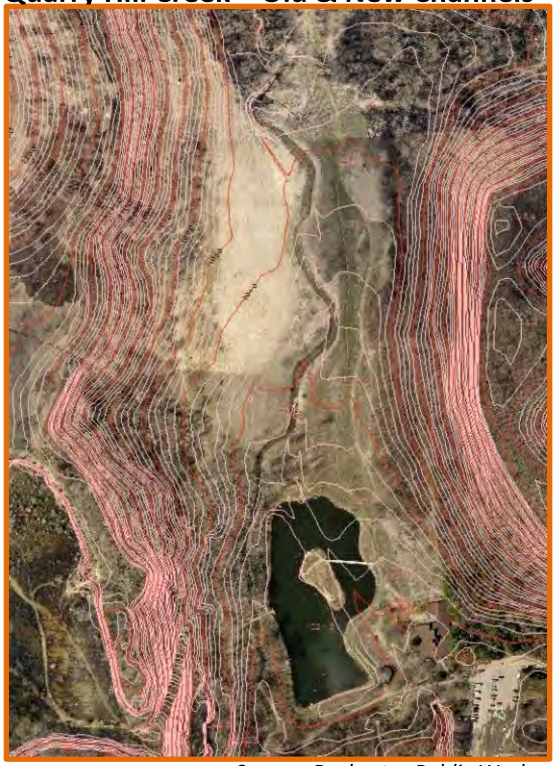
Restored Wetland

Source: Rochester Public Works

Floating Wetland

Source: Rochester Public Works

Quarry Hill Creek – Old & New Channels



Source: Rochester Public Works

Rochester also has a history of reconstructing its rivers. Flows from the Zumbro River were redirected into constructed "mill runs" to power flour and lumber mills in the late 1800's. Back in the 1930's, the original confluence of Silver Creek became part of Silver Lake and a new channel connecting Silver Creek to the Zumbro River was dug. Quarry Hill Creek was moved during the Great Depression by the Works Project Administration, possibly to protect the quarry road from constant flooding. Seventy years later, this caused upstream damages that were corrected by moving the lower portion of Quarry Hill Creek from east of the meadow back to its earlier location on the west side. At the same time, the uppermost western tributary to Quarry Hill Creek was engineered using natural processes and structures to control overland storm water flows and provide native habitat. The Zumbro was widened and deepened in the 1980's to provide protection from floods. Portions of Cascade Creek, Bear Creek and the mouth of Silver Creek were also modified to control floods (see Ch. 2 Rochester's Water History). Portions of Mayo Run were directed into underground storm sewers, so it is no longer a free flowing river. Over the last century and a half, humans have changed water to meet their needs. What will our practices be in the next century?

Important Artificial Water Body Construction Dates in History:

- 1911 Dam constructed on Zumbro River to form Mayowood Lake
- 1919 Dam constructed on the Zumbro River to form Lake Zumbro
- 1936 Dam constructed on Zumbro River to form Silver Lake
- 1978 Quarry Hill Pond built with a plastic liner for environmental education
- 1985 Foster Arend Lake and Park opened
- 1985 Rochester requires its first storm water management ponds
- 1986 Reservoir WR-6A (Willow Creek) built
- 1988 Reservoir WR-4 (near the Gamehaven Boy Scout Camp) built
- 1990 Reservoir SR-2 (Sliver Creek) built
- 1994 Reservoir BR-1 (Chester Lake) built
- 1994 Reservoir KR-6 (Kalmar Township, in west Rochester) built
- 1995 Reservoir KR-3 (Kalmar, south of landfill) built
- 1996 Reservoir KR-7 (Kalmar, east of Landfill) built
- 2010 Quarry Hill Pond reconstructed and expanded

Case Study: Sizing a Storm Water Pond

The effectiveness of treatment by a pond is dependent on the quality of the pond's design. Engineers are the professionals that have the knowledge and experience with hydrologic and hydraulic modeling to design wet sedimentation basins that meet these complicated requirements. These basins are also called wet extended detention ponds. In this exercise, you will be asked to complete two steps of this process.

Engineers, hydrologists, and other professionals work together to design and build ponds as part of the storm water management system. It is suggested that students also work together to solve the problems in this case study. Just as professionals have expertise in specific content areas, students also have different skill sets that complement each other. The important thing is to use every member's skill and knowledge in some way and to make sure every member of the group understands how the answers were calculated. Math, reading and problem solving skills are needed for real life applications. (NOTE: While this case study has left some terminology intact, it has been simplified for adaptation to the classroom.)

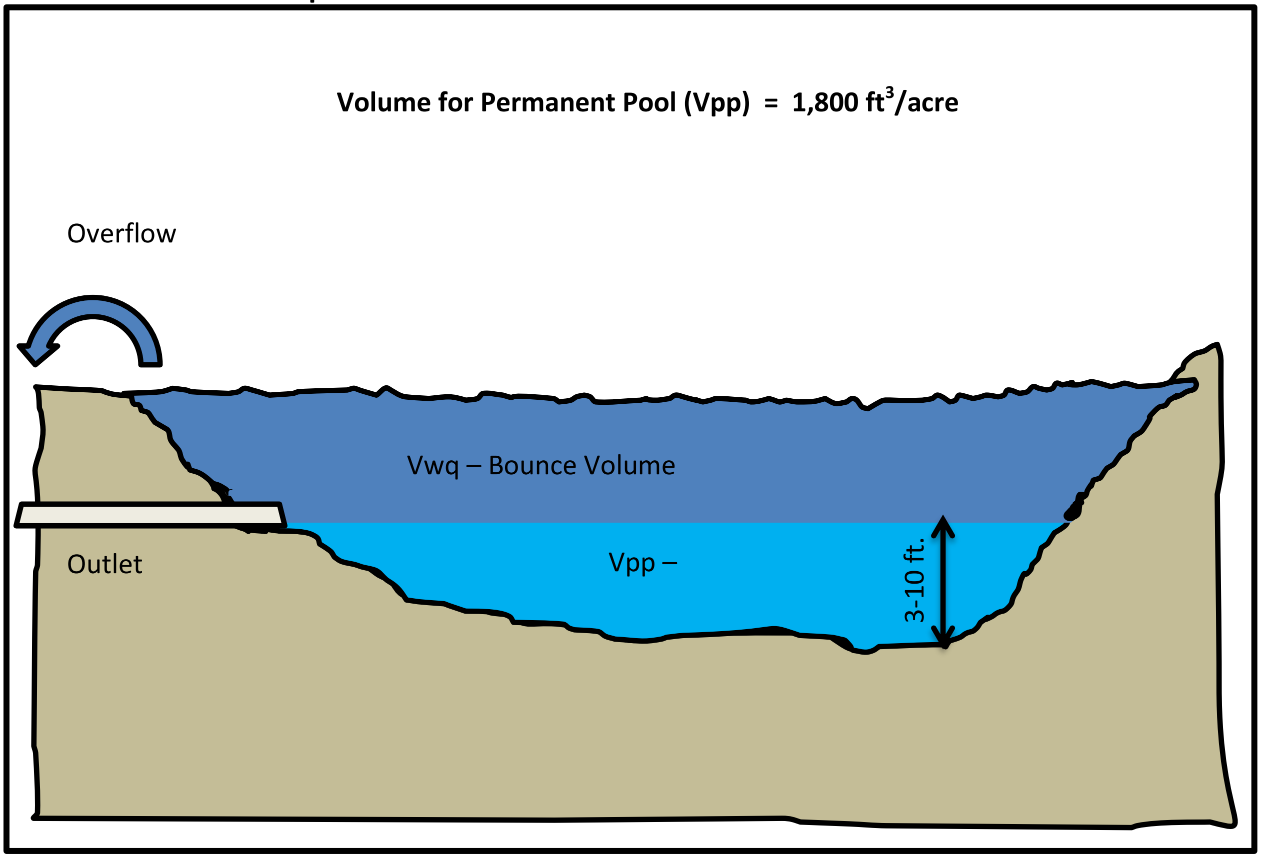
When Congress passed the Clean Water Act, the Environmental Protection Agency (EPA) had to develop federal rules that require the treatment of storm water runoff in cities like Rochester. EPA then gave authority to the Minnesota Pollution Control Agency (MPCA) to write the permits that meet the intent of the federal rules. Part of MPCA's Construction Storm water Permit contains the following requirements to address permanent treatment of storm water runoff in the constructed ponds:

Part III.D. PERMANENT STORMWATER MANAGEMENT SYSTEM (August 1, 2013 issued permit)
2. Wet Sedimentation Basin

a. *The Permitte(s) must design the basin to have a permanent volume of* ***1,800 cubic feet of storage*** *below the outlet pipe* ***for each acre that drains to the basin****. The basin's permanent volume must reach a minimum depth of at least three (3) feet and must have no depth greater than 10 feet. The basin must be configured such that scour or re-suspension of solids is minimized.*
b. *The Permittee(s) must design basins to provide live storage for a* ***water quality volume*** *(calculated as an instantaneous volume) of* ***one (1) inch of runoff*** *(or one (1) inch minus the volume of storm water treated by another system on the site)* ***from the new impervious surfaces*** *created by the project.*

A simple schematic of a treatment pond is shown below that demonstrates the two requirements listed above.

Storm Water Pond Requirements



Source: Rochester Public Works

According to the MPCA, "Ponds rely on physical, biological, and chemical processes to remove pollutants from incoming storm water runoff. The primary treatment mechanism is gravitational settling of particulates and their associated pollutants as storm water runoff resides in the pond. Another mechanism for the removal of pollutants (particularly nutrients) is uptake by algae and aquatic vegetation." Pollutants can react with other chemicals or they can shift to a gaseous state, thereby changing to non-toxic or less-threatening chemicals.

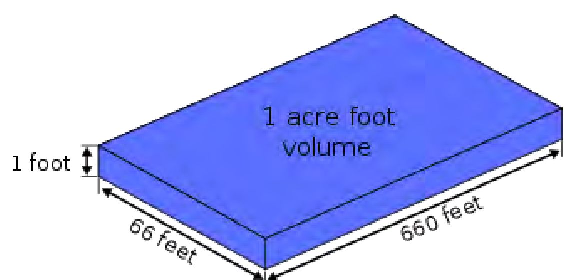
Using this information, solve the following problems.

1. a) A wet basin is required to have a permanent pool volume (Vpp) of 1,800 cubic feet of storage below the pond's outlet pipe for each acre that drains to the basin. Ridgeview Manor is a residential development in NW Rochester that contains homes, roads, parkland and wetlands. Assume the yellow line in the following map encompasses a drainage area of 50 acres and all the water within that area will flow to a pond to be located where the yellow oval is placed on the figure below. To treat the drainage from this area, how many cubic feet of storage will be needed below the outlet pipe? (Hint: 1,800 ft^3/1 acre = Vpp ft^3/50 acres.)

Answer: Vpp =_____________________________ ft^3

b) Cubic feet (ft^3) is one example of a volume measurement. Another common volume measurement is acre-feet. Imagine that one acre of land (66 ft X 660 ft) is covered by one foot of water. That amount of water is one acre-foot or 43,560 ft^3. How many acre-feet of water would need to be stored in this pond? (Hint: 1 acre/43,560 ft^3 = X acre-feet/Vpp)

Answer: __________________________ acre-feet



Source: Wikipedia

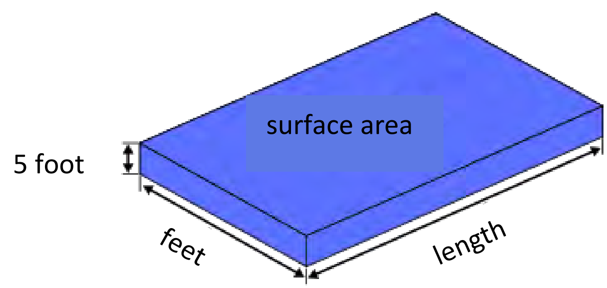
2. Constructed surfaces that prevent storm water from infiltrating into the ground are called impervious surfaces. Within this neighborhood, what types of impervious surfaces are present?

3. Assume that 16% of this drainage area is made up of impervious surfaces. How many acres of impervious surface would that be?

4. The total storage volume of the wet pond (Vts) will equal Vpp plus the additional storage needed for water quality treatment, which is called the water quality volume (Vwq), where Vwq equals 1.0 inch of runoff per impervious acre.
    a) What is the water quality volume needed to serve Ridgeview Manor?
    Vwq = (1 in)(___impervious acres)(1ft/12in) = _____ acre-feet
    (see answer #3)

    b) What is the total storage volume needed to serve Ridgeview Manor?
    Vpp _____acre-feet + Vwq ____ acre-feet =Vts ____ acre-ft
    (see answer #1b) *(see answer #4a)*

5. There is not a lot of room for the pond on the property, so it will need to be deeper than the minimum 3 feet deep. Assuming that the final permanent pool depth of the pond (Vpp) will be 5 feet, what will the surface area of the pond need to be? (Hint: See 1a; for easier calculating, assume that the pond is a prism, like the figure shown at the right).



6. If the pond (Vpp) is only allowed to be 100 feet wide, how long would it be? (Hint: L x W = Area)

(Answers on the next page.)

Answers:

1. a) $1,800\ ft^3$/acre x 50 acres = Vpp
   Vpp = $90,000\ ft^3$

   b) $90,000\ ft^3$ x 1 acre/$43,560\ ft^2$
   =$90,000\ ft^3$ x acre/$43,560\ ft^2$ = 2.066 acre-ft, or 2.07 acre-ft

2. Roofs, driveways, sidewalks, roads, bike trails

3. 50 acres x 0.16 = 8 acres of impervious surface

4. a) Water quality volume Vwq = (1 in)(8 impervious acres)(1ft/12in) = 0.666 or 0.7 acre- ft

   b) Total Storage Volume: Vpp: 2.07 acre-ft + Vwq 0.67 acre feet = Vts 2.74 acre-ft

   (see answer #1b) *(see answer #4a)*

5. $90,000\ ft^3/5\ ft = 18,000\ ft^2$

6. $18,000\ ft^2$ = L x W, where L x 100 ft
   L = $18,000 ft^2/100\ ft$ =180 ft