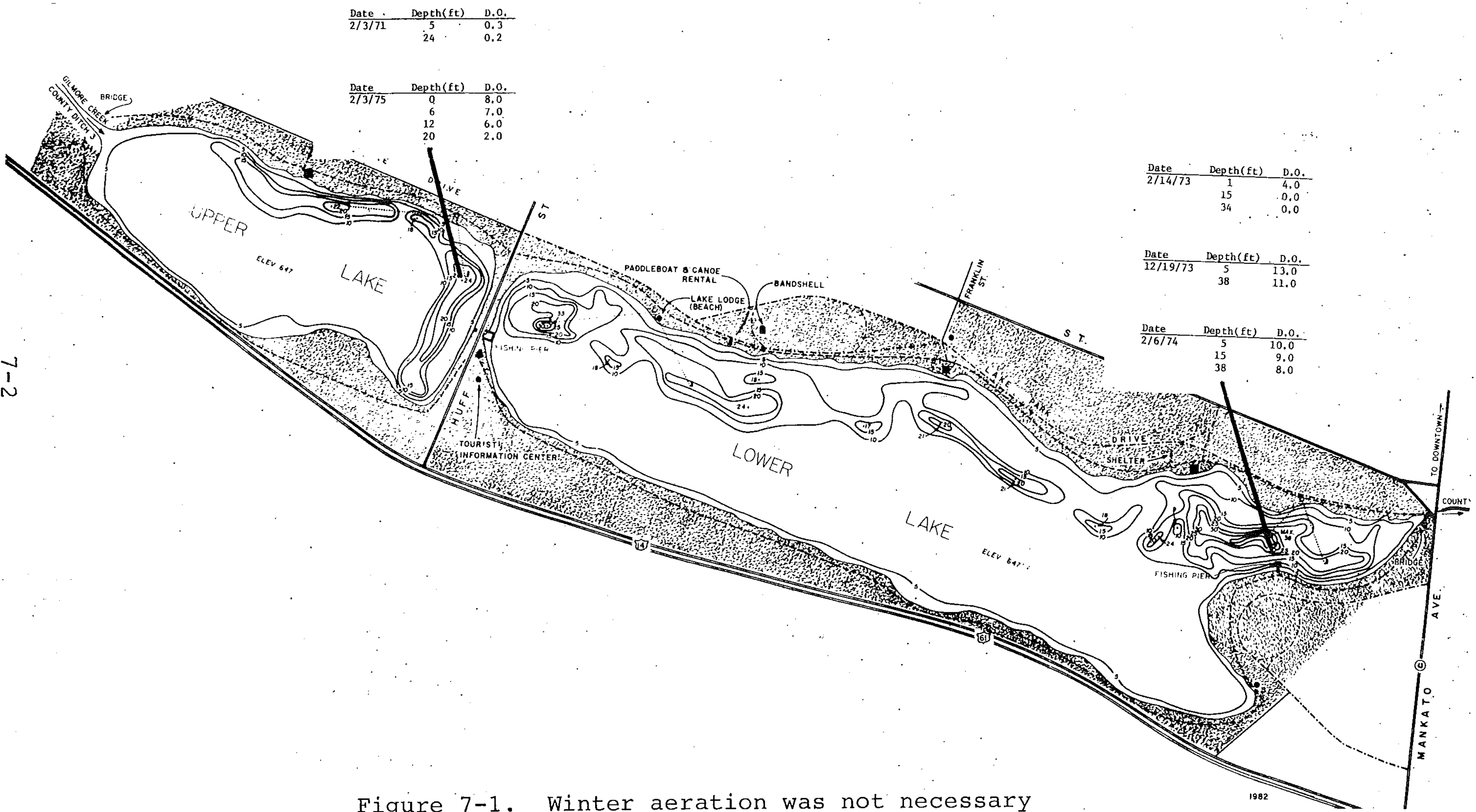
7. AERATION: PROBLEMS, MODIFICATIONS, COSTS, EFFECTS

During the first three years following reclamation, all three aeration units were turned on in the spring at the time of break-up (mid March-early April). They were run all summer to destratify the lake and then turned off just prior to freeze up (late November). There was no need to run them during the first few years because oxygen levels remained high (Fig. 7-1). On January 20, 1977, however, low dissolved oxygen levels made it necessary to start the compressor in the west lake and the one near Mankato Avenue (Fig. 7-2). (The unit at the bathing beach is never run until late winter because it would destroy the public skating rink.) The mid-winter start-up necessitated informing the public, putting up warning signs and moving fish houses. In 1978, the compressors were started on January 24. During the following winter, Winona State University's dissolved oxygen meters were all non-functional and routine dissolved oxygen measurements could not be taken until January 5, 1979, when tests showed that dissolved oxygen levels had fallen below 3 ppm at depths greater than 3 feet at all sample locations (Fig. 7-3). Unfortunately, the crisis came during a period of prolonged extreme cold when it would be very difficult to start the compressors because of the extreme viscosity of their crank case oil. At an emergency meeting with city officials, it was decided to heat the compressors with torches so they could be started. This was done successfully, but it was obvious that a winter kill had almost occurred. (Waiting until the "last minute" to start aeration can cause a winter kill by mixing extremely low-oxygen water from the lake bottom with the better-oxygenated water near the surface.) Therefore, it was decided that henceforth aerators would be run year-round, except the unit at the public beach which would only be run from early spring until freeze up. This schedule has worked well because it has eliminated crisis situations. Warning signs are erected early, and the public is informed via newspaper and radio. Because the same procedures are used yearly, the public has become accustomed to them; fishermen do not get a chance to locate their fish houses over aeration units.

Winter aeration in Minnesota can only be done by permit from the Department of Natural Resources. The permitting process has become increasingly stringent in recent years because of fatalities (usually snowmobilers at night) at aeration holes. The City of Winona's permit to aerate Lake Winona is on file at the office of the Director of Parks and Recreation.

A small ½h.p. surface aerator was installed at the Huff Street fishing pier in 1977. It keeps the area around the pier open all winter, thus preventing ice from damaging the pier. A third aerator (perforated PVC pipe) was installed at the East End Fishing Pier for the same reason. The latter unit is powered by the same compressor which operates the two original Helixors at the east end of the lake.



Date	Depth(ft)	D.O.
2/3/71	5	0.3
	24	0.2

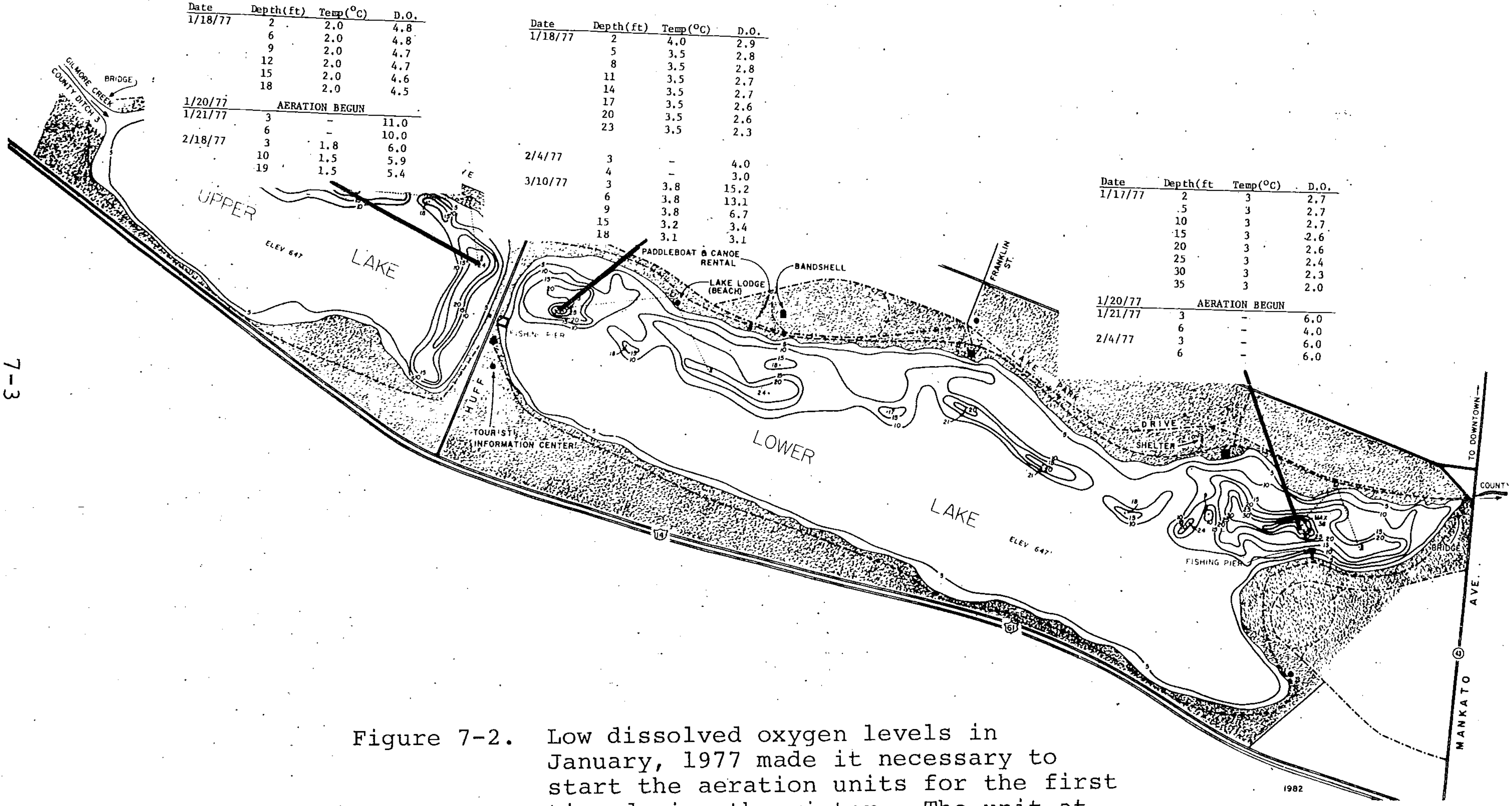
Date	Depth(ft)	D.O.
2/3/75	0	8.0
	6	7.0
	12	6.0
	20	2.0

Date	Depth(ft)	D.O.
2/14/73	1	4.0
	15	0.0
	34	0.0

Date	Depth(ft)	D.O.
12/19/73	5	13.0
	38	11.0

Date	Depth(ft)	D.O.
2/6/74	5	10.0
	15	9.0
	38	8.0

Figure 7-1. Winter aeration was not necessary during the first three winters following reclamation because dissolved oxygen levels remained high.

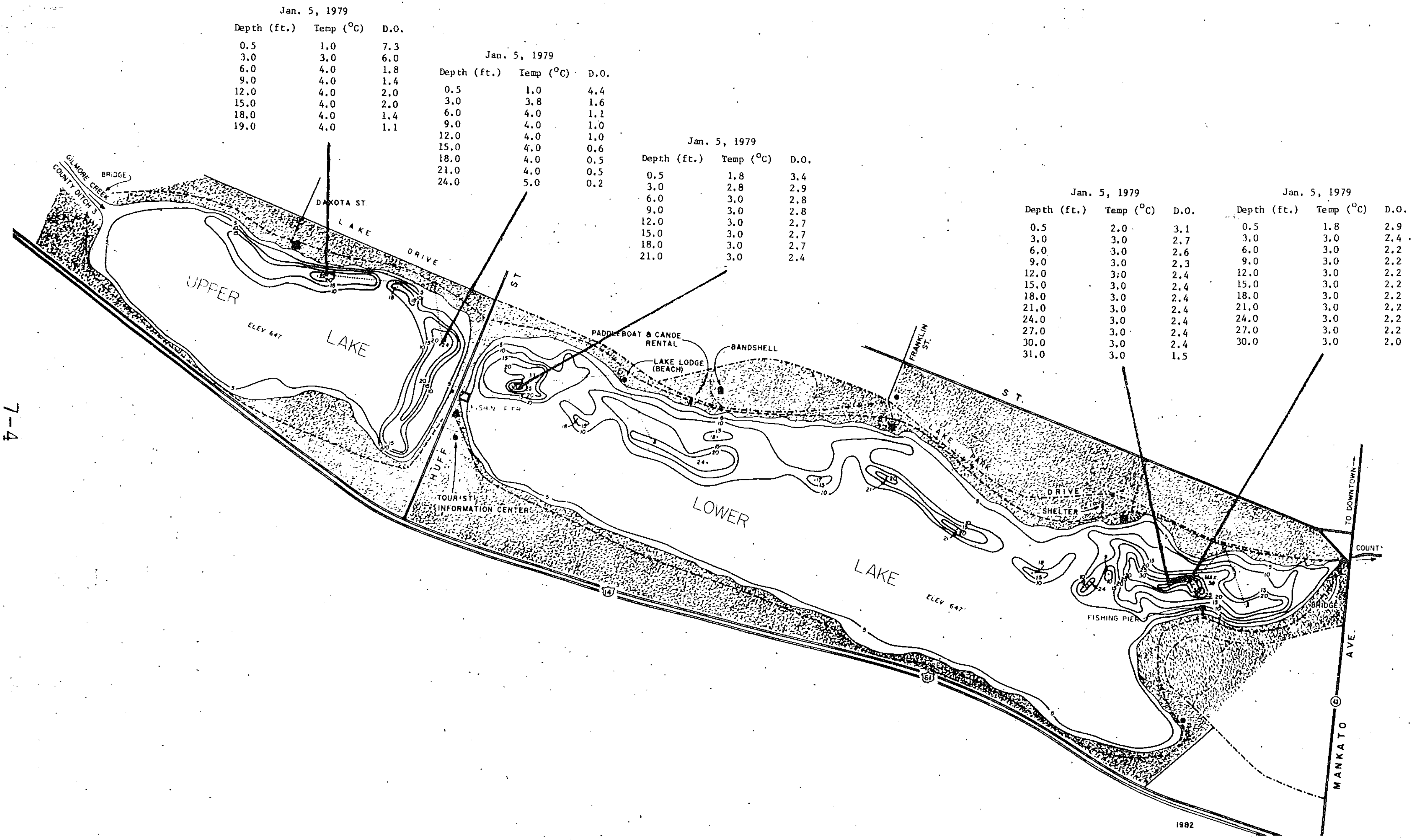


Date	Depth(ft)	Temp(°C)	D.O.
1/18/77	2	2.0	4.8
	6	2.0	4.8
	9	2.0	4.7
	12	2.0	4.7
	15	2.0	4.6
	18	2.0	4.5
1/20/77	AERATION BEGUN		
1/21/77	3	-	11.0
	6	-	10.0
2/18/77	3	1.8	6.0
	10	1.5	5.9
	19	1.5	5.4

Date	Depth(ft)	Temp(°C)	D.O.
1/18/77	2	4.0	2.9
	5	3.5	2.8
	8	3.5	2.8
	11	3.5	2.7
	14	3.5	2.7
	17	3.5	2.6
	20	3.5	2.6
	23	3.5	2.3
2/4/77	3	-	4.0
	4	-	3.0
3/10/77	3	3.8	15.2
	6	3.8	13.1
	9	3.8	6.7
	15	3.2	3.4
	18	3.1	3.1

Date	Depth(ft	Temp(°C)	D.O.
1/17/77	2	3	2.7
	.5	3	2.7
	10	3	2.7
	15	3	2.6
	20	3	2.6
	25	3	2.4
	30	3	2.3
	35	3	2.0
1/20/77	AERATION BEGUN		
1/21/77	3	-	6.0
	6	-	4.0
2/4/77	3	-	6.0
	6	-	6.0

Figure 7-2. Low dissolved oxygen levels in January, 1977 made it necessary to start the aeration units for the first time during the winter. The unit at the bathing beach was not started until spring breakup.



Jan. 5, 1979

Depth (ft.)	Temp (°C)	D.O.
0.5	1.0	7.3
3.0	3.0	6.0
6.0	4.0	1.8
9.0	4.0	1.4
12.0	4.0	2.0
15.0	4.0	2.0
18.0	4.0	1.4
19.0	4.0	1.1

Jan. 5, 1979

Depth (ft.)	Temp (°C)	D.O.
0.5	1.0	4.4
3.0	3.8	1.6
6.0	4.0	1.1
9.0	4.0	1.0
12.0	4.0	1.0
15.0	4.0	0.6
18.0	4.0	0.5
21.0	4.0	0.5
24.0	5.0	0.2

Jan. 5, 1979

Depth (ft.)	Temp (°C)	D.O.
0.5	1.8	3.4
3.0	2.8	2.9
6.0	3.0	2.8
9.0	3.0	2.8
12.0	3.0	2.7
15.0	3.0	2.7
18.0	3.0	2.7
21.0	3.0	2.4

Jan. 5, 1979

Depth (ft.)	Temp (°C)	D.O.
0.5	2.0	3.1
3.0	3.0	2.7
6.0	3.0	2.6
9.0	3.0	2.3
12.0	3.0	2.4
15.0	3.0	2.4
18.0	3.0	2.4
21.0	3.0	2.4
24.0	3.0	2.4
27.0	3.0	2.4
30.0	3.0	2.4
31.0	3.0	1.5

Jan. 5, 1979

Depth (ft.)	Temp (°C)	D.O.
0.5	1.8	2.9
3.0	3.0	2.4
6.0	3.0	2.2
9.0	3.0	2.2
12.0	3.0	2.2
15.0	3.0	2.2
18.0	3.0	2.2
21.0	3.0	2.2
24.0	3.0	2.2
27.0	3.0	2.2
30.0	3.0	2.0

Figure 7-3. Tests on January 5, 1979 showed less than 3 ppm of dissolved oxygen at all depths greater than 3 feet. This necessitated emergency start-up of aeration units.

It is obvious that winter aeration is an absolute necessity in Lake Winona. Winter kill would be inevitable without it. The ramifications of yearly winter kills are many, the main ones being the loss of the sport fishery and the labor and expense of yearly springtime cleanup of as many as 225,000 pounds of rotten fish.

Aeration is efficient in fall, winter and spring because the lake is not thermally stratified then. In spring and fall, the lake is easily circulated because the entire lake may be 4°C (39°F) from top to bottom. Undoubtedly, aeration is most effective during the spring and fall turnover periods. Aerators do not have to work hard then to lift low-oxygen water from the bottom toward the top because the water throughout the entire lake is approximately the same density. Water lifted by air bubbles to the surface is further circulated and oxygenated by the wind. Contrary to popular belief, there is little direct transfer of oxygen from the rising bubbles to the water. The bubbles merely lift the water to the surface where it absorbs oxygen from the atmosphere. Actually, an "aerator" is more properly called a circulator; it functions like a pump.

Aeration (circulation) is also efficient during the period of winter ice cover. At that time, the water temperature just beneath the ice is 0°C (32°F). The water at the lake bottom is slightly warmer (4°C, 39°F). This phenomenon is due to the fact that water reaches its maximum density at 4°C (Fig. 7-4). Density differences are not great during the period of ice cover, thus it is easy to lift bottom water to the surface where it absorbs oxygen from the air. The solubility of oxygen (and other gases) is inversely proportional to water temperature, consequently absorption of oxygen at the surface is very rapid at winter temperatures.

Summer aeration is another story, however. Most lakes at Winona's latitude thermally stratify during the summer (Fig. 4-3). At that time, warm (less dense) water floats atop the colder (denser) water nearer the bottom. The difference in density between the warm water (epilimnion) and the cold water (hypolimnion) is so great (Fig. 7-4) that the lake is very stable; its center of gravity is low. Circulation does not occur naturally between the epilimnion and hypolimnion. It is difficult in summer to lift the denser, colder water through the less dense, warmer water to the surface. Testing from June 20-July 10, 1985 (Fig. 7-5) revealed that the aeration was not noticeable even 100 yards from the aerators. Apparently, cooler (denser) water from the lake bottom is lifted to the surface where it flows outward for a short distance before it sinks to the bottom to be lifted again. Moreover, this relatively warm water (about 13°C, 55°F) does not absorb oxygen as readily as winter water.

To further complicate the situation, Lake Winona has become richer in nutrients and organic matter with each passing year because of storm sewer inflow. Organic sediments and rotting weeds exert a heavy demand for oxygen, as do zooplankton and fish. Consequently, Lake Winona becomes so deficient in dissolved oxygen during the July-September period that it is incapable of supporting game fish at depths greater than 5 feet. The aerators apparently create small, cool refuges where fish can escape the heat of the epilimnion. Without summer aeration, there would probably be summer kills of sensitive species.

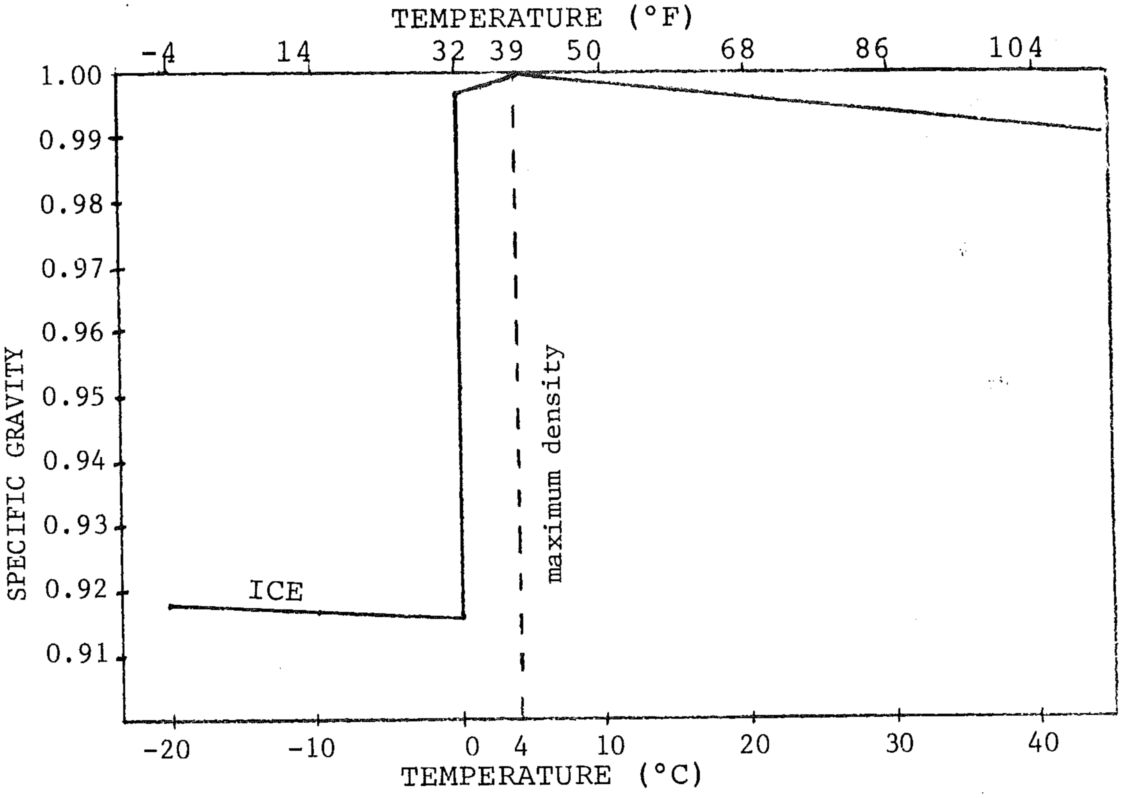
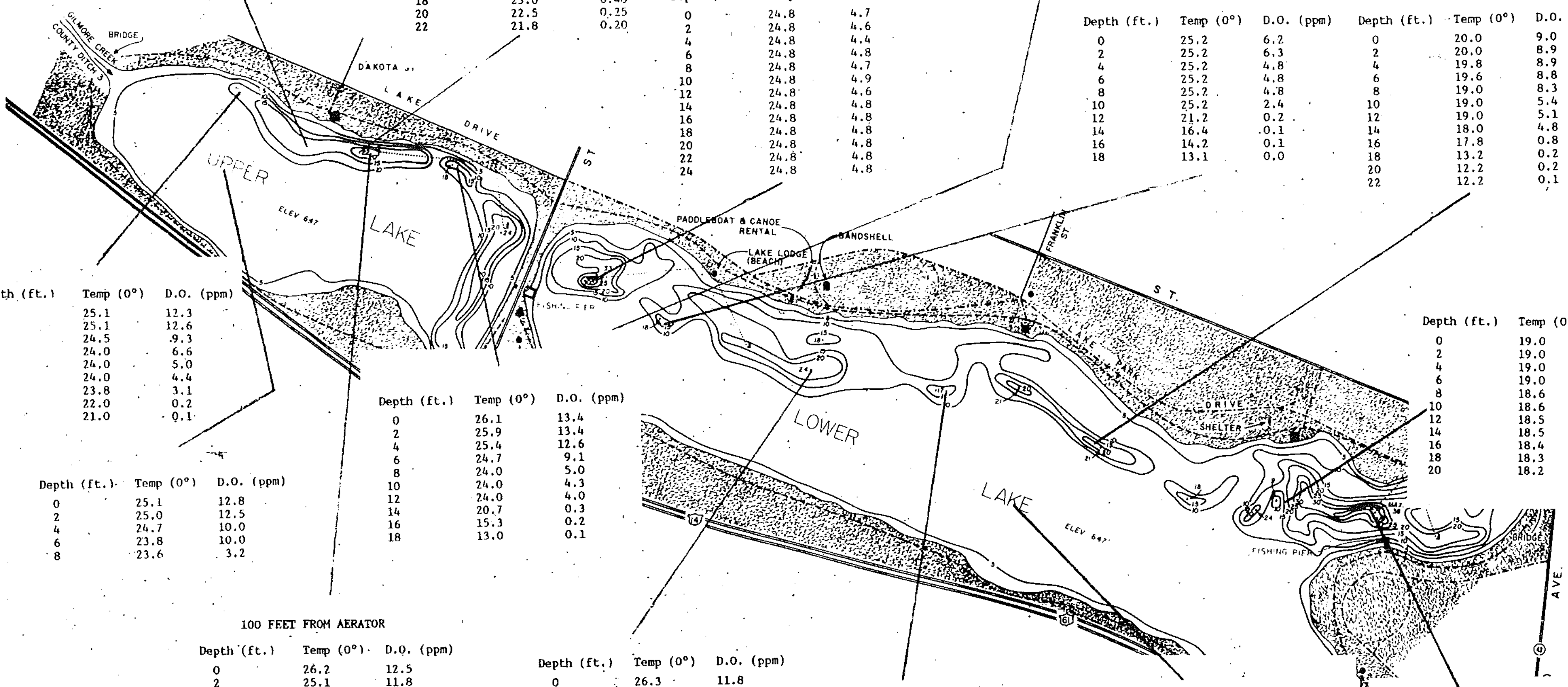


Fig. 7-4. Specific gravity (density) of water and ice at various temperatures.

Unfortunately, summer aeration does not oxygenate the rapidly-accumulating organic bottom sediments. Thus, they do not oxidize to carbon dioxide and water as they would if they were oxygenated. Because they are anerobic during the summer, the sediments cannot be inhabited by high quality fish food organisms like Hexagenia mayfly nymphs.

It is apparent that total aeration during the summer could not be accomplished without having Helixor units spaced in a grid pattern with the units less than 200 yards apart. The costs of such increased aeration would be prohibitive. A 1978 cost analysis showed that the east end compressor ran for 103 days at a total cost of $448 ($4.35 per day). The west lake compressor ran for 124 days at a total cost of $598 ($4.82 per day). Because the compressor at the bathing beach shares a meter with other equipment, it was not possible to determine costs. It is only run during the ice-free season. Although the present aeration system may seem expensive to operate, it is much less expensive than paying city crews to pick up hundreds of thousands of pounds of dead fish resulting from winter kills.

Presently, aeration is apparently the most effective, inexpensive treatment for "dying" lakes. It causes complex changes in lakes; and most of the impacts are not fully understood. The following information extracted from the literature



Depth (ft.)	Temp (0°)	D.O. (ppm)
0	25.1	12.6
2	25.1	12.2
4	24.7	8.1
6	24.0	5.9
8	24.0	5.7
10	24.0	3.8
12	23.8	2.0
14	23.2	0.4
16	21.0	0.2
18	17.3	0.1

20 FEET FROM AERATOR

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	24.6	10.2
2	25.1	11.3
4	24.6	9.1
6	24.6	9.4
8	24.6	9.1
10	24.1	5.0
12	24.1	3.5
14	23.3	2.5
16	23.3	0.75
18	23.0	0.40
20	22.5	0.25
22	21.8	0.20

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	26.3	7.7
2	25.2	7.0
4	25.1	6.2
6	25.0	4.8

20 FEET FROM AERATOR

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	24.8	4.7
2	24.8	4.6
4	24.8	4.4
6	24.8	4.8
8	24.8	4.7
10	24.8	4.9
12	24.8	4.6
14	24.8	4.8
16	24.8	4.8
18	24.8	4.8
20	24.8	4.8
22	24.8	4.8
24	24.8	4.8

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	25.2	6.2
2	25.2	6.3
4	25.2	4.8
6	25.2	4.8
8	25.2	4.8
10	25.2	2.4
12	21.2	0.2
14	16.4	0.1
16	14.2	0.1
18	13.1	0.0

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	20.0	9.0
2	20.0	8.9
4	19.8	8.9
6	19.6	8.8
8	19.0	8.3
10	19.0	5.4
12	19.0	5.1
14	18.0	4.8
16	17.8	0.8
18	13.2	0.2
20	12.2	0.2
22	12.2	0.1

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	25.1	12.3
2	25.1	12.6
4	24.5	9.3
6	24.0	6.6
8	24.0	5.0
10	24.0	4.4
12	23.8	3.1
14	22.0	0.2
16	21.0	0.1

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	19.0	8.3
2	19.0	8.3
4	19.0	8.2
6	19.0	8.2
8	18.6	8.2
10	18.6	8.2
12	18.5	7.8
14	18.5	7.8
16	18.4	7.7
18	18.3	7.5
20	18.2	6.4

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	26.1	13.4
2	25.9	13.4
4	25.4	12.6
6	24.7	9.1
8	24.0	5.0
10	24.0	4.3
12	24.0	4.0
14	20.7	0.3
16	15.3	0.2
18	13.0	0.1

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	25.1	12.8
2	25.0	12.5
4	24.7	10.0
6	23.8	10.0
8	23.6	3.2

100 FEET FROM AERATOR

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	26.2	12.5
2	25.1	11.8
4	24.6	11.6
6	24.6	11.6
8	23.8	11.4
10	23.8	11.4
12	23.8	11.4
14	23.8	11.4
16	23.4	11.2
18	22.9	11.0
20	22.2	10.7

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	26.3	11.8
2	26.3	9.8
4	25.0	7.4
6	25.0	5.9
8	25.0	5.0
10	25.0	3.2
12	25.0	3.2
14	25.0	0.7
16	24.6	0.2
18	22.9	0.1
20	21.9	0.1
22	18.5	0.1

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	26.3	12.4
2	26.3	12.1
4	26.3	11.8
6	26.3	7.2
8	25.0	2.3
10	24.9	0.4
12	24.0	0.1
14	18.6	0.1
16	16.4	0.0
18	14.2	0.0

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	26.3	12.9
2	26.3	12.1
4	26.3	8.5
6	25.4	6.9
7	25.0	5.7

20 FEET FROM AERATOR

Depth (ft.)	Temp (0°)	D.O. (ppm)
0	18.6	7.8
2	18.8	7.5
4	18.8	8.0
6	18.8	7.9
8	18.8	7.9
10	18.5	7.9
12	18.5	7.7
14	18.5	7.7
16	18.5	7.7
18	18.5	7.7
20	18.5	7.7
22	18.5	7.7
24	18.5	7.7
26	18.5	7.7
28	18.5	7.6
30	18.2	7.5

Figure 7-5. Effects of aeration on the dissolved oxygen concentrations of Lake Winona during mid-summer stratification. Note that the aerators have no observable effect at distances of 100 yards.

points up the complexity of the biological changes caused by aeration. As hypolimnetic waters are brought to the lake's surface, excess gases such as carbon dioxinde, hydrogen sulfide and ammonia are released to the atmosphere. In summer, artificial circulation promotes an increase in the heat content of the lake. Circulation during winter, on the other hand, reduces water temperatures overall because bottom waters are no longer insulated from the colder air by a surface layer of water or ice. If mixing is complete during summer, water clarity may increase because surface blooms of blue-green algae are distributed throughout the water column. On the other hand, if an undersized aerator is unable to achieve a complete mix, the resulting microstratification may provide a warm shallow-water "refuge" for blue-green algae (e.g. Aphanezomenon) yielding greater population densities after aeration than before. Complete mixing and aeration of an anoxic hypolimnion results in precipitation of phosphorus, iron and manganese complexes. Effective circulation causes the oxidation of ammonia to nitrate. Oxygenation of the hypolimnion causes formation of an oxidized microzone at the sediment-water interface which forms a barrier to the release of phosphates from the decomposing sediments. Aeration may add carbon dioxide and nutrients to surface waters causing a shift in phytoplankton from undesirable blue-greens to more desirable greens. Artificial circulation generally leads to an increase in the abundance of zooplankton and an expansion of their vertical distribution. Complete circulation may oxygenate anoxic sediments which were formerly day-time refugia for Chaoborus midge larvae and oligochaete worms. This is usually desirable because Chaoborus is migratory, leaving the sediments at night to feed on zooplankton near the surface at night when it is not readily preyed upon by sight-feeding fish like bluegills. Complete circulation usually results in increased depth distribution of fishes.