4.2.5 Dry Deposition

Dry deposition was also realized as a source of air borne pollutants that fall on the lake surface. Dry deposition was sampled by placing distilled water in an acid-washed container outside for a period of 77 hours beginning at 3:00pm on April 12, 2003. The water was analyzed by Microbac and annual pollutant levels falling on the lake surface were estimated based on concentrations of pollutants in the sample.

4.3 Analytical Methods

Analytical methods and their associated parameters used to analyze samples are listed in Table 4 and were performed by Microbac Laboratories in Erie, PA.

Table 4. Microbac Laboratories, Inc. analytical test methods

Non-Priority Metal Parameter	Microbac Analytical Method
P, Total, mg/L	EPA 365.1
N, Kjeldahl, mg/L	EPA 1979 351.3
BOD5 (mg/L)	SM 18 5210
TOC (mg/L)	EPA 1979 415.1
Calcium (mg/L)	EPA 200.7
Magnesium (mg/L)	EPA 200.7
Chloride (mg/L)	EPA 325.2
Sodium (mg/L)	EPA 200.7
Potassium (mg/L)	EPA 200.7
Sulfate (mg/L)	SM18 4500D
TDS (mg/L)	SM 18 2540C
COD (mg/L)	HACH 1979 8000
Sulfide (mg/L)	EPA 1979 376.1-2
Alkalinity, Total (ppm as $CaCO_3$)	SM 18 2320B
Alkalinity, Phenolphthalein (ppm as $CaCO_3$)	SM 18 2320B
Alkalinity, Bicarbonate (ppm as $CaCO_3$)	SM 18 2320B
Alkalinity, Carbonate (ppm as $CaCO_3$)	SM 18 2320B
N, Nitrate + Nitrite (ppm as $CaCO_3$)	EPA 1979 353.2
Chlorophyll a (mg/m^3)	SM18 10200H
Hardness	EPA 1979 ICP 200.7

5. WATER QUALITY ASSESSMENT – RESULTS and DISCUSSION

5.1 Sampling Results and Discussion

5.1.1 Temperature

5.1.1.1 Vertical Variation

Lake Pleasant is a dimictic lake: it undergoes two periods of seasonal turnover and two periods of stratification. During the stratified summer months, the epilimnion is the warmest, uppermost layer of water. The metalimnion, or thermocline, is the middle layer and is characterized by a rapid decline in temperature with declining elevation. The hypolimnion is the bottommost and coldest layer of water.

As the ambient temperature begins to rise in the spring, the ice and cooler water at the surface of the lake begin to warm. The warmer water near the bottom of the lake (winter hypolimnion) hovers at just above 4°C (Figure 10, 2/18/02). As the surface temperatures warm and approach 4°C, the point at which water is at its greatest density, the upper layer of water becomes denser than the lower layers, initiating internal mixing and convection currents. This process is evident in a temperature profile taken on 3/11/02 (Figure 10, 3/11/02). On 3/18/02, the lake was completely mixed, evident by a vertically uniform temperature profile of just above 4°C taken at the center sampling point (Figure 10, 3/18/02).

The surface water continues to warm causing boundaries to form between the warmer, less dense, upper waters and the cooler, denser lower waters. In 2002, summer stratification began between 4/10 and 4/17 (Figure 10, 4/10/02 and 4/17/02). The epilimnion forms and remains intact throughout the summer because water below this boundary is sequestered from solar heating and wind mixing.

Wind is the primary mechanical energy responsible for the maximum depth of mixing in the epilimnion. The premise is simple: more mechanical energy is needed to overcome density differences as temperature increases. More energy is required to mix warmer water than to mix colder water because the change in density between degree units decreases as the temperature declines and approaches 4°C. For example, the maximum water temperature for 2002, recorded on 7/2, was >27°C at the surface. Two meters down, the temperature was about 26°C. The difference in density between 27°C water and 26°C water is 2.7×10^{-4}g/mL (Murray State University website, 2003). In the hypolimnion, temperatures were in the 8 to 9°C range: the difference in density between 8°C water and 9°C water is 5×10^{-5}g/mL (MSU website, 2003). Breaking the temperature gradient in the colder water requires less energy than the warmer water because of the smaller difference in density between two neighboring whole number temperature values. Consequently, wind-generated energy is expended in Lake Pleasant within the upper 3-4m of water. As the epilimnetic temperature increases, the density difference between layers increases as well, making the demarcation between layers even more pronounced. The epilimnion continues to heat and mix throughout the summer, sequestering the lower layers from mechanical mixing and therefore, significant atmospheric O_2 inputs and solar heating.

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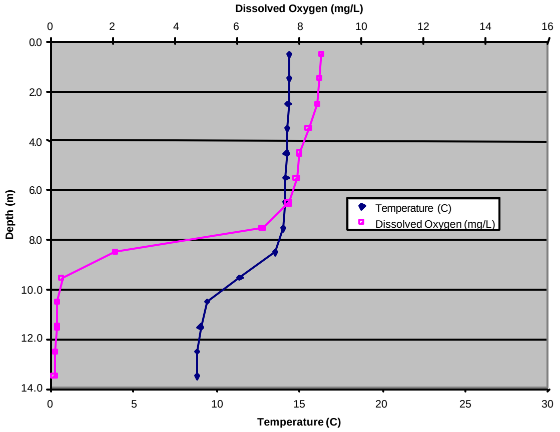

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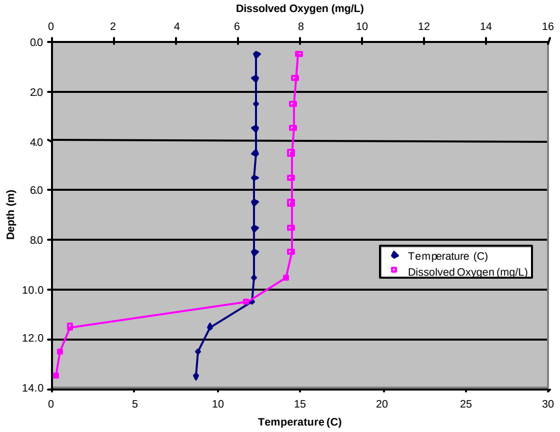

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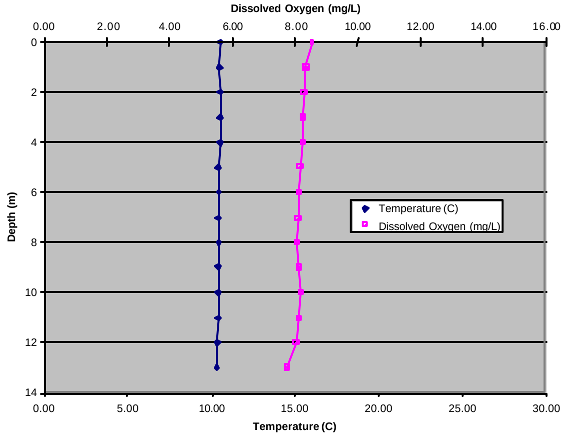

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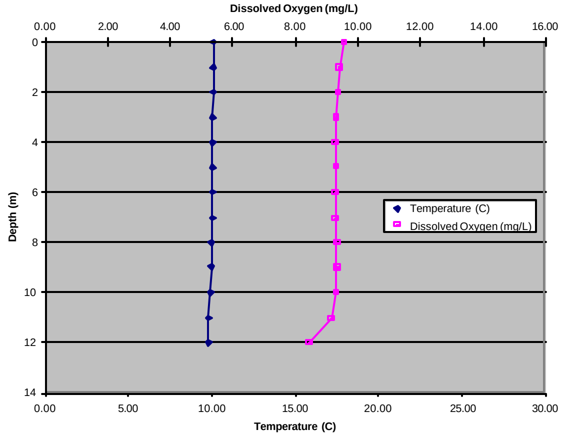

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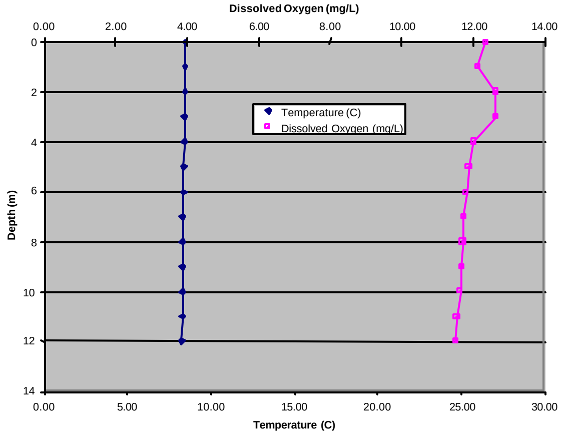

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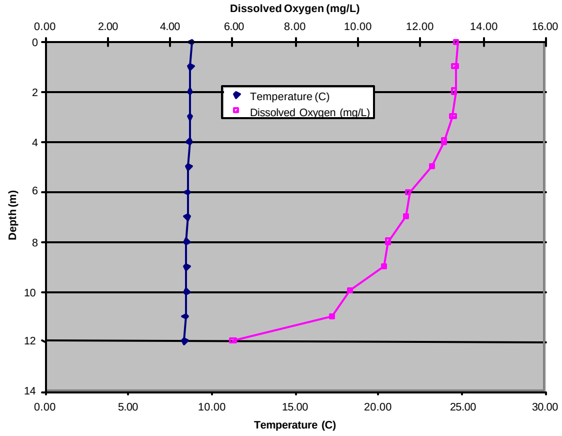

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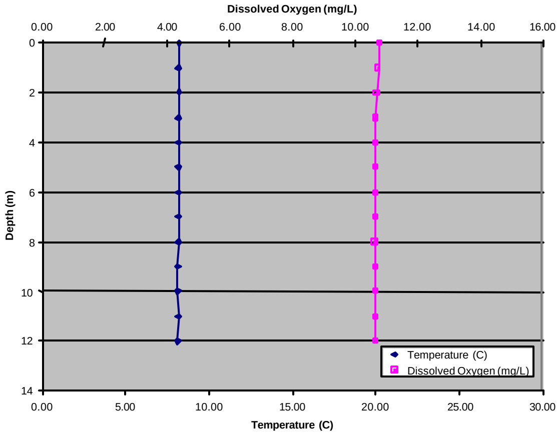

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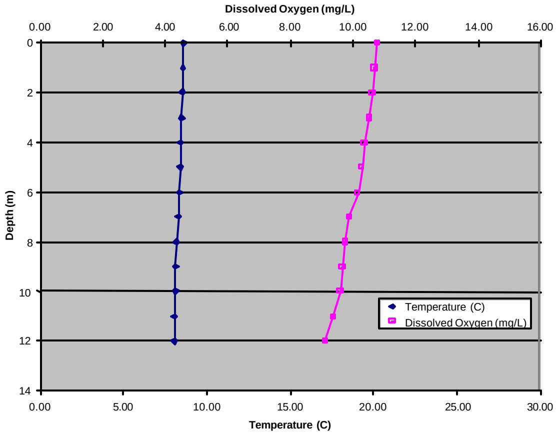

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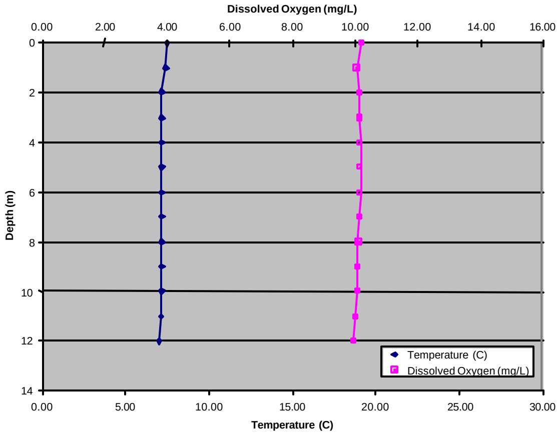

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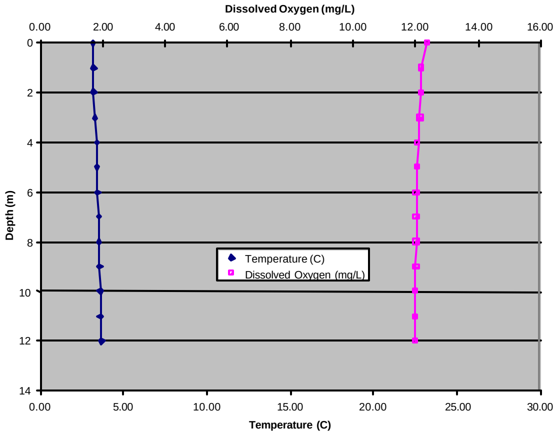

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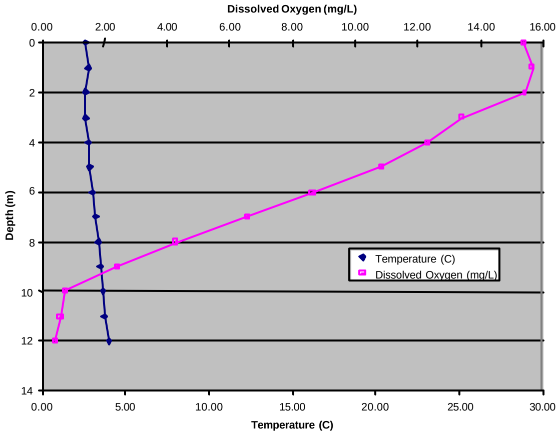

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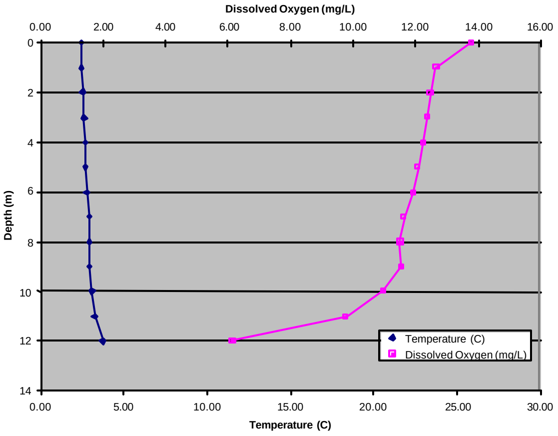

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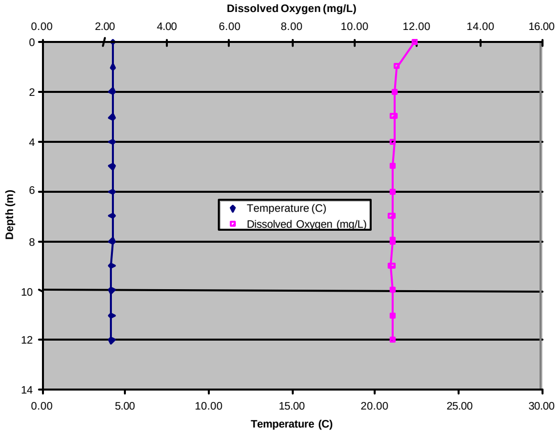

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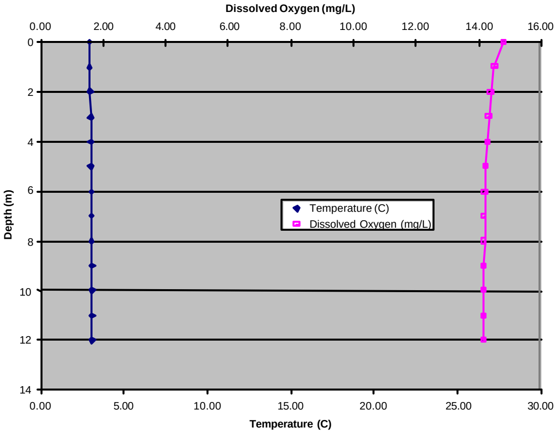

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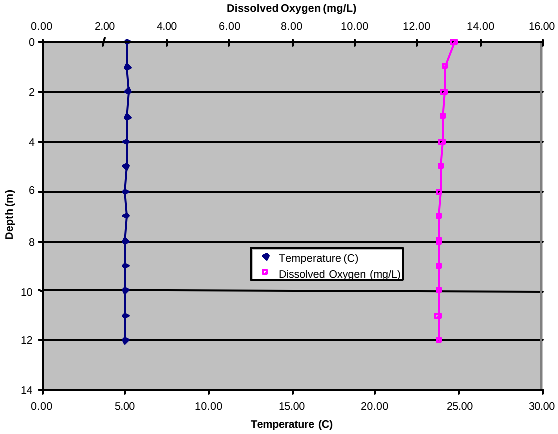

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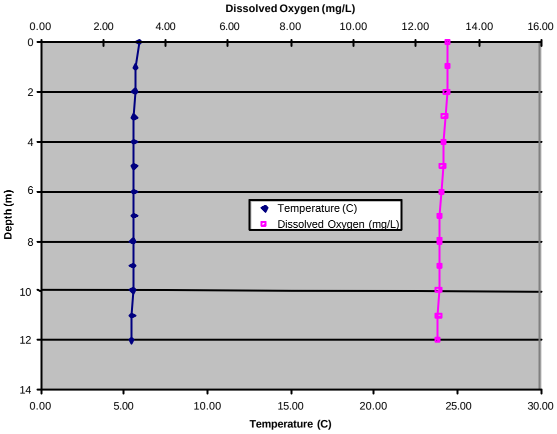

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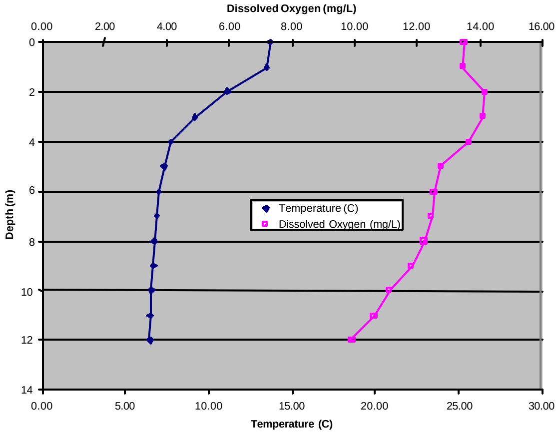

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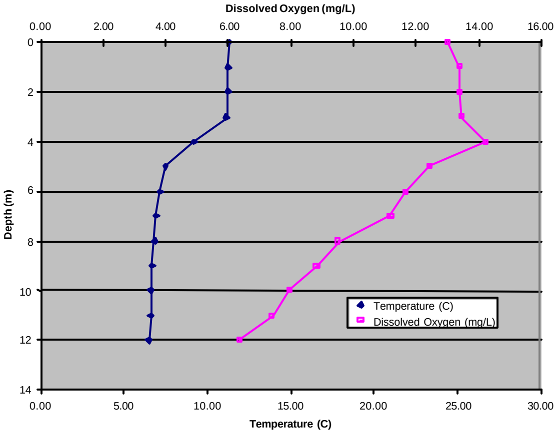

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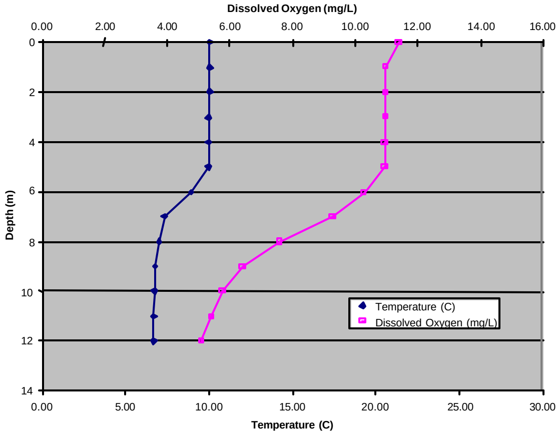

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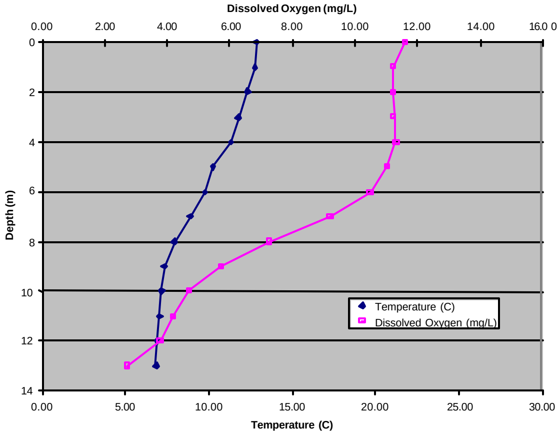

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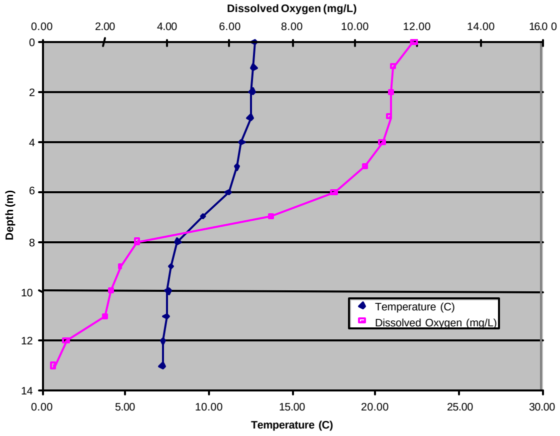

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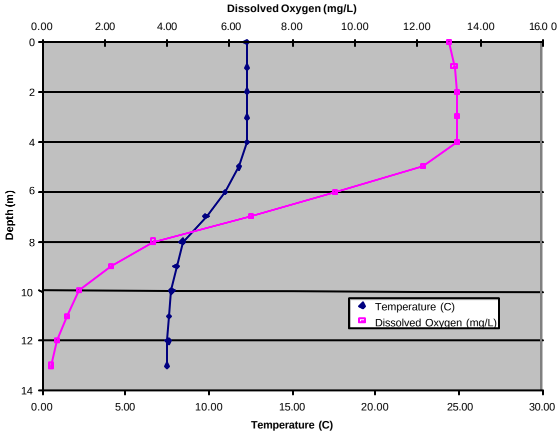

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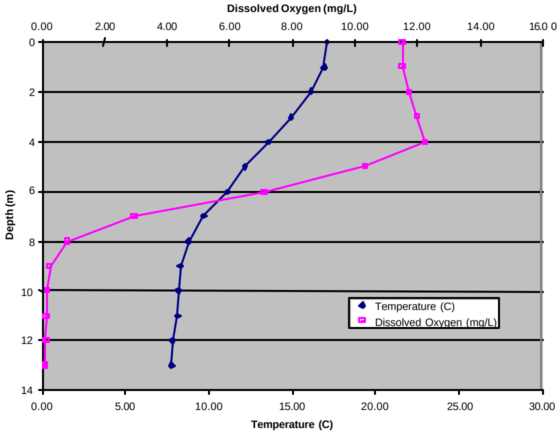

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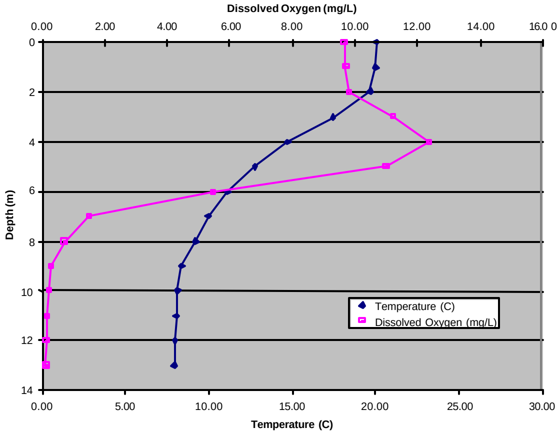

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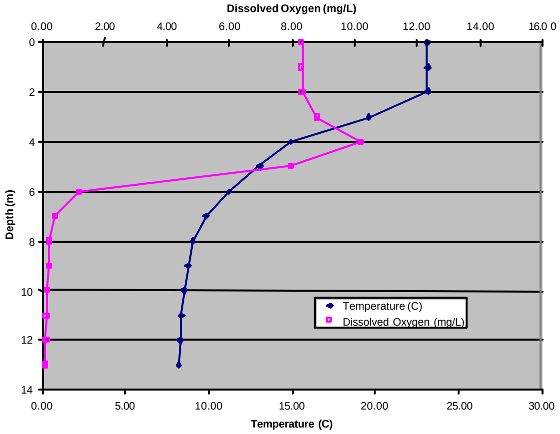

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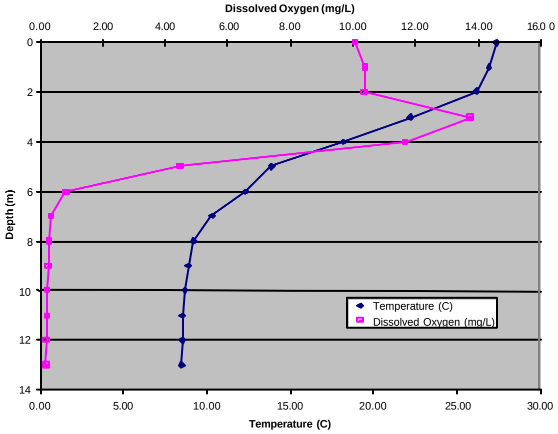

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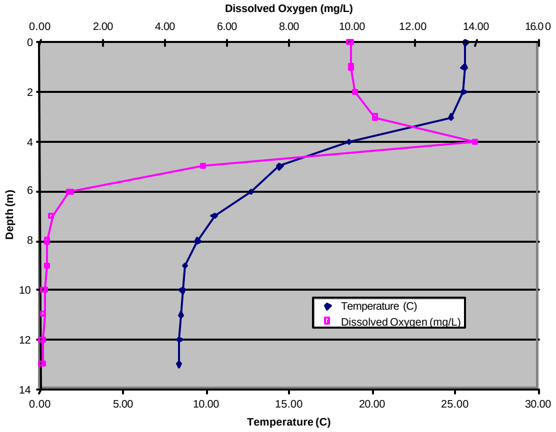

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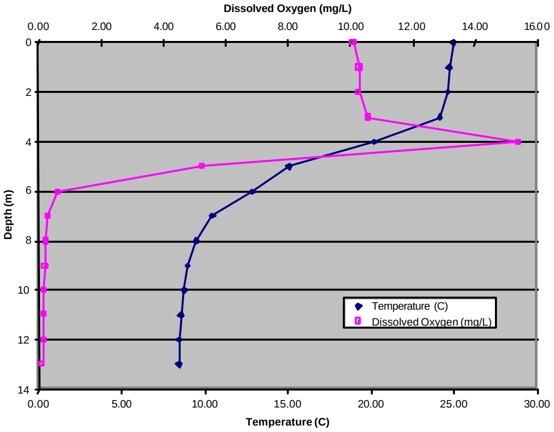

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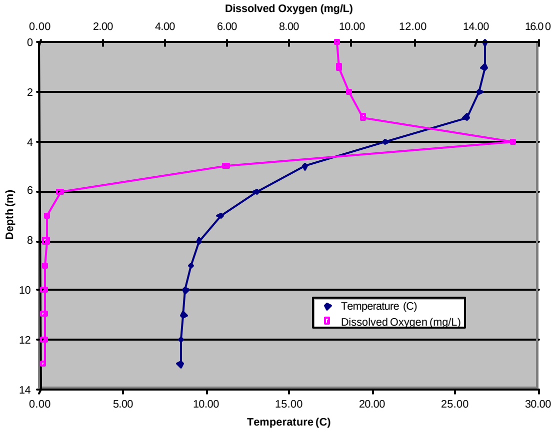

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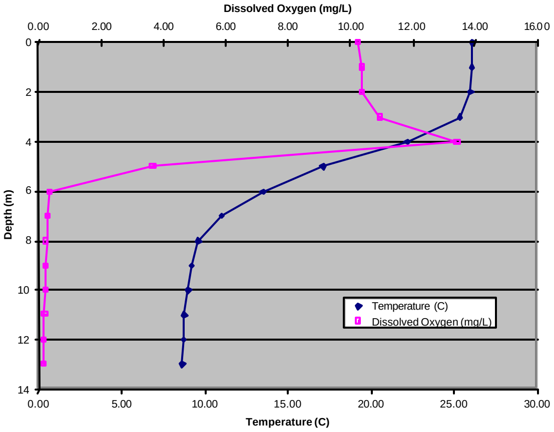

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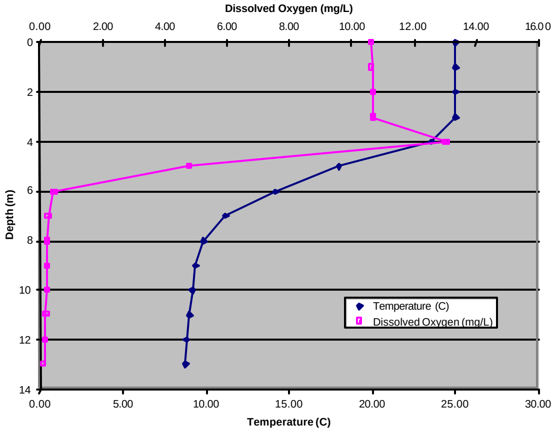

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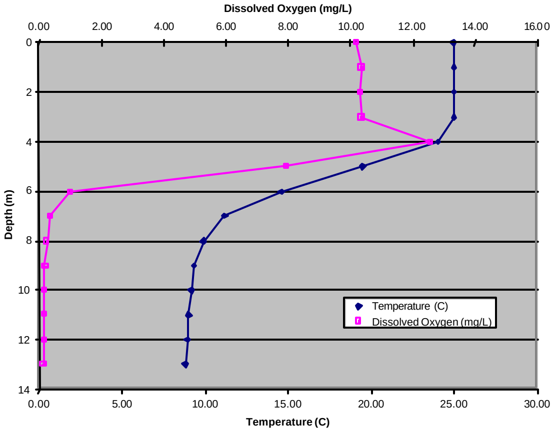

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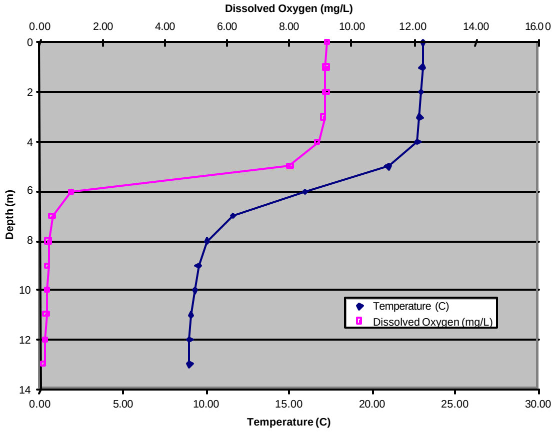

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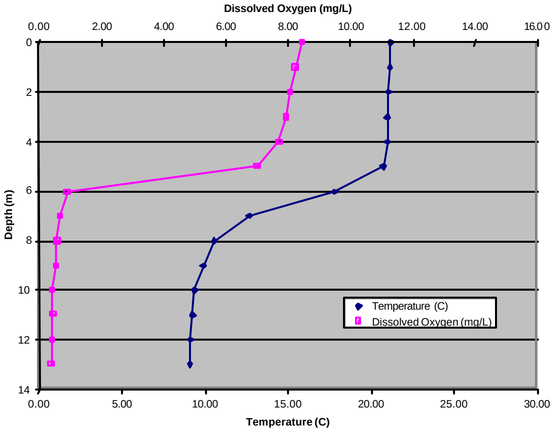

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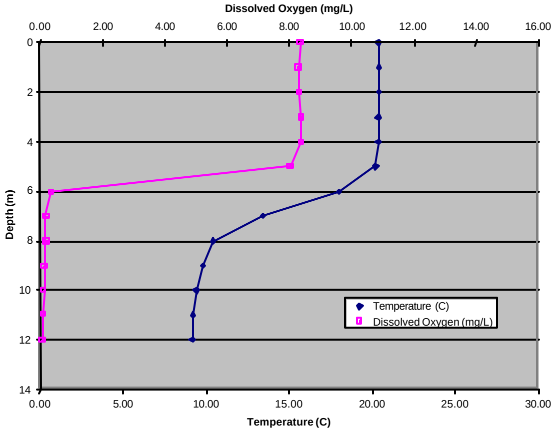

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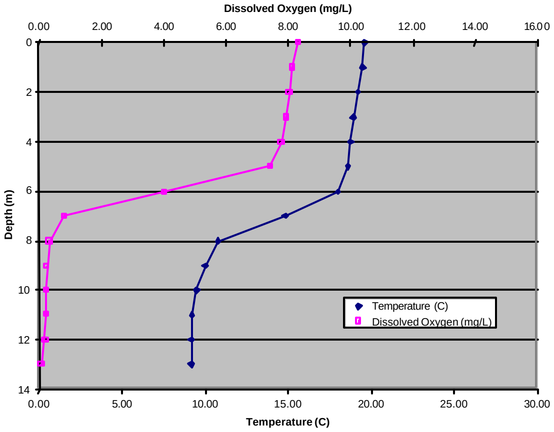

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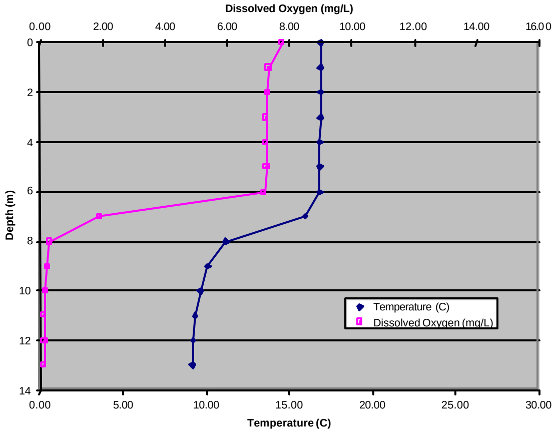

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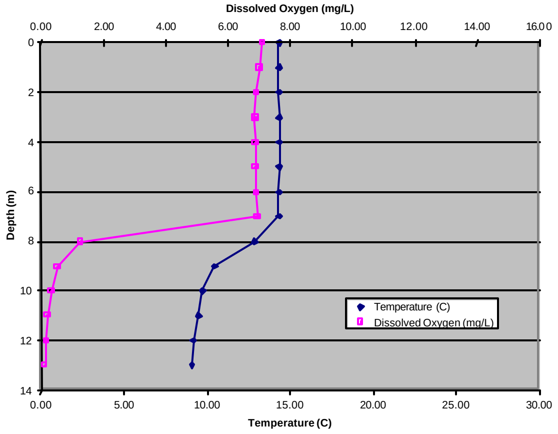

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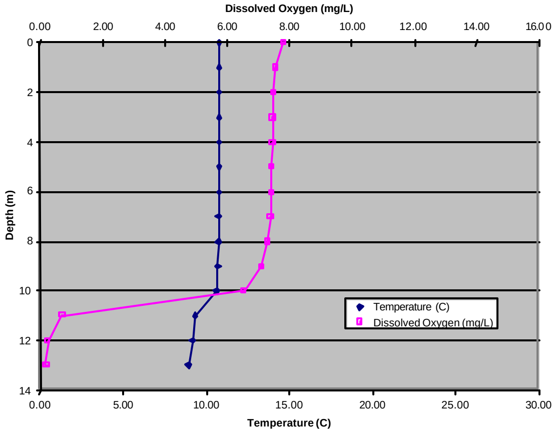

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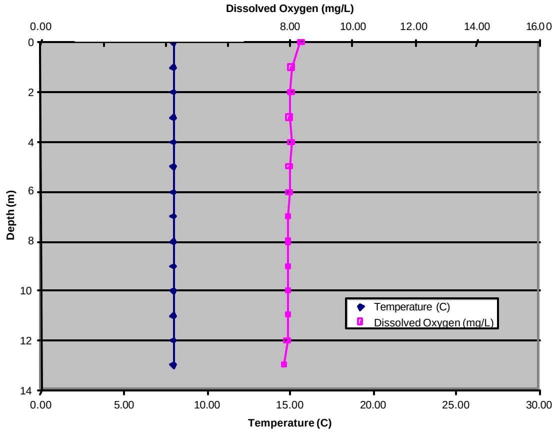

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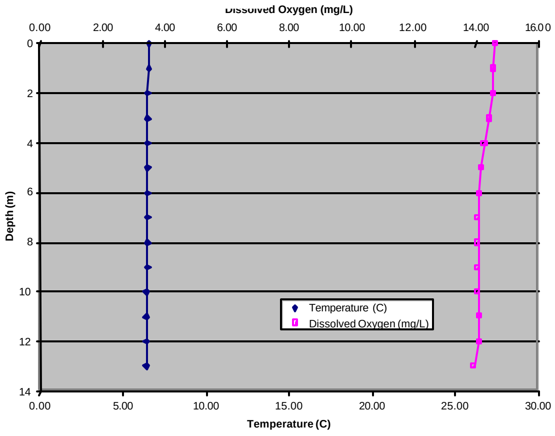


Figure 10. Dissolved Oxygen and Temperature Profiles measured at the center sampling point, from 10-13-01 through 11-20-02, with a YSI field meter

As the ambient temperature drops in the fall, the epilimnetic water cools and descends due to its increased density. As the layer descends, it begins to mix with the lower layers of water, initiating internal convection currents, until the entire lake is mixed and reaches thermal unity. The decrease in water temperature also increases the depth over which mechanical mixing may extend. This phenomenon is referred to as fall turnover.

It appears that fall turnover was already in progress on 10/13/01, the day that lake monitoring was initiated (Figure 10, 10/13/01). 2001 turnover was completed by 10/28/01 (Figure 10, 10/28/01).

A profile taken at the center sampling point on 9/6, revealed the first signs of fall turnover for 2002. Over the next two months, the epilimnion slowly descended while the metalimnion and the hypolimnion grew smaller and smaller (Figure 10, 9/6/02). At the completion of turnover in 2002, there was little vertical temperature variation in the lake.

Winter stratification occurs as the lake covers with ice. The water closest to the surface of the lake and under ice cover cools and is generally under 4°C. Slightly warmer water, just below 4°C, sinks forming the winter hypolimnion. Also, in shallower areas, such as the littoral zone, water can be heated to just above 4°C (Wetzel, 2001). This denser water flows along the sediment water interface, to the deepest region of the lake contributing to the slightly warmer winter hypolimnion. Stratification occurs in the winter despite the lack of large temperature differences in the water column because the ice cover reduces wind mixing to nearly zero. A profile that typifies these patterns of winter stratification was recorded on 12/26/01 and 2/18/02 (Figure 10, 12/26/01 and 2/18/02).

Lake turnover is an important phenomenon because dissolved oxygen gets replenished in the lower layers that were sequestered from atmospheric inputs and because parameters that are released under anoxic sediment conditions and concentrate in the hypolimnion, such as phosphorus and certain metals, get redistributed throughout the lake.

5.1.1.2 Horizontal Variation

Although vertical variations are well pronounced, there is little horizontal variation within the layers during stratification, as shown by temperature patterns recorded on 10-5-01 along a transverse section (from north to south) bordering the eastern shoreline (Figure 11). The epilimnion spans from approximately 0.0 to 3.5m, the metalimnion, or thermocline, from 3.5 to 9.5m, and the hypolimnion from 9.5 to 13.5 m. Sampling along this same transect also shows that parameters such as dissolved oxygen tend to exhibit a similar pattern as temperature because of density dependant mixing constraints within those layers (Figure 12).

Transects taken on 10/11/01, show that there is little temperature variation both vertically and horizontally within the lake during fall turnover (Figure 13).

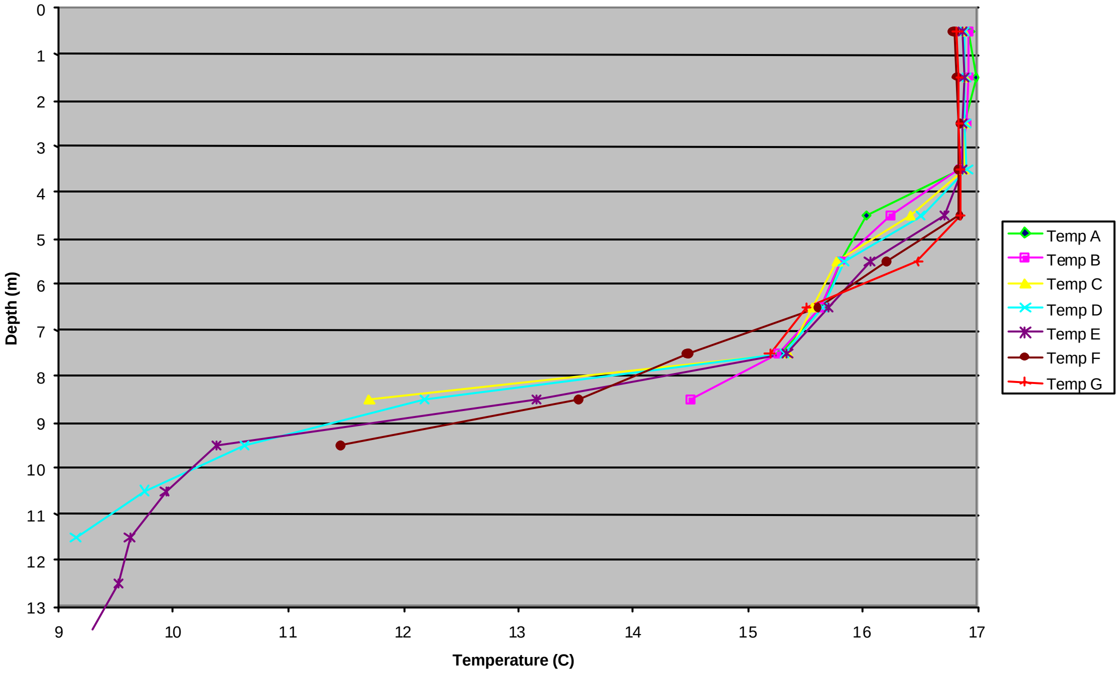


Figure 11. Temperature profiles measured along a north-south transect bordering the eastern shoreline of Lake Pleasant, 10/5/01

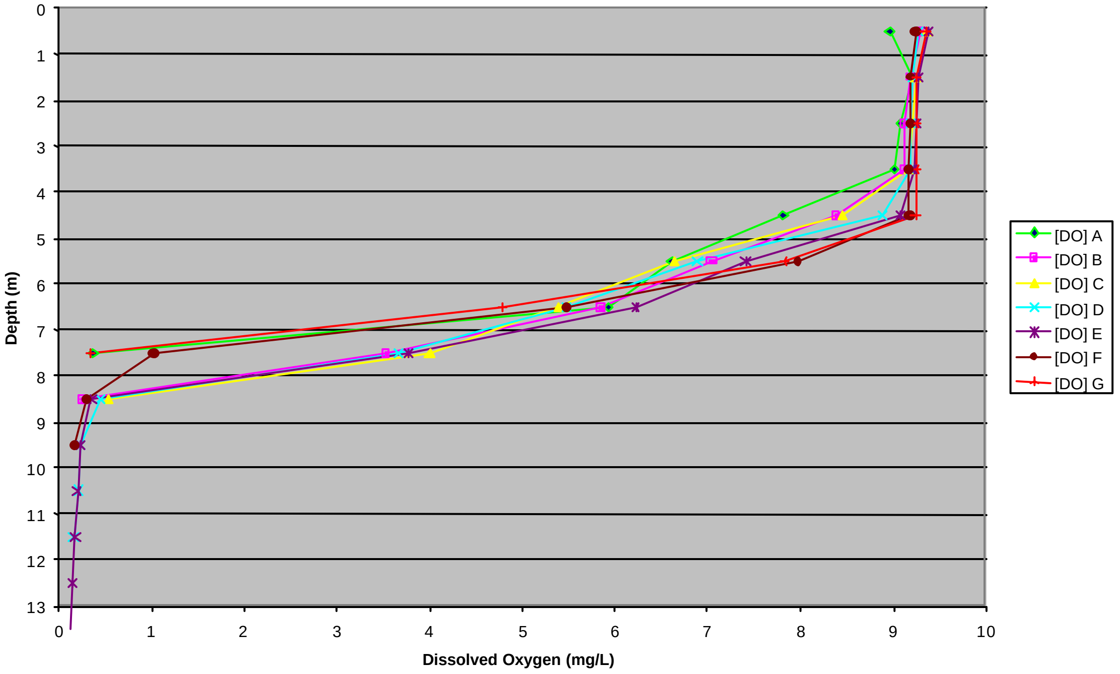


Figure 12. Dissolved oxygen (mg/L) (DO) measured along a north-south transect bordering the eastern shoreline of Lake Pleasant, 10/5/01

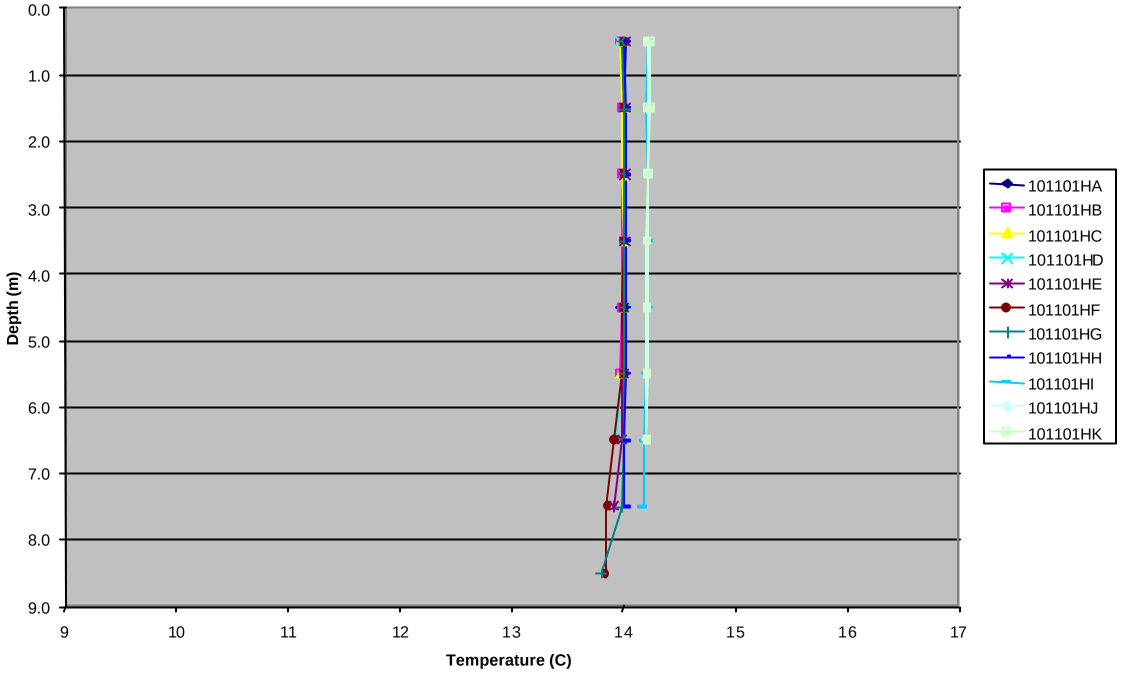
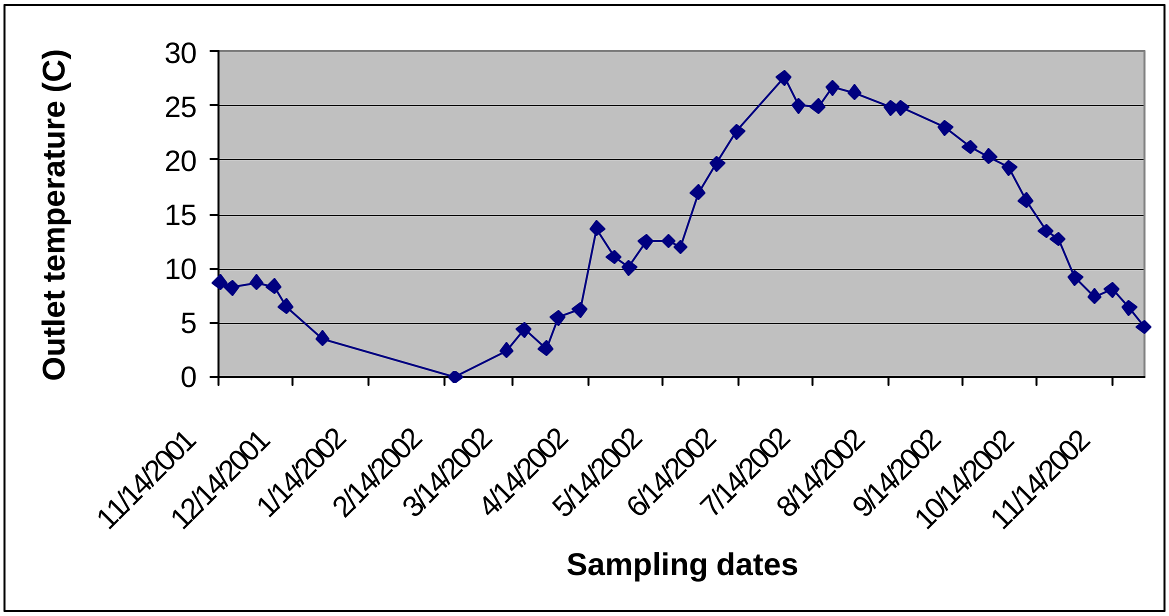
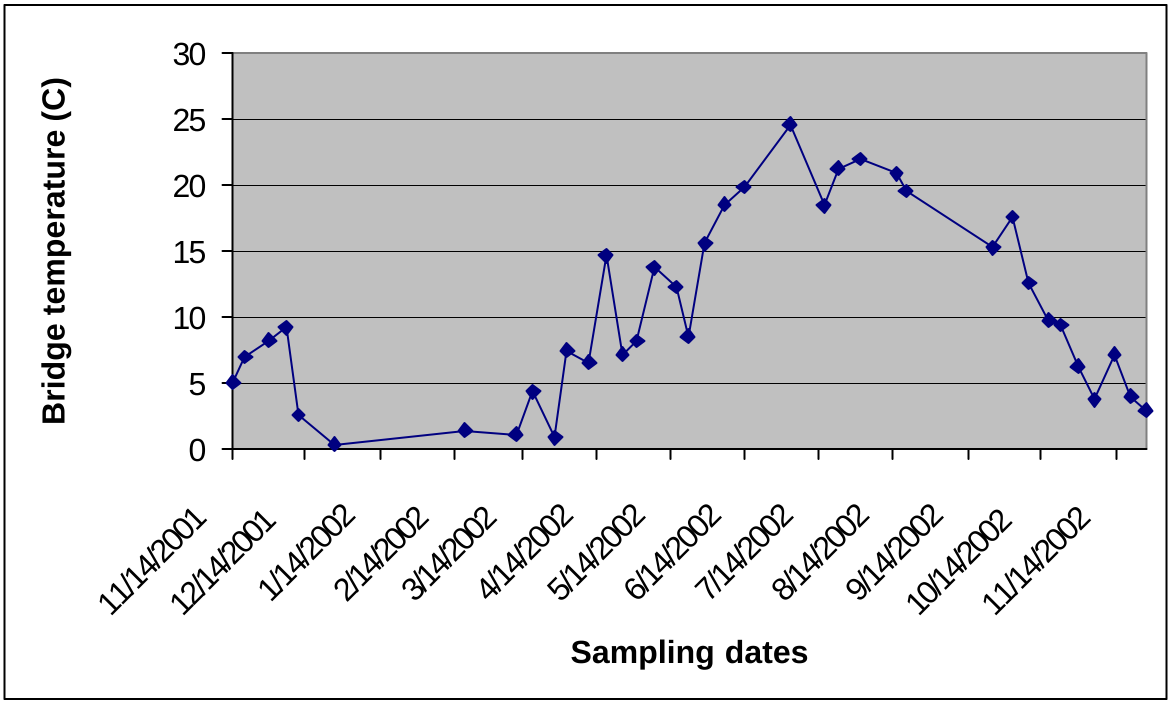


Figure 13. Temperature profiles measured along a north-south transect bordering the western shoreline of Lake Pleasant during fall turnover, 10/11/01

5.1.1.3 Surface Water Sites

Figure 14 shows temperature data for surface water sampling points outlet, bridge, UNT 1, stream and UNT 3. Data gaps during winter months indicate ice cover prevented sampling. Summer data gaps indicate sampling site was dry.

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25
20
15
10
5
0
11/14/2001
12/14/2001
1/14/2002
2/14/2002
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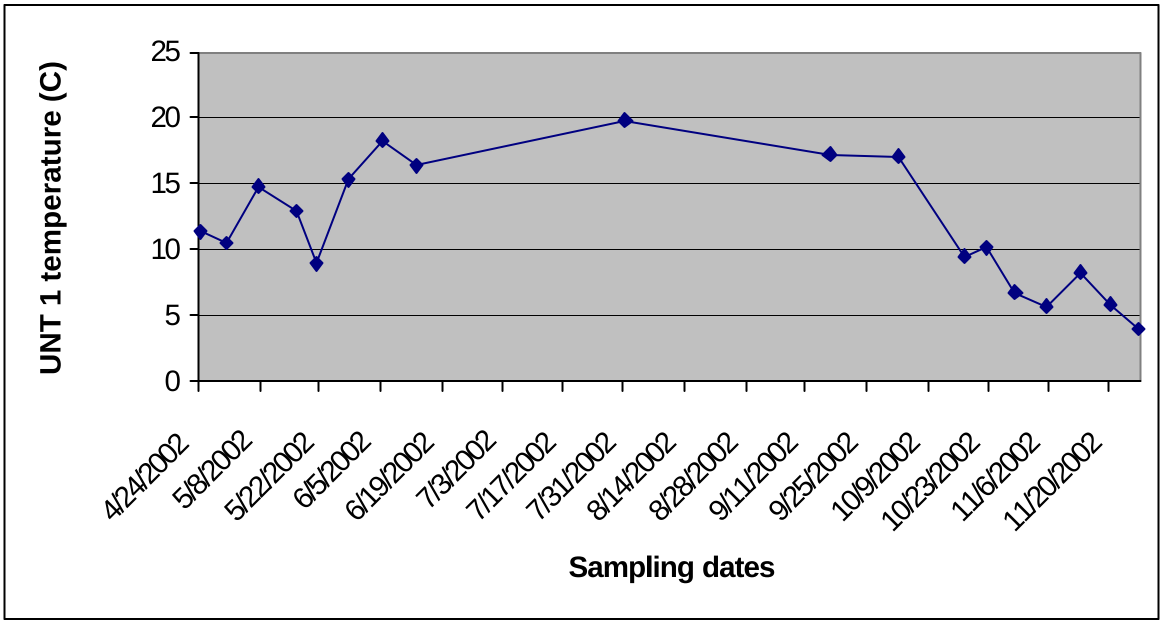
10/14/2002
11/14/2002
Sampling dates


UNT 1 temperature (C)
25
20
15
10
5
0
4/24/2002
5/8/2002
5/22/2002
6/5/2002
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7/31/2002
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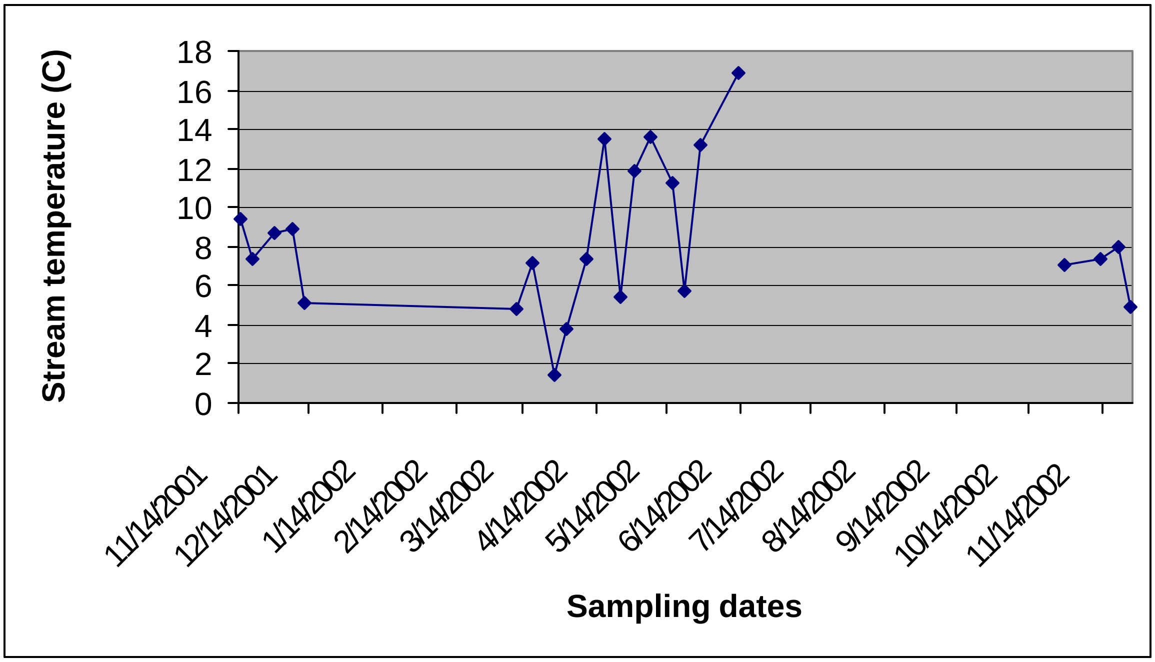
11/6/2002
11/20/2002
Sampling dates



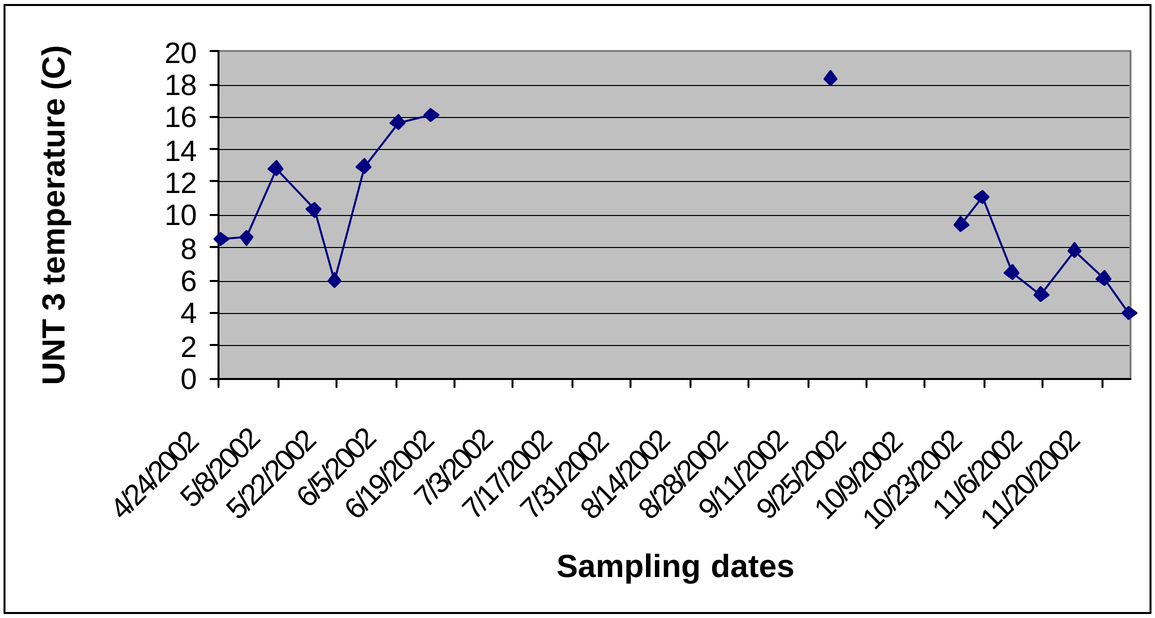


Figure 14. Water temperatures at surface water sampling points

5.1.2 Dissolved Oxygen

Dissolved oxygen measurements provide information about a lake's ability to support life, are important in the assessment of oxidation-reduction (red-ox) conditions, and are often reflective of the metabolic processes of the living organisms within a lake. For example, low DO levels in the hypolimnion can suggest nutrient enrichment of the water column. Low DO levels can also drive reducing conditions at the sediment-water interface, favoring the release of stored phosphorus and other constituents into the water column. This can contribute to eutrophication upon lake turnover and can result in turnover-associated algae blooms.

The percentage of dissolved oxygen saturation (DO%) represents the amount of dissolved oxygen that water contains relative to the absolute amount it can hold at a particular temperature and depth. Presentation of DO in this format eliminates variation in values based on changing temperature and pressure variables and converts DO values into units that are comparable vertically. DO% was measured directly with the YSI sonde but may be calculated using the following formula:

$$\%DO = 100 * (DO_c / DO_d)$$

where: %DO = Percent dissolved oxygen saturation

DO_c = Actual dissolved oxygen concentration measured at depth x and temperature y

DO_d = Theoretical maximum dissolved oxygen concentration at depth x and temperature y

5.1.2.1 DO Patterns During Stratification and Turnover

Dissolved oxygen profiles were used to assess stratification patterns and anoxic conditions within the entire lake. DO% values of 100 would be expected vertically throughout the lake if consumption and production (the coupling of respiration and photosynthesis) were balanced and the entire lake was open to atmospheric O_2 inputs. Theoretically, O_2 levels should be at 100% saturation during spring and fall turnover.

Supersaturation (values >100%) or undersaturation (values <100%) may occur depending upon the net metabolic rates of organisms. Since oxygen enters the lake both from the atmosphere and as a byproduct of photosynthesis, and because diffusion of excess O_2 back into the air is a slow process, DO% can exceed maximum saturation if O_2 production exceeds consumption. DO% can also fall under saturation if O_2 consumption exceeds production or if a physical barrier exists, such as with density stratification in the summer and winter, preventing atmospheric O_2 replenishment in the hypolimnion.

The DO profiles of Lake Pleasant reflect a clinograde pattern of DO distribution. Clinograde profiles are typical of eutrophic lakes that undergo stratification; often, the DO in the hypolimnion is rapidly depleted in the first few weeks of stratification and remains anaerobic until the next turnover period (Wetzel, 2001). This pattern is illustrated in the DO and temperature profiles of Lake Pleasant measured from 10/13/01 through 11/20/02 at the center sampling point (see Figure 10).

In stratified lakes, the balance of DO and dissolved CO_2 in the hypolimnion is controlled solely by hypolimnetic production and consumption (USGS website, 2003). Bacterial decomposition of dissolved and particulate organic matter at the sediment-water interface is most often responsible for the hypoxic (DO <1mg/L) conditions. While bacterial decomposition occurs throughout the water column, DO from the atmosphere or produced as a by-product of photosynthetic processes in the photic zone (upper 6m for Lake Pleasant) cannot be replenished to the deeper layers of the lake due to the lack of vertical mixing.

At fall turnover, on 11/14/01, the DO% values measured at the center sampling location ranged from a maximum of 105.4 % DO at the surface to a minimum of 97.8 % DO at the bottom of the lake (Figure 15). On 11/19/01, DO% rose to 113.3 at the surface and fell sharply to 51.4, just above the bottom. Increased photosynthesis near the surface coupled with increased decomposition near the bottom would explain the observed behavior. DO% values fell to 91.5% at the surface and rose to 90.3% at the bottom, stabilizing vertically in an undersaturated state by 11/29/01. The temperatures remained uniform vertically and were consistent in value over all three days at about 8ºC ±1º. Ideally, 100% saturation would be observed at turnover. Lake Pleasant values for 2001 fall slightly below complete saturation, implying that O_2 consumption exceeded production.

After turnover, DO levels remained fairly constant in the early winter months (measured through 12-26-01), fluctuating between about 8 and 12 mg/L – with little vertical variation. The profile generated from 2-28-02 data shows that during winter stratification beneath ice cover, the bottom 4 meters of water were hypoxic.

Lake Pleasant was supersaturated with DO at spring turnover on 3-27-02. Gradual temperature stratification occurred between April and May 2002 -- a hypoxic hypolimnion first appeared on 5-21-02 with the DO below 11m falling below 1mg/L. Temperature stratification was complete in June marked by a completely hypoxic hypolimnion (about 6-7m through bottom).

Lake Pleasant was supersaturated with O_2 at fall turnover 2002.