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Port of Seattle

EXAMINING THE EFFECTS OF RUNWAY DEICING ON DISSOLVED OXYGEN IN RECEIVING WATERS: RESULTS OF THE 1999-2000 WINTER SEASON

Seattle-Tacoma International Airport
Seattle, Washington

November 2000

Volume 1
Report

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of the two that may receive more deicing chemical applications. Thus, Des Moines Creek, particularly cell NP3 of NWP, has the potential to receive the highest loading from ground deicing chemicals than would other STIA drainage.

Moreover, because of the potential for extended detention periods in NWP, this water body, specifically cell NP3, has the potential to experience greater oxygen consumption from deicing chemicals than any other water body receiving STIA runoff. Subbasin SDS1 no longer drains any ramp or landside areas subject to routine ground deicing. Subbasin SDS4 drains 7% of the airfield impervious surfaces and drains directly to Des Moines Creek below Tyee pond.

Other minor subbasins in the Des Moines Creek watershed include SDS2, SDS5, SDS6 and SDS7, none of which experience routine ground deicing. Together, these four STIA subbasins drain 2.8% of the total impervious area. However, runoff from these subbasins enters cells NP1 and NP2 combined with drainage from other entities, including City of SeaTac (S. 188th St). Similar to the Lake Reba drainage, streets and parking in these non-Port areas could be subject to ground deicing by these other entities.

2.1.1 Ground Deicing Chemicals and Operations

The Port tracks and reports all applications of PA, SA and CMA ground deicing chemicals. These reports have been used to design the outfall sampling programs for this project and previous studies (POS, 1999c). Liquid PA (Cryotech E36 LRD) is used principally on the airfield and ramp areas. Solid CMA and SA (both Cryotech products) are used primarily on vehicle roadways on the landside of the airport. When necessary, the Port also applies sand mixed with CMA or SA. As a BMP, the use of urea and glycols for ground deicing was terminated in 1996. According to WSDOT, any chemical applications to state roadways in the vicinity would utilize liquid CMA (WSDOT, 2000).

In some cases, weather forecasts allow airport operations managers to call for chemical applications before ice forms on ground surfaces. These cases of "anti-icing" may result in smaller volumes used than would have been necessary had an ice bond formed prior to chemical application. In the event of snowfall, the Port typically applies chemicals after removing snow with plows and/or brush machinery. Doing so minimizes the volume of chemicals needed to break the ice bond with pavement. As outlined below, the Port moves snow from ramp areas to designated snow storage areas that drain to the IWS. Occasionally, frost or freezing precipitation occurs without snowfall, where chemical applications may be less than those associated with significant snowfall. For convenience in this report, the terms "deicing" and "deicer" are used collectively to refer to both ice removal and prevention activity.

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1 Executive Summary

The Washington State Department of Ecology (Ecology) has expressed concern that the oxygen demand of Seattle-Tacoma International Airport (STIA) snowmelt and stormwater runoff after runway and taxiway deicing events could affect dissolved oxygen levels in Miller and Des Moines Creeks. The Port of Seattle (Port) completed the Dissolved Oxygen Deicing Study (Cosmopolitan Engineering Group 1999) to evaluate potential dissolved oxygen effects from deicing during the winter of 1998-1999. Ecology reviewed the report and raised questions that could not be fully evaluated given the scope of the 1999 study (Ecology 1999). This study continues similar work to evaluate dissolved oxygen conditions occurring during the winter of 1999-2000. Comments from Ecology were addressed with an appropriate work plan described in this report.

The study is considered an investigative best management practice (BMP) pursuant to the Port's NPDES permit-required Stormwater Pollution Prevention Plan for STIA.

Background

The Port applies three types of deicing chemicals to prevent and/or remove ice on ground surfaces at the airport. These chemical applications on the airfield (runways and taxiways) ensure public safety and comply with FAA requirements. The Port applies liquid potassium acetate (PA), solid sodium acetate (SA) and solid calcium-magnesium acetate (CMA) to the airfield and landside ground surfaces.

The Port uses a suite of BMPs to minimize environmental effects of the deicing chemicals. Ice detection sensors in the runway pavement are used to evaluate when deicing chemicals are needed. The use of the chemicals listed above, which are low-BOD products, reduces possible effects on receiving-water dissolved oxygen. Other deicing chemicals, such as urea, are no longer used. Snow removed from the airfield is collected in areas that do not drain to the storm drainage system (SDS), thereby reducing the amount of deicing chemicals that would be included in meltwater. Finally, all of the areas where aircraft are serviced, including aircraft deicing/anti-icing fluid (ADAF (glycol)) application, drain to the IWS system.

The storm drainage system (SDS) configuration at STIA has two distinct flow regimes that affect transport of deicing chemicals:

- Most of landside areas (SDE4) drain directly to and rapidly through Des Moines Creek.
- Most of the airfield areas drain to two ponds (Lake Reba and Northwest Ponds (NWP)) where chemicals may be detained for varying periods prior to being flushed into Miller and Des Moines Creeks.

The 1998-99 study concluded that deicing chemicals, when "washed off" by rainfall and/or snowmelt, passed rapidly through both Des Moines and Miller Creeks. There was no reduction in DO concentration within either watershed when deicing chemicals were detectable in runoff. Trends in DO generally followed trends in rainfall (i.e. rainfall and runoff increased DO and DO decreased during periods of low rainfall). The lowest DO occurred in the ponds. But once the water left the ponds, DO rapidly rose towards saturation downstream. Des Moines Creek downstream of NW Ponds and Miller Creek downstream of Lake Reba rapidly reaerated under all conditions.

The 2000 study was designed to incorporate Ecology comments as follows:

- Calibration and monitoring procedures were modified to improve data quality,
- Additional data were collected to "trace" the presence (or absence) of deicing chemicals in the receiving water,
- Dissolved oxygen data were collected in adjacent water bodies not affected by deicing chemicals to determine if other Port activities or other (non-Port) sources were responsible for measured DO drops and increases, and
- DO monitoring was conducted only in the NW Ponds and Lake Reba, because the 1999 study showed rapid reaeration in the streams.
- The work plan was reviewed with Ecology prior to initiating monitoring.

Deicing Event Characteristics

In general, two factors characterize the potential environmental responses to ground-deicing events: 1) the weather conditions that cause the need for deicing, and 2) the subsequent weather patterns after chemical application. Deicing chemical volumes and application frequency depend on the type of precipitation, e.g. snow or frost, and increase with the severity and duration of subfreezing temperatures, and safety factors. Weather patterns after chemical application, particularly rainfall, determine how fast chemicals are washed off surfaces and transported through drainage systems and receiving waters.

In the 1999-2000 winter season, there were three distinct periods of winter weather, all in a two-week period of January 2000. Each event resulted in different areas, types, and volumes of ground-deicing chemical application. Unlike the last study period (98-99), these three events coincided with a protracted period of little rainfall, where a total of only 1.3" rain fell in the 18 day period after the first (snowfall) event. Because of limited snowfall, no snow was plowed or stored at the designated management areas. Ice did not form on either of the two ponds studied. Overall, these deicing-events were less severe than the last season's in terms of snowfall, duration of subfreezing temperatures, and volumes of ground and aircraft deicing chemical applications.

The first event began with about 3" snowfall on Jan 11, 2000 followed by rapid melting within 12 hours. Only 0.86" rain fell in the subsequent 5 days. Because the limited depth of snow began to melt immediately, no snow required plowing to the snow storage areas. The total ground-deicing chemicals applied during this short event amounted to approximately 90% of the total annual volumes applied. NPDES deicing event sampling coincided with this event at outfalls SDE4, SDS3, and SDS1. This event coincided with the largest number of aircraft deiced during the season.

The second event exhibited heavy frost that formed during cold, clear overnight skies on January 18th-19th and melted by midday on the 19th. During this short event, PA was applied to only the "touch down" areas of the runways, amounting to only 5% of the total annual PA applied. In contrast, heavy frost on landside ground surfaces necessitated heavier chemical applications on these surfaces than during the first event.

The third event exhibited minor frost on the evening of January 24th, resulting in minor chemical application only to limited landside areas. No chemicals were applied to the airfield. The total CMA and SA applied during this short event amounted to approximately 12% and 9%, respectively, of the annual total applied. No PA was used.

About half of the total potential BOD_5 from all applications of these chemicals was applied in the landside areas that drain directly to Des Moines Creek. Consequently, most of the other half of this total BOD_5 was applied to the airfield areas that drain to the two ponds. The biochemical oxygen demand (BOD), is a measure of the quantity of oxygen consumed in a 5-day period.

Key findings

The multiple tracers used in this study (to detect the presence of specific chemicals) showed that deicing chemicals washed into the ponds remained until sufficient rainfall and runoff flushed them into creeks. In contrast, peak concentrations of these chemicals passed rapidly through and out of the stream systems (downstream from the ponds) in 3 to 4 hours. Ion and conductivity tracers served well as low cost, conservative indicators of the beginning, end and duration of deicing chemical presence in runoff.

DO remained below saturation in both ponds over the more than 4-month duration of this study, including the more than 2-month period before the first ground deicing chemical application. Though undersaturated, DO in Lake Reba was higher than in Northwest Ponds. The calibration program discovered extreme DO stratification in NWP cell 1, which is upgradient of runway runoff from SDS3 that enters NWP cell 3. DO concentrations were near zero at times in the lower half of the water column while DO remained much higher in the upper half. Chemical profiles suggest large amounts of organic matter are responsible and that deicing chemicals were absent.

This study improved upon results from last year by doing more frequent calibration and recording a longer period of background DO more than 2 months prior to the first deicing event of Jan 12, 2000.

Limited modeling using the December 24, 1998 deicing event data predicted a limited DO sag in both creeks (Parametrix, 2000). The steady-state Multi-SMP model used the peak BOD_5 concentrations measured in this event. Sampling results indicated that peak BOD_5 concentrations in the receiving waters persisted for only a few hours and rapidly dropped to much lower levels. Consequently, the DO sag predicted by the peak BOD_5 concentrations used in the model would not be expected to persist for more than a few hours. However, actual instream monitoring during this event did not show the sag (Cosmopolitan, 1999).

There were very little aircraft -deicing/anti-icing fluids (ADAFs, i.e. glycols) that entered the ponds and creeks before and during the January 2000 ground-deicing events. Aircraft deicing and glycol usage were relatively low during the more than 2-month period prior to the first runway-deicing event. A number of storm samples taken in this period show no glycols entered Miller Creek/Lake Reba (via SDN4), and very little entered Des Moines Creek (via SDE4) and NW Ponds (via SDS3).

Results

DO Fluctuations

Patterns in DO were similar before, during and after the two runway-deicing events. The January events were followed by a relatively long period of little rainfall. Naturally falling DO during this period confounded the ability to determine if the falling DO was solely attributable to the presence of deicing chemicals.

The rapid and frequent cycling of DO in non-deicing periods appears most directly related to rainfall (rising DO) and dry periods (falling DO), with wind, sun and temperature effects also present. DO typically fell to 25% saturation during dry periods and as low as 5% saturation during the extended dry period in late January. These observations were similar and consistent with the 1998-99 study.

It is very difficult, if not impossible, to distinguish the degree that DO patterns are attributable to deicing chemicals. That is, the drop in DO in NWP coincided with one of the longest dry periods of the winter. This study has shown falling DO to be a natural phenomenon during periods of dry weather (including small storms producing insignificant runoff).

Natural Oxygen Demand and DO

DO was very low and stratified in cells 1 and 2 of Northwest Ponds during the more than 2-month period prior to the first ground-deicing event. There is apparently a strong, natural oxygen demand in cells 1 and 2, most likely due to autochthonous (internal) factors (i.e. not runoff). There is neither aircraft nor active taxiway deicing conducted within the four STIA subbasins that drain to cells 1 and 2.

Effect of Glycols from Aircraft

There is very little likelihood that DO patterns in the study period are attributable to ADAFs (glycols) in stormwater. Glycols were generally absent or at very low levels (<24 ppm) in stormwater samples taken in the Nov/Dec 1999 period prior to the first runway-deicing event.

The Jan 11-12 runway-deicing event coincided with the largest aircraft-deicing event during the 1999-2000 winter season. During this event, the volume of glycols found in stormwater runoff in the SDS represents a small fraction (less than 7 percent) of the total BOD_5 from all runway-deicing chemicals applied during the event (including the BOD_5 from the glycols found in storm drainage). Approximately 96 percent of the glycols used in the January 11-12 time frame were collected by the IWS (based on concentrations found in stormwater runoff from outfalls SDS3 and SDE4).

The efficacy of aircraft-deicing BMPs (application areas are confined to the IWS drainage area) is well demonstrated (POS, 1996-2000). The lack of demonstrable impact on DO in the ponds from runway-deicing activities, and the relatively small percentage of BOD_5 exerted by glycols (when compared to the runway-deicing chemicals applied) demonstrates that glycols from aircraft-deicing are also unlikely to have an adverse impact on DO.

Conclusions and Recommendations

The variation in weather patterns and low frequency of snow and ice in the Pacific Northwest typically result in two runway (ground surface) deicing events each winter season. This low frequency of occurrence, combined with weather variability prevents sampling of a representative range of possible weather conditions (rain, snowmelt, dry weather, wind, etc.) that can coincide with a deicing event, all of which appear to influence DO levels. In addition, the amount of chemicals applied varies with the severity of the winter weather.

Due to the variability of natural factors influencing DO, the relative infrequency of deicing events, and the amount of representative data collected for the two studies, additional sampling is not warranted. However, data are now available to model natural factors influencing DO in the ponds.

BOD exertion models could be used to determine a risk-based approach capable of defining critical scenarios when, in concert with natural conditions, DO might be affected adversely by deicing chemicals. However, sampling results have shown that reaeration from cascades, weirs, and other stream features are difficult to effectively model and demonstrate that DO impacts are not problematic in the streams.

The Port applies BMPs for pavement-deicing that are consistent with or exceed the requirements of the current Draft Ecology Stormwater Manual. Sampling has shown that deicing impacts are not apparent when compared to natural DO fluctuations.

Downstream reaeration has been confirmed with monitoring. Current BMPs are effective in minimizing the impacts associated with deicing activities at the airport; therefore additional BMPs are not warranted at this time. However, additional BMPs should be evaluated as new deicing products or other appropriate technology emerge.

2 Introduction

As a strategic safety measure for departing and arriving aircraft, the Port applies liquid potassium acetate (PA) to the airfield when ground temperatures cause freezing surface conditions, whether related to snowfall or not. The Port also applies solid calcium magnesium acetate (CMA) and sodium acetate (SA), sometimes mixed with sand, to roadways and parking areas as ground surface deicers on the landside of STIA. This study was designed to evaluate the potential effects these chemicals may have upon dissolved oxygen (DO) as they are transported from the storm drainage system (SDS) and into receiving waters. This study is considered an investigative best management practice (BMP) pursuant to the NPDES permit-required Stormwater Pollution Prevention Plan for STIA (POS, 1998). This study continues similar work performed during the 1998-99 winter season (Cosmopolitan, 1999).

2.1 Background

Seattle-Tacoma International Airport (STIA) lies about mid-way between the cities of Seattle and Tacoma, Washington. The airport was built in the 1940s and has expanded throughout the years to become the 18th busiest airport in the U.S. The highly urbanized cities of SeaTac, Des Moines, and Burien surround the airport. To manage the airport's runoff the Port implements a stormwater monitoring program and a Stormwater Pollution Prevention Plan (SWPPP), which among other activities, are key requirements of the individual NPDES permit for STIA that began in 1994.

STIA storm drainage discharges through 14 individual outfalls, four that drain to Miller Creek, eight that drain to Des Moines Creek, and two that drain to a City of SeaTac system. See Figure 2-1 and Figure 2-2. The STIA outfalls drain a total of 963 acres that contain about 44% impervious surfaces. A total area of 165 acres drains to Miller Creek representing 17% of the total airport drainage, and about 5% of the 8.1 square mile watershed. The remaining 798 acres drains to Des Moines Creek, and represents about 24% of this 5.8-square mile watershed. Another 370 acres, mostly the impervious surfaces of aircraft gate and ramp areas, drain to the Industrial Waste System (IWS) and the Industrial Waste Treatment Plant (IWTP.) Three large lagoons detain and equalize runoff flowing to the IWTP, which removes suspended solids and petroleum products using the dissolved air flotation unit process. The IWTP discharges directly to Puget Sound via a separate outfall that combines with the discharge from the Midway sewage treatment plant.

In the Miller Creek watershed, all runoff from operating potions of STIA (subbasins SDN1-SDN4 and NEPL) passes through the 4.3-acre Lake Reba stormwater detention facility, built in the early 1970s. In addition, more than 12 acres of highway SR518 and City of SeaTac streets drain to Lake Reba. The outlet of Lake Reba was improved and reconfigured in 1999, resulting in a shallower and smaller volume of dead storage than existed during the 1998-99 DO study[1]. Below Lake Reba, the instream Miller Creek Detention Facility (MCDF), built in 1992 provides only live storage of upstream flows, including the runoff from STIA (via Lake Reba) and other runoff from outlying areas including the Cities of Burien and SeaTac and portions of highways SR509 and SR518. These heavily traveled roadways could be subject to deicing by non-Port entities such as WSDOT.

In the Miller Creek watershed, airfield runoff originates in only subbasins SDN3 and SDN4, which comprise 16% of the total airfield and 10% of the total SDS area. Impervious surfaces subject to ground-deicing in these two subbasins total just 12% of those in the entire airfield. Subbasin SDN1 drains only 3.1 acres of landside areas (Air Cargo Road) subject to chemical application. Subbasin SDN2 discharges rarely and only when rainfall exceeds the capacity of the two IWS pump stations, which are stormwater BMPs. The STIA North Employees Parking Lot (NEPL) drains about 28 acres of impervious area, with only about half subject to ground-deicing. Thus, compared to Des Moines Creek, Miller Creek not only receives less runoff from STIA, but also receives runoff from a smaller area potentially subject to ground deicing.

In contrast, Des Moines Creek receives the majority of STIA runoff, especially the areas potentially subject to ground deicing. In the East branch of this creek, subbasin SDE4 drains 17 acres of taxiways, about 6% of the airfield impervious area, and about 40 acres of roadways, which represent the majority of the total landside areas subject to ground deicing. Runoff from SDE4 combines with City of SeaTac runoff, including International Boulevard (SR99) and Bow Lake discharges, then enters the East branch of Des Moines Creek. In the East branch, the instream Tyee detention pond lies just upstream of the confluence of the East and West branches and detains only live storage for brief periods after storms[2]. Thus ground-deicing chemicals applied within SDE4 pass more rapidly through the entire creek than those from SDS3 which are detained by the Northwest Ponds (NWP) on the headwaters of the West branch.

The NWP are comprised of 3 distinct cells, resembling small lakes, bounded by dense wetland vegetation. The acronym NWP used in this report refers to the entire 9-acre area of all three cells, which provides approximately 19 acre-feet of dead storage. Water depths in the permanent pools vary from 1-3 feet in the East (NP3) cell, while the two western cells (NP1 and NP2) are much deeper at 6-12 feet. In the late 1960s, previous property owners excavated peat deposits in this area. These excavations filled with water to become what is now known as the NWP. These ponds may serve in the future as part of a regional detention facility operated by the Des Moines Creek Basin Plan. Considerable summertime macrophyte growth exists in these ponds, predominantly in the shallower eastern NP3 cell. This eastern cell (NP3) receives runoff from subbasin SDS3, which drains 462 acres or 72% of the total airfield. Nearly all of the active runways and taxiways lie within SDS3, especially runway 34R/16L, the longer

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[1] After improving the outlet structure, Lake Reba has approximately 4 acre-feet of dead storage. Total storage capacity is approximately 15.8 acre-feet. See drawing STIA-9918-C23.

[2] According to drawing STIA-9918-C23, Tyee pond provides zero dead storage and 18.5 acre-feet total storage capacity.

of the two that may receive more deicing chemical applications. Thus, Des Moines Creek, particularly cell NP3 of NWP, has the potential to receive the highest loading from ground deicing chemicals than would other STIA drainage.

Moreover, because of the potential for extended detention periods in NWP, this water body, specifically cell NP3, has the potential to experience greater oxygen consumption from deicing chemicals than any other water body receiving STIA runoff. Subbasin SDS1 no longer drains any ramp or landside areas subject to routine ground deicing. Subbasin SDS4 drains 7% of the airfield impervious surfaces and drains directly to Des Moines Creek below Tyee pond.

Other minor subbasins in the Des Moines Creek watershed include SDS2, SDS5, SDS6 and SDS7, none of which experience routine ground deicing. Together, these four STIA subbasins drain 2.8% of the total impervious area. However, runoff from these subbasins enters cells NP1 and NP2 combined with drainage from other entities, including City of SeaTac (S. 188th St). Similar to the Lake Reba drainage, streets and parking in these non-Port areas could be subject to ground deicing by these other entities.

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In some cases, weather forecasts allow airport operations managers to call for chemical applications before ice forms on ground surfaces. These cases of "anti-icing" may result in smaller volumes used than would have been necessary had an ice bond formed prior to chemical application. In the event of snowfall, the Port typically applies chemicals after removing snow with plows and/or brush machinery. Doing so minimizes the volume of chemicals needed to break the ice bond with pavement. As outlined below, the Port moves snow from ramp areas to designated snow storage areas that drain to the IWS. Occasionally, frost or freezing precipitation occurs without snowfall, where chemical applications may be less than those associated with significant snowfall. For convenience in this report, the terms "deicing" and "deicer" are used collectively to refer to both ice removal and prevention activity.

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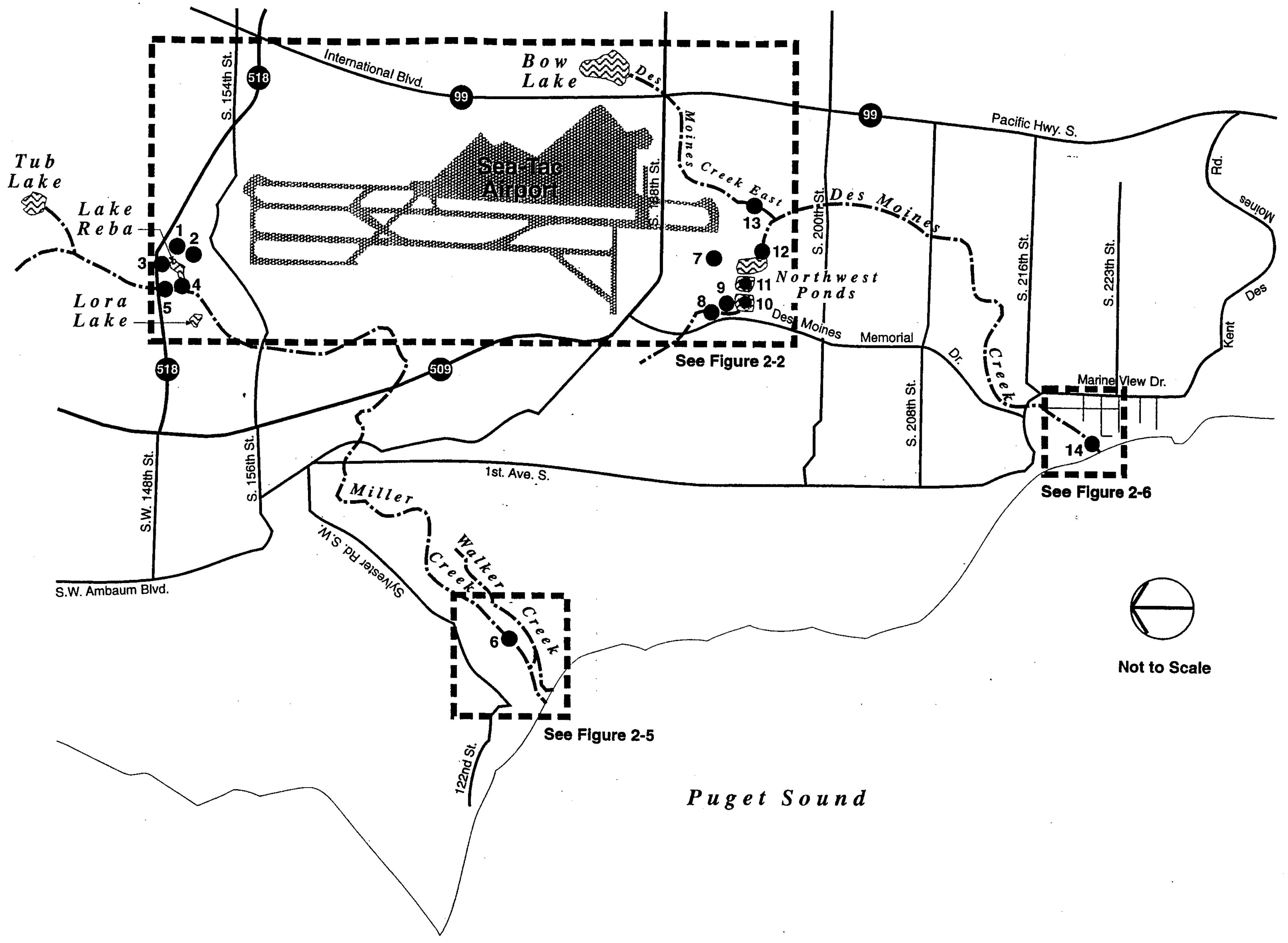
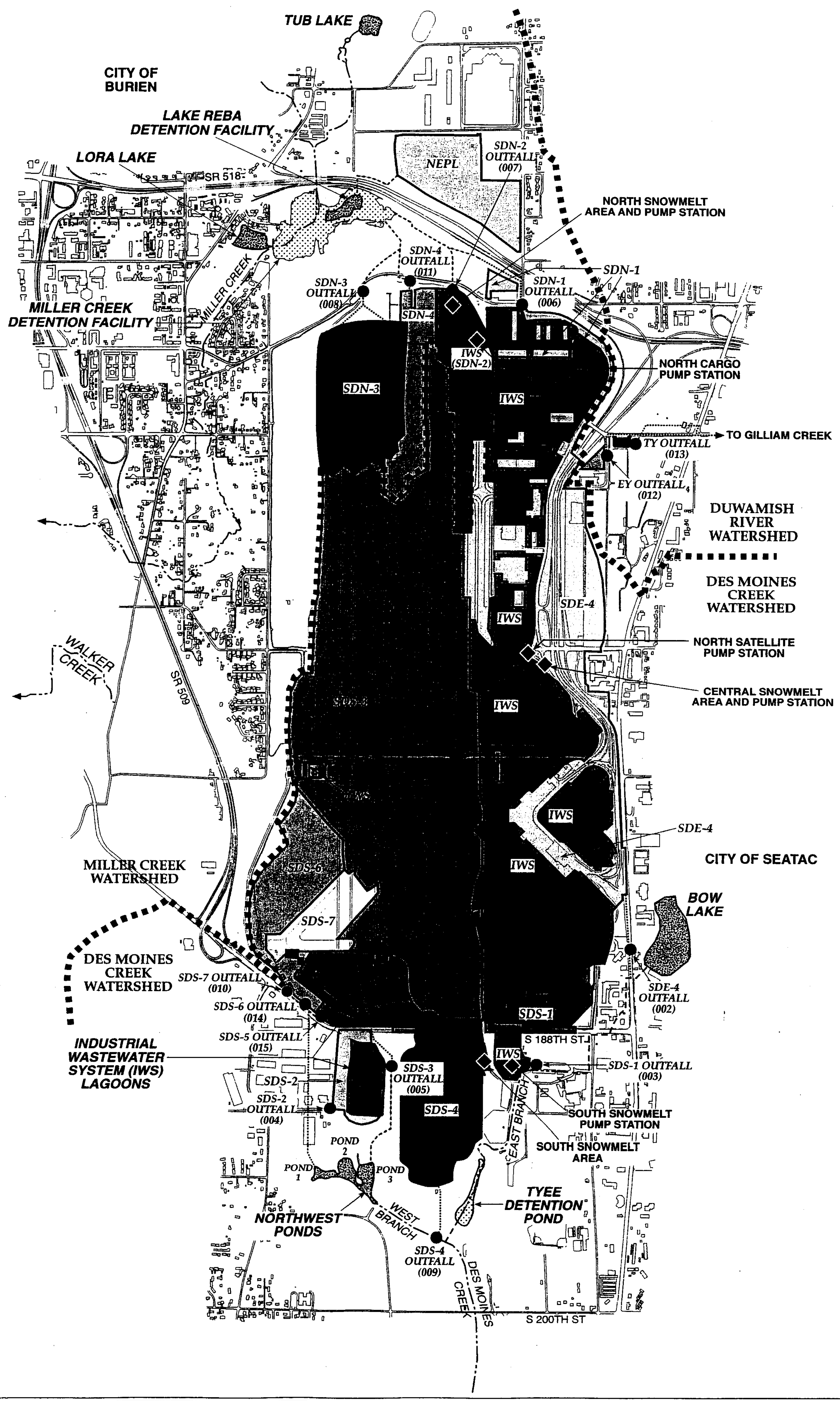


KEY

1	N1
2	N3N4
3	NEPL
4	Reba Out
5	MC Up
6	MC Mouth
7	S0S3
8	NP In
9	S567
10	NP 1
11	NP 2
12	NP Out
13	DME
14	DM Mouth

Port of Seattle
Sea-Tac International Airport
1999–2000 Runway Deicing Study

Figure 2-1
Site Location Map



Sea-Tac Airport/Stormwater Management Plan/556-2912-001/01(61A) 11/00 (K)

Figure 2-2
NPDES Drainage Subbasins, Snowmelt Areas and Pump Stations, and Permitted Outfalls

2.1.2 BMPs for Deicing

As part of the Stormwater Pollution Prevention Plan (SWPPP; POS, 1998) the Port implements an array of BMPs designed to minimize the potential for environmental effects associated with deicing chemical applications at STIA. The Port began implementation of many of these BMPs in 1996-1997. The list below summarizes these BMPs, which are also described in the SWPPP. Annual Stormwater Monitoring Reports have shown that these BMPs have been effective (POS 1998, 1999, 2000). Furthermore, these BMPs exceed the appropriate "applicable" and "recommend" BMPs described in the current draft of the Stormwater Management Manual for Western Washington ("Ecology Manual", Ecology, 2000).

1. Discontinued the use of urea as a ground-deicing chemical and substituted acetate-based products
    a. Eliminated the potential for toxicity associated with ammonia, a decomposition product of urea. Studies during the 1995-96 winter, when the last limited urea was used, showed ammonia concentrations in STIA outfall discharges were below toxic thresholds (POS, 1996).
2. Discontinued the use of glycols as ground deicers and substituted acetate-based products
    a. acetate-based replacement chemicals have lower BOD and less toxicity than glycols
3. Prevent stored bulk chemicals from entering SDS
    a. POS built a covered facility in 1997 to store bulk solid CMA, SA, sand and sand mixed with CMA and/or SA deicers
    b. POS maintenance stores and dispenses bulk PA liquid in tanks located in IWS drainage
4. Characterized BOD washoff functions
    a. Completed in 1996 during 4 events: January, February, November and December (POS 1996, 1997)
    b. Found that majority of chemicals washed off in first one inch of precipitation or less
5. Eliminated runoff from aircraft service areas. These BMPs eliminated sources of ADAFs and ground deicers in stormwater.
    a. Monitoring in 1995-96 showed that drainage from several areas near the terminal and other ramp areas was found to transport ADAFs to the stormdrains, principally SDE4 and SDS1.
        - POS designed and built North Satellite and North Cargo pump stations. These pump stations operate year round
    b. POS rerouted drainage by gravity flow to the IWS for other areas
    c. POS capped and/or plugged drains in other areas so that runoff flows to the IWS instead
6. All ADAFs are applied only in the gate (ramp) areas draining to the IWS.
7. Minimize potential for contaminated snowmelt to enter the SDS

    a. Monitoring in 1996 showed that snow plowed from gate areas contained ADAFs and ground deicers.
    b. POS built four designated snow storage areas that collect snowmelt and drain to the IWS
        i. 3 areas use pump stations
        ii. pump stations operate year round, thereby reducing other constituents in SDS discharges.
8. Minimize ground deicing chemical usage
    a. STIA Airfield Operations uses runway surface temperature detection devices to evaluate needs for chemical application
    b. follow chemical supplier recommendations to remove snow before applying ground deicing chemicals

2.2 Study Design

This section describes how the monitoring scheme for this project was designed. The types of monitoring, time periods, locations and sampling schemes are addressed. The Port reviewed this monitoring plan with Ecology on December 17, 1999[3].

The monitoring scheme for this project was based on previous work and an understanding of how winter weather patterns dictate and affect ground deicing chemical application. Incorporating a variety of sampling strategies, the design of this project targeted three types of monitoring scenarios related to certain conditions. These are 1) continuous receiving water DO monitoring over the fall and winter, 2) sampling runoff during a non-deicing storm event (to serve as background/control), and 3) sampling runoff related to ground deicing events. This continuous and event-based monitoring focused on certain indicators, or tracers, that signal the presence, magnitude and duration of deicing chemicals in the stream systems. Monitoring results were then compared to examine differences in DO during periods of chemical presence and absence.

2.2.1 Weather patterns and ground deicing frequency

In the past 5 winter seasons, brief periods of freezing conditions have generally occurred twice annually and have included overnight frost or snow that persisted for periods of only a few days. This pattern typical in the Pacific Northwest (PNW) results in much less frequent chemical applications than might have occurred at airports in the Midwest or northeastern United States and Canada. At STIA, the resulting ground-deicing chemical applications have varied according to the severity and duration of these conditions.

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[3] Port staff and consultants met with Ecology NW region, on December 17,1999 to review the scope and concepts of the monitoring plan intended for the 1999-2000 winter period.

During and after these ground-deicing events, a variety of monitoring has shown that the chemicals persisted in runoff for relatively short periods of time, with the majority washed off ground surfaces after the first one inch or less of cumulative precipitation, including snowmelt (POS 1996, 1997; Cosmopolitan 1999). Thus, to characterize the magnitude and duration of deicing chemical presence in runoff, this study targeted a sampling period coinciding with the first 1.5 inches of precipitation (including snowmelt) subsequent to deicing chemical application.

2.2.2 Continuous DO monitoring

Based on the results of past studies, continuous DO monitoring focused on the two ponds that receive runoff from the airfield. Continuous monitoring probes (Hydrolabs) were used to log DO, temperature and other parameters at the outlets of Lake Reba and Northwest Ponds. Because of the complex hydraulics of the multi-celled Northwest Ponds in the west branch of Des Moines Creek, DO was also logged in the two western cells (NP1 and NP2). The NP3 location was identical to the 1998-99 study, which assumed this location represents DO in discharges leaving the pond at the outlet (NPout) located about 50 feet to the east. Together, Lake Reba and the eastern cell of NW Ponds (NP3) receive runoff from virtually all (88%) of the airfield. See Figure 2-1 and Figure 2-2. Continuous monitoring was also planned for other key locations, including upstream of the ponds, but OEM software problems with new equipment delayed deployment until after the ground deicing events that occurred.

Past studies indicate that there is little if any likelihood of deicing chemicals affecting DO while in transit in the streams. Last year's work showed that instream DO generally increased with distance downstream (Cosmopolitan, 1999) during both non-deicing and deicing periods. This 1998-99 study and previous work (Taylor, 1996) also showed that travel times, and hence residence times, in the creeks were on the order of only a few hours during the wet winter season typical in the PNW. In addition, steady state modeling showed that for both creeks, the lowest instream DO attributable to deicing chemicals would occur about mid-reach, with rising concentrations downstream. This modeling used the Multi-SMP tool based on Streeter-Phelps concepts. Only peak BOD concentrations were tested and sampling indicates these peaks would persist only a few hours. Thus, the limited DO sag predicted by the model results from short-lived worst-case conditions. Again, actual monitoring during these periods showed that DO increased downstream with no sag apparent (Cosmopolitan, 1999).

Because these studies revealed that the deicing chemicals are rapidly conveyed through the stream system with little if any BOD exertion, this year's study focused on monitoring DO only in the ponds. These two bodies of water (Lake Reba and NW ponds) receive nearly all the runoff from the airfield (runways and taxiways) via outfalls SDN1-SDN4 and SDS3, and include runoff from limited landside areas as well. See Figure 2-2 through Figure 2-4. The hydraulic residence time in these ponds depends on rainfall and runoff patterns, resulting in much longer and more variable residence times than the stream travel times (Taylor, 1996). Therefore, the majority of deicing chemicals applied to the airfield runways and taxiways could have a higher potential to exert BOD and consume DO while in these ponds than when in the streams.

To improve the understanding of relationships and causal factors for DO fluctuations prior to deicing events, this year's study targeted a much longer period of continuous monitoring than last year's study. During the background period of last year's study, continuous monitoring showed that DO varied dramatically over time at all stations, principally in the ponds, and also instream. Patterns emerged where DO dropped rapidly to levels well below saturation during periods with little or no runoff, then rose sharply after significant precipitation. Furthermore, conductivity often mirrored these DO and rainfall patterns, indicating that runoff reduced the naturally higher receiving water conductivity. These patterns occurred early in the 1998-99 monitoring period, well before any ground deicing events and continued throughout the study. This year's study aimed to gather more information to characterize these dynamic background conditions.

2.2.3 Tracers

A key objective in this study was to provide the ability to establish periods of chemical presence and absence in the two pond systems. DO during these periods would be examined to compare differences in patterns and potential responses to deicing chemicals. As discussed above, the controls for these comparisons were established by several months of DO measurements recorded prior to ground deicing.

To signify the presence, duration and magnitude of ground-deicing chemicals in runoff, measurements of potassium, calcium and sodium ions and conductivity were used as tracers[4]. The three ions are specific and relatively unique to each ground-deicing chemical: potassium, calcium and sodium indicate PA, CMA, and SA, respectively[5]. Significant concentrations of these ions above background levels would thus indicate the presence of a specific chemical in runoff. Natural sources and sinks for these tracer ions were expected to be low enough that levels attributable to deicing chemicals would be significantly higher. The sampling during a non-deicing event would document background levels of these ions.

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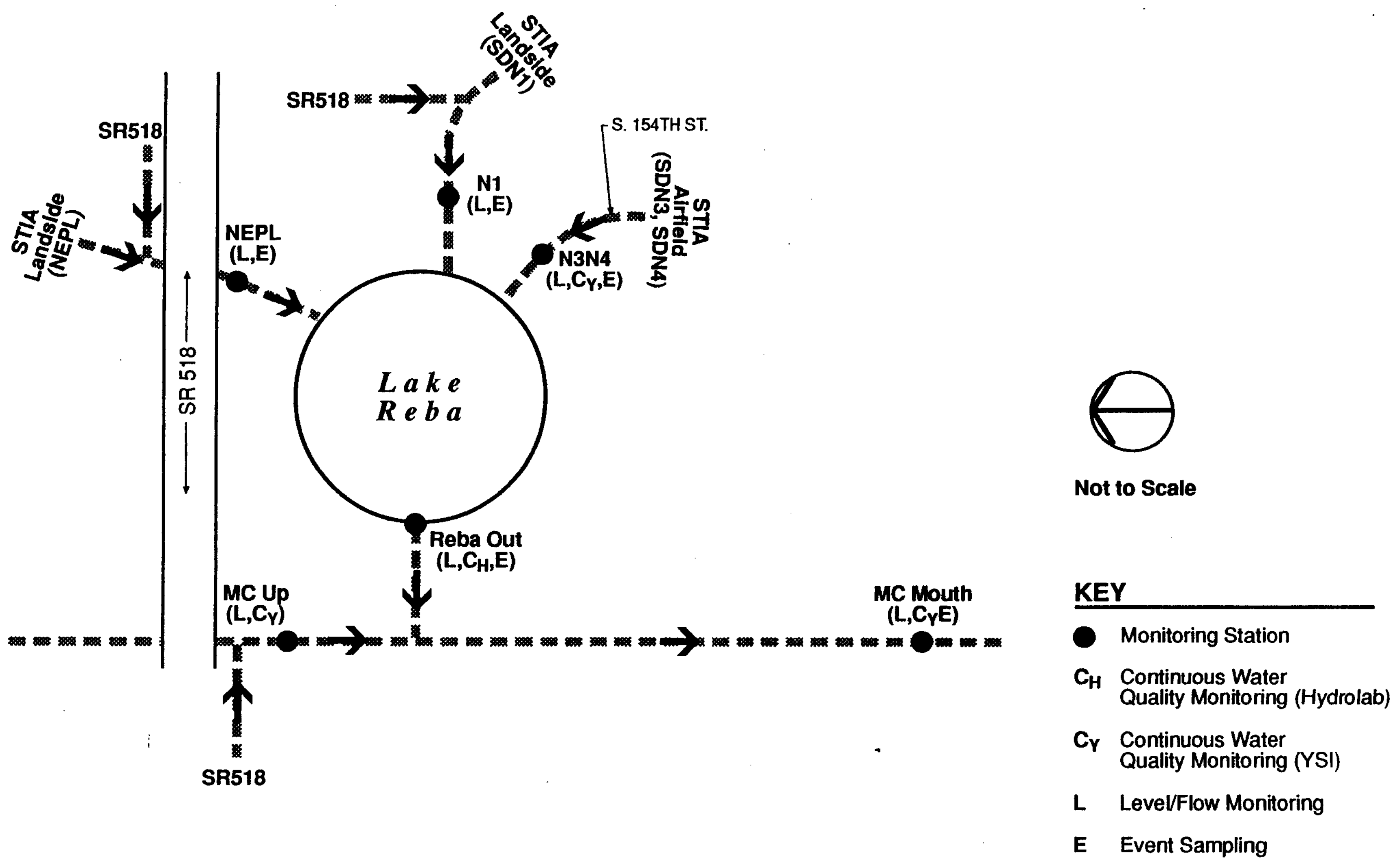
[4] A fourth tracer, fluorescence, was abandoned early in the project due to an inability to effectively resolve levels significantly higher than background readings. POS maintenance routinely adds fluorescent dye as a simple visual indication of volumes in bulk tank and application trucks. To achieve a high enough fluorescence signal above background, too large a volume of fluorescent dye would have been required to adequately dye the bulk tanks of PA prior to application.

[5] On January 3-5, 2000, analyses of PA in bulk tanks and loads in the two trucks used for application (#10 and #11) showed 25.7 to 26.5% potassium, and minor amounts of calcium (1.3 to 2 ppm) and sodium (138 to 224 ppm).

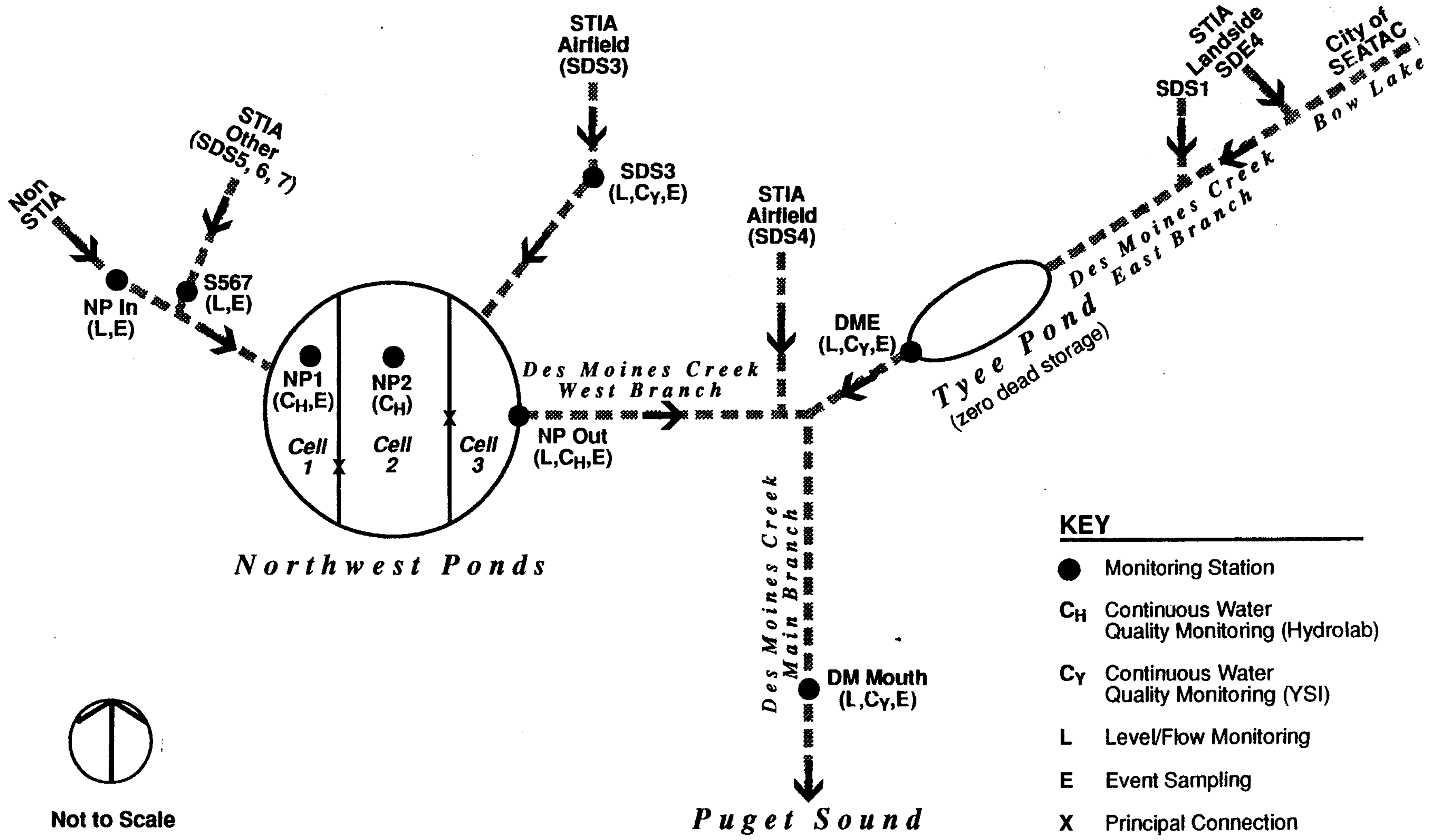


Port of Seattle
Sea-Tac International Airport

1999–2000 Runway Deicing Study

Figure 2-3

Miller Creek Watershed
Monitoring Location Schematic

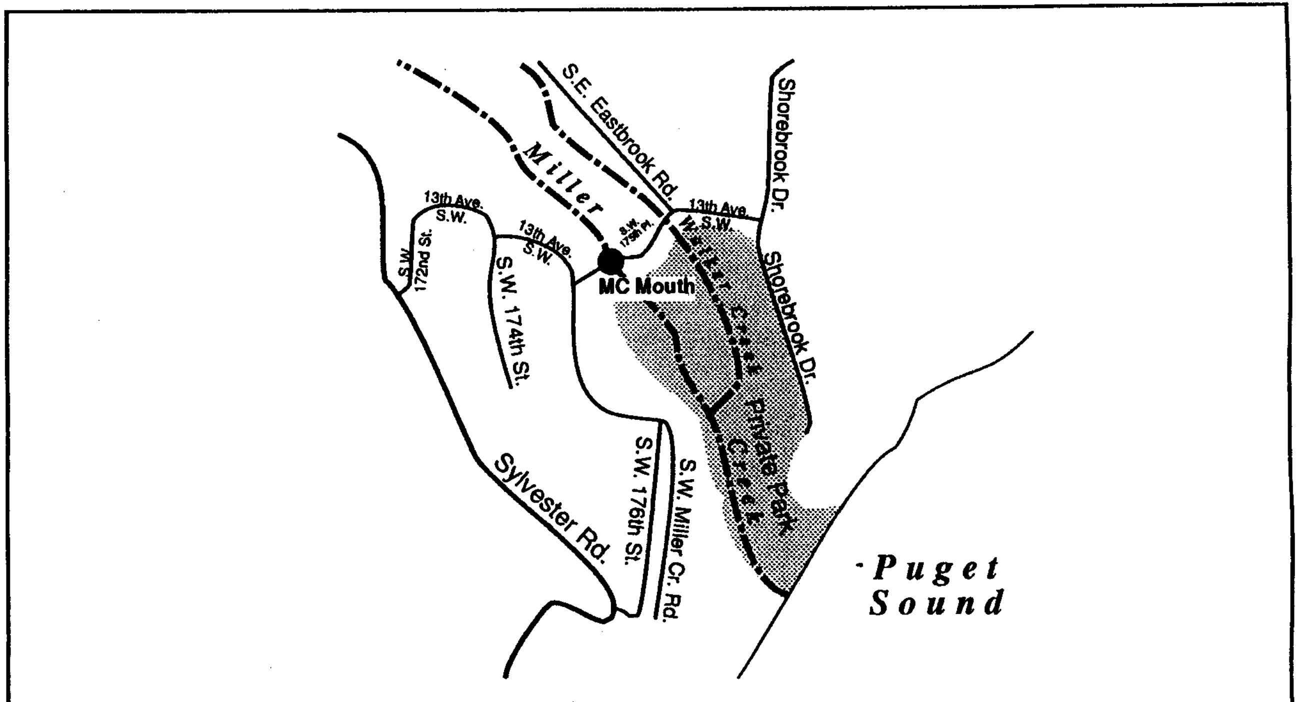


Port of Seattle
Sea-Tac International Airport

1999–2000 Runway Deicing Study

Figure 2-4

Des Moines Creek Watershed Monitoring Location Schematic



Walker Confluence shown at approximate location

Not to Scale

KEY

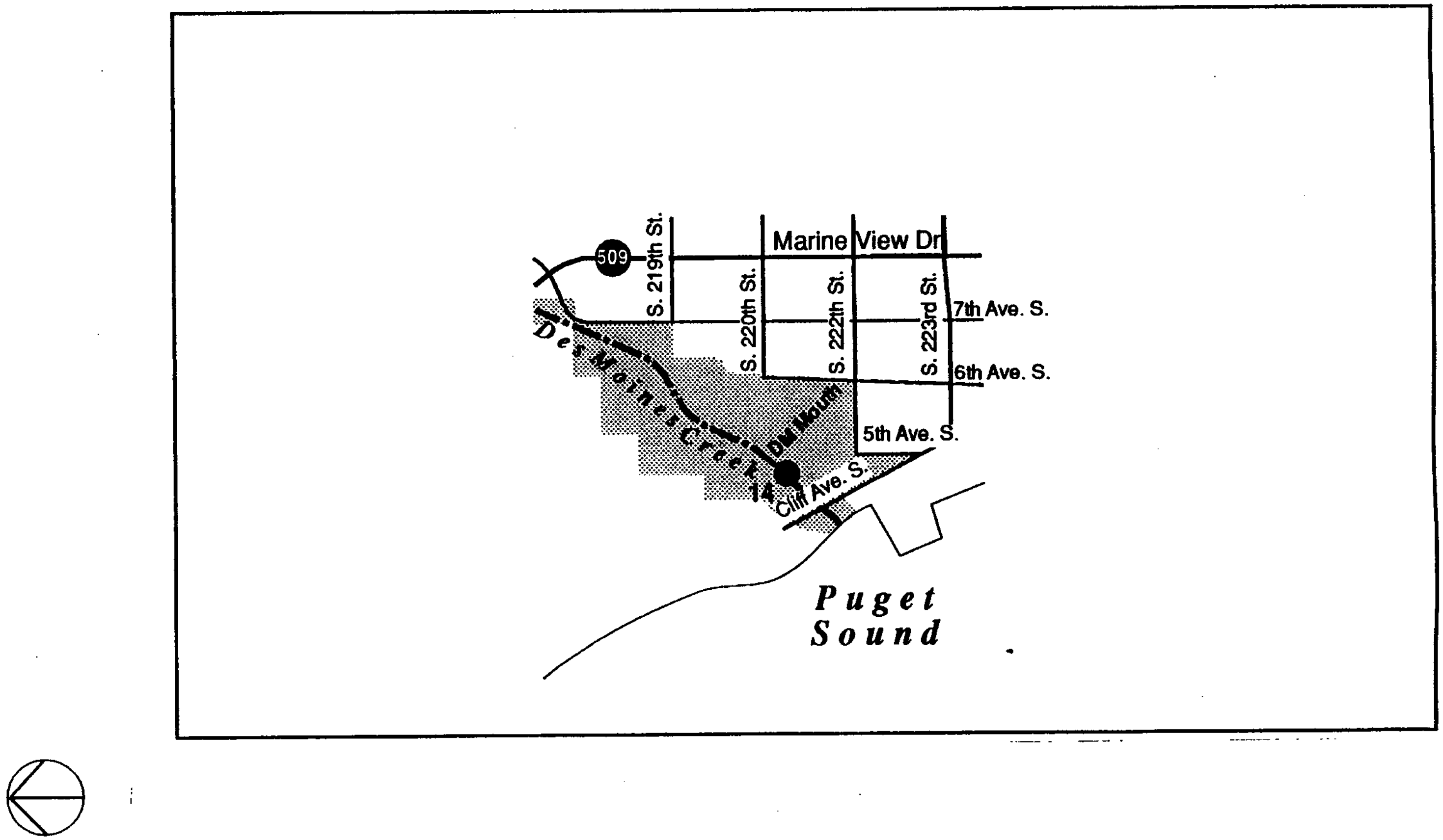
● Monitoring Station

BASE SOURCE: THOMAS BROS. MAP RENTON AUBURN KENT FEDERAL WAY, 1996

Port of Seattle
Sea-Tac International Airport
1999–2000 Runway Deicing Study

Figure 2-5

Miller Creek Mouth
Monitoring Station Location



Not to Scale

KEY

● Monitoring Station

BASE SOURCE: THOMAS BROS. MAP RENTON AUBURN KENT FEDERAL WAY, 1996

Port of Seattle
Sea-Tac International Airport
1999–2000 Runway Deicing Study

Figure 2-6

Des Moines Creek Mouth
Monitoring Station Location

Specific conductance, referred to hereafter as conductivity, was also used as a tracer because it provides an aggregate measure of all conductive ions associated with the acetate family of deicing chemicals used at STIA. Results from last year's work revealed that conductivity served as a tracer for deicing chemicals (Cosmopolitan, 1999). Conveniently, conductivity is a standard parameter available for measuring and logging continuously on the field instruments used to monitor DO in this study.

The acetate-based ground deicing chemicals used at STIA, namely PA, CMA and SA are highly ionic compounds that rapidly dissociate into acetate and a carrier ion, potassium, calcium (and magnesium), or sodium, respectively. Measurements of these ions and conductivity during non-deicing storm event runoff document the level and variation in background concentrations. Comparing these background measurements to results from a deicing event indicates when a particular chemical entered, peaked, and left the runoff at a particular point. Thus, the cessation of the washoff hydrograph at a particular station would be signaled when tracer ion levels dropped to and remained near background levels previously established.

This tracer approach has several advantages over using BOD as an indicator of deicing chemical presence. First, on a unit sample basis, the three ions yield more information at about the same analytical cost of BOD alone. BOD measurements reveal nothing about the identity of the particular sources present. Plus, BOD is not a conservative indicator, levels in a slug of water can change over time as aquatic biota consume the material. Second, because the ion analyses do not have the short holding time associated with BOD (48 hours) field work is more efficient. In last years' work, it took considerable effort in the field to handle and process the numerous samples within holding times. Finally, because WSDOT planned to use liquid CMA, calcium ion measurements could indicate potential contributions of chemicals applied by others to the major public roadways draining to the creeks[6].

2.2.4 Event-Based Monitoring

This study targeted sampling for two specific types of events and associated runoff. A non-deicing event was sampled in December well before any ground deicing chemical application. Results from this event established the baseline or background conditions occurring during runoff from a storm event that did not transport any deicing chemicals. This non-deicing event in effect served as the "control". The other type of event targeted was that which met the prescribed conditions occurring before, during and after ground deicing chemical applications representing the "treatments". The sampling

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[6] Per a phone conversation on January 7,2000 with a WSDOT staff manager, maintenance division regions 4 and 5, which serve the STIA vicinity, planned to use liquid CMA in the 1999-2000 season. In the Miller Creek drainage, potential WSDOT CMA applications on SR509 would appear at MCup, and applications on SR518 would appear at N1 and NEPL. In the Des Moines Creek drainage, WSDOT CMA applications on SR509 offramps would appear at NPin, applications on S. 188th St would appear at S567, and applications on SR99 (International Blvd) would appear at DME.

protocols and locations were similar for these two types of events to allow comparisons establishing patterns of chemical transport. Comparing concurrent DO patterns for these two types of events serves as the principal basis for determining if and to what degree the chemicals affect DO in the ponds.

During both the background and deicing event-sampling periods, automatic samplers collected a series of time-composite samples that represented 3 hours each[7]. These samples were intended to reveal the pattern of tracers and establish the washoff hydrograph showing rising, peak and falling concentrations associated with each event. To characterize the background storm event (December 11, 1999), the sampling targeted the first one-inch of rainfall associated with the particular storm event. For the deicing event sampling, the target hydrograph corresponded to the first 1.5 inches of precipitation subsequent to chemical application[7]. Past studies have shown that 80 to 90% of the deicing chemicals were washed off in the first inch (POS, 1996, 1997). Because of this constant-time sampling approach, each day during the first one inch of precipitation generated a total of 96 samples for the twelve stations. To minimize redundancy and analytical costs, samples with similar characteristics were composited to represent longer periods.

During the deicing event sampling, the cessation of the washoff hydrograph was signaled when tracer concentrations in samples fell to and remained near background. To aid sample handling in the field, conductivity in each sample was screened prior to laboratory analysis. These measurements established rising, peak and falling chemical concentrations during the respective hydrographs. In the event that the target hydrograph took place over more than several days, these measurements would allow individual samples to be composited to represent periods of similar conductivity readings, or to establish midpoints on trends of constant slope. For example, under the original plan, the first deicing event of January 2000 would have resulted in nearly 1000 samples because of the 14-day period needed to reach the target rainfall. To simplify sample handling and data reduction, and to reduce costs, a number of samples were composited as described above. In contrast, the 1998-99 study resulted in fewer samples because the target hydrograph of 1.5 inches occurred in less than 3 days, with a total of more than 4.5 inches falling in the two-week period after deicing.

2.2.5 Monitoring Locations

As described above, the monitoring scheme planned continuous monitoring at 10 locations and precipitation event-based monitoring at 12 stations[8]. These locations were selected based upon past experience as positions that best characterize water quality associated with deicing chemicals passing through the stream systems. Table 2-1 lists the monitoring locations and summarizes the type of sampling and equipment

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[7] Per the monitoring plan, sequential samples during the deicing event were collected every 6-hours after the first one-inch of rainfall.

[8] Problems with OEM software for six pieces of new equipment purchased specifically for this project prevented deployment at six locations until February 2000.

planned for each station. These locations were also chosen based on relationships to chemical application and transport characteristics. Five sampling locations were intended to characterize sources of deicing chemicals. Three locations characterized the chemical sinks represented by the ponds, while two cells of NWP served as controls. A station near each creek mouth was intended to reflect when the chemicals exited the respective stream. Most locations were identical to last years work, though some were moved to optimize work and/or provide more representative data.

2.2.5.1 Airfield source sampling sites

Airfield runoff was sampled at outfall SDS3 (at the NPDES location), and the inlet to Lake Reba that combines SDN3 and SDN4 drainage (N3N4). These two stations account for 88% of the total airfield drainage area with SDS3 draining 76% and N3N4 draining 12% of these impervious surfaces. The SDS3 station was identical to last year's work. However, the N3N4 station consolidated runoff from outfalls SDN3 and SDN4 at a single location, their inlet to Lake Reba, while adding limited runoff from S. 154th Street. The N3N4 location incorporates channelized flow through a forested area that was not taken into account in last year's sampling at the SDN3 and SDN4 outfalls.

A 17-acre area of taxiway subject to deicing drains to SDE4 and thence to Des Moines Creek directly without detention. This relatively small fraction (2.6%) of the total airfield would be represented in samples taken at the DME station in the East Branch of Des Moines Creek. SDS4 was not sampled because: 1) it drains a small fraction of the airfield impervious surfaces (7%), 2) it drains directly to Des Moines Creek, 3) previous work has shown that SDS4 deicing washoff behaves similarly to SDS3, and 4) cost/scope savings.

2.2.5.2 Landside source sampling sites

Landside runoff was characterized by samples taken at three locations: two inlets to Lake Reba and the DME station in the East Branch of Des Moines creek. The NEPL inlet to Lake Reba drains NEPL and portions of SR518. The N1 inlet to Lake Reba combines runoff from POS outfall SDN1, City of SeaTac roads, and SR518, all of which may be subject to deicing chemical application on public roadways. The N1 location aggregates more runoff than last year's location. The NEPL and DME locations are the same as during last year's work.

Table 2-1 Monitoring Locations

Miller Creek

		Station			Flow		continuous monitoring			Event Samples			
station name	**sources**	**locn**	**same as 98/99?**	**type**	**eqpt**	**method**	**DO/Temp**	**cond**	**eqpt**	**ion tracer**	**fluor**	**cond**	**notes**
MC up	upstream of POS	SR518 crossing	Y	instream	4230	stage-Q (KC)	X	X	YSI 600R				
MC Mouth		at KC gage above Walker confl.	Y	instream	4230	stage-Q (KC)	X	X	YSI 600R	X	X	X	
LR out	LR combined	LR outlet structure	moved from pond to outlet	pond	4150	direct (area-vel)	X	X	Hydrolab (POS)	X	X	X	
NEPL	NEPL, SR 518	LR inlet at SR518	Y	outfall	4150	direct (area-vel)				X	X	X	
N1	SDN1, SDN2, SR518, S. 154th, 24th Ave S	LR inlet	no, new location in lieu of outfall	outfall	4150	direct (area-vel)				X	X	X	
N3N4	SDN3, SDN4, S. 154th	LR inlet	no, new location in lieu of outfall	outfall	4150	direct (area-vel)			YSI 600XLM	X	X	X	3

Des Moines Creek

		Station			Flow		continuous monitoring			Event Samples			
station name	**sources**	**locn**	**same as 98/99?**	**type**	**eqpt**	**method**	**DO/Temp**	**cond**	**eqpt**	**ion tracer**	**fluor**	**cond**	**notes**
NP in	City/Industrial		Y	outfall	4150	direct (area-vel)				X	X	X	
NP 567	SDS5, SDS6, SDS7, S. 188th, Industrial	combined SDS5-7	Y	outfall	4150?	direct (area-vel)				X	X	X	
NP1	2 inlets above+ other w'hse	center of west cell	new	pond			X	X	Hydrolab (rental)	X	X	X	
NP2	SDS2, 16th Ave S	center of central cell	Y	pond			X	X	Hydrolab (rental)				
NP3	SDS3	~50 ft from outlet of east cell	Y	pond			X	X	Hydrolab (POS)				
NP out		NWP outlet/culvert	Y	instream	4230	stage-Q (KC)				X	X	X	
SDS3	SDS3, S. 188th	SDS3 outfall	Y	outfall	4230	stage-Q	X	X	YSI 600R	X	X	X	1, 2
DM E	SDE4, SDS1, City streets	Tyee outlet	Y	instream	4230	stage-Q (KC)	X	X	YSI 600R	X	X	X	
DM mouth		mouth at KC gage	Y	instream	4230	stage-Q (KC)	X	X	YSI 600R	X	X	X	

notes:

1. BOD5 to be analyzed in SDS3 runway deice event composite sample, required per NPDES permit
2. Outfall SDS4 assumed to have similar pollutagraph/hydrograph to SDS3 and therefore not sampled.
3. Added logger at N3N4 inlet to Lake Reba .

total # YSI	5
total # Hydrolab rented	2
total # Hydrolab owned	2
total # event samplers	12

Though subbasin SDS1 drains directly to the East Branch of Des Moines Creek, there are little if any deicing chemicals applied by the Port in the SDS1 drainage area. Major drainage reroutes in past years have removed virtually all ground surfaces from the SDS1 subbasin[9]. However, a non-Port area of S. 188th Street draining to SDS1 may be subject to chemical application by the City of SeaTac. Additional runoff from public roads such as International Boulevard drains to the east branch of Des Moines Creek and commingles with STIA landside runoff from SDE4 prior to exiting at the 5-foot diameter culvert near South 28th Street. Taking these facts into account, the monitoring design targeted sampling at the DME station that aggregates runoff from SDE4, SDS1 and the City.

2.2.5.3 *Pond Monitoring Stations*

After application, deicing chemicals enter and pass through the drainage system and streams in two principal transport regimes: rapid and detained. Runoff from the landside areas, primarily SDE4, enters Des Moines Creek directly, with relatively short retention provided by the live storage in Tyee pond. In contrast, Airfield runoff drains via outfalls SDS3, SDN3 and SDN4 through the two ponds that have considerable dead storage and variable retention times (Lake Reba and NW Ponds). See Figure 2-3 and Figure 2-4.

As discussed above, these two pond systems were the focus of continuous DO monitoring. Hydrolabs recorded DO for the outlets of both ponds (LRout and NP3) and the two cells of NW Ponds (NP1 and NP2) that are upstream of POS airfield runoff. These latter two cells, NP1 and NP2, were intended to serve as controls for DO responses because they do not receive runoff from airfield areas subject to routine deicing. Downgradient from these two cells, the airfield runoff from SDS3 (72% of the total airfield drainage area) enters only NP3, which drains directly into Des Moines Creek.

2.2.5.4 *Creek Mouth Stations*

A monitoring station was located near the mouth of each creek. The Des Moines Creek station "DMmouth" was located in a park at the small footbridge crossing about 500 linear feet from the mouth. The Miller Creek station "MCmouth" was located at the road crossing of SW 175th place. Both stations were the same as used in the 1998-99 study and are King County DNR gaging stations.

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[9] Less than 1 acre of ramp area near the South Satellite drained to SDS1. This drainage was rerouted to the IWS in September 2000.

2.3 Sample Size Considerations

The following summary discusses the issue of "sample size" that Ecology raised based on the first year's (1999) report. Ecology's concern was that the Port might be drawing conclusions based upon too few deicing sample events or that the events sampled may not well represent the range of possibilities.

2.3.1 Background

Ecology has expressed concern that the findings of last year's study were based on only two ground-deicing events (Ecology, 1999). This is a legitimate concern. But because of the infrequency and unpredictability of the weather conditions that necessitate deicing events, the Port has little ability to address this issue. Because Seattle has a relatively mild climate, ground-deicing is infrequent and of considerable variation in magnitude, extent and subsequent weather patterns. Based on classical hypothesis testing, it would take many years of study before a sufficient number of ground-deicing events would have occurred to give sufficient statistical power.

In classical hypothesis testing, one relies on replication both within and between levels of controlled factors to evaluate the effects of the factors on dependent variables of interest. Effects of uncontrolled variables, covariates, can also be included in an analysis. The confidence that one will detect an effect and the power to detect an effect if one exists are both increased by increasing the number of replicates within a level.

In this study, the controlled factor of interest is ground-deicing, the dependent variables of interest are dissolved oxygen concentration and saturation. The covariates that may affect the relationship between the control factor and these dependent variables include physical factors such as water temperature, conductivity, rainfall, wind speed, etc. Applications of deicing chemicals to airport runways and the periods of time after those applications when deicing chemicals are present in the ponds represent replicate deicing events. Periods of time before, between, and after deicing events represent replicate non-deicing events. The hourly measurements within each deicing and non-deicing event are sub or pseudo replicates of an event replicate that are used to increase the precision of the estimate of a variable during that replicate.

Findings from the past two study seasons indicate that the covariates that were measured, and most likely other unmeasured covariates, have a large effect on dissolved oxygen levels and create considerable variance in DO levels within a replicate deicing or non-deicing event. In other words, it is difficult to distinguish and determine the effects on DO of any single factor.

2.3.2 Approaches to address the sample size issue

There are multiple conventions available that can be used to statistically relate cause and effect and determine how much information is needed to gain confidence in the potential relationships.

- Usual conventions

To determine the number of replicates needed to detect an effect by a factor on the mean of a variable, one must identify a particular response variable of interest (e.g., mean DO, change in DO) and know something about the variance of that variable in space and time. The ratio of within- *vs*. between-level variance in the dependent variable is used to determine whether the independent factor has an effect. Information about the relative magnitudes of these two levels of variance is needed to determine the sample size required to distinguish between them with a specified level of confidence. In this study, the high variance in DO levels found to exist within replicate deicing and non-deicing events will require either large numbers of deicing events or that extremely large differences exist between mean DO levels during deicing and non-deicing periods for the effects of deicing to be detected. Considering the first premise, it would take many years before a sufficient number of deicing events could be sampled. Given the second premise, results from two season's study do not indicate large differences in DO between periods of deicing and non-deicing events.

- Other approaches

When investigating causal effects on environmental processes that do not occur frequently, that are highly variable, and/or that are strongly affected by other factors/variables other approaches are required. Linear and nonlinear statistical modeling approaches, including time series models, can be used to explain and predict variance in a dependent variable(s)of interest. Each approach assumes that the distribution of the variables and errors around the model meet certain requirements for the model findings to be valid. In general, modeling approaches that test for the effects of a factor involve looking for differences between the factor levels in either the mean of the dependent variable, the relationships between the dependent and independent variables, or the variance around the model.

When replication does not occur, "weight of evidence" approaches, Bayesian approaches, and, in some cases, simulation approaches (often a form of modeling approach) can be used. Each of these approaches can take multiple forms, depending on the issue of interest and the availability of other data, and each approach can be incorporated into another approach. In general, a weight of evidence approach involves analysis of additional data about related components of a system that can be used to support or refute the hypothesis of interest. A Bayesian approach would involve incorporating information from other studies to provide perspective on and "update" the distribution of the data from the current study. A simulation approach usually involves developing a model (even a "null" model), creating many replicate (virtual) outputs from the model, and evaluating the probability that a certain type of event, perhaps a real event that has occurred, would occur.

2.3.3 Adapting a method to the STIA DO Study

This year, deicing chemicals were applied intermittently during a two-week period to different areas of the airport. There were three distinct and short-lived weather patterns that caused freezing conditions and the need for ground deicing. These applications, which were of unequal magnitude and chemical composition, and their runoff into Lake Reba and NP3 constituted the replicate deicing events.

Consequently, this project's analysis needed to take a "weight of evidence" approach to put together a coherent picture of how the presence, magnitude and duration of deicing chemicals effect DO in Lake Reba and NP3 and to determine how those effects are passed on to Miller and Des Moines Creeks. The approach has incorporated statistical modeling, qualitative and quantitative investigations of other low-rain periods during the season, and information about the amount of rain required to "wash" the runway of chemicals, flushing rates of the ponds, and the presence of tracer ions in the ponds.

Statistical modeling involved investigating the relationships among all measured variables, including time. Investigations of other low-rain periods involved comparing patterns of DO during multiple low rain periods and looking for changes in covariates that could explain differences in DO patterns among periods. Findings from previous studies conducted by the Port were used to understand lag in time between application of the chemicals, chemical presence in the ponds, and residence times of chemicals in the ponds.

2.4 Potential Effects of Aircraft Deicing (glycols)

Ecology suggested that ADAF application has the potential to be a "continuous source" of BOD to the receiving waters (Ecology, 1999). This premise suggests that glycols enter waters in sufficient magnitude and frequency such that they could be responsible for the depressed DO exhibited in the ponds prior to ground-deicing during the 1998-99 DO study. However, the considerable monitoring data demonstrate infrequent, low levels of glycols in SDS discharges in the fall and early winter months prior to ground deicing events. Importantly, these results show that the IWS effectively captures nearly all glycols, even during major deicing events. Summaries of deicing event sample data have been presented in each Annual Stormwater Monitoring Report (POS, 1996, 1997, 1998, 1999, 2000).

Fall and winter 1999-2000 monitoring prior to the Jan 12, 2000 ground-deicing yielded glycol data for 8 events at a variety of outfalls. Ten of fourteen of these samples showed non-detectable glycols (<2 mg/l). Total glycols for outfall SDS3 samples ranged from 6 to 23 mg/l. During these events that coincided with periods of continuous monitoring, DO in Lake Reba and NWP increased in response to the rainfall.

Similarly, in the previous season, Fall and winter 1998-1999 monitoring prior to the December 24, 1998 ground-deicing yielded glycol data for 6 events at a variety of outfalls. Fourteen of these eighteen samples showed non-detectable glycols. Glycols were not detected in runoff samples during 5 events each at outfalls SDE4 and SDN4. Total glycols for outfall SDS3 ranged from non-detectable to a maximum of 12 mg/l in this period. These patterns were similar for samples collected during January and February 1999, after the December 1998 runway-deicing event. Annual Stormwater Reports have reported and summarized these results (POS, 1999, 2000).

Small amounts of ADAFs may enter the SDS via "shear and drip" after pushback when aircraft taxi to the airfield and proceed with their takeoff roll. The only subbasins contiguous with (IWS) application areas are SDS3 and SDE4, both of which drain to Des Moines Creek. The other airfield subbasins (SDS4, SDN3 and SDN4) are further removed from the terminal and drain much smaller and/or less significant areas of the airfield than either SDS3 or SDE4. All airfield drainage was removed from subbasin SDS1 and SDN2 and rerouted to the IWS in 1997. Monitoring data for all these airfield outfalls since institution of the BMPs mentioned above has shown that glycols rarely enter the SDS and usually only at low concentrations during the days of highest ADAF application associated with severe weather (POS, 1998-2000).

Considering Miller Creek outfalls first, glycols have routinely been undetected in SDN4 and SDN3. This is most likely due to the fact that these two outfalls are well removed from the terminal and principal taxiways, plus they have small runway drainage areas (12%) compared to SDS3 (76%). During the 1999-2000 study period, there was only a single discharge from SDN2, which occurred on Dec 15, 1999 during intense rainfall that exceeded the two pump stations' design capacity (these are BMPs). A low concentration of ethylene glycol (4.3 mg/l) was found in a sample from this short-lived pump station bypass to outfall SDN2. Finally, outfall SDN1, the remaining Miller Creek outfall drains only portions of Air Cargo road and cargo building rooftops and doesn't drain any airfield areas. Past sampling data for SDN1 showed consistently undetected glycols.

These facts show that Miller Creek has little if any potential to receive glycols from STIA. Results from all SDN4 samples taken in November and December 1998-1999 showed glycols were absent. Thus, any depressed DO exhibited in Lake Reba in this period was due to factors other than glycols. Prior to all SDN4 sampling, where glycols were not detected, DO was already low, then rose in response to precipitation and runoff during the storms sampled.

In the Des Moines Creek watershed, only outfalls SDS3, SDS4, and SDE4 drain areas capable of receiving ADAFs from shear and drip input. SDS3 contains 462 acres (76%) of the airfield impervious area, also draining portions of taxiways contiguous with IWS areas draining the ramp at B and C concourses and North and South satellites. SDS4 drains only the south end of runway 34R, used for aircraft taxiing and holding only during north flow operations which are typically associated with fair weather and hence, little if any ADAF application. Past data for SDS4 have shown many samples with non-detectable glycols. SDE4 drains 17 acres of taxiways A and B (6% of the airfield impervious area) that departing aircraft use during south flow operations associated with poorer weather and higher ADAF application. Samples from the past four winter seasons have shown that glycols were infrequently detected at these outfalls, where the highest concentrations occurred only during the few runway-deicing events.

Other Des Moines Creek outfalls from subbasins SDS2 and SDS5, SDS6, and SDS7 do not drain areas where glycol is applied, and are well-removed from the terminal. Prior to the January 2000 ground-deicing event, two samples from SDS1 showed undetectable glycols. Drainage from several small areas in SDS1 capable of receiving ADAFs was re-routed to the IWS this past summer. Thus, evidence shows that these five outfalls would not have discharged glycols to the creek or NWP.

During the December 24, 1998 event, estimates show that less than 1% of the ADAFs applied entered the SDS during the period associated with particular sample results. See Appendix F. The BOD5 from this small amount of glycols is minor in comparison to that associated with the ground-deicing chemicals. Estimates show that the BOD5 attributable to glycols (by shear and drip) was less than 2% of the total BOD_5 from all chemicals applied during the December 1998 ground-deicing event.

Thus, taking all these facts into account, ADAFs have little if any potential to adversely affect DO, or even enter the receiving waters in significant quantity. To reiterate, these facts are:

- the Port has instituted a number of glycol abatement BMPs,
- monitoring has shown that these BMPs have been effective,
- data and estimates show glycols to be a very small component of total BOD associated with winter weather conditions,
- routine low-level aircraft deicing that occurred in the fall and winter of 1999-2000 prior to the January 12th ground-deicing event did not result in significant glycols in the SDS, and
- DO during the events mentioned above rose sharply, indicating the absence of BOD effects attributable to glycols.

3 Methods and Results

This chapter discusses data collection methods and presents results for continuous monitoring and event-based samples collected during the study. These results include background (control) events and ground-deicing events, vertical water quality profiles of the NWP cells, and quality assurance.

3.1 Continuous Monitoring

This section describes how and where continuous monitoring instruments were deployed, the procedures and schedule employed for maintaining instruments and downloading data, and the methods used to assess and ensure data quality. As described in the previous chapter, continuous monitoring of DO and other parameters was planned for 10 stations. Monitoring locations are depicted in Figure 2-3 through Figure 2-6 and summarized in Table 2-1.

3.1.1 Monitoring Locations and Equipment

Two types of water quality sondes were used to continuously measure and record dissolved oxygen, temperature, and conductivity at four locations. A Hydrolab Minisonde was deployed at RebaOut and NP1 and two larger Hydrolab Data Sonde 3 units were deployed at the NP2 and NP3 stations.

YSI water quality sondes were planned for deployment at four instream stations and 2 outfalls for the duration the DO study. Although POS acquired these instruments for this project, problems with OEM hardware and software incompatibility delayed deployment until later in the study period.

At RebaOut the Minisonde was deployed from November 18, 1999 until March 8, 2000. This sonde was installed in the pond's outlet control structure next to the flow-control gate. The sonde was housed vertically in a 3-inch diameter perforated pipe that was secured to the gate frame. The sonde was positioned with the sensors in the vault sump just below the level of the outlet pipe invert, so that they would always be submerged yet would remain in the flow stream. An external 12-volt deep cycle battery powered the data sonde. During the 1998-99 study, the same type of data sonde was deployed near the middle of Lake Reba rather than at the outlet (Cosmopolitan, 1999). The new location was chosen to better represent the condition of water leaving the pond.

Hydrolab data sondes were deployed in each of the three cells of NWP for varying lengths of time from November 18, 1999 until March 8, 2000. The periods of deployment and types of instruments used in each cell is shown in Table 3-1. In cells 1 and 2, the data sondes were suspended from buoys anchored near the center of each cell (stations NP1 and NP2). In cell 3, the NP3 station had its instrument secured to a ring buoy anchored about 50 feet west of the pond outlet (NPout). The DataSonde 3 units were powered by an external 18-volt battery pack while the Minisondes were powered by an external 12-volt deep cycle battery. Each of the four Hydrolab data sondes was programmed to measure and record the water quality parameters once every hour. The sondes were equipped with stirrers that were activated each time that dissolved oxygen readings were taken.

Table 3-1 Hydrolab sonde deployment

Station	Instrument	Periods of Operation
RebaOut	Minisonde	10/29/99 – 5/3/00
NP1 (cell 1, west)	Data Sonde 3	11/12/99 – 1/13/00, 1/24/00 – 5/4/00
NP2 (cell 2, central)	Data Sonde 3	12/29/99 – 1/6/00, 2/1/00 – 2/26/00
NP3 (cell 3, east)	Minisonde	10/21/99 – 12/9/99, 12/17/99 – 12/30 99, 1/17/00 – 1/31/00, 2/2/00 – 2/29/00, 3/3/00 – 4/27/00

In the 1998-1999 study, data sondes were deployed in cells 2 and 3 of the Northwest Ponds, but not in cell 1. For this study, cell 1 was intended to act as a control because ground-deicing chemicals are not routinely applied to subbasins SDS5, SDS6 and SDS7, which drain to cell 1. To verify the suitability of cell 1 to serve as a control, water sampling was conducted during ground-deicing events at the two principal outfalls (NPin and S567) discharging to cell 1. Deicing-event water sampling was also conducted within cell 1 near the NP1 location to determine if deicing chemicals entered either from upstream (NPin, and S567), or in backflow from cells 2 and 3.

Over the length of the study, two strategies were used to position the data sondes vertically in the water column in each cell of NWP. Initially, the data sondes were positioned with their sensors at mid-depth in the water column. After several months of monitoring, QA samples and DO profiles indicated that dissolved oxygen levels decreased rapidly with depth beginning at about the midpoint of the water columns, particularly in cells 1 and 2. Because of the potential bias imparted by this "oxycline", in early February, the data sondes were elevated above it to provide more consistent background readings.

3.1.2 Continuous Monitoring QA/QC

Because of data sonde performance problems encountered during last year's study, the maintenance and calibration frequency for the Hydrolabs was increased for this study. The Hydrolab units at NWP and Lake Reba were on a weekly schedule for maintenance and download. Weekly cleaning prevented biofouling that could reduce sensor performance. Once every two weeks the DO sensor membranes were replaced and the units were calibrated. This maintenance and calibration schedule met or exceeded the manufacturer's recommendations for servicing the sensors.

Whenever the Hydrolabs were removed for maintenance or redeployed, grab samples were collected for conductivity analysis and DO analysis by the Winkler method. In situ measurements of DO and temperature were also taken using a portable meter at the time grab samples were collected. Refer to Appendix B for specific information about collection of field check samples and Hydrolab maintenance and calibration procedures.

3.2 Northwest Ponds Water Quality Profiles

Because a number of calibration samples for DO showed significant variability (> 20%) from concurrent data collected by the Hydrolabs, the study design was amended to explore vertical distribution of dissolved oxygen in each cell of NWP. Equipment calibration results for the Hydrolab sondes indicated that the instruments were functioning properly, therefore the calibration differences observed were attributed to environmental variability rather than instrument measurement error.

To confirm this assumption, in situ measurements of DO and temperature were taken and water samples were collected for analysis of other constituents, including tracer ions, along vertical transects in each cell of NWP. DO profiles were measured nine times at NP1, seven times at NP2 and 12 times at NP3. Profile samples were also collected for conductivity, specific ions, BOD, COD and ORP on other occasions. Table 3-2 lists the types and number of profile samples collected in each cell of the Northwest Ponds.

Table 3-2 Number of profiles sampled in the Northwest Ponds

Parameter	NP1	NP2	NP3
DO	9	7	12
Temperature	9	7	12
Conductivity	8	7	8
Potassium	8	7	8
Sodium	8	7	8
Calcium	8	7	8
BOD	8	7	8
COD	8	7	8
ORP	2	2	3

Dissolved oxygen and temperature was measured at each point along the vertical transects using a calibrated portable DO meter. In cell 1 and cell 2, measurements were taken at 1-foot intervals along the 10 to 12 foot deep profile. In the shallower cell 3 (6 foot deep), measurements were taken at 1/2-foot intervals. Water samples were collected from these same depths using a Van Dorn sampler. Please refer to Appendix B for more information on the profile sampling techniques.

3.3 Event-Based Monitoring

Water sampling was undertaken to characterize water quality conditions for outfalls, ponds, and streams during periods of stormwater runoff from background (non-deicing) and ground-deicing events. These events were defined in the monitoring plan and summarized in Section 2.2. The twelve sampling stations are depicted in Figure 2-3 through Figure 2-6 and Table 2-1. In most cases, autosamplers collected a series of time-paced composite samples throughout the events. Flowmeters were also used to monitor level and/or flow at certain stations. Water level/flow monitoring allowed automatic enabling of the samplers at the onset of storm runoff. This approach ensured consistent sampler actuation, while promoting safety by potentially eliminating the need for staff to work in the field during potentially hazardous winter driving conditions. Flowdata was also used to characterize water quality data relative to concurrent hydrograph stages.

3.3.1 Monitoring Locations and Equipment

The locations where flow meters and samplers were deployed are outlined in Section 2.2 and listed in Table 2-1. Isco area-velocity (model 4150) or bubbler (model 4230) flow meters were installed to measure water level and flow at the stations targeted in the monitoring plan. Water samples were collected using Isco model 3700 automatic samplers, except at MCup, where grab samples were collected manually. Each sampler was equipped with 24, 1-liter bottles. Please refer to Appendix B for details on specific monitoring instrument installations. Photographs of all of the monitoring stations are presented in Appendix A.

3.3.2 Preventive Maintenance and QA/QC

The Isco 4150 area/velocity and 4230 bubbler flow meters were downloaded, inspected, and maintained on a weekly basis. Each of the Isco 3700 samplers were programmed and calibrated and underwent diagnostics testing prior to deployment. The primary maintenance activity for the flow meters and samplers was ensuring that the batteries powering these units were charged. Batteries were checked about every 3 days before the samplers were enabled, and every day during the sampling event. Batteries were changed if the power dropped below 12.3 volts.

3.3.3 Background Event Sampling

A background sampling was conducted during the 0.81-inch storm event that began on December 11, 1999, which met target conditions of the monitoring plan. This background event occurred one-month prior to the first application of ground deicers at STIA during the 1999-2000 winter season. Automatic samplers at the nine sampling stations were enabled manually prior to the beginning of the storm between 16:00 and 17:00 12/10/00. Once enabled the samplers collected 100-ml aliquots every twenty minutes for 72 hours. Nine aliquots were deposited into each of the 24 sample bottles, thus each bottle contained a 3-hour time-composite sample.

The storm began at 23:00 on 12/11/99 and continued until 17:00 on 12/12/99. A total of 0.81 inches of rain fell during this period. Sampling routines continued through the hydrograph at each location, ending about 14:00 on 12/13/99. Samples that had been collected during the storm and subsequent storm runoff period were selected for laboratory analysis. Based on a review of the storm hyetograph and an estimate of the runoff period, this group included samples collected from 19:00 on 12/11/99 to 02:00 on 12/13/99. Samples collected during the background event were analyzed for conductivity, potassium, calcium, and sodium. Background event sampling was not conducted at three stations: MCmouth, DMmouth, and NP1.

3.4 Deicing Event Sampling

For the purposes of this study a ground deicing event was defined as the application of deicing chemicals to runways, taxiways and/ or other ground surfaces at STIA followed by snowmelt and/ or rainfall. Chemicals might be applied on multiple occasions during freezing conditions spanning several days in one event.

Per the monitoring plan, the ground-deicing event sampling strategy was designed to characterize runoff during three periods of a deicing event. Each of these periods had a specific sampling strategy described below:

1. Incipient background conditions immediately after chemical application but prior to runoff
2. Conditions during the first inch of rainfall
3. Conditions during the subsequent one-half inch of rainfall.

The incipient runoff was sampled during the afternoon and evening of 1/11/00, prior to the first deicing chemical applications at STIA. During this period two sets of grab samples were collected manually at the 12 automatic-sampling stations and at MCup. The second set of samples was collected a few hours before the first ground-deicing chemicals were applied.

After receiving notification that ground deicers had been applied, field staff manually enabled the automatic samplers at all twelve monitoring stations during the early morning of 1/12/00. At the time the samplers were enabled, temperatures were near freezing and the light precipitation was mixed rain and snow. To ensure sampling the initial runoff after chemical application, samplers were enabled manually between 03:15 and 04:45 on 1/12/00.

The auto-sampling program used during this initial runoff period was the same as that used for the background-sampling event: each bottle represented 3-hours, having nine 100-ml aliquots taken at 20-minute intervals. Under this routine, the 24-bottle configured samplers could run for up to 72-hours without reloading bottles. Because of the protracted nature of the deicing event, samples were retrieved and samplers were restarted several times during the course of the 14-day period sampled. At the end of each "round" of sampling, the samplers were reloaded with empty bottles, the sampling program was restarted, and the samples from that round were brought to the field lab for processing. Table 3-3 summarizes the period and the stations sampled during each round.

The sampling program for the initial runoff period was used for more than 5-days during Rounds 1 and 2, which continued from 1/12/00 07:00 to 1/17/00 13:00. During this period 0.86 inches of rain fell at STIA. A grab sample was collected at MCup daily during the first round of automatic sampling. A total of 4 grab samples were collected at MCup during the event.

Table 3-3 Summary of deicing event sampling periods

Sampling Station	Round 1 1/12/ 00 7:00-1/14/00 16:00	Round 2 1/14/00 19:00-1/17/00 13:00	Round 3 1/17/00 16:00-1/20/00 13:00	Round 4 1/20/00 16:00-1/26/00 10:00
NEPL	X	X		X
N1	X	X		X
N3N4	X	X	X	X
RebaOut	X	X	X	X
MCmouth	X	X		
NPin	X	X		X
S567	X	X		
NP1	X	X		
SDS3	X	X	X	X
NPout	X	X	X	X
DME	X	X	X	X
DMmouth	X	X		

The start and end times at each sampling station were within 3-hours of the times indicated for each round, except for Round 2 at NPOut, which went from 19:00 1/15/00 to 16:00 1/16/00.

Sample processing at the field lab included measuring the conductivity of all the samples as a screening method to determine presence/ absence of deicing chemicals. A significant increase in sample conductivity above levels observed during the background event and during incipient runoff was used to indicate the presence of ground deicers. Conversely, conductivity near background levels indicated samples contained little or no deicing chemical. All samples collected during the later half of Round 2 had conductivity near background levels, suggesting that the majority of deicing chemicals applied on 1/12/00 had already passed through the systems by the end of Round 2 and the total of 0.78-inch rainfall. Based on this information, and past experience with washoff rates[10], the fewer sampling stations were operated during the successive nine days of sampling in Rounds 3 and 4.

During Round 3, sampling continued at the primary sources of airfield runoff and at the ponds: N3N4 and RebaOut in the Miller Creek watershed, and at SDS3, NPout, and DME in the Des Moines Creek watershed. The SDS3 and N3N4 outfalls were considered the most likely locations where any remaining deicing chemical could be detected. Sampling continued at the ponds locations to ensure characterization of potential protracted retention periods. Only another 0.17 inches of rain fell during Round 3, bringing the cumulative rainfall to 0.98 inches.

On the night of January 18-19, 2000 low temperatures and clear skies caused heavy frost and prompted the second sequence of ground-deicing. Far less chemicals were applied in this second event than in the first. In response to these additional applications, three sampling stations that were shut down for Round 3 were brought back online for the fourth round of sampling. NEPL, N1, and NPin were restarted for Round 4 because they were thought to be likely locations where the ground deicers might be detected. For Round 4 the automatic sampler programs were modified to run longer. Samplers were set to collect 100 ml aliquots every 40 minutes, instead of every 20 minutes. Nine aliquots were still collected into each sample bottle, but each bottle now comprised a 6 hour time composite sample and the sampling routine ran twice as long as before (144 hours). During Round 4, another 0.35 inches of rain fell, bringing the total rainfall during the four rounds of sampling to 1.33 inches. Because of the unusual length of this period of low rainfall, and because total rainfall was near target amount of 1.5 inches, sampling was discontinued on January 26 after Round 4 was completed.

At the field lab, samples were analyzed for conductivity with a portable meter then a portion of each sample was transferred to a 250 ml bottle for delivery to the laboratory. All samples collected during Round 1 were submitted for analysis. According to the monitoring plan, certain samples from Rounds 2, 3, and 4 were composited based on the conductivity screening data, reducing analysis costs and minimizing redundancy.. Consecutive samples having similar conductivity were composited into a single sample. Samples positioned midway in a series of samples with conductivity trending up or down were combined into a single sample to represent the midpoint of this trend. These secondary composite samples were produced in the field lab by depositing equal portions of the selected discrete composite samples into a 250-ml bottle.

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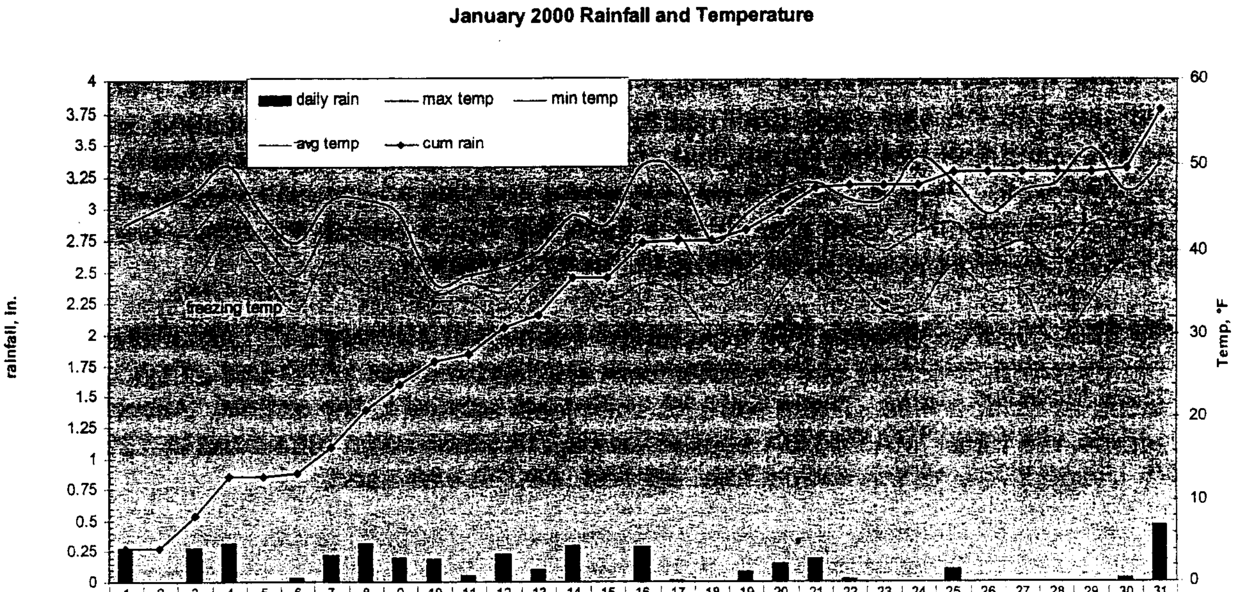
[10] Monitoring of four events in January, February, November and December 1996 showed that more than 80% of the chemicals had washed off surfaces after the first 1-inch of rain (POS, 1996, 1997).

3.5 Deicing Event Characterization

This section summarizes the ground-deicing events that occurred during the 1999-2000 study period. Figure 3-1, Figure 3-2, Table 3-4, and Table 3-5 summarize the associated weather patterns and chemical application volumes, respectively. The table in Appendix E contains a more detailed list of chemical applications, which was used in combination with SDS drainage maps to summarize application volumes for the subbasins draining to the respective monitoring locations used in this study. Event–based sampling of chemical-specific tracers was carried out during the two-week period comprising all three events.

Overall, compared to previous years, the three events that occurred ranked much lower in terms of total PA applied, the numbers of aircraft deiced and volumes of ADAF applied. Specifically, compared to the 12 events in the past 5 seasons, the first event (January 11-12, where 90% of the total chemicals applied in the 1999-2000 season were applied) ranked 7th for PA and 6th for ADAF volumes applied. The other two events of January 2000 ranked lowest of the twelve in the past 5 seasons for PA and ADAF volumes.

The amounts and types of precipitation causing the first two events were similar to last season's events, but were less severe than in past years such as 1996. The three events occurred in a 12-day period, but unlike last year, these events coincided with a protracted period of little rainfall, where only a total of 1.3" rain fell in the 18 day period after the first (snowfall) event. After the second event, there were 9 consecutive days with less than 0.1" daily rainfall before the next significant rainfall of 0.46" on January 31. Because of limited snowfall, no snow was plowed or stored at the designated management areas. Ice did not form on either of the two ponds studied (ice could inhibit atmospheric reaeration of DO in the ponds).



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
daily rain	0.27	0	0.27	0.31	0	0.03	0.21	0.31	0.2	0.19	0.05	0.22	0.1	0.29	0	0.28	0.01	0	0.08	0.15	0.19	0.02	0	0	0.1	0	0	0	0	0.03	0.46
max temp	43	45	47	50	44	41	46	46	44	36	37	38	40	44	43	50	49	41	44	47	48	46	46	51	48	44	47	48	52	47	50
min temp	37		36	42	37	33	40	36	35	34	34	32	36	37	34	36	35	30	29	35	39	37	33	33	38	35	35	29	34	39	37
avg temp	40		42	46	41	37	43	41	40	35	36	35	38	41	39	43	42	36	37	41	44	42	40	42	43	40	41	39	43	43	44
cum rain	0.27	0.27	0.54	0.85	0.85	0.88	1.09	1.4	1.6	1.79	1.84	2.06	2.16	2.45	2.45	2.73	2.74	2.74	2.82	2.97	3.16	3.18	3.18	3.18	3.28	3.28	3.28	3.28	3.28	3.31	3.77

Figure 3-1 January Weather Conditions

The first event began with light snowfall between 18:00 on January 11th, turning to light rain after noon on the 12th. The heaviest snow fell during the early morning hours of January 12th, with total accumulations of 2-3 inches. Chemical applications began just after midnight and were completed by 09:00 on the 12th. According to National Weather Service records, freezing temperatures existed for only 12-hours between midnight and noon on the 12th. Because little snow accumulated, which began to melt immediately, no snow required plowing to the snow storage areas.

According to Port records, the total PA and CMA applied during this short event amounted to 90% and 88%, respectively, of the total annual volumes applied. Records indicated that SA was not used. For the NPDES deicing-event samples collected during the rainfall of January 12th at the SDE4, SDS3, and SDS1 outfalls, total glycol concentrations were 12, 364 and 801 mg/l, respectively[11]. Only 0.86" rain fell in the subsequent 5 days, which was much less than in previous years.

The second event exhibited heavy frost that formed during cold, clear overnight skies on January 18-19 and melted by midday on the 19th. Chemical applications began

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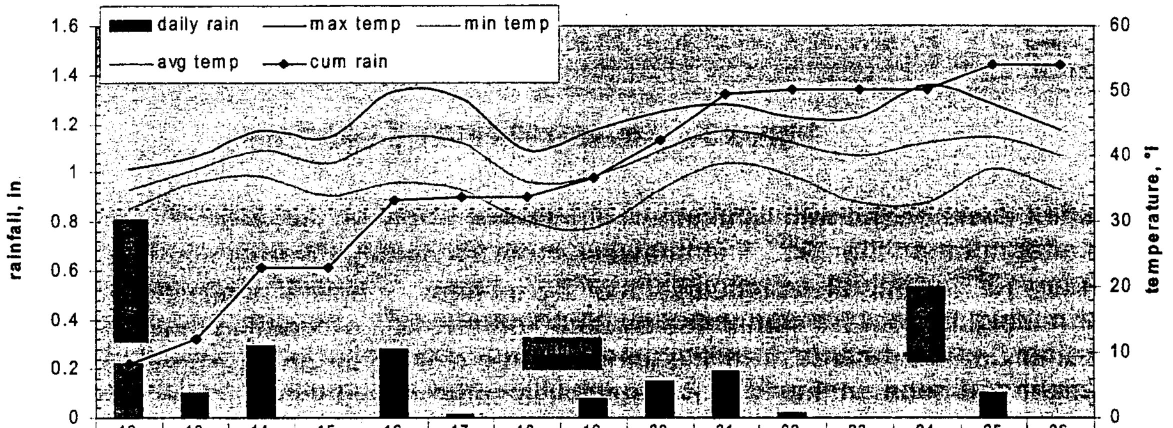
[11] In accordance with the NPDES permit, the SDE4 and SDS3 samples were flow-weighted composites and the SDS1 sample was a grab taken in the first hour of discharge. The elevated glycols in the SDS1 sample were attributed to runoff from a small area near the South Satellite gates S2 and S3. This drainage was rerouted to the IWS in September 2000. See Annual Stormwater Monitoring Report (POS, 2000).

January 19th by 02:30 and were completed by 07:00 that morning. During this short event, limited PA was applied to only the touch-down areas of the runways, amounting to only 5% of the total annual PA applied. In contrast, heavy frost on landside ground surfaces necessitated heavier chemical and abrasive (sand) applications. Records indicated only SA was used, the majority of which was applied without sand, amounting to 91% of the annual total SA applied. No CMA applications were recorded in this second event. Though WSDOT was observed applying chemicals to areas of SR509 north of the airport[12], in an area outside the Miller Creek watershed, they were unable to provide records of any applications in the STIA vicinity.

The third event exhibited minor frost on the evening of January 24th. According to records, minor amounts of chemicals were applied between 17:00 and 21:00, only to limited landside areas. There were no chemicals applied to the airfield. According to records, the total CMA and SA applied during this short event amounted to 12% and 9%, respectively, of the annual total applied. No PA was used.

Weather During January 2000
Period of Deicing Event Sampling



	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
▬ daily rain	0.22	0.1	0.29	0	0.28	0.01	0	0.08	0.15	0.19	0.02	0	0	0.1	0
—— max temp	38	40	44	43	50	49	41	44	47	48	46	46	51	48	44
—— min temp	32	36	37	34	36	35	30	29	35	39	37	33	33	38	35
—— avg temp	35	38	41	39	43	42	36	37	41	44	42	40	42	43	40
—◆— cum rain	0.22	0.32	0.61	0.61	0.89	0.9	0.9	0.98	1.13	1.32	1.34	1.34	1.34	1.44	1.44

Figure 3-2 Weather during Deicing Event Sampling Period

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[12] At 09:00 on January 19th, WSDOT truck #8A12-11 was observed applying liquid chemicals, presumed to be CMA, on the southbound lanes of SR509 just south of the 1st Avenue South bridge. This truck exited SR509 at South 128th Street. There was heavy frost on the SR509 roadway at this time.

Table 3-4 Reported Deicing Chemical Application Volume Summary[13]

PA, gal

day	Airfield	SDS3	SDS4	N3N4	DME	N1	NEPL	IWS	other	sum
11-Jan	5736	4599	427	710	443	0	0	150	0	6329
12-Jan	1047	839	103	130	2407	15	0	75	0	3569
18-Jan	0	0	0	0	0	50	0	0	0	50
19-Jan	472	236	236		4	20	0	1	0	497
28-Jan	0	0	0	0	5	0	0	0	0	5
sum	7255	5674	766	840	2859	85	0	226	0	10450
% total	69%	54%	7%	8%	27%	1%	0%	2%	0.0%	
% SDS	71%	55%	7%	8%	28%	1%	0%	na		

CMA, lb

day	Airfield	SDS3	SDS4	N3N4	DME	N1	NEPL	IWS	other*	sum
11-Jan	0	0	0	0	0	0	0	0	0	0
12-Jan	0	0	0	0	12300	0	4340	0	0	16640
18-Jan	0	0	0	0	0	0	0	0	0	0
19-Jan	0	0	0	0	0	0	0	0	0	0
24-Jan	0	0	0	0	200	900	0	0	1200	2300
sum	0	0	0	0	12500	900	4340	0	1200	18940
% total	0%	0%	0%	0%	66%	5%	23%	0%	6%	

*160th to Hwy 99 (City of SeaTac)

SA, lb

day	Airfield	SDS3	SDS4	N3N4	DME	N1	NEPL	IWS	other*	sum
11-Jan	0	0	0	0	0	0	0	0	0	0
12-Jan	0	0	0	0	0	0	0	0	0	0
18-Jan	0	0	0	0	0	0	0	0	0	0
19-Jan	0	0	0	0	23275	0	1650	0	250	25175
24-Jan	0	0	0	0	0	2690	0	0	0	2690
sum	0	0	0	0	23275	2690	1650	0	250	27865
% total	0%	0%	0%	0%	84%	10%	6%	0%	1%	

*160th to Hwy 99 (City of SeaTac)

Airfield is sum of SDS3, SDS4, and N3N4 (SDN3 +SDN4)

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[13] These tables summarize reported applications and do not incorporate CMA and SA transcription errors indicated by sampling results. Because of the small volume of PA applied on January 28th, and the fact that there were no other chemical applications on this date, this date was not considered a deicing event.

Table 3-5 Total Deicing Chemical Application Summary by Drainage[13]

	PA, gal	% of total	CMA, lb	% of total	SA, lb	% of total
L. Reba	925	9%	5,240	28%	4,340	16%
NW Ponds	5,674	54%	-	0%	-	0%
DME (rapid)	3,625	35%	12,500	66%	23,275	84%
IWS	226	2%	-	0%	-	0%
other	-	0%	1,200	6%	250	1%
total	10,450		18,940		27,865	

Lake Reba is sum of N1 (SDN1), NEPL< and N3N4 (SND3+SDN4). NWP is SDS3. See Section 2.2.5.3.

3.6 Data Summary/Results

The following sections summarize the continuous water quality monitoring data and results from water sampling conducted during the discrete background and deicing events. Raw data are presented graphically here and basic characteristics of the data (ranges, average values, trends) are discussed. The results of more rigorous statistical analysis of the data are presented in Appendix D.

3.6.1 Continuous Monitoring

This section focuses on the continuous DO and conductivity data that was collected at Lake Reba and the Northwest Ponds using the Hydrolabs. An assessment of the data quality is presented, followed by the results of a supplemental investigation of DO profiles in the Northwest Ponds. The section ends with a presentation of the continuous water quality data from the four monitoring stations.

3.6.2 Data Assessment

Appendix B provides a summary of methods, data and graphical plots used to assess the quality of continuous monitoring (DO) data. The data assessment criterion was based on relative percent difference (RPD) between instrument measurements and field calibration (Winkler and handheld instrument) DO data.

At Lake Reba the majority of the RPDs were within the acceptable range. RPDs for fifteen of twenty-three Hydrolab/Winkler data pairs and sixteen of nineteen Hydrolab/YSI data pairs are within ±20%. Two of the three Hydrolab/YSI RPDs that were beyond the limit have corresponding Hydrolab/Winkler RPDs that were within ±20%. Similarly, three of the Hydrolab/Winkler RPDs that were greater than ±20% have corresponding Hydrolab/Winkler RPDs that were acceptable. There were no YSI data corresponding with the first four Hydrolab/Winkler data pairs, who's RPDs are more than ±20%. Nonetheless, the overall calibration data show that continuous DO data for Lake Reba are reliable.

At the Northwest Ponds the difference between the Hydrolab readings and DO data collected concurrently by the other two methods was substantial at times, particularly at NP1. Overall, the Hydrolab readings were closer to the YSI measurements than to the Winkler measurements. The Van Dorn sampler integrated an 18-inch water column, which was shown to have considerable spatial variation over depth. As a result, the Winkler DO data did not represent a discrete stratum, as did the Hydrolab and handheld YSI probes.

At NP1, the RPD for concurrent Hydrolab and YSI measurements ranged from +3% to –174%, with ten of seventeen RPD values beyond the ±20% range. At NP3, the RPD for Hydrolab and YSI measurements ranged from +4% to –91%, with four of thirteen RPD values beyond the ±20% range.

The consistently large differences between the DO data collected by the three methods in the Northwest Ponds prompted a re-evaluation of the Hydrolab maintenance procedure and schedule, both of which were confirmed to be adequate by the manufacturer. An evaluation of Hydrolab deployment was conducted to determine whether environmental factors might have caused the Hydrolab data to be different from the YSI and Winkler data. A series of DO profiles were taken in each of the three cells, as discussed previously in Section 3.2.

The DO profile data indicated a relatively discrete oxycline (spanning a 2-3 foot depth) existed in each cell, with high DO levels above the oxycline and very low DO levels below it. The DO probes on the Hydrolabs were often positioned in this oxycline region where DO levels changed rapidly with depth. The YSI readings and Winkler samples were often taken at slightly different positions in the oxycline relative to the Hydrolab. Consequently, this fact likely resulted in the substantially different values for concurrent DO measurements taken for calibration.

The persistent presence of the oxyclines, particularly at NP1, prompted a change in the Hydrolab deployment strategy. Instead of positioning each Hydrolab at mid-depth in the water column, each instrument was positioned at mid-depth in the layer above the oxycline where the oxygen concentration was less spatially variable. Asa result of this adaptation, the RPD values for concurrent Hydrolab and YSI DO measurements were within ±20% percent for five of six measurements taken in NP3 and seven of eight measurements taken in NP1 following this change in deployment strategy.

3.6.3 Northwest Ponds Dissolved Oxygen Profiles

Dissolved oxygen profile data collected in each cell of NWP are shown in Figure 3-3 through Figure 3-5. Results of DO profiling indicate persistent DO stratification in each cell of the Northwest Ponds. DO stratification was most predominant at NP1 and NP2. See Figure 3-3 and Figure 3-4. DO profiles showed an upper layer of oxygenated water underlain by water containing very little DO. The transition between these two layers is abrupt. At NP1, DO levels dropped by 7-9 mg/L in three feet. DO levels in the upper layer ranged from 6-11 mg/L at NP1, 5-10 mg/L at NP2, and 4-9 mg/L at NP3. The DO concentration in the lower layer remained near 1 mg/L for NP1 and NP2, but ranged from less than 1 mg/L to 8 mg/L for NP3.

The thickness of the upper oxygenated layer varied over the course of the study, as the position of the transition zone (oxycline) moved up and down. For NP1 and NP2, the position of the oxycline ranged from 3 feet to 8 feet below the surface, but was usually from three to six feet deep. At NP3, an oxycline was seldom present, only very weak on three occasions. At other times the oxycline was positioned two to four feet below the surface at NP3.

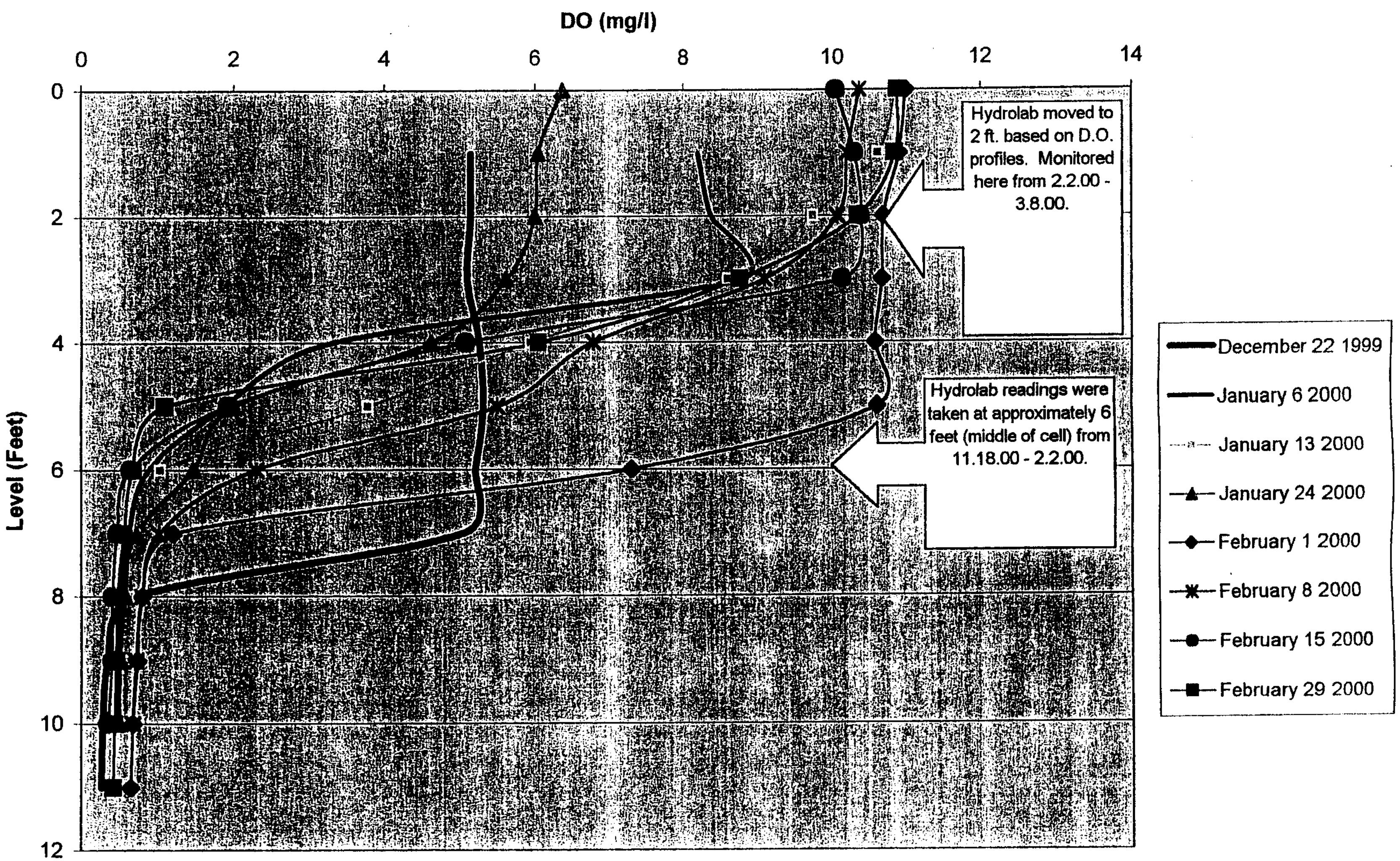
The continual vertical movement of the oxycline likely affected the operation of the Hydrolabs, particularly in cell 1. For most of the period of deployment (11/18/99 – 2/2/00) the cell 1 Hydrolab was positioned within the oxycline, usually about six feet from the surface. Many of the abrupt changes in DO concentrations recorded by this Hydrolab could have resulted from a vertical shift in the position of the oxycline rather than from radical changes in DO concentration throughout the cell.

There was less variation in DO between the YSI and Hydrolab data than between the Winkler and Hydrolab data because the YSI sensor could be positioned more precisely in the water column at the same level as the Hydrolab sensor. The Winkler samples were collected using a Van Dorn sampler, which captures an 18-inch deep column of water. As indicated by the profile data from cell 1, DO varied substantially within an 18-inch range in depth.

After repositioning the NP1 Hydrolab above the oxycline, near the middle of the upper, more oxygenated layer, starting on 2/2/00, the RPDs between the YSI readings and the Hydrolab readings were much smaller. The RPDs for seven of the eight subsequent readings were within the criterion of ±20%, and the eighth RPD was –23%.

3.6.4 Results of Continuous Water Quality Monitoring

DO levels at Lake Reba outlet and all 3 cells of the Northwest Ponds were highly variable throughout the monitoring period. See Figure 3-6. DO at NP1 displayed the greatest variability (variance of 7.9 mg/L), while DO variability at NP2, NPout, and RebaOut, were similar (variances of 4.0, 3.0 and 3.1 mg/L, respectively). DO levels remained below saturation at all four stations throughout the deployment period. See Figure 3-7. DO saturation was consistently higher at Lake Reba than in the Northwest Ponds. From late October to mid-May, DO percent saturation averaged 62% at RebaOut, 30% at NP1 and NP2, and 40% at NPOut. The pattern of DO concentration mimics the hyetograph for the period. In general, DO concentrations increased abruptly during storms and declined steadily during periods with little or no rain. Conversely, conductivity decreased rapidly during runoff and rose steadily between rainfall events as water levels in the ponds declined. See Figure 3-8 and Figure 3-9.



Hydrolab moved to 2 ft. based on D.O. profiles. Monitored here from 2.2.00 - 3.8.00.

Hydrolab readings were taken at approximately 6 feet (middle of cell) from 11.18.00 - 2.2.00.

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Figure 3-3

Northwest Ponds Cell 1 DO Profile

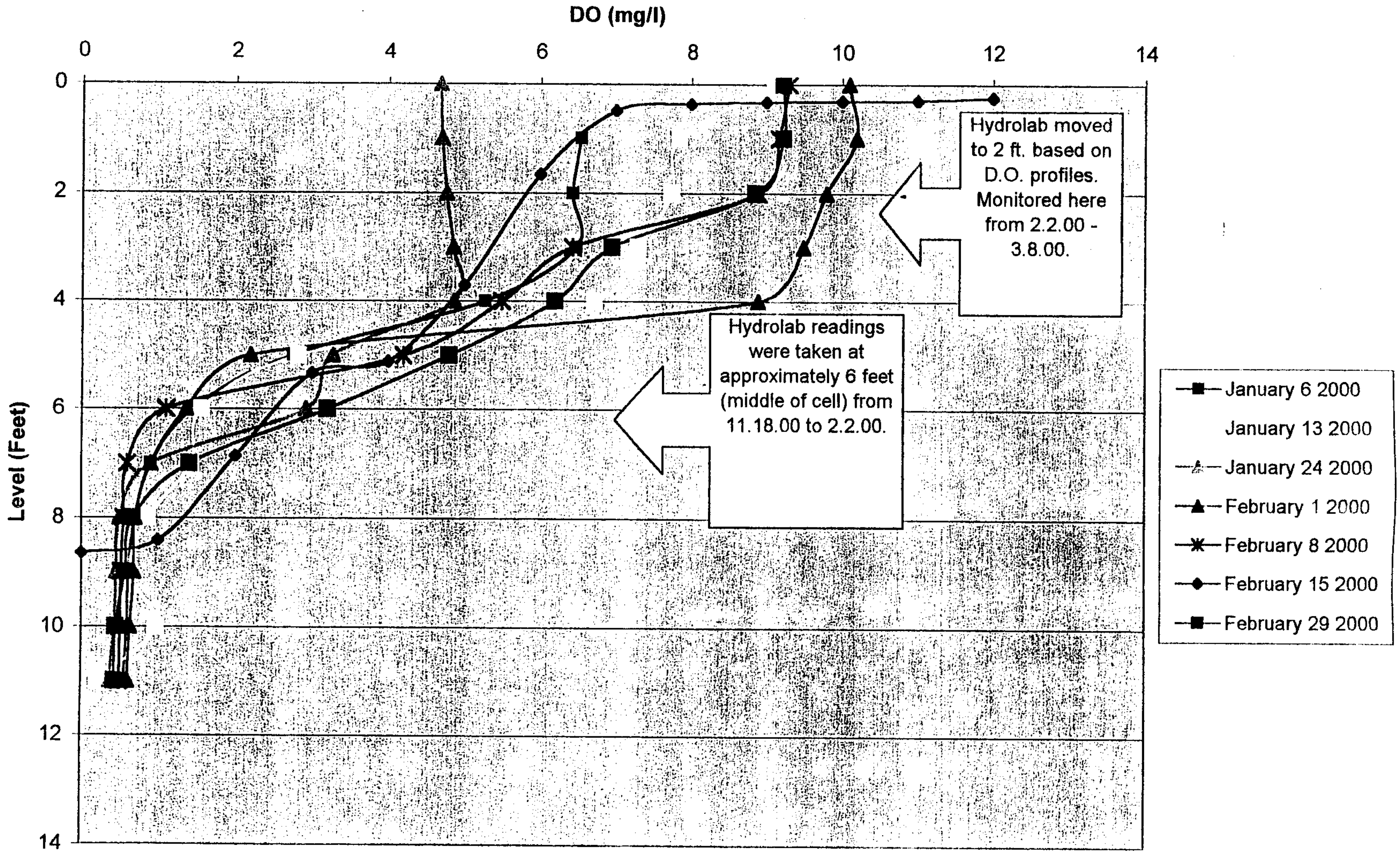

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Figure 3-4

Northwest Ponds Cell 2 DO Profile

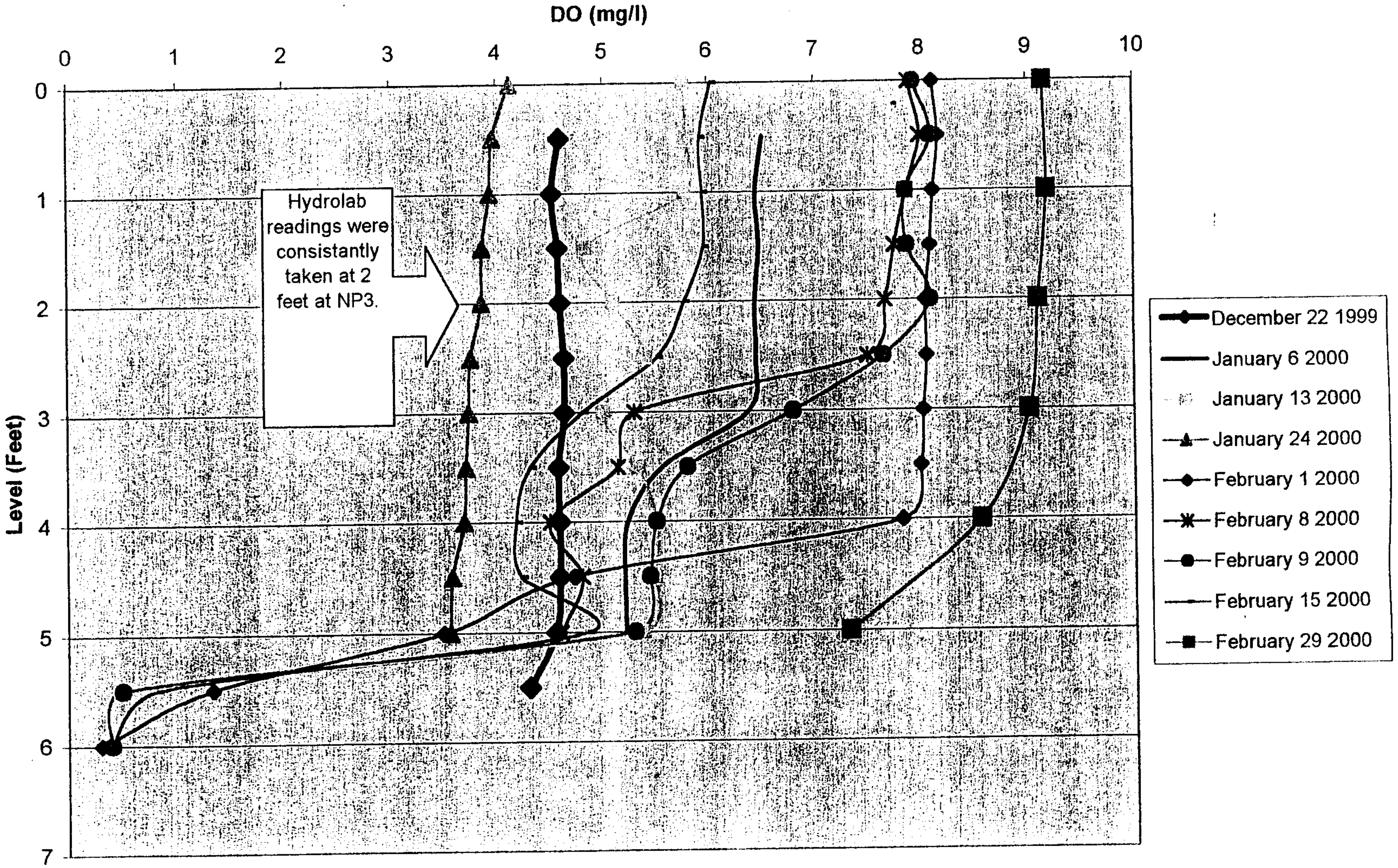

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Figure 3-5

Northwest Ponds Cell 3 DO Profile

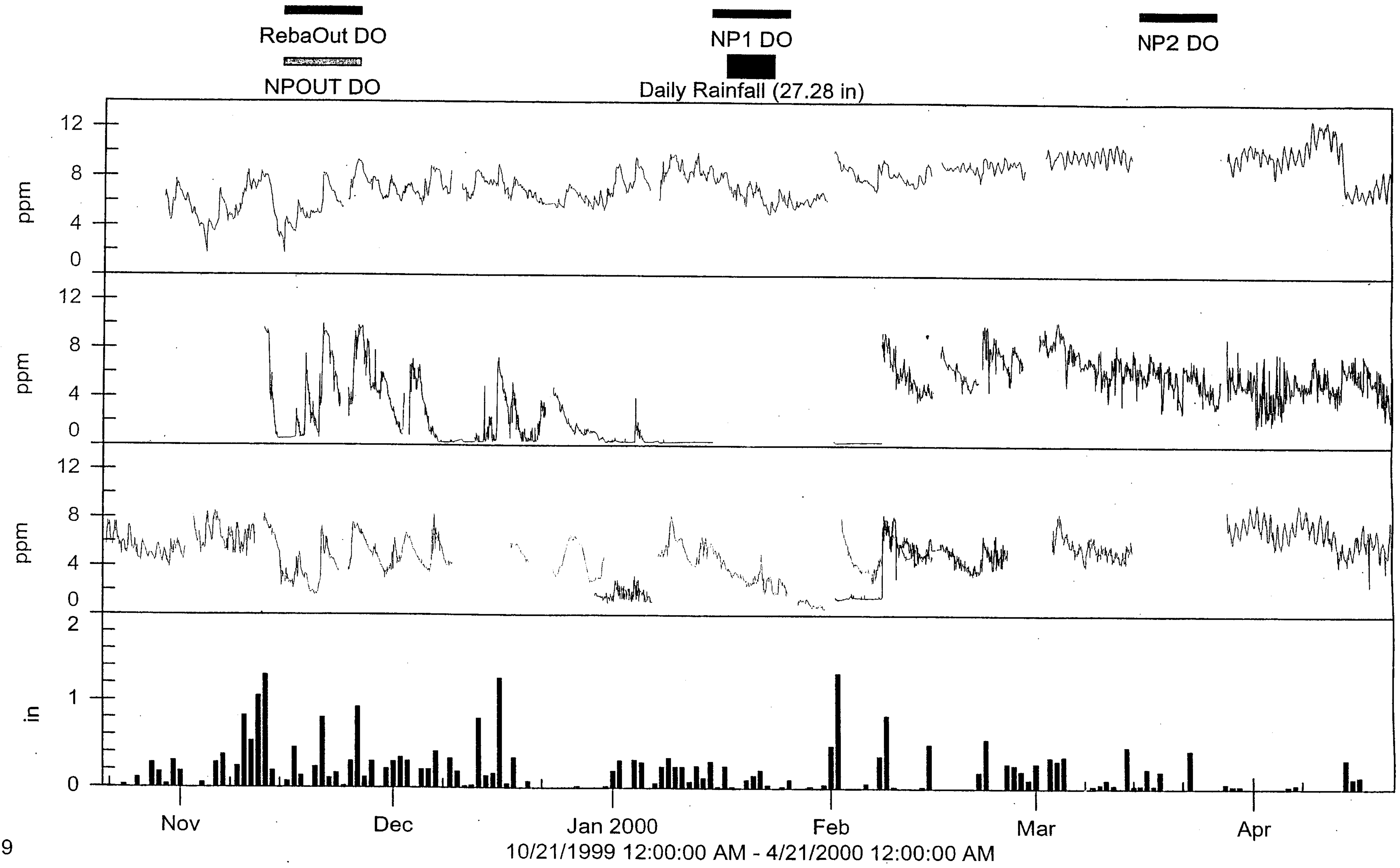

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Figure 3-6

Continuous DO (ppm) and Rainfall (in)
Lake Reba and Northwest Ponds

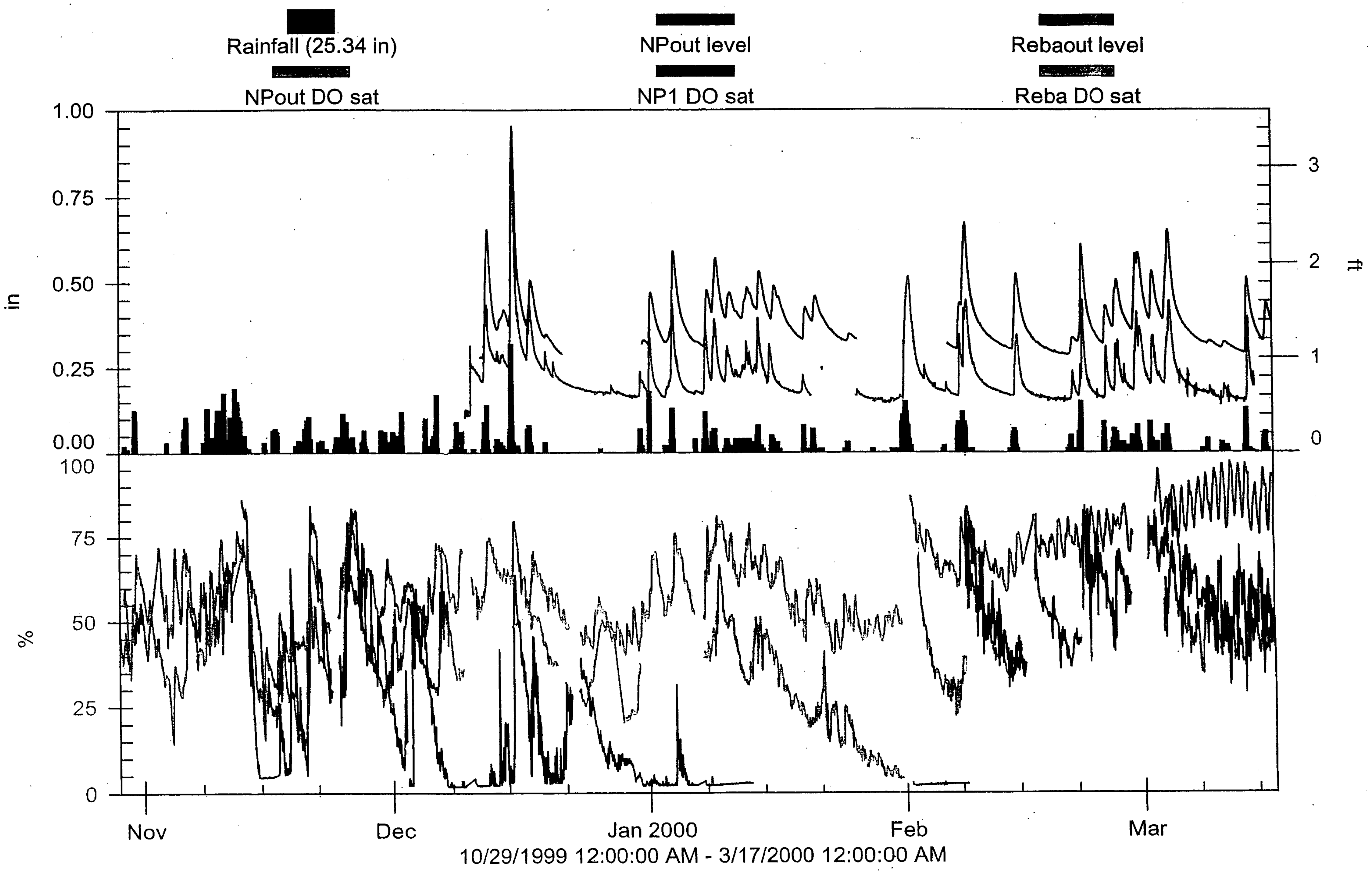

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Figure 3-7

Comparison of DO Saturation Levels
2000 DO Study

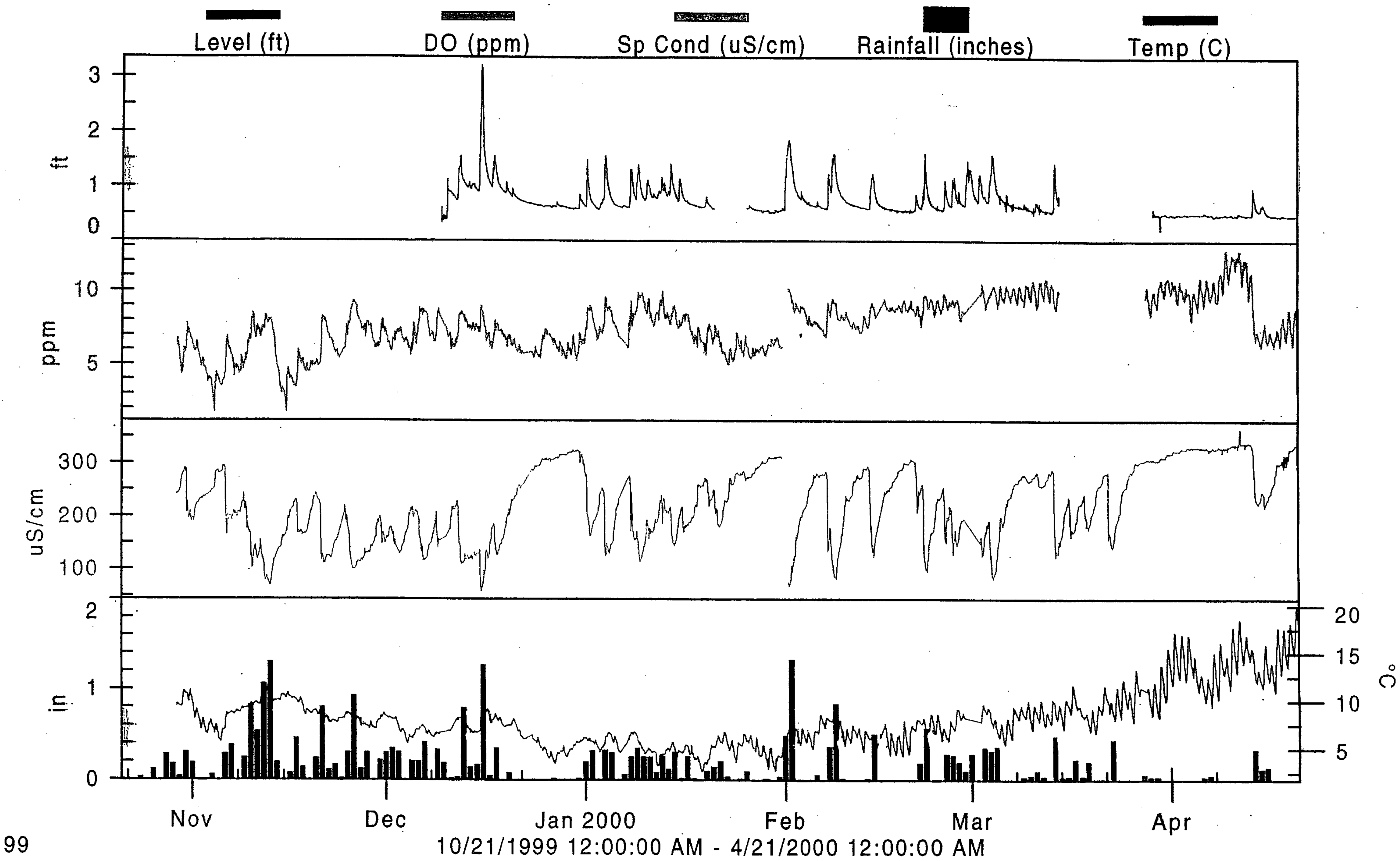

Figure 3-8

Lake Reba Outlet (RebaOut)
Continuous Monitoring Data

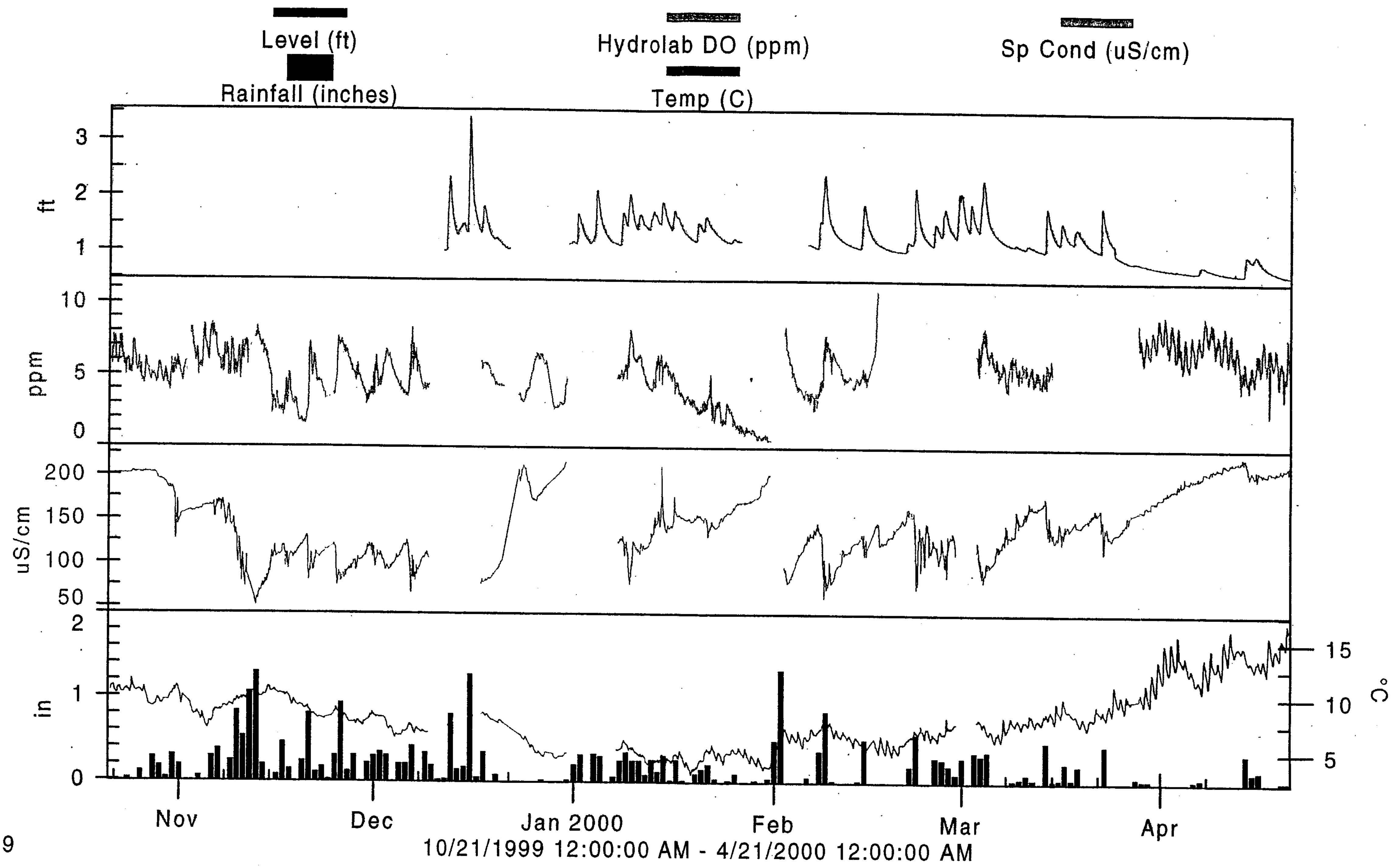

Figure 3-9

Northwest Ponds Outlet (NPOUT)
Continuous Monitoring Data

3.6.5 Background-Event Monitoring

The results from background event sampling supported the use of conductivity and the chemical-specific ions as tracers. Potassium, calcium, and sodium ions were present at relatively low levels before, during, and after the background storm event of December 11-12, 1999. At all stations, potassium concentrations remained below 5 ppm throughout the background event, except for an initial reading of 14 ppm at RebaOut, which occurred prior to the onset of storm runoff. See Figure 3-10 and Figure 3-11 for examples, all other plots are in Appendix C. Calcium and sodium concentrations were 40 ppm or lower before the storm and dropped to less than 20 ppm at all stations after rainfall runoff commenced. See Appendix C.

Similarly, conductivity levels were highest prior to the storm, ranging from 140 µS/cm at DME to 370 µS/cm at S567. Conductivity dropped during the storm, reaching levels below 90 µS/cm everywhere except RebaOut, where conductivity leveled off at around 130 µS/cm. As runoff abated, the ion concentrations and conductivity rebounded at most of the stations. See Appendix C.

Thus, with concentrations of the proposed tracers remaining constantly low or decreasing during the storm event, the background signal for these parameters would not interfere with a signal resulting from the presence of deicing chemicals. See Appendix D for the rigorous statistical analysis of how these tracer data were used to define deicing and non-deicing events. The next section of this report shows that as deicers washed off of ground surfaces, the levels of the corresponding ions and conductivity increased with flow rate, signifying the presence of the respective chemicals.

3.6.6 Deicing Event Sampling.

This section presents results of the tracer analysis relative to the timing and magnitude of chemical deicer applications at STIA. Data for each tracer ion/ deicing chemical pair are presented separately for the Miller Creek and Des Moines Creek watersheds. Plots of tracers for each monitoring location during the deicing event sampling are presented in Appendix C. Periods where tracers indicate deicing chemicals were present are shown in brackets. Each plot is accompanied by a table, which defines the periods of chemical presence. Figure 3-12 through Figure 3-16 show examples of plots discussed in this section. Other plots are in Appendix C.

Figure 3-12 and Figure 3-13 show time series plots for the respective sampling locations in the Miller and Des Moines Creek watershed, indicating PA applications and the conductivity signal during the sampling period. Figure 3-15 and Figure 3-16 show the potassium ion tracer signals for the Lake Reba and NWP outlets, respectively, and also indicate PA applications, rainfall, and pond level.

3.6.6.1 Tracers in Miller Creek

In the Miller Creek watershed, PA was first applied in the N3N4 and N1 basins early on January 12. A spike in both conductivity and potassium concentrations occurred at N3N4 and N1 during the afternoon on January 12. At RebaOut, there was no discernable conductivity signal following these applications, however the potassium concentration did respond on 1/13/00 (see Figure 3-15). On 1/18/00 and 1/19/00 additional, but much smaller volumes of PA were applied in the N1 basin. Sampling had been suspended at N1 at the time, but there was a tailing potassium signal when sampling resumed on 1/20/00. The conductivity and potassium data for RebaOut show no response following this application. See Figure 3-12 and Figure 3-15.

According to records, CMA was applied in the NEPL basin on 1/12/00 and in smaller amounts in the N1 basin on 1/24/00. A small spike occurred in conductivity at NEPL concurrent with the CMA application on 1/12/00 but there was no response in the calcium levels there. See Figure 3-12. The conductivity and calcium data for N1 do not indicate a response to the 1/24/00 CMA application. The conductivity and calcium data for RebaOut show no response following either of these applications. See Figure 3-12 and Appendix C.

Records showed that SA was applied in the NEPL basin on 1/19/00 and in the N1 basin on 1/24/00. Conductivity and sodium data for NEPL, N1, and RebaOut do not indicate a response to these applications. See Figure 3-12.

Sodium data for N1, NEPL, and N3N4 show elevated concentrations of sodium on 1/12/00 and 1/13/00, but did not correspond with recorded applications of SA at STIA on these days. Given WSDOT's plan to only use CMA for the season, it is unlikely that these signals were due to deicer use by other entities (WSDOT, 1999). There were no tracer signals apparent at MCMouth for any of the chemical applications.

3.6.6.2 Tracers in Des Moines Creek

In the Des Moines Creek subbasins, PA was first applied early on January 12 in the SDS3 basin and to portions of SDE4 draining directly to DME. Conductivity and potassium concentrations spiked at both of these stations during that afternoon. See Figure 3-13 and Appendix C). The wide potassium signal at NPout from January 13 to the 18th indicated an attenuated response (due to detention time) to the PA application in the SDS3 basin. See Figure 3-16. Conductivity at NPout did not exhibit a noticeable response concurrent with the potassium signal. See Figure 3-13. At Dmmouth, conductivity and potassium spiked on January 13, just hours after these tracers spiked at DME. There was a second application of PA in the SDS3 basin on January 19. Conductivity levels at SDS3 and NPout did not show a response, however potassium levels peaked above background at both stations on January 20, though the peaks were much less than during the first event. PA applications in the second event were only 5% of the PA applied during the first event.

According to records, CMA was also applied in areas draining to DME (principally in subbasin SDE4) on January 12 about the same time that PA was applied. Conductivity and calcium peaked above background at DME during the afternoon of January 12. However, there was no calcium signal at the DMmouth station, probably due to high background concentrations of calcium. Conductivity spikes at DME and DMmouth could be from any one or combinations of the chemicals applied in the DME watershed See Figure 3-13 and Appendix C.

Records showed that SA was applied just once in areas draining to DME, on January 19th. There was a very slow increase in the sodium concentration over three days beginning about January 19th, but concentrations were not much higher than background. Also, there was no corresponding response in conductivity following this recorded SA application during the second event. See Figure 3-14 and Appendix C. Interestingly, the peak sodium concentration during this second event (8 ppm) was much lower than a much more significant peak observed on January 12th (30 ppm). This January 12th sodium signal did not correspond with a record of SA application on that day.

At S567, potassium and sodium spiked above background on January 12th. At NPin, potassium was above background levels from January 14 through the 16th. Conductivity did not appear to indicate chemicals at S567 or NPin on January 12th. The Port's application records indicated no chemical applications in the subbasins associated with these two stations. Conductivity and ion tracers were within background levels at NP1 throughout the sampling period.

3.6.7 Data Summary QA/QC

Continuous water quality data was downloaded directly to Excel and transferred electronically into Flowlink 4, thus avoiding manual data entry and associated QC. Water level data was downloaded, processed, and analyzed in Flowlink 4. Laboratory data keyed into Excel spreadsheets were checked against the original data reports for entry errors. Lab data was transferred electronically from Excel to Flowlink 4, requiring no additional manipulation. Chemical analyses were conducted by Aquatic Research, Incorporated, accredited by Ecology. All QC results were within acceptable limits.

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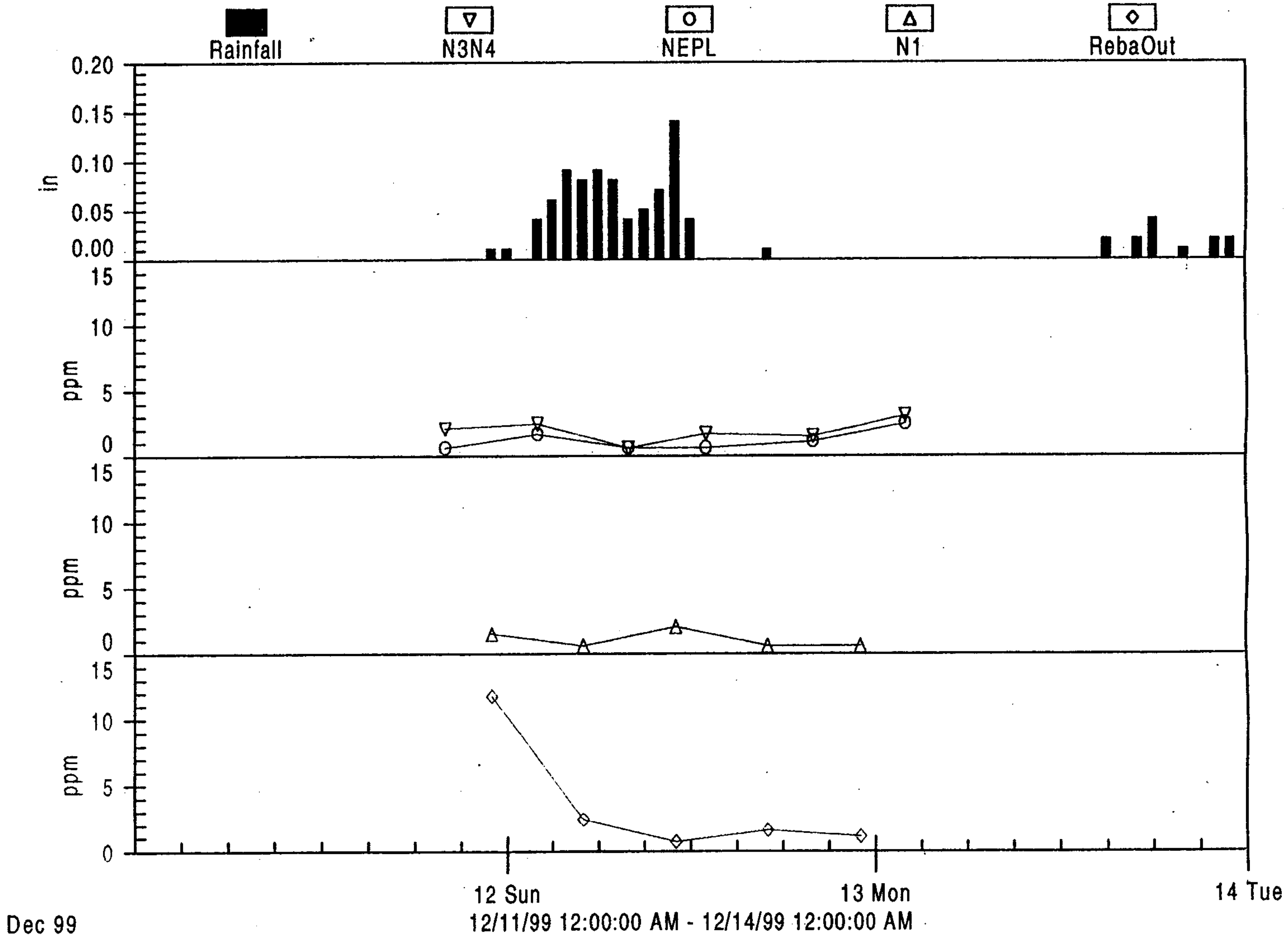

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Figure 3-10

Miller Creek Watershed
Potassium (ppm) During Background Event

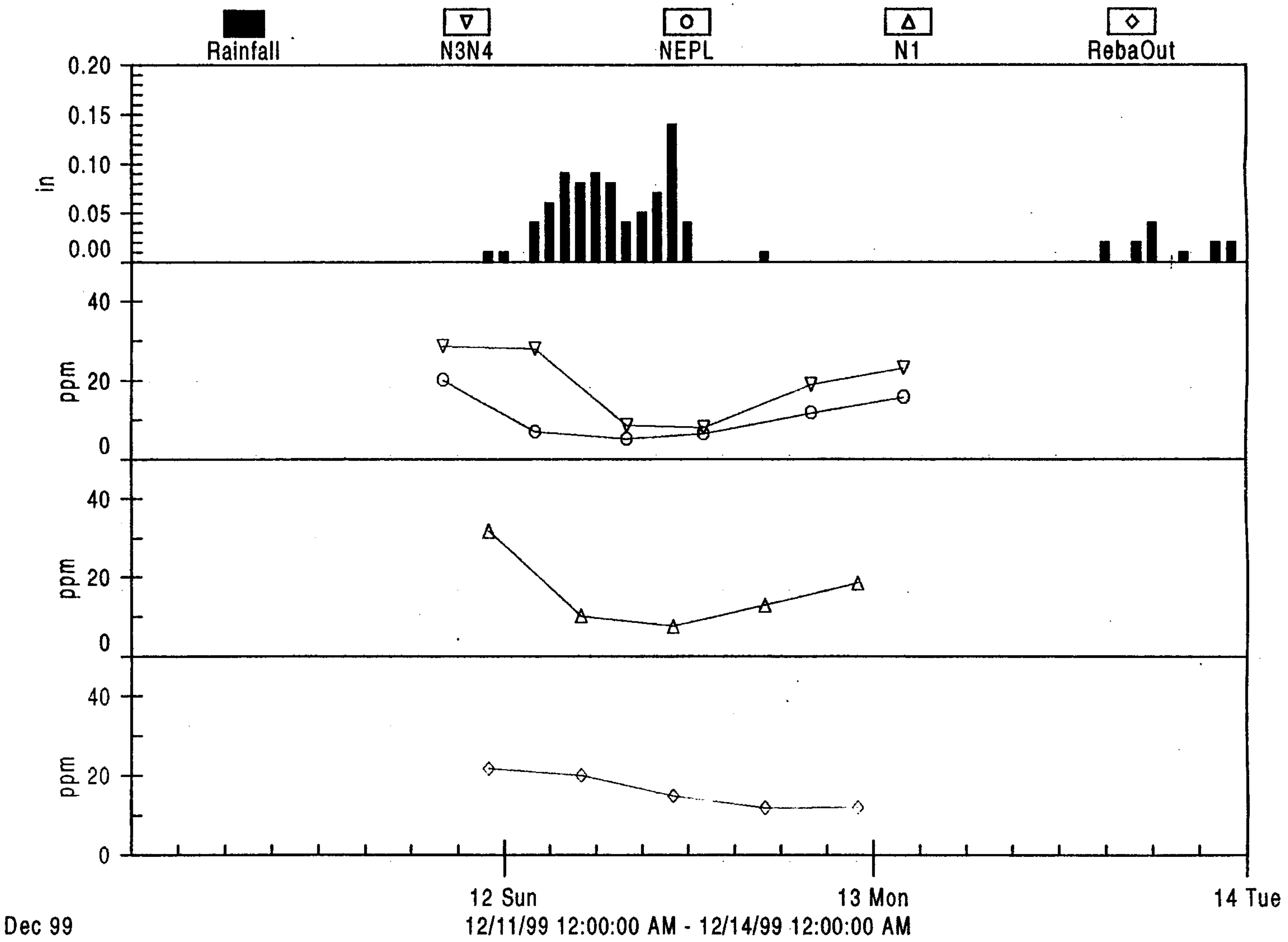

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Figure 3-11

Miller Creek Watershed
Calcium (ppm) During Background Event

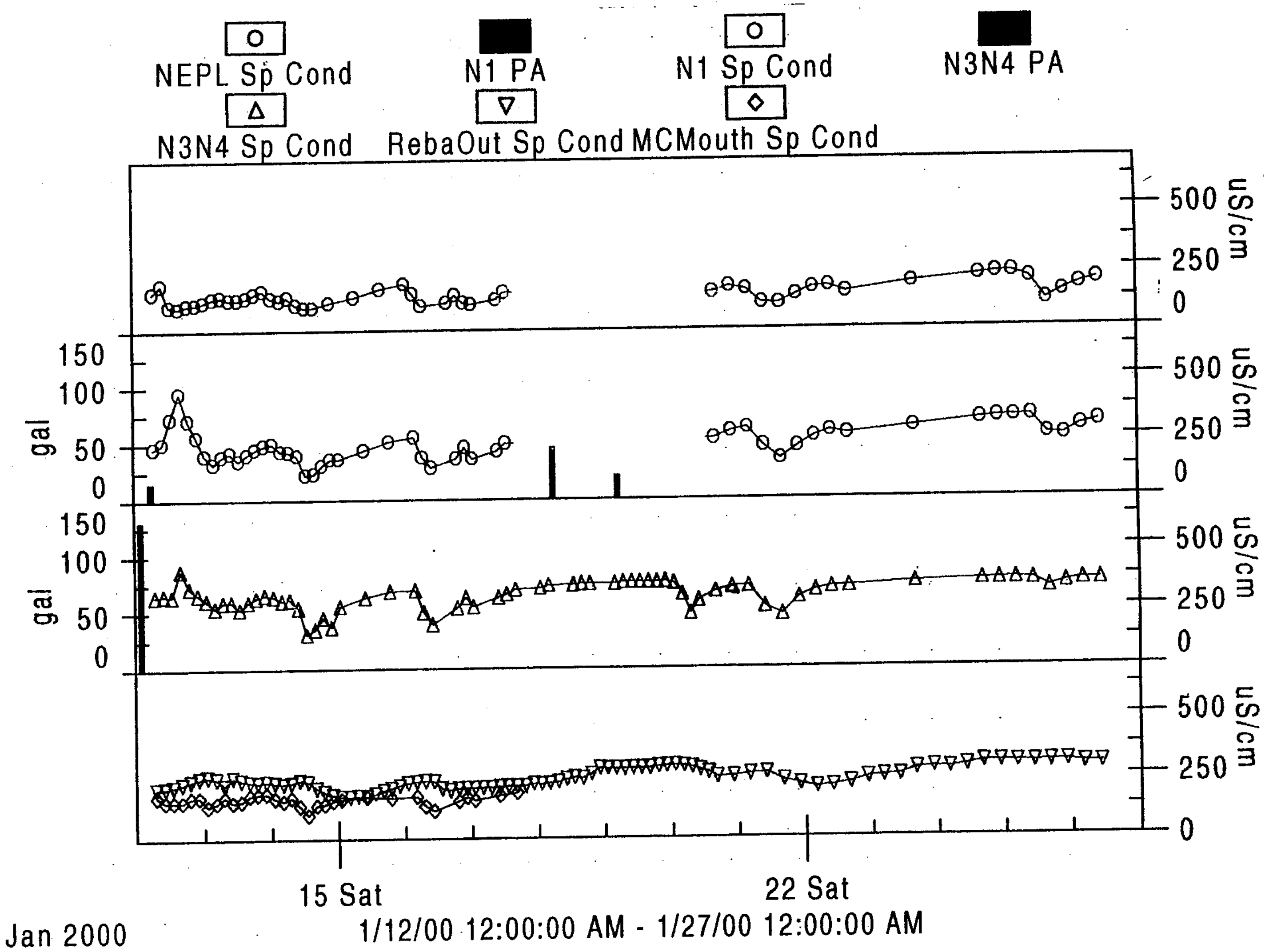

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Figure 3-12

Miller Creek Watershed
Potassium Acetate (PA) Application (gal)

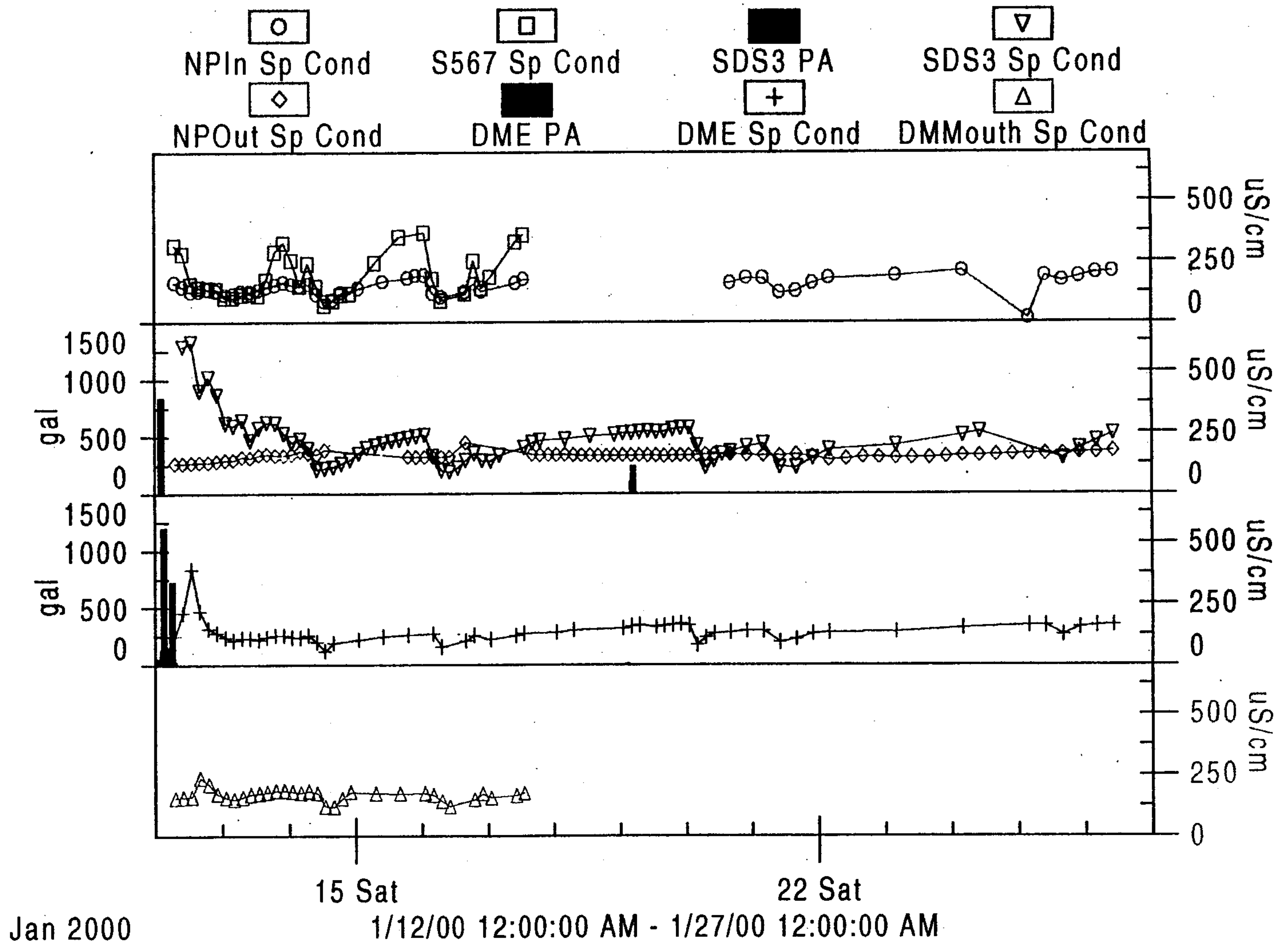

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Figure 3-13

Des Moines Creek Watershed
Potassium Acetate (PA) Application (gal)

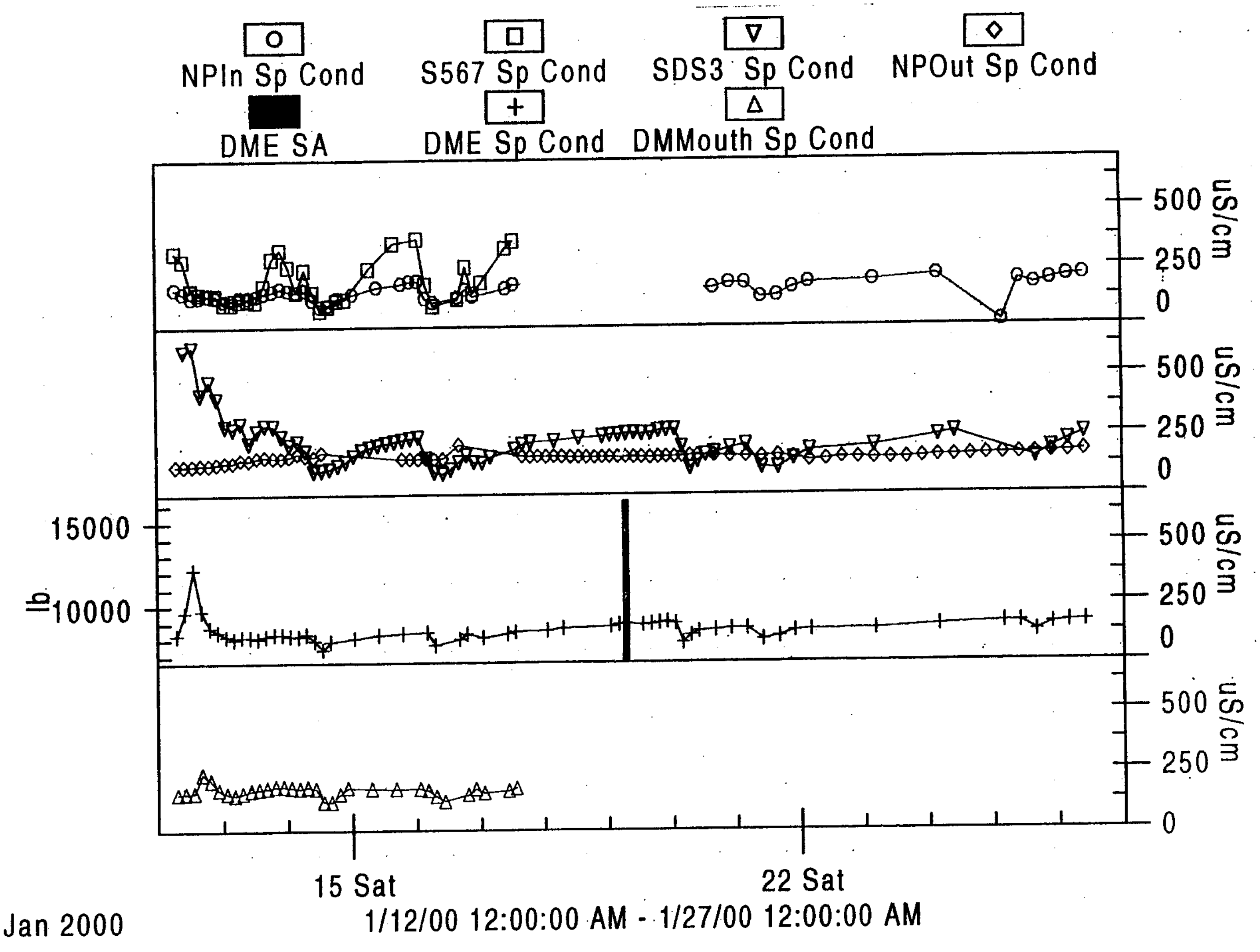

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Figure 3-14

Des Moines Creek Watershed
Sodium Acetate (SA) Application (lb)

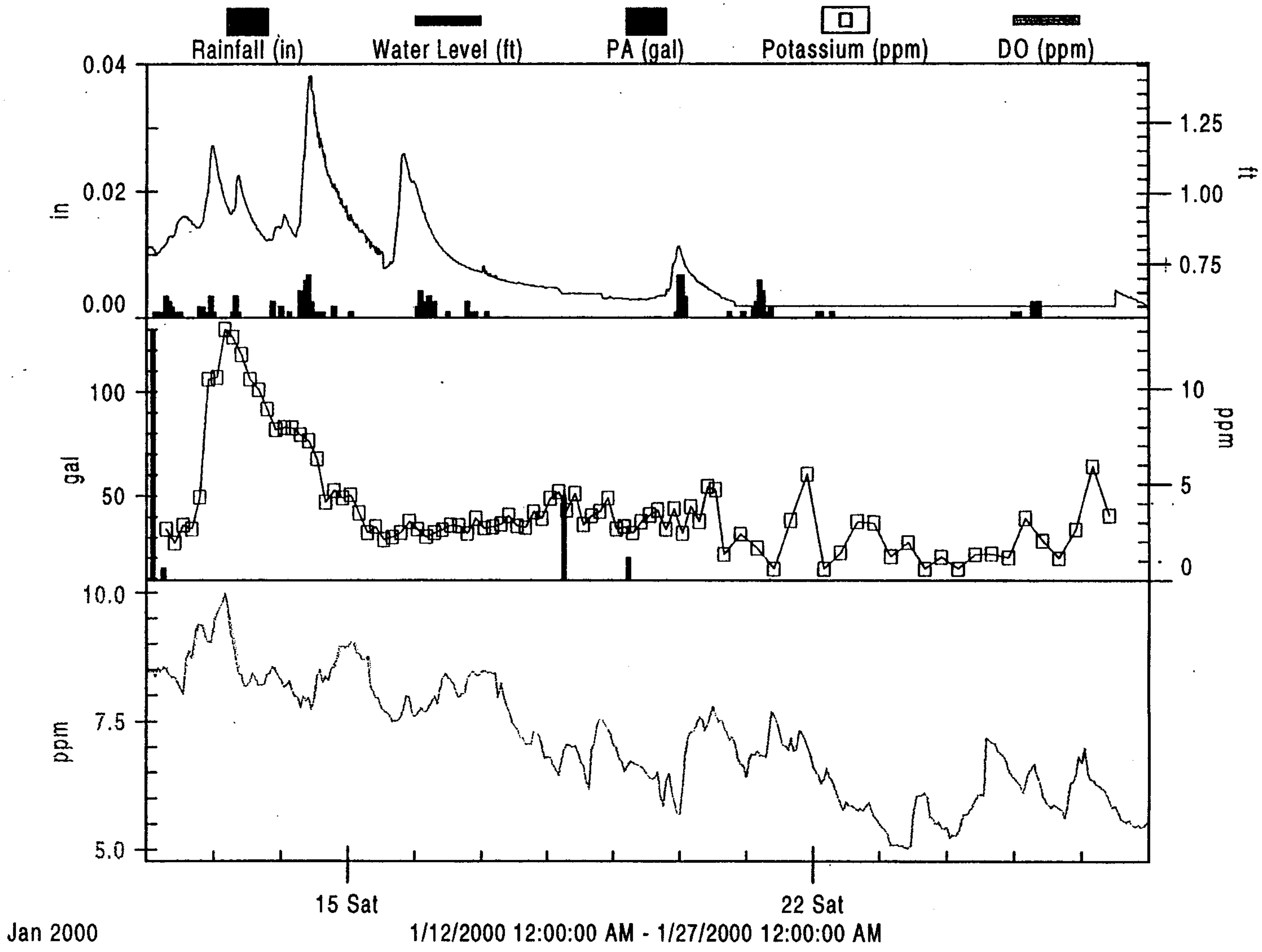

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Figure 3-15

Lake Reba Outlet (RebaOut)
Potassium Levels After PA Applications

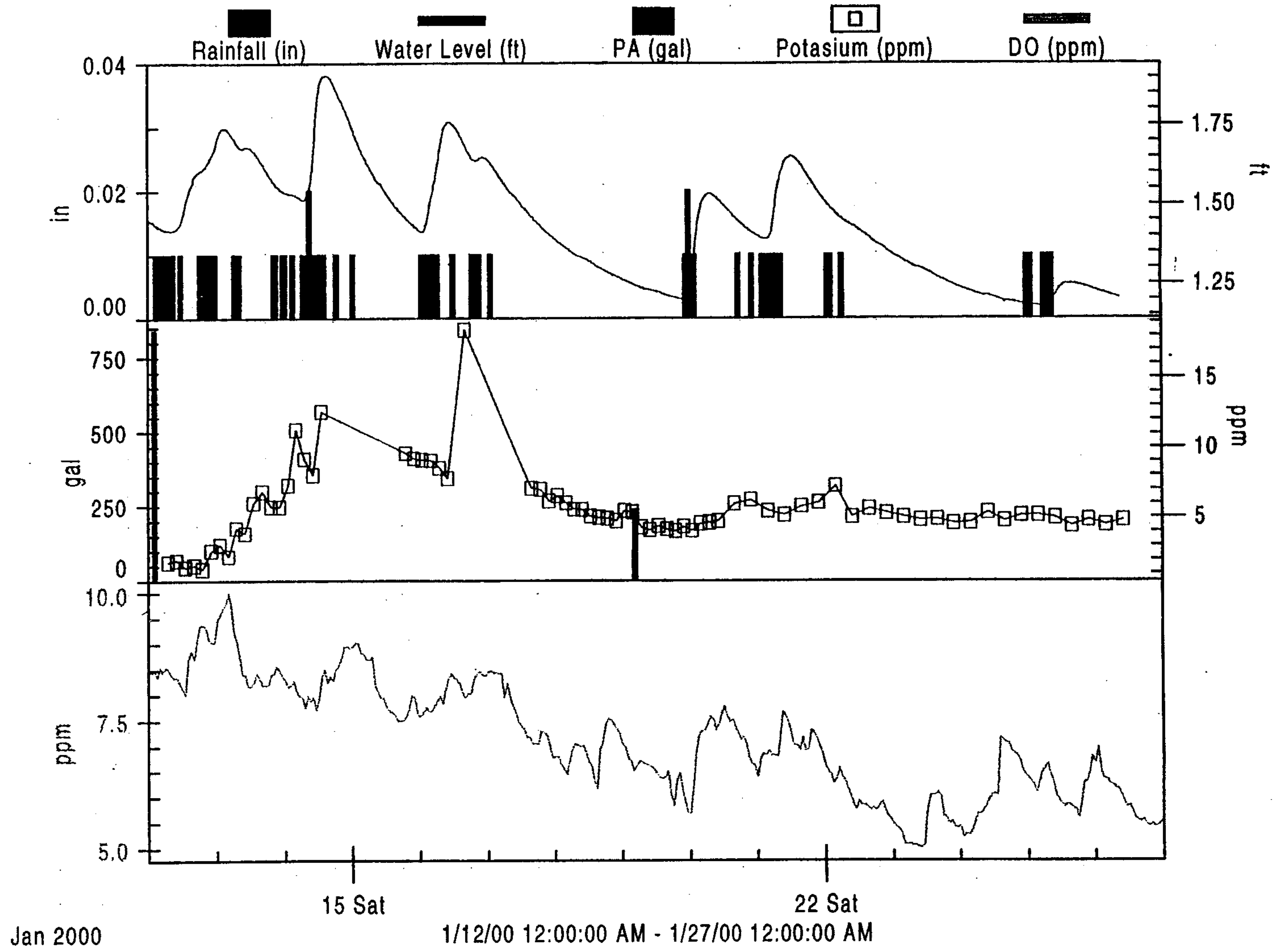

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Figure 3-16

Northwest Ponds Outlet (NPOut)
Potassium Levels After PA Applications

4 Synthesis and Discussion

This section assembles facts presented in previous chapters, synthesizes their significance and discusses the roles they play in the outcomes of this study. Each of six points is numbered and summarized below.

4.1 Dissolved oxygen in receiving waters varied considerably over time and space throughout the study period.

The variation in DO made it difficult to analyze what effects, if any ground deicing chemicals might have had on DO. During the entire monitoring period of nearly 5 months, DO levels remained below saturation in both pond systems. Importantly, these depressed levels existed for several months before ground deicer application. Evidence indicates that STIA runoff, including possible influences of glycols, could not be responsible for these naturally low background DO levels during this period. Furthermore, DO was most depressed in NWP cells 1 and 2, both of which are upstream of STIA drainage potentially influenced by glycols. Data from regional studies has shown that similar ponds, especially lacustrine (lake-type) wetlands, often exhibit undersaturated DO (Azous and Horner, 2000). Despite the under-saturation, DO in Lake Reba was about 2 to 4 mg/l higher than that in NWP. The following discussion explains the patterns in DO and how certain factors influenced the undersaturated DO measured for these ponds.

In both Lake Reba and the Northwest Ponds, DO levels generally fluctuated from 2 to 10 mg/l, with typical ranges during runoff events of 4 to 8 mg/l. DO concentrations changed by as much as 4 mg/l over periods as short as a few hours. These fluctuations were most pronounced in the two cells of the Northwest Ponds (NP1 and NP2) that do not receive runoff from portions of STIA that are deiced. Changes in DO levels at these locations were most likely the result of vertical DO stratification within the ponds rather than a change in DO throughout the pond caused by an external influence, such as stormwater runoff.

4.1.1 DO in Northwest ponds was highly stratified

Calibration results revealed some large differences between field equipment and control samples for the three NWP stations. A number of vertical profiles sampled in each of the three cells of the Northwest Ponds showed that a strong DO gradient in all three cells was responsible for a large part, if not all of these calibration differences. That is, instrument errors were not implicated. Though profiles indicate that runoff increased DO in the upper portions of each cell, DO in the lower water column tended to remain very low. The associated temperature gradients apparently played a role in resistance to vertical mixing.

This DO stratification, or oxycline, was most pronounced in NP1 where the DO concentration was near zero in the lower 4 to 6 feet of the water column while DO remained much higher in the upper 3 to 6 feet. The greatest changes in DO over depth were in the central 4 feet of the water column where DO dropped from 5-10 mg/l to near zero. This cell is about 12 feet deep, twice the depth of NP3 and is protected from wind by trees, characteristics that would tend to enhance DO stratification. As a result of these findings, the NP1 instrument was re-positioned above the most extreme portion of the gradient. The eight weekly profile samples showed these gradients persisted in all three cells. DO in the upper layers decreased with dry weather, while DO below the oxycline remained near zero. Despite the oxyclines, most of the NP3 profiles showed that DO changed by less than 0.5 mg/l in the top 2 to 3 feet of the NP3 water column. This means that the oxycline would have had very limited influence on data recorded at NP3 because the sensor was suspended above the oxycline.

Lake Reba and the Northwest Ponds both have abundant macrophyte growth that dies-back in the fall and winter, accumulating as organic material at the bottom of the ponds. See the photographs in Appendix A. Both ponds were excavated from peat deposits, of which some may still persist today. Profile samples collected near the bottom of the water column in the three cells of NWP contained large amounts of organic material and COD. These findings are consistent with the presence of decaying organic material that consumes oxygen in the lower portion of the water column. The persistent stratification discussed above tends to prevent reaeration of the lower water column. There was no ice cover on any of the ponds (that would have inhibited reaeration) during any period of this study.

The physical characteristics of these ponds can also influence some of the differences in the DO between the two pond systems. With an average depth of about 1 foot during dry periods, Lake Reba has less dead storage than even the shallowest of the three NWP cells (NP3), which has more than 4 feet of dead storage. Thus, the water column in Lake Reba is less likely to stratify.

4.1.2 DO response to weather patterns

Examination of the rainfall and DO time series data for Lake Reba and NP3 indicates that DO levels in both ponds responded markedly to rainfall, and lack thereof. During periods of dry weather and/or low runoff, DO levels generally declined over time, and then rose rapidly with the onset of rain. This apparent cause and effect relationship occurred throughout the monitoring period. For instance, in mid-November 1999, DO levels in both ponds were low during a period of predominantly dry weather, increased rapidly to about 8 ppm during a 0.88 inch storm on November 20, then declined steadily in the subsequent period of little rain See Figure 4-1. DO levels did not respond to small amounts of rain (0.25 in. and 0.16 in.) that occurred during isolated periods prior to and following the larger storm.

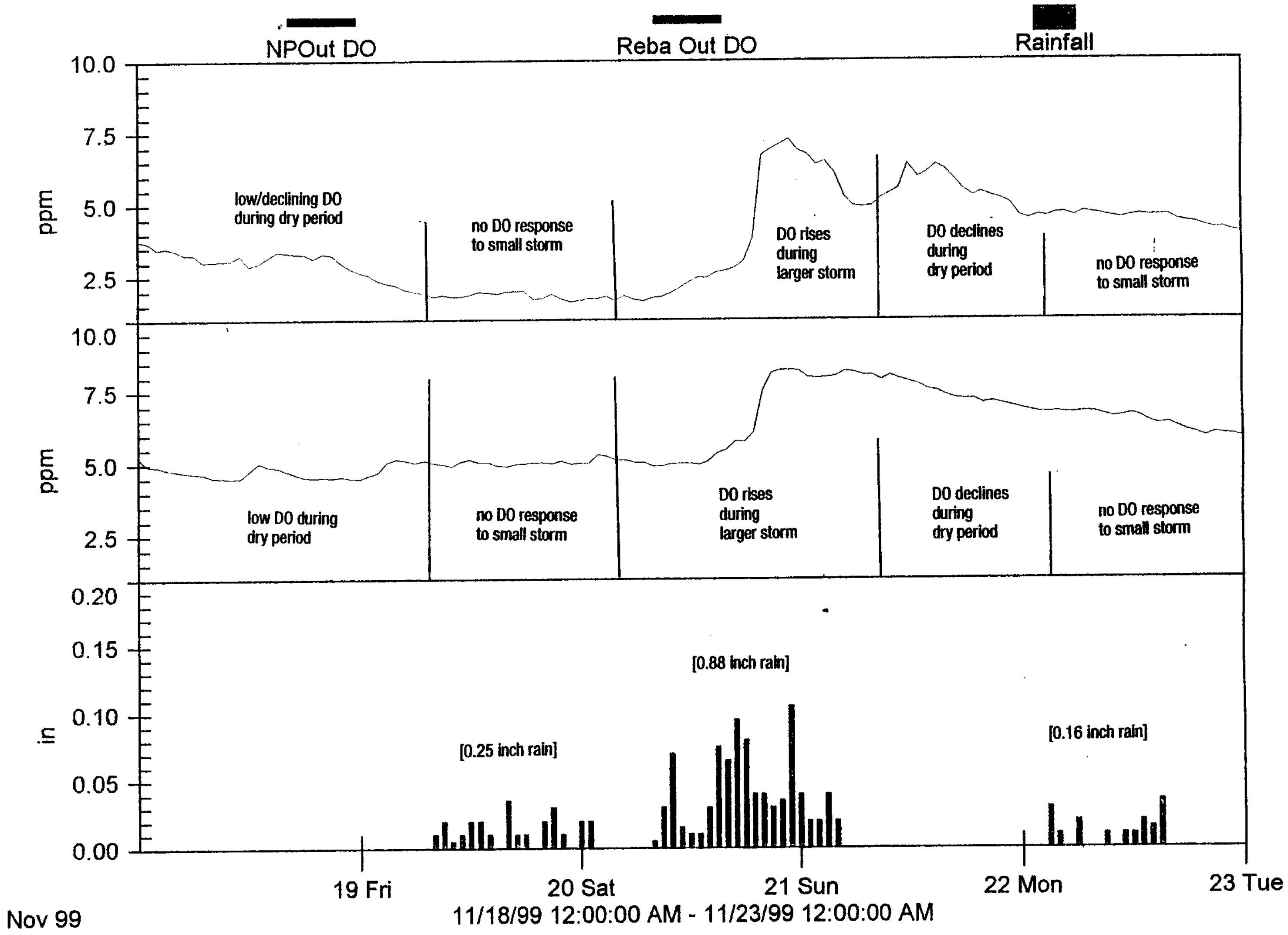

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Figure 4-1

DO Response to Rainfall
November 1999

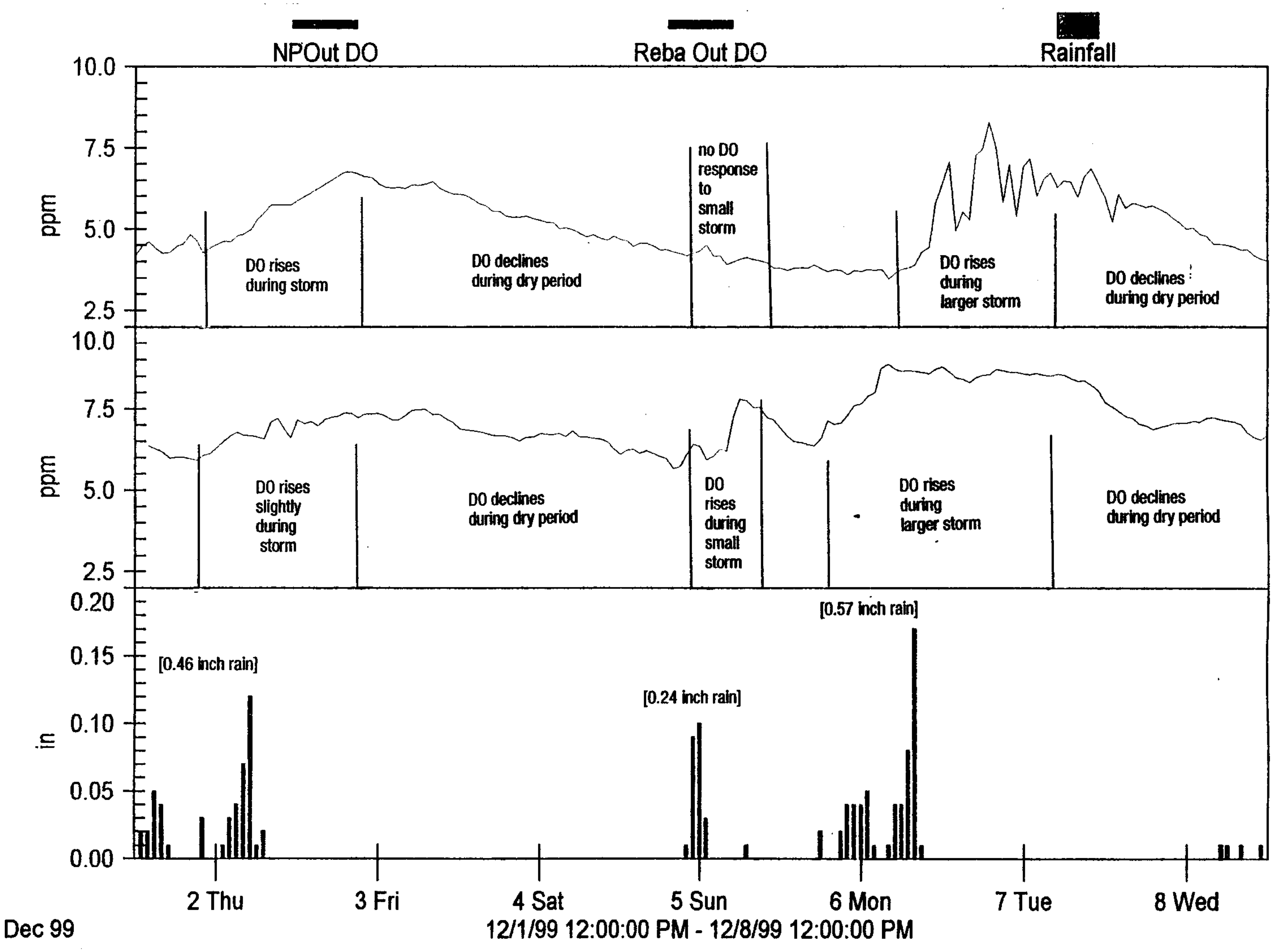

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Figure 4-2

DO Response to Rainfall
December 1999

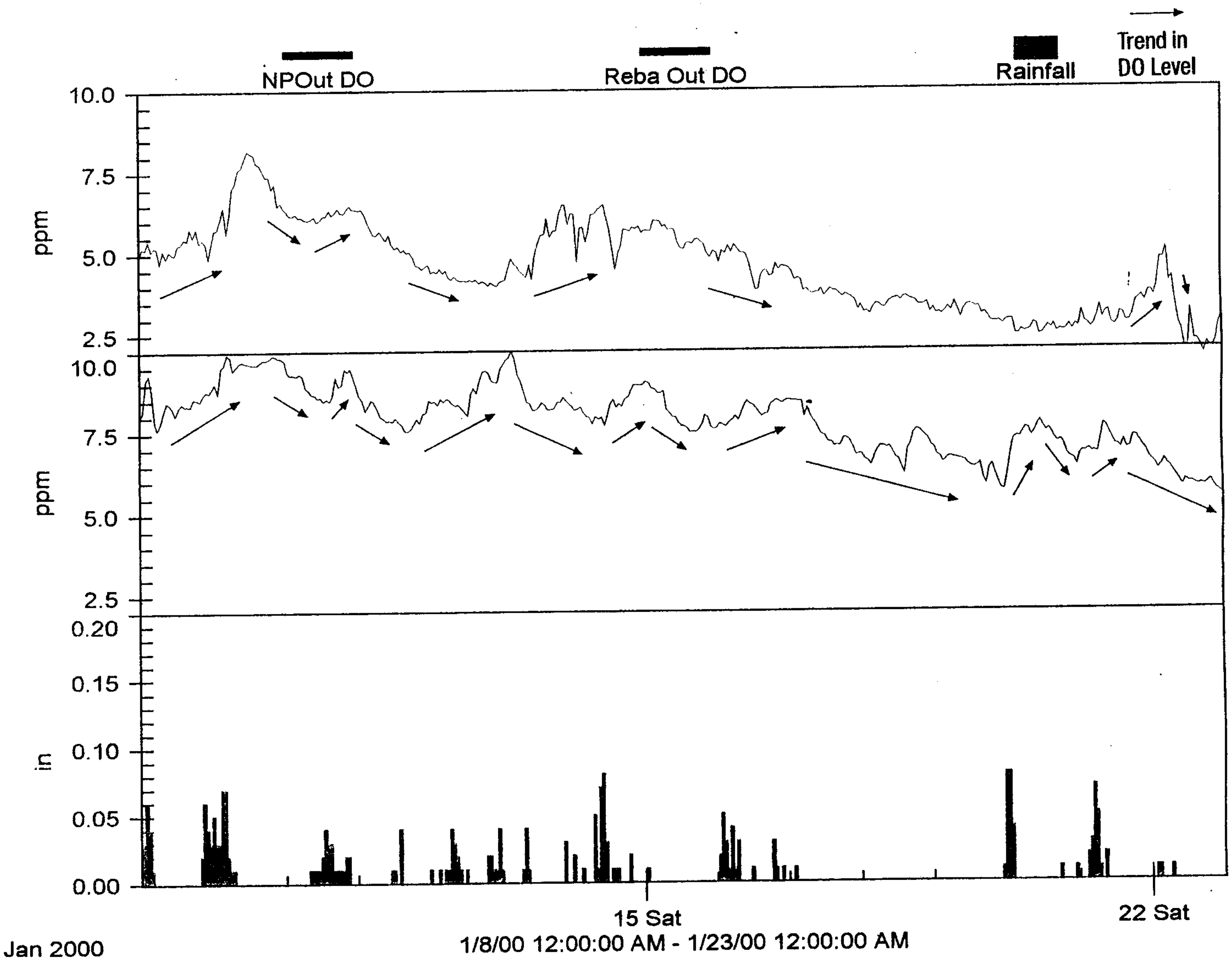

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Figure 4-3

DO Response to Rainfall
January 2000

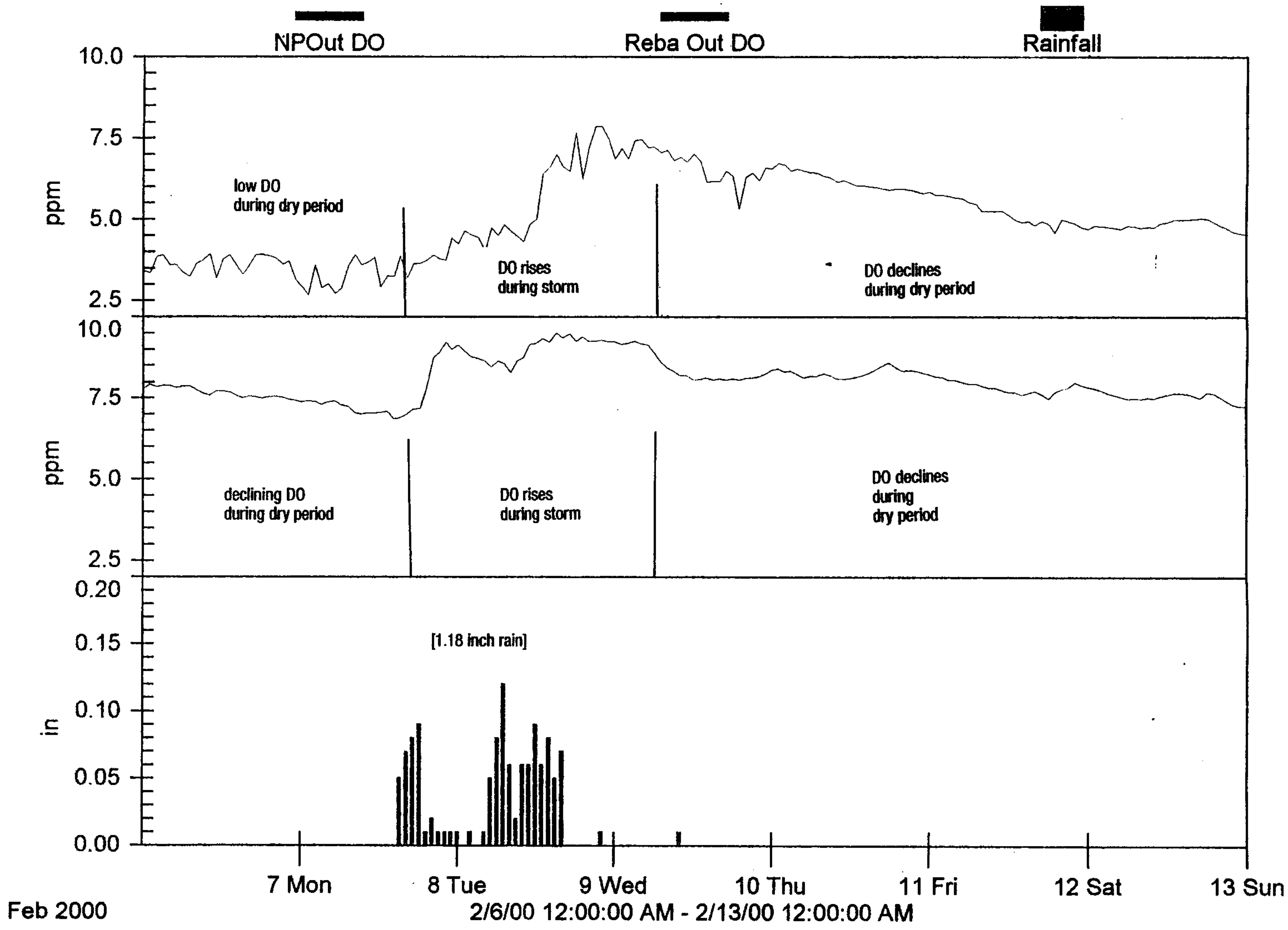

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Figure 4-4

DO Response to Rainfall
February 2000

This pattern suggests there is a threshold rainfall amount below which DO conditions in the ponds are not positively influenced by runoff. Other examples of similar DO patterns are apparent during early December, mid January, and early February. See Figure 4-2 through Figure 4-4.

Statistical analyses have shown that background DO conditions in Lake Reba and NWP were not comparable (see Appendix D). The response of DO in these ponds to other variables such as rain, water level, wind and water temperature are sufficiently different to preclude using the data sets from the two ponds as replicates.

4.2 Several tracers effectively signified the presence, magnitude and duration of certain ground deicing chemicals in runoff and the pond systems.

These tracers enabled segregation of DO data into periods of deicing and non-deicing events. These tracers provided a key to this study by enabling statistical tests of differences and patterns in DO during periods of chemical absence and presence. These tracers also confirmed travel and retention times for the deicing chemicals. The "deicer signal" indicated by the ions was not confounded by concurrent rising background concentrations in runoff.

4.2.1 Potassium and PA

Potassium measurements showed distinct signals at each station as the runoff containing deicing chemicals flowed through the stream systems. During the first event, where 95% of the PA was applied, potassium had high peak signal to (background) noise ratios ranging from a high of about 20 at SDS3 to a low of about 16 at N1. These signals were attenuated in the ponds where peak potassium signal to noise ratios for the outlets decreased to about 4. This attenuation of the potassium signal indicates the dispersion, and hence retention times of the slug of PA in the ponds. Downstream, at the Des Moines Creek mouth, the potassium had a ratio of about 4 while no signal was detected at the Miller Creek mouth. Overall, these signals were adequate to define the period of PA presence in the two pond systems and trace the PA in Des Moines Creek and the upper reaches of Miller Creek.

The potassium ion tracer correlated well in time and space with recorded chemical applications. At all outfalls, concentrations rose rapidly with the onset of storm runoff, peaked within the first 0.6 inches of precipitation (including snowmelt), then fell rapidly to background levels, particularly at the SDS3 outfall. Consistent with past washoff studies (POS, 1996, 1997), these results show that the first rainfall of less than one inch after chemical application rapidly conveyed the PA applications off the airfield. As expected, peak concentrations of potassium were highest at SDS3, where 57 percent of the PA was applied. Concentrations were lower for the other locations corresponding with lesser PA application and ranked as expected: N3N4>DME>N1. These responses verify earlier assertions about the relative proportions of PA applied in and transported to the watershed of each creek (see Section 2.1).

Weak but distinct potassium signals appeared at the two inlets of NP1 (S567 and NPin) and did not correlate with recorded chemical applications. Records indicated that no PA was applied in the SDS5-SDS7 subbasins that drain to the S567 inlet to NP1. No PA is stored in the snow equipment sheds in the SDS5 subbasin (this building houses much of the sand used, which according to records was dosed only with CMA or SA). Current port drainage maps do not indicate any Port property draining to the NPin outfall. It is conceivable that some roadways in the vicinity could be subject to WSDOT deicing, but according to their plan, they would have only used CMA. Under agreement with POS Maintenance, WSDOT may elect to use some of the Port's sand supply located in the Engineering Yard. This sand may be treated with small volumes of PA to prevent freezing. Because of a lack of record keeping at WSDOT, it is not clear if they used any of this sand, which could explain the potassium signals for both S567 and NPin. Nonetheless, these PA signals were minor compared to those corresponding with recorded PA applications, and no corresponding signal appeared in NWP cell 1 (at NP1).

4.2.2 Sodium and SA

Sodium signals also had adequate peak signal to noise ratios, ranging from about 6 to 2.5 for the sampling locations corresponding to certain applications. However, an accounting error is apparent because these signals appeared during the first event while applications records indicated SA use one week later in the second event. The sodium signals during the first event are considered reliable given the numerous data points well above background concentrations, plus the replication in signals at downstream stations. Furthermore, neither the DME station nor NEPL indicated a significant sodium signal in the second event, where the records had indicated 90% of the SA was used. Thus, these sodium signals mean that SA was actually used during the first event at the times when CMA applications were recorded. Data for other stations during the second event are inadequate to determine the presence of the SA at other locations, if it had been applied.

Despite the apparent recording error of chemical type, the signals corresponded with areas where chemicals were applied, and ranked appropriately relative to the recorded volumes applied: DME>NEPL. A significant sodium signal appeared at the Des Moines Creek mouth, while no clear signals were recorded at the Lake Reba outlet or Miller Creek mouth, which would have corresponded with the SA applications at NEPL. Thus, these signals were only adequate to define the travel time of the SA slug from SDE4 as it passed through the east branch of Des Moines Creek to the mouth.

Significant sodium signals also appeared at N1 and S567 during the first event and did not correspond with recorded SA applications in the associated subbasins. The N1 signal indicates an unrecorded SA application in the SDN1 subbasin on January 12th. Both bulk SA and SA-loaded sand is stored in the building located in the SDS5 basin. It is not clear whether the unexpected signal at S567 was due to handling the SA in the SDS5 subbasin, or due to a record keeping error. Nonetheless, these signals were much less than the sodium signal at DME that corresponded to the bulk of SA applications (in SDE4).

4.2.3 Calcium and CMA

Significant calcium signals appeared only at DME on January 12th and 20th. The first signal was lowest (19 ppm peak) and corresponded with recorded CMA applications in the landside area of SDE4. However, the second signal was higher (32 ppm peak) and did not correspond with a recorded CMA application. As mentioned above, this second CMA signal corresponded with an SA *application* recorded during the second event, but for which there was no corresponding sodium signal. Furthermore, this second CMA signal was concurrent with a potassium signal attributable to a recorded PA application in the second ground-deicing event. This concurrence of the two signals for PA and CMA clearly indicates CMA was applied during the second deicing event. Thus, the unexpected calcium signal during the second event corroborates the recording error transcribing the SA and CMA chemical applications, which is consistent with the discussion under sodium, above.

Calcium signals were weak at the other stations and inadequate to determine where and when the CMA slug passed through the systems. Background concentrations for calcium were about an order of magnitude higher than for the other tracer ions, which increases the inability to distinguish a discrete calcium signal. Nonetheless, because of it's similarity to solid SA, the solid CMA is believed to have behaved similarly in transport, travel and retention in the runoff and receiving water systems. Perhaps magnesium would have been a better indicator, which would need to be established by background sampling of this other ion constituent of CMA.

4.2.4 Conductivity

Conductivity yielded distinct signals for the outfalls, but was inconclusive regarding chemical presence in and transit through the two ponds. In the ponds, the pronounced background conductivity levels and natural variation masked the conductivity attributable to the presence of the chemicals, especially in Lake Reba. Conductivity performed suitably to indicate chemicals instream at the DME and DMmouth stations and the corresponding rapid transport flow regime discussed in Section 2.2.5.3.

Recall that conductivity represents an aggregate of all three chemical-specific ions (K^+, Ca^{2+}, and Na^{2+}), among other conductive ions. Analyses showed that during background, non-deicing conditions, conductivity was influenced more by calcium than by sodium or potassium, and that storm runoff decreased all these ions, particularly calcium. Consequently, in areas where CMA was not applied, rising conductivity attributable to a PA application would be masked by falling background calcium concentrations, which would tend to drive conductivity down. Conversely, at the tail of the storm hydrograph, background conductivity would tend to rise due to the higher concentrations of some ions in baseflow, while conductivity attributable to one specific ion from deicing chemicals would be dropping.

Nonetheless, conductivity showed distinct peaks at SDS3, DME, N1 and N3N4 that corresponded to chemical applications and their ion tracers. Furthermore, conductivity yielded further insight into the ponds' responses to weather patterns. In the 3-month background monitoring prior to the first ground-deicing event, conductivity showed dynamic rising and falling patterns, mirroring DO responses to runoff and dry weather.

4.2.5 Washoff, transport, travel and retention times

The potassium and sodium tracer data showed that shortly after application and the onset of runoff, deicing chemicals washed through the storm drain system quickly. Applications during the first event in the SDS3, SDN1, SDN3 and SDN4 (airfield) subbasins completely exited the respective outfalls by midday on January 14th, after the first 0.60-inch of precipitation (including snowmelt) that occurred after chemical applications.

Because of the zero dead storage of Tyee pond and the highly impervious SDE4 subbasin, flows traveled through Des Moines Creek rapidly to the creek mouth. This statement is supported by these facts: 1) tracers showed that the PA from applications on the STIA landside (SDE4) passed though the East branch of Des Moines Creek 24 hours after application and during the first 0.30-inch or less of precipitation, and 2) the peak of this PA slug measured at DME exited the creek within 3 hours at DMmouth. Peaks in the sodium signal occurred concurrently with the potassium signals at DME and DMmouth, corroborating this 3-hour peak-to-peak travel time between the two stations.

In contrast, the potassium tracer showed that the PA from SDS3 began exiting NWP about 24 hours after entering the pond, but persisted for more than 5 days in NWP before it was completely flushed into the creek. Similarly, the potassium tracer indicated a retention time of 57-hours in Lake Reba. Because much smaller amounts of PA were applied in the Miller Creek subbasins, the Miller Creek mouth did not exhibit a significant potassium signal. Given similar gradient and morphology, transit times in Miller Creek are expected to be similar to those found for Des Moines Creek.

4.3 Relative BOD loading

The tracer signals generally verified the assumptions used to develop the chemical applications allocated to each subbasin. More than 75% of the BOD_5 represented by all three chemicals was applied during the first event. Though the SA and CMA chemical types recorded were transcribed in some cases, the volumes recorded appear correct. Little change in BOD_5 allocations is expected due to this transcription error given the similarity in BOD for these two chemicals (Horner, 1996; Cryotech, 1999). Table 4-1 and Table 4-2 summarize these allocations without correcting for apparent transcription errors. These allocations are based on the recorded volumes applied, and reflect only an order of magnitude estimate for the BOD loadings that may have been actually transported to the receiving waters.

Based on these loading estimates alone, the potential for DO effects would be greatest during this first event of Jan 11-12, while subsequent events had much less BOD_5. The BOD_5 from the PA alone accounted for 87% of the total applied in the first event and 2/3 of the total for the season. Applications in Miller Creek (Lake Reba) subbasins accounted for only 12% of the total BOD_5, while applications in the Des Moines Creek subbasins were 86% of the total. All BOD_5 estimates are based upon actual data for tests run at 4°C from the 1996 study by Horner where the BOD of PA and other deicers was tested over periods up to 35 days.

Table 4-1 Estimates of BOD5 (lb) load allocations for Jan 11-12 event

	PA	% of total	CMA	% of total	SA	% of total	sum	% of total
L. Reba	1,920	8%	790	3%	-	0%	2,710	11%
NW Ponds	12,190	51%	-	0%	-	0%	12,190	51%
DME (rapid)	6,390	27%	2,250	9%	-	0%	8,640	36%
IWS	500	2%	-	0%	-	0%	500	2%
other	-	0%	-	0%	-	0%	-	0%
total	21,000	87%	3,040	13%	-	0%	24,040	100%

Table 4-2 Estimates of BOD5 (lb) load allocations for all three events

	PA	% of total	CMA	% of total	SA	% of total	sum	% of total
L. Reba	2,070	6%	960	3%	790	2%	3,820	12%
NW Ponds	12,720	40%	-	0%	-	0%	12,720	40%
DME (rapid)	8,120	25%	2,290	7%	4,260	13%	14,670	46%
IWS	510	2%	-	0%	-	0%	510	2%
other	-	0%	220	1%	50	0%	270	1%
total	23,420	73%	3,470	11%	5,100	16%	32,000	

4.3.1 Des Moines Creek subbasin BOD loading

Potassium acetate applications in the SDS3 (airfield) subbasin accounted for about 58% of the total BOD_5 from the PA applied in the first event. These applications in SDS3 amount to about 38% of the total BOD_5 attributable to all chemicals applied during the first event. Tracer data showed that this PA from SDS3 entered the NWP where it was detained for up to 5 days or more. In contrast, in the first event 44% of the total BOD_5 from all chemicals was applied to SDE4 areas where tracers showed runoff conveyed it rapidly through the East branch of Des Moines Creek to the mouth in about 3 to 6 hours. Overall, landside applications represented 58% of the season total, with 46% of the total applied in the SDE4 subbasin alone.

4.3.2 Miller Creek subbasin BOD loading

As shown in Table 4-1 and Table 4-2, BOD_5 from chemical applications in Miller Creek subbasins was much less than for Des Moines Creek. Applications to subbasins draining to Lake Reba were about 1/3 of the BOD_5 applied to areas draining to NWP. Thus, Lake Reba would have had less BOD_5 loading than the NWP facility.

4.4 Testing pond DO data during chemical absence/presence

Exploratory time-series analyses indicated that, for both ponds, the change in DO is an autoregressive process that is reset when inputs from rain and conductive ions change. That is, when weather conditions were relatively stable, DO concentration and saturation in any hour were strongly correlated with the concentration and saturation in the previous hour(s). The largest and most rapid changes in DO levels usually occurred in response to large and rapid changes in rain and conductivity. In particular, DO appeared to consistently return to background levels, though undersaturated, with the arrival of the first significant rain after a low rain period. During low rainfall periods, DO dropped concurrently with rising conductivity. These relationships were apparent and similar throughout the 5-month study period, and had no apparent relationship to the chemical applications.

Nonetheless, the tracer ions that were used in this study effectively allowed the definition of periods when deicing chemical were present in the ponds and at locations upstream and downstream of the ponds. During this study, the application of deicing chemicals coincided in time with a two-week period of relatively little rain, during which DO would likely have declined even if deicing chemicals had not been applied to the runways. Consequently, it is difficult to separate the effects of the deicing chemicals on DO from the naturally depressing effects of low rainfall[14]. Thus, it is not clear that the input of chemicals increased either the total decline or the rate of decline in DO. Interactions among physical factors specific to each pond during the presence of deicing chemicals produced slightly different DO responses in the two ponds. In fact, at Lake Reba, during the period of time when deicing chemicals were present in the pond, DO levels were slightly higher than during other portions of the study well before chemical applications.

Visual inspection of time series plots of conductivity and DO during the two-week deicing period and comparison of the cross-correlation functions and scatter plots of conductivity, water level, and temperature at the two ponds indicate that physical and

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[14] In statistical parlance, the effects of deicing and rain are confounded in this study.

biological processes at the two ponds differ. There is also evidence that the relationships among the measured variables changed during the deicing period, but it is not clear that the changes were caused by the presence of deicing chemicals. For example, there was a change in the correlation between level and temperature between non-deicing and deicing periods at both ponds, but it is unlikely that deicing chemicals might have caused this change. Changes in the level-temperature relationship, however, could affect the relationship between conductivity (which is affected by level) and DO (which is affected by both temperature and level).

4.5 The types of weather events that necessitated ground-deicing during this study differed from previous years.

Snowfall accumulations and the length of the freezing periods in large part determine the volumes of ground deicing chemicals needed to protect aircraft and vehicle safety. Meanwhile, weather patterns after deicing determine the overall fate and transport of the chemicals in the drainage system and receiving waters.

The minimal, short-lived snowfall accumulations and short freezing periods studied in this project resulted in smaller volumes of chemicals than past years. The three distinct periods of chemical applications in the latter half of January were associated with different weather and precipitation patterns, and resulted in highly disproportionate volumes of chemical applications. Rainfall less than one day after the first, and highest chemical application transported the vast majority of chemicals out of the SDS. Yet this limited runoff and the relatively low rainfall total of 1.5" in the subsequent two-week period resulted in 3 to 5 days or more detention periods in the two pond systems. This period of low rainfall and runoff after the January 11-12 deicing event was one of the longest in the 5-month fall and winter monitoring period for this project. The second and third events, both much less severe in terms of weather and chemical usage also occurred in this two-week period of little rainfall. The coincidence of this protracted dry period makes this year's events approach a worst-case scenario.

4.6 Monitoring for this project and others has provided a large body of information

The rapid chemical washoff rates and stream transit times have been sufficiently characterized in this and past work to preclude additional monitoring. Monitoring and modeling both indicate a minimal risk of adverse BOD exertion by ground deicing chemicals during stream transit. Because a large proportion of STIA ground-deicing activity typically takes place in the landside (SDE4) area, which drains rapidly through Des Moines Creek, this fact minimizes the potential for adverse effects in the creek.

The highly variable responses of DO in the receiving waters (ponds) to influences such as rainfall runoff and dry weather have been identified as important factors that influence background DO levels. These responses could be further characterized from the data gathered by this project. If further assessments are conducted, they should be based on the combination of return frequency for specific weather conditions pertaining to the severity of chemical application coupled with the return frequencies of varying degrees of subsequent rainfall and dry periods. These two factors would be important in determining the ultimate fate of the BOD attributable to the chemicals. Potential scenarios could then be identified and assessed for the varying degree and frequency of potential for BOD exertion in the ponds. A number of models are available to assess BOD loadings and exertion. Finally, any future work should involve investigation of contributions of BOD from underlying sediments within and terrestrial organic inputs to the ponds.

5 Conclusions and Recommendations

First, the study design and methods satisfied project objectives by providing the means to characterize the transport of ground-deicing chemicals in runoff. Patterns of transport, including washoff rates, travel and retention times were readily gleaned from data collected by this study. Importantly, study results provided clear methods to signify chemical presence, magnitude and duration in the ponds studied, improving upon previous work and providing a key tool for DO data analysis relative to potential effects of ground-deicing chemicals.

Second, there is a combination of highly disproportionate chemical applications relative to each creek coupled with two transport pathways (rapid, in a few hours via the east branch of Des Moines Creek; and detained for periods on the order of days via Lake Reba and NWP). In this year's case, in terms of total BOD_5, some 46% of the chemicals were applied in areas draining to the rapid transport pathway. Meanwhile, 52% of the total BOD_5 was applied unequally to the areas draining to the two pond systems: areas draining to NWP and Lake Reba received 40% and 12%, respectively. These transport and loading regimes would be expected to be similar for a wide range of events. Thus, due its higher loading and longer detention potential, NWP has the highest potential to experience adverse effects.

Third, the pattern of DO variation in Lake Reba and NWP established that DO concentrations were highly variable and influenced by natural phenomena. DO concentrations in both ponds fluctuated over wide ranges, trending upward with rainfall runoff and falling with dry weather. During the entire study period, DO in both ponds was undersaturated, particularly the deeper waters of cells 1 and 2 of NWP. Regional data for natural lacustrine wetlands, similar to the ponds, often show undersaturated DO. Results from this study support the conclusion that this depressed DO is the result of internal decomposition of macrophtyes and/or peat materials. Importantly, low DO in the ponds during the nearly 3-month monitoring period prior to the first ground-deicing event could not be attributed to aircraft deicing glycols because, especially for Lake Reba, samples showed that glycols were absent in stormwater samples.

Because the Lake Reba DO data is not subject to stratification influences, the dynamic conditions exhibited establish that background phenomena exist. The DO is influenced by factors other than ground-deicing chemicals. Relative to Northwest Ponds, Lake Reba in effect approaches a control, further supporting the evidence that the dynamic DO responses are a natural phenomenon . Finally, because of this high variability in the background conditions in both ponds, the potential for STIA ground-deicing to negatively influence DO could not be discerned, even by a variety of statistical analyses. Some of the lowest rainfall runoff conditions of the monitoring period occurred after chemical application and are believed solely responsible for the falling DO in Lake Reba during the period chemicals passed through the system. The weight of evidence presented by this report supports the conclusion that the ground-deicing events studied did not have a detectable effect on DO in the ponds. Future sampling is not warranted, but if modeling was undertaken, it could assess a much wider range of scenarios than could be sampled in a reasonable time-period.

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Logan

#7

Port of Seattle

EXAMINING THE EFFECTS OF RUNWAY DEICING ON DISSOLVED OXYGEN IN RECEIVING WATERS: RESULTS OF THE 1999-2000 WINTER SEASON

Seattle-Tacoma International Airport
Seattle, Washington

January 2001

Volume 2

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1 INTRODUCTION

This document presents the technical appendices (Volume 2) to the report entitled "Examining the Effects of Runway Deicing on Dissolved Oxygen in Receiving Waters: Results of the 1999-2000 Winter Season" (Volume 1, Report, November, 2000).

Appendix A

Photographs

1 MILLER CREEK WATERSHED SAMPLING STATIONS

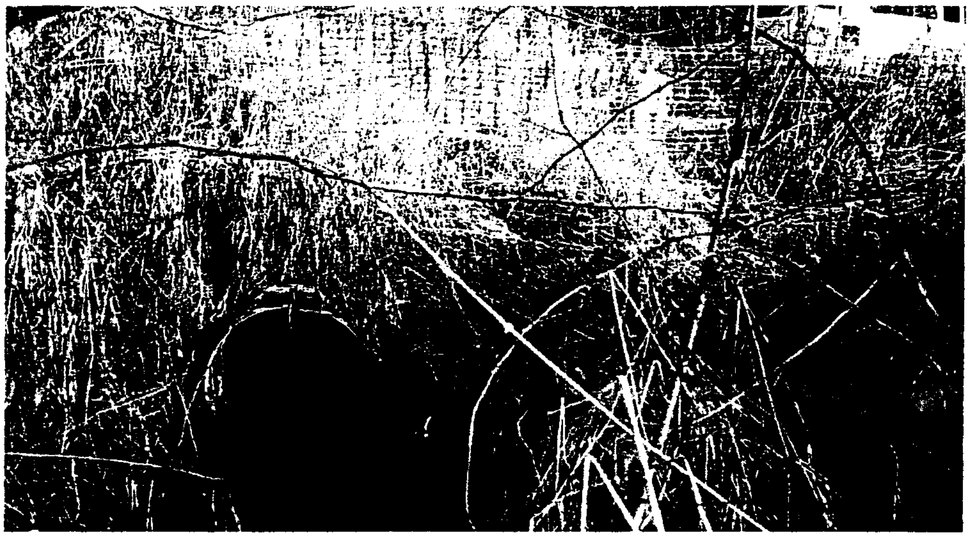

photo 1-1

N1 - culvert outlet

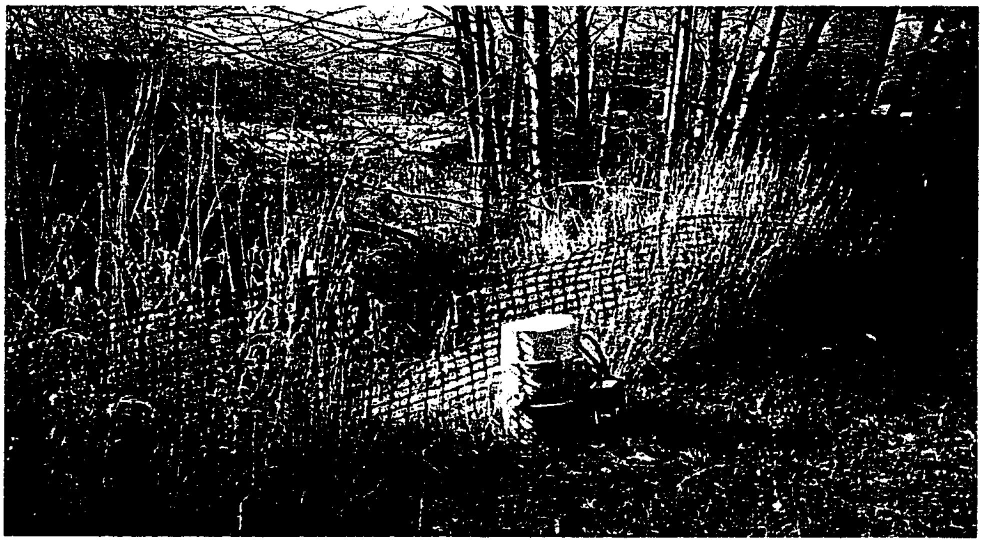

photo 1-2

N1- sampler and flow meter. Culvert outlet is on opposite side of orange fence

photo 1-3

N3N4 - culvert outlet

photo 1-4

N3N4 - Sampler and flowmeter. Culvert outlet on opposite side of orange fence

photo 1-5

NEPL – outlet (south end) of culvert under SR-518

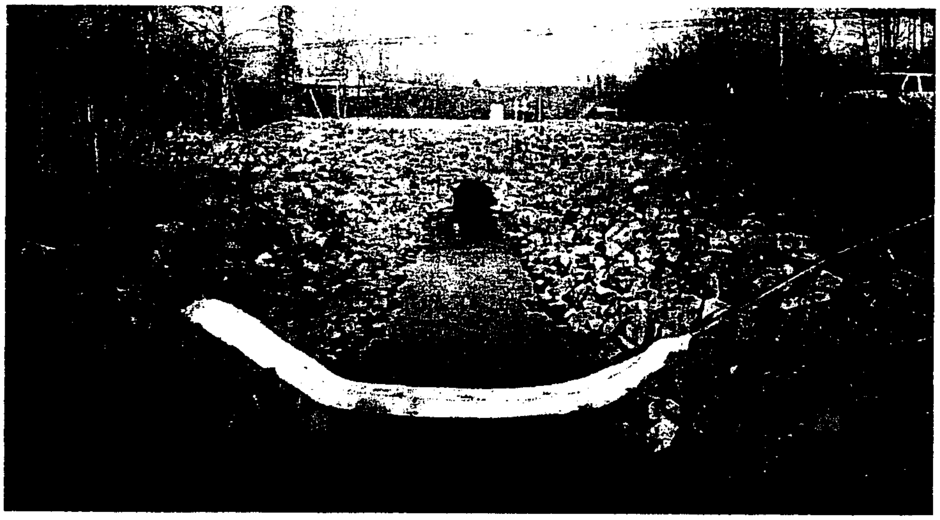

photo 1-6

RebaOut - outlet from control structure where flow measured

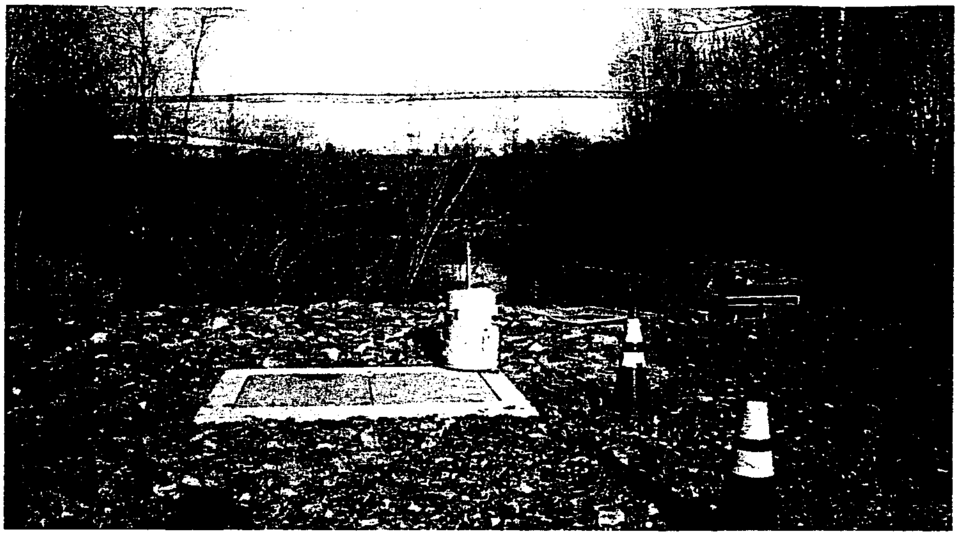

photo 1-7

RebaOut – samples collected in vault where Hydrolab housed

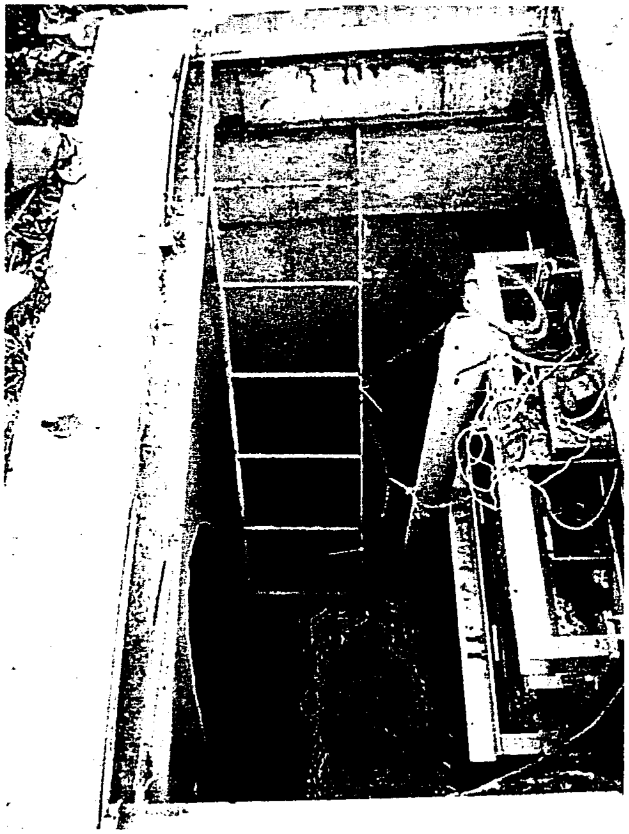

photo 1-8

RebaOut – control structure where samples collected– white pipe is Hydrolab housing

photo 1-9

Lake Reba 7/31/00, North to right. Outlet at top center, near aircraft wing. N1 and N3N4 inlets near lower left, and NEPL inlet near lower right not visible. Note floating macrophyte growth

photo 1-10

Lake Reba: 9/27/00 looking west from east end

photo 1-11

MCup –sampler and flowmeter

photo 1-12

MCmouth – stilling well from north bank upstream of bridge on SW 175th Place. Large stilling well is KCDNR station

2 DES MOINES CREEK WATERSHED SAMPLING STATIONS

photo 2-1

NPin – culvert outlet with sampler and flowmeter in the background

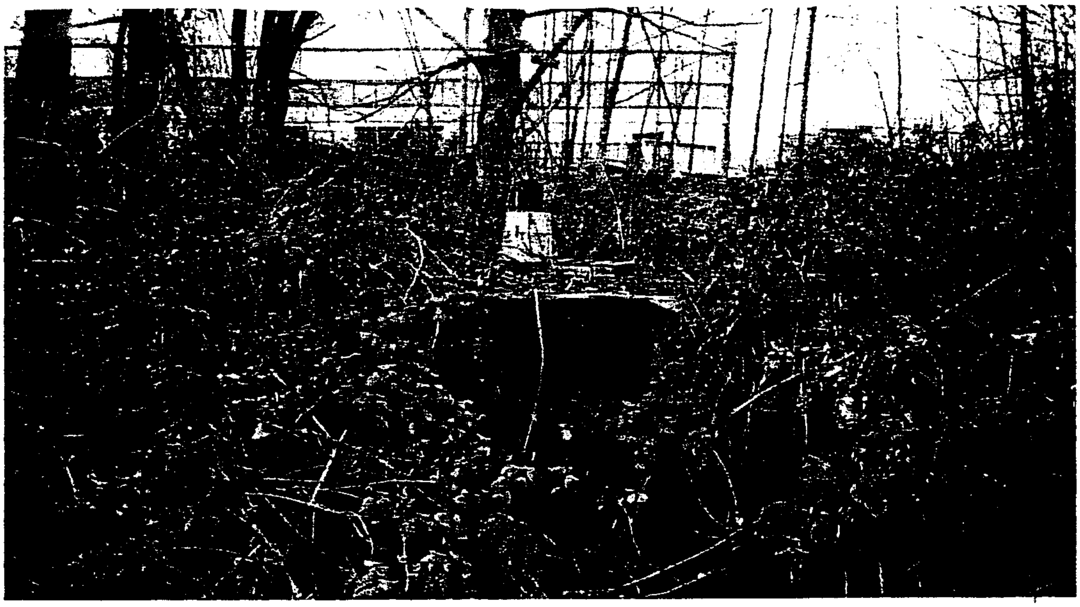

photo 2-2

S567 – culvert outlet with sampler in the background

photo 2-3

SDS3 – samples taken from upstream (left side) of weir

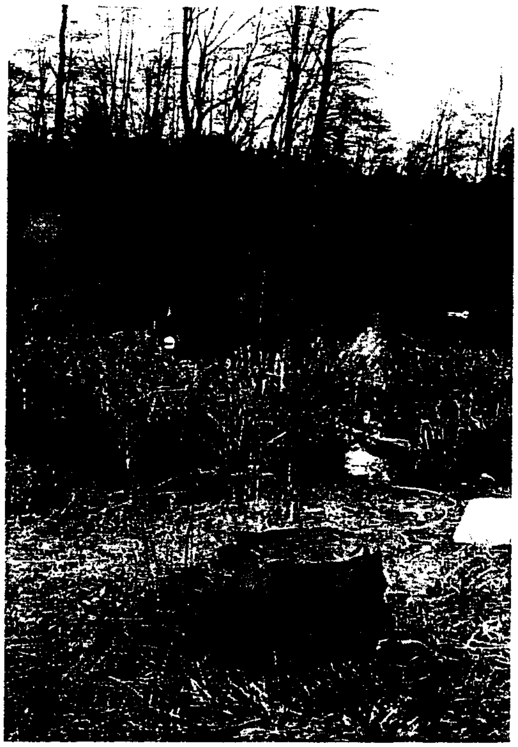

photo 2-4

NP1 – sampler in foreground under bag. Hydrolab buoy in upper right

photo 2-5

NPout - sampler and flowmeter at pond outlet. NP3 Hydrolab station is white buoy in right center

photo 2-6

NPout - outlet of Northwest Pond Cell 3 at culvert just right of center

photo 2-7

Northwest Pond Cell 3 – NP3 Hydrolab station at white buoy in center

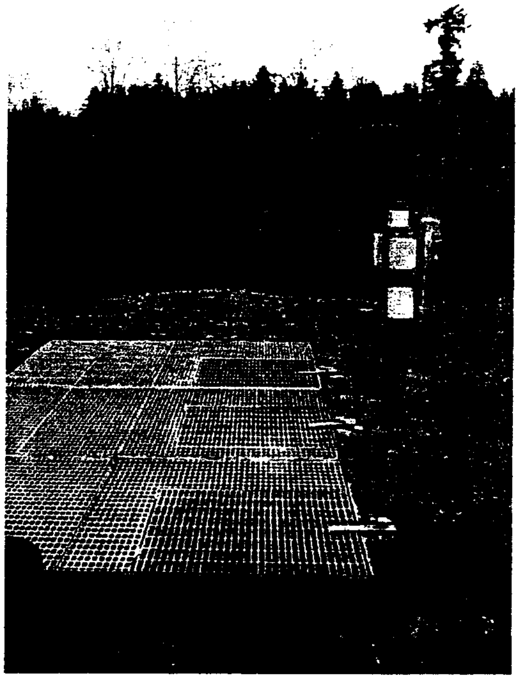

photo 2-8

DME - Tyee Pond control structure vault. KCDNR loggers on right

photo 2-9

DME – inside of Tyee Pond control structure

photo 2-10

DME – instream inlet to control structure on east branch where samples were collected

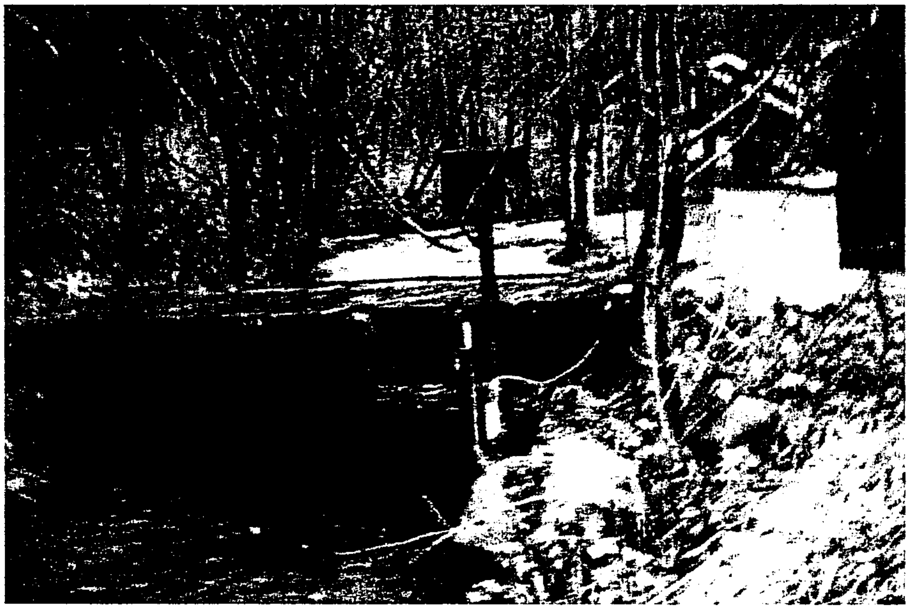

photo 2-11

DMmouth –sampler housing in white box on right end of footbridge. Large stilling well for KCDNR gage

Photo 2-12

NW Ponds from, Feb 00. North is to right

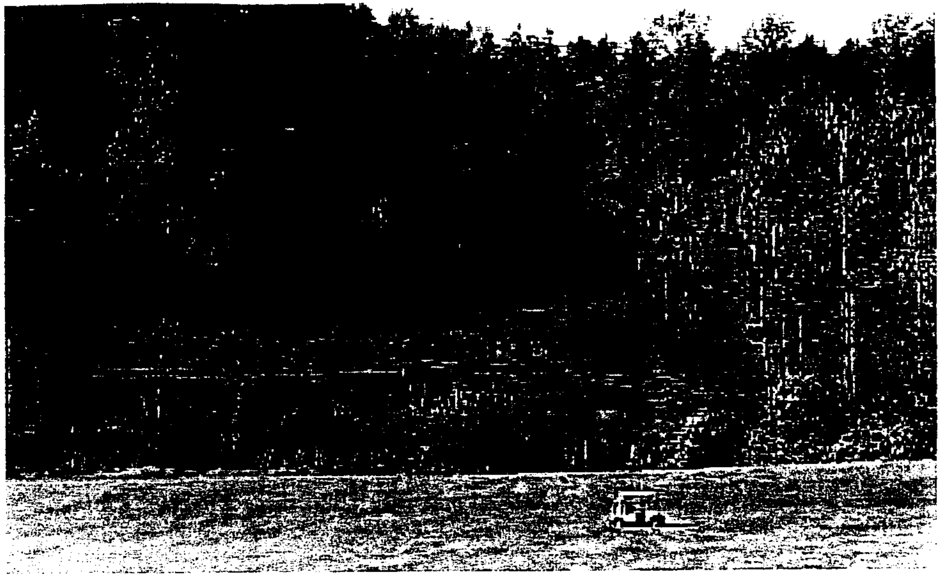

photo 2-13

NW Ponds: 9/27/00 looking West-Southwest. Note macrophyte growth ringing cell#3 in foreground. Cell 2 in center, Cell 1 in shadows in center of photo

photo 2-14

Detail near outlet of NW Ponds cell #3, 9/27/00, looking west (upgradient) from outlet structure note considerable macrophyte growth. White buoy left of center is NP3 Hydrolab station

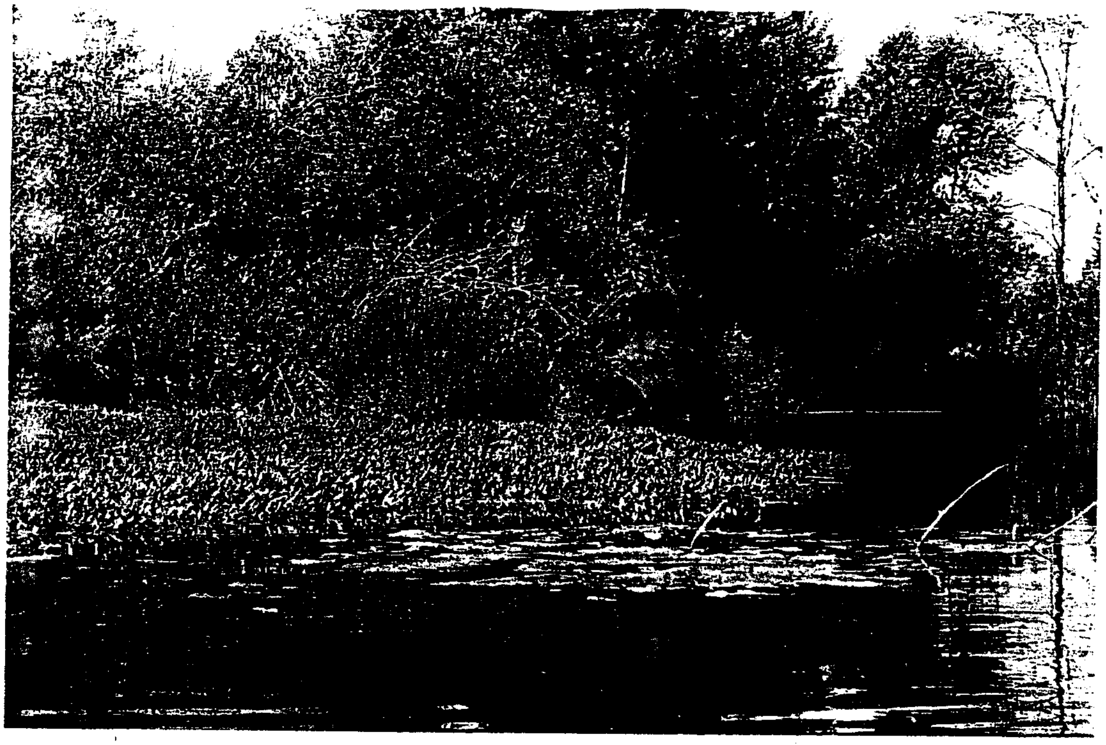

photo 2-15 NWP Cell 2 detail of macrophyte growth, August 2000

photo 2-16 NWP cell 3 macrophyte growth, looking towards outlet, August 2000

3 JANUARY 2000 RUNWAY DEICING EVENT PHOTOS

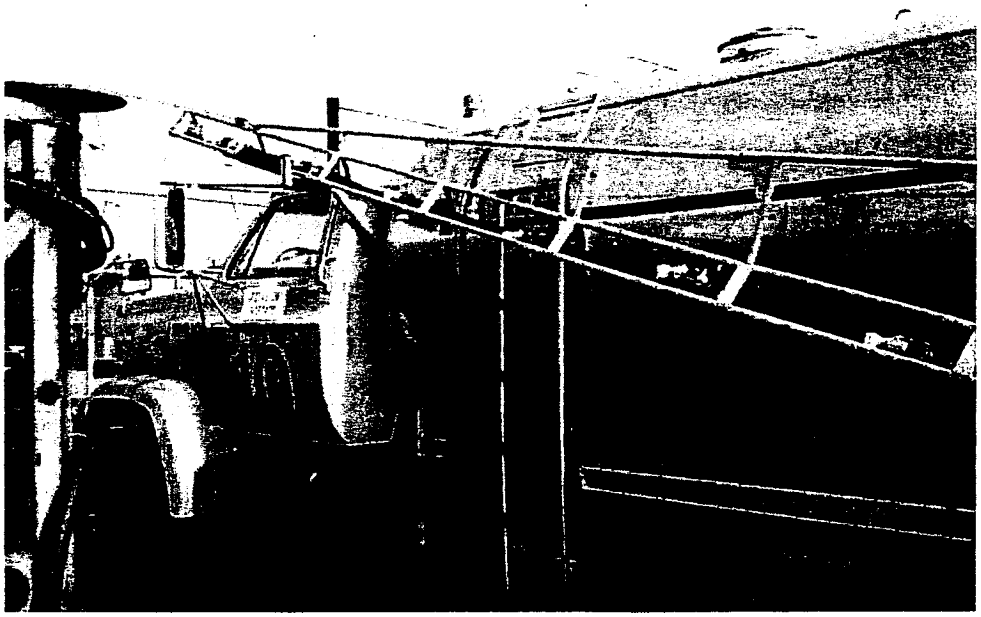

Figure 3-1 Liquid Potassium Acetate Application Truck #10.

Note pink color in vertical tube on tank shows liquid level

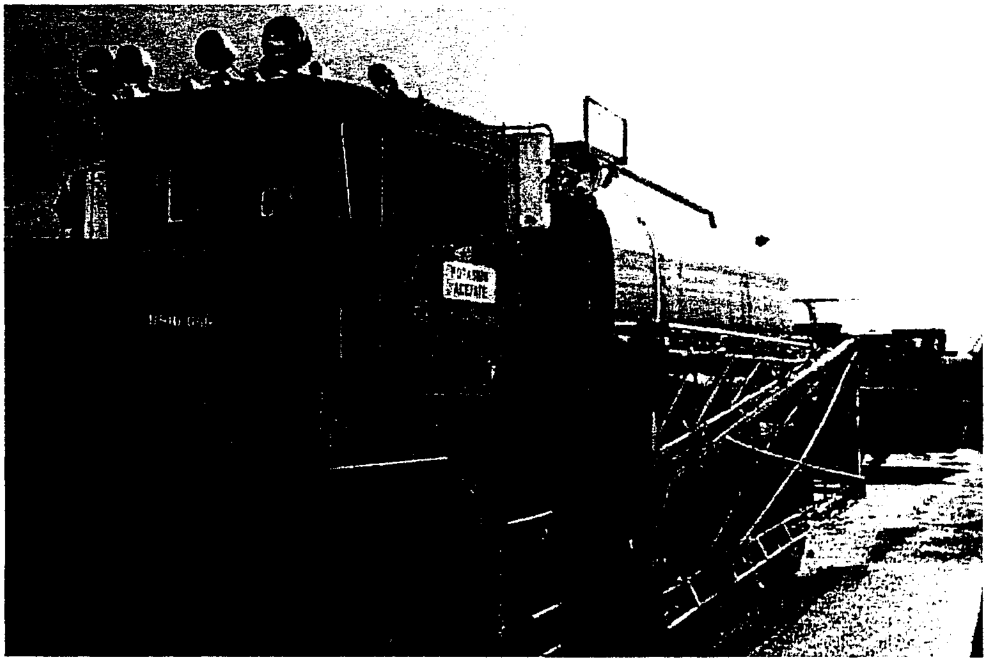

Figure 3-2 Liquid Potassium Acetate Application Truck #11.

Note pink color in vertical tube on tank shows liquid level and approximate volume

Figure 3-3 View NW over airfield during event 1, January 12, 2000,10:19

Taxiway A in foreground. Northbound MD80 aircraft on Taxiway B. Southbound 737 aircraft on takeoff roll on runway 16L. Note minor amount of snow plowed to edge; melting in progress.

Figure 3-4 View SW over airfield during event1, January 12, 2000, 10:20.

Taxiway A in foreground, southbound 737 aircraft on takeoff roll on runway 16L. Note minor amount of snow plowed to edge; melting in progress.

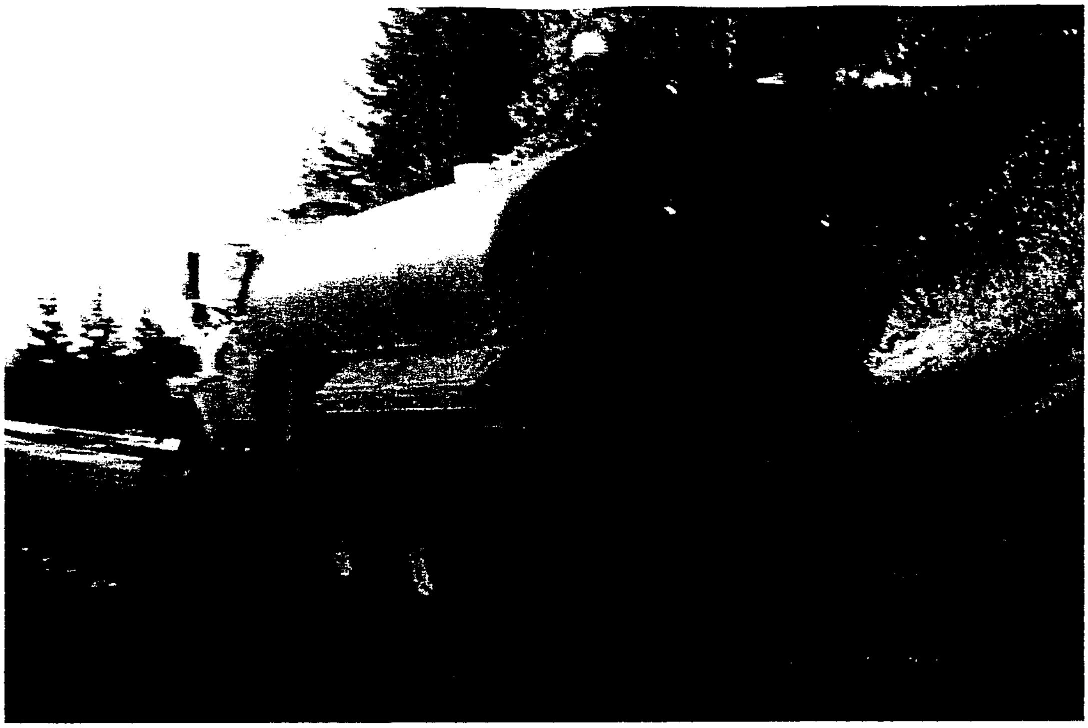

Figure 3-5 Event 2 WSDOT Liquid Deicer Applied on Southbound SR509, January 19, 2000, 07:31.

Figure 3-6 Event 2 WSDOT Liquid Deicer Applied on Southbound SR509, January 19, 2000, 07:30.

Note heavy frost on shoulder breakdown lanes

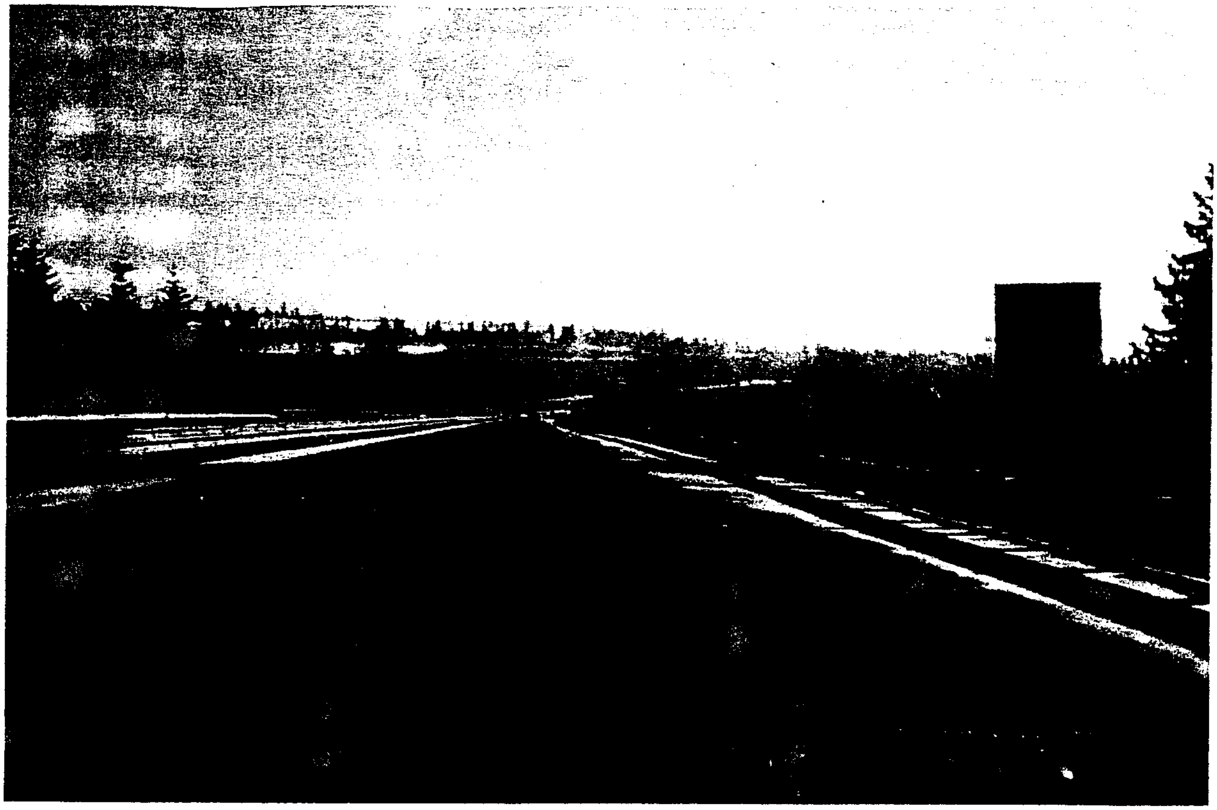

Figure 3-7 Eastbound SR518, January 19, 2000, 07:36.

Note heavy frost on shoulder breakdown lanes

3 APPENDIX B QA/QC AND FIELD METHODS

3.1 Introduction

This Appendix presents the quality assurance/quality control methods and field installation procedures used during the study. Plots of QC data and profiles of chemical constituent concentrations also appear in this appendix.

3.2 Hydrolab Maintenance, and Quality Control Procedures

Each week the Hydrolabs were removed from the water and were either taken to the stormwater field lab, if they were scheduled to be calibrated, or were cleaned and maintained at the station. At the time each unit was removed, the water depth at the station was measured and water samples were collected for dissolved oxygen and conductivity analysis by a contract laboratory. Water samples were taken using a Van Dorn sampler at the same depth that the sonde had been deployed. A portion of each sample was immediately fixed with reagents for subsequent Winkler DO analysis by the lab.

Dissolved oxygen and temperature were measured at the depth of the sonde using a YSI Model 95 hand held DO meter. When the Hydrolabs were redeployed after maintenance and calibration, these procedures were repeated, except that measurements and water samples were taken from the depth at which the unit would be deployed over the next week. Samples collected when the sondes were taken out were labeled "end", and samples collected when the units were put back were labeled "start".

Data was immediately downloaded from each sonde each time the unit was removed from the water for maintenance. Data was imported into an Excel worksheet and immediately reviewed for any data gaps and errors. The unit was then programmed for redeployment. Sensors were cleaned per the manufacturer's recommendations, battery voltage was checked and batteries were replaced if necessary. All activity was recorded in a weekly Field Log. The sonde was then redeployed, typically within an hour of when it was removed.

Every other week, the DO sensor on each sonde was calibrated according to the Hydrolab manual instructions. Conductivity was calibrated once, immediately prior to the initial deployment of each sonde. For DO calibration, the sondes were taken back to the stormwater laboratory and kept overnight. After each unit was cleaned and inspected, the DO sensor membrane and electrolyte was replaced and the sensor was soaked in deionized water for at least 12 hours prior to calibration. Calibration was performed according to the manufacturer, using the water-saturated air method, which assumes 100% DO saturation at ambient barometric pressure. Data sondes were typically taken out of service for less than 24 hours for calibration.

3.3 Northwest Ponds DO Profile Data Collection Procedures

At each monitoring location in the 3 cells of the Northwest Ponds (NP1, NP2, and NP3), measurements of DO and temperature were taken along vertical profiles using a YSI model 95 hand held DO meter. At NP1 and NP2, measurements were taken at 1-foot intervals along the 10 to 12-foot deep profile. In the shallower cell 3 (6 foot deep), measurements were taken at ½-foot intervals.

Grab samples were collected a short distance horizontally from where the DO measurements were taken to minimize errors from possible water strata mixing. At each station, grab samples were collected at the same depth interval that DO measurements were taken. Sampling proceeded from the surface to the bottom of the water column. A surface sample was collected by dipping the sample bottle directly into the pond. All other samples were collected with a Van Dorn sampler attached to the end of a pole. The sampler was lowered on the pole into the water column at a slight angle from horizontal and once positioned at the appropriate depth, the sampler was triggered to collect a sample. The planar location of the profile sampling varied by up to 20 ft due to boat drift. In each cell, the deepest sample typically contained a significant amount of unconsolidated sediment comprised mostly of fine, dark organic matter.

On two occasions, ORP was measured in every profile sample collected with the Van Dorn sampler. Before any water was removed from the sampler, the top of the cylinder was opened and the ORP probe from an Orion model 1230 pH/redox meter was slowly lowered to the bottom of the sampler and the readings were allowed to stabilize. The ORP readings taken in the first two Van Dorn samples at each station were compared to ORP measurements taken by lowering the probe into the water column. At each station, each pair of ORP measurements were within 5 mV of each other. Before taking the first reading at each cell, the ORP meter was checked against an ORP standard. The probe was rinsed with deionized water before each reading was taken.

3.4 Assessment methods for continuous monitoring data

To assess the success of the field quality control measures used for continuous water quality monitoring at Lake Reba and the Northwest Ponds, the differences between dissolved oxygen measurements obtained concurrently by three methods were calculated. Specifically, the relative percent difference (RPD) between each of the concurrent measurements was determined as follows:

$$RPD = [(M1 - M2) / ((M1+M2/2))] \times 100$$

where-

M1 = DO measurement by first method

M2 = DO measurement by second method

Three RPDs were calculated for each set of data: 1) the RPD between the Hydrolab and Winkler measurement, 2) the RPD between the Hydrolab and YSI measurement, and 3) the RPD between the Winkler and YSI measurement.

Time series charts of each set of these RPDs are presented for the Lake Reba Outlet, and three locations in NWP (NP1-NP3) in this Appendix. According to the monitoring plan, an RPD no greater than ±20% was considered acceptable, reflecting the measurement error inherent to employing the three methods under these circumstances. An RPD beyond ±20% warranted review of quality control procedures and revision of maintenance and calibration routine if necessary as well as an investigation of whether spatial variability or some other environmental factors were causing substantial differences in the measurements.

3.5 Monitoring Instrument Installations

Isco model 4150 area-velocity flowmeters were used to monitor flow at RebaOut, NEPL, N1, N3N4, NPin, and NP567. Each unit used an area velocity probe to measure water level and velocity. The probe was attached to a scissor-ring that was inserted into the pipe at each station. Each of the flowmeters was programmed to log level, flow, velocity, and sample events.

Isco model 4230 bubbler flow meters were used for continuous flow monitoring at MCup, MCmouth, NPout, SDS3, DME, and DMmouth. At each station, a bubbler line was attached to a section of steel rebar secured in the channel and the level was set using a staff gage or measurement from an established benchmark (tape-down measurement). Each time these instruments were maintained, the meter level was checked against the tape down measurement or staff gage.

Isco model 3700 samplers were deployed to collect water samples. Samplers were configured with 24, 1-liter polypropylene bottles. Sample bottles were washed and rinsed with deionized water prior to deployment. To accomplish level enabling, the samplers were hard-wired to flowmeters everywhere except at NP1. At that station, a level enabling triggering mechanism was installed at the pond's edge and was set to trigger at one-tenth foot above the water surface existing just before event sampling. With a rise in water level at the onset of runoff, the trigger mechanism became submersed, sending an electrical pulse to the sampler, which enabled the unit to begin the sampling routine.

Each sampler was equipped with a 5/8-inch vinyl suction line. At most stream sampling stations, the sampler suction line strainers were positioned mid stream, just above the channel bottom. At MCmouth and DMmouth, the strainers were positioned near the edge of the stream at mid-depth. The strainers were secured with zip-ties either to the flow meter cables, stilling wells, trash racks, or other structures.

At the pond stations the sampler strainers were positioned in a different manner. At NP1, the sampler strainer was suspended six feet below the water surface from a buoy located about 20 feet offshore, near the Hydrolab sonde. At NPout, the strainer was attached to the King County gage stilling well, located adjacent to the outlet culvert, at about mid-depth. At RebaOut the sampler strainer was installed in the vault sump, just below the elevation of the outlet pipe invert, next to the Hydrolab sonde. The strainer was zip-tied to the access ladder to keep it in place.

Twelve-volt deep cycle marine batteries powered all samplers and flowmeters. Each sampler was housed in a shelter or completely covered with a plastic bag to provide additional protection during deployment.

3.6 Constituent Data concurrent with NW Ponds DO Profiles

The table below summarizes the chemical constituents that were analyzed concurrently with DO in samples taken during vertical profile sampling in Northwest Ponds, cells 1-3 (stations NP1, NP2, and NP3). Plots of these profiles appear below. See Volume 1, Section 3.3 for a discussion of sampling methods.

Table 3-1 NW Ponds Profiles: Chemical Constituent Data

SAMPLE ID	depth, ft	COND (uS/cm)	BOD5 (mg/l)	COD (mg/l)	pH	Ca2+ (mg/l)	K+ (mg/l)	Na2+ (mg/l)
NP1 020800 0	0	65.4		5.0	6.55	8.83	1.10	2.60
NP1 020800 1	1	73.1		13.4	6.61	9.03	2.36	2.93
NP1 020800 2	2	83.5		13.0	6.60	9.80	0.30	4.21
NP1 020800 3	3	129		11.3	6.60	15.5	0.732	6.54
NP1 020800 4	4	133		14.2	6.61	15.4	2.06	7.03
NP1 020800 5	5	195		10.9	6.68	24.2	2.77	9.16
NP1 020800 6	6	172		14.6	6.58	21.6	2.73	7.68
NP1 020800 7	7	149		13.0	6.65	18.8	2.82	6.32
NP1 020800 8	8	237		5.0	6.62	29.8	3.56	10.1
NP1 020800 9	9	237		12.1	6.55	31.2	2.88	9.99
NP1 020800 10	10	178		111	6.54	22.9	3.65	8.71
NP2 020800 0	0	106		20.1	6.57	13.3	1.94	6.16
NP2 020800 1	1	107		21.8	6.56	14.4	1.71	7.47
NP2 020800 2	2	136		15.9	6.71	19.3	1.96	8.81
NP2 020800 3	3	137		12.1	6.47	18.1	2.03	9.01
NP2 020800 4	4	166		10.5	6.45	22.6	3.23	9.33
NP2 020800 5	5	173		18.4	6.46	22.5	4.13	9.81
NP2 020800 6	6	176		23.1	6.52	22.1	3.63	10.0
NP2 020800 7	7	190		15.9	6.64	25.0	1.69	9.09
NP2 020800 8	8	204		16.7	6.63	29.1	3.64	10.9
NP2 020800 9	9	192		16.7	6.71	27.2	2.57	10.7
NP2 020800 10	10	199		106	6.74	22.8	3.64	8.05
NP3 020900 0	0	86.2	4.00	16.3	6.81	8.27	1.04	2.18
NP3 020900 1	1	96.5	2.00	18.0	6.97	7.41	1.54	2.42
NP3 020900 2	2	103	2.00	13.0	6.62	9.06	1.79	2.84
NP3 020900 3	3	117	7.50	36.8	6.73	11.2	2.43	3.51
NP3 020900 4	4	109	27.5	58.3	6.57	8.55	1.87	3.07
NP3 020900 5	5	141	14.3	160	6.72	11.1	1.12	4.06
NP1 021500-0	0	110	2.00	5.0		12.2	1.08	2.76
NP1 021500-1	1	116	2.00	10.1		12.2	1.23	2.86
NP1 021500-2	2	137	2.00	10.5		13.9	1.31	3.30
NP1 021500-3	3	151	2.00	5.0		15.8	1.55	3.98
NP1 021500-4	4	178	2.00	16.3		18.7	1.79	4.79
NP1 021500-5	5	191	2.00	5.0		21.8	1.98	5.64
NP1 021500-6	6	221	4.34	11.3		26.4	2.28	6.30
NP1 021500-7	7	243	2.00	14.6		26.7	2.62	7.23
NP1 021500-8	8	233	2.00	16.7		25.9	2.38	6.70
NP1 021500-9	9	234	2.00	34.6		25.6	2.34	6.45

Table 3-1 (continued)

SAMPLE ID	depth, ft	COND (uS/cm)	BOD5 (mg/l)	COD (mg/l)	pH	Ca2+ (mg/l)	K+ (mg/l)	Na2+ (mg/l)
NP2 021500-0	0	131	2.00	19.7		18.8	1.31	3.57
NP2 021500-1	1	143	2.00	14.6		19.7	1.47	4.00
NP2 021500-2	2	152	2.00	10.5		20.8	1.55	4.45
NP2 021500-3	3	150	2.00	14.2		18.3	1.58	4.18
NP2 021500-4	4	170	2.00	11.7		21.9	1.90	5.12
NP2 021500-5	5	182	2.00	18.8		25.1	1.91	5.17
NP2 021500-6	6	190	2.00	5.0		23.5	2.12	5.41
NP2 021500-7	7	195	2.00	5.0		22.5	2.05	5.42
NP2 021500-8	8	215	2.00	12.6		28.9	2.65	6.15
NP2 021500-9	9	229	2.00	16.3		29.3	2.52	6.09
NP2 021500-10	10	253	31.8	178		30.8	2.93	6.66
NP3 021500-0	0	123	15.9	22.2		18.8	2.30	2.90
NP3 021500-1	1	123	15.5	18.0		21.0	2.11	2.91
NP3 021500-2	2	131	12.4	23.5		19.8	2.23	3.17
NP3 021500-3	3	136	11.4	18.8		20.4	2.30	3.30
NP3 021500-4	4	141	11.4	109		21.3	2.31	3.83
NP3 021500-5	5	135	22.9	149		20.7	2.58	3.48
NP1 022900-0	0	96.9	4.16	31.2		9.30	0.973	1.97
NP1 022900-1	1	104	2.00	28.2		10.7	1.04	2.04
NP1 022900-2	2	102	2.00	26.9		10.4	1.13	2.11
NP1 022900-3	3	103	2.00	24.3		10.8	0.820	2.16
NP1 022900-4	4	112	2.00	20.5		10.4	0.943	2.40
NP1 022900-5	5	119	2.00	21.8		11.4	1.20	2.47
NP1 022900-6	6	129	2.00	20.1		13.4	1.36	2.97
NP1 022900-7	7	205	2.00	27.7		22.2	2.22	5.26
NP1 022900-8	8	202	4.20	24.3		22.4	2.11	5.38
NP1 022900-9	9	226	5.58	24.8		23.7	2.26	5.52
NP1 022900-10	10	244	7.40	18.8		26.2	2.41	6.21
NP2 022900-0	0	123	2.00	13.8		10.9	1.09	2.51
NP2 022900-1	1	122	2.00	13.4		12.2	1.22	2.67
NP2 022900-2	2	119	2.00	16.3		12.2	0.911	2.85
NP2 022900-3	3	128	2.00	21.4		13.2	1.73	3.18
NP2 022900-4	4	148	2.00	22.6		16.0	1.51	3.78
NP2 022900-5	5	153	2.00	27.7		15.4	1.59	4.21
NP2 022900-6	6	170	2.00	19.3		17.8	1.65	4.23
NP2 022900-7	7	192	2.00	22.2		20.3	1.84	4.93
NP2 022900-8	8	199	2.00	14.2		22.7	1.97	5.29
NP2 022900-9	9	209	2.00	19.3		23.2	2.19	5.22
NP2 022900-10	10	224	2.00	23.1		26.6	2.28	5.77
NP3 022900-0	0	76.0	4.92	5.0		9.61	1.58	1.08
NP3 022900-1	1	77.3	5.94	5.0		9.30	1.68	1.10
NP3 022900-2	2	79.2	5.46	13.0		9.97	1.63	1.03
NP3 022900-3	3	82.4	4.90	14.2		10.0	1.78	1.22
NP3 022900-4	4	85.4	4.68	12.6		10.4	1.75	1.33
NP3 022900-5	5	86.1	36.4	716		8.78	1.99	1.57

Table 3-1 (continued)

SAMPLE ID	depth, ft	COND (uS/cm)	BOD5 (mg/l)	COD (mg/l)	pH	Ca2+ (mg/l)	K+ (mg/l)	Na2+ (mg/l)
NP1 030900 0	0	194	2.00	15.5		17.5	1.66	5.08
NP1 030900-1	1	200	2.00	10.1		18.7	1.97	5.20
NP1 030900-2	2	200	2.00	16.7		24.9	2.37	6.54
NP1 030900-3	3	204	2.00	10.1		26.0	2.55	6.27
NP1 030900-4	4	219	2.00	15.5		29.8	2.40	6.88
NP1 030900-5	5	204	2.00	15.9		25.7	2.81	6.45
NP1 030900-6	6	242	4.18	26.9		31.1	2.87	6.95
NP1 030900-7	7	275	7.14	24.8		35.0	3.10	7.98
NP1 030900-8	8	270	5.76	19.3		36.1	3.35	8.13
NP1 030900-9	9	293	10.6	24.3		35.0	3.40	8.57
NP1 030900-10	10	288	16.9	87.9		32.4	3.17	8.01
NP2 030900 0	0	165	2.00	10.9		15.8	1.63	3.67
NP2 030900-1	1	170	2.00	11.3		16.9	1.41	3.78
NP2 030900-2	2	176	2.00	9.6		14.6	1.81	3.70
NP2 030900-3	3	184	2.00	19.3		19.1	1.82	4.64
NP2 030900-4	4	187	2.00	13.4		19.0	1.92	4.63
NP2 030900-5	5	198	2.00	9.64		20.1	2.09	5.22
NP2 030900-6	6	205	2.00	10.5		20.7	2.21	4.96
NP2 030900-7	7	220	2.00	16.3		23.2	2.43	5.64
NP2 030900-8	8	256	5.48	63.2		29.0	2.76	6.10
NP2 030900-9	9	243	25.4	1939		22.9	2.42	5.39
NP3 030900 0	0	143	2.00	14.2		15.4	1.68	2.83
NP3 030900-1	1	147	2.00	17.6		15.8	1.66	2.76
NP3 030900-2	2	152	2.00	12.6		16.0	1.69	2.84
NP3 030900-3	3	160	2.00	10.5		17.5	1.96	3.01
NP3 030900-4	4	160	2.00	13.0		16.6	1.91	3.01
NP3 030900-5	5	158	10.7	24.3		16.6	1.92	3.21

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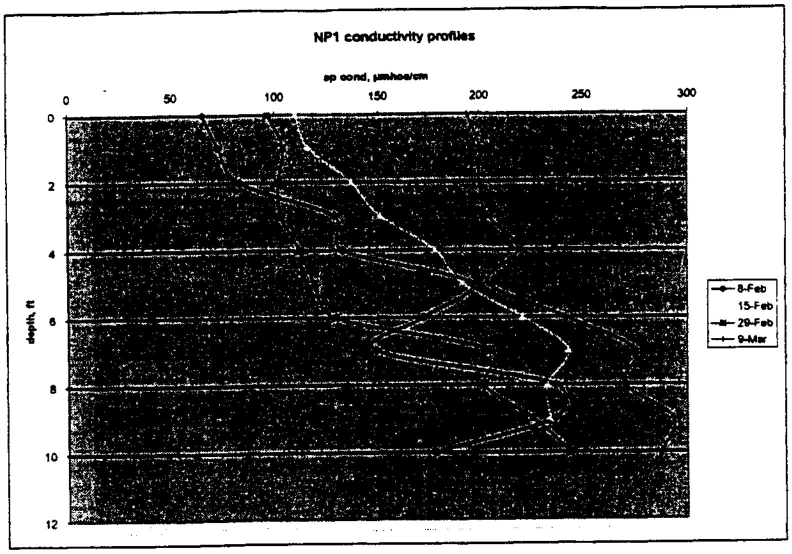
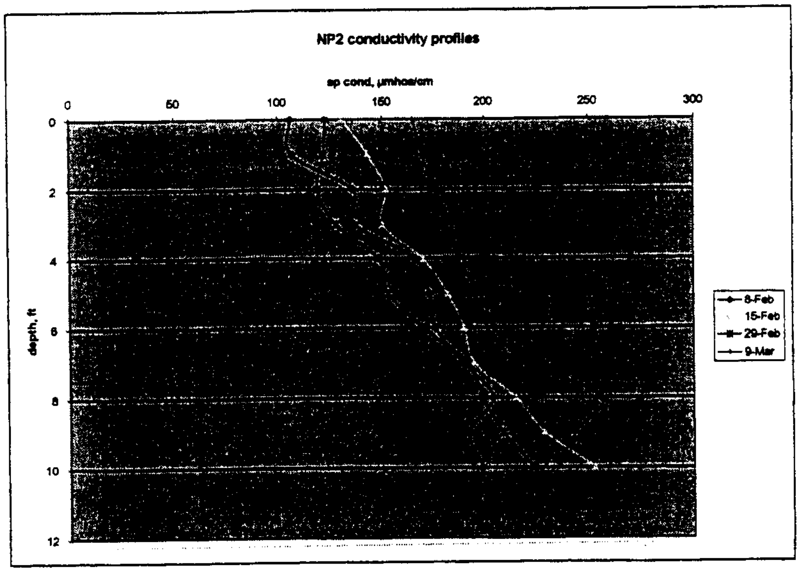
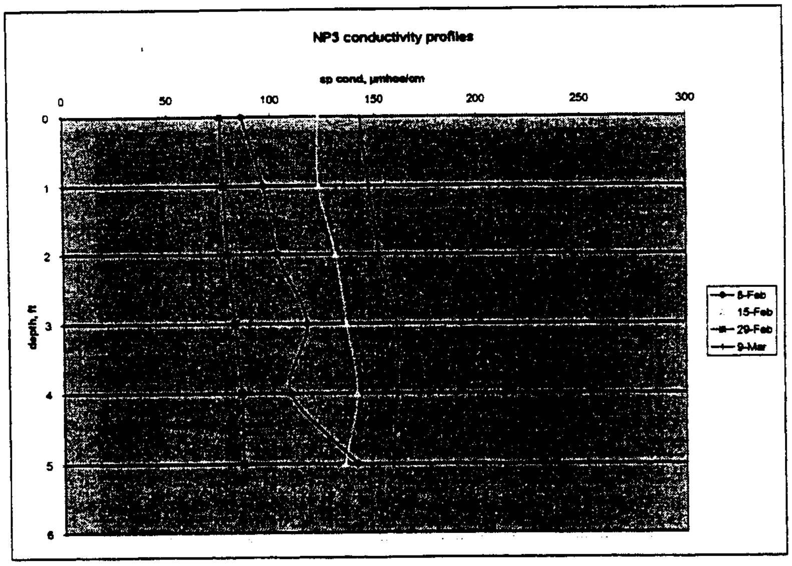
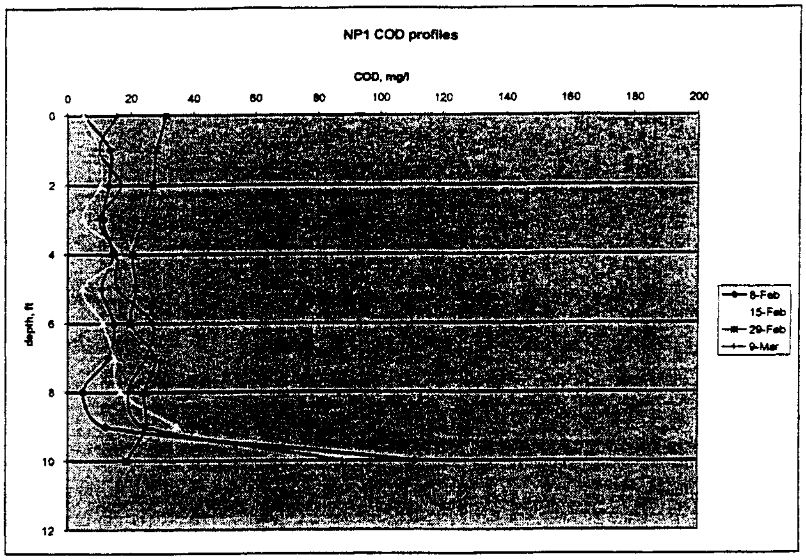

NP1 conductivity profiles
sp cond, µmhos/cm
0
50
100
150
200
250
300
depth, ft
0
2
4
6
8
10
12
8-Feb
15-Feb
29-Feb
9-Mar


NP2 conductivity profiles
sp cond, µmhos/cm
0
50
100
150
200
250
300
depth, ft
0
2
4
6
8
10
12
8-Feb
15-Feb
29-Feb
9-Mar


NP3 conductivity profiles
sp cond, µmhos/cm
0
50
100
150
200
250
300
depth, ft
0
1
2
3
4
5
6
8-Feb
15-Feb
29-Feb
9-Mar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COD, mg/l
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20
40
60
80
100
120
140
160
180
200
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2
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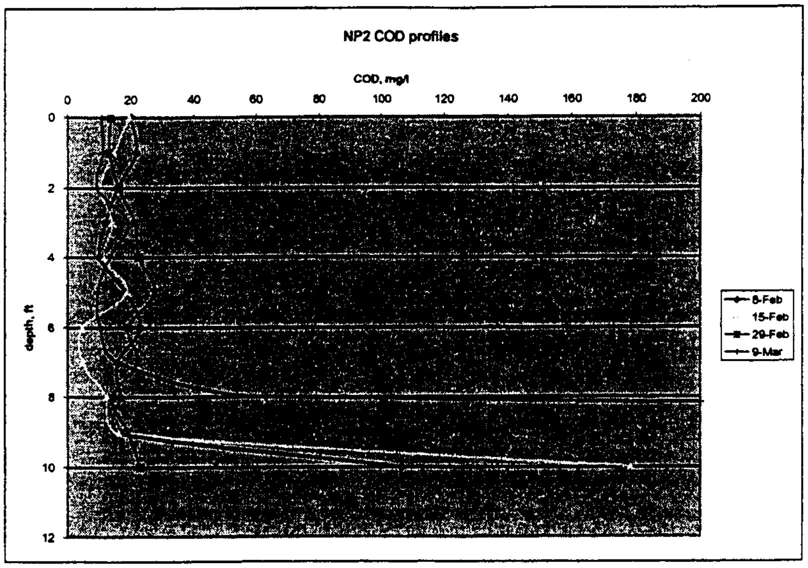
8
10
12
depth, ft
8-Feb
15-Feb
29-Feb
9-Mar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COD, mg/l
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20
40
60
80
100
120
140
160
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200
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2
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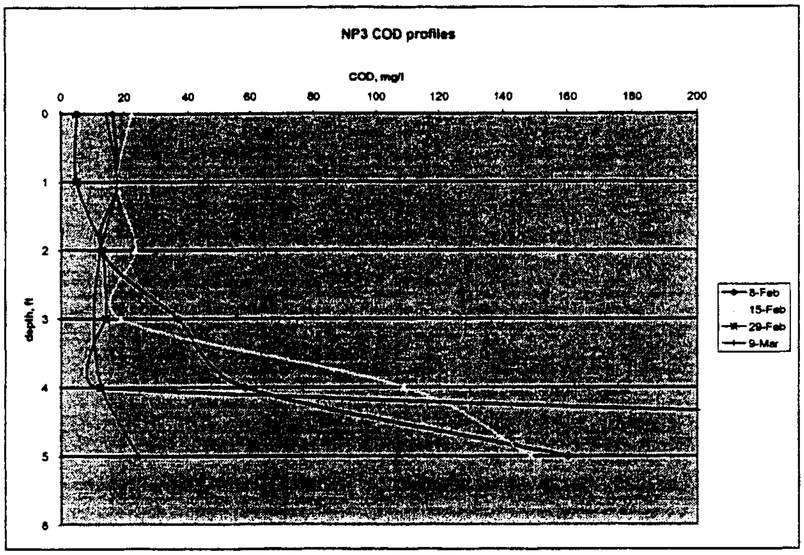
8
10
12
depth, ft
8-Feb
15-Feb
29-Feb
9-Mar


NP3 COD profiles
COD, mg/l
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20
40
60
80
100
120
140
160
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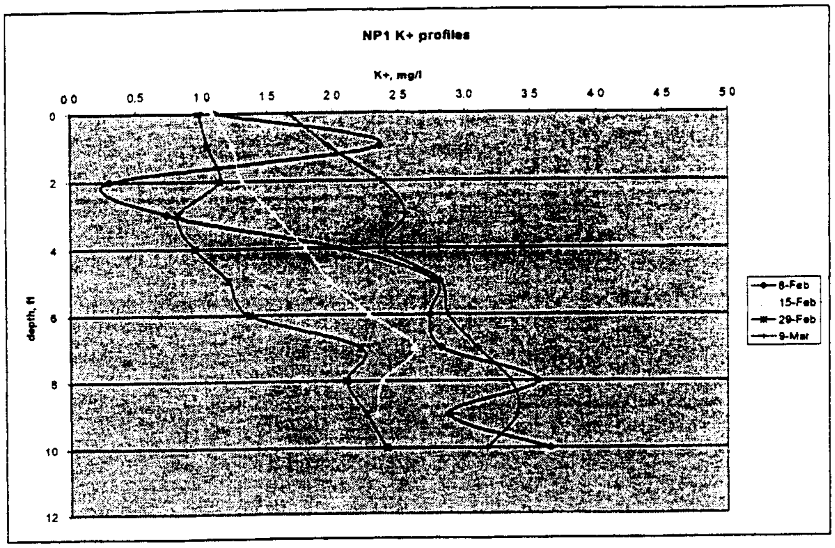
5
6
depth, ft
8-Feb
15-Feb
29-Feb
9-Mar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2.0
2.5
3.0
3.5
4.0
4.5
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8
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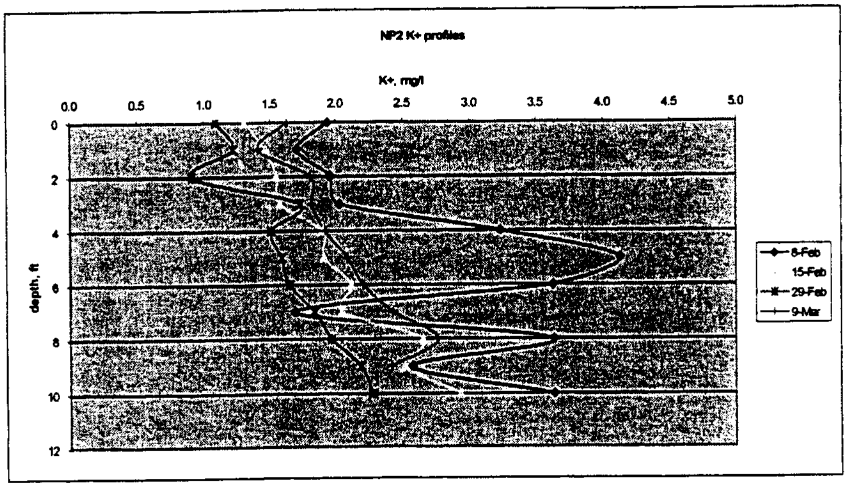
12
8-Feb
15-Feb
29-Feb
9-Mar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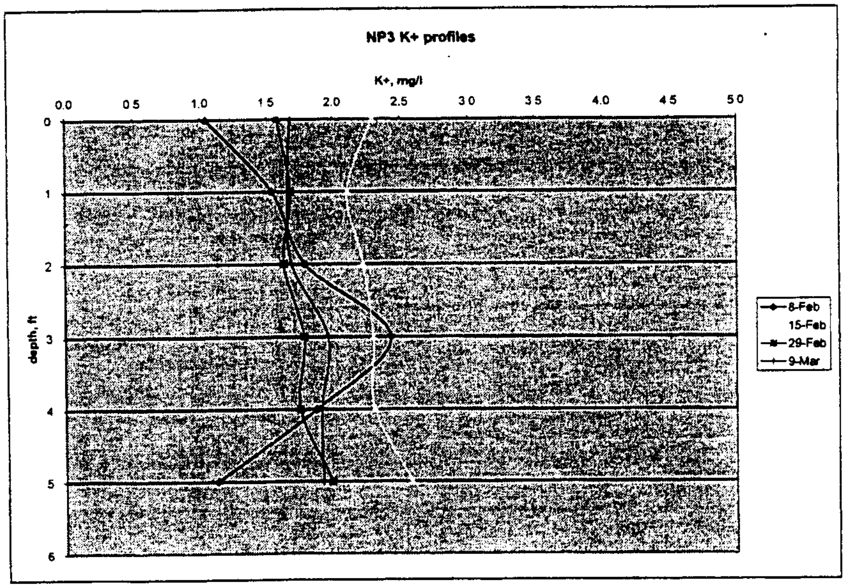
15-Feb
29-Feb
9-Mar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1.5
2.0
2.5
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3.5
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depth, ft
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8-Feb
15-Feb
29-Feb
9-Mar

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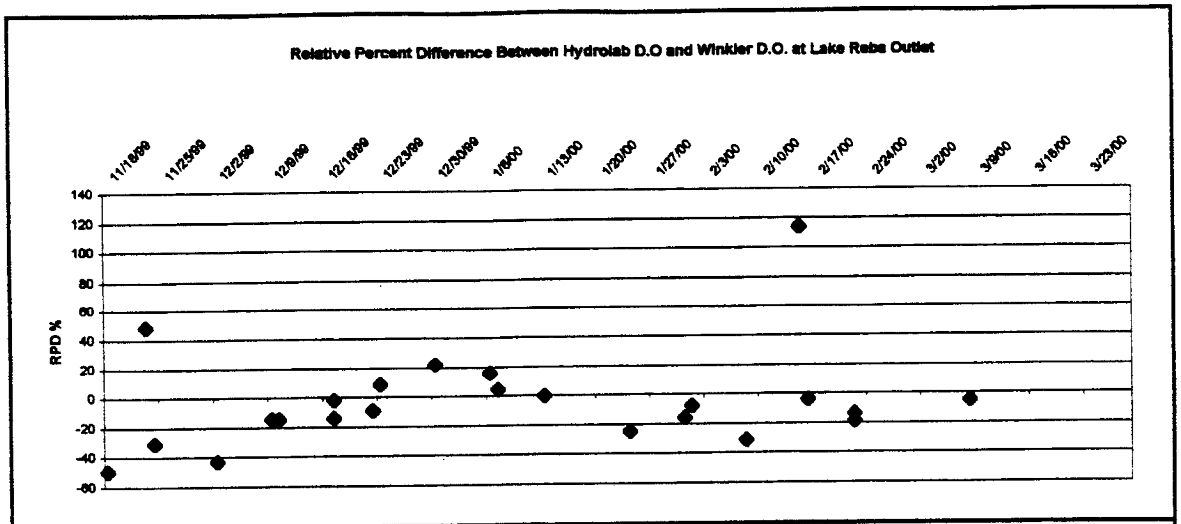
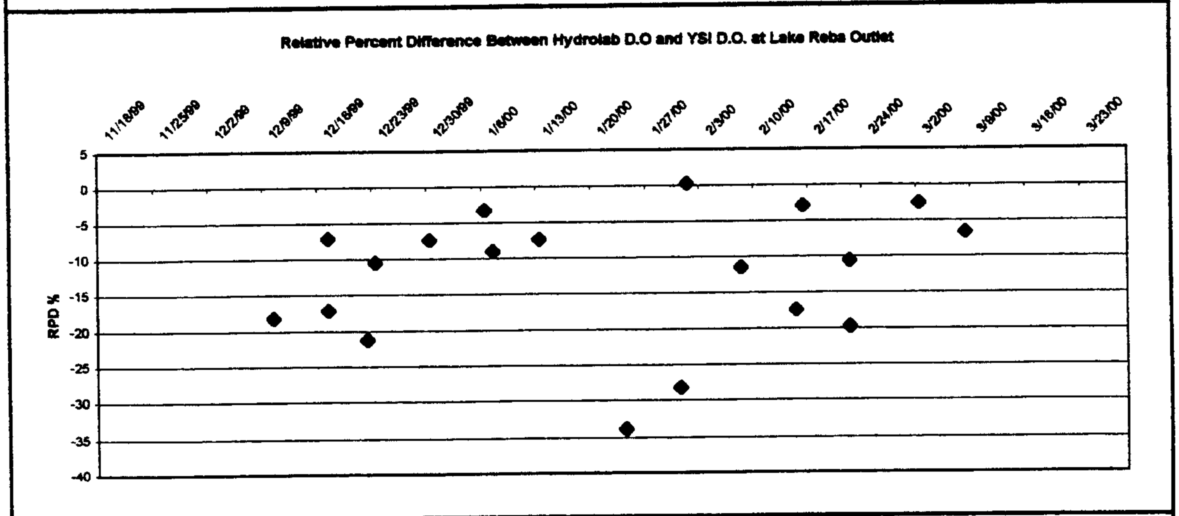
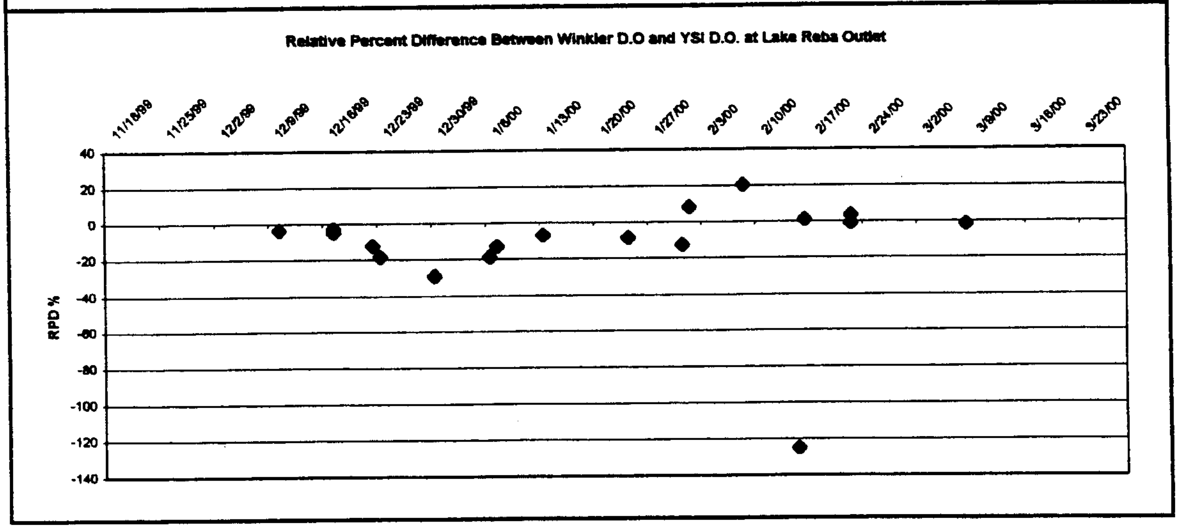
LAKE REBA
D.O. Measurement Relative Percent Differences (RPDs)



Relative Percent Difference Between Hydrolab D.O and Winkler D.O. at Lake Reba Outlet



Relative Percent Difference Between Hydrolab D.O and YSI D.O. at Lake Reba Outlet



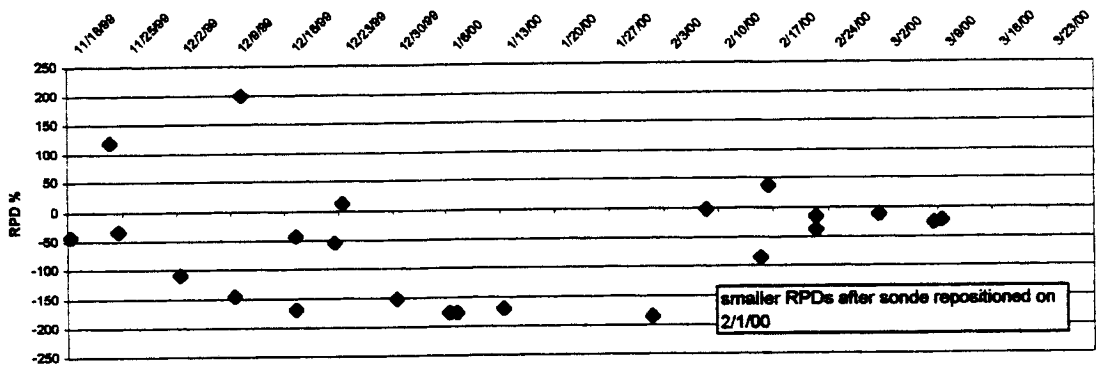
Relative Percent Difference Between Winkler D.O and YSI D.O. at Lake Reba Outlet

Continuous Monitoring QA/QC Results

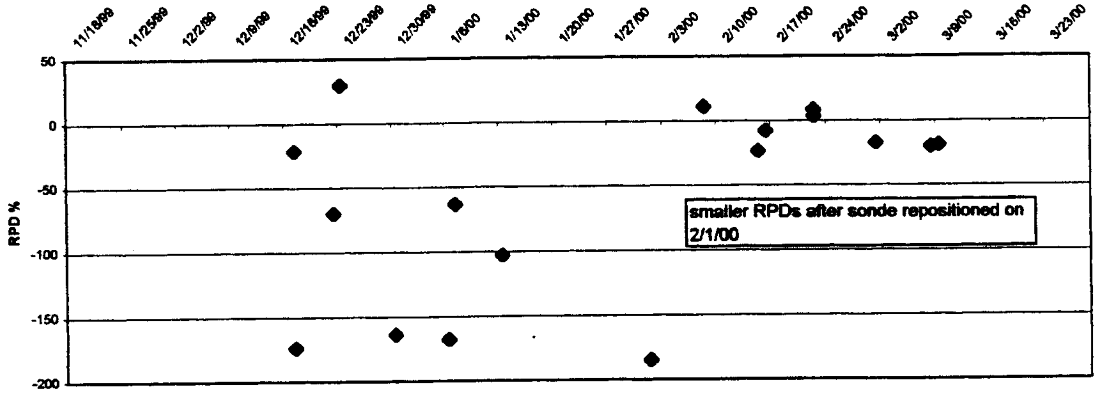
LAKE REBA

Date	Time	Date/Time	Winkler	YSI	Hydro DO	Conductivity	Hydro Cond.	Hydro Time	RPD Hydolab D.O., Winkler D.O.	RPD Hydolab D.O., YSI D.O.	RPD Winkler D.O., YSI D.O.
11/18/99	11:00	11/18/99 11:00	7.52	N/A	4.53	N/A	166.7	1100	-50		
11/23/99	14:45	11/23/99 14:45	3.3	N/A	5.41	231	164.2	1400	48		
11/24/99	11:32	11/24/99 11:32	8.4	N/A	6.15	191.6	206	1200	-31		
12/2/99	11:00	12/2/99 11:00	10.23	N/A	6.6	183(181)	155.4	1100	-43		
12/9/99	10:20	12/9/99 10:20	9.65	N/A	8.34	179	154.9	1000	-15		
12/10/99	11:00	12/10/99 11:00	8.6	8.92	7.43	N/A	161.5	1100	-15	-18	-4
12/17/99	10:30	12/17/99 10:30	6.95	7.15	6.02	202	175.4	1000	-14	-17	-3
12/17/99	16:00	12/17/99 16:00	7.3	7.67	7.14	205	185.3	1700	-2	-7	-5
12/22/99	13:00	12/22/99 13:00	6.3	7.13	5.76	289	260	800	-9	-21	-12
12/23/99	15:10	12/23/99 15:10	5.4	6.52	5.87	307	288	1600	8	-10	-19
12/30/99	13:16	12/30/99 13:16	4.46	5.99	5.56	339	323	1300	22	-7	-29
1/6/00	11:00	1/6/00 11:00	5.87	7.1	6.87	252	235	9:00	16	-3	-19
1/7/00	12:15	1/7/00 12:15	6.09	6.95	6.35	280	268	12:00	4	-9	-13
1/13/00	10:00	1/13/00 10:00	8.42	9.05	8.4	244	232	1000	0	-7	-7
1/13/00	10:30	1/13/00 10:30	NA	NA	NA	230	NA				
1/24/00	12:00	1/24/00 12:00	7.82	8.54	6.07	310	262	1200	-25	-34	-9
1/31/00	12:49	1/31/00 12:49	7.14	8.11	6.1	334	313	1300	-16	-28	-13
2/1/00	12:00	2/1/00 12:00	11	10.13	10.16	107	74.4	1400	-8	0	8
2/8/00	9:30	2/8/00 9:30	12	9.8	8.74	173	146	1000	-31	-11	20
2/15/00	9:30	2/15/00 9:30	2.25	9.77	8.2	210	158	900	114	-17	-125
2/16/00	12:00	2/16/00 12:00	9.67	9.56	9.29	273	236	1500	-4	-3	1
2/22/00	9:30	2/22/00 9:30	8.76	8.47	7.62	291	NA	9:00	-14	-11	3
2/22/00	9:45	2/22/00 9:45	9.7	9.8	8.04	289	254	900	-19	-20	-1
3/1/00	11:30	3/1/00 11:30	9.08	9.7	NA	155					
3/2/00	11:43	3/2/00 11:43	NA	10.07	9.82	NA				-3	
3/8/00	13:10	3/8/00 13:10	10.7	10.87	10.17	304		14:00	-5	-7	-2
3/28/00	13:00	3/28/00 13:00	9.26	10.26	NA	343					

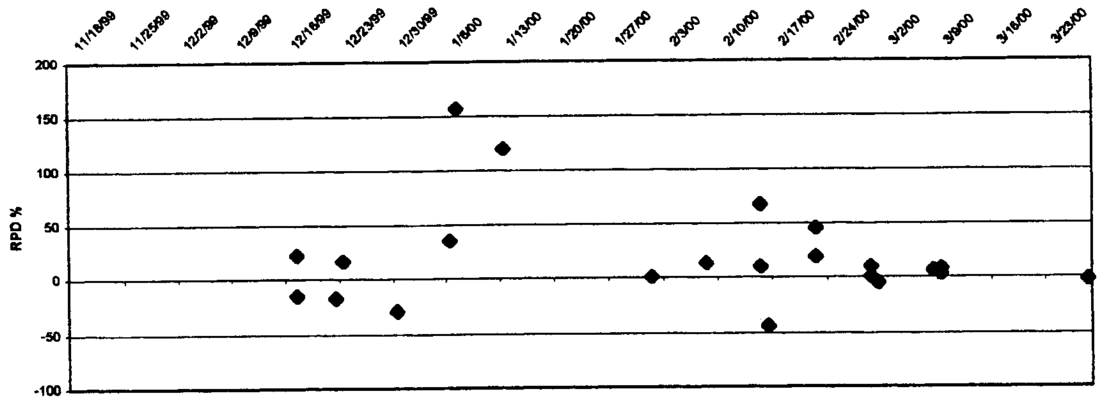
Northwest Pond Cell 1
D.O. Measurement Relative Percent Differences (RPDs)



Relative Percent Difference Between Hydrolab D.O and Winkler D.O. at NWP Cell 1



Relative Percent Difference Between Hydrolab D.O and YSI D.O. at NWP Cell 1



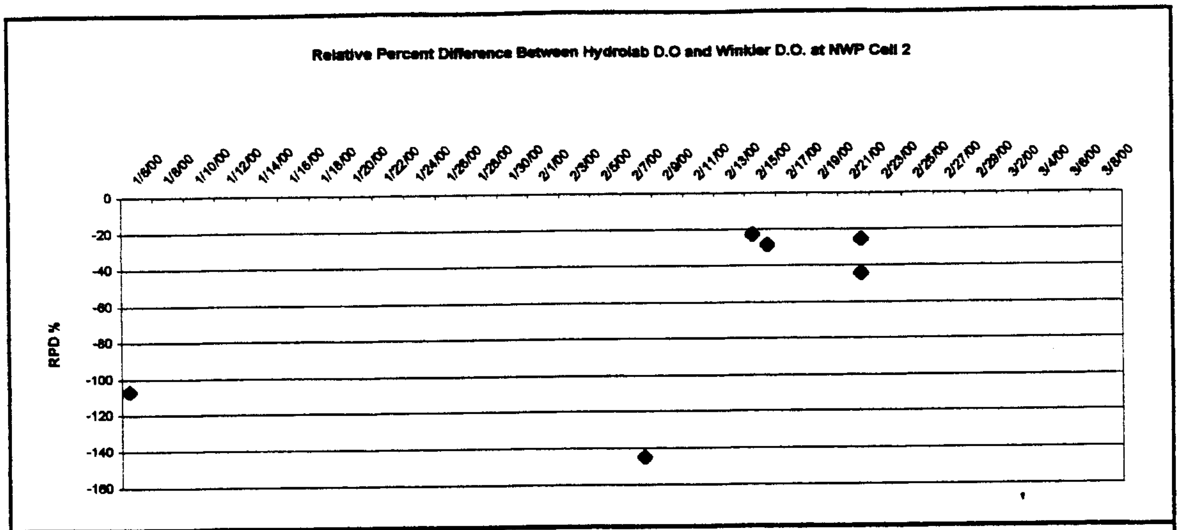
Relative Percent Difference Between Winkler D.O and YSI D.O. at NWP Cell 1

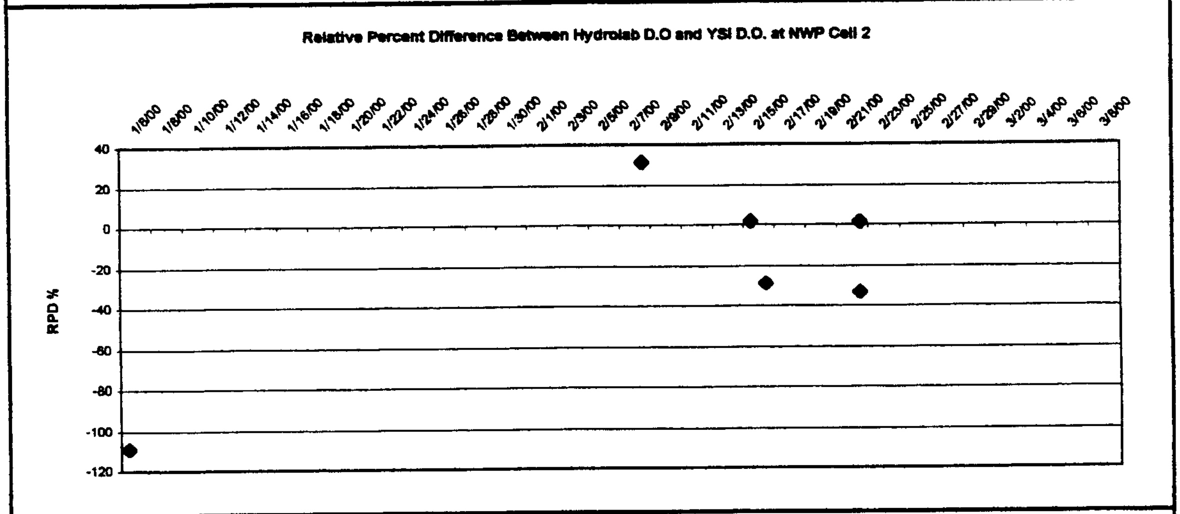
Continuous Monitoring QA/QC Results

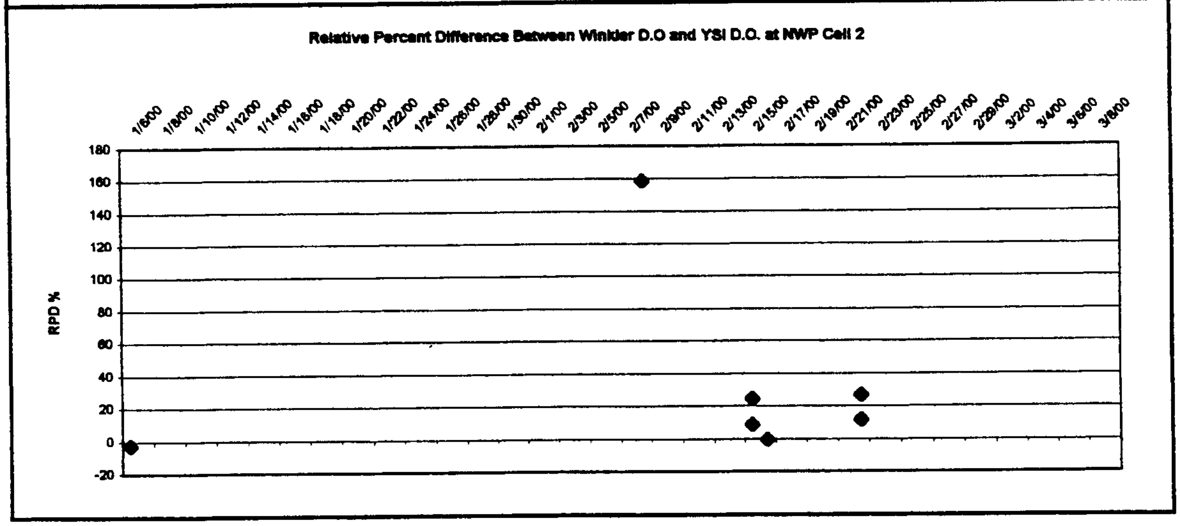
Northwest Pond Cell 1

Date	Time	Date/Time	Winkler	YSI	Hydro DO	Conductivity	Hydro Cond.	Hydro Time	RPD Hydolab D.O., Winkler D.O.	RPD Hydolab D.O., YSI D.O.	RPD Winkler D.O., YSI D.O.
11/18/99	13:00	11/18/99 13:00	6.3	N/A	4.08	N/A	201	1400	-43		
11/23/99	13:30	11/23/99 13:30	0.8	N/A	3.23	174	158	1300	121		
11/24/99	12:30	11/24/99 12:30	6.3	N/A	4.49	186	171	1300	-34		
12/2/99	13:40	12/2/99 13:40	8.04	N/A	2.34	131	140.2	1200	-110		
12/9/99	11:30	12/9/99 11:30	1.48	N/A	0.23	185	203	1100	-146		
12/10/99	12:30	12/10/99 12:30	0	N/A	0.49	N/A	212	1500	200		
12/17/99	11:30	12/17/99 11:30	7.53	8.77	0.62	139	168	1100	-170	-174	-15
12/17/99	15:30	12/17/99 15:30	5.98	4.8	3.88	146	169	1800	-43	-21	22
12/22/99	12:00	12/22/99 12:00	4.36	5.2	2.5	193	208	1200	-54	-70	-18
12/23/99	14:10	12/23/99 14:10	4.23	3.58	4.8	205	208	1600	13	29	17
12/30/99	13:16	12/30/99 13:16	4.46	5.99	0.6	107	243	1300	-153	-164	-29
1/6/00	12:30	1/6/00 12:30	4.71	3.3	0.29	203	241	1200	-177	-168	35
1/7/00	14:00	1/7/00 14:00	6.37	0.77	0.4	181	269	1400	-176	-63	157
1/13/00	12:00	1/13/00 12:00	4.12	1.03	0.33	151	250	1200	-170	-103	120
1/13/00	12:30	1/13/00 12:30	1.91	NA	NA	176	NA	NA			
1/24/00	12:10	1/24/00 12:10	2.11	1.49	NA	210	248	NA			
1/31/00	11:53	1/31/00 11:53	1.2	0.71	NA	232	248	NA			
2/1/00	12:00	2/1/00 12:00	9.52	9.45	0.37	93.4	246	1400	-185	-185	1
2/8/00	12:35	2/8/00 12:35	11.5	10.07	11.21	83.8	18	1300	-3	11	13
2/15/00	14:00	2/15/00 14:00	10.2	5.08	4.02	137	201	1200	-87	-23	67
2/15/00	14:00	2/15/00 14:00	2.22	2.01	NA	233	NA	NA			10
2/16/00	13:30	2/16/00 13:30	4.75	7.43	6.87	181	192	1500	36	-8	-44
2/22/00	11:50	2/22/00 11:50	6.49	5.38	5.56	213	226	11:00	-15	3	19
2/22/00	12:00	2/22/00 12:00	9.22	5.8	6.29	195	224	16:00	-38	8	46
2/29/00	14:10	2/29/00 14:10	9.67	8.76	NA	102	NA	NA			10
2/29/00	14:10	2/29/00 14:10	1.91	1.9	NA	202	NA	NA			1
3/1/00	15:21	3/1/00 15:21	9.01	9.51	7.99	146	NA	16:00	-12	-17	-5
3/8/00	12:00	3/8/00 12:00	8.88	8.32	6.8	191	NA	11:00	-27	-20	7
3/9/00	14:01	3/9/00 14:01	6.69	6.5	5.4	200	NA	14:00	-21	-18	3
3/9/00	14:01	3/9/00 14:01	0.13	0.12	NA	270	NA	NA			8
3/28/00	14:20	3/28/00 14:20	6.1	6.23	NA	220	NA	NA			-2

Northwest Pond Cell 2
D.O. Measurement Relative Percent Differences (RPDs)


Relative Percent Difference Between Hydrolab D.O and Winkler D.O. at NWP Cell 2


Relative Percent Difference Between Hydrolab D.O and YSI D.O. at NWP Cell 2


Relative Percent Difference Between Winkler D.O and YSI D.O. at NWP Cell 2

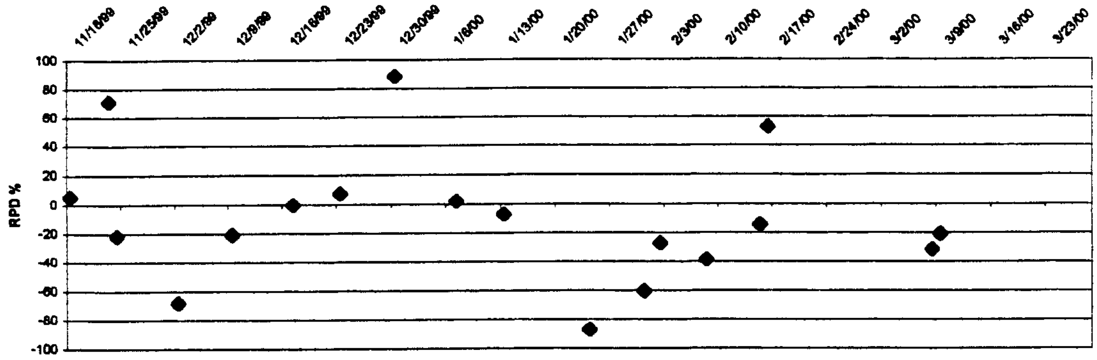
Continuous Monitoring QA/QC Results

Northwest Pond Cell 2

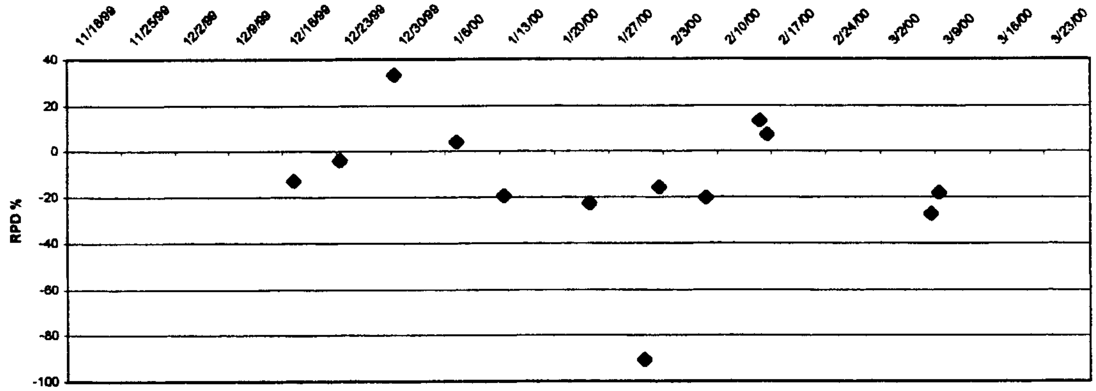
Date	Time	Date/Time	Winkler	YSI	Hydro DO	Conductivity	Hydro Cond.	Hydro Time	RPD Hydolab D.O., Winkler D.O.	RPD Hydolab D.O., YSI D.O.	RPD Winkler D.O., YSI D.O.
1/6/00	12:00	1/6/00 12:00	3.57	3.67	1.08	165	193	12:00	-107	-109	-3
1/7/00			NO HYDROLAB DEPLOYED								
1/13/00											
1/24/00											
1/31/00											
2/1/00	12:30	2/1/00 12:30	N/A	1.36	N/A	147		N/A			
2/8/00	12:30	2/8/00 12:30	9.47	1.1	1.51	126	N/A	1200	-145	31	158
2/15/00	13:30	2/15/00 13:30	6.81	5.33	5.42	152	N/A	1100	-23	2	24
2/15/00	13:30	2/15/00 13:30	0.97	0.89	NA	215	NA	NA			9
2/16/00	13:20	2/16/00 13:20	7.43	7.45	5.57	145	N/A	1500	-29	-29	0
2/22/00	11:39	2/22/00 11:39	6.14	4.7	4.76	188	NA	11:00	-25	1	27
2/22/00	12:00	2/22/00 12:00	6.58	5.85	4.18	194	NA	14:00	-45	-33	12
2/29/00	13:45	2/29/00 13:45	8.75	8.86	NA	123	NA	NA			
2/29/00	13:45	2/29/00 13:45	1.77	1.8	NA	199	NA	NA			
3/9/00	13:10	3/9/00 13:10	8.5	8:38	NA	176	NA	NA			
3/9/00	13:10	3/9/00 13:10	0.1	0.09	NA	256	NA	NA			

Northwest Pond Cell 3
D.O. Measurement Relative Percent Differences (RPDs)

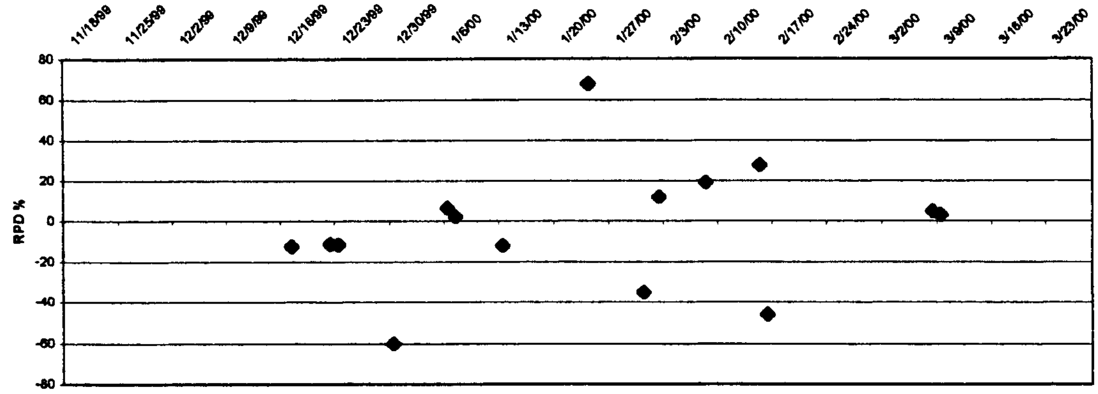
Relative Percent Difference Between Hydrolab D.O and Winkler D.O. at NWP Cell 3



Relative Percent Difference Between Hydrolab D.O and YSI D.O. at NWP Cell 3



Relative Percent Difference Between Winkler D.O and YSI D.O. at NWP Cell 3



Continuous Monitoring QA/QC Results

Northwest Pond Cell 3

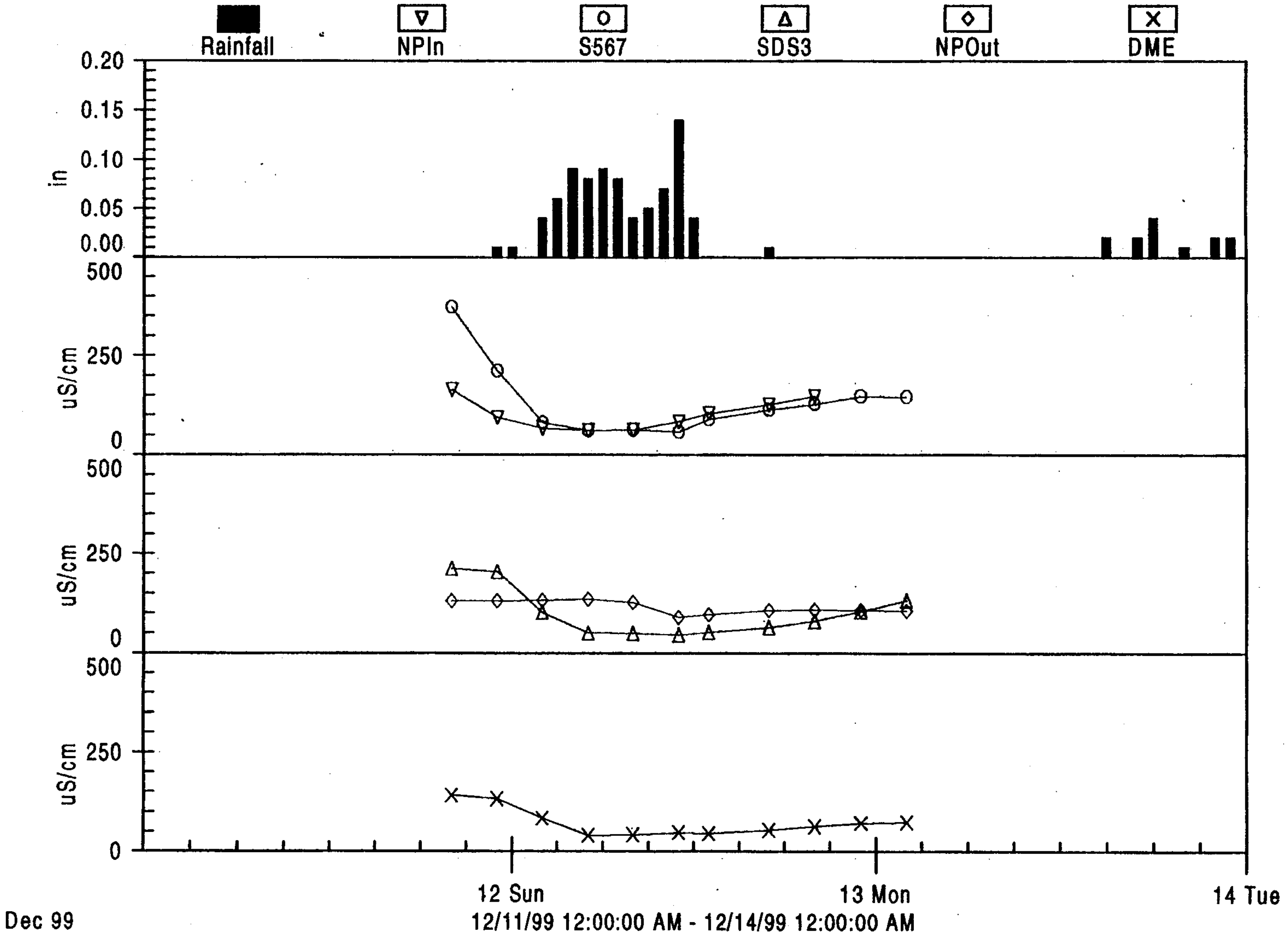
Date	Time	Date/Time	Winkler	YSI	Hydro DO	Conductivity	Hydro Cond.	Hydro Time	RPD Hydolab D.O., Winkler D.O.	RPD Hydolab D.O., YSI D.O.	RPD Winkler D.O., YSI D.O.
11/18/99	12:00	11/18/99 12:00	2.73	N/A	2.88	N/A	105.5	1200	5		
11/23/99	13:00	11/23/99 13:00	1.59	N/A	3.35	141.1	114.4	1200	71		
11/24/99	12:20	11/24/99 12:20	4.5	N/A	3.61	138.3	118.9	1300	-22		
12/2/99	13:10	12/2/99 13:10	11.68	N/A	5.74	87.6	103.5	1100	-68		
12/9/99	11:00	12/9/99 11:00	5.45	N/A	4.41	123.9	106.6	1000	-21		
12/10/99	12:05	12/10/99 12:05	5.14	5.1	N/A	N/A	N/A	N/A			
12/17/99	12:00	12/17/99 12:00	N/A	N/A	N/A	N/A	N/A	N/A			
12/17/99	15:05	12/17/99 15:05	6.01	6.8	5.98	94	76.2	1500	-1	-13	-12
12/22/99	11:00	12/22/99 11:00	4.11	4.6	N/A	133	N/A	N/A			-11
12/23/99	13:40	12/23/99 13:40	3.39	3.8	3.65	140	207	1400	7	-4	-11
12/30/99	12:00	12/30/99 12:00	1.21	2.25	3.14	225	209	1100	89	33	-60
1/6/00	11:30	1/6/00 11:30	5.93	5.56	N/A	108	N/A	N/A			6
1/7/00	14:20	1/7/00 14:20	4.78	4.68	4.87	131	125.7	1500	2	4	2
1/13/00	11:18	1/13/00 11:18	4.52	5.1	4.2	185	145.4	1100	-7	-19	-12
1/13/00	11:30	1/13/00 11:30	2.29	3.1		161					
1/24/00	14:11	1/24/00 14:11	7.82	3.86	3.07	310	156	1500	-87	-23	68
1/31/00	11:00	1/31/00 11:00	0.99	1.41	0.53	195	197	1100	-61	-91	-35
2/1/00	12:00	2/1/00 12:00	NA	NA	8.43		92	1400			
2/2/00	12:00	2/2/00 12:00	8.43	7.49	6.4	81.2	97.2	1300	-27	-16	12
2/8/00	12:18	2/8/00 12:18	7.39	6.11	4.99	113	110.3	1100	-39	-20	19
2/15/00	13:00	2/15/00 13:00	7.63	5.77	6.59	131	138.4	1500	-15	13	28
2/16/00	13:05	2/16/00 13:05	3.84	6.13	6.59	129	NA	1500	53	7	-46
2/22/00	11:00	2/22/00 11:00	5.90	4.3	NA	174	NA	NA			
2/22/00	12:00	2/22/00 12:00	5.87	5.45	NA	172	NA	NA			
2/29/00	12:15	2/29/00 12:15	8.92	9.11	N/A	79.2	NA	NA			
3/1/00	15:04	3/1/00 15:04	7.78	7.12	NA	111	NA	NA			
3/8/00	11:20	3/8/00 11:20	7.81	7.45	5.67	140	NA	1200	-32	-27	5
3/9/00	12:30	3/9/00 12:30	7.36	7.13	5.95	152	NA	1200	-21	-18	3
3/28/00	14:00	3/28/00 14:00	6.79	6.73	NA	173	NA	NA			

4 APPENDIX C PLOTS OF TRACERS FOR EACH MONITORING LOCATION

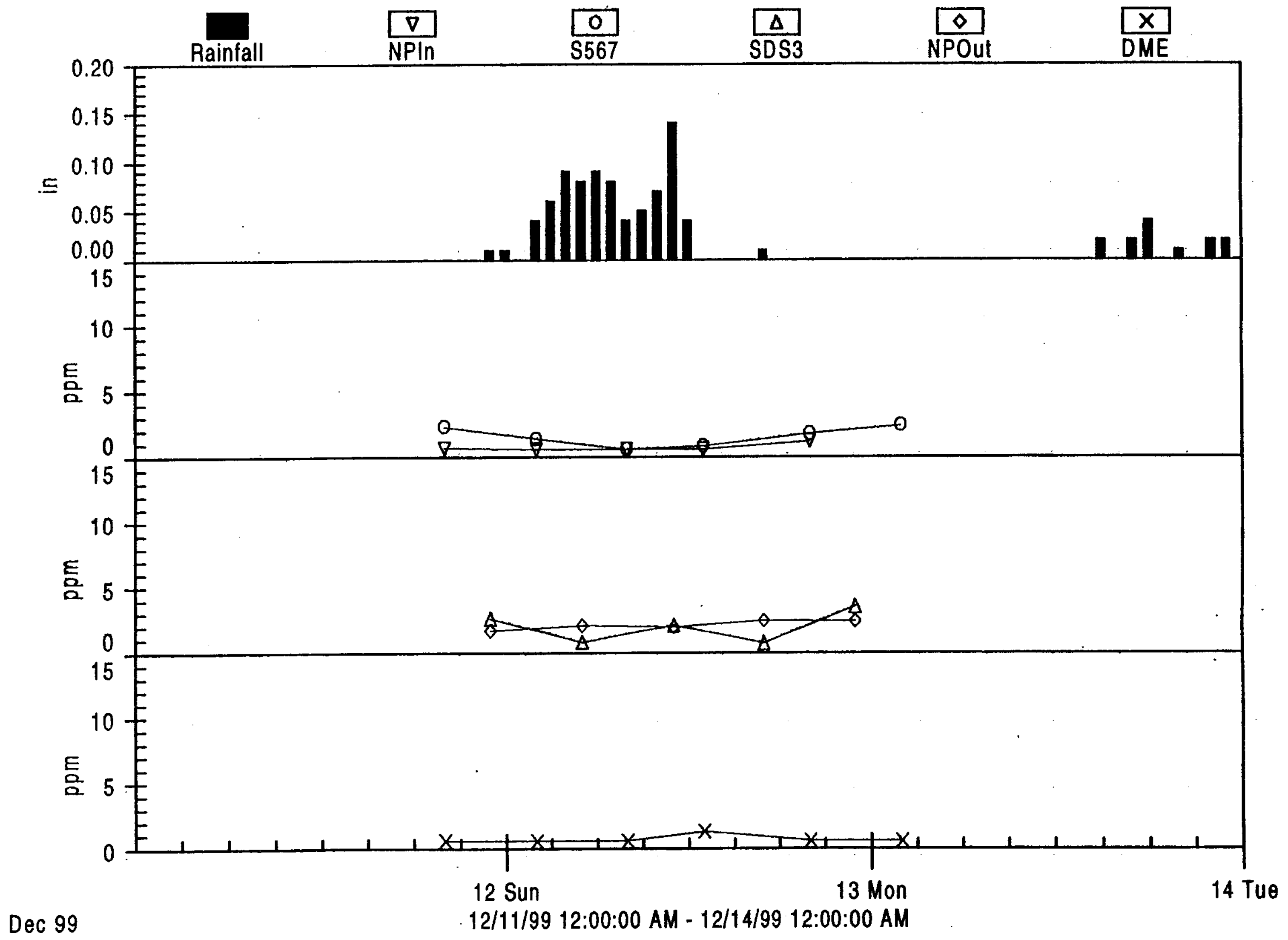
4.1 Introduction

This appendix contains four families of figures:

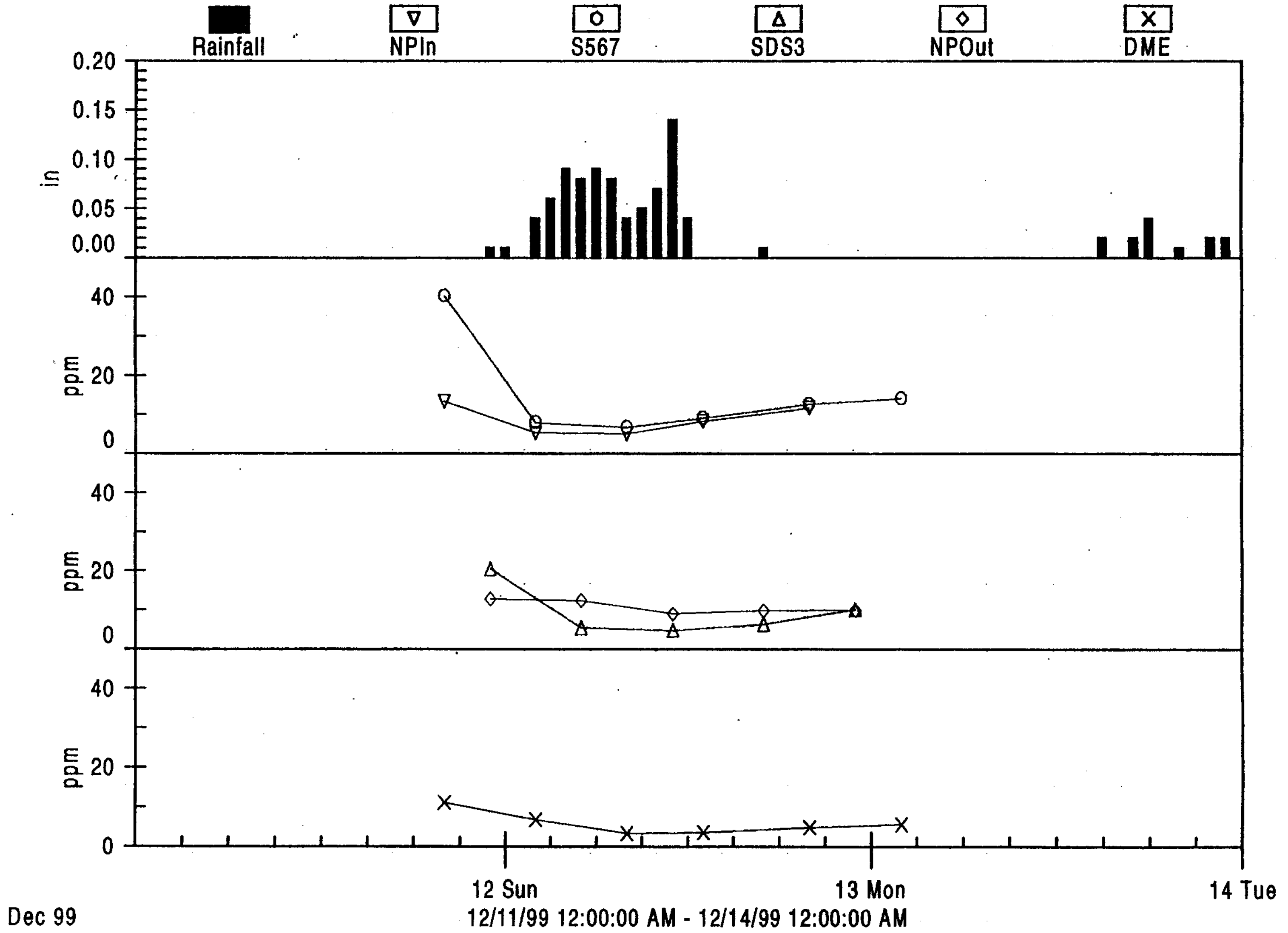
1) Background event (December 11-12, 1999) rainfall, conductivity and tracer ion concentrations for sampling stations in Des Moines and Miller Creek watersheds (several examples of these plots appear in Volume 1, Section 3 in Figures 3-10 through 3-12),
2) Deicing event (all three events in the period January 12-27, 2000) conductivity and corresponding chemical applications (CMA and SA)for sampling stations for both creeks,
3) Deicing event rainfall, water level, tracer ion concentration and corresponding chemical applications for the Lake Reba outlet (Miller Creek).
4) Tracer ion concentrations, chemical presence signal periods and chemical applications corresponding to each station sampled during the three deicing events (January 12-27, 2000).



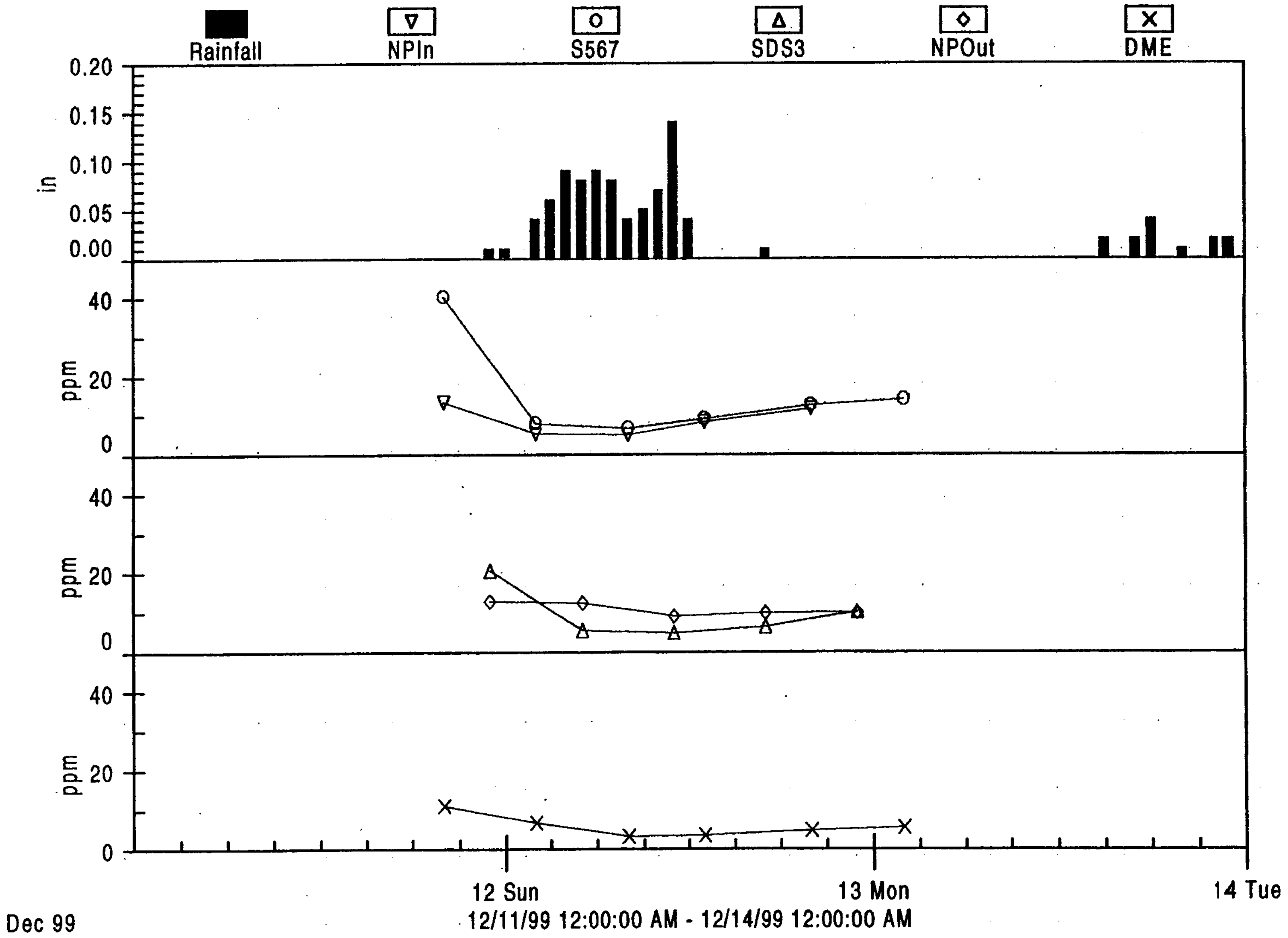
Des Moines Creek Watershed
Sp Cond (uS/cm) During Background Event



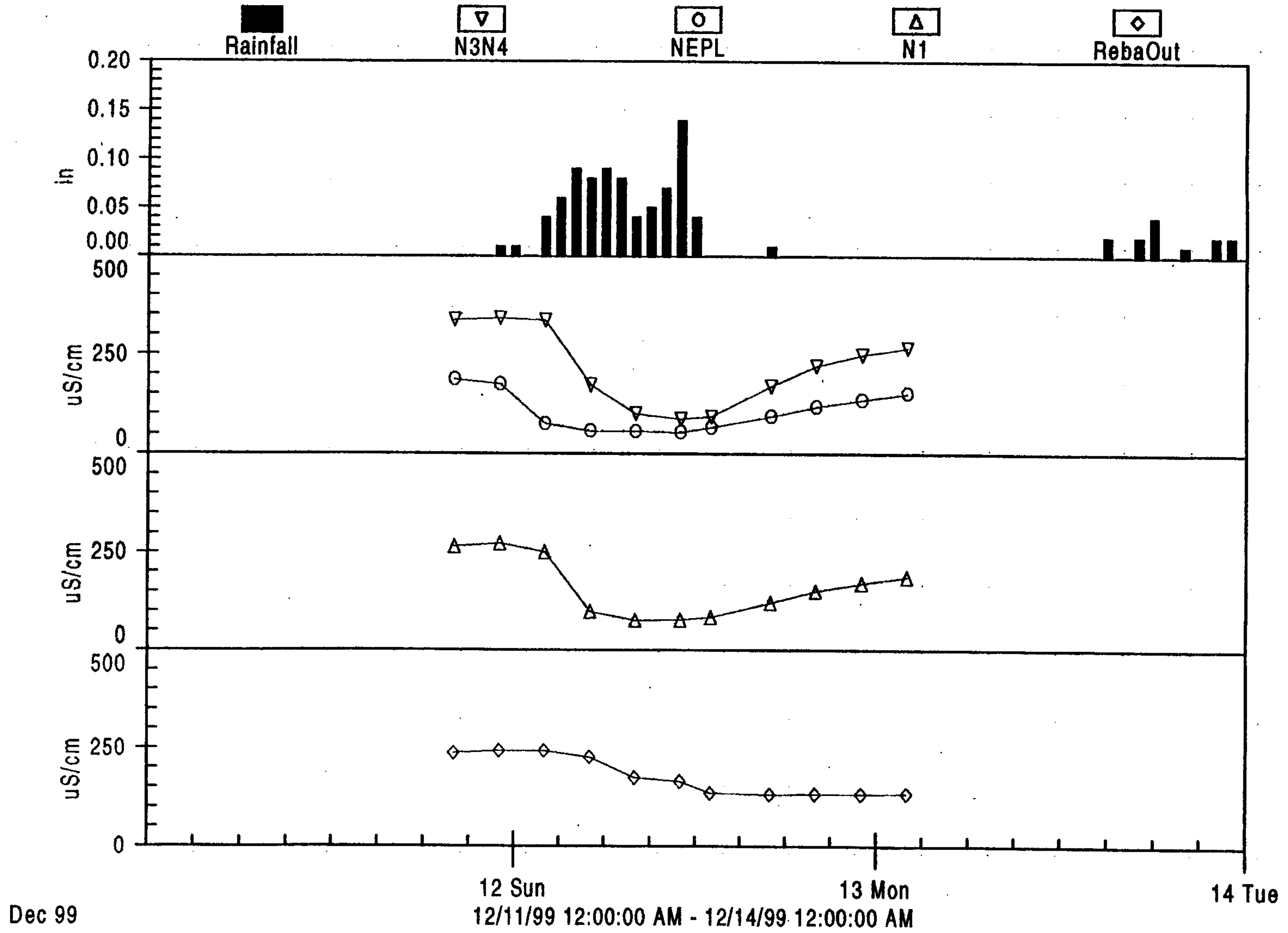
Des Moines Creek Watershed
Potassium (ppm) During Background Event



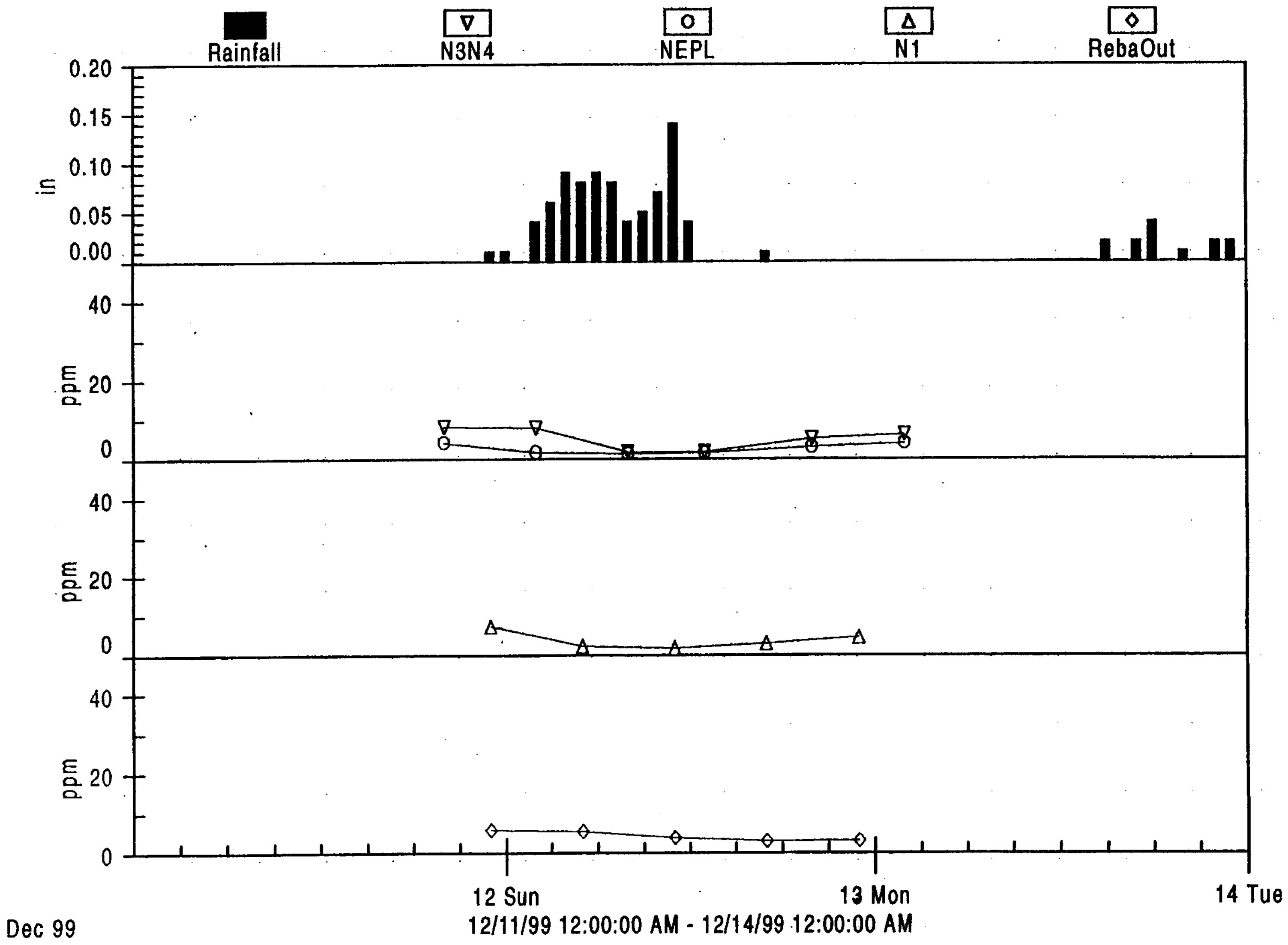
Des Moines Creek Watershed
Calcium (ppm) During Background Event



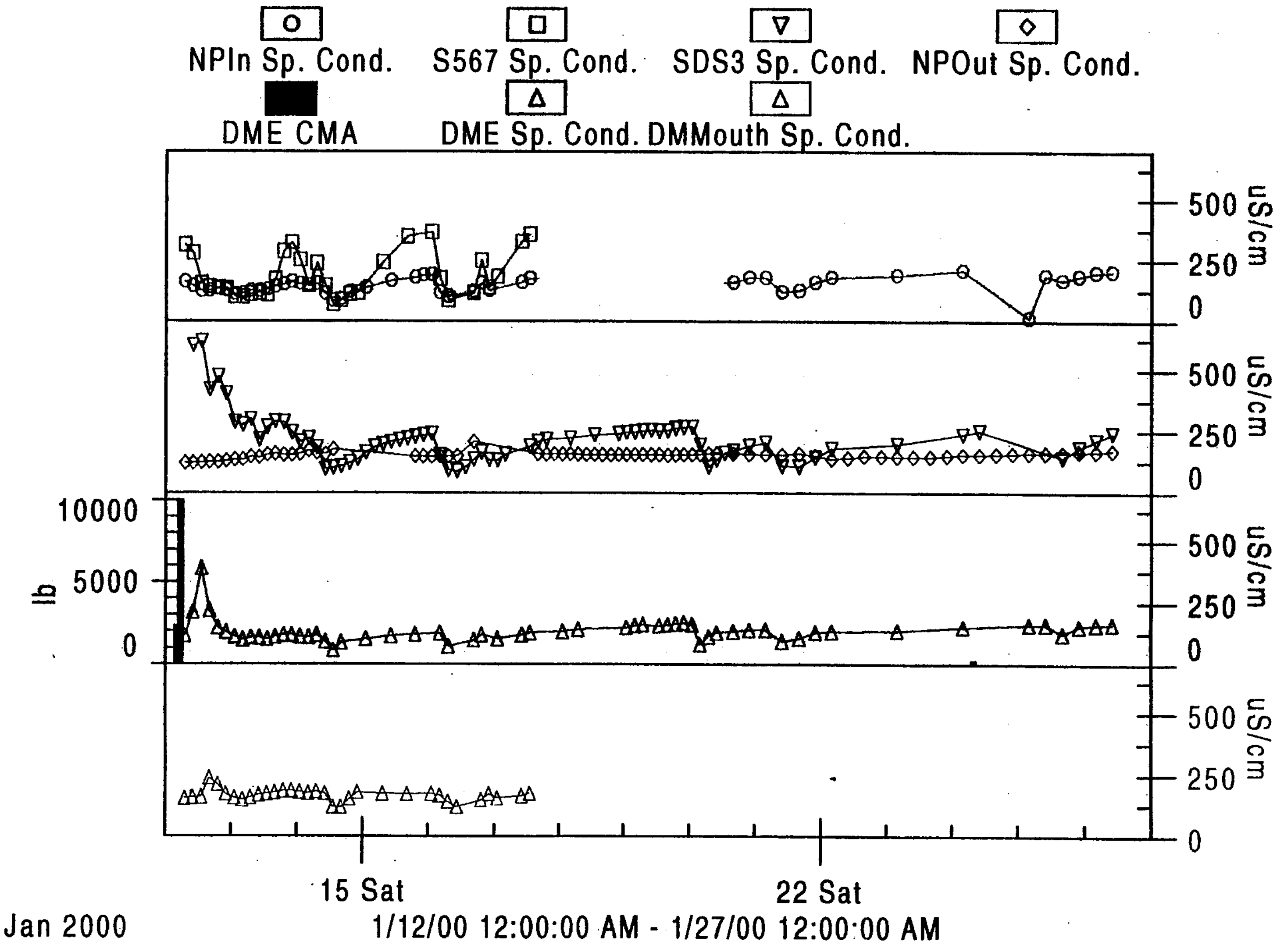
Des Moines Creek Watershed
Sodium (ppm) During Background Event



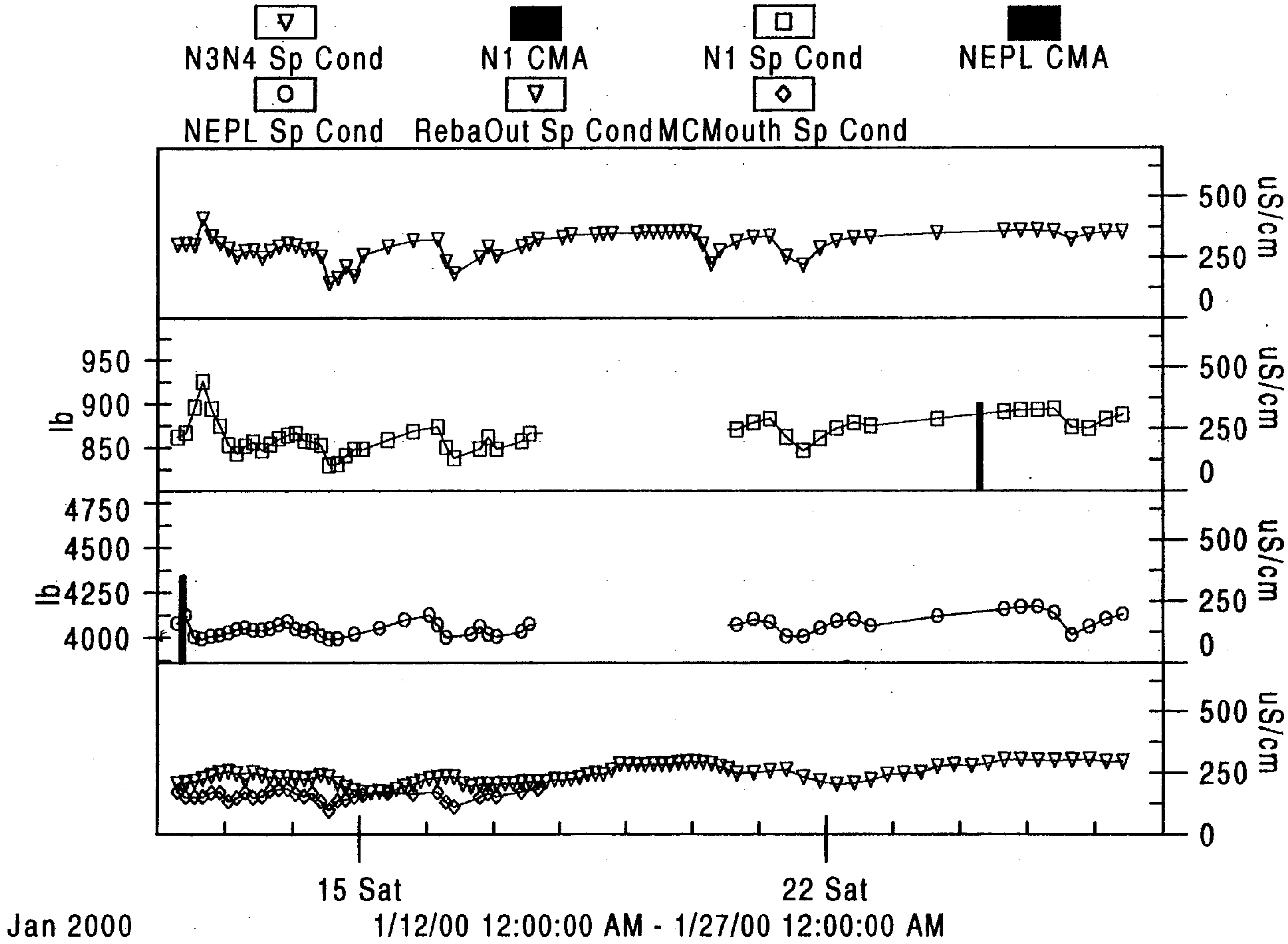
Miller Creek Watershed
Sp Cond (uS/cm) During Background Event



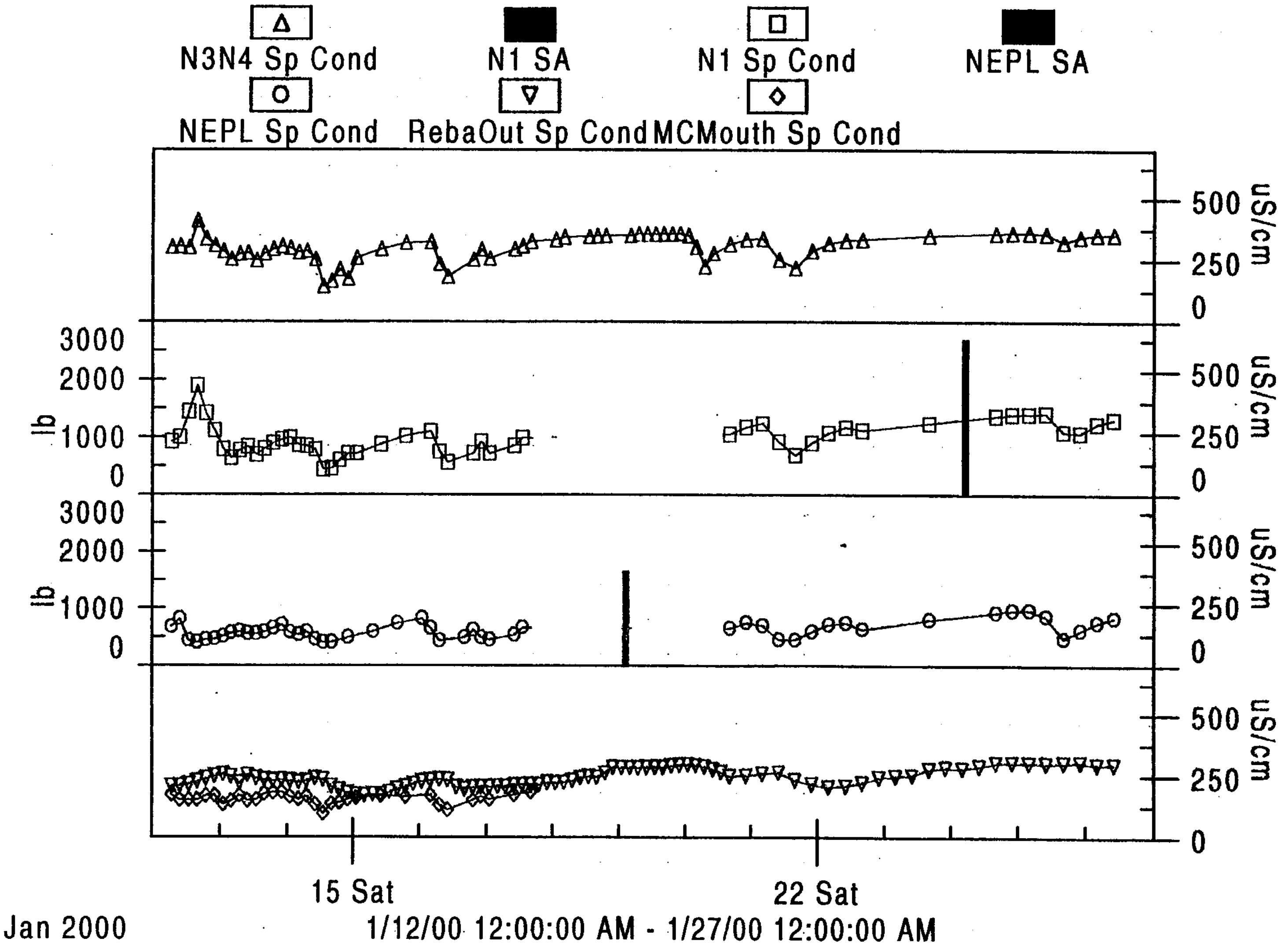
Miller Creek Watershed
Sodium (ppm) During Background Event



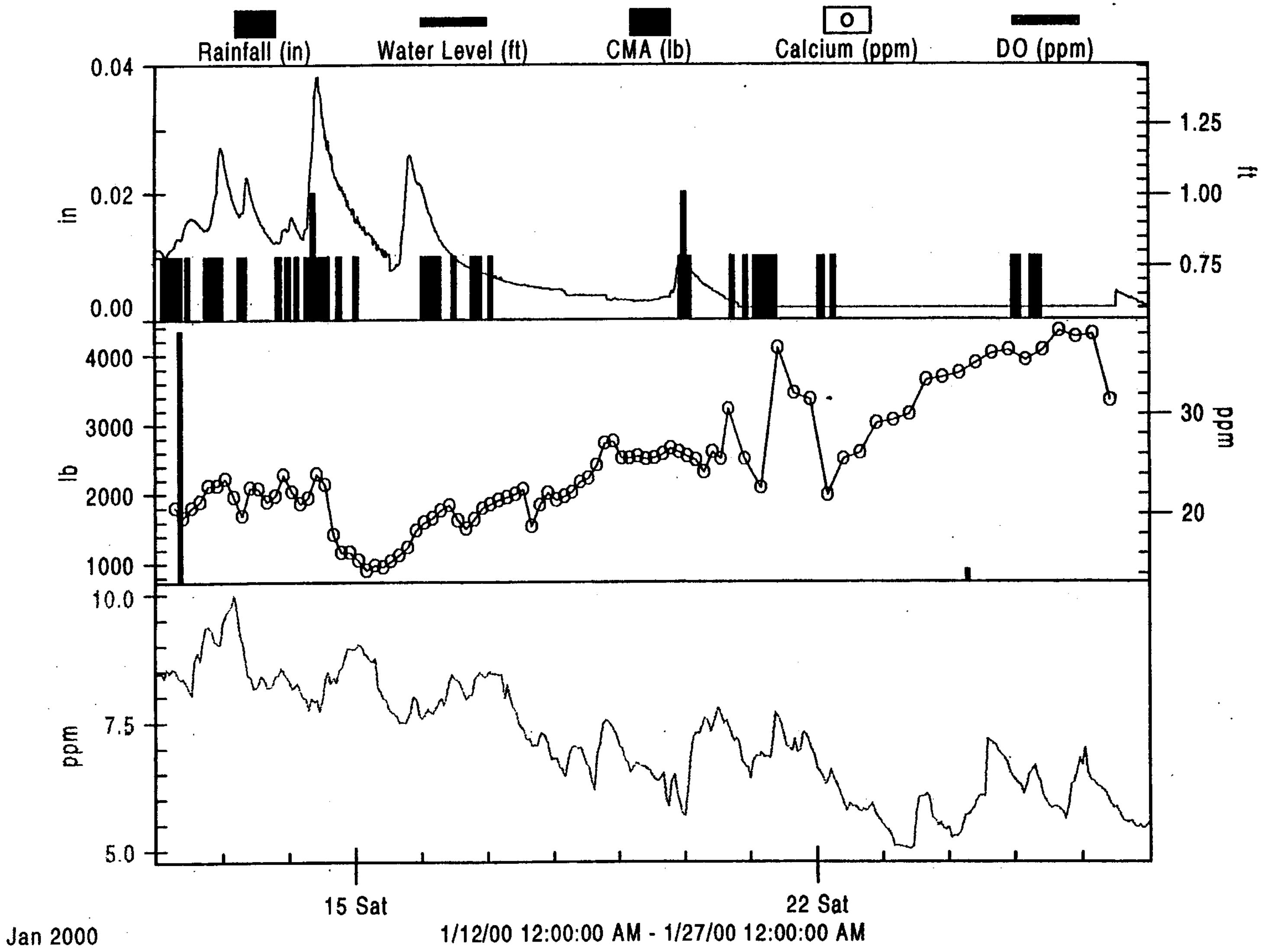
Des Moines Creek Watershed
Ca-Mg Acetate (CA) Application (lb)



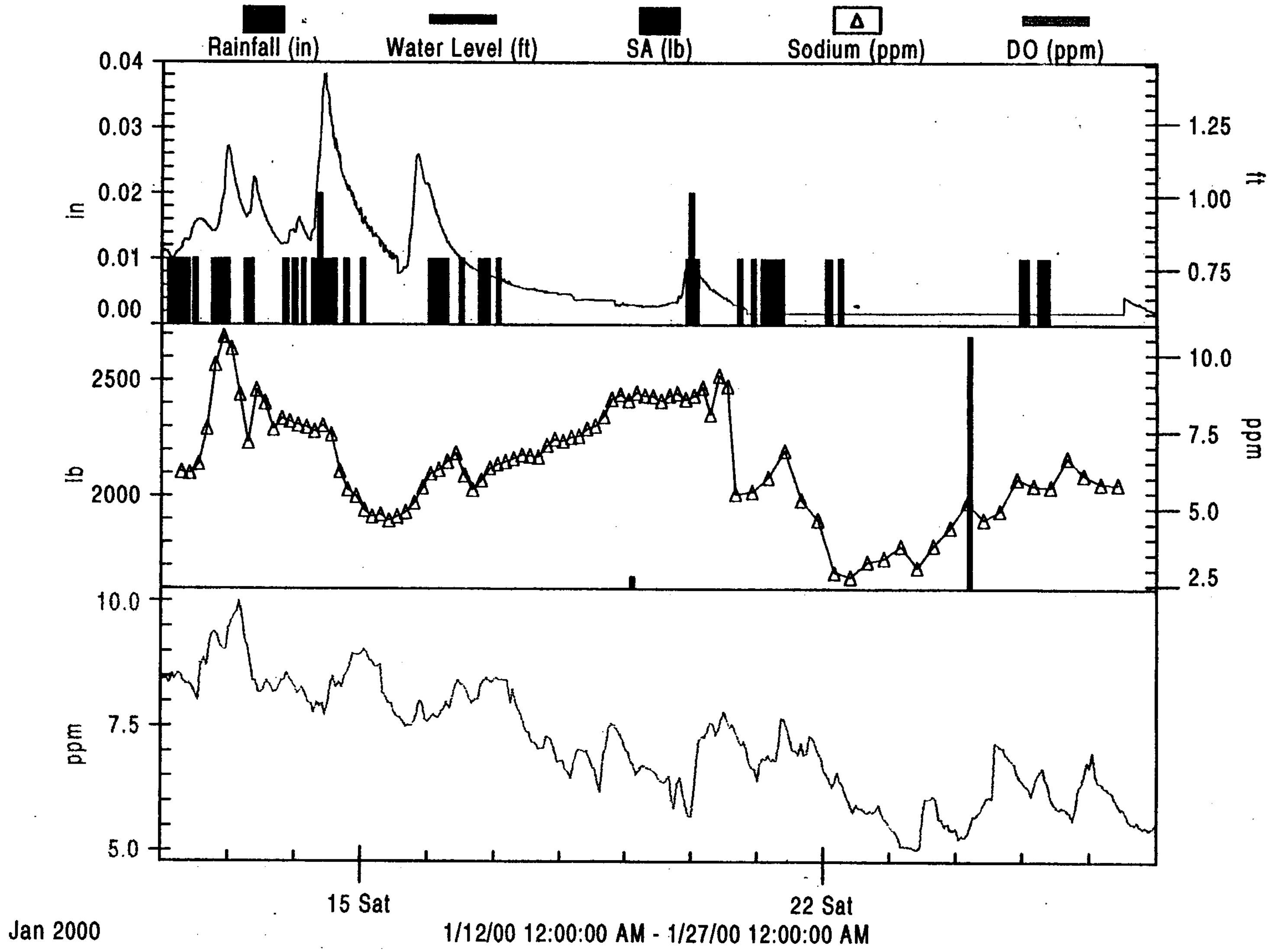
Miller Creek Watershed
Ca-Mg Acetate (CMA) Application (lb)



Miller Creek Watershed
Sodium Acetate (SA) Application (lb)

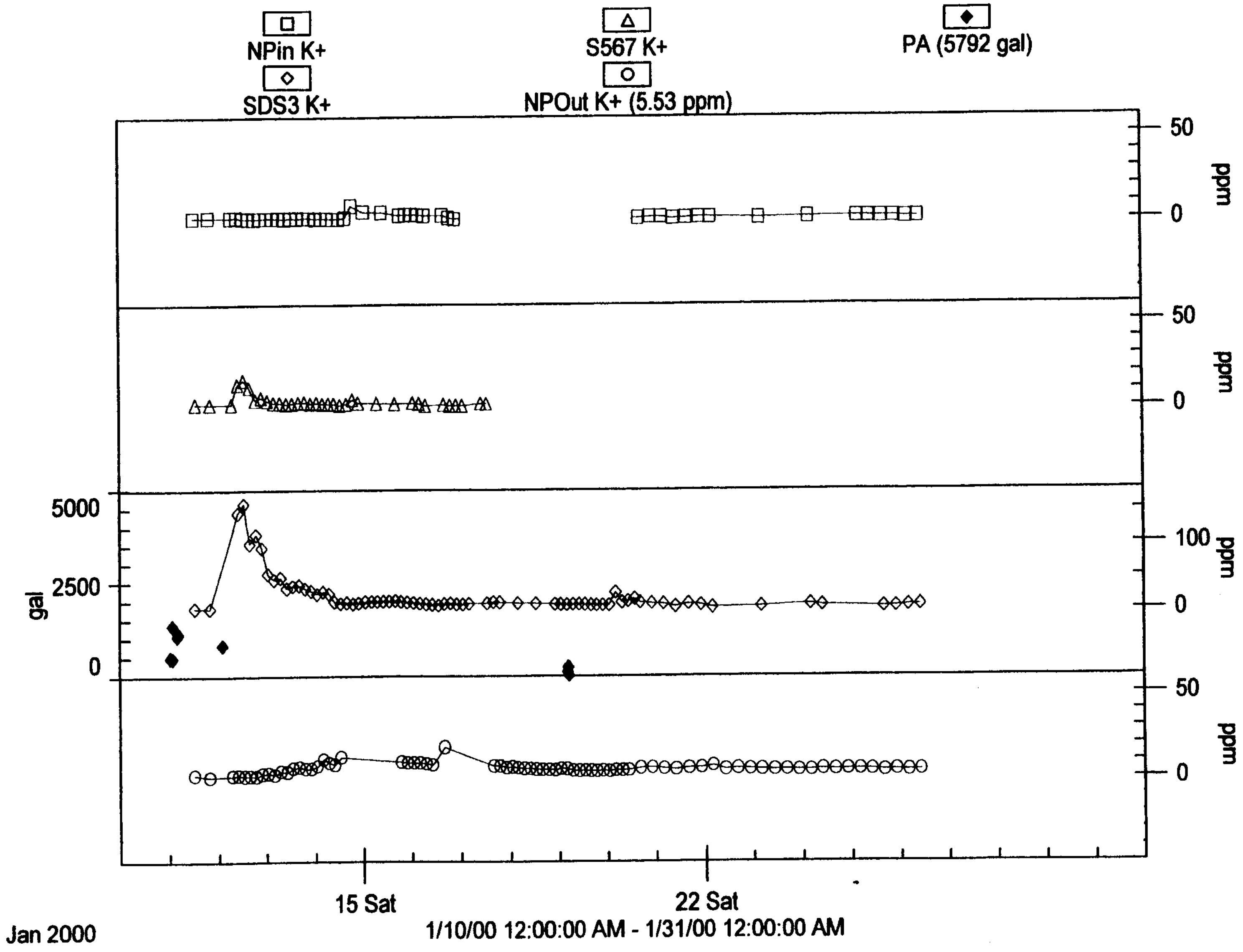


Lake Reba Outlet (RebaOut)
Calcium Levels After CMA Applications

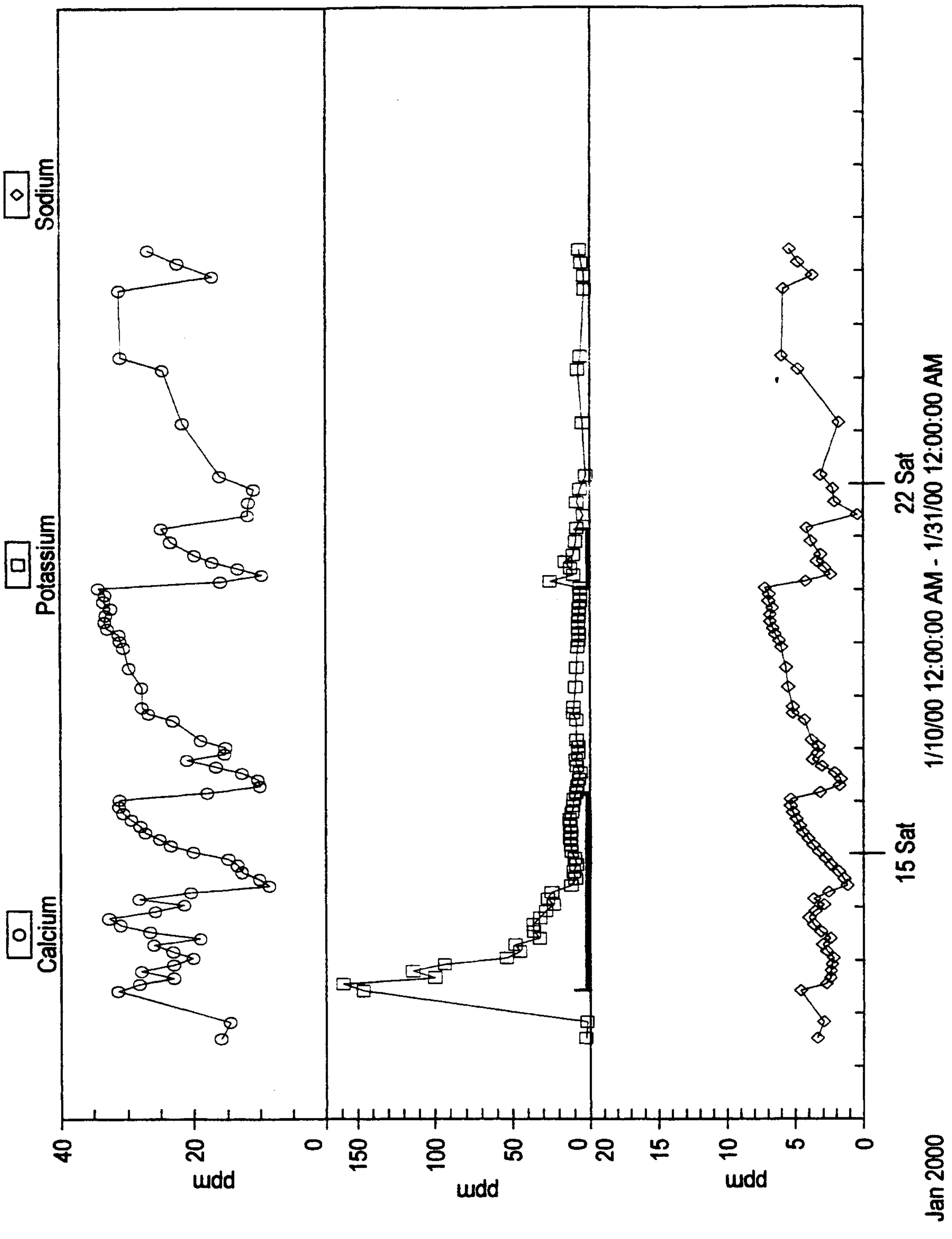


Lake Reba Outlet (RebaOut)
Sodium Levels After SA Applications

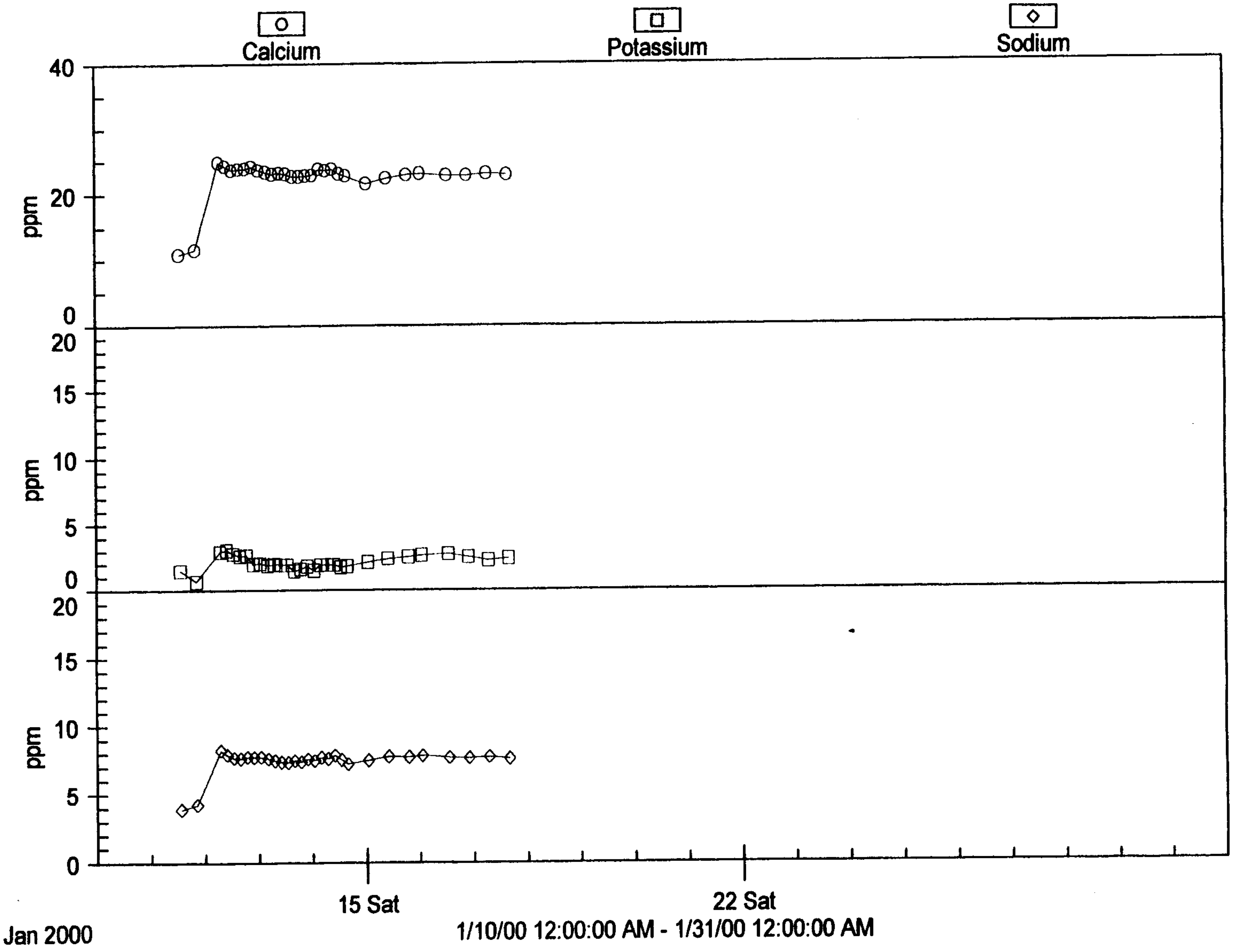
Potassium - Northwest Ponds Basin



SDS3 Tracers



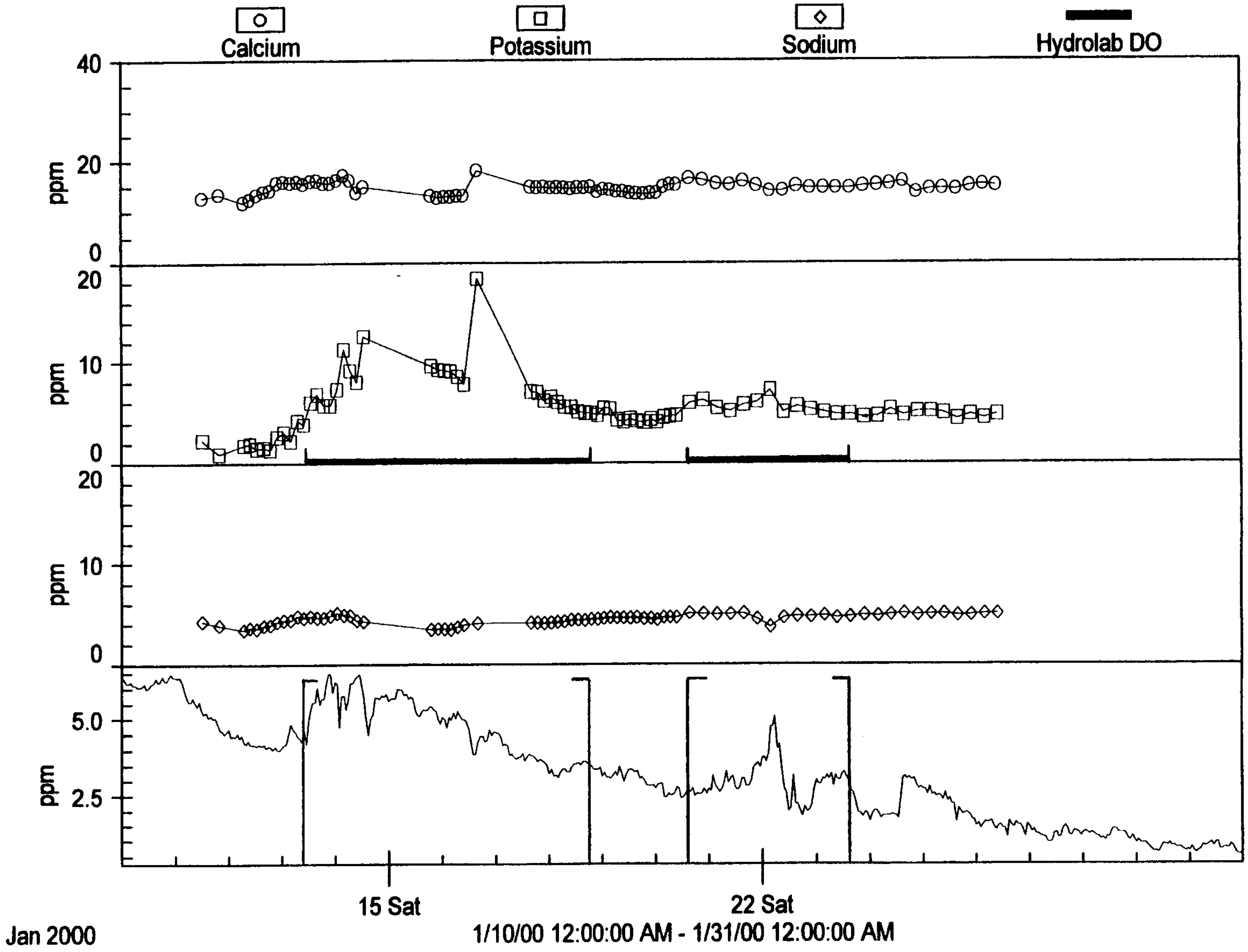
NP1Tracers


Calcium
Potassium
Sodium
40
20
0
ppm
20
15
10
5
0
ppm
20
15
10
5
0
ppm
15 Sat
22 Sat
Jan 2000
1/10/00 12:00:00 AM - 1/31/00 12:00:00 AM

NP1

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	N	N	N
Background Range (ppm)	10.9 - 24.9	0.6 - 3.0	3.9 - 8.3
Number of Signals	0	0	0
First Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-
Second Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-

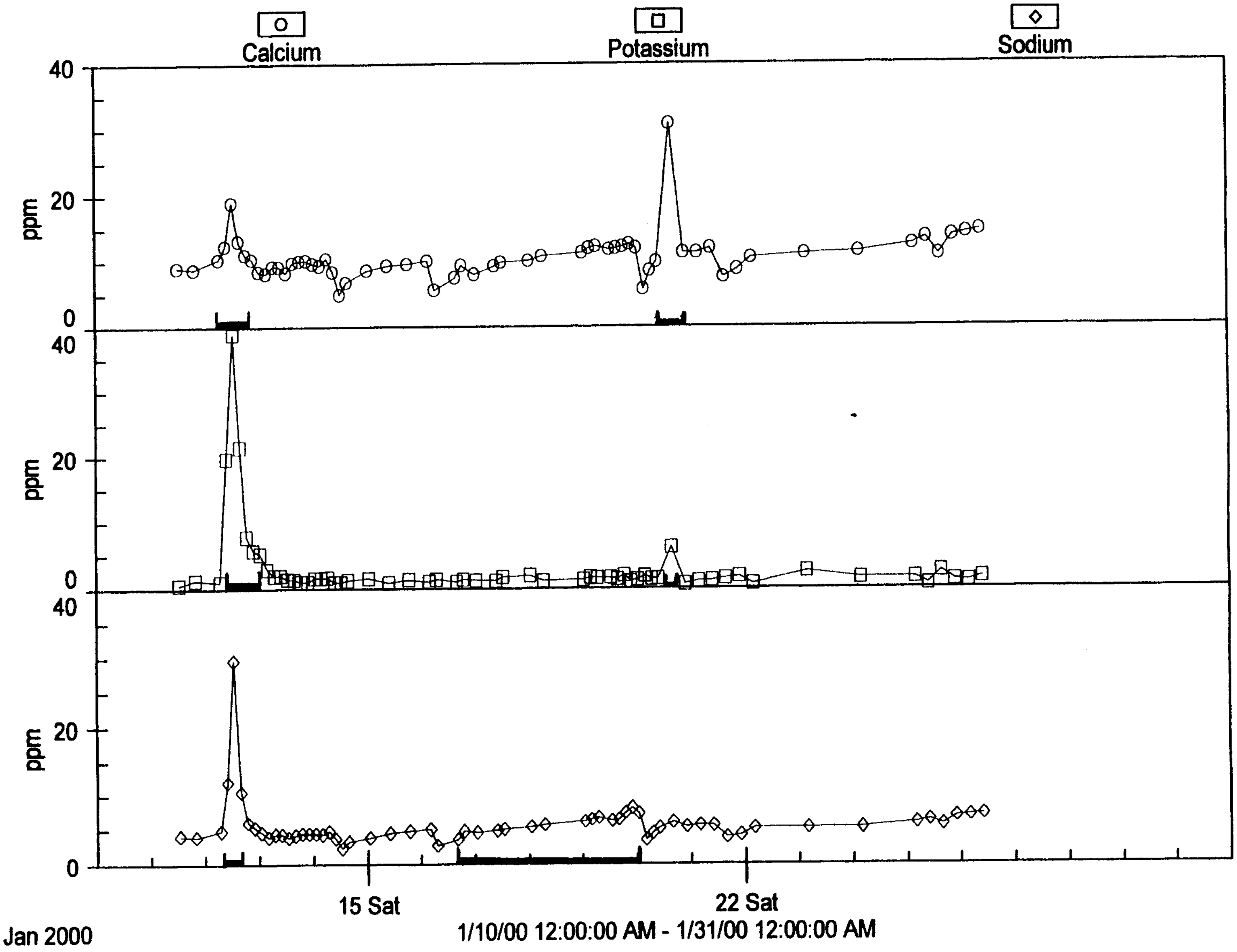
NPOut Tracers



NPOut

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	N	Y	N
Background Range (ppm)	11.9 - 18.1	1 - 5.3	3.4 - 5.1
Number of Signals	0	2	0
First Signal Characteristics			
Signal Start	-	1/13/00 13:00	-
Signal End	-	1/18/00 19:00	-
Signal Duration (hrs)	-	126.0	-
Signal Peak (date/ time)	-	1/16/00 16:00	-
Signal Max (ppm)	-	18.4	-
Signal/Noise	-	3.8	-
Notes	-	Signal defined using average of max/ min values after event (4.8 ppm)	-
Second Signal Characteristics			
Signal Start	-	1/20/00 16:00	-
Signal End	-	1/23/00 16:00	-
Signal Duration (hrs)	-	72.0	-
Signal Peak (date/ time)	-	1/22/00 4:00	-
Signal Max (ppm)	-	7.2	-
Signal/Noise	-	1.5	-
Notes	-	Signal defined using average of max/ min values after event (4.8 ppm)	-

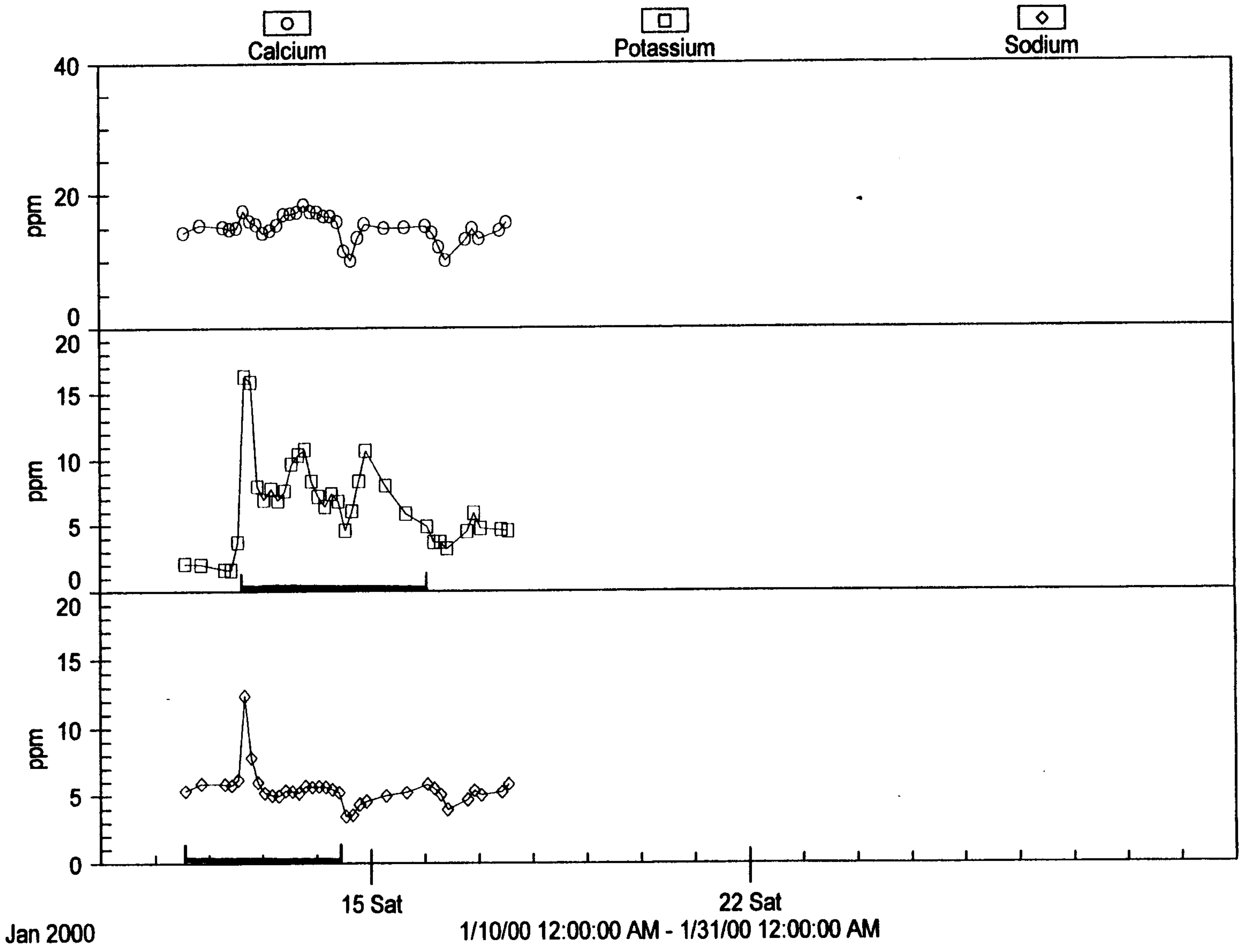
DME Tracers


Calcium
Potassium
Sodium
40
20
0
ppm
40
20
0
ppm
40
20
0
ppm
15 Sat
22 Sat
Jan 2000
1/10/00 12:00:00 AM - 1/31/00 12:00:00 AM

DME

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	Y	Y	Y
Background Range (ppm)	4.9 - 14.6	0.6 - 2.6	2.2 - 7.1
Number of Signals	1	2	2
First Signal Characteristics			
Signal Start	1/12/00 7:00	1/12/00 10:00	1/12/00 7:00
Signal End	1/12/00 22:00	1/13/00 7:00	1/12/00 22:00
Signal Duration (hrs)	15.0	21.0	15.0
Signal Peak (date/ time)	1/12/00 13:00	1/12/00 13:00	1/12/00 13:00
Signal Max (ppm)	19	38.8	29.6
Signal/Noise	1.9	8.6	6.3
Notes	-	-	First signal prior to documented application
Second Signal Characteristics			
Signal Start	-	1/20/00 16:00	1/16/00 19:00
Signal End	-	1/20/00 16:00	1/20/00 4:00
Signal Duration (hrs)	-	0.0	81.0
Signal Peak (date/ time)	-	1/20/00 16:00	1/19/00 22:00
Signal Max (ppm)	-	6.17	8.09
Signal/Noise	-	3.9	1.7
Notes	Second peak suspect, no incr. in flow, no inc. in cond.	-	Signal starts prior to second applic, could be background

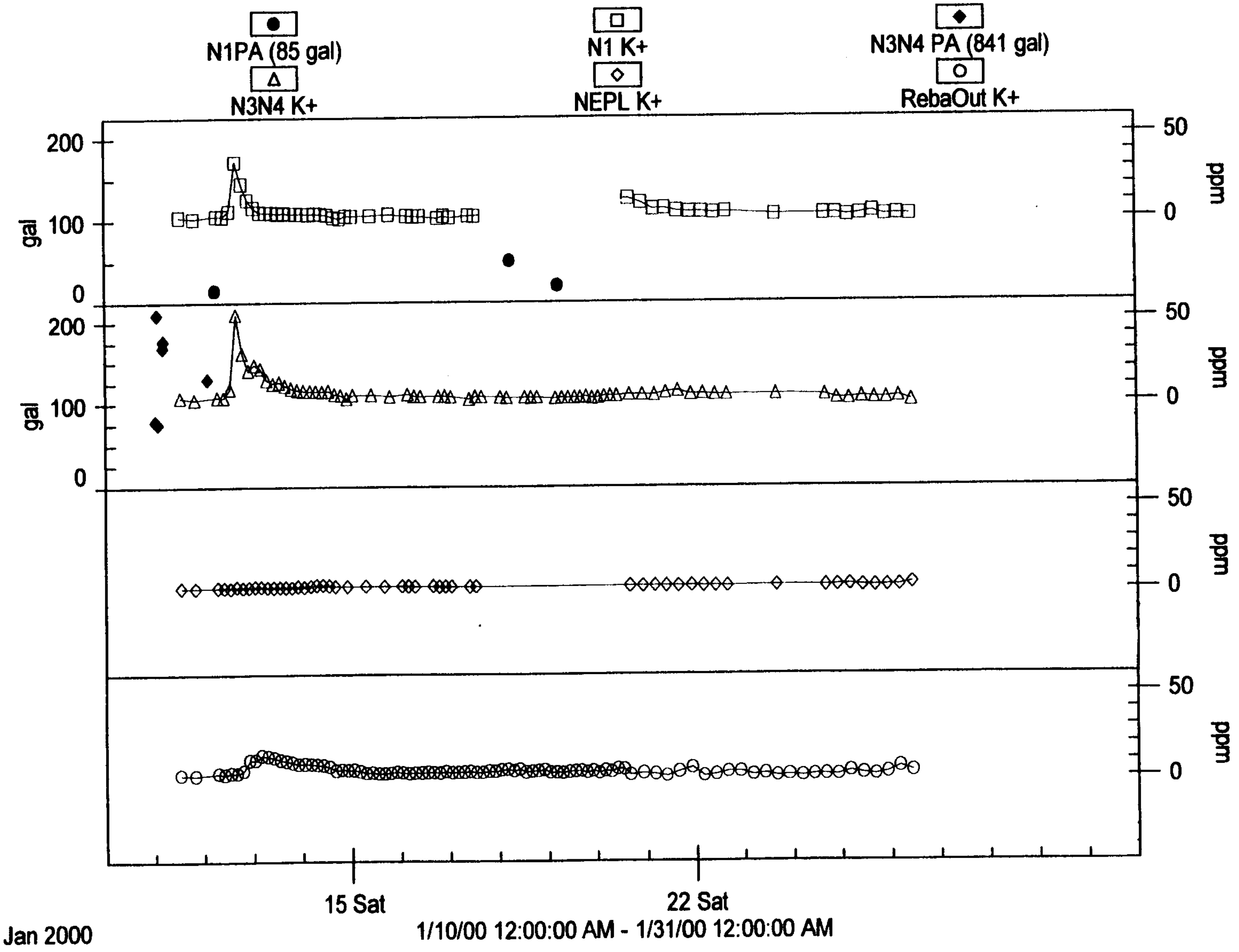
DMMouth Tracers



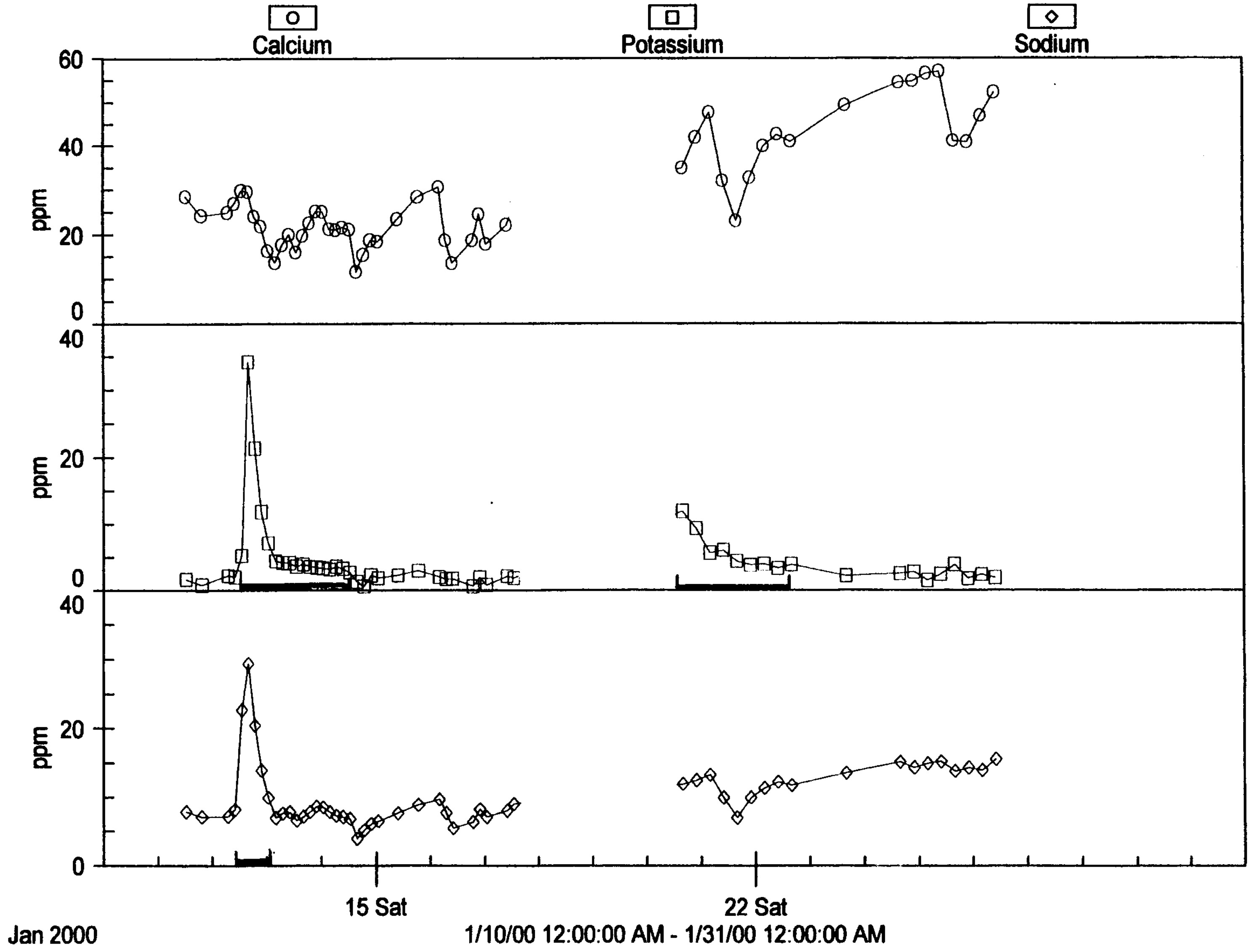
DMMouth

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	Y	Y	Y
Background Range (ppm)	10.1 - 18.4	1.6 - 5.9	3.5 - 5.8
Number of Signals	0	1	1
First Signal Characteristics			
Signal Start	-	1/12/00 16:00	1/11/00 13:20
Signal End	-	1/16/00 1:00	1/14/00 10:00
Signal Duration (hrs)	-	81.0	68.7
Signal Peak (date/ time)	-	1/12/00 16:00	1/12/00 16:00
Signal Max (ppm)	-	16.3	12.4
Signal/Noise	-	4.3	2.6
Notes	-	signal has 3 peaks	signal prior to documented application
Second Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-

Potassium - Lake Reba Basin



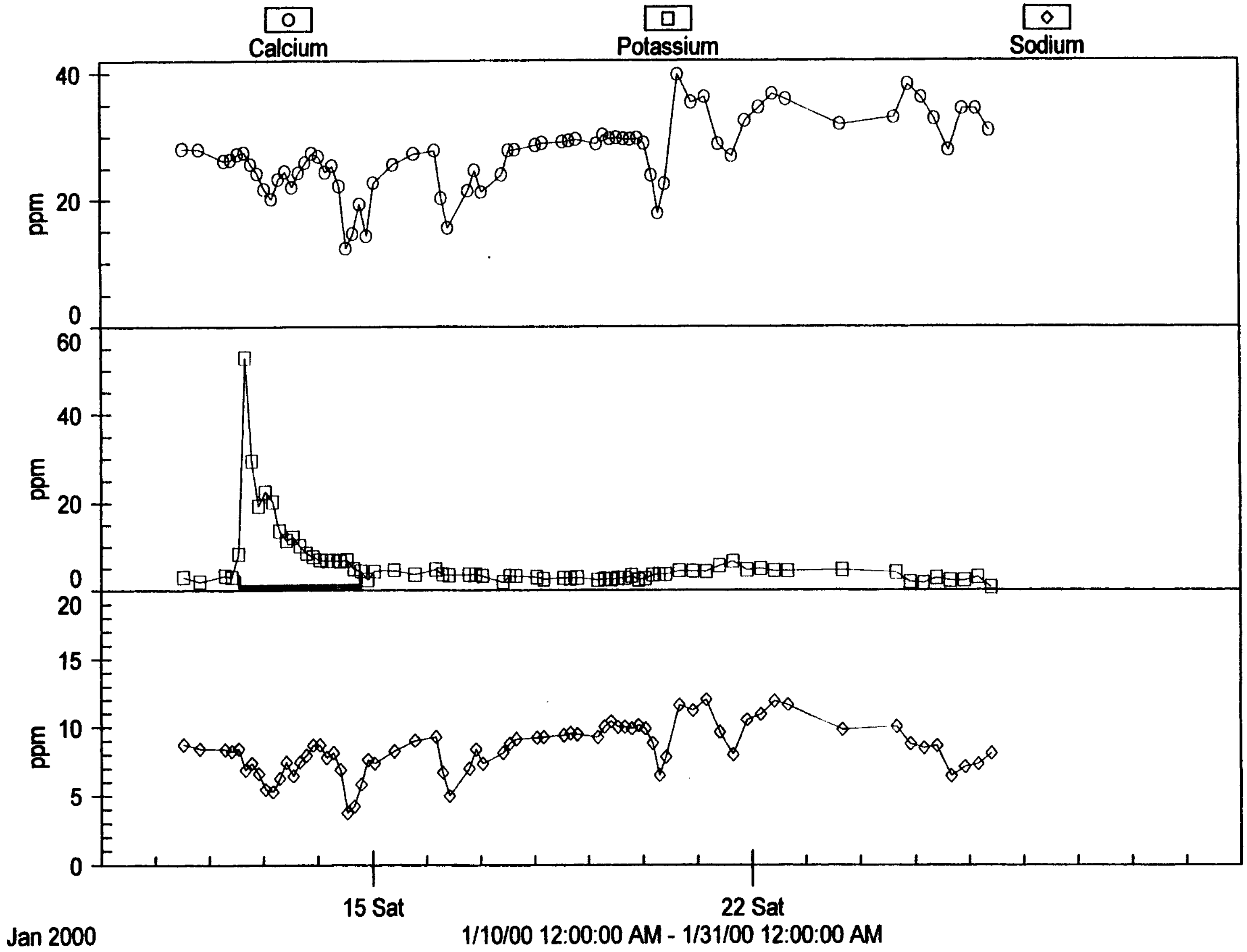
N1 Tracers


Calcium
Potassium
Sodium
ppm
60
40
20
0
ppm
40
20
0
ppm
40
20
0
15 Sat
22 Sat
Jan 2000
1/10/00 12:00:00 AM - 1/31/00 12:00:00 AM

N1

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	Y	Y	Y
Background Range (ppm)	14 - 55	0.6 - 3.9	3.9 - 15.5
Number of Signals	N	2	1
First Signal Characteristics			
Signal Start	-	1/12/00 13:00	1/12/00 13:00
Signal End	-	1/14/00 13:00	1/13/00 1:00
Signal Duration (hrs)	-	48.0	12.0
Signal Peak (date/ time)	-	1/12/00 16:00	1/12/00 16:00
Signal Max (ppm)	-	34.2	29.4
Signal/Noise	-	15.2	3.0
Notes	peak of 55 during dry after application	First signal prior to documented application	signal prior to documented application
Second Signal Characteristics			-
Signal Start	-	1/20/00 16:00	-
Signal End	-	1/22/00 16:00	-
Signal Duration (hrs)	-	48.0	-
Signal Peak (date/ time)	-	1/20/00 16:00	-
Signal Max (ppm)	-	12	-
Signal/Noise	-	5.2	-
Notes	-	sampled tail-end of second signal	-

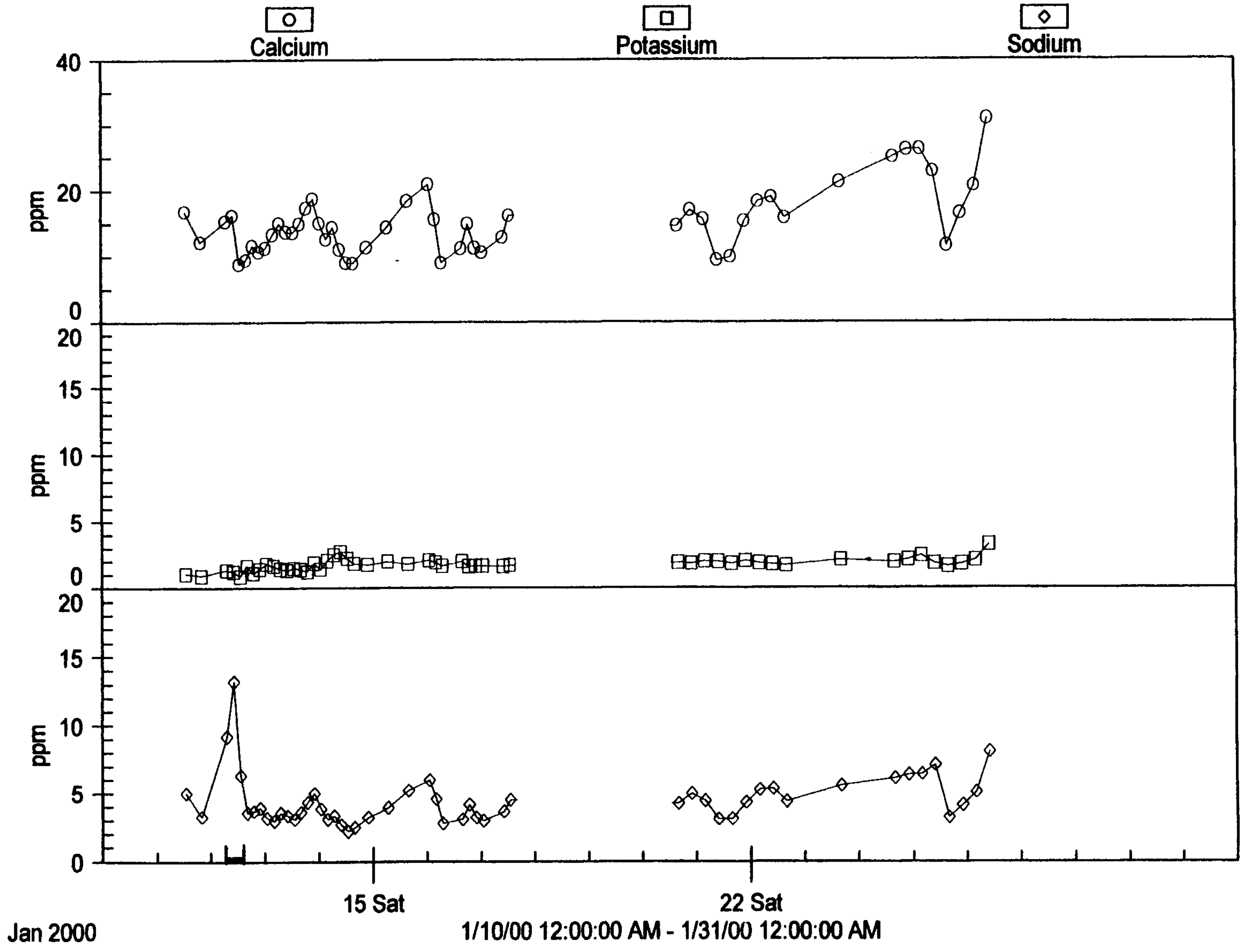
N3N4 Tracers



N3N4

	CMA/ Calcium	**PA/ Potas**	**SA/ Sodium**
Chemical Applied (Y/N)	N	Y	N
Background Range (ppm)	12 - 40	0.6 - 6.6	4 - 12
Number of Signals	0	1	0
First Signal Characteristics			
Signal Start	-	1/12/00 13:00	-
Signal End	-	1/14/00 19:00	-
Signal Duration (hrs)	-	54.0	-
Signal Peak (date/ time)	-	1/12/00 16:00	-
Signal Max (ppm)	-	52.9	-
Signal/Noise	-	14.7	-
Notes	-	-	-
Second Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-

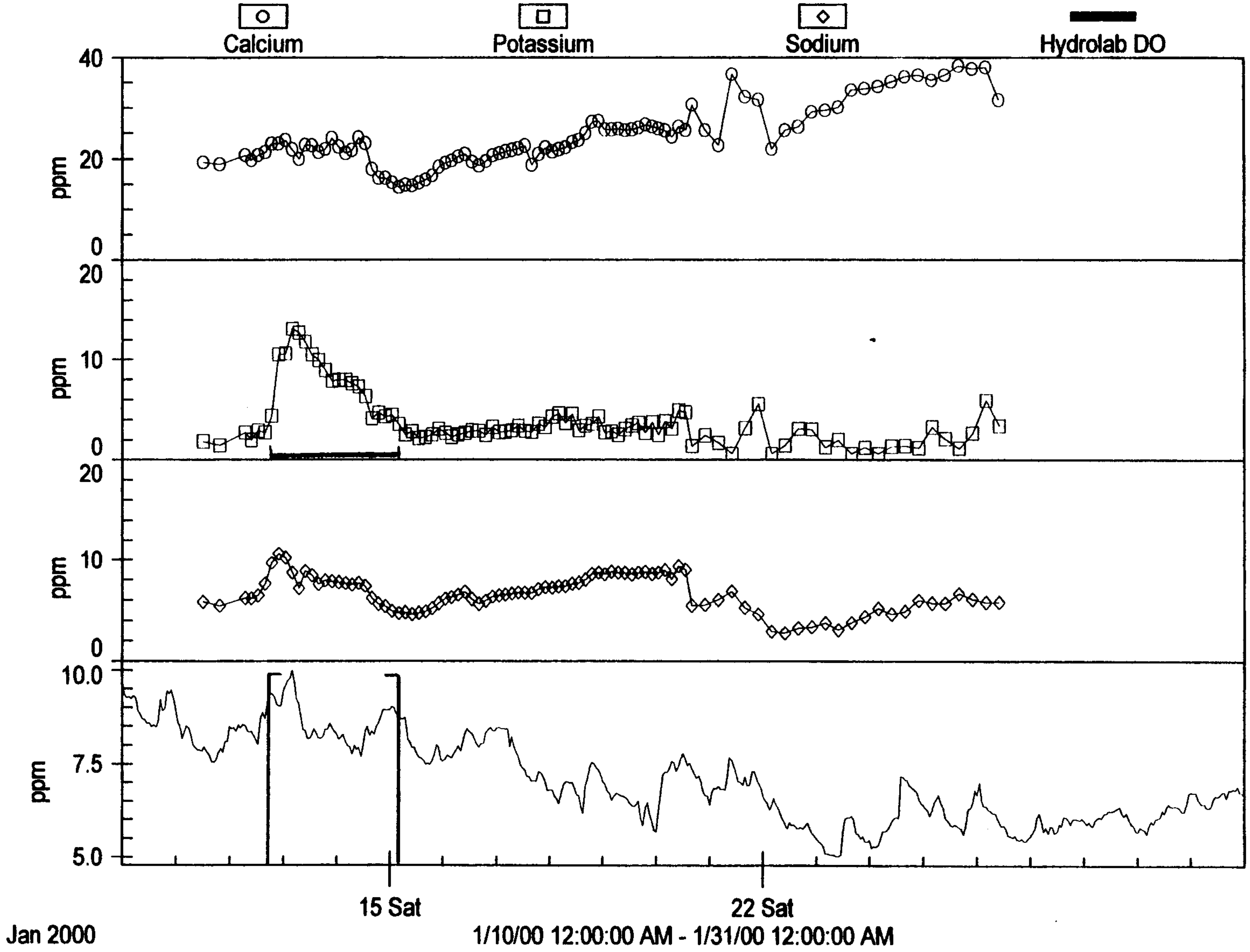
NEPL Tracers



NEPL

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	Y	N	Y
Background Range (ppm)	8.9 - 30.9	0.9 - 3.3	2.2 - 8.1
Number of Signals	0	0	1
First Signal Characteristics			
Signal Start	-	-	1/12/00 7:00
Signal End	-	-	1/12/00 13:00
Signal Duration (hrs)	-	-	6.0
Signal Peak (date/ time)	-	-	1/12/00 10:00
Signal Max (ppm)	-	-	13.2
Signal/Noise	-	-	2.5
Notes			signal prior to documented application
Second Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-

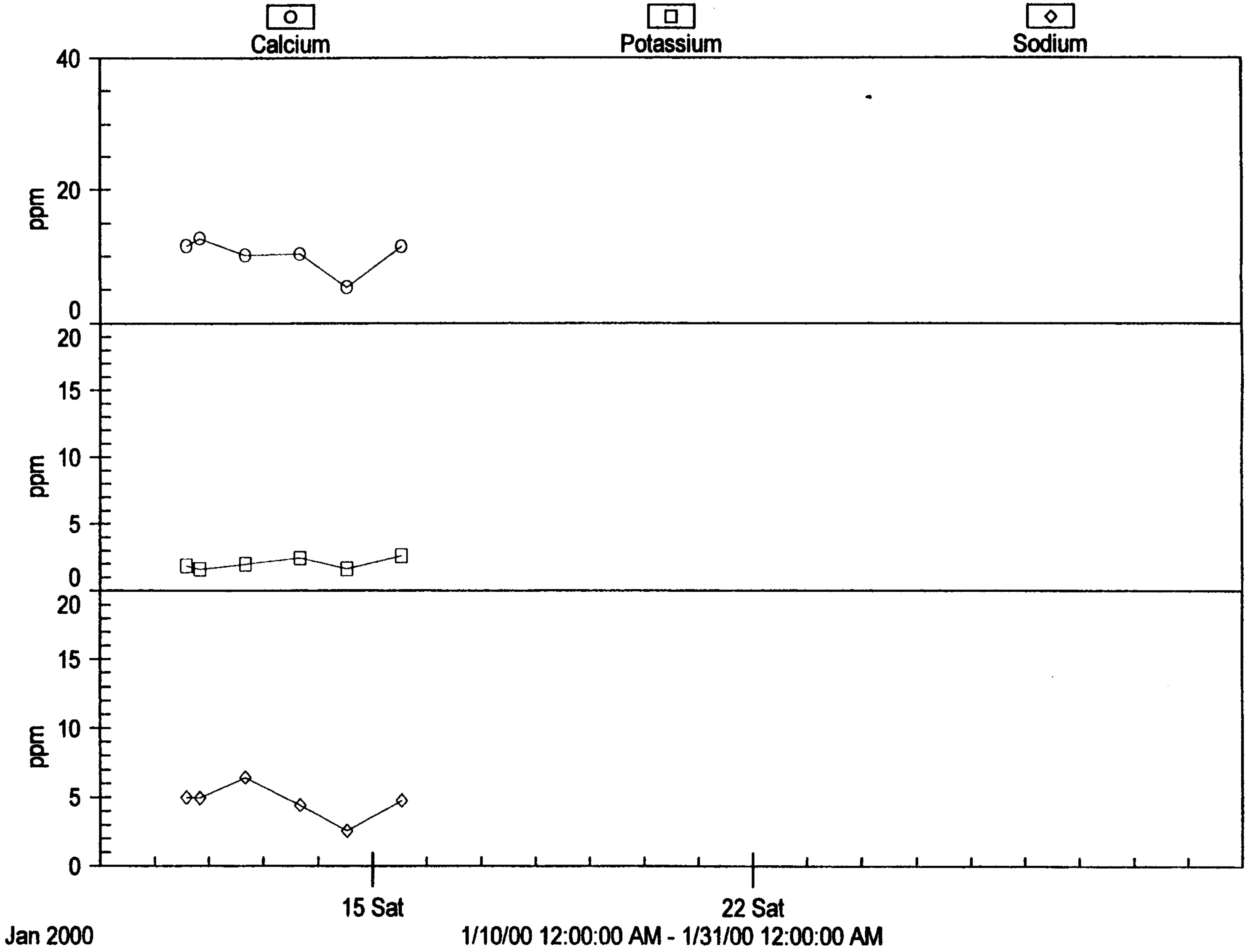
RebaOut Tracers



RebaOut

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	Y	Y	Y
Background Range (ppm)	14.4 - 38.3	0.6 - 5.9	2.8 - 10.6
Number of Signals	0	1	0
First Signal Characteristics			
Signal Start	-	1/12/00 19:00	-
Signal End	-	1/15/00 4:00	-
Signal Duration (hrs)	-	57.0	-
Signal Peak (date/ time)	-	1/13/00 4:00	-
Signal Max (ppm)	-	13.1	-
Signal/Noise	-	4.0	-
Notes	-	-	-
Second Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-

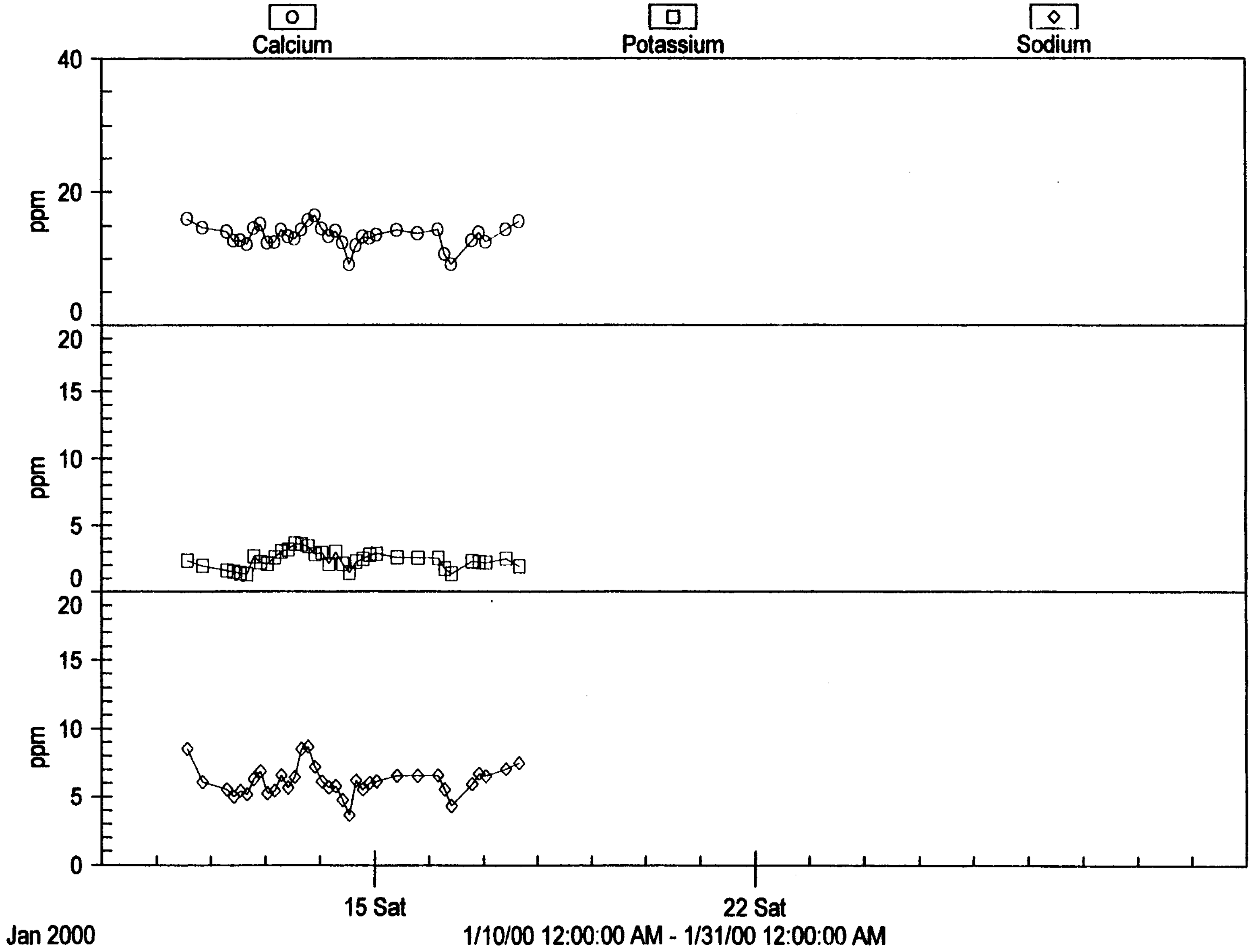
MCUp Tracers



MCUp

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	N	N	N
Background Range (ppm)	5.3 - 12.7	1.6 - 2.6	2.6 - 6.5
Number of Signals	0	0	0
First Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-
Second Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-

MCMouth Tracers



MCMouth

	CMA/ Calcium	PA/ Potas	SA/ Sodium
Chemical Applied (Y/N)	Y	Y	Y
Background Range (ppm)	9.3 - 16.5	1.3 - 3.6	3.7 - 8.7
Number of Signals	0	0	0
First Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-
Second Signal Characteristics			
Signal Start	-	-	-
Signal End	-	-	-
Signal Duration (hrs)	-	-	-
Signal Peak (date/ time)	-	-	-
Signal Max (ppm)	-	-	-
Signal/Noise	-	-	-
Notes	-	-	-

5 APPENDIX D DATA ANALYSIS METHODS AND RESULTS

5.1 Introduction

This Appendix presents a summary of the methods and results of statistical analyses conducted to determine if the presence of deicing chemicals in Lake Reba and Northwest Pond 3 causes a decrease in either the concentration or saturation of dissolved oxygen (DO) in the ponds. The methods and results in this appendix are first summarized with more information about theory, methods, and results presented in Sub-Appendices D1-D7.

Investigation of the effects of deicing chemicals on levels of DO[1] in Northwest ponds and Lake Reba, began with exploratory analyses conducted to visually investigate the range, variance, and temporal distributions of DO levels and changes, over 1, 6, and 8 hour periods, in DO levels. Exploratory analyses were also conducted to investigate the range, variance, and temporal distributions of selected physical variables, and changes in those variables, that were recorded during the monitoring period. These physical variables, including rainfall (as indicated by rising water level in the ponds), conductivity, water temperature, date and time,, and presence of deicing chemicals, were considered the "independent" variables that might be used to help explain or predict DO levels.

After the distributions of individual variables had been explored, the relationships between DO levels and the physical variables were explored using scatter plots, correlation analyses, and simple time-series techniques. Exploratory analyses were followed by statistical analyses, including hypothesis testing and simple time-series modeling, designed to test for differences between DO levels when deicing chemicals were present (treatment periods) and were not present (control periods) in the system.

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[1] The term DO levels will be used to refer to concentration and saturation of DO in Lake Reba and Northwest Ponds. Changes in levels will refer to changes in both concentration and saturation.

Effects of explanatory variables other than deicing chemicals were examined to determine how they could effect the distribution of DO levels and changes in level.

Although the study was originally designed to include "control" and "treatment" ponds and time periods, the highly stratified DO found in the control ponds (NWP cells 1 and 2) indicated that these ponds were not well-suited as controls for the two treatment ponds (NWP cell 3, and Lake Reba). The application of deicing chemicals to runway areas could not be planned so that the nature and timing of the treatment periods was a controlled aspect of the study. Over the course of the monitoring year, the need for application of deicing chemicals to ground surfaces was limited to a two-week period of time that was followed by the longest low rainfall period in the 4-month monitoring period. There was too little separation in time between chemical applications and dissimilar chemical applications for the three events in the two-week period to be considered replicates.

With the unsuitable control ponds, no replication of treatment periods, and no specific thresholds of DO change to test for, the types of analyses available for testing for the potential effects of deicing chemicals were limited and caution was required when interpreting the results(see Table 1). This study did not examine a predefined biologically significant threshold of potential effects (e.g., rate of change or total change in DO over a specific time period.) For these reasons, it was necessary to develop a "weight of evidence approach" to support or not support conclusions that deicing chemicals affect DO levels in the ponds.

Table 5-1. Factors that affected available analytical methods and interpretation of results.

1. **Lack of control ponds**
   - Northwest pond cells 1 and 2 (NP1 and NP2), lie upgradient of cell 3 (NP3). Runoff from outfall SDS3 transports the majority of deicing chemicals from the runways to NP3. Thus, NP1 and NP2 were intended to serve as control ponds unaffected by deicing chemicals. During the course of the study, it was discovered that DO in NP1 and NP2 was highly stratified and not comparable to the much more homogeneous DO exhibited in both NP3 or Lake Reba. Therefore, NP1 and NP2 were not well-suited to be considered control ponds.
2. **Lack of replicate treatment (deicing) events**
   - Deicing events were not separated sufficiently in time for their effects to be independent and loading quantity and/or chemical types used differed between events.
   - All deicing events occurred during a unique type of weather pattern: unusually low rainfall. This weather pattern was not repeated at other times during the monitoring program. Furthermore, this type of weather pattern has been shown in this study and previous work to result in naturally falling DO in both NP3 and Lake Reba.
3. **Effects of unmeasured variables.**
   - DO levels are affected by complex interactions among factors (variables), some of which were measured in this study (e.g., rainfall, water level, water temperature, conductivity) and some of which were not (e.g., local wind, retention periods of the ponds, etc.). Without replication, it is not possible to describe the nature of these, especially if unmeasured variables had measurable effects. That is, the likely possibility that unmeasured variables did affect DO levels complicates interpretation of results.
   - For example, the relationships between DO and explanatory variables differed at Lake Reba and NP3. It is likely that physical characteristics such as depth, volume, and turn over rates that differed between the ponds, also affected dissolved oxygen levels.
   - Within ponds, the distributions of DO levels differed between treatment and control periods. It was not possible to discriminate which factor (e.g., measured or unmeasured variables, including deicing chemical presence) caused these differences.
4. **No predefined measure of a significant effect on DO.**
   - Without a pre-specified definition of a threshold that would constitute a "deicing effect" (e.g., a given change in DO), it was difficult to search the data for a deicing effect. If multiple definitions had been created and searched for, the probability of spurious results would have been increased.

5.2 Exploratory Analyses

5.2.1 Methods

Exploratory Analyses were conducted to guide and focus statistical analyses of the effects of deicing chemicals on DO levels. In particular, the exploratory phase was designed to:

1) identify signals of deicing event(s) and explore relationships between conductivity and tracer ions during background and treatment periods to demonstrate the efficacy of conductivity as an aggregate tracer,
2) determine which of the measured physical variables, including rainfall, water level, conductivity, temperature, presence of deicing chemicals, and time (including temporal patterns in individual variables or relationships between variables) best predicted DO levels and changes in DO levels,
3) explore temporal scales of change, and
4) identify differences between NP3 and Lake Reba in terms of the relationships between DO and explanatory physical variables.

All analyses were conducted in SPSS for Windows Release 9.0.0. Most data were collected in and/or imported to Flowlink 4.1 software used to program and manage data for the field instrumentation. The Flowlink data were exported and visually checked against data transferred to Excel and SPSS data files. Outliers or missing values in time series plots and exploratory graphs were investigated and corrected as needed to confirm real data and/or missing values.

5.2.1.1 Identify signals of deicing event(s) and explore relationships between conductivity and tracer ion concentrations.

To identify a "signal" of a deicing event (i.e., a beginning and end of a treatment replicate) the following pieces of information were examined:

1. the times during which different deicing chemicals were applied to runways,
2. the quantities of deicing chemicals that were applied, and
3. presence of tracer ions associated with the deicing chemicals and their relationship to conductivity in Lake Reba and NP3

Concentrations of tracer ions (Na^{2+}, K^{+}, and Ca^{2+}), conductivity, and DO were plotted against time during a background (control) event from 12/11/99-12/13/99 and during the treatment period from 1/11/00 – 1/28/00 when deicing chemicals were applied. During the two-week treatment period, a peak in tracer concentration was identified as an isolated high point flanked on either side by progressively smaller concentrations. The magnitude of this peak value had to be substantially higher than the concentrations observed during the background event to be considered a "signal". The onset of a deicing signal was defined as the first tracer ion concentration immediately prior to the signal peak whose value was greater than the background concentration[2]. The end of the signal was defined as the last concentration immediately following the tracer peak whose value was greater than the background concentration. See Appendix C for more details.

Correlations between tracer ion concentrations and conductivity during control (12/11/99-12/13/99) and treatment periods (1/11/00 – 1/28/00) were compared to determine how well the ions correlated with applications of deicing chemicals.

5.2.1.2 *Determine the physical variables, including time, that best predict DO levels and changes in DO levels*

The variables measured during the study period that might affect DO levels or changes in level included conductivity, water temperature, rain, water level, and time. Although time is not really a causal variable, it can be considered a variable that integrates effects

---

[2] The average of the smallest minimum concentration and largest maximum concentration was used to define the "background" concentration around the tracer signal.

created by other causal variables. In addition, with time-series data, it is important to be certain that there is no correlation among data values before classical hypothesis tests are conducted.

The relationships between the measured physical variables and DO levels were explored using simple time series methods that provide insight into each variable's distribution over time and any temporal structure in relationships between variables. The autocorrelation function (ACF) was used to show how correlation among the data values of a variable is related to their separation in time (details described in Appendix D1). Relationships among variables were explored using the cross-correlation function (CCF) which shows how the correlation between the data values of two different variables is related to their separation in time. These exploratory analyses were largely qualitative; a more formal time series modeling was conducted in the second phase of analysis.

To investigate the potential effects of deicing chemicals, two definitions of a deicing treatment were created so that results using the two definitions could be compared. The first definition was based solely on the presence of deicing chemicals in the ponds as determined by tracer ion analyses (see Appendix C and related figures). According to the tracer ion data a deicing signal was present at the two ponds during the following times:

Lake Reba

- From January 12, 2000 19:00 to January 15, 04:00

NP3

- From January 13, 2000 13:00 to January 18, 19:00 and
- January 20, 2000 16:00 to January 23, 16:00

The periods of signal presence at each pond were defined as the treatment periods for the pond according to the "signal-based" definition of a deicing treatment. At Lake Reba, the treatment period constituted one continuous 2.5-day period. At NP3, the treatment period consisted of two different periods separated by a little less than two days (though it was not certain that the signal from the first event was completely extinguished prior to the onset of the signal associated with the next chemical applications). In each pond, all periods before or after the treatment period(s) were considered control periods.

The second, more conservative definition of a treatment period (the "time-based" definition) was the same at both ponds. Using this definition, all hours between the start of the first signal at Lake Reba and end of the last signal at NP3 (i.e., from January 12, 2000 at 19:00 through January 23, 16:00) were considered the treatment period. Hours outside that twelve-day (approximately two-week) period were considered control hours. The time-based definition excludes the uncertainty that chemicals were completely flushed between successive applications of deicing chemicals.

These two definitions were used to explore how tightly evidence of effects on DO levels were tied to the presence of deicing chemicals *vs.* other factors, besides deicing chemicals, that co-occurred during the treatment period. The interpretation of these analyses was complicated by the fact that each application of deicing chemicals included different volumes and/or types of chemicals applied (PA, SA and CMA)

5.2.1.3 Explore temporal scales of change.

Based on the results of exploratory analyses of the effects of time and temporal patterns, changes in the concentration and saturation of DO over 1 hour, 6 hour, and 8 hour periods were investigated as the measures of “change in DO”. Correlations between changes in explanatory variables and changes in DO levels were computed for treatment and control periods using both definitions of treatment.

between conductivity at the two ponds seems to be positive during control periods, but slightly negative and highly variable during treatment periods (Figures 1 and 2; Appendix D6, Figures 9, 10, bottom two rows).

5.2.3 Summary

Exploratory analyses support concepts about how the physical and biological processes at the two ponds differ. For example, levels of DO were generally higher at Lake Reba than at NP3 and changes in variables may occur more frequently and be larger at Lake Reba than at NP3 (see also Figures 1 and 2). There was also evidence that the relationships among the variables change during the treatment period, but it was not clear that the changes were caused by the presence of deicing chemicals.

The type and volumes of chemicals applied, pond depth and volume, and other unmeasured, local, physical factors also differed at the two ponds and interactions among these variables could have caused any of the effects that were seen. For example, it was not clear how the difference between the level-temperature correlations in the control and treatment periods at both ponds could be caused by deicing chemicals. Changes in the level-temperature relationship, however, could have affected the relationship between conductivity (which is affected by level) and DO (which is affected by both temperature and level).

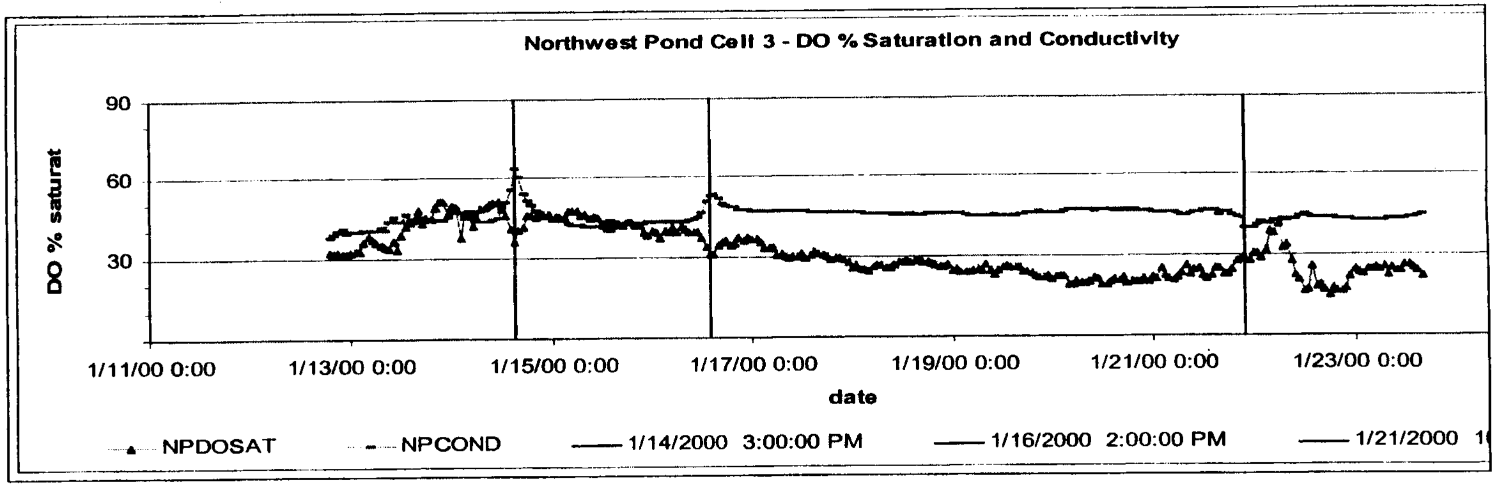

Figure 1. DO % Saturation and Conductivity at NP3 during two-week deicing period. Vertical lines indicate inflection points between different periods of conductivity.

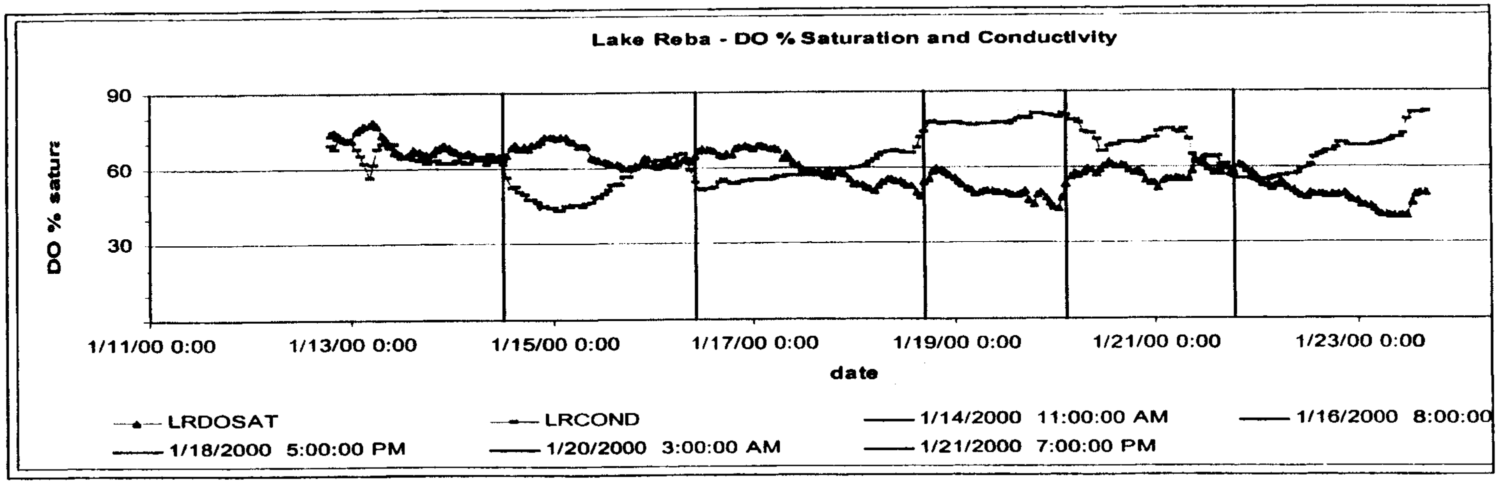

Figure 2. DO % Saturation and Conductivity at Lake Reba during two-week deicing period. Vertical lines indicate inflection points between different periods of conductivity.

5.3 Statistical Analyses.

Analytical methods included two basic approaches.

1) Model/Predict/Explain measured DO concentrations using contemporaneous data collected about physical variables. Models were used to remove variability in DO caused by variables not related to deicing to improve the ability to discern an effect of deicing.

2) Compare means, variances, temporal patterns, and relationships among variables during times with and without deicing chemicals. This approach was used to:

- identify changes in variance and patterns that might not be detected through modeling
- isolate variables used in modeling for more focused analysis
- identify evidence that unmeasured variables may affect DO concentrations

5.3.1 Methods

5.3.1.1 Approach 1: Model/Predict/Explain measured DO concentrations

Because the exploratory analyses showed that the data and their relationships were affected by their proximity in time, it was not appropriate to construct a General Linear Model to predict DO levels[3]. Instead, for each pond, time series models called Integrated Autoregressive Moving Average (ARIMA) models (Diggle, 1990) were fit to DO percent saturation to test for the significance of temporal components[4] and effects of temperature, conductivity, and presence of deicing chemicals (See Appendix D1 for details). Percent saturation was selected as the dependent variable because the

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[3] General linear models assume that residuals around the model are independent of one another. In time-series models they are correlated in time.

correlations between explanatory variables and percent saturation were found to be larger than correlations with DO concentration in the exploratory analyses.

The Akaiki Information Criterion (AIC) (Akaiki, 1973; Burnham and Anderson, 2000) was used to determine which ARIMA model fit the data best. The AIC is a measure of model fit that considers both the fit of the model and the number of parameters in the model. Models with the same "fit"[5] but fewer parameters are considered stronger models. The ARIMA model with the smallest AIC was considered the best fitting model in that it fit the data best with a minimum number of parameters.

5.3.1.2 Approach 2 - Compare means, variances, temporal patterns, and relationships among variables during times with and without deicing chemicals.

Using the second approach, nonparametric comparison of means (Mann Whitney U test)[6] and Levene's test for differences in variance were conducted to determine whether the means and/or variances of any of the variables differed between control and treatment periods. The variables tested included DO concentration, DO percent saturation, temperature, water level, conductivity, as well as change over 6 hour periods and percent change over 6 hour periods in each of those variables. Both definitions of deicing were used in order to discern the effects of deicing chemicals from the effects of other physical variables that affect DO levels.

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[4] Autoregressive components (AR), difference/change components (I), moving average components (MA). See Appendix AAA.

[5] As measured by the negative log liklihood for the model

[6] Mann Whitney U test compares means of data ranks. By comparing ranks, the test essentially compares the medians of two data sets.

5.3.2 Results/Findings

5.3.2.1 Approach 1. Model/Predict

1) **Over the course of the entire study period, DO percent saturation in both NP3 and Lake Reba was affected by water temperature, conductivity, deicing chemicals, and percent saturation during the previous hour. The nature of the effects of deicing chemicals could not be clearly discriminated from effects of the other variables.**

In both ponds, the best fitting ARIMA (1,1,1) model included a first order (1 hour) autoregressive, difference, and moving average component as well as temperature, conductivity, and presence of a deicing signal[7]. The ARIMA components had the highest significance levels, but all variables were highly significant ($p < 0.0001$). (Appendix D7). These results indicate that the physical variables, temperature, conductivity, and deicing chemicals affect DO levels, and that reactions of DO to these factors will be affected by DO levels in the previous hour. It seems reasonable that DO levels in a pond would respond relatively slowly to changes in environmental conditions, especially if the changes in conditions were also gradual. The autocorrelation seen in all variables in the exploratory analyses indicates that these kinds of gradual changes tend to be the rule. As will be seen in the next set of analyses, however, the nature of the effects by deicing chemicals can be difficult to predict.

5.3.2.2 Approach 2. Directly compare data from control and treatment periods.

2) The significance, magnitude, and direction of differences between hourly DO and 6-hour changes in DO during treatment and control periods depended on how the treatment period was defined. (Appendix D8).

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[7] That is, after the data were differenced by 1 hour, data were highly related to the data value in the hour previous hour and converting data to moving averages of two hour periods resulted in no significant loss of information.

As explained in Section 5.2.1, the treatment period was defined in two ways to discriminate between effects of deicing chemicals and physical factors on DO. Using the first definition, the treatment period was defined as only those hours when a deicing chemical signal was present in a particular pond. According to the second definition, the treatment period included all hours between the first signal at Lake Reba and last signal at NP3. In the case of NP3, there was little difference between these two definitions and the results of Mann-Whitney tests of differences between the medians of the two periods were similar for both time- and signal-based definitions of the treatment period. At Lake Reba, however, the signal-based period was considerably shorter than the time-based treatment period, and the results of the Mann-Whitney tests tended to depend more on the definition of the treatment period.

The signs and magnitudes of differences between the treatment periods, as well as the significance of the differences, differed between the two ponds with a few exceptions (Appendix D8, Tables 1, 2, 3, 4). Differences between periods may be due to the fact that the number and range of data values during the control periods were considerably larger than during the respective treatment periods (either definition). The control periods were on the order of several months, containing far greater variability in weather patterns than were experienced during the two-week treatment period.

For example, using either treatment definition, median water level was significantly higher during the treatment period than the control period at both ponds. Median water temperature was significantly lower during the treatment periods than during the control period at both ponds. Median conductivity was significantly lower at Lake Reba during the treatment period than the control period but did not differ between control and treatment periods at NP3 using either definition of treatment.

DO levels were lower and six-hour changes in DO were smaller during the treatment period than during the control period at both ponds using the time-based treatment definitions. Using the signal-based definition, DO levels during the treatment period were still lower than DO levels during the control period at NP3 but they were higher than control levels at Lake Reba. Lower conductivity during signal presence at Lake Reba could explain the elevated DO during that period. Consistent conductivity in NP3 was associated with a decrease in DO during signal presence, and indeed, during the entire two-week treatment period.

The results of hypothesis testing and time-series analysis of all the variables measured at the two ponds indicate that temperature, water level (which is driven by rainfall and groundwater), and conductivity (which is affected by level) are dynamic variables that have a strong effect on DO levels in the two ponds. Differences between the mean DO levels in the two ponds, visual inspection of time series and other exploratory graphs of the variables indicate that environmental processes differ between the two ponds. These local processes create different reactions in terms of DO levels. The dynamic nature of the multiple, interacting processes made it difficult to discriminate the effects of deicing chemicals.

5.3.3 Summary

Air temperature and rainfall affect water temperature, water level, and conductivity, which, in turn, affect DO levels in Lake Reba and NP3. Because a relatively unique period of prolonged, low temperatures and low rainfall followed deicing chemical applications, it was difficult to separate the effects of these two variables, and their effects on conductivity, from the effects of deicing chemicals on DO.

At Lake Reba, where a deicing signal was detected during only a subset of the low-rain, low-temperature period, DO levels were actually higher during signal presence than during other times of the year (including other times during the low rain/temperature period). This fact indicates that declines in DO after cessation of the deicing chemical signal were attributable to background processes – most likely, to low rainfall and runoff. Because Lake Reba is shallower than NP3, DO levels may respond more quickly to environmental inputs in Lake Reba than in NP3. Time series graphs from the two ponds also indicated that changes in "state" may occur more frequently in Lake Reba than in NP3 (see Figures 1, 2 for examples).

In general, the number and complexity of co-occurring factors are too complex for ongoing monitoring to effectively detect potential DO effects. These factors are:

- the infrequency of ground-surface deicing,
- the complexity of the natural DO response at the two ponds,
- the differences between the sizes and hydrological processes of the two ponds, and
- the different types of deicing chemicals that are likely to enter each pond.

Any further analyses should involve a risk-assessment approach. Such an approach could evaluate weather patterns that affect the frequency, magnitude, and duration of deicing events and the ability of the system to self correct when rainfall (and runoff) increases. This approach could be aimed to estimate the probability of occurrence for a range of deicing event scenarios and shed further light on the potential for associated adverse affects on DO in the two ponds.

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5.4 *Appendix D1.* ***Background information about time-series analyses methods.***

5.4.1 Methods

A plot of the ACF shows correlation between pairs of values of a single variable (i.e., autocorrelation) and how autocorrelation is related to the separation in time of the paired data values. When data are sampled at regular time intervals, as in this study, the separation in time is called a lag[8]. Autocorrelation coefficients (ACCs) are Pearson correlation coefficients, r, that range from negative one to positive one. No correlation is indicated when r is not statistically different than zero. Maximum positive correlation is indicated by $r = 1.0$ and maximum inverse correlation $r = -1.0$. The ACC at lag zero (no separation in time) is, by definition, one.

The partial autocorrelation function (PACF) plots the partial correlation coefficient (PACC) over time and shows the autocorrelation between data values when correlation caused by intermediate time lags has been removed.[9] The patterns of autocorrelation and partial autocorrelation are used to determine whether a time series is stationary (Diggle 1990, Cressie 1993) and to identify autoregressive (AR) and moving average (MA) components in the data. The assumption that the data are "stationary" must be met before time series the results of time series methods can be properly interpreted.[10] Stationarity is a relatively complex statistical property, with different levels, that relates to the consistency of temporal processes in the data.

Stationarity can be assessed by examining the patterns of the ACF and PACF for each variable. When necessary, the data can be "transformed" to produce a stationary

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[8] In this study, data were sampled hourly so a lag is one hour long.

[9] The partial autocorrelation coefficient is analagous to the partial correlation coefficient that looks at the correlation between two variables when the values of other correlated variables are kept constant.

[10] This is analagous to requiring that data be normal before results of general linear models such as Analysis of Variance and regression can be properly interpreted.

series. Differencing (subtracting each data value from the next data value in time) is a commonly used first transformation to produce stationarity. When data are differenced by 1, the time series is converted to a series of the hourly changes in the variable. When data are differenced by 2, they are converted to changes in hourly changes. Autocorrelation and partial correlation functions for each variable were plotted and visually inspected to determine what types of transformations were required to produce stationarity. In all cases, differencing by one was adequate to produce stationarity.

After a time series has been transformed so that it is stationary, patterns in the ACF and the PACF can be used to determine whether the series is predominantly an autoregressive (AR) process (i.e., data values are correlated with other data at certain time lags), a moving average (MA) or exponentially smoothed process, or a combination of both (ARMA). For example, if the ACF shows a rapid cut-off in the value of the ACCs after a certain time lag and/or the lag-one ACC is negative, a MA process of the order of the last significant time period is suggested (Diggle, 1990, Web site). If the ACF decays smoothly, the PACF can be checked. If the PACF shows a sharp cut-off and/or the first coefficient of the ACF is positive, then an AR process is suggested (Diggle, 1990, Web site). If the PACF does not show a cut-off, then an autoregressive-moving average (ARMA) process is suggested (Diggle, 1990). Diggle (p. 169) states "...we reemphasize that model identification as here presented is a subjective process, and that parsimony should be the guiding principle. If in doubt, we should opt for fewer rather than more parameters in the identified model, but include in the...diagnostic checking stage an assessment of whether additional parameters are needed to give an adequate fit."

After investigating the patterns of the stationary series, the series can be coded in terms of the number of lags involved in each process component (AR, I, MA), where the I indicates the number of times the data were differenced. For example, an undifferenced time series with a first-order autoregressive component would be coded (1,0,0). A time series that was differenced once and was a first-order moving average process would be coded (0,1,1).

5.5 Appendix D2. Results of Time Series Analyses.

5.5.1 Autocorrelation within variables

5.5.1.1 Whole time series

The Autocorrelation functions (ACFs) of all variables declined very slowly with time lag and coefficients for correlation between data values that were 1 hour apart (i.e., lag of 1) was close to 1 (perfect correlation). The Partial Autocorrelation functions (PACFs) indicated that a correlation between data values, when correlation caused by intervening data values was eliminated, became insignificant once data were 3 to 5 hours apart.

These characteristics indicated the need to difference all the variables to produce a stationary time series before the time series of different variables could be modeled and compared (See Appendix D1). After differencing (I = 1), all of the variables had stationary distributions and most of the variables were either autoregressive of order 1 to 3 or moving average processes of order 1 to 2.

DO and conductivity at NP3 appeared to be predominantly moving average processes (Table 1; Appendix D3, Figures 4,5), but the strength of the autocorrelation was low. DO concentration, DO saturation, and conductivity all hand negative, and very small, first autocorrelation coefficients after the series had been differenced. All variables at Lake Reba and temperature at NP3 had positive first ACCs of weak to moderate magnitude. Temperature has a strong cyclic pattern at both ponds such that temperatures that were 24 hours apart were similar, quite different than the temperature twelve hours earlier. The PACF indicates that a good deal of this pattern was due to correlation that was "passed" from hour to hour. The magnitude of the PACCs at longer lags was much lower than the magnitude of the ACC at a similar lag.

Table 1. Significant Autoregressive (AR) and Moving Average (MA) components of time series of DO, level, temperature, and conductivity at NP3 and Lake Reba for whole time series after time series were differenced to produce stationarity.

Variable	NP3	LR
DO concentration	MA(1)	AR(1-2)
DO % saturation	MA(2)	AR(2-3)
Level	AR(3)	AR(2)
Temperature	AR(2)	AR(2)
Conductivity	MA(1)	AR(2)

5.5.1.2 Treatment vs. control period

The time series of the treatment period was much shorter than the time series of the control period. In the cases of DO levels, water level, and water temperature at NP3, the autocorrelation pattern of the control period seemed to be repeated during the treatment period but the autocorrelation and partial autocorrelation coefficients became statistically insignificant because the sample size was so small (Table 2). For all other variables (all variables at Lake Reba and temperature and conductivity at NP3, a change in the pattern of the ACF and/or PACF was apparent). Because the sample sizes for the treatment periods were quite small, differences noted between treatment and control periods appeared relatively consistent using both definitions of deicing and it was not possible to distinguish effects of the definition of the treatment period on the ACFs of the variables.

5.5.2 Cross-correlations between variables

Because temporal patterns were not evindent in the CCFs as they were in the ACFs, correlations between variables were summarized using the Spearman Rank

Nonparametric Correlation Coefficient (Table 3). The strongest correlations were between level and temperature (*r* = -0.46, *r* = -0.74, Lake Reba and NP3 respectively), level and conductivity (*r* = -0.80, *r* = -0.76, Lake Reba and NP3 respectively), and DO percent saturation and temperature (*r* = 0.52 and *r* = 0.60, Lake Reba and NP3 respectively). DO concentration was moderately correlated with temperature at NP3 (*r* = 0.45).

Table 2. Significant Autoregressive (AR) and Moving Average (MA) components of time series of DO, level, temperature, and conductivity at NP3 and Lake Reba for treatment and control periods after time series were differenced to produce stationarity.

Variable	NP3 control	NP3 treatment	LR control	LR treatment
DO concentration	MA(1)	MA(1)*	AR(2)	AR(2)*^
DO % saturation	MA(2)	MA(1)*	AR(3)	AR(1)*^
Level	AR(3)	AR(2)*	AR(2)	AR(2)^
Temperature	AR(2-3)	AR(2)^	AR(2)	AR(1)*^
Conductivity	MA(3)	AR(1)^	AR(2)	AR(1)*^

* similar pattern but not all AR or MA coefficients significant due to small sample size

^ ACFs and PACFs for 2 periods have different shapes

Table 3. Nonparametric Spearman Rank Correlation between variables (equivalent to lag 0 nonparametric cross correlation).

		DO % saturation	Conductivity	Level	Temp
Lake Reba DO	R	**0.95**	**0.10**	**-0.11**	**0.26**
	P	<0.001	<0.001	<0.001	<0.001
	N	3925	3931	2855	3932
Lake Reba DO % saturation	R		**0.20**	**-0.30**	**0.52**
	P		<0.001	<0.001	<0.001
	N		4225	3198	4226
Lake Reba Conductivity	R			**-0.80**	**0.34**
	P			<0.001	<0.001
	N			2855	4233
Lake Reba Level	R				**-0.46**
	P				<0.001
	N				2855
NP3 DO	R	**0.97**	**0.03**	**-0.23**	**0.45**
	P	<0.001	<0.001	<0.001	<0.001
	N	3202	3202	1745	3202
NP3 DO % saturation	R		**0.16**	**-0.43**	**0.60**
	P		<0.001	<0.001	<0.001
	N		3501	2043	3501
NP3 Conductivity	R			**-0.76**	**0.39**
	P			<0.001	<0.001
	N			2325	3783
NP3 Level	R				**-0.74**
	P				<0.001
	N				2325

R: Spearman Rank Correlation Coefficient

P: Probability that Correlation = 0

N: Sample size

5.6 *Appendix D3. Autocorrelation and Partial Autocorrelation Coefficient Graphics*

Appendix D3. Figure 1.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for: DO concentration and DO % saturation in Northwest Pond Cell 3 and Lake Reba: full time series.

Appendix D3. Figure 2.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for: temperature and conductivity in Northwest Pond Cell 3 and Lake Reba: full time series.

Appendix D3. Figure 3.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for: water level in Northwest Pond Cell 3 and Lake Reba: full time series.

Appendix D3. Figure 4.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for: DO concentration and DO % saturation in Northwest Pond Cell 3 and Lake Reba: full time series.

Appendix D3. Figure 5.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for: temperature and conductivity in Northwest Pond Cell 3 and Lake Reba: full time series.

Appendix D3. Figure 6.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for: water level in Northwest Pond Cell 3 and Lake Reba: full time series.

Appendix D3. Figure 7.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for DO concentration in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 8.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for DO percent saturation in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 9.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for water level in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 10.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for water temperature in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 11.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for conductivity in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 12.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for DO concentration in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 13.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for DO % saturation in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 14.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for water level in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 15.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for water temperature in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

Appendix D3. Figure 16.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for conductivity in Northwest Pond Cell 3 and Lake Reba: control and treatment period time series.

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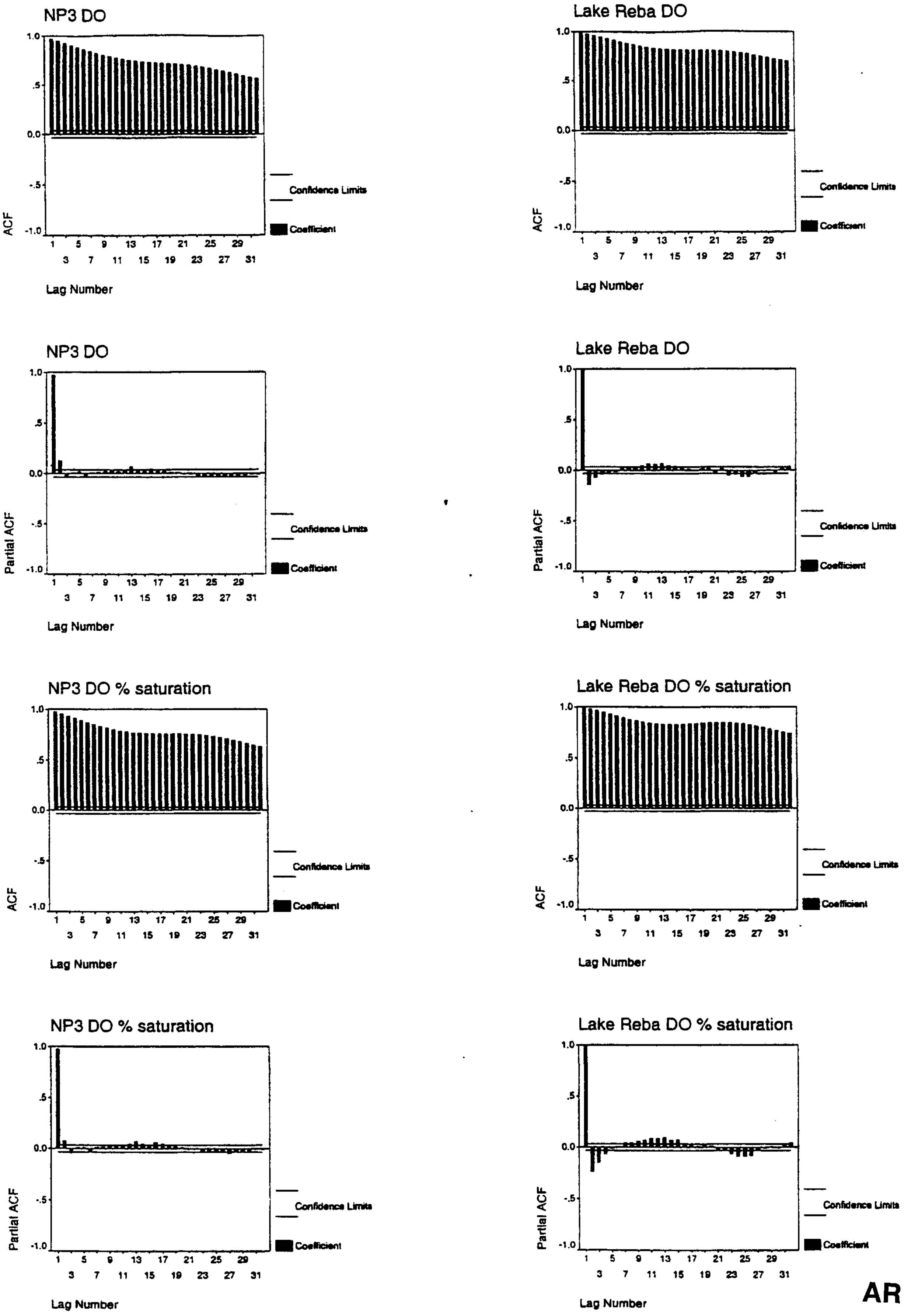
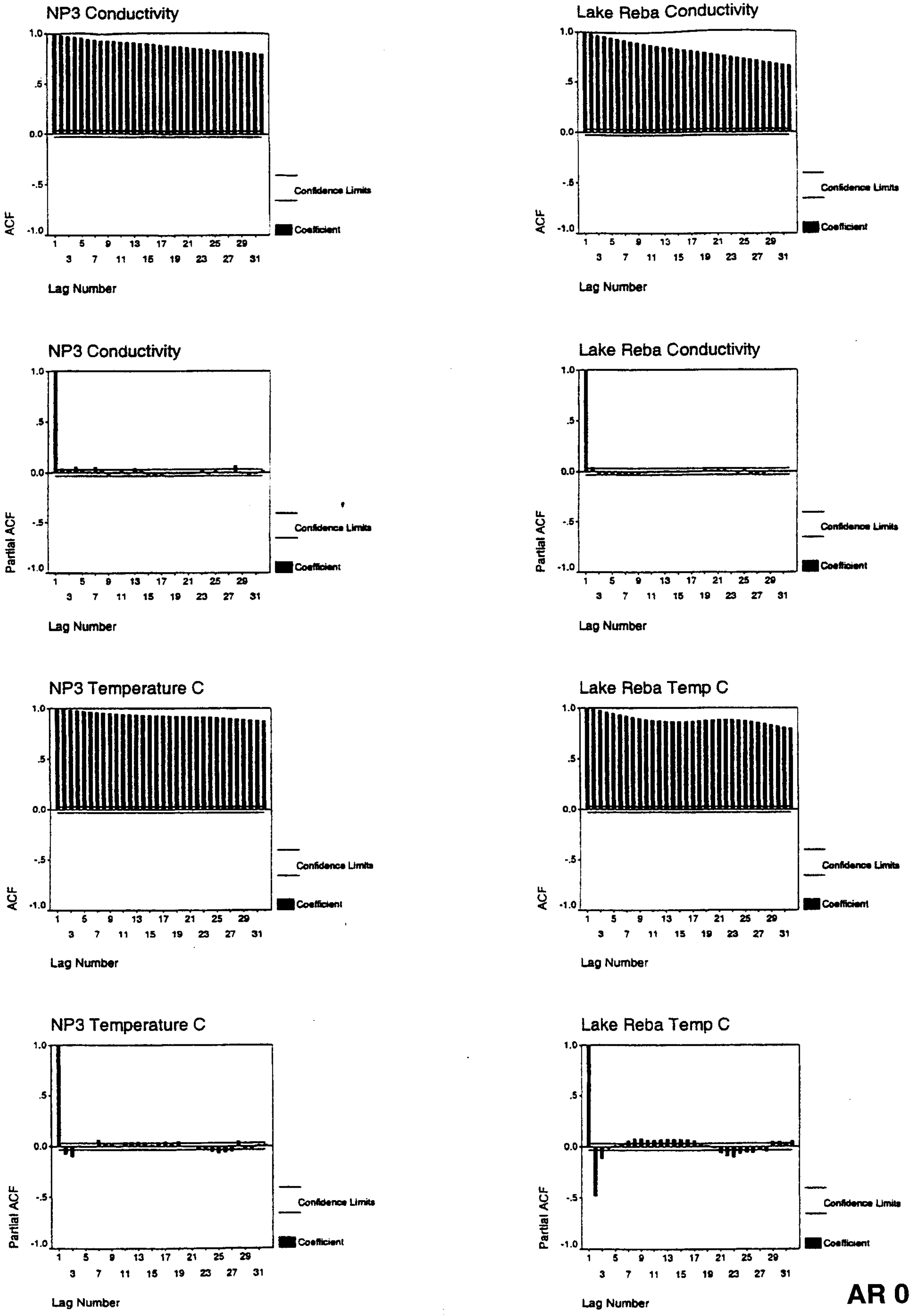


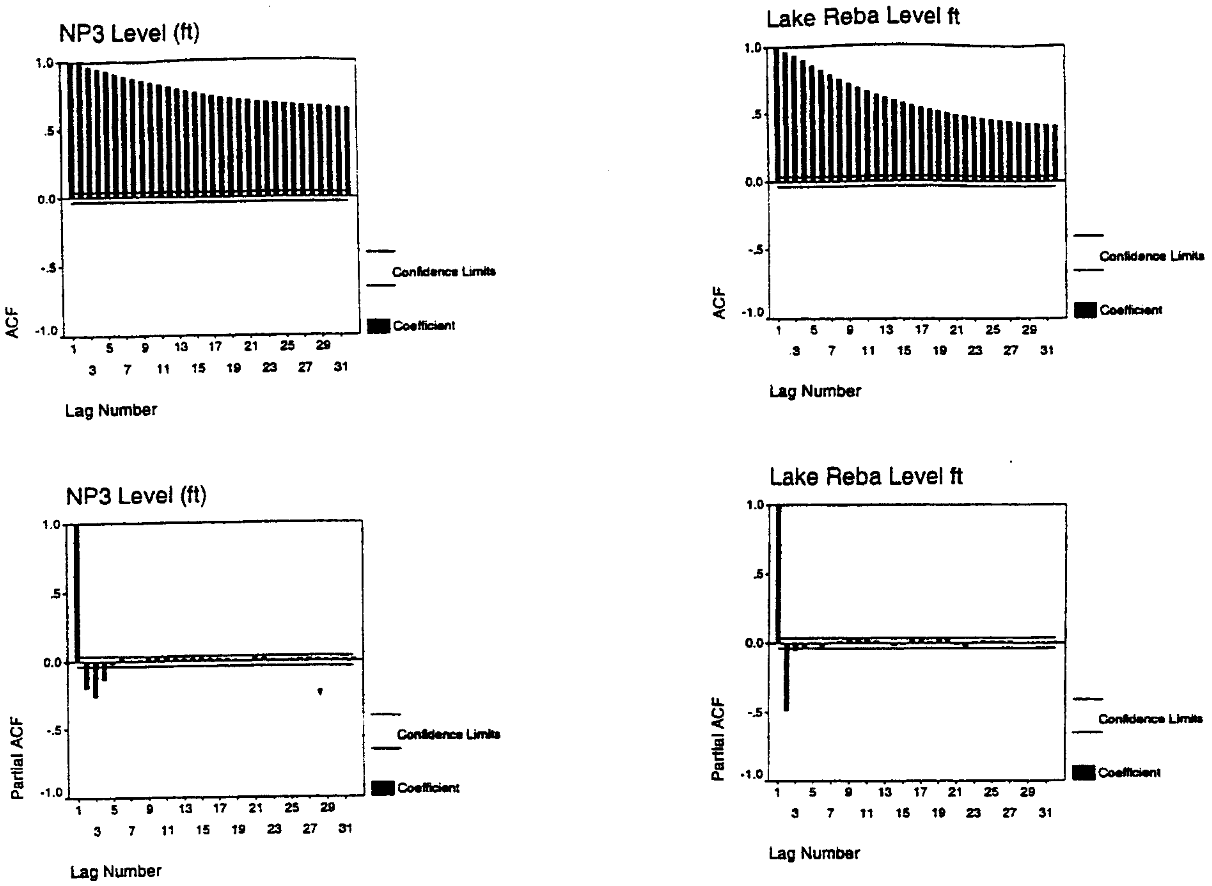
Appendix D3. Figure 1.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for:
DO concentration and DO % saturation in Northwest Pond Cell 3 and Lake Reba: full time series.



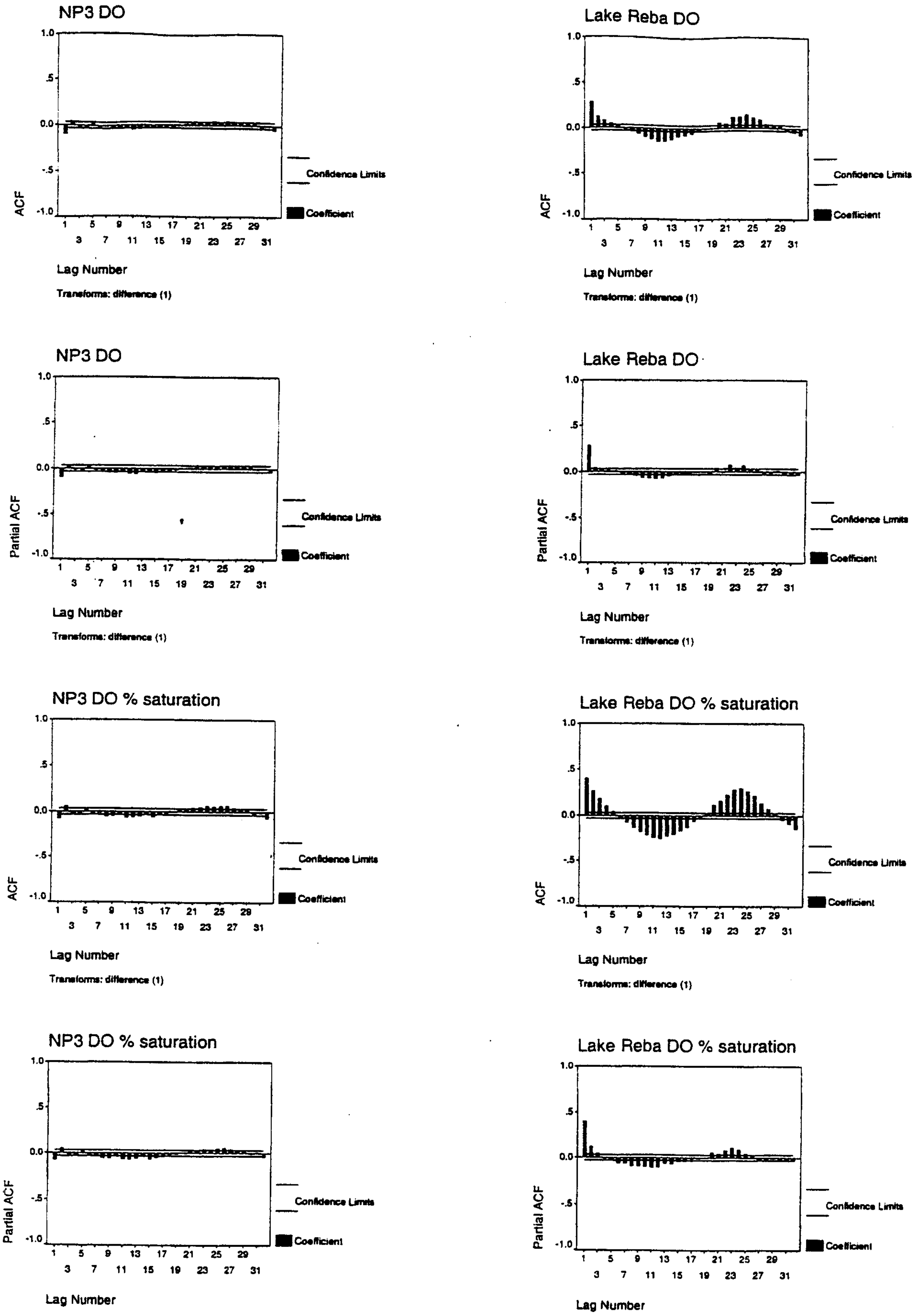
Appendix D3. Figure 2.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for: temperature and conductivity in Northwest Pond Cell 3 and Lake Reba: full time series.



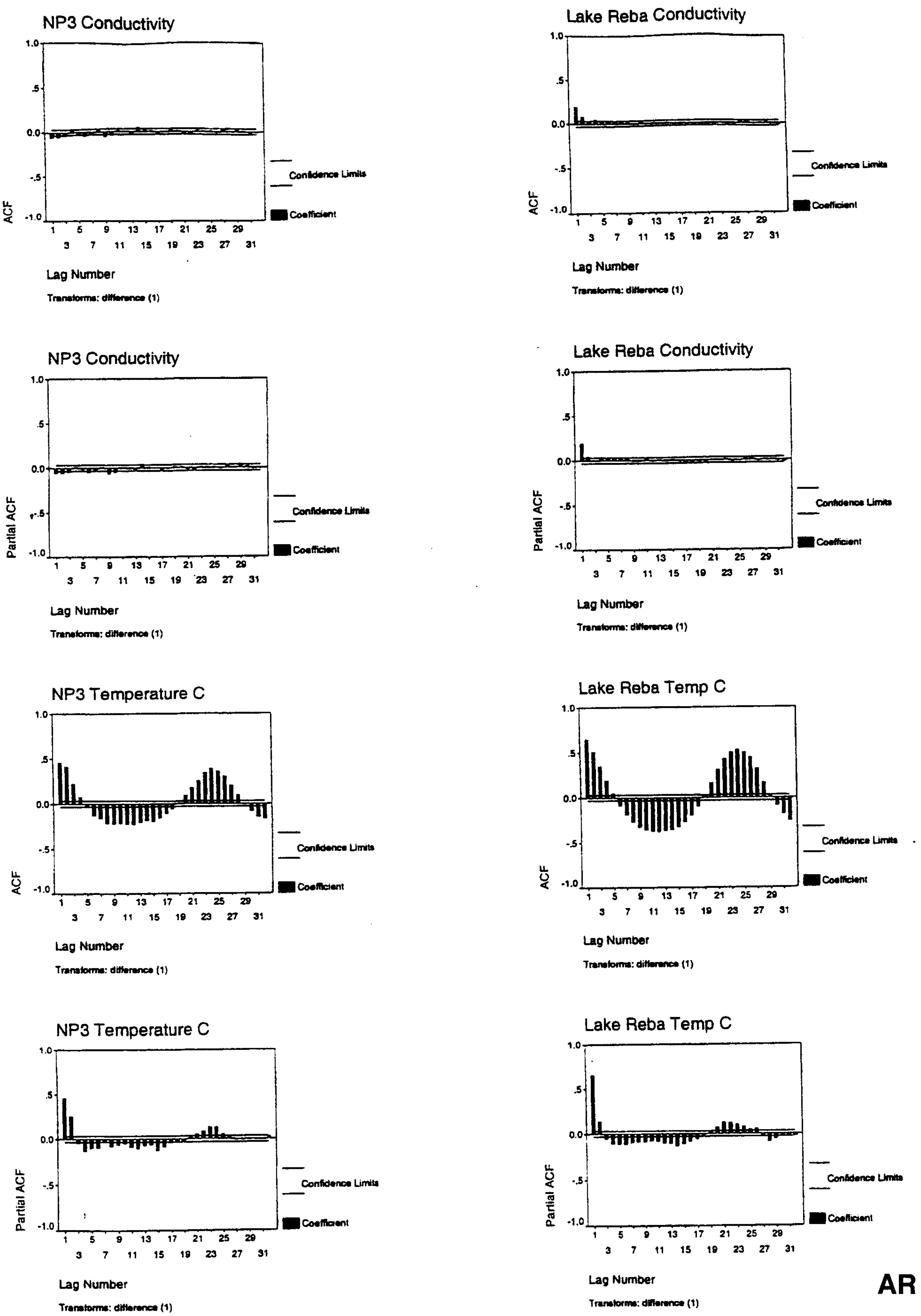
Appendix D3. Figure 3.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for: water level in Northwest Pond Cell 3 and Lake Reba: full time series.



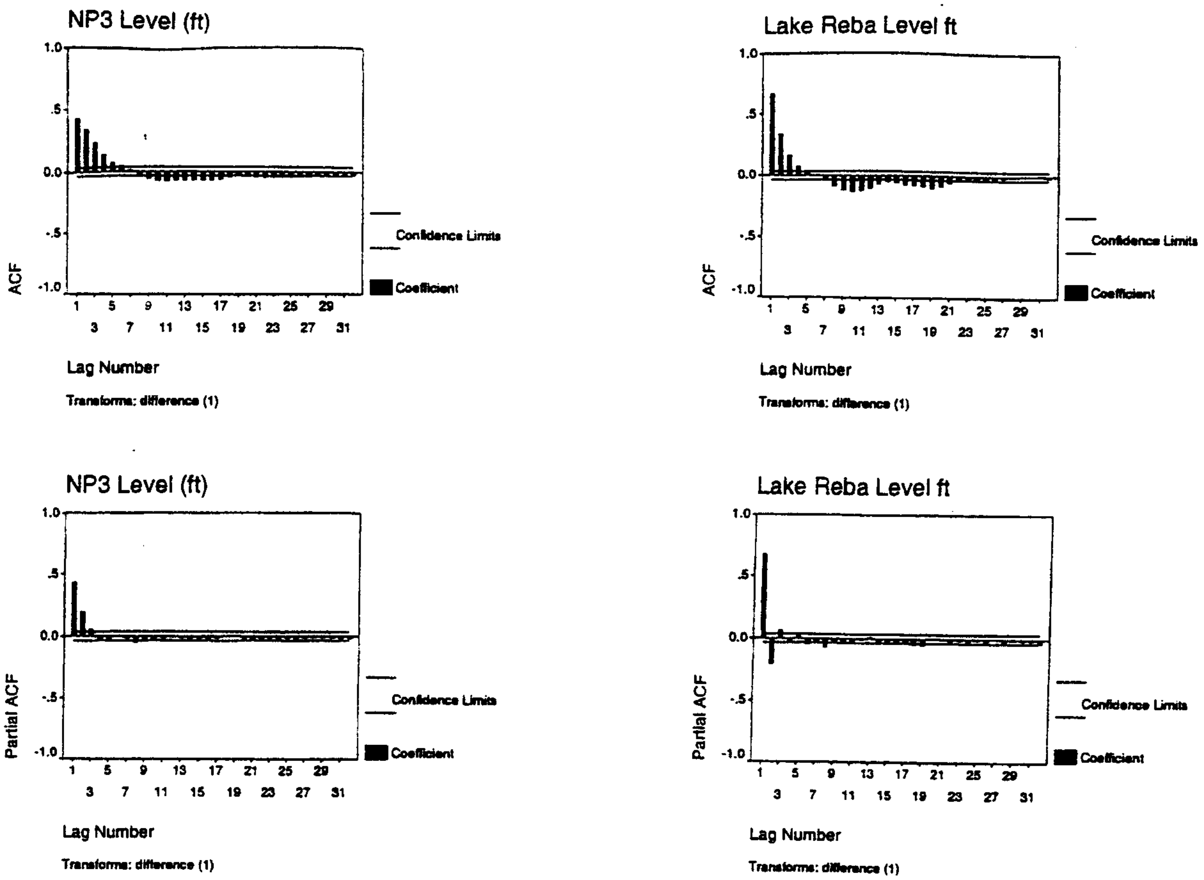
Appendix D3. Figure 4.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for: DO concentration and DO % saturation in Northwest Pond Cell 3 and Lake Reba: full time series.



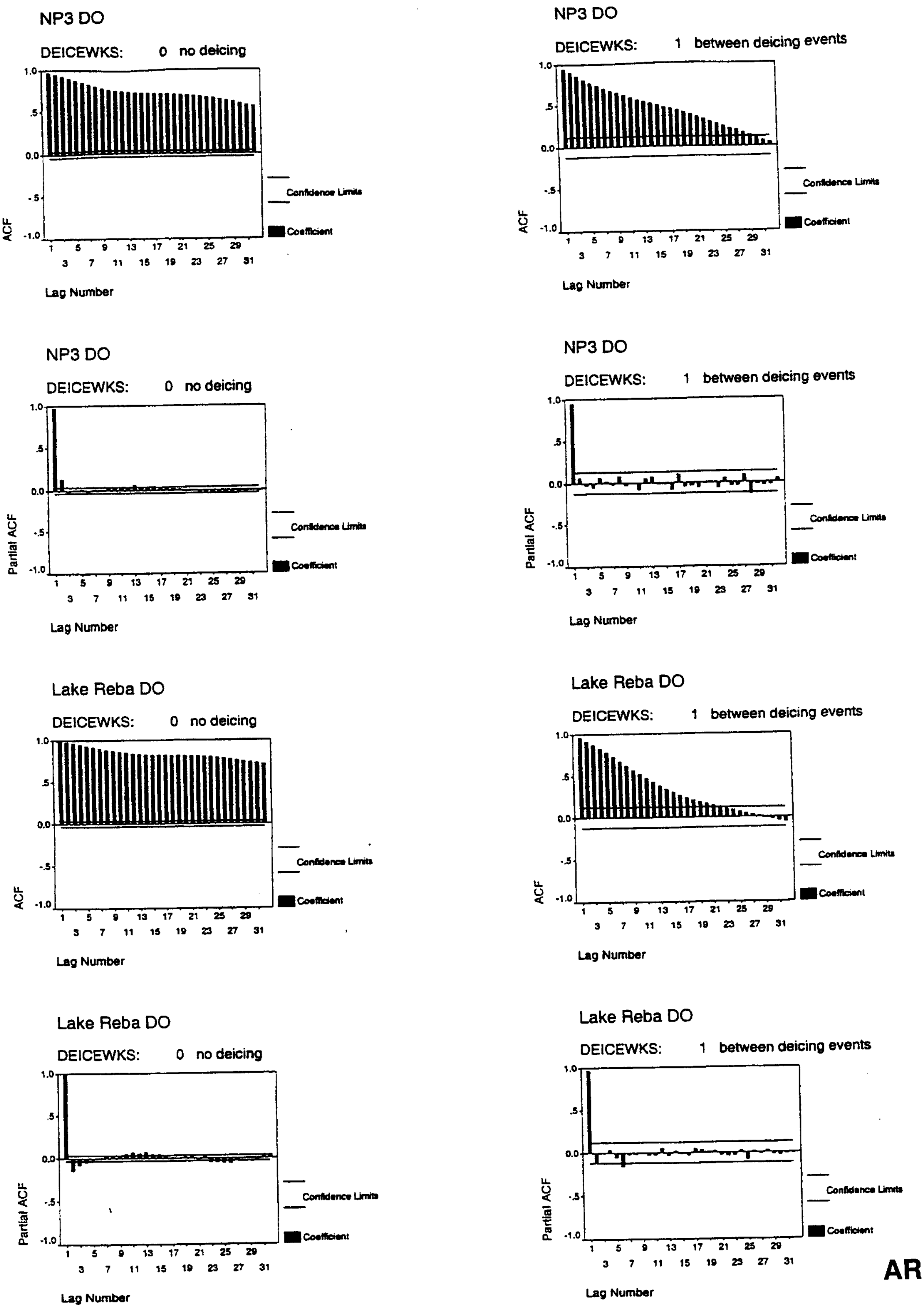
Appendix D3. Figure 5.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for: temperature and conductivity in Northwest Pond Cell 3 and Lake Reba: full time series.



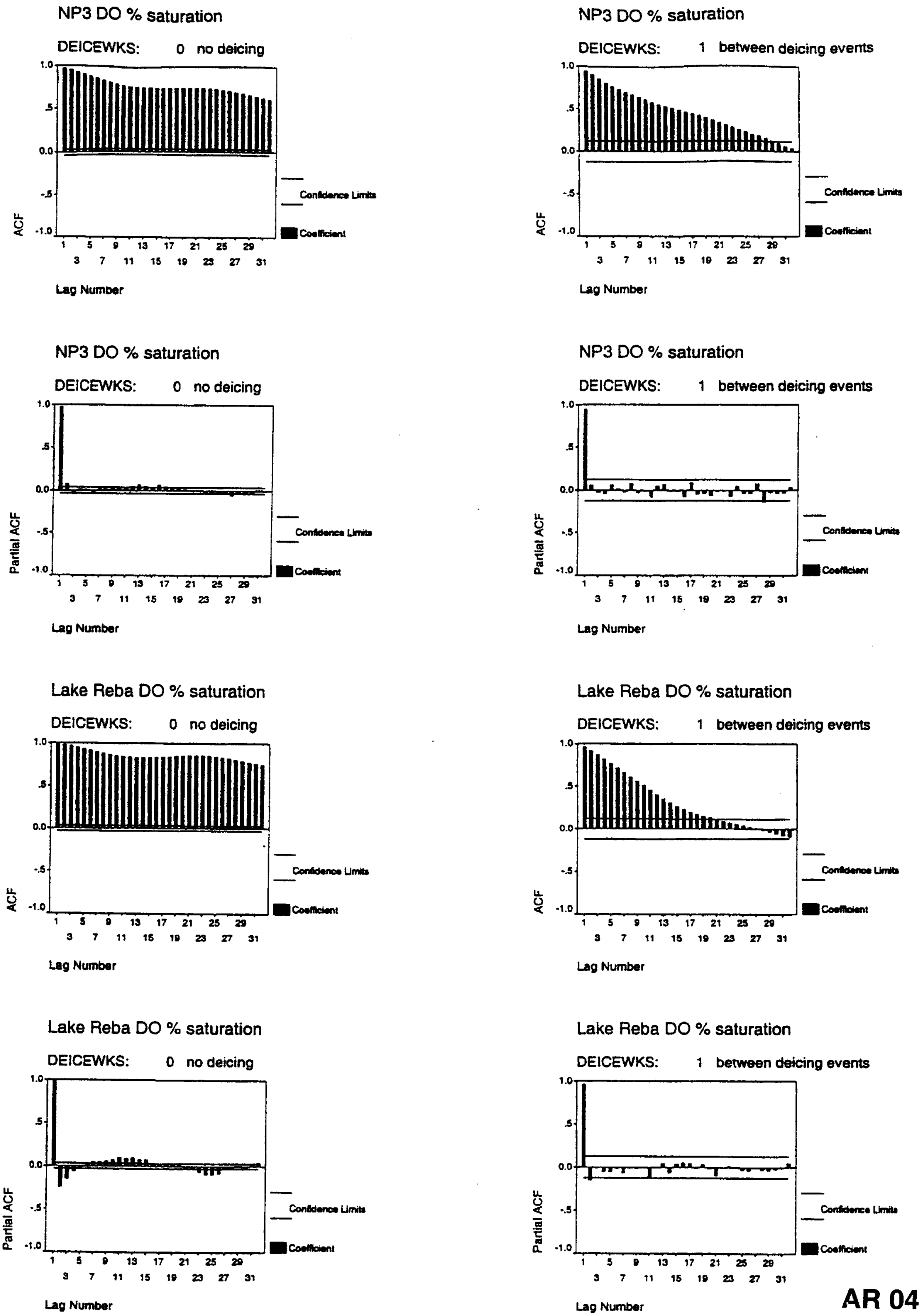
Appendix D3. Figure 6.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for: water level in Northwest Pond Cell 3 and Lake Reba: full time series.



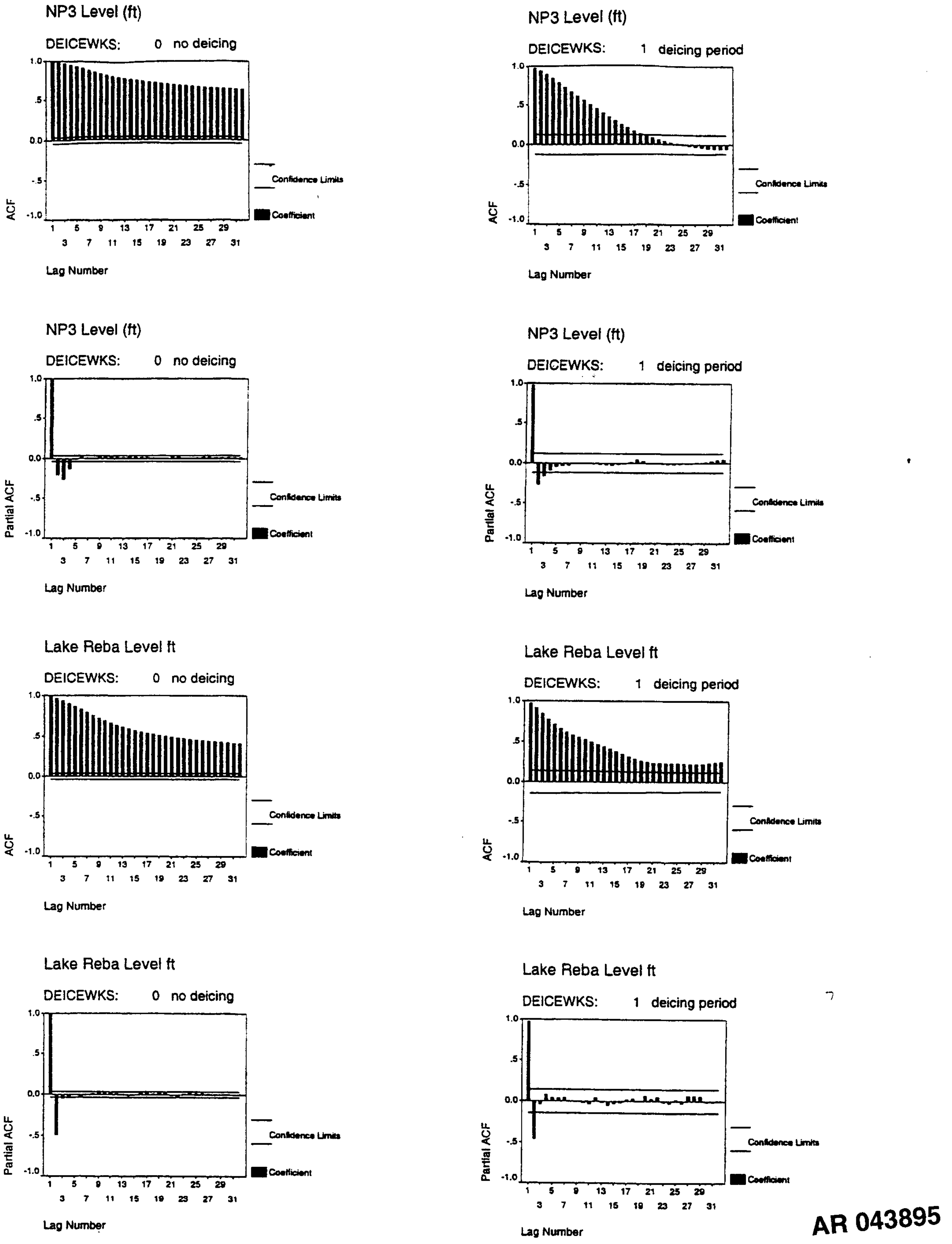
Appendix D3. Figure 7.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for DO concentration in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.



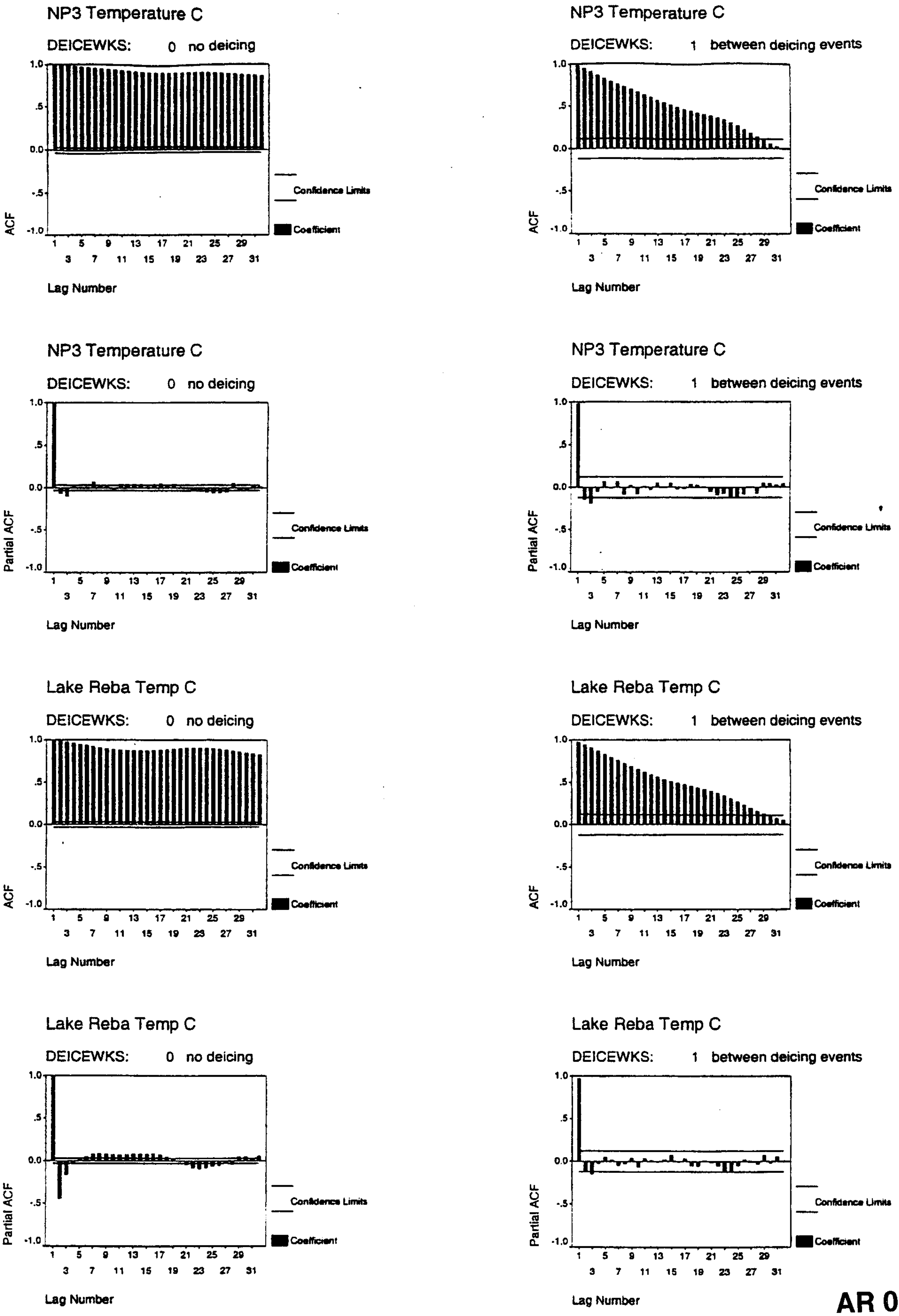
Appendix D3. Figure 8.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for DO % saturation in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.



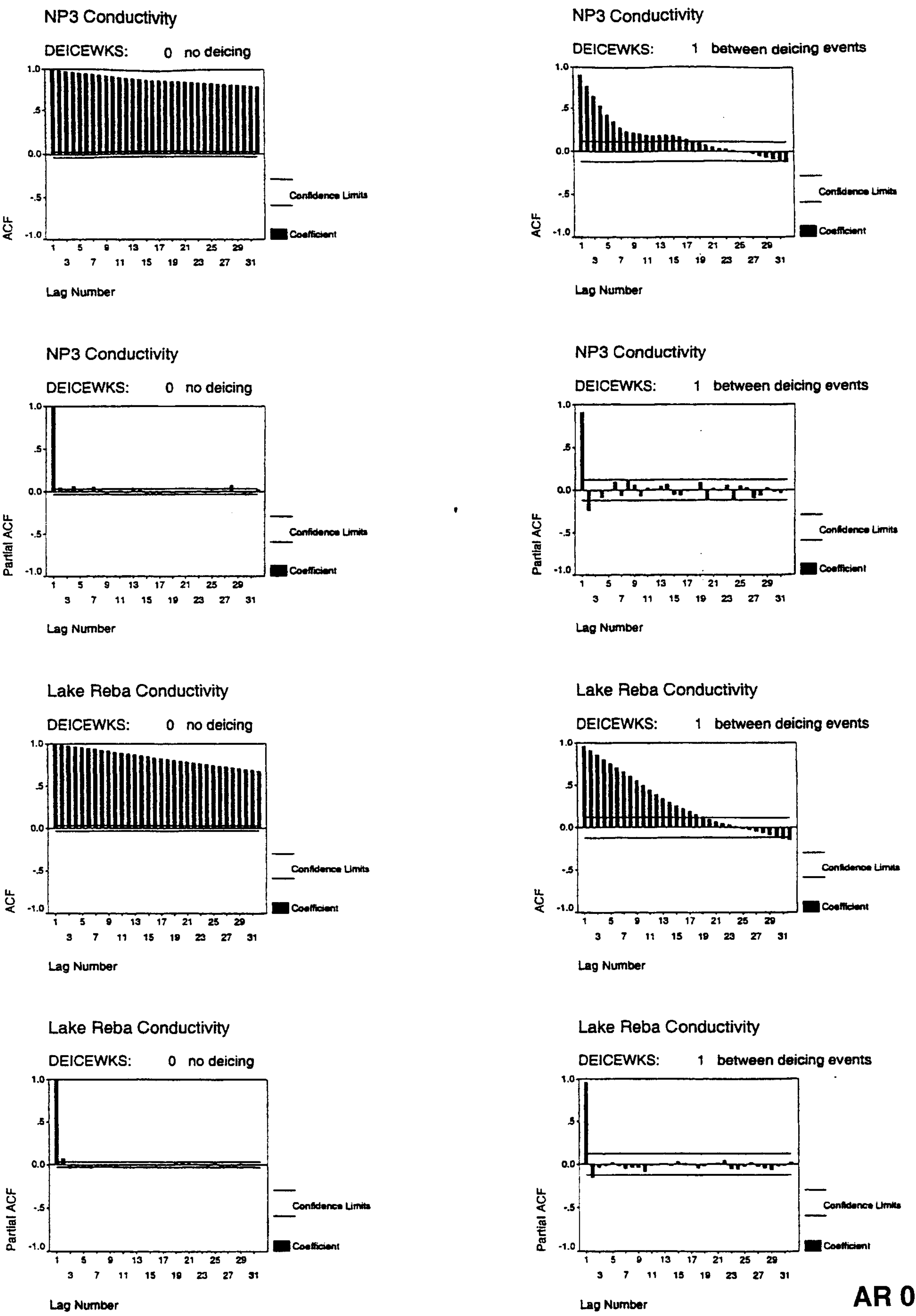
Appendix D3. Figure 9.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for water level in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.



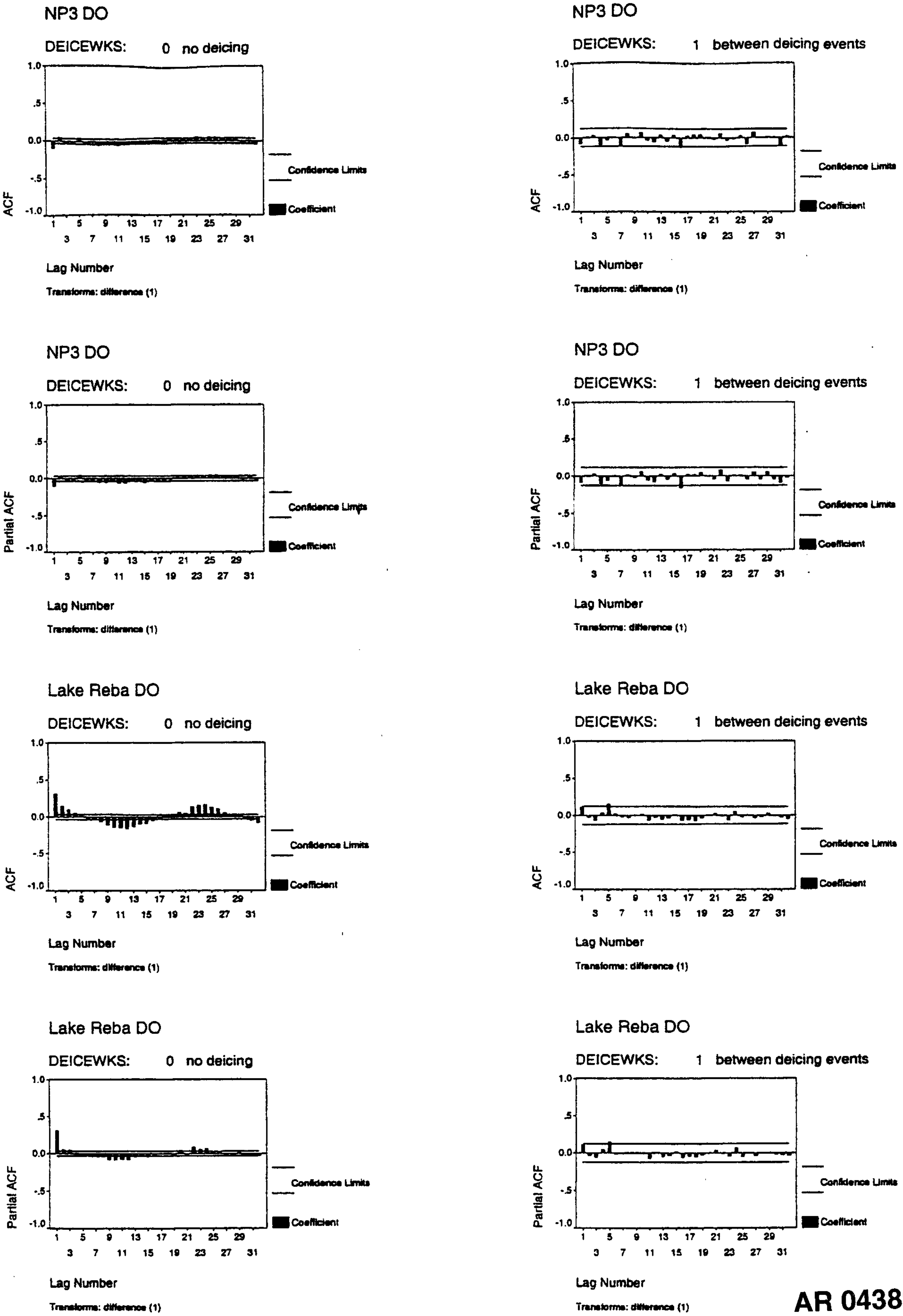
Appendix D3. Figure 10.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for water temperature in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.



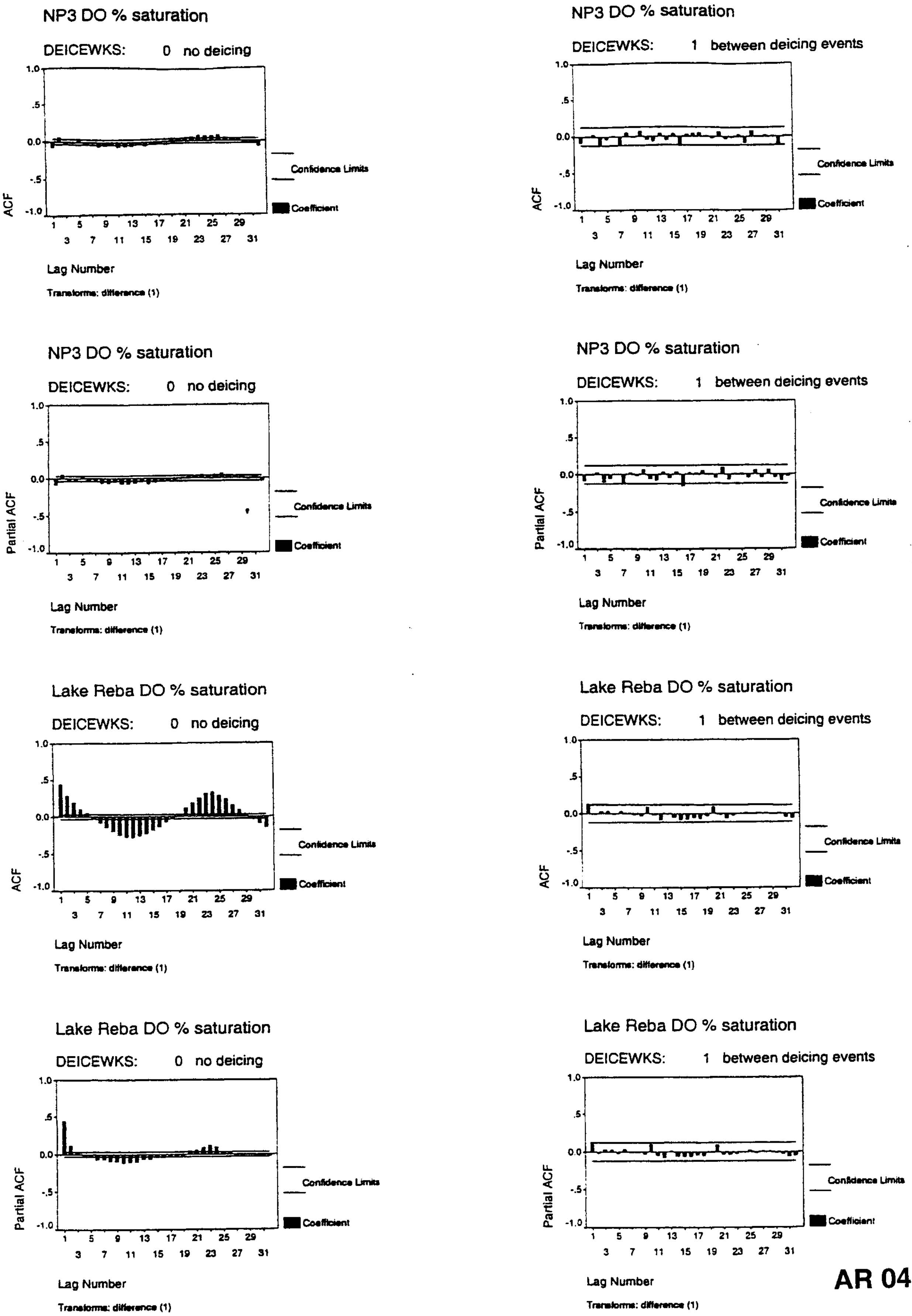
Appendix D3. Figure 11.

Autocorrelation and partial autocorrelation functions of (untransformed) time series data for conductivity in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.



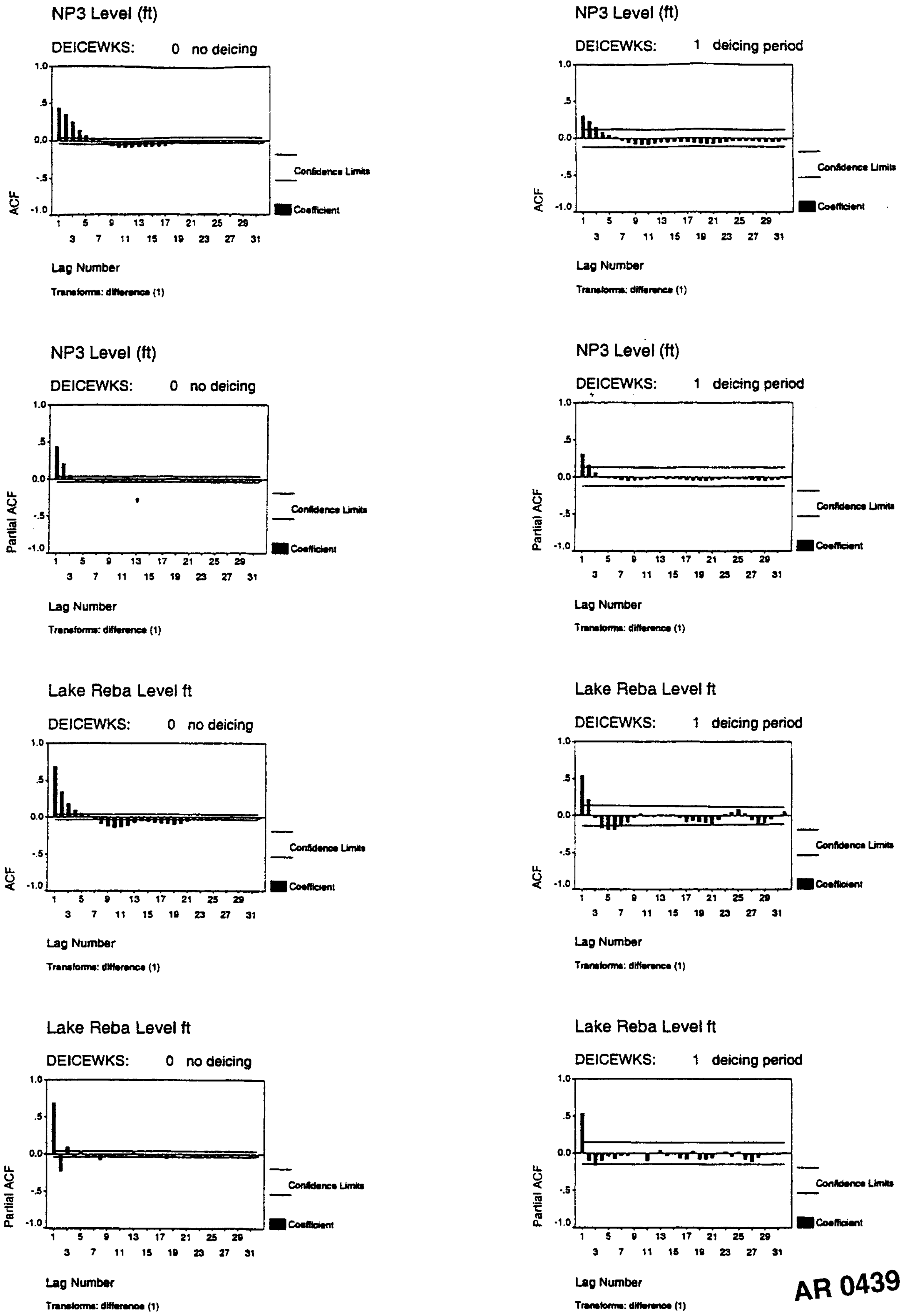
Appendix D3. Figure 12.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for DO concentration in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.



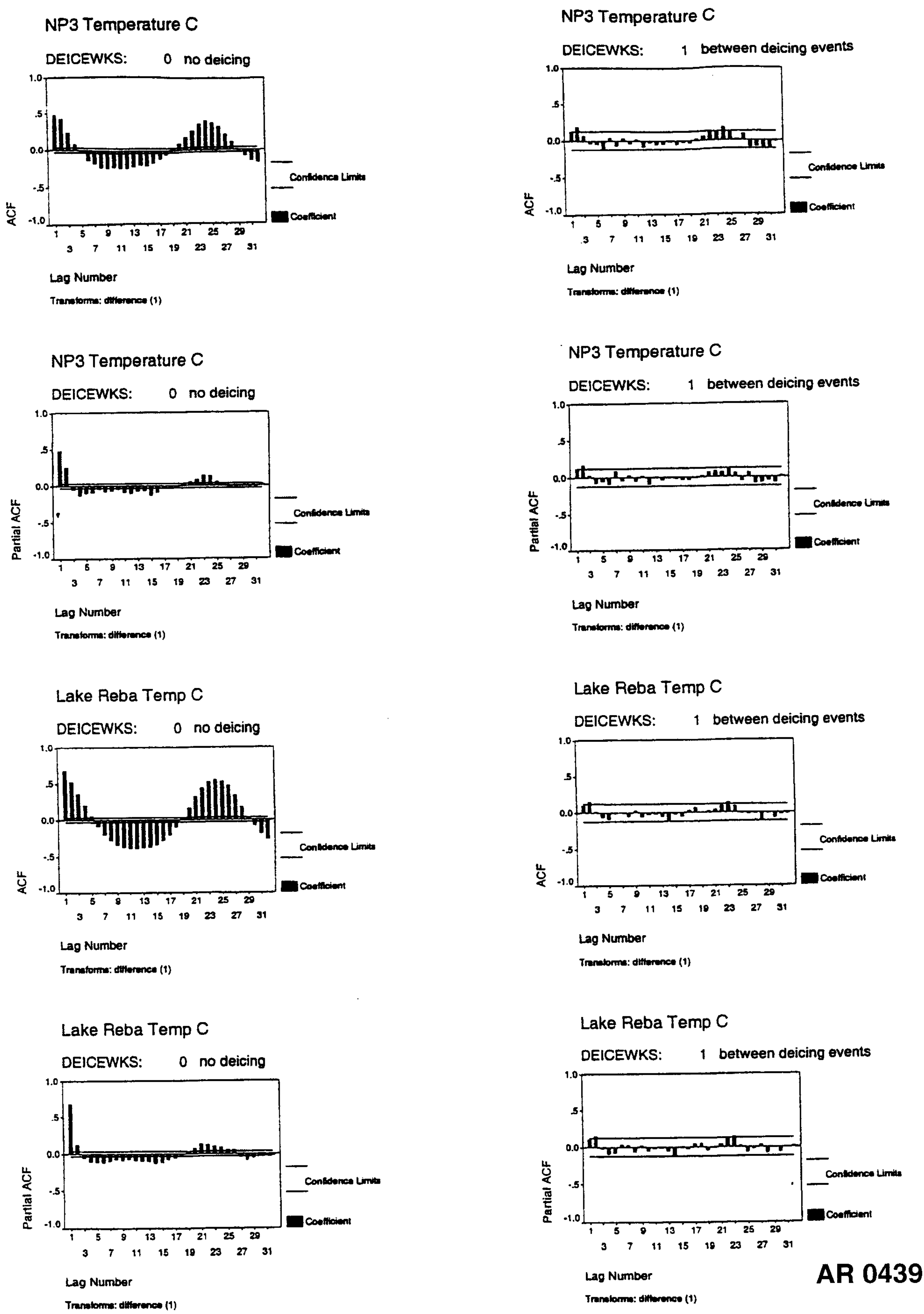
Appendix D3. Figure 13.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for DO % saturation in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.



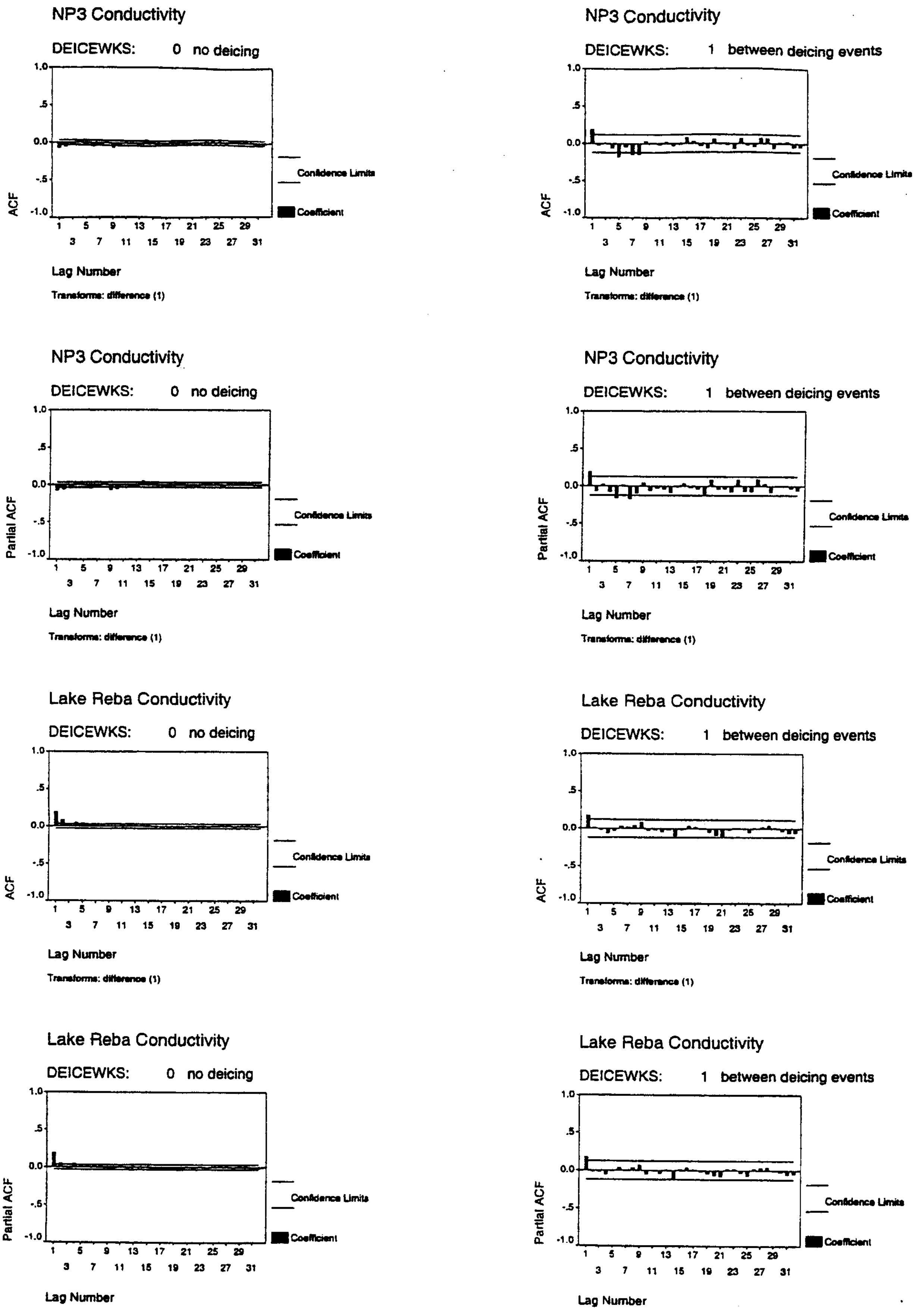
Appendix D3. Figure 14.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for water level in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.



Appendix D3. Figure 15.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for water temperature in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.


NP3 Conductivity

DEICEWKS: 0 no deicing

NP3 Conductivity

DEICEWKS: 1 between deicing events

NP3 Conductivity

DEICEWKS: 0 no deicing

NP3 Conductivity

DEICEWKS: 1 between deicing events

Lake Reba Conductivity

DEICEWKS: 0 no deicing

Lake Reba Conductivity

DEICEWKS: 1 between deicing events

Lake Reba Conductivity

DEICEWKS: 0 no deicing

Lake Reba Conductivity

DEICEWKS: 1 between deicing events

Appendix D3. Figure 16.

Autocorrelation and partial autocorrelation functions of (differenced) time series data for conductivity in Northwest Pond Cell 3 and Lake Reba: non deicing and deicing period time series.

5.7 *Appendix D4. Graphs of Cross Correlation Coefficients*

Note: PD = percent change
1, 6, 8 = hours of change
DO = DO concentration
DOS = DO % saturation
T = Temperature
C = Conductivity
L = Level
NP = NP3
LR = Lake Reba

For example:

PD1DONP = percent change over 1 hour intervals in DO concentration at NP3
PD6TLR = percent change over 6 hour intervals in temperature at Lake Reba

Appendix D4. Figure 1.

Cross-correlation functions of (untransformed) time series data for: DO concentration and DO % saturation, water level, temperature, and conductivity in Northwest Pond Cell 3 and Lake Reba.

Appendix D4. Figure 2.

Cross-correlation functions of (untransformed) time series data for: DO % saturation and water level, temperature, and conductivity in Northwest Pond Cell 3 and Lake Reba.

Appendix D4. Figure 3.
Cross-correlation functions of (untransformed) time series data for: temperature, water level, and conductivity in Northwest Pond Cell 3 and Lake Reba.

Appendix D4. Figure 4.
Cross-correlation functions of (untransformed) time series data for percent changes over 1 hour periods in: (column 1) DO concentration with DO % saturation, water level, conductivity, and temperature; (column 2) DO % saturation with water level, conductivity, and temperature; and water level with conductivity for Northwest Pond Cell 3: full time series.

Appendix D4. Figure 5.
Cross-correlation functions of (untransformed) time series data for percent changes over 1 hour periods in: (column 1) water level with temperature, conductivity with temperature in Northwest Pond Cell 3; DO concentration with DO percent saturation, water level in Lake Reba and (column 2) DO concentration with conductivity, and temperature; DO % saturation with water level and conductivity in Lake Reba: full time series.

Appendix D4. Figure 6.
Cross-correlation functions of (untransformed) time series data for percent changes over 1 hour periods in: DO % saturation with temperature and water level; water level with temperature, conductivity with temperature for Lake Reba: full time series.

Appendix D4. Figure 7.
Cross-correlation functions of (untransformed) time series data for percent changes over 6 hour periods in: (column 1) DO concentration with DO % saturation, water level, conductivity, and temperature; (column 2) DO % saturation with water level, conductivity, and temperature; and water level with conductivity for Northwest Pond Cell 3: full time series.

Appendix D4. Figure 8.
Cross-correlation functions of (untransformed) time series data for percent changes over 6 hour periods in: (column 1) water level with temperature, conductivity with temperature in Northwest Pond Cell 3; DO concentration with DO percent saturation, water level in Lake Reba and (column 2) DO concentration with conductivity, and temperature; DO % saturation with water level and conductivity in Lake Reba: full time series.

Appendix D4. Figure 9.
Cross-correlation functions of (untransformed) time series data for percent changes over 6 hour periods in: DO % saturation with temperature and water level; water level with temperature, conductivity with temperature for Lake Reba: full time series.

Appendix D4. Figure 10.
Cross-correlation functions of (untransformed) time series data for percent changes over 8 hour periods in: (column 1) DO concentration with DO % saturation, water level, conductivity, and temperature; (column 2) DO % saturation with water level, conductivity, and temperature; and water level with conductivity for Northwest Pond Cell 3: full time series.

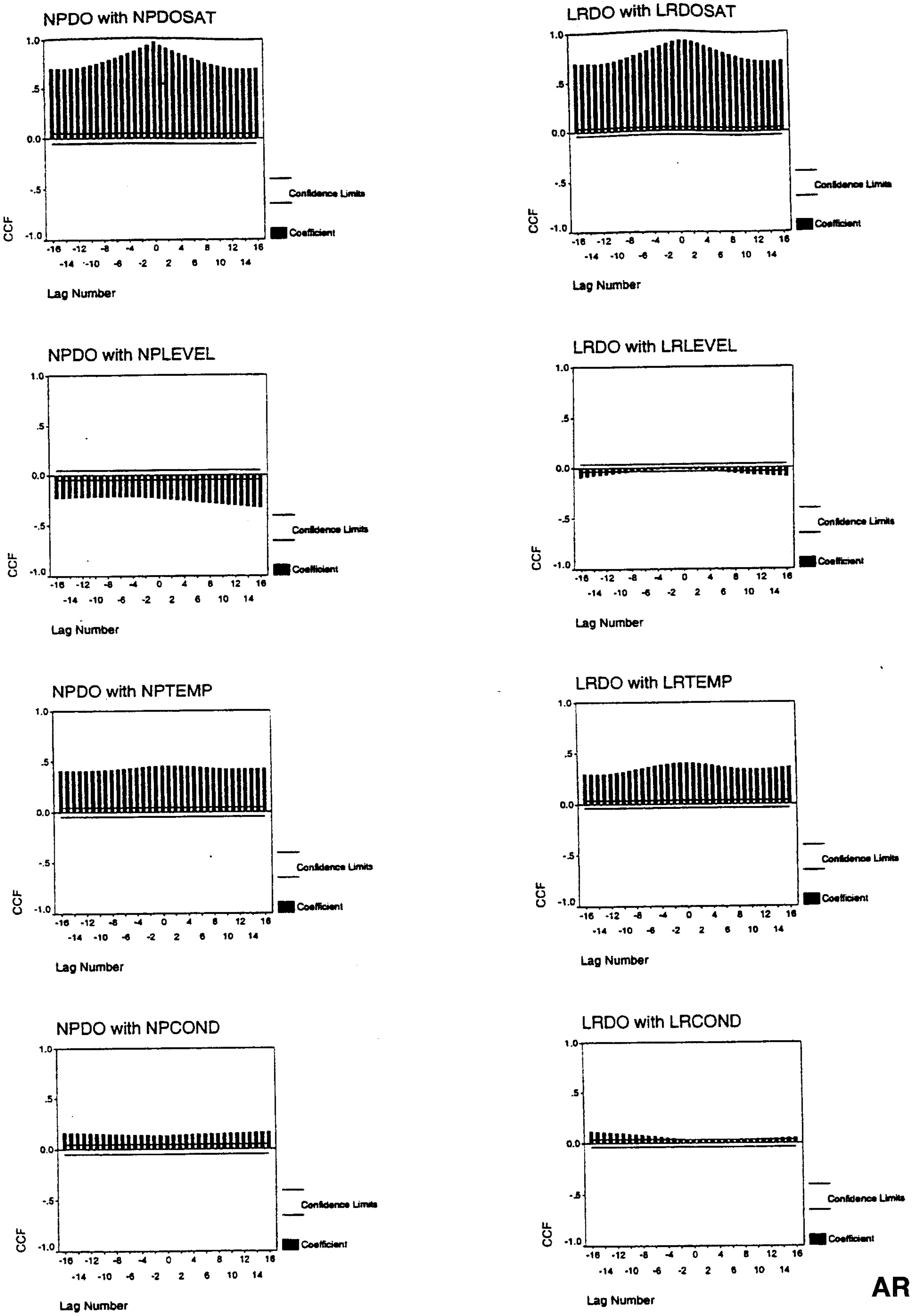
Appendix D4. Figure 11.
Cross-correlation functions of (untransformed) time series data for percent changes over 8 hour periods in: (column 1) water level with temperature, conductivity with temperature in Northwest Pond Cell 3; DO concentration with DO percent saturation, water level in Lake Reba and (column 2) DO concentration with conductivity, and temperature; DO % saturation with water level and conductivity in Lake Reba: full time series.

Appendix D4. Figure 12.

Cross-correlation functions of (untransformed) time series data for percent changes over 8 hour periods in: DO % saturation with temperature and water level; water level with temperature, conductivity with temperature for Lake Reba: full time series.

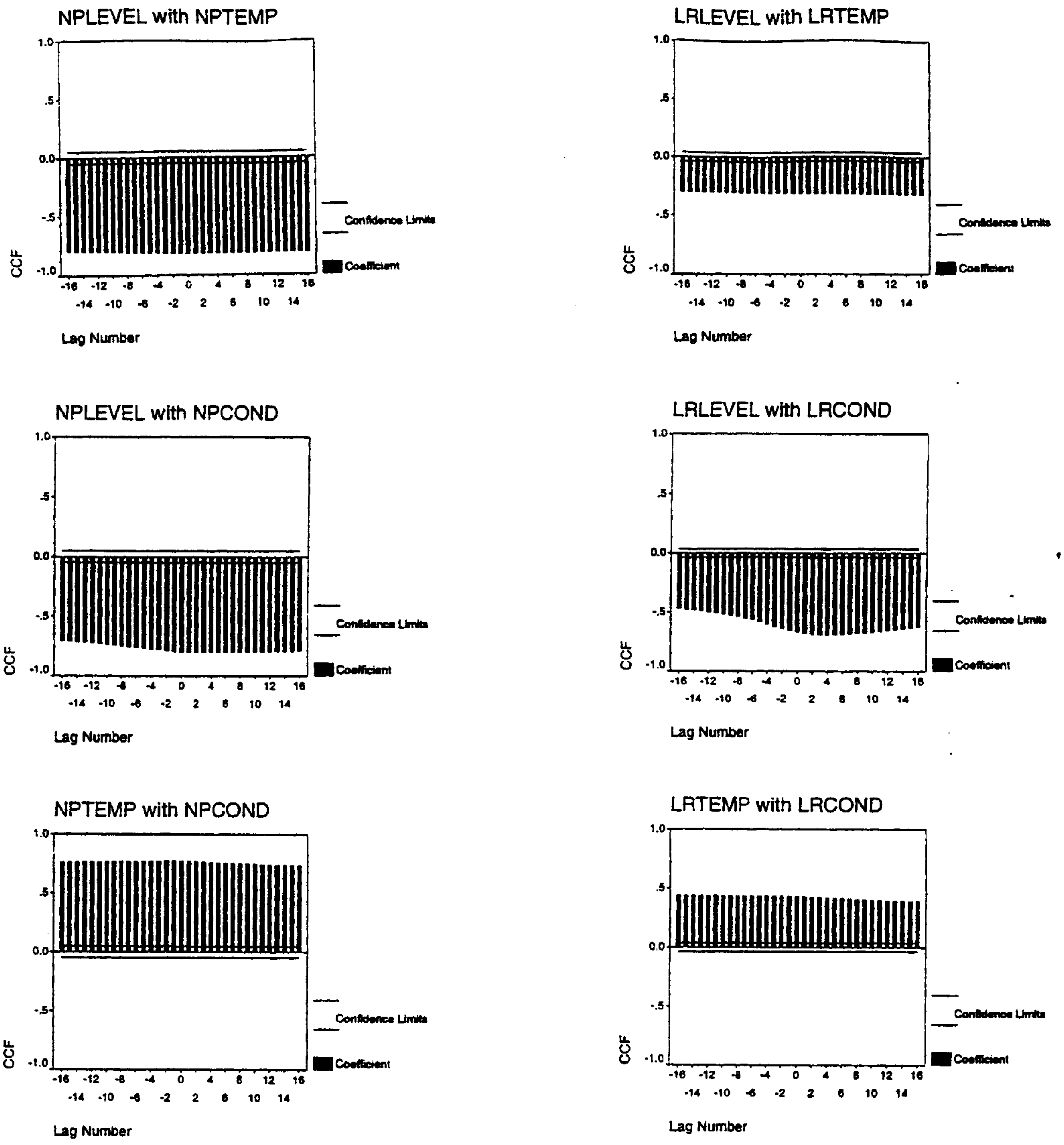
Appendix D4. Figure 13.

Cross-correlation functions of (untransformed) comparing time series data in NP3 and Lake Reba for: DO concentration, DO % saturation, water level, temperature, and conductivity; full time series.



Appendix D4. Figure 1.

Cross correlation functions of (untransformed) time series data for: DO concentration and DO % saturation, water level, temperature, and conductivity in Northwest Pond Cell 3 and Lake Reba.



NPLEVEL with NPTEMP

LRLEVEL with LRTEMP

NPLEVEL with NPCOND

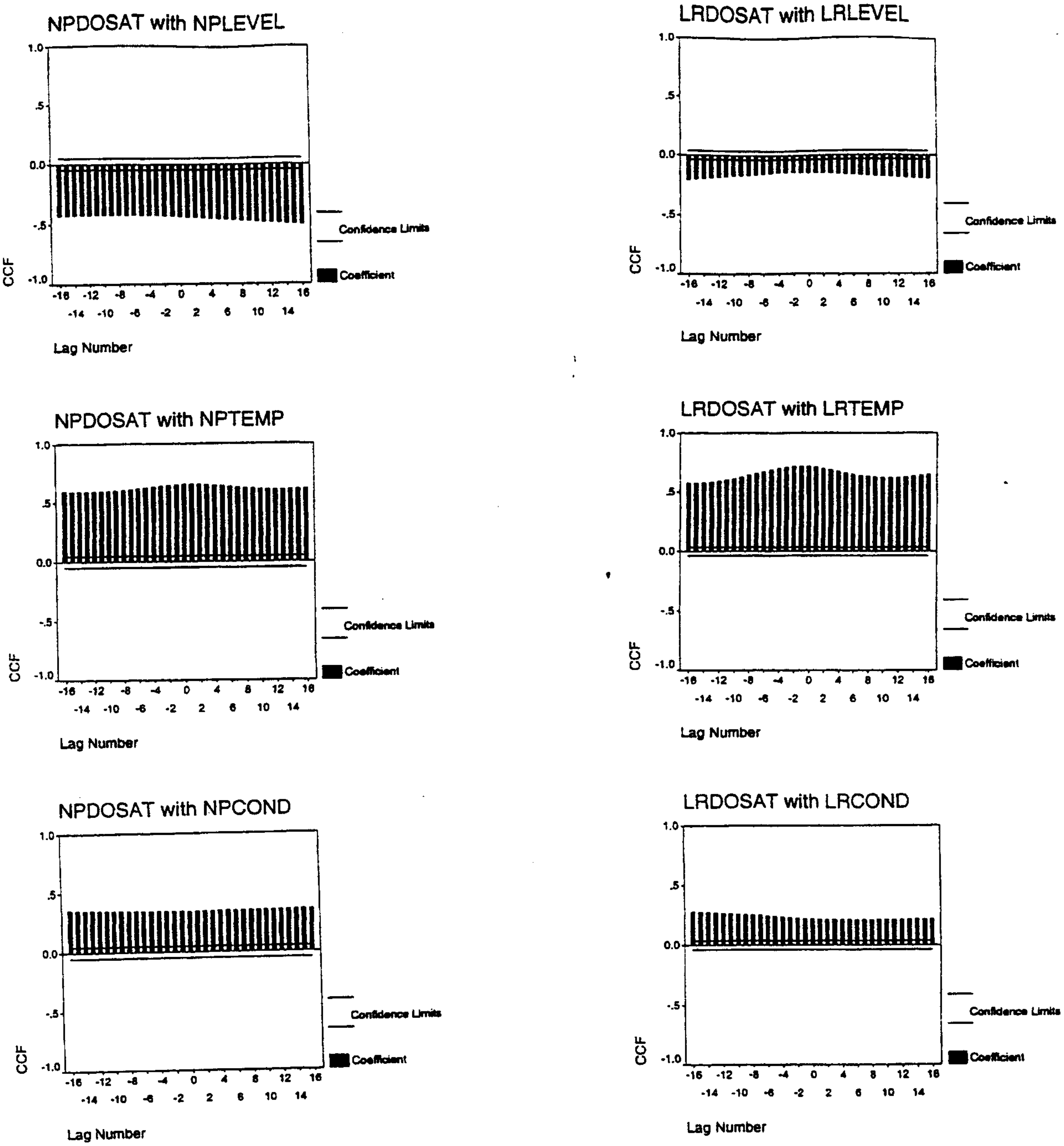
LRLEVEL with LRCOND

NPTEMP with NPCOND

LRTEMP with LRCOND

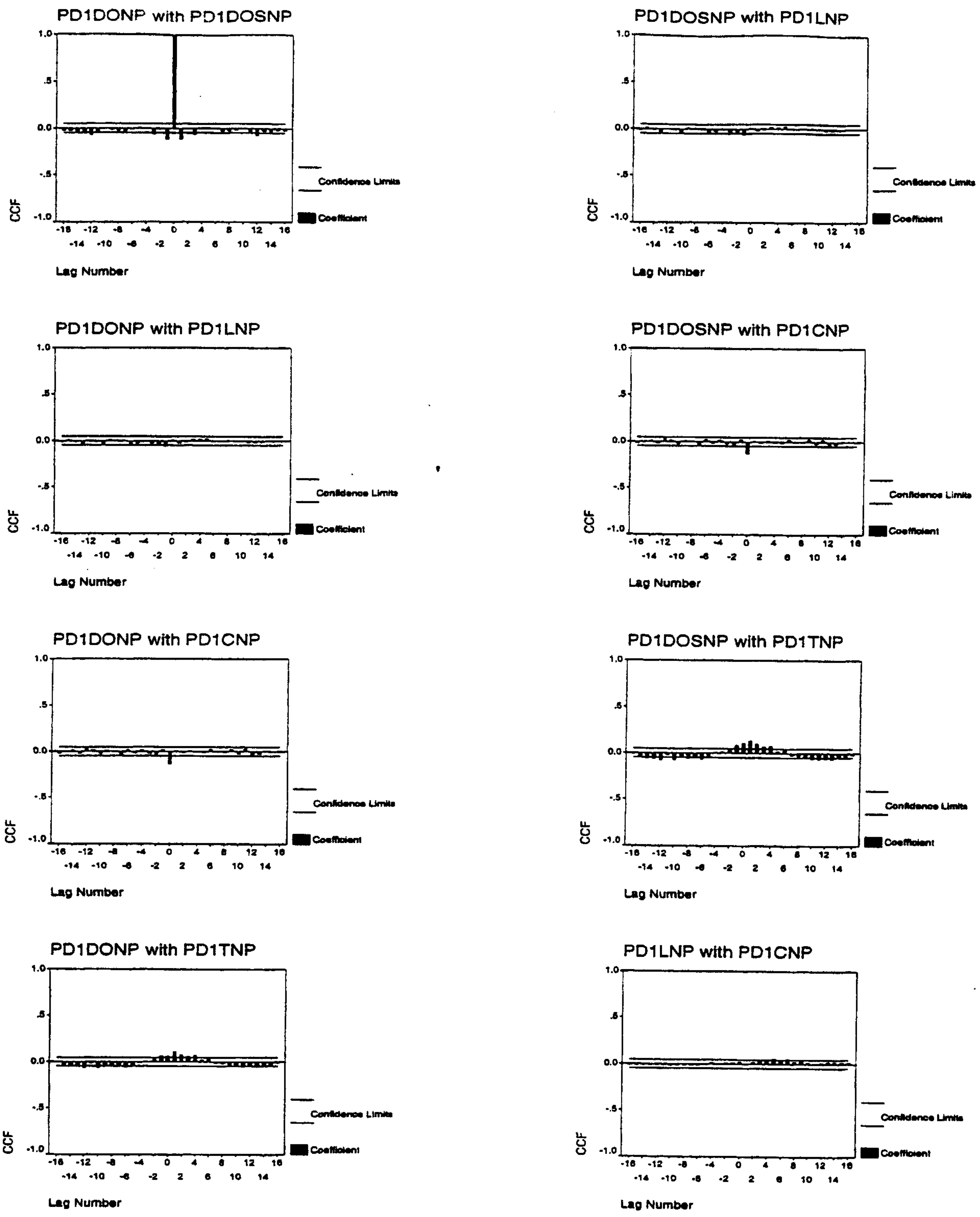
Appendix D4. Figure 2.

Cross correlation functions of (untransformed) time series data for: DO % saturation and water level, temperature, and conductivity in Northwest Pond Cell 3 and Lake Reba.



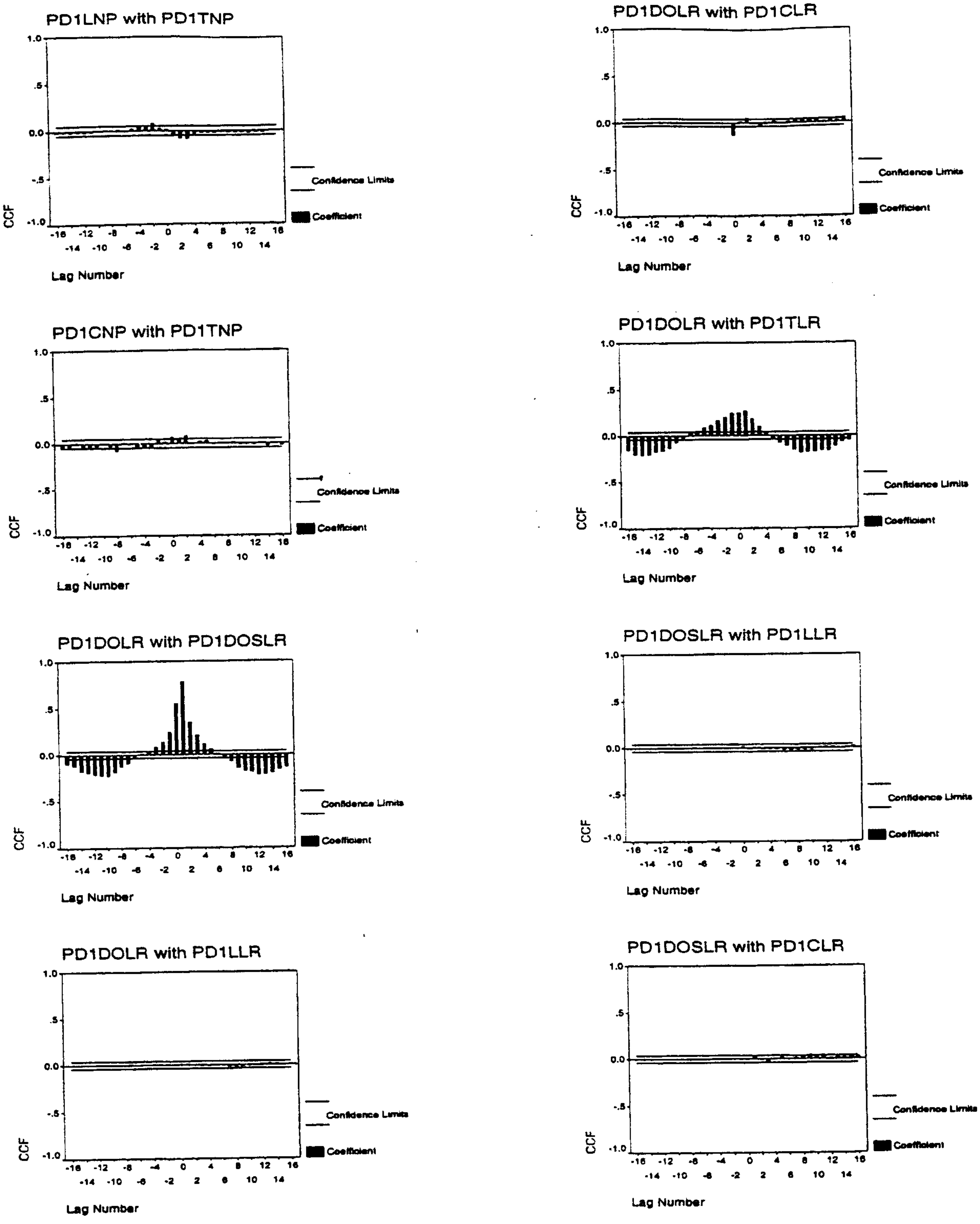
Appendix D4. Figure 3.

Cross correlation functions of (untransformed) time series data for: temperature, water level, and conductivity in Northwest Pond Cell 3 and Lake Reba.



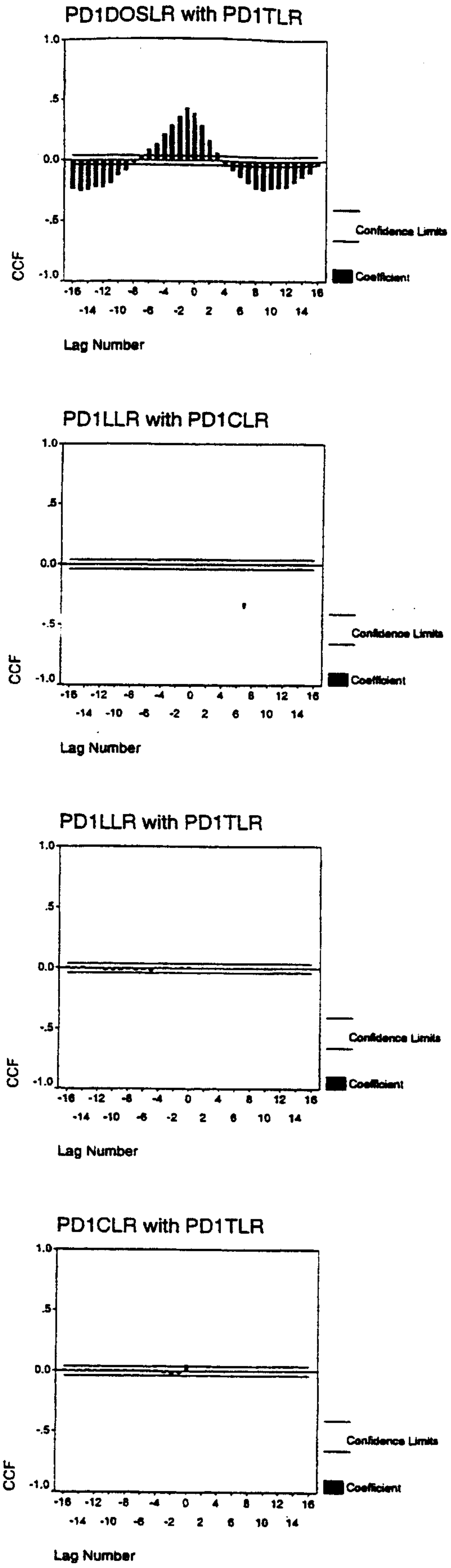
Appendix D4. Figure 4.

Cross correlation functions of (untransformed) time series data for percent changes over 1 hour periods in: (column 1) DO concentration with DO % saturation, water level, conductivity, and temperature; (column 2) DO % saturation with water level, conductivity, and temperature; and water level with conductivity for Northwest Pond Cell 3: full time series.



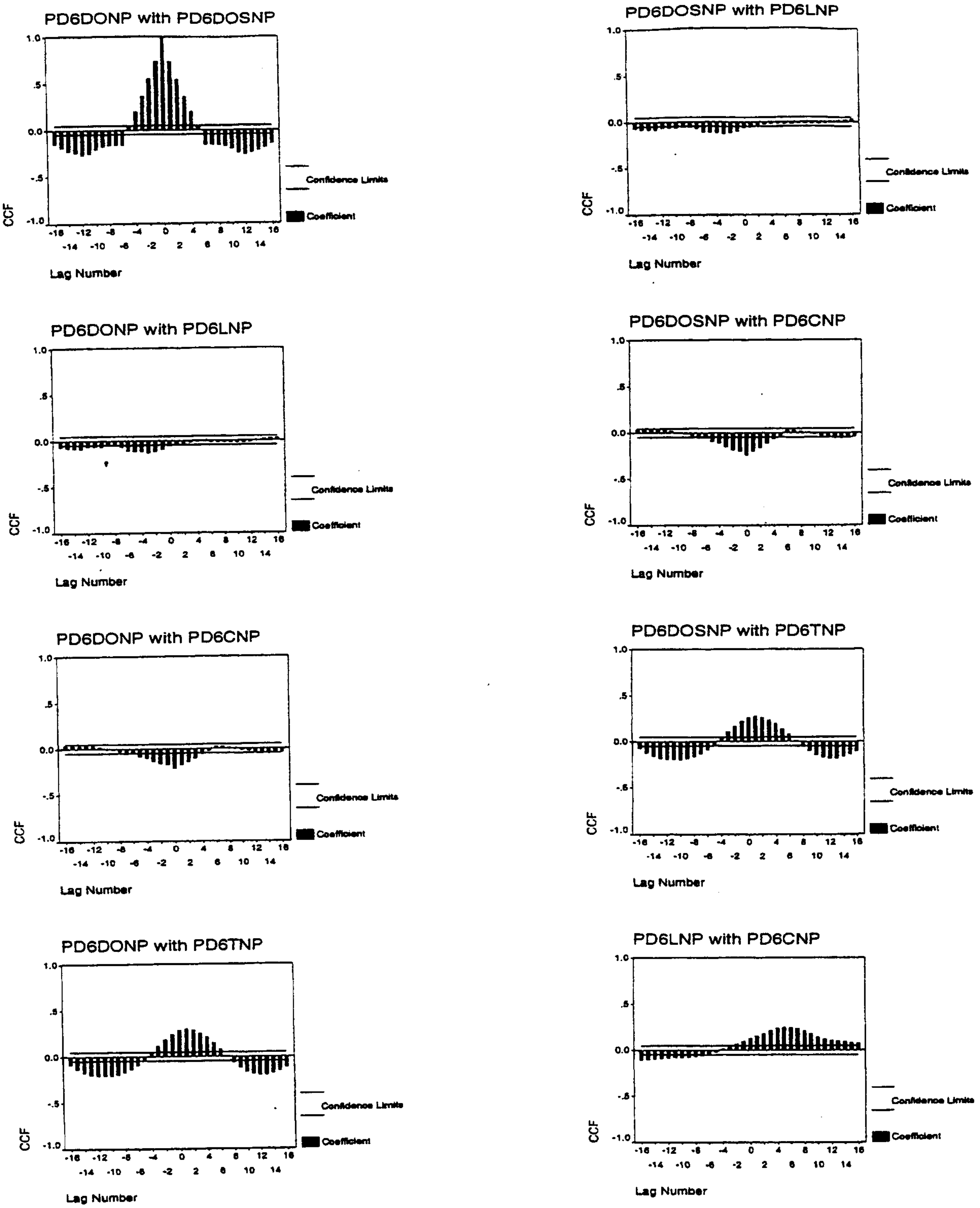
Appendix D4. Figure 5.

Cross correlation functions of (untransformed) time series data for percent changes over 1 hour periods in: (column 1) water level with temperature, conductivity with temperature in Northwest Pond Cell 3; DO concentration with DO percent saturation, water level in Lake Reba and (column 2) DO concentration with conductivity, and temperature; DO % saturation with water level and conductivity in Lake Reba: full time series.



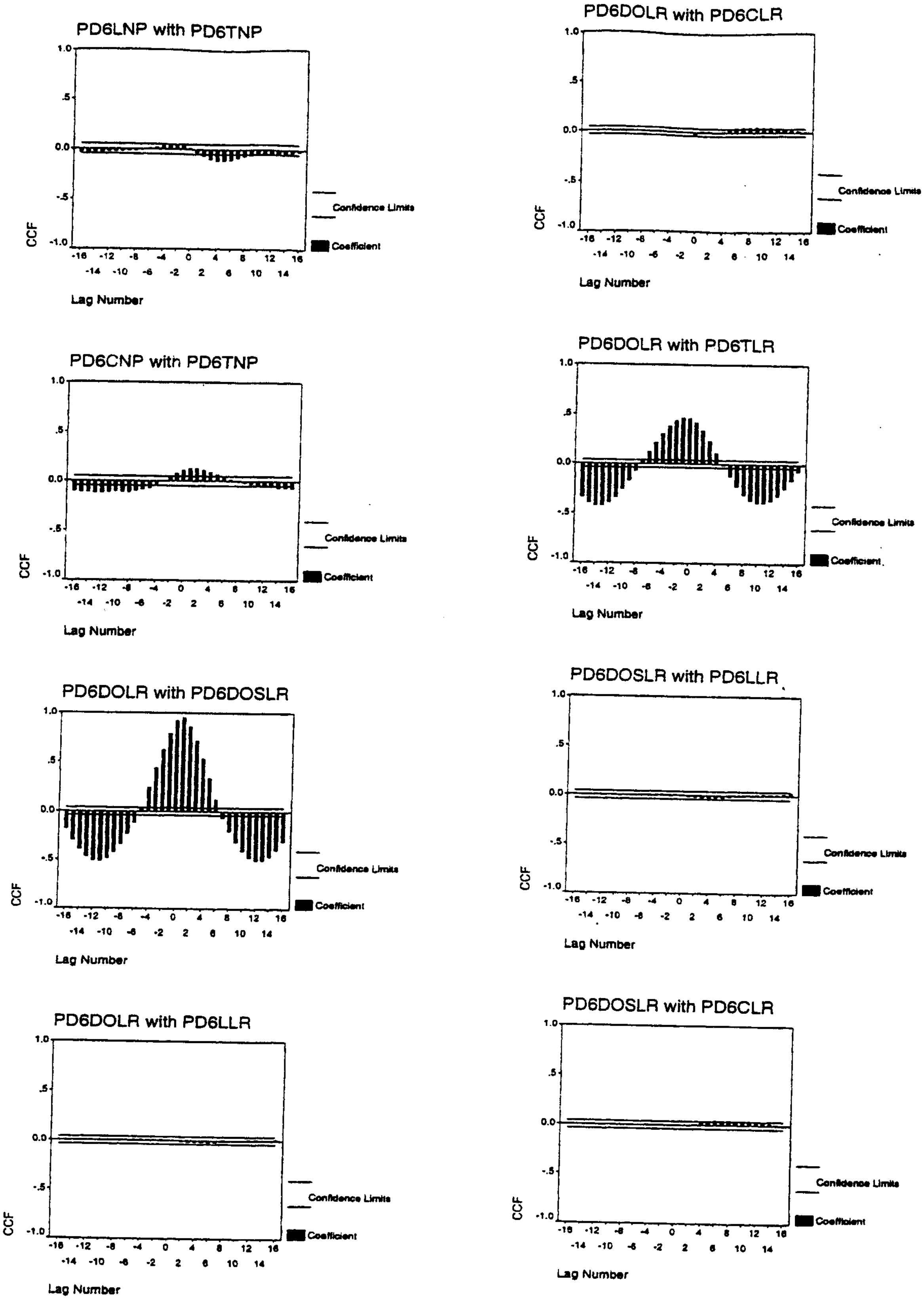
Appendix D4. Figure 6.

Cross correlation functions of (untransformed) time series data for percent changes over 1 hour periods in : DO % saturation with temperature and water level; water level with temperature, conductivity with temperature for Lake Reba: full time series.



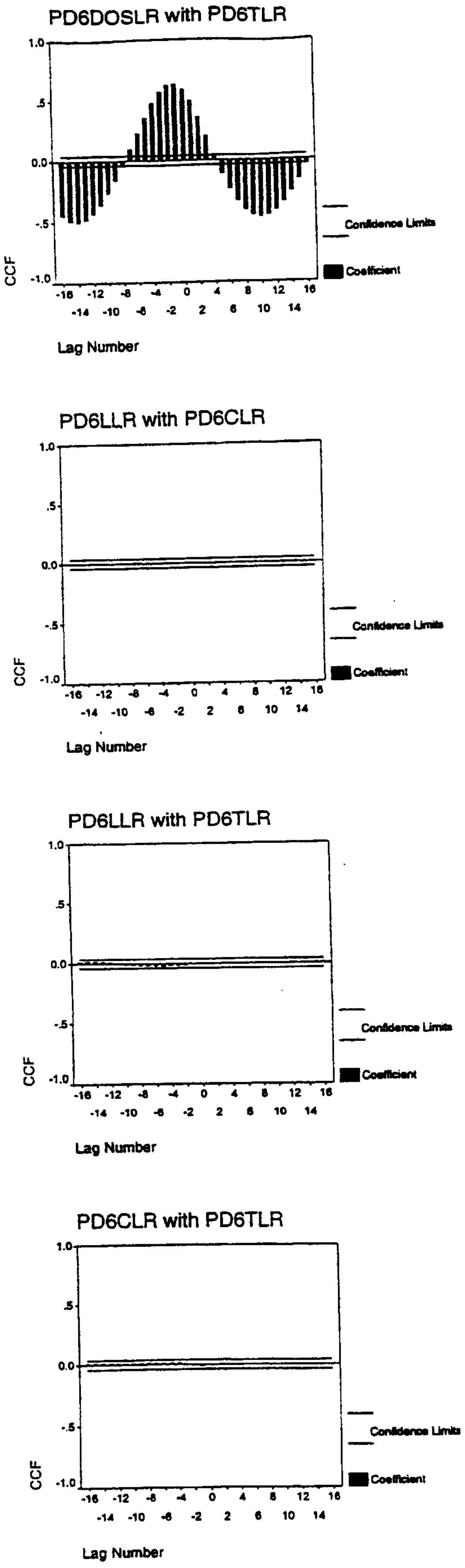
Appendix D4. Figure 7.

Cross correlation functions of (untransformed) time series data for percent changes over 6 hour periods in: (column 1) DO concentration with DO % saturation, water level, conductivity, and temperature; (column 2) DO % saturation with water level, conductivity, and temperature; and water level with conductivity for Northwest Pond Cell 3: full time series.



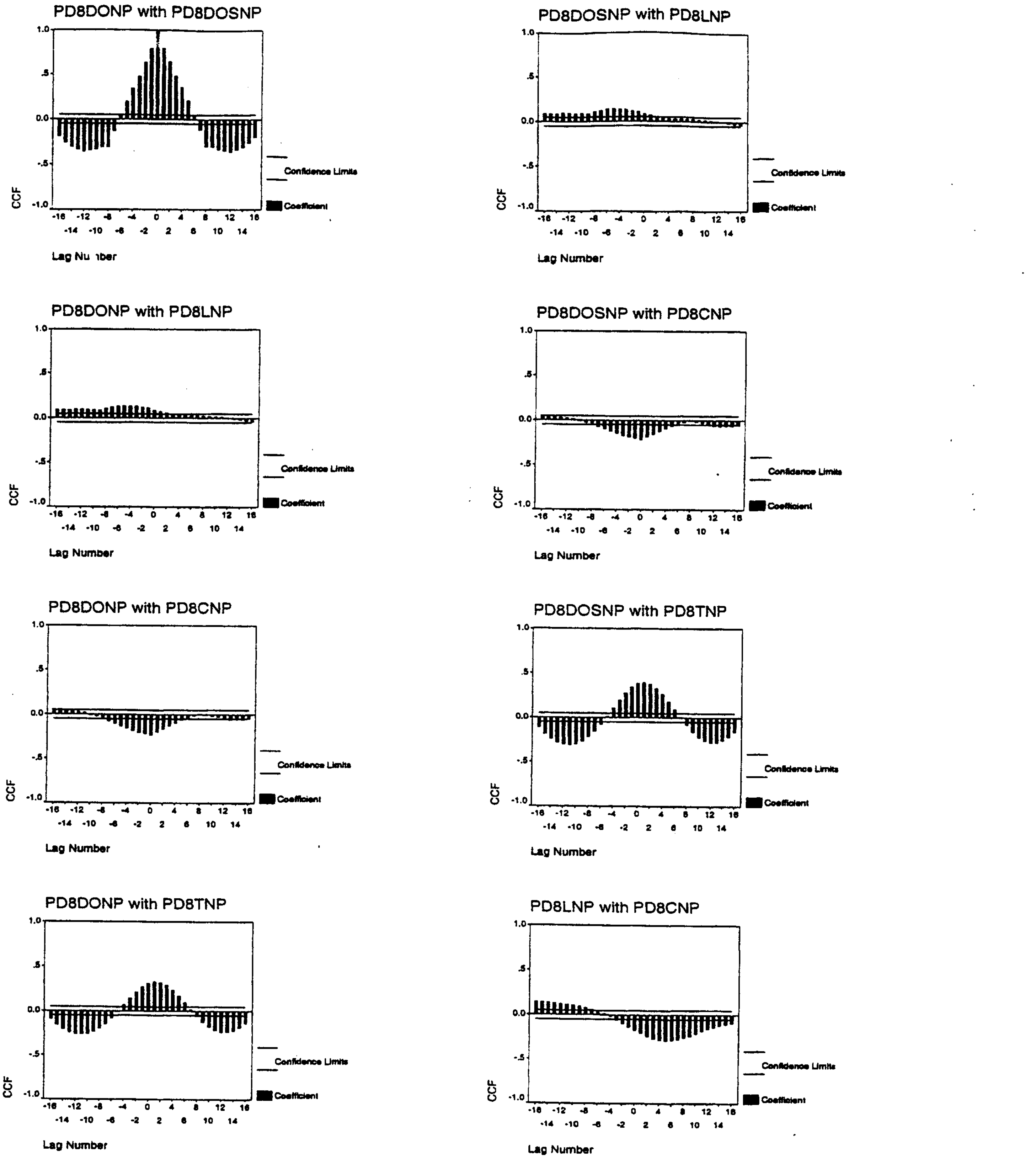
Appendix D4. Figure 8.

Cross correlation functions of (untransformed) time series data for percent changes over 6 hour periods in: (column 1) water level with temperature, conductivity with temperature in Northwest Pond Cell 3; DO concentration with DO percent saturation, water level in Lake Reba and (column 2) DO concentration with conductivity, and temperature; DO % saturation with water level and conductivity in Lake Reba: full time series.



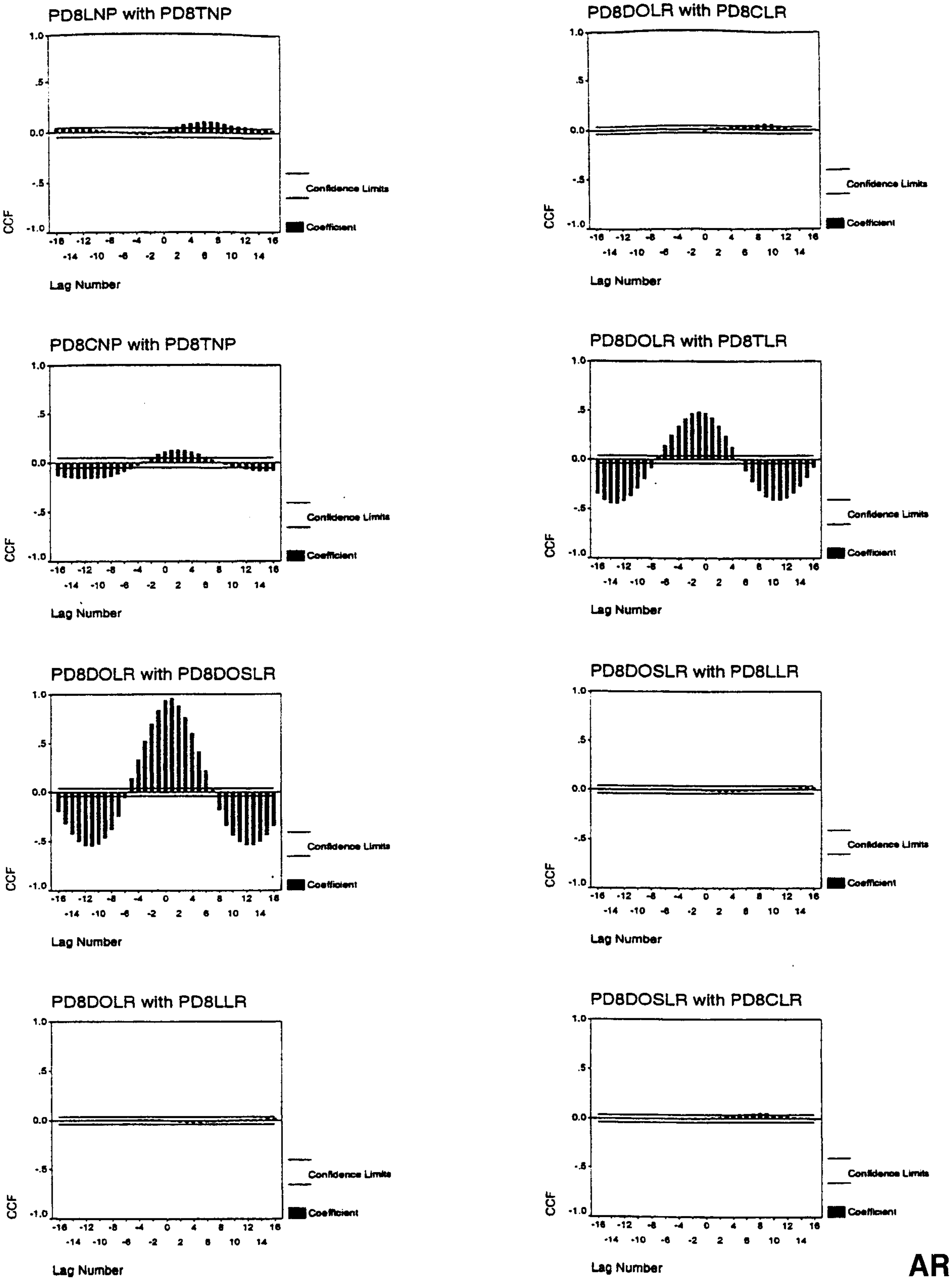
Appendix D4. Figure 9.

Cross correlation functions of (untransformed) time series data for percent changes over 6 hour periods in : DO % saturation with temperature and water level; water level with temperature, conductivity with temperature for Lake Reba: full time series.



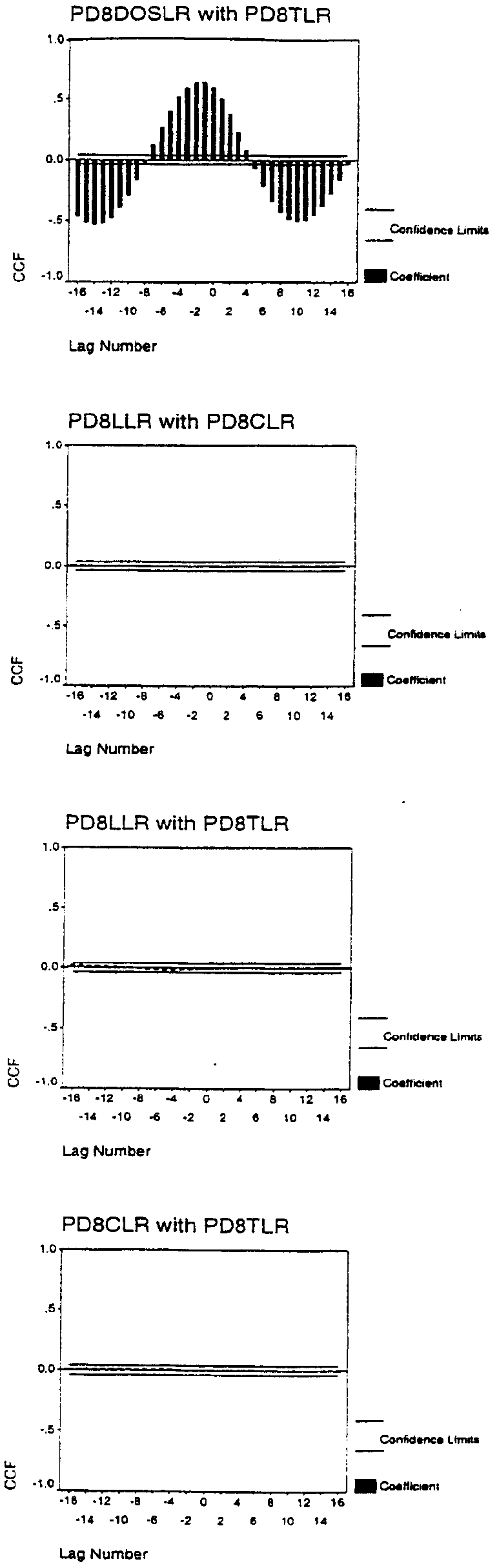
Appendix D4. Figure 10.

Cross correlation functions of (untransformed) time series data for percent changes over 8 hour periods in: (column 1) DO concentration with DO % saturation, water level, conductivity, and temperature; (column 2) DO % saturation with water level, conductivity, and temperature; and water level with conductivity for Northwest Pond Cell 3: full time series.



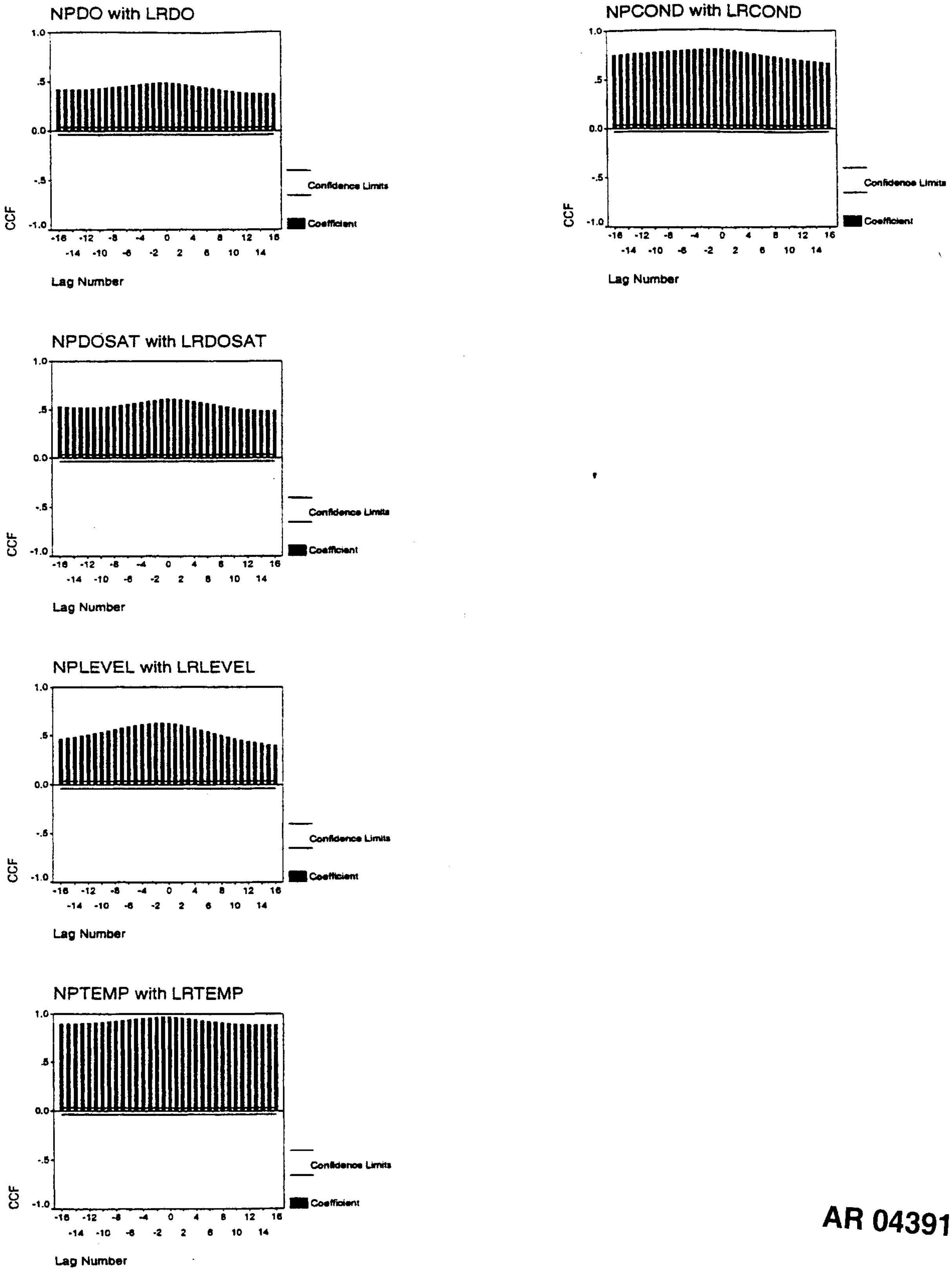
Appendix D4. Figure 11.

Cross correlation functions of (untransformed) time series data for percent changes over 8 hour periods in: (column 1) water level with temperature, conductivity with temperature in Northwest Pond Cell 3; DO concentration with DO percent saturation, water level in Lake Reba and (column 2) DO concentration with conductivity, and temperature; DO % saturation with water level and conductivity in Lake Reba: full time series.



Appendix D4. Figure 12.

Cross correlation functions of (untransformed) time series data for percent changes over 8 hour periods in : DO % saturation with temperature and water level; water level with temperature, conductivity with temperature for Lake Reba: full time series.



Appendix D4. Figure 13.

Cross correlation functions of (untransformed) comparing time series data in NP3 and Lake Reba for: DO concentration, DO % saturation, water level, temperature, and conductivity; full time series.

5.8 Appendix D5. Box Plots of Lake Reba and NP3 data.

Appendix D5. Figure 1.
Box plots of DO concentration, 6 hour changes in DO concentration, and 6 hour percent changes in DO concentration at NP3 and Lake Reba during control periods and the two week treatment periods.

Appendix D5. Figure 2.
Box plots of DO percent saturation, 6 hour changes in DO percent saturation, and 6 hour percent changes in DO percent saturation at NP3 and Lake Reba during control periods and the two week treatment periods.

Appendix D5. Figure 3.
Box plots of conductivity, 6 hour changes in conductivity, and 6 hour percent changes in conductivity at NP3 and Lake Reba during control periods and the two week treatment periods.

Appendix D5. Figure 4.
Box plots of temperature, 6 hour changes in temperature, and 6 hour percent changes in temperature at NP3 and Lake Reba during control periods and the two week treatment periods.

Appendix D5. Figure 5.
Box plots of water level, 6 hour changes in water level, and 6 hour percent changes in water level at NP3 and Lake Reba during control periods and the two week treatment periods.

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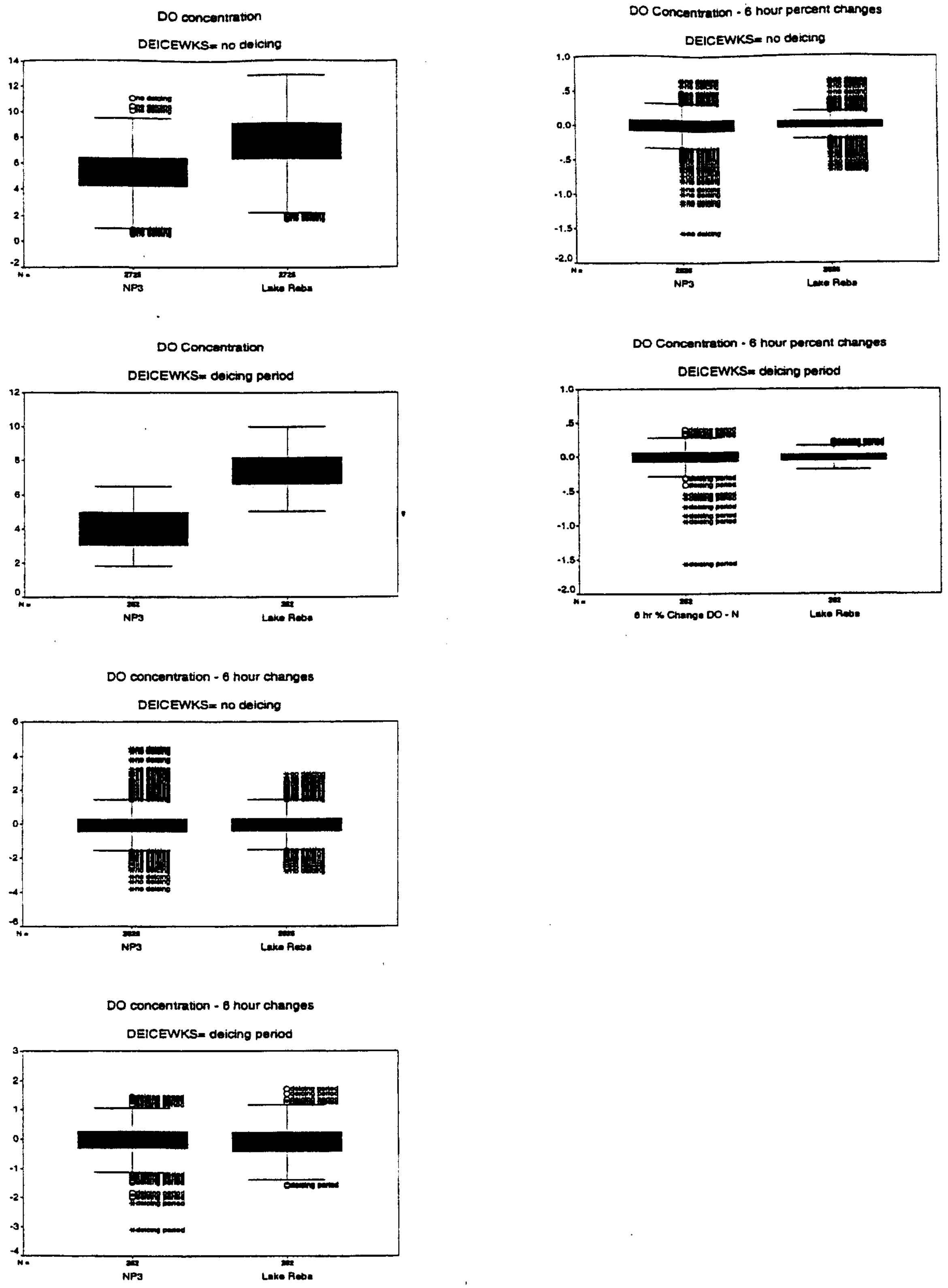
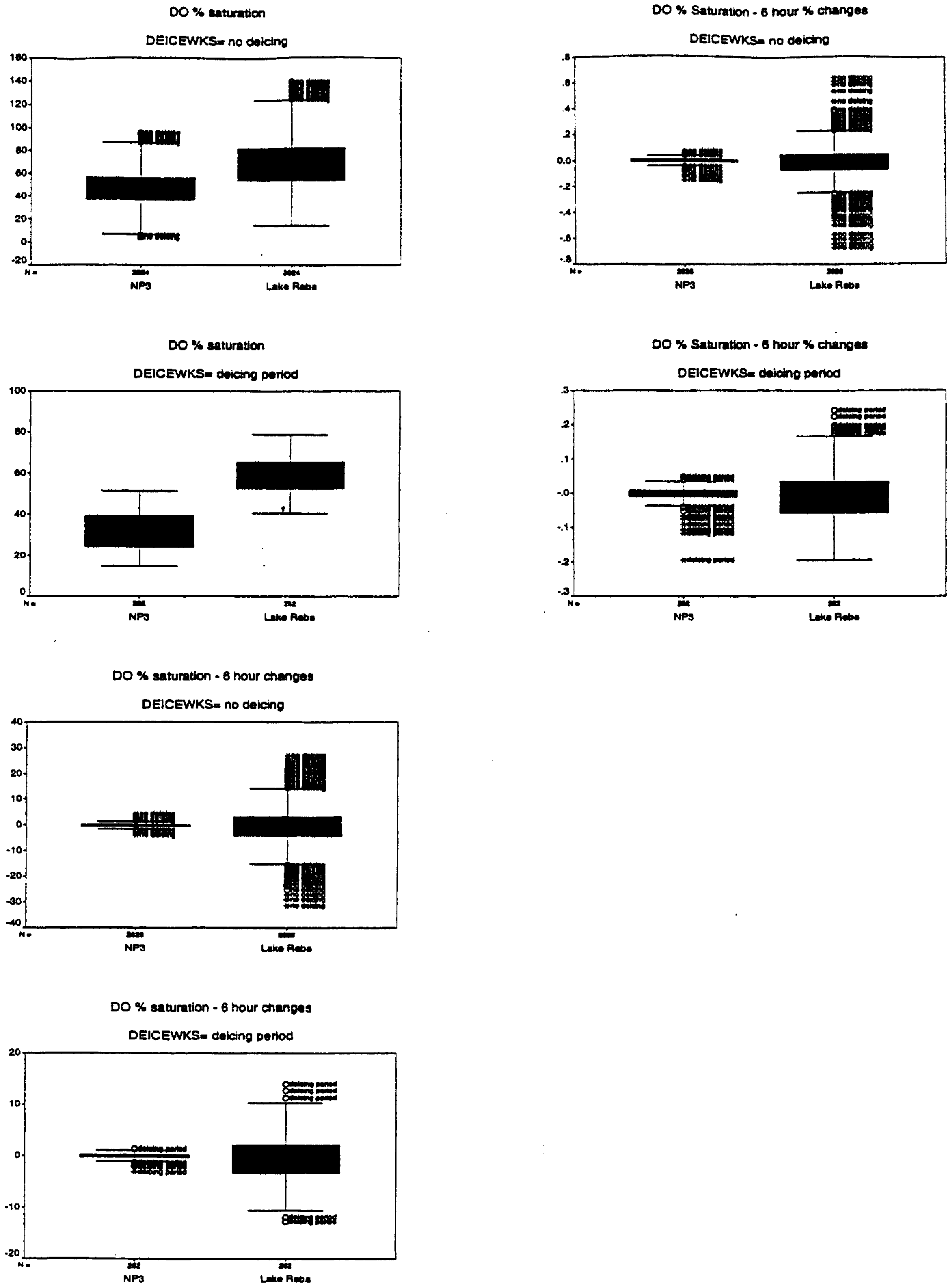


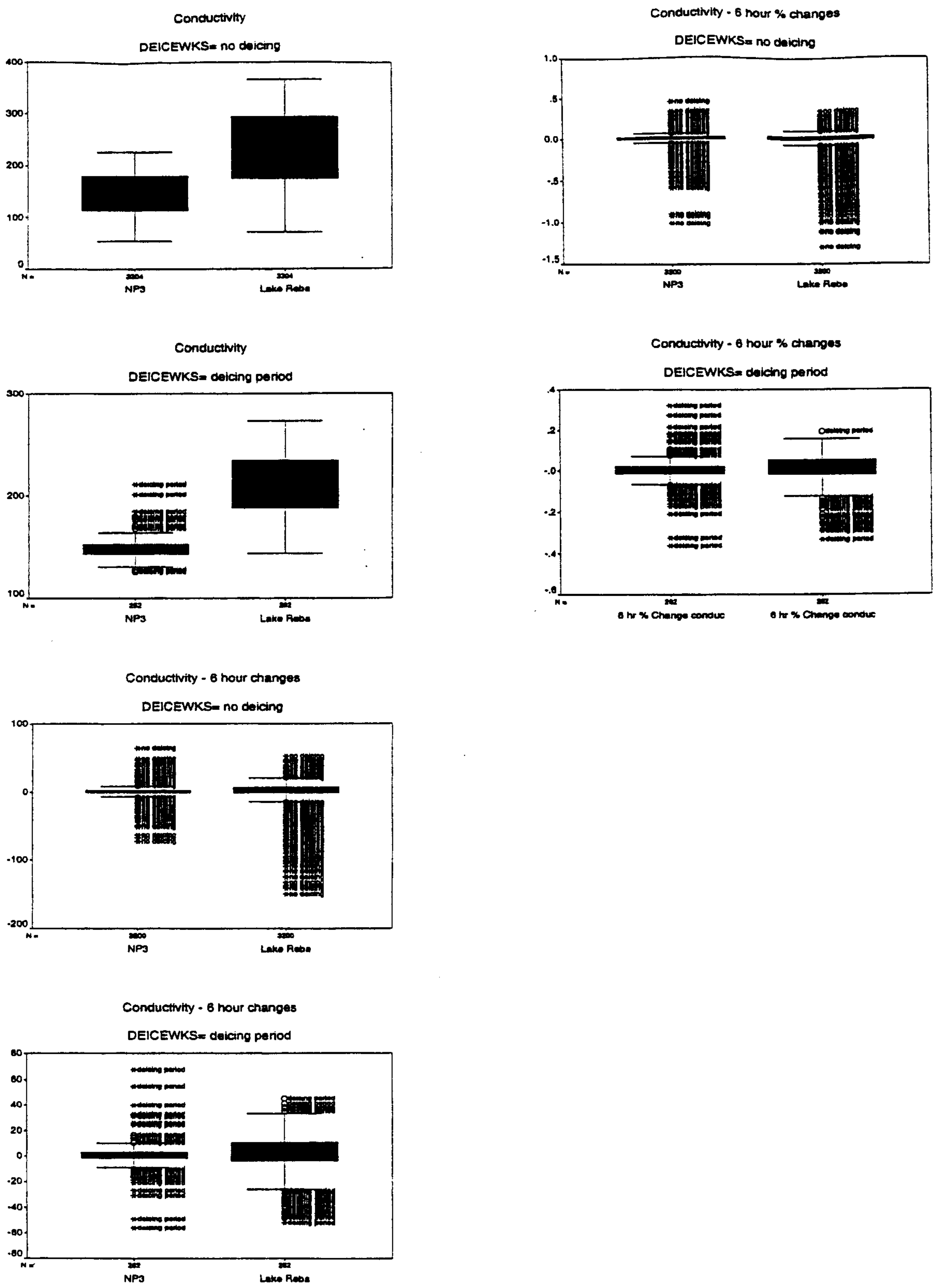
Appendix D5. Figure 1.

Box plots of DO concentration, 6 hour changes in DO concentration, and 6 hour percent changes in DO concentration at NP3 and Lake Reba during nondeicing periods and the two week non deicing periods.



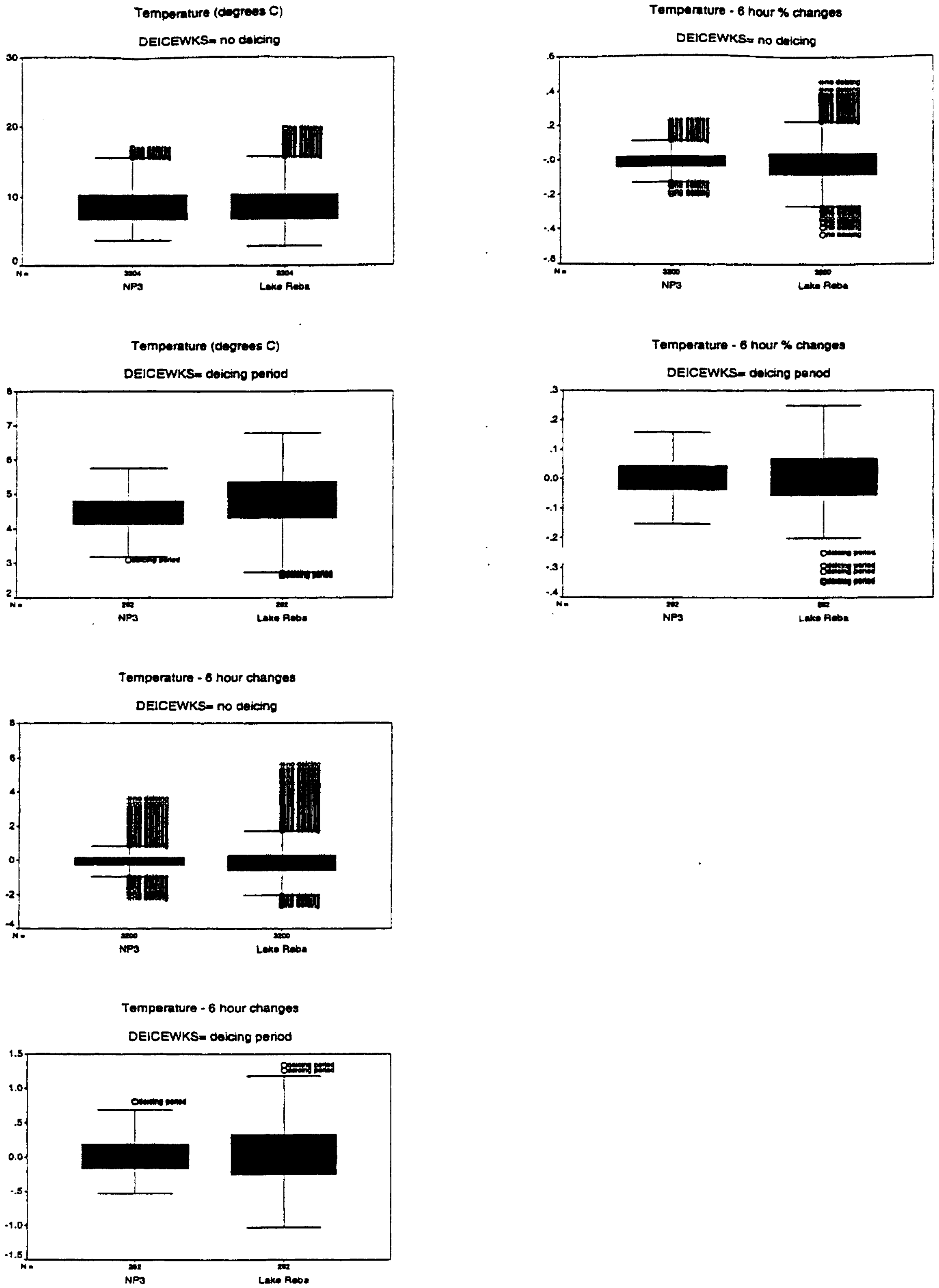
Appendix D5. Figure 2.

Box plots of DO percent saturation, 6 hour changes in DO percent saturation, and 6 hour percent changes in DO percent saturation at NP3 and Lake Reba during nondeicing periods and the two week non deicing periods.



Appendix D5. Figure 3.

Box plots of conductivity, 6 hour changes in conductivity, and 6 hour percent changes in conductivity at NP3 and Lake Reba during nondeicing periods and the two week non deicing periods.

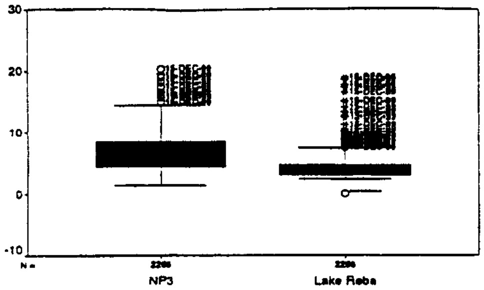


Appendix D5. Figure 4.

Box plots of temperature, 6 hour changes in temperature, and 6 hour percent changes in temperature at NP3 and Lake Reba during nondeicing periods and the two week non deicing periods.

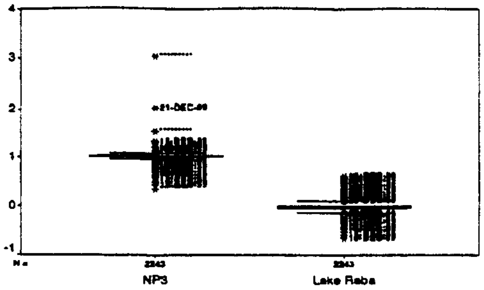
Level (ft)

DEICEWKS= no deicing



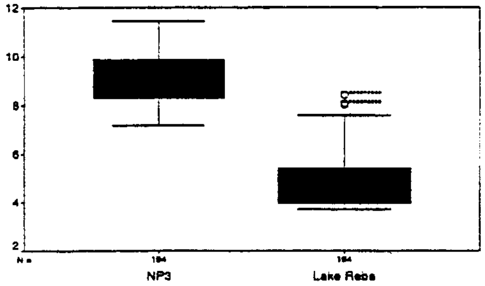
Level - 6 hour % changes

DEICEWKS= no deicing



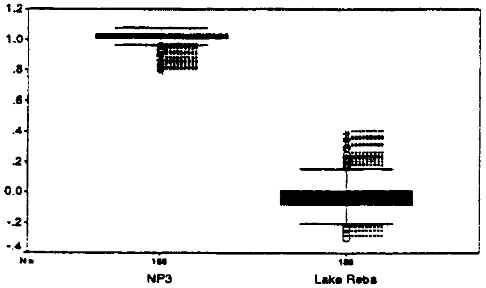
Level (ft)

DEICEWKS= deicing period



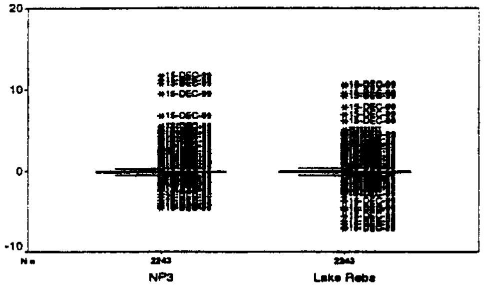
Level - 6 hour % changes

DEICEWKS= deicing period



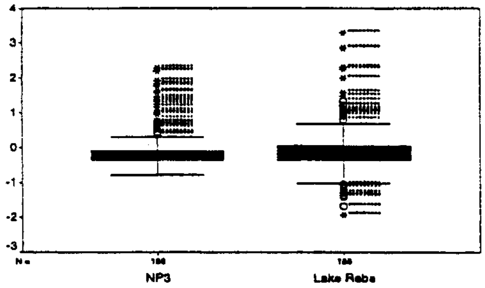
Level - 6 hour changes

DEICEWKS= no deicing



Level - 6 hour changes

DEICEWKS= deicing period



Appendix D5. Figure 5.

Box plots of water level, 6 hour changes in water level, and 6 hour percent changes in water level at NP3 and Lake Reba during nondeicing periods and the two week non deicing periods.

5.9 Appendix D6. Cross-correlation functions of physical variables and DO

Temperature-level:_Although the correlation between temperature and level was predominantly negative and did not have a strong temporal component during the control period at either pond (Figures 3 and 4), during the two-week treatment period (i.e., temporal definition of deicing), the cross-correlations between time and level were generally positive and appeared to be affected by time. The CCF for the signal-based and time-based treatment periods were quite different at the two ponds (compare columns 2 and 3 in Figure 3 and columns 2 and 4 in Figure 4). It may be interesting that during the time that a signal was present at Lake Reba (Figures 3 and 4, right hand column where LREVENT = 1) the CCFs of the two ponds were quite similar although they were experiencing different amounts of deicing chemicals at this time (i.e., the signal based definition differs between the two sites). This kind of finding may indicate that some other unmeasured variable was controlling the temperature-level relationship.

Level-Conductivity: Because sample sizes vary greatly between the treatment and control periods, it was difficult to know whether the subtle differences among the level-conductivity CCFs at Lake Reba represent real changes in the correlation structure or effects of samples size. At NP3, on the other hand, the CCFs for all the treatment periods (predominantly but weakly positive) were quite different from the CCF for the control period (strongly negative). As with temperature and conductivity, the period of time that a signal was present at Lake Reba seems to be a time that the level-conductivity relationship was different than during the longer time periods of the temporal and signal-based treatment periods at NP3.

Temperature-conductivity: The sign of the cross correlation coefficients changes during the treatment periods (both definitions) at both ponds. In addition, as with the other in Figures 3 and 4, time lag has a greater effect on the cross correlation coefficient during the treatment period than during the control period. Once more, at NP3, the CCF for the period of signal presence at Lake Reba had a markedly different shape than all the other treatment CCFs.

Appendix D6. Figure 1.

Cross-correlation functions of DO percent saturation and DO, water level, temperature, and conductivity at NP3 during control and treatment periods. In Column 1 (deicewks, control) and Column 2, (deicewks, treatment period), the treatment period was the entire two-week treatment period. In Column 3 (Npevent, present), the treatment period was the period of time that a deicing signal was present at NP3. In Column 4 (Lrevent, present), the treatment period was the period of time during which there was a deicing signal present at Lake Reba.

Appendix D6. Figure 2.

Cross-correlation functions of DO percent saturation and DO, water level, temperature, and conductivity at Lake Reba during control and treatment periods. In Column 1 (deicewks, control) and Column 2, (deicewks, treatment period), the treatment period was the entire two-week treatment period. In Column 3 (Npevent, present), the treatment period was the period of time that a deicing signal was present at NP3. In Column 4 (Lrevent, present), the treatment period was the period of time during which there was a deicing signal present at Lake Reba.

Appendix D6. Figure 3.

Cross-correlation functions of water level and conductivity, temperature and conductivity, and water level and temperature at NP3 during control and treatment periods. In Column 1 (deicewks, control) and Column 2, (deicewks, treatment period), the treatment period was the entire two-week treatment period. In Column 3 (Npevent, present), the treatment period was the period of time that a deicing signal was present at NP3. In Column 4 (Lrevent, present), the treatment period was the period of time during which there was a deicing signal present at Lake Reba.

Appendix D6. Figure 4.

Cross-correlation functions of water level and conductivity, temperature and conductivity, and water level and temperature at Lake Reba during control and treatment periods. In Column 1 (deicewks, control) and Column 2, (deicewks, treatment period), the treatment period was the entire two-week treatment period. In Column 3 (Npevent, present), the treatment period was the period of time that a deicing signal was present at NP3. In Column 4 (Lrevent, present), the treatment period was the period of time during which there was a deicing signal present at Lake Reba.

Appendix D6. Figure 5.

Scatter plots of water level and temperature, water level and conductivity at NP3. In Column 1 (deicewks, control , treatment period), the treatment period was the entire two-week treatment period. In Column 2 (Npevent, signal present, signal not present), the treatment period was the period of time that a deicing signal was present at NP3. In Column 3 (LRevent, signal present, signal not present), the treatment period was the period of time during which there was a deicing signal present at Lake Reba.

Appendix D6. Figure 6.

Scatter plots of conductivity and temperature, conductivity and DO % saturation at NP3. In Column 1 (deicewks, control , deicing period), the treatment period was the entire two-week treatment period. In Column 2 (Npevent, signal present, signal not present), the treatment period was the period of time that a deicing signal was present at NP3. In Column 3 (LRevent, signal present, signal not present), the treatment period was the period of time during which there was a deicing signal present at Lake Reba.

Appendix D6. Figure 7.

Scatter plots of water level and temperature, water level and conductivity at Lake Reba. In Column 1 (deicewks, control , deicing period), the treatment period was the entire two-week treatment period. In Column 2 (Npevent, signal present, signal not present), the treatment period was the period of time that a deicing signal was present at NP3. In

Column 3 (LRevent, signal present, signal not present), the treatment period was the period of time during which there was a deicing signal present at Lake Reba.

Appendix D6. Figure 8.

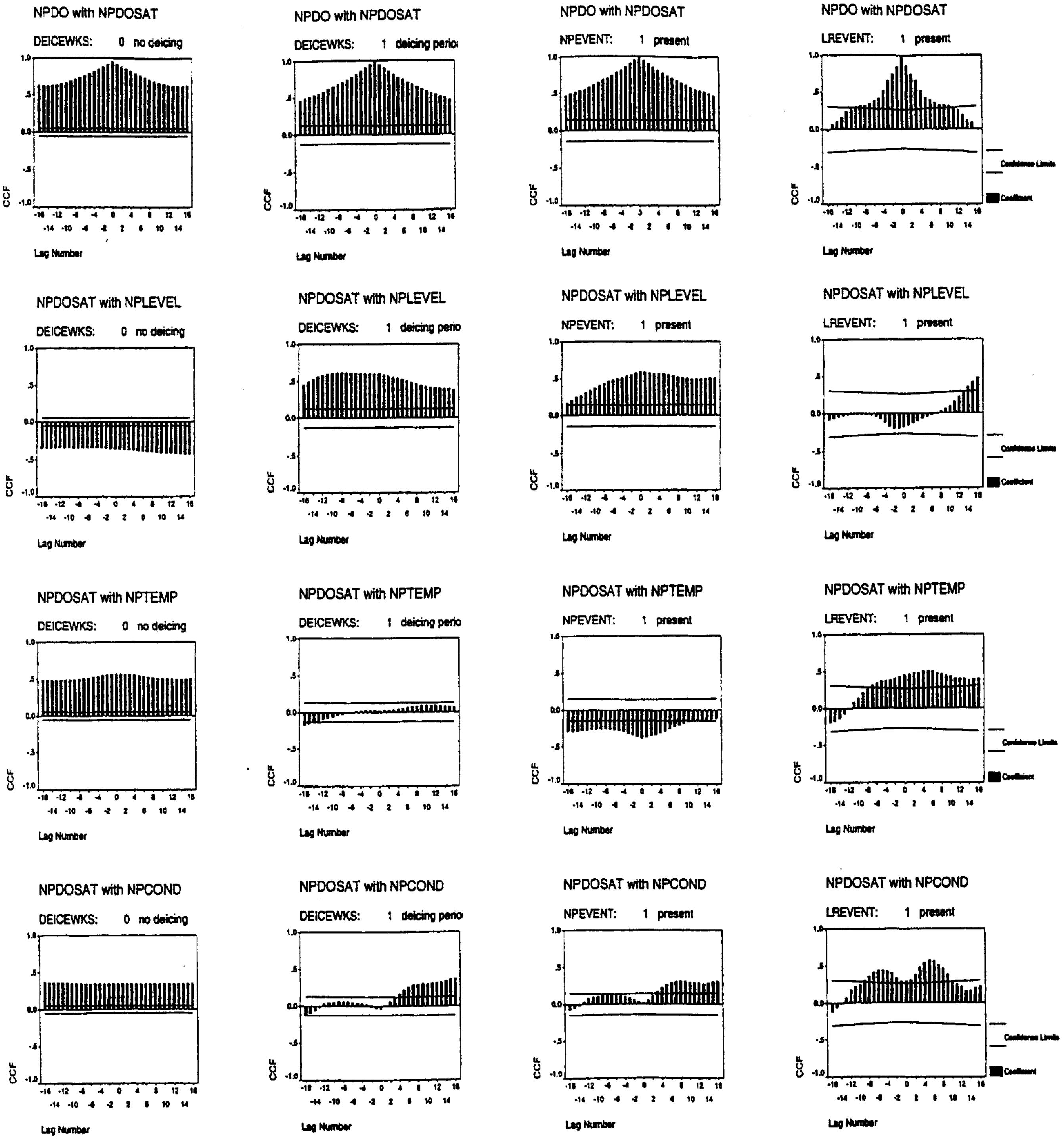
Scatter plots of conductivity and temperature, conductivity and DO % saturation at Lake Reba. In Column 1 (deicewks, control , deicing period), the treatment period was the entire two-week treatment period. In Column 2 (Npevent, signal present, signal not present), the treatment period was the period of time that a deicing signal was present at NP3. In Column 3 (LRevent, signal present, signal not present), the treatment period was the period of time during which there was a deicing signal present at Lake Reba.

Appendix D6. Figure 9.

Cross-correlation functions of DO percent saturation at Lake Reba and NP3 and conductivity at Lake Reba and NP3 during control and treatment periods. In Column 1 (deicewks), the treatment period was the entire two-week treatment period. In Column 2 (LRevent), the treatment period was the period of time during which there was a deicing signal present at Lake Reba. In Column 3 (NPevent), the treatment period was the period of time that a deicing signal was present at NP3.

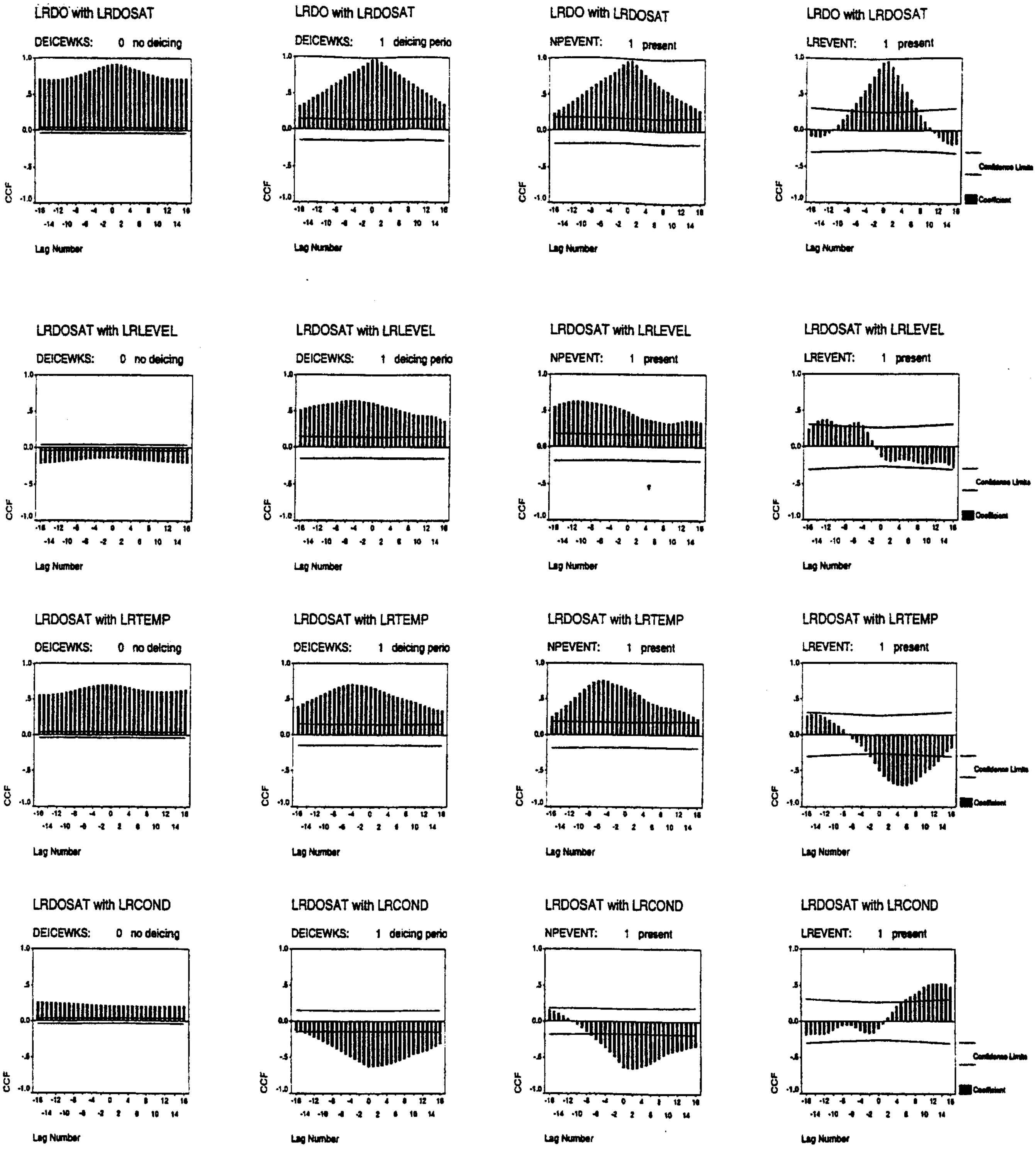
Appendix D6. Figure 10.

Scatter plots DO percent saturation at Lake Reba and NP3 and conductivity at Lake Reba and NP3 during control and treatment periods. In Column 1 (deicewks), the treatment period was the entire two-week treatment period. In Column 2 (LRevent), the treatment period was the period of time during which there was a deicing signal present at Lake Reba. In Column 3 (NPevent), the treatment period was the period of time that a deicing signal was present at NP3.



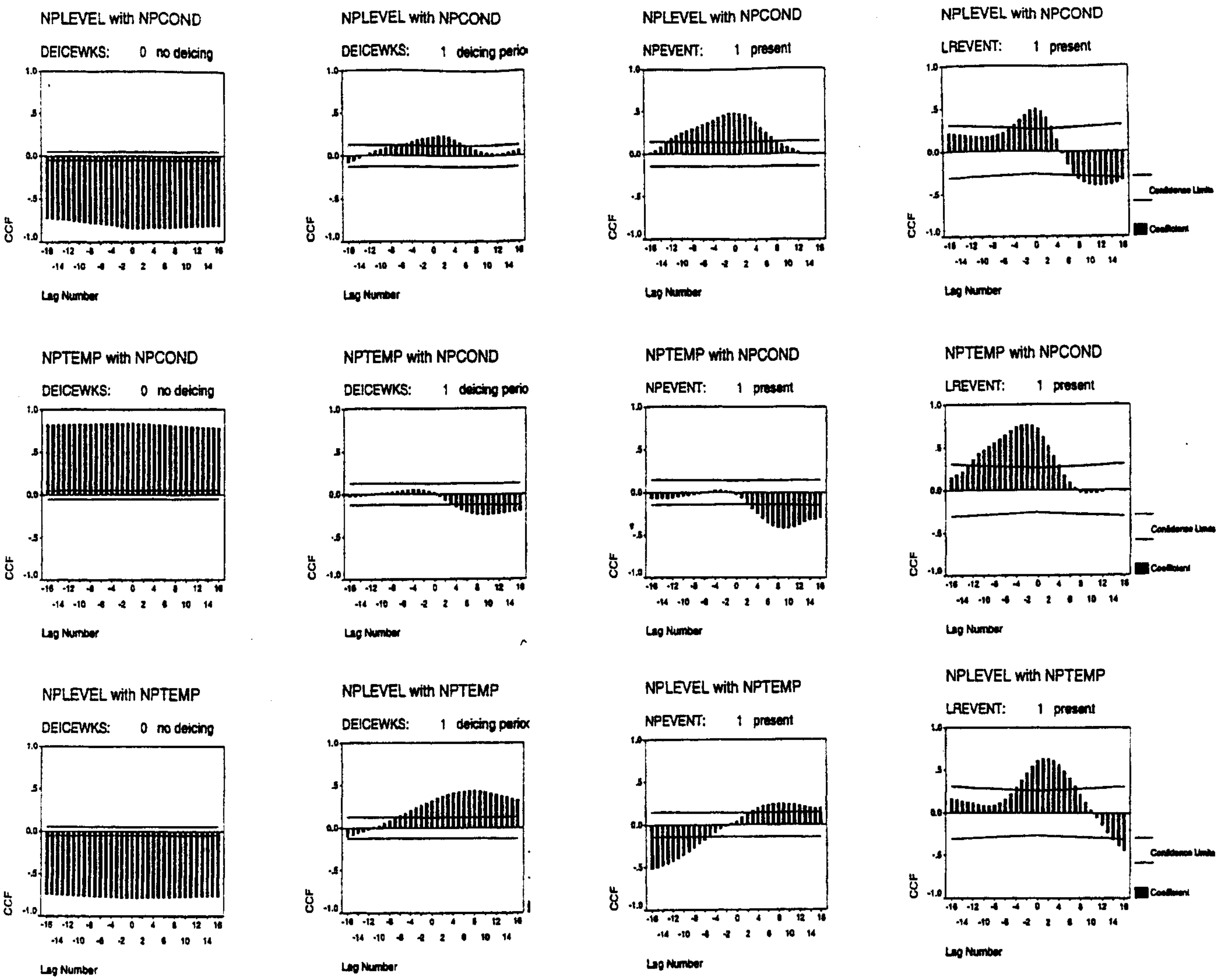
Appendix D6. Figure 1.

Cross-correlation functions of DO percent saturation and DO, water level, temperature, and conductivity at NP3 during non-deicing and deicing periods. In Column 1 (deicewks, no deicing) and Column 2, (deicewks, deicing period), the deicing period was the entire two-week deicing period. In Column 3 (Npevent, present), the deicing period is the period of time that a deicing signal was present at NP3. In Column 4 (Lrevent, present), the deicing period was the period of time during which there was a deicing signal present at Lake Reba.



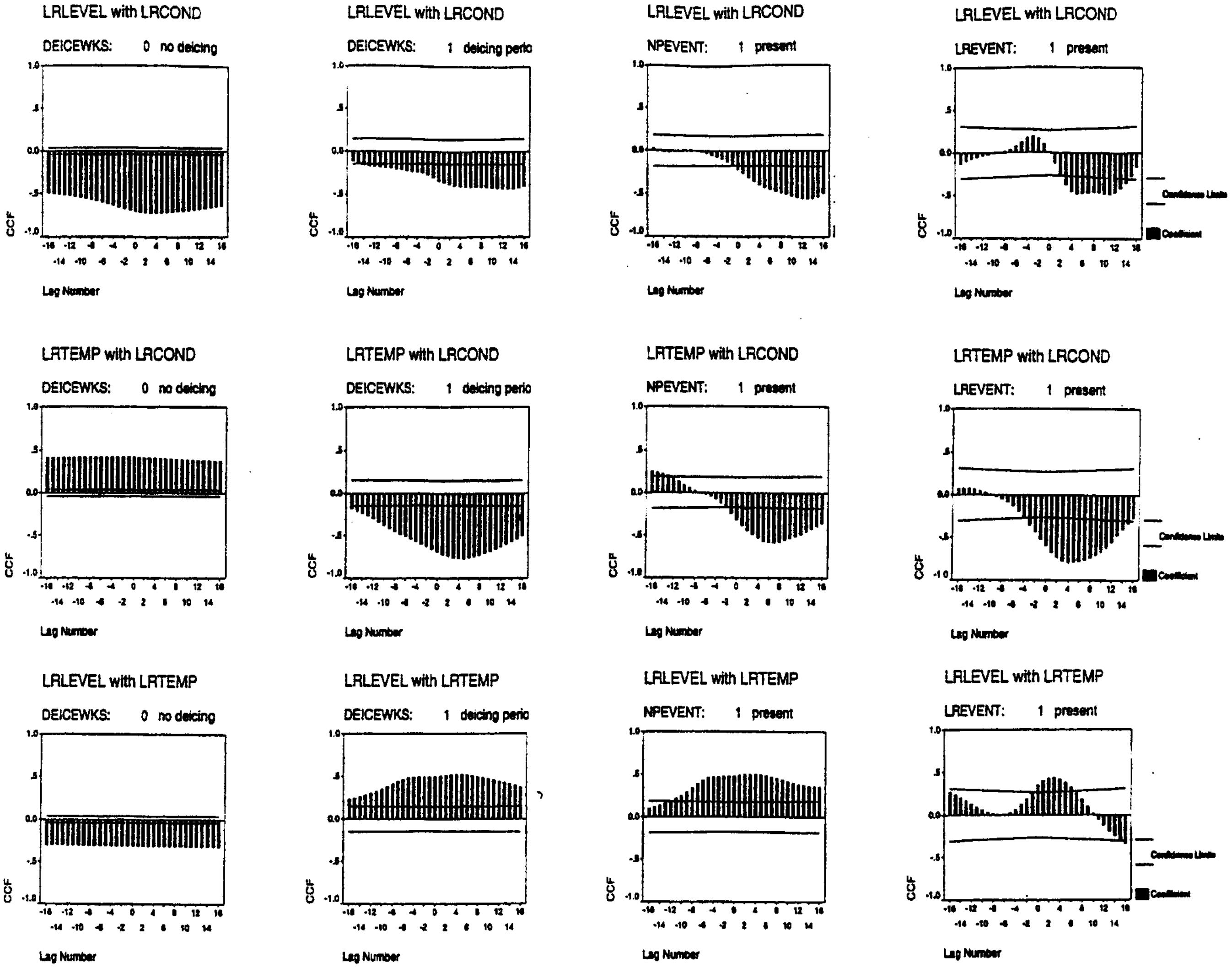
Appendix D6. Figure 2.

Cross-correlation functions of DO percent saturation and DO, water level, temperature, and conductivity at Lake Reba during non-deicing and deicing periods. In Column 1 (deicewks, no deicing) and Column 2, (deicewks, deicing period), the deicing period was the entire two-week deicing period. In Column 3 (Npevent, present), the deicing period is the period of time that a deicing signal was present at NP3. In Column 4 (Lrevent, present), the deicing period was the period of time during which there was a deicing signal present at Lake Reba.



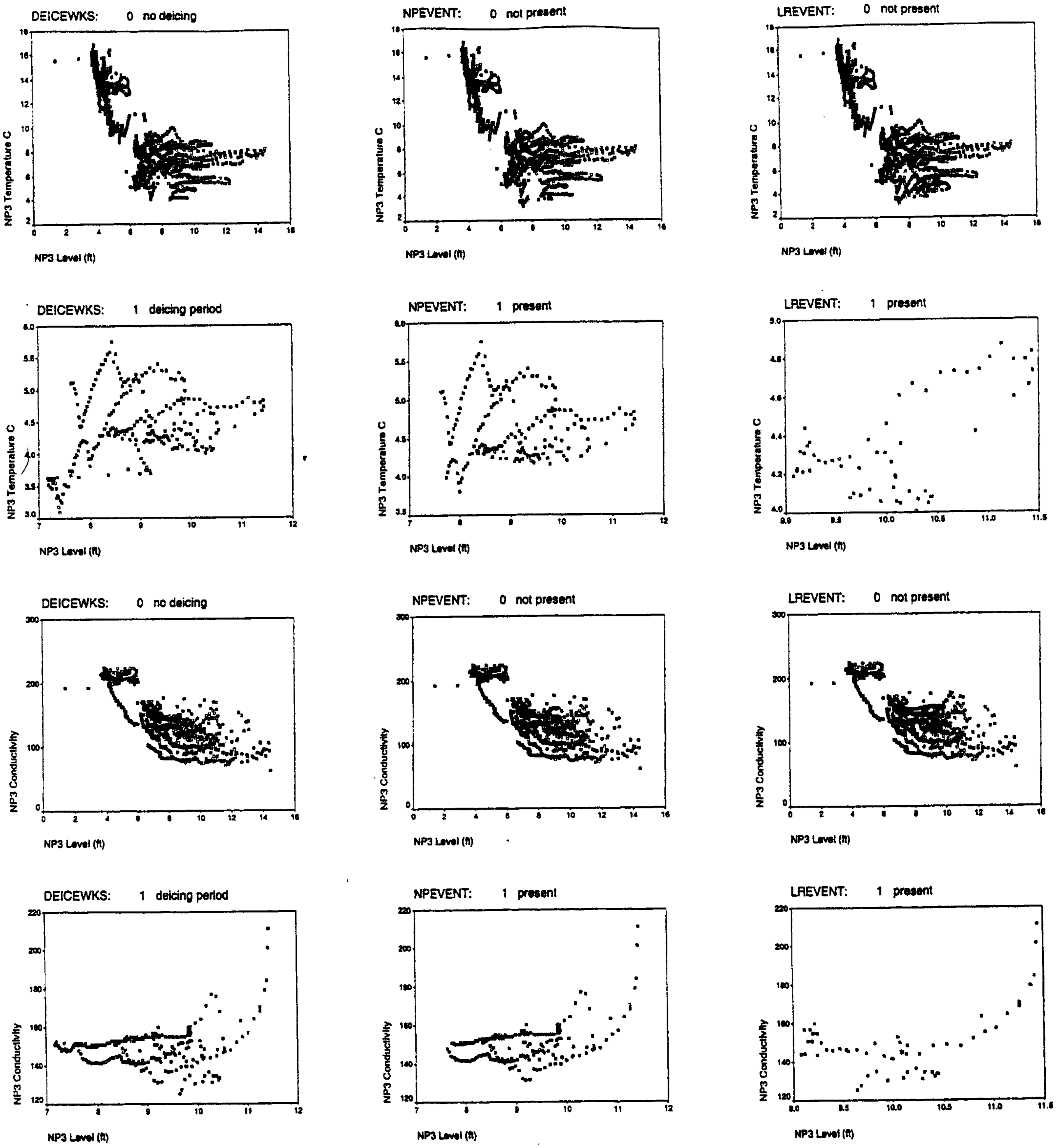
Appendix D6. Figure 3.

Cross-correlation functions of water level and conductivity, temperature and conductivity, and water level and temperature at NP3 during non-deicing and deicing periods. In Column 1 (deicewks, no deicing) and Column 2, (deicewks, deicing period), the deicing period was the entire two-week deicing period. In Column 3 (Npevent, present), the deicing period is the period of time that a deicing signal was present at NP3. In Column 4 (Lrevent, present), the deicing period was the period of time during which there was a deicing signal present at Lake Reba.



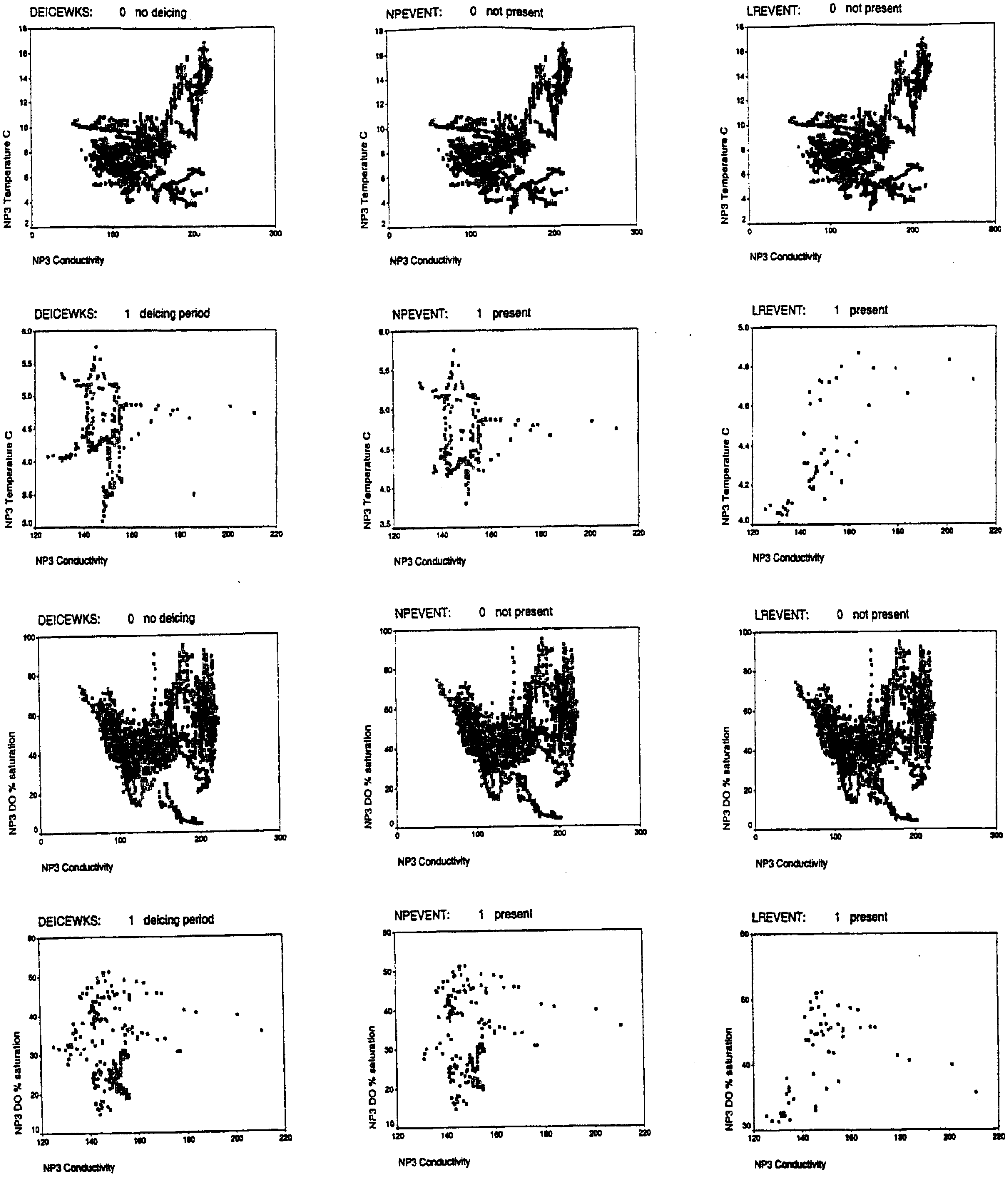
Appendix D6. Figure 4.

Cross-correlation functions of water level and conductivity, temperature and conductivity, and water level and temperature at Lake Reba during non-deicing and deicing periods. In Column 1 (deicewks, no deicing) and Column 2, (deicewks, deicing period), the deicing period was the entire two-week deicing period. In Column 3 (Npevent, present), the deicing period is the period of time that a deicing signal was present at NP3. In Column 4 (Lrevent, present), the deicing period was the period of time during which there was a deicing signal present at Lake Reba.



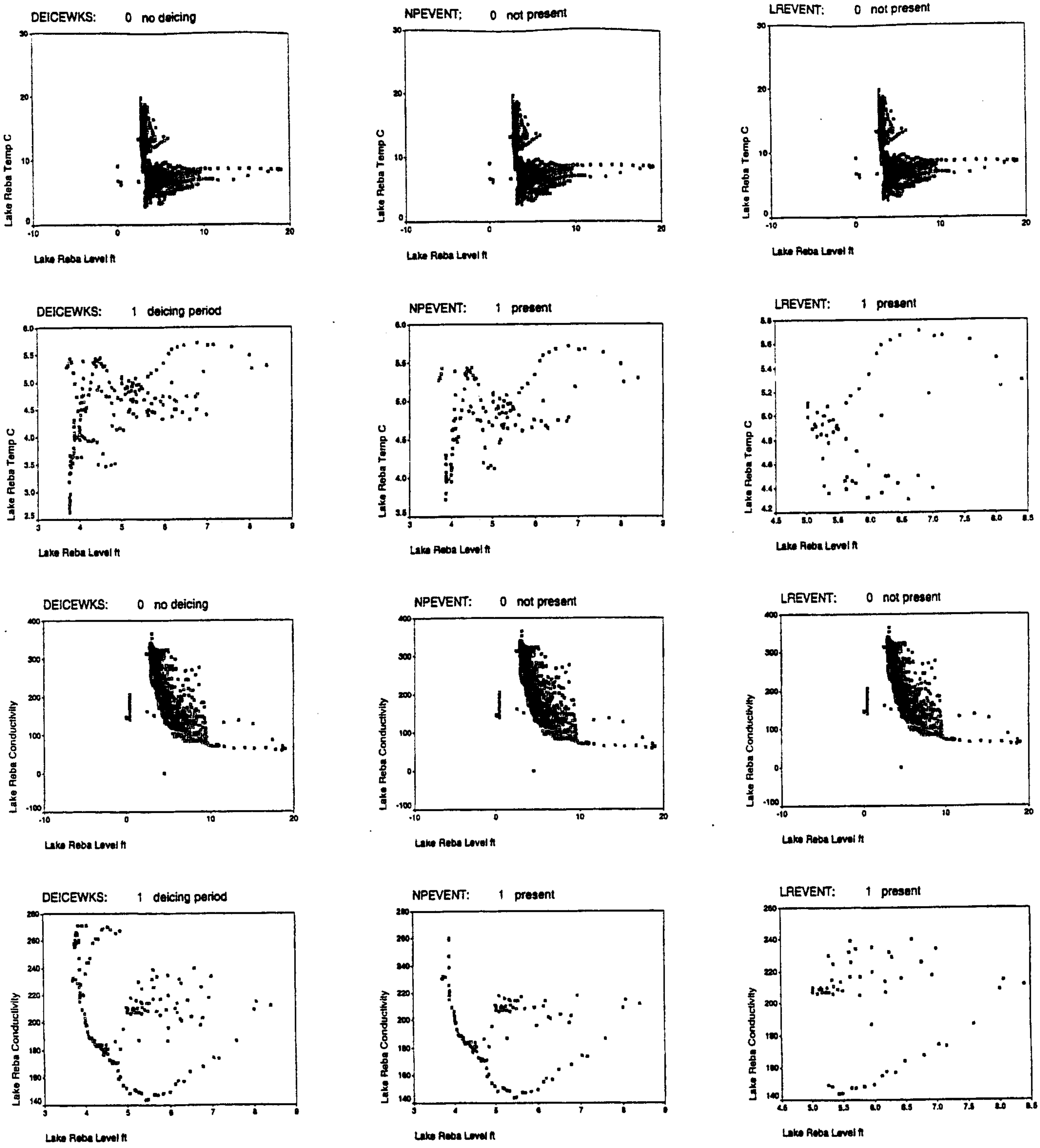
Appendix D6. Figure 5.

Scatter plots of water level and temperature, water level and conductivity at NP3. In Column 1 (deicewks, no deicing, deicing period), the deicing period is the entire two-week deicing period. In Column 2 (Npevent, signal present, signal not present), the deicing period is the period of time that a deicing signal was present at NP3. In Column 3 (LRevent, signal present, signal not present), the deicing period is the period of time during which there was a deicing signal present at Lake Reba.



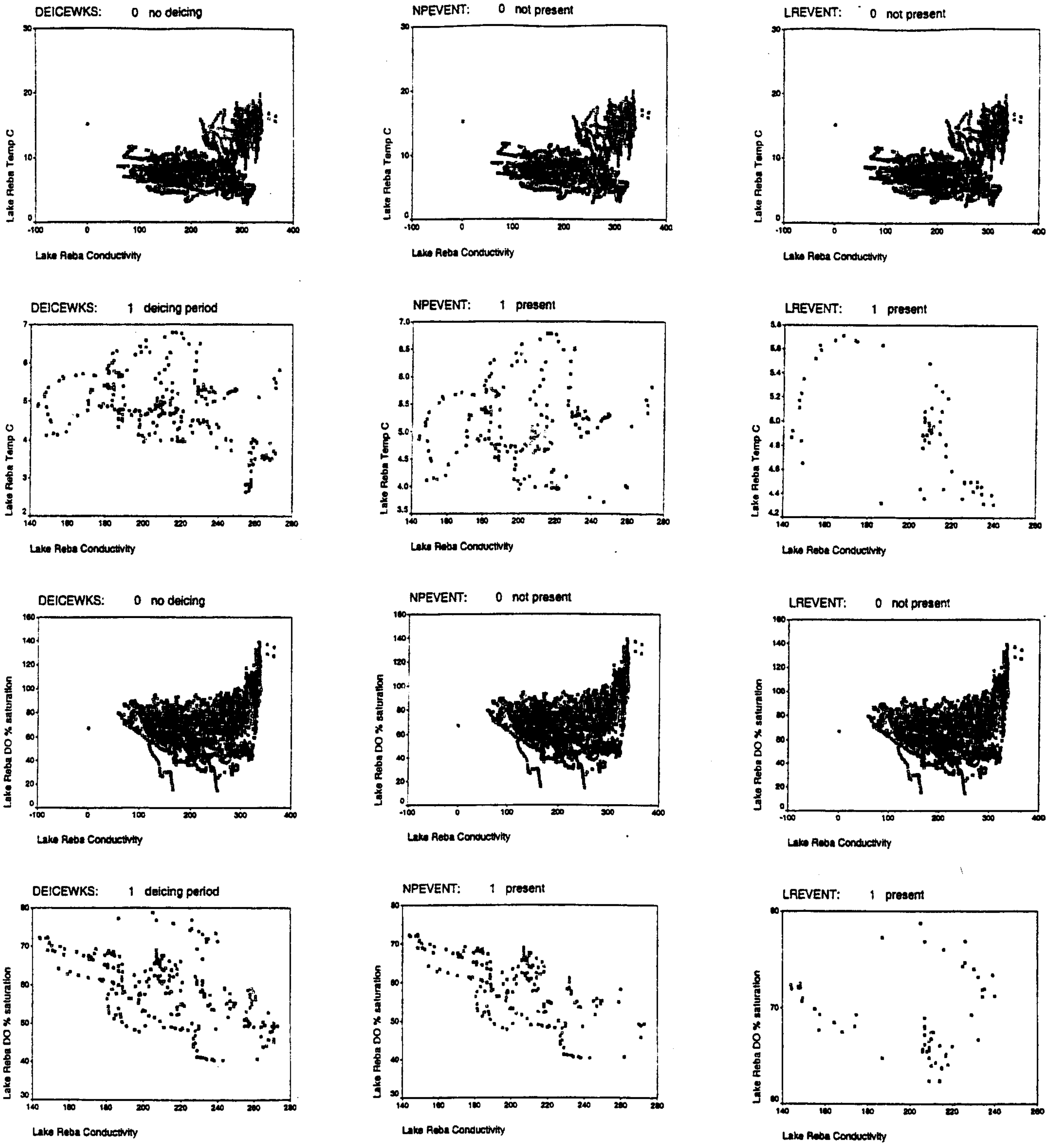
Appendix D6. Figure 6.

Scatter plots of conductivity and temperature, conductivity and DO % saturation at NP3. In Column 1 (deicewks, no deicing, deicing period), the deicing period is the entire two-week deicing period. In Column 2 (Npevent, signal present, signal not present), the deicing period is the period of time that a deicing signal was present at NP3. In Column 3 (LRevent, signal present, signal not present), the deicing period is the period of time during which there was a deicing signal present at Lake Reba.



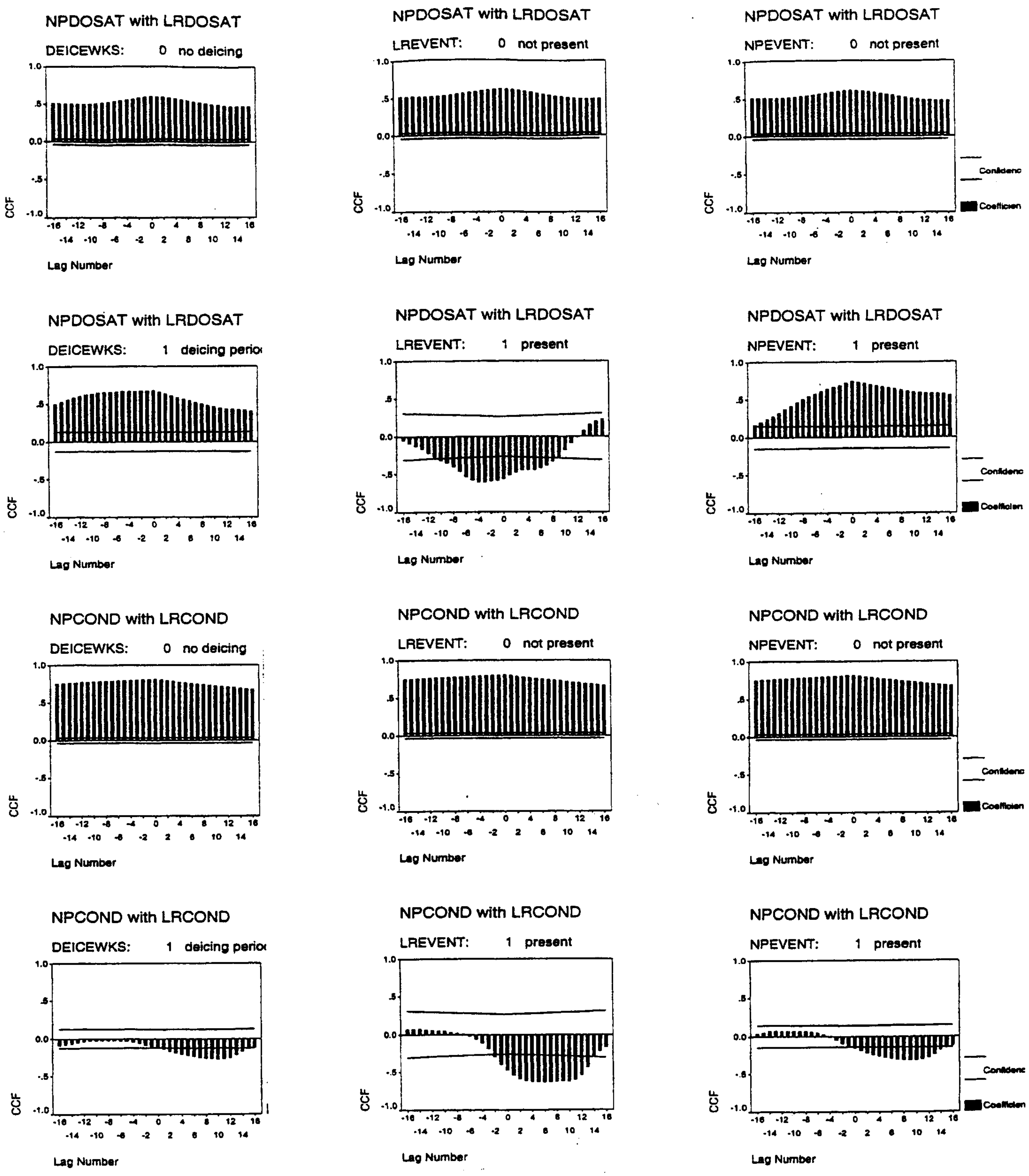
Appendix D6. Figure 7.

Scatter plots of water level and temperature, water level and conductivity at Lake Reba. In Column 1 (deicewks, no deicing, deicing period), the deicing period is the entire two-week deicing period. In Column 2 (Npevent, signal present, signal not present), the deicing period is the period of time that a deicing signal was present at NP3. In Column 3 (LRevent, signal present, signal not present), the deicing period is the period of time during which there was a deicing signal present at Lake Reba.



Appendix D6. Figure 8.

Scatter plots of conductivity and temperature, conductivity and DO % saturation at Lake Reba. In Column 1 (deicewks, no deicing, deicing period), the deicing period is the entire two-week deicing period. In Column 2 (Npevent, signal present, signal not present), the deicing period is the period of time that a deicing signal was present at NP3. In Column 3 (LRevent, signal present, signal not present), the deicing period is the period of time during which there was a deicing signal present at Lake Reba.



Appendix D6. Figure 9.

Cross-correlation functions of DO percent saturation at Lake Reba and NP3 and conductivity at Lake Reba and NP3 during non-deicing and deicing periods. In Column 1 (deicewks), the deicing period is the entire two-week deicing period. In Column 2 (LRevent), the deicing period is the period of time during which there was a deicing signal present at Lake Reba. In Column 3 (NPevent), the deicing period is the period of time that a deicing signal was present at NP3.

5.10 Appendix D7. Summary of ARIMA model results.

Table 1. Akaiki Information criterion and Residual variance for each ARIMA model fit to the data in each pond.

site	ARIMA parameters	AIC	Standard Error	Residual Variance
LR	1,1,1	16,231.5	1.64	2.69
	1,1,0	16,266.8	1.65	2.72
	0,1,1	16,342.3	1.66	2.77
	1,0,0	16,628.5	1.72	2.96
	0,1,0	16,637.1	1.72	2.97
	0,0,1	29,614.3	8.00	64.09
NP3	1,1,1	17,305.9	2.86	8.18
	0,1,1	17,311.5	2.86	8.19
	1,1,0	17,315.8	2.86	8.20
	1,0,0	17,366.1	2.88	8.32
	0,1,0	17,388.8	2.89	8.37
	0,0,1	24,008.9	7.49	56.13

5.11 Appendix D8. Results of Mann-Whitney non-parametric t-tests

This appendix presents results for Mann-Whitney non-parametric t-tests for differences between variable means during treatment and control periods as affected by the definition of the treatment period.

Table 1. Summary of results of Mann-Whitney non-parametric t-test for differences between variable means during treatment and control periods as affected by the definition of the treatment period. The treatment period was defined as (time) the same period of time at both ponds and (signal) as only those hours when a deicing signal was present at the pond (as determined by tracer ions, see text for explanation).

Treatment mean higher by both definitions		**Treatment and control means differ, but direction of difference depends on definition of treatment period**	
	6 hr % Change level - NP3	6 hr Change conductivity - NP3	time says treatment mean higher, signal says treatment mean lower
	6 hr Change level - NP3		
	6 hr Change temperature - LR		
	6 hr Change temperature - NP3		
	Level - LR		
	Level - NP3		
Treatment mean lower by both definitions			
	6 hr Change DO - NP3	6 hr % Change temperature - LR	time says treatment mean lower, signal says treatment mean higher
	6 hr Change DO saturation - NP3	6 hr % Change temperature - NP3	time says treatment mean lower, signal says treatment

			mean higher
	Conductivity - LR	DO - LR	time says treatment mean lower, signal says treatment mean higher
	Temperature - LR		
	DO - NP3		
	DO saturation - NP3		
	Temperature - NP3		
No significant difference by either definition			
	6 hr Change DO - LR		
	6 hr % Change DO - LR		
	Conductivity - NP3		
Treatment mean higher by signal			
	6 hr % Change conductivity - NP3	6 hr Change level - LR	time says treatment mean higher, signal says treatment mean lower
Treatment mean lower by signal			
	6 hr % Change level – LR	DO saturation – LR	time says treatment mean lower, signal says treatment mean higher
Treatment mean higher by time			
	6 hr Change conductivity – LR	6 hr % Change DO saturation – LR	time says treatment mean higher, signal says treatment mean lower
	6 hr Change DO saturation – LR	6 hr % Change DO saturation – NP3	time says treatment mean higher, signal says treatment mean lower
Treatment mean lower by time			
	6 hr % Change conductivity – LR		
	6 hr % Change DO – NP3		

Table 2. Means and standard deviations of selected variables during treatment and control periods using two definitions of deicing.

Pond	Variable	period	N	Mean	Standard deviation	Tracer signal	N	Mean	Standard deviation
NP3	DO	control	2933	5.27	1.73	not present	2995	5.23	1.73
		treatment	262	3.94	1.17	present	200	4.12	1.23
NP3	DO % saturation	control	3231	46.23	16.28	not present	3293	45.85	16.38
		treatment	262	31.16	9.25	present	200	32.70	9.62
NP3	Level (ft)	control	2689	6.95	2.37	not present	2751	6.99	2.37
		treatment	262	8.96	1.01	present	200	9.34	0.91
NP3	Temperature C	control	3513	8.78	2.93	not present	3575	8.70	2.97
		treatment	262	4.43	0.53	present	200	4.64	0.40
NP3	Conductivity	control	3513	149.07	42.48	not present	3575	149.04	42.12
		treatment	262	149.05	9.67	present	200	149.71	9.94
NP3	6 hr Change DO	control	2843	-0.03	0.80	not present	2905	-0.03	0.79
		treatment	262	-0.03	0.59	present	200	-0.01	0.66
NP3	6 hr Change DO saturation	control	2843	-0.03	0.80	not present	2905	-0.03	0.79
		treatment	262	-0.03	0.59	present	200	-0.01	0.66
NP3	6 hr Change temperature	control	3419	-0.01	0.56	not present	3481	-0.01	0.56
		treatment	262	0.02	0.29	present	200	0.03	0.31
NP3	6 hr Change conductivity	control	3419	0.24	8.18	not present	3481	0.27	8.13
		treatment	262	0.47	10.60	present	200	-0.06	11.89
NP3	6 hr Change level	control	2671	0.00	0.96	not present	2733	0.01	0.95
		treatment	262	-0.04	0.60	present	200	-0.11	0.59
NP3	6 hr % Change DO	control	2843	-0.0209	0.16	not present	2905	-0.0210	0.16

Pond	Variable	period	N	Mean	Standard deviation	Tracer signal	N	Mean	Standard deviation
		treatment	262	-0.0208	0.19	present	200	-0.0190	0.21
NP3	6 hr % Change DO sat	control	2843	-0.0024	0.02	not present	2905	-0.0024	0.02
		treatment	262	-0.0026	0.02	present	200	-0.0023	0.03
NP3	6 hr % Change level	control	2671	1.0049	0.10	not present	2733	1.0044	0.10
		treatment	262	1.0062	0.06	present	200	1.0142	0.06
NP3	6 hr % Change cond	control	3419	-0.0005	0.08	not present	3481	-0.0003	0.08
		treatment	262	0.0014	0.06	present	200	-0.0029	0.07
NP3	6 hr % Change temp	control	3419	-0.0034	0.06	not present	3481	-0.0035	0.06
		treatment	262	0.0019	0.07	present	200	0.0039	0.07
LR	DO	control	3670	7.78	1.79	not present	3874	7.74	1.76
		treatment	262	7.35	1.06	present	58	8.61	0.55
LR	DO % saturation	control	3972	69.30	19.04	not present	4176	68.65	18.86
		treatment	262	58.87	8.49	present	58	69.05	4.08
LR	Level ft	control	3230	3.75	2.10	not present	3367	3.78	2.06
		treatment	195	4.80	1.05	present	58	5.93	0.81
LR	Temp C	control	3971	8.85	3.29	not present	4175	8.66	3.33
		treatment	262	4.82	0.87	present	58	4.92	0.41
LR	Conductivity	control	3971	230.16	71.39	not present	4175	229.50	70.04
		treatment	262	212.93	32.05	present	58	199.91	29.08
LR	6 hr Change DO	control	3600	-0.01	0.65	not present	3804	-0.01	0.64
		treatment	262	-0.07	0.53	present	58	0.01	0.58
LR	6 hr Change DO saturation	control	3902	-0.09	7.30	not present	4106	-0.13	7.18
		treatment	262	-0.50	4.37	present	58	0.44	4.76
LR	6 hr Change level	control	3218	0.01	0.94	not present	3355	0.01	0.93
		treatment	195	-0.06	0.76	present	58	0.00	1.10

Pond	Variable	period	N	Mean	Standard deviation	Tracer signal	N	Mean	Standard deviation
LR	6 hr Change temperature	control	3901	-0.01	1.10	not present	4105	0.00	1.08
		treatment	262	0.03	0.47	present	58	0.06	0.31
LR	6 hr Change conductivity	control	3901	0.02	20.35	not present	4105	0.19	20.20
		treatment	262	1.11	18.05	present	58	-7.22	20.32
LR	6 hr % Change DO	control	3600	0.00	0.09	not present	3804	-0.0055	0.09
		treatment	262	-0.01	0.07	present	58	-0.0005	0.07
LR	6 hr % Change DO sat	control	3902	-0.007	0.10	not present	4106	-0.0072	0.10
		treatment	262	-0.012	0.08	present	58	0.0041	0.07
LR	6 hr % Change level	control	2859	-0.042	2.24	not present	2996	-0.0421	2.19
		treatment	195	-0.030	0.19	present	58	-0.0130	0.16
LR	6 hr % Change cond	control	3901	-0.196	11.87	not present	4105	-0.1857	11.57
		treatment	262	0.001	0.09	present	58	-0.0464	0.11
LR	6 hr % Change temp	control	3901	-0.008	0.11	not present	4105	-0.0075	0.11
		treatment	262	0.000	0.10	present	58	0.0120	0.06

Table 3. Ranks of selected variables used in Mann-Whitney U tests of differences between treatment and control periods using two definitions of deicing.

Pond	Variable	period	N	Mean rank	Tracer signal	N	Mean rank
NP3	DO	control	2933	1,663.63	not present	2995	1,639.98
		treatment	262	863.24	present	200	969.40
NP3	DO % saturation	control	3231	1,824.96	not present	3293	1,799.12
		treatment	262	785.56	present	200	888.89
NP3	Level (ft)	control	2689	1,397.46	not present	2751	1,413.40
		treatment	262	2,282.10	present	200	2,337.06
NP3	Temperature C	control	3513	2,009.15	not present	3575	1,975.33
		treatment	262	263.64	present	200	326.99
NP3	Conductivity	control	3513	1,882.31	not present	3575	1,882.88
		treatment	262	1,964.32	present	200	1,979.56
NP3	6 hr Change DO	control	2843	1,542.74	not present	2905	1,543.83
		treatment	262	1,664.36	present	200	1,686.14
NP3	6 hr Change DO saturation	control	2843	1,542.74	not present	2905	1,543.83
		treatment	262	1,664.36	present	200	1,686.14
NP3	6 hr Change temperature	control	2671	1,496.62	not present	2733	1,500.76
		treatment	262	1,165.05	present	200	1,005.72
NP3	6 hr Change conductivity	control	3419	1,825.55	not present	3481	1,829.15
		treatment	262	2,042.57	present	200	2,047.29
NP3	6 hr Change level	control	3419	1,853.03	not present	3481	1,857.90
		treatment	262	1,684.06	present	200	1,546.93
NP3	6 hr % Change DO	control	2843	1,545.13	not present	2905	1,543.86

Pond	Variable	period	N	Mean rank	Tracer signal	N	Mean rank
		treatment	262	1,638.43	present	200	1,685.74
NP3	6 hr % Change DO sat	control	2843	1,545.77	not present	2905	1,543.95
		treatment	262	1,631.44	present	200	1,684.51
NP3	6 hr % Change level	control	2671	1,445.64	not present	2733	1,439.38
		treatment	262	1,684.77	present	200	1,844.45
NP3	6 hr % Change conductivity	control	3419	1,831.16	not present	3481	1,834.12
		treatment	262	1,969.41	present	200	1,960.81
NP3	6 hr % Change temperature	control	3419	1,854.18	not present	3481	1,858.69
		treatment	262	1,669.02	present	200	1,533.05
LR	DO	control	3670	1,988.72	not present	3874	1,956.60
		treatment	262	1,655.28	present	58	2,627.56
LR	DO % saturation	control	3972	2,165.99	not present	4176	2,115.80
		treatment	262	1,382.35	present	58	2,239.97
LR	Level ft	control	2864	1,489.12	not present	3000	1,508.29
		treatment	194	2,125.58	present	58	2,626.24
LR	Temp C	control	3971	2,227.55	not present	4175	2,140.46
		treatment	262	441.42	present	58	427.98
LR	Conductivity	control	3971	2,140.53	not present	4175	2,124.90
		treatment	262	1,760.31	present	58	1,548.44
LR	6 hr Change DO	control	3600	1,936.58	not present	3804	1,928.32
		treatment	262	1,861.66	present	58	2,140.04
LR	6 hr Change DO saturation	control	3902	2,080.84	not present	4106	2,078.07
		treatment	262	2,107.28	present	58	2,396.46
LR	6 hr Change level	control	2845	1,525.28	not present	2981	1,519.46
		treatment	188	1,391.65	present	52	1,375.84

Pond	Variable	period	N	Mean rank	Tracer signal	N	Mean rank
LR	6 hr Change temperature	control	3901	2,064.53	not present	4105	2,075.92
		treatment	262	2,342.07	present	58	2,512.21
LR	6 hr Change conductivity	control	3901	2,077.10	not present	4105	2,091.05
		treatment	262	2,154.89	present	58	1,441.29
LR	6 hr % Change DO	control	3600	1,938.14	not present	3804	1,928.22
		treatment	262	1,840.31	present	58	2,146.38
LR	6 hr % Change DO sat	control	3902	2,084.16	not present	4106	2,078.10
		treatment	262	2,057.80	present	58	2,394.13
LR	6 hr % Change level	control	2845	1,524.51	not present	2981	1,519.39
		treatment	188	1,403.33	present	52	1,379.75
LR	6 hr % Change conductivity	control	3901	2,068.96	not present	4105	2,075.67
		treatment	262	2,276.14	present	58	2,529.73
LR	6 hr % Change temperature	control	3901	2,076.84	not present	4105	2,091.20
		treatment	262	2,158.87	present	58	1,430.84

Table 4. Summary of results of nonparametric Mann-Whitney U tests of differences between control and both defeinitions of treatment periods. P values < 0.05 indicate the difference between the time periods was statistically significant.

Nonparametric test	location	Was the mean greater when the signal was present or not present?	Was the mean greater during the treatment or the control period?	Mann-Whitney P value (signal-basis)	Mann-Whitney P value (time-basis)	summary
DO	NP3	not present	control	**0.00**	**0.00**	control mean higher
DO % saturation	NP3	not present	control	**0.00**	**0.00**	control mean higher
Level (ft)	NP3	present	treatment	**0.00**	**0.00**	treatment mean higher
Temperature C	NP3	not present	control	**0.00**	**0.00**	control mean higher
Conductivity	NP3	present	treatment	0.22	0.24	treatment mean higher
6 hr Change DO	NP3	present	treatment	**0.03**	**0.04**	treatment mean higher
6 hr Change DO saturation	NP3	present	treatment	**0.03**	**0.04**	treatment mean higher
6 hr Change level	NP3	present	treatment	**0.00**	**0.00**	treatment mean higher
6 hr Change temperature	NP3	not present	control	**0.00**	**0.01**	control mean higher
6 hr Change conductivity	NP3	not present	control	**0.00**	**0.00**	control mean higher
6 hr % Change DO	NP3	present	treatment	**0.03**	0.11	treatment mean higher
6 hr % Change DO sat	NP3	present	treatment	**0.03**	0.14	treatment mean higher
6 hr % Change level	NP3	present	treatment	**0.00**	**0.00**	treatment mean higher
6 hr % Change temperature	NP3	not present	control	**0.00**	**0.01**	control mean higher
6 hr % Change conductivity	NP3	present	treatment	0.10	**0.04**	treatment mean higher
DO	LR	present	control	**0.00**	**0.00**	results depend on definition of deicing
DO % saturation	LR	present	control	0.44	**0.00**	results depend on definition of deicing
Level (ft)	LR	present	treatment	**0.00**	**0.00**	treatment mean higher
Temperature C	LR	not present	control	**0.00**	**0.00**	control mean higher

Nonparametric test	location	Was the mean greater when the signal was present or not present?	Was the mean greater during the treatment or the control period?	Mann-Whitney P value (signal-basis)	Mann-Whitney P value (time-basis)	summary
Conductivity	LR	not present	control	**0.00**	**0.00**	control mean higher
6 hr Change DO	LR	present	control	0.15	0.29	results depend on definition of deicing
6 hr Change DO saturation	LR	present	treatment	**0.05**	0.73	treatment mean higher
6 hr Change level	LR	not present	control	0.24	**0.04**	control mean higher
6 hr Change temperature	LR	present	treatment	**0.01**	**0.00**	treatment mean higher
6 hr Change conductivity	LR	not present	treatment	**0.00**	0.31	results depend on definition of deicing
6 hr % Change DO	LR	present	control	0.14	0.17	results depend on definition of deicing
6 hr % Change DO sat	LR	present	control	**0.05**	0.73	results depend on definition of deicing
6 hr % Change level	LR	not present	control	0.25	0.06	control mean higher
6 hr % Change temperature	LR	not present	treatment	**0.00**	0.28	results depend on definition of deicing
6 hr % Change conductivity	LR	present	treatment	**0.00**	**0.01**	treatment mean higher

Appendix D References

Cressie, N.A.C. Statistics for Spatial Data. Wiley Series in Probability and Mathematical Statistics. 1993.

Diggle, P.J. Time Series, A Biostatistical Introduction. Clarendon Press, Oxford, England, 1990.

http://www.duke.edu/~rnau/411arim3.htm Identifying the numbers of AR or MA terms , Duke University, School of Business, BA411, Statistical Forecasting. Class notes.

6 APPENDIX E CHEMICAL APPLICATION SUMMARY

This appendix contains the list of chemical applications recorded and supplied by POS Aviation Maintenance. It does not reflect any corrections that the data in this report suggest. Corrections, as indicated by tracer data discussed in the report, are incorporated in the summary tables in the Appendix F. Applications were summarized for each SDS subbasin and drainage area corresponding to the sampling points used in this study. These applications were allocated to SDS subbasins (and drainage areas corresponding to sampling locations use din this project) based upon nomenclature used by POS maintenance for application areas and the corresponding drainage systems as shown on drawing STIA-9918.

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Summary of 2000 Ground Deicing Chemical Applications

							NPDES	DO study
Date	Time	Landside applications	AOA applications	Chemical	Chem qty	sand lb	subbasin	subbasin
1/12/2000	400	#1 offramp 170th	CMA (lb)	CMA (1/2)	2300	2300	SDE4	DME
1/12/2000	530	South Employee Lot		CMA (1/2)	10000	10000	NA	DME
1/24/2000	800	Fire Station AOA & Road side		CMA (1/2)	200	200	SDE4	DME
1/12/2000	900	north Lot		CMA (1/2)	4340	4340	NA	NEPL
1/24/2000	700	North Empl. lot to 160th Aircargo		CMA (1/2)	900	900	SDN1	N1
1/24/2000	900	160th East to Hy 99 & back		CMA (1/2)	1200	1200	NA	NA
1/11/2000	30		16/R-34/L Potassium Acetate (gal)	E-36	635		AF	AF
1/11/2000	130		16/L-34R	E-36	1697		AF	AF
1/11/2000	154		16/L-34R	E-36	612		AF	AF
1/11/2000	415		16/L-34R	E-36	1362		AF	AF
1/11/2000	435		16/R-34/L &TW/Q &TW/	E-36	1430		AF	AF
1/12/2000	215		16/R-34/L	E-36	1047		AF	AF
1/19/2000	430	Touchdown area 34/R		E-36	204		SDS4, SD	AF
1/19/2000	445	Touchdown area 34/L		E-36	237		SDS3	AF
1/19/2000	500	South end B/TW over 188th tunnel		E-36	31		SDS4, SD	AF
1/11/2000	315		TW/A	E-36	443		SDE4	DME
1/12/2000	115		Gate E-100	E-36	50		SDE4	DME
1/12/2000	215		AOA rd - So Hard stand	E-36	25		SDE4	DME
1/12/2000	245	170th Brg to Clock freeway N&S		E-36	125		SDE4	DME
1/12/2000	300		Hill behind D concourse	E-36	75		SDE4	DME
1/12/2000	305		B/TW & A/TW	E-36	1195		SDE4	DME
1/12/2000	400	Bus Route		E-36	150		SDE4	DME
1/12/2000	605		So. Sat & No. Sat & N/T	E-36	717		SDS1	DME
1/12/2000	620	Upper Dr		E-36	15		SDE4	DME
1/12/2000	630	Lower Dr		E-36	25		SDE4	DME
1/12/2000	645	170th Brg no		E-36	25		SDE4	DME
1/12/2000	700	170th Brg so		E-36	5		SDE4	DME
1/19/2000	229	Aircargo 4 to 161th east		E-36	3		SDE4	DME
1/19/2000	231	Aircargo 4 parking lot		E-36	1		SDE4	DME
1/28/2000	500	Upper Dr south		E-36	5		SDE4	DME
1/12/2000	608	160th Brg		E-36	15		SDN1	N1
1/18/2000	600	Aircargo road 160th to 154th		E-36	50		SDN1	N1
1/19/2000	525	Aircargo Rd 160th north to 154th		E-36	10		SDN1	N1
1/19/2000	525	Aircargo Rd 154th to 160th		E-36	10		SDN1	N1
1/11/2000	100	Parking G. spirals No & So		E-36	100		IWS	NA
1/11/2000	130	Parking G. Exit lane 1-10		E-36	10		IWS	NA
1/11/2000	200	Parking G. Exit from oversize lot		E-36	5		IWS	NA
1/11/2000	230	Parking G. Exit toll plaza		E-36	10		IWS	NA
1/11/2000	300	Parking G. taxi lot		E-36	10		IWS	NA
1/11/2000	315	Parking G. 3rd floor enterance		E-36	10		IWS	NA
1/11/2000	330	Dan Baker road (3rd floor enter.)		E-36	5		IWS	NA
1/12/2000	130		Gate E-185	E-36	50		IWS	NA
1/12/2000	200		South Hard Stand	E-36	25		SDS4	NA
1/12/2000	230		Cargo 4	E-36	25		IWS	NA
1/19/2000	225		Aircargo 4 fuel pumps	E-36	1		IWS	NA
1/19/2000	200	160th street east & west	Sodium Acetate (lb)	SA (1/2)	250	250	NA	NA
1/19/2000	230	North Emploee lot		SA (1/2)	1650	1650	NA	NEPL
1/19/2000	630	Upper Dr south		SA	350		SDE4	DME
1/19/2000	630	From 170th bridge north to clock		SA	2125		SDE4	DME
1/19/2000	630	Upper dr. So		SA	350		SDE4	DME
1/19/2000	630	170th bridge No & So to clock		SA	4250		SDE4	DME
1/19/2000	645	From clock south to 170th bridge		SA	4000		SDE4	DME
1/19/2000	645	From 170th bridge north to clock		SA	4000		SDE4	DME
1/19/2000	645	on ramp 170th		SA	50		SDE4	DME
1/19/2000	645	off ramp 170th		SA	50		SDE4	DME
1/19/2000	645	From clock south to 170th bridge		SA	4000		SDE4	DME
1/19/2000	645	From 170th bridge north to clock		SA	4000		SDE4	DME
1/19/2000	645	on ramp 170th		SA	50		SDE4	DME
1/19/2000	645	off ramp 170th		SA	50		SDE4	DME
1/24/2000	500	Aircargo Rd 160th north to 154th		SA	1345		SDN1	N1
1/24/2000	500	North Empl. lot to 160th Aircargo		SA	1345		SDN1	N1
12/3/1999	400	So Empl Lot				1	NA	DME

1999 - 2000 Chemical Application Summary
Sea-Tac International Airport

Summary of 2000 Ground Deicing Chemical Applications

Date	Time	Roadside applications	AOA applications	Chemical	chem qty	sand lb	NPDES subbasin	DO study subbasin
12/8/1999	915	So Empl Lot	SAND (lb) with minor chemical (PA) added to prevent freezing			1700	NA	DME
1/11/2000	430	Multi Lane-R/lane				100	SDE4	DME
1/12/2000	30	Upper & Lower Dr				11,000	SDE4	DME
1/12/2000	30	Upper & Lower Dr				11,000	SDE4	DME
1/12/2000	300	Upper & Lower Dr				11000	SDE4	DME
1/12/2000	300	Upper & Lower Dr				11000	SDE4	DME
1/12/2000	400	South remote Lot				1475	NA	DME
1/12/2000	430	Gate E-100				75	SDE4	DME
1/12/2000	500	South Lot				50	SDE4	DME
1/19/2000	645	188th No to Tunnel on Aircargo rd				845	NA	DME
1/19/2000	655	Aircargo rd So Tunnel to 188th st				845	NA	DME
1/19/2000	800	South Parking lot				800	SDE4	DME
1/19/2000	845	South enterance to parking				820	SDE4	DME
1/19/2000	900	Lower DR & Upper DR				1000	SDE4	DME
1/19/2000	900	North enterance to parking garage				200	SDE4	DME
1/19/2000	900	down ramp to parking garage				820	SDE4	DME
1/28/2000	2200	South GT lot				30	SDE4	DME
12/27/1999	600	160th Brige				50	SDN1	N1
1/11/2000	530	Aircargo Rd north				6000	SDN1	N1
1/12/2000	500	Biffy Dump				50	IWS	NA
1/12/2000	500	E-185				50	IWS	NA
1/12/2000	515	Delta Emplolee Lot				50	IWS	NA
1/15/2000	530	in front of g Bus - Limo lot 160th st				100	NA	NA
1/12/2000	300	north Lot				1525	NA	NEPL
1/12/2000	430	North Lot				50	NA	NEPL
1/18/2000	635	North Emploee Parking lot				3200	NA	NEPL
1/19/2000	800	North Emploee lot				3320	NA	NEPL

1. "CMA (1/2)" and SA (1/2) mean 50/50 sand/chemical mixture applied (solid)
2. Sand used on "roadside" had minor amount of liquid E36 (potassium acetate) sprayed on to prevent freezing.
3. Chemical application trucks used on the AOA have "dickey box" computer controller/flowmeters that calculate quantities to higher precision, hence the number of significant figures on some PA qtys.
4. applications were allocated to SDS subbasins (and drainage areas corresponding to sampling locations use din this project) based upon nomenclature used for application areas and corresponding drainage systems as shown on drawing STIA-9918.
5. All times indicated for January 11th are assumed to be for January 12th given that first notice of chemical applications was given on January 12, 01:39 AM. There were no freezing temperatures nor frozen precipitation recorded by the NWS on January 11th.
6. All chemical applications to the airfield (runways and taxiways as indicated in this table) were lumped into one volume and allocated amongst the SDS3, SDS4, SDN3 and SDN4 subbasins according to the percent of impervious area for each subbasin relative to the total impervious area of the entire airfield drainage.

E-36: Potassium Acetate E-36
SA: Sodium Acetate
CMA: Calcium Magnesium Acetate

7 APPENDIX F BOD ESTIMATES

This appendix summarizes methods used to estimate theoretical BOD loads described in this report. Importantly, the estimates of BOD attributable to ground-deicing chemicals are based only on the volumes applied, as recorded and summarized in Appendix E and tables in the main body of the report. That is, the load estimates do not necessarily reflect what occurred in discharges. All BOD estimates are based upon the actual data obtained by Horner (1996) for BOD rates of PA and CMA tested at 4°C over periods of one to 35 days. BOD attributable to SA is assumed to be similar to CMA, which is supported by the manufacturer's MSDS (Cryotech, 1999) and other literature (Horner, 1996b).

BOD estimates are the product of chemical volume (either reported or calculated otherwise) and the BOD values (g BOD per g chemical) listed in the tables, converted to pounds using the appropriate specific gravity listed on the suppliers' MSDS. Glycol volumes estimated in SDS3 and SDE4 discharges are the products of sample glycol concentration and total discharge volume that occurred during the sampling period.

Tables 7-1 through 7-4 show estimates of BOD for the January 11-12, 2000 ground-deicing event. Tables 7-4 and 7-7 compare the BOD attributable to glycols found in stormwater samples with BOD estimated for all chemicals applied during the January 2000 and December 1998 events, respectively. These two tables highlight the relevant BOD_{5+} estimates cited in the text of Volume 1, Executive Summary and Section 2.4. Tables 7-5 through 7-7 show BOD estimates for the December 24, 1998 event that are cited in the text of Volume 1, Section 2.4.

Table 7-1 Total Volumes of Ground Deicers and ADAFs (glycols) during the January 11-12, 2000 event

total volumes reported	area	*PA, lb	CMA, lb	SA, lb	EG, gal	PG, gal	PA, gal
	DME (SDE4)	30160	12300	0			2850
	NWP (SDS3)	57548	0	0			5438
	LR (N1, N3/N4)	9048	4340	0			855
	IWS	2381	0	0			225
	other	0	0	0			0
	sum	99,137	16,640	-	17	571	9,368
	*uses speicific gravity per MSDS of			1.275			

note: Ethylene (EG) and Propylene (PG) glycol volumes estimated using results from Jan 11-12 samples taken at SDS3 and SDE4. See Table 7-2 below.

Table 7-2 Estimates of Glycol Volumes from January 11-12, 2000 Deicing Event Stormwater Sample Results

	sample results, mg/l				estimated loads (gal)			·ADAFs applied (gal)**			% escape to SDS		
outfall	EG	PG	total glycols	stormwater discharge volume*, gal	EG	PG	total glycols	EG	PG	total	EG	PG	total glycols
SDE4	4.5	7.47	12	303,417	1	2	4	734	14904	15638	0.2%	0.02%	0.02%
SDS3	9.47	355	364	1,600,973	15	568	583	734	14904	15638	2.1%	3.8%	3.7%
				Sum:	17	571	586		3 day totals Jan 11-13		2.3%	3.8%	3.7%

*From Flowlink 4.1 data: volume discharged during flow-weighted composite sampling period

**as reported to POS by airlines, includes totals in dry period prior to first runoff sampled

Table 7-3 BOD5 Estimates for Ground Deicing Chemicals Applied in January 2000

BOD5 (lb) Estimates for Jan 11-12 event only

	PA*	% of total	CMA	% of total	SA	% of total	sum	% of total
L. Reba	2,440	8%	790	3%	-	0%	3,230	11%
NW Ponds	15,540	52%	-	0%	-	0%	15,540	52%
DME	8,140	27%	2,250	8%	-	0%	10,390	35%
IWS	640	2%	-	0%	-	0%	640	2%
other	-	0%	-	0%	-	0%	-	0%
total	26,760	90%	3,040	10%	-	0%	29,800	100%

* using specific gravity per MSDS of 1.275

BOD5 (lb) Estimates for all events of January 2000

	PA*	% of total	CMA	% of total	SA	% of total	sum	% of total
L. Reba	2,640	7%	960	3%	790	2%	4,390	11%
NW Ponds	16,210	42%	-	0%	-	0%	16,210	42%
DME	10,360	27%	2,290	6%	4,260	11%	16,910	44%
IWS	650	2%	-	0%	-	0%	650	2%
other	-	0%	220	1%	50	0%	270	1%
total	29,860	78%	3,470	9%	5,100	13%	38,400	

BOD rates from literature review and actual tests conducted by Horner (1996)

	% of ult BOD as f(time) @ 4°C**			
type	1	5	10	20
PA	51%	30%	56%	87%
CMA	51%	30%	56%	87%
SA	51%	30%	56%	87%

	g BOD/g compound @ 4°C		
type	BOD1	BOD5	ult BOD
PA	0.46	0.27	0.9
CMA	0.31	0.18	0.61
SA	0.31	0.18	0.61

**note: above values are as measured and include distinct lag phase

note: SA and CMA assumed to have similar lag to PA

Table 7-4 BOD Estimates for ground deicers and ADAFs (glycols) applied during January 11-12, 2000 event

	drainage area	BOD1	BOD2	BOD3	BOD4	BOD5	BOD10	BOD20	BOD26	ult BOD
total BOD	DME (SDE4)	17709	14629	12704	8469	10394	19248	30027	33107	34647
	NWP (SDS3)	26472	21868	18991	12661	15538	28774	44888	49491	51793
	LR (N1, N3/N4)	5515	4556	3957	2638	3237	5995	9352	10311	10790
	IWS	1095	905	786	524	643	1191	1857	2048	2143
	other	0	0	0	0	0	0	0	0	0
	sum (lb)	50,790	41,960	36,440	24,290	29,810	55,210	86,120	94,960	99,370
BOD from glycols	EG*	46	11	9	9	59	126	172	172	172
	EG % TG	1%	1%	1%	4%	3%	2%	2%	2%	2%
	EG % grand	0.1%	0.03%	0.02%	0.04%	0.2%	0.2%	0.2%	0.2%	0.2%
	PG*	3712	1237	742	247	1683	6434	9601	10146	10393
	TG sum	3758	1249	751	257	1741	6560	9773	10318	10565
	TG%grand	6.9%	2.9%	2.0%	1.0%	[illegible]	10.6%	10.2%	9.8%	9.6%
	grand total (lb)	54,550	43,210	37,190	24,550	31,550	61,770	95,890	105,280	109,940
	*uses specific gravity per MSDS of		1.045							
		values used in table above: gBOD/g compound @4°C (source: Homer, 1996)								
	chem type	BOD1	BOD2	BOD3	BOD4	BOD5	BOD10	BOD20	BOD26	ult BOD
g BOD/g	PA	0.46	0.38	0.33	0.22	0.27	0.5	0.78	0.86	0.9
	CMA	0.31	0.26	0.22	0.15	0.18	0.34	0.53	0.58	[illegible]
	SA	0.31	0.26	0.22	0.15	0.18	0.34	0.53	0.58	0.61
	EG	0.32	0.08	0.06	0.065	[illegible]	[illegible]	1.2	1.2	1.2
	PG	0.76	0.25	0.15	0.05	0.34	1.3	1.94	2.05	2.1
% ult	PA	51%	42%	37%	24%	30%	56%	87%	96%	100%
	CMA	51%	42%	37%	24%	30%	56%	87%	96%	100%
	SA	51%	42%	37%	24%	30%	56%	87%	96%	100%
	EG	27%	7%	5%	5%	34%	73%	100%	100%	100%
	PG	36%	12%	7%	2%	16.2%	62%	92%	98%	100%

literature/experimental values:

assume CMA and SA have decay rates similar to PA (use same %of ult BOD)

assume SA has same ultimate BOD as CMA

Table 7-5 Total Volumes of Ground Deicers and ADAFs (glycols) during December 24, 1998 event

	drainage area	PA*, lb	CMA, lb	SA, lb	EG, gal	PG, gal	PA, gal
total volumes reported	DME (SDE4)	58760	0	20000			5553
	NWP (SDS3)	112118	6000	0			10595
	LR (N1, N3/N4)	17628	800	4000			1666
	IWS	4639	0	0			438
	other	515	0	0			49
	sum	193,660	6,800	24,000	83	212	18,300
	*uses speicific gravity per MSDS of			1.275			

note: Ethylene (EG) and Propylene (PG) glycol volumes estimated using results from Dec. 24, 1998 samples taken at SDS3 and SDE4. See Table 7-6 below.

Table 7-6 Estimates of Glycol Volumes from December 24, 1998 Deicing Event Stormwater Samples

	sample results, mg/l				estimated loads (gal)			ADAFs applied (gal)**			% escape to SDS		
outfall	EG	PG	total glycols	stormwater discharge volume*, gal	EG	PG	total glycols	EG	PG	total	EG	PG	total glycols
SDE4	13	31	44	500,000	7	16	22	2280	39214	41494	0.3%	0.04%	0.05%
SDS3	32	82	113	2,400,000	77	197	271	2280	39214	41494	3.4%	0.50%	0.65%
				Sum:	83	212	293		8 day total Dec 18 25		3.7%	0.54%	0.71%

*From Flowlink 4.1 data: volume discharged during flow-weighted composite sampling period

**as reported to POS by airlines, includes 7-day period of dry-weather prior to first runoff sampled

Table 7-7 BOD Estimates for ground deicers and ADAFs (glycols) applied during December 24, 1998 event

	area	BOD1	BOD2	BOD3	BOD4	BOD5	BOD10	BOD20	BOD26	ult BOD
total BOD	DME (SDE4)	33265	27480	23864	15909	19525	36158	56406	62191	65084
	NWP (SDS3)	53445	44150	38341	25561	31370	58093	90624	99919	104567
	LR (N1, N3/N4)	9605	7935	6891	4594	5638	10440	16287	17958	18793
	IWS	2134	1763	1531	1021	1253	2319	3618	3989	4175
	other	237	196	170	113	139	258	402	443	464
	sum	98,690	81,520	70,800	47,200	57,920	107,270	167,340	184,500	193,080
BOD from glycols	EG*	231	55	41	45	283	608	830	830	830
	EG % TG	15%	11%	14%	34%	32%	21%	20%	19%	18%
	EG % grand	0.2%	0.07%	0.06%	0.09%	0.5%	0.6%	0.5%	0.4%	0.4%
	PG*	1322	441	264	88	599	2291	3418	3612	3700
	TG sum	1553	496	306	133	883	2899	4248	4442	4530
	TG% grand	1.5%	0.6%	0.4%	0.3%	[redacted]	2.6%	2.5%	2.4%	2.3%
	grand total	100,240	82,020	71,110	47,330	58,800	110,170	171,590	188,940	197,610
	*uses specific gravity per MSDS of		1.045							

this table uses same BOD rates as shown in the lower half of Table 7-4 above.

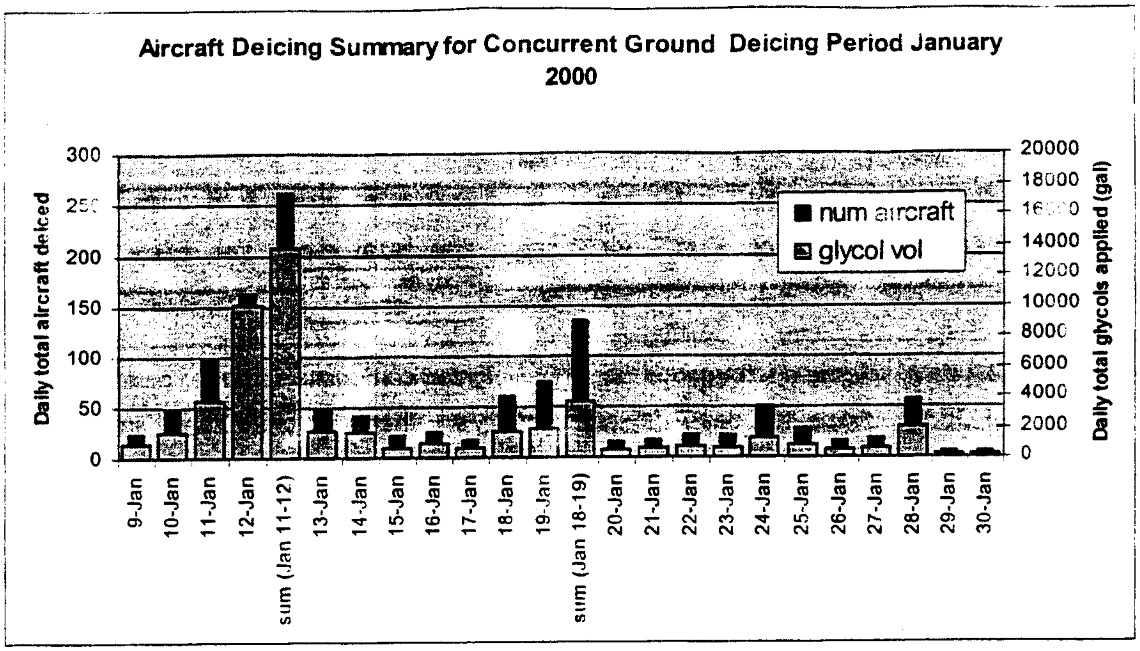

Figure 7-1 Aircraft Deicing Summary for January 2000 Deicing Event Period