Detecting Change in Lakes using EQuIS LakeWatch

California Lake Management Society
21st Annual Conference
October 12, 2006
Etiwanda, California

Scot D. Weaver, Vice President and Founder
Dr. Noel Burns

EarthSoft

Who are we?

EarthSoft

1. A software company, not a consultant
2. Experience developing environmental data management systems for more than 12 years
3. Expertise in limnology, environmental chemistry, geology and geotechnical engineering

Dr. Noel Burns—internationally renowned limnologist having studied inland waters around the globe for over four decades

Who are we?

Clients include:

- Over 250 analytical labs
- Over 100 consultants
- Six U.S. EPA Regions
- 18 state agencies
- Dept. of Defense, Dept. of Energy
- Many industrial clients
- Licenses in Korea, Japan, Vietnam, Kuwait, Singapore, England, Ireland, Italy, South Africa, Venezuela, Australia, Canada, Portugal, Belgium, China, Germany, UAE

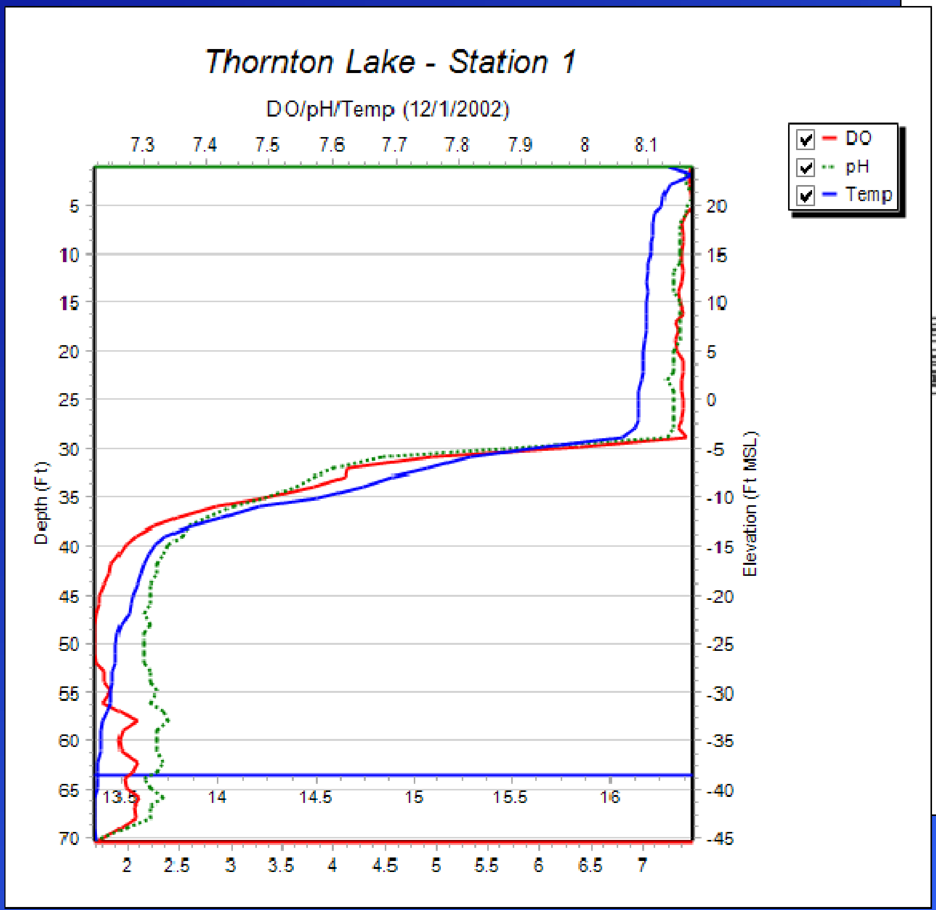
Who are we?

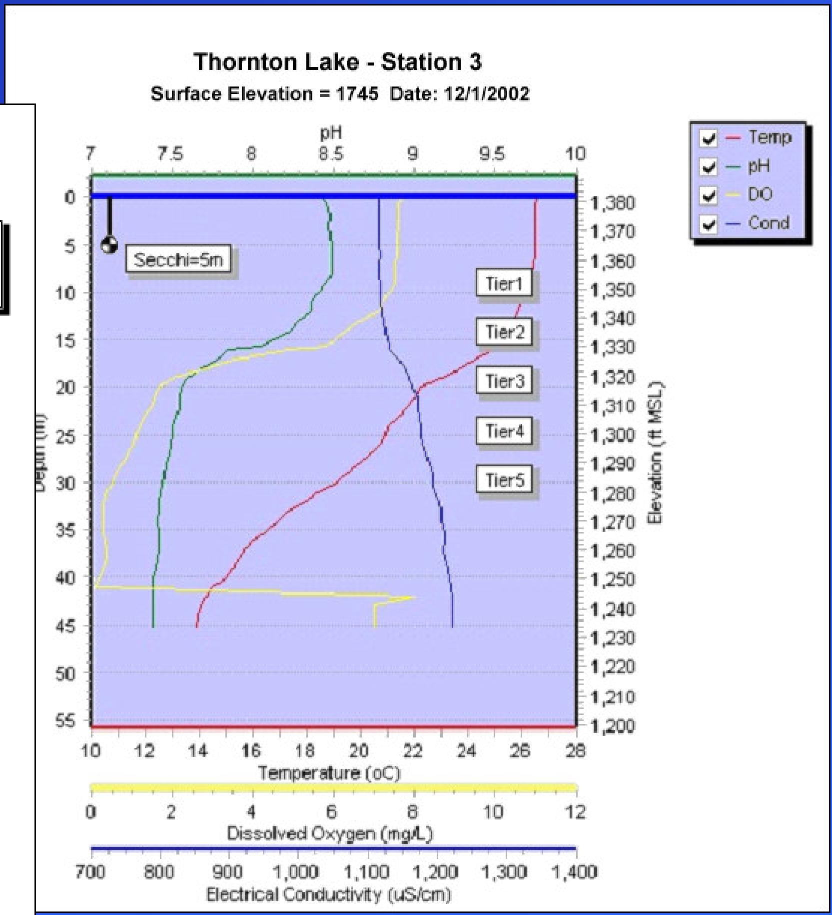
EarthSoft

- California DTSC
- California Department of Water Resources
- City of San Bernardino
- San Bernardino Valley Municipal Water District
- Sacramento County
- Los Angeles Department of Water & Power
- Santa Clara Valley Water District
- **Metropolitan Water District of Southern California**

EQuIS 5 Limnology Features

- Data Checking and Import from RUSS, Hydrolab, Licor, …
- Vertical Profiles





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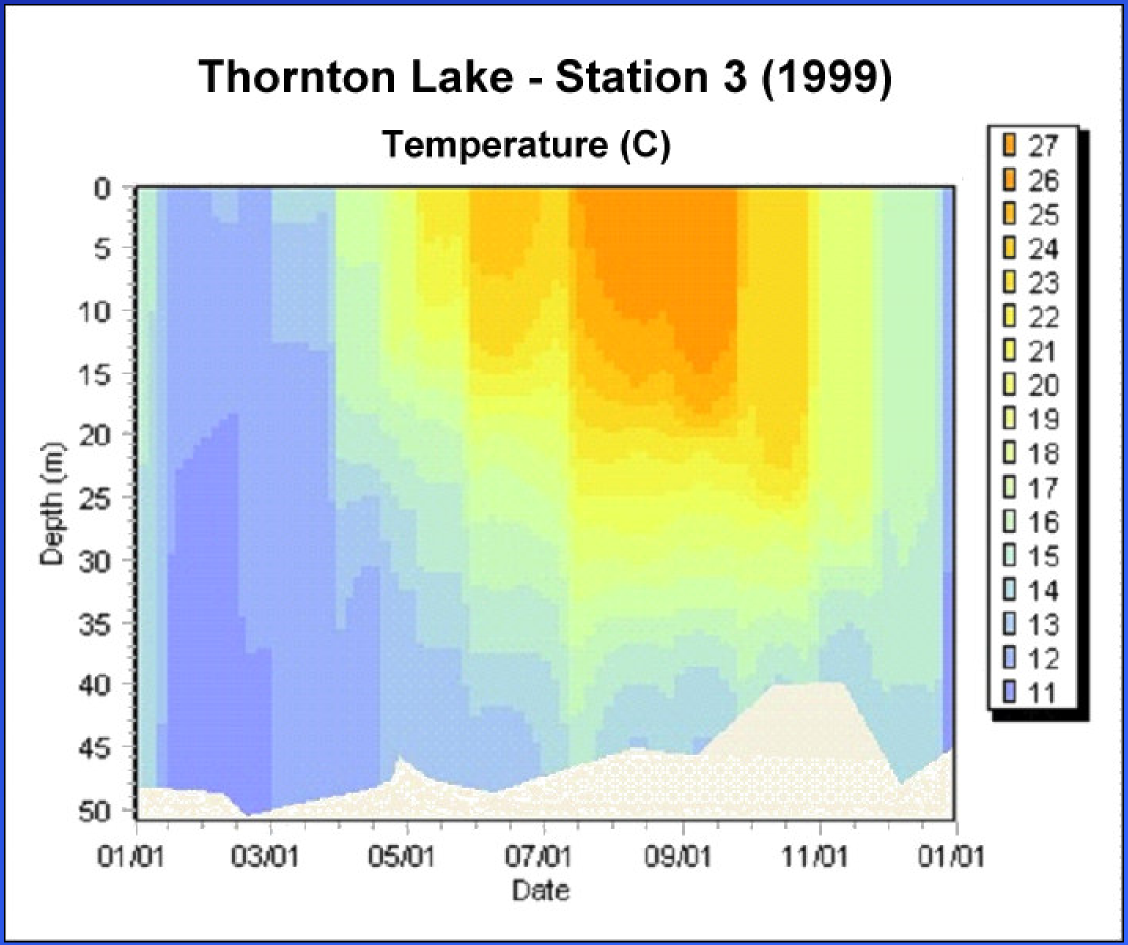
EQuIS 5 Limnology Features

- Data Checking and Import from RUSS, Hydrolab, Licor, …
- Vertical Profiles
- Isopleths



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In April 2006, EarthSoft teamed with Dr. Noel Burns of Lakes Consulting in New Zealand and acquired LakeWatch.

L A K E W A T C H

Software for Lake and Reservoir Monitoring

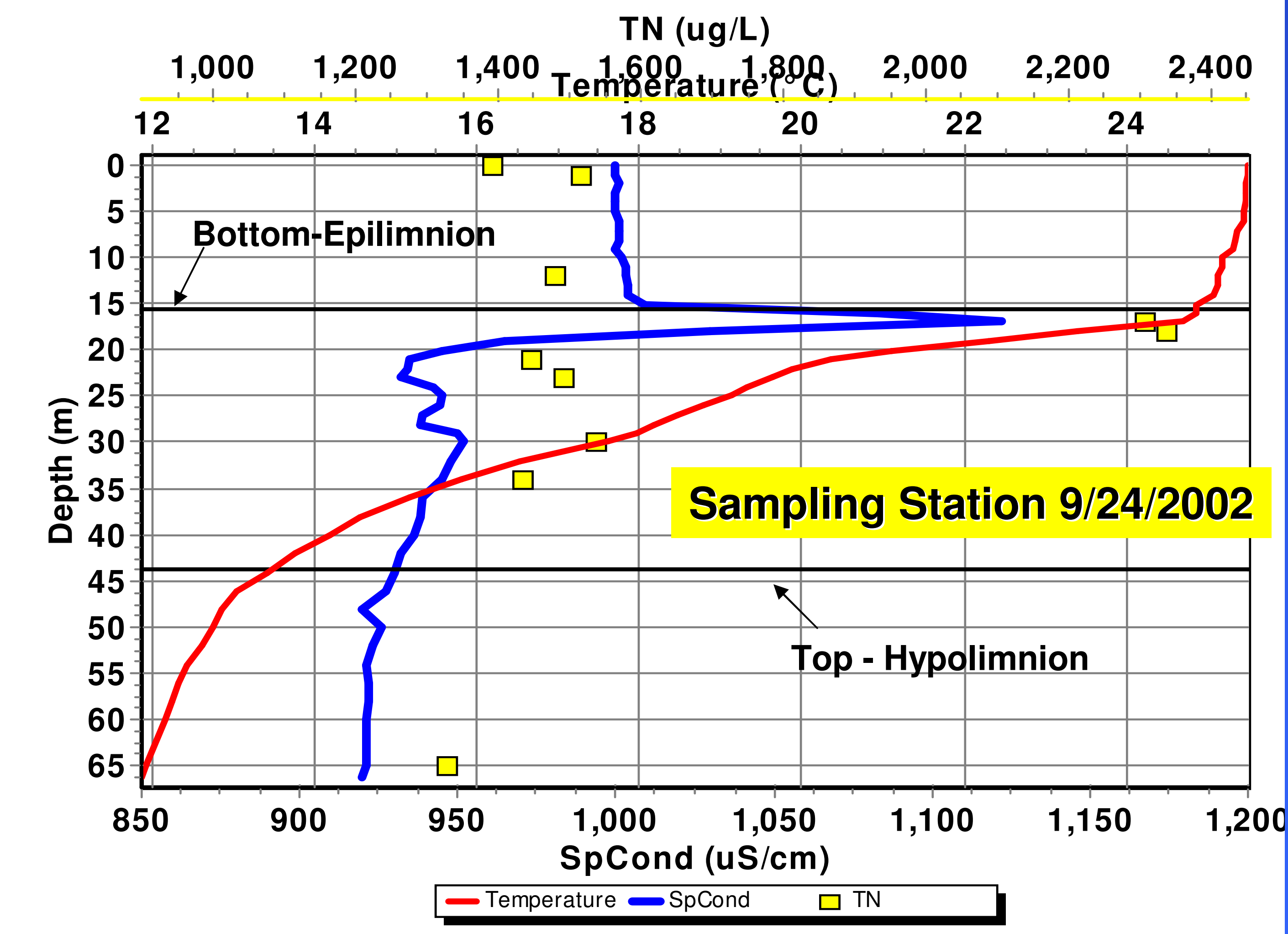
Case Study

In May 2000, a water authority established a major lake monitoring program to ensure that their lake would continue to be a high-quality, valuable water resource long into the future.

One component of the monitoring program includes analysis of physical and chemical data using EQuIS LakeWatch.

- Detailed review of each parameter.
- Display multiple profiles for determination of layers.
- Deseasonalize data for all parameters.
- Detect trends in parameters.
- Summarize results in pre-formatted reports, including annual trophic state and probability of change with time.

Event Profile



Conductivity and total nitrogen concentrations help define plume in top of thermocline

Profile Table

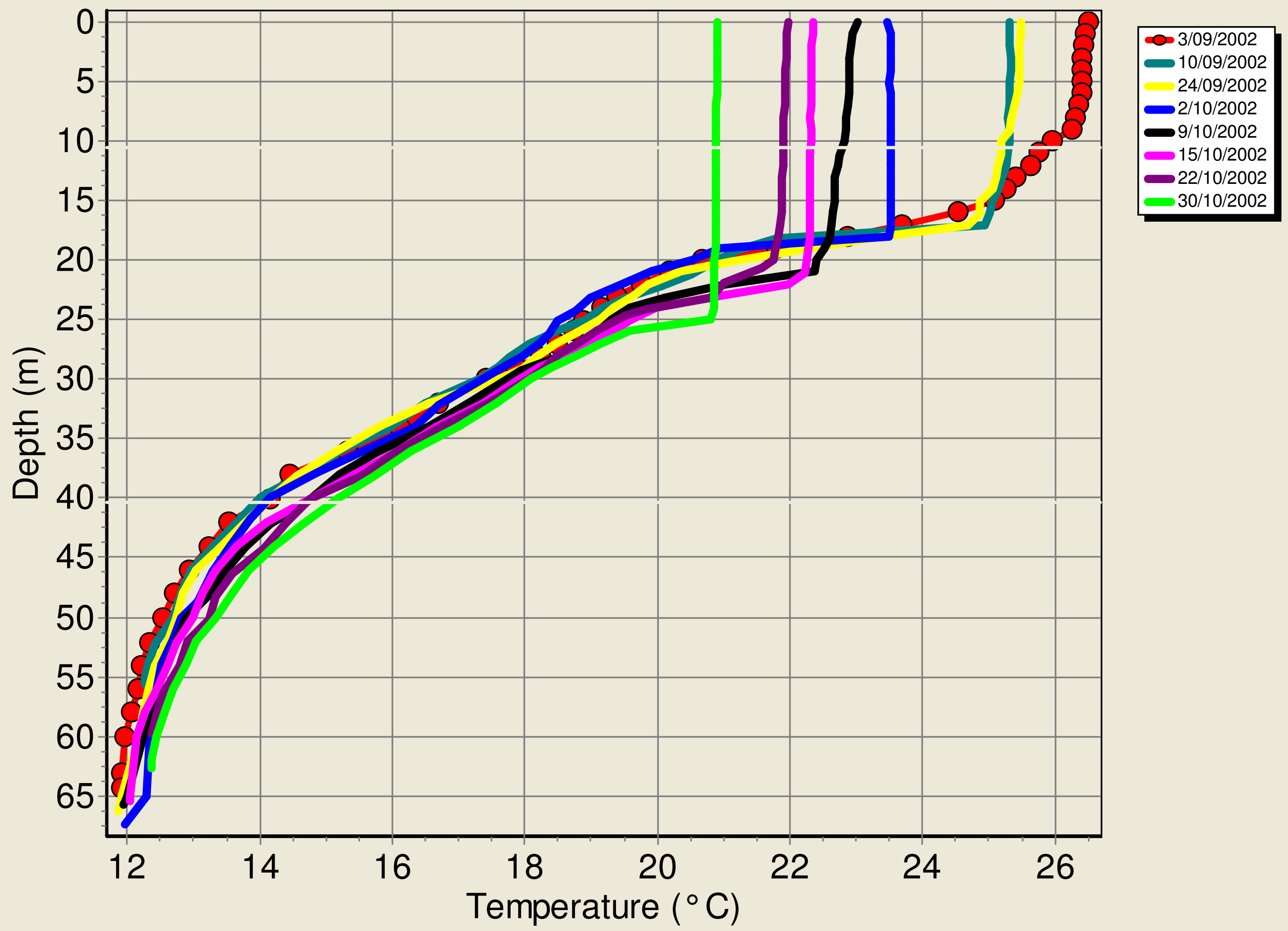
PROFILE LIST (All Variables)

Lake:			Station:			
Date	Depth (m)	Temp (c)	DO (%)	DO (mg/l)	Sp Cond (uS/cm)	H ion conc. (Units)
24/09/2002	0.00	25.50	113.36	8.91	1000.00	8.45
	1.00	25.49	114.36	8.99	1000.00	8.45
	2.00	25.47	113.68	8.94	1001.00	8.45
	3.00	25.47	114.07	8.97	1000.00	8.45
	4.00	25.47	113.94	8.96	1000.00	8.45
	5.00	25.46	112.77	8.87	1000.00	8.45
	6.00	25.45	113.64	8.94	1001.00	8.45
	7.10	25.38	112.23	8.84	1001.00	8.44
	8.20	25.35	111.91	8.82	1001.00	8.43
	9.10	25.32	111.47	8.79	1000.00	8.43
	10.00	25.19	105.89	8.37	1002.00	8.38
	11.10	25.18	104.35	8.25	1003.00	8.37
	12.00	25.14	102.88	8.14	1003.00	8.36
	13.00	25.12	102.47	8.11	1004.00	8.37
	14.00	25.07	100.73	7.98	1004.00	8.35
	15.10	24.87	97.47	7.75	1009.00	8.31
	16.10	24.86	91.04	7.24	1083.00	8.26
	17.00	24.69	81.85	6.53	1122.00	8.13
	18.00	23.40	73.91	6.04	1030.00	7.95
	19.00	22.31	77.44	6.46	965.00	7.95
	20.10	21.12	74.05	6.32	945.00	7.87
	21.00	20.35	68.67	5.95	935.00	7.83
	22.00	19.87	66.77	5.84	934.00	7.80
	23.00	19.65	66.02	5.80	932.00	7.80
	24.00	19.33	68.09	6.02	942.00	7.81
	25.00	19.14	68.51	6.08	945.00	7.79
	26.10	18.78	65.44	5.85	944.00	7.80

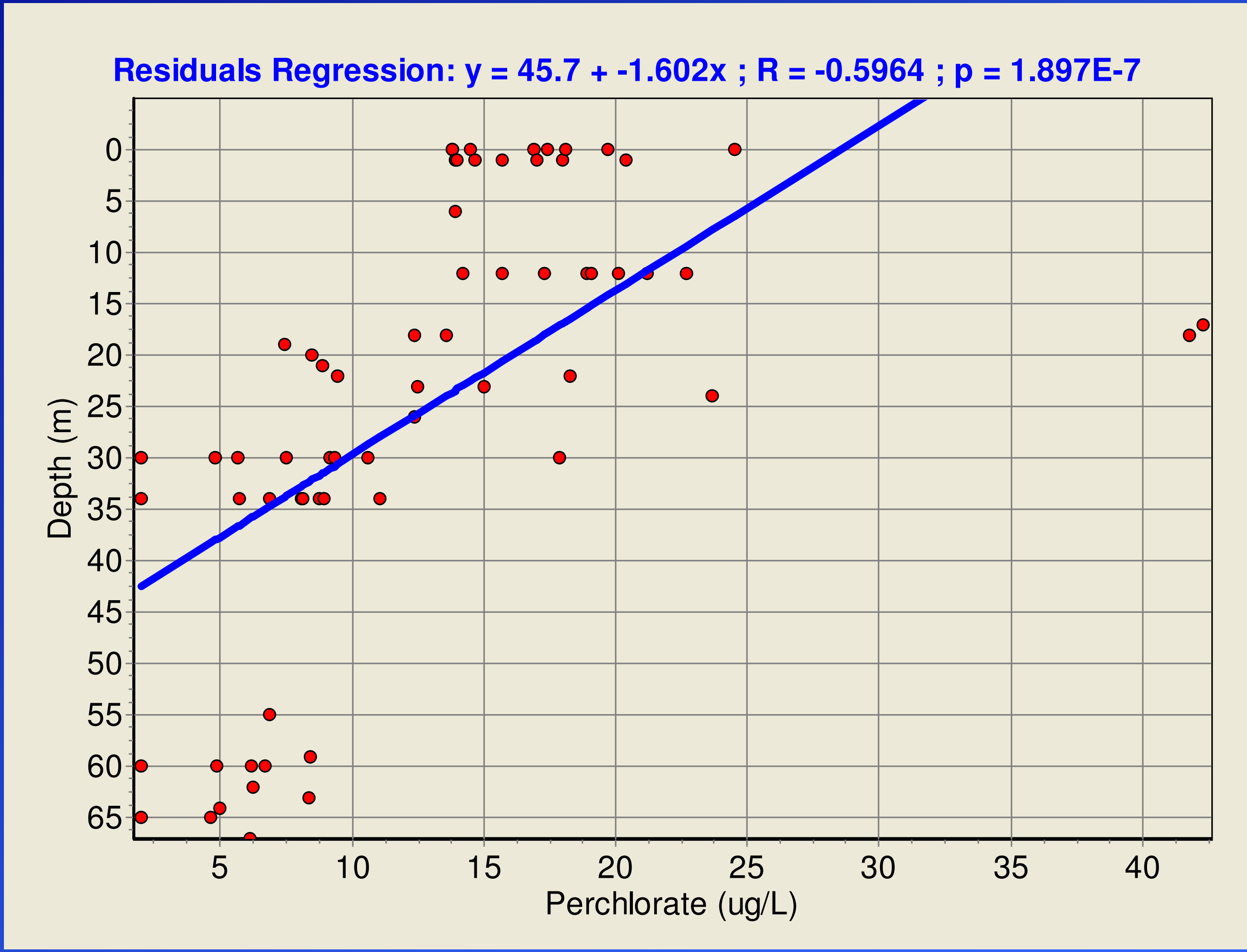
Sample Table

				SAMPLE LIST										
Lake:				Station:										
Date	Depth From (m)	TP (ugP/L)	TN (ug/L)	Chla (mg/m3)	NO3-N (ugN/L)	NH4-N (ugN/L)	PO4-P (ugP/L)	EC (us/cm)	TOC (mg/L)	Fecal Coli. (No./100 mL)	E. coli. (No./100mL)	Bromide (mg/L)	Perchlorate (ug/L)
24/09/2002	65.00	2.50	1325.40		293.90	40.00	2.50	921.00	3.04	2.00	0.50	0.03	4.66
	34.00	2.50	1434.10		251.40	40.00		945.00	3.18	0.50	0.50	0.03	6.89
	30.00	2.50	1534.90		306.40	40.00	2.50	952.00	3.17	0.50	0.50	0.03	7.50
	23.00	2.50	1489.00		216.10	40.00	2.50	932.00	3.51	0.50	0.50	0.06	12.50
	21.00	2.50	1445.70		84.00	40.00	5.30	935.00	3.22	0.50	0.50	0.05	8.88
	18.00	2.50	2334.60		298.50	40.00	2.50	1030.00	3.63	2.00	0.50	0.06	41.80
	17.00	2.50	2304.50		517.10	40.00	2.50	1122.00	3.82	2.00	0.50	0.03	42.30
	12.00	2.50	1478.00		84.00	40.00	2.50	1003.00	3.69	0.50	0.50	0.06	15.70
	1.00	2.50	1514.30		84.00	40.00	2.50	1000.00	3.71	0.50	0.50	0.06	14.00
	0.00	2.50	1391.00			40.00	2.50	1000.00	3.65	0.50	0.50	0.06	14.50

Multiple Profiles



Profile Scatter Points



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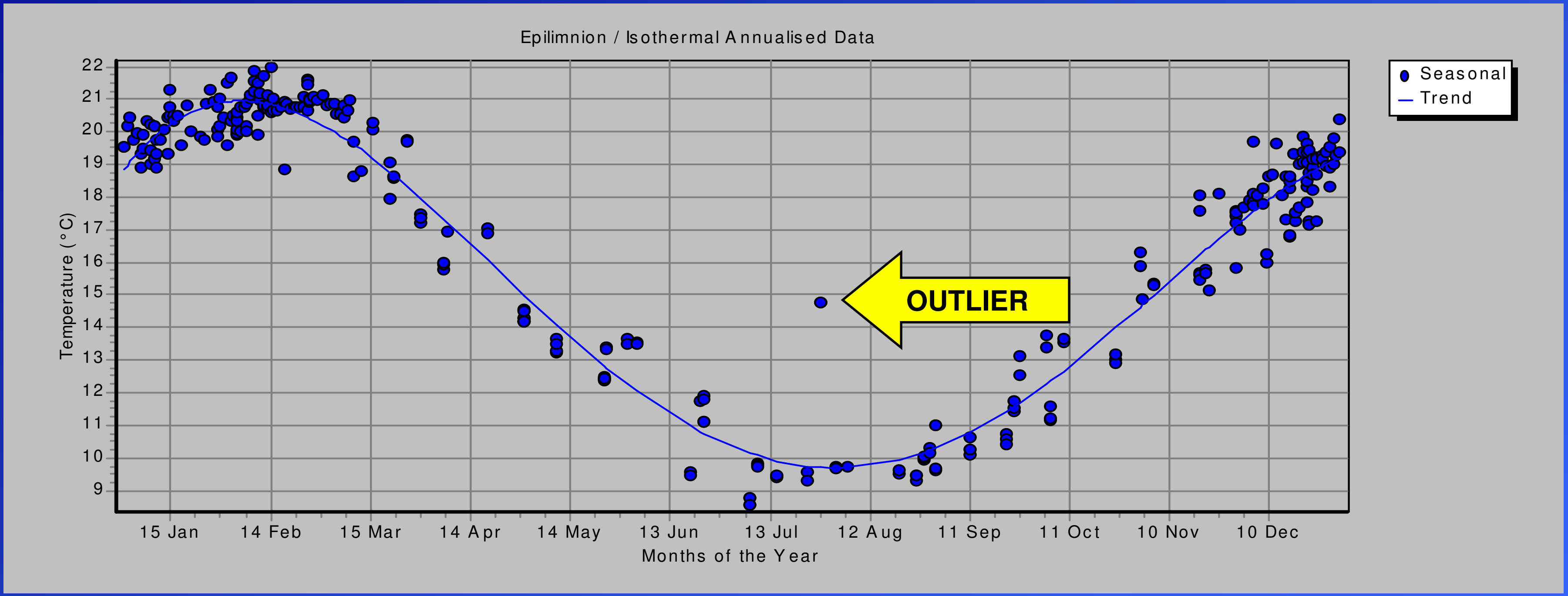
Data Trends

1. Data is first deseasonalized by plotting all data as a function of day and month only.

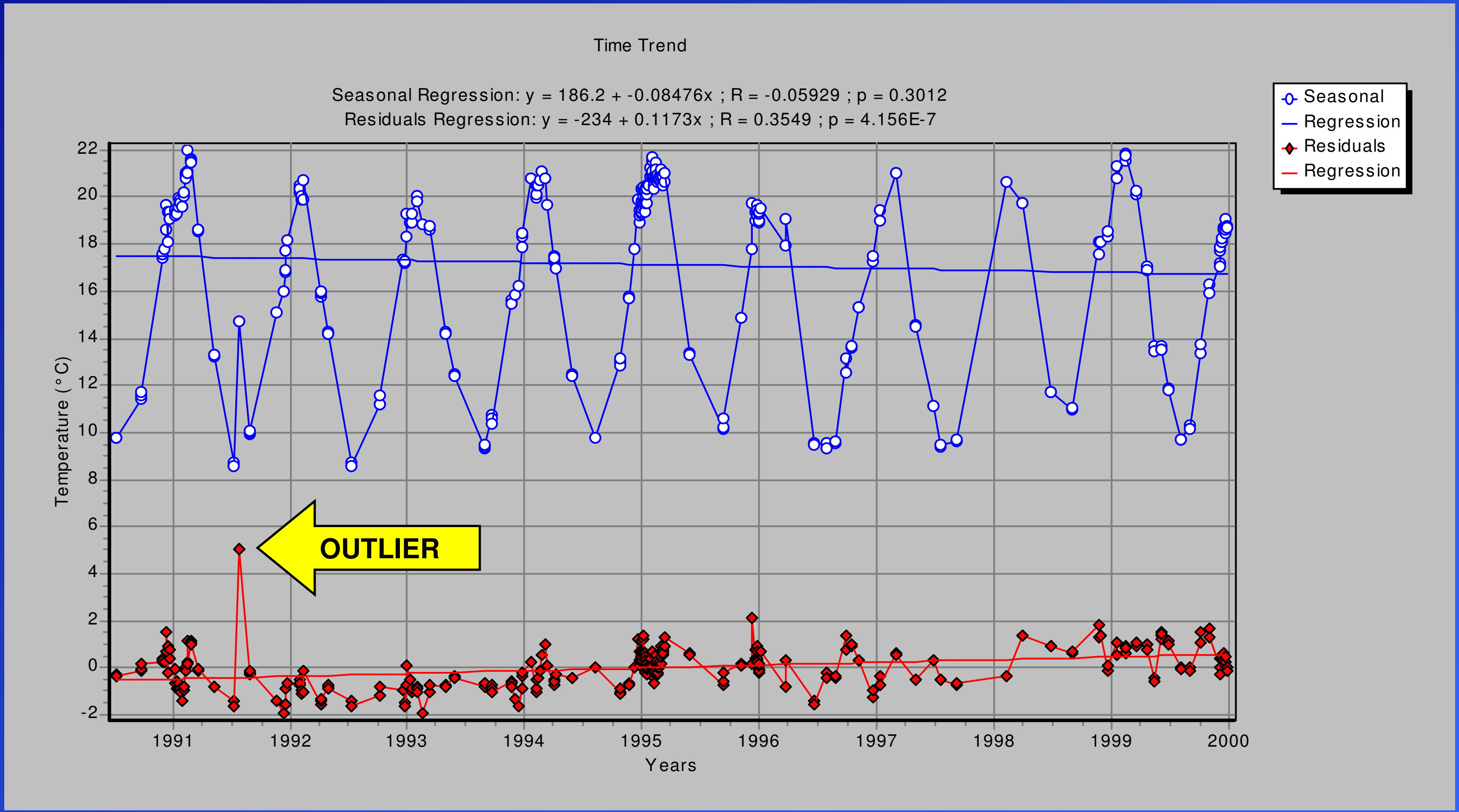
2. Polynomial curve is then fit to the data. Residuals are calculated for each data point.

3. Observed data and residual data are plotted as a function of time and trended. P-value of < 0.05 considered to be significant.

Deseasonalizing Data



Detecting Trends by Plotting Residuals



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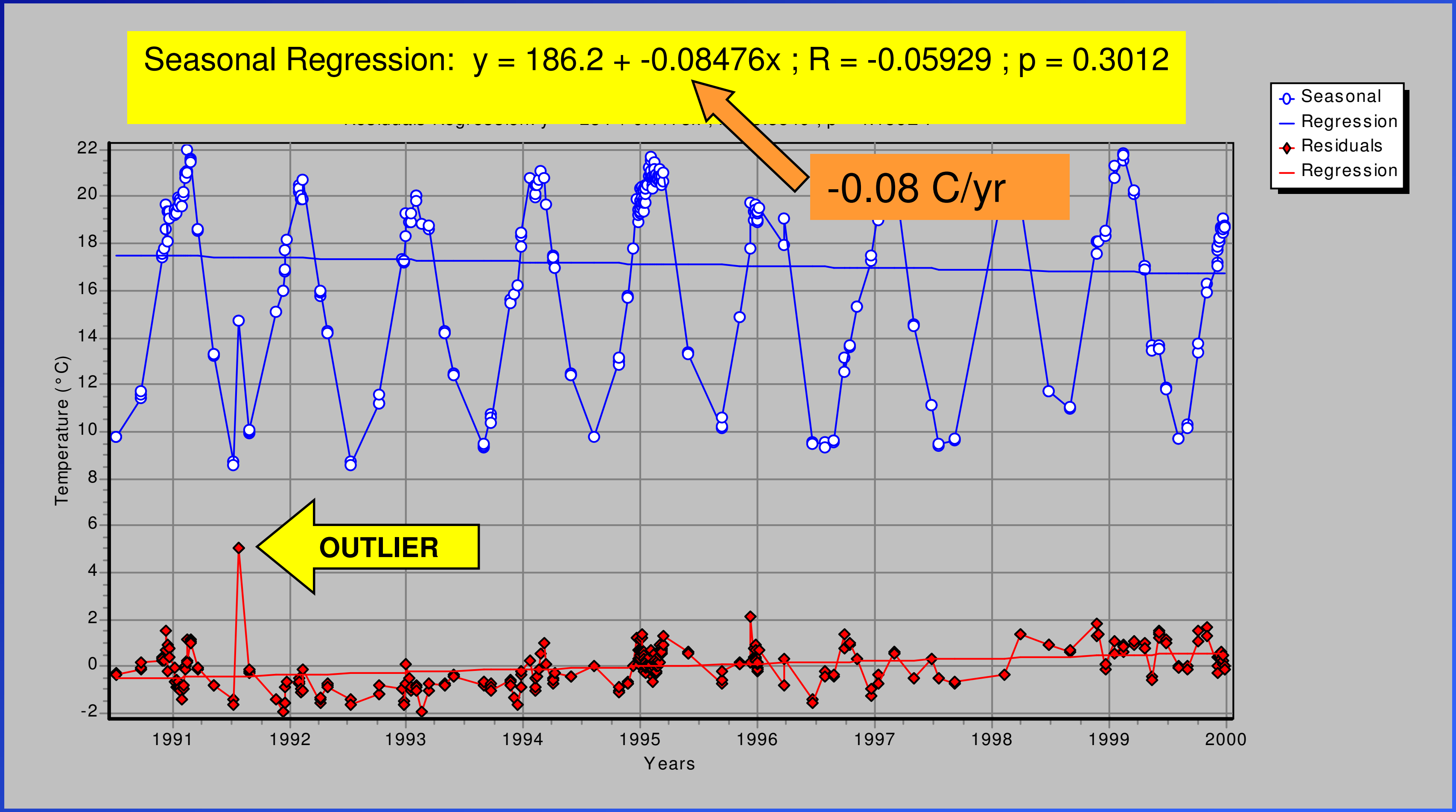
Detecting Trends by Plotting Residuals



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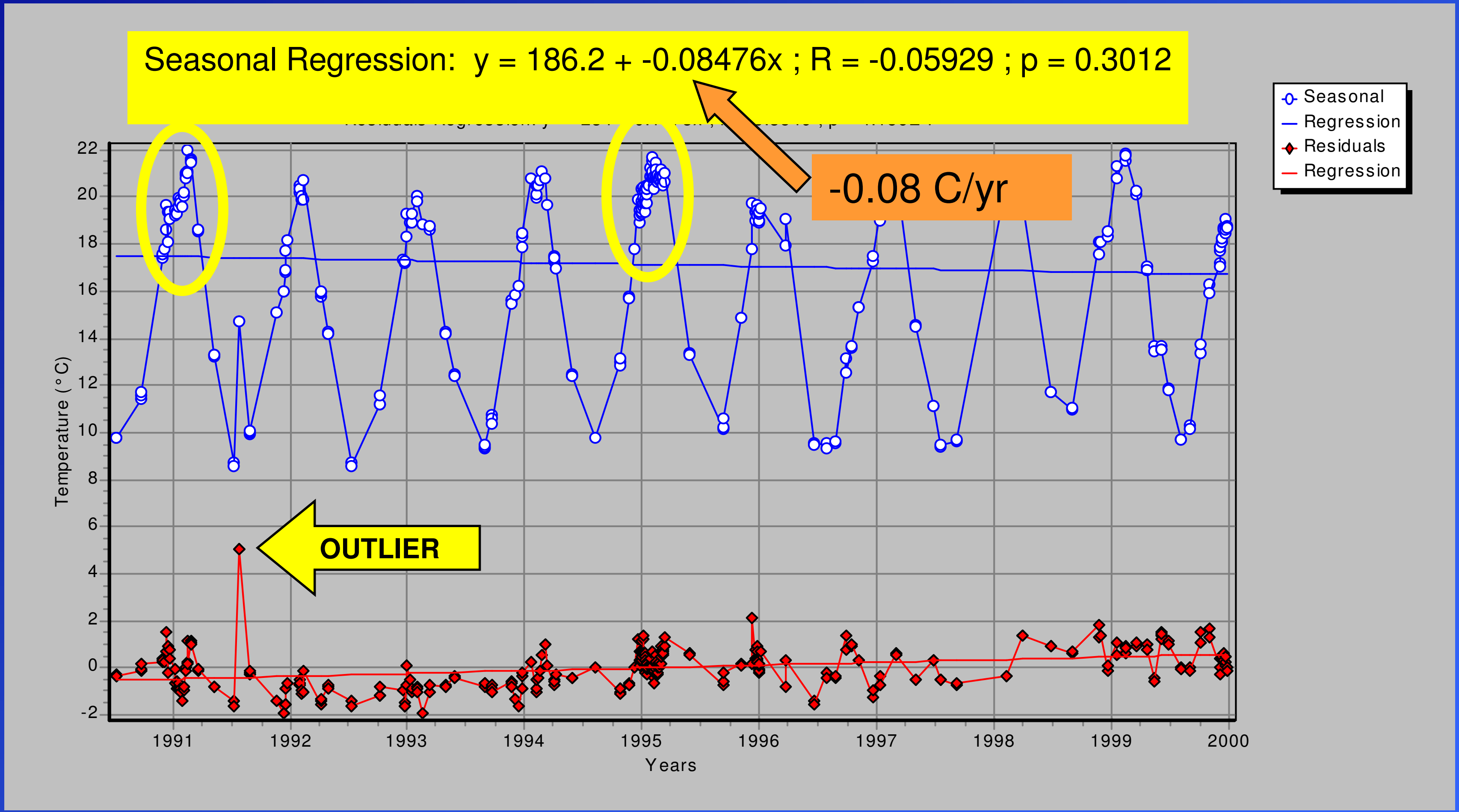
Detecting Trends by Plotting Residuals



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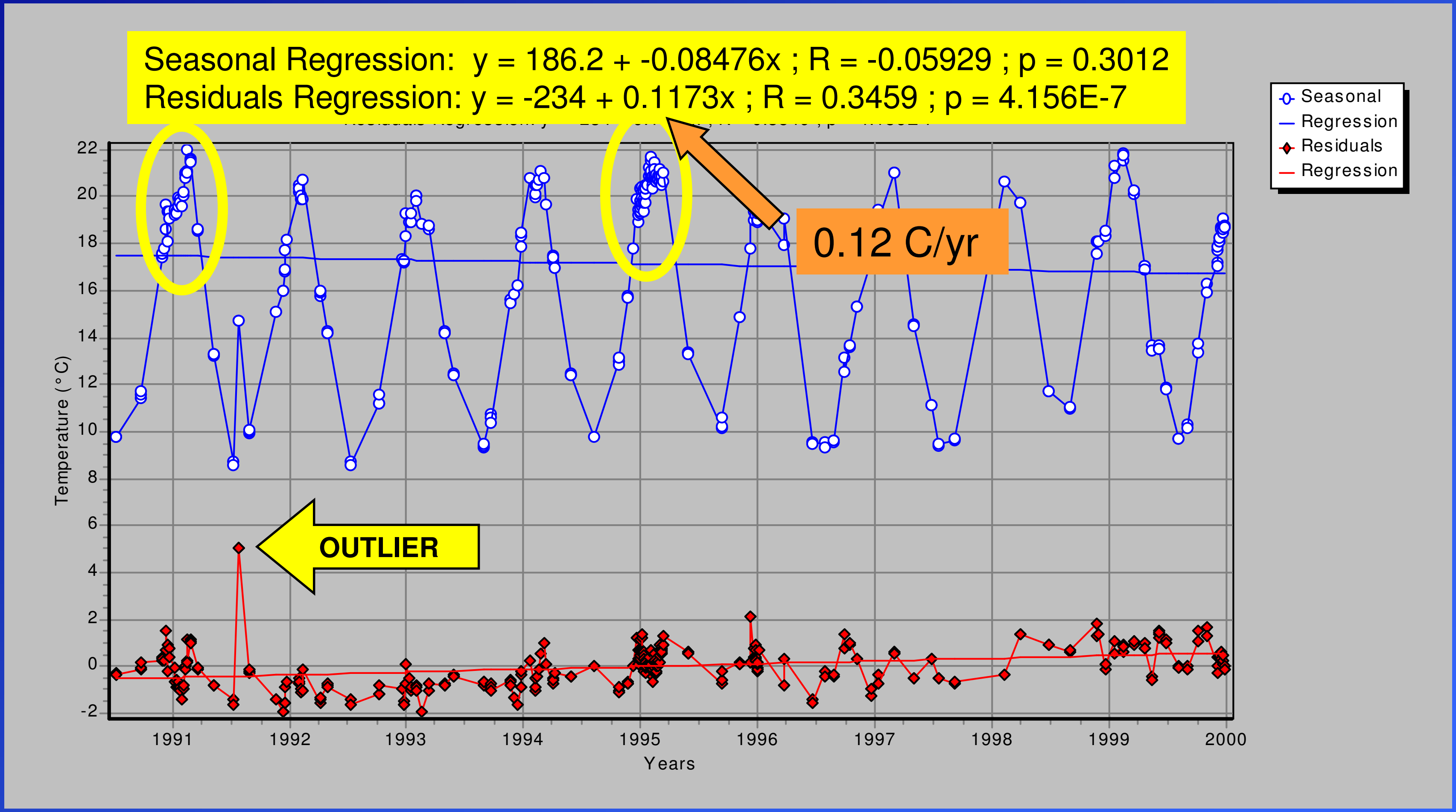
Detecting Trends by Plotting Residuals



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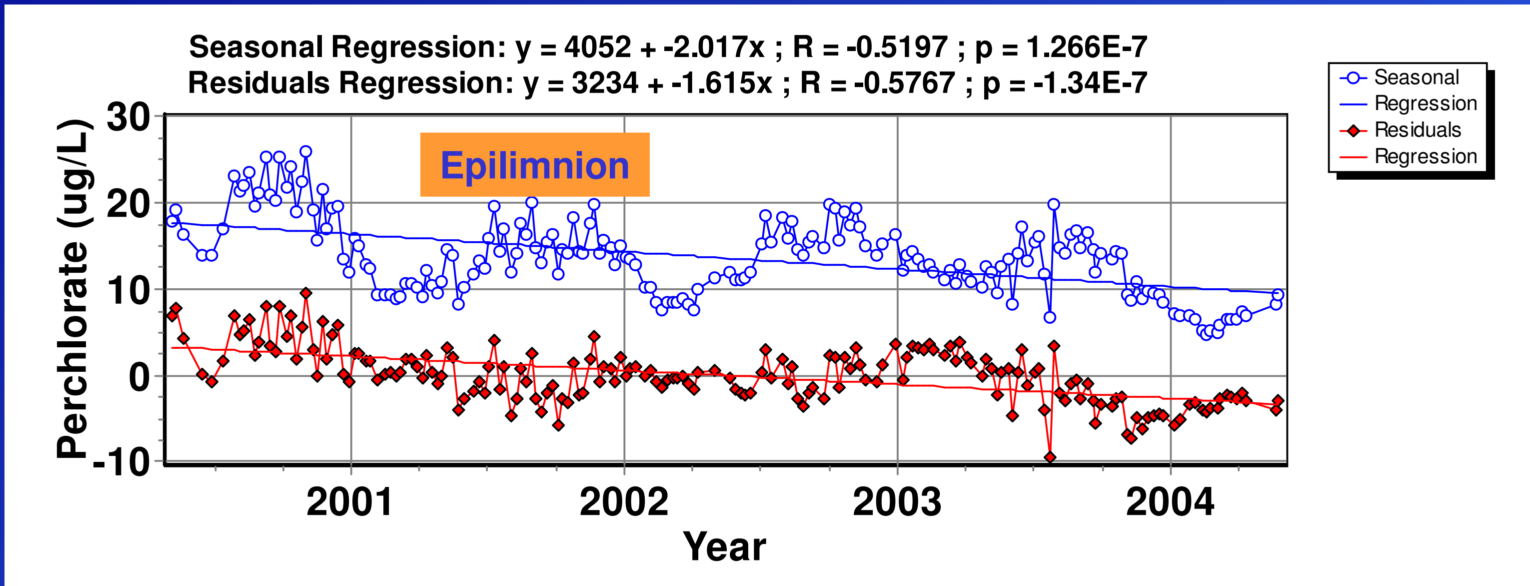
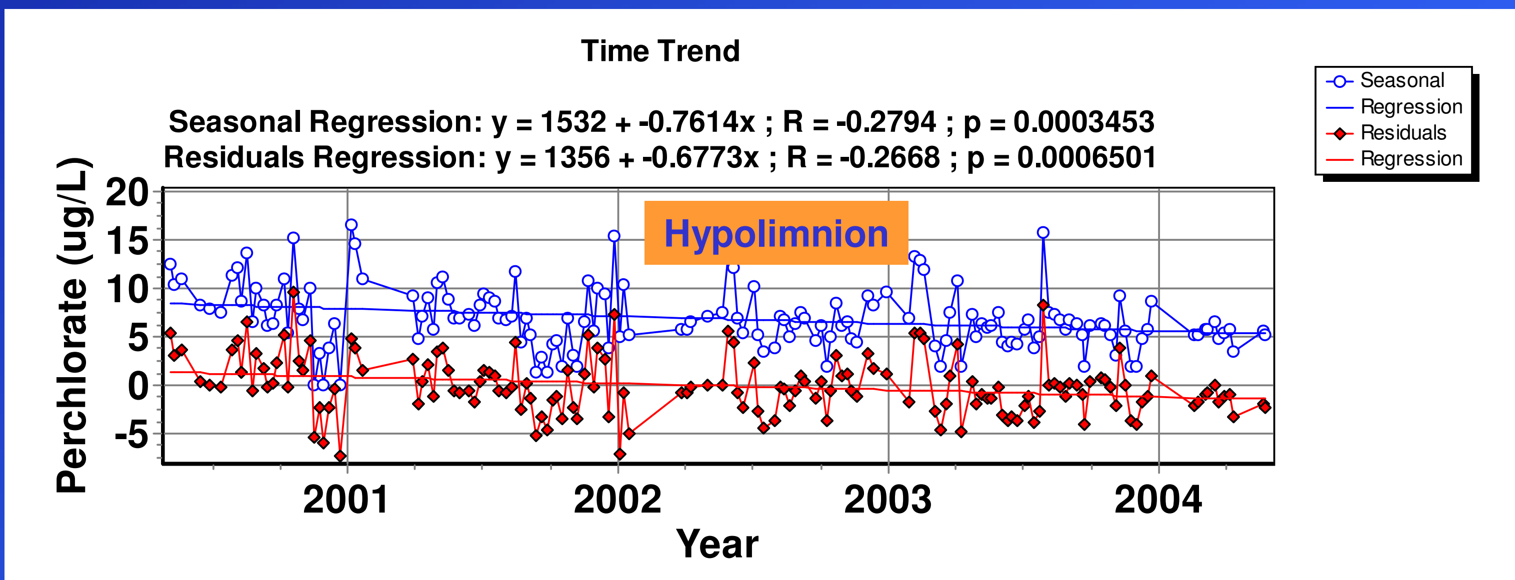
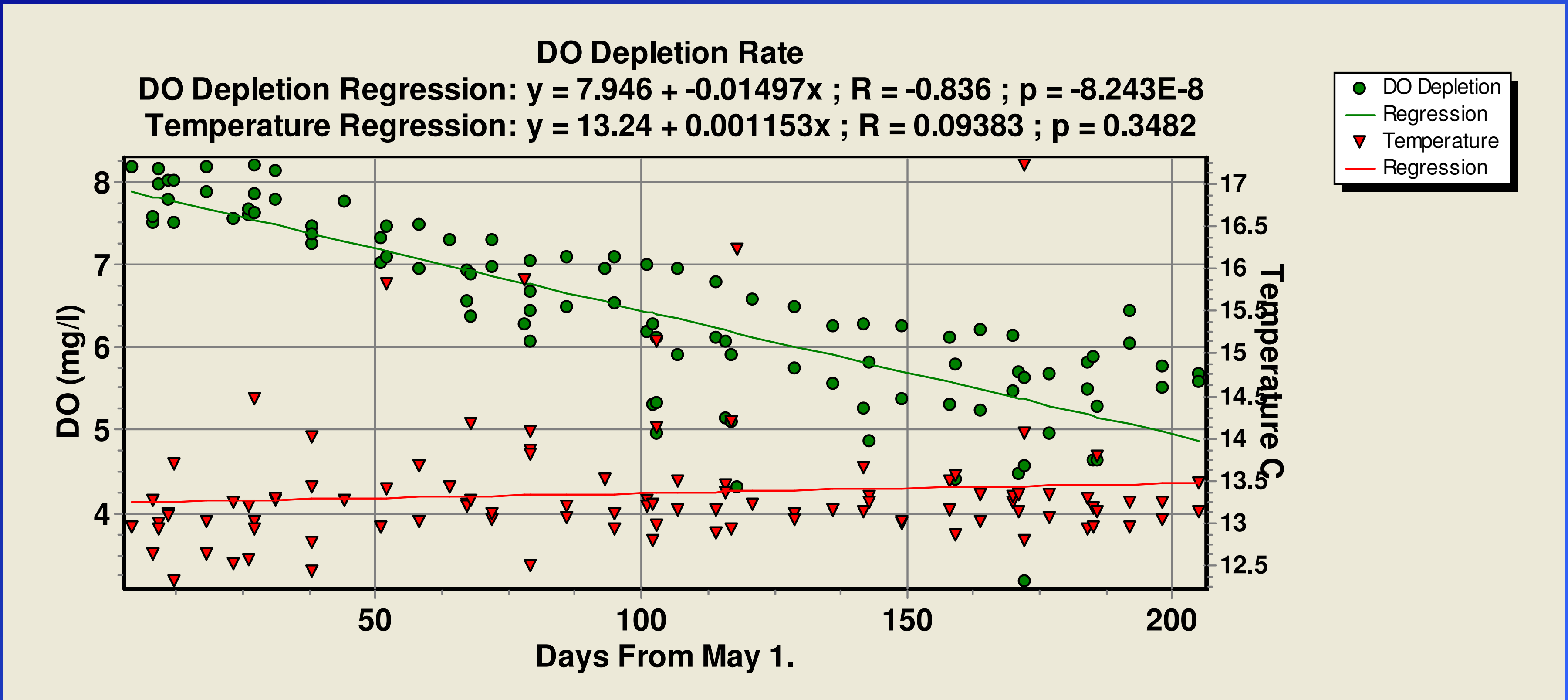
Detecting Trends by Plotting Residuals





Hypolimnetic Oxygen Depletion



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Hypolimnetic Volumetric Oxygen Depletion Report

Oxygen depletion rate is increasing.

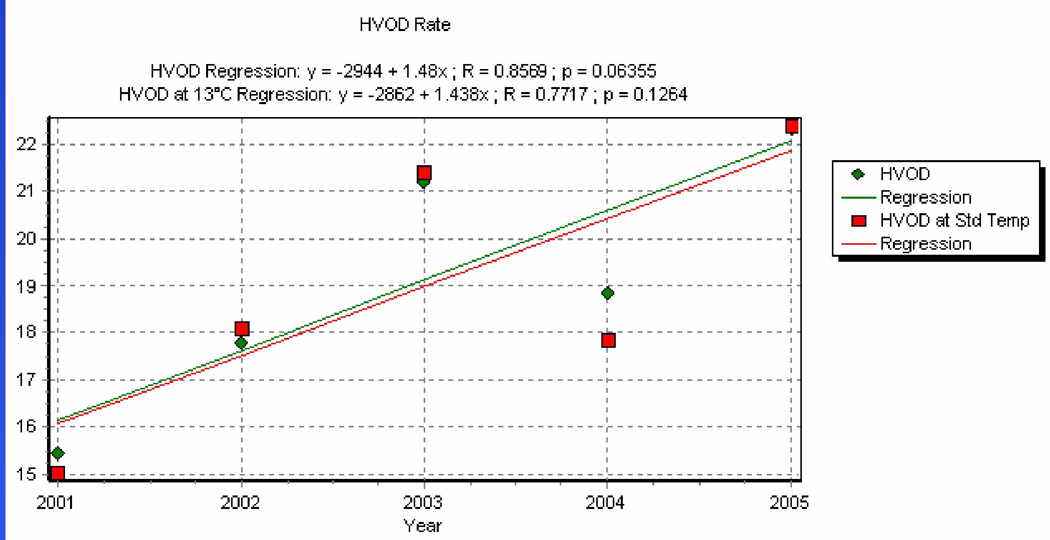
HVOD Analysis

Lake:

Stations:

Date From: 1/05/2000 **Date To:** 30/04/2005

Analysis Period	Average	Observed DO	Observed Rate Corrected to 13.0 °C (mg/m3/day)
01-May-2000 - 16-Nov-2000	13.36	15.4	15.1
01-May-2001 - 16-Nov-2001	12.73	17.8	18.1
01-May-2002 - 16-Nov-2002	12.84	21.2	21.4
01-Jun-2003 - 07-Nov-2003	13.76	18.8	17.9
01-May-2004 - 16-Nov-2004	12.96	22.3	22.4
Average	**13.13**	**19.1**	**19.0**



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Annual Sample Averages Report

	Annual Sample Averages For								**Lake**			
Eplilmnion												
Period			TP (ugP/L)	TN (ug/L)	Chla (mg/m3)	NO3-N (ugN/L)	NH4-N (ugN/L)	PO4-P (ugP/L)	EC (us/cm)	TOC (mg/L)	Bromide (mg/L)	Perchlorate (ug/L)
May 2000	to	Apr 2001	13.3	1811.4	16.7	961.0	16.3	08.4	1092.4	03.3	00.1	59.7
May 2001	to	Apr 2002	12.7	1625.5	14.6	830.4	73.5	05.0	1068.8	03.8	00.1	38.4
May 2002	to	Apr 2003	15.7	1318.7	08.6	743.5	45.5	03.6	1080.5	03.3	00.1	34.0
May 2003	to	Apr 2004	11.8	1174.5	07.5	829.0	17.2	04.7	1123.8	04.1	00.1	23.6
May 2004	to	Apr 2005	13.3	1244.3	08.2	918.4	25.2	03.2	1203.2	03.6	00.1	17.1
May 2005	to	Apr 2006	14.9	1296.1	03.7	1076.1	15.4	02.1	1227.5	04.0	00.1	13.4
Averages			13.6	1639.3	11.8	1286.1	199.3	17.3	1132.7	03.7	00.1	101.0
Thermocline												
Period			TP (ugP/L)	TN (ug/L)	Chla (mg/m3)	NO3-N (ugN/L)	NH4-N (ugN/L)	PO4-P (ugP/L)	EC (us/cm)	TOC (mg/L)	Bromide (mg/L)	Perchlorate (ug/L)
May 1994	to	Apr 1995		2264.7	16.3	1721.3	734.4	65.2				
May 2000	to	Apr 2001	08.7	1161.7	03.2	708.7	23.5	04.8	986.5	03.0	00.1	28.9
May 2001	to	Apr 2002	10.4	1477.8	31.4	689.4	72.5	05.2	1011.3	03.6	00.1	24.2
May 2002	to	Apr 2003	11.0	1279.8	31.1	729.3	47.5	03.7	1035.4	03.1	00.1	25.6
May 2003	to	Apr 2004	10.4	928.3	18.1	707.1	21.0	04.8	1088.7	03.7	00.1	17.3
May 2004	to	Apr 2005	10.7	1219.5	08.6	923.1	27.6	03.9	1142.2	03.5	00.1	12.8
May 2005	to	Apr 2006	18.4	1533.9		1281.7	26.4	02.4	1171.7	03.8	00.1	10.5
Averages			11.6	1815.4	15.7	1504.3	134.8	13.0	1072.6	03.5	00.1	66.7
Hypolimnion												
Period			TP (ugP/L)	TN (ug/L)	Chla (mg/m3)	NO3-N (ugN/L)	NH4-N (ugN/L)	PO4-P (ugP/L)	EC (us/cm)	TOC (mg/L)	Bromide (mg/L)	Perchlorate (ug/L)
May 2000	to	Apr 2001	10.2	999.4		556.5	13.3	05.5	914.4	02.7	00.1	13.1
May 2001	to	Apr 2002	11.9	1250.6	107.3	541.6	68.5	06.6	965.0	03.2	00.1	14.7
May 2002	to	Apr 2003	13.1	1076.0	01.4	590.5	48.6	05.3	1024.6	03.0	00.1	24.9
May 2003	to	Apr 2004	16.1	1104.8	08.4	762.0	20.7	06.4	1067.4	03.5	00.1	15.1
May 2004	to	Apr 2005	12.6	900.3		656.0	25.5	05.6	1059.4	03.3	00.1	05.3
May 2005	to	Apr 2006	20.4	778.9	09.0	619.1	16.8	05.3	1074.4	03.4	00.1	04.0
Averages			14.0	1817.1	22.9	1525.9	156.1	20.0	1017.5	03.2	00.1	179.5
All												
Period			TP (ugP/L)	TN (ug/L)	Chla (mg/m3)	NO3-N (ugN/L)	NH4-N (ugN/L)	PO4-P (ugP/L)	EC (us/cm)	TOC (mg/L)	Bromide (mg/L)	Perchlorate (ug/L)
May 2000	to	Apr 2001	10.9	1386.7	16.6	775.8	17.6	06.5	1012.5	03.1	00.1	38.2
May 2001	to	Apr 2002	11.7	1482.9	15.0	709.8	71.9	05.4	1022.3	03.6	00.1	27.5
May 2002	to	Apr 2003	14.5	1265.7	11.8	715.3	47.0	04.2	1057.0	03.2	00.1	30.1
May 2003	to	Apr 2004	12.6	1085.8	09.0	778.6	19.2	05.2	1112.6	03.9	00.1	20.2
May 2004	to	Apr 2005	12.7	1146.3	08.3	847.5	26.3	04.1	1162.5	03.5	00.1	13.5
May 2005	to	Apr 2006	17.8	1232.8	03.9	1017.6	19.4	03.2	1175.0	03.8	00.1	10.3
Averages			13.4	1969.5	14.8	1305.7	496.3	30.2	1090.3	03.5	00.1	97.9

Trophic Level Index Report

2000-2005 (1 May 2000 - 30 Apr 2005)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	-2.24	(0.02)	0.71	-79.37	(1.44)			
Average Over Period	5.62	(8.21)	8.27	967.78	(18.97)			
Percent Annual Change (%/Year)	**-39.86**	**0.00**	**8.59**	**-8.20**	**0.00**	**-7.89**	**8.42**	**0.40**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
May 2000 - Apr 2001	11.36	9.00	6.68	1,049.61	4.90	2.79	2.63	5.48	3.95	0.73			
May 2001 - Apr 2002	7.53	7.50	7.86	1,162.74	4.45	3.05	2.83	5.62	3.99	0.65			
May 2002 - Apr 2003	3.11	8.00	6.59	894.69	3.47	2.96	2.61	5.27	3.58	0.59			
May 2													
May 2													
Aver													**0.5201**

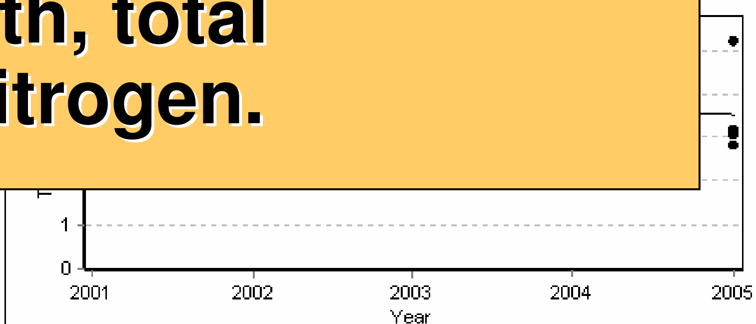
Burns Trophic Level Index (TLI) values are calculated from annual averages of chlorophyll, Secchi depth, total phosphorus and total nitrogen.

SU
PA
P-
TL
TL
P-

ASSESSMENT:

Mesotrophic
No Change

0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change



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Trophic Level Index Report

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Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
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Average Over Period	5.62	(8.21)	8.27	967.78	(18.97)			
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Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
May 2000 - Apr 2001	11.36	9.00	6.68	1,049.61	4.90	2.79	2.63	5.48	3.95	0.73			
May 2001 - Apr 2002	7.53	7.50	7.86	1,162.74	4.45	3.05	2.83	5.62	3.99	0.65			
May 2002 - Apr 2003	3.11	8.00	6.59	894.69	3.47	2.96	2.61	5.27	3.58	0.59			
May 2003 - Apr 2004	2.55	7.40	8.95	827.51	3.25	3.07	3.00	5.17	3.62	0.52			
May 2004 - Apr 2005	2.10	8.93	10.21	841.30	3.04	2.80	3.16	5.19	3.55	0.55			
Averages	**5.33**	**8.16**	**8.06**	**955.17**	**3.82**	**2.94**	**2.85**	**5.35**	**3.74**	**0.25**	**-0.12**	**0.18**	**0.5201**

SUMMARY:

PAC = -7.89 ± 8.42 % per year
P-Value = 0.40

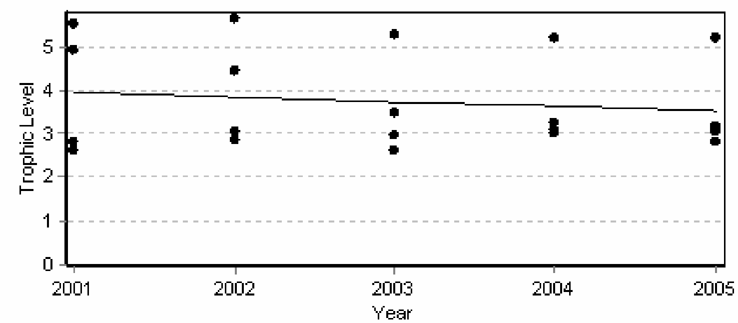
TLI Value = 3.74 ± 0.25 TLI units
TLI Trend = -0.12 ± 0.18 TLI units per year
P-Value = 0.5201

ASSESSMENT:

Mesotrophic
No Change

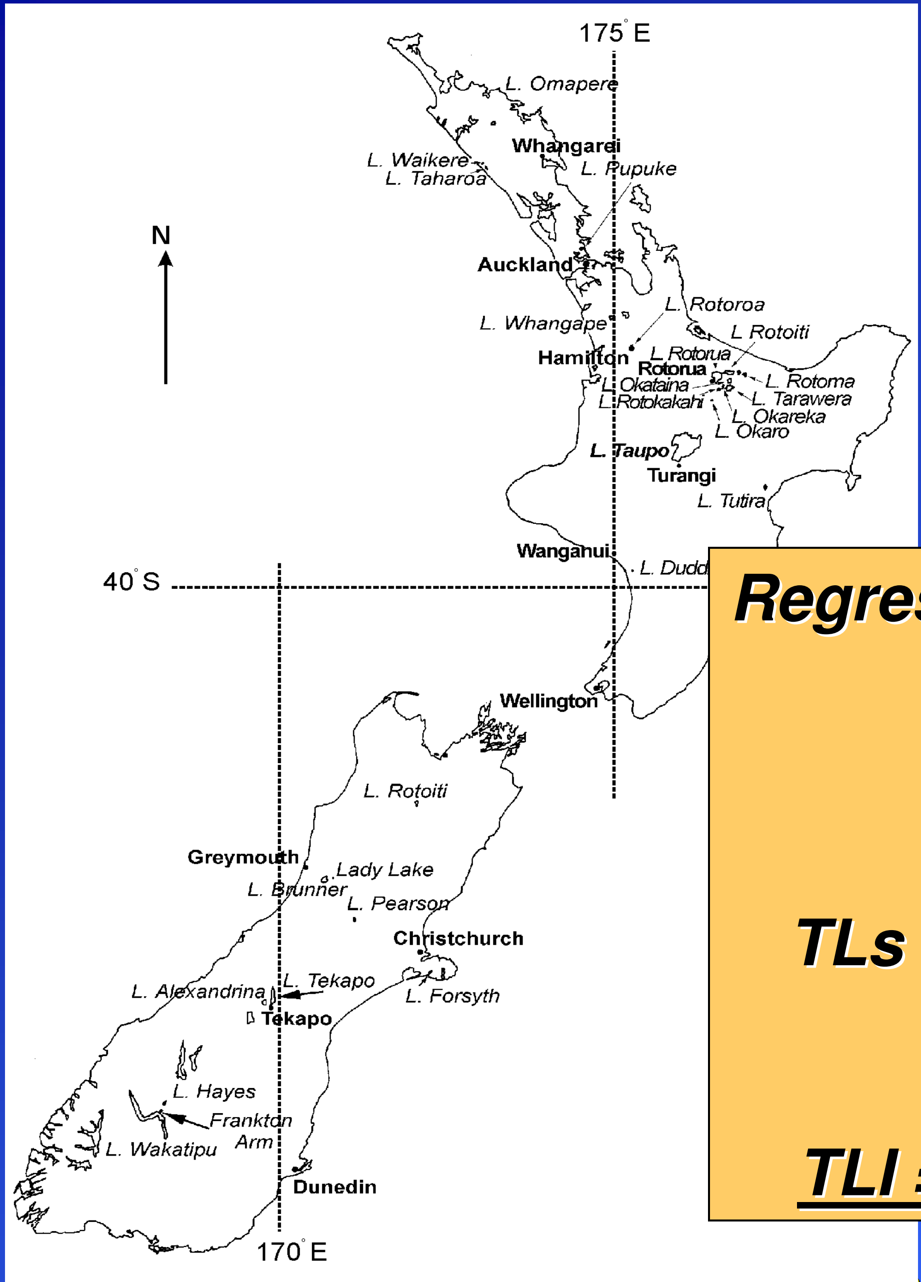
The guide used in the PAC average P-Value evaluation is

P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change



The trophic level of the lake is not changing.

Burns Trophic Level Index



Burns et al. (1999): 'A monitoring and classification system for New Zealand Lakes and Reservoirs.' ***Lake and Reservoir Management* 15 (4):255-271**

Regression Equations:

$$TLp = 0.218 + 2.92 \log(TP)$$

$$TLn = -3.61 + 3.01 \log(TN)$$

$$TLs = 5.10 + 2.60 \log(1/SD - 1/40)$$

$$TLc = 2.22 + 2.54 \log(Chla)$$

$$\underline{TLI = 1/4(TLp + TLn + TLs + TLc)}$$

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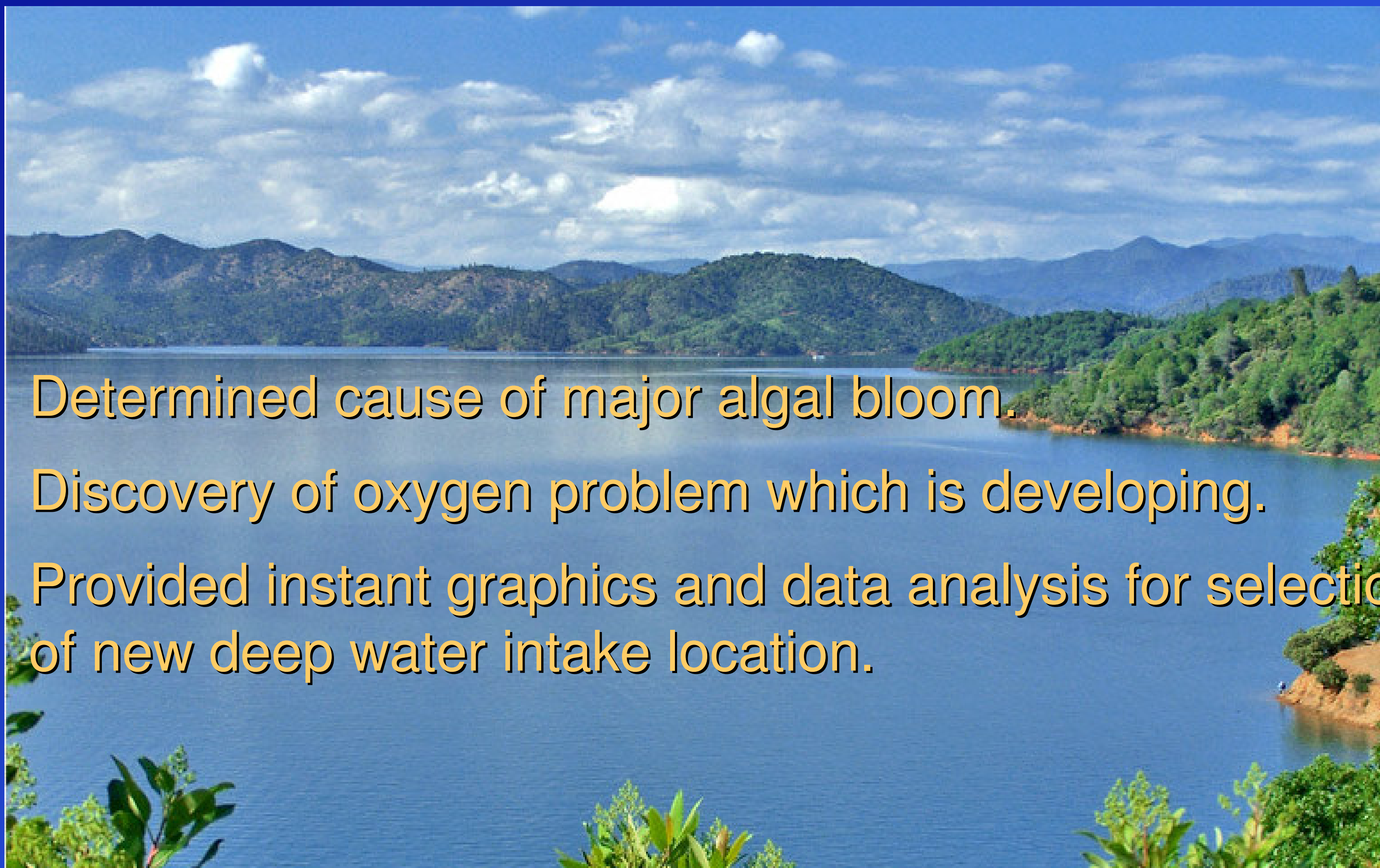
Burns Trophic Level Index

Lake Type	Trophic Level	Chla (mg/m3)	Secchi Depth (m)	TP (mg P/m3)	TN (mg N/m3)
Ultra-microtrophic	0.0 - 1.0	0.13 - 0.33	33 - 25	0.84 - 1.8	10.0 - 22
Microtrophic	1.0 to 2.0	0.33 - 0.82	25 -15	1.8 - 4.1	22 - 46
Oligotrophic	2.0 to 3.0	0.82 - 2.0	15 - 7.0	4.1 - 9.0	46 - 99
Mesotrophic	3.0 to 4.0	2.0 - 5.0	7.0 - 2.8	9.0 - 20	99 - 213
Eutrophic	4.0 to 5.0	5.0 - 12	2.8 - 1.1	20 - 43	213 - 458
Supertrophic	5.0 to 6.0	12 - 31.0	1.1 - 0.4	43 - 96	458 - 984
Hypertrophic	6.0 to 7.0	>31	<0.4	>96	>984

Baseline TLI value of a lake can be established. Rate of change of Trophic Level can be estimated with probability of change determined by average PAC.

EarthSoft

Case Study



1. Determined cause of major algal bloom.
2. Discovery of oxygen problem which is developing.
3. Provided instant graphics and data analysis for selection of new deep water intake location.

A Valuable Management Tool

Is it necessary to manage lakes for the future?

- Population is growing
- Enriched streams running into lakes
- More recreational use of lakes
- Increased agriculture with more fertilizer run-off
- LAKES ARE SLOWLY BECOMING MORE EUTROPHIC!

TLI/TSI: An Important Management Tool

- TLIs or TSIs give you an annual, numerical measure of lake trophic level.
- The TLI or TSI enables close, objective tracking of lake trophic change – even if very gradual.

This has been done successfully with 12 lakes in the Rotorua District of New Zealand.

TLI/TSI: An Important Management Tool

Rule: Remedial action be taken when the 3-year moving-average TLI for exceeds baseline TLI by 0.2 units for 2 years.

Lake	Draft Regional Water and Land Plan Baseline TLI	3-yr average TLI to 2000.
Rotoma	2.3	2.3
Okataina	2.6	2.6
Tarawera	2.6	2.6
Tikitapu	2.7	2.7
Okareka	3.0	3.4*
Rotokakahi	3.1	3.2
Rotoiti	3.5	3.9*
Rerewhakaaitu	3.6	3.6
Rotomahana	3.9	3.8
Rotoehu	3.9	4.7*
Rotorua	4.2	4.6*
Okaro	5.0	5.7*

* Lakes exceeding their designated baseline TLI.

TLI/TSI: An Important Management Tool

- Now in the Rotorua District, they do not fight anymore about whether lakes need improvement
- They now fight about the most cost-effective methods to improve the different lakes.
- Serious management action is being taken!

Thank you!

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