DEP Lakes Assessment Section

Androscoggin Lake – Dead River
Phosphorus and Hydrologic Loading Analysis

August 2003

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Appendix

Androscoggin Lake –Dead River Phosphorus Loading Analysis

Introduction:

This report analyzes total water and phosphorus loading from the Dead River and the portion of this attributable to point sources in the Androscoggin River. It includes examination of the trophic state of Androscoggin Lake, an analysis of the relationship of TP concentrations to secchi clarity, and provides a target phosphorus goal for lake protection from future nuisance blooms.

An analysis of various dam configurations was done to determine water and phosphorus loading from the Dead River to Androscoggin Lake. Information for this analysis was based in part on a hydrologic study done by EPRO Inc. (Dead River Dam study to Minimize Flood Flows from the Androscoggin River into Androscoggin Lake, April 2002, with update hydrologic estimates in March of 2003). This report is intended to provide comparisons of several dam scenarios to aid in a choice of options for nutrient control in the lake.

Additional information about the lake’s watershed, and previous water and phosphorus loading analyses, are available in the DEP reports of 9/24/01 (Androscoggin Lake Phosphorus Loading Analysis) and 5/28/02 (Androscoggin Lake-Dead River Loading Analysis). This report uses a different Dead River model and set of assumptions, as well as analyzing different dam configuration options (“Cases”).

Scenarios evaluated in this report include the following:
Table 1: Dam Scenarios:

Case #	Effective Dam Height (Ft MSL)	Dam Conditions
11	No Dam	Retain current sill at ca. 270 ft.
12	275.3	Current dam crest height
13	278.3 –278.8	3 and 3.5 foot boards, combination of 50% each
14	282	New Dam

<u>Water Input Events: Frequency and Duration</u>:

Daily flow readings for the Rumford and Swift River gauges from 1950 to 1999 were assembled as described in the 5/28/02 report. Flow calculation at the confluence is estimated based on a formula: Flow at Confluence of Dead River and Androscoggin = Flow Rumford + Flow Swift R. With the dam height at 275.3 ft MSL and no flashboards, flooding was assumed to be possible when the flow the Androscoggin at the Dead River confluence was estimated to be at 16,000 cfs or greater (DEP staff observations). Updated estimates of Dead River input were provided by EPRO (March 20, 2003) based on separate modeling which included estimates of inflow with no dam in place. (only the current sill ca 270 ft MSL).

Estimated daily flows were examined to determine the beginning and end dates for events that exceeded 16,000 cfs flow and which were separated by at least 1 day. In over 17,800 records, the number of separate events totaled 148 and range in duration from 1 to 15 days. These events were separated by anywhere from 1 to over 300 days. Under Case 12 (dam, no boards), the estimated number of input events per year is about 3, with 4 years having no event large enough to produce inflow. The table below illustrates the estimated duration and time separating these events. (see Appendix for list of events and estimated average and maximum flows for period).

Table 2: Flooding Events from Dead River Flow 1950-99 for Case 12
Present Dam Without Flashboards (n=148)*

Duration or Time Separating events (days)	# Events of Given Separation	Annual Frequency	# Events of Given Duration	Annual Frequency
0-2	21	0.43	90	1.9
3-5	14	0.29	39	0.81
6-9	12	0.25	14	0.29
10-14	8	0.16	5	0.1
15-29	16	0.33	0	0
>=30	77	1.6	0	0

*Based on flows calculated to exceed 16,000 cfs in the Androscoggin River

Adjustments for short duration events or short separation times between events (<=2 days each) are not included in this analysis. The May 2002 report suggested modeled effects are not large enough to warrant inclusion in the analysis and had relatively little effect on the outcome.

In addition to the 148 events identified above, there were numerous additional smaller events which would input river water if no dam were present (Case 11). A total of 408 additional events are identified as occurring when Androscoggin River flows > 8300 cfs are likely. This figure was chosen as producing potential Dead River water levels above about 271 ft MSL.

Table 3: Flooding Events from Dead River Flow 1950-99 for Case 11 (n=408)*

Duration or Time Separating events (days)	# Events of Given Separation	Annual Frequency	# Events of Given Duration	Annual Frequency
0-2	92	0.23	251	0.62
3-5	80	0.20	104	0.26
6-9	44	0.11	31	0.08
10-14	30	0.07	15	0.04
15-29	50	0.12	5	0.01
>=30	112	0.27	<5	<0.01

*Based on flows calculated between 8,300 and 16,000 cfs in the Androscoggin River

This is a rough estimate and relies on DEP staff observations which included some paired Androscoggin River flow estimates and water level measures below the top of the Dead River Dam (see Appendix). As detailed in the May 2002 report, a linear regression allowed an estimate of the relative water heights developed for these events. These observations are taken with the current dam in place, and thus do not reflect the actual hydrology which would develop if the dam were not there.

This analysis is approximate at best, but indicates that a relatively large number of low head events occurred over this time period. There were numerous events which would have been of short duration and which would tend to have less of an effect on the lake than the longer duration events. Less than 50% of these events would have added more than 10% to the total lake volume. Nevertheless, the large number and frequency of these events translates into substantial phosphorus loading.

Input Event Size (Water Volume):

The revised EPRO analysis (Table 4) provides estimated volumes of water input to Androscoggin Lake by events of differing recurrence intervals.

Table 4
Dead River Dam: Summary of Options 3/21/03
Data Provided by EPRO

Frequency	Maximum Inflow cfs	acre-feet	Lake Level	Time to drain days
Case 11	No Dam			
<1-year	2000	8926	273.9	4
1-year	3200	11702	274.5	5
2-year	4200	15074	275.2	7.5
5-year	5800	21719	276.6	8.5
10-year	8000	30942	278.5	9
25-year	9700	43835	281.2	11
Case 12	Existing Dam			
<1-year	500	1091	272.2	1.5
1-year	1000	1983	272.4	2
2-year	2000	5554	273.6	4
5-year	5000	14380	275.2	7
10-year	7500	23107	276.9	9
25-year	9200	35455	279.4	12
Case 13	3/3.5' boards			
<1-year	0	0	272	0
1-year	0	0	272	0
2-year	400	992	272.2	0.1
5-year	3200	6697	273.5	4
10-year	6800	15669	275.3	8
25-year	9000	28364	278	11.5
Case 14	Crest elev. 282			
<1-year	0	0	272	0
1-year	0	0	272	0
2-year	0	0	272	0
5-year	0	0	272	0
10-year	2500	2479	272.5	2
25-year	6500	12198	274.6	7.5

Average annual water input to the lake was estimated as in the May, 2002 report for the 148 events which may have overtopped the dam for Cases 12-

14. Inflow was added for 408 other events which might have produced inflow without the dam in place. The Dead River water levels have been observed to have a roughly linear relationship between Androscoggin River flows of 16,000 cfs and 5700 cfs. This gives an estimate of about 1930 cfs per foot of stage height produced. For each event in the Androscoggin River beween 8300 cfs (about -4 ft at the dam face) and 16,000 cfs (dam crest), an estimate of Dead River water levels and a portion of the event size for > 1 year frequency events (8926 acre feet) was assigned. Estimated water loads from the Dead River for Case12 are displayed in the figures below.

Figure 1: Annual Water Loads for Case 12

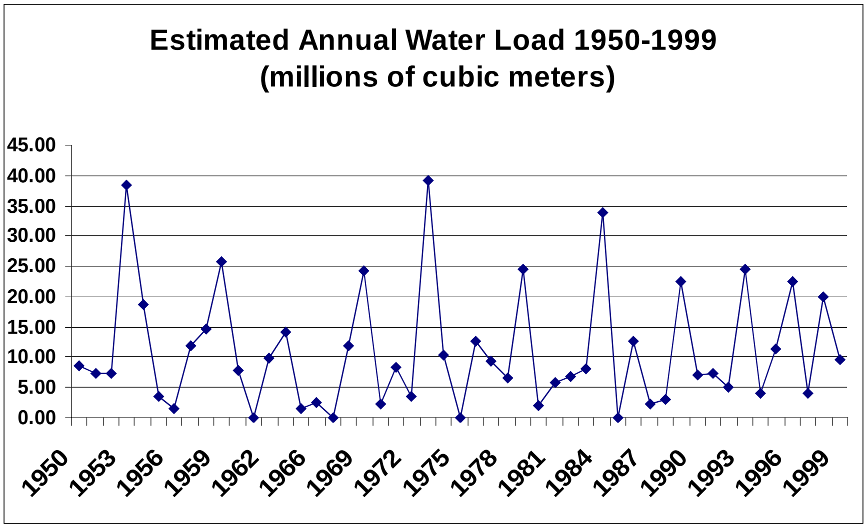
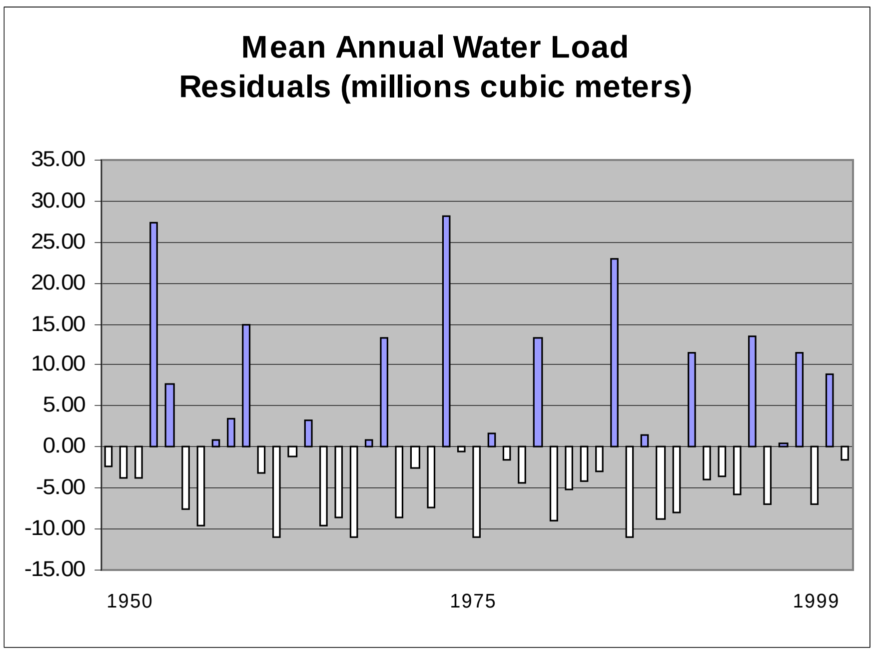


Figure 2: Annual Water Residuals for Case 12



Residuals are used to display the difference between the long term means and yearly estimates. Positive residuals indicate the magnitude of increased input for that year. Both time series and residuals show no clear trends in river input to the lake.

Phosphorus Loading Estimates and Lake Response:

The 556 events were segregated by year, and phosphorus input, lake phosphorus response, average water loading, and flushing rates were estimated. The following statistics estimated for the 49 years are included in the Appendix.

Water loading (Q) is the total of all Dead River input events for each year averaged over all years. Flushing rate (Flush) divides the lake volume at 269-270' MSL (70.8 x10^6 m^3) by the mean water loading from the Dead River (Q) plus upstream and direct watershed input.

Total phosphorus loading from the Dead River input is the estimated water input Q times concentration, tallied as LOAD. Both 44 ppb and 80 ppb were used as mean concentrations to estimate the lake effect of the Dead River. Previous DEP reports used 44 ppb, which is consistent with many of the available samples volunteers have taken during Dead River inflows (range 13-170 ppb). Values of Dead River samples tend to support the lower figure. Use of the higher figure results in a modeled lake condition that more closely approximates recent lake conditions.

The indirect loading of point sources to the lake via the Dead River (PS) and the effect of these on the lake (DELTAPS) are estimated at two levels. Actual flows and licensed discharges on record result in between 609-757.7 # TP per day from point sources. The lower figure represents flows from currently operating sources and the higher figure includes all significant licensed discharges (some sources in New Hampshire are currently not operating). If full licensed flows were achieved, the additional 150 #/day loading would increase calculated concentrations in the Androscoggin River by 4 % (1.9 ppb. in a river at 40-80 ppb and 16,000 cfs flow).

The total water mass input for each inflow event and the calculated river concentration resulting from point source discharges were used to estimate the TP load to Androscoggin Lake from point sources. As river flow increases, the concentration in the river due to point sources goes down due to dilution.

Total lake response to phosphorus input contributed by all sources is estimated as DELTA in the Appendix. A summary by dam option is presented in Table 5 and Figure 3 as ppb change due to each category of source. These include point and non-point sources to the Dead River from Androscoggin River, non-point sources in the direct watershed plus upstream lakes and atmospheric input, and internal loading. The latter two categories were estimated in the September 2001 report.

The lake response model (Vollenweider) was applied using average annual flushing rates, phosphorus loading and lake volume to estimate the effects of various dam options. This model estimates spring overturn conditions and the internal loading effect must be added to approximate late summer conditions. The flushing rates varied from a mean of 2.0 (Case 14) to 3.2 (Case 11, no dam) which is within the range developed for the model. The added volume from low head events has the effect of increasing the flushing rate and phosphorus loading, but the increased flushing rates partially offset the effects of increased loading. It is important to recognize that these response models assume the lake is at relatively steady state, and predict conditions over a long time span. Year to year variation will not show up immediately, as there is lag time in response.

There are a number of sources of error in these estimates. Among these are included inherent errors in assigning non-point source loads to various land uses and estimates of low head input events. The extreme nature of the larger events (water loading by 1-3 events per year) which dominate the Dead River input suggest that the lake response models are an approximation of the true situation in a lake. Regardless of this, the models are useful for comparison of the various dam scenarios.

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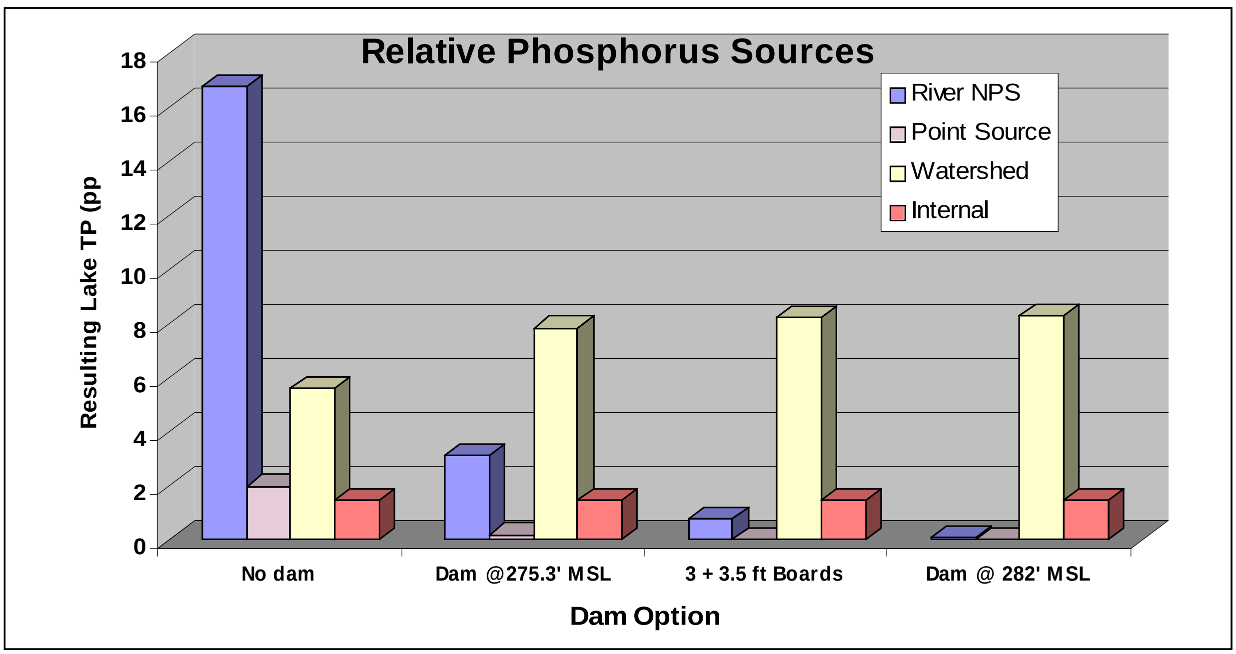
Table 5:	Proportional Effects of Sources on Total Phosphorus in Lake					
		Dead River	Dead River	Direct	Internal	Total
		NPS Only	Point Source	Watershed	Sources	
Case 11	No dam	16.78	1.99	5.64	1.5	25.91
Case 12	Dam @275.3' MSL	3.10	0.20	7.86	1.5	12.66
Case 13	3 + 3.5 ft Boards	0.81	0.04	8.21	1.5	10.56
Case 14	Dam @ 282' MSL	0.08	<0.01	8.32	1.5	9.91

The figure below illustrates the estimated effect of inputs from all sources. It shows a significant advantage of having the current dam in place (Case 12) vs. no dam (Case 11). Having the dam in place has the effect of reducing the overall effect of phosphorus loading to the lake by as much as 13 ppb. Addition of 3 & 3.5 foot flashboards (Case 13, current configuration) may produce another 2 ppb TP reduction over time.

Figure 3: Relative Effects of Phosphorus Sources on Androscoggin Lake



Predictions in Table 5 imply that the Dead River will produce 1-4 ppb over what would be expected from only the direct watershed and internal loading. (Cases 12 or 13) The model puts the lake at 11-13 ppb, which is somewhat below what the late summer lake conditions have been over the last decade

(12-20 ppb). As noted above, errors in land use loading estimates, lake modeling, or underestimation of the total loading from the Dead River can partially account for this. Regardless, the relative benefits of dam options suggest that the current configuration achieves most of the benefits to be expected and that a new dam does not offer a large additional increment of protection for the lake.

Trophic State of Androscoggin Lake:

Secchi Clarity and Trophic State

Water quality conditions of most Maine lakes are expressed in terms of clarity (Secchi readings) or Trophic State, which is numerical index based on clarity, phosphorus or Chlorophyll-a (measures of productivity). There is an excellent record of clarity readings, due in large part to volunteer efforts and the trophic state index can be calculated from that. We also have good records of phosphorus and Chl_a, but these are not adequate for long term calculations of Trophic State (see Appendix). Maine water quality standards require that a lake be free of sustained and repeated algal blooms (clarity readings of less than 2 meters) and that the trophic state is stable or decreasing.

More than 340 total secchi readings are on file for Basin 1 (the main sample station for the lake). About 300 secchi readings were taken during the May-September period (most susceptible to bloom conditions). The distribution of these readings is shown below. There is only one record of a bloom event where secchi clarity dropped below 2 meters (1.1m in 1999). Readings of 2-3 meters were achieved during about 6 % of the monitored events during May - September.

Figure 4

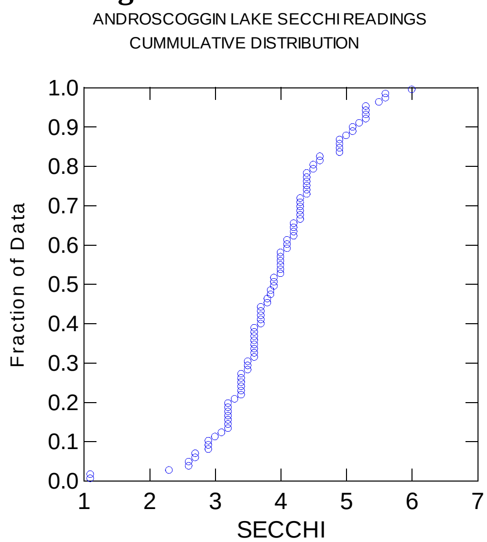
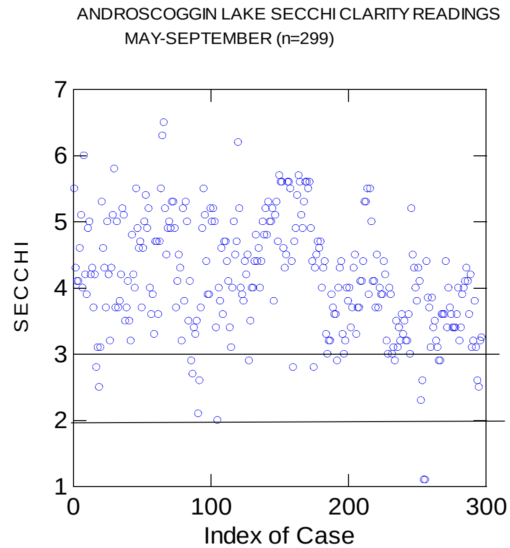


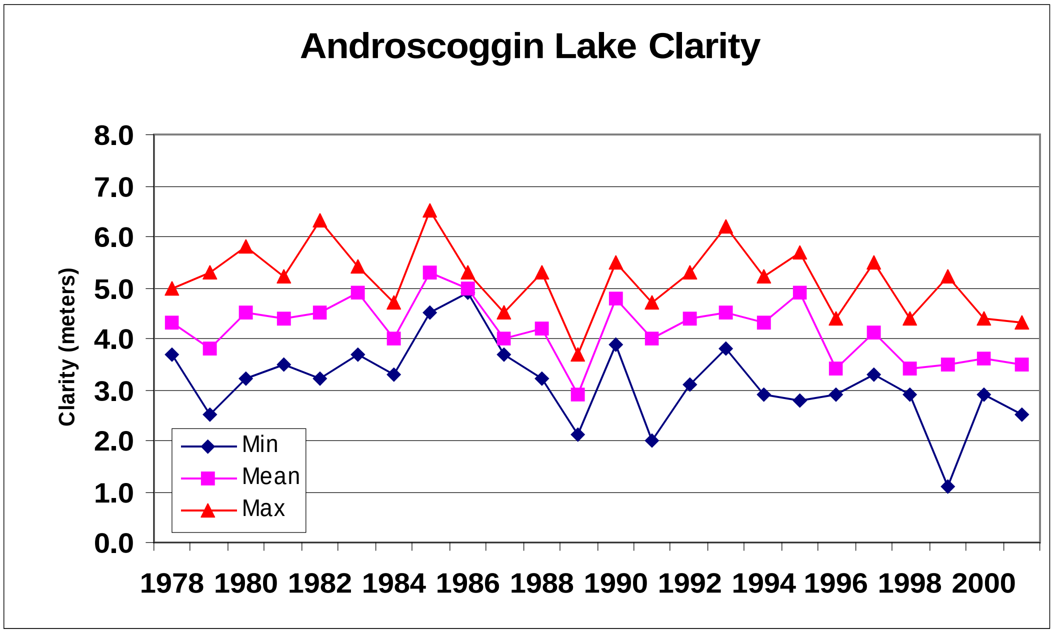
Figure 5



Trends in Clarity and Trophic State

The figures below indicate the long term condition of Androscoggin Lake with respect to clarity readings and TSI for data up to and including 2002.

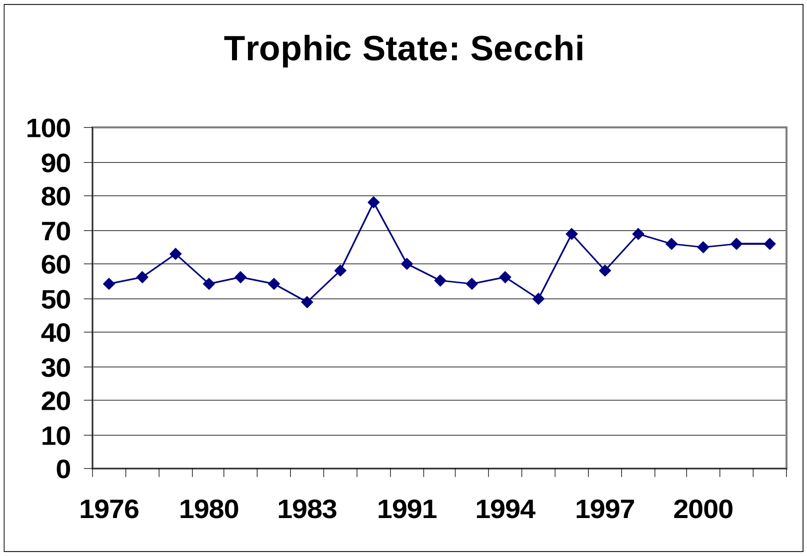
Figure 6: Long Term Clarity Record

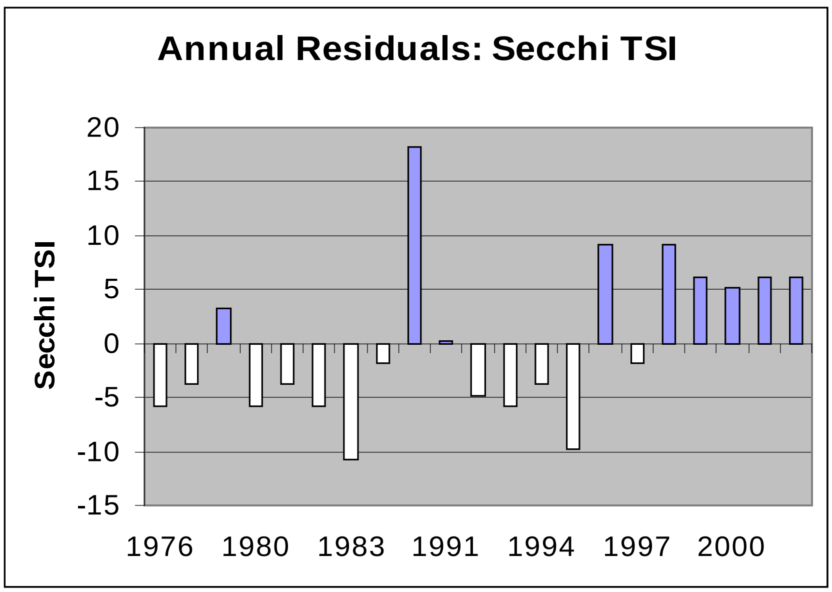


Adequate data exist to examine yearly patterns from 1978 on. Though subject to substantial inter-annual variation, clarity appeared relatively stable until 1997. Since that year, clarity is lower than the long term summer average (4.2 meters). Adequate data exist to calculate the trophic state index (TSI, based on annual mean Secchi readings) for 20 of the last 30 years. One significant gap exists between 1984 and 1987. Except for one excursion in 1989, TSI appeared relatively stable from 1976 to 1996-97.

Some lakes will show an increase or decrease in clarity for several years followed by an abrupt shift in the other direction. One of the confounding factors is that weather conditions during several years of the last decade have been drier and hotter than usual. A large number of lakes have been either more or less clear than their long-term means. Changing land use patterns are probably not great enough to account for these anomalies.

Figures 7 & 8: Long Term Trophic State





The residuals indicate that for the last 5 years, trophic state has been 5-8 points higher than the long term mean. At this time, Androscoggin Lake does not violate state standards with respect to algae blooms. However, for both TSI and Secchi data, the apparent shift in productivity after 1997 is of concern. While it is too early to interpret these data as a "trend" in the usual sense, it is clear that the last 4-5 years clearly differ from the long term average. If this persists over the next few years, we may conclude that the lake has undergone a significant change in its trophic state.

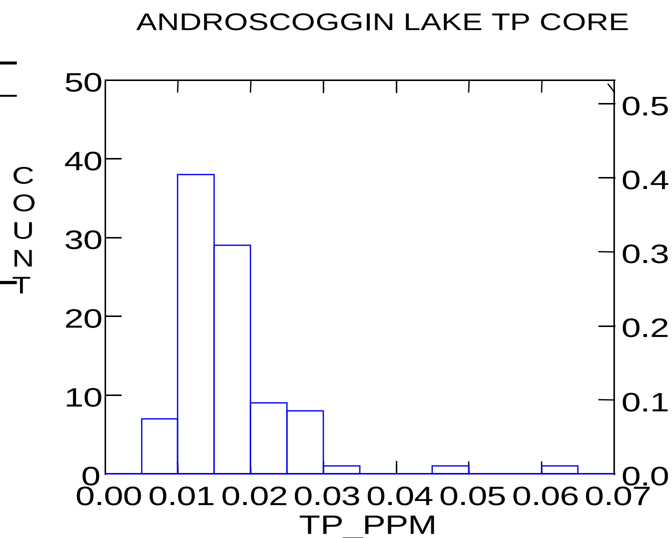
Secchi Clarity and Total P Relationships

We have a total of 94 events where TP core (mixed layer) samples were taken along with secchi data. 78 records are from the months of June-September. Core TP data ranged from 9-63 ppb, with May-September values evenly split above and below 15 ppb.

Table 6 Statistics for Secchi vs TP in Androscoggin Lake Cores (1976 to 2001)

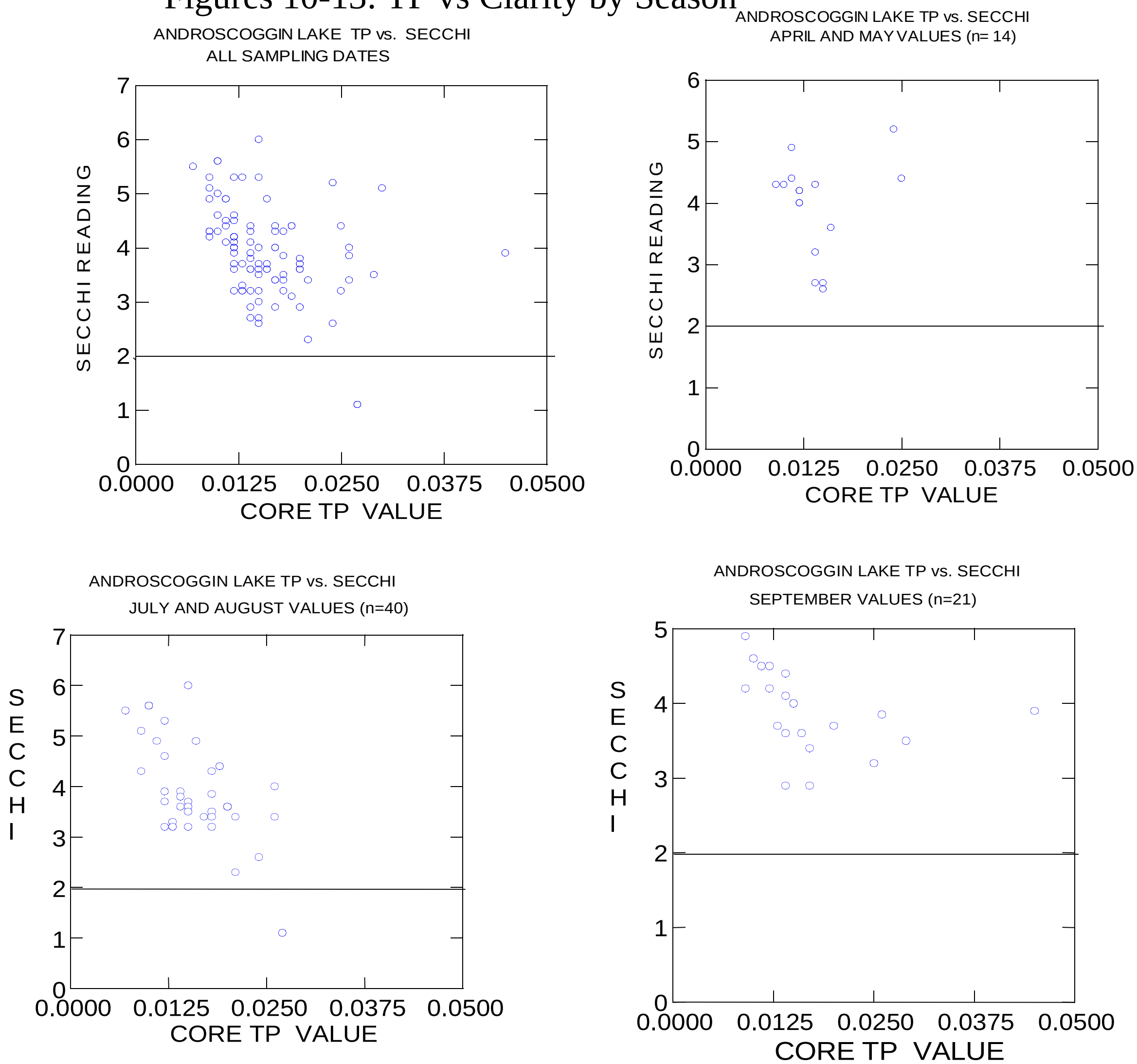
	TP_PPM	SECCHI
N of cases	94	94
Minimum	0.007	1.100
Maximum	0.063	6.000
Median	0.015	3.900
Mean	0.016	3.917
Standard Dev	0.008	0.872

Figure 9: Core TP



The general relationship between single TP samples and secchi on each day is illustrated below. While there is high variability of TP-Secchi relationships for instantaneous readings, these graphs give some idea of the past performance of lake clarity under varying TP levels. When the data are segregated between early season (April-May), mid Summer (July-August), and late summer (September) we can see that the distribution of TP values are slightly higher in the summer and clarity slightly lower than the other two time periods.

Figures 10-13: TP vs Clarity by Season



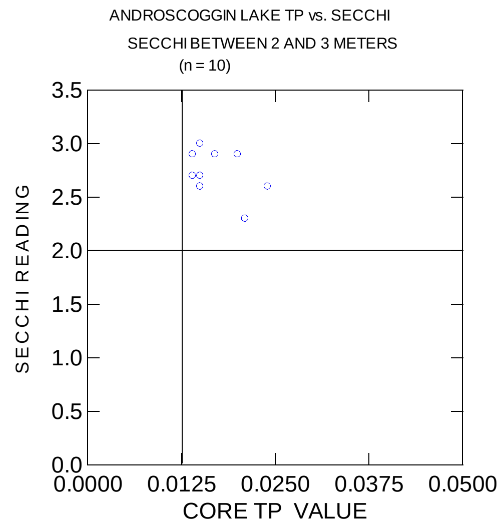
Clarity between 2 and 3 meters does not violate water quality standards (e.g. not defined and a “bloom”). It does indicate higher than desired algal productivity, placing the lake at higher risk for bloom conditions. For all 9 events where secchi clarity was between 2 and 3 meters the TP was above 13 ppb (average 17 ppb). Two events are at 14-15 ppb. and 3 events at 15-16 ppb. TP as high as 20 ppb resulted in reduced visibility of 2-3 meters about 20 % of the time and has not produced repeated or sustained bloom conditions. Only one other event was a “true bloom” (secchi < 1.1 m) with TP at 27 ppb.

Table 7

TP Ranges and Secchi Response

# Readings	TP Range	Secchi range
7	<10	>4.1
11	10-12	4.1-5.0
28	12-15	2.7-5.3
29	15-20	2.6-6.0
19	>20	1.1-5.2
Total = 94		

Figure 14



The lake generally starts out at 11-14 ppb in May-early June and reaches higher levels (median values at 15 ppb, usual range between 13-20 ppb). Much of this summer increase (estimated at about 1-2 ppb) is probably due to in-lake sources. Core TP values for May- September are usually below 20 ppb, with close to 40% between 10 and 15 ppb. Past performance of Androscoggin Lake indicates that summer TP readings in excess of 15 ppb may cause occasional blooms but the likelihood is much higher at readings above 17 ppb. Conversely, readings at or below 13 ppb should provide the lake with significant protection against blooms.

Conclusions:

The lake does not currently violate water quality standards with respect to algae blooms. However, during the 1998-2002 period, the lake was at a higher than average trophic state compared to its long term mean. This apparent shift in trophic state is of concern, but a few more years of data are needed to confirm if this is other than a temporary alteration in the lake's productivity.

Recent data suggest that current phosphorus levels do not provide much of a safety margin for avoiding algal blooms. A late summer TP average below the current 15 ppb is needed to reduce the likelihood of blooms. A long term goal of 13 ppb would help considerably. In addition, this summertime TP reduction of about 2 ppb would probably return the lake closer to its pre-1998 trophic level. The addition of the current boards should provide a margin of safety by lowering the summertime total phosphorus readings about 1-2 ppb as predicted. However, full benefits of these boards will take quite some time to be realized.

Point source contribution to the overall trophic status of the lake appears to have been about 1-2% of total (6% if the Dead River contribution) with the previous dam configuration (no boards). This should be reduced further with addition and maintenance of the new board configuration.

From the perspective of lake phosphorus concentrations, the higher the dam the less phosphorus loading and better lake response should be. In Case 14 (new dam with crest at 282'), the Dead River phosphorus loading would be very low, as only the 10 year and larger events would overtop the dam and larger events (>=25 year) would be needed for significant water input. The new dam would offer only about an extra 0.5 ppb improvement compared to the current dam with boards. The highest incremental benefit for lake phosphorus loading appears to be maximizing the effective dam height with flashboards at the current site. A new dam and higher crest heights would not provide proportionally increased benefits.

APPENDICES

Table : Model Runs at 44 ppb River Concentration TP

Total P Loading in Kg Year (includes all sources)

Dam Option =>	LOAD11	LOAD12	LOAD13	LOAD14
N of cases	49	49	49	49
Minimum	754.600	0.000	0.000	0.000
Maximum	10210.200	1726.560	1232.440	426.800
Median	3823.600	351.560	0.000	0.000
Mean	3890.238	484.620	120.784	11.889
Standard Dev	1988.169	435.386	232.016	61.855

Total Lake TP Concentration (ppb) Due to River Input (includes all sources)

Dam Option =>	DELTA11	DELTA12	DELTA13	DELTA14
N of cases	49	49	49	49
Minimum	2.900	0.000	0.000	0.000
Maximum	19.000	5.900	4.400	1.700
Median	10.700	1.400	0.000	0.000
Mean	10.327	1.814	0.467	0.049
Standard Dev	3.669	1.518	0.864	0.248

Table : Model Runs at 80 ppb River Concentration TP

Total P Loading in Kg Year (includes all sources)

Dam Option =>	LOAD11	LOAD12	LOAD13	LOAD14
N of cases	49	49	49	49
Minimum	1372.000	0.000	0.000	0.000
Maximum	18564.000	3139.200	2240.800	776.000
Median	6952.000	639.200	0.000	0.000
Mean	7073.159	881.127	219.608	21.616
Standard Dev	3614.853	791.611	421.847	112.464

Total Lake TP Concentration (ppb) Due to River Input (includes all sources)

Dam Option =>	DELTA11	DELTA12	DELTA13	DELTA14
N of cases	49	49	49	49
Minimum	5.200	0.000	0.000	0.000
Maximum	34.600	10.700	8.000	3.000
Median	19.500	2.500	0.000	0.000
Mean	18.771	3.302	0.849	0.086
Standard Dev	6.681	2.756	1.569	0.436

Model Runs for TP Loading Due to Point Sources

Total P Loading to Lake in Kg/yr from Point Sources only:
609 #TP/day Licensed input to Androscoggin River

Dam Option =>	PS11	PS12	PS13	PS14
N of cases	49	49	49	49
Minimum	198.400	0.000	0.000	0.000
Maximum	1885.200	192.100	102.500	35.500
Median	672.600	42.700	0.000	0.000
Mean	745.910	52.133	10.622	0.980
Standard Dev	371.647	42.104	19.585	5.137

In-Lake TP Changes Due to River Input of Point Sources
609 # TP/day Licensed input to Androscoggin River

Dam Option =>	DELTAPS11	DELTAPS12	DELTAPS13	DELTAPS14
N of cases	49	49	49	49
Minimum	0.700	0.000	0.000	0.000
Maximum	3.600	0.700	0.400	0.100
Median	1.900	0.200	0.000	0.000
Mean	1.990	0.198	0.043	0.002
Standard Dev	0.690	0.155	0.082	0.014

Total P Loading to Lake in Kg/yr from Point Sources only:
757.7 #TP/day Licensed input to Androscoggin River

Dam Option =>	PS11	PS12	PS13	PS14
N of cases	49	49	49	49
Minimum	246.800	0.000	0.000	0.000
Maximum	2345.100	238.900	127.500	44.100
Median	836.700	53.100	0.000	0.000
Mean	928.037	64.861	13.202	1.220
Standard Dev	462.318	52.364	24.350	6.384

In-Lake TP Changes Due to River Input of Point Sources

757.7 # TP/day Licensed input to Androscoggin River

Dam Option =>	DELTAPS11	DELTAPS12	DELTAPS13	DELTAPS14
N of cases	49	49	49	49
Minimum	0.900	0.000	0.000	0.000
Maximum	4.500	0.800	0.500	0.200
Median	2.400	0.200	0.000	0.000
Mean	2.478	0.243	0.051	0.004
Standard Dev	0.864	0.185	0.094	0.029

Hydrologic Estimates: Inflow to Androscoggin Lake and Resultant Flushing Rate For 49 years of Record During 1950-1999

Flushing Rate Based on Annual Water Input: Direct Watershed + Dead River

Dam Option =>	FLUSH11	FLUSH12	FLUSH13	FLUSH14
N of cases	49	49	49	49
Minimum	2.240	2.000	2.000	2.000
Maximum	5.280	2.550	2.390	2.140
Median	3.230	2.110	2.000	2.000
Mean	3.248	2.155	2.038	2.004
Standard Dev	0.638	0.140	0.074	0.020

Annual Water Input: Millions Cubic Meters

Dam Option =>	Q11	Q12	Q13	Q14
N of cases	49	49	49	49
Minimum	17.150	0.000	0.000	0.000
Maximum	232.050	39.24	28.01	9.700
Median	86.900	7.990	0.000	0.000
Mean	88.414	11.014	2.745	0.270
Standard Dev	45.186	9.895	5.273	1.406