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SUSPENDED SEDIMENTS AND RELATED LIMNOLOGY OF AN ALPINE LAKE SYSTEM

3rd Year End Report

V. Alexander, J. Mellor, and R. J. Barsdate

1 June 1977 - 30 September 1978

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ABSTRACT

Three summer field seasons have been used to study methods for assessing impact of construction activity on arctic tundra lakes in terms of change in suspended sediment load regime. An aerial photographic method for evaluating and monitoring distribution of suspended sediment loads was investigated in addition to studying suspended sediment impact on primary productivity.

Films and cameras were compared during the first season. Plus-X Aerographic (2402) black and white film used in a 9 $\frac{1}{2}$ " format T-11 mapping camera was found to be the most advantageous combination for our purposes.

During the second season, good quality aerial photographs were taken of lakes with large gradients in suspended sediment load. These photographs were used to investigate methods and limitations of density slicing technique in determining and illustrating suspended sediment load distribution in surface, lake waters. Aerial photography was found to be helpful within a lake with large changes in suspended sediment load of fairly uniform sediment particle size. Photographic film density analysis cannot be used to monitor subtle sediment input (i.e. road dust or minor long-term erosion) into lakes adjacent to the pipeline. Fairly gross quantities of suspended sediment that are visually observable must exist before this photographic technique is viable.

Two field efforts were conducted in the third field season. Total primary production (benthic and pelagic) was found to be approximately 5 times greater with about one order of magnitude less suspended sediment load (1.46 mg/l vs. 10.22 mg/l). On 21 August 1977 an aerial reconnaissance

of the pipeline and haul road was accomplished from Galbraith Lake north to Coleen Lake. The only lakes with observable suspended sediment load from 5,000 feet altitude were lakes with resuspended sediment from wind generated wave activity.

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INTRODUCTION

A fundamental aim of this work is to determine what, if any, changes occur in arctic (defined here as lakes north of the Brooks Range) lakes due to road construction. Aerial photographic methods to determine suspended sediment load (SSL) and the significance of SSL impact on arctic lakes have been studied for the past three years. A by-product of any construction, such as the Trans-Alaska Pipeline, is surface disturbance which creates erosion that adds sediment to adjacent wetlands. The quantities and significance of sediment load additions are dependent on many engineering, landscape, and wetland characteristic factors. Suspended sediment loads are rapidly transported away from areas of erosion by riverine systems or can rapidly settle to the bottom of lacustrine systems to form bottom sediments. Thus, the rationale for this project was centered about methodology for rapid assessment of suspended sediment load regimes and SSL impact on arctic lakes. We sought to determine effects of SSL on some limnological processes of an arctic lake system and evaluate the use of remote-sensing techniques in monitoring the sediment load. In culmination, we flew the Trans-Alaska Pipeline north of the Brooks Range to observe and assess SSL along the pipeline corridor.

This report includes the studies related specifically to suspended sediment load impact on arctic lakes. In an effort to bring the recommendations of this study into perspective, we will briefly review the significant results of the first year of work. We will detail results from the analysis of aerial photographs taken during the second summer season. Finally, we will describe accomplishments of the past year (third year) of field work and concluding analyses.

First Year's Conclusions

Peters and Schrader Lakes, on the north slope of the Brooks Range, Alaska, were selected as a natural laboratory in which to compare aerial photographic estimates of SSL with *in situ* information on transmissivity and SSL. At the same time, these lakes provided an opportunity to study limnological features associated with varying sediment content: a distinct gradient in sediment load exists between the heavy glacial input at the southern end of Lake Peters and the clearer waters at the N. E. end of Schrader Lake. A marked discontinuity occurs at the entrance of Schrader Lake after the water passes through a shallow, narrow channel joining the two lakes (Alexander *et al.*, 1976).

Cameras and films were tested and compared for effectiveness in discriminating between and ease of photographically recording suspended sediment loads. Because a VP-8 density slicer (VP-8 Image Analyzer, Interpretation Systems Inc.) was used to contour isodensities on film transparencies, format size was critical. The large format (231 mm or 9 1/2") from a T-11 aerial mapping camera was much preferable to the 70 mm format from a Hasselblad or the 35 mm format from a single lens reflex for all vertical photography that was used for analysing density of film transparencies. A hand-held 35 mm camera was useful for obtaining oblique perspectives of the lake systems.

Three film types were tested in each of the cameras. Prints of the Schrader Lake plume are shown for each film type in Figures 1, 2, and 3. The Plus-X Aerographic (2402) black and white film had the fastest film speed of the films used. Aerographic films with fairly fine grain yet higher film speed are now available and would be advantageous for arctic

Figure 1. Aerial photograph of Schrader Lake suspended sediment plume, 19 August 1975 [Kodiak Aerochrome Infrared (2443) false color Film].

Figure 2. Aerial photograph of Schrader Lake suspended sediment plume, 19 August 1975 [Kodiak Aerochrome MS (2448) color positive Film].

Figure 3. Aerial photograph of Schrader Lake suspended sediment plume, 19 August 1975 [Kodiak Plus-X Aerographic (2402) black and white Film].

research, particularly when working with low light levels which can occur during early and late summer season work. Black and white film is not as sensitive to ambient temperature changes as infrared film and is the least expensive to purchase and process. The VP-8 image analysis does not differentiate between color and black and white densities. Some capability to analyse visually is lost in going to the exclusive use of black and white film. However, for our use black and white (2402) film was satisfactory.

Second Year (Photographic Analysis and Resulting Conclusions)

The resulting transformation of a black and white aerial photograph into a color density-sliced image of Schrader Lake is illustrated in Figures 4a and b. Figure 4a is a black and white photomosaic of the Schrader Lake Basin taken on 31 July 1976. The turbid Lake Peters' water enters Schrader Lake, forming a plume depicted as changes in greyness (density) within the black and white photograph. The VP-8 image analyzer converts these film densities into color, which represent discrete bands of density (Figure 4b). Each interface between color changes is a contour of iso-density that define lake waters with similar properties of light absorption and or SSL. The final step is to convert the bands of color into numerical ranges of suspended sediment load (Figure 4c and 5). Figure 4c has numbered contour lines that represent the color interfaces on Figure 4b for Schrader Lake. The same 3 series of steps were taken to obtain the contour lines for Lake Peters and Schrader together as shown in Figure 5. The final step was to correlate film densities with SSL. Figure 6 has ground-truth SSL data sampled on 31 July 1976 plotted against VP-8 film

- a. Schrader Lake black and white photo mosaic (3 aerial photographs taken 31 July 1976).

- b. Schrader Lake VP-8 image mosaic (from 3 each Fig. 4a, 31 July 1976 photographs) depicting slicing at equal density intervals.

- c. Schrader Lake approximate suspended sediment loads on 31 July 1976, assigned to density slice analysis contours shown in Fig. 4b.

Figure 4. A series of three Schrader Lake images are used to determine and illustrate suspended sediment concentrations throughout the surface waters of Schrader Lake.

Figure 5. Peters and Schrader Lakes with optical density contours which approximate contours of suspended sediment load on 31 July 1976 (from density slice analysis)

Figure 6. Best fit curve depicting correlation between millivolts representing VP-8 density slice data and actual suspended sediment loads at ground-truth sites within Peters and Schrader Lakes on 31 July 1976.

densities (in millivolts) for specific sites within Peters and Schrader Lakes from photographs taken on the same date. The curve is a best fit used to assign SSL values to the isodensity contours and show the correlation between film density and suspended sediment load. Our SSLs are determined gravimetrically, and are in reality total suspended solids. However, the organic constituents within the suspended solids are so minor, that we will refer to our gravimetric determination as SSL.

Figure 7 illustrates the fate of suspended sediments entrained in the water moving through these two lakes. Lake Peters water has a fairly uniform, but high SSL throughout the entire basin, although a subtle SSL reduction does occur along the length of Peters. The slight apparent increase (Figure 7) in suspended sediments within the channel connecting Peters to Schrader may be caused by one or more of the following factors. This channel is very shallow ($\frac{1}{2}$ -2 m). Some sediments may be resuspended and or mixed up into surface waters by water currents within the channel. Edge effect and or shoals may also be affecting the density slicing of photography within this shallow, narrow channel.

The colder (Alexander *et al.*, 1976) heavily sediment laden surface water from Lake Peters dives under the Schrader surface water creating a sediment plume which disappears rapidly. Surface suspended sediment loads continue to decline toward the Schrader outlet until within about 1-2 kilometers from the outlet SSLs begin to increase again. This marked increase in SSL corresponds with a decrease in lake depth as we near the outlet. Some of the cold, dense sediment laden water that had disappeared from the surface at the Schrader headwaters are returned to the surface prior to exiting through the outlet. Schrader Lake is undoubtedly acting

Figure 7. Suspended sediment loads with distance along Peters and Schrader midlake line (density slice data from 31 July 1976 photograph).

as a sediment trap, but a significant quantity of sediment is returned to the surface and flows out of Schrader Lake. On 31 July 1976, Schrader Lake had approximately 5.9 mg/l suspended sediment entering from Lake Peters and had less than 2.7 mg/l suspended in water flowing out. However, since the concentration of suspended sediments are beneath the surface water for the majority of the Schrader Basin, Schrader waters have greater light penetration than Lake Peters providing potentially greater photosynthetic production.

The potential for determining gross differences in suspended sediment load (Schrader Lake) and depicting shoals within Toolik Lake (Figure 8) lacking in suspended sediment, was evidenced with the summer 1976 data collected (Alexander *et al.*, 1977). The SSL data (Figure 5) illustrating sediment distribution within both Peters, and Schrader Lakes was utilized for placement of transects within the Lakes for comparing the effects of differing SSLs on lake productivities in the third year of this study. These results will be discussed later.

The accuracy of SSL distribution determinations by aerial photography is limited. A number of variables can effect aerial photographic film densities used to determine SSLs by VP-8 density slicing. This variables include:

- a. film types (i.e. film speeds, and spectral sensitivities);
- b. camera filters;
- c. atmospheric conditions and altitude of photography (i.e. haze);
- d. lens characteristic (i.e. light aberrations due to lens distortion);
- e. camera settings (i.e. f stops and shutter speeds);
- f. film processing;

Figure 8. Map of Toolik Lake shoals (from 0 to ~ 3 m depth) derived from a density sliced image of an aerial photograph taken on 28 July 1976.

- g. shadows from clouds or mountains;
- h. lake bottom characteristics (i.e. shoals and reflectance of benthic substrate);
- i. vegetation (i.e. submerged and emergent);
- j. water surface reflectance (i.e. constantly changing light reflectance due to size of wind generated waves);
- k. off axis variations in radiance film exposure from uneven sunlight conditions (Bressette, 1978);
- l. and finally, water transparency that is dependent upon SSL as well as suspended plankton and detrital loads.

With experience and proper photographic mission planning the detrimental effect of variables (a) through (f) on film density should be minimal. The aerial photographer should be aware of any camera, lens, film, filter, or atmospheric problems that might effect film densities and work toward maintaining as much uniformity in exposures as possible documenting any changes that effect continuity of film exposure for that photographic mission. Density variations due to (g) through (i) can usually be discerned by visual interpretation and or VP-8 density slice analysis of individual photographs. The data in error can then be corrected or discarded as required for optimum photointerpretation. Variables (j) through (l) are very changable in both space and time. Some correction for surface reflection (glint) can be made by discarding portions of photographs with obvious glint problems. We did not attempt sophisticated correction for off-axis variations in radiance film exposure from camera fall-off or uneven sunlight conditions for this study. These variations can be normalized to the nadir value using flight data (Bressette, 1978). Therefore, density contours from VP-8 image analyses were not continuous at the edge of adjacent scenes. However, the scenes overlapped by

approximately 60 percent. By discarding erroneous edges of adjacent scenes, acceptable mosaicking of VP-8 density contours was achieved in most cases. Plankton and suspended detritus effect light absorption within the water and hence film densities much the same as SSL. Total suspended solids is the most appropriate designation for the parameter measured by analysis of film densities.

Too many variables change rapidly with space and time to allow us to calibrate a photographic system that will repeatedly provide quantified water transparency data from film density analysis. Successive flight data or even lakes separated by a few miles in space and time must have individual ground truth data for quantifying accurate distributions of SSL within a lake system. Qualitative distribution of SSL are easily discernable from aerial photographs and need no ground truth data to be usable. But no matter how the data is used, uniform sky conditions and equal conditions for film exposure are a must for film density analysis.

Within limitations and conditions described above, SSL distributions (summer 1976 and 1977) have been defined for some arctic lake systems that have significant suspended sediment loads. This methodology has greatest potential where limited ground truth is available for lakes with visible variation in SSL. The product is a map with contoured SSL distribution throughout the water body.

Third Year Studies

Research Plan for Summer, 1977

During the summer of 1977, the field program was two-fold:

1. Peters and Schrader Lakes were visited from 30 July to 3 August 1977 to study the effects of vastly different (1.46 mg/l vs.

10.22 mg/l) SSL on lake chemistry and metabolism. This effort was launched to help define the effect suspended sediment on arctic lake productivity.

2. The second effort on 21 August 1977 was an aerial survey of lakes adjacent to the pipeline corridor from Galbraith Lake north to Prudhoe Bay (Figures 17 and 18). Aerial photographs and surface water samples were taken for SSL determinations in Galbraith and Coleen Lakes. Both lakes had visible sediment plumes. These were the only lakes observed during this mission with sufficient suspended sediment to warrant aerial photographic analysis of SSL.

Each of the two field efforts were separate in time, space, and discipline. The methods and results of each study follow as separate entities.

Peters and Schrader Primary Productivity vs. SSL.

Methods

Figure 5 was used to select two transects in areas of differing SSL within the two lake system. A transect with low SSL was selected in Schrader Lake (Figure 9). A transect with high SSL was chosen in Lake Peters (Figure 9). Each site was investigated intensively to evaluate the following:

- Suspended Sediment Loads (SSL) by gravimetric determination;
- Light Attenuation (LA) with a photometer (LI-COR Quantum/Radiometer) Photometer;
- Alkalinity by titration;
- Chlorophyll α (Strickland and Parson, 1968); and
- Primary Productivity from both water column and benthic substrate (Vollenweider, 1978).

Figure 9. Peters and Schrader Lake study transects, Summer, 1977.

The above data was used to investigate the impact of suspended sediments upon benthic and mid-water productivities.

Samples for mid-water primary productivity measurements (PP) were collected with a Van Dorn Water Sampler to depths greater than the depth at which the 1 percent light level occurred. Benthic PPs were taken to the same depth as the mid-water PPs. Two sampling methods were used to obtain benthic PP. The nearshore environment was rocky, requiring us to sample rock surfaces for epilithic primary productivity and chlorophyll. The surface of rocks were capped with 3.175 cm diameter chambers used for ^{14}C incubations. The same chambers were used to define the area to be scraped for chlorophyll determinations. The nearshore rock zone graded into a sediment substrate. Samples for epipelagic primary productivity and chlorophyll were collected by coring the sediments with a 3.5 cm diameter corer. Alliquot core and whole rock chambered samples were used for *in situ* incubation of ^{14}C PP and for chlorophyll determinations.

A photometer was used at the deep end of each transect to determine the light extinction coefficient (k) and the water depth at which 1 percent incident light remained. A surface water sample was taken at this same location to ascertain alkalinity and 33L.

The purpose in studying primary productivity was to compare the gross primary productivity of waters with a change in SSL. To make this comparison where two (Peters and Schrader) lake basins were involved, we formulated a hypothetical lake basin with characteristics similar to those of Peters and Schrader Lakes. Figure 10 has hypsographic curves plotted for both Peters and Schrader Lakes. The hypsographic curves were derived from Hobbie, 1962 bathymetric data. The curves are very similar down to

Figure 10. Peters and Schrader Lakes hypsographic curves.

20 m depth which is below the 1 percent light level (depth of significant water column or benthic PP) in both lakes. The average slope of the lake bottoms to 20 m depth can be used for the hypothetical basin PP calculations without much deviation from actual values for Peters and Schrader lakes. Schrader Lake has a surface area of 12.4 km^2 , whereas Peters surface area is 6.4 km^2 . An average of 9.4 km^2 was used for the hypothetical lake in which we will calculate total basin primary productivity assuming conditions that existed at our specific study transects within the actual lake basins are uniform and homogeneous over the entire hypothetical lake basin. The hypothetical lake basin PP totals are comparable with Schrader and Peters lakes physical and chemical conditions yet devoid of basin morphology PP input variables. We use this reduction in PP input variables later to compare basin PP totals relative and limited to SSL specifically.

Results

Table 1 accumulates the data taken at the two transect sites. The data in this table is presented graphically in Figures 11 through 16 to illustrate SSL effects and allow discussion of these results. Finally, a comparison of individual lake results utilizing the hypothetical lake developed in the methods section will provide a summation of results.

Chlorophyll a data

Lake Peters benthic chlorophyll a (chl a) data is plotted with depth in Figure 11. A peak of 107 mg/m^2 occurs at 2 m depth. The 1 percent light level occurs at 3.55 m where the chl a values begin to decrease, but chl a is still considerably above the values near the surface. The 455

TABLE 1

PETERS AND SCHRADER LAKES TRANSECT DATA
(sampling completed from 30 July-2 August 1977)

Date (1977)	Station	Depth m	Suspended Sediment Load mg/ℓ	Light Penetration 1%I ₀	Temperature °C	Alkalinity mgC/ℓ	Pigment Analysis Chl a* Chl a/Phaeo. ratio	Primary Productivity (PP)	PP/Chl a ratio†		
LAKE PETERS TRANSECT											
31 July	Midwater	0	10.22	3.55m**	1.28**	11.1**	5.98**	.43 mgC·m ⁻³ ·hr ⁻¹			
31 July	Midwater	1						.30 mgC·m ⁻³ ·hr ⁻¹			
31 July	Midwater	2						.03 mgC·m ⁻³ ·hr ⁻¹			
31 July	Midwater	4						.07 mgC·m ⁻³ ·hr ⁻¹			
1 August	Epilithic	.25					19.2 mg/m ²	.60 mgC·m ⁻² ·hr ⁻¹	.031		
1 August	Epilithic	.5					21.1 mg/m ²	1.24 mgC·m ⁻² ·hr ⁻¹	.059		
1 August	Epilithic	1.0					34.6 mg/m ²	.74 mgC·m ⁻² ·hr ⁻¹	.021		
31 July	Clear Water Seep	.25	much less Suspended Sediment Load (<10.22 mg/ℓ)				455.0 mg/m ²	.21	68.31 mgC·m ⁻² ·hr ⁻¹	.150	
2 August	Epipellic	2	10.22	3.55m	1.28	11.1	5.98	107.1 mg/m ²	1.62	1.01 mgC·m ⁻² ·hr ⁻¹	.0094
2 August	Epipellic	4						74.8 mg/m ²	2.72	0.14 mgC·m ⁻² ·hr ⁻¹	.0019
SCHRADER LAKE TRANSECT											
1 August	Midwater	0	1.46	15.5**	.32**	11.1**	5.51**	3.75mg/m ³	.09 mgC·m ⁻³ ·hr ⁻¹	.024	
1 August	Midwater	2							.24 mgC·m ⁻³ ·hr ⁻¹		
1 August	Midwater	4						3.85mg/m ³	.32 mgC·m ⁻³ ·hr ⁻¹	.083	
1 August	Midwater	10						3.86mg/m ³	1.31	.26 mgC·m ⁻³ ·hr ⁻¹	.067
1 August	Midwater	20						7.60mg/m ³	1.67	.05 mgC·m ⁻³ ·hr ⁻¹	.0065
30 July	Epilithic	.25						19.7 mg/m ²		.91 mgC·m ⁻² ·hr ⁻¹	.046
30 July	Epilithic	.5						20.4 mg/m ²	3.02	1.59 mgC·m ⁻² ·hr ⁻¹	.078
30 July	Epilithic	1						21.0 mg/m ²	20.00	1.21 mgC·m ⁻² ·hr ⁻¹	.058
30 July	Epilithic	2						20.2 mg/m ²	3.53	.79 mgC·m ⁻² ·hr ⁻¹	.039
30 July	Epilithic	4						21.6 mg/m ²	15.80	.68 mgC·m ⁻² ·hr ⁻¹	.031
30 July	Epipellic	7						75.0 mg/m ²	.72	1.06 mgC·m ⁻² ·hr ⁻¹	.041
30 July	Epipellic	9						61.4 mg/m ²	.63	1.01 mgC·m ⁻² ·hr ⁻¹	.061
30 July	Epipellic	15						167.5 mg/m ²	.32	0.09 mgC·m ⁻² ·hr ⁻¹	.0005
30 July	Epipellic	15						22.0 mg/m ²	.49	0.06 mgC·m ⁻² ·hr ⁻¹	.0037
30 July	Epipellic	20						44.7 mg/m ²	1.52	0.12 mgC·m ⁻² ·hr ⁻¹	.0027

* Chlorophyll *a*

† Per hour of production

** Used for calculations at all depths

Figure 11. Lake Peters chlorophyll *a* with depth (at SSL of 10.22 mg/l, 31 July - 2 August 1977).

Figure 12. Schrader Lake chlorophyll *a* with depth (at SSL of 1.46 mg/l, 30 July - 1 August 1977).

Figure 13. Lake Peters primary productivity with depth (at SSL of 10.22 mg/ℓ , 31 July - 2 August 1977).

Figure 14. Schrader Lake primary productivity with depth (at SSL of 1.46 mg/ℓ , 30 July - 1 August 1977).

Figure 15. Lake Peters primary productivity/chlorophyll *a* ratios with depth (at SSL of 10.22 mg/ℓ, 31 July - 2 August 1977).

Figure 16. Schradler Lake primary productivity/chlorophyll a ratios with depth (at SSL of 1.46 mg/l, 30 July - 1 August 1977).

mg/m^2 epilithic chl a value listed for the clear water seep was a special case in Lake Peters (Figure 9). The clear water seep (low in suspended sediments) entered Peters below lake level creating a very localized near-shore area of clear water with significantly greater algal mass on the rocks subjected to these uniquely transparent waters.

Schrader Lake chl a data is shown in Figure 12. Both benthic and water column data were collected. The benthic chl a values are an order of magnitude greater than water column values. Schrader shallow, benthic chl a values are similar ($\sim 20 \text{ mg/m}^2$) to those in Peters. Peters and Schrader benthic chl a curves have maximum peaks that occur in water depths slightly above 1 percent light level depths of 3.55 m and 15.5 m respectively. The maximum chl a peak in Schrader was 167 mg/m^2 at 15 m substrate depth. By 20 m depth the chl a dropped to 45 mg/m^2 .

The effect of SSL on the algal standing crop (chl a) is evident from a comparison of Figures 11 and 12. The Peters and Schrader benthic chl a curves are very similar in shape and amplitude. However, the chl a values that exist over 20 m water depth in Schrader Lake are compressed into only 4 m (1/5) of the water depth in Lake Peters.

Primary Productivity Data

Primary productivity (PP) data from Peters and Schrader water columns and benthic substrates are graphically illustrated in Figures 13 and 14 respectively. A comparison of the Peters and Schrader PP curves show Peters PP data is compressed into one-fifth the water depth over which Schrader PP values occur. General PP amplitudes for both lakes are very similar. Surface suppression of water column PP appears in Schrader

Lake (.1 mg C·m⁻³·hr⁻¹), while achieving a maximum in Lake Peters surface water (.4 mg C·m⁻³·hr⁻¹). Water column PP decrease in both lakes to levels at or below .1 mg·C·m⁻³·hr⁻¹ at the 1 percent light level. Benthic PP was significantly greater (2-6 times) than water column PP throughout most of the photic zone of both lakes.

Both Peters and Schrader Lakes benthic PP curves are bimodal. An epilithic PP peak occurs near one-half meter water depth within both Peters and Schrader substrates with values of 1.24 and 1.59 mg C·m⁻²·hr⁻¹ respectively. A second lesser PP peak occurs in the epipelagic data. This peak (1.01 mg C·m⁻²·hr⁻¹) occurs at 2 m depth in Lake Peters. Schrader Lake has an epipelagic PP peak of similar magnitude (1.07 mg C·m⁻²·hr⁻¹), but at a greater depth (7-8 m). Primary productivity values decline to less than .2 mg C·m⁻³ or m⁻²·hr⁻¹ for both water column and benthic data at depths near 1 percent light level.

Primary production/chlorophyll *a* ratios (PP/chl *a* ·hr) are plotted against depth for Peters and Schrader Lakes in Figures 15 and 16 respectively. The benthic PP/chl *a* (standing crop) ratios increase to one-half meter depth and decrease with increasing depth beyond one-half meter in both lakes. This was due to the high PP peak with no corresponding standing crop at one-half meter water depths. This phenomenon does not show up at the second epipelagic PP peak, as higher benthic chl *a* values exist at these depths. The Schrader Lake water column ratios show a more gradual increase leveling off and then decreasing with depth. No distinct shallow water peak occurs as in the benthic data. The water column ratio increases to about 4 m depth, remains about the same to 10 m and then begins a rapid decline with depth.

Conclusions

Utilizing the hypothetical lake discussed in methods, we are able to illustrate the effect of SSL on the total production of a water body which is similar in bathymetry and areal extent to Peters and Schrader Lakes. The primary production (PP) curves in Figures 13 and 14 were used to calculate total PP at 1.46 mg/l and 10.22 mg/l SSL within this hypothetical water body. The resultant totals and relative contributions by benthic and water column PP are shown in Table 2.

Benthic PP accounted for about 5 percent of the total while water column PP was about 95 percent of the total. This occurred irrespective of SSL. Benthic PP was greater per unit area in the shallow water, but this water body has such a large deep basin that the water column PP outweigh benthic PP considerably. The ratio of benthic vs. water column PP is controlled by bathymetry or the amount of benthic substrate receiving sufficient light for photosynthetic activity. Shallow lakes have a much greater potential for significant contributions of benthic PP to the total PP.

The percent benthic PP contribution to total basin PP could be greater than 50 percent in shallow (2 m) arctic coastal plain lakes with similar benthic and water column PP rates.

Suspended sediment load may not have affected the percentage contribution of benthic vs. water column PP, but it had significant impact on total basin primary production. The PP at 1.46 mg/l SSL contributes 4.6 times as much fixed carbon (349.5×10^5 mg C/hr) than the heavily sediment loaded (10.22 mg/l) water (76.3×10^5 mg C/hr). This amounts to almost a 5 fold increase in total basin primary productivity with less than an order of magnitude decrease in suspended sediment load (10.22 to 1.46 mg/l).

TABLE 2

PRIMARY PRODUCTION TOTALS RELATIVE TO SUSPENDED SEDIMENT LOAD
 WITHIN A HYPOTHETICAL LAKE BASIN SIMILAR IN BATHYMETRY
 AND SIZE TO PETERS AND SCHRADER LAKES
 (water chemistry and PP data from 30 July-2 August 1977)

Hypothetical Lake Condition Description	Total Lake Basin Primary Production (PP) mg C/hr x 10 ⁵			% PP Benthic	% PP Water Column
	Water Column	Benthic	Total		
"Schrader Lake Like" SSL ~ 1.46 mg/l	332.8	16.7	349.5	4.8	95.2
				or ~5%	or ~95%
"Lake Peters Like" SSL ~ 10.22 mg/l	72.6	3.7	76.3	4.9	95.1
Ratios of PP at 10.2 mg/l vs. 1.46 mg/l	1:4.6	1:4.5	1:4.6		

Pipeline Reconnaissance

Methods

On 21 August 1977, an aircraft with photo-mapping equipment and a float plane for ground-truthing were flown along the North Slope section of the Trans-Alaska Pipeline Road (Figures 17 and 18). The most southerly extent was Galbraith Lake. Aerial photographs and water samples were obtained from Galbraith at the southern extreme and from Coleen Lake (first lake north of Deadhorse Airport) at the northern extreme of our flight line. Good weather allowed for visual inspection of all lakes adjacent (approximately two miles either side) to the pipeline road between Galbraith and Coleen Lakes. Galbraith and Coleen Lakes and one or two other smaller lakes, with fairly extensive sediment covered shoals, had significant suspended sediments loads. These SSLs were a result of resuspended benthic sediment stirred by wind generated waves. No additional lakes were sighted with sufficient suspended sediment to warrant aerial photography or to be evident from our 5,000 foot observation altitude.

Aerial photographs of Galbraith and Coleen Lakes were density sliced and analysed for suspended sediment distribution as described in the second year section on photographic analysis. The correlation of suspended sediment load and film densities is not nearly as good as that achieved for Peters and Schrader Lakes (Figure 6). The primary reasons for this are: (1) the existence of shoals; and (2) the possibility of significant changes in the light reflecting and absorbing qualities of suspended sediments in Galbraith and Coleen Lakes. A large range of particle sizes is maintained by active resuspension of benthic substrates by wind generated waves. We suggest that rapidly changing sediment particle sizes and suspended sediment

Figure 17. Galbraith Lake ground-truth station positions, 21 August 1977.

Figure 18. Coleen Lake ground-truth station positions, 21 August 1977.

loads with depth and distance from source material in Galbraith and Coleen Lakes make correlation of film densities with very few SSL ground-truth measurements difficult.

The fine glacial silts of small, uniform particle size in Peters and Schrader lakes did not present this difficulty. Any lakes or rivers with sufficient energy to provide active resuspension of bottom sediments into the surface layers being photographed and analysed for SSL distribution may prove to be difficult to analyse with precision. Although some precision may have to be given up, the analysis can give useful results.

Results

During the August pipeline corridor lake survey, we noted very few lakes with observable SSLs from the air. The lakes observed that appeared free of SSL may actually have had measurable SSL by gravimetric determination, but did not have sufficient suspended sediment to be visible from the air nor discernable on aerial photographs. Most of these lakes and ponds are both small (<0.5 km) and shallow (<2 m). The small quantities of airborne sediment from road dust or longer distance wind dispersed dust and waterborne sediment from the lakes' water-sheds, were not retained in sufficient quantities within the surface waters to be visible from the air by late August. Most small lakes and ponds have little to no channel forming drainage network that would provide an erosional sediment input. A lake's watershed is frequently only slightly larger than the surface area of the lake itself. Water is transported to the lake margin by sheet flow with little to no possibility for erosion. For these reasons annual sediment input must be extremely low in these small lakes with little or no channel flow capable of carrying sediments to a lake. Small

increases in sediment input (i.e. dust from the haul road) may have an effect on the lake system, but neither the precision nor the spot checking capabilities of aerial survey are adequate for quantifying the SSL levels involved or for elucidating the impact of such small changes on lakes of low SSL.

The lakes in which we observed sediment plumes during the August survey seem to have some common features. These include the existence of sediment laden shoals from which bottom sediments are continually resuspended in the water column. The larger the lake the greater the fetch for the wind to generate waves of sufficient size to resuspend bottom sediments. Some large yet very shallow lakes along the Beaufort Sea Coast seem constantly stirred up by the relentless coastal plain winds resulting in a relatively high SSL throughout the ice free season.

Suspended sediment loads of from 1.48 to 11.13 mg/l were measured in Galbraith Lake and from 3.72 to 9.50 mg/l in Coleen Lake on 21 August 1977 (Table 3). Figure 17 and 18 show station positions for Galbraith and Coleen Lakes respectively. Utilizing the ground-truth SSL shown in Table 3 we get the approximate SSL distribution for Galbraith Lake shown in Figure 19. The shoals from which wind waves resuspended sediment are shown in two locations on the eastern shore of Galbraith Lake. The distribution of suspended sediments within this basin is relative to and centered about these two shoals. The same conditions of sediments emanating from an area of wave activity on western shoreline shoals was determined for Coleen Lake and need not be illustrated here.

TABLE 3

GALBRAITH AND COLEEN LAKES FIELD DATA
21 August 1977

Station	Ave. Susp. Sed. (mg/l)	Secchi Disc (m)	Depth of 1% Light Level (I_0)	k^*	Water Roughness (cm)	Water Depth (m)
Galbraith						
G-1	1.96	3	7.9m	.88	0	5.5
G-2	1.48	2.5	7.4m	.59	0-1	4
G-3	4.22	1.5			1-4	
G-4	2.79	1.75	6.5m	.68	1-4	5
G-5	11.13	1.5	4.9m	1.32	1-4	3.75
Coleen						
C-1	3.72	1.5	4.1	1.14	1-6	1.5
C-2	9.50		3.0	1.50	10	0.5

* Coefficient for light extinction

Figure 19. Galbraith Lake contours of optical density which approximate contours of suspended sediment load (from 21 August aerial photographs).

Conclusions

A point to be made in this discussion is that lake depth, fetch and a bottom sediment source may be prime factors in determining a lake's susceptibility to high SSLs. Once a critical SSL is achieved in a shallow lake system the flora and fauna that would normally trap or aggregate the sediment may decline and allow SSL to increase. In those lakes with no deep basin to trap these resuspended sediments, the increase in SSL beyond a critical level may be a natural process which is difficult to reverse.

No construction related SSLs were detected along the haul-road north of Galbraith Lake on 21 August 1977. This is as might be expected since major civil construction was complete.

The only significant SSLs observed on 21 August 1977 were resuspended sediments from shoals. This type of suspended sediment is very apparent and is significant to the productivity of lake systems affected. This is not to say that lakes adjacent to the pipeline will not be affected by construction related sediment input, but that those with already very high SSL should not be impacted by relatively small additions. However, should finer sediment which remains in suspension longer be input, some impact could result.

The sediment input (i.e. road dust and minor erosion) from construction activities is in most cases small and subtle. Photographic monitoring of short time frame inputs is possible if weather and mission timing cooperate. However, photographic density analysis cannot be used effectively to determine minor subtle sediment input over long periods of time. Other methods must be employed (i.e. sediment traps or constant *in situ* water sampling) to observe small long-term suspended sediment input. This approach,

as well as, studies of the chemical implication of road-dust input, is being examined in a parallel study.

The techniques utilized in this study are applicable for bodies of water with a visually observable range in SSL distribution. Some ground-truth is necessary to correlate SSL with density slice data. The technique is valuable for identifying source and quantifying distribution and fate of suspended sediment. Some pulses of sediment input may occur over a short period of time in conjunction with specific site construction. Aerial photography can be used to monitor and assess the source, fate, and distribution of sediments entering a water body as a result of a construction activity or a natural source. The magnitude and duration of suspended sediment loads within Arctic lakes are significant factors effecting their productivity.

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