Limnological exploration of Flakevatn,
a high mountain lake in central Norway.
Annual heat budget and silica content.

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ABSTRACT

Flakevatn, a high mountain glacial lake situated in central Norway, has been investigated for annual heat budgets, minerogenic and biogenic silica content of water and sediment. Minerogenic silica content was related to potential buffering capacity of glacial ooze during expected glacial ooze event. More accurate estimate of annual heat budget has been deduced from ice cover observations and water column temperatures in the years 2005 and 2004. Strøm 1965 estimate of Flakevatn's annual heat budget was recalculated using a different ice cover composition and 6 water column strata to a more reasonable value of 19526 cal cm^{-2}. This lake belongs in a cold monomictic lake category and is estimated to have annual heat budget of 15673 cal cm^{-2} in the year 2004 and 13074 cal cm^{-2} in the year 2005.

During year 2005, the melt-water did not supply large amounts of glacial ooze and thus did not visibly produce late-summer glacial ooze event in Flakevatn. Turbidity during 2005 was very low but it was observed increasing in mid September due to glacial ooze buildup in the epilimnion. Conductivity and pH of water samples at the epilimnion depths did not significantly change with filtration, but alkalinity did. The dissolved silica measured in inflows to Flakevatn and in reference streams Midtdal and Blåis has been found to be in a similar value range. This investigation suggests phyllite, a metamorphic mineral common to both locations, as a primary source of dissolved silica. Conductivity and pH were not found to be related to increases in minerogenic silica. Statistical test showed presence of a relationship between an increase in alkalinity and rise in minerogenic silica. This relationship does not have sizeable support due to low number of samples although it cannot be ruled out. Biogenic silica in Flakevatn sediment was the lowest of the three ultraoligotrophic lakes (Klaretjern and Lutvann) examined, suggesting that the silica character of this lake is primarily minerogenic.

1. INTRODUCTION

High mountain lakes have recently been focused on by researchers interested in detecting climate changes and sensing atmospheric-borne pollution (Catalan J et al. 2002, Wright and Cosby 2004). Wright et al. 2005 reports recent reductions in acidification of central Norwegian mountain lakes and establishes optimistic atmosphere for the near future. Sensitivity of these remote sites is specifically exemplified by a glacial lake Flakevatn, deemed biologically near sterile. Flakevatn's research record is limited in size, but offers sufficient appeal for further investigation.

This is a semi-arctic lake, since water column temperatures during 'warm' years exceed the temperature of maximum density (Strøm 1940). Summer and winter heat budget investigations done on Flakevatn in 1933 and 1965, are rough approximations due to sparse measurements performed on two separate days nearly thirty years apart (Strøm 1934 and Strøm 1966). These estimates are rooted in the classical works by Birge on examining and evaluating heat budgets of lakes (Birge 1914). Heat budget studies are still relevant for investigation, since recent work on Italian lakes links morphometry to heat budgets (Ambrosetti and Barbanti 2002).

In addition to having 'peculiar' aspects of heat budgets, Flakevatn has been mentioned to occasionally experience late-summer clouding due to heavy runoff of accumulated glacial clay. Glacial ooze events are common in high mountain lakes situated next to glaciers. During 1933 expedition, Dr. Kaare M. Strøm observed Flakevatn to be bluegreen in color and transparent down to 6m depth (Strøm 1934).

pH values of Norwegian mountains were investigated as early as 1925 and highly alkaline measurements were associated with phyillite dominant localities (Strøm 1925). Keller and Reesman 1963 analysis of Norwegian glacial milks has revealed that lakes receiving mainly granitic matter are low in pH and silica. In Strøm 1943 and 1947 studies high mountain lakes, known to be receiving glacial clay, were observed to be strongly basic despite having low amounts of common buffers such as bicarbonate. Strøm 1947 proposes glacial clay, the minerals having silicate as a major component; to serve a role of a key buffer. Glacial clays often are composed of negatively charged layers that allow for adsorption of protons and cations (Håkenson et al.1983). Buffering can be accomplished via formation of diatom frustules (Milligan and Morel 2002) and by ample

supply of glacial clay. In March 2005, snow in Flakevatn catchment has been observed to have low pH (personal communication with Trine Holm). It is likely that there is a relationship between higher amounts of nitrogen recorded in Flakevatn (Hagnar 2005), low snow pH and air borne pollution.

Silica can enter the system in dissolved form as silicic acid ($[SiO_x(OH)_{4-2x}]_n$) and in amorphous form as organic (diatom frustules) and inorganic particles.

Rippey 1976 notes that clay minerals cannot be primarily responsible for the silica dissolution but that only amorphous silica shows an increasing solution rate with pH. Similar observations have been made on the Antarctic continent where glacially eroded rocks do not appear to represent a significant source of dissolved silica for Antarctic waters (Hurd 1977). Flakevatn has a short ice-free season and inputs of glacial ooze become visible in August, after thermocline has been well established.

Along with the ooze, measurable inputs of silicic acid or dissolved silica are flowing into Flakevatn. Lithology, continental weathering intensity, climate variation and diatom production, are responsible for variations in the average global delivery of dissolved silica to the ocean (Conley 1997, Humborg et al. 2000, Conley 2002).

In general, dissolved silica is essential for formation of amorphous silica by diatoms, phytoliths, radiolarians, silicoflagellates, and sponge spicules (Conley 1988, Conley 1991, Conley 1998).Biogenic silica or polymerized silica in diatoms is more acidic than silicic acid and is present at a high concentration on the diatom surface. Buffering role of biogenic silica has been linked to activity of carbonic anhydrase, an enzyme catalyzing conversion of bicarbonate to carbon dioxide (Milligan and Morel 2002)

 The loss of silicon from the water column during the spring bloom is probably the result of two biological transport systems: the free settling of diatom frustules and sinking of zooplankton fecal pellets that contain diatom frustules (Conway et al. 1977).

One of the prerequisites for Flakevatn's spring bloom is abundant dissolved silica (silicic acid) alongside phosphorus and nitrogen (Bialey-Watts 1976). Prior to spring bloom, total phosphorus has been found to be particularly low in Flakevatn while total nitrogen in comparison to phosphorus was much higher (Hagnar 2005). In the pristine conditions, waters originating from melting glacier ice contain little or no nitrate and thus cannot be a significant contributor of nitrogen to the lake's surface layers (Strøm 1933).

The difference in the speed of biogeochemical cycling of Si (slow) and P (rapid) can influence the outcome of the competition and seasonal algal succession (Conway 1977, Conely et al. 1988, Gibson 2000).

Lakes undergoing eutrophication would initially experience rise in diatom population. This increase would be followed by their sedimentation and burial, eventually depleting dissolved silica from being available to future diatom generations (Conley et al. 1993, Conley 2000). The solubility of biogenic silica (BSi) is affected by pH as a result of the dissociation of silicic acid. This effect becomes increasingly important at pH values above 9 and the effects are only slight below pH 7 (Conley and Scavia 1991). Dissolution rate of BSi is strongly affected by temperature with exponentially increasing dissolution rates as temperature rises (Conley 1991).

Laboratory measurements of BSi in sediments are preferentially done via wet chemical digestion technique using weak base Na_2CO_3 (Kamatani 1980, Paasche 1980, Lyle et al. 2002). Use of stronger base (Greenberg 1957) and single time point of digestion can lead to overestimation of biogenic silica in sediments. Adsorption of dissolved silica (DSi) to sediments is problematic at solid solution ratios over 2.5g/L. Small volume differences in sub-samples can generate large differences in silica measurements. Better replication and more consistent results have been obtained with the use of digestion bottles with flat bottom (Conley 1998).

This study will evaluate annual heat budget of a high mountain lake and attempt to assess whether silica content correlates with changes in physio-chemical aspects proposed by Strøm 1934, 1947, namely pH and alkalinity.

2. STUDY AREA

The study at Flakevatn was conducted in several expeditions during spring/summer of 2005. Flakevatn is located between Ulvik and Hardanger communes within Hordaland county. This is a very windy location, which proved to be a major obstacle to successful sampling. Ice cover composition was determined in March 2005. Geologically, the area surrounding Flakevatn is dominated by phyllites and gneissic granites. Vegetation is present at non-glaciated end of Flakevatn with grasses as the dominant flora. Thick covers of mosses are found in the area near minor water inputs to Flakevatn. Water samples were collected in the vicinity of Flakevatn glacier at the area of deepest point, at major and minor water inputs to the lake and reference streams Midtdal and Blåisen.

2.1 Geography and Geology

Flakevatn, Picture 1(Appendix 2), elevated at 1448m above sea-level, is sited at North Latitude 60°38' to 60°40' and about 7°35' E of Greenwich. This lake is positioned approximately 7km from Finse railway station. It is easily tracked down by way of a tourist trail. The domed glacier Hardangerjøkulen to the south and the mountain range Hallingskarvet to the north, are two geomorphological features that qualify Flakevatn. Hallingskarvet is glaciated in its western part (Strøm 1934).

The Caledonian mountain chain, formed hundreds of millions years ago, is the geological backbone of Scandinavia. Today we observe only roots of this mountain chain. The foundation of this massif is archaean rock, minerologically equivalent to granite or slightly gneissic granite (Fægri 1967). Above this base we find a phyllite zone, foliated metamorphic rocks consisting of metamorphous shales and schists. This zone reaches up to 1700m altitude (Strøm 1934). Older archaean rock is found overlying phyllite zone, at the summits of the highest mountains (Fægri 1967).

Soil formed through disintegration of this parent rock is qualitatively very poor Picture 2 (Appendix 2). Decomposition of plant material introduces humic acids into the soils, further limiting the survival of plants to only tolerant few. Consequently, this soil is easily removed through erosion, exposing great parts of the peneplain (Fægri 1967). Figure 1.1 depicts K.A. Strøm's 1933 description of Flakevatn geology and post-Strøm investigation into Flakevatn area. Recent expedition indicates that among granite

minerals, chamosite and anorthite are the dominant constituents. The extension of phyllite zone into the ablation zone of the western glacier is still under investigation.
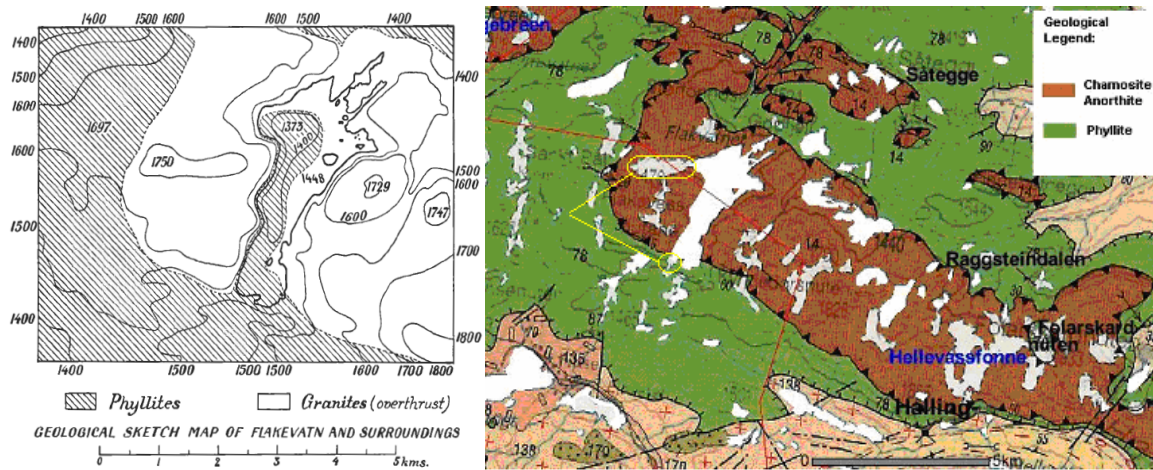
Figure 1.1 : Past and Present Geological map of Flakevatn and watershed bedrock
Figure to the left is taken from Strøm 1934.
Recent geological investigation into Flakevatn area obtained from http://www.ngu.no
Granites are shown to have chamosite and anorthite in their composition.
Areas stressed in yellow (to the right) denominate glaciers closest to Flakevatn.

The mineralogical composition of bedrock found in the catchment of Flakevatn, seen in Table 1 (Appendix 1), shows silicate (SiO_2) as being the dominant component of granite and phyillites. Two reference streams, Midtdal and Blåisen are located on the plateau opposite to Flakevatn, with geologically similar terrain, shown in Figure 1 (Appendix 1). Two lowland ultraoligotrophic lakes, Klaretjern and Lutvann, serve as references for Flakevatn's sediment analysis. Klaretjern, Picture 3 (Appendix 2), is located in Aremark commune of Østfold county, and is sited at 59° 8' 14" N and 11°38'54" E.
Water samples, taken on 12.08.2004, have been analyzed by NIVA and pH of this lake was determined to be approximately 5.2. Lutvann, Picture 4 (Appendix 2), is located in Oslo commune of Oslo county. This lake is sited at 59°54'48" N and 10°52'42" E.
The water of this lake has a steady pH of 7.

2.2 Meteorology and Hydrology

Weather conditions at Flakevatn are marked with prevalent winds. Strøm 1934 work determined monthly temperature averages for Finse area from a 60 year record (1861-1920). Extrapolation of Finse temperature values to Flakevatn location was based on records from Hallingskeid, Grjotruste, Fagernut, Slirå and Finse weather stations. These five stations had varied observation periods Hallingskeid (1904-1912), Grjotruste (1904-1908), Fagernut (1905-1908), Slirå (1925-1931) and Finse (1904-1924).

Monthly temperature averages at Flakevatn were product of averaging two different calculation methods (Strøm 1934). Temperature gradients between Finse and Flakevatn varied between months and the largest differences were observed during summer months, as seen in Figure 1.2.
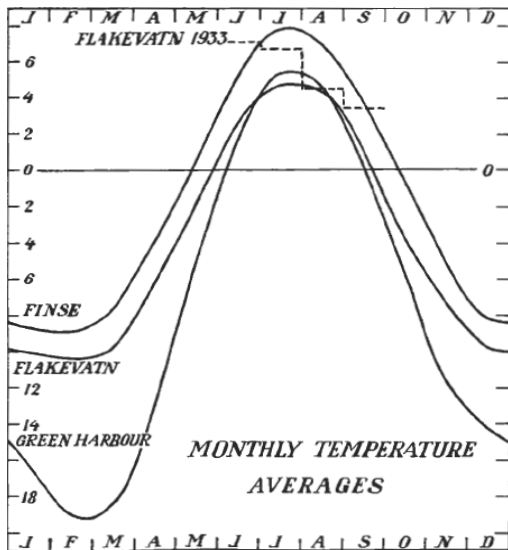
Figure 1.2: Strøm 1934 extrapolation of Flakevatn temperature. Extrapolation gradient for Flakevatn is based on average of several weather stations.

Because today some of these original stations are no longer in operation, it is necessary to introduce a consistent temperature gradient of – 0.4°C per 100ms rise in altitude (Sømme and Østbye 1997). Flakevatn is shielded by Hallingskarvet and it is almost certain that this lake experiences localized changes in temperature.

Finse temperature and extrapolated Flakevatn temperature in Graph 1.1 show a similar temperature cycling over different time periods. One exception is that July and August monthly temperature averages have markedly increased in 2000-2005 period while winter

months' temperatures have remained the same as in the previous periods. This difference is likely the reason why the glacier at Flakevatn has been observed to be receding. Precipitation report for Finse area has to be applied to Flakevatn locality, because this is the nearest site with available records.
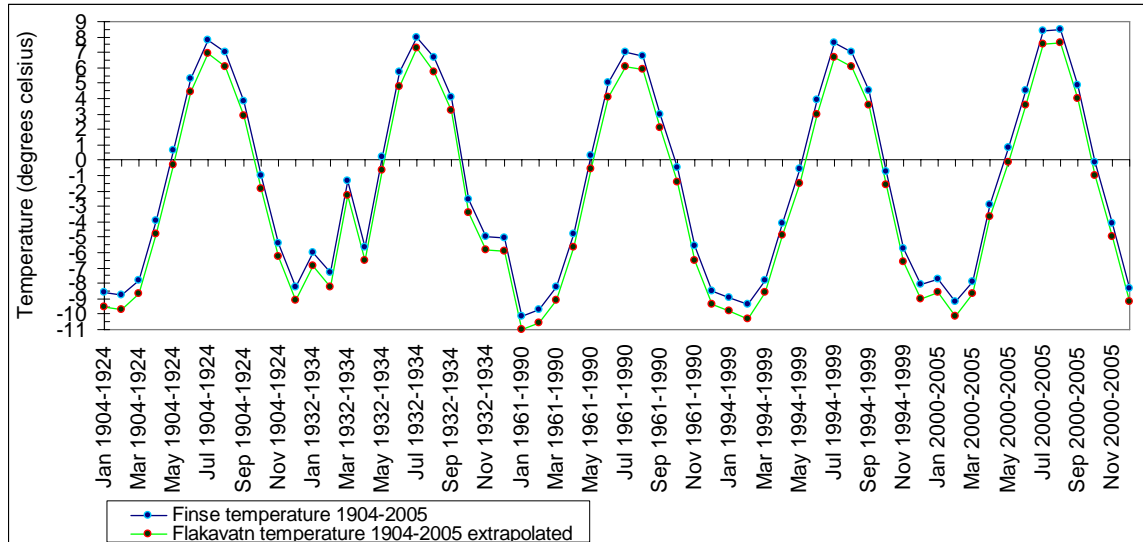
Graph 1.1 Meteorological records for Flakevatn area extrapolated from Finse temepratures
The graph presents monthly temperature means from different length periods (1904-1924, 1932-1934, 1961-1990, 1994-1999, 2000-2005) to indicate whether temperature has changed over period of 100 years. The graph was produced using monthly temperature average data supplied by Meteorological Institute of Oslo (http://www.met.no).

The average monthly precipitation for March-September, shown in Graph 1.2, has been much lower in 2000-2005 than it has in 1994-1999. Conversely, the winter precipitation averages for October to February have been markedly greater for 2000-2005.
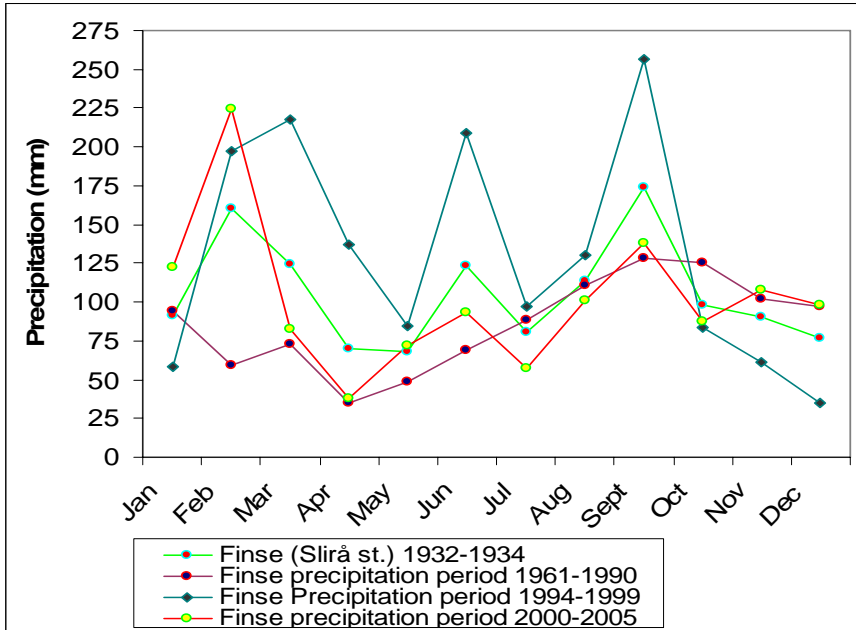
Graph 1.2: Monthly average precipitation for Finse area for periods over last 100 years. 1932-1934 period is recorded at Slirå station and taken to be the same at Finse area.

Hydrographical map of Flakevatn area, shown in Figure 1.3, places the major water inflow at the south eastern edge of the lake. This is a steady all-year-round inflow. At the commencement of summer thawing, the north western glacier supplies significant amount of melt water. There are numerous minor inflows, Picture 5 (Appendix 2).


Figure 1.3 : Map of Flakevatn area hydrography. The map, obtained from www.ngu.no denominates in red the major inflow from the south east end of the lake and input from glacier located north west. The major outflow is denominated in green on the north eastern edge of the lake.

2.3 Water column temperatures and chemistry

Two Flakevatn investigations in August 1933 and June 1965 have produced water column temperature measurements in summer and winter period. Figure 1.4 shows strong summer stratification in August and a weakly stratified water mass in June.

Strøm suspects that isothermy occurs frequently in a normal summer due to regular nocturnal frosts (Strøm 1934). In August, the greatest thermal resistance to mixing is found at 10-12m, within thermocline layer. Flakevatn is isothermous from below 20m. Ambrosetti and Barbanti 2002 found that in the deep lakes 90% of the annual energy exchange takes place within a surface layer representing about 14-16% of the maximum depth. In shallow lakes this layer grows to as much as 82% of the maximum depth. Water profile in August, shown in Figure 1.5, notes a uniform oxygen profile suggestive of low nutrient status of the lake and low microbial activity. On August 24th 1933, Flakevatn had pH of 8.2 up to 30m depth and 7.1 at 65m. Conductivity (χ_{18}) was observed to increase around 2m depth in the epilimnion. Low surface conductivity values are due to colder snow melt water diluting the warmer surface layer. Strøm 1934 considers Flakevatn conductivity values to be low taking into account that Flakevatn is surrounded with phyllitic rocks. Higher conductivity and pH values in the 2-30m layer have been ascribed to recent infusion of greater quantities of glacial ooze. Investigation done on September 8th 2004 shows the appearance of Flakevatn during glacial ooze event, seen in Picture 1.1 below.
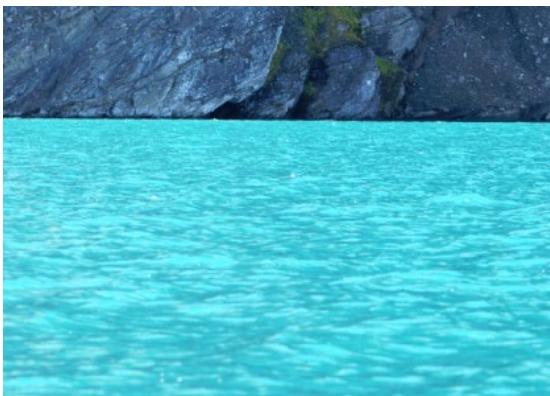

Picture 1.1: Flakevatn in late summer glacial ooze event (personal communication with Dag Klaveness).

The drop in conductivity and pH values, seen in the 30-70m layer, are due to low vertical intermixing. This layer is 'the winter waters' that are not influenced by glacial ooze (Strøm 1934). A relationship between alkalinity and glacial ooze has been

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proposed in Strøm 1947, Figure 1.6, where lakes as Flakevatn are expected to have alkaline pH.
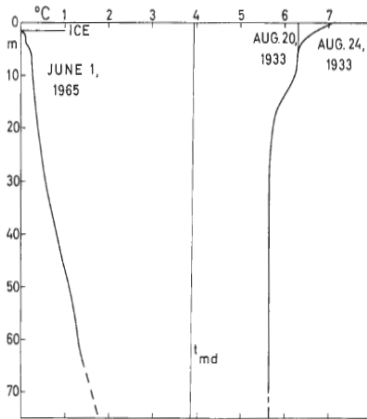
Figure 1.4:
Strøm 1965
temperature records
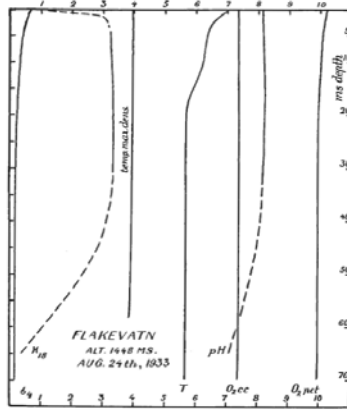
Figure 1.5:
Strøm 1934
Conductivity (χ_{18}), pH and Oxygen content
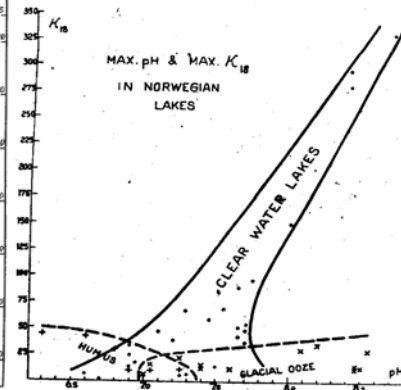
Figure 1.6
Strøm 1947
Correlation between χ_{18} and pH

Recently, Hagnar 2005 investigation presents NIVA analysis of Flakevatn full water column profile sampled on May 26th 2004. Conductivity measured in range 9.0-10.3 μS cm⁻¹, alkalinity 0.058-0.062 mekv L⁻¹ and pH in range 6.58-6.59.

2.4 Flora

In Scandinavia, the upper limit of conifers differentiates the montane from sub-alpine regions. Flakevatn is located in the upper alpine region (regio alpine superior), a belt where there is no more coherent vegetation cover. Snow beds cover large parts of this area so plants are found in patches between the boulders. Species of *Dryas*, *Duncus* and *Carex*, are observed to grow along the tourist track.

Orange-brown lichen *Caloplaca elegans* is seen in the drier places (Fægri 1967). *Anthelia* sp. and *Polytrichum norvegicum* are some of the typical mosses found near Flakevatn (Hestmark 1997). Hagnar 2005 investigation, displayed in Table 2 (Appendix), has produced some data on the phytoplankton occurring in Flakevatn. In May 2004 a chrysophycean *Bitrichia chodatii* dominated the phytoplankton community at 2m depth.

2.5 Morphometry

Flakevatn is a glacial lake, thought to have been formed by three cirque glaciers corresponding to three depressions, seen in Figure 1.7 and 1.8, at the present lake bottom; 68m, 49m and 75m. Lake in itself is about 4 km long and 2 km wide, covering 3.34km^2 area without islands and holding 0.1km^3 of water that is being renewed every 7 years (Strøm 1934). This is a medium sized lake if one were to classify it according to surface area (Kalff 2002). It is elliptical in shape as described by the shoreline development factor (D = 2.8). Effective fetch of this lake is 3.3km. Further morphometric details are presented in Table 1.1.

Altitude	1448 m	
Maximum depth (Z_{max})	75 m (77 m)[1]	
Mean depth (Z_{mean})	30.12 m	
Maximum effective length ($L_{eff.max.}$)	4.5 km	
Maximum effective width ($W_{eff.max.}$)	2.1 km	
Shore length (including islands)	18km	
Shoreline Development Factor (D)	2.8	
Area (A) at 0 m	3.34 km^2	
15 m	2.25 km^2	
30 m	1.79 km^2	
45 m	0.84 km^2	
60 m	0.36 km^2	
75 m	0.01 km^2	
Volume of layer 0 - 10 m	0.0276 km^3	
10 – 20 m	0.0225 km^3	
20 – 30 m	0.0199 km^3	
30 – 40 m	0.0146 km^3	
40 – 50 m	0.0084 km^3	
50 – 60 m	0.0048 km^3	
60 – 70 m	0.0025 km^3	
70 – 75 m	0.0003 km^3	
Volume (V) Total	0.1006 km^3	
Fetch area ($F_{area} = A^{1/2}$)	1.83 km	
Effective Fetch ($F_{eff} = (L_{eff.max.} + W_{eff.max.})/2$)	3.3 km	
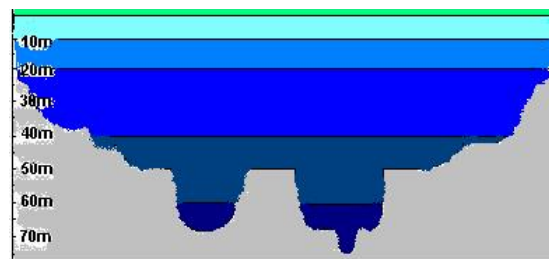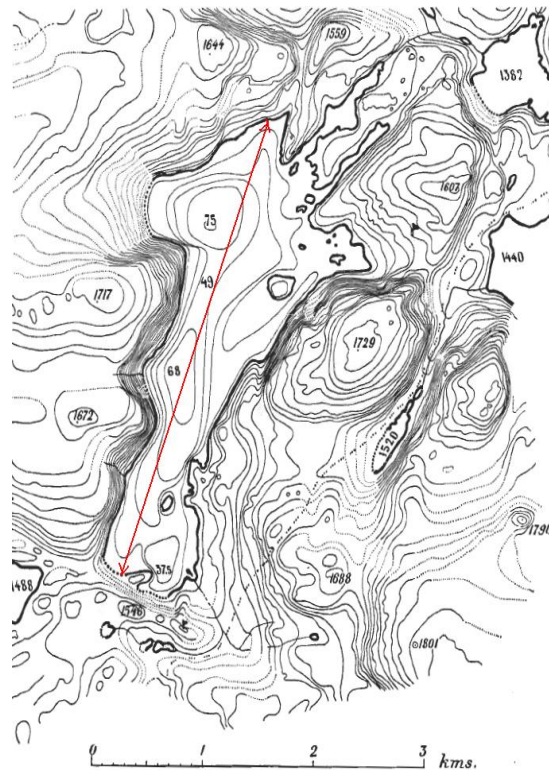
Table 1.1 Morphometrical data measurements cited from Strøm 1934 work on Flakevatn

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[1]Maximum depth has been measured to be deeper than previously thought by Strøm.

[2]Fetch and Effective Fetch have been calculated from Strøm 1934 data

Figure 1.7 (top right) is a bathymetric map of Flakevatn from Strøm 1934; the map shows major sounded depths and the edges of a glacier are represented by dotted lines.

Figure 1.8 (bottom right) is vertical profile cross section of Flakevatn based on sounded depths along red line on the bathymetric map.

3. MATERIALS AND METHODS

3.1 Study Design

In the period of spring/summer 2005, several expeditions were carried out for basic limnology investigation. Flakevatn was studied for transparency depth, turbidity and the temperature changes in the water column. Sediment samples and water samples were collected for chemical analysis.

Qualitative observations of snow cover were done in mid March alongside temperature measurements. Temperature data was obtained using inverting thermometer with focus on temperature variation beyond 20m depth.

The results of this study were to confirm or disagree with Strøm's original estimate of Flakevatn's annual heat budget. Water samples were collected using standard water sampler and delivered into 250mL or 1L polypropylene bottles. Duplicate samples were taken on special occasions to measure alkalinity, pH and conductivity without disturbing the original samples. At the commencement of melting, the major and minor inflows to Flakevatn were sampled for dissolved silica analysis.

All collected water samples were to be stored in $4 \pm 0.1°C$ cooling room allowing for maintenance of samples' chemical integrity. pH, alkalinity and conductivity measurements were carried out in a given order.

Filtration of the water samples was performed to detect any measurable changes in the pH, alkalinity and conductivity through loss of buffering capacity of minerogenic silica. Biogenic silica in water samples was to be estimated through measurement of dissolved silica released from filtered particulates previously digested with a weak base. Total silica in water samples was to be determined through measurement of dissolved silica released

from organic and inorganic sources. Minerogenic silica was to be evaluated as the amount of total silica after the deduction of biogenic silica.

Sediment cores were sectioned and analyzed for water and organic carbon content to determine porosity, compaction of sediment, and level of oligotrophy.

Cores from two lowland ultra-oligotrophic lakes, Lutvann and Klaretjern, were used as references for Flakevatn. Sediment samples were to be digested in alkaline conditions in order to determine levels of biogenic silica.

The study evaluates presence of a glacial ooze event through qualitative (observation) and quantitative means (turbidity measurements). Changes in pH, conductivity and alkalinity at 2m and 10m (epilimnion), are quantifiable chemical aspects of a glacier lake and they test for glacial ooze buffering capacity. Both depths are epilimnion depths serving for comparative differences. Biogenic and total silica in the epilimnion are to be correlated to pH, conductivity, and alkalinity. Lastly, estimate of sediment's organic carbon and biogenic silica content in the upper 8cm layer can tell something about lakes' recent level of oligotrophy and the lake's silica character.

3.2 Sampling

Field sampling at Flakevatn had two different objectives. First aim was to measure temperature prior to and post-melting of ice cover at Flakevatn. Second aim was to detect levels of glacial ooze at regular intervals and any resulting changes to water chemistry and silica content. Table 2.1 shows the timescale and depth choice during sample collection. Major constraints on the sampling efficiency were wind, travel and setup time, as well as short day length.

Day	03	03	26	21	13	04	10	28	31	20	06	18	19
Month	03	05	05	07	07	08	08	08	08	09	10	10	10
Year	05	05	05	05	05	05	05	05	05	05	05	05	05
Temp. Depth (m)	2	0				0	0	0	0				
	10	10		2		2	2	2	2				
	30	20		10		10	5	5	5				
	50	40		20		20	10	10	10				
	70	60		40		40	20	20	20				
		70		60		60	40	40	40				
		75		70		70	60	60	60				
				75		75	75	75	75				

Water Sample Depth (m)								
0	10		2	2	2	10	2	0
1			5	10	10		10	
			10					
[1]	[3]	[5]	20				[6]	[7]
[2]	[4]		40					
			60					
			75					

Table 2.1: Flakevatn 2005 depths of temperature measurements; water samples and cores
[1] Major inflow [2] Minor inflow [3] Blåis [4] Midtdal [5] Klaretjern core [6] Flakevatn core [7] Lutvann core

3.3 Analysis Methods

3.3.1 Temperature and Heat Budgets

Temperature of the water column was measured directly using reversing thermometer. Messenger was released down the thermometer line once the thermometer has reached the desired depth. After 2 minutes, the thermometer was hoisted up. Temperature was recorded from the main scale and adjusted with readings from the auxiliary scale (Welch 1948). Summer and winter heat budgets were determined using reduced thickness method as done in Strøm 1934.

3.3.2 Transparency, Color and Turbidity

Transparency was determined using a circular Secci disk measuring 20cm in the diameter. The tabulated depth is the mean between disappearance and reappearance depths. Eye-sight was the final means of judgment.

Color was determined against Secci disk at the half depth of its reappearance.

The turbidity was measured using highly accurate portable DRT-15CE turbidimeter against reference standards; 0.02, 0.1, 10, 100 NTU (HF Scientific inc. 2004).

All turbidity measurements were carried out in 4°C cooling room. The turbidimeter, Picture 6 (Appendix 2), was allowed 30 minutes to adjust to temperature before measurements were carried out.

3.3.3 Conductivity

Conductivity, or electrolyte content, was measured in microsiemens (μS) cm^{-1} after samples have reached the room temperature. Conductivity meter (CDM 80), Picture 7 (Appendix 2) provided by Blindern Limnology laboratory, was used for direct measurements.

3.3.4 pH & Alkalinity

Both pH and alkalinity were measured using Radiometer Copenhagen meters, Picture 8 (Appendix 2). This is a multi-function instrument composed of TT80-Titrator / ABU80-autoburette standard alkalinity meter and PHM 82 standard pH meter. pH measurements were taken at the first stable reading. Titration of the water samples during alkalinity analysis was done using dilute 0.02N HCl. Alkalinity measurements were obtained from slope of titration curves using standard procedure described in Bøyum and Kaasa 2001.

3.3.5 Biogenic and Total Silica in the Epilimnion

A select set of water column samples were analyzed for biogenic and total silica content. Only August 4th had a full water column depth profile for analysis while the rest of the samples focused on 2m and 10m depths. Water column biogenic silica was analyzed using a modified DJ Conley 1989 method. IR spectroscopy, Picture 9 (Appendix 2), was the primary technique for measuring reactive silicate via molybdate method described in Bøyum and Kaasa 2001. Silica standards were prepared using deionized water due to detectable silica impurities in the distilled water. All containers and tools used for handling samples, Picture 10 (Appendix 2), were either plastic or polypropylene minimizing contamination with non-sample silica.

100mL of each sample was filtered was using 0.6μm Nuclepore polycarbonate filters mounted on Naglene filter holders with receiver cat. Nos. 300-4000. Once filtration has ended, filters were transferred with plastic forceps into pre-labeled 50mL centrifugation vials containing 10mL of pre-made 0.2N NaOH. The vials were gently rotated to completely soak and flatten the filter surface. The vial caps were very lightly untwisted to prevent pressure buildup prior to lowering the containers into 100°C water bath for 15 minutes. At the end of digestion, samples were removed and placed into ready made ice bath for 5 minutes to reach the room temperature. All samples at this point were neutralized with 10mL of 0.2N HCl. Biogenic silica (BSi) in the water column samples was calculated by the formula:

DSi (IR spectroscopy)*0.02 L (volume of NaOH + HCl) * 1/ 0.1L (amt. filtered)

Total silica content of the water column samples was analyzed using Golterman et al.1978 method and measured via Bøyum and Kaasa 2001 molybdate method. Minerogenic silica content was obtained by subtracting biogenic silica from total silica.

10mL of each water sample was placed in clean platinum crucibles containing 10mL of pre-made 2% $NaKCO_3$. Samples were heated at 900°C for 5 minutes in the electric furnace shown in Picture 11 (Appendix 2). After cooling to the room temperature, precipitate crystals were dissolved in 40mL deionized water and transferred to a 100mL polyethylene bottle. Crucibles were rinsed twice with water and 1mL of pre-made 2M H_2SO_4 was slowly added to each sample. After mixing, water was added up to final 100mL sample volume. The amount of total silica in water column was measured by the formula: DSi (measured using IR) * 10 (dilution factor)

3.3.6 Sediment Analysis

3.3.6.1 Sectioning

Three sediment cores, obtained from Flakevatn, Lutvann and Klaretjern , were kept in the 4°C cooling room until sectioning was performed. Sediment cores were sectioned using assembled apparatus, seen in Picture 12 (Appendix 2), at 1cm intervals. Only the top 8cm of each core were sampled. 1cm sections were delivered into the centrifugation containers and weighed as a check on sectioning consistency.

3.3.6.2 Water content

Prior to measurement of the water content of sediment, the sediment samples were thoroughly mixed using vortex machine for 1 minute. Aluminum dishes, covered outside with a gold organic coating, were used for water and organic carbon measurements. These containers were labeled and weighed prior to and after drying, presented in Picture13 (Appendix 2). A single empty container was used as a reference for any changes to container mass during analysis.

Well mixed wet sediment was delivered using plastic spoons and left to dry over night in the electric furnace at 110°C (Bøyum and Kaasa 2001). Sediment sample weights were corrected for the mass lost from reference containers during drying process. Approximately half of the dried sediment was delivered into prelabeled plastic ziplock bags for later analysis. The remaining half of the dried sediment was kept in cooling room at 4°C.

3.3.6.3 Organic Carbon content

Organic carbon content of sediment was determined using dried sediment from previous analysis. Same reference containers from the drying analysis were used in the combustion

analysis. Combustion was performed in the electric furnace at 550°C for 2 hours (Bøyum and Kaasa 2001). After being allowed to cool, combusted sediment samples were weighed, delivered into prelabeled plastic ziplock bags and stored in the cooling room.

3.3.6.4 Biogenic Silica content

Several procedures for determining biogenic silica in sediment were attempted before arriving at the most suitable one. Biogenic silica content in the three cores from three different ultra-oligotrophic lakes was determined using modified Conley and Newberry 1989 procedure. Dried sediment was first pulverized to powder-sized particles. Range of 23-25mg samples of dried sediment from each centimeter of the core were delivered into flat bottomed 125mL containers. 40mL of pre-made 0.1% Na_2CO_3 base was added to each container and placed in the sonic bath. Sonic treatment, Picture 14 (Appendix 2), lasted for 10 minutes. The samples were then placed into 82.5°C water bath, Picture 15 (Appendix 2), and gently shaken at 50rpm. After 3h, samples were taken out and cooled in the ice bath for 5 minutes to quickly reach room temperature. 1mL of sample supernatant was taken out and delivered into 15mL vials containing pre-made 9mL of 0.1N HCl. This transfer procedure was repeated after 4h and 5h to obtain rate of change in dissolved silica released from the sediment. All samples were analyzed for dissolved silicate via IR spectrophotometry using molybdate method described in Bøyum and Kaasa 2001. Necessary volume corrections were taken into account.

4. RESULTS AND OBSERVATIONS

4.1 Water column temperature

<u>Predicted Thermocline depth</u>

Hanna 1990, Kling 1988, and Baigun and Marione 1995 suggest array of models for determining the planar thermocline depth (z_t) in lakes from different regions. Poland and Canada region model was found to be the most appropriate one for central Norway. The planar thermocline depth, Z_t, is equal to mixing depth(Z_{mix}) $\pm$ 2.4m.
$Z_{mix,}$ = 4.6 (0.5(Maximum Effective Length + Maximum Effective Width))^0.41.
Predicted range of thermocline according to this model is 5.1-9.9m. Flakevatn has had temporary stratification at approximately 4-6m in mid august 2005, 8-12m in mid august 2004 and 7-12m in mid august 1933.

2005 and 2004 water column temperature profiles

Winter 2005 temperature profile (Graph 2.1) shows almost no presence of a thermocline formation. Sinusoidal appearance of April and May temperature curves still suggests a thermocline at approximately 10m.
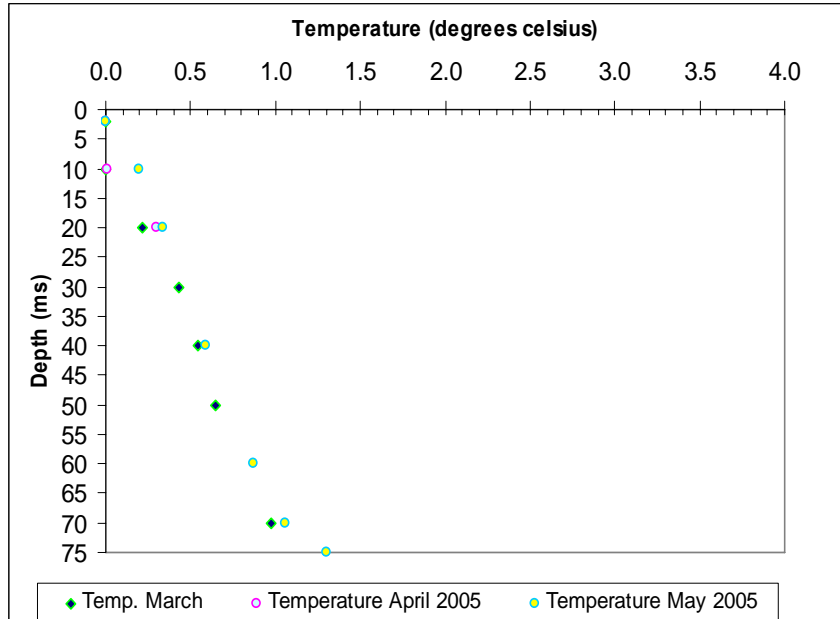
Graph 3.1: Flakevatn water column stratification in winter 2005.

Temperatures for March and April at 2 and 10m overlap. The graph shows gradual weakening of the light thermocline from April to May.

Throughout the winter/summer period in 2005, seen in Graph 3.1 and 3.2, temperature changes have shown predictable trends as observed in lakes of alpine character (Kalff 2002). In July 2005, at the completion of ice melting, Flakevatn had a 0°C surface temperature and isothermous conditions from 2m downwards. During 2005 summer period, the temperature did not rise above 4°C. Unstable stratification on almost daily basis is normal in these conditions. During these temporary stratifications, thermoclines were developing around 5m depth. These fluctuations are due to different densities of water layers being disrupted and rapidly mixing.
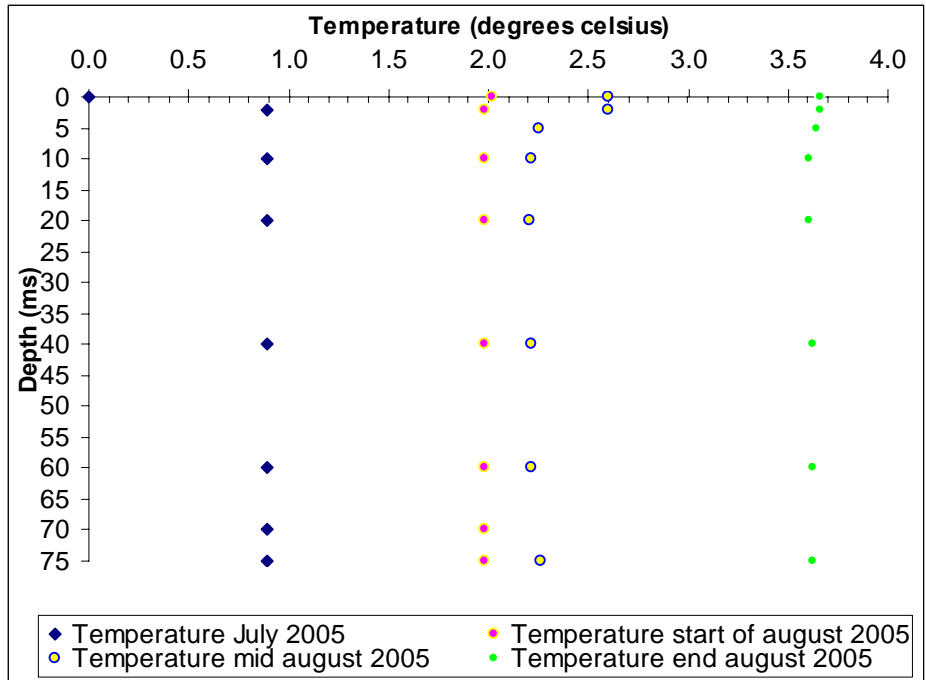
Graph 3.2: Flakevatn water column turnovers and stratification for 2005.

The graph shows spring turnover in July 21st and summer stratification in mid august.

In comparison to year 2005, 2004 winter/summer temperature conditions are quite different as observed in Graph 3.3. Ice partially disappeared in March 2004, a month earlier than it did in 2005. With surface temperature at about 0°C, a weak thermocline is established at about 5m. Relatively isothermous conditions are established at the end of July to start of August (~3.2°C). By mid august, there is a large increase in surface temperatures to 7.2°C and thermocline is positioned at about 10m. Full isothermy appears at the start of September (~5.4°C), signifying the fall turnover.
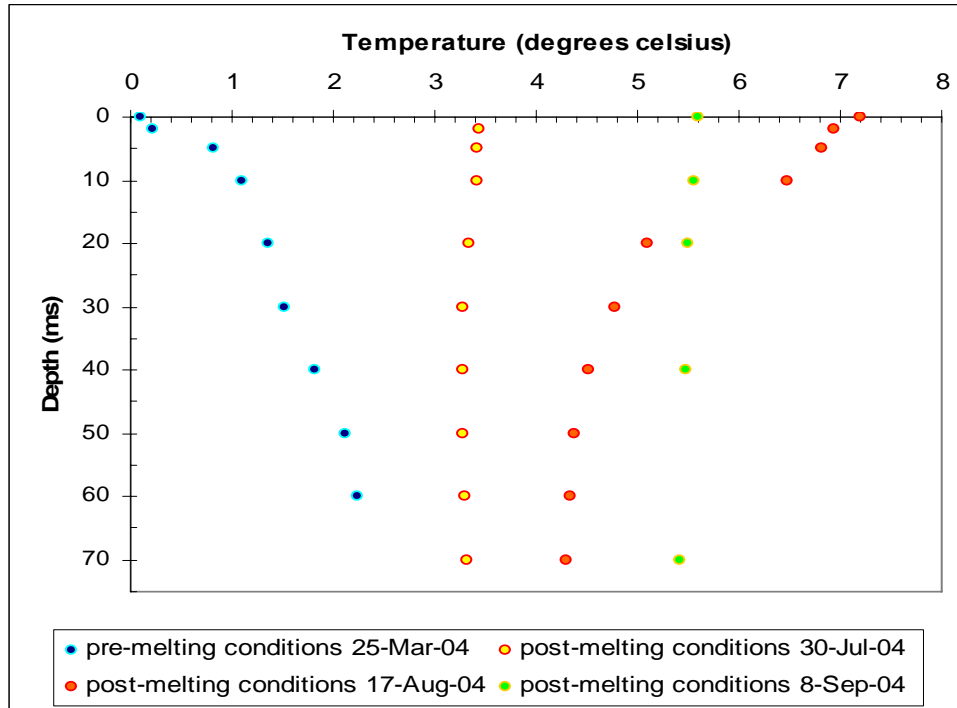
Graph 3.3: Flakevatn water column stratifications and turnovers in 2004

Graph presents Flakevatn water column pre- and post-melting temperatures in 2004

Light temporary stratification occurs during mid winter with thermocline forming at about 2m.

Spring turnover occurs at the end of July 2004. Summer stratification is established

during August. Fall turnover occurs at the start of September 2004.

4.2 Heat budgets

4.2.1 Corrections to Strøm 1934 and 1965

Investigation into Strøm 1934 and 1965 regarding Flakevatn summer and winter heat
budgets has revealed several discrepancies that are necessary to be corrected. Calculation
of the summer and the winter heat budgets in these two studies has been based on a
simple reduced thickness method. 4°C is used as a reference temperature. This method is
accurate in estimating heat budgets if large number of depth intervals are available.
Table 3 (Appendix 1) shows that upon increasing number of depth intervals, the
differences in rounded values start becoming apparent. These differences reflect on how
accurate the estimates of heat budgets are. As Table 4 (Appendix 1) illustrates, the
corrected heat budgets show a significant discrepancy in summer and winter heat budgets
from the original estimates, being around 250 cal cm^{-2} and 1600cal cm^{-2} respectively.

Strøm 1934 calculation of summer heat budget was based on seven temperature measurements from a single day, while 1965 calculation of winter heat budget was based on temperature measurements from ten depths. Both winter and summer heat budget calculations were based on temperature averages from three layers, 0-10m, 10-20m and 20-75m, seen in Figure 3.1. Summer heat budget estimate (1933), assumed the same temperature from 30-70m. Additionally, Table 4 (Appendix 1) shows that summer estimate of 10-20m was in fact estimate of 10-15m because temperature from 20m is missing in the record. Furthermore, both summer and winter estimates lack 75m temperature measurement, and thus 20-75m layer estimate is in fact 20-70m layer.
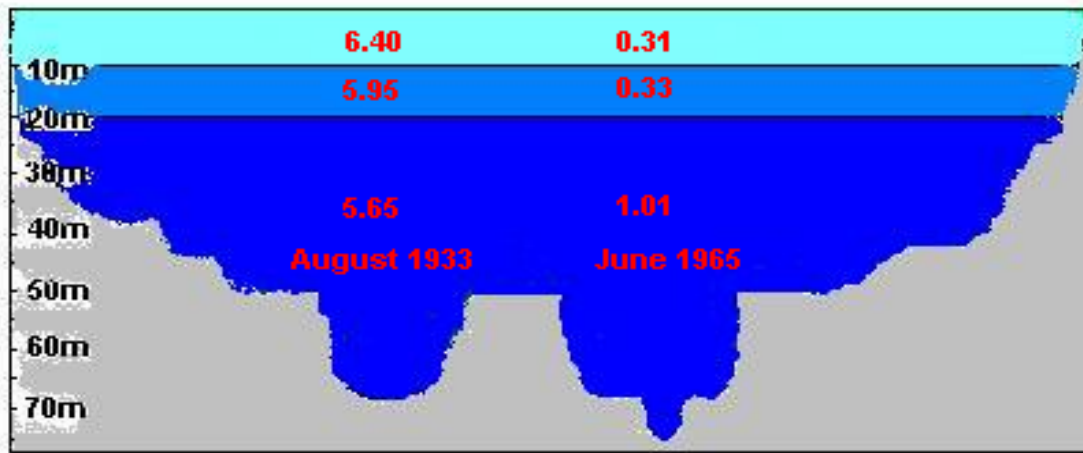
Figure 3.1: Strøm's 1933 and 1965 temperature averages applied to the summer and the winter heat budgets. This general vertical profile of Flakevatn is based on Strøm 1934 major sounded depths. His 1933 temperature averages for three layers (0-10m, 10-20m and 20-75m) were used for the summer heat budget. His 1965 temperature averages for the same three layers were used for the winter heat budget.

According to Strøm et al. 1965, the total winter heat budget for Flakevatn is - 22510 cal cm^{-2} and the summer heat budget is +5792 cal cm^{-2}. Winter heat budget is the sum of the amount of heat required to melt 150cm thick homogenous ice cover or -12000 cal cm^{-2} and heat required for the Flakevatn's water mass or -10510 cal cm^{-2}.
Recalculation of Strøm's estimate of the latent heat required to melt evenly distributed 150cm of ice shows a significant ~1000 cal/cm^2 difference, or it changes the original -12000 cal cm^{-2} to 10958 cal cm^{-2}. Recalculation of the heat required for the Flakevatn's

water mass changes the original estimate of -10510 cal cm^{-2} to 9947 cal cm^{-2}. Thus Strøm's original winter heat budget estimate should be -20905 cal cm^{-2}.

Strøm 1934 original summer heat budget estimate is 5792 cal cm^{-2}, but when it is recalculated, this value is in fact 6051 cal cm^{-2}. By summing these two heat budgets, the annual Flakevatn heat budget, based on Strøm 1934 and 1965 three strata and 150cm thick ice, should be 26956 cal cm^{-2}.

4.2.2 Ice cover observations

During year 2004 investigation, the ice disappeared on 27th July and it was estimated to have reappeared on 31st October. Year 2005 had similar timing of ice disappearance and reformation, 21st July and October 15th respectively. The total depth of snow and ice covering Flakevatn is estimated to be 2m. Ice cover was penetrated using a standard manual ice drill.

The Flakevatn layering in 2005 coincided with layer composition found in 2004, seen in Figure 3.2. Two ice layers, with combined 40cm thickness, are drastically different from Strøm's single 150cm ice thickness. Latent heat of evenly distributed 40cm thick ice is calculated to be -2922 cal cm^{-2}. In total, this change in heat reduces Flakevatn's original winter heat budget estimate from -20905 cal cm^{-2} to 13455 cal cm^{-2}, given that Strøm's 3 strata method is used.

Figure 3.2: Flakevatn winter 2004/2005 ice/snow cover vertical profile**.** The profile shows interchanging layers of snow, ice and ice/water slurry. 40cm of ice is a more accurate estimate than Strøm 1965 150cm thick ice.

4.2.3 Heat budgets estimates: 3 strata versus 6 strata

To effectively compare Strøm's summer and winter heat budgets with 2004/2005 heat budgets, it is necessary to utilize both 3 strata and 6 strata methods.

Latent heat of ice is added to the winter heat budgets. 40cm thick ice cover ice with latent heat of fusion at -2922 cal cm^{-2} is used in all estimates. Three-layer method is based on Strøm's three layers (0-10m, 10-20m and 20-75m) while six-layer method uses six layers (0-2m, 2-10m, 10-20m, 20-40m, 40-60m, 60-75m). Table 3.1 presents recalculated heat budgets from Strøm 1934 and 1965 annual heat budget estimates.

Date	Heat Budget 3 layer method + 40cm of ice for winter budget (cal cm^{-2})	Heat Budget 6 layer method + 40cm of ice for winter budget (cal cm^{-2})
24-Aug 33	6051	6071
1-Jun-65	-13455	-12896
25-Mar-04	-14445	-11055
30-Jul-04	-1947	-1942
17-Aug-04	4423	4618
8-Sep-04	4560	4576
3-Mar-05	-16970	-14170
3-May-05	-16373	-13863
21-Jul-05	-9615	-9637
4-Aug-05	-6076	-6072
10-Aug-05	-5069	-5175
28-Aug-05	-1091	-1096
31-Aug-05	-1163	-1174

Table 3.1: Comparison of Heat budgets estimated using original Strøm's 3 layers method versus 6 layers method.The table presents chronological heat budget estimates, with values highlighted in red representative of summer heat budget estimates and values highlighted in blue representative of winter heat budget estimates. - 2922 cal/cm^2 (heat for melting of 40cm thick ice) is added to all winter heat budget values.

Winter heat budgets estimated using 3 strata are significantly different from winter heat budgets estimated using 6 layers.

Graph 3.1 shows that use of Strøm's 3 layer method consistently overestimates the winter heat budget as opposed to using 6 water column layers.

However, summer heat budget estimates nearly coincide. The annual heat budget for 2004 and 2005 is based on 6 layers method and is 15673 cal cm^{-2} and 13074 cal cm^{-2}

respectively. Flakevatn's annual heat budget is more likely to fluctuate between these two values.
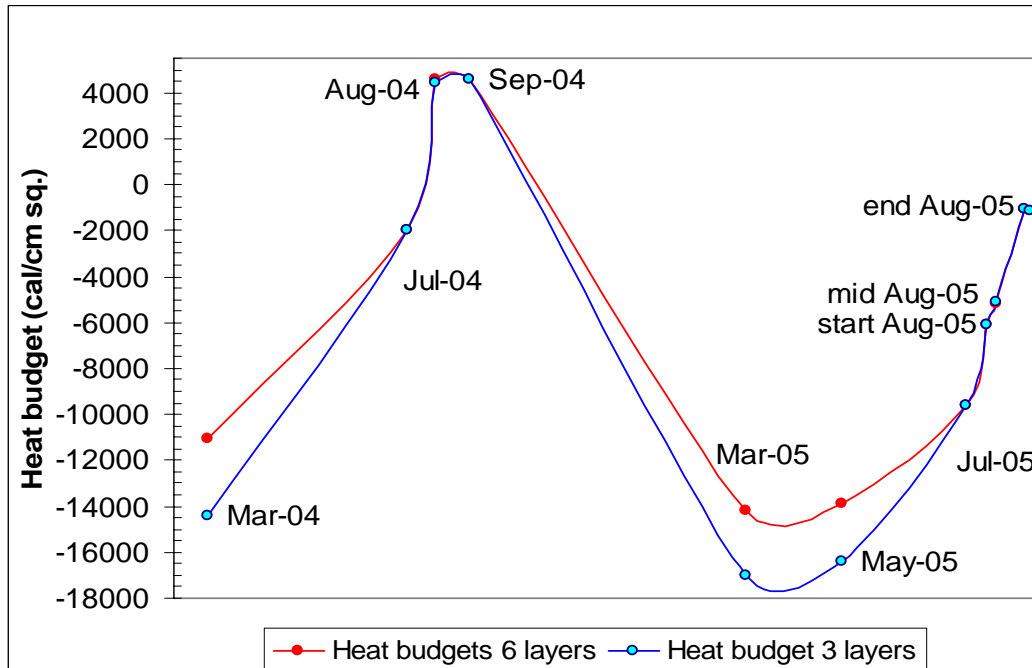
Graph 3.1: Comparison of 3 layer versus 6 layers method estimates of heat budget
The graph shows a period from winter 2004 to the summer of 2005
Winter heat budgets have latent heat of fusion for 40cm of ice added.

4.3 Transparency, Color and Turbidity

Strøm 1934, speaks of glacial runoff being the source of the milky grey color in Flakevatn in August 1933. 1933 and 2004 were both warmer years than 2005. Due to higher average summer temperatures in 1933, the greater amounts of glacial melt water must have washed out greater amounts of glacial ooze. In 2005 this was not the case, and most of the water inputs came from the snow melt.

On each sampling occasion, Flakevatn was transparent down to 12m depth.

At the same time, Flakevatn was observed to be bluegreen in color with no visible glacial ooze. Since Flakevatn is known to receive glacial silt and clay inputs, it is necessary to investigate turbidity as one of qualifiers of lake's clay particle content. All samples for year 2005, presented in Table 5 (Appendix 1), have shown an extremely low turbidity, truly characterizing Flakevatn as a clear-water lake.

Late in the summer season, end of August to end of September, shown in Graph 4.1, the epilimnion turbidity has increased drastically in comparison to prior measurements. The highest recorded turbidity is observed in September followed by a sharp drop in October measurement.
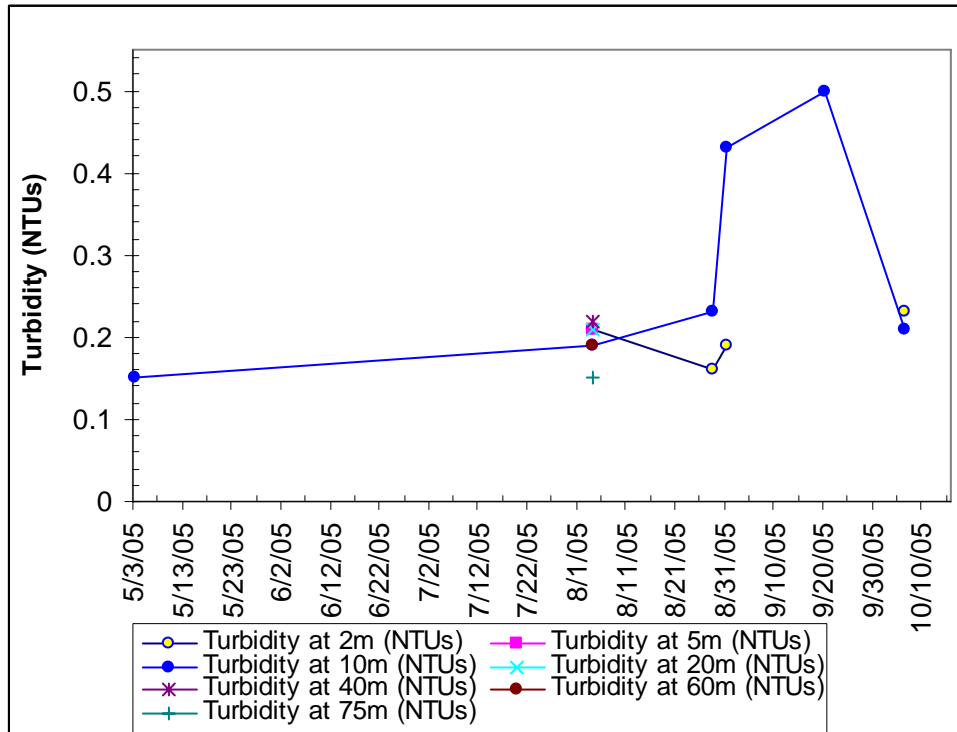
Graph 4.1: Turbidity progression at 2 and 10m depths in Flakevatn during 2005

4.4 Conductivity, pH and Alkalinity

Conductivity, pH and alkalinity were measured before and after filtration of select set of water samples. Epilimnion depths, 2 and 10m, were examined for any time changes in these three characteristics. September 20th measurements at 2m depth are not present in the dataset. August 4th 2005 was the only date that had a full water column profile, shown in Table 6 (Appendix 1). Looking at August 4th 2005 profile, filtration changed very little in the pH, conductivity and alkalinity. These were the conditions prior to anticipated glacial milk event.

The time scale of conductivity changes, presented in Graph 5.1, shows an increase in conductivity at the start of August in both filtered and unfiltered samples at 2 and 10m. It is possible that this increase in conductivity in epilimnion is due to the initial pulse of airborne electrolytes trapped within the snow. Stable stratification forming around this

time, levels off the concentration of electrolytes until end of September followed with a slight increase in conductivity at the start of October. Both depths (2 and 10m) are following the same trends, with filtered sample measurements showing only slight deviation from unfiltered conductivities.
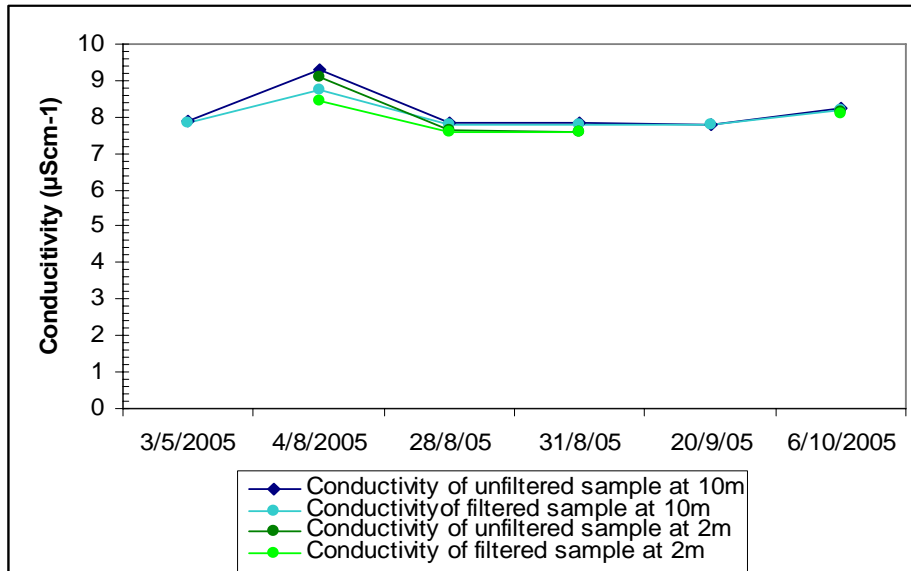
Graph 5.1: Changes in conductivity with filtration at 2m and 10m

The time scale of pH changes at two depths of filtered and unfiltered samples, presented in Graph 5.2, shows minor difference in pH. An exception to this is 2m sample measurement at the start of August, followed by a decrease in difference between filtered and unfiltered measurements. September 20th measurement at 10m shows a markedly larger difference with filtration.
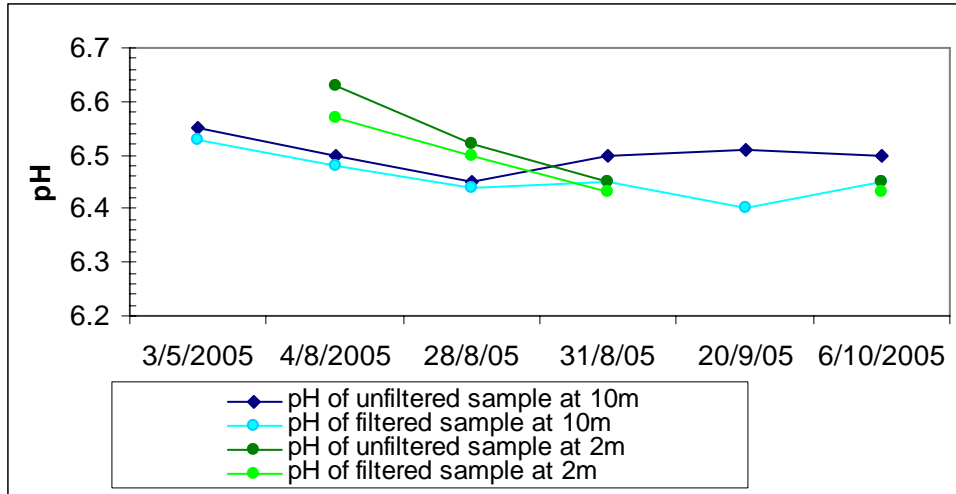
Graph 5.2 Changes in pH with filtration at 2m and 10m.

The time scale of alkalinity changes, presented in Graph 5.3, shows a different situation at two depths. Filtration at 2m up to end of August, resulted in larger differences in alkalinity than at 10m. This trend reversed at the end of August. September 20th measurement at 10m shows significantly greater difference in alkalinity, similar to difference observed in pH measurements. This difference is possibly due to greatest accumulation of glacial clay in the epilimnion at this time.
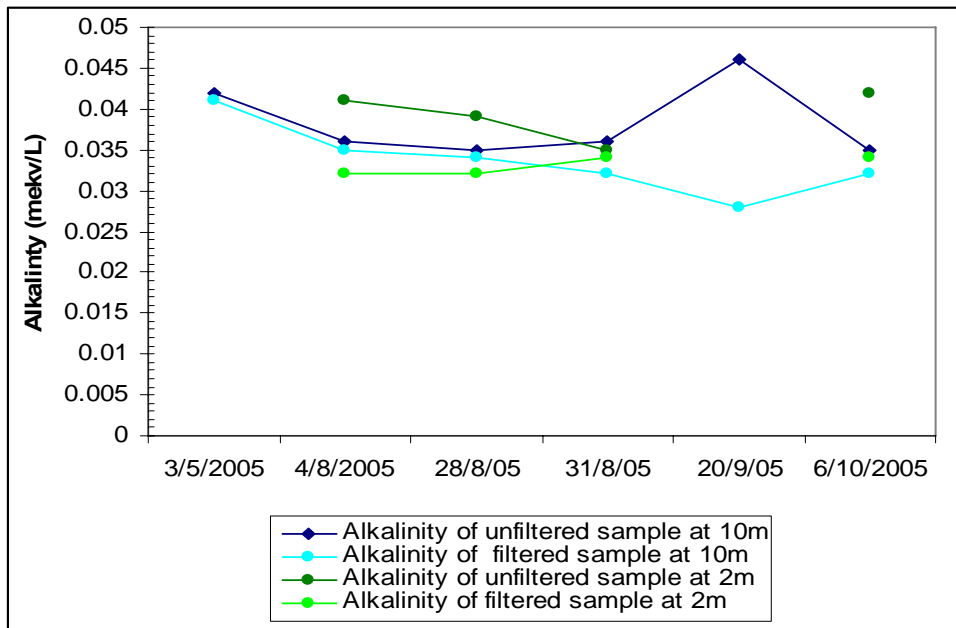
Graph 5.3: Changes in alkalinity with filtration at 2m and 10m

4.5 Water silica content: Minerogenic, Biogenic and Total

In the period of March to October 2005, water samples were collected from Flakevatn, 2m and 10m depths, minor and major water inflows to Flakevatn, and Finse area reference streams Blåis and Midtdal. In early March, Flakevatn surface samples (0 and 1m) had dissolved silica content of 188 μg L^{-1} and 186 μg L^{-1} respectively

Major and minor water inflows, Blåis and Midtdal, were analyzed for dissolved silica (minerogenic inputs) using standard Graph 1 (Appendix 1). At the beginning of May, shown in the Table 8 (Appendix 1), minor inflow to Flakevatn contributed 166 μg L^{-1} of dissolved silica while major inflow to Flakevatn contributed 258 μg L^{-1}. At the end of July, Finse area reference streams, Blåis and Midtdal, shown in Table 8 (Appendix 1), have been measured to have 214 μg L^{-1} and 344 μg L^{-1} respectively.

Water column samples collected at 2 and 10m depth have been analyzed for biogenic silica and total silica content and analysis values are presented in Table 9 (Appendix 1). Picture 19 (Appendix 2) illustrates the levels of dissolved silica.

Graph 6.1 presents these two measurements on a time scale from beginning of May until beginning of October 2005. Biogenic silica content at 2m was slightly larger at the start of August than it was at 10m, possibly due to the diatom bloom at this time. Past August, both depths showed relatively the same biogenic silica measurements in a range of 30-50 μg/L. Total silica levels showed a much greater fluctuations due to the inputs of minerogenic silica into the system. At the start of May, total silica content at 10m was higher than biogenic silica content by about 120 μg L^{-1}. This difference was reduced to 20 μg L^{-1} at the start of August. At the same time, total silica content at 2m was significantly higher than any other silica measurement at this time (difference being about 600 μg L^{-1}). Past August, Total silica content at 2m falls to the range of 170-270 μg L^{-1}. At 10m there is a significant increase of total silica content in the mid September (1280 μg L^{-1}). At the start of October there is a significant drop in the total silica content at this depth.
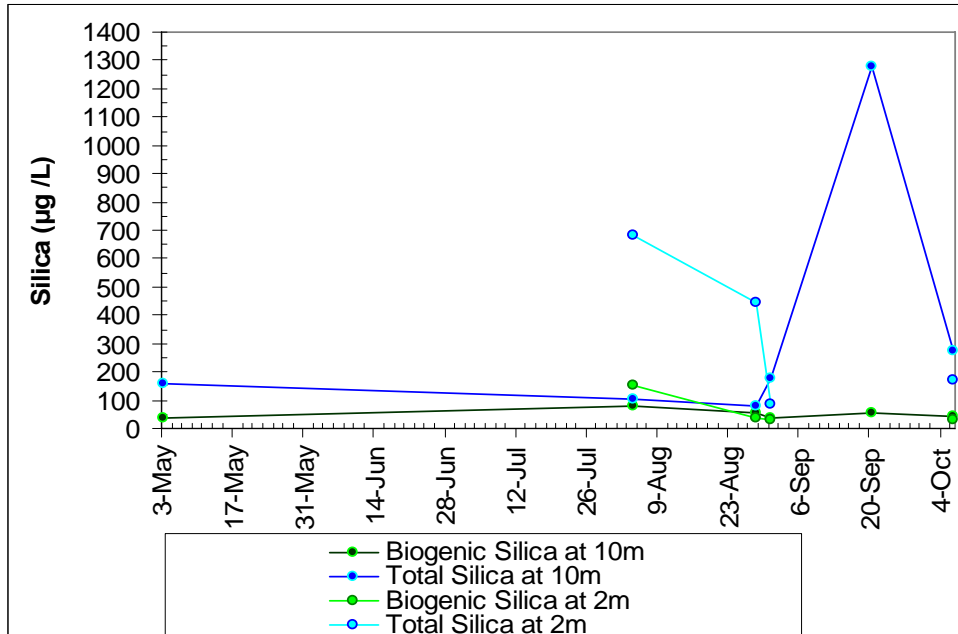
Graph 6.1: Flakevatn's Biogenic and Total Silica levels measured at 2 and 10m depths during 2005

4.6 Sediment Analysis

A core from Flakevatn sampled in October 2005, is compared for water content, organic carbon content, and biogenic silica content, to two cores from two lowland ultraoligotrophic lakes, Klaretjern and Lutvann. Upper 8cm of each core were analyzed.

4.6.1 Qualitative observations

Flakevatn:

The core shown in Picture 16 (Appendix 2) was taken on October 6th 2005 at 56m depth. The sediment is dark gray in color and largely composed of glacial clay and silt. The particles are very fine in size. The consistency is very viscous suggesting high compaction. There is no odor to the sediment. The desiccation leaves behind about ½ of the dried sediment. The dried sediment is gray with glazed appearance. The combusted sediment is brick orange in color. Both dry and combusted sediment, shown in Picture 18- left (Appendix 2) are easily turned into powder.

Klaretjern:

The core, shown in Picture 17 (Appendix 2) was taken in 13th July 2005 at the location of maximum depth (about 35m). The sediment is dark greenish-grey in color partly due to non-decomposed detritus. In the top 2cm, there is a dark green fluffy cover, probably being recently accumulated detritus. The core has a weak moss-like odor but no H_2S smell that would suggest significant microbial activity. The particles are very fine in size but the sediment itself is very runny in the top 8cm. The water easily percolates the particles. Upon drying, about ¼ of the sediment is leftover. The combustion of the sediment leaves minerogenic matter as flakes. The combusted sediment is light orange in color. Both dry and combusted sediment, shown in middle of Picture 18 (Appendix 2) are easily turned into powder.

Lutvann:

The core was taken on October 18th 2005 at the location of maximum depth . The sediment within the core container is dark gray. There is no odor to the sediment, suggestive of low microbial activity. The grains are coarser in size than they are in Flakevatn sediment. Drying leaves behind about ¼ of the initial sediment weight. The dried sediment is dark gray in color. The combusted sediment is brick orange in color. Both dry and combusted sediment, shown to the right of Picture 18 (Appendix 2), are easily turned into powder.

4.6.2 Water content and Organic carbon

Graphs 2, 3 and 4 (Appendix 1) show some of the sediment characteristics in three ultraoligotrophic lakes. The top 8cm of each core was high in water content due to low compaction of the sediment particles. Flakevatn core had a water content range of 65-48%. Klaretjern core had consistently high water content in the range of 72-74%. Finally, Lutvann core had the highest water content in the range of 86-88%.

Organic carbon content of all three lakes was low, as anticipated by their established nutrient status. Flakevatn core was analyzed to have organic carbon content at the range 3.4 – 4.3%. Klaretjern core showed an organic content in the range of 6.6 – 7.9% while Lutvann had a range of 2.2-2.9%.

4.6.3 Biogenic Silica

All three cores were examined for biogenic silica content through digestion method over period of 5 hours. Absorbance values for each subsample of each sediment section are recorded in Table 10 (Appendix 1) and converted to dissolved silica concentration of original sample at each time point of digestion, presented in Table 11 (Appendix 1). Shown in Picture 20 (Appendix 2) is the development of digestion or increased release of dissolved silica combining with molybdate to form a stronger blue color of the complex. Graphs 5, 6 and 7 (Appendix 1) outline the progression of this analysis. Each analyzed section represents a centimeter of top 8cm of the core.

The dissolved silicate, released from the sample of sediment section, was measured at 3h, 4h and 5h. At the point where curve levels off, the minerogenic silica starts being released from the sediment (Conley 1989). Reduced regression was used to find intercept of each curve. Each intercept value corresponds to the amount of biogenic silica within the section sample. These values are presented in Table 7.1.

SEDIMENT SECTION	LAKE	1	2	3	4	5	6	7	8
Sample weight (mg)	Flakevatn	25.0	23.2	25.1	24.6	24.7	24.1	25.1	25.2
	Klaretjern	24.2	25.1	23.5	24.4	25.1	25.1	24.6	25.0
	Lutvann	23.2	25.0	23.5	23.3	25.7	25.6	24.7	25.1
Intercept [DSi] or [BSi] (µg/L)	Flakevatn	2753	1731	1386	1267	1647	812	1199	905
	Klaretjern	13249	12796	18753	28644	28807	23044	23305	22881
	Lutvann	32340	40264	43456	35168	44655	42952	45052	44823
Biogenic Silica weight (mg)	Flakevatn	0.110	0.069	0.055	0.054	0.066	0.032	0.048	0.036
	Klaretjern	0.530	0.511	0.743	1.146	1.152	0.922	0.932	0.915
	Lutvann	1.294	1.611	1.738	1.407	1.786	1.718	1.802	1.793
Biogenic silica % of sediment sample weight	Flakevatn	0.44	0.30	0.22	0.22	0.27	0.13	0.19	0.14
	Klaretjern	2.19	2.04	3.16	4.70	4.59	3.67	3.79	3.66
	Lutvann	5.58	6.44	7.40	6.04	6.95	6.71	7.30	7.14

Table 7.1: Biogenic silica content in three ultraoligotrophic lakes' sediment sections. Least squares regression analysis was used in determining the intercept from the change in DSi concentration vs. time.

In the Flakevatn upper 8cm of the sediment, biogenic silica represents 0.13-0.44% of the total sediment weight. This range is significantly less than those of Klaretjern and Lutvann, 2.04-4.70% and 5.58-7.40% respectively.

5. STATISTICS

5.1 Effect of filtration procedure on changes in pH, conductivity and alkalinity

Changes in pH, conductivity and alkalinity were investigated before and after filtration of water samples taken at 2m and 10m. These measurements were done in order to determine whether particulate matter, mainly suspended glacial clay, had any significant buffering capacity. Graph 7.1 shows that pH at 2m and 10m changed with filtration, seen in negative skewing of box plots in filtered samples in comparison to unfiltered samples. At 2m, both filtered and unfiltered data sets are positively skewed, shown by the larger upper quartile. In 2m filtered water samples, the median decreased along with upper quartile while data distribution in lower quartile of the data set remained the same.

At 10m, both filtered and unfiltered data sets are mildly positively skewed. However, filtration resulted in rise of distribution of data in the upper quartile while the median of the filtered box was negatively skewed.

Graph 7.2 shows that conductivity at 2m and 10m does not noticeably change with filtration, seen by the lack of change in the position of the box plots with filtration.

At both 2m and 10m, filtered and unfiltered boxes are positively skewed, seen in the larger size of the upper quartile. This skew is stronger in 10m data set. Furthermore, the upper quartile reduces in data distribution with filtration.

Graph 7.3 illustrates visible change in the alkalinity with filtration at 2m and 10m, demonstrated by the noticeable negative skew of the filtered boxes and change in both distributions of upper and lower quartiles. The change is more drastic with filtration in 2m data set, where the negative skew of the unfiltered samples changes to equal distribution in filtered samples. At 10m, filtered samples are still positively skewed, but the difference is much smaller between upper and lower quartile.
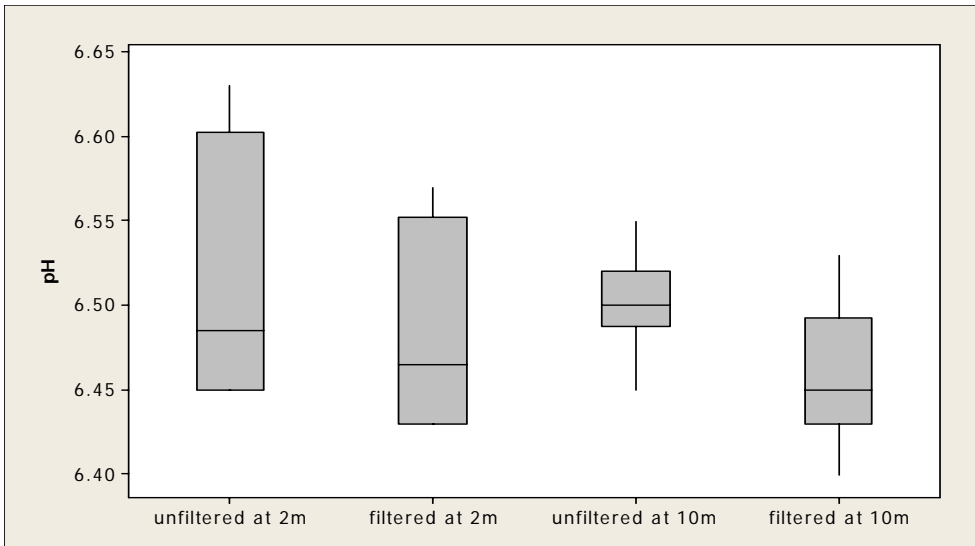
Graph 7.1 Changes in pH with filtration at 2m and 10m depths

Graph shows smallest observation, lower quartile, median , upper quartile and largest observation. No outliers are present.
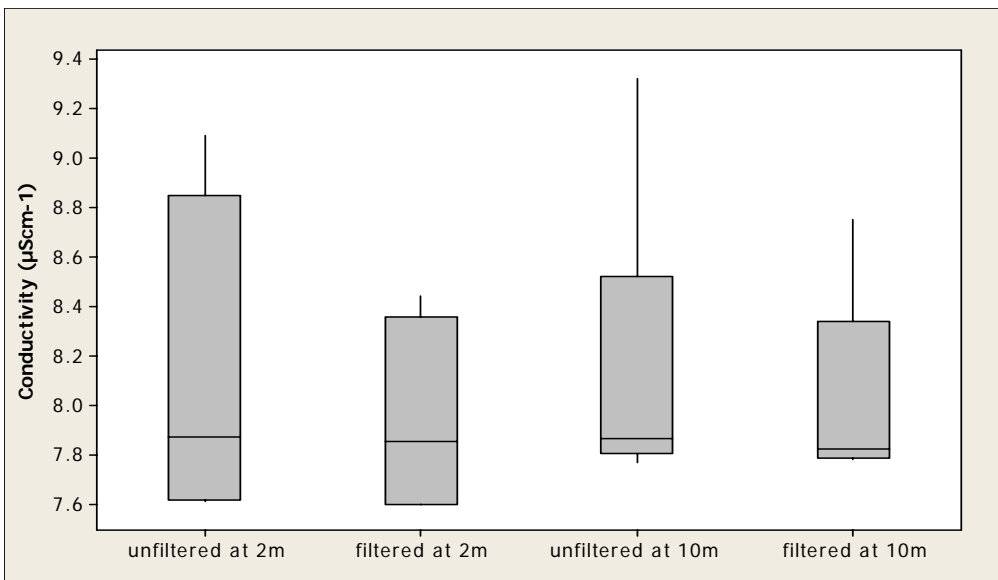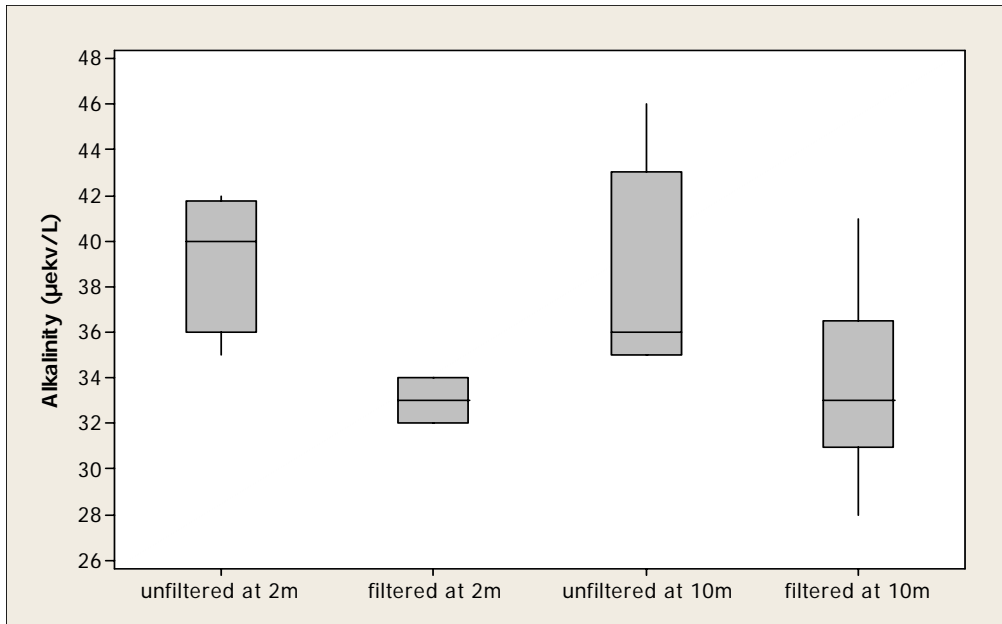

Graph 7.2 Changes in conductivity with filtration at 2m and 10m depths

Graph shows smallest observation, lower quartile, median , upper quartile and largest observation. No outliers are present.

Graph 7.3 Changes in Alkalinity with filtration at 2m and 10m depths

Graph shows smallest observation, lower quartile, median , upper quartile and largest observation. No outliers are present.

5.2 Correlation of Alkalinity, conductivity and pH of unfiltered and filtered water samples with Minerogenic silica

The data for 2m and 10m was pooled together to establish greater sample size for testing significance of correlations. pH, conductivity and alkalinity of filtered and unfiltered samples were correlated to minerogenic silica. All values except pH are in μekv units. Pearson correlation values, shown in Table 8.1, were used as a statistical determinant of possibility that a relationship is significant. The significance probability (p-value) further characterized these relationships with $\alpha = 0.05$ and the null hypothesis discarding any relationship between minerogenic silica and pH, conductivity and alkalinity.

Mann-Whitney test was selected as a conservative evaluation of relationships previously found to be significant by Pearson correlation (Bhattacharyya and Johnson 1977). Both pH and conductivity of unfiltered and filtered samples had low Pearson correlations and high p-values. Thus, these two functions are discarded from further testing. A high positive correlation of alkalinity to minerogenic silica suggests buffering capacity is present for these water samples. A considerable negative correlation was found between alkalinity of filtered samples and minerogenic silica, suggesting that buffering capacity was lowered with filtration.

	pH unfiltered	pH filtered	Conductivity unfiltered	Conductivity filtered	Alkalinity unfiltered	Alkalinity filtered
Pearson correlation	0.409	-0.092	-0.068	-0.110	0.744	-0.668
P-value	0.240	0.801	0.851	0.761	0.014	0.035

Table 8.1 Correlation of filtered/unfiltered pH, conductivity and alkalinity measurements with Minerogenic Silica measurements.

Pearson correlation coefficient is designed to measure the closeness of the relationship to a straight-line form. High p-values support null hypothesis (lack of relationship).

Mann-Whitney test, presented in Table 8.2, was used to determine whether correlation of alkalinity to minerogenic silica is statistically relevant. Findings of this analysis suggest that correlation of alkalinity of unfiltered and filtered samples to minerogenic silica are significant in 2.5% of the cases investigated. The test identifies that a relationship exists between alkalinity of unfiltered water samples and minerogenic silica and that this relationship is statistically significant.

	Median	Mann-Whitney test (adjusted for ties)
Minerogenic Silica	138.4	
Alkalinity unfiltered and Minerogenic Silica	37.5	0.0254
Alkalinity filtered and Minerogenic Silica	33.0	0.0250

Table 8.2 Mann-Whitney test for relationships between minerogenic silica and alkalinity unfiltered/filtered.

6. DISCUSSION AND CONCLUSIONS

6.1 Meteorology, Stratification and Heat Budgets

The analysis of Flakevatn's temperature records from 2004 and 2005 shows two drastically different situations. The Poland and Canada model for predicting the thermocline position based on lake's morphometric characteristics, anticipates the thermocline in Flakevatn at 5.1 to 9.9m depth.

2005 was a significantly colder year with common isothermous conditions due to water mass being below 4°C. Recurrent winds and probably night frosts would contribute to this interchange between stratified and unstratified water column. Year 2004, similar to year 1933, was a warm year with stable stratification developing in mid august. It would be safe to conclude that Flakevatn is a cold monomictic lake during 'warm' years. Finse area meterological records show that the monthly temperature trends have stayed more or less the same over 100 years. This is seen in R^2 values comparison of periods in Table 9.1 and graphs 8-13 (Appendix 1). The absence of data from the records of monthly temperature averages was in the range of few days.

PERIOD	1904-1924	1932-1934	1961-1990	1994-1999	2000-2005
1904-1924		$R^2 = 0.88$			$R^2 = 0.99$
1932-1934			$R^2 = 0.87$		$R^2 = 0.84$
1961-1990				$R^2 = 0.99$	
1994-1999					$R^2 = 0.99$
2000-2005					

Table 9.1 Comparison of monthly temperature averages between periods

R^2 values near 1.00 suggest strong linear fit of data and high similarity between monthly averages from different periods over 100 years period.

In this investigation the mean temperatures of each stratum are obtained from two temperature measurements at the borderline of strata. Calculating the mean temperature of each successive stratum is done by using a lower borderline temperature measurement This practice introduces error when the temperature is rapidly declining within water column (Birge 1914).

Annual heat budget for Flakevatn has been overestimated first in the use of low number of strata for reduced thickness heat budget calculation and second, in the use of too large of an ice cover thickness in determining winter heat budget.

Determining winter heat budget appears to be more problematic than evaluating summer heat budget. In the winter months, Flakevatn has a definitive variability in temperatures from 20-75m. Figure 9.1 shows measurement differences in tenths of a degree, yet being significant enough to generate overestimation of winter heat budget.
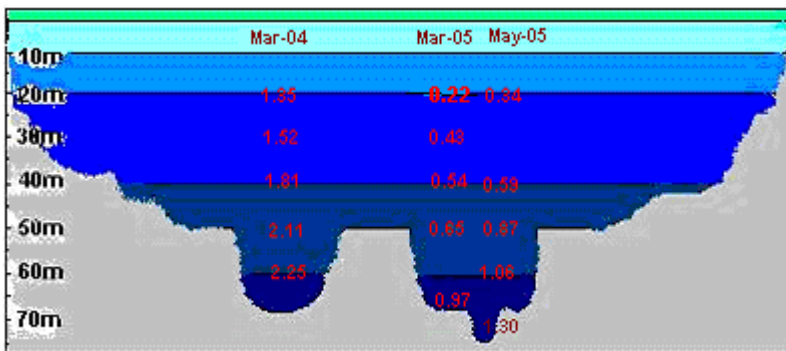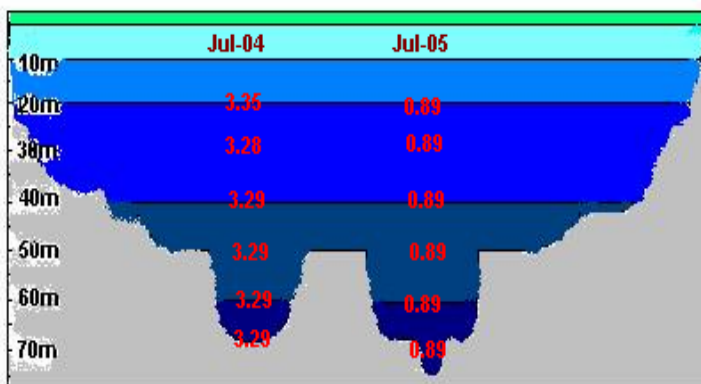

Figure 2.1 Change in winter temperatures below 20m depth
The figure is a comment on the differences observed in calculating the
winter heat budgets using 3 layers versus 6 layers method.
Temperatures shown are direct measurements at each depth.

The use of a single layer for 20-75m depth as dictated by three-layer method overvalues the winter heat budget in 2004 and 2005 at around 3000 cal cm^{-2}.

In the summer months, Flakevatn has a uniform temperature profile from 20-75m as seen in the Figure 9.2. The differences are measured in hundredths of a degree, allowing for small difference between summer heat budget estimates using either 3 or 6 layer method.

Figure 9.2 Change in summer temperatures below 20m depth. The figure is a comment on the match of summer heat budgets calculated using 3 layers versus 6 layers method. Temperatures shown are direct measurements.

The composition of ice cover is the largest part of the Flakevatn's winter heat budget overestimation. By using 150 cm thickness of ice, Flakevatn's winter heat budget was estimated to be 9000 cal cm^{-2} larger than it is likely to be. Both years 2004 and 2005 showed a varied composition of ice cover with combined thickness being around 40cm. Furthermore, the temperature trends over past century have shown a relatively the same monthly temperature averages.

This high mountain lake has been evaluated to have an annual heat budget of 15 673 cal cm^{-2} during 'warm 2004 year' and 13074 cal cm^{-2} during 'cold 2005 year'. It would be safe to expect that Flakevatn would continue to have annual heat budget values in between those two values.

6.2 Glacial ooze events, changes in water chemistry and silica content

Glacial ooze events at Flakevatn have been recorded twice in four expeditions (August 1933, June 1965, 2004 and 2005). These are late summer events. Influx of glacial ooze is dependant on the melt water washing off the deposits of freshly crushed bedrock beneath the glacier. In addition to this, precipitation could wash off the deposits of ground bedrock from former glacier locations. In general, the temperature has been lower during summer months (June, July and August), seen in Graph 14 (Appendix 1) 2005 than in 2004 and 1933 by 0.7°C and 0.9°C, respectively.

The precipitation in winter months (October-March), shown in Graph 15 (Appendix 1), has been lower in 2003-2004 and in 1932-1934, than it was in 2004-2005. On average, these differences were 42mm and 79mm, respectively.

Glacial ooze events are dependant on the random chance of melt water encountering significant deposits of ground rock and carrying it off into the lake in a short period of time. It is likely that in 2005, most of the melt water came from the melting of snow cover. Snow cover was observed at Flakevatn in 2005 late into the summer season. Turbidity measurements have shown an upward trend with warming up, due to the snow melt and inputs of clay particles. Higher turbidity in September is due to highest inputs of eroded matter to the lake from surrounding tributaries.

Filtration of the epilimnion water samples changed very little in conductivity but pH and alkalinity showed some visible changes with filtration. These changes were noted in the larger divergence of filtered samples pH and alkalinity curves from unfiltered samples

later in the season. The statistical significance of these changes was correlated to the minerogenic silica or quantities of glacial ooze. Water samples showed a rise in biogenic silica in the early august Total silica or mainly minerogenic silica at 2m experienced a decrease with formation and reformation of thermocline while at 10m the highest recorded levels were in mid September. The pH values of epilimnion waters throughout 2005 were measured to be around 6.5 which is drastically different from Strøm 1934 late August pH of 8.2. It is possible that Flakevatn experiences alkaline pH only during glacial ooze events.

Measurements of dissolved silica in Midtdal and Blåisen, 214µg L^{-1} and 344 µg L^{-1} respectively, established a range in which major inflow to Flakevatn should be found. Major inflow to Flakevatn as Midtdal and Blåisen are located in phyllite dominant terrain. Major outflow contributed 258 µg L^{-1} while minor outflow recorded 188µg L^{-1} dissolved silica to Flakevatn. From these measurements, it can be suspected that phyllite is the major minerogenic source to dissolved silica in Flakevatn.

From conductivity, pH and alkalinity, only alkalinity was found to have a statistically significant relationship with minerogenic silica. There is a suggestion that alkalinity is correlated with glacial ooze quantities and that this is not just a chance event, although low number of samples and more conservative statistical testing showed that support for this relationship is not large enough to confidently claim so.

Flakevatn is decisively a minerogenic system when the analysis of cores is taken into account. Low levels of dissolved silica, 183.5µg L^{-1} Table 9(Appendix) in the 'winter waters' above sediment also suggest low exchange of silica at the sediment water interface. Flakeveatn has been found to be a strongly ultraoligotrophic lake in comparison to two low land ultraoligotrophic lakes Klaretjern and Lutvann. This lake's sediment has a low organic carbon content (3.4 – 4.3%) and lowest water content in the top 8cm of the core. Moreover, Flakevatn sediment has the lowest level of biogenic silica 0.13-0.44% from the three lakes examined. Lutvann measured lower levels of organic carbon content (2.2-2.9%) than Flakevatn but higher biogenic silica (5.58-7.40%). This could be in part due to higher microbial activity in the Lutvann sediment and larger diatom blooms.

7. ACKNOWLEDGEMENTS

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9. APPENDIX 1
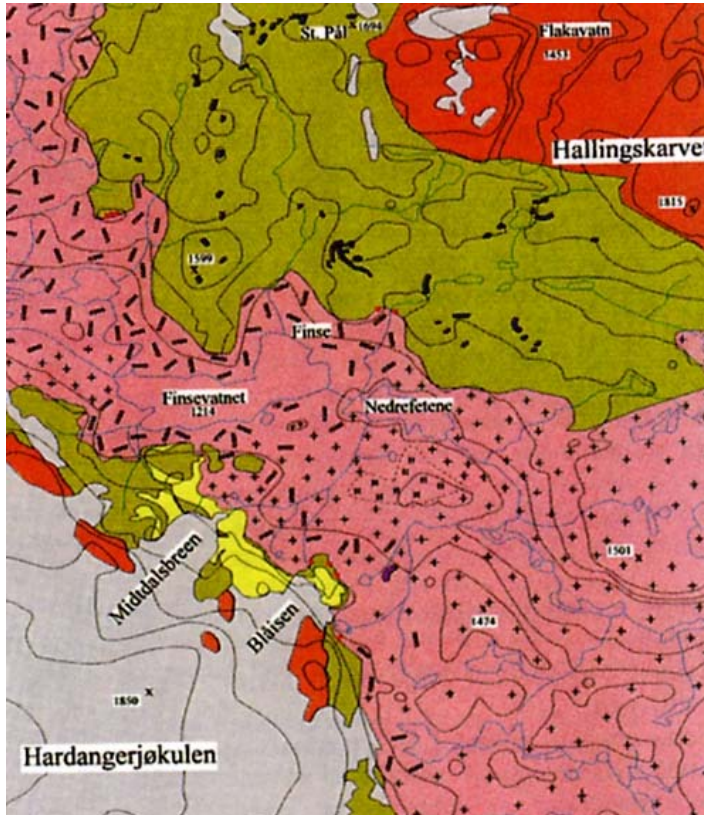
Figure 1: Geology of Finse valley terrain taken from Sømme and Østbye 1997**.** Green color denotes phyllites. Red color denotes granite. Both Blåisen and Midtdal are located in a geologically similar area. The map also shows Flakevatn catchment completely dominated by granite. This is most likely a rough approximation on the investigator's behalf.

Table 1

Chamosite $(Fe^{2+},Mg, Fe^{3+})_5Al(Si_3Al)O_{10}(OH,O)_8$		Anorthite $Na_{0.1-0.0}Ca_{0.9-1.0}Al_{1.9-2.0}Si_{2.1-2.0}O_8$		Phyllite
SiO_2	26.40 - 26.65 %	SiO_2	45.88%	$NaClO_2$; $Mg(ClO_2)_2$ Chlorite
Al_2O_3	18.23 – 16.14%	TiO_2	0.04	$KAl_2(ALSi_3O_{10})(F,OH)_2$ Muscovite
Fe_2O_3	5.70 – 6.69 %	Al_2O_3	34.31	SiO_2 Quartz
FeO	25.87 – 34.43 %	Fe_2O_3	0.83	
MnO	0.04 %	CaO	18.28	
MgO	11.35 – 4.47 %	Na_2O	0.82	
CaO	0.42%	K_2O	0.11	
Na_2O	0.17%	H_2O^+	0.14	
K_2O	0.17%			
H_2O^+	10.60 – 11.42%			
H_2O^-	1.05 – 0.08%			
Hardness	2-3	Hardness	6-6.5	N/A

Table 1: Composition of major mineral constituents in Flakevatn catchment

Composition was obtained from http://www.minsocam.org/handbook/ and stresses difference in silica content and hardness of two granite minerals. Phyllite composition is generalized to three major minerals due to its varied composition.

Table 2

Investigation	Main Phytoplankton observed	
Strøm 1938		*Eurycercus glacialis*
Hagnar 2005	Chrysophyceae	*Bitrichia chodatii*
		Kephyrion cf. boreale
		Synura sp.
	Chlorophyceae	*Chlamydomonas* spp.
	Cryptophyceae	*Cryptomonas* sp.
	Dinophyceae	*Gymnodinium* sp.
		Peridinium sp.

Table 2: Flakevatn phytoplankton survey

Major classes of phytoplankton recorded in Flakevatn in past investigations. Hagnar 2005

listed major groups from a May 2004 sample.

Table 3

Depth intervals (ms)	Volumes (km^3)	Reduced depth thickness (cm)	Støm's reduced thickness (cm)
0-2	0.00552	165	827
2-10	0.02208	661	
10-20	0.0225	673	674
20-40	0.0345	1033	
40-60	0.0132	395	1511
60-75	0.0028	84	
Total 0-75	0.1006	3011	3012

Table 3: Modification of Strøm 1934 reduced depth thickness intervals

Table presents further division of Strøm's original 3 layers to 6 layers in order to

gain a better estimate of Flakevatn's heat budget differences.

Table 4

Water Layer (ms)	Reduced thickness (ms)	Corrected Reduced Thickness (ms)	Summer Heat budget Aug 24 1933 (cal/cm^2)	Corrected Strøm's Summer Heat Budget (cal/cm^2)	Winter heat budget Jun 1, 1965 (cal/cm^2) + 150cm of ice	Corrected Strøm's Winter heat budget(cal/cm^2) + 150 cm of ice
0-10	8.27	8.26	1985	2157	-	-3176
10-20 (10-15 for summer)	6.74	6.74	1314	696	-	-2250
20-75	15.11	15.12	2493	3198	-	-4521
Total	30.12	30.14	5792	6051	-10510 <u>- 12000</u> - 22510	-9947 <u>-10 958</u> -20905

Table 4 : Strøm's 1933 and 1965 estimates and correction to these estimates.

Table shows original Strøm 1933 and 1964 values and these values recalculated along with

budget estimates. Correction to reduced thickness was merely difference in rounding off numbers

which in turn produced a difference in heat budget estimate. Strøm's winter heat budget was estimated using his estimate of ice thickness to be 150cm. Corrections to winter heat budget are again product of differences in rounding off reduced thickness.

Table 5

Date	Depth (ms)	Turbidity (NTUs)
26/5/05	10	0.15
4/8/05	2	0.21
4/8/05	5	0.21
4/8/05	10	0.19
4/8/05	20	0.21
4/8/05	40	0.22
4/8/05	60	0.19
4/8/05	75	0.15
28/8/05	2	0.16
28/8/05	10	0.23
31/8/05	2	0.19
31/8/05	10	0.43
20/9/05	10	0.50
6/10/05	2	0.19
6/10/05	10	0.21
19/10/05	0	0.23

Table 5: Turbidity measurements in Flakevatn water samples.

Flakevatn turbidity measurements in general focused on 2 and 10m depths as thermocline is located in region of 10m depth. It was assumed that due to windy conditions, the sinking out of fine glacial clays would be hindered.

Table 6

| Depth (ms)	pH unfiltered	pH filtered (centrifuged)	Conductivity unfiltered (μScm^{-1})	Conductivity filtered (μScm^{-1})	Alkalinity unfiltered (mekv/L)	Alkalinity filtered (mekv/L)
2	6.63	6.57	9.09	8.44	0.041	0.032
5	6.5	6.53	9.24	8.54	0.033	0.033
10	6.5	6.48	9.32	8.75	0.036	0.035
20	6.47	6.53	9.41	8.49	0.037	0.018
30	6.53	6.5	9.54	8.75	0.072	0.033
40	6.5	6.53	9.45	8.77	0.066	0.040
60	6.5	6.5	9.5	8.67	0.056	0.031
75	6.5	6.48	9.66	8.75	0.066	0.040

Table 6: pH , Conductivity and Alkalinity measurements of filtered versus unfiltered samples in Flakevatn water column profile on August 4th 2005

Table 7

Date	Depth (ms)	pH unfiltered	pH filtered	Conductivity unfiltered (μScm^{-1})	Conductivity Filtered (μScm^{-1})	Alkalinity unfiltered (mekv/L)	Alkalinity filtered (mekv/L)
3/5/05	10	6.55	6.53	7.90	7.85	0.042	0.041
4/8/05	2	6.63	6.57	9.09	8.44	0.041	0.032
4/8/05	10	6.50	6.48	9.32	8.75	0.036	0.035
28/8/05	2	6.52	6.50	7.63	7.61	0.039	0.032
28/8/05	10	6.45	6.44	7.83	7.80	0.035	0.034
31/8/05	2	6.45	6.43	7.61	7.60	0.035	0.034
31/8/05	10	6.50	6.45	7.82	7.79	0.036	0.032
20/9/05	10	6.51	6.40	7.77	7.78	0.046	0.028
6/10/05	2	6.45	6.43	8.12	8.10	0.042	0.034
6/10/05	10	6.50	6.45	8.25	8.20	0.035	0.032
19/10/05	0	6.51	-	8.70	-	0.036	-
Midtdal	0	6.85	-	18.96	-	0.075	-
Blåis	0	6.65	-	8.98	-	0.025	-

Table 7: Changes in pH, conductivity and alkalinity with filtration in the Flakevatn eplimnion 19/10/05 surface water sample was not checked for filtration changes. Midtdal and Blåis streams were used as reference for pH, conductivity and alkalinity of the general area.

Graph 1
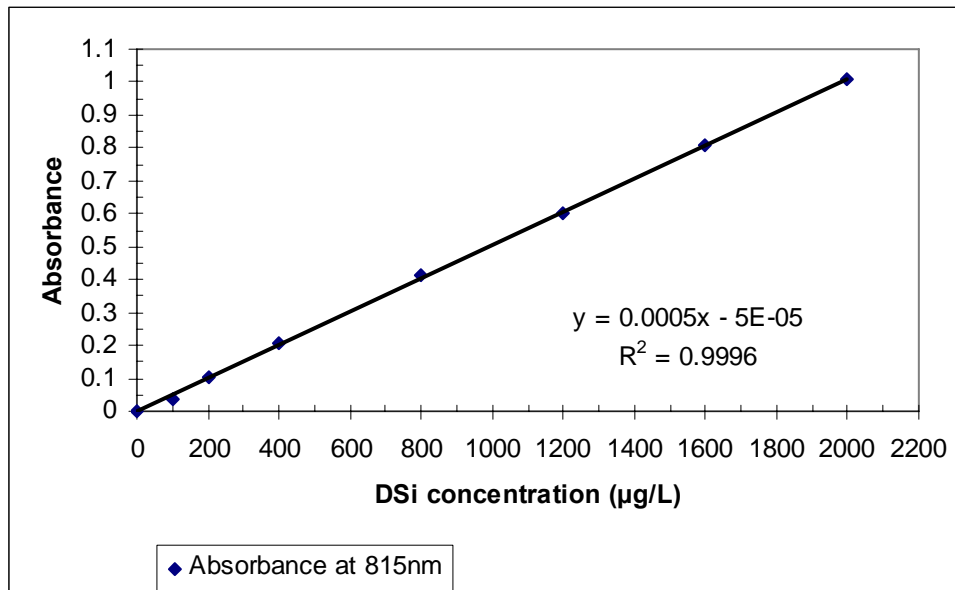
**Graph 1:** Standard curve for dissolved silicate (DSi) measurement

The graph presents a standard curve of absorption values at 815nm wavelength of IR measured via molybdate method. The R^2 value shows the general fit of the data.
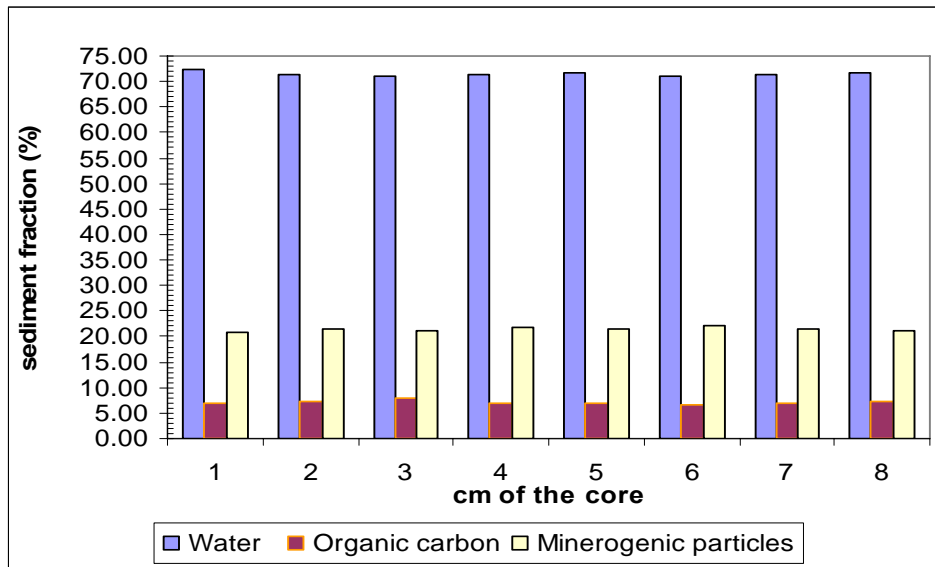
Table 8

Sample location	Absorbance at 810nm	Silica content (µg/L)
Midtdal	0.172	344
Blåis	0.107	214
Flakevatn 0m - surface	0.094	188
Flakevatn 1m	0.093	186
Minor inflow	0.083	166
Major inflow	0.129	258

Table 8: Preliminary Flakevatn dissolved silica measurements; reference locations and inflows

Table 9

| Date	Depth (ms)	Biogenic Si Absorbance (815nm)	Biogenic Si (µg/L SiO$_3$)	Total Si Absorbance (815nm)	Total Si (µg/L SiO$_3$)
03/05/05	10	0.017	35.2	0.091	158.5
04/08/05	2	0.046	86.4	0.405	681.8
04/08/05	10	0.045	81.8	0.059	105.2
28/08/05	2	0.016	33.5	0.262	443.5
28/08/05	10	0.029	55.2	0.043	78.5
31/08/05	2	0.015	31.8	0.046	83.5
31/08/05	10	0.019	38.5	0.102	176.8
20/09/05	10	0.027	51.8	0.763	1278.5
06/10/05	2	0.015	31.8	0.098	170.2
06/10/05	10	0.022	43.5	0.159	271.8
Above Sediment				0.106	183.5

Table 9: Flakevatn epilimnion water measurements of biogenic silica and total silica content via IR spectrophotometry.

Graph 2
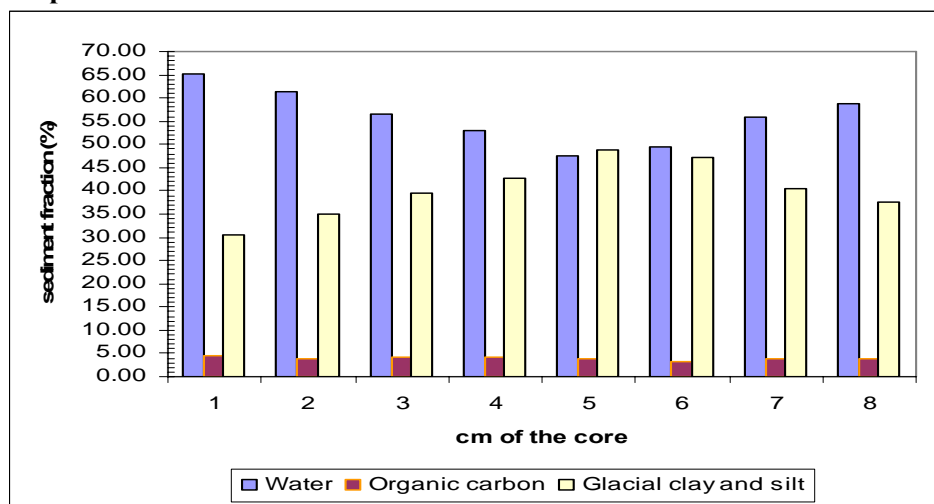
Graph 2: Flakevatn October 6th 2005 top 8 cm core analysis.

Graph 3

Graph 3: Klaretjern July 13th 2005 top 8cm core analysis

Graph 4
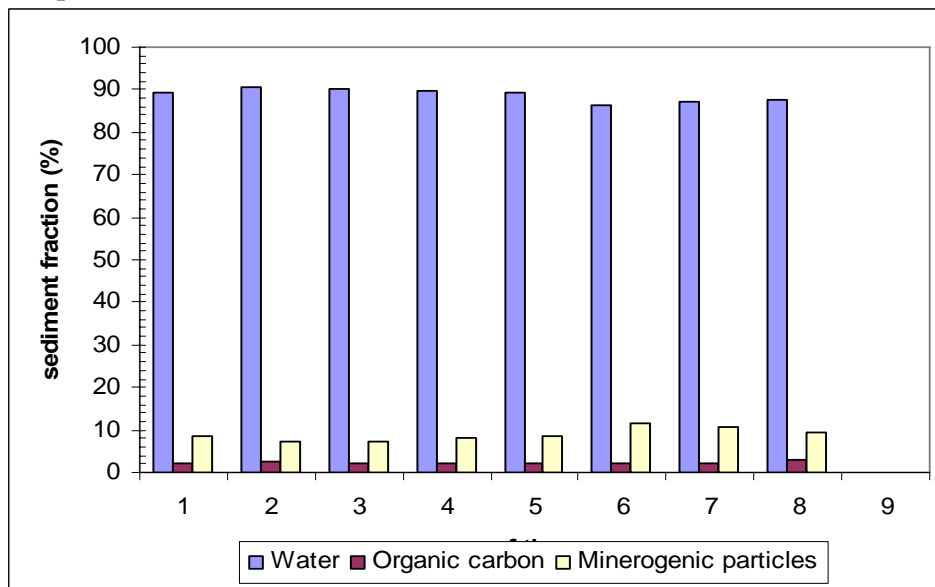
Graph 4: Lutvann October 18th 2005 top 8cm core analysis

Table 10

Sediment section (cm of the top 8cm)	sample weight (mg)	Absorbance at 3h digestion (nm)	Absorbance at 4h digestion (nm)	Absorbance at 5h digestion (nm)
Flakevatn				
1	25.0	0.139	0.153	0.157
2	23.2	0.090	0.099	0.104
3	25.1	0.071	0.075	0.081
4	24.6	0.066	0.070	0.074
5	24.7	0.076	0.080	0.083
6	24.1	0.063	0.080	0.086
7	25.1	0.056	0.060	0.062
8	25.2	0.050	0.055	0.060
Klaretjern				
1	24.2	0.627	0.653	0.670
2	25.1	0.601	0.625	0.640
3	23.5	0.818	0.830	0.836
4	24.4	1.291	1.331	1.340
5	25.1	1.381	1.484	1.492
6	25.1	1.218	1.375	1.390
7	24.6	1.119	1.202	1.210
8	25.0	1.110	1.195	1.207
Lutvann				
1	23.2	1.429	1.440	1.460
2	25.0	1.779	1.810	1.820
3	23.5	1.901	1.920	1.930
4	23.3	1.590	1.638	1.652
5	25.7	1.970	1.990	2.010
6	25.6	1.880	1.900	1.910
7	24.7	1.970	1.990	2.000
8	25.1	1.960	1.980	1.990

Table 10: Absorbance measurements via IR spectroscopy of samples from top 8cm sediment Core sections from three lakes. Digestion is carried out with 1% Na_2CO_3 at 3,4 and 5h time points.
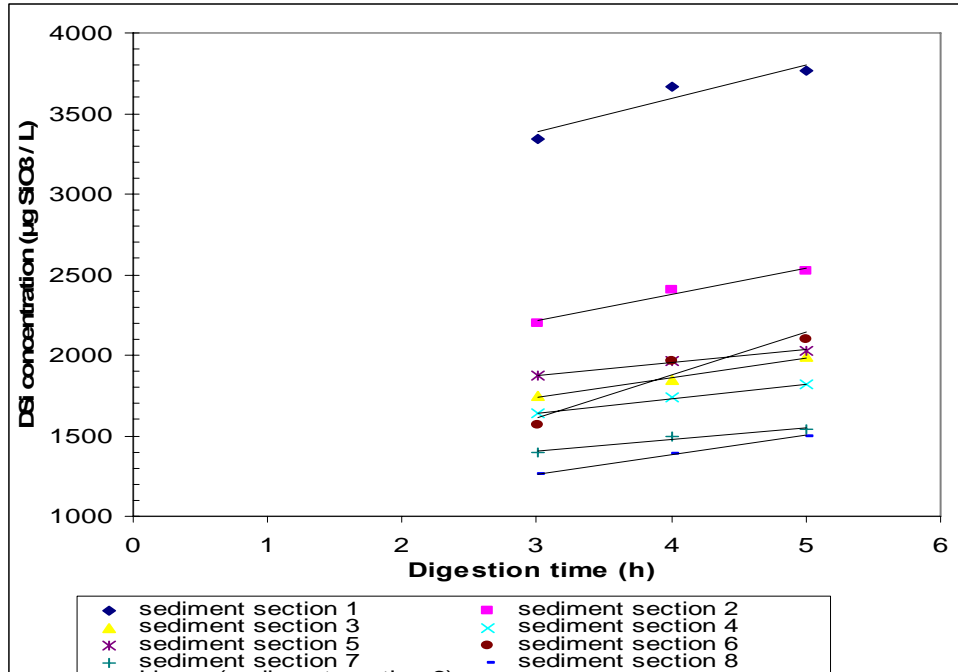
Table 11

Sediment section (cm of the top 8cm)	Subsample at 3h digestion DSi concentration (μg/L)	Sample at 3h digestion DSi concentration (μg/L)	Subsample at 4h digestion DSi concentration (μg/L)	Sample At 4h digestion DSi concentration (μg/L)	Subsample at 5h digestion DSi concentration (μg/L)	Sample at 5h digestion DSi concentration (μg/L)
Flakevatn						
1	239	3346	262	3668	269	3766
2	157	2198	172	2408	180	2520
3	125	1750	132	1848	142	1988
4	117	1638	124	1736	130	1820
5	134	1876	140	1960	145	2030
6	112	1568	140	1960	150	2100
7	100	1400	107	1498	110	1540
8	90	1260	99	1386	107	1498
Klaretjern						
1	1052	14728	1095	15330	1124	15736
2	1009	14126	1049	14686	1074	15036
3	1370	19180	1390	19460	1400	19600
4	2159	30226	2225	31150	2240	31360
5	2309	32326	2480	34720	2494	34916
6	2037	28518	2299	32186	2324	32536
7	1872	26208	2010	28140	2024	28336
8	1857	25998	1999	27986	2019	28266
Lutvann						
1	2389	33446	2407	33698	2440	34160
2	2972	41608	3024	42336	3040	42560
3	3175	44450	3207	44898	3224	45136
4	2657	37198	2737	38318	2760	38640
5	3290	46060	3324	46536	3357	46998
6	3140	43960	3174	44436	3190	44660
7	3290	46060	3324	46536	3340	46760
8	3274	45836	3307	46298	3324	46536

Table 11: Measurements of dissolved silica concentration in the 3h,4h and 5h digestion subsamples from each sediment section of three lakes. Sample concentrations are calculated from subsample concentrations using dilution factors.
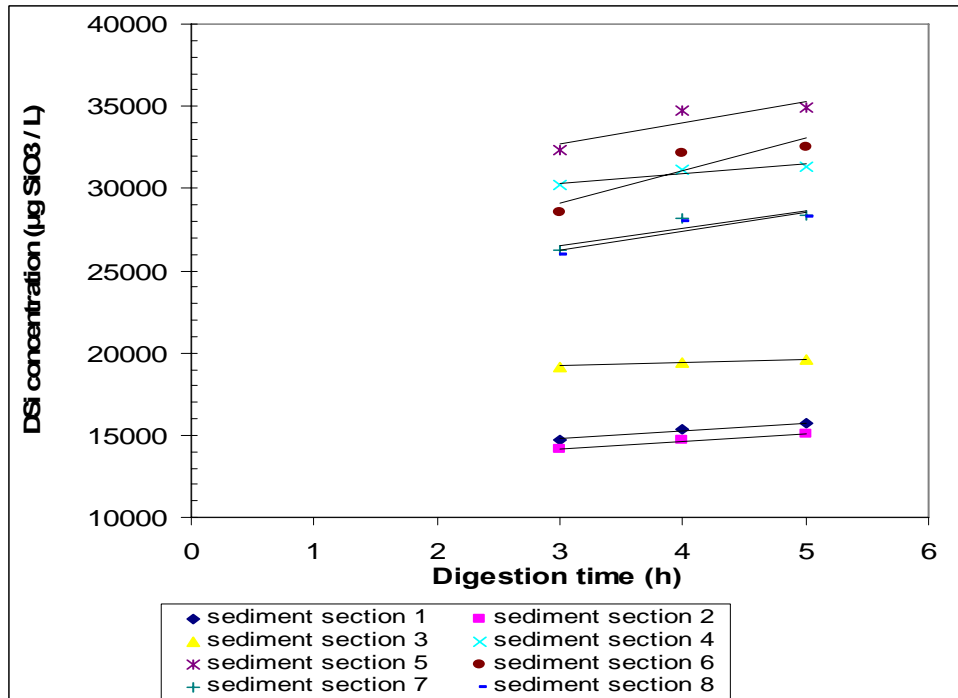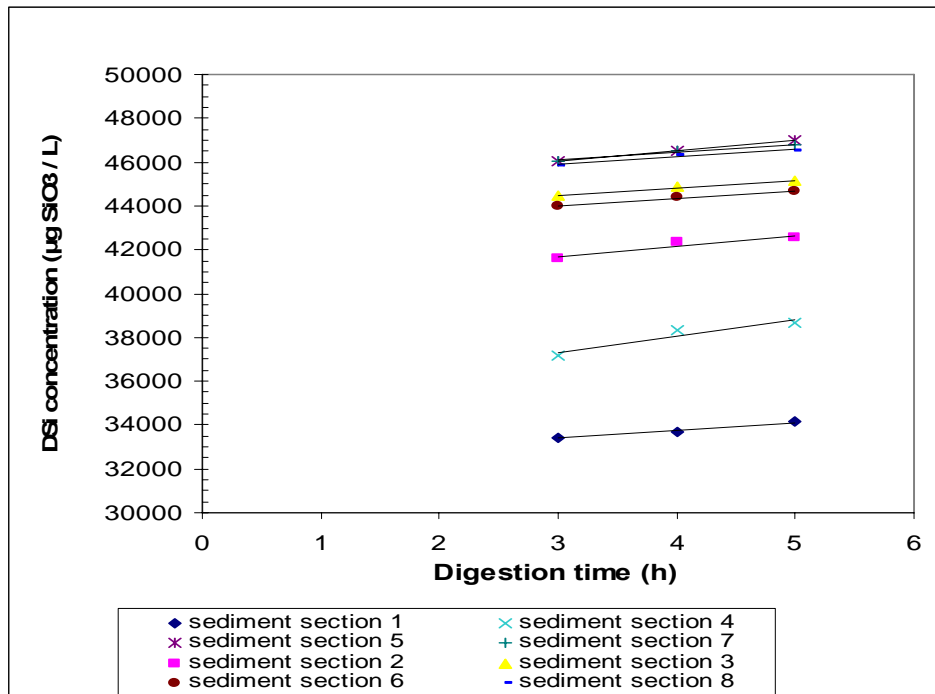
Graph 5

Graph 5: Flakevatn sediment sections' release of dissolved silica (DSi) with increase in digestion time. Graph is based on values presented in Table 11.
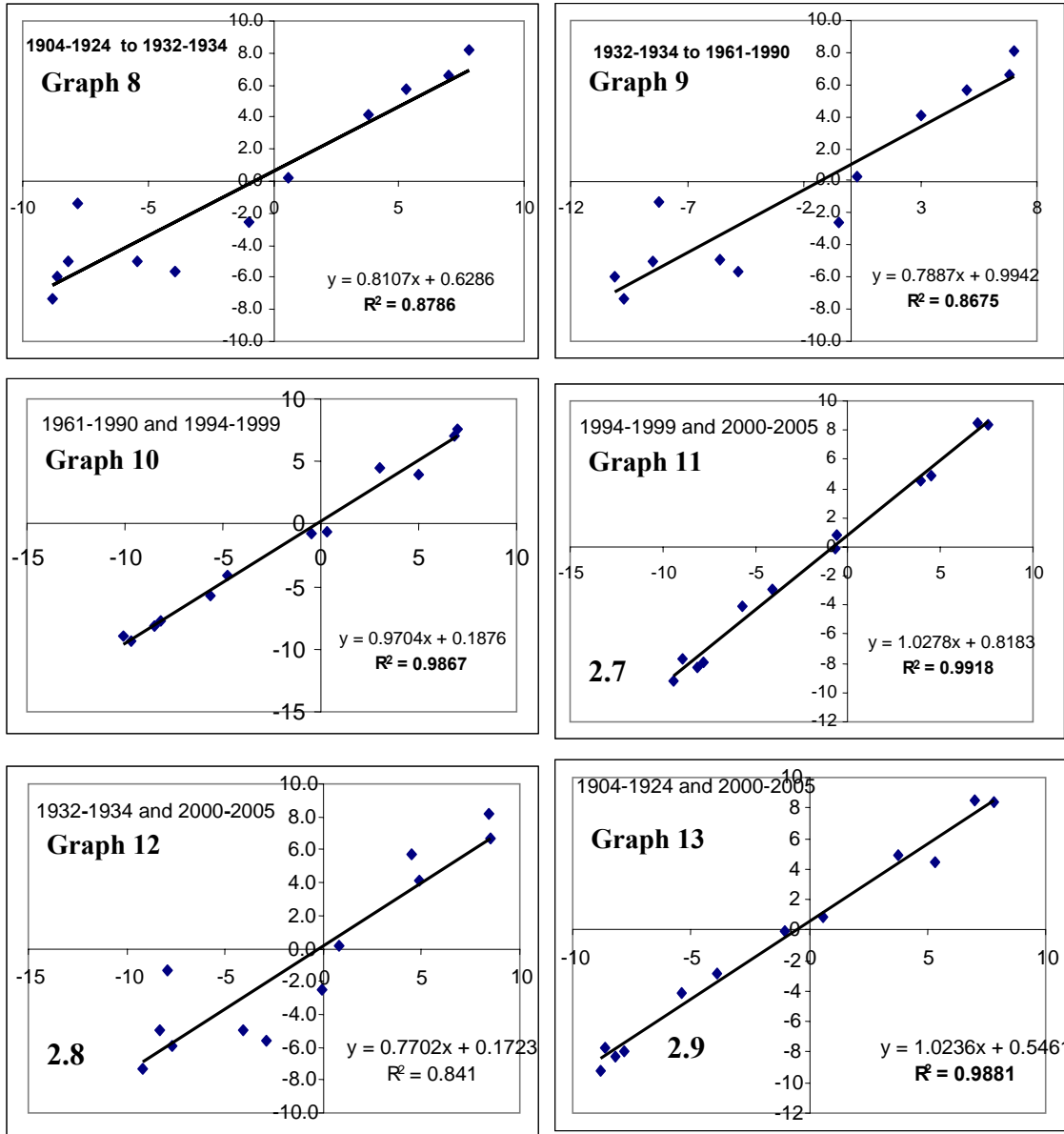
Graph 6

Graph 6: Klaretjern sediment sections' release of dissolved silica (DSi) with Increase in digestion time. Graph is based on values presented in Table 11.
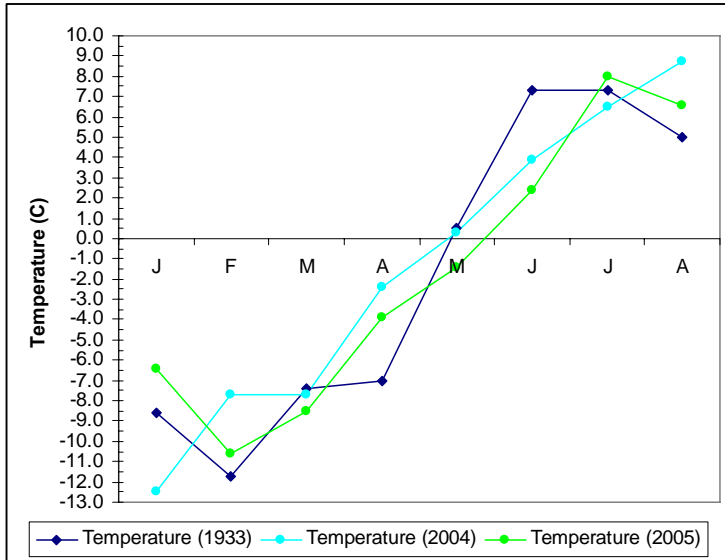
Graph 7

Graph 7: Lutvann sediment sections' release of dissolved silica (DSi) with

Increase in digestion time. Graph is based on values presented in Table 11.

Graphs 8 – 13

Graph 8 1904-1924 to 1932-1934
y = 0.8107x + 0.6286
R² = 0.8786

Graph 9 1932-1934 to 1961-1990
y = 0.7887x + 0.9942
R² = 0.8675

Graph 10 1961-1990 and 1994-1999
y = 0.9704x + 0.1876
R² = 0.9867

Graph 11 1994-1999 and 2000-2005
y = 1.0278x + 0.8183
R² = 0.9918
2.7

Graph 12 1932-1934 and 2000-2005
y = 0.7702x + 0.1723
R² = 0.841
2.8

Graph 13 1904-1924 and 2000-2005
y = 1.0236x + 0.5461
R² = 0.9881
2.9

Graphs 8 – 13: Comparison of averages of month temperatures between periods

The series of graphs present fitness of monthly temperature averages for different length periods at Finse area. The period 1932-1934 monthly temperatures averages are extrapolated from Slirå weather station (altitude 1300m) to Finse weather station (altitude 1222m) using 0.4°C per 100ms altitude gradient.

Graph 14: Temperature averages for glacial ooze events The graph presents monthly temperature averages for Flakevatn area. 1932-1933 period has been extrapolated to Flakevatn area from Slirå station. 2003-2004 and 2004-2005 period has been extrapolated from Finse station.

Graph 15
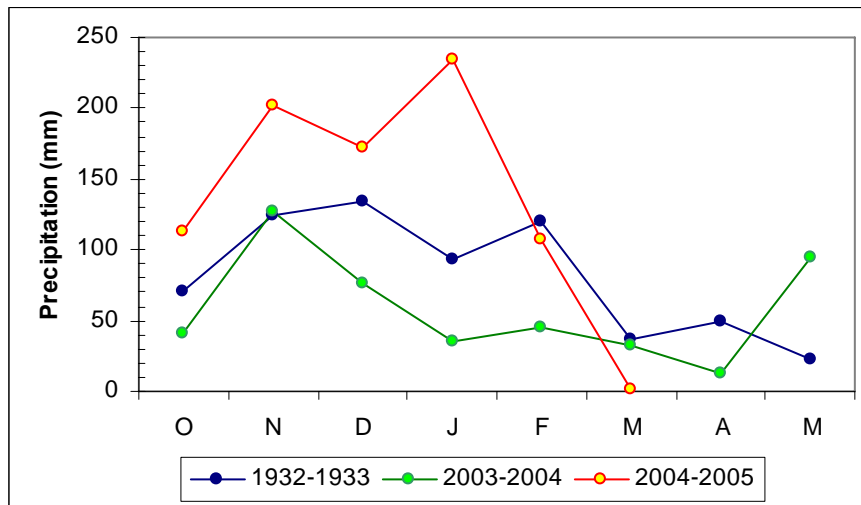
Graph 15 Winter months' precipitation averages for glacial ooze events

The graph presents monthly temperature averages for Flakevatn area.

1932-1933 period has been extrapolated to Flakevatn area from Slirå station.

2003-2004 and 2004-2005 period has been extrapolated from Finse station to Flakevatn area.

10. APPENDIX 2

Picture 1: Flakevatn - August 2005

Picture 2: Finse valley terrain

Picture 3: Klaretjern - July 2005

Picture 4: Lutvann - June 2005

Picture 5: Flakevatn minor inflow

Picture 6: Turbidimeter: DRT-15CE

Picture 7: Conductivity meter: CDM80

Picture 8: Alkalinity meter (bottom) TT80-Titrator/ABU80-Autoburette and pH meter (top) PHM 82
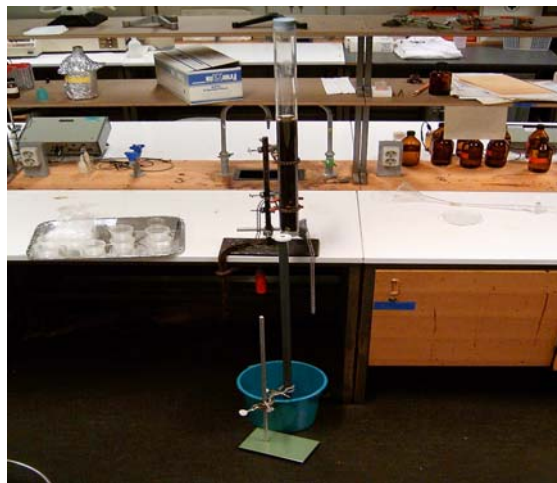

Picture 9: IR double-beam spectrophotometer Shimadzu UV-210A

Picture 10: Silica analysis lab set-up

Picture 11: Electric furnace Heraeus M104/K114

Picture 12: Core sectioning set-up

Picture 13: Wet sediment drying and combustion

Picture 14: Sonic bath – Sonorex RK 106S

Picture 15: Water bath
Infors AG CH-410S Bottmingen

Picture 16: Flakevatn core extracted
October 6th 2005

Picture 17: Klaretjern core extracted July 13th 2005

Picture 18: Flakevatn (left), Klaretjern (middle) Lutvann (right) dry and combusted sediment

Picture 19: Total and Biogenic Silicate in Flakevatn water samples

Picture 20: Flakevatn (bottom), Klaretjern (middle) and Lutvann(top) Dissolved silica released from sediment samples after 3h (left), 4h(middle) and 5h (right) digestion.