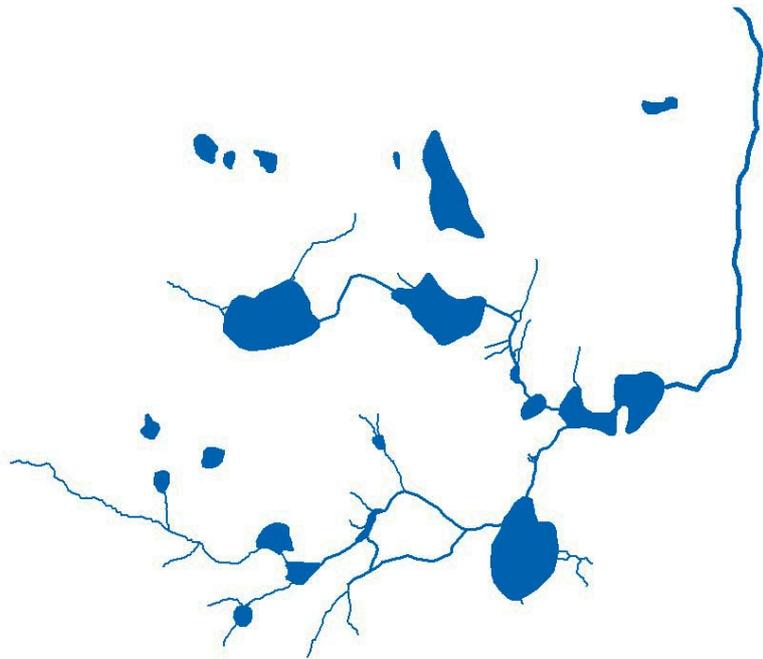


Expansion contraction cycle of a stream/lake network in a high alpine floodplain



Diploma thesis by

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'A group of lakes confronts the investigator as a series of very complex physicochemical and biological systems, each member of which has its own characteristics and yet also has much in common with the other members of the group. It is the diversity in unity that gives the peculiar fascination to limnology.'

- G. Hutchinson (1957).

Table of contents

I Summary.....	1
II Zusammenfassung.....	3
1 Introduction.....	6
1.1 History.....	6
1.2 Ecology of a stream/lake network.....	7
1.3 The long-term monitoring program.....	8
1.4 Objectives of the study.....	9
2 Description of the study area.....	10
2.1 Geographical situation.....	10
2.2 Swiss National Park.....	12
2.3 Geological situation.....	13
2.4 Climate.....	13
3 Methods and Materials.....	14
3.1 Sampling dates and investigated parameters.....	14
3.2 Physico-chemical parameters.....	15
3.2.1 Temperature.....	15
3.2.2 Turbidity.....	15
3.2.3 Conductivity.....	16
3.2.4 Discharge.....	16
3.2.5 Velocity.....	16
3.2.6 Oxygen.....	17

3.3	Water chemistry.....	18
3.3.1	Particulate organic carbon (POC).....	19
3.3.2	Particulate nitrogen and particulate phosphorus (PN/PP).....	19
3.3.3	Ammonia (NH ₄ -N).....	19
3.3.4	Nitrite (NO ₂ -N).....	19
3.3.5	Nitrate (NO ₃ -N).....	19
3.3.6	Dissolved nitrogen and dissolved phosphorus (DN/DP).....	19
3.3.7	Phosphate (Soluble reactive phosphorus, ortho-phosphate, PO ₄ -P).....	20
3.3.8	Dissolved organic carbon (DOC).....	20
3.3.9	Total inorganic carbon (TIC).....	20
3.3.10	Silica (SiO ₂).....	20
3.3.11	Sulphate (SO ₄) and Chlorine (Cl ⁻).....	20
3.3.12	Calcium (Ca ²⁺), magnesium (Mg ²⁺), sodium (Na ⁺) and potassium (K ⁺).....	20
3.3.13	Heavy metals.....	21
3.4	Global Positioning System (GPS) / Geographic Information System (GIS).....	21
3.5	Moss coverage.....	22
3.6	Substrate size.....	22
3.7	Statistical analysis.....	22
4 Results and Discussion.....		23
4.1	Thermal patterns.....	23
4.2	Oxygen.....	33
4.3	Physico-chemical parameters.....	37
4.4	Contraction of the floodplain channel network.....	53
4.5	Grain size distribution.....	61

4.6 Moss coverage.....	65
5 Outlook.....	69
6 Conclusion.....	70
7 Literature cited.....	71
8 Appendix A: Physico-chemical data.....	78
9 Appendix B: Water temperature based on temperature loggers.....	87
10 Appendix C: ANOVA Results.....	91
11 Acknowledgements.....	93
Eidesstattliche Erklärung.....	95

I Summary

The present study primarily focused on the spatial and temporal variability in chemical and physical properties of various stream reaches and lake outlets (29 sample sites) in a high alpine floodplain (2616 – 2682 m a.s.l.). The study also included the assessment of diel oxygen variability, the development of a method for estimating moss abundance, the determination of grain sizes for the uppermost sediment layer, and the application of GPS (Global Positioning System) and post-processing of data in a GIS (Geographic Information System). Data were collected monthly from July to October 2002 in the Macun Lakes area (3.6 km²), a high alpine floodplain composed of a stream/lake continuum, situated in the crystalline Alps in the Swiss National Park, canton Graubunden (Southeast Switzerland). The survey was part of a larger, ongoing long-term monitoring program to document and monitor environmental changes in this remote and sensitive area.

The presence of rock-glaciers in the study area and the associated seasonality in snow-melt and glacial-melt acted as major determinants of the flow regime, channel stability, temporal changes in chemical variables, and water temperature. Total channel length, measured by the application of GPS and GIS, decreased by ca. 60% during the study period. This remarkable reduction over time was caused by the abating influence of snowmelt water and rock-glacial runoff, respectively, consequently leading to a shift from a glacial to a groundwater dominated stream/lake network system.

In general, all sites were oligotrophic, with clear water (turbidity < 6.6 NTU). Although low conductivity values are known for streams flowing on crystalline rocks of low solubility in a small catchment, the values measured in this study were extremely low, never exceeding 26.5 $\mu\text{S}/\text{cm}$. A principal component analysis (PCA) based on physico-chemical data was used to explore the patterns of variation in the data, and served to discriminate northern and southern sample sites within the research area, as well as temporal patterns. The spatial separation was mainly associated with temperature, PN, PP, POC (being lower in the South), and $\text{NO}_2 + \text{NO}_3\text{-N}$ (being lower in the North). Higher particulate constituents and lower $\text{NO}_2 + \text{NO}_3\text{-N}$ concentrations in the North are probably caused by biological processes in the lakes. Temporal separation, on the other hand, reflected higher conductivities in September and October due to the contraction of the stream/lake network system, and higher $\text{NH}_4\text{-N}$ concentrations in July

and August due to nutrient release from snow and ice melt. Although topographically situated in the northern groundwater fed area, all statistical analyses associated sample site 2 to the rock-glacier influenced southern system. This placement is probably due to a glacial moraine located above site 2, slowly evolving into a rock-glacier, causing typical seasonal melt-water runoff.

Water temperature varied distinctively between sample sites and dates. The lowest temperature (-0.7°C) was recorded at a rock-glacier influenced sample site, whereas side slope seeps exhibited the highest temperatures (26.8°C), and lake outlets cooled later in the season due to latent heat in the lakes. In contrast to permanent sites, temporary sites showed the highest diel temperature fluctuations. However, even the groundwater fed sites were not as constant in temperature as known from other studies, suggesting a low storage capacity of side slopes for groundwater and an associated short groundwater residence time, especially when considering the low conductivity values and the strong decrease in discharge and total channel length.

Oxygen concentrations exhibited great spatial and temporal variability, but biological reasons for these patterns, as expected, could not be verified. In fact, changes in oxygen concentrations are probably a result of physical processes.

Distinct patterns for spatial differences in moss abundance and grain size distribution were not observed. These findings should mainly serve as baseline information for the long-term monitoring program, as the primary goal was to develop a method for estimating moss abundance.

In conclusion, this study revealed high spatial and temporal heterogeneity in physico-chemical characteristics, channel stability, and biological in-lake processes, as well as the ongoing geomorphological changes in the Macun Lakes area.

II Zusammenfassung

Die vorliegende Studie konzentrierte sich primär auf die Untersuchung zeitlicher und räumlicher Variabilität von chemisch-physikalischen Eigenschaften verschiedener Bachabschnitte und Seenausflüsse (29 Probenahmestellen) in einer hochalpinen Aue (2616 - 2682 m ü.N.N.) Des Weiteren umfasste die Studie die Bestimmung von Sauerstoffkonzentrationen über mehrere Tage, die Entwicklung einer Methode zur Bestimmung von Moos-Abundanz, die Bestimmung von Korngrößen der oberen Sedimentschicht sowie die Anwendung von GPS (Global Positioning System), und die Nachbearbeitung der Daten mit Hilfe eines GIS (Geographisches Informations System). Die Datenaufnahme erfolgte monatlich von Juli bis Oktober 2002 im Gebiet der Macun-Seen (3,6 km²), einer hochalpinen Aue mit verzweigtem Bach/See-Gewässernetz. Das Untersuchungsgebiet ist Teil des schweizerischen Nationalparks in Graubünden (südöstliche Schweiz), und liegt im Bereich der kristallinen Alpen. Die Studie war Teil eines umfangreichen, weiterführenden Langzeit-Monitoring-Programms, das Umweltveränderungen des Gebietes überwachen und dokumentieren soll.

Die im Untersuchungsgebiet vorhandenen Blockgletscher mit ihrer saisonabhängigen Schnee- und Eisschmelze bestimmten massgeblich das Durchflussregime, die Gerinnestabilität, die temporäre Veränderung der Konzentration chemischer Inhaltsstoffe, sowie die Wassertemperatur. Die Länge der Fliesswege wurde mit Hilfe von GPS- und GIS-Anwendung bestimmt, und reduzierte sich während des Untersuchungszeitraumes um ca. 60%. Diese bemerkenswerte Reduzierung war in dem nachlassenden Schmelzwassereinfluss bzw. Blockgletscherabfluss begründet, der die Verlagerung einer Gletscherwasser beeinflussten Aue, hin zu einer hauptsächlich Grundwasser beeinflussten Aue zur Folge hatte.

Generell wiesen alle Probenahmestellen geringe Trübungswerte auf (Trübung < 6,6 NTU) und konnten als oligotroph eingestuft werden. Obwohl geringe Leitfähigkeit für Bäche eines kleinen Einzugsgebietes mit kristallinem Untergrund von geringer Löslichkeit typisch ist, waren die hier gemessenen Leitfähigkeitswerte extrem niedrig (< 26,5 µS/cm). Die chemisch-physikalischen Daten wurden mit Hilfe einer Hauptkomponentenanalyse (Principal Component Analysis, PCA) auf Variationsmuster hin untersucht. Dies führte sowohl zu einer Unterscheidung südlich und nördlich im Untersuchungsgebiet gelegener Probenahmestellen, als auch zur Offenlegung zeitlicher

Muster. Die räumliche Einteilung wurde hauptsächlich durch die Wassertemperatur, den partikulären Stickstoff, partikulären Phosphor, partikulären organischen Kohlenstoff (niedrigere Messwerte im Süden) und die Nitratkonzentrationen (niedrigere Messwerte im Norden) bestimmt. Höhere Anteile partikulärer Inhaltsstoffe und niedrigere Nitratwerte im Norden des Untersuchungsgebietes sind wahrscheinlich auf biologische Prozesse in den Seen zurückzuführen. Die zeitliche Auftrennung hingegen wurde einerseits durch höhere Leitfähigkeitswerte im September und Oktober aufgrund der Kontraktion des Gewässernetzes sowie andererseits durch höhere Ammoniumkonzentrationen im Juli und August aufgrund frei werdender Nährstoffe aus Schmelzwässern bewirkt. Obwohl Probenahmestelle 2 topographisch gesehen eindeutig dem nördlichen, Grundwasser beeinflussten Teil des Untersuchungsgebietes zuzuordnen ist, zeigten die Ergebnisse der statistischen Berechnungen eine Zuordnung zu dem südlichen, Gletscherwasser beeinflussten Teil. Diese statistisch verifizierte Zuordnung ist wahrscheinlich in einer oberhalb der Probenahmestelle 2 lokalisierten Endmoräne begründet, deren langsame Genese zu einem Blockgletscher zu typischem saisonalem Schmelzwasserabfluss führt.

Die Wassertemperatur variierte stark zwischen den einzelnen Probenahmestellen und Probenahmedaten. Die geringste Temperatur wurde mit $-0,7^{\circ}\text{C}$ an einer Blockgletscherwasser beeinflussten Stelle gemessen, wohingegen Hangwasser von Seitenarmen des Gewässernetzes die höchsten Temperaturen aufwies (max. $26,8^{\circ}\text{C}$). Seenausflüsse kühlten sich aufgrund latenter Wärme in den Seen erst spät in der Saison ab. Im Gegensatz zu den permanent wasserführenden Probenahmestellen, wiesen die temporär trockenen Bachabschnitte die grössten Wassertemperaturamplituden innerhalb des Tagesverlaufs auf. Jedoch wiesen selbst die Grundwasser gespeisten Probenahmestellen nicht die Temperaturstabilität auf, die allgemein durch andere Studien belegt wird. Das lässt eine geringe Speicherkapazität der angrenzenden Seitenhänge, und die damit verbundene kurze Grundwasserverweildauer vermuten, insbesondere wenn man zusätzlich die geringen Leitfähigkeitswerte sowie die Reduzierung der Abflussmenge und der Länge der Fliesswege berücksichtigt.

Auch die Sauerstoffmesswerte wiesen grosse räumliche und zeitliche Variabilität auf, jedoch konnten die erwarteten biologischen Ursachen hierfür nicht

verifiziert werden. Vielmehr sind wahrscheinlich physikalische Prozesse die Ursache der Sauerstoffkonzentrationsschwankungen.

Bestimmte Muster für räumliche Unterschiede der Moos-Abundanz sowie der Korngrößenverteilung konnten nicht festgestellt werden. Die hier gewonnen Erkenntnisse stellen lediglich eine Basisinformation für das Langzeit-Monitoring-Programm dar, da das Primärziel der Entwicklung einer Methode zur Erfassung der Moos-Abundanz galt.

Zusammenfassend lässt sich sagen, dass die Studie eine grosse zeitliche und räumliche Variabilität der chemisch-physikalischen Eigenschaften, der Gerinnestabilität, der biologischen Prozesse innerhalb der Seen und die fortwährenden geomorphologischen Veränderungen im Gebiet der Macun-Seen aufgedeckt hat.

1 Introduction

1.1 History

Most of the water in the world has its origin in mountains. Evapotranspiration rates in high mountains are lower than in lowlands because temperature is lower and rainfall higher as incoming air is forced to rise, cools, and then precipitates. As a consequence, almost all major rivers and groundwater aquifers flow from the mountains. Therefore, it is not possible to understand the ecology of freshwaters if not in the context of mountain lakes and streams (Marchetto, 1998).

The first scientist to use the term limnology in a publication was Francois Forel. His three volume treatise on Lake Geneva, published over the period 1892 to 1904, is considered the first book on limnology. Its 14 chapters define the main supporting fields of modern lake limnology (Edmondson, 1994) and reinforce the idea that limnology is the application of all relevant basic sciences to the analysis of lakes as fundamental units of study. But even before Forel coined the term limnology, its integrative nature had been stressed (National Research Council, 1996). Already in 1887 Stephen Forbes described a lake as a “little world within itself – a microcosm within which all the elemental forces are at work and the play of life goes on in full but on so small a scale as to bring it easily within the mental grasp.” Considering lakes as microcosms is particularly suitable for high mountain lakes, as they present a large range in shape, surface area, depth, water retention time, chemical characteristics, as well as seasonal and inter-annual variability (Marchetto, 1998). The notion of lakes as microcosms (or integrated ecosystems) has pervaded their study ever since Forbes’ time, even though the concept has been broadened and refined as twentieth century science has become more sophisticated (National Research Council, 1996).

Based on stream biology, which was mostly descriptive through the first half of the twentieth century and focused on the distribution and taxonomy of stream organisms, stream ecology, or stream limnology as a subdiscipline of limnology (analogous to lake limnology) began to develop in the 1950s and 1960s.

Hynes’ 1970 book “The ecology of running waters” is usually regarded as the first book on stream ecology. Only recently have limnologists increasingly recognized

that streams, lakes, and wetlands must be considered as interconnected systems in the context of their watersheds and airsheds (National Research Council, 1996).

1.2 Ecology of a stream/lake network

High mountain lotic as well as lentic habitats are characterised by special abiotic factors. Elevation has a major effect on the temperature of mountain waters due to its influence on air temperature. There is an average 6.5°C decrease in air temperature for every 1000 m increase in elevation, and water temperatures tend to track air temperatures except when covered by ice or during the influence of snowmelt or spate (Ward, 1985). Insolation, which is normally high in habitats above tree line in spite of exposition (e.g., north vs. south facing), can modify the impact of air temperature. However, even though light availability is not limited, autotrophic production is limited by low water temperatures and nutrient levels, and by the short growing season (Ward, 1992). Because of high slopes, mountain headwaters tend to have high current velocity and well-oxygenated water. All dissolved gases are in balance with the atmosphere, and the decreasing gas solubility with increasing elevation, caused by decreasing atmospheric pressure, is countered by the increase of solubility at low water temperatures (Ward, 1992).

After Ward (1994), “alpine streams” as a term used to define running waters of the alpine zone can be separated into kryal, krenal, and rhithral streams, depending on the origin of their water. Kryal streams are glacial fed biotopes, characterised by temperatures near 0°C, barren rocky shores and substantial flow fluctuations in summer due to freeze-thaw cycles. Their water may be clear or turbid depending on suspended glacial flour. Krenal streams are springbrooks, occur at all altitudes, and are fed by groundwater. Compared to surface water, springs have minor fluctuations in flow, water temperature and chemistry, and are summer-cool and winter-warm habitats (Ward, 1994). Rhithral biotopes exhibit wider temperature ranges than kryal and krenal streams. They are largely fed by seasonal snowmelt, thus can be found in alpine catchments below the permanent snow line. (Ward, 1994).

Considering lakes and streams in a network, lakes have a major influence on water chemistry, temperature and particulate loads. They act as nutrient and sediment sinks as well as a temperature buffer. These effects will have a decreasing influence

with decreasing depth and water residence time, and a small watershed to lake area ratio. Comparing streams and lakes in a network, Kling et al. (2000) found that lake sites had higher values of particulate carbon, nitrogen, phosphorus and chlorophyll *a*, whereas stream sites tended to have higher values of major anions and cations. Observing spatial patterns, they found that conductivity, Ca^{2+} , Mg^{2+} , alkalinity, dissolved inorganic carbon and pH increased with lake chain number (high to low altitude in the basin). Soranno et al. (1999) also found increasing values for total nutrient (TP and TN) and chlorophyll with increasing lake chain number.

Observing spatial patterns at a larger scale, high mountain streams and lakes respond to the seasonal freezing (contraction) and thawing (expansion) cycle. The influence of snowmelt water in spring and of glacial ablation in summer plays a major role. With decreasing temperatures in autumn and winter, these water sources are reduced, discharge and the length of flowpaths are shortened, and the network shifts to a groundwater influenced system.

As mentioned above, there is a lack of studies that consider lakes, streams, and wetlands as spatially and functionally connected systems. With a few exceptions, recent research regards these aquatic ecosystems as isolated entities, as reflected in the numerous journals, conferences, and scientific societies that each subdiscipline uses (Lewis et al., 1995; Gorham, 1996). In the few cases where more than one ecosystem type has been investigated, mostly the effect of one on the other has been examined (Gorham, 1996), rather than integrating them into a single conceptual framework (Soranno et al., 1999).

1.3 The long-term monitoring program

Remote high alpine ecosystems play an important role in studies on global change. Lotic and lentic ecosystems are especially suitable for such studies due to their climatic sensitivity, shallow soil cover, modest size of watersheds, and rapid flushing rates that make them sensitive to most environmental inputs and changes. Thus, issues such as greenhouse warming, depleting of stratospheric ozone, and reduction in species diversity, can be carried out quite effectively in high mountain remote areas (Marchetto, 1998). In contrast to lowland areas, remote mountain lakes can yield important information on historical background conditions, and they are suitable as early response

indicators regarding both climatic change and atmospheric deposition of pollutants (Johannessen, Mosello, 1990). However, according to Ward (1994), there is little known about headwater segments situated at high altitudes compared to streams originating at low altitudes.

For these reasons, the Swiss National Park initiated a long-term monitoring program for the Macun Lakes area in 2002. The Macun area is suitable for such a program, as it is a remote high alpine region where human impacts were minimal and are now forbidden. Several universities and institutes take part in the program of assessing various ecological parameters and processes of the lakes and streams. The present study also provided some baseline information for this long-term monitoring program.

1.4 Objectives of the study

High mountain areas are characterised by special abiotic factors such as extreme environmental conditions, steep slopes, and the lack of higher vegetation. Consequently, these heterogeneous regions are regarded to be harsh environments with high spatial and temporal variability. The study area additionally featured the presence of rock-glaciers, reinforcing the temporal variability due to their influence on water temperature, flow regime and other physico-chemical parameters.

- Thus, this study especially focused on spatial and temporal variations along the lake/stream continuum.

Water samples were collected over a period of four months (July – October) in order to estimate temporal changes in chemical variables as well as spatial differences between sample sites. This, together with physical parameters assessed by in-situ measurements, and the fact that half of the sample sites went dry over the time of investigation, the hypothesis that the Macun Lakes area is a high alpine flood plain highly affected by environmental changes in space and time was confirmed.

The study also encompassed a number of secondary objectives:

- The development of a method for estimating moss abundance in stream segments in alpine floodplains.

This objective was completed to add to and enhance the long-term monitoring program of the Macun Lakes region. Moss abundance was assessed at selected sample sites. Mosses are sensitive to environmental change and thus provide good basic information for long-term monitoring.

- The measurement of dissolved oxygen concentrations in various stream reaches towards an understanding of spatial variability in the amount of oxygen as influenced by moss abundance.

To check whether mosses have an influence on the amount of oxygen over the day night cycle, oxygen saturation and the amount of dissolved oxygen was estimated at three sample sites. Two sample sites were affected by the presence of mosses, and one site had no moss coverage. We expected that channels with high moss abundance would exhibit greater variability in oxygen concentrations than channels lacking moss. Measurements were undertaken for a period of three days in August and September at each site.

- The application of GPS and the post processing of data in a GIS.

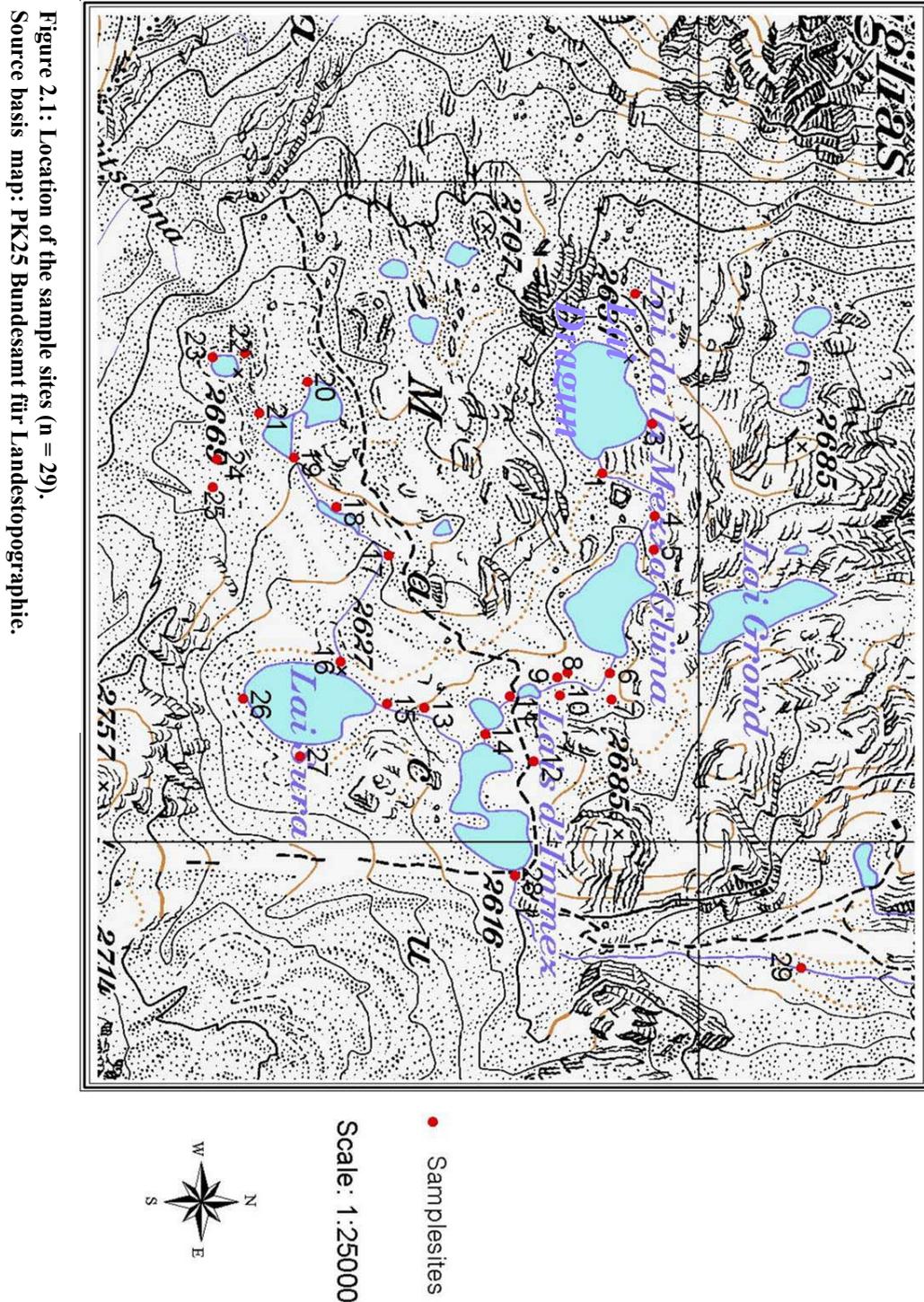
This objective was accomplished both with the goal of visualising the contraction of the flowpaths over the time of investigation and the purpose of locating sample sites for the long-term monitoring program.

2 Description of the study area

2.1 Geographical situation

The Macun area (3.6 km²) is located in Graubunden between the villages of Lavin and Zernez. It is a high alpine cirque with elevations over 2600 m a.s.l., and is surrounded by mountains of 2800 to 3100 m in the East, South and West. The main

outlet is to the North flowing steeply into the Engadine valley (1412 m a.s.l.), and drains into the Inn River (Schanz, 1984). The lakes are typical glacial-derived systems often referred to as cirque lakes and moraine dammed lakes, respectively (see Dodds, 2002). The southern part of the area is influenced by the presence of rock-glaciers. The location of all sample sites is shown in figure 2.1, coordinates and elevations can be found in Appendix A.



2.2 Swiss National Park

The Swiss National Park was the first national park in Central Europe, established on August 1st 1914. It is the only national park in Switzerland, covering an area of about 172 km² with an elevation range from 1400 to 3200 m a.s.l., and is

situated in the Engadine (canton Graubünden, southeast Switzerland). On August 1st 2000 the park was enlarged by the Macun Lake area (3.6 km²); the first step towards further plans of enlargement. According to the International Union for the Conservation of Nature (IUCN), the Swiss National Park belongs to the group of strict nature reserves (Category I) in which any kind of human interference is strictly prohibited. (Schweizerischer Nationalpark, 2001).

2.3 Geological situation

The Macun Lake area is situated in the middle of the “Nunagruppe” which is a part of the “Silvrettadecke”. In the East, the area is bordered by the “Unterengadiner Fenster”, in the South by the “Scarldecke” (Boesch et al., 1953). The crystalline subsoil mainly consists of orthogneiss. As a result of the characteristic tendency of crystalline rocks to slow weathering, it appears they have limited possibility of affecting the chemical composition of the lakes and streams in the study area (Bortolami, 1998).

2.4 Climate

Climate data were taken from Buffalora climate station (1968 m a.s.l.), located about 14 km southeast from the Macun area. Temperature data showed a wide interannual as well as interdaily range, 52.8°C and 22.8°C at its maximum, respectively. In 2001, the highest temperature recorded was 24.5°C on 31 July and the lowest temperature was -28.3°C on 24 December. The surrounding mountains, the Bernina massif in the Southwest, Silvretta in the North, and Ortler in the Southeast restrict the supply of moist air (Mürle, 2000), resulting in low precipitation rates (850 mm/y in 2001). The low winter and the quite high summer temperatures as well as the low precipitation rates characterise the continental climate of this region.

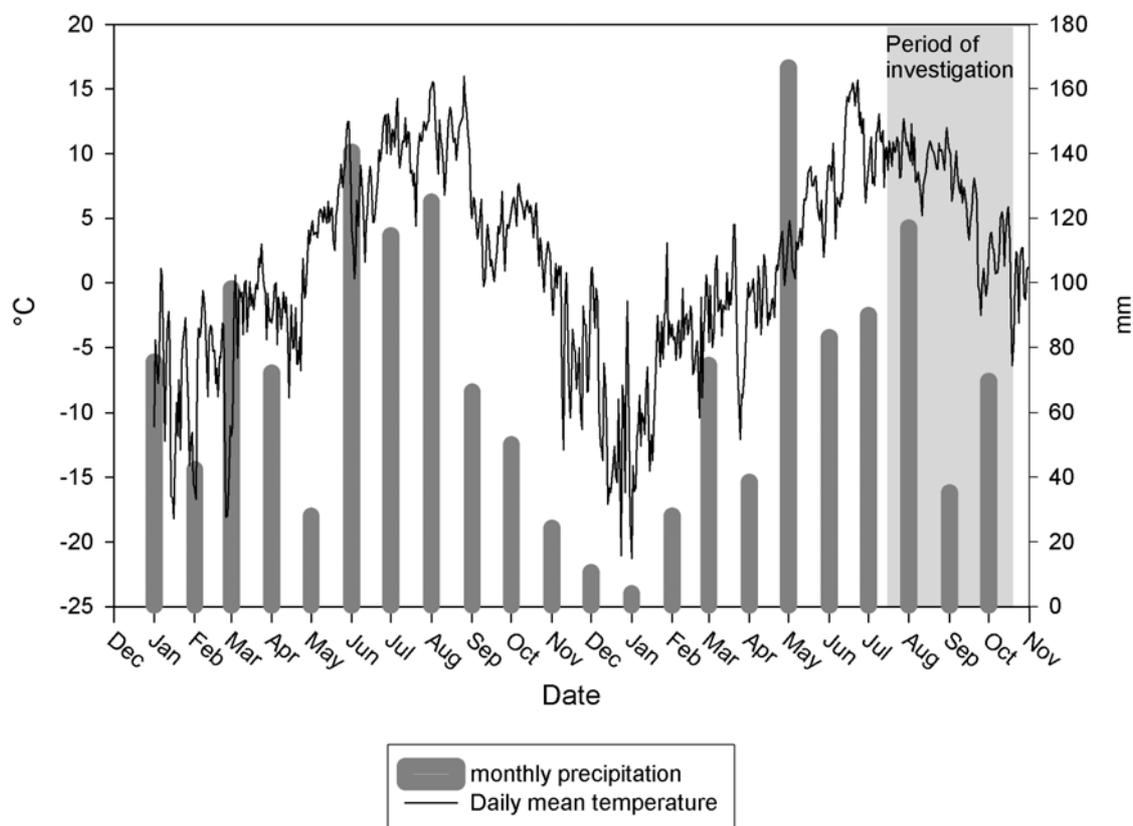


Figure 2.2: Daily mean temperature (°C) and average monthly precipitation (mm) at Buffalora climate station from January 1st 2001 until October 31st 2002. Meteo Schweiz kindly provided the data.

3 Methods and Materials

Simple, standardised methods must be used for long-term monitoring due to obvious changes in personnel over time and to get comparable data.

3.1 Sampling dates and investigated parameters

Sampling was limited to the period of July 2002 to October 2002 because of accessibility due to weather conditions.

Since more than half of all sample sites went dry during the period of investigation, water sampling as well as the collection of physico-chemical parameters ranged from 29 sites in July to 13 sites in October.

Table 3.1: Sampling dates for collection of different parameters

Date	Physico-chemical parameters	Water chemistry	GPS	Moss coverage	Substrate size	Dissolved Oxygen
15.07.- 19.07.02	X	X	X		X	
13.08.- 16.08.02	X	X		X	X	X
16.09.- 19.09.02	X	X	X		X	X
15.10.- 17.10.02	X	X				

3.2 Physico-chemical parameters

In-situ measurements included temperature, turbidity, conductivity, discharge, water velocity and dissolved oxygen.

3.2.1 Temperature

Water temperature was recorded continuously at 1-h intervals using StowAway™ XTI™ and StowAway™ TidbiT™ (Onset Corp., N. Falmouth, Massachusetts, USA) as well as TR MINILOG (VEMCO Ltd., Shad Bay, N.S., Canada) temperature loggers. Loggers were placed in stainless steel cases, installed at 17 locations in mid July, and retrieved in mid September. Some permanent sites had temperature recorded for one year. In the office, the recorded data were downloaded to the PC.

Additionally, temperature was measured manually at each sampling site each visit with a portable conductivity meter LF 323 (WTW, Weinheim, Germany) containing a temperature probe.

3.2.2 Turbidity

Turbidity was measured using a portable turbidity meter (Cosmos, Züllig AG, Rheineck, Switzerland) and expressed as NTUs (Nephelometric Turbidity Units).

3.2.3 Conductivity

Conductivity measurements were performed with a portable LF 323 conductivity meter (WTW, Weinheim, Germany). The reference temperature was set at 20°C, and conductivity was expressed in $\mu\text{S}/\text{cm}$.

3.2.4 Discharge

For the calculation of discharge, an integrating salt-dilution discharge meter (Husky, Hunter) was used. A NaCl-tracer solution (1 kg NaCl per 5 L water) was added to the stream to establish a concentration-time curve by measuring the arriving conductivity. Conductivity was measured at a point where lateral mixing was suspected to be complete (approximately 30+ metres downstream). The integrating salt-dilution discharge meter calculated discharge from integration of the “concentration hydrograph” (Gordon et al., 1992). The equation for computing discharge is (Shaw, 1988):

$$Q = 1000 \frac{\nabla c_t}{\int_{t_1}^{t_2} (c - c_0) dt}$$

Where:

Q = Discharge of the stream

∇ = Volume of tracer solution introduced into the stream

c_0 = Background concentration of the stream

c = Changing concentration of tracer measured downstream

c_t = Concentration of tracer in introduced solution

t_1 and t_2 = Initial and final times of measurement (in seconds)

3.2.5 Velocity

Current velocity was measured with a portable velocity meter (MiniAir2, Schildknecht) expressed in m/sec.

3.2.6 Oxygen

Oxygen measurements were performed with a calibrated portable Oximeter Oxi 340-B/Set (WTW, Weinheim, Germany). Oxygen was expressed as mg/l and in % saturation. In August as well as in September the amount of oxygen at three different sites was recorded continuously at 1-h intervals for a period of 72 h.

Two sites were covered by moss, whereas one site had no moss present. The probes were fixed at 10 cm depth in the stream water where current velocity was at least 0.17 m/sec. The Oximeter itself was enclosed in a waterproof plastic box (Fig. 3.1).



Figure 3.1: Experimental set-up for dissolved oxygen measurements.

Since saturation of oxygen is influenced by the current O_2 partial pressure and temperature, measured oxygen data were corrected by the following equations:

$$S_0 = 14.60307 - t * 0.4021469 + t^2 * 0.00768703 - t^3 * 0.0000692575$$

$$P_m = 10^{[\log(760) - m/18400]}$$

$$S_m = S_0 * P_m / 760$$

Where:

t = Water temperature

So = Saturation at 760 Torr

Sm = Saturation at m a.s.l

Pm = Atmospheric pressure at m a.s.l in Torr.

3.3 Water chemistry

Water samples were taken with a rinsed 250 ml plastic cylinder and filtered through a pre-ashed (500°C) glass fibre filter (Whatman GF/F, Ø 47 mm, mesh ~0.7 µm) using a hand pump. The first filter was not used, the filtered water was used to rinse a 300 ml polyethylene bottle. Then two aliquots (250 ml) were each filtered through a pre-ashed filter, and the filters stored in plastic petri dishes. Filtered water (300 ml) was poured in the rinsed polyethylene bottle and 15 ml was poured in a 15 ml polypropylene tube for the detection of heavy metals. The latter were cleaned prior to filling with 0.01 M HNO₃ for at least 24 h. The sample was acidified with HNO₃ (65% suprapur) to prevent adsorption of metal ions to the sides of the container (Reeve, 2002). Filtered and unfiltered blanks showed that the glass fibre filters increased the zinc values, therefore membrane filters should be used for future filtering. Furthermore, the 300 ml polyethylene bottles increased the DOC values, thus small glass bottles were used for the analysis of DOC in September 2002. Filtered water and filters were stored between one and three days at 4°C (water) or frozen (filters) before analysis in the laboratory.

One filter was used for the analysis of particulate organic carbon (POC), and another filter for particulate nitrogen and phosphorus (PN/PP). The filtered water served for analysis of ammonia (NH₄-N), nitrite (NO₂-N), nitrate (NO₃-N), dissolved nitrogen (DN), phosphate (PO₄-P), dissolved phosphorus (DP), dissolved organic carbon (DOC), total inorganic carbon (TIC), silica (SiO₂), sulphate (SO₄), calcium (Ca²⁺), magnesium (Mg²⁺), sodium (Na⁺), potassium (K⁺), chlorine (Cl⁻), and the heavy metals lead (Pb), copper (Cu), manganese (Mn), cadmium (Cd), iron (Fe) and zinc (Zn).

3.3.1 Particulate organic carbon (POC)

Pre-ashed (500°C) Whatman GF/F filters containing particles from 250 ml filtered stream water were ashed at 880°C. The developing CO₂ was removed with nitrogen and quantified in a Fuji electric infrared gas analyser (Uehlinger et al., 1984).

3.3.2 Particulate nitrogen and particulate phosphorus (PN/PP)

Pre-ashed (500°C) Whatman GF/F filters containing particles of 250 ml filtered stream water were digested with a K₂S₂O₈ solution at 121°C at 1.1 bar (Ebina et al., 1983). Nitrogen compounds were hydrolysed to nitrate, and phosphorous compounds to ortho-phosphate. Further determinations are described in section 3.3.5 (nitrate) and 3.3.7 (phosphate).

3.3.3 Ammonia (NH₄-N)

Ammonia was determined using the Indophenol-blue method (Eidgenössisches Departement des Inneren, 1983).

3.3.4 Nitrite (NO₂-N)

Nitrite was quantified by photospectroscopy using a Hitachi U-1000 Spectrophotometer (DEV, 1989).

3.3.5 Nitrate (NO₃-N)

Nitrate was determined according to Downes (1978) and Stöckli (1985) with the automated hydrazine reduction method and subsequent Griess-reaction to a red azo dye by continuous flow analysis in a Bran+Luebbe Autoanalyzer 3 Spectrophotometer.

3.3.6 Dissolved nitrogen and dissolved phosphorus (DN/DP)

For the assessment of dissolved nitrogen and dissolved phosphorus, total dissolved phosphorus (TDP) and nitrogen were oxidised with K₂S₂O₈ at 121°C at 1.1 bar to nitrate and ortho-phosphate (Ebina et al., 1983) and quantified colorimetrically for nitrate and phosphate determination.

3.3.7 Phosphate (Soluble reactive phosphorus, ortho-phosphate, PO₄-P)

The assessment of PO₄-P concentrations was according to the molybdenum blue method (Vogler, 1965), using continuous flow analysis in a Bran+Luebbe Autoanalyzer 3 Spectrophotometer.

3.3.8 Dissolved organic carbon (DOC)

DOC was measured by first acidifying the filtered water samples with HCL. The inorganic particles were thereby decomposed to CO₂ which was stripped with clean air. The remaining organic carbon was then burned at 680°C, and the emerging CO₂ was analysed with a Shimadzu TOC-5000A Analyser by non-disperse IR gas analysis.

3.3.9 Total inorganic carbon (TIC)

For the determination of total inorganic carbon, the filtered water sample was enclosed in an IC reaction container and acidified by phosphorous acid. Carrier gas was bubbled through the sample and took along with the CO₂, which was finally analysed in the non-disperse IR gas analyser.

3.3.10 Silica (SiO₂)

Silica was quantified by the heteropolyblue method, using continuous flow analysis (CFA) (APHA, 1985).

3.3.11 Sulphate (SO₄) and Chlorine (Cl)

Sulphate and chlorine were measured by Ion Chromatography.

3.3.12 Calcium (Ca²⁺), magnesium (Mg²⁺), sodium (Na⁺) and potassium (K⁺)

Calcium, magnesium, sodium and potassium were determined by an inductive coupled emission spectrometer (SPECTRO, Analytische Geräte, Kleve, Germany).

3.3.13 Heavy metals

Lead (Pb) and cadmium (Cd) were assessed by Atomadsorption Spectrometry (GAAS: Perkin-Elmer 5100 ZL), and copper (Cu), manganese (Mn), iron (Fe) and zinc (Zn) by induced coupled plasma-optical Emission Spectrometry (ICP-OES: Spectro Ciros).

3.4 Global Positioning System (GPS) / Geographic Information System (GIS)

Trying to figure out where you are and where you're going is probably one of man's oldest pastimes (Trimble, 2002). Nowadays this goal is reached by having access to GPS-technology. It is a satellite-based radio positioning system that provides a 24 hour, three dimensional position, velocity and time information to users with suitable ground receiving equipment (Van Sickle, 1996). There are currently two GPS systems available to civilian users. The NAVSTAR system is owned by the United States and is managed by the Department of Defense. The GLONASS system is owned by the Russian Federation. While both NAVSTAR and GLONASS systems are global positioning systems, the NAVSTAR system is often referred to (in the U.S., anyway) as *the* GPS because it was generally available first.

In this study, a differential GPS (DGPS, type Pro XR/XRSTM, Trimble Navigation limited, Sunnyvale, CA, USA) was used to record the coordinates of all sample sites, and to map the flow paths in the study area, in order to show spatial and temporal changes in the channel network. Differential GPS involves the cooperation of two receivers, one is placed above a known point (Base), while the other is moved around (Rover) to unknown points within the survey area (Brasington et al., 2000). A stationary base in Zürich (Latitude: 47°22'55.09510" N, Longitude: 8° 32' 32.81330" E, Height: 494.841 m) served as base with a 5 sec logging interval and an elevation mask set to 4° to the receiver Trimble 5700. The rover used during the field survey was set to an elevation mask of 10°, to a logging interval of 5 sec and to the overdetermined 3-D mode. The coordinate system was set to CH 1903 and the PDOP mask to 6.0. The carrier mode was on, with a minimum time of 45 min, and 5 satellites. With these settings, the data acquisition was done by stop and go point measurements (Brasington

et al., 2000). Data from the rover were post processed by the software package Pathfinder Office 2.70 with Centimeter Option (Trimble Navigation limited, Sunnyvale, CA, USA) using data from the base station which was downloaded before from the internet (<http://www.allnav.ch/ssfzh1/index.htm>). Afterwards the recorded point features were exported as shape files into the Geographic Information System ArcView 3.2aTM (ESRI, Redlands, CA, USA) and digitised to show the extent of the channel network.

3.5 Moss coverage

At 7 sample sites, mosses were collected and sent for identification. Moss coverage was assessed by transects. Moss thickness (cm) was measured every 30 cm across the channel width. This procedure was repeated every 2 m downstream for a total reach length of at least 10 m. In order to find the same location for future investigations, the coordinates were recorded by GPS. Thickness data were statistically analysed with excel 97TM (Microsoft Corporation, USA) and smoothed to develop a 3D graph with sigma plot 7.0TM (SPSS Science, Chicago, IL, USA).

3.6 Substrate size

Substrate size was assessed at 17 sample sites by measuring the b-axis of 50 randomly selected stones. The results were divided into 3 classes: gravel (2-64 mm), cobble (64-256 mm), and boulder (>256 mm); distribution was expressed in %. Statistical analyses were done using excel 97TM, visualisation by sigma plot 7.0TM. Additionally, slope at each study site was measured with a clinometer.

3.7 Statistical analysis

The descriptive statistic comprised the calculation of mean, minimum, maximum, range, standard deviation, standard error, median and coefficient of variation. One-way ANOVA was used to compare differences in physico-chemical parameters among dates for all sample sites combined, for permanent southern sites combined and for permanent northern sites combined. Supplementary one-way ANOVAs were used to test differences among the permanent southern sites, the

permanent northern sites, the temporary southern sites, and the temporary northern sites for July. A two-way ANOVA was applied to determine effects of space and time on physico-chemical parameters among the permanent southern and northern sites. An effect was considered to be significant if $p < 0.05$. In this case, each ANOVA was followed by a Post Hoc Tukey Test. Before accomplishment of each ANOVA, data were log transformed ($\log(x+1)$; Zar, 1984).

Principal components analysis (PCA) was used to visualise important variables that separated or grouped sites among sampling dates. Data were transformed (average = 0, standard deviation = 1) prior to analysis. Parameters with data gaps were not taken into consideration for any statistical analyses. All calculations were accomplished with excel 97TM and Statistica 6.0[©] (StatSoft, Inc., Tulsa, OK, USA).

4 Results and Discussion

4.1 Thermal patterns

Temperature loggers were installed at 17 selected sample sites (Fig. 4-1). Data of the logger at site 15 could not be used due to battery failure. All temperature data of the remaining 16 loggers showed a temperature decrease in mid August. This decrease was caused by heavy precipitation and low air temperatures (see climate data of Buffalora climate station, Fig. 2.1). The cold rain and snow (min. air temperature 600 m below the study area at the climate station was already -1.4°C on 14.08.02) cooled water temperatures.

A strong decrease in water temperature from all surface spot measurements was observed from September to October. A one-way ANOVA showed significant differences in temperature between July and October ($p = 0.004$), August and October ($p = 0.0003$) and between September and October ($p = 0.002$).

A minimum water temperature of -0.68°C was measured in the main channel below sample sites 24 and 25 on 15.09.02, reflecting the influence of the rock-glacier above. Maximum temperature, on the other hand, reached a value of 26.8°C on 28.07.02 at sample site 27 (Table 4.1). This extremely high value was recorded probably because

sample site 27 was a small shallow seep; thus the logger could not be placed deep in the waterbody and therefore was strongly effected by radiation. Slow velocities and low discharge (ca. 1.4 l/sec) reinforced this effect, as well as a low gradient area above the seep where water could be heated in small pools.

The whole floodplain can be divided into two main areas, one northern and one southern, according to the origin of their water. The northern system appeared to be mainly affected by groundwater, whereas the southern system seemed to be mainly fed by glacial meltwater. Compared to the South, water temperatures were generally higher for the whole period of investigation in the North (Fig. 4.2). Temperature differences between the North and South were highest in July and August due to the cooling effect of glacial melt-water in the South, and approached similar temperatures in September and October as a result of abating glacial influence. The water of both systems drains into Lake Immex.

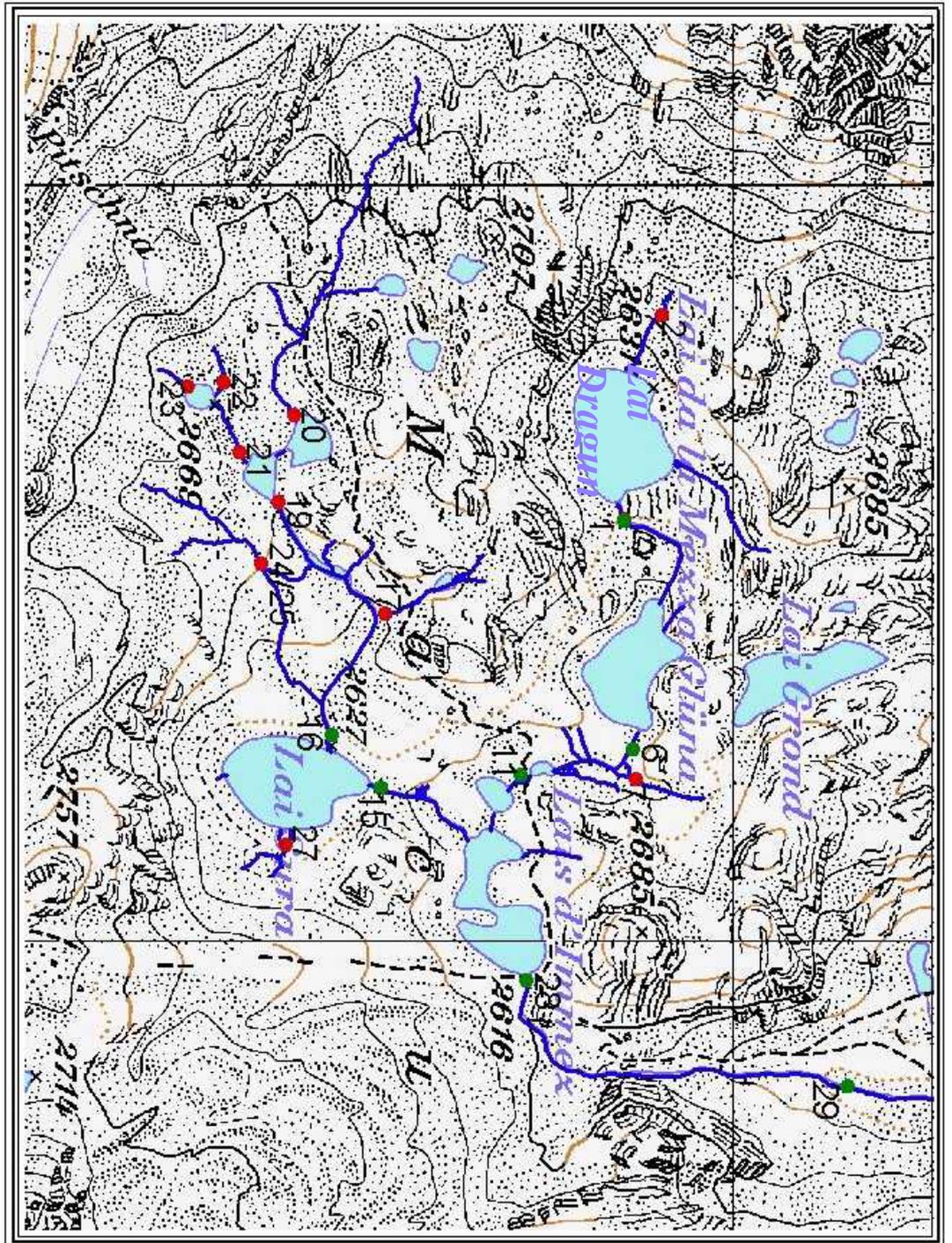


Figure 4.1: Temperature logger locations.
 Source basis map: PK25 Bundesamt für Landestopographie.

Table 4.1: Minimum (Min), maximum (Max), mean, standard deviation (\pm SD) and coefficient of variation (CV as %) of temperature logger data for July, August, and September 2002 separately and for the period July until September 2002.

Sample Site	Date	Min	Max	Mean	\pm SD	CV(%)
1	Jul.	7.77	13.02	10.07	1.22	12.11
	Aug.	7.31	13.02	10.47	1.01	9.64
	Sept.	8.07	11.47	9.36	0.76	8.12
	Jul.-Sept.	7.31	13.02	10.10	1.11	10.99
2	Jul.	0.67	1.47	0.93	0.20	21.46
	Aug.	0.51	1.47	0.92	0.19	20.72
	Sept.	0.67	1.14	0.98	0.12	12.26
	Jul.-Sept.	0.51	1.47	0.94	0.18	19.15
6	Jul.	5.34	16.22	10.88	1.83	16.82
	Aug.	7.06	15.12	11.02	1.51	13.70
	Sept.	7.21	12.78	9.33	1.29	13.82
	Jul.-Sept.	5.34	16.22	10.60	1.71	16.13
7	Jul.	4.94	12.41	7.61	2.03	26.69
	Aug.	4.01	11.94	7.28	1.71	23.50
	Sept.	3.38	14.28	7.06	2.07	29.32
	Jul.-Sept.	3.38	14.28	7.27	1.87	25.72
11	Jul.	4.56	19.27	10.74	3.24	30.17
	Aug.	4.87	18.14	10.38	2.76	26.60
	Sept.	4.56	12.94	8.16	1.95	23.88
	Jul.-Sept.	4.56	19.27	9.95	2.91	29.25
16	Jul.	2.42	14.21	7.27	2.76	37.97
	Aug.	1.16	13.28	6.32	2.58	40.79
	Sept.	3.21	9.88	5.72	1.53	26.76
	Jul.-Sept.	1.16	14.21	6.40	2.47	38.59
17	Jul.	6.89	15.11	9.08	1.91	21.03
	Aug.	2.98	16.06	8.24	2.32	28.14
	Sept.	1.24	16.38	6.61	2.83	42.81
	Jul.-Sept.	1.24	16.38	7.87	2.59	32.91
19	Jul.	3.99	14.07	7.97	2.23	27.99
	Aug.	1.30	11.91	7.19	2.18	30.31
	Sept.	3.83	9.26	6.07	1.24	20.44
	Jul.-Sept.	1.30	14.07	7.09	2.11	29.76

Table 4.1: Minimum (Min), maximum (Max), mean, standard deviation (\pm SD) and coefficient of variation (CV as %) of temperature logger data for July, August, and September 2002 separately and for the period July until September 2002 (continued).

Sample Site	Date	Min.	Max.	Mean	\pm SD	CV(%)
20	Jul.	2.30	18.60	6.63	2.61	39.36
	Aug.	1.30	14.20	6.15	2.62	42.62
	Sept.	-0.10	12.10	5.08	2.06	40.52
	Jul.-Sept.	-0.10	18.60	6.00	2.60	43.33
21	Jul.	1.11	19.58	8.21	3.82	46.52
	Aug.	0.14	20.55	7.10	4.15	58.42
	Sept.	-0.49	17.16	5.96	3.33	55.86
	Jul.-Sept.	-0.49	20.55	7.11	3.95	55.56
22	Jul.	2.67	12.97	5.74	2.42	42.14
	Aug.	1.39	14.53	8.36	2.93	35.04
	Sept.	6.12	11.57	8.23	1.15	13.97
	Jul.-Sept.	1.39	14.53	8.07	2.60	32.22
23	Jul.	0.25	0.57	0.35	0.08	23.08
	Aug.	0.09	1.22	0.48	0.23	47.54
	Sept.	0.41	6.57	1.19	1.03	86.20
	Jul.-Sept.	0.09	6.57	0.68	0.67	98.53
24/25	Jul.	-0.03	11.09	3.63	2.90	79.93
	Aug.	-0.03	8.30	2.37	2.04	86.15
	Sept.	-0.68	10.32	2.40	1.88	78.24
	Jul.-Sept.	-0.68	11.09	2.70	2.33	86.30
27	Jul.	4.67	26.79	10.66	5.25	49.25
	Aug.	0.23	24.71	8.35	5.11	61.20
	Sept.	-0.90	19.86	5.63	3.86	68.51
	Jul.-Sept.	-0.90	26.79	7.83	5.06	64.62
28	Jul.	5.20	14.00	10.11	1.75	17.31
	Aug.	4.60	13.20	9.95	1.83	18.40
	Sept.	7.00	11.00	8.59	0.87	10.12
	Jul.-Sept.	4.60	14.00	9.67	1.74	17.99
29	Jul.	4.52	9.64	6.54	1.35	20.66
	Aug.	2.96	10.27	5.96	1.34	22.49
	Sept.	3.43	8.25	5.04	1.04	20.64
	Jul.-Sept.	2.96	10.27	5.76	1.36	23.61

After flowing through the lake, the water temperature at the lake outlet (site 28) is nearly the average water temperature between the northern and southern systems. About 500 m downstream (site 29), essentially outside the Macun area, water temperature is cooled due to the input of a rock-glacier between sample site 28 and 29. Based on the influence of that rock-glacier, sample site 29 showed similar thermal patterns as the southern rock-glacier influenced system of the Macun area. The thermal patterns explained above are shown in Figure 4.2.

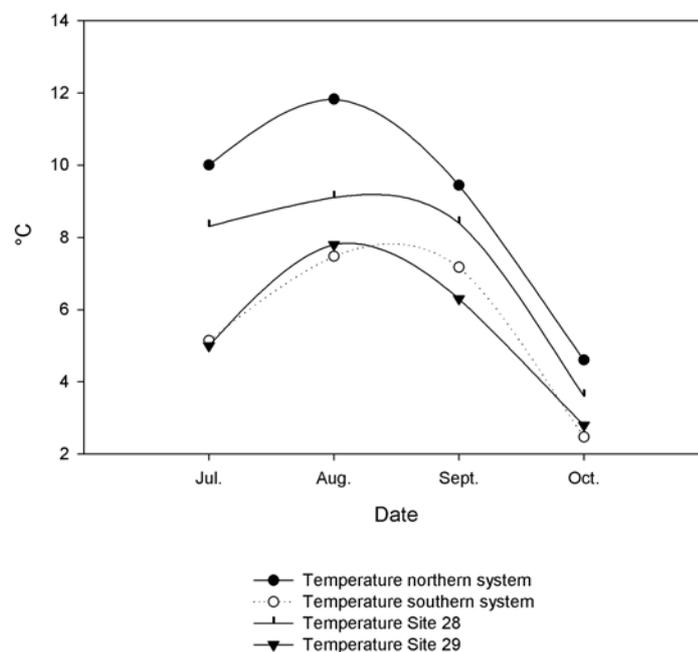


Figure 4.2: Thermal pattern comparison of the North system (monthly mean temperature of all permanent northern sites (n = 6)), South system (monthly mean temperature of all permanent southern sites (n = 7)), site 28 and site 29 over time (July-October 2002). Temperature data were assessed by monthly surface water spot measurements.

In the northern as well as in the southern system exist several temporary sites which became dry during July and August, respectively. These sites showed the greatest temperature diel amplitude. The highest value of these daily fluctuations was measured at site 27 (20.1°C). However, the permanent sites also had quite high diel amplitudes (max. amplitude at site 16: 10.2°C), reflecting the large influence of air temperature and the lack of a tree canopy.

Exceptions to these high diel fluctuations were observed at site 2 and site 23 which seemed to be directly influenced by the meltwater of rock-glaciers. In stream segments adjacent to a glacier, temperatures vary around 0°C with seasonal fluctuations

of only 1 or 2°C (Uehlinger, Zah & Ward, 1998; Füreder, 1999). As a consequence, the most stable thermal conditions were measured at the two sites adjacent to the glacier. For example, the diel amplitude only reached maximum values of 0.49°C (site 2) and 0.97 °C (site 23), and amplitudes over the period of investigation were 0.96°C at site 2 and 1.13°C at site 23. Although also being influenced by glacial meltwater, the temperature logger in the main channel below site 24 and 25 recorded higher daily temperature amplitudes (max. amplitude: 10.2°C). This result is attributed to the greater longitudinal distance (ca. 150 m) from the rock-glacier and the greater influence of air temperature.

Figure 4.3 shows the thermal patterns of the northern and southern systems with closer consideration of downstream temperature changes. Red curves indicate the downstream temperature gradient of the northern main channel from sample site 1 (highest elevation) over sample sites 6, 11 and 14 to sample site 28 for the period from July to October. Black curves indicate the same for the southern main channel with sample sites 20 (highest elevation), to 19, 16, 15 and 28, respectively. At sample site 28 the water from both systems is mixed, after passing through Lake Immex.

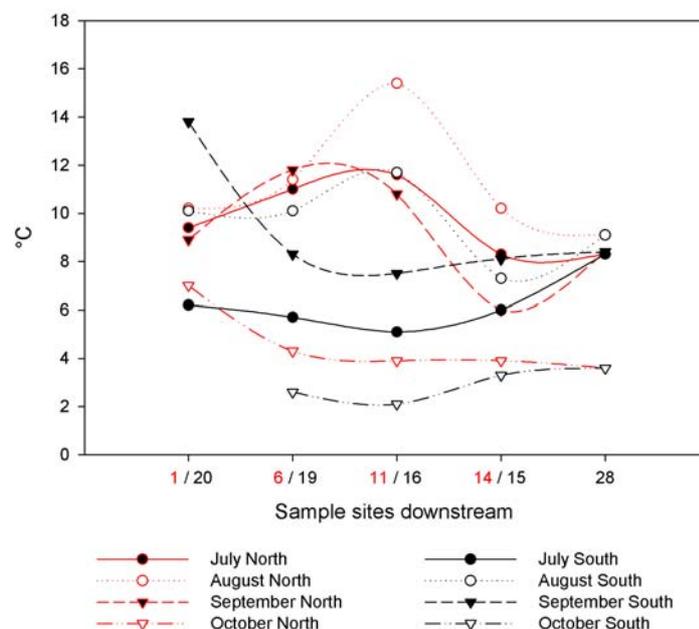


Figure 4.3: Thermal patterns vs. space (downstream, and North/South differentiation) and time. Red curves indicate temperatures for the northern system moving downstream (sites 1, 6, 11 and 14), black curves temperatures for the southern system moving downstream (sites 20, 19, 16 and 15). Temperature data were assessed by monthly surface water spot measurements (July-October 2002).

Considering the red curves (northern system) a general downstream temperature increase occurred from site 1 to site 11 and a decrease from site 11 to site 28 from July through September. The increase of 4°C from site 6 to site 11 (longitudinal distance ca. 200 m) in August is due to strong radiation that heated the shallow water in the stony plain between the two sites. At site 14, temperature decreased again because water of the small lake upstream of site 14 retained latent heat. Sample site 1, located at the outlet of Lake Dragun, had the highest temperature in October compared to sample sites downstream. Lake Dragun functions as a temperature buffer, accumulating the heat during summer and retaining it in autumn.

Considering the black curves (southern system), a temperature decrease from site 20 to site 16, and an increase from site 16 to site 28 occurred from July through October. In August, temperature increased from site 20 to site 16 (Lake Sura inlet), and cooled by 4.4°C at site 15 (Lake Sura outlet). Water reached the lowest temperature at the lake outlet (site 15) in August compared to the upstream sites. Water temperature in September and October was higher in the outlet (site 15) than in the lake inlet (site 16). An explanation for the higher outlet vs. inlet temperatures in autumn is the abating influence of glacial melt-water that drains into the South of Lake Sura.

At sample sites 1, 6, 11, 15, 16, 28 and 29 temperature loggers were already installed in September 2001, thus temperature patterns for an annual cycle are available. Data for site 15 are not available for July to September 2002. The recorded temperature showed essentially no pattern between mid November and mid June (temperature about 0°C, Fig. 4.4). Temperature decreased to about 0°C in the three lake outlets (site 1, 15 and 28), first in mid January due to accumulated heat in the lakes. Water temperature then strongly increased from mid June to mid July (Fig. 4.4). Consequently, degree-days also increased strongly from June to July (Fig. 4.5a). Daily temperature fluctuations also increased in this period, decreasing again in autumn with decreasing water temperature (Fig. 4.4)(cp. Meyer, 1990; Crisp & Le Cren, 1970). Compared to September 2001, average water temperature was 3.5°C higher in September 2002. Mean air temperature at Buffalora climate station was 3.4°C in September 2001 and 5.1°C in September 2002.

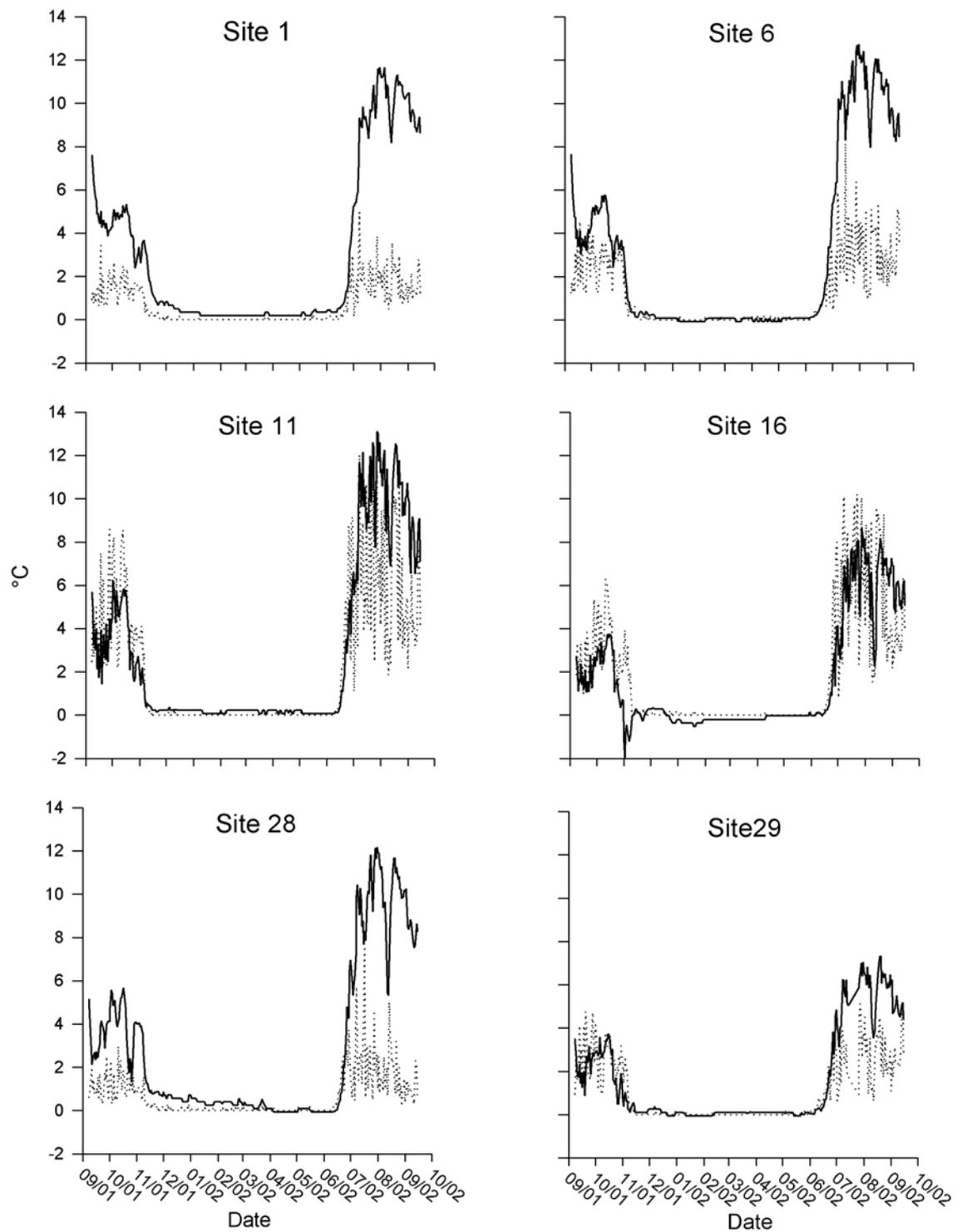


Figure 4.4: Patterns of stream temperature at selected sites (n = 6) from Sept. 2001 to Sept. 2002. Curves indicate daily mean temperatures and daily range of logger data. Daily mean temperature °C: solid line, Daily range °C: dotted line.

Annual degree-days were highest at site 1 (972) and decreased downstream from site 6 (960) to site 11 (927) (Fig. 4.5b). This pattern is due to the slightly higher monthly heat sums from September 2001 to February 2002 at site 1 compared to sites 6 and 11 (Fig. 4.5a), caused by released heat from Lake Dragun.

Sites 16 and 29, both influenced by glacial meltwater, showed similar temperature patterns. Degree-days for each month were nearly zero from November 2001 to May 2002. From June 2002 to July 2002 degree-days increased from 20 to 188 (site 16) and from 32 to 164 (site 29). For sites 1, 6, 11, and 28 a stronger increase was observed, as these sites reached on average 288 degree-days in July (Fig. 4.5a). The lower heat sums for site 16 and 29 are also reflected in their annual degree-days, reaching values of 519 and 527, respectively.

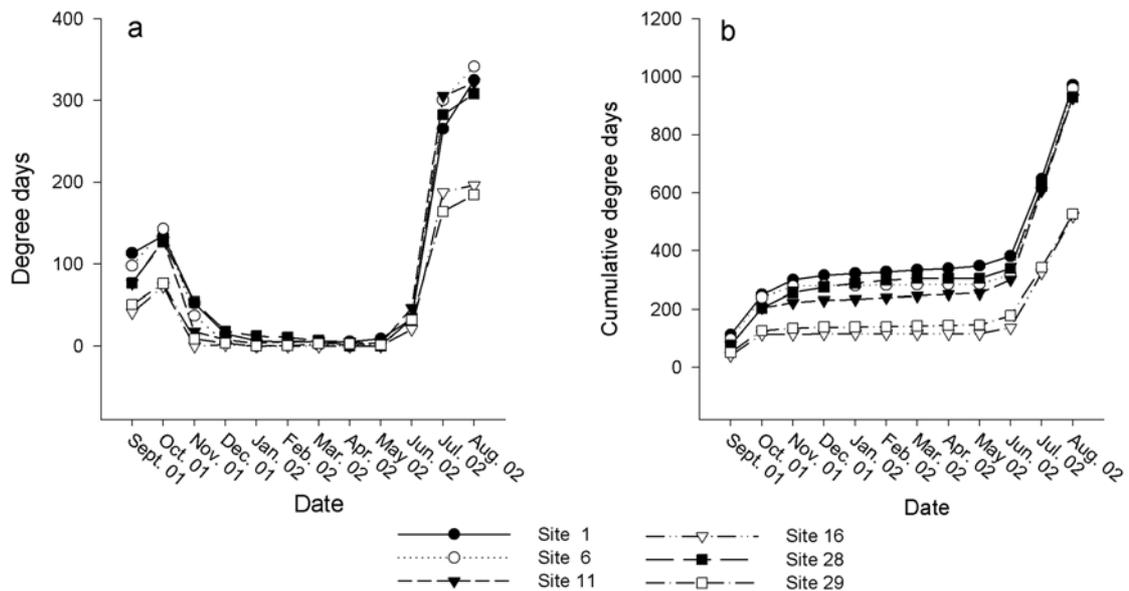


Figure 4.5: Monthly degree days (a) and cumulative degree days (b) of monthly temperature sums (= average monthly temperature * no. of days) from September 2001 until August 2002.

4.2 Oxygen

From August 13 to 16, 2002 the amount of dissolved oxygen was recorded continuously at 1h intervals at sample sites 1, 14 and 19. From September 16 to 19, 2002, oxygen measurements were undertaken at sample sites 1, 15 and 19 because sample site 14 was dry. Thus, I primarily will compare site 1 and site 19 in the following. Sample sites 14, 15 and 19 were influenced by the presence of mosses, whereas sample site 1 had no moss present. The weather was sunny in both months during the period of measurement, so higher amplitudes of dissolved oxygen were expected at the moss covered sites due to higher photosynthetic activity.

Indeed, site 1 showed the smallest amplitudes of dissolved oxygen in both months (0.59 mg/l in August and 0.56 mg/l in September) (Fig. 4.6, cp. Fig. 4.8) but also the smallest amplitudes in temperature (3.6°C in both months) (Table 4.2). These stable thermal conditions are attributed to the lake outlet, where temperature is ameliorated by Lake Dragun. As a consequence, small fluctuations in dissolved oxygen seemed mainly to be a result of physical processes.

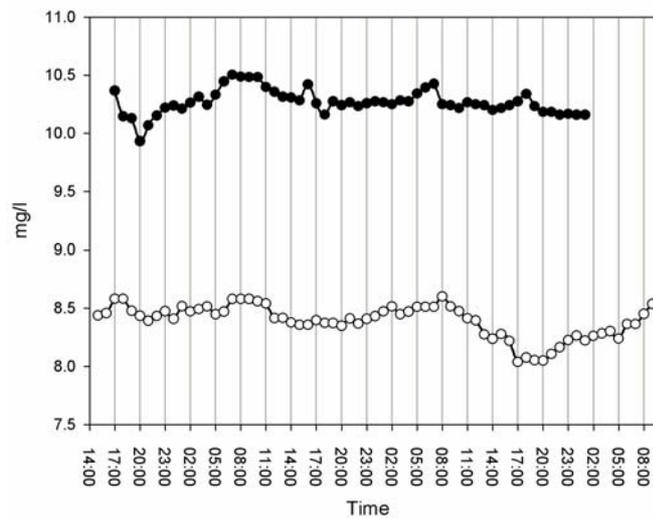


Figure 4.6: Dissolved oxygen (mg/l) at sample site 1 in August (filled circles) and September (open circles).

In August, the highest mean temperature and highest value for dissolved oxygen was measured at site 1, causing a mean over-saturation of 123 % (Table 4.2, Fig. 4.7).

Site 19, on the other hand, had the lowest mean temperature and a lower mean value for dissolved oxygen but was still over-saturated (102 %) in August (Table 4.2).

Table 4.2: Mean, range, coefficient of variation (CV as %) for dissolved oxygen (mg/l), oxygen saturation (% saturation), and temperature (°C) in August and September at sample sites 1, 14, 15 and 19.

		August			September		
		1	14	19	1	15	19
mg/l	Mean	10.2	8.3	9.1	8.4	8.6	9.5
	Range	0.5	1.2	1.7	0.5	1.1	1.2
	CV (%)	1.0	3.4	5.5	1.7	3.3	3.7
% Saturation	Mean	123.4	99.7	102.4	99.2	98.6	102.7
	Range	12.5	12.1	12.2	8.0	4.6	8.7
	CV (%)	2.6	3.2	3.4	2.0	1.5	1.9
°C	Mean	9.1	9.0	6.3	8.4	6.9	4.3
	Range	3.6	8.2	9.5	3.6	6.0	5.8
	CV (%)	11.4	24.7	40.3	12.5	24.3	32.1

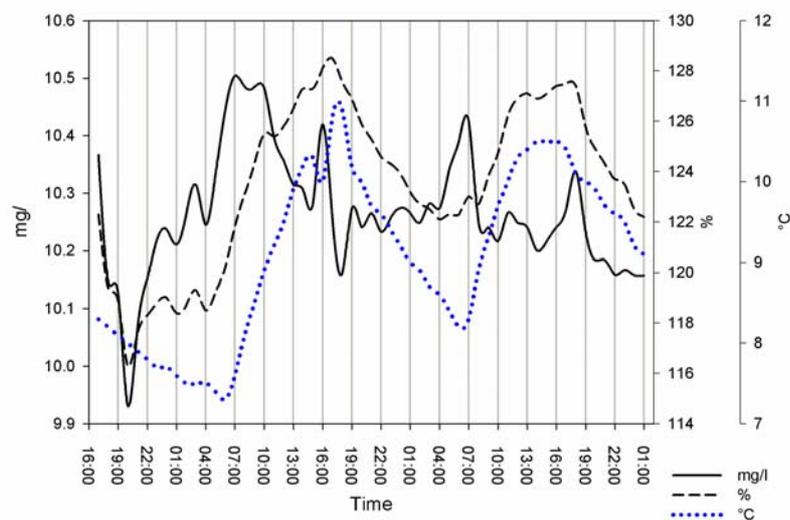


Figure 4.7: Dissolved oxygen (mg/l), saturation (%) and temperature (°C) at sample site 1 in August.

A distinct pattern was observed at site 19 in August. During the period of investigation, temperature rose continuously, and as a consequence, dissolved oxygen decreased. Heavy rainfall occurred for three days before the period of measurement in August, perhaps enhancing values for dissolved oxygen due to the input of cold, oxygen rich

rainwater (see chapter 4.1). The resulting higher discharge may have provided better aeration, reinforcing the increase in oxygen. Uehlinger, Naegli and Fisher (2002) found similar results, where a small spate resulted in a distinct but transient increase in oxygen. Beneath raising temperatures, the abating influence of the oxygen saturated rainwater might have been another reason for the decrease in dissolved oxygen during the period of investigation.

The high diurnal variation in dissolved oxygen as observed at site 19 in August and September (Fig. 4.8) is usually due to photosynthesis, and not aeration, since oxygen production is high during daylight hours, but not at night (Hitchman, 1978). Jakob and Tschumi (1988) found similar results with highest oxygen values between 10:00 and 16:00 hour. However, highest concentrations of dissolved oxygen were measured in the morning (ca. 7:00 hour) when temperatures were lowest. Oxygen concentrations were lowest with highest temperatures in the afternoon (ca. 18:00 hour). The opposite was shown by the curve for saturation, which followed the pattern of the temperature curve (Fig. 4.9). This leads to the suggestion that site 19 also is mainly affected by physical instead of biological processes.

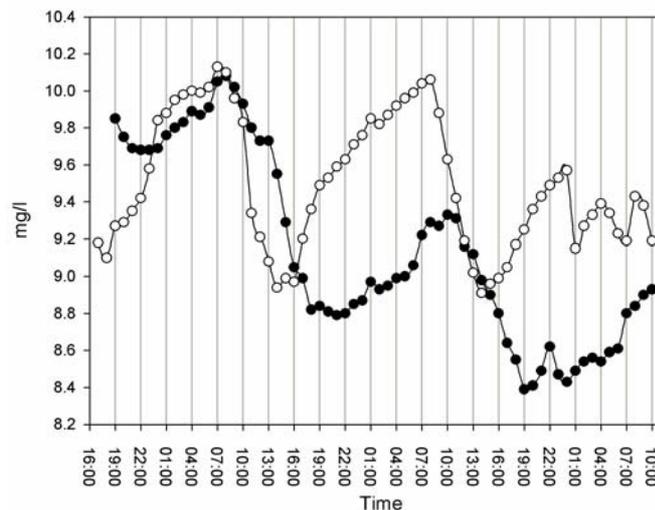


Figure 4.8: Dissolved oxygen (mg/l) at sample site 19 in August (filled circles) and September (open circles).

Although diel fluctuations in dissolved oxygen were low at site 1, values were about 2 mg/l higher in August than in September (Fig. 4.6). Site 19, in contrast, had high diel

fluctuations in dissolved oxygen, but smaller differences between August and September (Fig. 4.8). Perhaps the presence of mosses facilitates a stable oxygen balance.

Oxygen values were higher at site 1 in August, whereas in September values were higher at site 19 (Table 4.2).

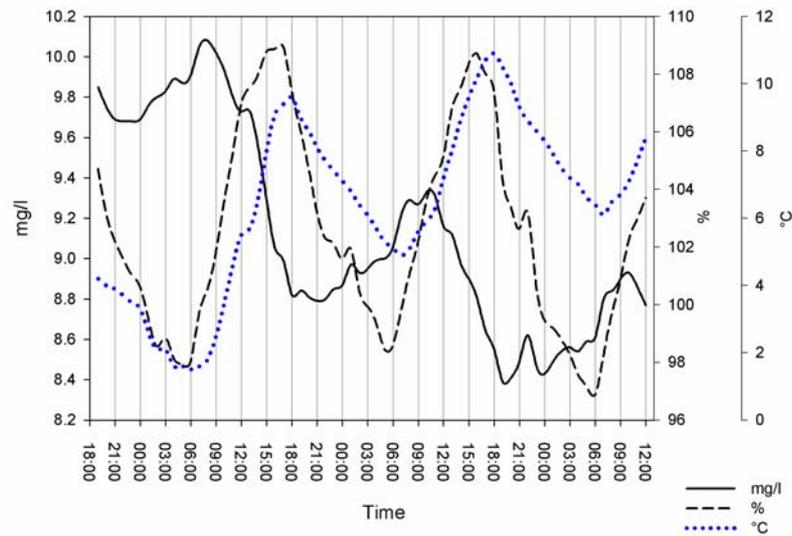


Figure 4.9: Dissolved oxygen (mg/l), saturation (%) and temperature (°C) at sample site 19 in August.

Oxygen concentrations of a natural stream are affected by four main processes: photosynthetic production, diffusion, respiration and drainage accrual (El-Shaarawi, 1988). These parameters were not determined due to logistic and transportation problems of equipment to the remote area of the Macun Lakes. Thus it is not possible to make a predication about metabolism. Another reason why discussing the results, especially the effect of mosses on oxygen balance of the selected stream segments are only assumptions, is the fact that both sample sites are in the reach of a lake. Hence the oxygen measurements were influenced by the lakes metabolism.

4.3 Physico-chemical parameters

Physico-chemical data for sites that were sampled for at least two months are summarised in Table 4.3.

In general, concentrations of measured parameters were below the critical limit for drinking water based on material from DVWK (1993). Because concentrations of SO_4 , Cl^- , Ca^{2+} , Mg^{2+} , K^+ , Na^+ , Cd, Pb, Fe, Mn, and Cu were near or below detection limits they are not listed in Table 4.3.1, or used in statistical analyses. DOC also was eliminated due to sampling errors in July and August. Mean conductivity varied between 2.6 and 26.5 $\mu\text{S}/\text{cm}$. Mean turbidity values ranged from 0.09 to 6.61 NTU. Differences in conductivity and turbidity between sample sites were more pronounced in the southern system (CV = 46% and 97%, respectively) compared to the northern system (CV = 30% and 68%, respectively). Mean nutrient concentrations ranged from 2 to 8 $\mu\text{g}/\text{l}$ $\text{NH}_4\text{-N}$, 5 to 341 $\mu\text{g}/\text{l}$ $\text{NO}_2 + \text{NO}_3\text{-N}$, 134 to 490 $\mu\text{g}/\text{l}$ DN, 11 to 123 $\mu\text{g}/\text{l}$ PN, 0 to 6.5 $\mu\text{g}/\text{l}$ $\text{PO}_4\text{-P}$, 0.5 to 10 $\mu\text{g}/\text{l}$ DP, 1 to 10 $\mu\text{g}/\text{l}$ PP, 0.2 to 0.6 mg/l TIC, and 0.1 to 1.4 mg/l POC.

A principal component analysis (PCA) based on 8 physico-chemical parameters measured in July 2002 separated the sample sites into two groups: one group with sample sites situated in the North of the research area and the other group with sample sites situated in the South. Another separation was observed within the northern sites where the temporary sites clustered from the permanent sites (Fig. 4.10). The first two axes explained 67.5% of the variation among sample sites. The northern system was separated from the southern system on axis-1 by higher temperatures, and lower concentrations of nitrate-N and DN. The effect was even more pronounced for the temporary northern sites which clustered at the right site of axis-1. The second axis, explaining 25.8% of the variation, distinguished all permanent northern sites by higher concentrations of DP and $\text{PO}_4\text{-P}$, whereas most of the southern sites (permanent and temporary) were located at the negative end of axis-2 and thus had lower DP and $\text{PO}_4\text{-P}$ concentrations.

Table 4.3: Mean, standard deviation (SD), minimum (Min), and maximum (Max) values for physico-chemical parameters.

Site		Conductivity µs/cm	Turbidity NTU	Temperature °C	NH ₄ -N µg/l	NO ₂ -N µg/l	NO ₂ -N ± NO ₃ -N µg/l	DN µg/l	PN µg/l
1	Mean ± SD	6.7 ± 0.3	1.4 ± 0.8	8.9 ± 1.4	6.5 ± 5.7	0.7 ± 0.5	47.0 ± 40.0	200.2 ± 30.1	123.0 ± 58.7
	Min-Max	6.3 - 7.1	0.5 - 2.0	7.0 - 10.2	1.0 - 12.0	0.0 - 1.0	11.0 - 84.0	167.0 - 230.0	68.0 - 181.0
2	Mean ± SD	9.7 ± 1	1.2 ± 0.5	0.6 ± 0.3	4.5 ± 1.7	0.7 ± 1.0	326.0 ± 47.0	480.7 ± 106.8	12.7 ± 15.8
	Min-Max	8.5 - 10.8	0.6 - 1.6	0.4 - 1.0	2.0 - 5.5	0.0 - 2.0	258.0 - 362.0	354.0 - 615.0	1.0 - 36.0
3	Mean ± SD	4.8 ± 1.1	0.7 ± 0.3	5.9 ± 4.3	5.6 ± 3.8	0.3 ± 0.6	147.3 ± 54.0	313.3 ± 64.7	20.0 ± 2.6
	Min-Max	4.0 - 6.0	0.4 - 1.2	1.3 - 9.8	3.0 - 10.0	0.0 - 1.0	102.0 - 207.0	274.0 - 388.0	18.0 - 23.0
4	Mean ± SD	6.6 ± 0.2	1.4 ± 0.6	8.8 ± 3.4	5.2 ± 3.5	0.7 ± 0.5	45.5 ± 38.0	196.7 ± 25.3	120.2 ± 77.0
	Min-Max	6.3 - 7.0	0.6 - 2.0	3.9 - 11.9	1.0 - 9.5	0.0 - 1.0	8.0 - 83.0	171.0 - 220.0	34.0 - 192.0
6	Mean ± SD	5.4 ± 0.3	1.8 ± 1.0	9.5 ± 3.6	4.5 ± 3.9	0.7 ± 0.5	21.7 ± 18.9	193.2 ± 34.6	112.0 ± 42.2
	Min-Max	5.3 - 5.9	0.5 - 2.5	4.3 - 11.8	1.0 - 10.0	0.0 - 1.0	6.0 - 48.0	164.0 - 242.0	64.0 - 157.0
7	Mean ± SD	6.3 ± 1	0.5 ± 0.2	11.8 ± 1.7	3.2 ± 1.8	1.0 ± 0.0	67.0 ± 76.4	242.0 ± 151.3	15.0 ± 2.7
	Min-Max	5.6 - 7.0	0.3 - 0.7	10.6 - 13.0	2.0 - 4.5	1.0 - 1.0	13.0 - 121.0	135.0 - 349.0	13.0 - 17.0
10	Mean ± SD	4.7 ± 1.2	0.2 ± 0.0	14.3 ± 4.2	2.5 ± 0.7	0.5 ± 0.7	7.0 ± 9.9	264.0 ± 134.3	25.5 ± 7.7
	Min-Max	3.9 - 5.6	0.2 - 0.2	11.3 - 17.3	2.0 - 3.0	0.0 - 1.0	0.0 - 14.0	169.0 - 359.0	20.0 - 31.0
11	Mean ± SD	6.0 ± 0.5	1.4 ± 0.7	10.3 ± 4.8	3.4 ± 2.3	1.0 ± 0.0	20.7 ± 17.6	244.2 ± 72.3	98.7 ± 48.1
	Min-Max	5.5 - 6.8	0.5 - 2.4	3.9 - 15.4	1.0 - 6.5	1.0 - 1.0	5.0 - 45.0	179.0 - 333.0	33.0 - 139.0
12	Mean ± SD	4.3 ± 1.2	0.3 ± 0.1	16.9 ± 7.1	8.0 ± 2.1	1.0 ± 0.0	5.5 ± 7.7	211.0 ± 134.3	32.5 ± 6.3
	Min-Max	3.5 - 5.2	0.2 - 0.3	11.9 - 21.9	6.5 - 9.5	1.0 - 1.0	0.0 - 11.0	116.0 - 306.0	28.0 - 37.0
13	Mean ± SD	13.0 ± 0.3	0.5 ± 0.0	8.3 ± 7.1	5.7 ± 5.3	NA	52.0 ± 46.6	176.5 ± 129.4	35.0 ± 11.3
	Min-Max	12.8 - 13.3	0.5 - 0.6	3.3 - 13.4	2.0 - 9.5		19.0 - 85.0	85.0 - 268.0	27.0 - 43.0

Table 4.3: Mean, standard deviation (SD), minimum (Min), and maximum (Max) values for physico-chemical parameters (continued).

Site		Conductivity µs/cm	Turbidity NTU	Temperature °C	NH ₄ -N µg/l	NO ₂ -N µg/l	NO ₂ -N ± NO ₃ -N µg/l	DN µg/l	PN µg/l
14	Mean ± SD	7.2 ± 2.0	1.2 ± 0.5	7.1 ± 2.7	5.4 ± 1.9	0.7 ± 0.5	55.2 ± 7.5	217.7 ± 35.1	67.7 ± 31.9
	Min-Max	4.7 - 9.0	0.4 - 1.9	3.9 - 10.2	4.0 - 7.5	0.0 - 1.0	47.0 - 63.0	166.0 - 244.0	27.0 - 103.0
15	Mean ± SD	9.6 ± 2.3	1.0 ± 0.3	6.2 ± 2.1	2.5 ± 1.6	1.7 ± 0.5	197.5 ± 26.3	344.2 ± 35.8	33.2 ± 13.2
	Min-Max	6.6 - 12.2	0.7 - 1.3	3.3 - 8.1	1.0 - 4.5	1.0 - 2.0	177.0 - 236.0	291.0 - 368.0	21.0 - 52.0
16	Mean ± SD	8.8 ± 1.6	0.7 ± 0.5	6.6 ± 4.0	4.9 ± 3.7	0.7 ± 0.9	251.7 ± 38.3	371.2 ± 42.8	11.7 ± 4.6
	Min-Max	6.5 - 10.1	0.2 - 1.2	2.1 - 11.7	1.0 - 8.0	0.0 - 2.0	219.0 - 295.0	313.0 - 406.0	7.0 - 17.0
17	Mean ± SD	2.9 ± 0.3	0.4 ± 0.5	10.4 ± 1.4	3.5 ± 2.1	1.0 ± 0.0	12.0 ± 17.0	134.5 ± 84.1	12.5 ± 2.1
	Min-Max	2.6 - 3.2	0.1 - 0.7	9.4 - 11.4	2.0 - 5.0	1.0 - 1.0	0.0 - 24.0	75.0 - 194.0	11.0 - 14.0
18	Mean ± SD	9.7 ± 2.0	0.2 ± 0.1	3.8 ± 0.8	2.5 ± 1.6	0.3 ± 0.6	293.7 ± 68.5	411.7 ± 76.9	21.0 ± 9.5
	Min-Max	7.6 - 12.1	0.1 - 0.3	2.8 - 4.6	0.0 - 4.0	0.0 - 1.0	199.0 - 359.0	297.0 - 461.0	12.0 - 33.0
19	Mean ± SD	7.5 ± 1.8	0.7 ± 0.5	6.7 ± 3.3	5.0 ± 4.2	1.5 ± 1.3	304.5 ± 53.8	415.2 ± 79.4	25.2 ± 18.2
	Min-Max	5.6 - 9.2	0.5 - 1.5	2.6 - 10.1	1.0 - 11.0	0.0 - 3.0	231.0 - 354.0	301.0 - 476.0	12.0 - 52.0
20	Mean ± SD	5.8 ± 0.9	0.4 ± 0.2	10.0 ± 3.8	6.6 ± 7.5	1.0 ± 0.0	264.6 ± 45.8	413.3 ± 102.9	11.0 ± 4.3
	Min-Max	4.7 - 6.5	0.3 - 0.7	6.2 - 13.8	0.0 - 15.0	1.0 - 1.0	2124.0 - 303.0	295.0 - 482.0	8.0 - 16.0
21	Mean ± SD	7.5 ± 2.4	1.2 ± 0.2	11.9 ± 5.2	2.0 ± 1.4	1.5 ± 0.7	270.5 ± 68.6	424.0 ± 178.2	13.5 ± 2.1
	Min-Max	5.7 - 9.3	1.1 - 1.3	8.3 - 15.6	1.0 - 3.0	1.0 - 2.0	222.0 - 319.0	298.0 - 550.0	12.0 - 15.0
23	Mean ± SD	8.3 ± 4.4	2.6 ± 1.1	0.2 ± 0.1	5.0 ± 5.6	NA	219.0 ± 69.3	345.5 ± 54.4	27.5 ± 0.7
	Min-Max	5.1 - 11.5	1.8 - 3.3	0.1 - 0.3	1.0 - 9.0		170.0 - 268.0	307.0 - 384.0	27.0 - 28.0
24	Mean ± SD	10.0 ± 7.0	1.9 ± 1.3	7.2 ± 6.3	5.7 ± 5.3	2.0 ± 1.4	330.0 ± 141.4	490.0 ± 223.4	29.0 ± 31.1
	Min-Max	5.1 - 15.0	1.0 - 2.9	2.8 - 11.7	2.0 - 9.5	1.0 - 3.0	230.0 - 430.0	332.0 - 648.0	7.0 - 51.0

Table 4.3: Mean, standard deviation (SD), minimum (Min), and maximum (Max) values for physico-chemical parameters (continued).

Site		Conductivity $\mu\text{s/cm}$	Turbidity NTU	Temperature $^{\circ}\text{C}$	$\text{NH}_4\text{-N}$ $\mu\text{g/l}$	$\text{NO}_2\text{-N}$ $\mu\text{g/l}$	$\text{NO}_2\text{-N} \pm \text{NO}_3\text{-N}$ $\mu\text{g/l}$	DN $\mu\text{g/l}$	PN $\mu\text{g/l}$
25	Mean \pm SD	16.7 \pm 6.0	3.0 \pm 1.0	2.9 \pm 2.9	2.9 \pm 2.1	1.0 \pm 0.0	340.7 \pm 70.1	476.2 \pm 83.8	12.5 \pm 3.7
	Min-Max	9.0 - 23.4	1.6 - 4.2	0.1 - 2.7	1.5 - 6.0	1.0 - 1.0	268.0 - 436.0	351.0 - 528.0	9.0 - 17.0
26	Mean \pm SD	12.3 \pm 8.2	4.0 \pm 3.6	0.5 \pm 0.6	4.0 \pm 1.4	NA	245.0 \pm 137.2	387.0 \pm 172.4	11.0 \pm 11.3
	Min-Max	6.5 - 18.1	1.4 - 6.6	0.1 - 0.9	3.0 - 5.0		148.0 - 342.0	265.0 - 509.0	3.0 - 11.0
27	Mean \pm SD	12.0 \pm 2.5	1.3 \pm 0.3	13.2 \pm 5.8	4.5 \pm 4.9	0.5 \pm 0.7	58.0 \pm 49.5	211.0 \pm 84.8	30.5 \pm 4.9
	Min-Max	10.3 - 13.8	1.0 - 1.5	9.1 - 17.3	1.0 - 8.0	0.0 - 1.0	23.0 - 93.0	151.0 - 271.0	27.0 - 34.0
28	Mean \pm SD	9.3 \pm 1.8	1.0 \pm 0.3	7.3 \pm 2.5	3.4 \pm 1.8	1.0 \pm 0.0	145.2 \pm 36.5	304.0 \pm 59.1	31.5 \pm 17.1
	Min-Max	6.9 - 11.3	0.7 - 1.4	3.6 - 9.1	1.0 - 4.5	1.0 - 1.0	112.0 - 184.0	237.0 - 360.0	15.0 - 55.0
29	Mean \pm SD	18.8 \pm 7.1	2.2 \pm 1.2	5.5 \pm 2.1	2.1 \pm 0.8	0.7 \pm 0.5	227.5 \pm 41.4	384.0 \pm 45.5	31.2 \pm 22.6
	Min-Max	10.9 - 26.5	0.8 - 3.4	2.8 - 7.8	1.0 - 3.0	0.0 - 1.0	171.0 - 266.0	316.0 - 410.0	17.0 - 65.0

Table 4.3: Mean, standard deviation (SD), minimum (Min), and maximum (Max) values for physico-chemical parameters (continued).

Site		PO ₄ -P µg/l	DP µg/l	PP µg/l	TIC mg/l	POC mg/l	SiO ₂ mg/l
1	Mean ± SD	1.2 ± 0.5	3.5 ± 1.9	9.7 ± 4.9	0.6 ± 0.3	1.3 ± 0.8	2.2 ± 0.3
	Min-Max	1.0 - 2.0	2.0 - 6.0	5.0 - 14.0	0.3 - 0.9	0.4 - 2.1	1.9 - 2.5
2	Mean ± SD	6.7 ± 1.3	10.2 ± 4.8	1.3 ± 1.9	0.5 ± 0.3	0.1 ± 0.0	3.8 ± 0.7
	Min-Max	5.0 - 8.0	5.0 - 16.0	0.0 - 4.0	0.2 - 0.8	0.1 - 0.1	3.2 - 4.6
3	Mean ± SD	0.6 ± 0.6	3.0 ± 1.6	3.0 ± 2.0	0.4 ± 0.2	0.2 ± 0.1	2.1 ± 0.3
	Min-Max	0.0 - 1.0	2.0 - 5.0	1.0 - 5.0	0.2 - 0.7	0.2 - 0.3	1.9 - 2.3
4	Mean ± SD	1.2 ± 1.5	4.5 ± 3.0	10.0 ± 6.0	0.3 ± 0.2	1.0 ± 0.7	2.2 ± 0.3
	Min-Max	0.0 - 3.0	2.0 - 8.0	3.0 - 16.0	0.2 - 0.5	0.2 - 1.9	1.9 - 2.6
6	Mean ± SD	1.5 ± 1.0	3.5 ± 2.6	10.2 ± 5.0	0.4 ± 0.1	1.4 ± 0.8	1.7 ± 0.3
	Min-Max	1.0 - 3.0	1.0 - 7.0	5.0 - 15.0	0.2 - 0.5	0.5 - 2.1	1.4 - 2.0
7	Mean ± SD	1.0 ± 0.0	1.5 ± 0.7	1.5 ± 0.7	0.4 ± 0.3	0.2 ± 0.1	2.5 ± 0.3
	Min-Max	1.0 - 1.0	1.0 - 2.0	1.0 - 2.0	0.2 - 0.6	0.1 - 0.2	2.3 - 2.7
10	Mean ± SD	1.5 ± 0.7	3.0 ± 1.3	2.0 ± 1.4	0.4 ± 0.3	0.3 ± 0.1	2.1 ± 0.1
	Min-Max	1.0 - 2.0	2.0 - 4.0	1.0 - 3.0	0.2 - 0.7	0.2 - 0.4	2.1 - 2.2
11	Mean ± SD	1.7 ± 1.7	5.0 ± 2.6	9.2 ± 4.8	0.4 ± 0.1	1.1 ± 0.7	1.7 ± 0.3
	Min-Max	0.0 - 4.0	2.0 - 8.0	3.0 - 13.0	0.2 - 0.5	0.2 - 1.7	1.4 - 2.1
12	Mean ± SD	2.5 ± 0.7	3.0 ± 0.0	2.5 ± 0.7	0.3 ± 0.2	0.3 ± 0.0	1.7 ± 0.2
	Min-Max	2.0 - 3.0	3.0 - 3.0	2.0 - 3.0	0.2 - 0.5	0.3 - 0.3	1.6 - 1.9
13	Mean ± SD	0.0 ± 0.0	0.5 ± 0.7	2.5 ± 0.7	NA	0.4 ± 0.2	NA
	Min-Max	0.0 - 0.0	0.0 - 1.0	2.0 - 3.0		0.2 - 0.5	

Table 4.3: Mean, standard deviation (SD), minimum (Min), and maximum (Max) values for physico-chemical parameters (continued).

Site		PO ₄ -P µg/l	DP µg/l	PP µg/l	TIC mg/l	POC mg/l	SiO ₂ mg/l
14	Mean ± SD	1.5 ± 1.9	4.2 ± 2.5	6.7 ± 4.1	0.4 ± 0.2	0.7 ± 0.3	2.2 ± 0.4
	Min-Max	0.0 - 4.0	2.0 - 8.0	2.0 - 12.0	0.2 - 0.6	0.2 - 1.0	1.8 - 2.7
15	Mean ± SD	1.2 ± 1.9	3.5 ± 3.2	4.7 ± 2.9	0.3 ± 0.1	0.4 ± 0.3	2.1 ± 0.6
	Min-Max	0.0 - 4.0	1.0 - 8.0	3.0 - 9.0	0.2 - 0.4	0.2 - 0.8	1.4 - 2.7
16	Mean ± SD	1.2 ± 1.3	5.0 ± 3.2	2.2 ± 1.5	0.3 ± 0.1	0.3 ± 0.2	2.2 ± 0.7
	Min-Max	1.0 - 3.0	2.0 - 9.0	1.0 - 4.0	0.3 - 0.4	0.1 - 0.5	1.4 - 2.8
17	Mean ± SD	2.0 ± 2.8	2.5 ± 2.1	1.5 ± 0.7	0.2 ± 0.1	0.2 ± 0.1	1.7 ± 0.0
	Min-Max	0.0 - 4.0	1.0 - 4.0	1.0 - 2.0	0.1 - 0.3	0.1 - 0.2	1.7 - 1.7
18	Mean ± SD	1.5 ± 1.3	4.7 ± 3.1	3.2 ± 2.2	0.3 ± 0.1	0.2 ± 0.1	2.5 ± 0.2
	Min-Max	0.0 - 3.0	2.0 - 9.0	1.0 - 6.0	0.3 - 0.4	0.1 - 0.4	2.4 - 2.7
19	Mean ± SD	2.0 ± 0.8	4.0 ± 3.5	4.0 ± 3.6	0.2 ± 0.2	0.1 ± 0.1	1.9 ± 0.6
	Min-Max	1.0 - 3.0	1.0 - 9.0	1.0 - 9.0	0.0 - 0.4	0.1 - 0.2	1.3 - 2.6
20	Mean ± SD	1.3 ± 1.4	4.0 ± 3.6	1.6 ± 0.6	0.3 ± 0.1	0.1 ± 0.0	1.6 ± 0.5
	Min-Max	0.0 - 3.0	1.0 - 8.0	1.0 - 2.0	0.2 - 0.5	0.1 - 0.1	1.0 - 2.1
21	Mean ± SD	2.0 ± 0.0	3.5 ± 0.7	2.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.0	1.6 ± 1.0
	Min-Max	2.0 - 2.0	3.0 - 4.0	2.0 - 2.0	0.2 - 0.3	0.2 - 0.2	0.9 - 2.3
23	Mean ± SD	2.0 ± 0.0	4.0 ± 0.0	4.5 ± 2.1	NA	0.2 ± 0.1	NA
	Min-Max	2.0 - 2.0	4.0 - 4.0	3.0 - 6.0		0.1 - 0.3	
24	Mean ± SD	1.5 ± 2.1	2.5 ± 0.7	9.0 ± 9.9	0.1 ± 0.1	0.4 ± 0.3	1.9 ± 1.5
	Min-Max	0.0 - 3.0	2.0 - 3.0	2.0 - 16.0	0.1 - 0.2	0.2 - 0.7	0.8 - 3.0

Table 4.3: Mean, standard deviation (SD), minimum (Min), and maximum (Max) values for physico-chemical parameters (continued).

Site		PO ₄ -P µg/l	DP µg/l	PP µg/l	TIC mg/l	POC mg/l	SiO ₂ mg/l
25	Mean ± SD	2.7 ± 0.9	5.7 ± 3.6	3.2 ± 1.9	0.4 ± 0.1	0.1 ± 0.1	2.4 ± 0.8
	Min-Max	2.0 - 4.0	3.0 - 11.0	2.0 - 6.0	0.4 - 0.5	0.1 - 0.2	1.5 - 2.8
26	Mean ± SD	2.5 ± 0.7	3.5 ± 2.1	2.0 ± 1.3	NA	0.2 ± 0.1	NA
	Min-Max	2.0 - 3.0	2.0 - 5.0	1.0 - 3.0		0.1 - 0.3	
27	Mean ± SD	1.0 ± 0.0	3.0 ± 2.8	5.5 ± 2.1	0.2 ± 0.3	0.3 ± 0.0	1.8 ± 0.5
	Min-Max	1.0 - 1.0	1.0 - 5.0	4.0 - 7.0	0.0 - 0.4	0.3 - 0.3	1.5 - 2.2
28	Mean ± SD	1.2 ± 1.3	3.2 ± 3.3	4.5 ± 1.6	0.3 ± 0.2	0.3 ± 0.1	2.1 ± 0.6
	Min-Max	0.0 - 3.0	0.0 - 7.0	3.0 - 6.0	0.0 - 0.4	0.1 - 0.4	1.4 - 2.7
29	Mean ± SD	2.0 ± 0.8	4.5 ± 3.1	5.0 ± 3.4	0.6 ± 0.1	0.3 ± 0.1	2.3 ± 0.7
	Min-Max	1.0 - 3.0	2.0 - 9.0	3.0 - 10.0	0.5 - 0.6	0.2 - 0.5	1.6 - 3.0

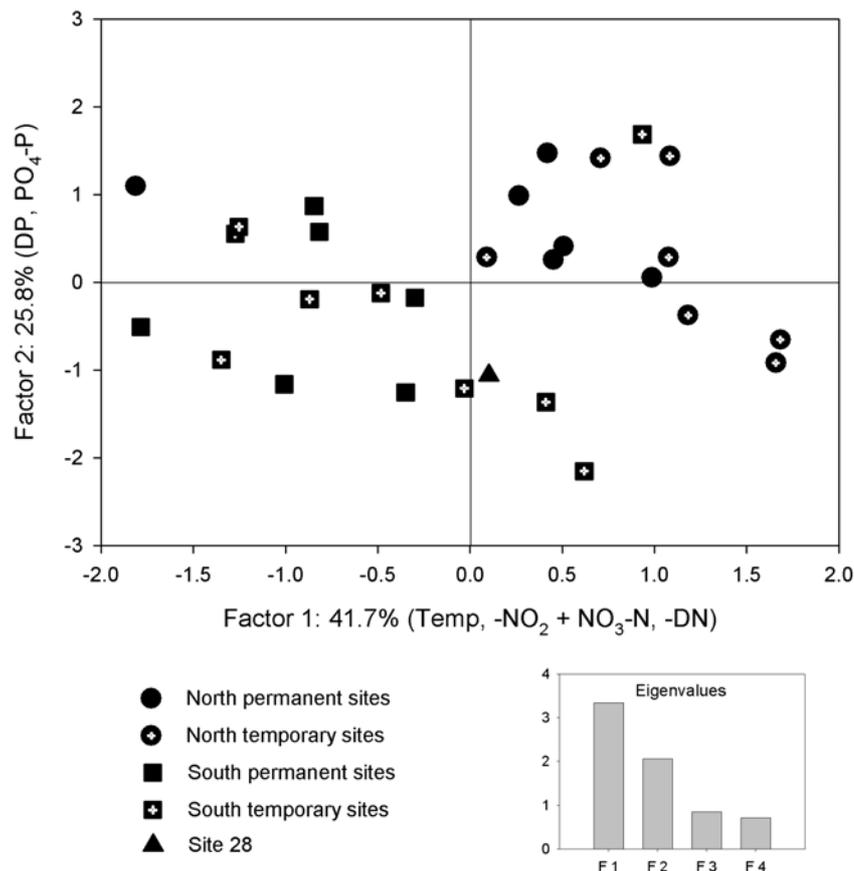


Figure 4.10: F1-F2 scatterplot of a principle component analysis (PCA) based on 8 physico-chemical variables measured for all sample sites ($n = 29$) in July 2002.

Another PCA based on 12 physico-chemical parameters measured each month was completed for the permanent sites (Fig. 4.11). This PCA illustrated the temporal and spatial correlation among the sample sites as revealed by the significant parameters. The primary and secondary axes explained 40.2% and 21.3% of the variation, respectively. The sample sites were spatially separated on the primary axis and temporally on the secondary axis. The northern system was characterised by higher concentrations of PN, PP, POC and lower concentrations of $\text{NO}_2 + \text{NO}_3\text{-N}$ compared to the South. A temporal separation occurred on the secondary axis with higher conductivities and lower $\text{NH}_4\text{-N}$ concentrations in September and October compared to July and August.

Site 28 is influenced by water from the southern as well as from the northern system, as reflected by its position almost in the centre of the scatterplots of both PCAs.

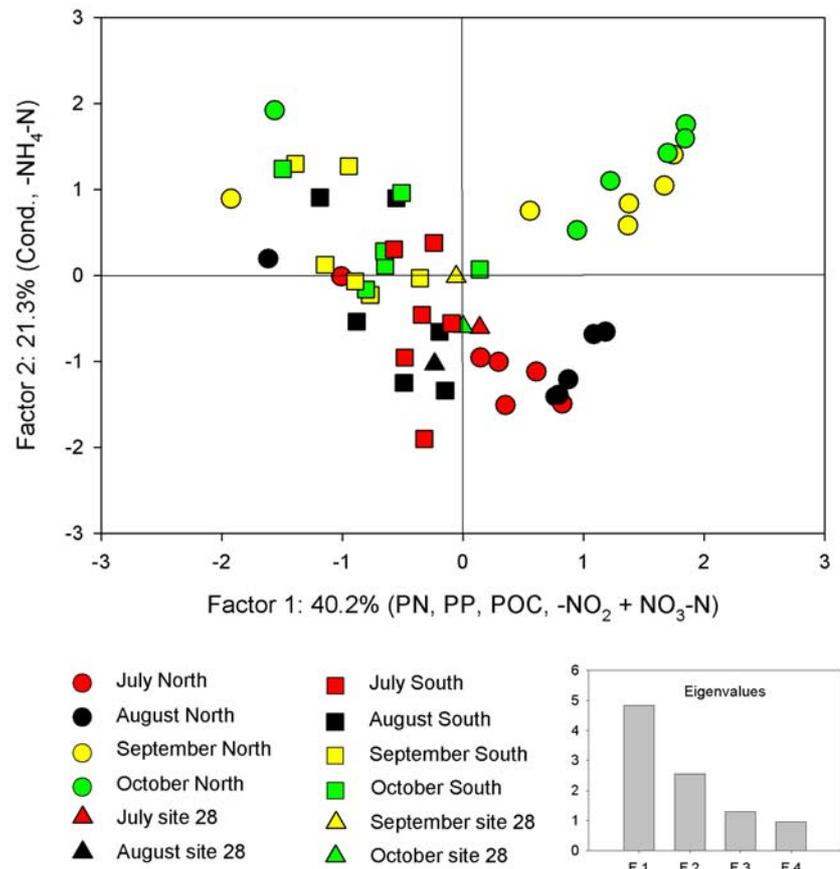


Figure 4.11: F 1-F 2 scatterplot of a principle component analysis (PCA) based on 12 physico-chemical variables measured for the permanent sample sites ($n = 13$) in July, August, September, and October 2002.

Sample site 2, situated in the upper left quarter of both scatterplots, is an outlier concerning the distinction between the North and South. Although topographically located in the North, both PCAs associated site 2 with the southern sites. This association was mainly caused by higher $\text{NO}_2 + \text{NO}_3\text{-N}$, DN and DP concentrations, lower temperatures, and lower PN, PP and POC concentrations; these being typical for the southern system. The similarities with the southern system, in which the predominant water source is meltwater from rock-glaciers, in measured parameters are probably due to the existence of a rock-glacier draining into site 2. According to the findings of Barsch (1969), a moraine was located above site 2 in 1969. Since moraines can evolve into rock-glaciers (Barsch, 1969), this may explain the similarities to the rock-glacier influenced southern sites. This hypothesis becomes even more likely when

considering the genesis of the rock-glacier above site 25 which, according to Barsch (1969), arose from a terminal moraine.

Low conductivity values as measured here are typical for streams flowing on crystalline rocks of low solubility (e.g., see Hieber, 2002). Another reason is the small catchment area of Macun, since weathering of crystalline bedrock is mainly controlled by physical processes and physical weathering is significantly lower in small catchments (Kamenik et al., 2001). Groundwater is known to have higher conductivities. However, the northern system is predominantly influenced by groundwater, implying a short residence time of water in the aquifer (Gurnell & Fenn, 1985; Fenn, 1987). The PCA (Fig. 4.11) clearly revealed a temporal pattern showing higher conductivity values for September and October compared to July and August. In particular, temporal patterns are characterised by an increase in conductivity in the South (doubling from July to October) and in the temporary sites (nearly doubling within 1 month), a slight increase in the North and a moderate increase at site 28 (Fig. 4.12).

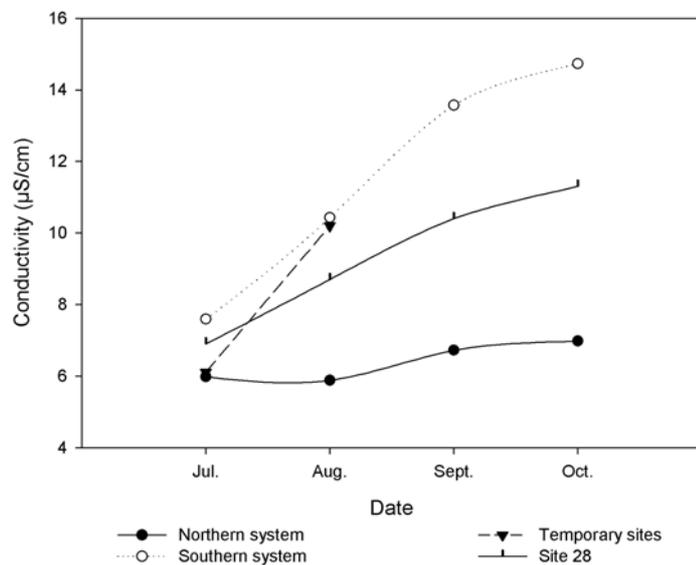


Figure 4.12: Conductivity concentration comparison of the northern system (monthly mean values of all permanent northern sites (n = 6)), southern system (monthly mean values of all permanent southern sites (n = 7)), temporary sites (monthly mean values of northern and southern temporary sites (n = 15)) and site 28 over time (July-October 2002).

Low conductivity in July is probably due to a dilution effect of meltwater from snow. The increase of conductivity was associated with the contraction of the stream

network system (see chapter 4.4) and was most pronounced for the temporary sites which fell dry within one month. With decreasing temperatures, and the consequent lower influence of glacial meltwater, the southern system showed increasing values over time ($p < 0.05$, ANOVA) whereas the northern system, which does not contract as much, showed no significant temporal variation ($p > 0.05$, ANOVA). The curve for site 28 approaches the curve for the North over time because the influence of the South decreased each month.

In general, turbidity levels were very low at all sites (maximum value: 6.6 NTUs at site 26 in July). However, a significant temporal variation was observed in the North ($p < 0.05$, ANOVA) in contrast to the South ($p > 0.05$, ANOVA), and a slight temporal decrease was seen at the temporary sites as well as at site 28 (Fig. 4.13).

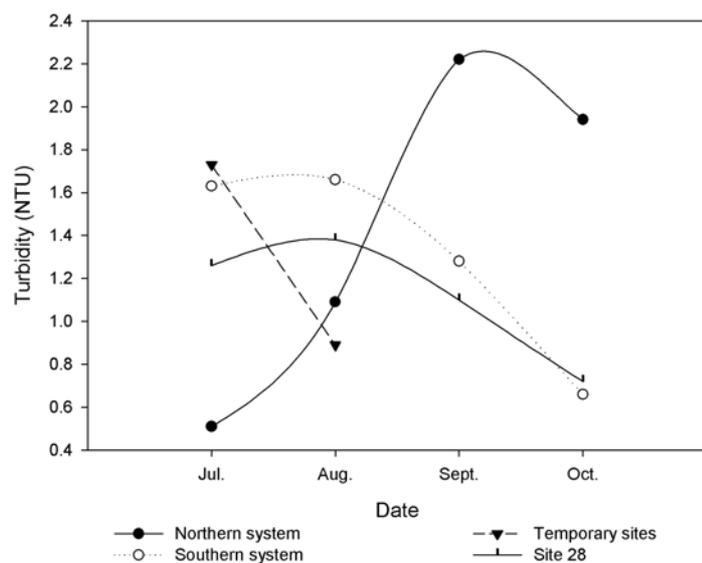


Figure 4.13: Turbidity level comparison of the northern system (monthly mean values of all permanent northern sites ($n = 6$)), southern system (monthly mean values of all permanent southern sites ($n = 7$)), temporary sites (monthly mean values of northern and southern temporary sites ($n = 15$)) and site 28 over time (July-October 2002).

The decrease in turbidity values at the temporary sites can be explained by decreasing snowmelt-water influence and the associated release of particles. In the southern system the decline was probably caused by the reduced influence of glacial meltwater. The northern system, in contrast, was characterised by increasing turbidity values up to September which might be due to increased biological processes reflecting seasonal changes in lake productivity.

As already shown by PCA, the separation between North and South was reduced to a few important parameters. The biggest difference between North and South was observed in $\text{NO}_2 + \text{NO}_3\text{-N}$ concentrations (Fig. 4.14). The lower concentrations of $\text{NO}_2 + \text{NO}_3\text{-N}$ in the North are probably due to biological processes. The lakes became darker over time, probably indicating an increasing amount of phytoplankton. This suggestion coincides with studies of Barbieri (2001) who found maximum population development of phytoplankton during August and September in two southern alpine lakes situated above 2000 m a.s.l. This effect was more pronounced for lakes in the northern system, which also had more fish (density and species, J. Ortlepp, pers. comm.). One reason for the pronounced internal lake processes in the North could be water depth. The northern lakes Dragun and Mezza Glüna have an average depth of 4.8 m and 6.6 m, respectively. Lake Sura in the South, in contrast, is only 2.3 m deep on average (Niederhauser, 1993). Baron and Caine (2000) explored the temporal coherence of physical and chemical characteristics of two series of alpine lakes in the Colorado Rocky Mountains. They found that deeper lakes (maximum mean depth 7.7 m) tended to have slower flushing rates and that the longer water residence time allowed for the manifestation of internal lake processes. Internal processes in shallower lakes, in contrast, are obscured by hydrologic flushing by upstream waters. In the Macun area, this effect is reinforced by smaller catchments of the deeper northern lakes Dragun and Mezza Glüna (20 ha and 28 ha, respectively) (Niederhauser, 1993), extending the water residence time. The catchment of the southern Lake Sura on the other hand is 117 ha (Niederhauser, 1993), shortening the water residence time. Thus, lake dynamics like nutrient uptake by phytoplankton may have caused the generally lower concentrations of $\text{NO}_2 + \text{NO}_3\text{-N}$ in the North, the decrease over time, and the decrease from a lakes inlet to its outlet. These results are similar to Kling et al. (2000) who found that lakes tended to “consume” $\text{NH}_3\text{-N}$ as water flowed through them.

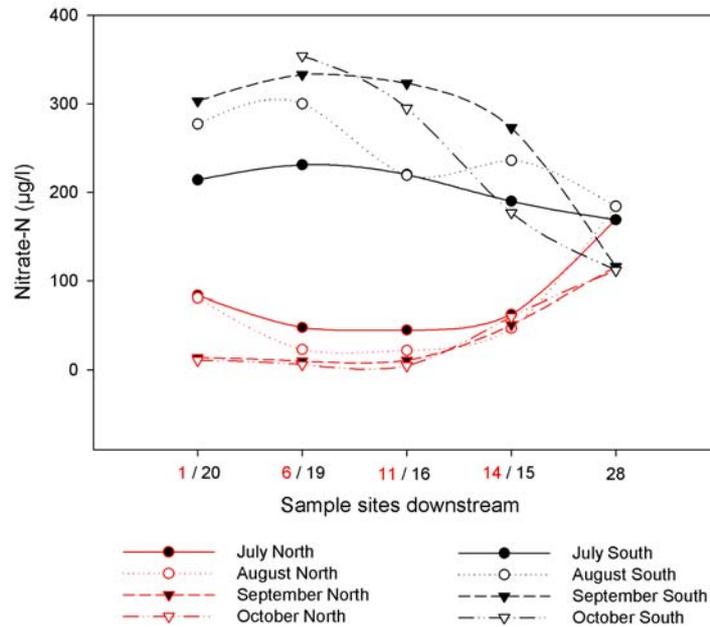


Figure 4.14: $\text{NO}_2 + \text{NO}_3\text{-N}$ concentrations vs. space (downstream, and North/South differentiation) and time. Red curves indicate concentrations for the northern system moving downstream (site 1, 6, 11 and 14), black curves concentrations for the southern system moving downstream (site 20, 19, 16 and 15).

Higher concentrations in the South on the other hand might be caused by less biological activity, snowmelt (Donath & Robinson, 2001), and icemelt of the adjacent rock-glaciers and associated ion release (Fountain, 1996; Kuhn et al., 1998; Kuhn, 2001).

Another North to South gradient was observed for DN, in which concentrations were about twice as high in the South than in the North. Temporary sites showed an increase from July to September, whereas site 28 again became closer to the North from September on, demonstrating that the North became the predominant water source over time (Fig. 4.15).

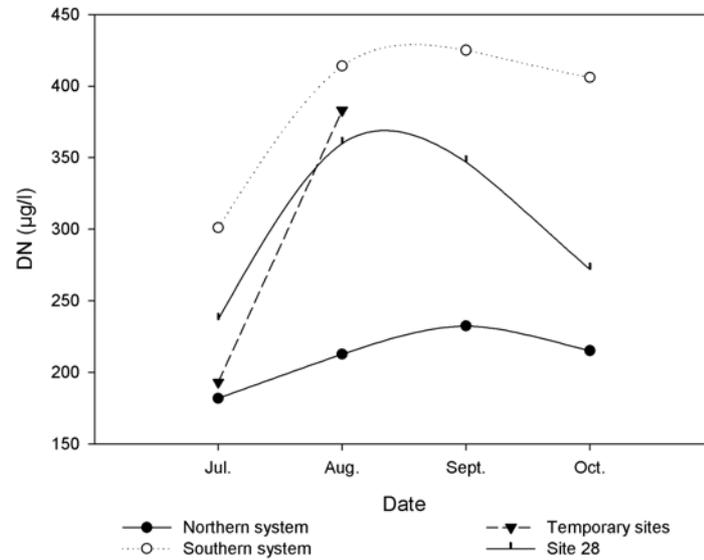


Figure 4.15: DN concentration comparison of the northern system (monthly mean values of all permanent northern sites (n = 6)), southern system (monthly mean values of all permanent southern sites (n = 7)), temporary sites (monthly mean values of northern and southern temporary sites (n = 15)) and site 28 over time (July-October 2002).

The differences between North and South in DN concentrations are similar to the $\text{NO}_2 + \text{NO}_3\text{-N}$ patterns. It is likely that dissolved nitrogen also is consumed by phytoplankton, supporting Kamenik et al. (2001), who assumed increased biological activity removed dissolved nitrogen from alpine lakes.

Particulate constituents (PP, PN, POC), on the other hand, showed opposite patterns. The concentrations of these 3 parameters strongly increased in the northern system over time. In this respect, a two-way-ANOVA revealed significant differences in the northern system for September and October compared to July (PN and PP), and for July and August compared to September and October (POC)(see Appendix C: Figs. C 4.3-1, C 4.3-2, C 4.3-3). The southern system showed slightly increasing values, and temporary sites tended to decrease slightly (Figs. 4.16, 4.17 and 4.18).

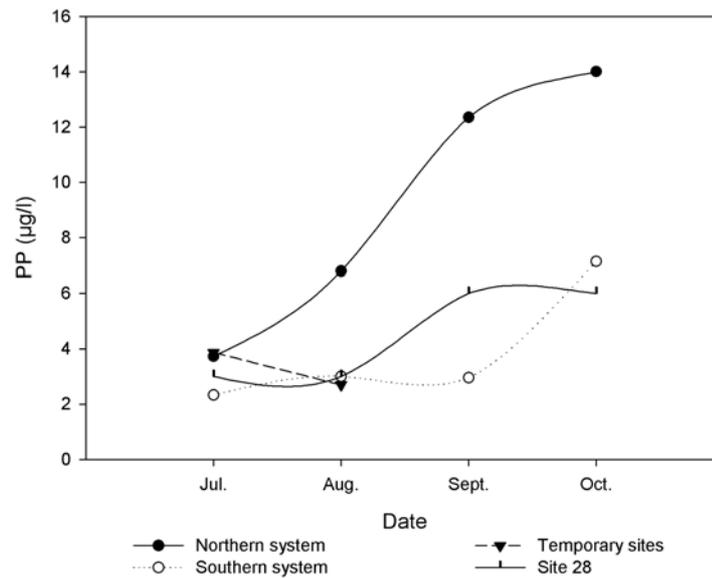


Figure 4.16: PP concentration comparison of the northern system (monthly mean values of all permanent northern sites ($n = 6$)), southern system (monthly mean values of all permanent southern sites ($n = 7$)), temporary sites (monthly mean values of northern and southern temporary sites ($n = 15$)) and site 28 over time (July-October 2002).

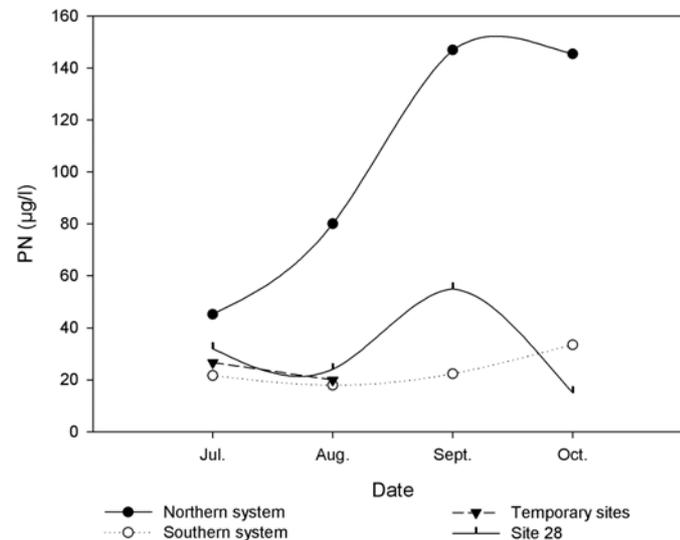


Figure 4.17: PN concentration comparison of the northern system (monthly mean values of all permanent northern sites ($n = 6$)), southern system (monthly mean values of all permanent southern sites ($n = 7$)), temporary sites (monthly mean values of northern and southern temporary sites ($n = 15$)) and site 28 over time (July-October 2002).

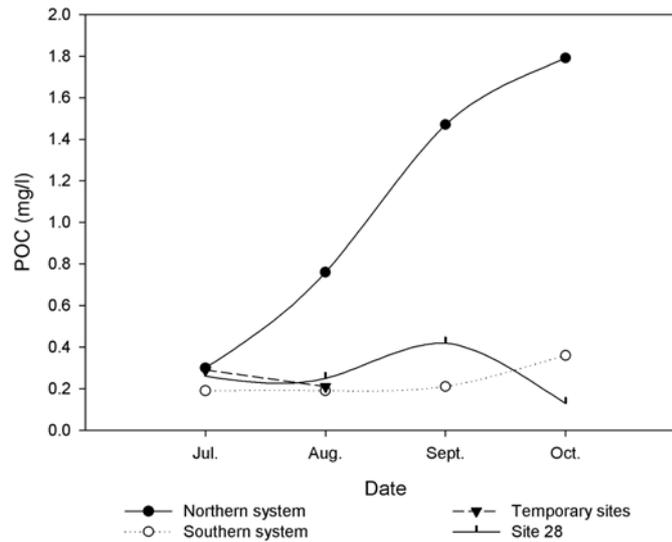


Figure 4.18: POC concentration comparison of the northern system (monthly mean values of all permanent northern sites (n = 6)), southern system (monthly mean values of all permanent southern sites (n = 7)), temporary sites (monthly mean values of northern and southern temporary sites (n = 15)) and site 28 over time (July-October 2002).

Higher particulate concentrations may be soil derived, since the soil and the vegetation is more developed in the North and some stream segments partly flow over grass. This assumption seems to be unlikely however, because it can not explain the significant temporal differences. More probable is the hypothesis that the patterns for particulate constituents also were affected by the development of phytoplankton, because after uptake of DP by phytoplankton it becomes incorporated and can be measured as PP. But also POC is, among other things, represented by phytoplankton. PN is mainly derived by decomposition and excrements and consequently increases with increasing amounts of phytoplankton and fish. Testing a site/date effect, two-way-ANOVA revealed significant differences for $\text{NO}_2 + \text{NO}_3\text{-N}$, DN, PN, PP and POC, supporting the hypothesis of increased biological activity (see Appendix C: Figs. C 4.3-1, C 4.3-2, C 4.3-3, C 4.3-4, C 4.3-5).

4.4 Contraction of the floodplain channel network

The channel network of the Macun floodplain can be divided into different channel types. First, the system exhibited the general distinction of the northern and southern parts. Furthermore, a breakdown into permanent and temporary stream segments was observed. Most of the sample sites on the permanent streams were located on the main channel, only a few were on smaller side channels, namely site 2 and 25 (rock-glacier runoff) and site 18 (groundwater). The temporary sites were fed by glacial and snowmelt water as well as groundwater. Stream reaches downstream from Lake Immex outlet (site 28) were not taken into consideration in the channel network analyses. During the period of investigation, the channel network was subject to marked contraction. The total channel length (T) decreased from 3913 m in July to 1675 m in October (-57% = 2238 m) (Fig. 4.20). Contraction of high alpine systems was also found in other studies (e.g. Malard et al., 1999; Malard et al., 2000; Tockner et al., 1997).



Figure 4.19: Contraction of the channel network. Red arrows mark the former water level. The lower right picture shows a dried lake at sites 22 and 23, the other pictures were taken at the lake of site 20. All pictures were taken in the middle of September.

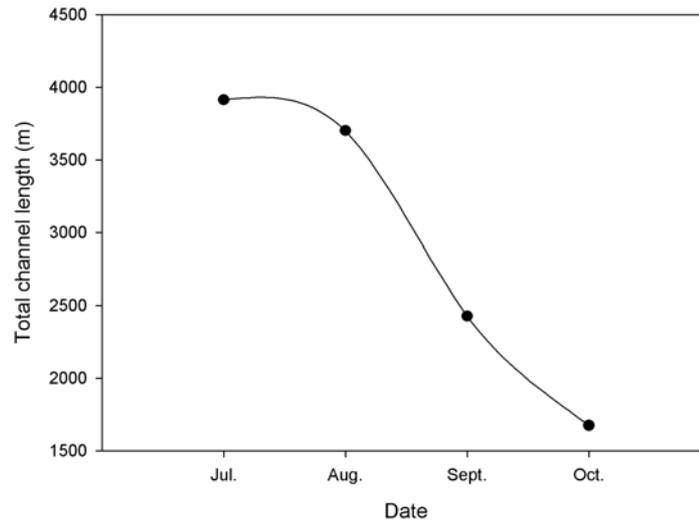


Figure 4.20: Temporal changes in total channel length.

System contraction occurred first between July and August via drying of side-slope seeps (sites 5, 8, and 9 in the North, and site 22 in the South, Figs. 4.23, 4.24). The largest reduction occurred between August ($T = 3700$ m) and September ($T = 2427$ m) when 10 sample sites fell dry (sites 7, 10, and 12 in the North, and site 13, 17, 21, 23, 24, 26, and 27 in the South, Figs. 4.24, 4.25). This contraction is equivalent to a reduction of 1273 m (35%) in total channel length. These results correlate to the discharge regime, where the greatest reduction also occurred between August and September (Table 4.4).

Table 4.4: Discharge (Q) at sample sites 1 (North), 25 (South) and 28 (Lake Immex outlet) expressed in l/sec for July, August and September 2002.

	1	25	28
Jul.	22.8	35.1	142.0
Aug.	36.6	33.4	122.8
Sept.	1.6	2.0	32.2

However, considering the northern and southern flowpaths separately (Fig. 4.21), the southern channel network is apparently subject to greater contraction. Here the largest contraction took place between September ($T = 1877$ m) and October ($T = 936$ m), equivalent to a reduction of 941 m (50%) (Figs. 4.25, 4.26). This major contraction was caused by reduced glacial meltwater from freezing, confirmed by the significant water temperature shift from September to October (see chapter 4.1).

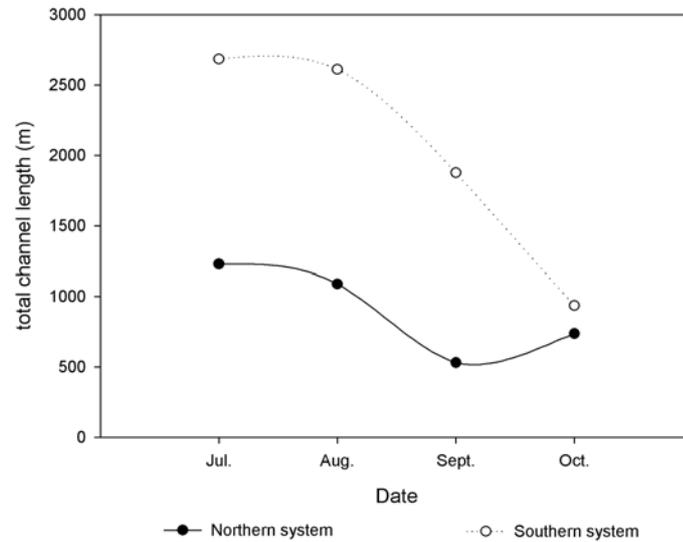


Figure 4.21: Temporal changes in total channel length for the northern and southern system separately.

The northern channel network, in contrast, was more stable over time, as it was mainly fed by groundwater. The largest decrease for T was observed between August ($T = 1089$ m) and September ($T = 531$ m) by more than 50%. The decrease in discharge also was most pronounced from August to September (Table 4.4). The increase in T from September to October is due to site 3 falling dry in September and then again flowing in October. The southern channel network decreased by 1749 m (65%) between July and September, whereas the northern flowpaths only contracted by 490 m (40%) in this time. These results strongly suggest that the floodplain is predominantly fed by meltwater in early summer and shifts to a groundwater influenced system in late summer and autumn. Increasing values of SiO_2 over time (Fig. 4.22) support this hypothesis, and are also found in other studies (e.g., Malard et al., 1999).

However, the North also showed a strong decrease in discharge from August to September (Table 4.4), quite low conductivity values (Fig. 4.12), and a reduction in total channel length by 40% during the period of investigation. This suggests a short groundwater residence time, and a low storage capacity of side-slopes for groundwater.

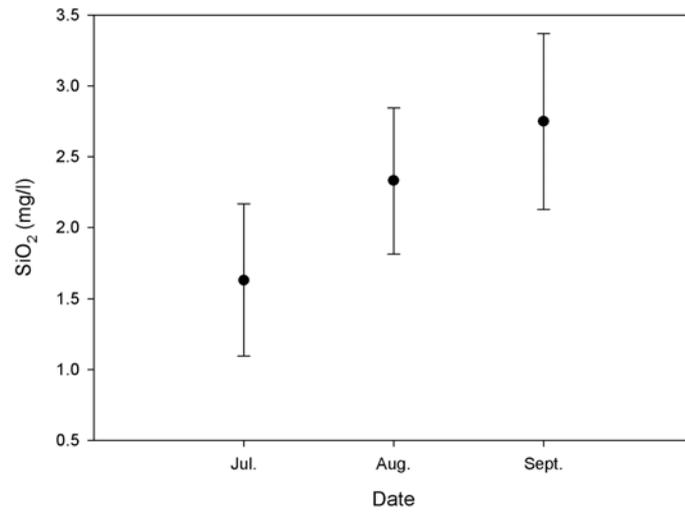
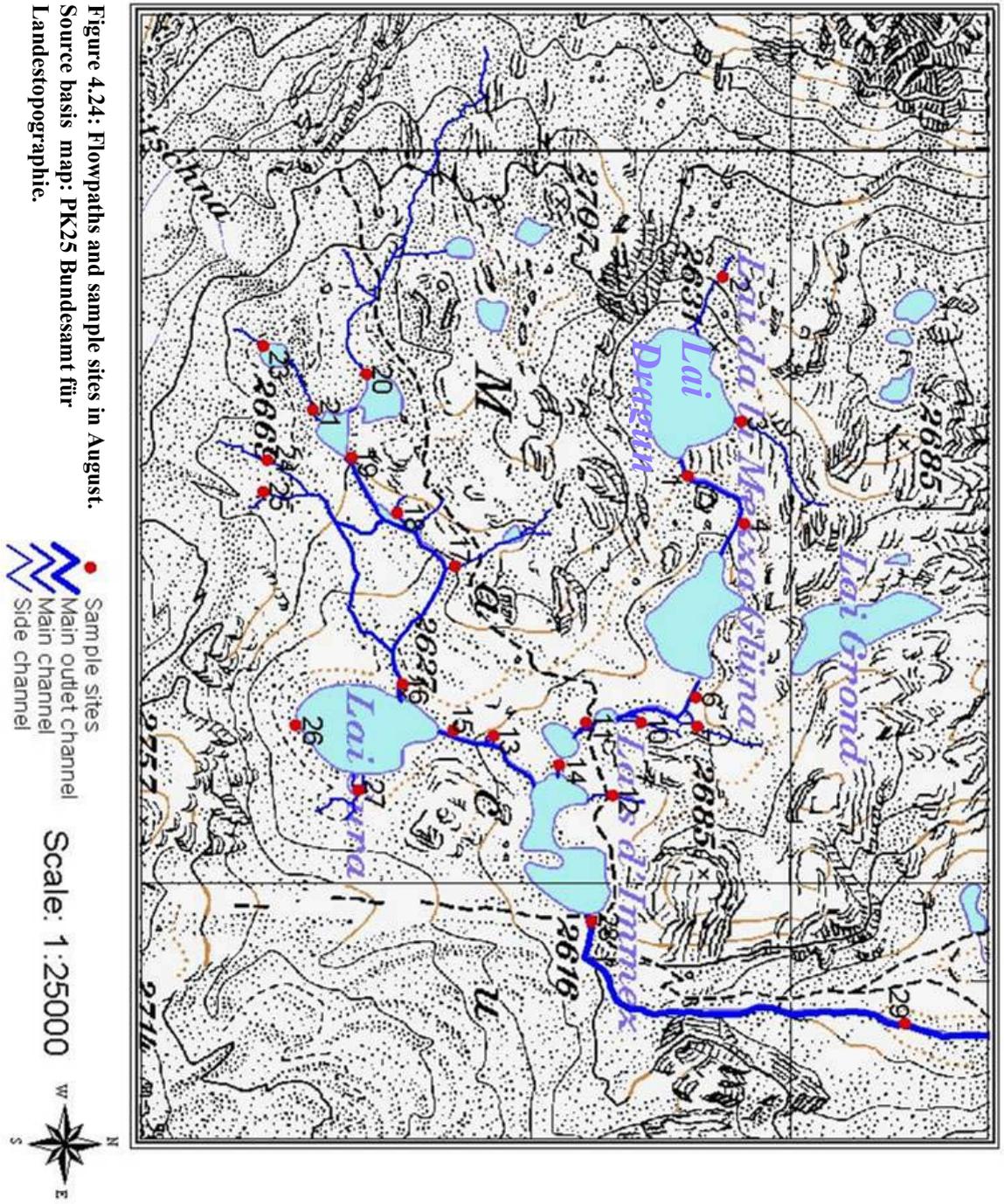
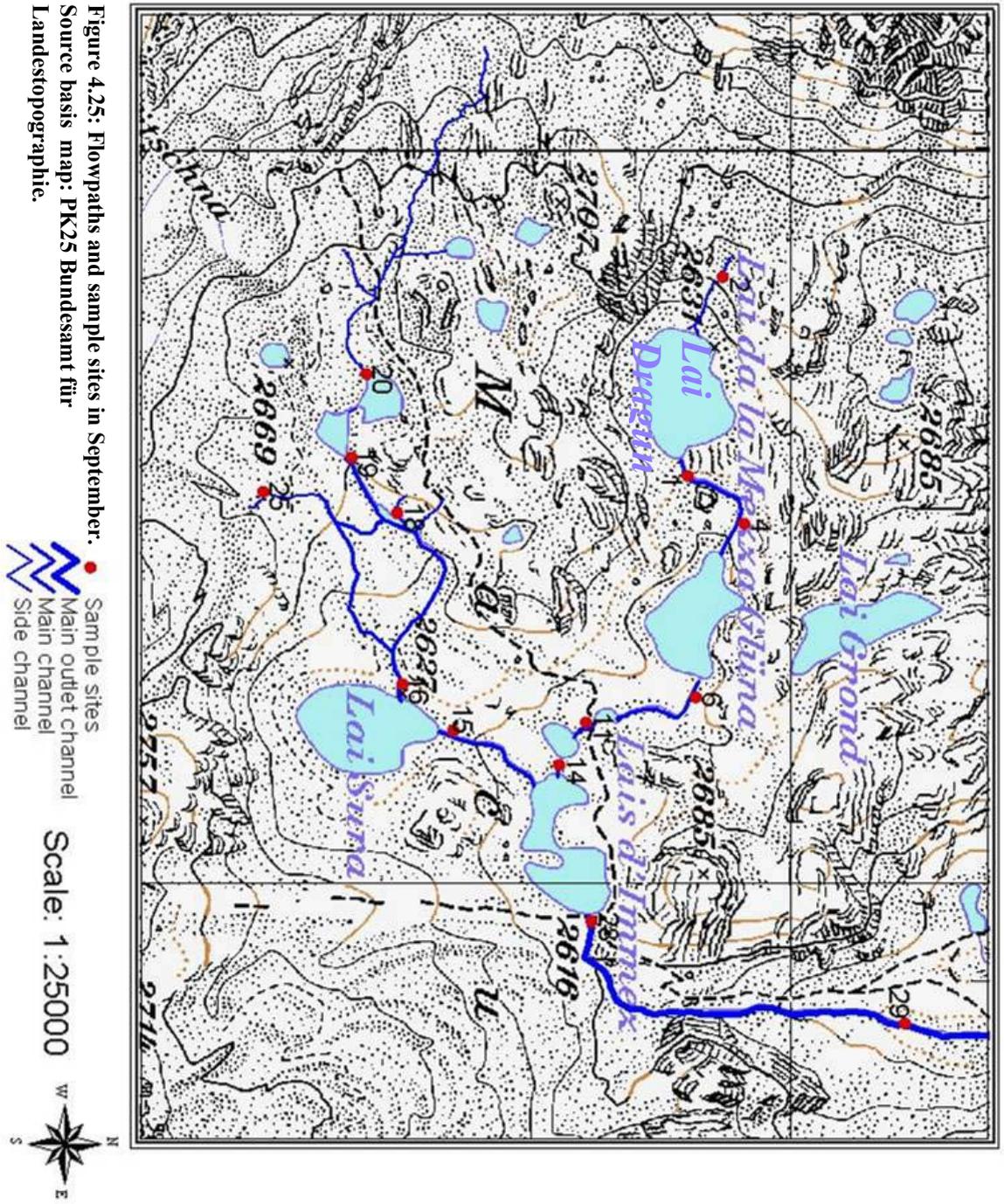
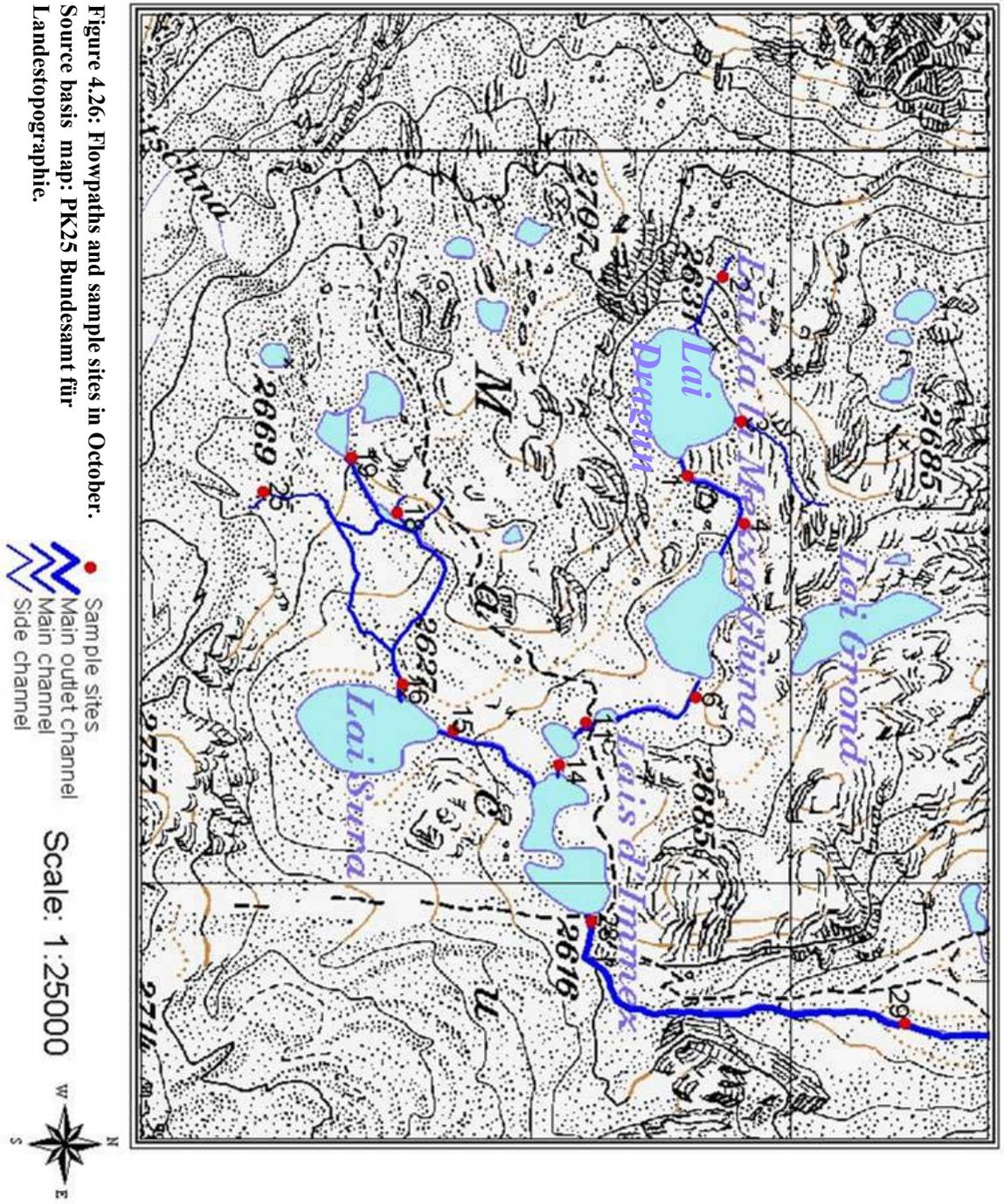


Figure 4.22: Temporal changes in SiO_2 concentrations (monthly mean values for all permanent sites ($n = 13$) \pm standard deviation).







4.5 Grain size distribution

Figure 4.27 and Table 4.5 show the grain size distribution of selected sample sites ($n = 17$). For all sample sites, apart from sites 2, 25 and 27, cobble was the predominant grain size ($> 44\%$) and was distributed relative uniformly ($CV < 43.5\%$). Those latter sample sites were characterised by a predominance of gravel ($> 60\%$) and a slightly higher variation ($CV < 50.7\%$) (Fig. 4.27, Table 4.5). Temporary sites tended to have smaller variation for boulders ($CV < 40\%$) in contrast to permanent sites ($CV < 85\%$).

As there could be observed no distinct pattern in grain size distribution, the results should mainly serve as baseline information for the long-term monitoring program.

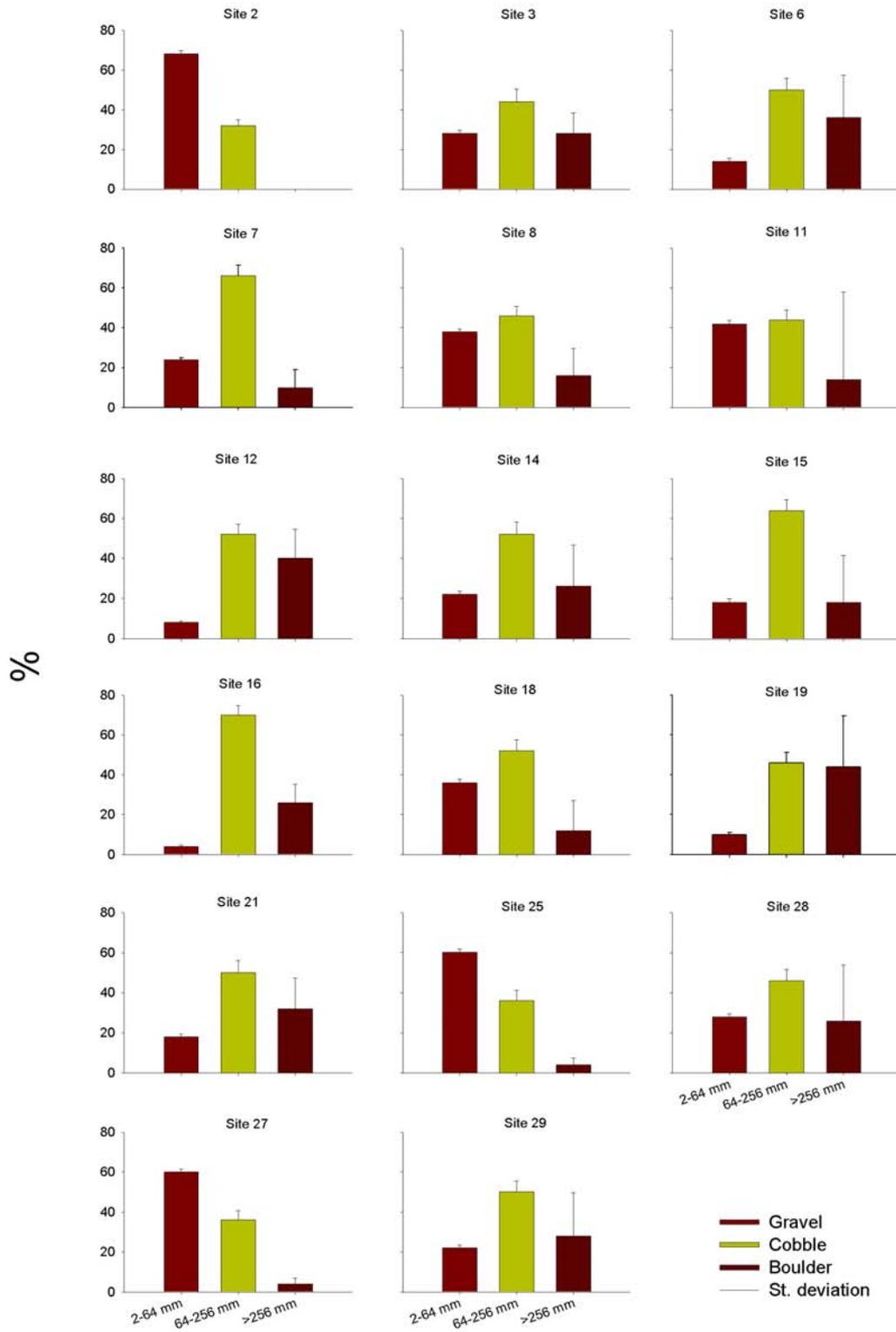


Figure 4.27: Grain size distribution (as %) and standard deviation of the uppermost sediment layer at selected sample sites (n = 17).

Table 4.5: Percentage, standard deviation (SD), and coefficient of variation (CV as %) for gravel, cobble, and boulder at selected sample sites (n = 17).

		site 2	site 3	site 6	site 7	site 8	site 11
Gravel	Percentage	68.00	28.00	14.00	24.00	38.00	42.00
	SD	1.74	1.76	1.50	0.94	1.37	1.63
	CV (%)	50.68	41.81	34.91	19.40	47.33	46.30
Cobble	Percentage	32.00	44.00	50.00	66.00	46.00	44.00
	SD	2.90	6.30	5.73	5.30	4.78	4.85
	CV (%)	28.50	42.01	41.07	37.71	37.29	40.22
Boulder	Percentage	0.00	28.00	36.00	10.00	16.00	14.00
	SD		10.26	21.51	8.96	13.73	43.93
	CV (%)		26.03	53.40	22.74	35.55	85.42
		site 12	site 14	site 15	site 16	site 18	site 19
Gravel	Percentage	8.00	22.00	18.00	4.00	36.00	10.00
	SD	0.58	1.60	1.80	0.71	1.73	1.14
	CV (%)	16.49	38.28	41.60	12.85	45.89	24.78
Cobble	Percentage	52.00	52.00	64.00	70.00	52.00	46.00
	SD	5.08	6.21	5.37	4.89	5.41	5.18
	CV (%)	33.26	43.49	36.23	32.78	40.21	32.53
Boulder	Percentage	40.00	26.00	18.00	26.00	12.00	44.00
	SD	14.69	20.73	23.60	9.39	15.08	25.43
	CV (%)	34.41	47.04	50.21	26.54	40.04	48.61

Table 4.5: Percentage, standard deviation (SD), and coefficient of variation (CV as %) for gravel, cobble, and boulder at selected sample sites (n = 17) (continued).

		site 21	site 25	site 27	site 28	site29
Gravel	Percentage	18.00	60.00	60.00	28.00	22.00
	SD	1.33	1.64	1.48	1.49	1.49
	CV (%)	29.26	51.84	42.67	36.63	34.85
Cobble	Percentage	50.00	36.00	36.00	46.00	50.00
	SD	5.98	5.29	4.50	5.65	5.48
	CV (%)	29.52	39.05	38.04	41.55	39.26
Boulder	Percentage	32.00	4.00	4.00	26.00	28.00
	SD	15.33	3.54	2.83	27.79	21.73
	CV (%)	25.11	8.31	10.10	53.28	44.09

4.6 Moss coverage

The total area which was estimated and the cross sectional area, respectively, varied for each sample site (from 42 m² and 1020 cm² at site 24 to 189 m² and 14700 cm² at site 19) due to different geomorphological conditions of the stream reaches. This makes it difficult to directly compare the mapping of the different sample sites. However, the primarily goal was to develop a method for estimating moss abundance, thus the results should serve as baseline information for the long-term monitoring program. Since the exact coordinates of the area estimated are known, this method is suitable for monitoring changes in moss abundance at each site.

Among the moss sample sites (n = 7), a great variation in moss thickness and coverage as well as in identified species was estimated. Temporary sites had the lowest average thickness (from 0.26 cm at site 3 to 0.54 cm at site 21), whereas permanent sites exhibited greater average thickness (from 0.86 cm at site 14 to 1.4 cm at site 19). Highest moss abundance was observed at site 19, where more than 50% of the estimated area was covered by moss, in contrast to site 14 where only 17% was covered by moss.

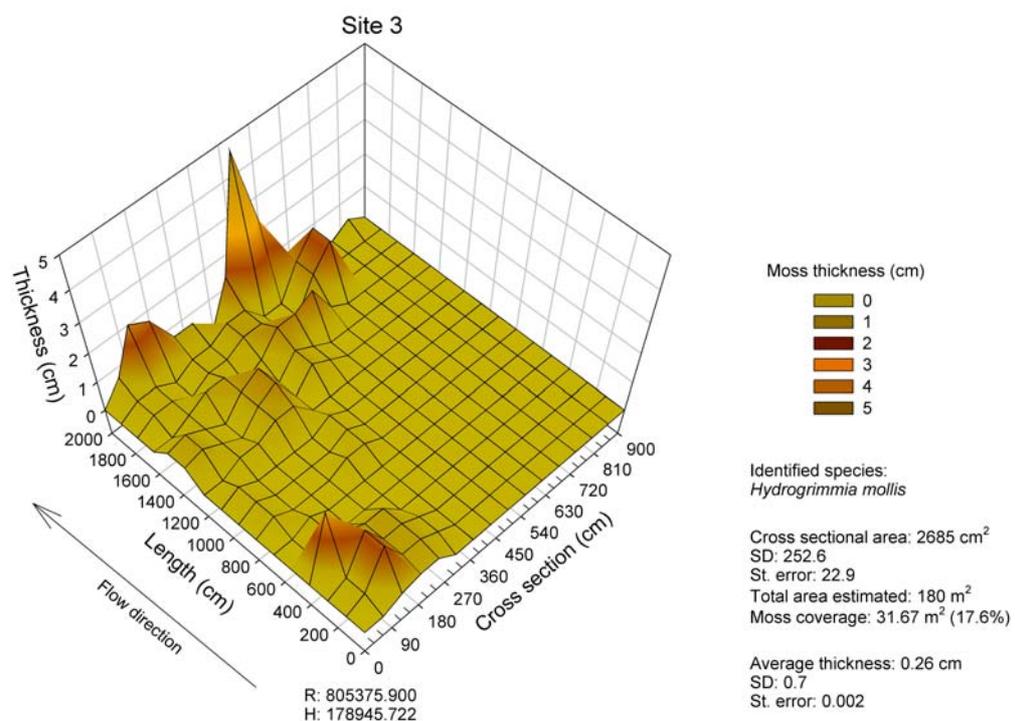


Figure 4.28: Moss coverage for the total area estimated at site 3, including identified species, standard deviation (SD) and standard error (St. error) for the cross sectional area and the average thickness, respectively. R= easting, H= northing.

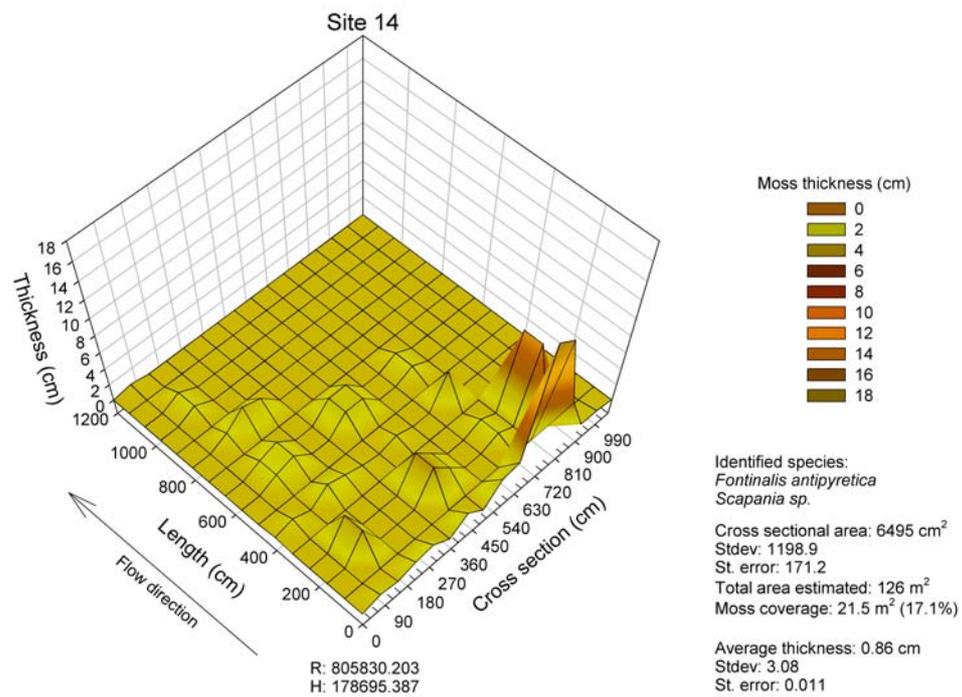


Figure 4.29: Moss coverage for the total area estimated at site 14, including identified species, standard deviation (SD) and standard error (St. error) for the cross sectional area and the average thickness, respectively. R= easting, H= northing.

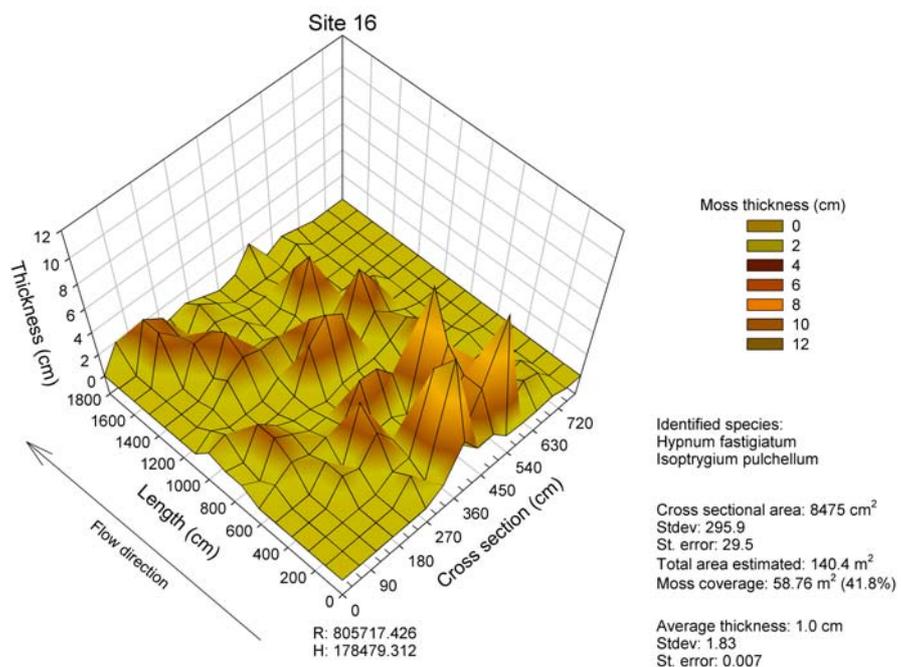


Figure 4.30: Moss coverage for the total area estimated at site 16, including identified species, standard deviation (SD) and standard error (St. error) for the cross sectional area and the average thickness, respectively. R= easting, H= northing.

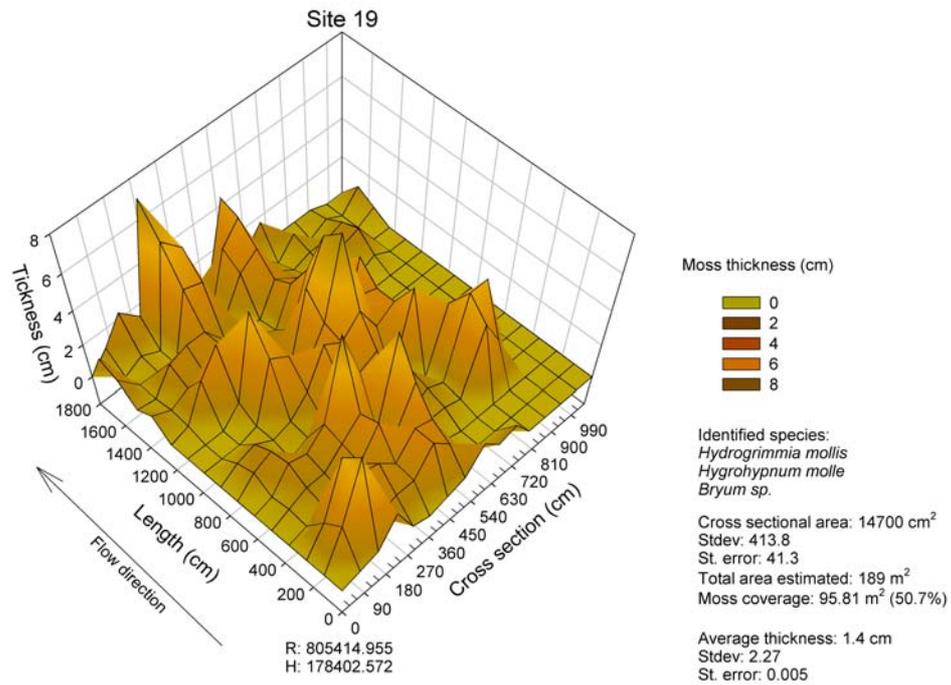


Figure 4.31: Moss coverage for the total area estimated at site 19, including identified species, standard deviation (SD) and standard error (St. error) for the cross sectional area and the average thickness, respectively. R= easting, H= northing.

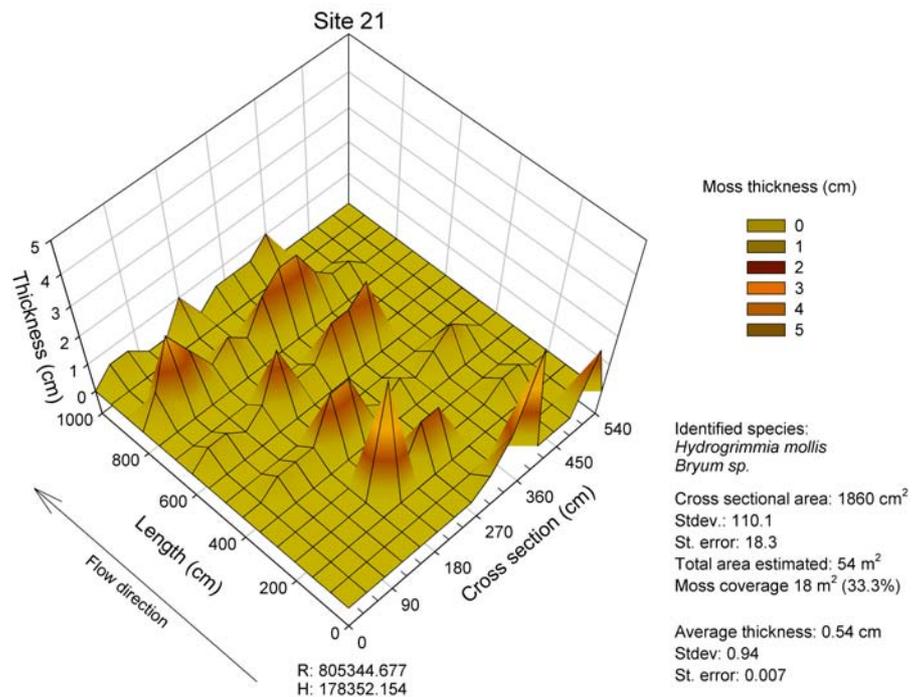


Figure 4.32: Moss coverage for the total area estimated at site 21, including identified species, standard deviation (SD) and standard error (St. error) for the cross sectional area and the average thickness, respectively. R= easting, H= northing.

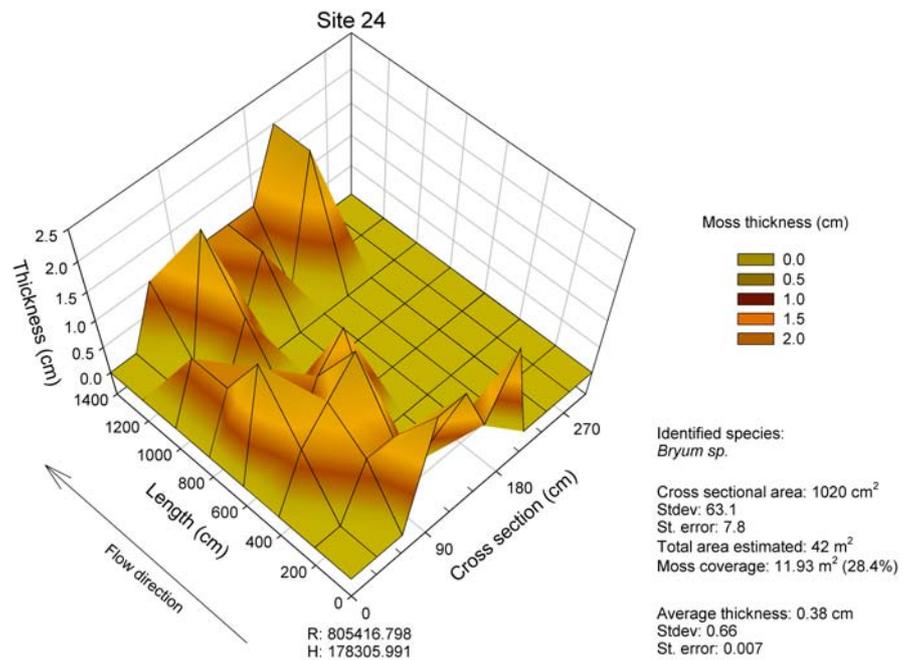


Figure 4.33: Moss coverage for the total area estimated at site 24, including identified species, standard deviation (SD) and standard error (St. error) for the cross sectional area and the average thickness, respectively. R= easting, H= northing.

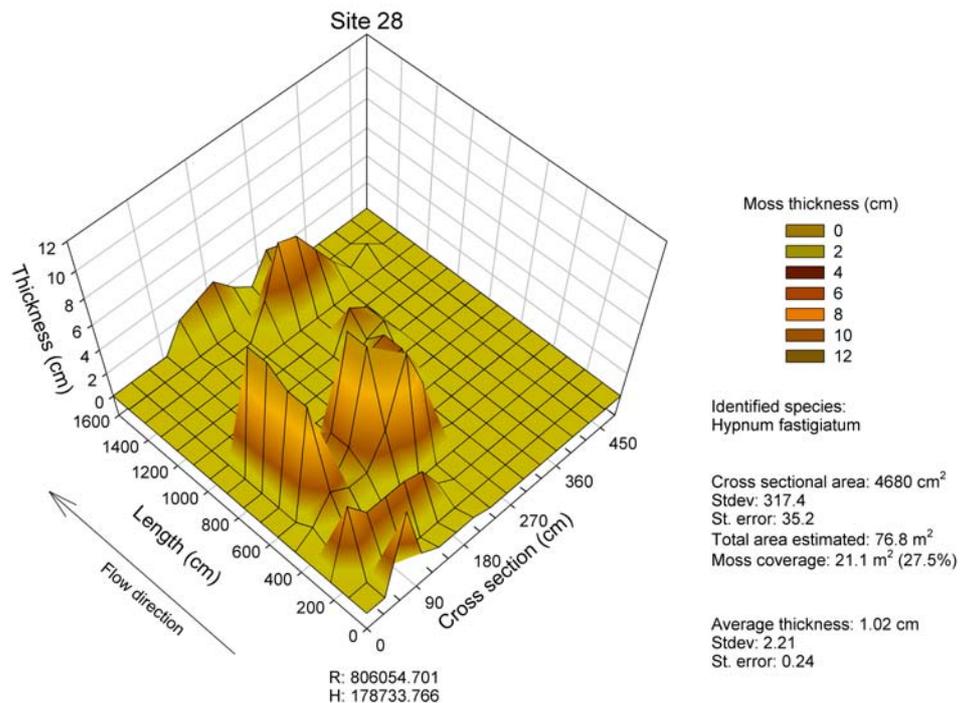


Figure 4.34: Moss coverage for the total area estimated at site 28, including identified species, standard deviation (SD) and standard error (St. error) for the cross sectional area and the average thickness, respectively. R= easting, H= northing.

5 Outlook

The three month survey of the Macun area revealed marked variability in space and time of the stream network system. However, in order to allow for the long-term monitoring program, year-round data collection should be aspired. Thus, the possibility of a correct understanding of overall ecosystem structure and functioning would be provided (Brittain & Millner, 2001). A first step in this direction was done by recording water temperature over an annual cycle. Permanent discharge recording would enhance understanding of the systems expansion/contraction cycle. Furthermore, more research is needed to fill the gap of knowledge concerning habitat structure and colonization patterns of macrophytes, since they are sensitive to environmental changes, as this study only provides baseline information for moss abundance at selected sample sites. The research reported here was somewhat constrained by logistic problems with equipment transport, time consuming mountain hikes, the at times harsh weather conditions, and the general conflict of tourism needs vs. the requirements of scientific research. The latter could be improved through better awareness by the public to the benefits of scientific research and better knowledge regarding the uniqueness of the Macun Lakes area, thus allowing eco tourism and the unconfined possibility of research in the Swiss National Park.

6 Conclusion

The results of this study clearly demonstrate that the investigated floodplain is subject to major spatial and temporal variability. The variability was most pronounced for water chemistry and temperature, whereas the water source (meltwater/groundwater) mainly accounted for the spatial heterogeneity and the season mainly for temporal heterogeneity.

Due to the water source, the floodplain can be divided in a northern groundwater influenced area, and one southern area, dominated by meltwater from rock-glaciers. Although the rock-glaciers did not exhibit the variability of 'normal' glaciers (e.g., more stable in turbidity and discharge), and the groundwater sites did not show as stable thermal and physico-chemical conditions as known from other studies, the discrimination into a northern and southern area for the floodplain was apparent due to distinct physico-chemical patterns, and was statistically supported.

The driving force for temporal variability were the seasonal changes in the harsh alpine climate, leading to a remarkable expansion/contraction cycle of the water system associated with typical seasonal physico-chemical characteristics.

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8 Appendix A: Physico-chemical data

Table A1: Physico-chemical data.

Sample Site	Date	Coordinates		Elevation m	Conductivity µs/cm	Turbidity NTU	Temperature °C	Detection limit µg/l			
		Easting	Northing					10 NH ₄ -N µg/l	NO ₂ -N µg/l	100 NO ₂ -N + NO ₃ -N µg/l	100 DN µg/l
1	17.07.2002	805441	178859	2637	6.3	0.48	9.4	11	1	84	221
1	16.08.2002				6.3	1.02	10.2	12	1	81	230
1	17.09.2002				7.1	2.08	8.9	2.5	1	14	183
1	16.10.2002				7	1.96	7	1	0	11	167
2	17.07.2002	805168	178907	2674	8.5	0.8	0.6	5	1	258	354
2	16.08.2002				9.4	1.6	0.5	5.5	0	362	469
2	17.09.2002				10.1	1.5	1	5.5	2	351	615
2	16.10.2002				10.8	0.65	0.4	2	0	334	485
3	17.07.2002	805366	178932	2639	4.3	0.39	6.5	10	1	133	274
3	16.08.2002				4	1.24	9.8	4	0	102	278
3	16.10.2002				6	0.61	1.3	3	0	207	388
4	17.07.2002	805505	178937	2634	6.3	0.6	9.7	9.5	1	83	179
4	16.08.2002				6.3	0.9	11.9	6	1	73	217
4	17.09.2002				6.7	2	9.7	4.5	1	18	220
4	16.10.2002				7	1.95	3.9	1	0	8	171
5	17.07.2002	805557	178935	2632	3	0.17	12.4	0		0	106
6	17.07.2002	805744	178871	2624	5.4	0.53	11	10	1	48	164
6	16.08.2002				5.3	1.36	11.4	3	1	23	193
6	17.09.2002				5.5	2.7	11.8	4.5	1	10	242
6	16.10.2002				5.9	2.49	4.3	1	0	6	174
7	17.07.2002	805783	178873	2623	5.6	0.33	10.6	4.5	1	13	135
7	16.08.2002				7	0.68	13	2	1	121	349
8	17.07.2002	805742	178808	2622	3.4	<1	14	1		0	149
9	17.07.2002	805750	178792	2621	4.4	<1	14.4	10	1	0	241
10	17.07.2002	805778	178797	2621	3.9	0.24	11.3	3	1	0	169
10	16.08.2002				5.6	0.23	17.3	2	0	14	359
11	17.07.2002	805778	178723	2620	5.5	0.49	11.6	6.5	1	45	179

Table A1: Physico-chemical data (continued).

Sample Site	Date	Coordinates		Elevation m	Conductivity µs/cm	Turbidity NTU	Temperature °C	Detection limit µg/l			
		Easting	Northing					10 NH ₄ -N µg/l	NO ₂ -N µg/l	100 NO ₂ -N + NO ₃ -N µg/l	100 DN µg/l
11	16.08.2002				6.8	1.26	15.4	1	1	22	192
11	17.09.2002				5.8	2.4	10.8	4	1	11	273
11	16.10.2002				6	1.89	3.9	2	1	5	333
12	17.07.2002	805878	178758	2619	3.5	0.21	11.9	9.5	1	0	116
12	16.08.2002				5.2	0.31	21.9	6.5	1	11	306
13	17.07.2002	805796	178597	2627	12.8	0.62	3.3	2		19	85
13	16.08.2002				13.3	0.6	13.4	9.5	0	85	268
14	17.07.2002	805836	178686	2617	6.4	0.43	8.3	6.5	1	63	166
14	16.08.2002				4.7	0.93	10.2	7.5	1	47	231
14	17.09.2002				8.5	1.9	6	3.5	1	51	244
14	16.10.2002				9	1.43	3.9	4	0	60	230
15	17.07.2002	805789	178542	2631	6.6	1.26	6	4.5	1	190	291
15	16.08.2002				9.2	1.28	7.3	1	2	236	356
15	17.09.2002				10.9	0.85	8.1	1.5	2	187	362
15	16.10.2002				12.2	0.73	3.3	3	2	177	368
16	17.07.2002	805565	178545	2650	6.5	0.88	5.1	8	0	220	313
16	16.08.2002				8.7	1.25	11.7	8	2	219	401
16	17.09.2002				10.1	0.4	7.5	2.5	1	273	406
16	16.10.2002				9.9	0.21	2.1	1	0	295	365
17	17.07.2002	805726	178474	2634	2.6	0.09	9.4	5	1	0	75
17	16.08.2002				3.2	0.74	11.4	2	1	24	194
18	17.07.2002	805491	178467	2656	7.6	0.21	4.2	0		199	297
18	16.08.2002				8.8	0.2	3.6	3	1	294	443
18	17.09.2002				12.1	0.3	4.6	3	0	323	461
18	16.10.2002				10.8	0.14	2.8	4	0	359	446
19	17.07.2002	805416	178405	2668	5.6	0.52	5.7	11	1	231	301
19	16.08.2002				6.7	0.57	10.1	4	2	300	423

Table A1: Physico-chemical data (continued).

Sample Site	Date	Coordinates		Elevation m	Conductivity µs/cm	Turbidity NTU	Temperature °C	Detection limit µg/l		100 DN µg/l	
		Easting	Northing					10 NH ₄ -N µg/l	100 NO ₂ -N + NO ₃ -N µg/l		
19	17.09.2002				9.2	1.5	8.3	4	3	333	461
19	16.10.2002				9	0.41	2.6	1	0	354	476
20	17.07.2002	805302	178425	2670	4.7	0.53	6.2	0	1	214	295
20	16.08.2002				6.5	0.68	10.1	15	1	277	463
20	17.09.2002				6.2	0.35	13.8	5	1	303	482
21	17.07.2002	805350	178353	2673	5.7	1.35	8.3	1	1	222	298
21	16.08.2002				9.3	1.06	15.6	3	2	319	550
22	17.07.2002	805258	178333	2675	6.2	1.38	4.9	2	1	222	342
23	17.07.2002	805264	178286	2675	5.1	3.38	0.1	9		170	307
23	16.08.2002				11.5	1.82	0.3	1	1	268	384
24	17.07.2002	805420	178291	2679	5.1	2.91	2.8	9.5	1	230	332
24	16.08.2002				15	1	11.7	2	3	430	648
25	17.07.2002	805466	178287	2682	9	4.25	1.7	6	1	268	351
25	16.08.2002				15.6	3.5	2.7	2	1	338	516
25	17.09.2002				19.3	2.8	7	1.5	1	321	528
25	16.10.2002				23.4	1.59	0.1	2	1	436	510
26	17.07.2002	805782	178330	2632	6.5	6.61	0.1	3		148	265
26	16.08.2002				18.1	1.45	0.9	5	2	342	509
27	17.07.2002	805869	178414	2632	10.3	1.51	9.1	1	1	93	151
27	16.08.2002				13.8	1.03	17.3	8	0	23	271
28	17.07.2002	806050	178730	2616	6.9	1.26	8.3	1	1	169	237
28	16.08.2002				8.7	1.38	9.1	5	1	184	360
28	17.09.2002				10.4	1.1	8.4	4.5	1	116	347
28	16.10.2002				11.3	0.72	3.6	3	1	112	272
29	17.07.2002	806190	179152	2552	10.9	3.06	5	1	1	171	316
29	16.08.2002				15.3	3.43	7.8	2	1	249	402
29	17.09.2002				23	2	6.3	2.5	1	224	410
29	16.10.2002				26.5	0.84	2.8	3	0	266	408

Table A1: Physico-chemical data (continued).

Sample Site	Date	Coordinates		Elevation m	PN µg/l	5		PP µg/l	DOC mg/l	TIC mg/l	POC mg/l	SiO ₂ mg/l	SO ₄ mg/l	Cl ⁻ mg/l
		Easting	Northing			PO ₄ -P µg/l	DP µg/l							
1	17.07.2002	805441	178859	2637	68	1	2	5		0.7	0.4	1.9	<5	<0.5
1	16.08.2002				77	1	2	6		0.3	0.75	2.2	<5	<0.5
1	17.09.2002				181	2	6	14	1.2	0.7	1.88	2.5	<5	<0.5
1	16.10.2002				166	1	4	14		0.9	2.14			
2	17.07.2002	805168	178907	2674	9	5	5	0		0.6	0.08	3.2	<5	<0.5
2	16.08.2002				5	7	8	0		0.2	0.11	3.7	<5	<0.5
2	17.09.2002				1	8	12	1	2	0.4	0.06	4.6	<5	<0.5
2	16.10.2002				36	7	16	4		0.8	0.05			
3	17.07.2002	805366	178932	2639	23	1	2	1		0.4	0.19	1.9	<5	<0.5
3	16.08.2002				18	1	2	3		0.2	0.23	2.3	<5	<0.5
3	16.10.2002				19	0	5	5		0.7	0.32			
4	17.07.2002	805505	178937	2634	34	2	2	3		0.5	0.21	1.9	<5	<0.5
4	16.08.2002				77	0	2	7		0.2	0.61	2.2	<5	<0.5
4	17.09.2002				178	3	8	14	0.9	0.2	1.14	2.6	<5	<0.5
4	16.10.2002				192	0	6	16		0.5	1.94			
5	17.07.2002	805557	178935	2632	20	0	1	1			0.17			
6	17.07.2002	805744	178871	2624	64	1	1	5		0.5	0.45	1.4	<5	<0.5
6	16.08.2002				91	1	2	7		0.2	0.97	1.8	<5	0.5
6	17.09.2002				157	3	7	14	1.9	0.4	1.9	2	<5	<0.5
6	16.10.2002				136	1	4	15		0.5	2.13			
7	17.07.2002	805783	178873	2623	17	1	1	1		0.6	0.13	2.3	<5	<0.5
7	16.08.2002				13	1	2	2		0.2	0.17	2.7	<5	<0.5
8	17.07.2002	805742	178808	2622		0	0							
9	17.07.2002	805750	178792	2621		2	4			0.4		2.8	<5	<0.5
10	17.07.2002	805778	178797	2621	20	2	2	1		0.7	0.21	2.1	<5	<0.5
10	16.08.2002				31	1	4	3		0.2	0.35	2.2	<5	0.6
11	17.07.2002	805778	178723	2620	33	4	4	3		0.5	0.23	1.4	<5	<0.5

Table A1: Physico-chemical data (continued).

Sample Site	Date	Coordinates		Elevation m	PN µg/l	5		PP µg/l	DOC mg/l	TIC mg/l	POC mg/l	SiO ₂ mg/l	SO ₄ mg/l	Cl ⁻ mg/l
		Easting	Northing			PO ₄ -P µg/l	DP µg/l							
11	16.08.2002				93	1	2	8		0.2	0.87	1.8	<5	<0.5
11	17.09.2002				139	2	8	13	1.2	0.4	1.59	2.1	<5	<0.5
11	16.10.2002				130	0	6	13		0.4	1.71			
12	17.07.2002	805878	178758	2619	28	3	3	2		0.5	0.26	1.6	<5	<0.5
12	16.08.2002				37	2	3	3		0.2	0.3	1.9	<5	<0.5
13	17.07.2002	805796	178597	2627	43	0	0	3			0.49			
13	16.08.2002				27	0	1	2		0.2	0.21	2.9	<5	0.6
14	17.07.2002	805836	178686	2617	27	4	3	2		0.5	0.22	1.8	<5	<0.5
14	16.08.2002				62	0	2	6		0.2	0.59	2.2	<5	<0.5
14	17.09.2002				79	2	8	7	0.9	0.6	0.84	2.7	<5	<0.5
14	16.10.2002				103	0	4	12		0.5	1.04			
15	17.07.2002	805789	178542	2631	30	4	4	3		0.4	0.2	1.4	<5	<0.5
15	16.08.2002				21	0	1	4		0.2	0.28	2.2	<5	<0.5
15	17.09.2002				30	1	8	3	3.6	0.3	0.24	2.7	<5	<0.5
15	16.10.2002				52	0	1	9		0.4	0.83			
16	17.07.2002	805565	178545	2650	14	3	3	1		0.4	0.12	1.4	<5	<0.5
16	16.08.2002				17	0	2	3		0.3	0.19	2.3	<5	<0.5
16	17.09.2002				7	1	9	1	1.4	0.4	0.24	2.8	<5	<0.5
16	16.10.2002				9	1	6	4		0.4	0.5			
17	17.07.2002	805726	178474	2634	11	4	4	1		0.3	0.09	1.7	<5	<0.5
17	16.08.2002				14	0	1	2		0.1	0.21	1.7	<5	<0.5
18	17.07.2002	805491	178467	2656	33	0	2	4			0.36			
18	16.08.2002				12	1	5	1		0.3	0.12	2.4	<5	<0.5
18	17.09.2002				15	3	9	2	2.4	0.4	0.11	2.7	<5	<0.5
18	16.10.2002				24	2	3	6		0.4	0.26			
19	17.07.2002	805416	178405	2668	12	1	1	1		0.2	0.1	1.3	<5	<0.5
19	16.08.2002				21	2	3	4		0	0.14	1.9	<5	<0.5

Table A1: Physico-chemical data (continued).

Detection limit µg/l		Coordinates		Elevation	PN	5	5	PP	DOC	TIC	POC	SiO ₂	SO ₄	Cl ⁻
Sample Site	Date	Easting	Northing	m	µg/l	PO ₄ -P µg/l	DP µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
19	17.09.2002				16	3	9	2	1.8	0.3	0.17	2.6	<5	<0.5
19	16.10.2002				52	2	3	9		0.4	0.09			
20	17.07.2002	805302	178425	2670	16	0	1	1		0.2	0.07	1	<5	<0.5
20	16.08.2002				8	1	3	2		0.5	0.11	1.7	<5	<0.5
20	17.09.2002				9	3	8	2	0.9	0.3	0.11	2.1	<5	<0.5
21	17.07.2002	805350	178353	2673	15	2	3	2		0.3	0.18	0.9	<5	<0.5
21	16.08.2002				12	2	4	2		0.2	0.15	2.3	<5	<0.5
22	17.07.2002	805258	178333	2675	17	2	3	2		0.3	0.2	0.9	<5	<0.5
23	17.07.2002	805264	178286	2675	27	2	4	6			0.29			
23	16.08.2002				28	2	4	3		0.4	0.14	1.7	<5	<0.5
24	17.07.2002	805420	178291	2679	51	3	3	16		0.2	0.69	0.8	<5	<0.5
24	16.08.2002				7	0	2	2		0.1	0.16	3	5.1	<0.5
25	17.07.2002	805466	178287	2682	14	2	3	2		0.5	0.1	1.5	<5	<0.5
25	16.08.2002				9	2	5	2		0.4	0.13	3	<5	<0.5
25	17.09.2002				10	4	11	3	3	0.4	0.09	2.8	5.9	<0.5
25	16.10.2002				17	3	4	6		0.5	0.2			
26	17.07.2002	805782	178330	2632	19	2	2	3			0.33			
26	16.08.2002				3	3	5	1		0.2	0.1	4	<5	<0.5
27	17.07.2002	805869	178414	2632	34	1	1	4		0.4	0.26	1.5	<5	<0.5
27	16.08.2002				27	1	5	7		0	0.34	2.2	<5	<0.5
28	17.07.2002	806050	178730	2616	32	1	1	3		0.4	0.26	1.4	<5	<0.5
28	16.08.2002				24	1	5	3		0	0.25	2.2	<5	<0.5
28	17.09.2002				55	3	7	6	1.4	0.4	0.42	2.7	<5	<0.5
28	16.10.2002				15	0	0	6		0.4	0.13			
29	17.07.2002	806190	179152	2552	17	2	2	3		0.6	0.2	1.6	<5	<0.5
29	16.08.2002				21	2	5	4		0.6	0.2	2.4	<5	0.5
29	17.09.2002				22	3	9	3	0.6	0.6	0.21	3	5.1	<0.5
29	16.10.2002				65	1	2	10		0.5	0.51			

Table A1: Physico-chemical data (continued).

Sample Site	Date	Coordinates		Elevation m	Ca ²⁺ mg/l	Mg ²⁺ mg/l	K ⁺ mg/l	Na ⁺ mg/l	0.01	0.5	0.02	0.01	1
		Easting	Northing						Cd µg/l	Pb µg/l	Fe mg/l	Mn mg/l	Cu µg/l
1	17.07.2002	805441	178859	2637	<5	<2.5	<0.5	<2.5	<0.01	0.7	<0.02	<0.01	1.9
1	16.08.2002				<5	<2.5	<0.5	<2.5					
1	17.09.2002				<5	<2.5	<0.5	<2.5	0.08	0.6	<0.02	<0.01	<1.0
1	16.10.2002												
2	17.07.2002	805168	178907	2674	<5	<2.5	<0.5	<2.5	<0.01	<0.5	<0.02	<0.01	1.8
2	16.08.2002				<5	<2.5	<0.5	<2.5					
2	17.09.2002				<5	<2.5	<0.5	<2.5	0.02	<0.5	<0.02	<0.01	<1.0
2	16.10.2002												
3	17.07.2002	805366	178932	2639	<5	<2.5	<0.5	<2.5					
3	16.08.2002				<5	<2.5	<0.5	<2.5					
3	16.10.2002												
4	17.07.2002	805505	178937	2634	<5	<2.5	<0.5	<2.5	<0.01	<0.5	<0.02	<0.01	1.2
4	16.08.2002				<5	<2.5	<0.5	<2.5					
4	17.09.2002				<5	<2.5	<0.5	<2.5	0.02	<0.5	<0.02	<0.01	1.2
4	16.10.2002												
5	17.07.2002	805557	178935	2632									
6	17.07.2002	805744	178871	2624	<5	<2.5	<0.5	<2.5	<0.01	<0.5	<0.02	<0.01	1.6
6	16.08.2002				<5	<2.5	<0.5	<2.5					
6	17.09.2002				<5	<2.5	<0.5	<2.5	0.02	<0.5	<0.02	<0.01	1
6	16.10.2002												
7	17.07.2002	805783	178873	2623	<5	<2.5	<0.5	<2.5	<0.01	<0.5	<0.02	<0.01	1.5
7	16.08.2002				<5	<2.5	<0.5	<2.5					
8	17.07.2002	805742	178808	2622									
9	17.07.2002	805750	178792	2621	<5	<2.5	<0.5	<2.5	<0.01	0.5	<0.02	<0.01	3.8
10	17.07.2002	805778	178797	2621	<5	<2.5	<0.5	<2.5	<0.01	<0.5	<0.02	<0.01	2
10	16.08.2002				<5	<2.5	<0.5	<2.5					
11	17.07.2002	805778	178723	2620	<5	<2.5	<0.5	<2.5	<0.01	<0.5	<0.02	<0.01	1

Table A1: Physico-chemical data (continued).

Sample Site	Date	Coordinates		Elevation m	Ca ²⁺ mg/l	Mg ²⁺ mg/l	K ⁺ mg/l	Na ⁺ mg/l	0.01	0.5	0.02	0.01	1
		Easting	Northing						Cd µg/l	Pb µg/l	Fe mg/l	Mn mg/l	Cu µg/l
11	16.08.2002				<5	<2.5	<0.5	<2.5					
11	17.09.2002				<5	<2.5	<0.5	<2.5	0.09	0.5	<0.02	<0.01	<1.0
11	16.10.2002												
12	17.07.2002	805878	178758	2619	<5	<2.5	<0.5	<2.5	<0.01	0.5	<0.02	<0.01	1.4
12	16.08.2002				<5	<2.5	<0.5	<2.5					
13	17.07.2002	805796	178597	2627									
13	16.08.2002				<5	<2.5	<0.5	<2.5					
14	17.07.2002	805836	178686	2617	<5	<2.5	<0.5	<2.5	<0.01	0.5	<0.02	<0.01	2.1
14	16.08.2002				<5	<2.5	<0.5	<2.5					
14	17.09.2002				<5	<2.5	<0.5	<2.5	0.04	0.8	<0.02	<0.01	1.6
14	16.10.2002												
15	17.07.2002	805789	178542	2631	<5	<2.5	<0.5	<2.5	0.02	<0.5	<0.02	<0.01	1.5
15	16.08.2002				<5	<2.5	<0.5	<2.5					
15	17.09.2002				<5	<2.5	<0.5	<2.5	0.04	<0.5	<0.02	<0.01	<1.0
15	16.10.2002												
16	17.07.2002	805565	178545	2650	<5	<2.5	<0.5	<2.5	<0.01	0.6	<0.02	<0.01	2.2
16	16.08.2002				<5	<2.5	<0.5	<2.5					
16	17.09.2002				<5	<2.5	<0.5	<2.5	0.02	<0.5	<0.02	<0.01	1.2
16	16.10.2002												
17	17.07.2002	805726	178474	2634	<5	<2.5	<0.5	<2.5	0.01	<0.5	<0.02	<0.01	1.7
17	16.08.2002				<5	<2.5	<0.5	<2.5					
18	17.07.2002	805491	178467	2656									
18	16.08.2002				<5	<2.5	<0.5	<2.5					
18	17.09.2002				<5	<2.5	<0.5	<2.5	0.08	0.8	<0.02	<0.01	1.7
18	16.10.2002												
19	17.07.2002	805416	178405	2668	<5	<2.5	<0.5	<2.5	0.01	<0.5	<0.02	<0.01	1.5
19	16.08.2002				<5	<2.5	<0.5	<2.5					

Table A1: Physico-chemical data (continued).

Sample Site	Date	Coordinates		Elevation m	Ca ²⁺ mg/l	Mg ²⁺ mg/l	K ⁺ mg/l	Na ⁺ mg/l	Detection limit µg/l				
		Easting	Northing						Cd µg/l	Pb µg/l	Fe mg/l	Mn mg/l	Cu µg/l
19	17.09.2002				<5	<2.5	<0.5	<2.5	0.03	<0.5	<0.02	<0.01	1.1
19	16.10.2002												
20	17.07.2002	805302	178425	2670	<5	<2.5	<0.5	<2.5	<0.01	<0.5	<0.02	<0.01	1.6
20	16.08.2002				<5	<2.5	<0.5	<2.5					
20	17.09.2002				<5	<2.5	<0.5	<2.5	0.03	0.7	<0.02	<0.01	1.2
21	17.07.2002	805350	178353	2673	<5	<2.5	<0.5	<2.5	<0.01	<0.5	<0.02	<0.01	2.4
21	16.08.2002				<5	<2.5	<0.5	<2.5					
22	17.07.2002	805258	178333	2675	<5	<2.5	<0.5	<2.5	0.02	<0.5	<0.02	<0.01	3.6
23	17.07.2002	805264	178286	2675									
23	16.08.2002				<5	<2.5	<0.5	<2.5					
24	17.07.2002	805420	178291	2679	<5	<2.5	<0.5	<2.5	0.07	<0.5	<0.02	<0.01	5
24	16.08.2002				<5	<2.5	<0.5	<2.5					
25	17.07.2002	805466	178287	2682	<5	<2.5	<0.5	<2.5	0.22	<0.5	<0.02	<0.01	3.2
25	16.08.2002				<5	<2.5	<0.5	<2.5					
25	17.09.2002				<5	<2.5	0.65	<2.5	0.02	<0.5	<0.02	<0.01	1.8
25	16.10.2002												
26	17.07.2002	805782	178330	2632									
26	16.08.2002				<5	<2.5	<0.5	<2.5					
27	17.07.2002	805869	178414	2632	<5	<2.5	<0.5	<2.5	0.05	0.7	<0.02	<0.01	3.1
27	16.08.2002				<5	<2.5	<0.5	<2.5					
28	17.07.2002	806050	178730	2616	<5	<2.5	<0.5	<2.5	0.03	0.5	<0.02	<0.01	2.9
28	16.08.2002				<5	<2.5	<0.5	<2.5					
28	17.09.2002				<5	<2.5	<0.5	<2.5	0.01	<0.5	<0.02	<0.01	1
28	16.10.2002												
29	17.07.2002	806190	179152	2552	<5	<2.5	<0.5	<2.5	0.1	<0.5	<0.02	<0.01	2.8
29	16.08.2002				<5	<2.5	<0.5	<2.5					
29	17.09.2002				<5	<2.5	<0.5	<2.5	0.01	0.6	<0.02	<0.01	3.6
29	16.10.2002												

9 Appendix B: Water temperature based on temperature loggers

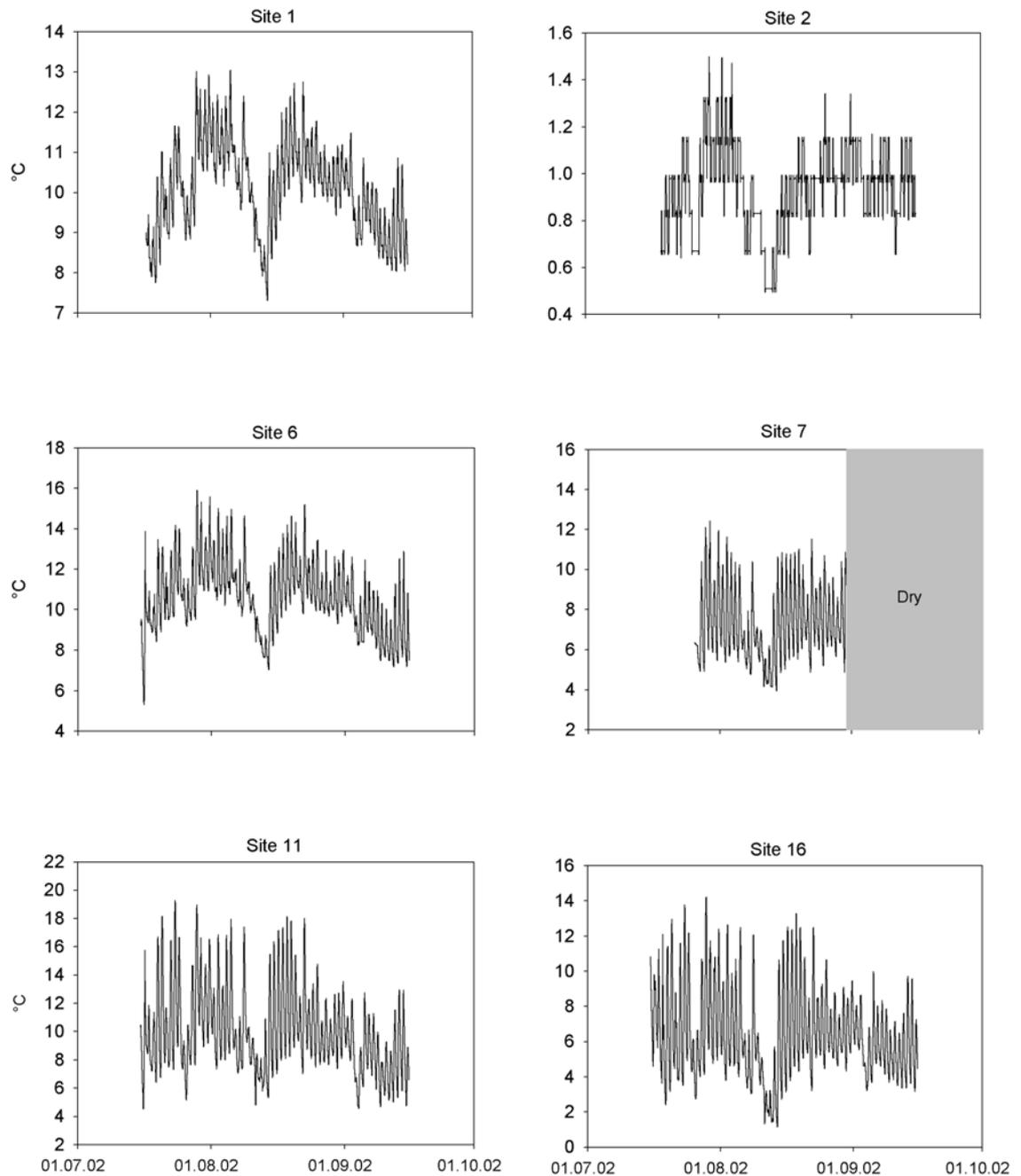


Figure B 4.1-1: Temperature logger data from July to October 2002.

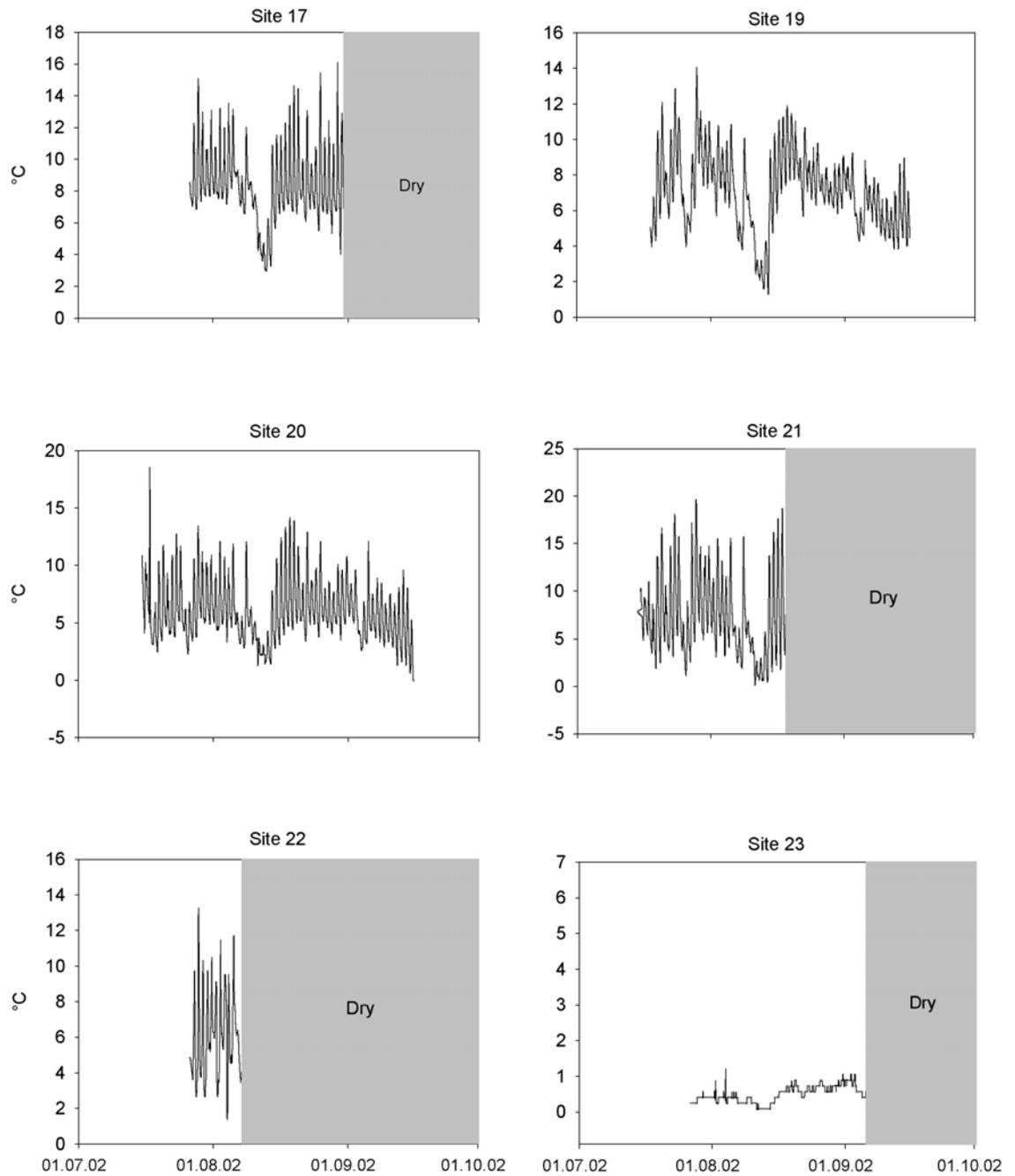


Figure B 4.1-1: Temperature logger data from July to October 2002 (continued).

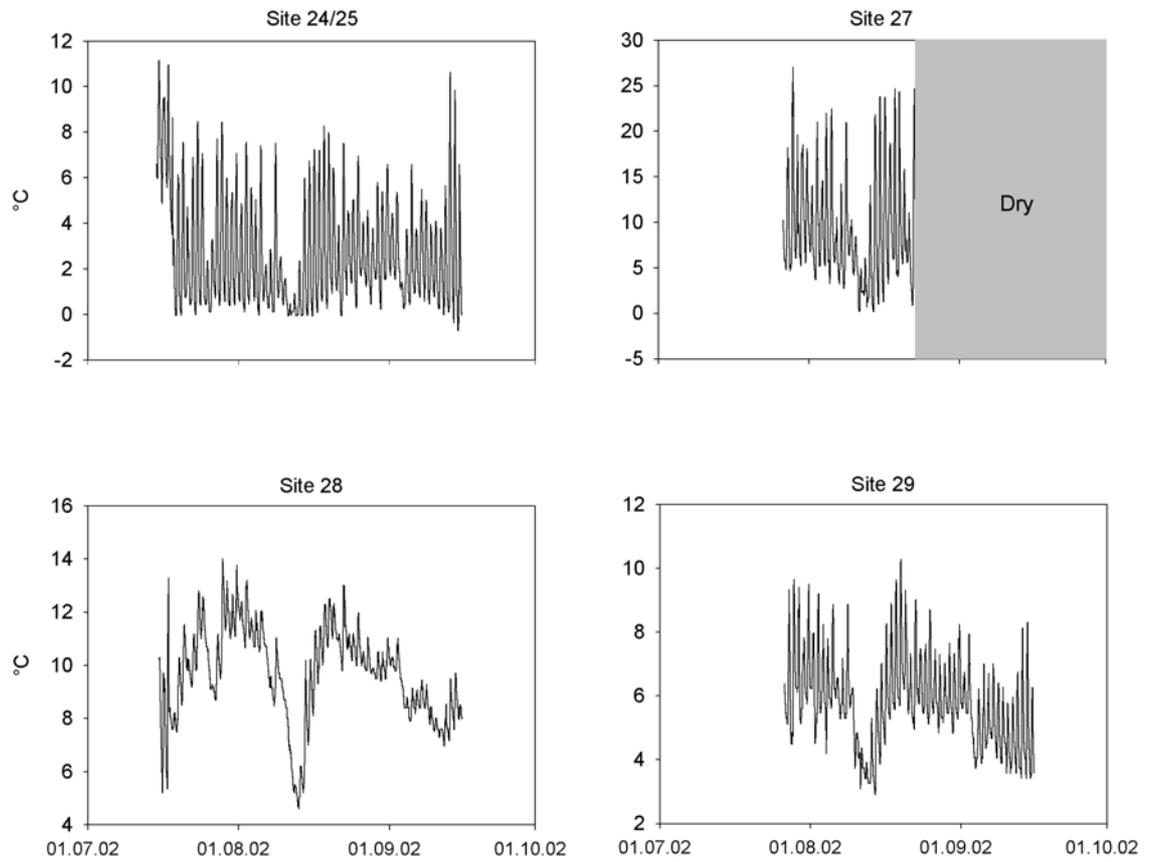


Figure B 4.1-1: Temperature logger data from July to October 2002 (continued).

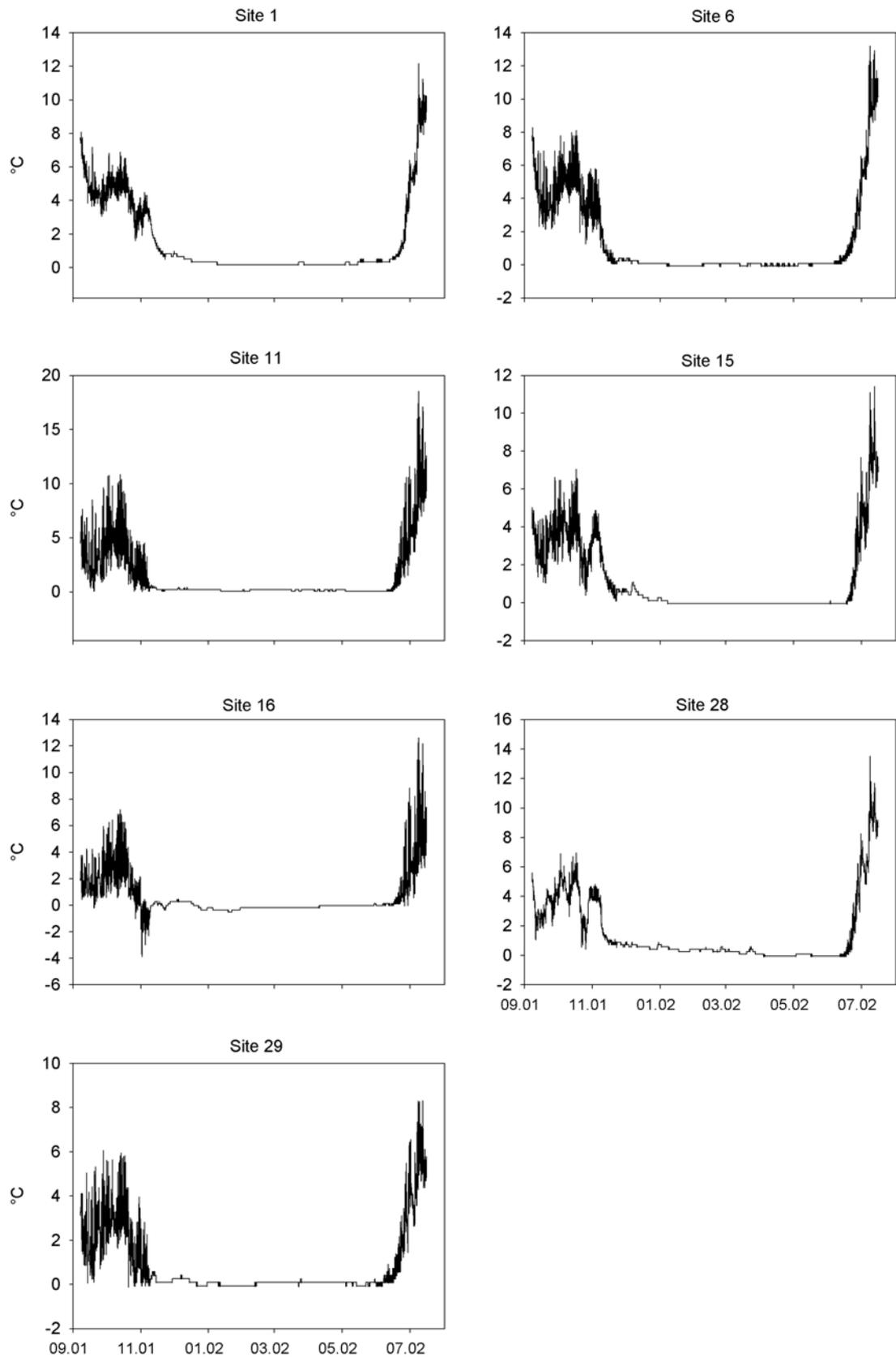


Figure B 4.1-2: Temperature logger data from September 2001 to July 2002.

10 Appendix C: ANOVA Results

Tukey HSD test; variable PN (permanent13) Probabilities for Post Hoc Tests Error: Between MS = .06413, df = 44.000										
Cell No	Category	Date	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
			1.6349	1.9041	2.1522	2.1559	1.2828	1.1966	1.1602	1.4617
1	North	17/07/02		0.699118	0.044379	0.041884	0.249049	0.071025	0.038290	0.927775
2	North	16/08/02	0.699118		0.776853	0.763868	0.002277	0.000450	0.000268	0.066444
3	North	17/09/02	0.044379	0.776853		1.000000	0.000139	0.000133	0.000133	0.000598
4	North	16/10/02	0.041884	0.763868	1.000000		0.000138	0.000133	0.000133	0.000561
5	South	17/07/02	0.249049	0.002277	0.000139	0.000138		0.997147	0.976568	0.846614
6	South	16/08/02	0.071025	0.000450	0.000133	0.000133	0.997147		0.999991	0.434584
7	South	17/09/02	0.038290	0.000268	0.000133	0.000133	0.976568	0.999991		0.275666
8	South	16/10/02	0.927775	0.066444	0.000598	0.000561	0.846614	0.434584	0.275666	

Figure C 4.3-1: Post Hoc Tukey Test results for PN. Significant differences in red.

Tukey HSD test; variable PP (permanent13) Probabilities for Post Hoc Tests Error: Between MS = .02950, df = 44.000										
Cell No	Category	Date	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
			.64751	.89012	1.1155	1.1741	.44804	.50990	.52595	.87183
1	North	17/07/02		0.352638	0.002245	0.000509	0.469931	0.849925	0.914687	0.32141
2	North	16/08/02	0.352638		0.446417	0.178173	0.001246	0.007656	0.012139	1.00000
3	North	17/09/02	0.002245	0.446417		0.999385	0.000133	0.000136	0.000139	0.22721
4	North	16/10/02	0.000509	0.178173	0.999385		0.000133	0.000133	0.000133	0.06285
5	South	17/07/02	0.469931	0.001246	0.000133	0.000133		0.995952	0.983853	0.00041
6	South	16/08/02	0.849925	0.007656	0.000136	0.000133	0.995952		1.000000	0.00294
7	South	17/09/02	0.914687	0.012139	0.000139	0.000133	0.983853	1.000000		0.00505
8	South	16/10/02	0.321413	1.000000	0.227218	0.062856	0.000417	0.002941	0.005050	

Figure C 4.3-2: Post Hoc Tukey Test results for PP. Significant differences in red.

Tukey HSD test; variable POC (permanent13) Probabilities for Post Hoc Tests Error: Between MS = .00317, df = 44.000										
Cell No.	Category	Date	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
			.11331	.24351	.38606	.44068	.06971	.07042	.07477	.11360
1	North	17/07/02		0.014453	0.000133	0.000133	0.870800	0.879947	0.927502	1.000000
2	North	16/08/02	0.014453		0.005424	0.000172	0.000191	0.000195	0.000229	0.004773
3	North	17/09/02	0.000133	0.005424		0.785216	0.000133	0.000133	0.000133	0.000133
4	North	16/10/02	0.000133	0.000172	0.785216		0.000133	0.000133	0.000133	0.000133
5	South	17/07/02	0.870800	0.000191	0.000133	0.000133		1.000000	1.000000	0.771395
6	South	16/08/02	0.879947	0.000195	0.000133	0.000133	1.000000		1.000000	0.785345
7	South	17/09/02	0.927502	0.000229	0.000133	0.000133	1.000000	1.000000		0.861776
8	South	16/10/02	1.000000	0.004773	0.000133	0.000133	0.771395	0.785345	0.861776	

Figure C 4.3-3: Post Hoc Tukey Test results for POC. Significant differences in red.

Tukey HSD test; variable NO ₂ +NO ₃ -N (permanent13) Probabilities for Post Hoc Tests Error: Between MS = .04208, df = 44.000										
Cell No	Category	Date	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
			1.8026	1.6412	1.2583	1.0884	2.3251	2.4276	2.4026	2.4342
1	North	17/07/02		0.914052	0.003111	0.000176	0.001425	0.000205	0.000279	0.000193
2	North	16/08/02	0.914052		0.086422	0.002570	0.000144	0.000133	0.000134	0.000133
3	North	17/09/02	0.003111	0.086422		0.890443	0.000133	0.000133	0.000133	0.000133
4	North	16/10/02	0.000176	0.002570	0.890443		0.000133	0.000133	0.000133	0.000133
5	South	17/07/02	0.001425	0.000144	0.000133	0.000133		0.972213	0.994562	0.961100
6	South	16/08/02	0.000205	0.000133	0.000133	0.000133	0.972213		0.999997	1.000000
7	South	17/09/02	0.000279	0.000134	0.000133	0.000133	0.994562	0.999997		0.999986
8	South	16/10/02	0.000193	0.000133	0.000133	0.000133	0.961100	1.000000	0.999986	

Figure C 4.3-4: Post Hoc Tukey Test results for NO₂ + NO₃-N. Significant differences in red.

Tukey HSD test; variable DN (permanent13) Probabilities for Post Hoc Tests Error: Between MS = .00557, df = 44.000										
Cell No	Category	Date	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
			2.2594	2.3282	2.3643	2.3182	2.4864	2.6225	2.6459	2.6128
1	North	17/07/02		0.825180	0.358195	0.912989	0.000207	0.000133	0.000133	0.000133
2	North	16/08/02	0.825180		0.994074	0.999999	0.012154	0.000133	0.000133	0.000133
3	North	17/09/02	0.358195	0.994074		0.975464	0.104302	0.000138	0.000133	0.000144
4	North	16/10/02	0.912989	0.999999	0.975464		0.006279	0.000133	0.000133	0.000133
5	South	17/07/02	0.000207	0.012154	0.104302	0.006279		0.014730	0.002460	0.029590
6	South	16/08/02	0.000133	0.000133	0.000138	0.000133	0.014730		0.998329	0.999995
7	South	17/09/02	0.000133	0.000133	0.000133	0.000133	0.002460	0.998329		0.985739
8	South	16/10/02	0.000133	0.000133	0.000144	0.000133	0.029590	0.999995	0.985739	

Figure C 4.3-5: Post Hoc Tukey Test results for DN. Significant differences in red.

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Eidesstattliche Erklärung

Hiermit versichere ich, dass diese Arbeit selbständig durchgeführt wurde und keine anderen als die angegebenen Hilfsmittel und Quellen benutzt sowie Zitate kenntlich gemacht wurden.

Sebastian Matthaer

Dübendorf, 15.04.03