Ecological Assessment of Springs and Spring Brooks in the Swiss National Park: Combining Fieldwork with Geodesy (GPS/Tachymetry) and GIS

Diploma Thesis by

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Table of contents

I. Summary

The study focused on the temporal and spatial pattern of environmental factors and the energy base of five subalpine springs and spring brooks in the Swiss National Park (Canton of Grisons, southeast Switzerland) from June to October 2001. Three springs were located in the Fuorn River corridor, one in the Spöl Valley, and one in Val da l´Aqua. The springs were similar in altitude (1800 to 2000 m a.s.l.) and lithology (limestone). Spring inventory comprised four rheocrenes and one limnocrene. Two springs were subject to human impact, one was influenced by sewage from a nearby tourist facitity, and one by a hiking trail.

To assess, evaluate and model spatial and temporal pattern at a high resolution, approved ecological field methods were combined with (1) geodetic techniques (Global Positioning System, Tachymetry) and a Geographic Information System (GIS). Measurements included assessment of spring (2) habitat morphology, (3) light availability, (4) grain size distribution and (5) benthic organic matter distribution, (6) physico-chemical characteristics, such as temperature, conductivity and nutrients, as well as (7) periphyton.

(1) The methodological approach revealed that geodetic methods allowing a rapid and highly accurate spatial survey (accuracy: > 6.2 cm vertical, > 2 cm horizontal) can be successfully applied in small-scale environments, even in subaqueous areas where photogrammetry is restricted and low in accuracy.

(2) The investigated springs comprised a wide range of morphologically different and stable habitat types due to the absence of disturbance. The different morphotypes ranged from large and complex channel morphologies (about 680 m^2) with dense moss cover to linear springs smaller than 16 m^2, where mosses were nearly absent.

(3) Light availability and (4) grain size distribution varied distinctively among springs.

(5) Benthic organic matter included both allochtonuous (riparian vegetation) and autochtonuous (moss, algae) inputs.

(6) Instantaneous spatial temperature ranges varied from 2.9 °C to 19.2 °C within different springs between June and August, which contrasts with the usually suggested thermal stability of springs. Hydrochemical conditions varied greatly among springs, for example average conductivity ranged from 146 to 2058 µS/cm. In general, the springs were relatively nutrient poor (e.g. average NH_4-N < 9.6 µg/l and PO_4-P < 0.7 µg/l) except for parts of the sewage influenced spring. Temporal variability was mainly a result of nutrient delivery in June immediately after snowmelt.

(7) Periphyton varied seasonally with highest biomass in July and August and among springs (e.g. mean chlorophyll *a* values ranged from 7.1 to 46.1 mg/m^2). Within springs periphyton was patchily distributed (e.g. chlorophyll *a*: 85 < CV < 127 %).

Based on principal component analysis and morphological aspects three different spring categories were identified: (1) Large and heterogeneous rheocrenes with dense moss cover, containing large grain sizes, high amounts of strongly attached organic matter and high concentrations of nitrate and chlorophyll *a*; (2) Small linear rheocrenes primarily indicated by small grain sizes and high amounts of fine particulate organic matter and total inorganic carbon; (3) A limnocrene characterised by an individual hydrochemistry and high amounts of coarse particulate organic matter. In conclusion, the investigated springs proved to be highly individual habitat types showing substantial spatial and temporal variability.

II. Zusammenfassung

Ziel dieser Studie war es die zeitlichen und räumlichen Muster verschiedener Umweltfaktoren und der Energiebasis von fünf Quellen und Quellbächen im Schweizer National Park (Engadin, Kanton Graubünden) von Juni bis Oktober 2001 zu untersuchen. Drei dieser Quellen liegen im Fuorntal, eine im Spöltal und eine im Val da l´Aqua zwischen 1800 und 2000 m über NN. Alle Systeme haben einen ähnlichen lithologischen Ursprung (Kalkstein). Vier der Quellen können dem rheocrenen und eine dem limnocrenen Typus zugeordnet werden. Eine der Quellen war durch Abwassereinleitung und eine durch einen Wanderweg beeinflusst.

Um die zeitlichen und räumlichen Muster hochauflösend zu erfassen, auszuwerten und zu modellieren, wurden ökologische Feldmethoden mit (1) geodätischen Techniken (Global Positioning System, Tachymetry) und einem Geographischen Informations System (GIS) verknüpft. Die Arbeit umfasste die Aufnahme der (2) Habitatmorphologie, (3) potentiellen Besonnung, (4) Korngrössenverteilung, (5) Verteilung des benthischen partikulären Materials, (6) physikalisch chemischen Charakteristiken und des (7) Periphytons der einzelnen Quellen und Quellbäche.

(1) Der methodologische Ansatz zeigte, dass geodätische Methoden eine schnelle und genaue räumliche Aufnahme erlauben (Genauigkeit > 6,2 cm vertical, > 2 cm horizontal) die erfolgreich auf diese relativ kleinen Systeme angewendet werden konnte, in denen Photogrammetrie versagt oder zu ungenau ist.

(2) Die untersuchten Quellen beinhalteten aufgrund fehlender Störungen, eine Vielzahl morphologisch unterschiedlicher und stabiler Habitat Typen. Die unterschiedlichen Morphotypen reichten von weiträumigen komplexen Wasserkörpern (ungefähr 680 m^2) mit dichter Moosbedeckung bis hin zu linearen Quellen kleiner als 16 m^2 in denen Moose fast gänzlich fehlten.

(3) Die Quellen unterschieden sich stark in ihren potentiellen Besonnungsraten, aufgrund unterschiedlichem Randbewuchs.

(4) Die vorherschenden Korngrössen variierten stark von Quelle zu Quelle.

(5) Benthisches organisches Material bestand sowohl aus allochtonem (Randbewuchs) und autochtonem (Moos, Algen) Material.

(6) Die Temperaturenschwankungen innerhalb der einzelnen Quellen reichten von 2,9 °C bis 19,2 °C, was für diese normalerweise temperaturstabilen Systeme ungewöhnlich ist. Darüberhinaus variierte die Hydrochemie stark zwischen den einzelnen Systemen, z.B.

reichten die durchschnittlichen Leitfähigkeitswerte von 146 bis 2058 µS/cm. Generell waren die Quellen recht Nährstoffarm was sich z.B. in Durchschnittskonzentrationen < 9,6 µg NH_4-N/l und < 0,7 µg PO_4-P/l ausdrückte, mit Aussnahme der abwasserbeeinflussten Teile einer Quelle. Die zeitliche Variation war auf erhöhte Nährstoffzulieferung im Juni direkt nach der Schneeschmelze zurückzuführen.

(7) Periphyton variierte saional mit höchster Biomasse im Juli beziehungsweise August und auch zwischen den Systemen, z.B. reichten durchnittliche Chlorophyll *a* Werte von 7,1 bis 46,1 mg/m^2. Auch innerhalb der einzelnen Systeme war die Biomasse sehr unterschiedlich was sich z.B. in Variationskoeffizienten zwischen 85 und 127% für Chlorophyll *a* zeigte.

Auf der Basis einer Hauptkomponentenanalyse und anhand morphologischer Aspekte wurden drei verschiede Quellkategorien unterschieden: (1) Räumlich grosse und heterogene Rheokrenen mit dichtem Moosbewuchs, vorherrschend grossen Korngrössen, hohen Mengen an festanhaftendem organischem Material und hohen Nitrat und Chlorophyll *a* Konzentrationen; (2) Räumlich kleine lineare Rheokrenen mit haupsächlich kleinen Korngrössen und hohen Mengen an feinpartikulärem organischem Material und totalem inorganischem Kohlenstoff; (3) Eine Limnokrene mit einer sehr individuellen Hydrochemie und hohen Mengen an grobpartikulärem organischem Material.

Zusammenfassend kann gesagt werden, dass es sich bei den untersuchten Quellen um sehr individuelle Habitat-Typen mit einer sowohl starken räumlichen als auch zeitlichen Variabilität handelte.

1 Introduction

1.1 History

Throughout the centuries springs have been a symbol of purity, clarity and distinctiveness. For a long time they were adored, regarded by everyone and protected. Humans have been puzzled about the origin of springs for a long time (Maringer, 1975). In central Europe only a few springs remaine pristine, most of them having been obstructed, filled up or ringed (Zollhöfer, 1997). Paulus (1995) mentioned that the biggest threat to springs is the lack of knowledge about these systems. According to Odum (1971), springs have an importance as a study area that exceeds by far their size.

At the beginning of the 20^{th} century springs began to attract the interest of German and Swiss limnologists (e.g. Steinmann, 1915; Thienemann 1924; Nadig, 1942). Today, research on springs is concentrated in North America, Germany and Scandinavia (Zollhöfer, 1999).

1.2 Studies on springs

According to Zollhöfer (1999) studies on springs in the last decades can be grouped into four categories:

- Longitudinal studies of downstream changes in physical, chemical, and biological characteristics of spring brook ecotones
- Research on relict or endemic spring species
- Year-round studies of springs and spring brooks
- Comparison of springs within geographical regions.

Nevertheless, ecological and evolutionary studies of springs have been scarce, relative to investigations of ponds, lakes, streams and other aquatic ecosystems (Glazier, 1998). Information about springs, in subalpine or alpine environments are especially rare (Klein, 1998; Schanz, 1983; Nadig 1942), which contrasts with the relatively detailed knowledge of spring biotopes of middle and lower elevations (Ward 1994). In these regions, several studies have been conducted (e.g. Zollhöfer, 1999; Knott & Jasinska, 1998; Cushing, 1996; Williams & Hogg, 1988).

In the Swiss National Park (SNP) only a few studies on springs have been completed. For example, Nadig (1942) studied five springs and their spring brooks draining into the Fuorn River. He found significant differences with respect to water chemistry (dissolved oxygen, sulfate, nitrate and organic matter) and invertebrate communities. The invertebrate inventory of the five different springs comprised 160 taxa. Schanz (1983) examining algal communities of five spring sites in the same catchment (elevation 1800 – 2000 m a.s.l.), listed 163 algal taxa excluding diatoms.

1.3 Ecology of springs

Springs can be classified as krenal systems (Ward, 1994), linking the phreatic zone to the spring brook (Cantonati et al., 1996). They are small discrete ecosystems (Glazier, 1998), which are extremely sensitive because of their small size, isolation, and special habitat conditions essential for life (Zollhöfer, 1997). Dimensions of springs can vary from ground water seeps of few square centimeters to ponds more than 120 m wide (e.g. Zollhöfer, 1999; Van Everdingen, 1991; Nadig, 1942). Geologically, springs can be described as groundwater outcrops, contrasting with surface waters by minor fluctuations in water temperature, water chemistry and flow regime (e.g. McCabe, 1998; Cantonati et al., 1996; Roca et al., 1992; Williams, 1991; Ocanã & Morales, 1990). Smith & Lavis (1975) also describe annual temperature ranges less than 1 °C, with diurnal fluctuations that are not detectable by standard methods, and Klein (1998) mentioned the remarkable constant and benign physical and chemical habitat conditions of high elevation springs. According to Williams (1991) springs are the most predictable freshwater habitats. Springs influence the downstream spring brook. For example, close to the spring annual temperatures of alpine rheocrenes vary only 1-2 °C over the annual cycle and alpine or arctic spring brooks remain ice-free throughout the winter (Malard et al., 1999; Ward, 1994). According to Ward (1992), the temperature measured in a spring usually is equal to the average annual air temperature in the same region. However, such conditions may not be present in all systems (Smith, 1985). Increasing distances from the source results in increasing annual and diurnal variability in response to the ambient air temperature and solar radiation (Resch, 1983), whereby closed canopies and steep valleys reduce the effect of radiation on the water temperature (Cushing, 1996). For example, Resh (1983) recorded a diurnal temperature range of 20 °C, 19 m downstream of the source of a Californian spring. Increasing discharge lowers the daily fluctuation and extends the stabilizing influence to the spring brook (Smith & Lavis, 1975).

Usually springs tend to have relatively constant concentrations of dissolved minerals (Van der Kamp, 1995), even during periods of rainfall, snowmelt and drought, in contrast to surface fed streams. The solute concentrations depend on the geology of the passed strata (Freeze & Cherry, 1979). According to Mattson et al. (1995), the water chemistry of springs is usually very different compared to surface waters in the same region because retention of infiltrated water may range from days to many years (Van der Kamp, 1995). In response to surface water infiltration water chemistry and discharge of the spring will change. The extent of changes depends on precipitation, snowmelt, and the morphology of the spring brook channel and catchment area (Ryan & Meiman, 1996). But the relationships between precipitation events and spring discharge and chemistry are complex (McCabe, 1995).

Springs are, more or less, sealed from the atmosphere, which results in different dynamics of soluble gases compared to open systems (Snoeyink & Jenkins, 1980). For example, dissolved oxygen concentrations often are low, although saturation may react rapidly in turbulent spring brooks (Van der Kamp, 1995).

Organic matter is an important energy source for most lotic primary consumers (Cummins, 1974). Compared to surface streams, ground water usually contains minor amounts of organic matter. Dissolved organic matter in springs includes humic acids and other highly refractory compounds in the range of 0.1-10 mg/l (Freeze & Cherry, 1997). However, spring brooks are subject to allochthonous and autochthonous organic matter input (Cushing, 1996), with the main part of organic matter entering through bank runoff or aeolic transport (Bretschko, 1991). The quantities of detritus generally increases downstream depending on riparian vegetation (Vuori & Joensuu, 1996) and channel morphology (Klein, 1997). Bedload transport is known to effect benthic organic matter including algae (Uehlinger et al., 1998). However, springs are characterized by stable substrate conditions due to low water velocity.

Periphyton communities in freshwater ecosystems are complex microcosms, composed mainly of living, senescent and dead autotrophic (microalgae) and heterotrophic microorganisms (bacteria, fungi, protozoa and micrometazoa) and fine particulate matter, embedded in a polysaccharid matrix of biological origin (Masseret, 1998). Species composition of the peripyton assemblage varies seasonally even in constant temperature springs. Studies of stony temperate streams in Europe, Japan and North America suggested a fairly regular seasonal pattern in temperate streams. Generally the total abundance of diatoms is greatest in spring and a secondary peak can occur in autumn. Other groups can become abundant during summer, particularly green algae and cyanobacteria. Patchiness in the distribution of peripyton is also apparent, even at a small scale (Allan, 1995).

Light is a fundamental variable for benthic algae for photosynthesis, but also temperature, nutrients, grazers, substrate stability, substrate size and velocity (Rolland et al., 1997; Hill, 1996). Temperature affects biochemical reactions (DeNicola, 1996); low nutrient levels can stipulate growth limitation (Borchard, 1996); and unstable substrate condition can lead to physical damage and lowered light availability (Peterson, 1996). According to Rolland et al. (1997) the greatest periphyton diversity and chlorophyll concentrations were found on pebble substrata where current velocity was moderate. All these factors interact with different affects on the spatial and temporal heterogeneity in benthic algal biomass, species composition, physiology and physiognomy (Peterson, 1996). Springs host different aquatic communities that are well-adapted to this environment. At elevations between 1000 and 2000 m a.s.l., springs are considered to be hotspots of biodiversity (Danielopol et al., 1997). Faunistically, approximately 1500 species have been recorded from European springs, whereof 465 (31%) are crenobiontic or crenophilic, i.e. their occurrence is more or less restricted to spring ecosystems (Illies, 1978). According to Zollhöfer (1999) the autecology of crenobiontic species is still poorly understood and faunal studies have been concentrated on macroinvertebrates, mostly on Tricoptera.

1.4 Objectives of the study

The previous paragraphs emphasized the perception of springs as stable and predictable ecosystems. However, spring ecosystems may exhibit substantial spatio-temporal heterogeneity in harsh environments such as the Alps, where high variation in flow and temperature, steep slopes (fast mass and energy transfer), and small catchments with shallow aquifers limit the attenuation of environmental extremes in groundwater fed systems such as springs. This issue has been addressed in the following study.

The main focus of the investigation was the characterization of spatial and temporal patterns of the abiotic environment and the energy base of spring ecosystems in the Swiss National Park. This included the assessment of spring habitat morphology, physico-chemical characteristics, such as temperature, conductivity and nutrients as well as grain size, benthic organic matter distribution, and periphyton. To model and track temporal and spatial patterns at a high resolution, approved ecological field methods were combined with geodetic techniques (Global Positioning System, Tachymetry) and a Geographic Information System (GIS) at four springs.

2 Description of the study area

2.1 Geographical situation

The five springs in the Swiss National Park (SNP) included: (1) Buffalora, (2) Fuorn, and (3) God dal Fuorn spring situated in the Fuorn river corridor, (4) Spöl spring in the Spöl valley, and (5) Val da l´Aqua spring in the Val da l´Aqua valley. See *Figure A2.1* for detailed information about the sites.

2.2 Swiss National Park

The Swiss National Park was founded in 1914 and is situated in the Engadine (Canton of Grisons, southeast Switzerland). The park covers an area of 169 km^2 and has been recently enlarged by the Macun lake area (3.6 km^2). Elevations range from 1400 to 3200 m a.s.l. and include areas in the subalpine and alpine vegetation zone. The National Park is a designated International Union for the Conservation of Nature (IUCN) category nature reserve (wilderness area) in which all human activities are strictly prohibited (Schweizerischer Nationalpark, 2001).

2.3 Geological situation

The geology of the SNP is formed by the austroalpine napes with crystalline rocks, Triassic dolomite and limestone sediments.

All springs were aligned along the Gallo line, which is mentioned as an important spring horizon, at the border between the main dolomite group, the Raibler/Verrucano layer and the lower border of the Middle-Triassic formation (Trümpy et al., 1997; Dösseger, 1987).

Buffalora and Fuorn springs, are situated in the Verrucano/ Raibler formation, mainly consisting of dolomite (Trümpy et al., 1997; Dösseger, 1987). According to Boesch (1937) Buffalora is a moraine spring. Bader (1977) presumed a subterranean connection to the river in the Val Nüglia, where surface water is infiltrating into the gravel far above the Chasa dal Stradin before it emerges at the Fuorn valley contraction. The God dal Fuorn spring is situated in the Münstertaler Verrucano (dolomite, silt-, sandstones, conglomerates and breccia) originating within an erosion fan. The Spöl spring originates in the middle Triassic Vallatscha dolomite, being covered by moraine material. The Val da l´Aqua spring emerges from moraine material that is underlayed by the Quattervals unit (dolomite and partly limestone) of the main dolomite group (Trümpy et al., 1997; Dösseger, 1987).

2.4 Climate

The Fuorn and Spöl valleys are bordered by high mountains, the Bernina massif in the southwest, Silvretta in the north and Ortler in the southeast. These mountain ranges restrict the supply of moist air, which results in low annual precipitation. Precipitation averaged only 937 mm/y at Buffalora (1968 a.s.l.) between 1920-92. This and high seasonal temperature variations, and high radiation (1783 hours of sunshine) characterize the continental climate of this region in the eastern Alps (Mürle, 2000). From October 1st 2000 until September 30th 2001 average temperature was 1.7 °C at Stabelchod and 1 °C at Buffalora, the corresponding monthly precipitation values averaged 90 mm and 101 mm, respectively (*figure 2-1*).

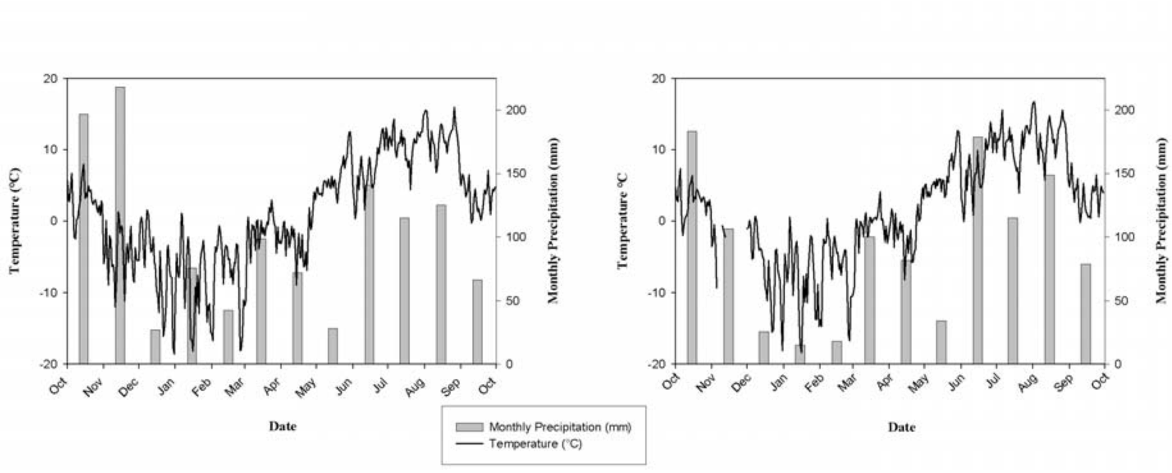

Figure 2-1 Temperature (°C) and average monthly precipitation (mm) for stations Buffalora (left) and Stabelchod (open canopy) (right) from October 1st 2000 until September 30th 2001. Data were kindly provided by the WSL and the SMA.

3 Sampling sites

According to Steinmann (1907) and Thienemann (1927) four of the sampled springs can be described as rheocrenes, except from the God dal Fuorn spring which is a typical limnocrene. Two of the springs are subject to human impact, the Buffalora spring is influenced by sewage from a nearby tourist facility, and the Spöl spring by a hiking trail. The lower part of the God dal Fuorn spring brook is channeled, and Nadig (1942) reported earlier impacts that will be described later. The following chapters are a general description of the sampled springs. Morphological details are given in *chapter 5.3*.

3.1 Buffalora spring

The Buffalora spring complex (R: 816348.73; H: 170227.28) is situated in a valley contraction of the Fuorn V-shape valley close to the southeast border of the SNP about 80 m southwest of the tourist facility Chasa dal Stradin. The spring area is located about 1 m above the Fuorn river bed at an elevation of 1960 m a.s.l.. Steep slopes of the Fuorn river terrace form the north and east boundaries of the system, which are sparsely covered by mountain pines. To the south the spring is delineated by the gravel bars of the Fuorn river and to west by the river channel and the steep slopes of Mutera da Chantun. Spring water emerges from distinct spring holes and seep areas. Subterranean flow is also apparent. This results in a large and heterogeneous spring complex that expands during snowmelt and contracts throughout the summer.

Picture 3-1: Buffalora spring, downstream view (left) and upstream view (right).

Mosses covered large parts of the spring brook. Close to the border of the SNP the outflow of the sewage filter plant of Chasa dal Stradin is surface connected to the spring brook.

3.2 Fuorn spring

Picture 3-2: Fuorn spring west part (left) and east part (right)

The Fuorn spring (R: 814264.96; H: 171232.23) is also situated in the Fuorn V-shape valley about 130 m southwest of parking lot no. 9 and about 1 to 2 m above the Fuorn river bed at an elevation of 1889 m a.s.l.. The meandering river is the southern border and a tributary of the Fuorn River forms the east boundary of the spring. To north and south, steep slopes of God (forest) val Brüna consisting of larch and white pine trees border the spring complex. The water, which emerges from various seep areas and a few spring holes, feeds a complex system. Large areas are covered by moss. Contracting of the spring system became apparent during summer. No human impact was evident. High amounts of woody debris were found within spring, being derived from the dense God val Brünna forest.

3.3 God dal Fuorn spring

The God dal Fuorn spring (R: 812186.75; H: 171674.46; elevation about 1822 m a.s.l.), a large limnocrene is situated in the ancient terraces of the Fuorn river corridor (Dösseger, 1987) at the base of the north slope of Munt la Schera. The more than two meter deep pond is fed by a perennial spring at the bottom (Nadig, 1942). The spring brook begins as an outflow of the pond. Forest surrounds the spring. According to Nadig (1942) the spring can be separated into several sections:

The pond is enclosed by steep slopes which form a cirque and the middle of the pond is plant free but surrounded by a belt of mosses and algae up to the shore. The outlet, dominated by moss and macrophytes, emerges into the upper stream. The following moss section, naturally dammed by overblown trees, is nearly completely covered by slightly sintered moss and iron ore deposits and splits into two small brooks in the grass section, before reuniting in the confluence. The confluence enters a pipe that drains into the Fuorn river. Nadig (1942) described human impact in the form of artificial damming in the western parts of the pond and outlet.

Picture 3-3: God dal Fuorn pond (left) and pond outlet (right).

3.4 Spöl spring

The Spöl spring (R: 809813.06; H: 169592.60) is situated at an elevation of 1773 m a.s.l. at the northeast slope of the V-shaped Spöl valley. The spring originates in a small depression surrounded by forest. The only source discharges into a relatively straight northeast running brook which is cut by a hiking trail about 5 m downstream of the spring. Organic matter exported from the upper part accumulates downstream and divides the brook into numerous channels over a distance of about 6 m. The whole brook was covered by moss with higher densities in the upper section.

Picture 3-4: Spöl spring, upstream (left) and downstream (right)

3.5 Val da l´Aqua spring

Picture 3-5: Val da l´Aqua spring, upstream (left) and downstream (right).

The Val da l´Aqua spring (R: 809426.79; H:169098.84; elevation 1747 m a.s.l.) in the Val da l´Aqua, a side valley of the Spöl valley, emerges in a former channel of the Val da l´Aqua river from moraine material, which now flows about 6 m adjacent the spring. Overblown trees form two small ponds. Forest (*Pinus montana*) and grassland surrounded the spring. Mosses were nearly absent.

4 Methods

4.1 Parameters and sampling dates

Sampling started in June 2001 and ended in October 2001. The sampling schedule and number of samples taken at each site are summarized in *table 4-1.*

Table 4-1: Schedule of sampling dates and numbers of samples (n) for each spring and each parameter.

	Buffalora	n	Fuorn	n	God dal Fuorn	n	Spöl	n	Val da l´Aqua	n
Physico-chemical parameters	6/7+6/14	20	6/8	5	6/8	12	6/7	4	6/6	4
	7/3+7/11	20	7/3	5	7/4	12	7/4	4	7/4	4
	8/7+8/13	18	8/7	4	8/7	12	8/7	4	8/7	4
Periphyton	6/14	12	6/14	9	6/14	5	6/14	4	6/14	3
	7/14	12	7/14	9	7/14	5	7/14	4	7/14	3
	8/14	11	8/14	8	8/14	5	8/14	4	8/14	3
Radiation	7/26	20	7/26	12	7/26	11	7/24	6	7/24	7
Benthic organic Matter	8/24	11	8/24	8	8/24	6	8/25	3	8/25	3
Sediment	8/24	11	8/24	8	8/24	6	8/25	3	8/25	3
Geodesy	Aug-Oct	-	Aug-Sep	-	Sep	-	-	-	Sep	-

Additionally the Fuorn river and Val dal Aqua river were sampled simultaneously in physico-chemical parameters. Temperature was logged in each spring during the entire sampling season.

4.2 Geodesy

GPS and Tachymetry were applied to assess the morphology of four springs and spring brooks and for the location of sampling sites within each spring.

4.2.1 Global Positioning System (GPS)

The GPS 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). The Russian GLONASS and the US NAVSTAR are currently in use. At the moment the most common system in use is the US NAVSTAR better known as US GPS (Brasington et al., 2000), but see e.g. Twigg (1998); Teunissen &

Kleusberg, (1998); Hoffmann-Wellenhoff et al. (1997); Bannister et al., (1996); Van Sickle (1996); Fix & Burt (1995) for further information on GPS.

In this study a differential GPS (DGPS, type Pro XR/XRS™, Trimble Navigation limited, Sunnyvale, CA, USA) was used to asses the morphology, channel network, moss coverage and sampling sites of two springs (Buffalora and Fuorn). The data were processed with a Geographical Information System (GIS), but see *chapter 4.3*. A DGPS requires two receivers, one of which is placed above a known point (Base), while the other (Rover) is moved to unknown points within the survey area (Brasington et al., 2000). Data from the Rover collected in the field 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. This technique increases the normal GPS resolution by a factor > 10 (Zah, 2001).

Table 4-2: Settings used for GPS field survey.

	GPS Rover	GPS Base
Coordinate System	CH 1903	CH 1903
Carrier Mode	On; Minimum time: 45 min	
Logging Intervals	5 s	Measurements: 5 s Positions 30 s
Feature	Point	Point
Position Mode	Overdetermined 3D	Overdetermined 3D
Elevation Mask	10	15
PDOP Mask	6.0	6.0
Satellites	5 minimum	5 minimum

Table 4-2 shows the settings used for field survey. For the two surveyed springs the same fixpoint was used (R 816265.970 H 170258.630; elevation 2005.59 m). The distance between base and rover was about 100 m at Buffalora spring and about 1350 m at Fuorn spring.

The data acquisition was done by stop and go point measurements in tightly spaced transects (Brasington, 2000). To facilitate orientation in the field, the positions of characteristic spots like single trees or big rocks were determined. In areas with heavy breaks of slope or extreme irregular surfaces, point density was increased. The channel network and moss coverage was mapped separately from ground morphology by assessing the borders of the upper water level or moss carpet, respectivly. The originating error E by combining these measurements was calculated by equation (1):

$$E = \sqrt{(e)^2 + (e)^2} \qquad \textbf{(1)}$$

where e is the error of each separate mapping.

4.2.2 Tachymetry

At God dal Fuorn and Val da l´Aqua spring, where GPS application failed because of dense canopy, Tachymetry was applied. Tachymetry allows the determination of position and elevation simultaneously. The point position results from direction and distance measurements, the elevation is determined by trigonometry (Welsch, 1984). The standard error of precision is usually less than 0.005 m for electronic Tachymeters, independent from distance (Gelhaus & Koluch, 1997). For this study an electronic Tachymeter (Leica TC 500) with a reflector was used to assess the morphology of the God dal Fuorn and Val da l´Aqua spring. The reflector was used like a rover and the surveying technique was the same as described for GPS measurements. Before mapping the Tachymeter was oriented relative to north (0 GON) and leveled. All measurements were done from one Tachymeter position except at God dal Fuorn spring where a three points traverse was necessary. Parameters assessed were the horizontal angle, the vertical angle and the elevation. The initial position of the Tachymeter was set to Xs = 0 and Ys = 0. Afterwards all measured polar coordinates (horizontal angle; vertical angle) were transformed into Cartesian coordinates by equations (2) and (3):

$$Xn = Xs + Dhor * COS \frac{AZ}{63.66198} \qquad \textbf{(2)}$$

$$Yn = Ys + Dhor * SIN \frac{AZ}{63.66198} \qquad \textbf{(3)}$$

where *Xn* and *Yn* are the calculated Cartesian coordinates, *Xs* and *Ys* the initial Tachymeter position, *Dhor* the horizontal angle and *AZ* the vertical angle (Azimut).

4.3 Geographic Information System (GIS)

All field data were digitized and processed with the Geographic Information System ArcView 3.2a™ (ESRI, Redlands, CA, USA). Additionally the optional extensions 3D Analyst, Spatial Analyst, and several user extensions (ESRI, 2001) were used. The software Surfer 7™ (Golden Software, Inc., Golden, CO, USA) was applied for visualizations.

Point features, exported as shape files into ArcView (AV) from Pathfinder Office 2.70 were used to create a triangulated irregular network (TIN), which was subsequently transformed to a GRID. GRIDs were tested for best resolution (*see chapter 5.2*). Geomorphologic surface slope derived from GRID by the AV slope function was overestimated. For this, slope was either derived from water surface or by a direct method (maximum altitude-minimum altitude / talweg length * 100) (Zah, 2001). Subtraction of "water surface GRID" and "morphology GRID" was applied to determine water depth. Volumes were determined by using AV area and volume statistics. All Interpolations were based on Inverse Distance Weight Interpolation (IDW). Channel width was determined by creating 0.5 m transects throughout the channel network, using the AV buffer and clip function. Additionally, depth of God dal Fuorn pond and its sludge layer, measured by the length of a rod, were taken as point features into AV.

4.4 Moss

Moss cover was simultaneously assessed with channel morphology (*chapter 4.2*). To determine the amounts of moss AFDM in Buffalora spring, moss cores were taken 4 x haphazardly by a PVC pipe (300 cm^2), dried at 60 °C, weighed, ashed at 500 °C and weighed again. Afterwards values were calculated for the whole spring system, expressed in kg/m^2 AFDM and in kg AFDM for the entire system.

4.5 Potential solar radiation

Quantification of potential solar radiation was based on hemispherical photographs taken with a digital camera (Nikon Coolpix 900) equipped with a Fisheye lens (Nikon FC-E8, 0.21x). Before the pictures were taken the camera was leveled and oriented to north. All pictures were taken 50 to 60 cm above water level. The pictures were evaluated with HemiView 2.1 canopy analyses software (Delta-T Devices, Ltd.). Riparian shading was expressed as total clear sky radiation above the canopy corrected for intercepting surface orientation in $MJ/m^2/a$ and in percent.

4.6 Grain sizes and benthic particulate organic matter (BPOM)

Grain size samples were taken with a shovel and pre-sieved through an 8 mm metal sive on site. The fraction < 8 mm was stored in plastic bags for transportation and kept frozen at -25 °C until proceeded. In the laboratory, particulate organic matter was elutriated with deionized water (Zah, 2001). Coarse POM particles were manually separated. The remaining sediment was dried for 24 h at 60 °C, weighed, ashed at 500 °C for three hours and weighted again to determine strongly attached organic matter (SOM). The ashed sediment was separated with a sieve cascade into five fractions (8-4 mm; 4-2 mm; 2-0.63 mm and < 0.063 mm). Single fractions were expressed in percent of total sediment.

Elutriated POM was wet sieved through a cascade into three fractions (> 1 mm; 1-0.063 mm and < 0.063 mm). For the smallest fraction, an aliquot was filtered through a pre-weighted glass fibre filter (Whatman GF/F; Ø 47 mm). POM fractions and filters were dried at 60 °C for 24 h, weighted, ashed at 500 °C for three hours and weighed again to assess the amount of organic matter expressed as strongly attached organic matter (SOM). All derived POM fractions were assigned as coarse particulate organic matter (CPOM > 1 mm), fine particulate organic matter (FPOM < 1 mm) and strongly attached organic matter (SOM), expressed in percent of total POM.

4.7 Physico-chemical parameters

On site measurements comprised velocity, temperature, conductivity, oxygen and pH. Velocity was determined with the velocity area method at 40% depth using a portable Velocity meter (Schildknecht, MiniAir 2) expressed in m/s. Temperature was semi-continuously recorded during the study at 1-h intervals using StowAway™ XTI (Onset Corp., USA) and TR MINILOG (VEMCO Ltd., Shad Bay, N.S., Canada) temperature loggers. Additional temperature records were manually retrieved using a conductivity meter as described next. Conductivity measurements were performed with a portable conductivity meter LF 323 (WTW, Weinheim, Germany), with reference temperature set to 20°C. Conductivity was expressed as µS/cm. For the assessment of oxygen, a portable and calibrated Oxymeter Oxi 340-B/Set (WTW, Weinheim, Germany) was used. The amount of oxygen was expressed as mg/l and in % saturation. Measurements of pH were done with a portable and calibrated pH meter 330/Set-1 (WTW, Weinheim, Germany).

For the assessment of nutrients and dissolved and suspended organic matter, spring water samples were collected with one-liter polyethylene bottles, or with a 150 ml syringe when the water level was to low. For a vertical profile of the God dal Fuorn pond, water was pumped from different depths (0.05 m; 0.5 m; 1 m; 1.50 m; 2 m; 2.5 m). All samples were stored in a cooling box at about 4°C for transportation. In the laboratory three aliquots (250 ml) were each filtered through at 500 °C pre-ashed glass fibre filter (Whatman GF/F; Ø 47 mm; mesh ~0.7 µm).

The filtered water was used for the following analyses: For the determination of ammonia (NH_4-N) the Indophenol-blue method was applied (Eidgenössisches Departement des Inneren, 1983). Nitrite (NO_2-N) and nitrate (NO_3-N) were quantified by photospectroscopy using a Hitachi U-1000 Spectrophotometer (DEV, 1989) after the Griess-reaction method. For the assessment of dissolved nitrogen (DN) and dissolved phosphorous (DP), nitrogen were oxidized with $K_2S_2O_8$ at 121°C at 1.1 bar to nitrate and ortho-phosphate (Ebina et al., 1983) and quantified colorimetrically according to nitrate and phosphate determination. To measure phosphate (soluble reactive phosphorous, PO_4-P), the PO_4-P concentration was assessed by the molybdenum blue method (Vogler, 1965), using segmented continuos flow technique (CFA) (APHA, 1989). Dissolved organic carbon (DOC) was measured by first acidifying the filtered water samples with HCl. The inorganic particles were then decomposed to CO_2 which was stripped with clean air. Then the remaining organic carbon was oxidized at 680 °C and the emerging CO_2 was analyzed with a Schimadzu TOC-5000A Analyser by non-disperse IR gas analysis. For the determination of total inorganic carbon (TIC) the filtered water sample was enclosed in an IC reaction chamber and acidified by phosphorous acid. CO_2 was stripped and analyzed as described above. Calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na) and potassium (K) were meassured by an inductive coupled emmission spectrometer (SPECTRO, Analytische Geräte, Kleve, Deutschland). Silica (SiO_2) was quantified by the heteropolyblue method, using a CFA as described above. Iron was quantified with an atom absorption spectrometer (AAS). Chlorine (Cl^-) and sulphate (SO_4) were measured by Ion Chromatography.

The filters were used for the analyses of particulate nitrogen and phosphorous (PN/PP), particulate organic carbon (POC) and ash-free dry mass (AFDM). For the determination of PN/PP, particulate samples were digested with a $K_2S_2O_8$ solution at 121 °C at 1.1 bar (Ebina et al., 1983). Nitrogen compounds were hydrolyzed to nitrate (NO_3-N) and phosphorous compounds to ortho-phosphate. Nitrate was measured with the automated hydrazine reduction method and subsequent Griess-reaction to a red azo colorant by CFA in a Bran+Lübbe Autoanalyser 3 Spectrometer (Downes, 1987; Stöckli, 1985). Simultaneous to nitrate and nitrite analyses, ortho-phosphate was determined with a parallel CFA according to Vogler (1965). For the POC analyses the filters were ashed at 880 °C and the developing CO_2 was determined with an IR-CO_2 analyser (Uehlinger et al., 1984). AFDM was assessed by drying the filters at 60 °C for at least 24 hours, weighting and burning at 500 °C for 3 hours to substract the final weight (APHA, 1985).

4.8 Periphyton

At each site within the springs, five stones were collected haphazardly for periphyton biomass analyses. The rocks were stored in plastic bags for transportation and kept frozen at –25 °C until processed in the laboratory. From each stone periphyton was removed with a metal wire brush and rinsed with water into a small bucket. Moss, when present, was removed from stones before processing. Two aliquots of the periphyton suspension were filtered through glass fibre filters (Whatman GF/F; Ø 47 mm). The first filter was used for the determination of chlorophyll *a* and *b*, after being extracted in 90 % ethanol and boiled in a water bath at 70 °C for 10 min. Afterwards a reverse phase HPLC-System (Kontron Instruments) was used to assess the chlorophyll (Murray et al., 1986). The second filter was used for determination of AFDM as described above. To calculate the amount of chlorophyll *a* and *b* expressed per unit stone area in mg/m^2, the a- and b- axis of every stone was measured. Stone area *S* was calculated by equation (4):

$$S = a * b * \frac{\pi}{4} \qquad \textbf{(4)}$$

where *a* is the a-axis diameter and *b* is the b-axis diameter.

4.9 Statistical analyses

Descriptive statistics included the calculation of minimum, maximum, mean, standard deviation and coefficients of variation. Linear regressions were used to determine relations of SOM to periphyton values and grain sizes. A Single linkage cluster analysis with euclidian distances was applied to describe the sewage influence at the Buffalora spring. Data were standardized to get an average of zero and a standard deviation of one. A Principal Component Analyses (PCA) was used to describe spatial and temporal variations among sites in physico-chemical habitat characteristics and major determinants separating the different springs. Data were standardized as described above. To evaluate effects of space and time on physico chemical values and on periphyton within and among each system a two way ANOVA followed by a Post Hoc Tukey test was applied. Data were log transformed (*log(x+1)*; Zar, 1984). An effect was considered to be significant if $p < 0.05$. Forward

multiple stepwise regression was used to explore potential influence of abiotic factors on periphyton. To support the decision of which factor should be considered significant, the Akaike Information Criterion (AIC) (5) (Rawlings et al., 1998; Akaike, 1969) and the Schwarz Bayesian Criterion (SBC) (6) (Rawlings et al., 1998; Schwarz, 1978), were calculated for the selected submodels in the forward analyses:

$$AIC = n\ln(RSS) + 2p - n\ln(n) \quad (5)$$

$$SBC = n\ln(RSS) + p\ln(n) - n\ln(n) \quad (6)$$

where n is the number of data points, RSS is the residual sum of squares and p is the number of parameters of each submodel.

In general, sites with data gaps were not considered for statistical analyses. All calculations were done with Microsoft Excel 97, Statistica 97 for Windows and ADE 4.0-Software (Chessel & Dolèdec, 1996).

5 Results

5.1 GPS and Tachymetry

Buffalora- and Fuorn spring were mapped with GPS, God dal Fuorn- and Val dal Aqua with Tachymetry. The Spöl spring was mapped using traditional methods to avoid disturbance of the fragile system.

5.1.1 Point precision and density

Average precision at both springs was ≤ ± 2 cm horizontally and ≤ ± 6.2 cm vertically, for geomorphological mapping and ≤ ± 1.2 cm horizontally and ≤ ± 4.7 cm vertically for water surface mapping, respectively, 95 percent of measurement time (2σ). Both precisions were about 1.6 times lower at the Fuorn spring compared to Buffalora spring.

To account for point errors at 2σ implies therefore an additional potential combined vertical error (morphological mapping and water surface mapping) of 5.52 cm, i.e. + 2.76

and –2.76 cm at Buffalora spring and 7.78 cm, i.e. +3.89 and –3.89 cm at Fuorn spring, respectively. The precision of tachymetric measurements could not be quantified. *Table 5-1* gives detailed information about point precision.

Table 5-1: Minimum (Min), maximum (Max), mean (ξ), standard deviation (SD) and coefficients of variation (CV) for horizontal and vertical point precision for morphological and water surface GPS mapping at Buffalora- and Fuorn spring in cm.

Site	Precision	Min	Max	ξ	SD	CV (%)
Buffalora	Horizontal	1.0	3.5	1.2	0.22	18.5
(morph.)	Vertical	2.0	10.3	3.8	1.01	26.6
Buffalora	Horizontal	1.0	1.4	1.2	0.04	8.0
(water)	Vertical	3.2	6.5	4.0	0.71	17.7
Fuorn	Horizontal	1.0	2.4	2.0	0.50	25.0
(morph.)	Vertical	2.1	11.0	6.2	2.10	33.9
Fuorn	Horizontal	1.0	1.1	1.0	0.05	4.7
(water)	Vertical	3.3	6.1	4.7	0.52	11.2

Table 5-2: Surface area (m^2), number of mapped points and points per square meter of surveyed sites

Site	Buffalora	Fuorn	God dal Fuorn	Val dal Aqua
Surface area m^2	6694	2315	1000	74
No. of points	4268	1793	602	310
Points/m^2	0.6	0.7	0.6	4.2

Point density ranged from 0.6 to 0.7 points per square meter at Buffalora, Fuorn and God dal Fuorn spring. At Val da l´Aqua spring the number of points per square meter was increased up to 4.2 (*table 5-2*), to avoid a loss of potentially important breaks of slope, such as bank edges.

5.2 DEM terrain modeling

GRID resolutions were tested for topographic changes with decreasing GRID cell sizes according to Brasington et al. (2000). The results are shown in *table 5-3* for the Buffalora spring. GRIDs from all other sites were treated in the same way.

Table 5-3: Changes in planimetric area (m^2), surface area (m^2), volume (m^3) and minimum (Min), maximum (Max), mean (ξ) and standard deviations (SD) of slope (°) with decreasing GRID cell sizes. Additionally the volume was calculated as the percentage to the volume of GRID size 0.05m.

Grid Size (m)	No. of cells	Planimetric Area (m^2)	Surface Area (m^2)	Volume (m^3)	Volume (%)	Min Slope (°)	Max Slope (°)	ξ Slope (°)	SD Slope(°)
0.05	5101776	6378	6693	24174	100.0	0.0	86.6	10.3	9.4
0.10	1275444	6367	6701	24127	99.8	0.0	82.8	10.2	9.4
0.25	204259	6357	6665	24085	99.6	0.0	74.0	9.9	9.2
0.50	50830	6325	6642	23752	98.2	0.1	60.5	9.6	8.9
1.00	12750	6294	6583	23662	97.8	0.2	38.8	9.0	8.5
2.00	3225	6154	6350	22409	92.6	0.2	38.1	8.1	7.9

Major changes in parameters occurred at a cell size ≤ 0.25 m, similar values were obtained for Fuorn and God dal Fuorn site. Based on these results, later processing was standardized on a GRID resolution of 0.1 m at these sites. At Val dal Aqua site processing resolution was increased to 0.025 m to provide highest accuracy.

5.3 Morphology

5.3.1 The Buffalora spring

At Buffalora, an area of about 6700 m^2 was mapped. This included the spring and the adjacent Fuorn river. *Figure A5-1* shows the morphology of the mapped area and its location in the river terraces.

5.3.1.1 Wetted area

The whole area can be divided in the spring brook channel network, a small sewage channel fed by the outflow of the Chasa dal Stradin sewage treatment plant and the Fuorn river channel.

Table 5-4: Area (m^2) and perimeter (m) of the different mapped sections and its percentage to the whole mapped channel network.

	Area (m^2)	Perimeter (m)	Area (%)
Spring brook network	912	539	53
Sewage channel	15	480	1
Fuorn river channel	786	35	46

The channel network was estimated based on morphological aspects, field survey and photographs with an area of about 1300 m^2 in the beginning of June before contraction. The contraction of the system affected mainly the southeast part of the spring (*figure A5-2*). The spring brook mapped in August covered an area of about 900 m^2, which made a loss of about 400 m^2 during contraction (*figure A5-3*). *Table 5-4* summarizes some morphological characteristics of the mapped channel network in August.

Table 5-5: Maximum (Max), mean (ξ) standard deviation (SD) and volume (m^3) of GRID calculated water depth in cm (n=91257) and average slope of water surface in the different mapped sections.

	Max	ξ	SD	Volume (m^3)	Volume (%)	Width (m)	Slope surface (%)
Spring brook network	42	10.1	8.6	92	50.0	0.8-15.0	7.2
Sewage channel	13	4.9	3.5	1	0.5	0.7- 1.2	9.5
Fuorn river channel	87	12.0	7.9	91	49.5	1.1- 5.8	3.6

In *table 5-5* descriptive statistics of the GRID based water depth are shown, as well as the water body volume and average slope of the water surface. Water depths are modeled in *figure A5-4*. The spring brook channel network comprised a water volume of about 90 m^3 with an average depth of 10 cm. The volume of the adjacent Fuorn river comprised also about 91 m^2. Brook width ranged from 0.8-15 m, with an average water surface slope of about 7.2%.

Manually retrieved water depth for the spring brook (n = 130) averaged 11.1 cm (max: 38.8 cm) corresponded with water depth derived from GRIDs ($R^2 = 0.54$).

5.3.1.2 Moss coverage

Moss covered about 770 m^2 of the spring brook area (*figure A5-5*), of which 680 m^2 (75 m^3) were located in the wetted channel area (89%). Thickness of moss cover in the spring brook network was similar to water depths (*table 5-5*). Thickness of moss patches outsite the wetted area could not be derived from GRID. AFDM of moss within the wetted channel area of the spring brook was calculated at 3.2 ± 0.6 kg per m^2 and 240 ± 52 kg for the whole system.

5.3.2 The Fuorn spring

An area of about 2300 m^2 was mapped at the Fuorn spring. The topography of the spring is depicted in *figure A5-6*.

5.3.2.1 Wetted area

The mapped area of the Fuorn spring can be divided as spring brook east, spring brook west and Fuorn river channel (*figure A5-7*). The spring brooks covered an area of about 300 m^2 (154 m^2 east part and 147 m^2 west part, respectively). Channel width ranged from 0.2 to 6.6 m (*table 5-6*).

Table 5-6: Area (m^2) and perimeter (m) of the different mapped sections and the area as percentage to the whole mapped channel network. Additionally, the range in channel width (m) is displayed.

	Area (m^2)	Perimeter (m)	Area (%)	Width (m)
Brook east	154	169	31	0.2-5.7
Brook west	147	177	33	0.2-6.6
Fuorn river	543	199	36	4.3-8.3

Manually measured depth averaged 5.7 cm with a maximum of 19 cm, were related to GRID calculated depth ($R^2 = 0.21$). Average water surface slope of about 10% (9.2% brook east and 10.8% brook west, respectively) was calculated.

5.3.2.2 Moss coverage

About 95 m^2 (32%) of the spring brook was covered by moss of which about 52 m^2 (54%) were situated in the western part of the brook and 44 m^2 (46%) in the southern part (*figure A5-8*).

5.3.3 The God dal Fuorn Spring

The mapped area of the God dal Fuorn spring comprised about 1000 m^2. *Figure A5-9* shows the complex topography of the limnocrene and its spring brook.

5.3.3.1 Wetted area

According to Nadig (1942) and based on morphological characteristics the wetted area was split into seven sections: pond, outlet, upper section, moss section, grass section east, grass trench west, and confluence (*figure A5-10*). Morphological characteristics are summarized in *table 5-7*.

Table 5-7: Area (m^2), perimeter (m), area as percentage to the whole mapped channel network, length (m), range of width (m) and mean values of direct slope (%) of different mapped sections.

	Area (m^2)	Perimeter (m)	Area (%)	Length (m)	Width (m)	Direct Slope (%)
Pond	91	36.6	54.1	-	9.5-11.9	-
Outlet	18	18.5	11.0	6.3	2.2- 3.5	3.9
Upper section	8	19.7	4.6	8.3	0.6- 1.5	11.8
Moss section	38	27.4	22.9	9.3	1.7- 6.2	12.1
Grass section west	5	19.5	2.9	8.1	0.3- 1.3	29.2
Grass section east	5	22.2	3.1	10.3	0.1- 1.7	21.9
Confluence	1	7.8	0.5	3.5	0.1- 0.3	18.2

The spring brook including the pond covered an area of about 168 m^2 (pond 91 m^2). Pond width ranged from 9.5 to 11.9 m. The spring brook had a length of about 46 m and widths ranged from 0.1 to 6.3 m. Direct slope varied highly between 3.9 to 29.2%. In 1942 the pond width ranged from 4.8 m to 11 m and pond area was about 62 m^2, and the grass section was not divided in two channels (Nadig, 1942).

Water depth could not be assessed by tachymetry because of shallow water, swampy parts in the brook and large depth of the pond. Pond depth averaged about 0.9m, with maximum depth of 2.6 m. *Figure A5-11* shows a bathymetric map of the pond, which comprised a volume of about 88 m^3. Nadig (1942) suggested a maximum pond deep of 2.4 m by using same measurement. Manually measured depth in the brook averaged 4.3 cm, with a maximum depth of 26 cm in the outlet.

5.3.3.2 Moss coverage and plant cover

Mosses, macrophytes and algae with an area of about 55 m^2 covered wide parts of the pond surface down to the bottom. Nearly the whole moss section was covered by moss (area about 40 m^2) and a small patch was found in the left grass trench (*figure A5.12*).

5.3.3.3 Sludge layer

A layer of fine sediments and organic matter (sludge), with a volume of about 25 m^3, extended from the pond outlet to the end of the moss section and covered an area of about 64 m^2. Maximum deep was about 1.5 m (ξ = 0.4 m). *Table 5-8* gives detailed information of layer morphology, which is also depicted in *figure A5-13*.

Table 5-8: Area (m^2), volume (m^3), area as percentage to the whole mapped area, volume as percentage to the whole calculated volume, maximum and average depth (m) of the sludge layer in the different mapped sections.

	Area (m^2)	Volume (m^3)	Area (%)	Volume (%)	Depth Max (m)	Depth Mean (m)
Outlet	18	7	29	28	0.82	0.43
Upper section	8	3	12	12	0.94	0.47
Moss section	37	15	59	60	1.53	0.45

5.3.4 The Spöl spring

Total channel length was about 14 m, with a slope about 21%. Channel with ranged from about 0.2 m in the upper part to about 2.5 m in the lower part. Water depth averaged 3.2 cm with a maximum of 12 cm.

5.3.5 The Val da l´Aqua spring

At the Val da l´Aqua spring an area of about 75 m^2 was mapped. In *figure A5-14* the spring topography is illustrated.

5.3.5.1 Wetted area

The wetted area was divided into source-, mid- and pond section based on morphological characteristics. Sections are depicted in *figure A5-15* and *table 5-9* summarizes morphological values. The spring covered an area of about 12.5 m^2 with a length of about 15 m. Channel width ranged from 0.2 to 1.2 m and direct channel slope from 1.5 to 8.2%.

Table 5-9: Area (m^2), perimeter (m), area as percentage to the whole mapped channel network and length (m) of the different mapped sections. Additionally, range of channel width (m) and direct slope (%) are displayed.

	Area (m^2)	Perimeter (m)	Area (%)	Length (m)	Width (m)	Direct Slope (%)
Source section	3.0	7.4	23.8	2.8	0.6-1.1	8.2
Mid section	3.2	14.8	25.4	6.2	0.2-0.6	4.8
Pond section	6.3	15.0	50.8	5.8	0.4-1.2	1.5

Manually measured depth averaged 3.8 cm with a maximum of 15 cm. Manually measured and GRID derived depths were poorly correlated ($R^2 = 0.21$).

5.3.5.2 Moss coverage

Moss patches covered an area of about 1.3 m^2 (10%), of which 1.1 m^2 (85%) were located in the source area (*figure A5-16*).

5.4 Potential solar radiation

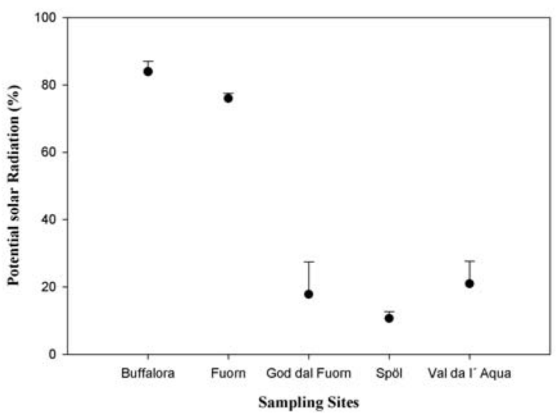

Figure 5-1 Percentage of radiation that reached the water surface at about 60 cm high. Error bars mark 1 ± SD.

Table 5-10: Minimum (Min), maximum (Max), mean (ξ), standard deviation (SD) and coefficients variations (CV) of total potential radiation below canopy in MJ/m/a (A) and in percent (B), corrected for intercepting surface orientation.

Site	Abbreviation	Min	Max	ξ	SD	CV (%)
Buffalora	A	5489	6352	6051	226	4 %
(n=20)	B	76 %	88 %	84 %	3 %	
Fuorn	A	5212	5579	5478	109	2 %
(n=12)	B	72 %	77 %	76 %	2 %	
God dal Fuorn	A	426	2699	1407	757	54 %
(n=11)	B	5 %	34 %	18 %	10 %	
Spöl	A	616	1011	834	153	18 %
(n=6)	B	8 %	13 %	11 %	2 %	
Val da l´Aqua	A	967	2390	1656	534	32 %
(n=7)	B	12 %	30 %	21 %	7 %	

In the open canopied Buffalora and Fuorn spring incoming solar radiation was high (ξ > 76%) with small spatial variations (CV < 4%). God dal Fuorn, Spöl and Val da l´Aqua spring were mostly shaded (ξ < 18%). Changes in canopy density resulted in higher variations of solar radiation at God dal Fuorn and Val da l´Aqua spring (32 < CV < 54%) (*figure 5-1 and table 5-10*).

5.5 Grain size distribution

Figure 5-2 and *table 5-10* shows the grain size distribution in all springs. At sites GS4 and GS6 of the God dal Fuorn spring grain sizes were < 0.063 cm (*figure A5- 19*).

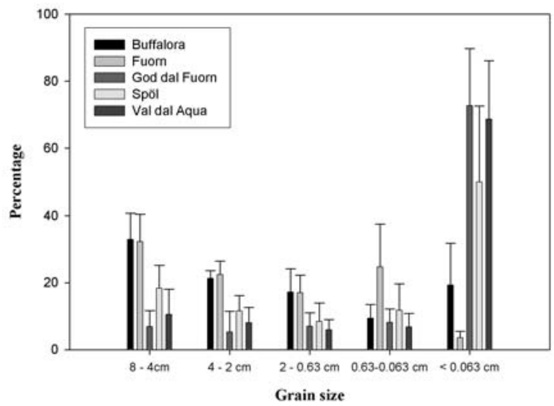

Figure 5-2: Mean for different grain sizes at each sampling site. Error bars indicate 1 ± SD.

Table 5-11: Mean (ξ), standard deviation (SD) and coefficients of variation (CV) for different grain size distributions in percent for each spring.

Site		8-4 cm	4-2 cm	2-0.63 cm	0.63-0.063 cm	< 0.063 cm
Buffalora (n=11)	ξ	32.9	21.2	17.2	9.4	19.3
	SD	7.8	2.3	7.0	4.1	12.5
	CV (%)	23.7	10.9	40.5	44.0	65.0
Fuorn (n=8)	ξ	32.2	22.5	17.1	24.7	3.6
	SD	8.6	4.0	5.2	12.8	1.9
	CV (%)	25.6	17.8	30.5	51.7	51.1
God dal Fuorn (n=6)	ξ	18.3	11.6	8.5	11.8	49.9
	SD	4.8	6.1	4.0	4.0	17.0
	CV (%)	26.2	52.6	47.2	34.0	34.1
Spöl (n=3)	ξ	8.2	6.4	8.4	9.8	67.2
	SD	6.7	4.1	4.8	7.6	20.4
	CV (%)	81.2	64.5	57.6	77.7	30.4
Val da l´Aqua (n=3)	ξ	10.5	8.0	6.0	6.8	68.6
	SD	7.5	4.6	3.0	4.0	17.5
	CV (%)	70.9	57.0	50.7	58.7	25.4

Sediments of the Buffalora and Fuorn springs were primarily dominated by the size class > 2 cm (ξ > 21.2%) which was uniformly distributed in space (CV < 25.6 %). Higher variations were apparent for classes < 0.63 cm (CV < 44%) in these systems (*figure A5-17 and A5-18*). In the God dal Fuorn, Spöl and Val da l´Aqua springs the fraction < 0.063 cm (ξ > 49.9%) prevailed, and with a relative uniform distribution in space (CV < 34.1%). Grain size classes between 4 and 0.63 cm varied distinctly within the God dal Fuorn, Spöl and Val da l´Aqua springs (47.2 < CV < 64.5%) as well as grain sizes 8-4 cm in Spöl and Val da l´Aqua spring (CV >70.9%) (*figure A5-19 to A5-21*). In the Val da l´Aqua spring, grain size decreased downstream.

5.6 Benthic organic matter

At two sites in the God dal Fuorn spring (GS4 and GS6) strongly attached organic matter (SOM) could not be determined due to the lack of coarse inorganic sediment (*figure A5-24*).

The ternary plot (*figure 5-3*) and values displayed in *table 5-12*, distinctly separated God dal Fuorn and Val da l´Aqua springs from Buffalora, Fuorn and Spöl springs.

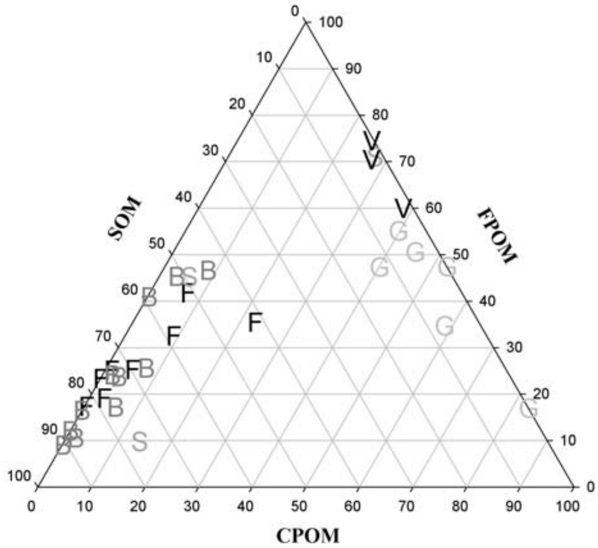

Figure 5-3: Ternary plot for parameters CPOM, FPOM and SOM in percent. Abbreviations: B: Buffalora; F: Fuorn; G: God dal Fuorn; S: Spöl; V: Val da l´Aqua.

Table 5-12: Mean (ξ), standard deviation (SD) and coefficients of variation (CV) for BPOM, FPOM and SOM in percent for each spring.

Site		CPOM	FPOM	SOM
Buffalora (n=11)	ξ	2.2	19.7	78.2
	SD	2.1	11.7	12.7
	CV (%)	95.8	59.6	16.3
Fuorn (n=8)	ξ	6.2	27.4	66.4
	SD	7.5	8.4	14.4
	CV (%)	120.9	30.6	21.7
God dal Fuorn (n=6)	ξ	52.2	43.3	4.4
	SD	18.8	15.2	5.2
	CV (%)	34.6	35.0	116.6
Spöl (n=3)	ξ	15.8	41.9	42.3
	SD	10.9	30.7	37.7
	CV (%)	69.2	73.4	89.1
Val da l´Aqua (n=3)	ξ	30.2	68.1	1.7
	SD	7.1	7.5	1.1
	CV (%)	23.4	11.0	63.3

SOM dominated in the Buffalora and Fuorn spring (ξ > 66.4%), whereas fine particulate organic matter (FPOM) and coarse particulate organic matter (CPOM) prevailed in the God dal Fuorn and Val da l´Aqua springs (30.2 < ξ < 43.3%). However, within springs variability was high, as for example, CPOM values in the Fuorn spring (CV = 120.9%), SOM values in the God dal Fuorn spring (CV = 116.6%), or all BOM fractions in the Spöl spring (CV > 69.2%) (*figure A5-22 to A5-26*). Distinct downstream gradients were observed in the Fuorn spring (CPOM between sites FB4 to FB6) and in the Spöl spring (FPOM, SOM).

Correlations between SOM and grain sizes were significant ($p < .05$) for the grain size fractions 4-2 cm and < 0.063 cm and explained 96 and 48% of the variation in SOM. Chlorophyll *a* and DOC explained between 7 and 18% of the variation in SOM.

5.7 Physical and chemical parameters

Except from Spöl spring site, all sampling sites for each spring are shown in *figure A5.27 to A5-30.*

5.7.1 Velocity

Average velocities were relatively low and varied between 0.02 m/s in the Val da l´Aqua spring and 0.28 m/s in the God dal Fuorn spring. The highest maximum velocity was found in the God dal Fuorn spring (0.93 m/s) where the spring brook entered the pipe. All springs were characterized by high spatial variations (CV > 72%) in velocity. Data of the velocity measurements are in appendix B.

5.7.2 Thermal patterns

In *table 5.13* descriptive statistics of temperature logger data from June to October 2001 are summarized. Temperature curves (hourly values) are depicted in *figure A5-31 to A 5-35*. Loggers BL2 at Buffalora spring and FL2 and FL3 at Fuorn spring fell partly dry during contraction of the systems. The logger placed in the Fuorn river at Buffalora was lost during the study.

In general, surface water temperatures decreased in the beginning of September due to decreasing air temperatures, except from Fuorn spring with temperatures rising until beginning of October. Daily temperature fluctuation was lowest at site BL2 (Buffalora) and increased continuously with distance from source in Spöl and Val da l´Aqua springs.

Table 5-13: Minimum (Min), maximum (Max), mean (ξ), standard deviation (SD) and coefficients of variation (CV) of logger data within each spring and in the Fuorn river. Additionally, distance from source and the temperature gradient for linear springs are displayed. Asterisks mark loggers, of which data were erased.

Site	Sampling Site	Min	Max	ξ	SD	CV (%)	Source Dist. (m)	Temperature Gradient (°C/m)
Buffalora	BL1	2.6	10.9	6.6	1.76	26.6	10.2	
	BL2*	3.1	10.4	6.6	2.12	32.1	0	
	BL3	2.3	7.9	5.3	1.04	19.6	7.6	
Fuorn	FL1	2.7	6.3	4.6	0.75	16.5	13.9	
	FL2*	2.6	8.8	6.2	4.04	25.7	9.7	
	FL3*	4.9	12.8	6.1	2.00	32.9	0.2	
	Fuorn River	1.4	9.4	6.0	1.09	18.2	-	
God dal Fuorn	GL1	5.7	8.4	6.5	0.42	6.4	2.0	0.010
	GL2	5.6	11.7	7.0	0.82	11.7	5.4	
	GL3	5.3	9.0	6.8	0.59	8.6	15.3	
	GL4	3.8	11.3	6.9	1.04	15.1	33.5	
Spöl	SL1	4.8	7.7	6.3	0.7	11.1	1.0	0.008
	SL2	4.5	8.4	6.4	0.9	14.0	5.0	
	SL3	3.4	9.2	6.4	1.12	17.2	12.0	
Val da l´Aqua	VL1	5.0	8.9	7.0	0.82	11.7	0.3	0.140
	VL2	4.4	13.5	7.5	1.59	21.2	8.0	
	VL3	4.3	24.2	8.8	3.36	38.2	13.0	
God dal Fuorn (vertical profile)	0.05m	1.5	15.5	7.5	1.37	18.2	-	
	0.7m	5.8	7.5	6.1	0.29	4.8	-	
	1.3m	6.1	7.8	6.4	0.27	4.2	-	
	1.9m	6.0	6.5	6.2	0.05	0.8	-	
	2.5m	6.0	6.6	6.2	0.08	1.3	-	

However, average hourly temperatures from June to October ranged from 5.3 °C in Buffalora spring to 8.8 °C in Val da l´Aqua spring. Minimum hourly temperatures ranged from 1.5 °C in God dal Fuorn spring (vertical profile in 0.05 m) to 5.7 °C at God dal Fuorn pond margins (depth 0.8 m), and maximum hourly water temperatures from 6.3 °C in the Fuorn spring to 24.2 °C in the Val da l´Aqua spring. Seasonality in temperature was most pronounced in the Val da l´Aqua spring (11 < CV < 38.2%) and least in the Spöl (11.1 < CV < 17%) and the God dal Fuorn springs (6.4 < CV < 18.2%). Spatial temperature variations were lowest in the Spöl spring (3.6 °C) with a temperature gradient of 0.008 °C/m and most pronounced in the Val da l´Aqua spring (19.2 °C) with a temperature gradient of 0.14 °C/m. Vertical temperatures in the God dal Fuorn pond ranged from 1.5 to 15.5 °C at 0.05 m and a sharp thermocline was apparent between 0.7 and 0.05 m. Below 0.7 m temperatures were relatively constant (CV < 4.8 °C). Diel temperature fluctuations in the surface waters were most pronounced at site VL3 (Val da l´Aqua) (19.9 °C) and lowest at site GL1 (God dal Fuorn) (2.7 °C). The Fuorn river showed higher diel temperature pulses (8 °C) than in the adjacent springs (< 6.6 °C).

Surface spot measurements from June to August confirm temperature data from loggers and support the high spatial variability. Remarkable were the higher pond temperatures in the God dal Fuorn spring compared to the brook (*figure A5-36*), which indicated that the brook was mainly fed by pond water entering from depth > 0.7 m. A general trend in increasing thermal heterogenity was visible in the Fuorn and Buffalora springs. Fuorn spring was characterized by slightly higher temperatures in the eastern parts (*figure A5-37*), which was mainly a result of lower water depth in this part. A change from lowest to highest temperatures near spring sources was obtained at Buffalora spring in August due to increasing air temperature in combination with precipitation events and decreasing discharge (*Figure A5-38*). Spot measurement data are in appendix C.

5.7.3 Hydrochemistry

In *table 5-14 and 5-15* physico-chemical parameters are summarized. CL^-, Fe, Na^+ and K^+ were mostly absent or below detection limit. These values are not listed and were not considered in statistical analyses. Two sites in the Buffalora and one in the Fuorn spring fell dry during summer. All values are listed in appendix C. The vertical profile of dissolved oxygen in the God al Fuorn pond was not assessed because water had to be pumped from the different depths by suction. In the Buffalora spring, cluster analyses (*figure 5-4*) separated potentially sewage-affected sites (BW3 to BW10, B5, B10) from unaffected sites (B1 to B4, B6, B8). The sewage influence also became evident from conductivity measurements performed in October 2001 (*figure A5-39*).

Apart from the sewage influenced Buffalora sites (see below) mean nutrient concentrations ranged from 2.0 to 9.6 µg NH_4/l, 0.0 to 0.5 µg NO_2-N/l, 0.1-217.7 µg NO_3-N/l, 26.6 to 318.3 µg DN/l, 5.3 to 43.5 µg PN/l, 0 to 0.7 µg PO_4-P/l, 1.1 to 2.3 µg DP/l, 0.6 to 5.4 µg PP/l, 0.4 to 1.5 mg DOC/l, 20.3 to 45.1 mg TIC/l and 0.1 to 0.7 mg POC/l. These data characterize the investigated springs as nutrient poor, except for the relatively high NO_3-N ($204.9 < \xi < 217.7$ µg/l) and DN ($280.3 < \xi < 318.3$ µg/l) concentrations in the Buffalora and Fuorn springs. Average suspended AFDM ranged from 0.2 at unaffected Buffalora sites to 4.2 mg/l in God dal Fuorn spring. The lower vertical profile in the God dal Fuorn pond was different in chemistry compared to surface water; for example below 0.05 m DN and PN values averaged only 17.7 and 5.5 µg/l.

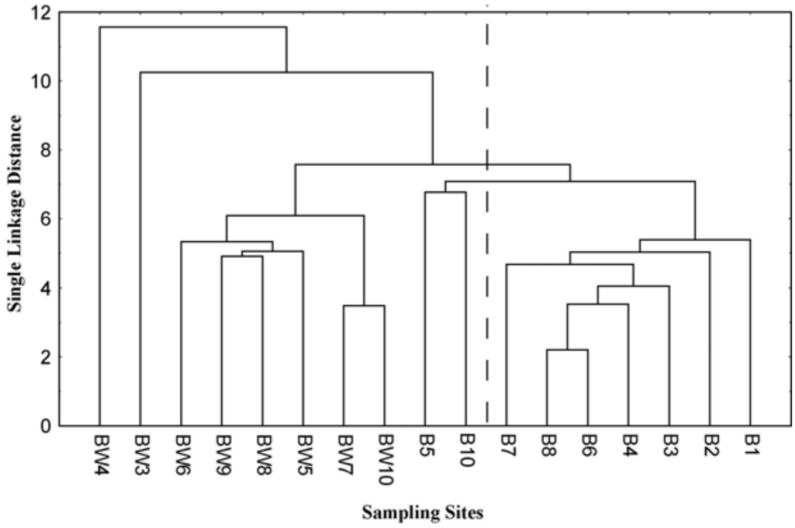

Figure 5-4: Single linkage cluster analysis with euclidian distances for physico chemical data at Buffalora spring.

Mean conductivity ranged from 146 µS/cm in the Buffalora spring (unaffected sites) to 2028 µS/cm in the God dal Fuorn spring. The high variation in the God al Fuorn spring (974 to 2210 µS/cm) was a result of precipitation events. All sites were well-oxidized (ξ > 100.3%), except for the God dal Fuorn spring (ξ = 41.2%). The pH values of the investigated springs varied from 7.6 to 8.4.

Average concentrations of geological parameters ranged from 1.2 to 8.2 mg SiO_2/l, 5.0 to 1061.0 mg SO_4/l, 0.6 to 13.9 mmol Ca^{2+}/l and 0.4 to 2.7 mmol Mg^{2+}/l. All values were maximum in the God dal Fuorn spring.

The sewage influence in the Buffalora spring comprised an area of about 280 m^2 (30%) where average nutrient concentrations were high, in particular NH_4-N (17.8 µg/l), PN (9.6 µg/l) and DP (33.8 µg/l). The spatial variation of DP, as an example is modeled in *figure A5-40.*

Hydrochemical conditions varied highly between springs. Two-way ANOVA ($p < .05$) demonstrated a significant site effect for each parameter and a significant influence of time (date) for the parameters NO_3-N, DN, PP, TIC, and POC. Site and date effects were only significant for NO_3-N. The subsequent post hoc comparison of the date effect ($p < .05$) showed significantly higher values for POC and NO_3-N in June compared to July and August, for PP in August compared to June, for DN in June compared to July and for TIC in June compared to August.

Low nutrient concentrations and minor temporal variation charcaterized the adjacent Fuorn and Val da l'Aqua river, e.g. NH_4-N: ξ < 2.7 µg/l, PP: ξ < 1.2 µg/l. Only

Table 5-14: Mean (ξ), standard deviation (SD), minimum (Min) and maximum (Max) values for physico-chemical parameters.

Site		Conductivity (µs/cm)	NH_4-N (µg/l)	NO_2-N (µg/l)	NO_3N (µg/l)	DN (µg/l)	PN (µg/l)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)
Buffalora Unaffected(n=23)	ξ±SD	146.0± 7.1	2.0± 2.3	0.0±0.2	217.7± 19.8	318.3±101.6	6.9± 5.9	0.3±0.5	2.3±1.2	0.6±0.5
	Min-Max	136.4-155.5	0.0-10.0	0.0- 1.0	174.0-255.0	216.0- 624.0	3.0-30.0	0.0- 2.0	1.0- 5.0	0.0- 2.0
Buffalora Affected (n=31)	ξ±SD	188.2± 15.4	17.8± 76.9	0.3±0.3	204.9± 44.2	280.3± 94.7	9.6± 6.0	27.2±29.2	33.8± 34.7	2.0±1.5
	Min-Max	155.9-211.0	0.0-410.0	0.0- 1.0	151.0-312.0	182.0- 651.0	3.0-33.0	2.0- 98.0	3.0-122.0	0.0- 5.0
Fuorn (n=14)	ξ±SD	207.4± 18.8	2.6±2.6	-	190.0± 14.2	278.4±129.1	5.3± 4.9	0.2±0.4	1.2±0.4	0.6±0.9
	Min-Max	176.1-242.0	0.0- 7.0	-	163.0-214.0	200.0- 714.0	2.0-21.0	0.0- 1.0	1.0- 2.0	0.0- 3.0
God dal Fuorn (n=18)	ξ±SD	2028.4± 281.1	9.6± 7.1	0.5±1.2	0.0±0.0	89.1±113.0	43.5± 66.6	0.4±0.5	2.1±2.6	4.0± 4.6
	Min-Max	974.0-2210.0	2.0-27.0	0.0- 5.0	1.0- 6.0	5.0- 401.0	2.0-285.0	0.0- 1.0	0.0- 5.0	0.0-18.0
God dal Fuorn vert. (n=18)	ξ±SD	2058.1± 255.6	9.5± 6.0	0.5±1.2	-	26.6± 25.1	9.6±10.4	0.7±0.5	1.1±1.0	5.4± 9.4
	Min-Max	1245.0-2210.0	2.0-25.0	0.0- 5.0	-	5.0- 89.0	2.0- 42.0	0.0- 2.0	0.0- 3.0	0.0-41.0
Spöl (n=12)	ξ±SD	310.0± 8.0	2.0±1.5	-	35.5± 6.9	70.0± 17.2	7.9± 4.1	-	2.3±1.1	0.9±0.6
	Min-Max	299.0-318.0	0.0- 6.0	-	27.0- 47.0	47.0-104.0	4.0-20.0	-	1.0- 5.0	0.0- 2.0
Val da l´Aqua (n=12)	ξ±SD	341.9± 9.6	2.7±2.7	-	44.9± 14.4	129.4± 50.6	10.0± 4.7	0.0±0.0	2.1±1.4	1.0±0.5
	Min-Max	329.0-355.0	1.0- 8.0	-	28.0- 70.0	76.0-253.0	5.0-17.0	0.0- 1.0	0.0- 5.0	0.0- 2.0
Fuorn river Buffalora (n=3)	ξ±SD	195.5± 20.1	2.7±2.3	-	146.8± 18.1	196.0± 14.7	3.7±1.7	0.5±0.7	2.7±0.7	0.5±0.5
	Min-Max	172.6-210.0	0.0- 4.0	-	130.0-166.0	179.0-207.0	2.0- 5.0	0.0- 1.0	2.0- 3.0	0.0- 1.0
Fuorn river Fuorn (n=3)	ξ±SD	192.3± 13.2	1.0±1.0	-	181.6± 10.1	242.2± 5.1	4.7±2.3	0.3±0.6	1.9±0.8	0.7±0.3
	Min-Max	178.7-205.0	0.0- 2.0	-	170.0-188.0	239.0-248.0	3.0- 7.0	0.0- 1.0	1.0- 3.0	0.0- 1.0
Val da l´Aqua river (n=3)	ξ±SD	185.9± 18.8	0.7±0.6	-	210.1± 69.9	283.7± 93.9	6.4±2.3	0.3±0.3	2.0±1.8	1.2±0.4
	Min-Max	164.6-200.0	0.0- 1.0	-	155.0-289.0	204.0-387.0	5.0- 9.0	0.0- 1.0	0.0- 4.0	1.0- 2.0

Table 5-15: Mean (ξ), standard deviation (SD), minimum (Min) and maximum (Max) values for physico-chemical parameters. Asterisks mark unmeasured oxygen values for the vertical profile at God dal Fuorn pond.

Site		DOC (mg/l)	TIC (mg/l)	POC (mg/l)	SiO_2 (mg/l)	SO_4 (mg/l)	Ca^{2+} (mmol/l)	Mg^{2+} (mmol/l)	pH	O_2 (%)	AFDM (mg/l)
Buffalora	**ξ±SD**	0.4±0.1	20.3± 1.5	0.2±0.1	1.2±0.2	5.0± 0.2	0.6± 0.0	0.4±0.0	8.4± 0.2	101.4± 5.6	0.2±0.1
Unaffected (n=23)	**Min-Max**	0.3- 0.6	18.6-24.5	0.0- 0.3	0.8- 1.5	4.6- 5.7	0.5- 0.6	0.4- 0.5	8.2- 8.9	89.2-111.9	0.0- 0.8
Buffalora	**ξ±SD**	0.6±0.1	25.2± 1.8	0.1±0.1	1.8±0.2	7.0± 1.0	0.6± 0.3	0.4±0.1	8.4± 0.2	110.3± 14.1	2.2±0.5
Affected (n=31)	**Min-Max**	0.4- 1.0	21.4-28.2	0.1- 0.4	1.0- 2.1	5.0- 8.2	0.1- 0.8	0.2- 0.6	8.0- 8.9	90.0- 140.7	1.3- 3.0
Fuorn	**ξ±SD**	0.6±0.1	28.4± 2.8	0.3±0.5	1.9±0.2	6.2± 1.6	0.8± 0.1	0.6±0.1	8.4± 0.1	100.3± 7.2	1.1±0.8
(n=14)	**Min-Max**	0.4- 0.8	23.4-31.8	0.1- 2.0	1.6- 2.2	5.0-10.4	0.6- 0.9	0.4- 0.7	8.2- 8.5	89.5- 111.5	0.0- 3.2
God dal Fuorn	**ξ±SD**	3.1±3.1	28.6± 4.3	0.7±0.8	6.4±2.3	1061.0± 379.7	11.0± 3.6	2.5±0.8	7.7± 0.3	41.2± 32.0	3.8± 2.6
(n=18)	**Min-Max**	0.4- 8.2	16.3-33.2	0.1- 2.9	2.4- 8.5	413.0-1470.0	4.7-14.7	1.2- 3.3	7.1- 8.1	2.2- 101.9	2.4- 9.4
God dal Fuorn	**ξ±SD**	0.8±0.9	29.8± 2.0	1.0±1.7	8.2±0.8	1344.7± 165.8	13.9± 1.8	2.7±0.6	7.6± 0.1	*	4.2± 2.0
vert. (n=18)	**Min-Max**	0.3- 3.1	25.7-32.0	0.1- 7.0	6.1- 9.0	870.0-1517.5	8.9-15.9	1.3- 3.4	7.5- 8.0	*	2.3-10.9
Spöl	**ξ±SD**	0.9±0.1	45.1± 1.5	0.2±0.1	7.2±1.2	12.2± 0.4	0.9± 0.3	1.0±0.0	8.1± 0.1	110.6± 11.8	2.3±0.3
(n=12)	**Min-Max**	0.8- 1.1	43.1-47.7	0.1- 0.4	5.9- 8.7	11.7-13.0	0.5- 1.2	1.0- 1.1	8.2- 8.4	98.0- 128.3	1.9- 2.8
Val da l´Aqua	**ξ±SD**	1.5±0.1	42.4± 1.1	0.2±0.1	2.4±0.5	39.3± 2.6	1.4± 0.1	0.9±0.1	8.4± 0.9	106.0± 14.3	2.3±0.3
(n=12)	**Min-Max**	1.3- 1.7	40.9-43.7	0.1- 0.5	1.9- 3.2	36.6-42.9	1.2- 1.5	0.8- 1.0	7.8-10.1	86.0- 135.0	1.8- 3.1
Fuorn river	**ξ±SD**	0.6±0.2	27.4± 3.2	0.2±0.1	1.8±0.5	6.4± 1.5	0.8± 0.1	0.5±0.1	8.3± 0.1	99.7± 9.7	2.1±0.2
Buffalora (n=3)	**Min-Max**	0.4- 0.8	24.3-30.7	0.1- 0.4	1.3- 2.3	5.0- 7.9	0.7- 0.8	0.4- 0.6	8.2- 8.4	88.5- 107.4	2.0- 2.3
Fuorn river	**ξ±SD**	0.6±0.1	26.9± 2.1	0.3±0.1	1.9±0.4	6.3± 1.1	0.8± 0.1	0.6±0.1	8.4± 0.1	111.0± 3.2	1.7±0.5
Fuorn (n=3)	**Min-Max**	0.4- 0.6	25.6-29.3	0.2- 0.4	1.4- 2.2	5.0- 7.0	0.7- 0.8	0.5- 0.6	8.2- 8.5	107.6- 114.0	1.2- 2.2
Val da l´ Aqua	**ξ±SD**	0.6±0.2	20.2± 3.0	0.6±0.5	1.5±0.2	23.1± 6.9	0.9± 0.1	0.3± 0.1	8.3± 0.1	101.7± 9.4	2.3±0.2
river (n=3)	**Min-Max**	0.4- 0.7	18.1-23.6	0.2- 1.1	1.3- 1.7	18.5-31.1	0.8- 1.0	0.1- 0.4	8.2- 8.4	95.4- 112.5	2.1- 2.5

NO_3-N (< 210.1 µg/l) and DN (< 283.7 µg/l) were relatively high. The chemistry of the Fuorn river was similar to that of the Buffalora (unaffected) and Fuorn spring sites. However, the chemistry of Val da l´Aqua spring and the adjacent stream was different (*Table 5-14 and 5-15*).

5.8 Physico-chemistry among and within sites

PCA summarized all physical and chemical variables spatially and temporally for the different springs, including the sewage affected sites of the Buffalora spring but excluding the vertical profile of God dal Fuorn pond, because of its lack of oxygen values. Components with factor weights < 40% (temperature, NO_2-N, TIC, pH, POC, velocity) for the primary axis (F1) and < 35% (NH_4-N, PO_4-P, DP, AFDM) for the secondary axis (F2) in a previous analyses were excluded. The final analyses are shown in *figure 5.5* and *table 5-16*. The primary and secondary axis explained 60 and 21% of the variation, respectively.

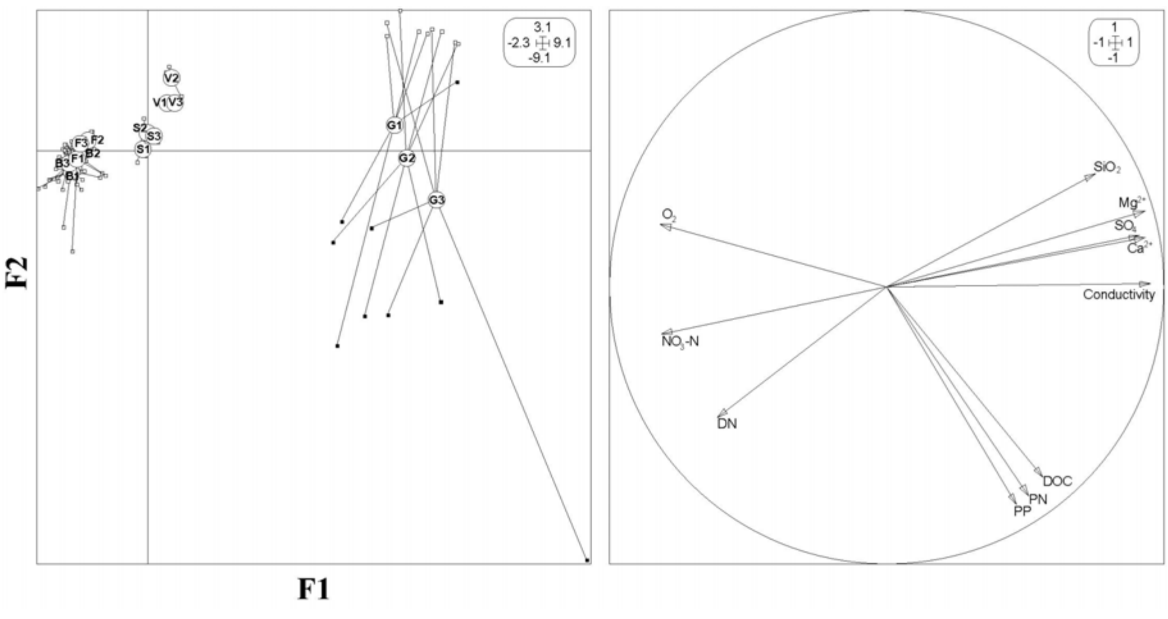

Figure 5-5: Scatter plot of the principal component analyses (PCA) (left) and correlation circle (right). Rectangles mark single sampling sites within each spring. Filled rectangles mark God dal Fuorn pond sites. Abbreviations: B: Buffalora; F: Fuorn; G: God dal Fuorn; S: Spöl; V: Val da l´Aqua. 1: June; 2: July; 3: August.

The springs were mainly separated along the primary axis, which was positively correlated with geological parameters SiO_2, Mg^{2+}, Ca^{2+}, SO_4 and conductivity and negatively correlated with NO_3-N and DN. The Buffalora and Fuorn springs clustered at one end of this gradient and God dal Fuorn showed highest separation at the other end. Monthly variation within springs was mainly shown along the secondary axis (PN, PP, DOC). Monthly separation was maximum for God dal Fuorn spring. Pond and brook sites of God dal Fuorn spring, as well as sewage influenced sites of Buffalora spring, showed highest variation within the spring, and were mainly separated along the secondary axis.

Table 5-16: Relative factor weights (%) of the major physico chemical parameters of the first two axis F1 and F2 and Eigenvalues (%) of Principal Component Analysis (PCA) of all springs excluding the vertical profile at God dal Fuorn pond.

F1 (60%)		F2 (21%)	
Conductivity	91.3	**PN**	57.3
O_2	66.7	**PP**	62.2
NO_3-N	66.1	**DOC**	47.7
DN	37.2		
SiO_2	57.0		
SO_4	84.0		
Ca^{2+}	87.2		
Mg^{2+}	87.1		
Eigenvalues	6.6		2.3

5.9 Periphyton

Figure 5-6 shows the distribution of chlorophyll *a*, *b* and AFDM measured at each site. One site in the Buffalora and one in the Fuorn spring fell dry during the sampling season. Detailed data are in appendix D and periphyton sampling sites are depicted in *figure A5-41 to A5-44*.

Chlorophyll *a* and *b* and AFDM were significant correlated ($p < .05$; $R^2 > 0.39$), except for AFDM and chlorophyll *b* in Buffalora spring ($p = .078$). Two-way ANOVA ($p < .05$) showed a significant site effect for chlorophyll *a*, *b* and AFDM for each spring, except for AFDM in the God dal Fuorn spring, chlorophyll *a* and *b* in the Spöl spring and chlorophyll *b* in the Val da l´Aqua spring. A date effect lacked for Chlorophyll *b* in Spöl spring and for chlorophyll *a* and AFDM in Val da l´Aqua spring. Interactions between date and site were not significant in Val da l´Aqua spring, as well as for chlorophyll *b* in Spöl spring (*table 5-16*). All periphyton parameters showed significantly higher values in July or August, except for AFDM in the Buffalora spring, which was highest in June. Chlorophyll *b* in the Spöl and chlorophyll *a* and AFDM in the Val da l´Aqua spring but varied not significantly from June to August. (Post Hoc Tukey test; $p < .05$) (*figure 5-6*). The spatial variability within a single sampling site (five stones) was usually high as indicated by high standard deviations (*figure 5-6*). Among springs, mean chlorophyll *a* values ranged widely from 7.1 mg/m^2 in God dal Fuorn spring to 46.1 mg/m^2 in Buffalora spring. Chlorophyll *b* values were generally low and ranged from 0.6 mg/m^2 (God dal Fuorn) to 1.8 mg/m^2 (Buffalora). Mean AFDM values were lowest in Spöl spring (8.7 g/m^2) and highest in Val da l´Aqua spring (19.8 g/m^2) (*figure 5-7*).

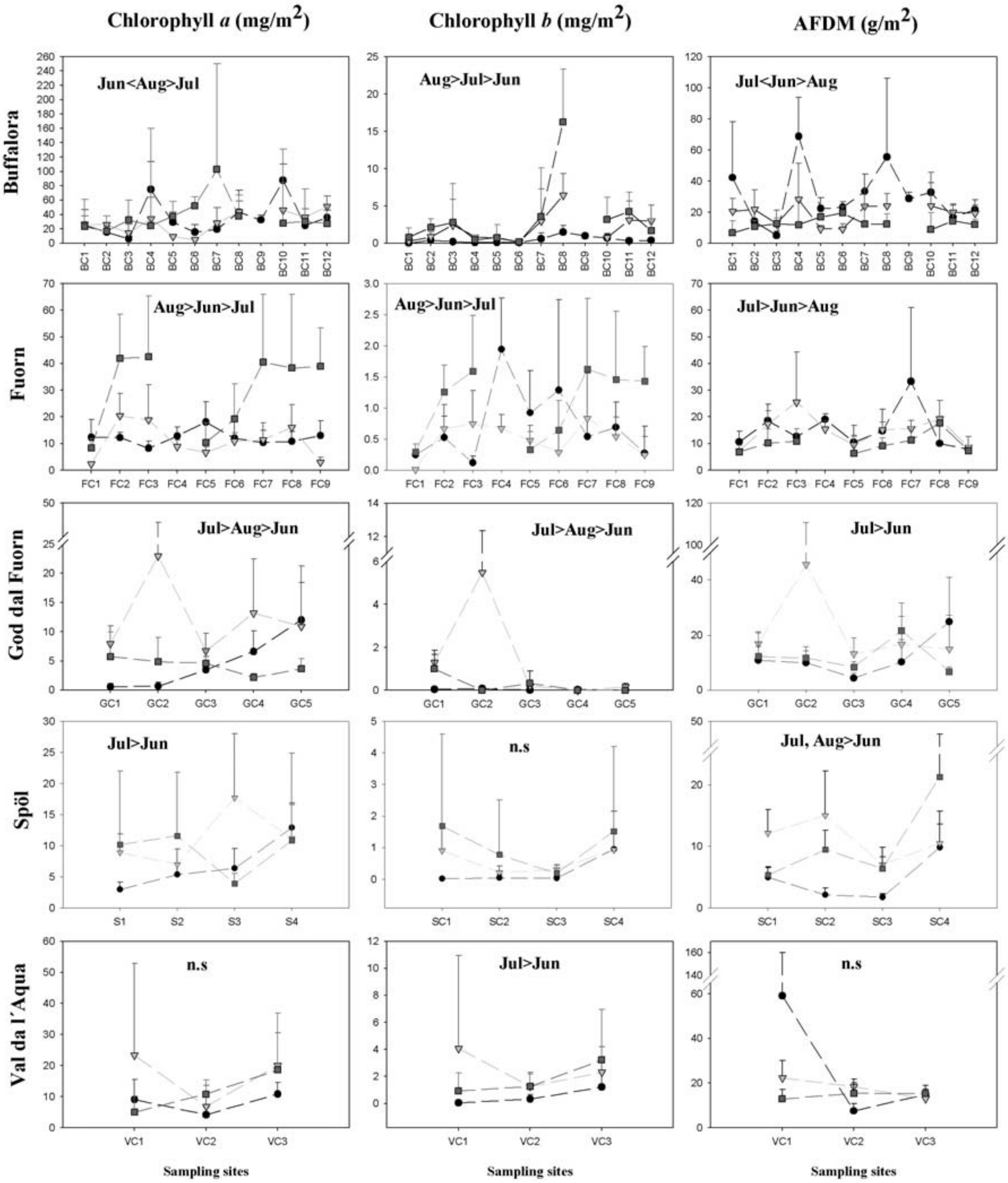

Figure 5-6: Chlorophyll *a*, *b* and AFDM values for each system in June, July and August. Dots mark June values, triangles July values and squares August values. Additionally, the results of the Post Hoc Tukey test for date effects are displayed (n.s. = non significant).

Variation of periphyton in each spring during the investigation was high. Coefficients of variation ranged from 85% (Spöl) to 127% (God dal Fuorn) for chlorophyll *a*, from 99% (Fuorn) to 371% (God dal Fuorn) for chlorophyll *b* and from 70% (Fuorn) to 171% (Val da l´Aqua) for AFDM.

Post hoc comparisons following a one way ANOVA revealed significantly higher values ($p < .05$) in Buffalora spring for chlorophyll *a*, compared to each other spring, as well as for chlorophyll *b* with exception from Fuorn spring. Significantly lower ($p < .05$) AFDM values, compared to each other spring were calculated for Spöl spring (*table 5-18*).

Table 5-17: Results of a two way ANOVA comparing site, date and site, and date. (+) marks significant values ($p < 0.5$) (n.s. = non significant).

System	Parameter	Site effect	Date effect	Interaction effect
Buffalora	**Chlorophyll *a***	+	+	+
	Chlorophyll *b*	+	+	+
	AFDM	+	+	+
Fuorn	**Chlorophyll *a***	+	+	+
	Chlorophyll *b*	+	+	+
	AFDM	+	+	+
God dal Fuorn	**Chlorophyll *a***	+	+	+
	Chlorophyll *b*	+	+	+
	AFDM	n.s.	+	+
Spöl	**Chlorophyll *a***	n.s.	+	+
	Chlorophyll *b*	n.s.	n.s.	n.s.
	AFDM	+	+	+
Val da l´Aqua	**Chlorophyll *a***	+	n.s.	n.s.
	Chlorophyll *b*	n.s.	+	n.s.
	AFDM	+	n.s.	n.s.

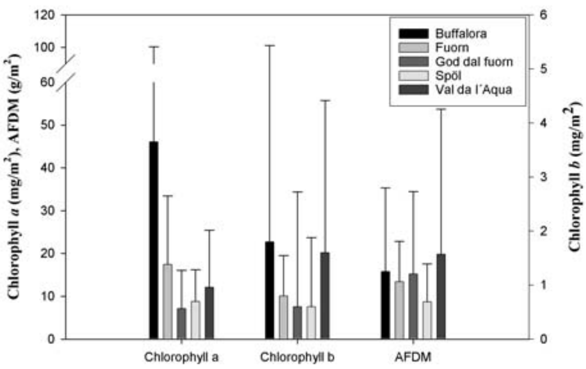

Figure 5-7: Distribution of Chlorophyll *a, b* and AFDM among sites. Error bars mark the 1 ± SD.

Table 5-18: Sites and compared significant sites as a result of Post Hoc comparisons for chlorophyll a, b and AFDM. Asterisks mark significantly higher values for term site. Non-significant sites are not displayed. Abbreviations: B: Buffalora; F: Fuorn; G: God dal Fuorn; S: Spöl; V: Val dal Aqua.

	Chlorophyll *a*	**Chlorophyll *b***	**AFDM**
Site	Compared sign. sites	Compared sign. sites	Compared sign. sites
B	F*, G*, S*, V*	F*, G*, S*, V	S*, V
F	B, G*, S*	B, G*	S*
G	B, F, V	B, F, V	S*
S	B, F	B, V	B, F, G, V
V	B, G*	G*, S*	B*, S*

5.10 Periphyton and habitat charateristics

Chlorophyll *a* and AFDM were tested for a relation between environmental parameters such as B-axis diameter (DB), potential radiation, velocity above substratum and the nutrients PO_4-P, DP, PP using forward multiple stepwise regression. Independent parameters not directly assessed at periphyton sampling sites were obtained by interpolation from GRID. Regression models explained only a small amount of the variation of chlorophyll *a* ($R^2 < 0.26$) and AFDM at Buffalora and Spöl spring ($R^2 < 0.24$) (see appendix E). Full regression analyses for AFDM ($R^2 > 0.43$) in Fuorn, God dal Fuorn and Val da l´Aqua spring are shown in *table 5-19*, and finally, regression models are

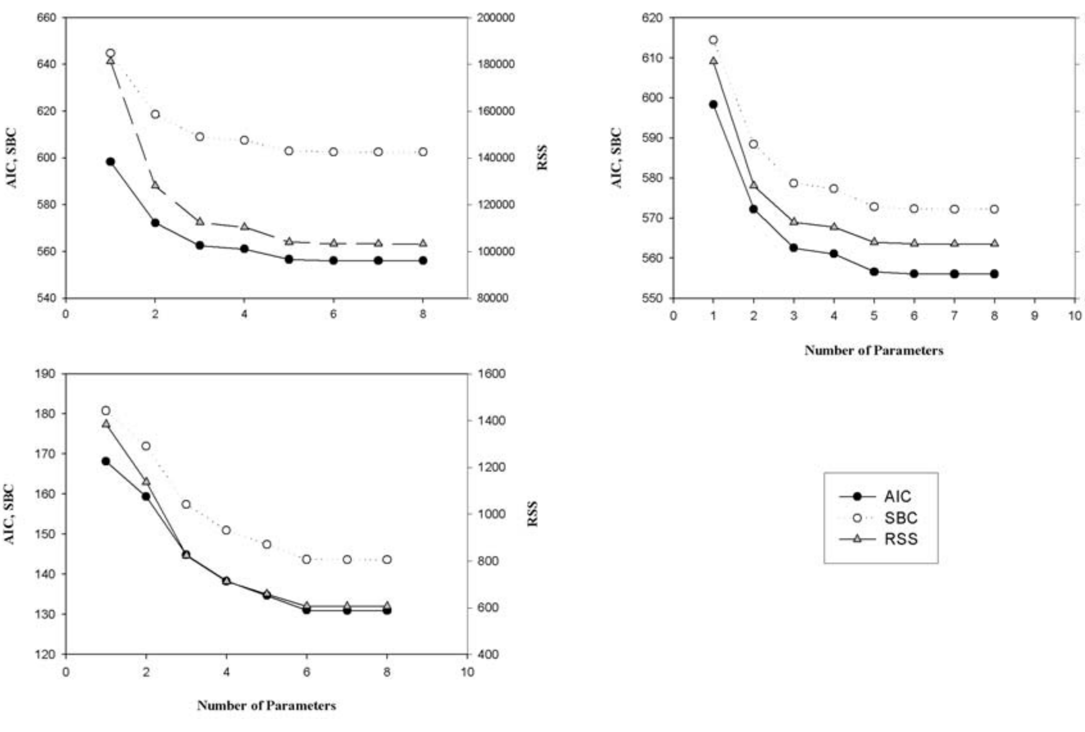

Figure 5-8: Results of a forward multiple stepwise regression analysis. Evaluation of the best submodels for AFDM in the Fuorn (top left), God dal Fuorn (top right) and Val da l´Aqua (bottom left) springs. Displayed are the AIC, SBC and RSS as function of the number of submodel parameters.

In the Fuorn spring PO_4-P, DB, radiation, PP and DP (in order of entrance) were considered as important factors in the evaluated seven parameter submodel explained 43% of the variation. For AFDM of the God dal Fuorn spring the regression procedure provided a five-parameter model including PO_4-P, DB, radiation, PP and DP as important factors, which explained 43% of the variation. In the evaluated five parameter submodel temperature, DB, velocity, DP and PO_4-P were indicated as important factors for the Val da l´Aqua spring, explaining 56% of the variation.

Table 5-19: Evaluation of the best submodels for a given number of influence factors of AFDM using the forward addition procedure. P = number of parameters (including the constant) (+) indicates, which parameters were considered in each submodel. Finally, selected models and factors contained in these models are shown bold.

Site	p	Const.	Influence factor and model parameter						RSS	R^2	Added Factor
			PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)	Rad. (%)	Velo. (m/s)	Temp. (°C)			
Fuorn	1	+							181224	0.000	
	2	+	+						128097	0.332	**PO_4-P**
	3	+	+						112493	0.379	**DB**
	4	+	+			+			110345	0.391	**Radiation**
	5	+	+		+	+			103982	0.426	**PP**
	6	+	+	+	+	+			103270	**0.430**	**DP**
	7	+	+	+	+	+	+		103186	0.431	Velocity
	8	+	+	+	+	+	+	+	103185	0.431	Temperature
God dal Fuorn	1	+							181226	0.000	
	2	+	+						128099	0.293	**PO4-P**
	3	+	+						112495	0.379	**DB**
	4	+	+			+			110347	0.391	**Radiation**
	5	+	+		+	+			103938	0.426	**PP**
	6	+	+	+	+	+			103271	**0.430**	**DP**
	7	+	+	+	+	+	+		103187	0.431	Velocity
	8	+	+	+	+	+	+	+	103187	0.431	Temperature
Val da l´Aqua	1	+							1382.6	0.000	
	2	+						+	1136.6	0.178	**Temperature**
	3	+						+	823.0	0.405	**DB**
	4	+					+	+	712.0	0.485	**Velocity**
	5	+		+			+	+	657.9	0.524	**DP**
	6	+	+	+			+	+	605.9	**0.562**	**PO_4-P**
	7	+	+	+	+		+	+	604.9	0.562	PP
	8	+	+	+	+	+	+	+	604.6	0.563	Radiation

5.11 Major determinants of springs

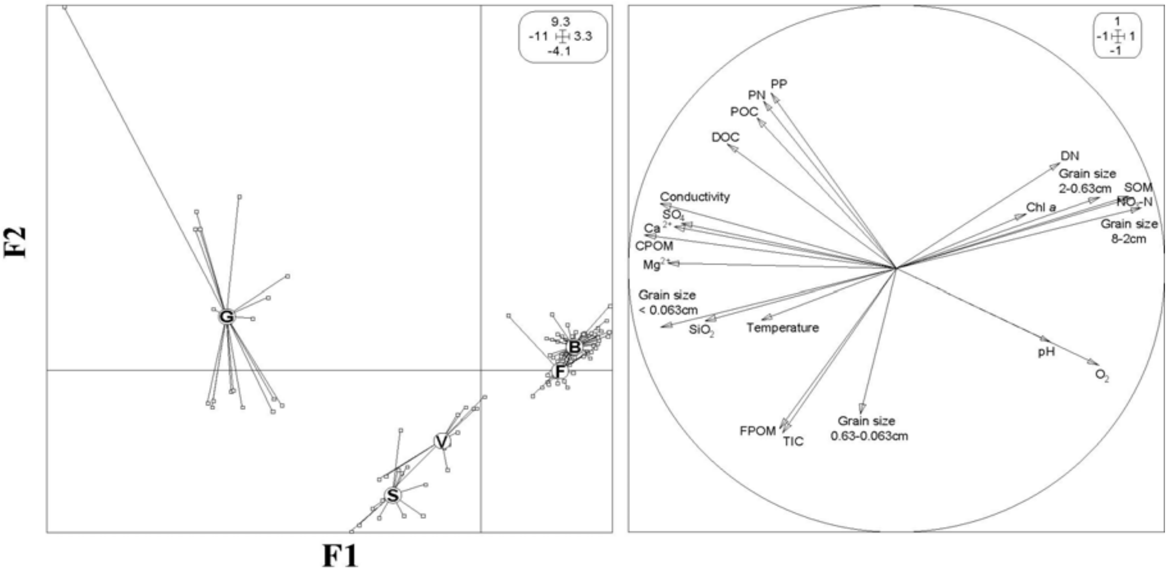

Figure 5-9: Scatter plot of the principal component analyses (PCA) (left) and correlation circle (right). Abbreviations: B: Buffalora; F: Fuorn; G: God dal Fuorn S: Spöl; V: Val da l´Aqua.

Table 5-20. Relative factor weights (%) of the major determinants on the first two axis F1 and F2 and Eigenvalues of Principal Component Analysis (PCA) of all springs.

F1 49 %		F2 15 %	
Conductivity	77.3	**PN**	40.1
Temperature	25.1	**PP**	44.2
pH	33.3	**TIC**	39
O_2	56.9	**POC**	32.5
NO_3-N	78.6	**Grain size 0.63-0.063 cm**	30.7
DN	37.5	**FPOM**	36.9
DOC	39.5		
SiO_2	50.9		
SO_4	63.9		
Ca^{2+}	68.8		
Mg^{2+}	72.6		
Chlorophyll *a*	22.5		
Grain size 8-4 cm	83.7		
Grain size 2-0.63 cm	57.5		
Grain size < 0.063 cm	76.9		
CPOM	87.9		
SOM	75.2		
PH	33.3		
Eigenvalues	1.28		3.84

In order to evaluate the major factors separating different springs, a PCA based on sampling sites of physico-chemical parameters was performed. Considered factors comprised physico-chemical parameters, grain size, BOM and periphyton parameters, which were obtained by interpolating GRID (except for Spöl spring). Factors with low loading (< 20%) in a previous analysis were excluded: NH_4-N, NO_2-N, PO_4-P, DP, AFDM, grain size 4-2 cm, chlorophyll *b*). The final result is displayed in *figure 5-9*. The primary and secondary axis explained 49 and 15% of the variation (*table 5-20*), respectively. High conductivity, SO_4, Ca^{2+}, Mg^{2+} and CPOM distinctively separated God dal Fuorn spring on axis F1. Buffalora and Fuorn spring were mainly separated by high DN, NO_3-N, chlorophyll *a*, SOM, grain sizes 8-4 cm and 2-0.63 cm at the other end of axis F1. Val dal Aqua and Spöl spring were characterized by higher FPOM and TIC values and grain sizes 0.63- 0.063 cm on axis F2.

6 Discussion

The study of the five springs in the Swiss National Park, supported by mapping and calculations based on GPS and tachymetrie techniques and DEM differencing, revealed the spatial and temporal heterogenity of biotic and abiotic factors. However, temporal dynamics are presumly underestimated because sampling was limited to a four month period during summer.

6.1 Geodesy and GIS

Geodetic methods in combination with GIS for hydrological surveys are common (e.g. Brassington et al., 2000; Gurnell and Montgomery, 2000; Bates & Lane, 1999; Milne & Sear, 1997; Fix & Burt, 1995), but at a much larger spatial scale than in this spring study.

Geodetic assessment and analyses are complicated by the propagation of errors in the various stages of data collection and processing, such as individual errors during field surveys and changes in satellite constellations (GPS), which affect the accuracy of mapped points (see Smith, 1997), and also errors during GRID calculations. However, all stages of these processes have been scrutinized and a methodology for the assessment of errors has been presented.

My results indicate the suitability of the geodesy/ GIS method for the study of small systems while also showing its limits. The average horizontal and vertical accuracy (*chapter 5.1.1*) of DGPS measurements was similar to that reported by Twigg (1998). He suggested stop and go accuracy to be in the range of 1–3 cm + 2 ppm for plan measurements and typically double lower accuracy for elevations. Accuracy is strongly influenced by steep valley side slopes, which are typical for many alpine valleys, and affect GPS measurements by limiting the number of available satellites as at the Fuorn spring site. Moreover accuracy declines with increasing distance between base and rover. This and in addition the potential combined error of ± 3.9 cm affected GRID calculations, as for example volume calculations of shallow water bodies at the Fuorn spring.

Therefore, GPS surveys should be done at once to avoid combined errors. The accurate Tachymetry proved to be suitable for the assessment of small canopied springs, but here the small scale and individual errors (e.g. reflector position) restricted volume calculations of the shallow water bodies. For the Buffalora spring, GPS provided the necessary data for full three-dimensional modeling. However, collecting data with GPS and Tachymetry has an impact on fragile systems such as springs. This prohibited the application of geodetic methods in the Spöl spring.

The construction of TINs by Delaunay triangulation has been described as exact because the survey points are directly incorporated as vertices and well suited to irregular survey formats (Brasington et al., 2000) as, for example, in this study. The subsequent conversion of TINs to GRIDs was chosen to make full use of the raster modeling tools available in GIS, including GRID comparisons (e.g. subtracting of GRIDs to derive water depths), although calculation can introduce some errors (*chapter 5.2*).

The prediction of values by interpolation is a common practice in studies involving environmental variables (e.g. Diem & Combrie, 2002; Shaap et al., 2002; Xu et al.; 2001; Castrignanò et al., 2001; Lagacherie & Voltz, 2000). In this study prediction by interpolation was based on Inverse Distance Weights (IDW) interpolation. An attractive feature of IDW is the weighting by inverse squared distance, which makes the interpolation sensibly local and produces no discontinuities because the weights never become zero. Disadvantages of IDW are that the choice of the weighting function is arbitrary and there is no measure of error. Further, it does not account for the spatial distribution of sampling points (Webster & Oliver, 2001). In this study, the number of data points used for interpolation is scarce (see also Diem & Combrie, 2002). For abiotic parameters predictions can be presumed as correct due to their relatively homogenous distribution (e.g. no extreme small-scale changes in physico-chemical parameters). Interpolation of periphyton values may be critical, because of extreme small-scale variation (*see chapter 5.9*).

6.2 Morphology and grain size distribution

The investigated springs differed widely in size and complexity (*chapter 6.3.*). Three morphologically different spring types can be distinguished: Two large and heterogeneous rheocrenes with dense moss covers contracting throughout summer, two small linear rheocrenes and one limnocrene consisting of a pond and brook.

These springs seem to be morphologically stable in time. The comparison of the recent morphological characteristics with the morphology mapped by Nadig (1942) at God dal Fuorn showed only minor changes such as pond enlargement and channel splitting in the grass section in a time span of about sixty years. Today human impacts at the pond margins and upper section described by Nadig (1942) are covered by vegetation. The Buffalora and Fuorn springs may be inundated by the adjacent Fuorn river during floods, but the dense moss cover indicates a minor impact of such events. Both springs provide numerous morphologically stable, small-scaled habitat types such as small pools, runs and moss stands.

The grain size distribution (*table 5-11*) reflects the location of the springs. The Buffalora and Fuorn springs are located in the former terraces of the Fuorn river. The relatively homogeneous distribution of the dominating grain sizes (> 2 cm) in space apparently results from former bedload transport of the Fuorn river. The God dal Fuorn and Spöl spring, dominated by grain sizes < 0.063 cm, are located in a depression surrounded by steep slopes, which retains the larger particles. Low velocities prevent the transport of larger grain sizes (see Morisava, 1968), this explains the downstream increase in grain sizes < 0.063 cm in the Val da l´Aqua spring.

6.3 Benthic particulate organic matter (BPOM)

An important fraction of organic matter in many streams is of allochtonous origin entering stream channels through bank runoff, aerial and lateral transport (Bretschko, 1991), and includes particulate matter such as leaf (needle) litter, twigs, cones, and grass. Hydrological import from upstream reaches is typically lacking in springs. Moreover, spring morphology can influence the organic matter input (Klein, 1997). Low current velocities may limit the export of organic matter from springs.

The relative contribution of CPOM, FPOM and SOM differed widely among springs (*table 5-12*). CPOM, consisting mainly of needle deposition and root fragments, was low at

Buffalora and Fuorn spring due to the lack of trees in the vicinity of the springs. High CPOM values in the other springs reflect dense canopy (God dal Fuorn, Spöl, Val da l´Aqua). In the God dal Fuorn system, CPOM concentrations were highest at pond margins, which may be explained by a “funnel” effect of the surrounding steep slopes. FPOM in the Buffalora and Fuorn springs may be presumed of allochtonous and autochtonuos origin (high moss densities). FPOM concentrations were highest in springs with dense canopies (God dal Fuorn, Spöl and Val da l´Aqua spring). The primary FPOM source is presumably the adjacent terrestrial vegetation because benthic primary producers are scarce. The dominance of the SOM fraction in the Buffalora and Fuorn springs presumably results from the grain size being > 2 cm, favoring the growth of algae. Zah (2001) hypothesized that the origin of SOM fractions might be algal exudates and groundwater DOC. Except for SOM the main source for BOM in the investigated springs was the surrounding canopy in combination with geomorphological aspects. Moreover, the relative homogenous BOM distribution indicated that transport of organic matter is lacking or limited.

6.4 Temperature

The results have shown that temperatures ranged widely among springs and also partly within springs (*chapter 5.7.2*). Even close to the spring holes temperature ranges from 2.9 °C to 7.9 °C were recorded, which is higher than the 1-2 °C range during an annual cycle, considered to be typical for springs (Füreder, 1999; Malard et al., 1999; Ward, 1994). Only in the God dal Fuorn pond at 2.5 m was the temperature range low (0.6 °C). Remarkably was the spatial temperature variation of 19.2 °C on a longitudinal distance of about 19 m in the Val da l´Aqua spring. Based on these results, the sampled springs can not be considered as temperature stable. In other springs, as for example in the Val Roseg catchment Klein (1998), observed temperatures, which were less variable (maximum longitudinal range: 2.8 °C). In a Mid Appalachian spring, Gooch and Glazier (1991) obtained much lower temperature variations (maximum range: 1.9 °C).

Temperature patterns in the investigated springs resulted from several factors. These include the large size in the Buffalora and Fuorn spring, declining discharge (reduction of water depth), high radiation, and variations in surface and subsurface flow. Moreover, dense moss lowers current velocity and enhances solar heating. The extraordinary longitudinal temperature pattern in the Val da l´Aqua spring results from high radiation, low current velocity, shallow depth and the dark colour of the organic sediment. The Spöl spring and the God dal Fuorn spring brook were the most thermally constant systems, which may be explained by the relatively high riparian shading. The vertical profile at God dal Fuorn spring reflects the stable lake stratification; thermal variations are mainly limited to the uppermost 0.7 m of the water column.

6.5 Hydrochemistry

Chemical characteristics among the investigated springs differed remarkably (*table 5-14 and 5-15 and figure 5-5*). Within springs, the low coefficient of variation for conductivity (CV < 14%) indicated generally relatively stable spatial and temporal chemical conditions. Only in the Buffalora spring, where sewage influence affected parts of the spring complex, the CV equaled 70%. Adjacent river sites were also remarkably stable in conductivity (CV < 10%). All springs were relative nutrient poor as also shown in other studies on springs (e.g. Klein, 1998; Cushing, 1996) except from high nitrate values in the Buffalora and Fuorn springs.

The geochemical parameters SiO_2, Mg^{2+}, Ca^{2+}, SO_4 (*figure 5-5*) reflected the ground water flowpath through geological strata, and distinctly separated the springs. The Buffalora and Fuorn springs were relatively similar in chemistry. In both springs, NO_3-N and DN were high, and may be explained by nutrient enriched groundwater (Brunke & Gonser, 1997) or subsurface connection to the nearby Val Nüglia river (Buffalora spring, Bader, 1977) or Stabel Chod river (Fuorn spring). The most individual system was the God dal Fuorn spring the only limnocrene investigated during this study. The high conductivity reflects the high concentration of SO_4, Ca^{2+} and Mg^{2+}. Dissolved nutrients, PN, PP and DOC separated pond and brook sites (*figure 5-5*). Higher nutrient concentrations may be explained by the fact the pond is a trap for particulate matter. In contrast, the brook is apparently a transfer area.

Nutrient concentrations were subject to distinct seasonal variations. For example NO_3-N, POC, DN and TIC concentrations were significantly higher in June immediately after snowmelt, whereas concentrations of PP were significantly higher in August. Therefore, snow can be considered as a main source for nutrients, at least in late spring. Several studies demonstrated interactions between the nutrient and water cycle, in particular the seasonally storage of nutrients in snowpack and ice. Nutrients such as NO_3 are imported by atmospheric deposition and remobilized during melting period (e.g. Tockner et al., 2002; Kuhn, 2001; Kuhn et al., 1998).

High spatial heterogenity is in accordance with many other studies on alpine springs and ground water fed brooks (e.g. Edet et al., 2000; Tockner et al., 1999; Klein, 1998; Kumar et al., 1997; Van Everdingen, 1991), but the investigated springs were also subject to distinct seasonal variations. Moreover they were as variable in time as their adjacent rivers.

6.6 Periphyton

Periphyton in the studied springs indicated seasonal variation with a trend of highest abundance in July or August. However, I am aware the study was relatively short for a reliable detection of changes in time.

With respect to overall biomass and assemblage composition, algal assemblages change seasonally in most streams (Robinson et al., 2000). For example, at high elevations early summer communities shift from dominating diatom assemblages of low biomass to a periphyton complex dominated by blue-green algae of high biomass in July and August (Vavilova, 1999). Ward (1979) described similar patterns for a spring brook system, with increasing biomass from February into the summer months, and decreasing values during late summer and autumn. Additionally, he mentioned springs are characterized by a rich diatom flora (Ward, 1994). Disturbance of periphyton communities by high flow events resulting in sediment turnover has been discribed by numerous authors (e.g. Robinson et al., 2000; Uehlinger et al., 1998; Millner & Petts, 1994). However, in the investigated springs, disturbance by spates can be excluded because the springs lacked a surface connection to the adjacent river even at high flows (Buffalora, Fuorn, Val da l'Aqua) or are far away from any river (God al Fuorn, Spöl). Variation in light availability due to high turbidity, as for example in glacial streams, can be excluded (Rinke et al., 2001, Uehlinger et al., 1998).

Periphyton biomass differed significantly between springs and was patchily distributed within springs and spring sites (*figure 5-6*). In general, factors such as B-axis diameter, potential radiation, velocity above substratum and nutrients (PO_4-P, DP, PP) were poor predictors of biomass (*chapter 5.10*). The analyses did not include the effect of grazing, which can be important (Allan, 1995). In the Val da l´Aqua spring, regression explained 57% of the variation of AFDM by temperature, B-axis diameter, velocity, DP and PO_4-P;

temperature, b-axis diameter and velocity alone were responsible for 49% of the variation of AFDM. The interplay of nutrients, light, temperature, and substrata presumably plays an important role for periphyton distribution among the investigated springs. Chlorophyll *a* values were highest in the Buffalora spring (46.1 mg/m^2), which is nutrient enriched by sewage and unshaded. In contrast, chlorophyll *a* averaged only 7.1 mg/m^2 in the highly shaded and nutrient poor God dal Fuorn spring where, in addition, lime sinter may affect periphyton accrual.

6.7 Spring types

Springs differed distinctively in grain sizes, benthic organic matter, physico-chemical parameters and periphyton (*figure 5-9*). Based on these parameters, the discriminant analysis separated three spring categories:

- Category (1), comprising the Buffalora and Fuorn springs, is characterized by coarse sediments, high amounts of SOM and chlorophyll *a,* and high DN and NO_3-N values.
- Category (2) includes the Spöl and Val da l'Aqua springs, where fine sediments, high high FPOM and TIC prevail.
- Category (3), consisting only of God dal Fuorn spring, is characterized by differences in physico-chemical parameters that were high within the spring and high CPOM.

This is an attempt of a regional spring habitat typology based on habitat characteristics. It is expected that it will also be reflected by a corresponding structure of benthic macroinvertebrate communities.

6.8 Spring habitats

Habitat conditions and their potential effects on spring biota are the outcome of environmental features acting at different hierarchical levels:

(1) At the **macrohabitat level** comprising size and system complexity, springs varied from large and complex rheocrenes to small linear springs where mosses were nearly absent. System size has an effect on species richness, e.g. small streams and large rivers, even at the same altitude, are different in habitat diversity, and thus, faunal assemblages (Jacobsen et al., 1997). Therefore, decreasing size and complexity among the investigated springs is expected to effect species richness. Moreover, the contracting of the large

rheocrenes after spring snowmelt may increase invertebrate density and predation pressure (Robinson, pers. corr.)

(2) At the **mesohabitat level** springs differ greatly with respect to grain size and BOM distribution, physico-chemical parameters and periphyton. Substratum directly and indirectly effects benthic organisms (Allan 1995). Substratum may provide surfaces to cling to or burrow in, shelter from current, material for construction of cases and tubes, refuge from predators and also influences the availability of interstitial space as habitat, the supply of water, dissolved oxygen and the availability of nutrients and food (Zollhöfer, 1999; Gooch & Glazier 1991). In springs, fauna-substratum relationships are considered to be complex because springs are highly diverse and some taxa have no specific substrate preferences (Zollhöfer 1999). Diverse (taxonomy, life forms) algae assemblages reach highest abundances on pebble and cobble substratum (Cattaneo et al., 1997; Rolland et al., 1997). Different chemical conditions may also effect the composition of algal biofilms (Allan 1995). Periphyton provides an important food source for different organism groups (Allan, 1995) and photosynthesis of benthic algae is an important energy source supporting the heterotrophic communities (Uehlinger et al., 1998). Benthic organic matter is an important energy resource for many lotic consumers (Cummins, 1974; Hynes, 1963).

(3) At the **microhabitat level** small-scale variations, as for example in temperature, become important. Temperature, a key variable affecting the structure of benthic communites, is considered to be the main cause for the longitudinal zonation of aquatic insects (Füreder, 1999; Ward, 1982). According to Ward (1994), longitudinal patterns as a result of temperature changes are less distinct in krenal systems. However, some of the investigated springs were characterized by high longitudinal and vertical temperature gradients, which is expected to influence community composition.

Adopting the landscape filter theory (Tonn, 1990; Poff, 1997) the above described three habitat levels act as filters through which species of the regional species pool must pass to be present at a given spring site. To pass through a filter, a species requires organism traits that match the selective filter characteristics.

7 Outlook

The results of this study provides an overview of the variability of environmental factors in five spring systems in the Swiss National Park and can serve as a framework to add future information. More research is needed to assess the spatial and temporal variability during an entire annual cycle. More information is required to fill the gap of knowledge with respect to benthic communities, in particular macroinvertebrates.

Three different spring categories were discriminated based on similarities in morphological and environmental factors. This is a first attempt of a spring habitat typology in the SNP that may be used as a starting point for developing a regional habitat typology. The application of geodesy in combination with GIS could be used to establish habitat descriptions that would allow to predict species distribution and abundance across different hierarchical levels.

Moreover, geodesy and GIS application may be used for long-term monitoring of habitat changes, especially at the Buffalora and Fuorn springs; for example, to assess the variability of the channel network and changes in moss coverage. Geodesy and GIS would provide background data to be used for restoration of springs and long-term monitoring of restoration projects.

8 Conclusion

The investigated springs proved to be highly individual systems showing substantial spatial and temporal variability within the three-month survey. Temperature, in particular, showed high variability in space and time but the temporal variation of chemical parameters was substantial, too. These springs may be more stable than other lotic ecosystems at the same elevation but they exhibit substantial variation that reflects to some extent the high seasonal variation of the inner-Alpine climate in combination with the geomorphic characteristics of a high Alpine valley.

9 Literature cited

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10 Appendix A: Figures

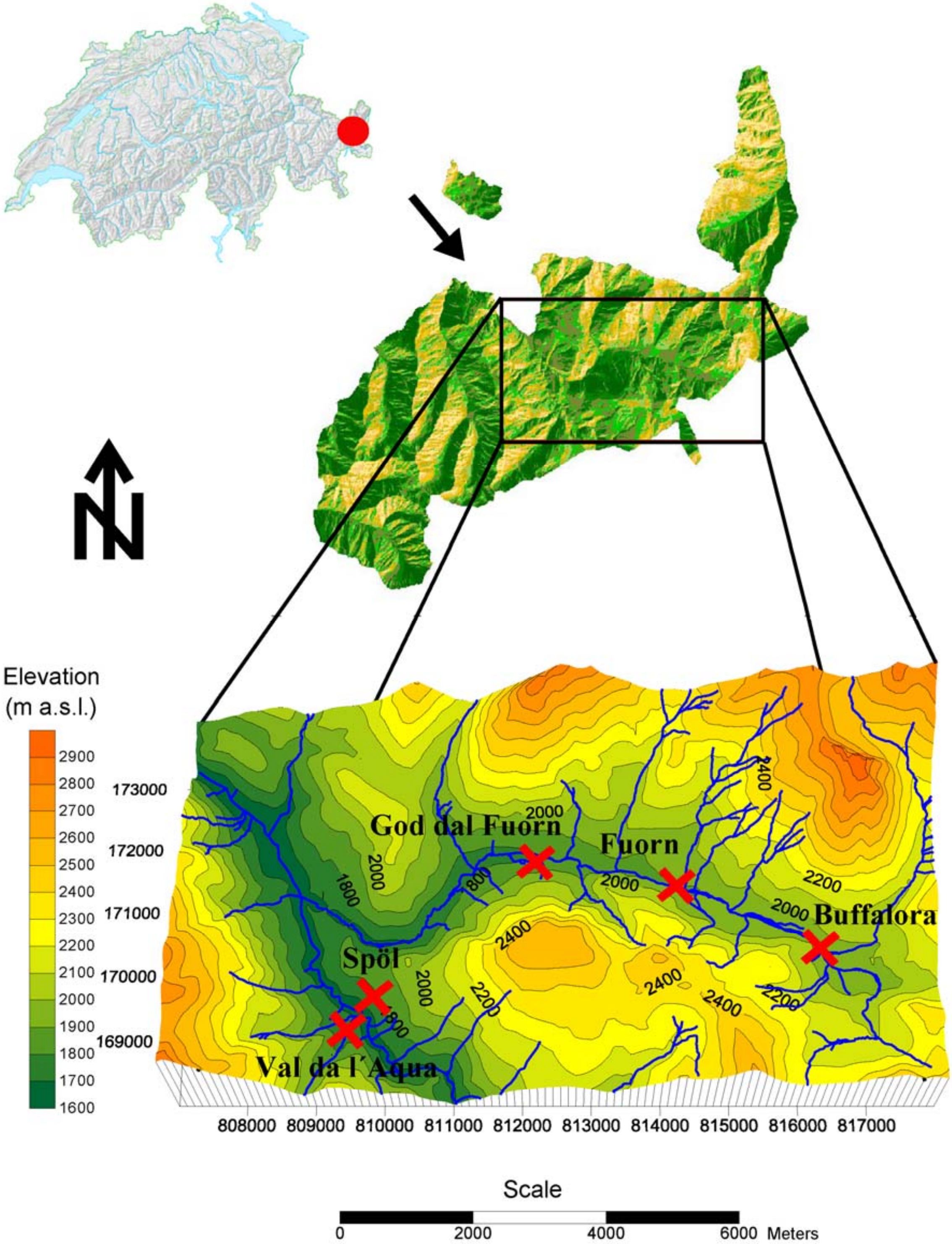

Figure A2.1: Situation of investigated springs in the Swiss National Park (DHM 25 © GIS-SNP).

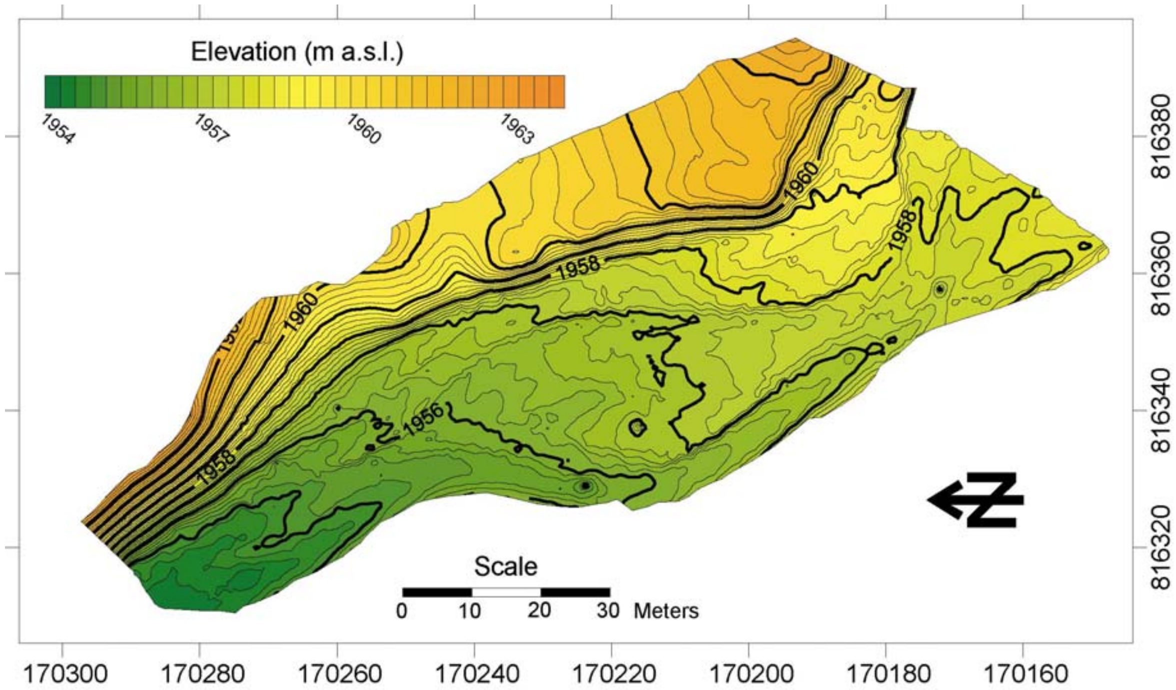

Figure A5-1: Topography of Buffalora spring.

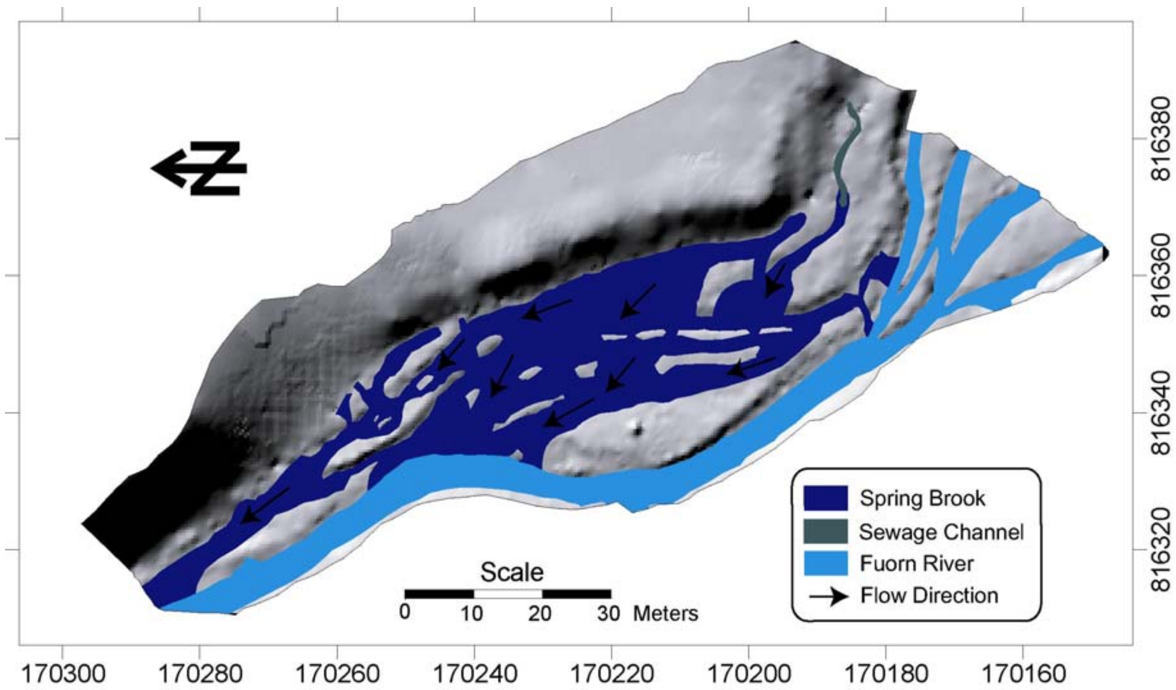

Figure A5-2: Different channel sections at Buffalora spring in June before contracting.

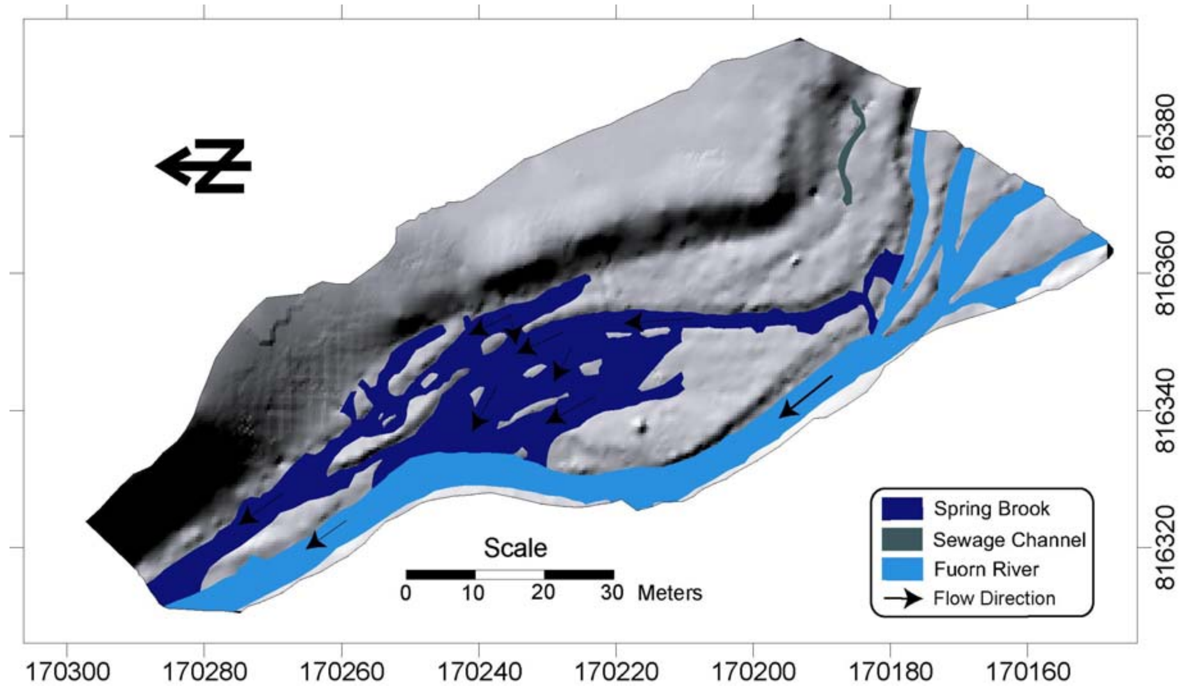

Figure A5-3: Constantly wetted channel sections at Buffalora spring in August after contraction.

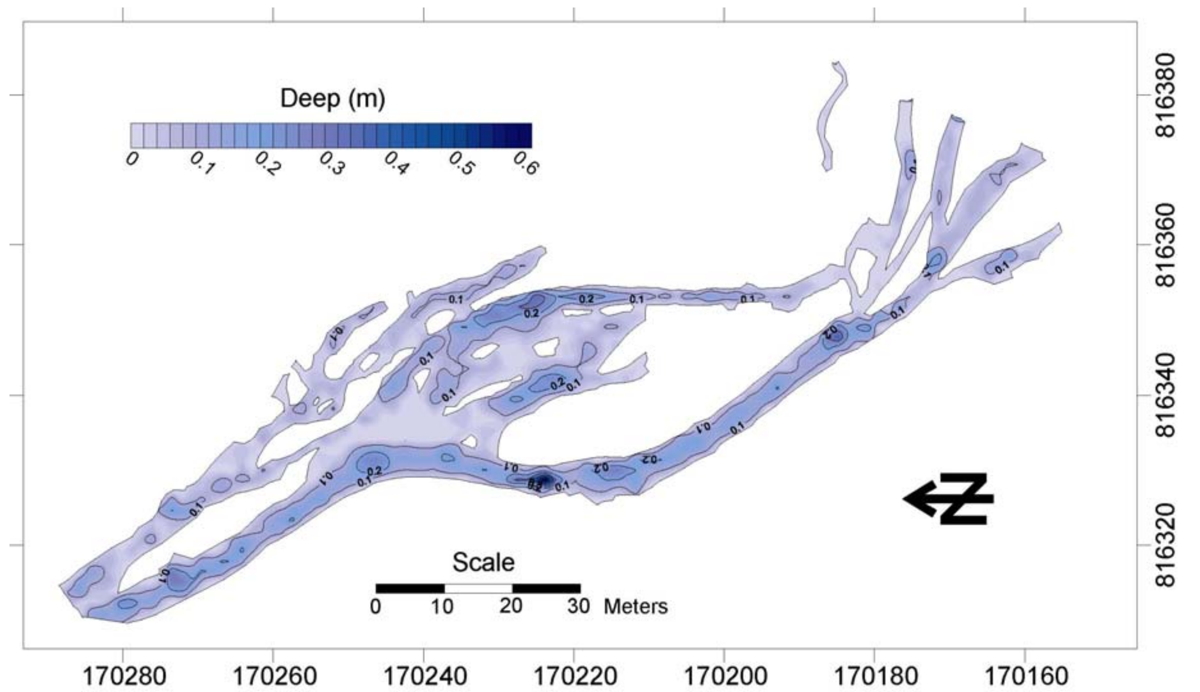

Figure A5-4: Water depth at Buffalora spring in the constantly wetted channel area.

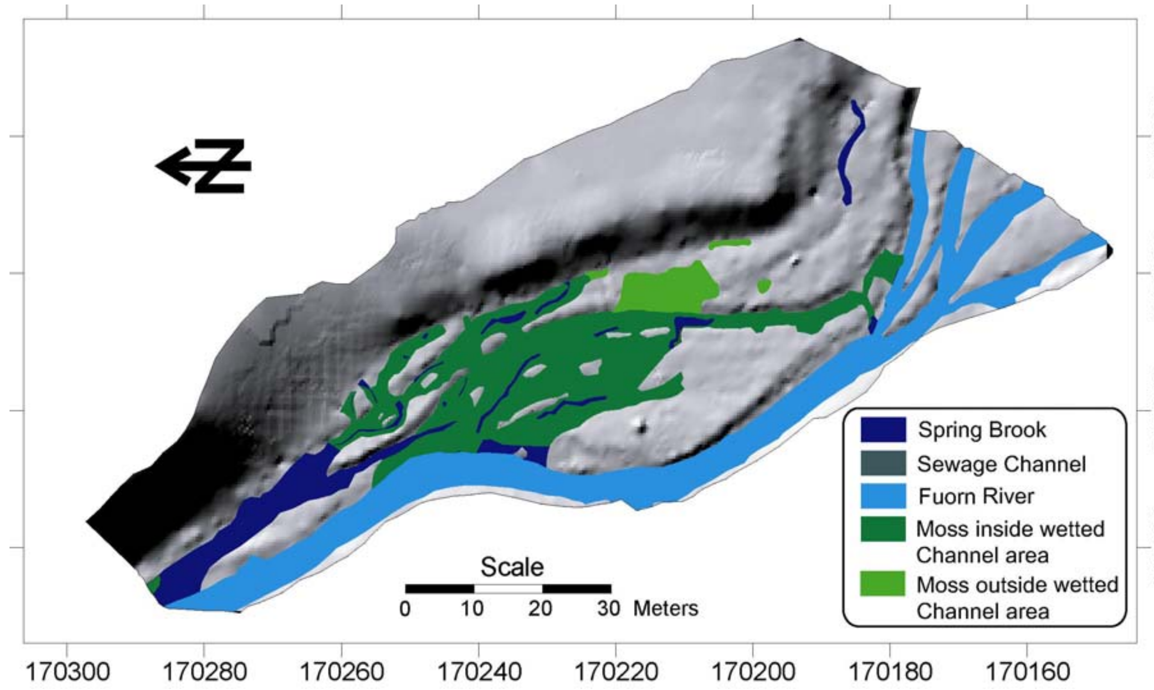

Figure A5-5: Moss coverage at Buffalora spring.

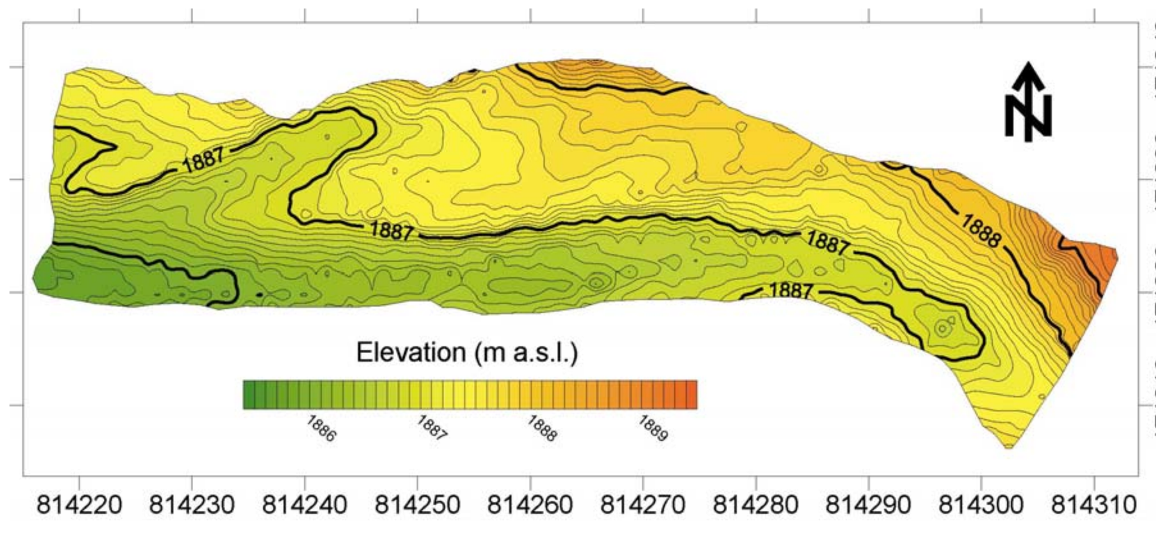

Figure A5-6: Topography of Fuorn spring.

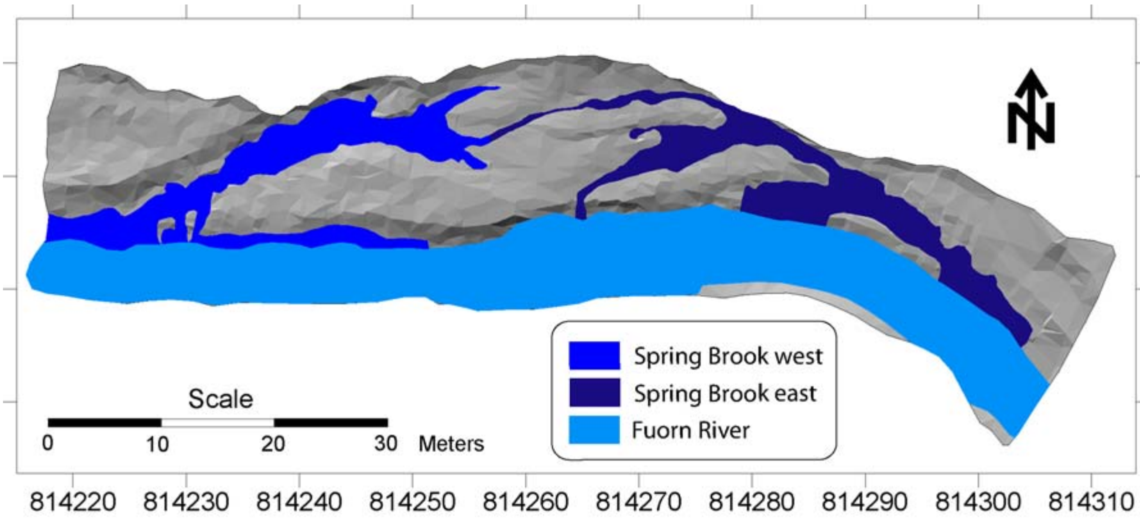

Figure A5-7: Constantly wetted channel sections of Fuorn spring

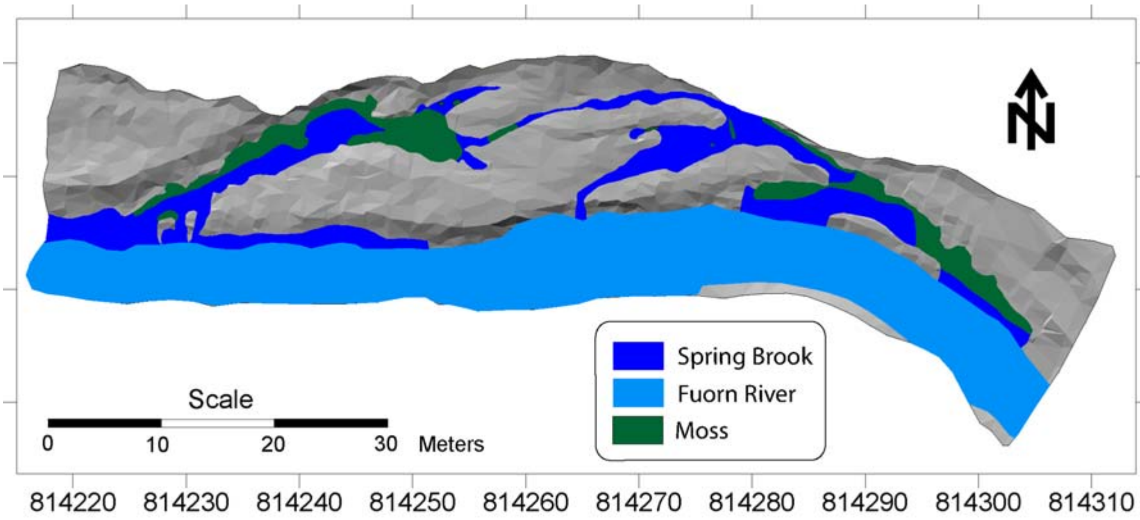

Figure A5-8: Moss coverage at Fuorn spring.

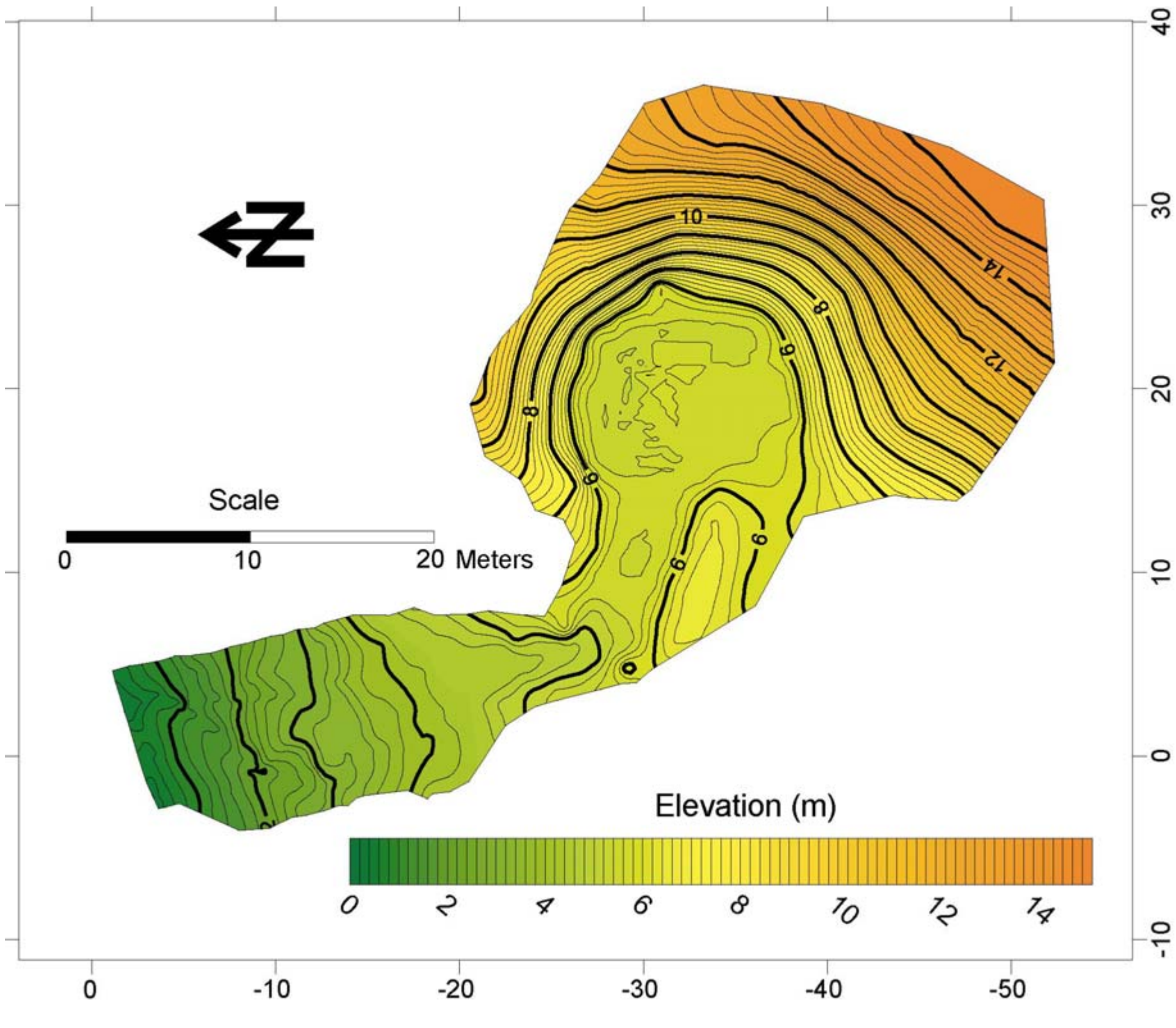

Figure A5-9: Topography of God dal Fuorn spring.

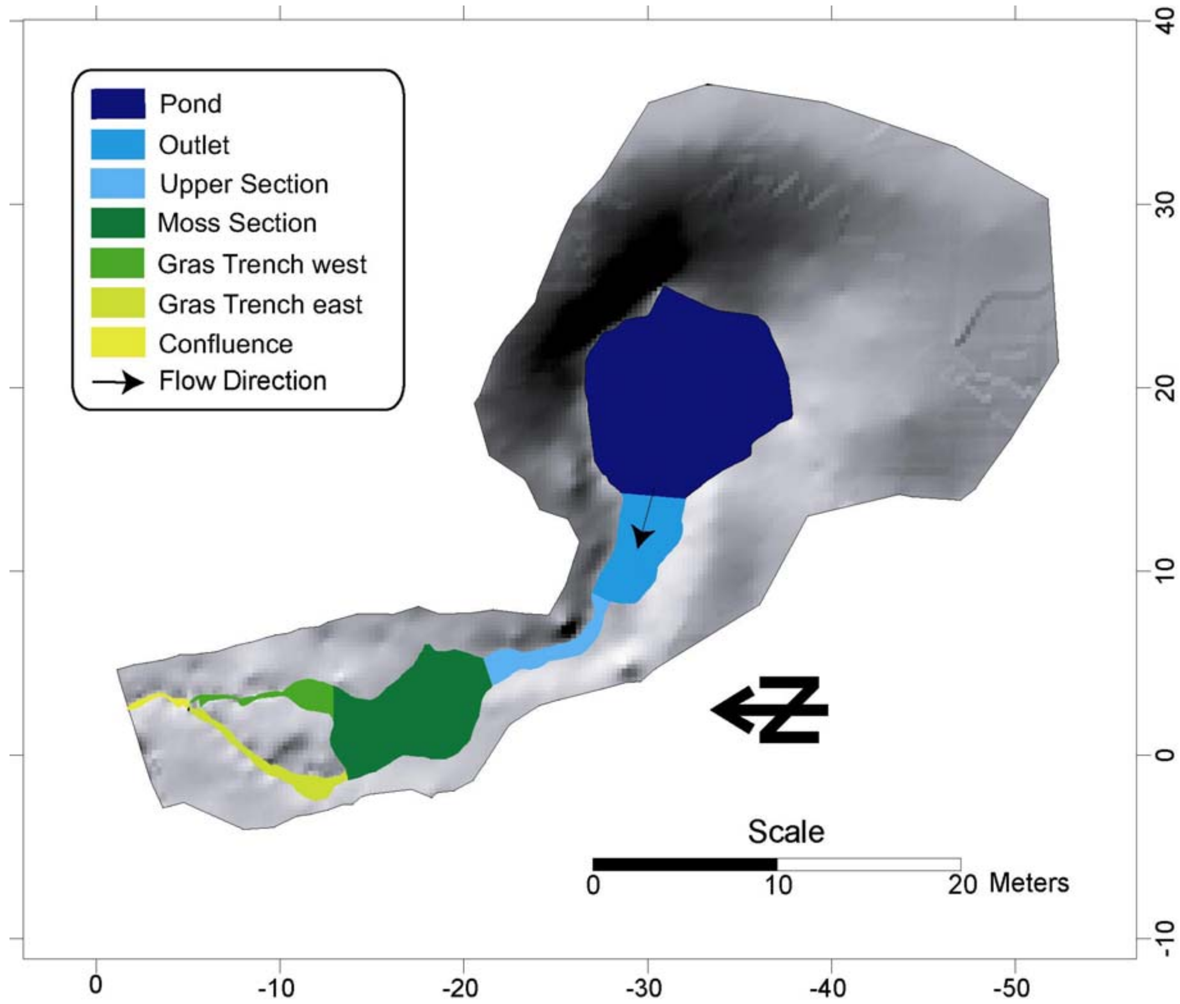

Figure A5-10: Different channel sections at God dal Fuorn spring.

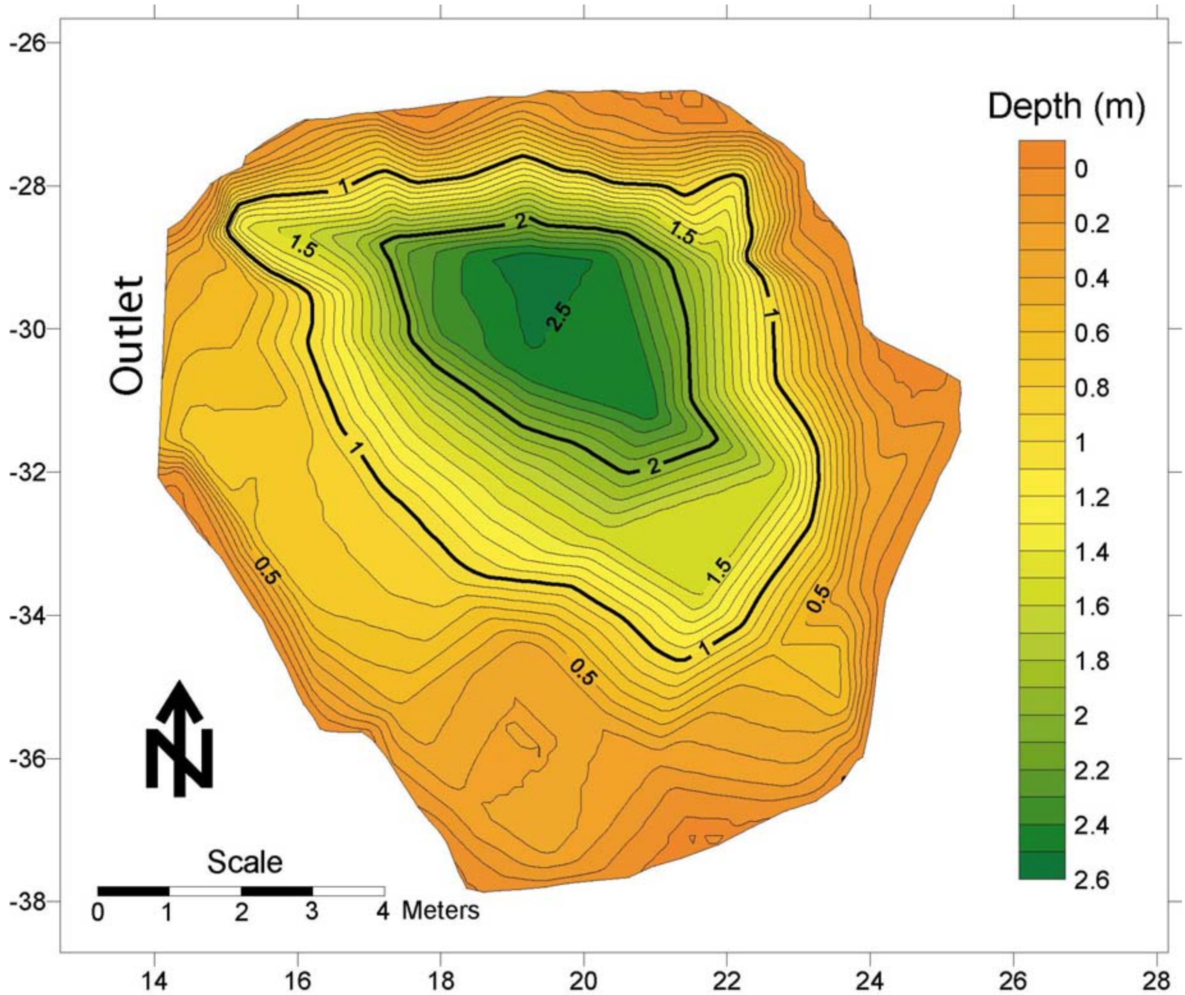

Figure A5-11: Bathymetric map of God dal Fuorn pond.

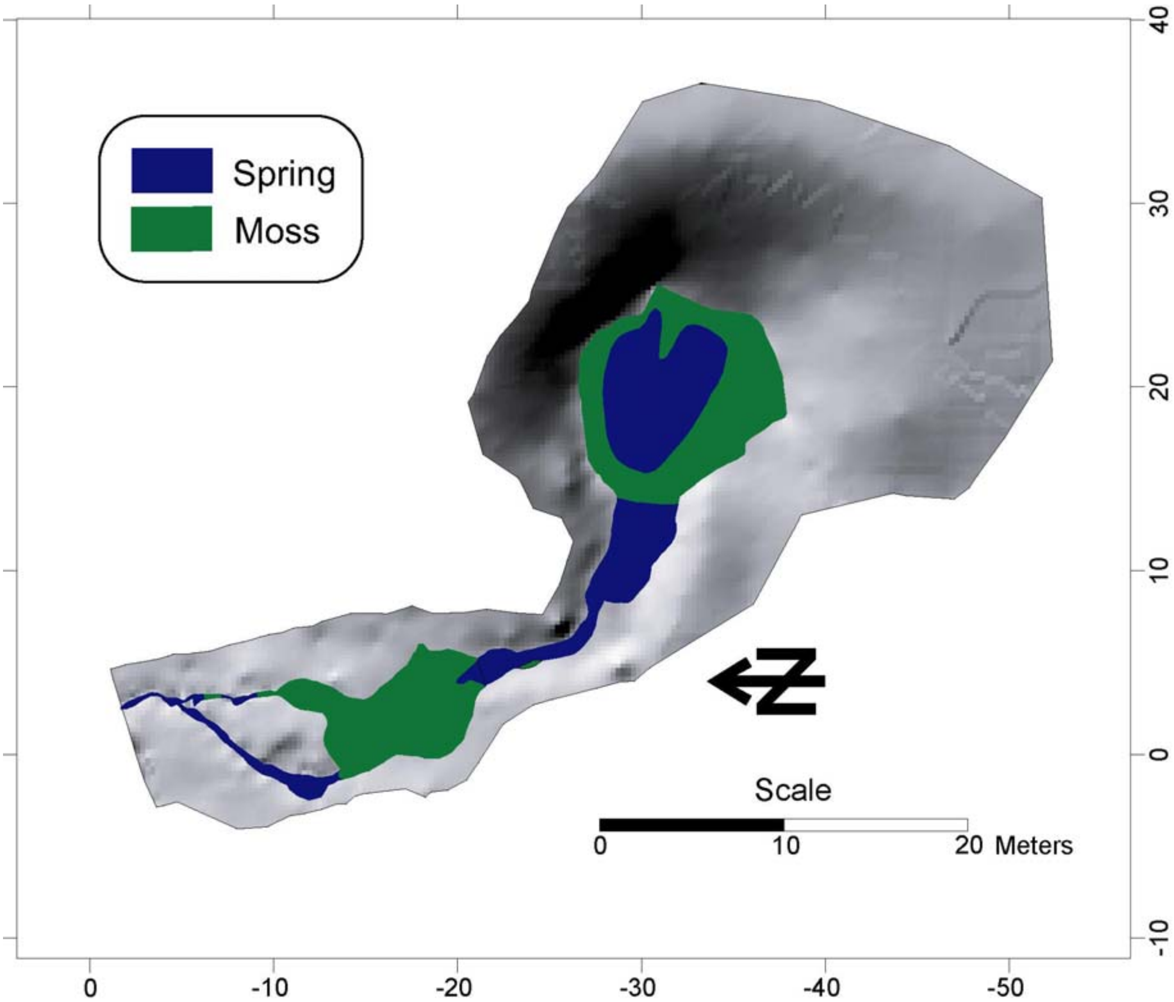

Figure A5-12: Moss coverage at God dal Fuorn spring.

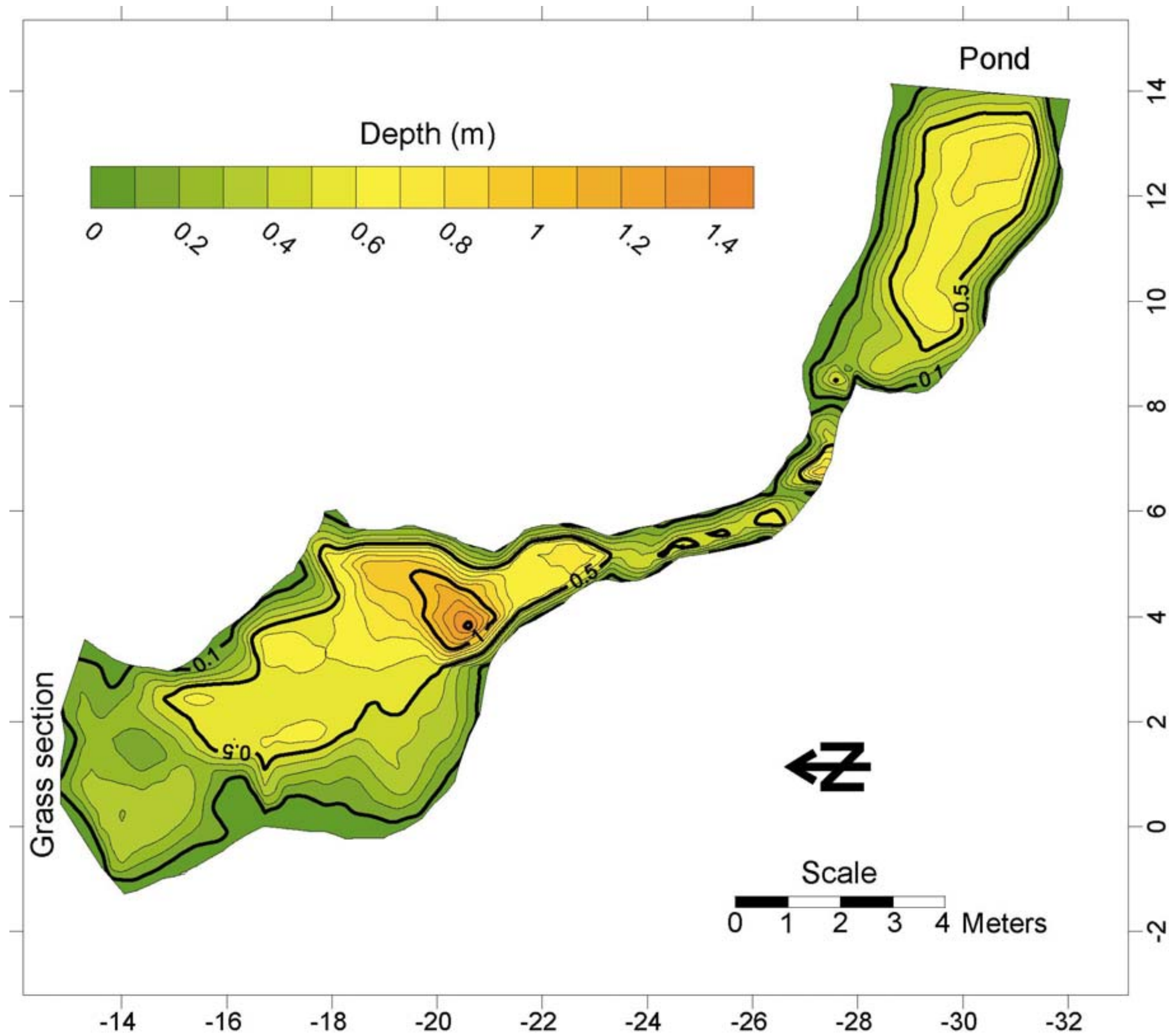

Figure A5-13: Depth of the sludge layer in the outlet, upper and moss section of God dal Fuorn spring.

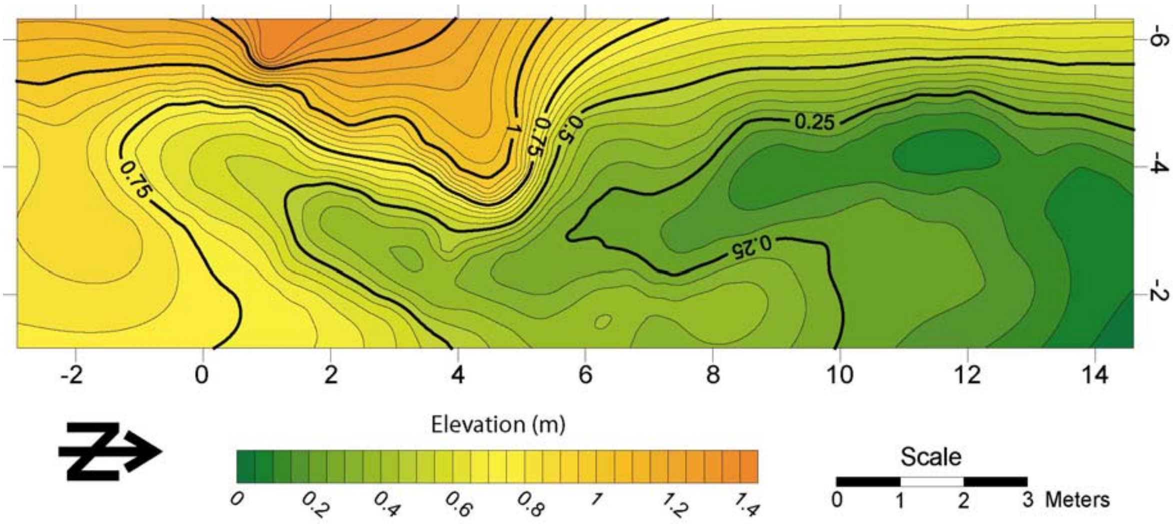

Figure A5-14: Topography of Val da l´Aqua spring.

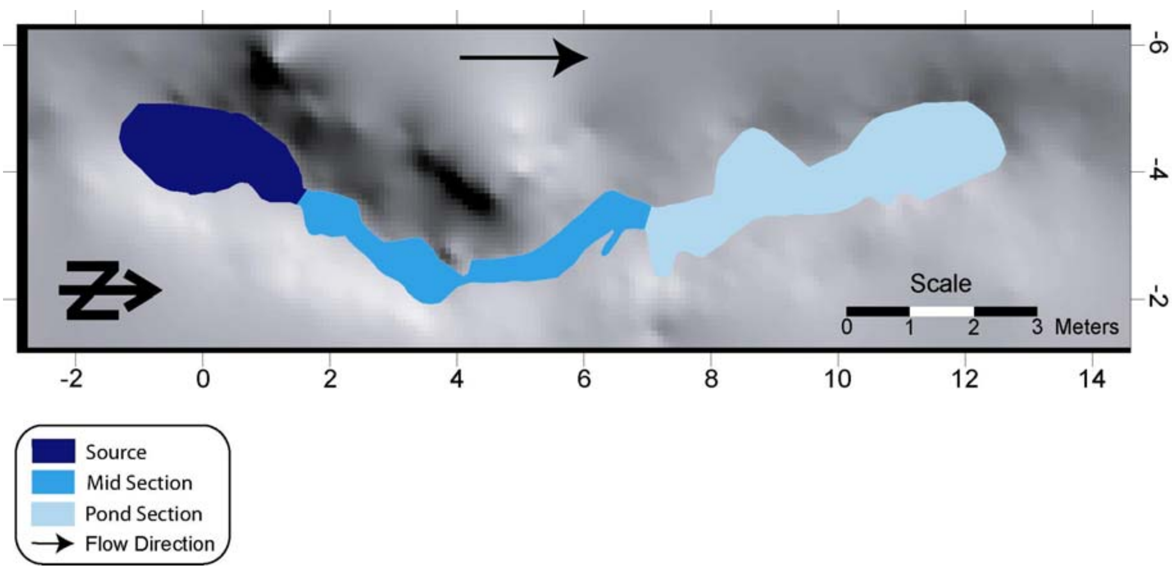

Figure A5-15: Different channel sections at Val da l´Aqua spring.

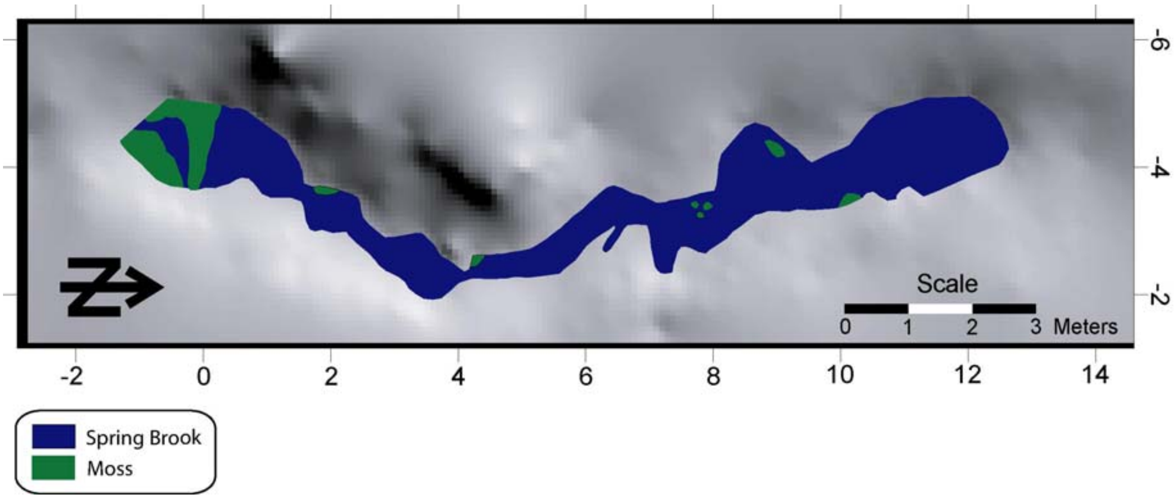

Figure A5-16: Moss coverage at Val da l´Aqua spring.

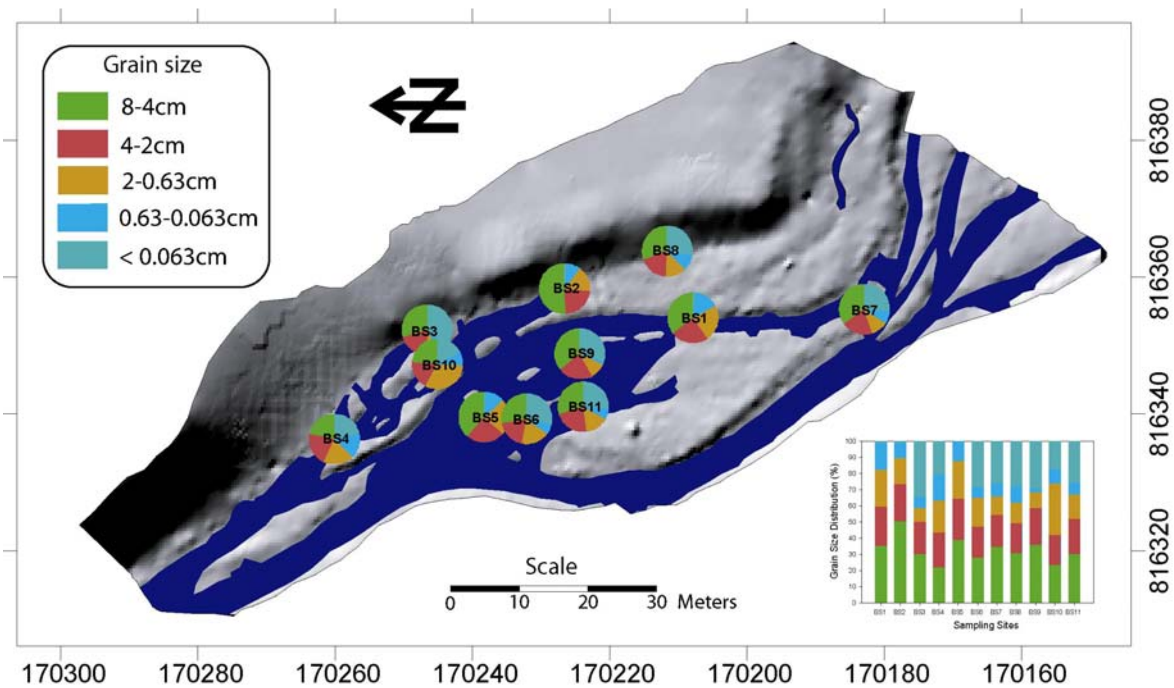

Figure A5-17: Grain size distribution at Buffalora spring.

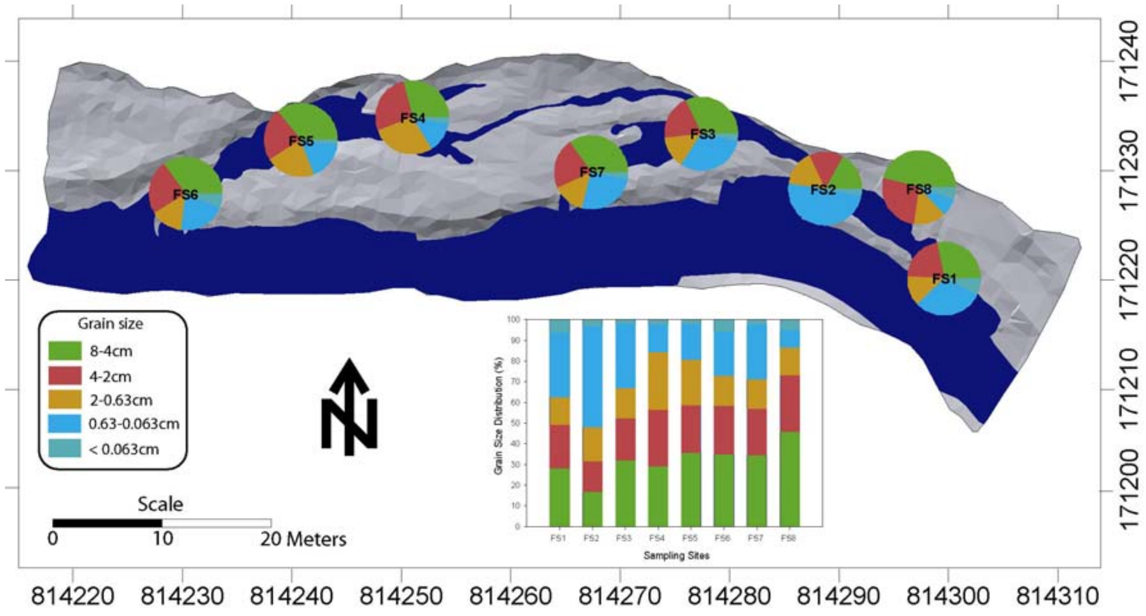

Figure: A5-18: Grain size distribution at Fuorn spring.

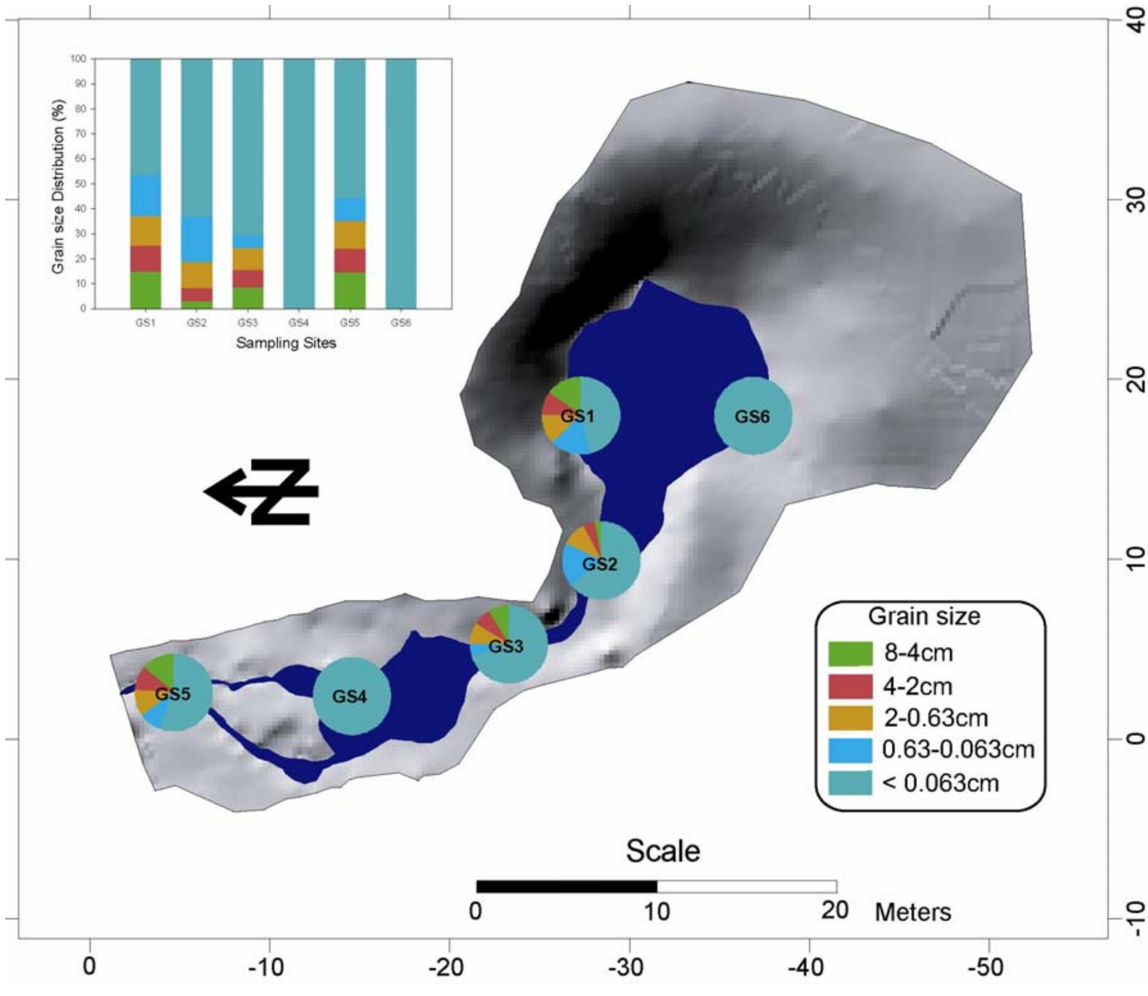

Figure A5-19: Grain size distribution at God dal Fuorn spring.

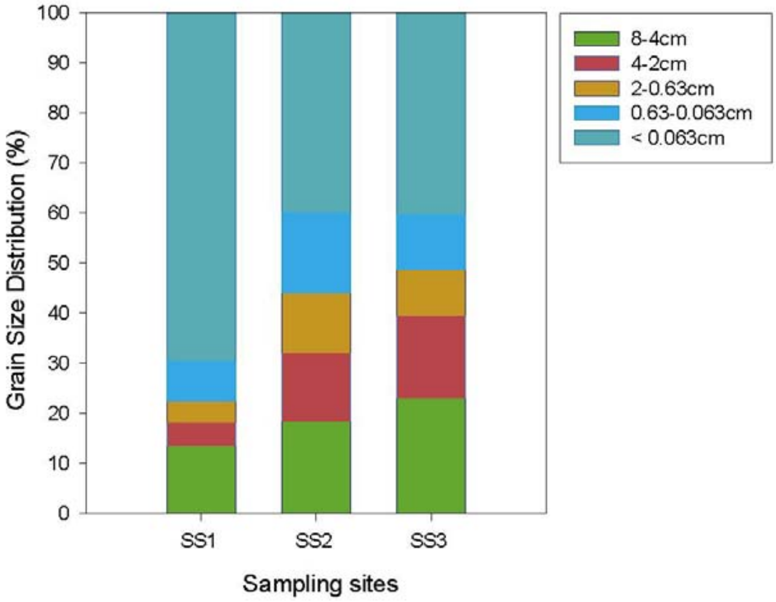

Figure A5-20: Grain size distribution at Spöl spring.

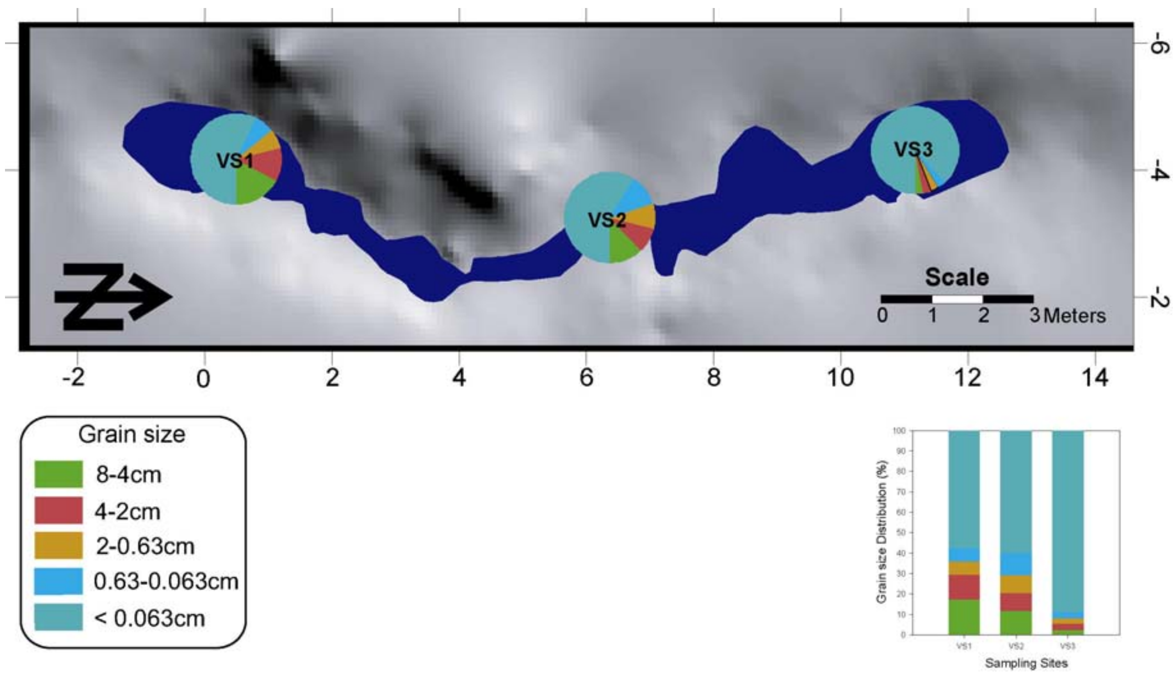

Figure A5-21: Grain size distribution at Val da l´Aqua spring.

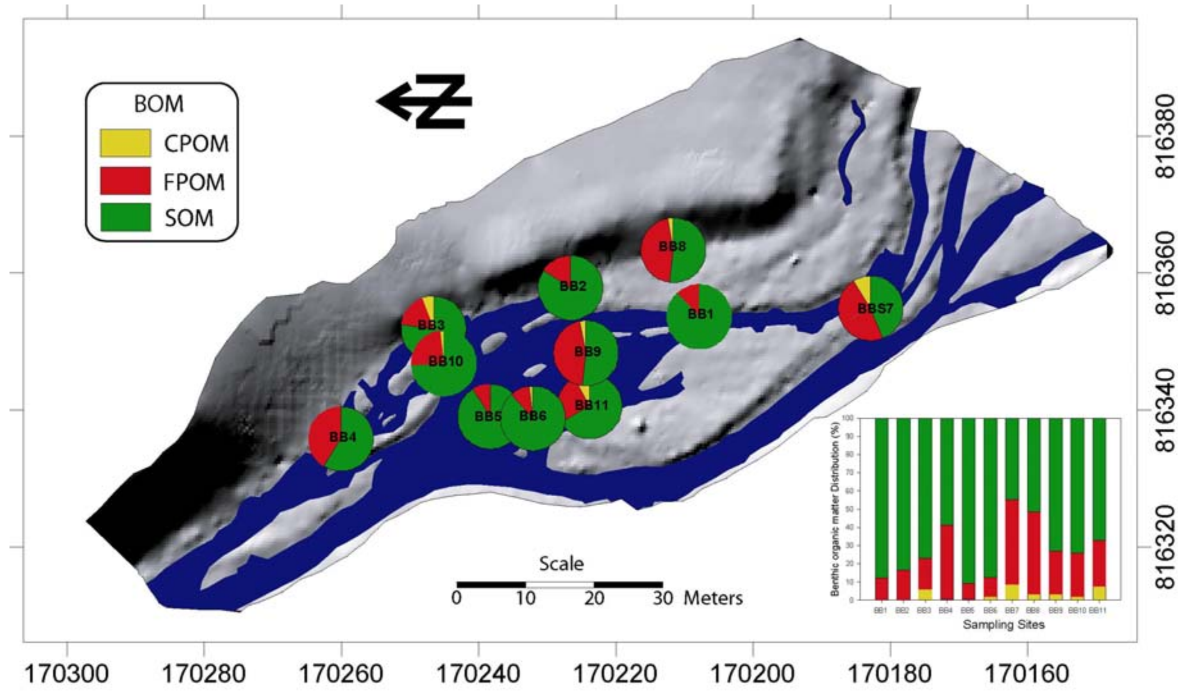

Figure A5-22: Benthic organic matter distribution at Buffalora spring.

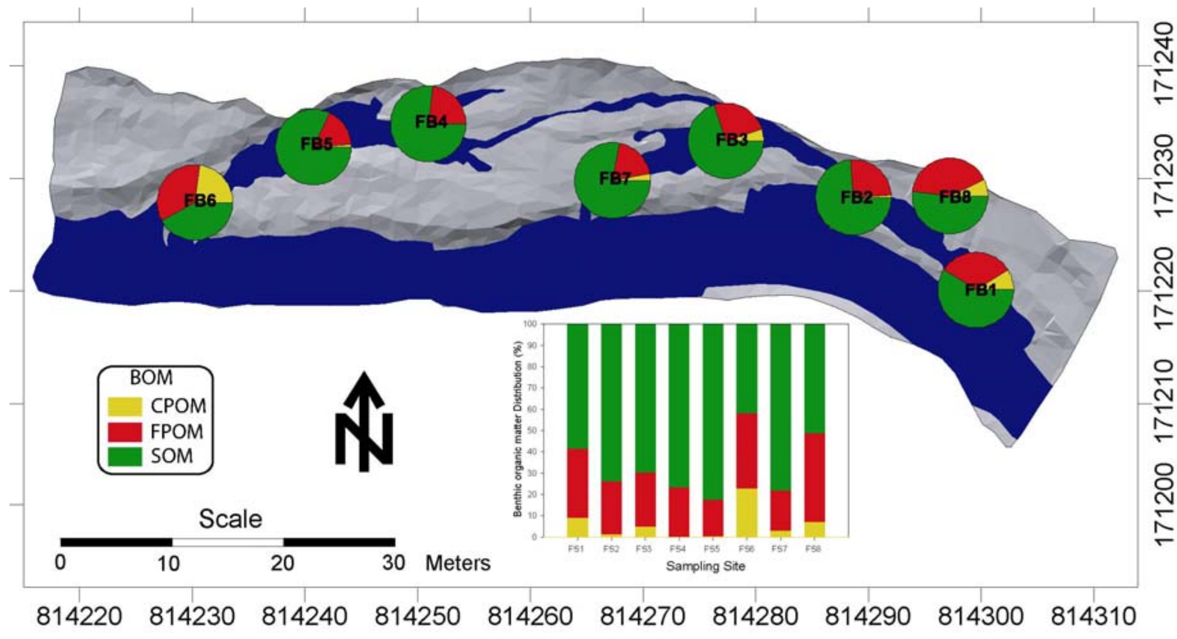

Figure A5-23: Benthic organic matter distribution at Fuorn spring.

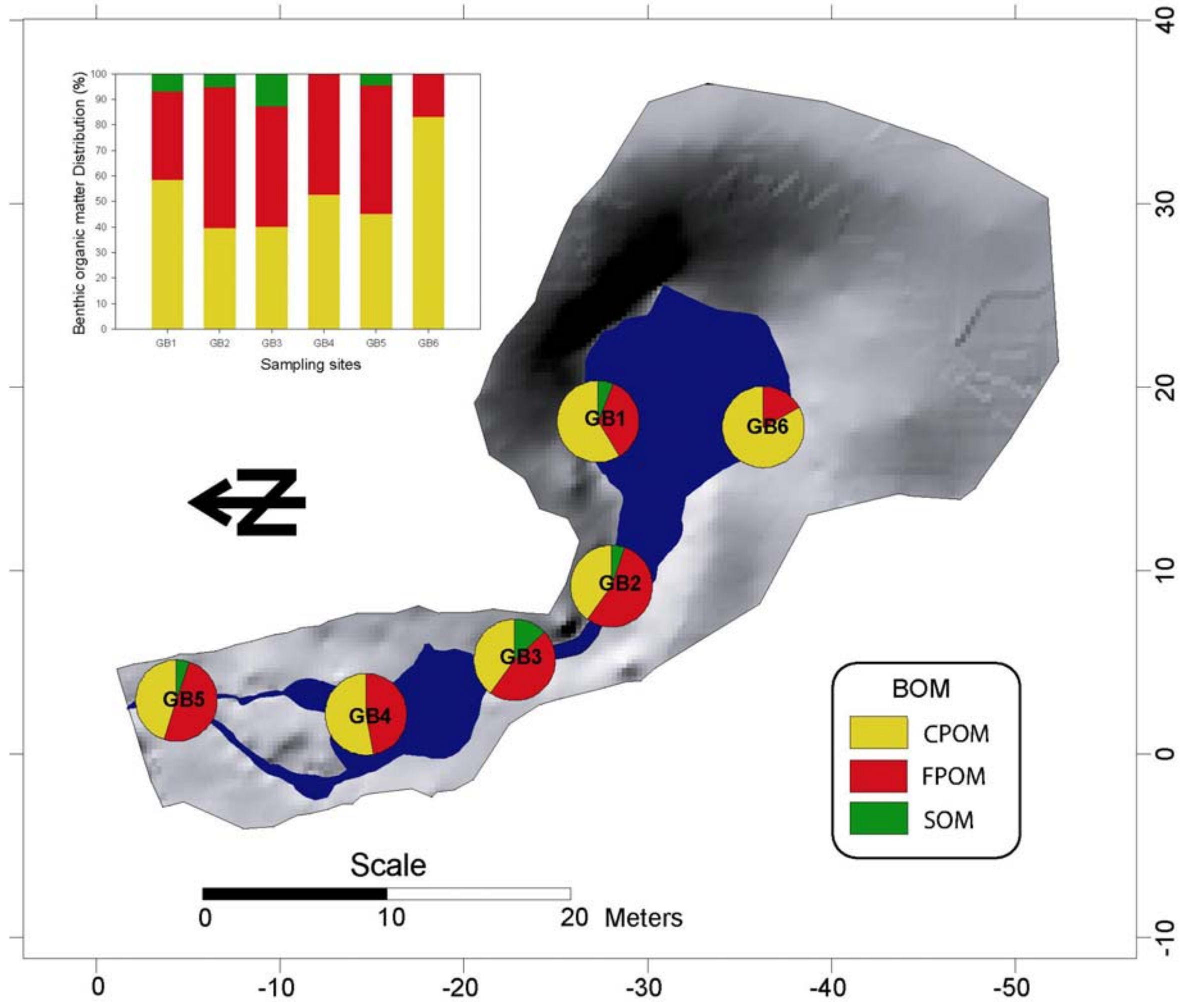

Figure A5-24: Benthic organic matter distribution at God dal Fuorn spring.

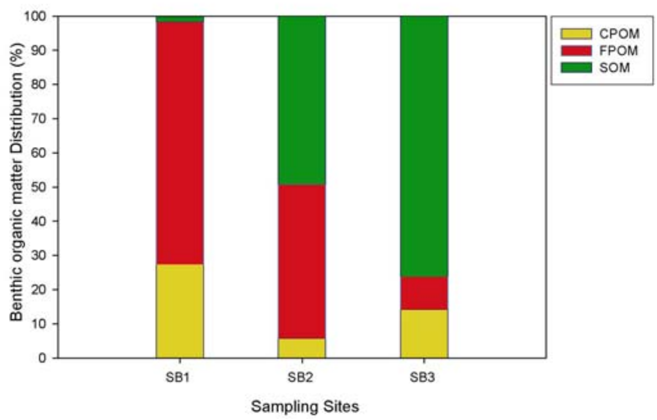

Figure A 5-25: Benthic organic matter distribution in the Spöl spring.

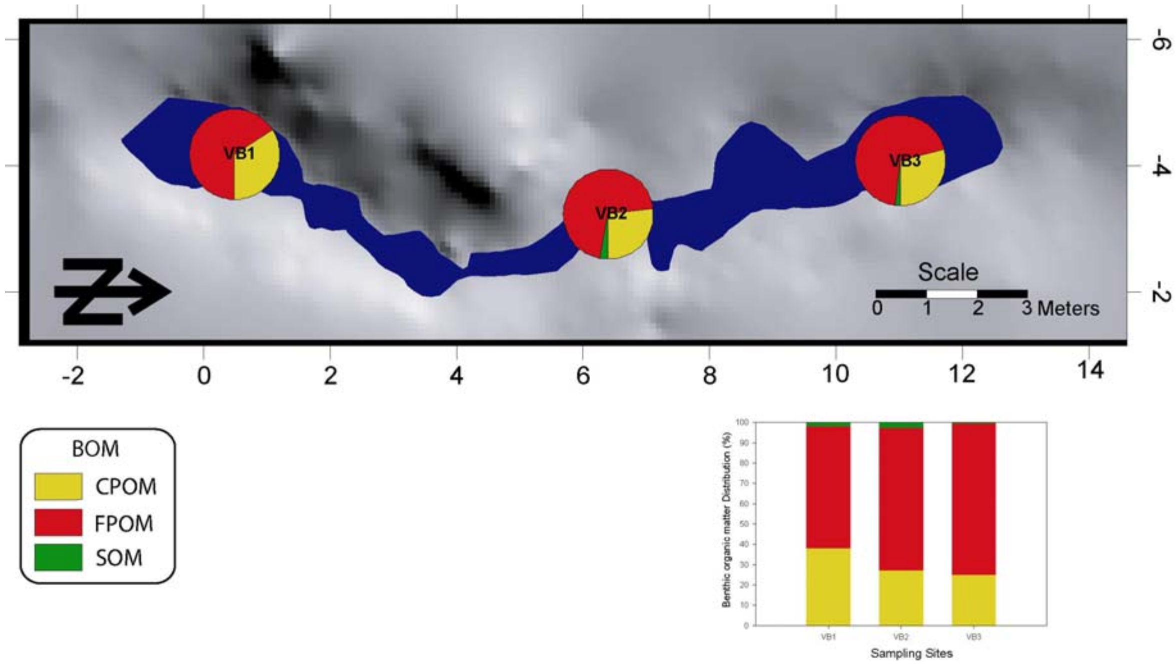

Figure A5-26: Benthic organic matter distribution at Val da l´Aqua spring.

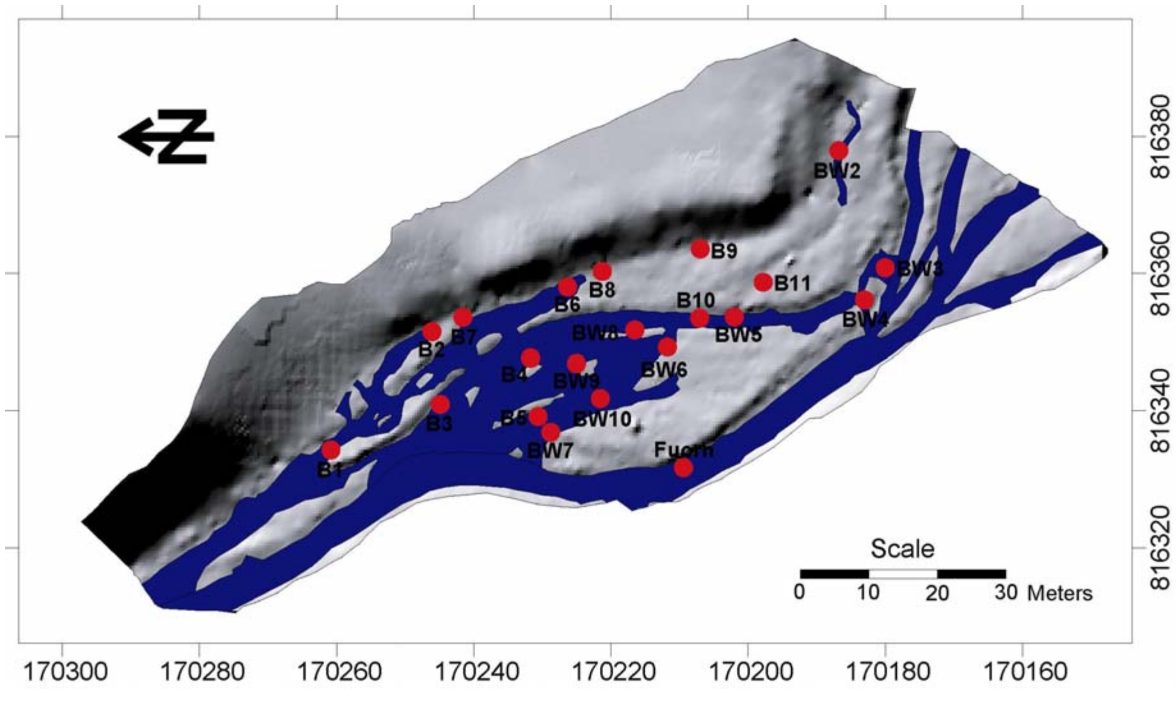

Figure A5-27: Physico chemical sampling sites at Buffalora spring.

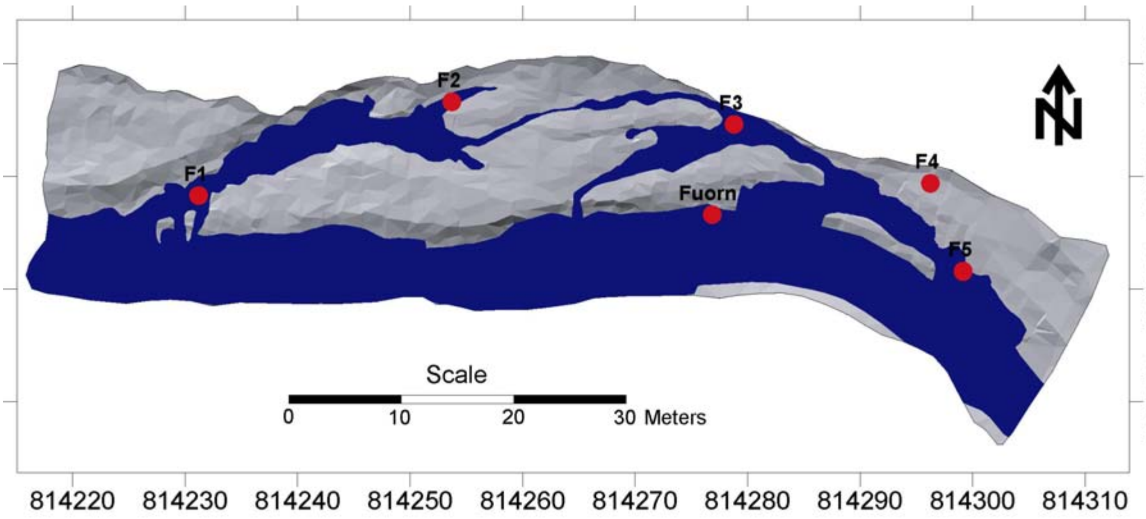

Figure A5-28: Physico chemical sampling sites at Fuorn spring.

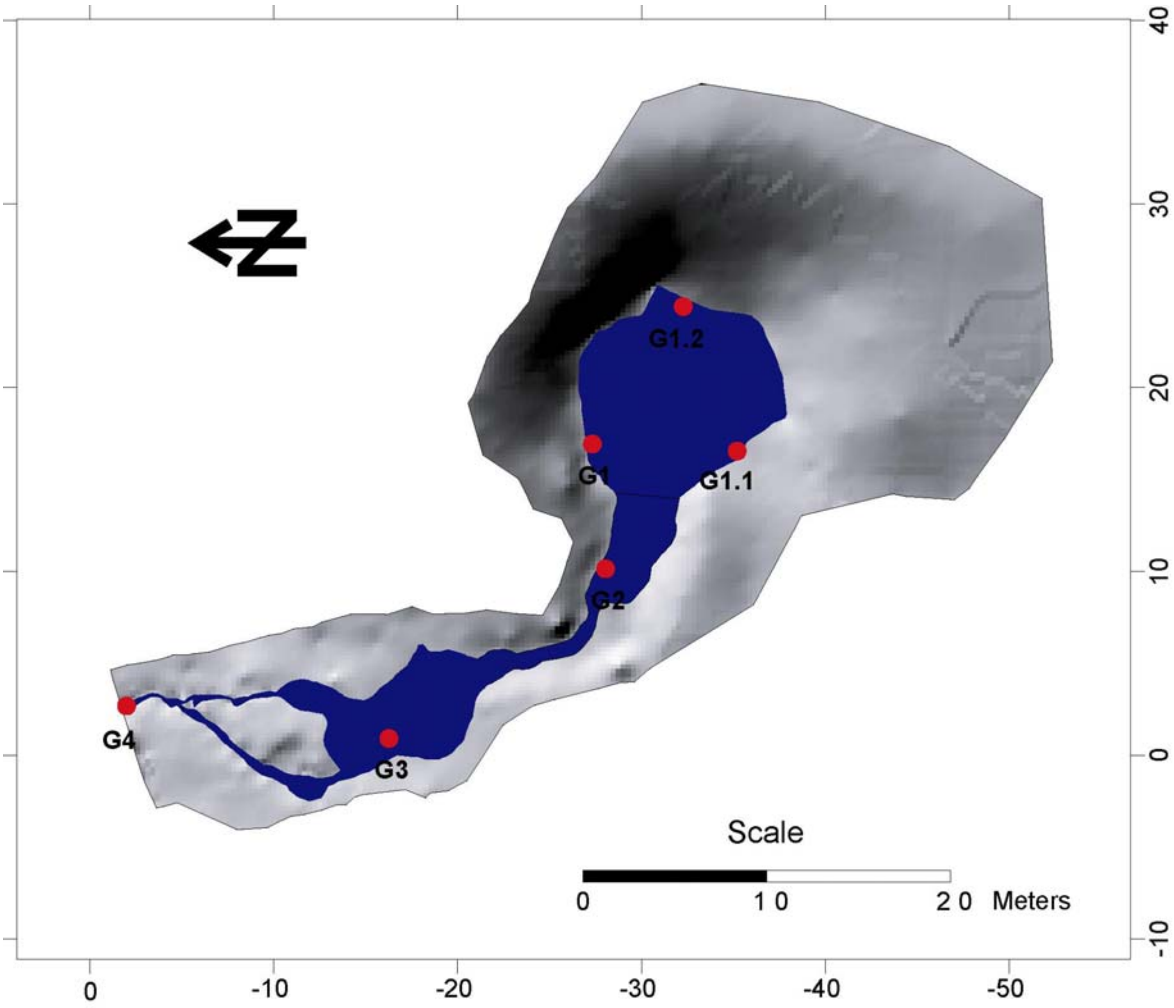

Figure A5-29: Physico chemical sampling sites at God dal Fuorn spring.

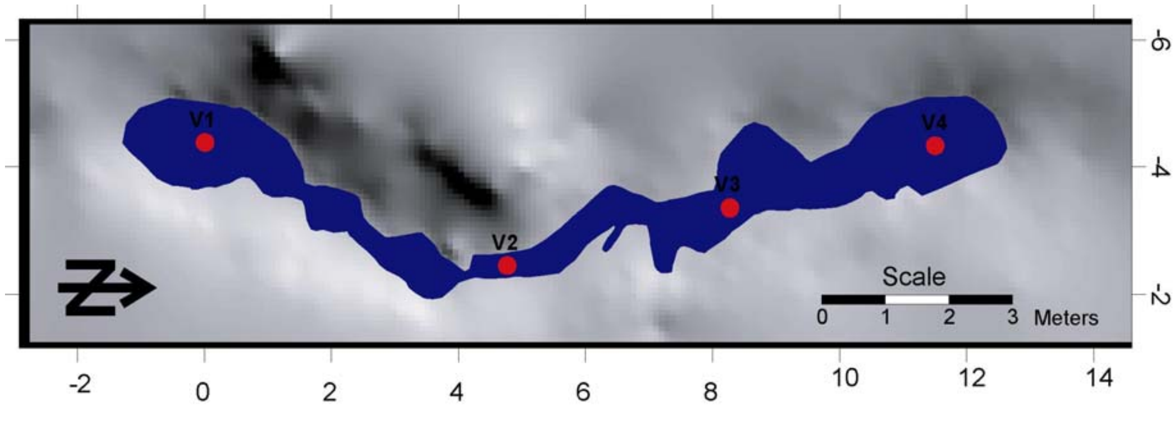

Figure A 5-30: Physico chemical sampling sites at Val da l´Aqua spring.

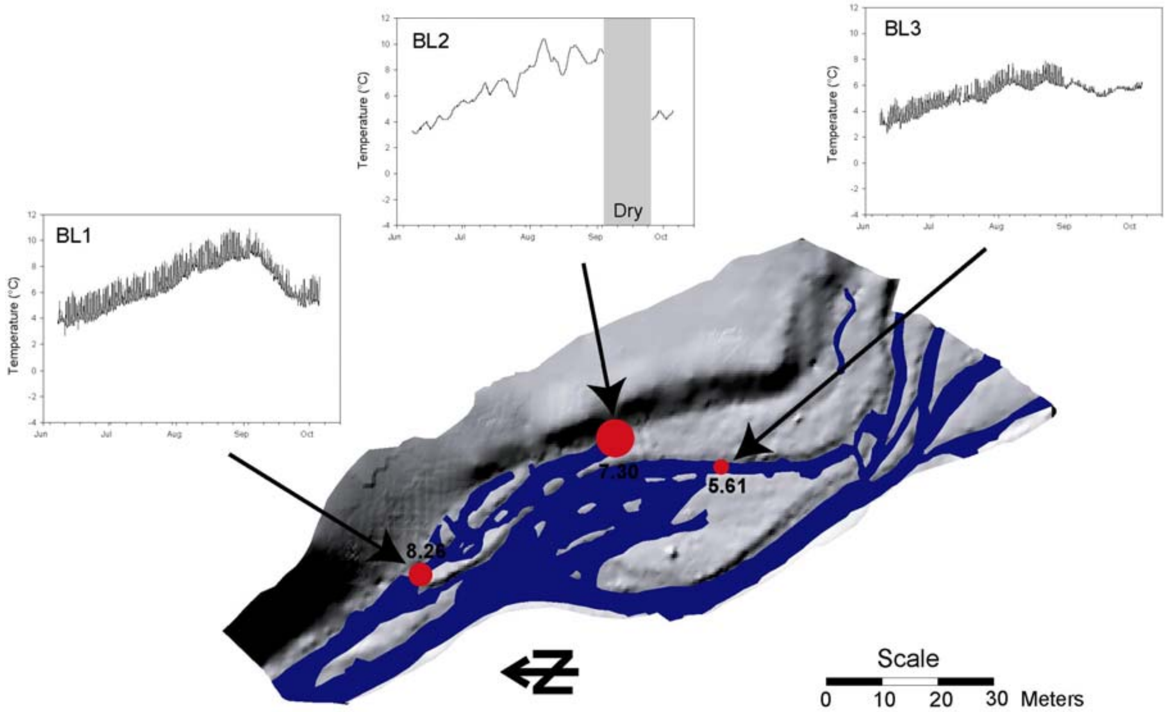

Figure A5-31: Temperature logger data and temperature ranges at Buffalora spring.

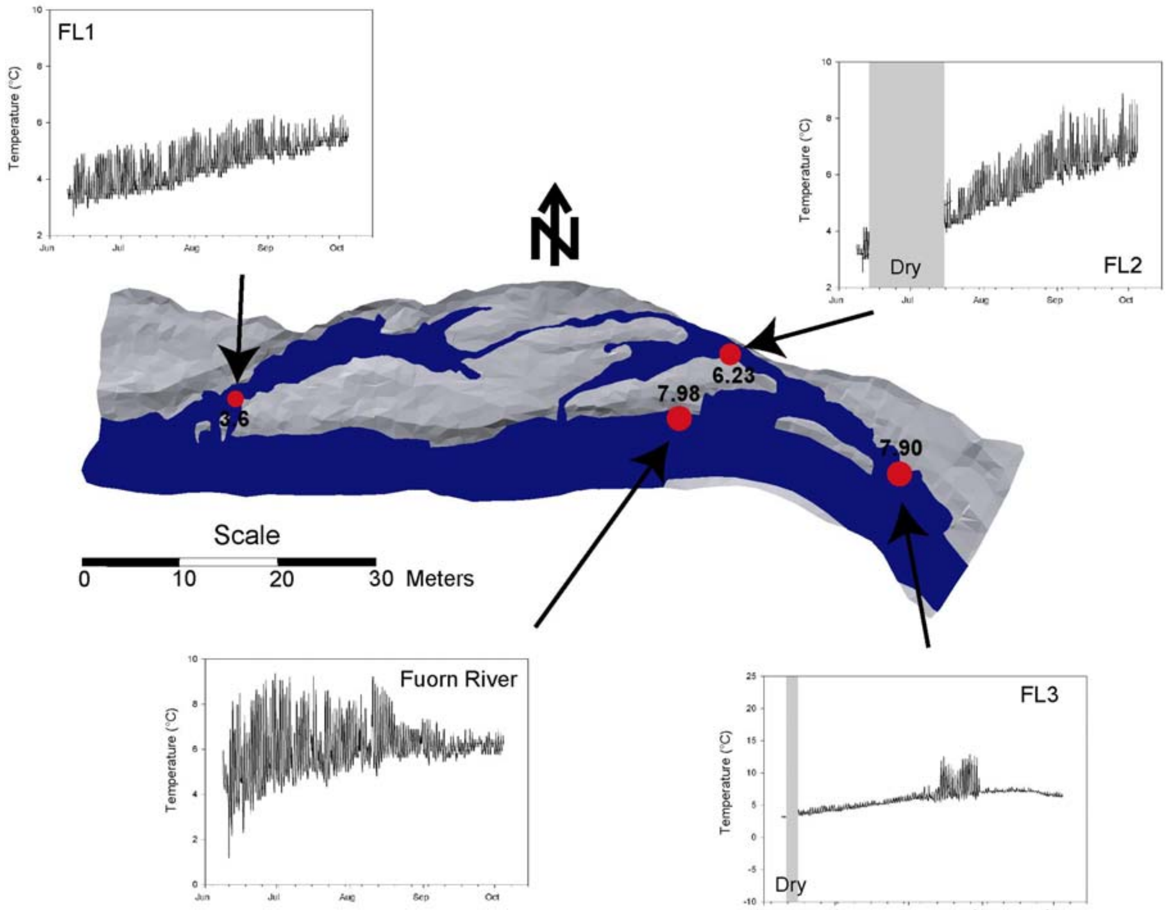

Figure A5-32: Temperature logger data and temperature ranges at Fuorn spring.

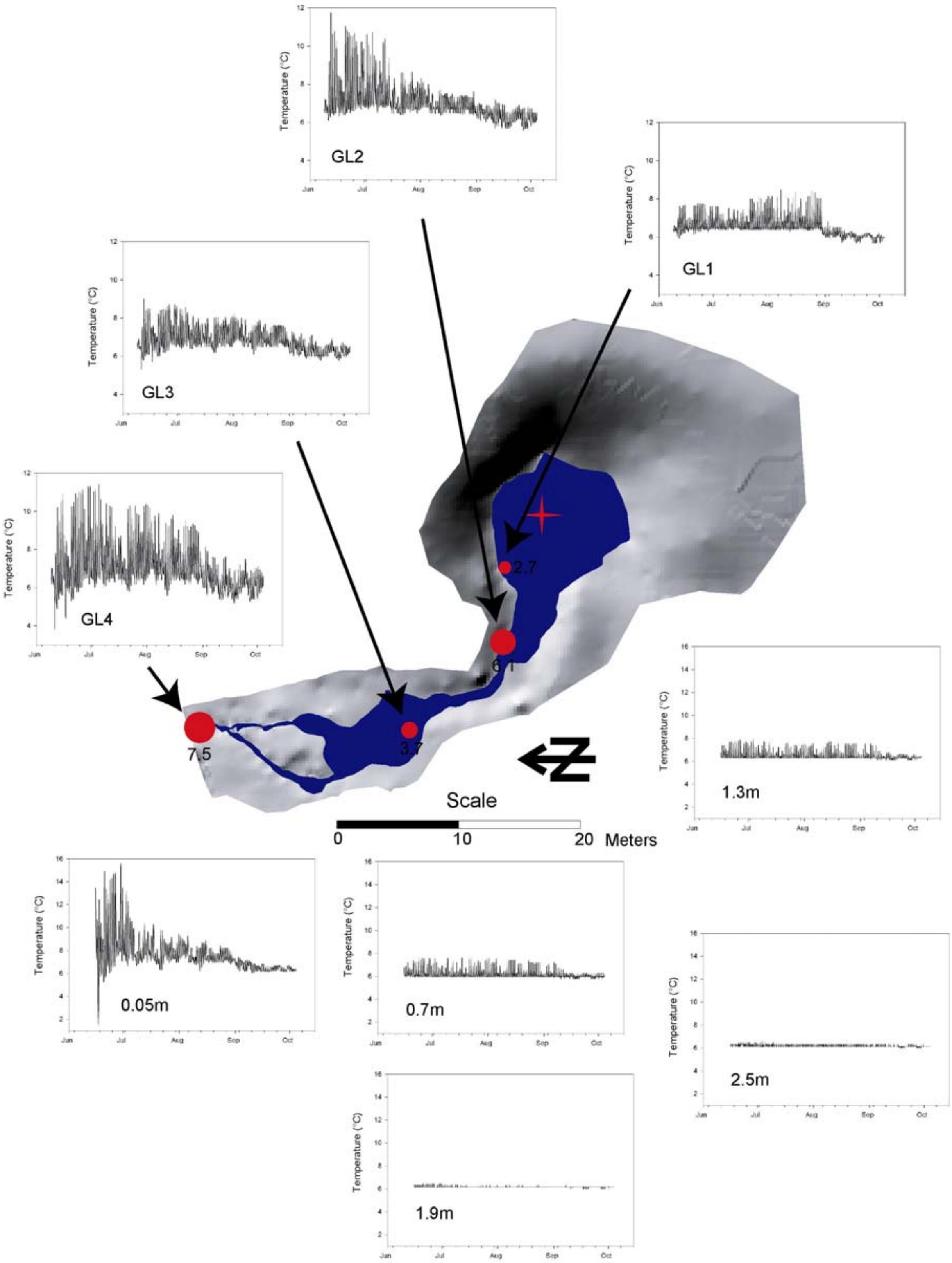

Figure A5-33: Temperature logger data at God dal Fuorn spring. Star in the middle of the pond mark the location for the vertical temperature profile.

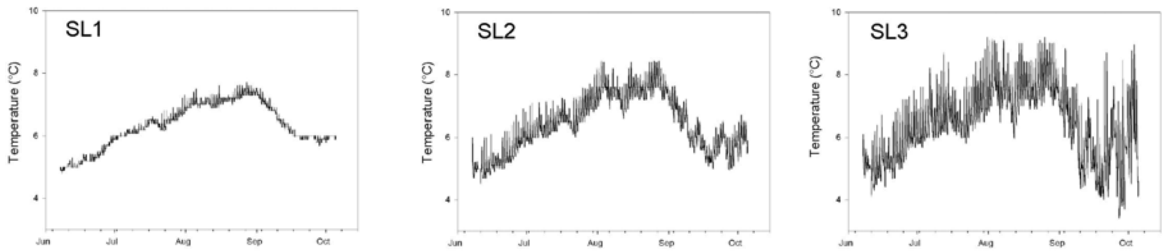

Figure A5-34: Temperature logger data at Spöl spring (downstream gradient).

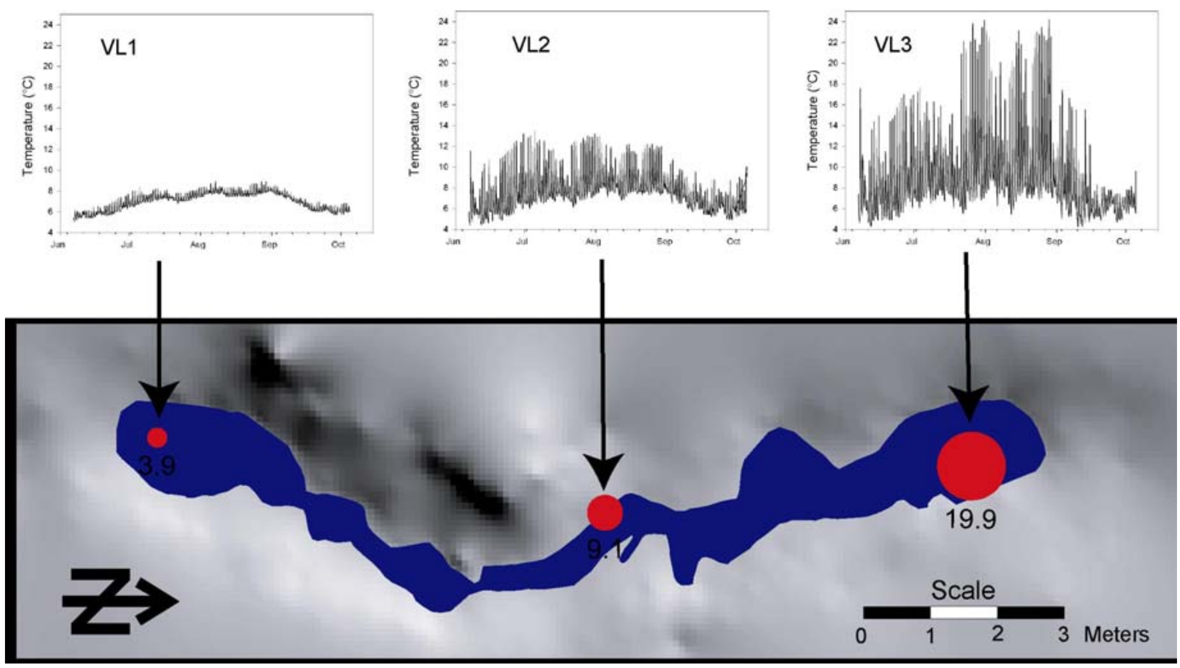

Figure A5-35: Temperature logger data at Val da l´Aqua spring.

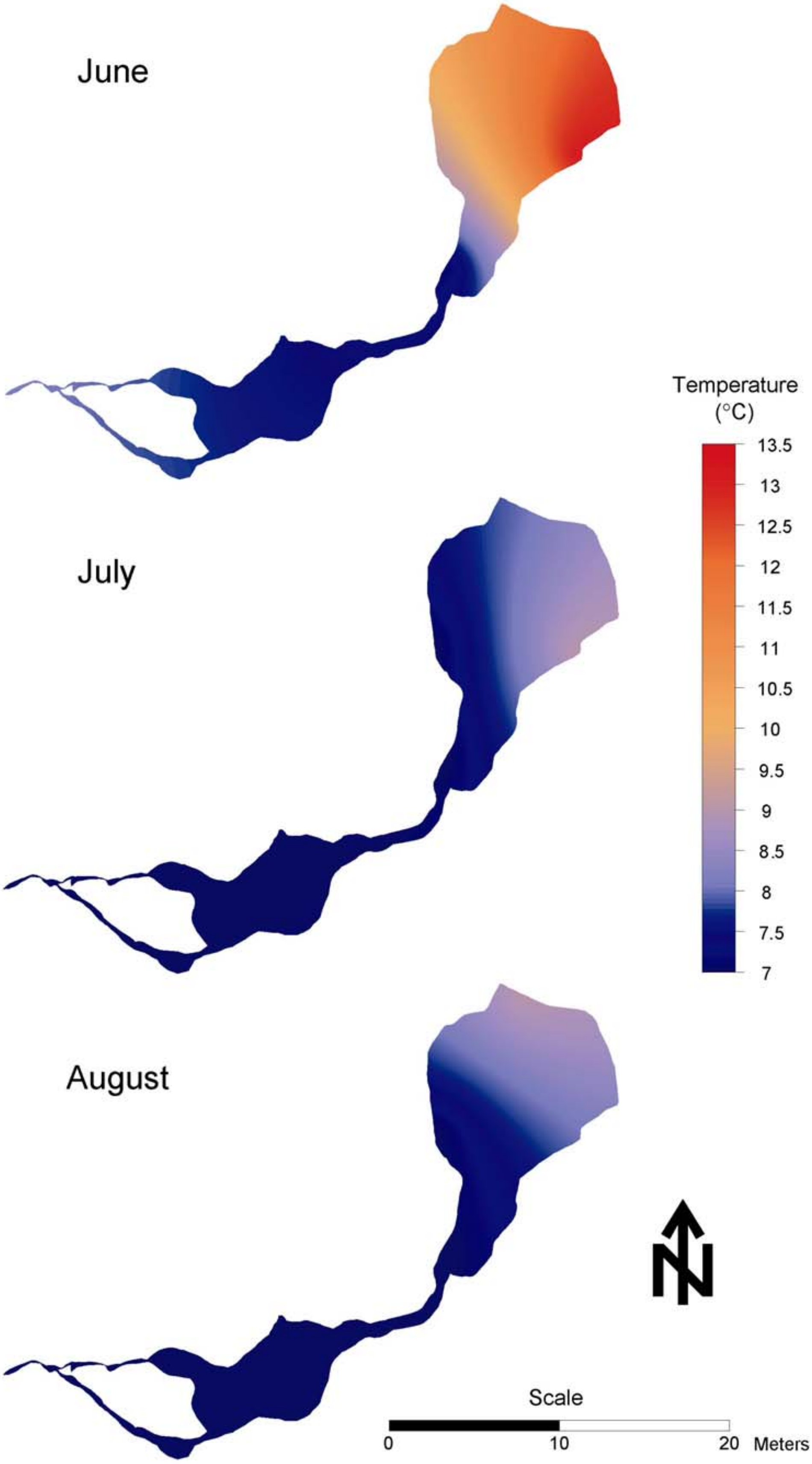

Figure A5-36: Surface spot temperatures at God dal Fuorn Spring in June, July and August.

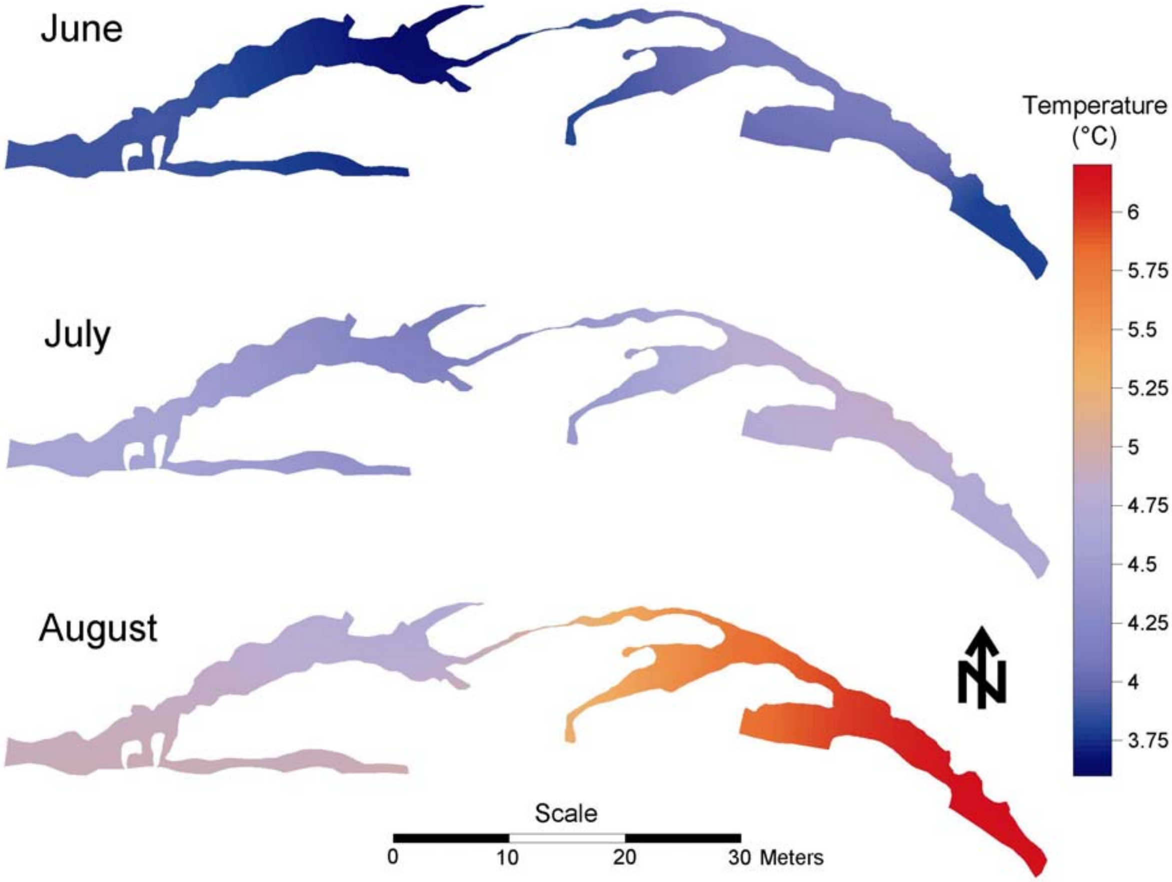

Figure A5-37: Surface spot temperatures at Fuorn spring in June, July and August.

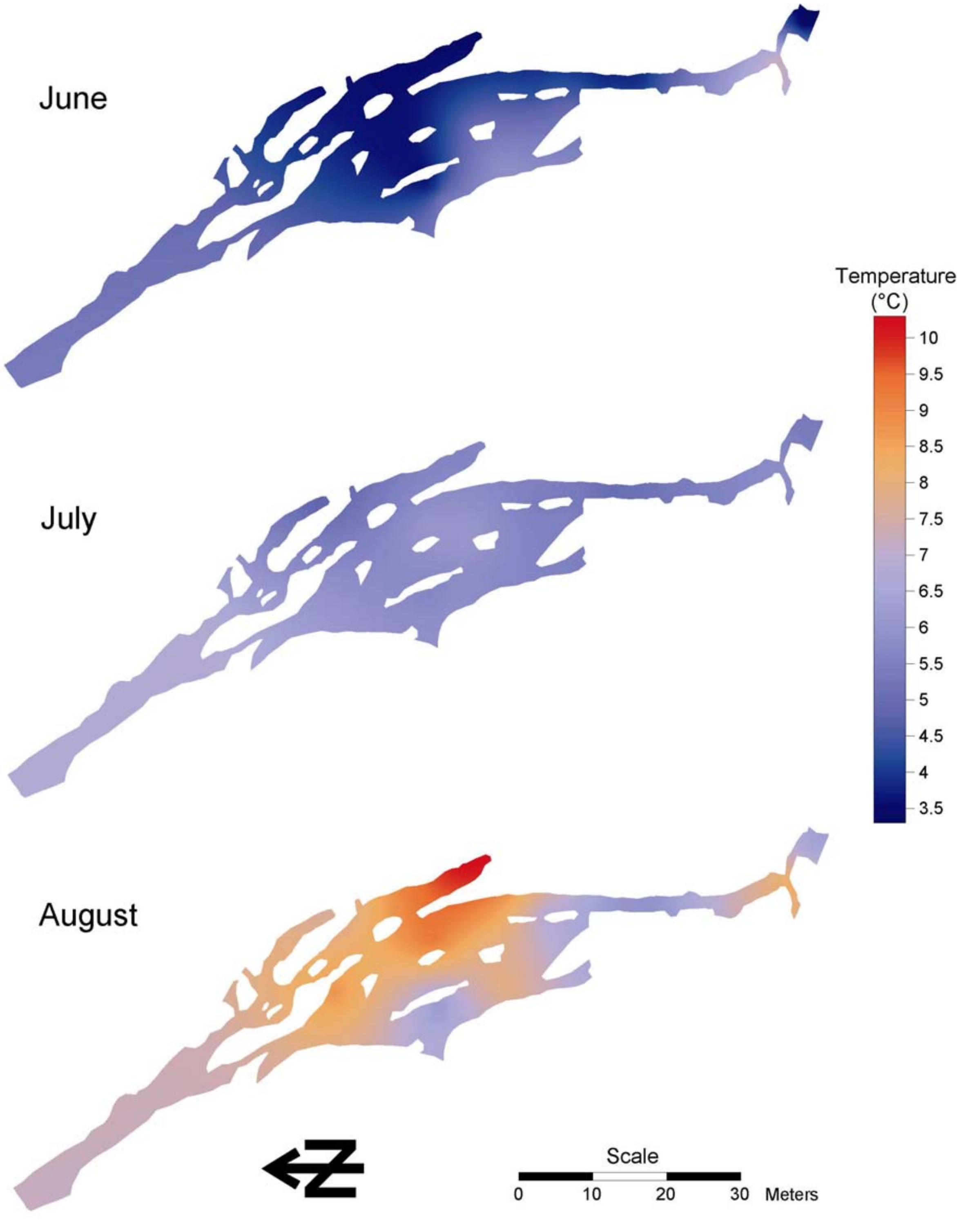

Figure A5-38: Surface spot temperatures at Buffalora spring in June, July and August.

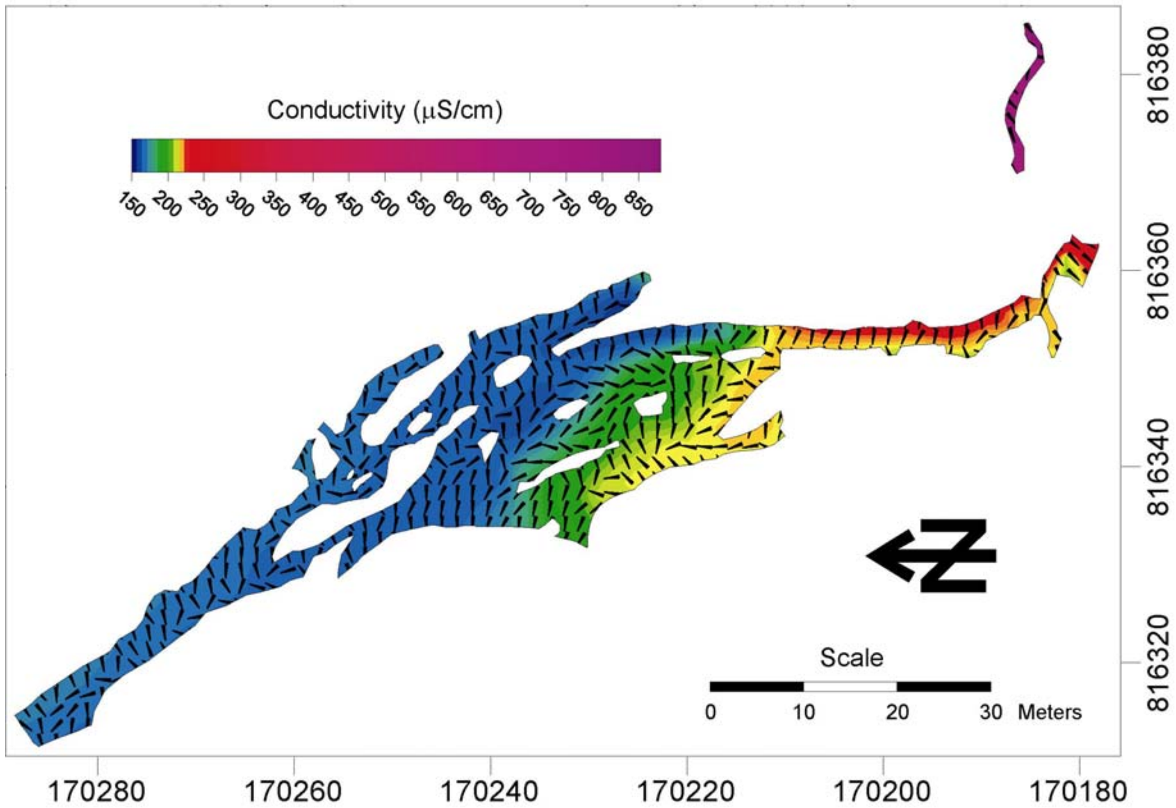

Figure A5-39: Conductivity spot measurements at Buffalora spring in October used as an indicator for sewage influence. Arrows describe geomorphologic surface orientation.

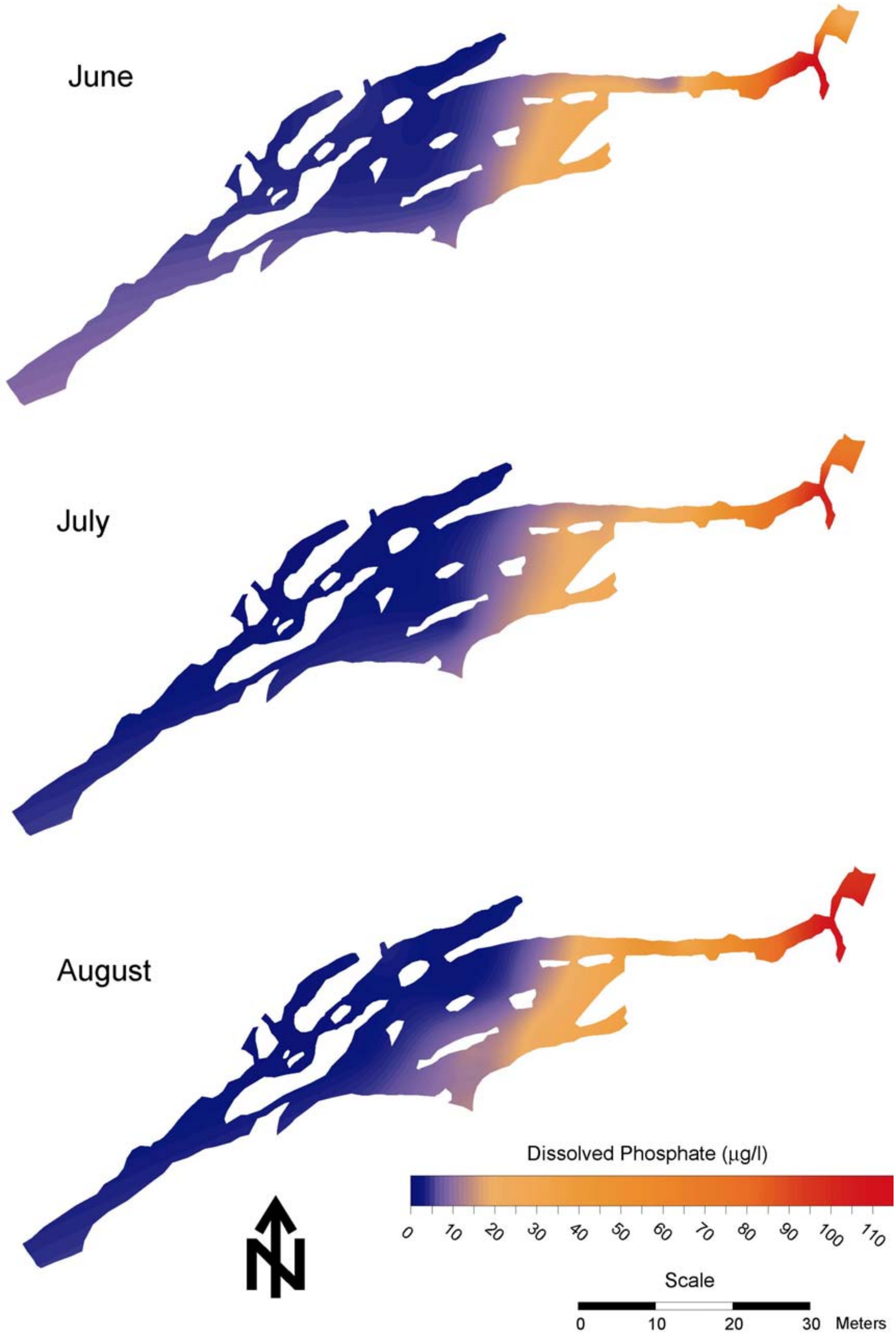

Figure A5-40: Dissolved phosphate values at Buffalora spring in June, July and August.

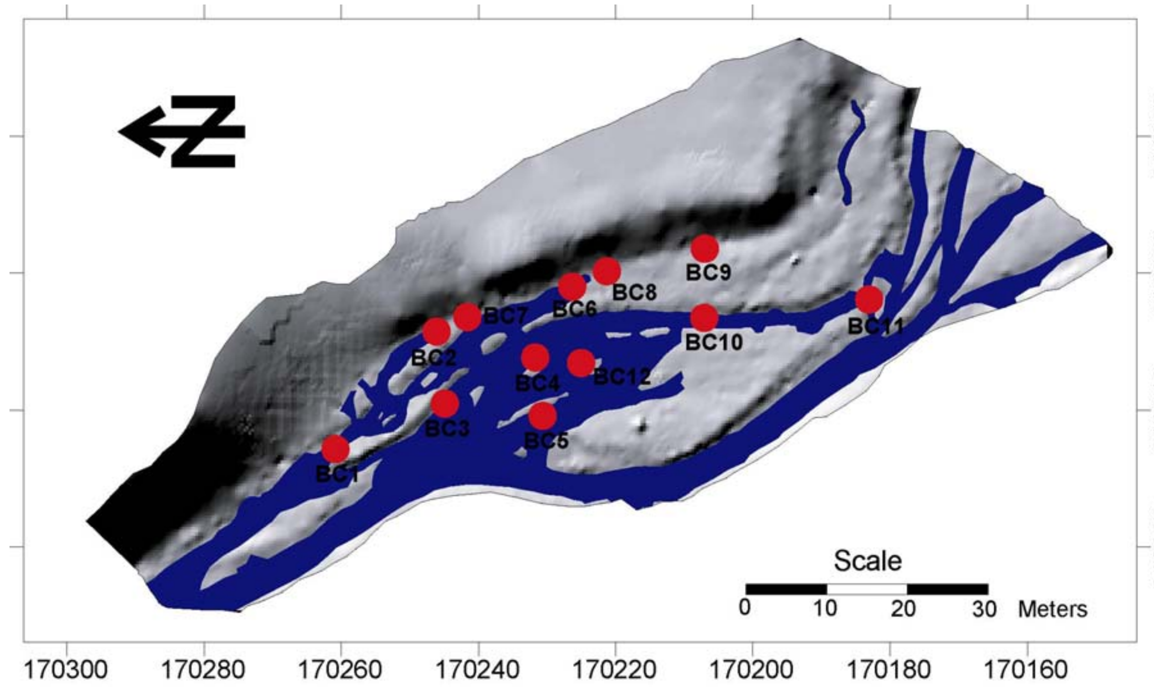

Figure A5-41: Periphyton sampling sites at Buffalora spring.

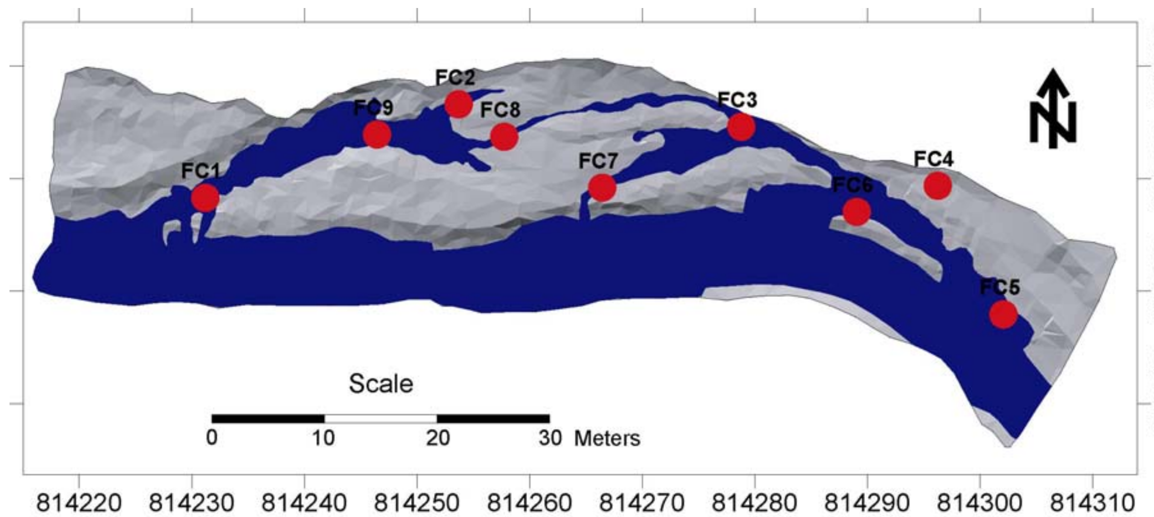

Figure A5-42: Periphyton sampling sites at Fuorn spring.

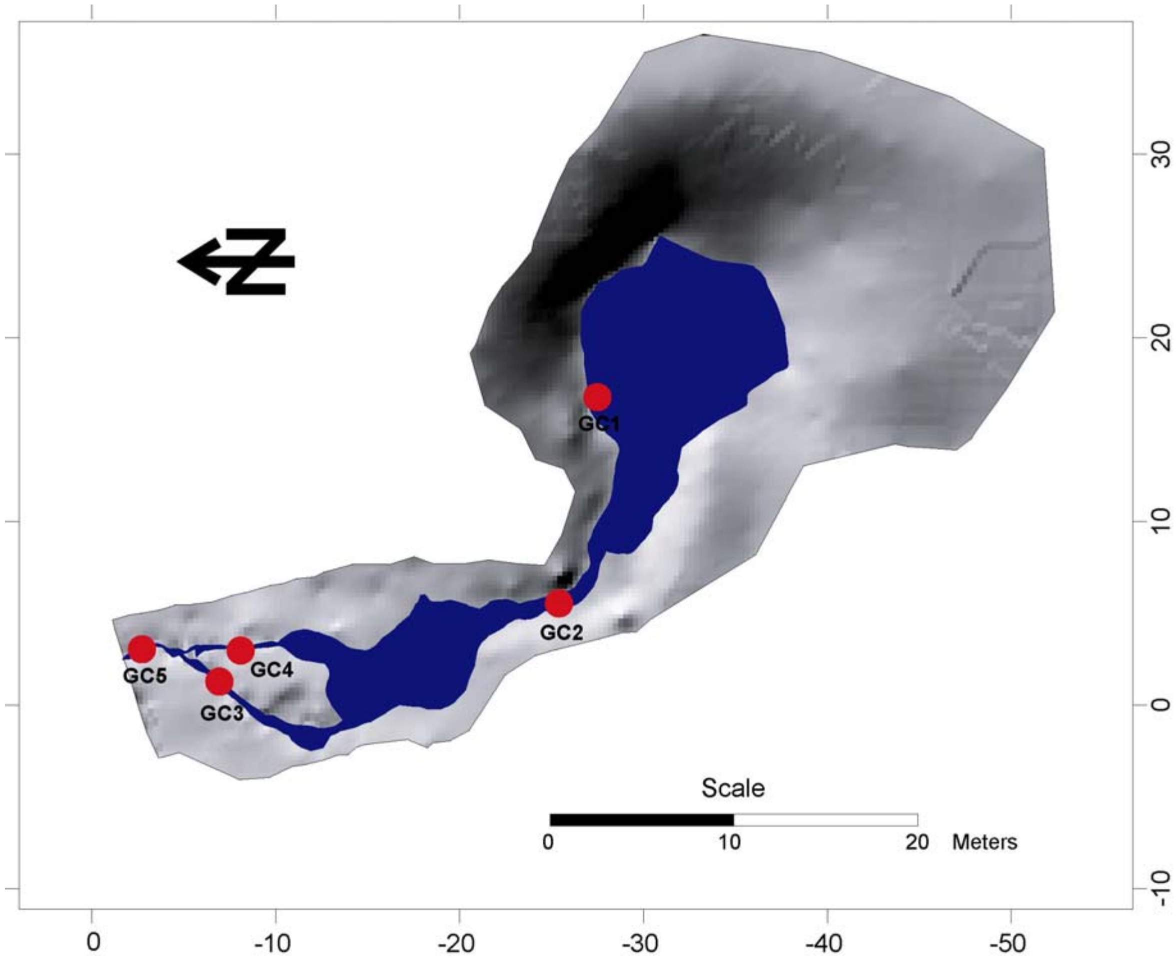

Figure A5-43: Periphyton sampling sites at God dal Fuorn spring.

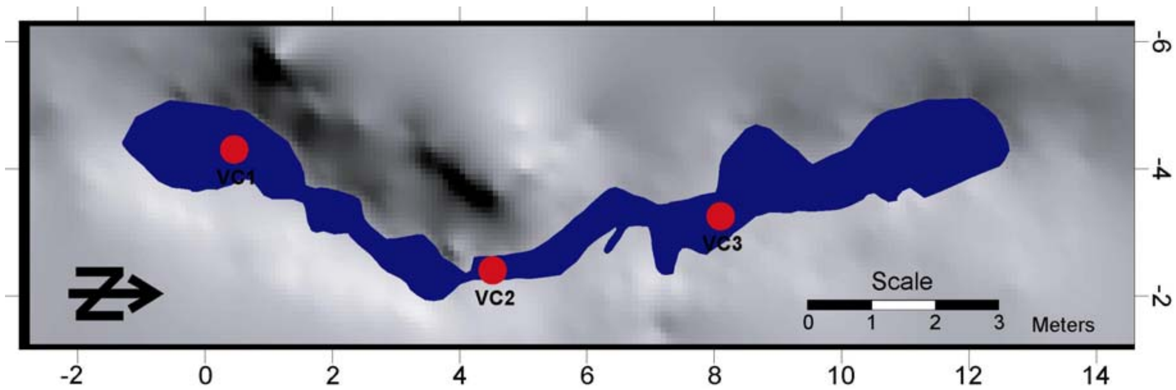

Figure A5-44: Periphyton sampling sites at Val da l´Aqua spring.

11 Appendix B: Velocity data

Table B1: Minimum (Min), maximum (Max), mean (ξ), standard deviation (SD) and coefficients of variation (CV) of velocity (m/s) measurements for each site and date and for spot measurements taken in August 2001.

	Date	Min	Max	ξ	SD	CV (%)
	June	0.00	0.54	0.13	0.13	104.3
Buffalora	July	0.00	0.43	0.19	0.14	74.4
(n=19)	August	0.00	0.70	0.19	0.18	96.9
	Spot (n=140)	0.00	0.66	0.15	0.15	100.0
	June	0.06	0.41	0.18	0.14	77.2
Fuorn	July	0.02	0.43	0.14	0.17	125.0
(n=5)	August	0.00	0.31	0.11	0.12	115.1
	Spot (n=37)	0.01	0.39	0.13	0.11	84.6
	June	0.00	0.70	0.16	0.28	176.6
God dal Fuorn	July	0.00	0.93	0.20	0.36	181.2
(n=6)	August	0.00	0.91	0.18	0.36	202.5
	Spot (n=30)	0.00	0.97	0.28	0.31	110.7
	June	0.00	0.39	0.17	0.16	97.0
Spöl	July	0.01	0.12	0.07	0.05	67.0
(n=4)	August	0.01	0.29	0.15	0.12	78.8
	Spot (n=25)	0.00	0.21	0.09	0.12	133.0
	June	0.00	0.17	0.06	0.08	145.8
Val dal Aqua	July	0.02	0.11	0.06	0.05	78.3
(n=3)	August	0.00	0.10	0.06	0.04	72.0
	Spot (n=30)	0.00	0.07	0.02	0.02	100.0

12 Appendix C: Physico-chemical data

Table C1: Physico chemical values at Buffalora unaffected sites and river site.

Site	Date	Temperature (°C)	Conductivity (µs/cm)	PH	O_2 (mg/l)	O_2 (%)	NH_4-N (µg/l)	NO_2-N (µg/l)	NO_3N (µg/l)	DN (µg/l)	PN (µg/l)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)
B1	6/7/01	5.0	154.2	8.9	11.6	108.7	1.0	1.0	174.0	506.0	6.0	1.0	5.0	1.0
B2	6/7/01	3.6	154.9	8.6	10.3	97.7	2.0	0.0	223.0	624.0	5.0	2.0	5.0	0.0
B3	6/7/01	4.0	152.0	8.7	10.5	101.1	3.0	0.0	213.0	422.0	7.0	1.0	3.0	0.0
B4	6/7/01	3.7	152.0	8.6	10.7	102.6	0.0	0.0	210.0	461.0	9.0	0.0	3.0	1.0
B6	6/7/01	3.4	152.0	8.6	10.5	99.4	1.0	0.0	228.0	350.0	4.0	0.0	2.0	0.0
B7	6/7/01	3.6	155.5	8.5	10.3	98.3	0.0	0.0	217.0	271.0	5.0	1.0	4.0	0.0
B8	6/7/01	3.4	151.5	8.6	10.4	98.2	1.0	0.0	226.0	299.0	3.0	0.0	3.0	0.0
B9	6/7/01	4.0	152.2	8.6	9.9	95.0	0.0	0.0	234.0	266.0	3.0	0.0	4.0	0.0
Fuorn	6/7/01	6.4	204.0	8.4	9.8	101.3	0.0	0.0	130.0	179.0	5.0	1.0	2.0	1.0
B1	7/3/01	6.8	138.6	8.5	10.0	103.8	1.0	0.0	178.0	216.0	10.0	0.0	1.0	1.0
B2	7/3/01	4.8	139.2	8.3	9.4	93.7	3.0	0.0	209.0	226.0	3.0	0.0	1.0	0.0
B3	7/3/01	5.9	136.7	8.5	9.7	96.9	6.0	0.0	206.0	397.0	4.0	0.0	2.0	0.0
B4	7/3/01	6.1	137.2	8.5	10.2	102.2	2.0	0.0	203.0	227.0	18.0	0.0	3.0	0.0
B6	7/3/01	5.6	136.6	8.3	10.1	100.5	1.0	0.0	214.0	243.0	5.0	1.0	1.0	0.0
B7	7/3/01	5.0	141.6	8.2	9.1	89.2	1.0	0.0	204.0	218.0	6.0	1.0	1.0	1.0
B8	7/3/01	5.7	136.4	8.3	10.1	101.7	5.0	0.0	217.0	245.0	5.0	1.0	1.0	0.0
B9	7/3/01	6.3	136.8	8.3	9.2	99.0	10.0	0.0	213.0	318.0	30.0	0.0	2.0	1.0
Fuorn	7/3/01	8.5	172.6	8.2	8.5	88.5	4.0	0.0	166.0	202.0	2.0	0.0	0.0	0.0
B1	8/7/01	7.4	151.3	8.3	10.1	106.3	1.0	0.0	212.0	262.0	6.0	0.0	2.0	1.0
B2	8/7/01	7.6	149.8	8.2	9.5	99.9	2.0	0.0	212.0	281.0	10.0	0.0	2.0	2.0
B3	8/7/01	8.8	144.8	8.3	9.9	108.3	1.0	0.0	239.0	297.0	6.0	0.0	1.0	1.0
B4	8/7/01	9.3	144.2	8.3	10.1	109.5	1.0	0.0	247.0	301.0	3.0	0.0	1.0	1.0
B6	8/7/01	10.3	143.2	8.3	9.6	108.7	2.0	0.0	255.0	314.0	3.0	0.0	2.0	1.0
B7	8/7/01	7.9	154.6	8.2	9.4	99.4	2.0	0.0	217.0	279.0	5.0	0.0	4.0	1.0
B8	8/7/01	10.2	142.8	8.2	10.0	111.9	1.0	0.0	254.0	304.0	5.0	0.0	2.0	1.0
Fuorn	8/7/01	6.1	210.0	8.2	10.58	107.4	4.0	0.0	145.0	207.0	4.0	0.0	2.0	1.0

Table C1: Continued

Site	Date	DOC (mg/l)	TIC (mg/l)	POC (mg/l)	SiO_2 (mg/l)	SO_4 (mg/l)	Cl^- (mg/l)	Ca^{2+} (mmol/l)	Mg^{2+} (mmol/l)	Fe (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	AFDM (mg/l)
B1	6/7/01	0.6	22.3	0.2	0.8	5.1	<1.0	0.6	0.5	<0.3	<5.0	<5.0	0.3
B2	6/7/01	0.6	24.5	0.3	1.3	5.0	<1.0	0.6	0.5	<0.3	<5.0	<5.0	0.2
B3	6/7/01	0.5	21.6	0.3	1.3	5.0	<1.0	0.6	0.5	<0.3	<5.0	<5.0	0.2
B4	6/7/01	0.6	22.1	0.3	1.1	5.0	<1.0	0.6	0.5	<0.3	<5.0	<5.0	0.2
B6	6/7/01	0.6	22.0	0.2	1.4	5.3	<1.0	0.6	0.4	<0.3	<5.0	<5.0	1.8
B7	6/7/01	0.5	22.3	0.3	1.3	5.1	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.2
B8	6/7/01	0.5	21.6	0.3	1.4	5.3	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.2
B9	6/7/01	0.4	21.7	0.3	1.3	5.7	<1.0	0.6	0.5	<0.3	<5.0	<5.0	0.1
Fuorn	6/7/01	0.8	30.7	0.3	1.7	6.4	1.1	0.8	0.6	<0.3	<5.0	<5.0	0.4
B1	7/3/01	0.4	19.5	0.1	0.9	4.8	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.0
B2	7/3/01	0.3	19.7	0.0	1.0	5.2	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.2
B3	7/3/01	0.5	19.3	0.1	1.2	5.2	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.2
B4	7/3/01	0.3	19.3	0.1	0.9	5.0	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.2
B6	7/3/01	0.3	19.3	0.1	0.9	5.0	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.1
B7	7/3/01	0.4	19.9	0.1	1.0	4.6	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.1
B8	7/3/01	0.3	19.2	0.1	0.9	4.7	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.2
B9	7/3/01	0.4	19.4	0.2	0.9	4.9	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.2
Fuorn	7/3/01	0.4	0.13	0.1	1.3	5.0	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.3
B1	8/7/01	0.4	19.7	0.1	1.3	4.7	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.2
B2	8/7/01	0.4	19.6	0.1	1.5	5.0	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.2
B3	8/7/01	0.4	18.8	0.2	1.4	5.2	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.2
B4	8/7/01	0.4	18.7	0.1	1.4	5.2	<1.0	0.5	0.4	<0.3	<5.0	<5.0	0.2
B6	8/7/01	0.5	18.8	0.1	1.4	4.8	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.2
B7	8/7/01	0.5	19.5	0.2	1.4	4.8	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.4
B8	8/7/01	0.4	18.6	0.1	1.4	5.0	<1.0	0.6	0.4	<0.3	<5.0	<5.0	0.8
Fuorn	8/7/01	0.6	24.4	0.1	2.3	7.9	<1.0	0.8	0.6	<0.3	<5.0	<5.0	0.3

Table C2: Physico chemical data at Buffalora affected sites.

Site	Date	Temperature (°C)	Conductivity (µs/cm)	PH	O_2 (mg/l)	O_2 (%)	NH_4-N (µg/l)	NO_2-N (µg/l)	NO_3N (µg/l)	DN (µg/l)	PN (µg/l)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)
B5	6/7/01	3.5	168.8	8.6	9.6	90.0	0.0	0.0	189.0	252.0	14.0	1.0	5.0	1.0
B10	6/7/01	3.8	172.0	8.7	10.5	95.9	0.0	0.0	185.0	247.0	5.0	10.0	17.0	1.0
B11	6/7/01	4.7	164.5	8.5	9.8	99.2	1.0	0.0	163.0	224.0	17.0	20.0	31.0	2.0
BW3	6/14/01	3.3	184.5	8.1	10.2	103.3	11.0	0.0	213.0	306.0	3.0	21.0	28.0	3.0
BW4	6/14/01	7.4	179.1	8.4	11.7	124.5	13.0	1.0	270.0	415.0	20.0	93.0	122.0	5.0
BW5	6/14/01	3.8	197.3	8.3	11.1	107.2	6.0	0.0	177.0	252.0	4.0	8.0	9.0	3.0
BW6	6/14/01	5.0	193.5	8.4	11.3	112.1	5.0	0.0	184.0	265.0	7.0	20.0	28.0	3.0
BW7	6/14/01	5.3	196.0	8.5	12.4	124.6	7.0	1.0	154.0	206.0	5.0	6.0	7.0	3.0
BW8	6/14/01	4.2	181.0	8.5	11.3	109.2	8.0	0.0	192.0	283.0	12.0	16.0	20.0	4.0
BW9	6/14/01	5.0	159.5	8.6	11.3	110.4	4.0	0.0	198.0	252.0	6.0	5.0	8.0	3.0
BW10	6/14/01	5.8	190.4	8.6	12.5	126.8	9.0	1.0	162.0	230.0	9.0	12.0	18.0	3.0
B5	7/3/01	5.6	155.9	8.4	10.6	105.7	1.0	0.0	189.0	216.0	9.0	2.0	3.0	0.0
B10	7/3/01	5.0	175.3	8.3	10.0	97.7	3.0	0.0	196.0	264.0	11.0	12.0	20.0	1.0
BW2	7/11/01	15.2	1120.0	7.5	8.5	80.6	159.0	0.0	55.0	66303.0	4940.0	22500.0	26410.0	1354.0
BW3	7/11/01	5.3	204.0	8.3	8.4	91.9	410.0	0.0	232.0	651.0	33.0	70.0	71.0	4.0
BW4	7/11/01	5.9	209.0	8.3	9.1	94.5	0.0	1.0	255.0	338.0	10.0	98.0	106.0	0.0
BW5	7/11/01	5.1	211.0	8.3	10.1	98.5	0.0	0.0	174.0	212.0	11.0	22.0	23.0	1.0
BW6	7/11/01	5.5	208.0	8.3	10.0	99.4	0.0	0.0	168.0	217.0	15.0	18.0	18.0	3.0
BW7	7/11/01	5.9	210.0	8.5	10.8	109.4	0.0	1.0	151.0	182.0	9.0	8.0	9.0	0.0
BW8	7/11/01	5.4	199.2	8.3	10.0	100.0	0.0	0.0	171.0	210.0	5.0	18.0	19.0	0.0
BW9	7/11/01	6.1	170.8	8.5	9.9	99.7	0.0	0.0	185.0	231.0	9.0	8.0	8.0	0.0
BW10	7/11/01	5.7	208.0	8.5	10.6	107.7	6.0	1.0	170.0	196.0	8.0	16.0	16.0	0.0
B5	8/7/01	6.0	176.7	8.3	10.7	107.0	1.0	1.0	223.0	290.0	7.0	6.0	13.0	2.0
B10	8/7/01	6.1	200.0	8.1	10.1	101.1	1.0	1.0	286.0	362.0	11.0	32.0	50.0	2.0
BW3	8/13/01	6.3	190.1	8.0	9.2	99.4	2.0	0.0	312.0	395.0	9.0	77.0	98.0	2.0
BW4	8/13/01	8.4	190.0	8.3	10.8	111.2	2.0	0.0	303.0	376.0	7.0	93.0	114.0	2.0
BW5	8/13/01	5.9	189.4	8.3	12.4	122.4	2.0	0.0	223.0	272.0	7.0	26.0	310.0	2.0
BW6	8/13/01	6.6	186.5	8.9	12.2	124.8	3.0	0.0	211.0	263.0	10.0	24.0	30.0	2.0
BW7	8/13/01	6.7	185.6	8.5	13.2	134.6	2.0	1.0	186.0	237.0	7.0	9.0	10.0	1.0
BW8	8/13/01	6.9	181.1	8.4	12.9	132.3	2.0	0.0	214.0	260.0	6.0	15.0	20.0	2.0
BW9	8/13/01	7.9	167.5	8.5	12.9	136.5	2.0	1.0	206.0	255.0	5.0	5.0	6.0	1.0
BW10	8/13/01	8.0	188.1	8.5	13.6	140.7	2.0	1.0	195.0	240.0	7.0	16.0	22.0	2.0

Table C2: Continued

Site	Date	DOC (mg/l)	TIC (mg/l)	POC (mg/l)	SiO_2 (mg/l)	SO_4 (mg/l)	Cl^- (mg/l)	Ca^{2+} (mmol/l)	Mg^{2+} (mmol/l)	Fe (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	AFDM (mg/l)
B5	6/7/01	0.6	24.1	0.7	1.6	5.8	<1.0	0.6	0.5	<0.3	<5.0	<5.0	1.8
B10	6/7/01	0.7	26.6	0.3	1.6	7.1	1.3	0.7	0.6	<0.3	<5.0	<5.0	1.8
B11	6/7/01	1.0	23.8	0.4	1.1	5.2	<1.0	0.7	0.5	<0.3	<5.0	<5.0	2.3
BW3	6/14/01	0.6	25.8	0.1	1.9	7.8	1.7	0.1	0.3	<0.3	<5.0	<5.0	1.3
BW4	6/14/01	0.7	24.3	0.2	2.0	6.2	1.6	0.1	0.3	<0.3	<5.0	<5.0	2.2
BW5	6/14/01	0.6	26.3	0.1	2.0	7.9	1.7	0.2	0.3	<0.3	<5.0	<5.0	2.1
BW6	6/14/01	0.7	25.8	0.1	1.8	7.5	1.7	0.2	0.3	<0.3	<5.0	<5.0	1.6
BW7	6/14/01	0.5	26.3	0.1	1.9	8.2	1.9	0.2	0.3	<0.3	<5.0	<5.0	2.4
BW8	6/14/01	0.6	25.0	0.2	1.8	6.8	1.5	0.1	0.3	<0.3	<5.0	<5.0	2.5
BW9	6/14/01	0.6	22.8	0.1	1.6	5.2	1.1	0.1	0.2	<0.3	<5.0	<5.0	2.0
BW10	6/14/01	0.6	26.0	0.2	1.9	7.5	1.7	0.1	0.2	<0.3	<5.0	<5.0	2.7
B5	7/3/01	0.4	21.4	0.1	1.0	5.0	<1.0	0.6	0.4	<0.3	<5.0	<5.0	1.3
B10	7/3/01	0.5	24.0	0.1	1.5	5.4	<1.0	0.6	0.5	<0.3	<5.0	<5.0	1.7
BW2	7/11/01	33.5	105.9	5.6	31.9	23.0	69.5	1.0	0.7	<0.3	25.8	111.3	8.3
BW3	7/11/01	0.5	27.3	0.1	1.8	7.7	2.1	0.7	0.5	<0.3	<5.0	<5.0	1.7
BW4	7/11/01	0.6	27.7	0.1	1.9	7.6	2.0	0.8	0.5	<0.3	<5.0	<5.0	2.2
BW5	7/11/01	0.5	28.2	0.1	1.9	8.2	2.0	0.8	0.5	<0.3	<5.0	<5.0	1.8
BW6	7/11/01	0.5	27.7	0.1	1.8	8.0	1.9	0.7	0.5	<0.3	<5.0	<5.0	1.7
BW7	7/11/01	0.5	27.6	0.1	1.9	7.8	1.8	0.8	0.5	<0.3	<5.0	<5.0	2.0
BW8	7/11/01	0.4	26.4	0.1	1.8	7.3	1.7	0.8	0.5	<0.3	<5.0	<5.0	3.1
BW9	7/11/01	0.4	23.2	0.1	1.6	5.5	<1.0	0.6	0.4	<0.3	<5.0	<5.0	2.4
BW10	7/11/01	0.5	27.6	0.1	1.7	8.0	1.9	0.8	0.5	<0.3	<5.0	<5.0	1.8
B5	8/7/01	0.5	22.8	0.1	1.7	6.6	1.0	0.7	0.5	<0.3	<5.0	<5.0	1.6
B10	8/7/01	0.6	24.8	0.1	2.0	7.6	1.4	0.8	0.6	<0.3	<5.0	<5.0	1.9
BW3	8/13/01	0.6	23.6	0.2	1.8	7.6	1.1	0.7	0.5	<0.3	<5.0	<5.0	2.1
BW4	8/13/01	0.6	25.1	0.2	1.9	7.7	1.4	0.7	0.5	<0.3	<5.0	<5.0	2.3
BW5	8/13/01	0.7	24.4	0.2	1.8	7.4	1.1	0.7	0.5	<0.3	<5.0	<5.0	2.0
BW6	8/13/01	0.6	24.2	0.2	2.1	7.3	1.1	0.7	0.5	<0.3	<5.0	<5.0	2.9
BW7	8/13/01	0.6	23.9	0.1	1.8	7.3	1.1	0.7	0.5	<0.3	<5.0	<5.0	2.5
BW8	8/13/01	0.5	23.4	0.1	1.6	6.8	<1.0	0.7	0.5	<0.3	<5.0	<5.0	3.0
BW9	8/13/01	0.5	21.8	0.1	1.4	5.8	<1.0	0.7	0.5	<0.3	<5.0	<5.0	2.3
BW10	8/13/01	0.6	23.9	0.1	1.6	7.3	1.1	0.7	0.5	<0.3	<5.0	<5.0	3.0

Table C3: Physico chemical values at Fuorn spring and river site.

Site	Date	Temperature (°C)	Conductivity (µs/cm)	pH	O_2 (mg/l)	O_2 (%)	NH_4-N (µg/l)	NO_2-N (µg/l)	NO_3N (µg/l)	DN (µg/l)	PN (µg/l)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)
F1	6/8/01	3.9	225.0	8.5	102.5	10.7	1.0	0.0	196.0	714.0	2.0	0.0	1.4	0.0
F2	6/8/01	3.6	225.0	8.5	99.8	10.5	0.0	0.0	199.0	317.0	6.0	0.0	1.4	0.1
F3	6/8/01	4.1	242.0	8.4	109.8	11.5	0.0	0.0	214.0	296.0	6.0	0.0	0.5	0.1
F4	6/8/01	4.2	210.0	8.3	103.7	10.6	1.0	0.0	178.0	254.0	3.0	0.0	1.5	0.1
F5	6/8/01	3.8	201.0	8.4	101.0	10.7	1.0	0.0	163.0	219.0	21.0	0.0	1.0	3.4
Fuorn	6/8/01	5.7	205.0	8.4	114.0	11.5	0.0	0.0	170.0	239.0	3.0	0.0	2.8	0.4
F1	7/3/01	4.6	229.0	8.2	97.1	9.9	4.0	0.0	180.0	200.0	2.0	1.0	1.0	0.1
F2	7/3/01	4.1	219.0	8.3	90.8	9.5	7.0	0.0	191.0	217.0	6.0	1.0	0.9	0.0
F3	7/3/01	4.8	204.0	8.3	93.2	9.6	7.0	0.0	205.0	235.0	5.0	0.0	0.8	0.0
F4	7/3/01	4.9	188.7	8.3	90.5	9.2	5.0	0.0	181.0	241.0	4.0	1.0	1.2	0.4
F5	7/3/01	4.7	192.4	8.3	89.5	9.2	6.0	0.0	174.0	216.0	5.0	0.0	1.6	0.4
Fuorn	7/3/01	7.9	178.7	8.2	111.5	10.6	1.0	0.0	188.0	240.0	7.0	1.0	1.2	0.6
F1	8/7/01	11.5	206.0	8.4	107.0	11.1	1.0	0.0	184.0	236.0	3.0	0.0	0.6	0.4
F2	8/7/01	10.6	201.0	8.4	102.9	10.7	1.0	0.0	203.0	251.0	2.0	0.0	1.6	0.7
F3	8/7/01	11.2	176.1	8.5	111.0	11.3	2.0	0.0	202.0	252.0	4.0	0.0	1.7	1.0
F5	8/7/01	10.5	184.3	8.5	105.8	10.5	1.0	0.0	192.0	251.0	4.0	0.0	1.4	0.8
Fuorn	8/7/01	10.7	193.3	8.5	107.6	10.7	2.0	0.0	187.0	248.0	4.0	0.0	1.7	1.0

Table C3: Continued

Site	Date	DOC (mg/l)	TIC (mg/l)	POC (mg/l)	SiO_2 (mg/l)	SO_4 (mg/l)	Cl^- (mg/l)	Ca^{2+} (mmol/l)	Mg^{2+} (mmol/l)	Fe (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	AFDM (mg/l)
F1	6/8/01	0.8	31.8	0.3	2.0	10.4	2.0	0.9	0.7	<0.3	<5.0	<5.0	0.5
F2	6/8/01	0.7	31.5	0.3	1.9	7.7	2.7	0.9	0.7	<0.3	<5.0	<5.0	1.0
F3	6/8/01	0.7	31.6	0.1	1.8	5.4	8.5	0.9	0.7	<0.3	<5.0	<5.0	0.5
F4	6/8/01	0.7	29.9	0.1	1.8	5.3	3.7	0.8	0.6	<0.3	<5.0	<5.0	0.7
F5	6/8/01	0.6	29.5	2.0	1.9	6.0	1.1	0.8	0.6	<0.3	<5.0	<5.0	3.2
Fuorn	6/8/01	0.6	29.3	0.3	1.9	6.8	1.0	0.8	0.6	<0.3	<5.0	<5.0	1.7
F1	7/3/01	0.5	31.5	0.1	1.9	8.0	1.8	0.8	0.6	<0.3	<5.0	<5.0	0.4
F2	7/3/01	0.6	30.3	0.1	1.8	5.6	2.6	0.8	0.6	<0.3	<5.0	<5.0	1.0
F3	7/3/01	0.5	27.7	0.1	1.6	5.0	3.6	0.8	0.5	<0.3	<5.0	<5.0	0.0
F4	7/3/01	0.4	26.6	0.1	1.7	5.0	1.3	0.7	0.4	<0.3	<5.0	<5.0	0.8
F5	7/3/01	0.4	27.0	0.2	1.8	5.1	0.7	0.7	0.5	<0.3	<5.0	<5.0	1.7
Fuorn	7/3/01	0.4	25.7	0.3	1.4	5.0	0.5	0.7	0.5	<0.3	<5.0	<5.0	2.2
F1	8/7/01	0.6	26.7	0.1	2.2	6.7	1.4	0.8	0.6	<0.3	<5.0	<5.0	1.2
F2	8/7/01	0.5	26.0	0.2	2.1	5.5	2.4	0.7	0.5	<0.3	<5.0	<5.0	1.0
F3	8/7/01	0.6	23.4	0.1	1.8	5.0	1.1	0.6	0.5	<0.3	<5.0	<5.0	2.0
F5	8/7/01	0.5	24.3	0.2	2.0	6.0	0.7	0.7	0.5	<0.3	<5.0	<5.0	1.2
Fuorn	8/7/01	0.6	25.6	0.2	2.2	7.0	0.7	0.8	0.6	<0.3	<5.0	<5.0	1.2

Table C4: Physico chemical values at God dal Fuorn spring.

Site	Date	Temperature (°C)	Conductivity (µs/cm)	pH	O2 (mg/l)	O_2 (%)	NH_4-N (µg/l)	NO_2-N (µg/l)	NO_3N (µg/l)	DN (µg/l)	PN (µg/l)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)
G1	6/8/01	9.3	2030.0	8.1	1.5	18.5	27.0	0.0	0.0	27.0	19.0	0.0	2.0	4.0
G1.1	6/8/01	13.1	2030.0	7.1	6.8	72.2	9.0	0.0	0.0	401.0	65.0	0.0	5.0	12.0
G1.2	6/8/01	11.5	1899.0	7.5	4.6	56.3	14.0	1.0	1.0	118.0	34.0	0.0	3.0	6.0
G2	6/8/01	7.1	2110.0	7.9	1.6	16.5	21.0	0.0	0.0	21.0	5.0	0.0	0.0	0.0
G3	6/8/01	7.6	2110.0	7.8	5.4	55.7	20.0	1.0	1.0	21.0	7.0	0.0	2.0	1.0
G4	6/8/01	8.2	2050.0	8.0	9.1	96.0	17.0	5.0	6.0	23.0	13.0	0.0	1.0	1.0
G1	7/4/01	6.7	2200.0	7.5	2.5	32.2	6.0	0.0	0.0	115.0	103.0	1.0	2.0	7.0
G1.1	7/4/01	9.1	2000.0	7.3	1.9	22.2	8.0	1.0	1.0	271.0	59.0	1.0	5.0	5.0
G1.2	7/4/01	8.3	974.0	7.6	0.3	2.2	3.0	0.0	0.0	73.0	49.0	1.0	2.0	4.0
G2	7/4/01	6.6	2210.0	7.6	1.0	10.4	7.0	0.0	0.0	7.0	14.0	1.0	1.0	1.0
G3	7/4/01	6.6	2210.0	7.7	4.5	44.9	5.0	0.0	0.0	5.0	9.0	1.0	1.0	1.0
G4	7/4/01	6.6	2170.0	7.9	8.9	89.8	5.0	0.0	0.0	5.0	5.0	1.0	1.0	0.0
G1	8/7/01	6.7	2170.0	7.6	0.9	8.9	2.0	0.0	0.0	118.0	35.0	0.0	4.0	3.0
G1.1	8/7/01	8.2	2010.0	7.6	3.3	35.3	8.0	1.0	0.0	233.0	63.0	0.0	4.0	7.0
G1.2	8/7/01	9.1	1888.0	7.5	0.8	7.5	5.0	0.0	0.0	151.0	285.0	0.0	4.0	18.0
G2	8/7/01	7.0	2150.0	7.6	1.8	17.8	6.0	0.0	0.0	6.0	11.0	0.0	1.0	1.0
G3	8/7/01	7.2	2160.0	7.7	5.2	52.9	5.0	0.0	0.0	5.0	6.0	0.0	0.0	1.0
G4	8/7/01	7.4	2140.0	8.0	9.9	101.9	5.0	0.0	0.0	5.0	2.0	0.0	1.0	1.0
G2.5m	6/15/01	10.3	2120.0	7.5	-	-	16.0	0.0	0.0	7.0	9.0	0.0	0.0	15.0
G2m	6/15/01	9.6	2040.0	7.5	-	-	7.0	0.0	0.0	18.0	8.0	1.0	1.0	7.0
G1.5m	6/15/01	9.6	2160.0	7.6	-	-	18.0	0.0	0.0	12.0	3.0	0.0	0.0	4.0
G1m	6/15/01	11.2	2130.0	7.7	-	-	12.0	0.0	0.0	19.0	4.0	0.0	0.0	4.0
G0.5m	6/15/01	11.2	2140.0	7.5	-	-	13.0	0.0	0.0	16.0	6.0	0.0	0.0	4.0
G0.05m	6/15/01	14.1	1658.0	7.7	-	-	7.0	0.0	0.0	89.0	23.0	0.0	2.0	5.0
G2.5m	7/11/01	8.2	2180.0	7.6	-	-	6.0	0.0	0.0	7.0	5.0	1.0	1.0	1.0
G2m	7/11/01	8.5	2200.0	7.7	-	-	5.0	0.0	0.0	5.0	8.0	1.0	1.0	2.0
G1.5m	7/11/01	7.8	2210.0	7.6	-	-	4.0	0.0	0.0	5.0	4.0	1.0	1.0	0.0
G1m	7/11/01	8.1	2200.0	7.6	-	-	4.0	0.0	0.0	5.0	6.0	1.0	1.0	0.0
G0.5m	7/11/01	8.2	2200.0	7.5	-	-	6.0	0.0	0.0	29.0	5.0	1.0	1.0	1.0
G0.05m	7/11/01	12.3	1732.0	7.7	-	-	2.0	0.0	0.0	69.0	42.0	0.0	0.0	3.0
G2.5m	8/13/01	10.1	2170.0	7.5	-	-	13.0	0.0	0.0	13.0	9.0	1.0	2.0	41.0
G2m	8/13/01	9.5	2160.0	7.6	-	-	25.0	0.0	0.0	25.0	4.0	2.0	1.0	2.0
G1.5m	8/13/01	10.4	2170.0	7.5	-	-	10.0	0.0	0.0	70.0	4.0	2.0	2.0	2.0
G1m	8/13/01	9.3	2170.0	7.6	-	-	12.0	0.0	0.0	36.0	5.0	1.0	1.0	3.0
G0.5m	8/13/01	10.7	2160.0	7.6	-	-	8.0	0.0	0.0	15.0	2.0	1.0	3.0	1.0
G0.05m	8/13/01	14.3	1245.0	7.8	-	-	3.0	0.0	0.0	40.0	26.0	1.0	3.0	3.0

Table C4: Continued

Site	Date	DOC (mg/l)	TIC (mg/l)	POC (mg/l)	SiO_2 (mg/l)	SO_4 (mg/l)	Cl^- (mg/l)	Ca^{2+} (mmol/l)	Mg^{2+} (mmol/l)	Fe (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	AFDM (mg/l)
G1	6/8/01	0.6	31.8	1.8	8.1	1250.0	<1.0	14.3	3.3	<0.3	<5.0	<5.0	6.5
G1.1	6/8/01	5.6	30.4	1.4	4.1	530.0	<1.0	6.1	1.2	<0.3	<5.0	<5.0	5.3
G1.2	6/8/01	4.3	30.5	0.3	5.1	540.0	<1.0	5.9	1.5	<0.3	<5.0	<5.0	5.0
G2	6/8/01	0.5	31.6	0.2	8.1	1260.0	<1.0	13.0	3.1	<0.3	<5.0	<5.0	4.1
G3	6/8/01	0.4	31.5	0.2	8.3	1290.0	<1.0	13.1	3.3	<0.3	<5.0	<5.0	5.3
G4	6/8/01	0.6	30.8	0.4	8.1	1230.0	<1.0	12.3	3.0	<0.3	<5.0	<5.0	5.0
G1	7/4/01	6.0	16.3	1.2	2.6	988.0	<1.0	10.3	2.4	<0.3	<5.0	<5.0	5.0
G1.1	7/4/01	8.2	26.9	0.8	3.1	565.0	<1.0	6.6	1.3	<0.3	<5.0	<5.0	3.5
G1.2	7/4/01	5.4	29.3	0.9	4.0	413.0	<1.0	4.7	1.4	<0.3	<5.0	<5.0	3.3
G2	7/4/01	0.5	29.9	0.1	8.4	1470.0	<1.0	14.3	3.1	<0.3	<5.0	<5.0	4.7
G3	7/4/01	0.4	31.0	0.1	8.5	1470.0	<1.0	14.4	3.1	<0.3	<5.0	<5.0	3.2
G4	7/4/01	0.4	30.2	0.1	8.1	1430.0	<1.0	14.0	3.0	<0.3	<5.0	<5.0	2.9
G1	8/7/01	5.8	20.1	0.6	2.4	842.0	<1.0	7.8	1.4	<0.3	<5.0	<5.0	3.8
G1.1	8/7/01	7.7	30.6	1.4	4.7	621.0	<1.0	7.5	1.4	<0.3	<5.0	<5.0	5.8
G1.2	8/7/01	7.7	33.2	2.9	6.7	1001.0	<1.0	11.1	2.6	<0.3	<5.0	<5.0	9.4
G2	8/7/01	0.8	26.8	0.1	8.4	1411.0	<1.0	14.7	3.2	<0.3	<5.0	<5.0	4.3
G3	8/7/01	0.5	26.7	0.1	8.1	1421.0	<1.0	14.6	3.2	<0.3	<5.0	<5.0	4.0
G4	8/7/01	0.6	26.6	0.1	8.4	1381.0	<1.0	13.2	2.6	<0.3	<5.0	<5.0	2.4
G2.5m	6/15/01	0.6	31.2	4.0	8.3	1360.0	<1.0	12.8	2.7	<0.3	<5.0	<5.0	7.4
G2m	6/15/01	0.7	31.4	1.0	8.1	1270.0	<1.0	11.8	2.6	<0.3	<5.0	<5.0	4.3
G1.5m	6/15/01	0.4	31.8	0.2	8.5	1280.0	<1.0	12.8	2.8	<0.3	<5.0	<5.0	4.1
G1m	6/15/01	0.3	32.0	0.3	8.3	1320.0	1.3	13.5	2.9	<0.3	<5.0	<5.0	3.8
G0.5m	6/15/01	0.4	31.9	0.2	8.1	1310.0	<1.0	13.4	2.9	<0.3	<5.0	<5.0	3.1
G0.05m	6/15/01	3.0	27.6	0.5	6.4	870.0	<1.0	8.9	2.2	<0.3	<5.0	<5.0	3.7
G2.5m	7/11/01	0.3	31.4	0.1	8.3	1517.5	<1.0	15.0	2.1	<0.3	<5.0	<5.0	4.4
G2m	7/11/01	0.3	30.5	0.9	8.3	1453.2	<1.0	15.0	2.1	<0.3	<5.0	<5.0	4.1
G1.5m	7/11/01	0.3	31.2	0.3	8.3	1471.2	<1.0	14.8	2.0	<0.3	<5.0	<5.0	3.2
G1m	7/11/01	0.3	31.3	0.1	8.3	1461.8	<1.0	15.4	2.5	<0.3	<5.0	<5.0	2.7
G0.5m	7/11/01	0.3	31.3	0.1	8.2	1458.8	<1.0	15.2	2.2	<0.3	<5.0	<5.0	2.3
G0.05m	7/11/01	3.1	25.7	0.6	6.1	1071.8	<1.0	11.8	1.3	<0.3	<5.0	<5.0	3.3
G2.5m	8/13/01	0.4	28.2	7.0	9.0	1432.0	<1.0	15.9	3.4	<0.3	<5.0	<5.0	10.9
G2m	8/13/01	0.4	28.3	0.3	8.9	1444.0	<1.0	15.2	3.3	<0.3	<5.0	<5.0	3.0
G1.5m	8/13/01	0.6	28.3	0.5	8.9	1443.0	<1.0	15.5	3.4	<0.3	<5.0	<5.0	3.9
G1m	8/13/01	0.5	28.3	0.4	9.0	1436.0	<1.0	15.0	3.3	<0.3	<5.0	<5.0	3.6
G0.5m	8/13/01	0.5	28.4	0.2	8.8	1429.0	<1.0	15.1	3.4	<0.3	<5.0	<5.0	4.3
G0.05m	8/13/01	2.4	27.3	0.6	7.6	1176.0	<1.0	12.5	2.7	<0.3	<5.0	<5.0	3.6

Table C5: Physico chemical values at Spöl spring.

Site	Date	Temperature (°C)	Conductivity (µs/cm)	pH	O_2 (mg/l)	O_2 (%)	NH_4-N (µg/l)	NO_2-N (µg/l)	NO_3N (µg/l)	DN (µg/l)	PN (µg/l)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)
S1	6/7/01	4.7	299.0	8.5	10.1	98.0	2.0	0.0	47.0	89.0	9.0	0.0	2.0	1.0
S2	6/7/01	4.7	300.0	8.5	10.2	99.0	1.0	0.0	43.0	85.0	4.0	0.0	3.0	1.0
S3	6/7/01	4.8	300.0	8.4	10.2	99.0	2.0	0.0	42.0	104.0	6.0	0.0	3.0	1.0
S4	6/7/01	4.9	299.0	8.3	10.2	99.0	6.0	0.0	42.0	82.0	9.0	0.0	1.0	1.0
S1	7/4/01	6.2	315.0	8.4	12.7	128.3	2.0	0.0	39.0	59.0	6.0	0.0	2.0	0.0
S2	7/4/01	6.3	315.0	8.4	12.4	124.2	3.0	0.0	34.0	47.0	4.0	0.0	1.0	0.0
S3	7/4/01	6.6	314.0	8.2	12.6	125.9	2.0	0.0	33.0	52.0	7.0	0.0	3.0	0.0
S4	7/4/01	7.1	313.0	8.3	12.2	122.1	1.0	0.0	30.0	65.0	20.0	0.0	3.0	1.0
S1	8/7/01	6.9	317.0	8.3	10.2	104.0	0.0	0.0	32.0	60.0	7.0	0.0	3.0	1.0
S2	8/7/01	7.4	317.0	8.3	10.7	108.5	1.0	0.0	28.0	56.0	7.0	0.0	2.0	1.0
S3	8/7/01	7.8	318.0	8.3	10.7	110.2	2.0	0.0	28.0	67.0	8.0	0.0	2.0	2.0
S4	8/7/01	8.6	315.0	8.2	9.7	102.5	2.0	0.0	27.0	74.0	9.0	0.0	5.0	2.0

Table C5: Continued

Site	Date	DOC (mg/l)	TIC (mg/l)	POC (mg/l)	SiO_2 (mg/l)	SO_4 (mg/l)	Cl^- (mg/l)	Ca^{2+} (mmol/l)	Mg^{2+} (mmol/l)	Fe (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	AFDM (mg/l)
S1	6/7/01	1.0	45.6	0.3	6.0	11.7	<1.0	1.2	1.1	<0.3	<5.0	<5.0	2.1
S2	6/7/01	0.9	47.7	0.3	6.1	12.0	<1.0	1.2	1.1	<0.3	<5.0	<5.0	2.3
S3	6/7/01	1.0	45.5	0.3	6.1	12.0	<1.0	1.2	1.0	<0.3	<5.0	<5.0	2.8
S4	6/7/01	1.1	44.9	0.4	5.9	12.0	<1.0	1.2	1.0	<0.3	<5.0	<5.0	2.6
S1	7/4/01	0.8	46.2	0.1	8.6	11.8	<1.0	1.1	1.0	<0.3	<5.0	<5.0	2.1
S2	7/4/01	0.8	46.3	0.1	8.7	12.4	<1.0	1.1	1.0	<0.3	<5.0	<5.0	2.4
S3	7/4/01	0.9	46.1	0.1	8.7	12.2	<1.0	1.1	1.0	<0.3	<5.0	<5.0	2.3
S4	7/4/01	0.8	45.9	0.3	8.7	12.2	<1.0	1.2	1.0	<0.3	<5.0	<5.0	2.2
S1	8/7/01	0.8	43.4	0.2	6.6	13.0	<1.0	0.5	1.1	<0.3	<5.0	<5.0	1.9
S2	8/7/01	0.9	43.4	0.2	6.9	12.5	<1.0	0.5	1.1	<0.3	<5.0	<5.0	2.3
S3	8/7/01	0.9	43.1	0.2	6.9	12.5	<1.0	0.5	1.1	<0.3	<5.0	<5.0	2.2
S4	8/7/01	1.0	43.3	0.1	6.9	12.6	<1.0	0.5	1.1	<0.3	<5.0	<5.0	2.7

Table C6: Physico chemical values at Val da l´Aqua spring.

Site	Date	Temperature (°C)	Conductivity (µs/cm)	pH	O_2 (mg/l)	O_2 (%)	NH_4-N (µg/l)	NO_2-N (µg/l)	NO_3N (µg/l)	DN (µg/l)	PN (µg/l)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)
V1	6/7/01	5.2	332.0	7.8	8.8	86.0	1.0	0.0	70.0	197.0	15.0	1.0	5.0	1.0
V2	6/7/01	5.7	330.0	8.0	9.6	95.0	1.0	0.0	64.0	138.0	15.0	0.0	3.0	1.0
V3	6/7/01	6.3	329.0	8.1	10.0	100.0	2.0	0.0	59.0	253.0	17.0	0.0	3.0	2.0
V4	6/7/01	7.0	330.0	8.1	10.0	100.0	1.0	0.0	55.0	135.0	7.0	0.0	2.0	0.0
River	6/7/01	3.8	193.1	8.2	11.1	97.3	1.0	0.0	289.0	387.0	5.0	1.0	4.0	1.0
V1	7/4/01	7.0	349.0	7.8	9.5	98.3	2.0	0.0	42.0	84.0	5.0	0.0	0.0	0.0
V2	7/4/01	10.6	345.0	8.0	11.0	121.6	8.0	0.0	35.0	76.0	13.0	0.0	1.0	1.0
V3	7/4/01	14.5	342.0	8.2	9.9	128.0	1.0	0.0	28.0	85.0	12.0	0.0	0.0	1.0
V4	7/4/01	17.2	341.0	8.1	10.5	135.0	8.0	0.0	29.0	118.0	15.0	0.0	3.0	1.0
River	7/4/01	4.1	164.6	8.3	10.2	95.4	0.0	0.0	155.0	204.0	9.0	0.0	0.0	1.0
V1	8/7/01	8.6	354.0	9.6	8.2	100.0	2.0	0.0	46.0	108.0	5.0	0.0	3.0	2.0
V2	8/7/01	9.5	355.0	10.1	9.4	108.5	1.0	0.0	38.7	113.0	5.0	0.0	3.0	2.0
V3	8/7/01	11.2	350.0	9.4	10.1	105.3	3.0	0.0	36.0	136.0	7.0	0.0	3.0	1.0
V4	8/7/01	12.8	346.0	8.2	9.6	104.0	6.0	0.0	28.0	110.0	7.0	0.0	2.0	1.0
River	8/7/01	11.7	200.0	8.4	11.7	112.5	1.0	0.0	186.0	260.0	5.0	0.0	3.0	2.0

Table C6: Continued

Site	Date	DOC (mg/l)	TIC (mg/l)	POC (mg/l)	SiO_2 (mg/l)	SO_4 (mg/l)	Cl^- (mg/l)	Ca^{2+} (mmol/l)	Mg^{2+} (mmol/l)	Fe (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	AFDM (mg/l)
V1	6/7/01	1.6	43.4	0.4	2.1	37.6	<1.0	1.5	1.0	<0.3	<5.0	<5.0	2.3
V2	6/7/01	1.5	43.3	0.5	2.0	36.8	<1.0	1.5	0.9	<0.3	<5.0	<5.0	2.3
V3	6/7/01	1.7	42.8	0.4	1.9	36.7	<1.0	1.5	0.9	<0.3	<5.0	<5.0	2.3
V4	6/7/01	1.6	42.6	0.3	1.9	36.6	<1.0	1.5	0.9	<0.3	<5.0	<5.0	1.8
River	6/7/01	0.7	23.6	0.4	1.4	19.8	<1.0	1.0	0.4	<0.3	<0.5	<0.5	2.2
V1	7/4/01	1.3	43.0	0.1	2.1	39.8	<1.0	1.4	0.9	<0.3	<5.0	<5.0	2.1
V2	7/4/01	1.4	43.7	0.2	2.2	37.8	<1.0	1.4	0.8	<0.3	<5.0	<5.0	2.1
V3	7/4/01	1.7	43.4	0.2	2.1	37.8	<1.0	1.4	0.8	<0.3	<5.0	<5.0	2.5
V4	7/4/01	1.6	43.2	0.2	2.1	37.8	<1.0	1.4	0.9	<0.3	<5.0	<5.0	2.4
River	7/4/01	0.4	18.1	1.1	1.3	18.5	<1.0	0.8	0.1	<0.3	<0.5	<0.5	2.5
V1	8/7/01	1.6	41.1	0.2	2.8	42.9	<1.0	1.2	0.8	<0.3	<5.0	<5.0	2.1
V2	8/7/01	1.4	40.9	0.1	3.0	42.7	<1.0	1.2	0.8	<0.3	<5.0	<5.0	3.1
V3	8/7/01	1.4	40.9	0.2	3.2	42.6	<1.0	1.3	0.8	<0.3	<5.0	<5.0	2.3
V4	8/7/01	1.5	40.9	0.2	2.7	42.6	<1.0	1.3	0.8	<0.3	<5.0	<5.0	2.6
River	8/7/01	0.5	18.8	0.2	1.7	31.1	<1.0	0.8	0.3	<0.3	<5.0	<5.0	2.1

13 Appendix D: Periphyton Data

Table D1: Mean ± standard deviation of periphyton at the Buffalora spring.

	Chlorophyll *a*			Chlorophyll *b*			AFDM		
Site	**June**	**July**	**August**	**June**	**July**	**August**	**June**	**July**	**August**
BC1	25.2±21.3	26.2±11.6	22.9± 38.2	0.0±0.0	0.3±0.0	0.8±1.2	42.1±36.1	20.5± 8.3	6.6± 7.8
BC2	15.0± 8.2	26.0±12.0	16.9± 20.9	0.4±0.3	0.8±0.7	2.1±1.2	14.0± 7.9	21.7±12.8	10.7± 3.8
BC3	6.2± 3.2	14.3±12.4	32.3± 27.7	0.2±0.1	2.4±3.4	2.8±5.2	5.0± 2.7	12.5± 8.9	12.5± 3.6
BC4	74.8±38.9	34.1±30.0	24.4±135.3	0.1±0.2	0.8±0.2	0.5±0.6	68.7±25.0	28.1±23.3	11.8±15.1
BC5	28.9±14.4	9.1± 2.4	37.3± 21.0	0.1±0.2	0.7±0.4	0.8±1.7	22.3± 7.0	9.2± 2.1	16.8± 2.3
BC6	15.1±10.5	4.8± 1.1	52.2± 12.6	0.1±0.1	0.2±0.2	0.2±0.4	23.0± 3.7	9.1± 3.3	19.4± 4.3
BC7	19.4± 5.1	28.0±21.5	102.8±147.2	0.6±0.8	2.9±4.3	3.5±6.5	33.3±11.1	23.8±11.0	12.2±13.0
BC8	43.1±30.6	43.4±15.2	37.5± 29.5	1.5±0.9	6.4±2.9	16.3±7.1	55.3±50.7	24.0± 7.9	12.3± 6.7
BC9	32.3± 7.0	dry	dry	1.0±0.2	dry	dry	28.6± 4.1	dry	dry
BC10	87.5±22.5	45.8±39.1	28.0±103.2	0.7±0.5	0.8±0.5	3.2±3.0	32.8± 6.0	23.9±21.6	8.8±10.8
BC11	24.7± 6.8	35.9±12.1	30.1± 45.2	0.3±0.2	3.1±2.5	4.2±2.6	16.5± 7.9	20.0± 5.2	14.2± 6.8
BC12	35.7±10.5	51.0±15.0	27.3± 26.4	0.4±0.2	3.0±2.1	1.7±1.6	21.4± 6.5	19.2± 5.3	12.0± 3.3

Table D2: Mean ± standard deviation of periphyton at the Fuorn spring.

	Chlorophyll *a*			Chlorophyll *b*			AFDM		
Site	**June**	**July**	**August**	**June**	**July**	**August**	**June**	**July**	**August**
FC1	12.2±6.7	2.2± 0.9	8.3± 3.5	0.2±0.2	0.0±0.0	0.3±0.1	10.6± 3.9	7.2± 2.2	6.8±1.2
FC2	12.2±2.0	20.4± 8.3	41.9±16.6	0.5±0.3	0.7±0.4	1.3±0.4	18.5± 6.2	17.4± 4.9	10.1±5.2
FC3	8.3±2.6	18.8±13.2	42.5±22.9	0.1±0.1	0.7±0.5	1.6±0.9	12.5± 3.1	25.5±18.8	10.8±4.7
FC4	12.8±3.4	8.9± 2.5	dry	1.9±0.8	0.7±0.2	dry	19.0± 2.1	15.3± 3.2	dry
FC5	18.1±7.6	6.6± 2.0	10.4± 7.4	0.9±0.7	0.5±0.2	0.3±0.3	10.5± 6.3	9.5± 3.6	6.3±6.3
FC6	12.0±6.2	10.9± 3.1	19.2±13.2	1.3±1.5	0.3±0.3	0.6±0.5	14.7± 8.2	15.1± 2.9	9.2±3.0
FC7	10.4±4.5	11.4± 6.4	40.5±25.4	0.5±0.3	0.8±0.7	1.6±1.1	33.3±27.6	15.6± 3.0	11.3±5.1
FC8	10.8±3.7	16.1± 8.5	38.3±27.7	0.7±0.4	0.5±0.3	1.5±1.1	10.0± 7.3	19.2± 6.9	17.7±2.5
FC9	12.9±5.6	3.0± 1.8	39.0±14.3	0.3±0.4	0.2±0.3	1.4±0.6	7.8± 4.7	8.5± 4.2	7.2±2.1

Table D3: Mean ± standard deviation of periphyton at the God dal Fuorn spring.

	Chlorophyll *a*			Chlorophyll *b*			AFDM		
	June	**July**	**August**	**June**	**July**	**August**	**June**	**July**	**August**
GC1	0.5±0.6	8.0± 3.1	5.8±4.2	0.0±0.1	1.3±0.6	1.0±0.7	10.8± 5.1	17.0± 4.3	12.2±8.6
GC2	0.6±0.7	22.9±24.2	4.9±4.2	0.1±0.1	5.5±6.9	0.0±0.0	9.9± 4.4	45.6±65.0	11.7±4.1
GC3	3.5±2.3	6.7± 3.0	4.6±2.2	0.0±0.0	0.2±0.1	0.3±0.6	4.3± 1.8	13.2± 5.8	8.3±2.1
GC4	6.6±3.6	13.2± 9.2	2.1±0.7	0.0±0.0	0.0±0.0	0.0±0.0	10.2± 8.2	16.7±10.1	21.7±9.8
GC5	12.0±6.3	10.9±10.4	3.6±1.7	0.0±0.0	0.2±0.2	0.0±0.0	24.9±16.1	15.0±12.3	6.7±1.8

Table D4: Mean ± standard deviation of periphyton at the Spöl spring.

	Chlorophyll *a*			Chlorophyll *b*			AFDM		
	June	**July**	**August**	**June**	**July**	**August**	**June**	**July**	**August**
S1	2.9±1.2	8.9± 3.0	10.1±11.9	0.0±0.0	0.9±0.7	1.7±2.9	4.9±1.7	12.1±3.8	5.3± 1.2
S2	5.3±1.9	7.0± 2.5	11.6±10.2	0.0±0.1	0.2±0.2	0.8±1.7	2.1±1.1	15.0±7.2	9.5± 3.1
S3	6.3±3.2	17.7±10.3	3.9± 1.6	0.0±0.1	0.3±0.2	0.2±0.3	1.7±0.5	7.0±2.8	6.4± 1.9
S4	12.9±4.0	11.1± 5.5	10.8±14.1	0.9±1.2	0.9±0.6	1.5±2.7	9.8±5.8	10.5±3.1	21.3±26.2

Table D5: Mean ± standard deviation of periphyton at the Val da l´Aqua spring.

	Chlorophyll a			Chlorophyll b			AFDM		
	June	**July**	**August**	**June**	**July**	**August**	**June**	**July**	**August**
VC1	9.1±6.5	23.3±29.5	5.0± 5.2	0.1±0.0	4.1±6.9	0.9±1.3	59.1±100.9	22.2±8.0	12.9±4.2
VC2	4.2±2.3	6.9± 6.7	10.8± 4.6	0.3±0.3	1.2±1.1	1.2±0.9	7.5± 3.4	18.4±3.5	15.4±4.8
VC3	10.8±3.8	20.0±10.5	18.6±18.3	1.2±1.1	2.3±1.9	3.2±3.7	14.9± 2.5	12.9±4.4	15.3±3.7

14 Appendix E: Periphyton regressions

Buffalora spring

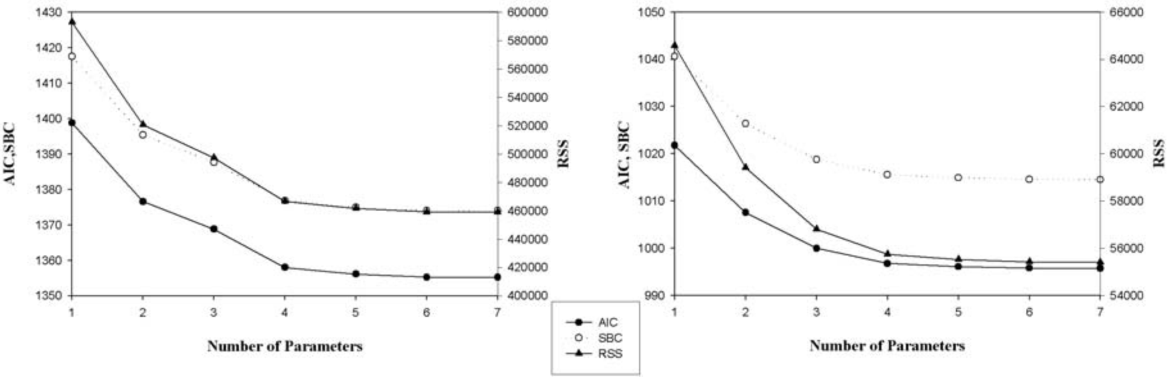

Figure E1: Results of a forward stepwise multiple regression analysis. Evaluation of the best models for Chlorophyll *a* (left) and AFDM (right) at Buffalora spring. Displayed are the AIC, SBC and RSS as function of the number of submodel parameters.

Table E1: Evaluation of the best submodels for a given number of influence factors using the forward elemination procedure. P = number of parameters (including the constant) (+) indicates, which parameters were considered in each submodel. Finally, selected models and factors contained in these models are shown in bold.

Dep. Var.	P	Const.	Influence factor and model parameter						RSS	R^2	Added Factor
			DB (cm)	DP (µg/l)	PP (µg/l)	Rad. (%)	Velo. (m/s)	Temp. (°C)			
Clorophyll *a*	1	+							**593239**	**0.000**	
	2	+						+	**520639**	**0.122**	**Temperature**
	3	+					+	+	**497323**	**0.161**	**Velocity**
	4	+				+	+	+	**466796**	**0.213**	**Radiation**
	5	+	+			+	+	+	**461606**	**0.221**	**DB**
	6	+	+	+		+	+	+	459125	0.226	DP
	7	+	+	+	+	+	+	+	459038	0.226	PP
AFDM	1	+							**64578**	**0.000**	
	2	+					+		**59404**	**0.080**	**Velocity**
	3	+					+	+	**56890**	**0.120**	**Temperature**
	4	+				+	+	+	**55742**	**0.137**	**Radiation**
	5	+		+		+	+	+	**55522**	**0.140**	**DP**
	6	+	+	+		+	+	+	55421	0.142	DB
	7	+	+	+	+	+	+	+	55399	0.142	PP

Fuorn spring

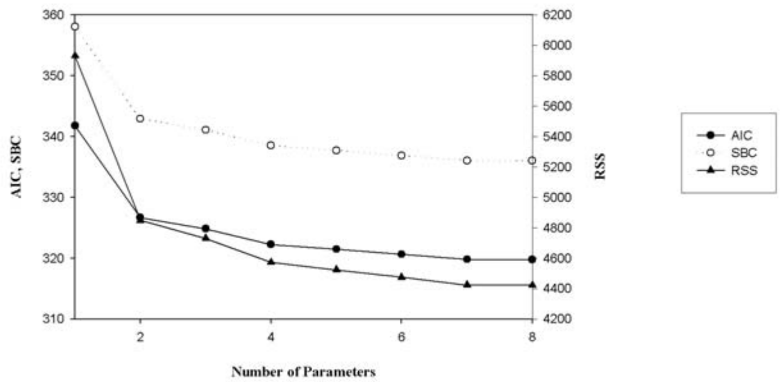

Figure E2: Results of a forward stepwise multiple regression analysis. Evaluation of the best models for Chlorophyll *a* at Fuorn spring. Displayed are the AIC, SBC and RSS as function of the number of submodel parameters.

Table E2: Evaluation of the best submodels for a given number of influence factors using the forward elemination procedure. P = number of parameters (including the constant) (+) indicates, which parameters were considered in each submodel. Finally, selected models and factors contained in these models are shown bold.

Dep. Var.	P	Const.	Influence factor and model parameter							RSS	R^2	Added Factor
			DB (cm)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)	Rad. (%)	Velo. (m/s)	Temp. (°C)			
Clorophyll *a*	1	+								5928.7	0.000	
	2	+		+						4847.9	0.182	**PO_4-P**
	3	+		+		+				4729.7	0.202	**PP**
	4	+		+		+		+		4571.3	0.229	**Velocity**
	5	+	+	+		+		+		4523.6	0.237	**DB**
	6	+	+	+		+		+	+	4474.1	0.245	**Temperature**
	7	+	+	+		+	+	+	+	**4423.7**	**0.254**	**Radiation**
	8	+	+	+	+	+	+	+	+	4421.7	0.254	DP

God dal Fuorn spring

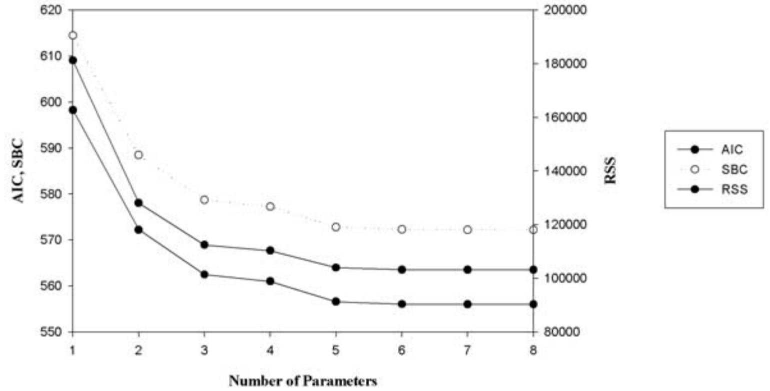

Figure E3: Results of a forward stepwise multiple regression analysis. Evaluation of the best models for Chlorophyll *a* at God dal Fuorn spring. Displayed are the AIC, SBC and the RSS as function of the number of submodel parameters.

Table E3: Evaluation of the best submodels for a given number of influence factors using the forward addition procedure. P= number of parameters (including the constant) (+) indicates, which parameters were considered in each submodel. Finally, selected models and factors contained in these models are shown in bold.

Dep. Var.	p	Const.	Influence factor and model parameter							RSS	R^2	Added Factor
			DB [cm]	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)	Rad. (%)	Velo. (m/s)	Temp. (°C)			
Clorophyll *a*	1	+								5928.7	0.000	
	2	+		+						4847.8	0.182	**PO4-P**
	3	+		+		+				4729.7	0.202	**PP**
	4	+		+		+		+		4571.3	0.228	**Velocity**
	5	+	+	+		+		+		4523.5	0.237	**DB**
	6	+	+	+		+		+	+	4474.1	0.245	**Temperature**
	7	+	+	+		+	+	+	+	**4423.7**	**0.253**	**Radiation**
	8	+	+	+	+	+	+	+	+	4421.7	0.254	DP

Spöl spring

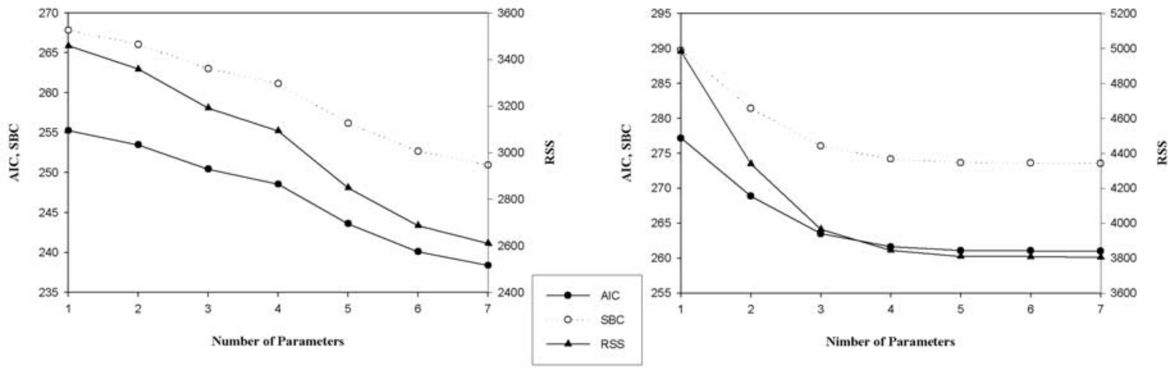

Figure E4: Results of a forward stepwise multiple regression analysis. Evaluation of the best models for Chlorophyll a (left) and AFDM (right) at Spöl spring. Displayed are the AIC, SBC and RSS as function of the number of submodel parameters.

Table E4: Evaluation of the best submodels for a given number of influence factors using the forward addition procedure. P = number of parameters (including the constant) (+) indicates, which parameters were considered in each submodel. Finally, selected models and factors contained in these models are shown in red.

Dep. Var.	p	Const.	Influence factor and model parameter						RSS	R^2	Added Factor	Improved Models
			DB [cm]	DP (µg/l)	PP (µg/l)	Rad. (%)	Velo. (m/s)	Temp. (°C)				
Chlorophyll *a*	1	+							3458.8	0.000		
	2	+					+		3358.4	0.029	**Velocity**	
	3	+				+	+		3191.8	0.077	**Radiation**	
	4	+		+		+	+		3092.7	0.106	**DP**	2
	5	+		+	+	+	+		2848.7	0.176	**PP**	1
	6	+		+	+	+	+	+	**2686.9**	**0.223**	**Temperature**	1
	7	+	+	+	+	+	+	+	2610.7	0.245	DB	
AFDM	1	+							4981.0	0.000		
	2	+						+	4338.0	0.129	**Temperature**	
	3	+					+	+	3965.4	0.204	**Velocity**	
	4	+		+			+	+	3844.4	0.228	**DP**	
	5	+		+		+	+	+	**3810.4**	**0.235**	**Radiation**	
	6	+	+	+		+	+	+	3808.6	0.235	DB	
	7	+	+	+	+	+	+	+	3804.3	0.236	PP	

Val da l´Aqua spring

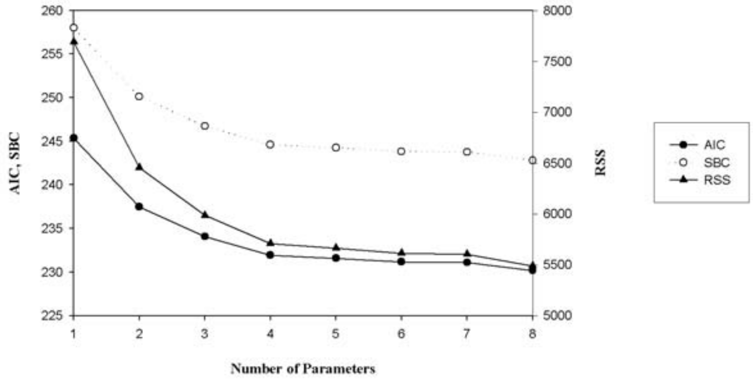

Figure E5: Results of a forward stepwise multiple regression analysis. Evaluation of the best models for Chlorophyll *a* at Val da l´Aqua spring. Displayed are the Akaike Information Criterion (AIC), the Schwarz Bayesian Criterion (SBC) and the residual sum of squares (RSS) as function of the number of submodel parameters.

Table E-5: Evaluation of the best submodels for a given number of influence factors using the forward elemination procedure. P = number of parameters (including the constant) (+) indicates, which parameters were considered in each submodel. Finally, selected models and factors contained in these models are shown in red.

Dep. Var.	p	Const.	Influence factor and model parameter							RSS	R^2	Added Factor	Improved Models
			DB (cm)	PO_4-P (µg/l)	DP (µg/l)	PP (µg/l)	Rad. (%)	Velo. (m/s)	Temp. (°C)				
Clorophyll *a*	1	+								7689.4	0.000		
	2	+	+							6455.7	0.160	**DB**	3
	3	+	+						+	5986.5	0.221	**Temperature**	3
	4	+	+			+			+	5709.4	0.257	**PP**	2
	5	+	+		+	+			+	**5665.1**	**0.263**	**DP**	
	6	+	+		+	+		+	+	5612.3	0.270	Velocity	
	7	+	+		+	+	+	+	+	5604.0	0.271	Radiation	
	8	+	+	+	+	+	+	+	+	5487.8	0.286	PO_4-P	

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Eidesstattliche Erklärung

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

Michael Döring
Dübendorf, 15.05.2002