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The Hydro-Morphological Index of Diversity: a planning tool for river restoration projects

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Preface

Flood protection and river engineering projects nowadays have to improve also the ecological condition of the river. Very often the space is not available for a full restoration of the river morphology. Therefore the hydro-morphological heterogeneity has to be optimized within certain space constraints. For such projects a tool for practitioners would be very helpful which allows to quantify the habitat heterogeneity enhancement for different project alternatives and to recommend the best alternative in view of eco-morphological perspective.

In his research project Dr. Walter Gostner proposed a new Hydro-Morphological Index of Diversity (HMID), which allows a quantitative statement of the enhancement of habitat heterogeneity during the comparison of different project alternatives in the framework of river engineering projects. Compared to other existing habitat indices, which are mostly based on visual, qualitative assessment in the field and therefore influenced by the subjectivity of the observers, the new HMID is based on statistical parameters calculated by numerical 2D and 3D simulations during project planning and thus can be denoted fully objective.

The HMID was developed on the basis of very extensive field campaigns by recording a large amount of hydraulic and geomorphic data as it has been done rarely before. In order to see clearly the hydro-morphological heterogeneity several very contrasting sites from fully natural to very channelized stretches have been analysed on three different gravel bed rivers in the Swiss Pre-alps (Bünz, Venoge, Sense). By comparing the variability of the numerous hydraulic and morphological parameters between the studied stretches a formula for the HMID could be proposed. Dr. Walter Gostner could show that the coefficients of variation of flow velocity and water depth alone are sufficient to obtain a reliable and predictive HMID. With the development of the HMID Dr. Walter Gostner made available a very useful predicting tool to evaluate the ecological potential of river engineering projects.

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Prof. Dr. Anton Schleiss

”Der reißende Strom wird gewalttätig genannt,
doch niemand nennt das Flussbett,
das ihn einengt, gewalttätig“
Bertolt Brecht

River Venoge: an ice disk rotating on the surface (Winter 2012)

“Any attempt to fully represent a complex issue and its numerous interlinkages with
other issues in a quantitative modeling framework is doomed to failure”
Jan Rotmans

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Abstract

Contemporary river engineering must guarantee effective long-term flood protection while also improving stream ecology. Therefore, river engineering projects must aim at optimizing hydromorphological heterogeneity, as this is an acknowledged basic condition for maintaining and improving stream biodiversity.

In the present project, a new Hydro-Morphological Index of Diversity (HMID) was developed. The purpose of the HMID is to deliver a tool for the practitioner engaged in planning of integrated river engineering projects where habitat enhancement constitutes one of the project targets. By calculating the HMID, a quantitative statement of habitat heterogeneity enhancement for different project alternatives is possible, and therefore recommendations of which alternatives to prioritize from an ecomorphological perspective can be given.

The HMID was developed within the framework of the “Integrated River Management” project, an interdisciplinary research program involving different University Institutes in Switzerland.

During extensive field campaigns, hydraulic and geomorphic data were recorded at morphologically contrasting sites at three streams in Switzerland (Bünz, AG; Venoge, VD; Sense, FR/BE). By means of correlation analysis, relationships between the measured variables could be detected. Being significantly correlated to a number of hydraulic and geomorphic variables, the hydraulic variables flow velocity and water depth were found to accurately represent the hydromorphological template of a stream. A formula for the HMID could be proposed by comparing the variability of these two hydraulic variables between the study reaches. The developed formula used the coefficient of variation of flow velocity and water depth as a measure to describe hydromorphological variability.

A good correlation of HMID scores with rankings obtained by means of a multimetric visual habitat assessment method supported the capability of the HMID to represent the hydromorphological state of a stream. Correlation between HMID scores and macroinvertebrate-based biotic indices, on the other hand, did not meet expectations for all tested stream reaches.

Numerical modelling for the study reaches at the river Sense was conducted to examine the temporal variability of the hydraulic variables and the HMID. HMID scores were calculated for different discharges, and temporal variability was found lower in natural than in channelized reaches. The increments of the hydraulic variables flow velocity and water depth for changing discharge are greater in channelized than in natural reaches. Thus, aquatic biota in channelized reaches must cope not only with a degraded habitat template but also with higher stress conditions. However, physical habitats in natural reaches lose stability when discharges with major bed reshaping processes occur. These high discharges correspond to intermediate disturbance events, which are important towards maintaining ecological functions.

In a case study, the suitability of the HMID for application was demonstrated. After completion of a restoration project, a stream reach should be characterized by a high HMID which for most of the year remains approximately constant, thus being characterized by a low temporal variability (unless discharges above a disturbance threshold occur). In this way, the necessary hydromorphological template to achieve a high ecological potential for a restored stream reach can be provided.

However, it must be avoided that high hydromorphological heterogeneity becomes a primary aim in itself. For a sound restoration project, processes at the watershed scale also must be included. In particular, it is necessary to evaluate the sediment regime of the entire watershed (mainly of the upstream areas), in order to estimate the long-term geomorphic evolvement of the project reach and to verify whether a dynamic equilibrium for the reach can be obtained. Finally, the ecological success of habitat enhancement measures depends on the conditions of other potential stressors (e.g. sedimentation, excessive nutrients, chemical pollution, habitat fragmentation, strongly modified flow regime). An integrated vision of these factors is a primordial rule for ecologically successful river restoration projects.

Keywords: Habitat degradation, biodiversity, river restoration, restoration potential, gravel bed rivers, hydromorphology, physical heterogeneity, hydraulic variables, spatial and temporal variability, duration curves, numerical modelling, predictive tools, dynamic equilibrium, disturbance concepts

Zusammenfassung

Der moderne Flussbau muss nicht nur das Verlangen nach nachhaltigem Hochwasserschutz erfüllen, sondern strebt auch eine Verbesserung der Fließgewässerökologie an. Durch entsprechende Gestaltung ist in flussbaulichen Projekten ein möglichst großer Strukturreichtum anzustreben, da dieser zweifelsfrei eine der Grundvoraussetzungen für eine hohe Biodiversität in einem Fliessgewässer darstellt.

In der vorliegenden Arbeit wird ein neuer hydromorphologischer Index der Diversität (HMID) vorgestellt. Mit dem HMID steht dem Wasserbauer ein Werkzeug zur Verfügung, das es ihm erlaubt, bei flussbaulichen Projekten die Verbesserung des Strukturreichtums quantitativ zu bewerten, damit die zur Diskussion stehenden Projekvarianten zu optimieren und Empfehlungen für die aus gewässerökologischer Sicht zu priorisierenden Varianten abzugeben.

Der HMID wurde im Rahmen des Projektes „Integrales Flussgebietsmanagement“ entwickelt, einem interdisziplinären Forschungsprogramm unter Einbeziehung mehrerer universitärer Institute verschiedener Ausrichtung in der Schweiz.

In umfangreichen Feldkampagnen wurden hydraulische und geomorphische Größen an drei Fließgewässern in der Schweiz (Bünz, AG; Venoge, VD; Sense, FR/BE) erhoben, wobei Gewässerabschnitte mit unterschiedlicher morphologischer Ausprägung gewählt wurden. Mittels statistischen Auswertungen konnten Zusammenhänge zwischen den Variablen aufgezeigt werden. Die hydraulischen Größen Fließgeschwindigkeit und Fließtiefe sind imstande, die Strukturvielfalt eines Abschnittes ausreichend zu charakterisieren, da sie aufgrund der vorhandenen Korrelationen wichtige geomorphische Grössen und andere komplexe hydraulische Variablen repräsentieren. Anhand eines Vergleichs der Variabilität der hydraulischen Grössen zwischen den Untersuchungsabschnitten wurde eine mathematischen Formulierung für den HMID vorgeschlagen. Diese enthält als Masszahl zur Beschreibung der Variabilität den Variationskoeffizienten der Fliessgeschwindigkeit und der Fliesstiefe.

Es konnte eine gute Korrelation zwischen der vorgeschlagenen Formulierung für den HMID und einer visuellen, multimetrischen Bewertungsmethode nachgewiesen werden. Erwartete Korrelationen zwischen dem HMID und auf Makroinvertebratenerhebungen basierenden biotischen Indizes hingegen konnten in den untersuchten Gewässerabschnitten nicht aufgezeigt werden.

Um auch die zeitliche Variabilität der hydraulischen Größen und des HMID untersuchen zu können, erfolgte für die Untersuchungsabschnitte an der Sense eine numerische Modellierung. Für eine Reihe von Abflüssen mit unterschiedlicher Überschreitungsdauer wurde der HMID ermittelt. Die zeitliche Variabilität der aquatischen Habitate ist in natürlichen Abschnitten geringer als in kanalisierten Abschnitten. In einem künstlichen Fließgewässer bedeuten sich änderende Abflüsse eine stärkere Änderung der hydraulischen Größen als in natürlichen Abschnitten. Deshalb sind aquatische Lebewesen in einem künstlichen Fließgewässer nicht nur mit einem verarmten Lebensraum konfrontiert, sondern sind auch einem größeren Stress ausgesetzt.

Erst bei bettbildenden Abflüssen verlieren die Habitate in natürlichen Fließgewässern ihre Stabilität. Diese Ereignisse kommen den in der Natur mit bestimmten Frequenzen auftretenden Störungen gleich, die für den Erhalt der Ökosysteme wichtig sind.

In einem Fallbeispiel wurde die Anwendbarkeit des HMID in wasserbaulichen Projekten gezeigt. Wenn man das Ziel erreicht, ein Fließgewässer mit einem hohen HMID auszustatten und gleichzeitig dessen zeitliche Stabilität bis zum Eintreten von Schwellenereignissen zu gewährleisten, schafft man die notwendigen strukturellen Voraussetzungen für ein hohes ökologisches Potenzial.

Damit eine hohe hydromorphologische Vielfalt nicht zum Selbstzweck verkommt, sind außerhalb des Projektperimeters liegende Prozesse mit einzubeziehen. Um positive Lebensbedingungen langfristig erhalten zu können, sind Untersuchungen des Geschiebehaushaltes in Verbindung mit abflussdynamischen Prozessen auf der Einzugsgebietsebene notwendig. Durch entsprechende Überprüfungen kann geprüft werden, ob für den betroffenen Fließgewässerabschnitt ein dynamischesGleichgewicht erreicht werden kann. Der ökologische Erfolg struktureller Maßnahmen hängt schlussendlich davon ab, ob auch andere wichtige Faktoren (z.B. Nährstoff- und Sedimenteinträge, chemische Belastung, Fragmentierung, verändertes Abflussregime, usw.) auf der Einzugsgebietsebene richtig erkannt und analysiert werden und nicht einer oder mehrere dieser Faktoren einen Erfolg von vorneherein kompromittieren können.

Schlüsselwörter: Habitatdegradierung, Biodiversität, Fliessgewässerrevitalisierung, Revitalisierungspotenzial, kiesführende Flüsse, Hydromorphologie, physikalische Hetergenität, hydraulische Variable, raümliche und zeitliche Variabilität, Dauerkurven, numerische Modellierung, Vorhersageinstrumente, dynamisches Gleichgewicht, Ökosystemstörungen

List of Symbols and Abbreviations

Latin symbols and abbreviations

EPFL	…	École Polytechnique Fédérale de Lausanne	
LCH	…	Laboratoire de Constructions Hydrauliques	
VAW	…	Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie	
EAWAG	…	Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz	
WSL	…	Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft	
HMID	…	Hydro-Morphological Index of Diversity	[-]
RBP	…	Rapid Bioassessment Protocols	[-]
EPT	…	Ephemeroptera – Plechoptera – Trichoptera taxa	[-]
g	…	gravitational acceleration	$[m^2/s]$
v	…	flow velocity	[m/s]
h	…	water depth	[m]
B_f	…	river bed width at bankfull flow	[m]
Q	…	discharge	$[m^3/s]$
Q_{180}	…	discharge exceeded for 180 days of the year (other days exceedences expressed in an analogue way)	$[m^3/s]$
Q	…	specific discharge	$[l/s,km^2]$
D_m	…	mean diameter of sediment grain size distribution	[cm or mm]
D_{50}	…	diameter for which 50% of sediment by weight is smaller (other characteristic diameters expressed in an analogue way)	[cm or mm]
k_S	…	equivalent sand roughness	[cm]
k_{St}	…	Strickler value	$[m^{1/3}/s]$
n	…	Manning's roughness value	$[s/m^{1/3}]$
Re	…	Reynolds number	[-]
Fr	…	Froude number	[-]
CV	…	coefficient of variation	[-]
CVv	…	CV of flow velocity	[-]

CVh	…	CV of water depth	[-]
CVs	…	CV of bed sediment	[-]
V(i)	…	partial diversity of a hydraulic variable (i)	[-]
R	…	correlation coefficient	[-]
R^2	…	coefficient of determination (Squared correlation coefficient)	[-]
CSD	…	cross section diversity	[-]
TWD	…	thalweg diversity	[-]
S	…	slope	[-]
W	…	distance between points along thalweg	[m]
X	…	distance between points along transect	[m]
Y	…	height (elevation) of transect survey point transect	[m]
Z	…	height (elevation) of thalweg survey point	[m]

Greek symbols

μ	…	mean value	[-]
σ	…	standard deviation	[-]
ν	...	cinematic viscosity of water	$[m^2/s]$
ρ	...	specific weight of water	$[kg/m^3]$
τ	…	shear stress	$[N/m^2]$

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1 Introduction

1.1 Motivation of the research project

Looking at Figure 1.1, the observer immediately notices large differences between the two streams shown in the photographs. An opinion poll among the observers, asking the question which of the two streams offers better conditions for aquatic life would lead to an unambiguous result. The majority would agree that the stream in the image on the right side hosts a richer, more abundant and even more diverse aquatic flora and fauna.

The biological integrity of streams depends on a multitude of abiotic and biotic factors (Figure 1.2). Channel character and flow conditions are reflected in the hydraulic and geomorphic template, commonly referred to as hydromorphology, and belong to the key factors for biological integrity. Composition and diversity, abundance and the structure of the aquatic population strongly depend on the hydromorphology (Jungwirth et al., 2003) since the channel provides habitat for the biota and physical framework for ecological processes (Elosegi et al., 2010).

Figure 1.1 Examples of streams with strongly contrasting morphology (Left: Torrente Gromolo, Liguria. Right: Sense in Canton Fribourg, Switzerland)

Nevertheless, the majority of our streams and rivers rather result in the heavily modified and degraded state shown on the left hand-side of Figure 1.1 than in the state shown on the right hand-side. There are different reasons for river alteration induced by human impact:

- Streams are very useful and mankind since ever is seeking the proximity of streams and rivers. The ancient cultures only could develop due to the existence of rivers such as Euphrat and Tigris or the Nile. Using their water for different purposes, they became part of their life and culture.

Water is extracted for irrigation, drinking and industrial purposes, modifying the hydrological regime of the affected rivers.

In addition, the hydrostatic potential of water is used for power generation entailing several consequences for the exploited streams:

  - Due to water withdrawal reaches with residual flow are originated;
  - Dams, erected for water impoundment, cause an interruption of the longitudinal connectivity of streams with modifications of the hydrological and sedimentological regime;
  - Downstream of hydropower stations where peak energy is produced reaches are affected by hydropeaking;
  - Sediment release activities from filled reservoirs or from sand traps cause an artificial sediment load. If not done properly, they often cause harmful effects for the affected aquatic biota.

Furthermore, rivers are used as traffic infrastructure for navigation, their sediments are extracted for industrial use and they very often work as sewer systems.

- However, streams are also a threat to mankind: floods are amongst the most impressing natural disasters; they cause huge losses of human lives and values. Therefore and in order to gain arable land, streams very often were and still are squeezed into an artificial channel form, here and there they were even displaced underground. In addition, torrents with steep slopes where debris flow events occur, were trained in the past with the help of check dam series and debris retention basins, retaining large portions of the sediment that usually reached the main stems of the watersheds.
- However, river channelization is carried out not only for flood protection. It includes all further processes of river engineering for the purpose of drainage improvement, maintenance of navigation, reduction of bank erosion or relocation for highway construction (Brookes, 1988).
- Moreover, in the watersheds of the streams human activities change the natural drivers of channel morphology on a global scale. Urbanization for example increases hydrological extremes, and clearing of forests for agriculture increases sediment yield (Elosegi et al., 2010).

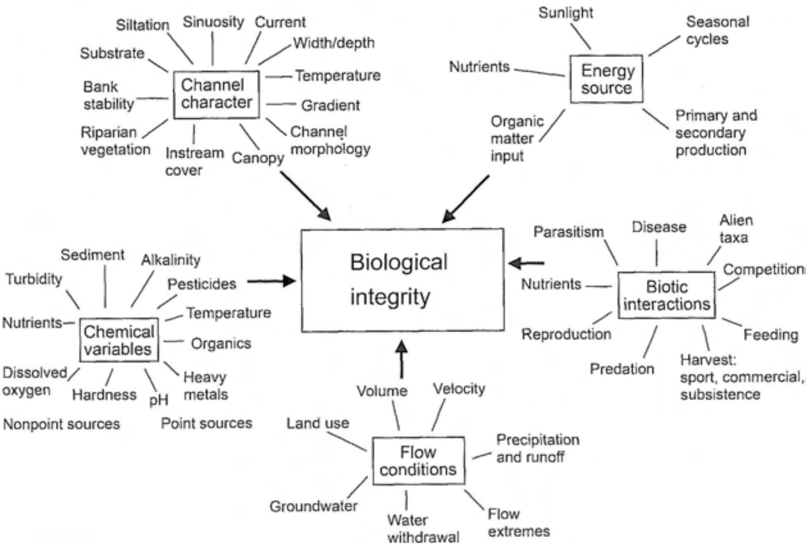


Figure 1.2 Factors influencing the ecological integrity of streams (from Karr & Chu, 2000).

Consequently, a strikingly small fraction of the world's rivers remains unaffected by humans (Vörösmarty et al., 2010). In Switzerland, for example, only about 10 % of all streams remain in a natural or near natural state (BUWAL, 1997), whereas 15'000 km of streams are modified (BAFU, 2010). In Austria, only 6 % of the large rivers can be found in a very good ecomorphological state (Muhar et al., 2000). In the US, from 1840 – 1990 around 320'000 km of rivers were modified. 60 % of Europe's wetlands have already been lost (UNEP/DEWA 2004) through conversion to alternative use or simply through lack of conservation over the last 50 to 100 years.

Over half of the world's accessible runoff presently is appropriated for human use (Allan & Castillo, 2007), and that fraction is projected to grow to 70 % by 2025 (Postel et al., 1996).

These artificial and human induced modifications of streams have caused severe impacts to aquatic biota: in Switzerland, for example, only 10 % of the pristine fish biomass has survived (Peter, in Häusler, 2011). At the heavily degraded river Inn in Austria for example around 1920 fish stock surveys indicated at range of more than 24 species (Jungwirth et al., 1989), whereas today the only indigenous and reproducing species are grayling (*Thymallus thymallus*) and the brown trout (*Salmo trutta fario, L.*) (Muhar et al., 1995).

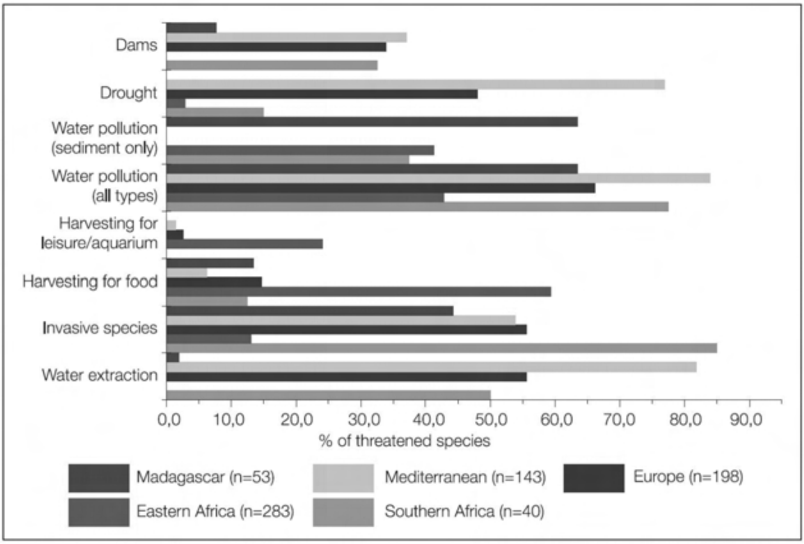


Figure 1.3 A regional breakdown of the major threats to freshwater fishes. These threats have led to species being assessed as threatened according to the IUCN Red List Criteria (Darwall et al., 2008).

Throughout the globe, many pressures affect freshwaters with an important percentage of species included on the Red List of the International Union for Conservation of Nature (Figure 1.3).

Of all types of ecosystems, those of flowing waters are amongst the most damaged by human activities (Sala et al, 2000). However, in the last decades awareness has increased that streams are not only a resource to exploit, or an element to be protected from. Nowadays the essential role of rivers within our environment is widely recognized: they are key elements for the formation of our landscapes and for the geodiversity of our globe, and, even more, they are acknowledged hotspots of biodiversity (Allan & Castillo, 2005) with essential functions on the river scale, but also in a more global context.

Since the sixties of the last century, in the industrial countries huge efforts have been undertaken to bring sewage treatment plants in operation in order to purify domestic and industrial wastewater. Due to these efforts, chemical and organic pollution of freshwaters nowadays is under control in large parts, this aspect thus is not more the major concern for the ecological integrity of streams. Water management authorities have diverted their main focus towards hydromorphology (see also Chapter 1.4), as it is believed to provide the physical template offering the habitat mosaic for the aquatic biota. Therefore in modern river engineering projects, frequently under the frame of integrated river management plans, engineers have the task not only to design river channels in a proper way for flood protection, but they also should have the knowledge how to design projects in a way that allows to provide the best ecological potential to a stream from a hydromorphological perspective. Each structural intervention at streams therefore should fulfill not only flood protection demands, but also improve the hydromorphological situation in a way to provide the best possible potential for ecological recovery. Moreover, river restoration projects are defined also in cases where there is no necessity to undertake flood protection measures. In this cases ecological recovery is the main task of the projects.

Up to now river restoration has been an intuitive matter, conditioned by the experience and understanding of project engineers, landscape architects or biologists. Moreover, river restoration projects have not been driven by ecological needs, but rather by the question of land availability, economical budgets or simplicity in their execution (from a burocratic, societal and technical point of view). Success control of river restoration projects has revealed that ecological targets frequently were not achieved, rendering such projects more an exercise in gardening or in landscape architecture.

In order to obtain better results in the future, scientific understanding at the interface between the abiotic (hydromorphological) environment and the biotic characteristics of streams has to be strengthened, and thus the role of hydromorphology at an ecologically relevant scale have become a key topic of research in water sciences. Deepened and broaded insights in this field serve to provide water management authorities and engineers with efficient, quantitative and easy-to-use tools allowing them to improve river engineering projects from an ecological point of view.

The present research aims at delivering a contribution in this scientific field. Based on extensive field works, numerical modelling and statistical analysis a new Hydro-Morphological Index of Diversity (HMID) pooling the hydromorphological characteristics of a stream reach in a single metric was developed. The HMID is based on statistical parameters of the hydraulic variables water depths and flow velocity, which were found to represent, due to strong correlations with other relevant hydraulic and geomorphic variables, the hydromorphological template of a stream in a proper manner.

The HMID was designed to be an applicative tool in river engineering works. By comparing HMID scores for different project options the alternative delivering the best physical framework for recovery of ecological health can be defined.

1.2 Basic hypotheses

At the beginning of the research project the following hypotheses were defined as background for the development of the HMID:

- The hydromorphological variability of a stream reach can be characterized by the statistical parameters of hydraulic or/and geomorphic variables;
- There are strong correlations between hydraulic and geomorphic variables and within hydraulic variables;
- With the help of a mathematical formulation it is possible to pool the non correlated hydraulic and/or geomorphic variables in a single index able to characterize exhaustively the hydromorphological variability of a stream reach;
- The spatial variability of hydraulic variables is directly correlated to the geomorphic diversity of a stream. In addition, a geomorphic more diverse stream guarantees a greater temporal stability, in other words, a reduced temporal variability of hydraulic variables. This hypothesis suggests that vice versa at streams with a strongly modified morphology, i.e. at channelized or resectioned river sites, spatial variability is reduced and temporal variability increased with a resulting instability of hydraulic habitats.
- In addition, also for water temperature it can be supposed that spatial variability is higher in natural than in heavily modified streams.

The research then demonstrated that these basic hypotheses can principally be confirmed.

1.3 Characteristics, purpose and application of HMID

1.3.1 Allocation of HMID at a spatial scale

Streams and their watersheds are characterized by a hierarchical structure and can be observed at different scales. Many concepts support the thesis that ecological integrity depends on factors acting at different scales (see Chapter 3.2) The HMID is to be applied at a mesohabitat (sensu Frissell et al., 1986), hydromorphologic unit (sensu Parasiewicz, 2001; Parasiewicz, 2007a) or geomorphic and hydraulic unit (sensu Brierley & Fryirs, 2008) scale.

1.3.2 What is different in comparison to other indices?

The HMID uses the coefficient of variation CV of the hydraulic variables flow velocity v and water depth h that are acknowledged to characterize the aquatic habitat. The CV adjusts the sample standard deviation σ by the mean μ and is thus a better comparative measure of variability than variance alone (Schneider, 1994). Other methods classifying streams from a hydromorphological point of view, e.g. the Swiss modular stepwise procedure, are usually based on visual, qualitative assessment in the field and therefore exposed to subjective judgment of the observer. The HMID on the contrary, being based on statistical parameters, can be denoted as fully objective.

Another important difference to other indices is that field work can be diminished to a necessary minimum. The main part for calculating the HMID is desk work consisting in implementation of a numerical hydraulic model of the stream reach under study, execution of several runs with varying discharges, statistical elaboration of hydraulic variables and accomplishment of further checks.

1.3.3 Where are the advantages?

The use of numerical tools for hydraulic modelling is a today’s standard in river engineering projects. For the elaboration of flood hazard maps and flood protection projects water authorities the more and more request the application of two-dimensional (2D) models where the main channel as well as the floodplains are 2D-modelled.

The times were the relevant software either was purchasable only at a high cost or developed for scientific use without graphical user interface and therefore anything else than user friendly and reserved for academic applications are not long over. However, nowadays there are numerous examples of software that is economically affordable or even released for free, coming along with a user friendly graphical interface and characterized by a high reliability and excellent performance. The software BASEMENT for example (Faeh et al., 2006 – 2011), combined with pre- and postprocessing tools, offers a huge variety of options for the hydraulic modelling of different requirements. Therefore, numerical 2D-models have entered the doors of many consulting engineering offices finding a broad field of application.

Thus, in present times it is common that in engineering projects for flood protection numeric 2D-models are used as a key tool both to assess the present discharge capacity of the stream reach and to evaluate the future flood behaviour of the project alternatives under study. For this purpose, steady or non-steady simulation of flood events with different return periods are conducted. However, the defined 2D-model environment can easily be employed to carry out simulations also for discharges differing from floods. Therefore few additional time is needed to conduct a simulation for discharges relevant to calculate the HMID. For the project alternatives under study the hypothetical morphology has to be defined in a way that takes into account geomorphic characteristics of mesohabitats such as riffle-pool sequences, geometries of gravel bars, backwater areas, pools, etc. (see for example Richards, 1976; Newbury et al., 2011; Rhoads et al., 2011). Alternatively, if a reliable 2D-model where sediment transport processes are modelled with a mobile bed is at hand, bed forms will be built autonomously by the model upon modelling of a bed reshaping discharge. Using the numerical output of the 2D-model the step to elaborate statistical parameters of water depth and flow velocity and to calculate the HMID is a simple one. Summarizing, the great advantage of an index such as the HMID is, upon the existence of a numerical 2D-model, the few further amount of time needed for calculating it. As a consequence, temporal variability of hydraulic variables and HMID can easily be evaluated which is a great deal in comparison to field work. Each field campaign infact represents a single snapshot in time, and to gain a valid appraisal of temporal variability field work has to be repeated several times.

1.3.4 What is the added value and where are the potentials?

There are already many indices to assess hydromorphology (see Chapter 3.7). The main task of these indices, be it multimetric or multivariate ones, is to assess the state of a stream reach. These activities fulfill different purposes for public authorities. Based on comprehensive and region wide assessments it is possible to gather an overview of the streams and their abiotic and biotic quality. This is important to recognize areas and stream reaches with urgent need for action and to define order of priorities for river conservation or restoration activities. Moreover, using these indices for the pre-post comparison of river restoration works their success can be monitored.

In contrast to these indices, the HMID has predictive power and allows an a priori judgment. As explained in the above chapter, the main application field of the HMID are river engineering projects. The nature of projects is that they reflect a status that in the physical reality doesn’t exist yet, project designs exist on digital or paper mediums. Therefore methods requesting field activity with visual assessment of the real world are not appropriate to assess a hypothetical status that still has to be realized. The HMID on the contrary has been developed to be applied in river engineering projects mainly to examine the future status of a geomorphic layout that has still to be realized. By evaluating project alternatives differing in their geomorphic layout, and by using the HMID being able to compare the alternatives in term of the ecological potential they might provide, the chances for success of river restoration projects should increase and allow to achieve faster and more often the main restoration goals such as an enhanced ecological integrity of streams or the biodiversity recovery of stream biota.

Recapitulating, when applied according to its purpose, the HMID fills the gap that exists, on a temporal successional scale, between the assessment of a present status and the success control of a realized river engineering project (see Figure 5.1).

1.3.5 Where are the caveats and drawbacks?

It is beyond doubt that hydromorphological variety is a mandatory condition for a rich biodiversity. However, as shown in Figure 1.2, also other conditions have to be fulfilled for the ecological integrity of streams. Many experiences, learned also within the frame of this project, demonstrate that hydromorphological diversity alone is not sufficient for ecological health (Stäheli, 2008, Gostner & Schleiss, 2010; Alp et al., 2011).

To prevent that river restoration projects with the focus on hydromorphological improvement become not an end in itself and have to be checked off as belonging to the "field of dreams" demonstrations (*build and they will come*) (Palmer et al., 1997; Hildebrand et al., 2005), the project focus has to be extended to processes lying beyond the project area (Palmer et al., 2005; Brierley & Fryirs, 2008; Rau & Peter, 2011). Before defining a project at the geomorphic-hydraulic unit scale (sensu Brierley & Fryirs, 2008) a guiding image should be established and several questions be answered at a larger scale:

- Which key biological functions are missing and should be recovered by means of the project?
- Which target species are in the focus of the project? Which key habitats do they need? Are there a species pool and a recolonization path available? Are target species able to overcome natural and artificial obstacles eventually present?
- Are there concerns with longitudinal, lateral and vertical connectivity of the stream reach under study to be solved? Is the stream strongly fragmented?
- Are there other abiotic stressors (for instance a strongly modified hydrological regime, sedimentation due to intense agricultural and forestry activities in the

watershed, overdone riparian vegetation clearing activities, chemical and biological intrusions from industry or agriculture, clogging tendencies of the river bed) that might be hindering the efforts in hydromorphological improvement?

An important issue to mention in this context is the long-term sediment regime and, as a consequence, the long-term trend of the HMID for a stream reach under study. Streams offering positive hydromorphological conditions at the long term are characterized by their dynamic equilibrium. In periodic intervals bed forming processes with the shift and turnover of habitats take place, but concurrently there are no irreversible sedimentation or channel incision tendencies. Within the frame of river engineering projects the evaluation of river bed changes, based on long term bed load modelling studies, is a must. In alpine regions, there are many examples that bed load retention in the upper watershed areas and gravel extraction activities have caused irreversible bed incisions. Due to these processes in a stream reach where by means of a restoration project a diverse habitat mosaic was recovered degradation processes might rapidly occur and habitat diversity vanish within few years. Hence the target of an equilibrated dynamic sediment regime is not only a matter of long-lasting flood protection measures, but also important to maintain an ideal physical template for the aquatic biota.

1.3.6 Which applications are not appropriate?

The HMID is mainly a predictive tool to be applied in river engineering projects. Subsequently some non-purposes of the HMID are illustrated.

It is not the aim of the present research to develop an alternative habitat or ecomorphological assessment index. In the last decades, numerous assessment indices, taking into account particularities and customs on a regional and national scale, have been developed and implemented in the daily routine of water management authorities and consulting offices. These indices usually are based on visual assessment methods. Depending on the degree of detail and sophisticatedness of the indices, the amount of time needed to classify whole watersheds with the entirety of its stream branches usually is affordable. As a consequence, the use of HMID as an assessment tool, even if theoretically feasible, is not an alternative as it would be much more time consuming requesting a topographical survey of the streams, evaluation of bed and bank rugosity and, if not available, establishment of a numerical 2D-model.

In the same way the HMID is also not foreseen to be applied in success control of river restoration measures. Firstly, for this field exist numerous methods, too (f.i. Woolsey et al., 2005) and secondly, in success control mainly recovery of aquatic biota is the focus of investigation and thus the HMID, being based on the hydromorphological conditions, is not the appropriate tool for it.

Furthermore, for the moment the HMID is not thought to constitute an alternative to habitat simulation models or indices that focus mainly on modified hydrological regimes. In the last years many habitat simulation models have been developed, mainly to give recommendations for residual flow allocations (see also Chapter 3.9). Their main purpose is to make sure that habitat suitability for target species, due do water withdrawals for hydropower or other uses, is not falling under a certain acceptable level. In addition, the aim of the HMID is not to compete with indices such as LIFE or CEFI (see Chapter 3.9) that are applied at a broad and beyond watershed scale and mainly concentrate, similar to habitat simulation models, on streams with modified hydrological regimes, despite differentiating things upon their morphological characteristics.

Concluding, the HMID, which is applied on a mesohabitat scale, furthermore doesn’t substitute any sound, interdisciplinary and integral approaches that are necessary on a watershed scale in order to define and realize projects with a significant improvement of ecological integrity.

1.4 Legal framework

Environmental protection at its beginnings was an intuitive matter. Gradually laws, directives and policies were established in order to deliver the legal background for environmental subjects.

In Switzerland, several laws are to be considered in relation to freshwaters. The Swiss Federal Law for Water Bodies (state of 1 August 2008), article 4.2, for examples states that

> *Every intervention at a stream should conserve or restore its natural alignment. The stream and its banks have to be shaped in a way that*
>
> *a. they offer heterogeneous habitats for the aquatic and terrestrial fauna and flora;*
>
> *b. the connectivity between surface and sub-surface waters is conserved;*
>
> *c. a riparian vegetation, typical for the place of intervention, can develop.*

In 2011 another important law in Switzerland was released: the regulation for the protection of waters (state of 1 June 2011) obliges the Cantons to restore streams, upon definition of priority programs, within the next 20 years (Art. 41d):

> *The Cantons elaborate the data base that is necessary for the definition of restoration projects. This data base comprises the ecomorphological assessment of the water bodies, the artificial structures as well as the ecological potential and the importance for the landscape of the water bodies. Within 20 years they define the stream reaches to be restored, the kind of measures and the delays for the realization. Restoration projects should be prioritized if*
>
> *a. the benefit for nature and landscape is great;*
>
> *b. the ratio between benefits and costs is great;*
>
> *c. in combination with other measures the benefit is increased, for example by protection of natural areas or by enhancing the flood safety.*

In the European Union, there are three important directives. The Directive 2000/60/EC (European Commission, 2000) establishes a framework for Community action in the field of water policy (European Water Framework Directive - WFD). It stipulates (art. 4, comma 1, letter a) that

> *(iii) Member States protect and enhance all artificial and heavily modified bodies of water, with the aim of achieving good ecological potential and good surface water chemical status at the latest 15 years from the date of entry into force of this Directive.*

In art. 11, comma 3, letter (i) basic measures are described as the minimum requirements to complied with, that shall consist, amongst others, of

> *measures to ensure that the hydromorphological conditions of the bodies of water are consistent with the achievement of the required ecological status or good ecological potential for bodies of water designated as artificial or heavily modified.*

Furthermore, the flood risks Directive 2007/60/EC (FRD) (European Commission, 2007) requires EU Member States to undertake a preliminary assessment of flood risks and, for areas with a significant flood risk, to prepare flood hazard and flood risk maps and flood risk management plans. In the premises, subparagraph 14, flood risk management plans are evoked with a view to give rivers more space and

> *consider where possible the maintenance and/or restoration of floodplains, as well as measures to prevent and reduce damage to human health, the environment, cultural heritage and economic activity.*

In art. 7, comma 3 there is a clear cross connection to the WFD as member states in flood risk management plans shall

> *take into account relevant aspects such as costs and benefits, flood extent and flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains, the environmental objectives of Article 4 of Directive 2000/60/EC, …*

Finally, the most recent of the three, the directive 2009/28/EC (European Commission, 2009), deals with the promotion of the use of energy from renewable sources. In art. 3, comma 1 each member state is invited to

> *ensure that the share of energy from renewable sources … in gross final consumption of energy in 2020 is at least its national overall target for the share of energy from renewable sources in that year … Such mandatory national overall targets are consistent with a target of at least a 20 % share of energy from renewable sources in the Community's gross final consumption of energy in 2020.*

This directive indirectly implies an intensified exploitation of each renewable energy source available, in order to reach the stated goals. Thus, there will be also new hydropower projects that usually are believed to worsen the ecomorphological state of streams. That's why fundamental and applied research focusing on the link between hydromorphology and aquatic biota is essential in order to understand these interactions and in order to be able to adopt measures that entail positive effects for both the ecological status of streams and a sustainable supply of the societies with renewable energies.

1.5 Conceptual framework

The present research has been carried out within the frame of the interdisciplinary project "Integrated River Management" (www.rivermanagement.ch) which has the objective of understanding the ecological and socio-economical consequences of river training works and providing advice for future interventions on river systems (Ribeiro, 2011). Several research departments at different universities in Switzerland were involved, namely LCH (EPF Lausanne), VAW (ETH Zürich), EAWAG and WSL (Figure 1.4). At LCH, the following research topics were investigated:

- Flood protection measures and habitat quality (A)
- Improvement of habitat conditions in case of hydropeaking (B)
- Morphology of restored river confluences (C)
- Stability and connectivity of block ramps (D)

The present research project corresponds to topic A of the project whereas the topics B, C and D were treated in Ribi (2011), Ribeiro (2011) and in Studer & Schleiss (2010).

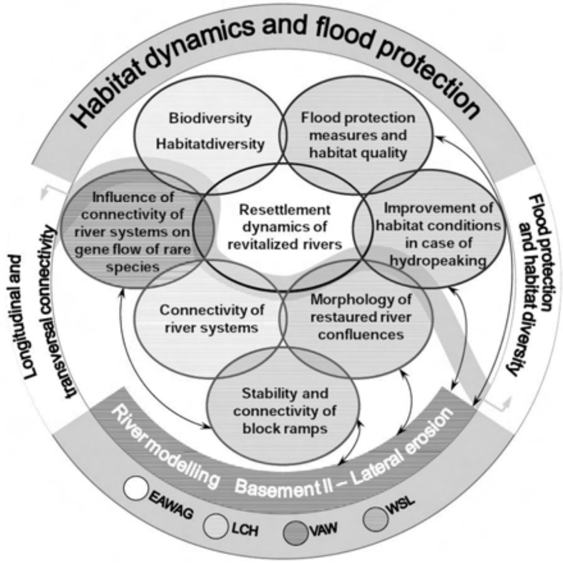


Figure 1.4 Diagram of the Integrated River Management project (from Ribeiro, 2011).

2 Structure of this document

The present document is structured into several chapters dealing with different topics. After the introduction (Chapter 1) where the global frame of the project is outlined and the present Chapter 2 follows the review of literature connected with the topics of the present research (Chapter 3). Chapter 4 enlightens the general follow up of the project approach with the working steps that have been carried out. Chapters 5 to 9 are based on five distinct papers. The first three papers are to be submitted to scientific journals, whereas the last two papers have been presented to international conferences. Each of the papers treats a specific working step of the present research. Chapter 5 to 7 are directly related to the development and application of the HMID, whereas Chapter 8 and 9 represent two special studies that have been conducted within the frame of the above mentioned “Integrated River Management” project providing interesting insights into two different topics.

The main topic of Chapter 5 is the development of the HMID. The field work carried out at three Swiss streams is described, the statistical elaborations including correlation analysis between geomorphic and hydraulic variables as well as the differences in spatial diversity between sites are explained and the proposed formula for the HMID is justified. Correlations with visual assessment methods and biotic indices complete the analysis. In the discussion the purpose and scope of the HMID are outlined, the differences to other indices such as visual assessment methods enlightened and the main advantages and drawbacks shown.

Chapter 6 enlarges the analysis of spatial variability with a detailed investigation of temporal variability. With the help of numerical modelling of the 5 study sites at river Sense and application of the HMID it is shown that at natural, barely modified sites hydraulic variables are not only spatially more variable, but also temporal more stable. On the contrary, at channelized sites spatial variability is strongly reduced whereas temporal variability is high. In the discussion the concept of variability and dynamism in streams is addressed. At natural sites that at a larger temporal scale seem more dynamic aquatic habitats are relatively stable until the occurring of threshold events, whereas at channelized sites aquatic habitats are not stable and the aquatic biota therefore suffers a major stress. The chapter confirms that the HMID is an appropriate tool to describe hydromorphological characteristics of a stream reach.

Chapter 7 treats the application of the HMID by means of a case study. For a channelized stream different projects alternatives under discussion are examined using the HMID. By investigating hydromorphological variability also on a temporal scale the variants are compared and an advice for the variant to choose from a hydromorphological point of view is given. In the discussion the additional value of the HMID for river engineering projects is exposed. However, also caveats are shown with important features to consider at a spatial and temporal scale for ecologically successful river restoration projects.

The topic of Chapter 8 is an investigation of flood frequencies for gravel bars at the naturally braided study site n°1 at river Sense that is characterized by the presence of indicators for high biotic integrity such as German Tamarisk (*Myricaria Germanica*) and gravel bar grasshopper (*Chorthippus pullus*). By the means of numerical modelling discharges corresponding to different return periods are examined. The study demonstrates that gravel bars where German Tamarisk is present are flooded and reshaped with a return frequency of about 5-7 years. On gravel bars with more frequent inundations the German Tamarisk doesn’t manage to develop in time, whereas on gravel bars that are flooded less frequently the plant is overruled by other, stronger species.

Chapter 9 finally treats another important abiotic factor for river biota, and precisely the water temperature. A detailed field campaign, carried out at two different moments in the season, has revealed that the spatial variability of temperature, similar to hydraulic variables, differs among morphologically contrasting sites with a higher spatial diversity at natural sites. As a consequence, also with regard to water temperature it can be concluded that at natural sites refugia for aquatic biota are more frequent than at channelized sites.

3 Literature review

3.1 In general

The aim of this chapter is to give an overview about literature concerning the disciplines in fluvial sciences, which concern the present research topic. The present research, according to the scientific nomenclature, can certainly be stated to belong to the field of ecohydromorphology (according to Figure 3.1), which in the international nomenclature is denoted alternatively as ecomorphology, eco-geomorphology or ecohydrology, or to the field of hydromorphology being the discipline that puts the focus on abiotic factors affecting freshwater biota (Logan & Furze, 2002).

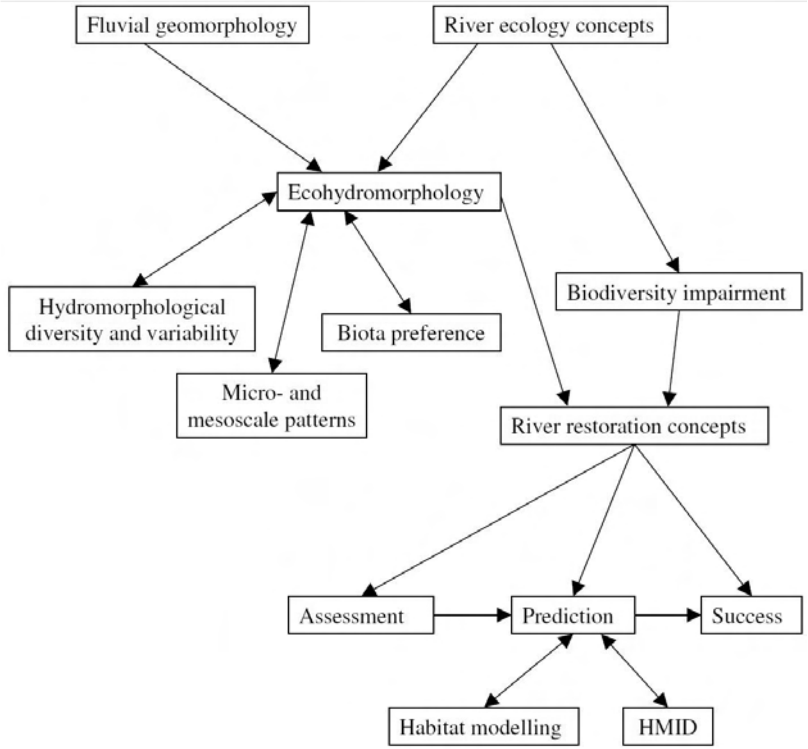


Figure 3.1 Schematic overview of topics in literature in connection with the present research

A multitudinous amount of literature is produced in fluvial sciences, thus it is self-evident that this overview is far from being exhaustive (see for example also the considerable literature review focused on the ecology of braided rivers of Gray & Harding, 2007). Especially the topics that have to be interpreted as “biological science” in the strict sense (for example methods to evaluate biotic conditions of a stream, theories about nutrient cycling, food webs, gene flow, etc.) are only touched marginally and merely if necessary for the understanding of the hydromorphological concepts.

River engineers have long been dealing with the science of fluvial morphology (chapter 3.2), as streams have been seen as elements to be protected for or to be exploited. However, towards the end of the last century, the more and more streams have been recognized to be important ecosystems. Consequently, various theories of river ecology have been developed (Chapter 3.3). In this context an important sub-discipline has evolved investigating and enlightening the status of today’s rivers comprising investigations on particular reasons for biodiversity impairment imputable at hydromorphological factors (Chapter 3.4). There is general consensus about the fact that physical degradation is one of the major causes for biodiversity impairment of streams. The impact of the physical environment on aquatic biota and the relative interactions have become a major field of research and have been gathered under the terms of hydromorphology, ecogeomorphology or ecomorphology (Chapter 3.5) which has developed as interdisciplinary research topic gathering the fields of hydromorphology (which is the concentrate of the originally separated disciplines of hydrology, morphology and hydraulics) and ecology. It is worth mentioning different sub-disciplines to be seen as part of this field: the conceptual research about diversity and variability in hydromorphology (Chapter 3.5.1), studies about micro- and mesoscale patterns of hydraulic variables (Chapter 3.5.2), and investigations addressing the preference of aquatic biota for specific physical characteristics (Chapter 3.5.3).

Since several decades streams are an object of rehabilitation or restoration. Due to the awareness that streams fulfill important ecological, societal and economic functions scientist, water authorities, NGO’s and political exponents have rendered river restoration a trendy and popular discipline. In science river restoration has become a proper discipline (Chapter 3.6), with debate being intense and far from being unanimous concerning the approaches for prioritizing, planning, realization and monitoring of relative projects. Within this frame, to assess the actual status of streams is one of the important activities of practitioners, as it is an important management tool for water authorities not only to define river restoration projects, but also for other purposes. Multitudes of methods are in use all over the globe (Chapter 3.7). Frequently these methods, as well as other methods, are applied also to monitor the success of river restoration projects by comparing the status of stream reaches before and after manipulation (Chapter 3.8).

A particular field is occupied by models that are used to predict consequences of hydromorphological modifications on aquatic biota (Chapter 3.9). These models are increasingly employed to predict changes in habitat due to morphological modifications, even if they were developed and frequently used when changes in the hydrological regime, mainly water withdrawal, are the topic and recommendations for instream flow allocations have to be delivered.

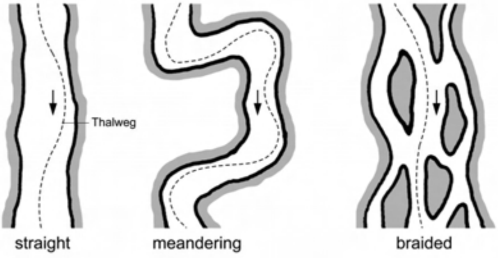


Figure 3.2 Main morphological river types (from Scheuerlein, 1984)

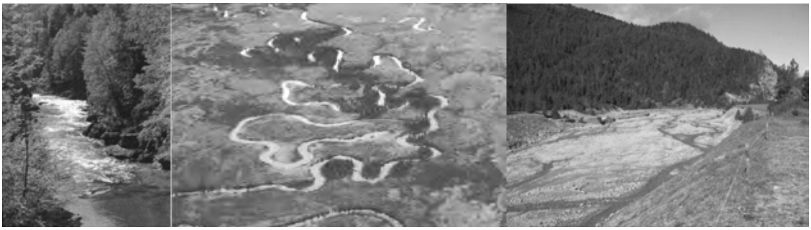


Figure 3.3 Straight river type (left, from Jungwirth et al., 2003), meandering river type (middle, from Jungwirth et al., 2003), braided river type (right)

3.2 Fluvial morphology

The literature concerning the appropriate design of channels from a geomorphic point of view is vast and has developed over many decades. In principle, three main morphological types exist (Mangelsdorf & Scheuermann, 1980; Scheuerlein, 1984) (Figure 3.2):

- Straight rivers,
- braided rivers,
- meandering rivers (see Figure 3.3 for examples).

The transitions between the three main types are gradual and therefore river types representing mixed forms of two or three of the main types exist. The key factors influencing the river type are slope and bankfull discharge (Figure 3.4).

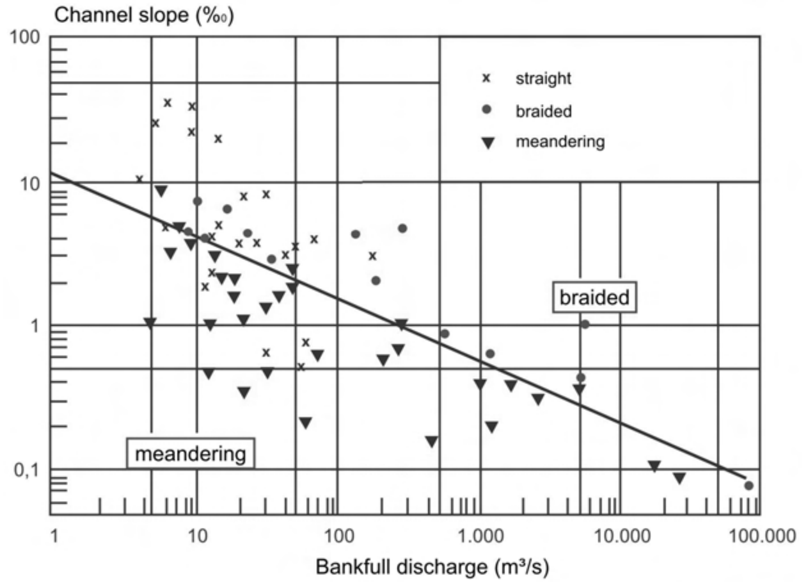


Figure 3.4 Relationship between river slope, discharge and morphological type of the river (from Leopold & Wolman, 1957)

Lane (1953, 1955) conceived the epoch-making concept of dynamic equilibrium (Figure 3.5). In a very simplified way, the fluvial dynamics is like a permanent oscillation of the pointer of a scale where one of its pans is filled with sediment and the other with water. As these two elements are very variable in space and time, there is a permanent adjustment of the river morphology to erosion/sedimentation phenomena. A stream is defined to be in its dynamic equilibrium if it is able to maintain, over the time, its dimension, pattern and profile in such a manner that it is neither aggrading or degrading and is able to transport water without adverse consequence on flow and detritus of its watershed. This state depends mainly on the sediment supply from upstream and the transport capacity of the stream.

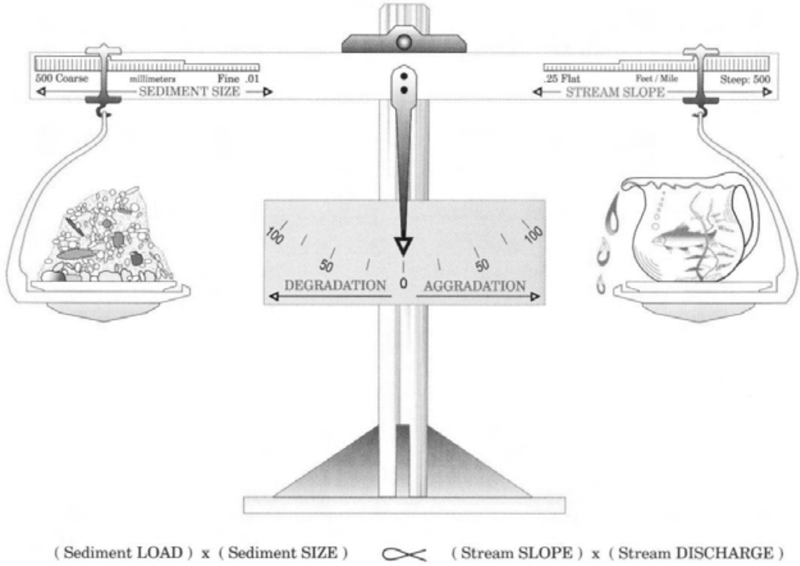


Figure 3.5 Schematic representation of the relationship for qualitative analysis (from Lane, 1953, 1995)

In their important work Leopold et al. (1964) argued that streams in their natural state constantly seek their own stability. As it was formulated later, a stream can fully express its natural characteristics, if it is morphologically stable (Rosgen, 1996).

Other examples of advances in river morphology over the decades are:

- Schumm’s (1997) relationships include river cross-section geometry. These allow a prediction of morphological changes when a change in the control variables water or sediment is to be expected.
- Parker (1979) and Ikeda et al. (1998) published studies concerning the equilibrium width a stream will obtain if there aren’t any lateral constraints based on the effective discharge which is similar to the bankfull discharge.
- Rosgen (1996) proposed the concept of natural channel design (NCD). Starting from the three main morphological types, he developed 8 major types of stream based on hydraulic-geometry relations and four other measures of channel shape to distinguish the dimensions of alluvial stream channels as a function of the bankfull stage. Six classes of particle size of bed and bank material are used to further subdivide each of the major categories, resulting in 48 stream types. Additional subtypes have also been identified representing intermediate cases between the eight major stream types

and making for as many as 94 possible types. The approach has been strongly criticized as putting too much emphasis on channel form with the consequence of sculpting instream structural attributes such as the frequency of riffle-pool complexes (Palmer et al., 2008) or as not being able to predict stable morphologies in currently unstable alluvial systems (Simon, 2008).

- Da Silva (1991) developed a pattern diagram which can be used to predict stream morphology (single-thread, alternating gravel bars or multi-thread) depending on the D_{50} of the river bed material, the bankfull width and the water depth at the effective channel forming discharge which is to be set as a flood with a return period of 2 – 5 years.
- Sear et al. (2003) point out clearly that sound stream channel design has to include a sedimentological study of the entire watershed, in order to avoid river restoration projects to fail. They report examples where re-established riffle-pool structures failed as, due to income of fine sediments from upstream, they were siltated after a few years or where the same happened to specially created spawning areas.
- Brierley & Fryirs (2005) defined the River Styles Framework, which is a geomorphic river classification scheme and explained how river systems continually adjust to disturbance events. In geomorphic terms, river behaviour can be interpreted from the assemblages of channel and floodplain geomorphic units that occur along a reach. They also underlined the concept of different spatial scales appropriately framed in terms of nested hierarchical arrangements.
- Piégay et al. (2005) gave a review of techniques available for delimiting the erodible river corridor. Their main point is to see riverbank erosion not as hazard to be prevented, but as a key factor for channel dynamics and to recognize that bank erosion provides ecosystem services and other benefits. Based on these considerations, simple rules how to identify the erodible river corridor are given.
- Shields & Copeland (2006) provide a good overview of empirical and analytical approaches for stream channel design. In this paper again it is argued that empirical approaches, such as NCD, are outmoded and that analytical approaches enable hydraulic engineers reduce failure risk in the design of stream channels. Analytical approaches (e.g. Millar & MacVicar, 1998; Copeland et al., 2001) are based on one- or two-dimensional representations of water flow and sometimes they include refinements such as sediment transport relations that handle a distribution of bed

material grain sizes, unsteady flows, bank stability or flow-dependent flow resistance functions.

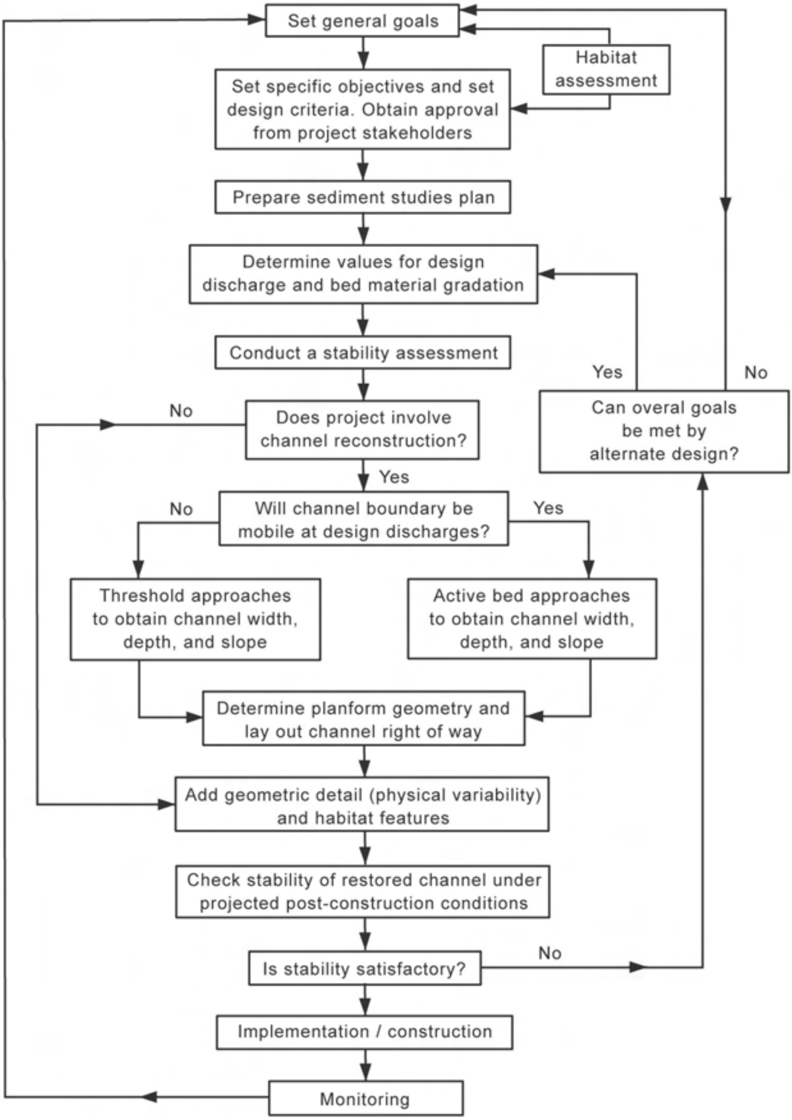


Figure 3.6 Analytical design approach for stream channel design restoration projects (from Shields et al., 2003)

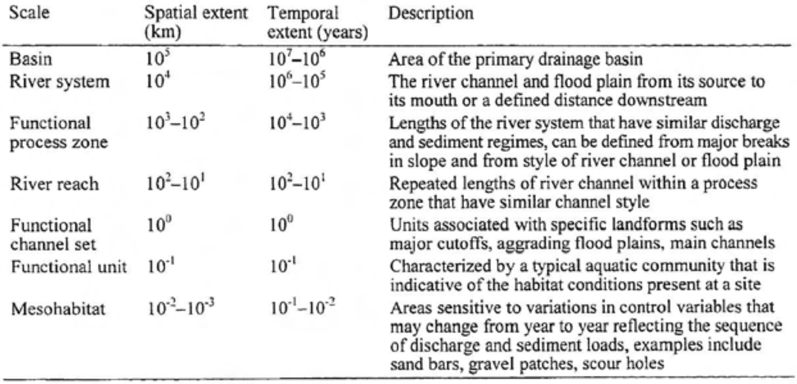
Users of the analytical approach (Figure 3.6) must incorporate ecological criteria ("habitat assessment") and a stability assessment that includes the important step of placing the project reach within its spatial and temporal geomorphic context (Kondolf et al., 2001).

- Schweizer et al. (2007) – within the framework of the "Rhone/Thur River Rehabilitation Project", the predecessor of the present "Integrated River Basin" project – elaborated, based on the work of da Silva (1991), a model to predict stream morphology and hydraulic consequences (velocity and depth distribution, risk of river bed siltation) of river rehabilitation.
- Nardini & Pavan (2012) finally propose a new comprehensive approach to predict morphology after stream restoration as it comprises the historical geomorphic evolution, current equilibrium analysis, together with mechanistic expert-based reasoning, supported by some analytical hydraulics. The methodology consists, after having defined geomorphic homogeneous river stretches (according to Brierley & Fryirs, 2005), of 7 steps to follow that, accompanied by some cross-controls, allows to make predictions of the morphology after stream restoration.

3.3 General concepts of river ecology and life in rivers

Hutchinson (1959) already stressed the role of what he called the mosaic nature of the environment proposing the concept of the multidimensional niche, suggesting that organisms are influenced by a set of factors (bionomic, physical, chemical factors) which are conditioning available habitats for aquatic species. Concepts of stream ecology, which see rivers as whole ecosystems, integrated within their watersheds as well as connected along their flow paths, and to their surrounding landscape, have become to be disseminated since the 1970s. Vannote et al. (1980) delineated the river continuum concept (RCC), emphasized the longitudinal dimension of stream ecosystems and described the entire fluvial system as a continuously integrating series of physical gradients driven primarily by changes in channel morphology. However, the RCC was also criticized, and in other concepts morphological discontinuity was in the focus, as for example in the Serial Discontinuity Concept (Ward & Stanford, 1983) or in the network dynamics hypothesis (Benda et al., 2004). The flood pulse concept promulgated the view that rivers and their fringing floodplains are integrated components of a single dynamic system, linked by strong interactions between hydrological and ecological processes. The major driving force is the pulsing of river discharge that determines the degree of connectivity and the exchange processes of matter and organisms across river floodplain gradients (Junk et al., 1989; Tockner et al., 2000).

Amoros et al. (1987) and Ward (1989) stressed the fact that streams are connected in three spatial dimensions and, when adding the temporal scale, in four dimensions. Thus, streams form an ecosystem that is strongly influenced by their surrounding watershed (Wiens, 2002). Additionally, streams have to be seen as hierarchically organized systems incorporating, on successively lower levels, stream segment, reach, pool/riffle and microhabitat subsystems (Frissell et al., 1986), where the hierarchy is spatially nested.



Scale	Spatial extent (km)	Temporal extent (years)	Description
Basin	10^5	10^7–10^6	Area of the primary drainage basin
River system	10^4	10^6–10^5	The river channel and flood plain from its source to its mouth or a defined distance downstream
Functional process zone	10^3–10^2	10^4–10^3	Lengths of the river system that have similar discharge and sediment regimes, can be defined from major breaks in slope and from style of river channel or flood plain
River reach	10^2–10^1	10^2–10^1	Repeated lengths of river channel within a process zone that have similar channel style
Functional channel set	10^0	10^0	Units associated with specific landforms such as major cutoffs, aggrading flood plains, main channels
Functional unit	10^{-1}	10^{-1}	Characterized by a typical aquatic community that is indicative of the habitat conditions present at a site
Mesohabitat	10^{-2}–10^{-3}	10^{-1}–10^{-2}	Areas sensitive to variations in control variables that may change from year to year reflecting the sequence of discharge and sediment loads, examples include sand bars, gravel patches, scour holes

Table 3.1 Spatial and temporal hierarchical geomorphological classification scheme (from Petts & Amoros, 1996)

Also Petts & Amoros (1996) take the same line and sustain that larger-scale factors set the conditions within which smaller-scale factors form. At the top of the hierarchy, catchments persist at larger spatial scales and longer time scales. This pattern continues until coming down to the bottom of the hierarchy where mesohabitats persist at small temporal and spatial scales (Table 3.1).

Poff et al. (1997) underpinned the role of the flow regime as being of central importance in sustaining the ecological integrity of flowing water systems. The flow regime influences integrity both directly and indirectly, through their effects on other primary regulators of integrity.

Karr (1991) and Karr & Chu (2000) individuate five principal factors containing chemical, physical and biological components that are commonly altered by human actions and responsible for biodiversity impairment of rivers (Figure 1.2).

Stanford et al. (2005) investigated the dynamism of streams by defining the shifting habitat mosaic of river ecosystems and arguing that in braided reaches due to a more heterogeneous fluvial environment a more diverse aquatic and terrestrial environment is expected.

The Riverine Ecosystem Synthesis (Thorp et al., 2006) finally depicts rivers as an array of large hydrogeomorphic patches.

3.4 Present condition of rivers and reasons for biodiversity impairment

A varied literature exists investigating the present status of streams in the world and explaining reasons for their degradation. Vörösmarty et al. (2010) for example present the worldwide synthesis to jointly consider human and biodiversity perspectives on water security and affirm that a strikingly small fraction of the world’s rivers remain unaffected by humans.

Many other sources can be found which give statements about the status of rivers throughout the globe, as for example in Dynesius & Nilsson (1994), BUWAL (1997), Muhar et al. (2000), Sala et al. (2000), Hauer & Lorang (2004), Allan & Castillo (2007), Darwall et al. (2008).

A lot of studies exist enlightening singular physical reasons responsible for biodiversity impairment. Besides of chemical (e.g. water pollution) or biological reasons (e.g. invasion by exotic species, genetic issues), within a geomorphological frame major reasons for biodiversity impairment are:

- channelization and resectioning of streams (Dynesius & Nilsson, 1994; Nilsson & Berggren, 2000);
- fragmentation of streams, in the longitudinal direction by means of weirs and check dams and the lateral direction by realization of rigid river banks creating a clear separation line between the stream and its floodplain (Nilsson et al., 2005);
- flow modifications due to water withdrawal (Postel & Carpenter, 1997; Vörösmarty et al., 2000; Nilsson et al., 2005);
- erection of impoundments and dams (Chao, 1995; Nilsson & Berggren, 2000);
- flushing activities to remove sediment from reservoirs;
- sedimentation: resulting from excessive land use by humans within a watershed sedimentation is seen as a major physical factor impairing stream ecosystems, thus making many streams unable to achieve expected levels of biological integrity

(Kaller & Hartman, 2004; Williams, 2005; Dudgeon et al., 2006). Sedimentation can also result in clogging of the river bed which is seen as threatening factor for important ecological functions (e.g. spawning activity etc.) (Schälchli, 1992);

- gravel retention and extraction;
- removal of large woody debris.

3.5 Eco-geomorphology

If the present status of rivers in the world is critical, there is large consensus that habitat degradation is one of the main reasons. The impacts of the physical environment on aquatic biota and the relative interactions have become a major field of research. Different terms have been coined to stress this interplay (Elosegi et al., 2010). In Europe, this particular research field is gathered under the term "Hydromorphology" which has been firstly used by the authors of the Water Framework Directive (WFD, European Commission, 2000). Hydromorphology encompasses both the hydrological and morphological characteristics of water bodies to move away from the concept that any management actions must emphasize the uniqueness of individual rivers, requiring models linking biota to hydromorphological characteristics using data from across regions, countries and ecoregions (Dunbar et al., 2010). Thoms & Parsons (2002) use a broader term writing of "eco-geomorphology" (alternatively also the terms ecomorphology and ecohydrology ar in use) as interdisciplinary approach to the study of river systems that integrates hydrology, fluvial geomorphology and ecology. This approach facilitates a new understanding of river systems by bridging dominant paradigms from individual disciplines. Fisher et al. (2007) stress the notion of "functional ecomorphology" as the running water ecosystems are governed by the interaction of landscape form and ecological function.

Several sub-disciplines, in some cases originated before the term hydromorphology has gained common use, belong to this field and are briefly introduced henceforward.

3.5.1 Diversity and variability in hydromorphology

Palmer et al. (1997) released an essay about the importance of variance in community restoration ecology. Entire volumes are dealing with variability (Schneider, 1994; Gurnell & Petts, 1995; Schumm, 2005). In 2006, the journal "River research and applications" emitted a special issue on variability in riverine ecosystems (Thoms, 2006). Also "Hydrobiologia" organized a special issue on habitat complexity (Kovalenko et al., 2012). It can therefore be resumed that variability plays an essential role in hydromorphology, especially at the interface with biotic processes. Variability referring to morphological, hydrological and hydraulic characteristics is investigated on the spatial as well as on the temporal scale. However, flow is seen as the maestro that orchestrates pattern and process in river ecosystems (Walker et al., 1995). Poff et al. (1997) remain on this track and describe natural flow of a river as varying on time scales of hours, days, seasons, years and longer with physical habitat that changes dramatically with the rise and the fall of the water stage.

Other studies demonstrate a direct association between flow variability and physical complexity of channel morphology (Thoms et al., 2006). A growing body of research suggests that spatial complexity of the channel and river corridor is critical for ecosystem integrity at different scales (Thoms, 2006; Elosegi et al., 2010) and that diversity and productivity of stream food webs are related to habitat heterogeneity (Negishi & Richardson, 2003). The riverine ecosystem synthesis concept (RES, Thorp et al., 2006) predicts that biodiversity, system metabolism, and many other functional processes are enhanced by habitat complexity and that biocomplexity should be greater in functional process zones that are more hydrogeomorphically complex than in simpler river segments (Thorp et al., 2010).

3.5.2 Micro- and mesoscale patterns of hydraulic variables

Lamouroux et al. (1992), Lamouroux et al. (1995) and Lamouroux (1998) present different studies where the distribution of point shear stress, velocity and water depth are analyzed. Velocity distribution for example can be expressed mathematically as a two-parameter function that is a combination of a centered and of a decentered model.

Schweizer et al. (2007) bases his models on the just mentioned studies and developed an approach to predict joint velocity and depth distribution for instream habitat assessment.

Jowett (1993) proposed an approach how to relate flow velocity and water depth directly to the classical mesohabitat features pools, run and riffles in order to enable a mathematical description of these mesohabitats facilitating the description of the habitat mosaic.

3.5.3 Micro- and macro-scale preferences of biota

If the term ecology etymologically is derived from the greek “oikos”, “the household”, than the physical mosaic refers to the house itself with the different available habitats (“living areas” respectively “rooms”). Habitat has been described as providing the template upon which evolution acts to forge characteristic life history strategies

(Southwood, 1997). Accordingly, the physical properties of any given habitat within a river ecosystem will determine the type, abundance and arrangement of biological assemblages found there (Thoms, 2006). Therefore, the study of preferences of biota to physical properties has absorbed the efforts of many researchers.

Different variables have been used to describe the physical properties of habitats.

At the micro-scale level the most used are flow velocity, water depth and substrate characteristics. However, also other variables such as shear stress, Reynolds or Froude number have been employed. Species specific preference curves in relation to single habitat-related factors such as ranges in flow velocity, water depth, substrate have been developed for both fish species at different life stages and macroinvertebrates (Smith & Aceituno, 1987; Marcus et al., 1990; Rubin et al., 1991; Heggenes, 1996; Vismara et al., 2001; Armstrong et al., 2003). Other approaches try to understand hydraulics from the fish's perspective developing alternative mathematical formulations of hydraulic habitat (Goodwin et al., 2006). Further physical factors that have been related to habitat selections by aquatic biota are temperature and light (Heggenes & Dokk, 2001), bottom shear stress as descriptor of near-bed conditions (Ulfstrand, 1967; Minshall, 1984, Statzner et al., 1998; Schmedtje, 1996) or Reynolds and Froude number (Heed & Rinne, 1991; Bisson et al., 1988; Bates, 2000). Minshall (1984) studied the relationship between aquatic insects and substratum conditions because substratum largely determines the micro-environmental conditions under which aquatic insects live, thus profoundly affecting their growth and survival. Analyzing grain size curve of spawning areas Plasseraud et al. (1990) and Beard & Carline (1991) investigated specific habitat requirements of fishes. Kaller & Hartman (2004) showed that macroinvertebrate EPT taxa are highly sensitive to deposition of fine sediments.

Also at the meso-scale respectively reach related level numerous studies have analyzed the importance of hydromorphological characteristics. By means of field experiments Jungwirth & Winkler (1983) showed a correlation between the variance of maximum flow depth in river reaches and fish biomass. There is also evidence that large woody debris, by providing nutrients and creating favorable habitats such as pools, positively influences the richness and abundance of fish or macroinvertebrates (Robison & Beschta, 1990; Zauner, 1993; Miller et al., 2009). Furthermore, also the terrestrial biota has been linked to hydromorphological variables at a reach-scale level. Tockner (2006) describes a link between total length of river banks per valley length and the abundance of breeding pairs of Waterfowls (for example little ringed plover). At river Tagliamento, one of the last wild braided rivers in the Alps, the density of little ringed plover increases directly with the length of river banks which in natural braided streams amounts to 25 km per valley length of 1 kilometre. *Chorthippus pullus* (Gravel Bank Grasshopper) and *Myricaria germanica* (German Tamarisk) are rare species and thus good indicators of biotic integrity and are frequently found in mid- and side-channel bars, being strongly related to fine sediments and gravel bars with specific inundation frequencies (Reich, 1991; Lawler et al., 2003; Tockner et al., 2006, Gostner et al., 2010).

However, biomass, abundance and diversity of aquatic biota depend not only on physical patterns at the micro-scale level. Macro-scale conditions build the superior frame within which aquatic biota develops. The fish regions for example are conditioned by water temperature, oxygen content, stream power, general substrate composition, etc. (Jungwirth et al., 2003). Landscape characteristics (watershed size, percent forest, average stream width, stream gradient, relief ratio, drainage density and altitude) for example have been found to influence the presence, assemblage structure and biomass of brown trout (Lanka & Hubert, 1987) whereas other studies show that also for macroinvertebrates regional conditions might be more relevant for their local composition than micro-scale patterns (Jähnig et al., 2010).

3.6 River restoration and the reference condition concept

Due to the vital importance to recover lost biodiversity in streams, river restoration throughout the globe has become very popular. The term “stream restoration” is used for a huge and sometimes contrasting variety of activities, even if commonly “restoration” refers to the return of a degraded ecosystem to an approximation of its remaining natural potential, although the more properly term for it would be “rehabilitation” (Shields et al., 2003). From its very beginnings in the 1930s when the USDA Forest service started undertaking “stream improvement” with the intent of increasing salmonid production (Everset & Sedell, 1984), over its broad implementation from the late 1970s (Sear, 1994) stream restoration has gained enormously in popularity (Wheaton, 2004) accomplishing important steps.

During the last decades stream restoration has become an integrated, comprehensive, interdisciplinary and participative exercise. Several benchmark-settings researchers have defined basic guidelines for realizing ecologically successful river restoration projects. Palmer et al. (2005) define five criteria to be satisfied for ecological success: i) the existence of a guiding image; ii) enhancement of ecological conditions must be a main target; iii) self-sustaining capacity of the stream is better than prior to restoration; iv) no lasting harm is done during the works; v) some level of pre- and post-project assessment is conducted and the information made available. Gregory (2008) refines these five criteria defining six principles emphasizing the dynamic nature of river ecosystems: i) ecological restoration as the design of an ecologically sound future; ii) conservation of healthy components of the ecosystem is the first priority; iii) ecological restoration is based on restoring dynamism; iv) riverine and network based practices must be incorporated; v) river restoration should be conducted within a framework of multiple spatial scales; vi) river management must anticipate future changes. Wohl et al. (2005) proposed two themes to advance the scientific basis for river restoration. First, because natural variability is an inherent feature of all river systems, they hypothesize that restoration of process is more likely to succeed than restoration aimed at a fixed end point. Second, because physical, chemical, and biological processes are interconnected in complex ways across watersheds and across timescales, they hypothesize that restoration projects are more likely to be successful in achieving goals if undertaken in the context of entire watersheds. Brierley & Fryirs (2008) define five geomorphic principles that underpin prospects for genuine river repair: i) respect river diversity; ii) differentiate behaviour and change; iii) frame the trajectory of river adjustment, and responses to human disturbance, in relation to system evolution; iv) appraise system (dis)connectivity; v) determine the potential for river recovery.

To recapitulate, there is almost unanimous consensus that for successful river restoration a watershed scale perspective that considers the complete fluvial landscape is critical (Logan & Furze, 2002; Bannister et al., 2005; Kondolf et al., 2007; Nilsson et al., 2007; Benda et al., 2011).

However, heavy debates among researchers are conducted concerning two contrasting principles: should restoration aim at recovering the form or at recovering the function? Practitioners with a formation in river morphology tend more towards the recovering of a form (Rosgen, 1996) whereas there is a broad group of researchers arguing that the primary target of river restoration must be the recovery of ecological functions (Kondolf et al., 2001; Simon et al., 2007; Palmer, 2008). Other researchers aim at conciliating the concepts stating that to sustainably restore river ecosystems, the processes that create and maintain river channels should be restored, and that these processes can then create the forms (Kondolf et al., 2006).

Two important topics persistent in nearly each framework for river restoration are the concept of the reference condition (Stoddard et al., 2006; Nestler et al., 2010) and of the guiding image (*Leitbild*) (Kern, 1992a; Muhar, 1994; Hughes, 1995; Jungwirth et al., 2002, Palmer et al., 2005). The reference condition of a river is by definition the state that could be obtained by abandoning any form of human interference at rivers and their surroundings. The most ambitious goal of river restoration is to achieve the reference condition again. However, it is rather unrealistic to omit every human action within a river watershed and create states based on historical conditions. That is the reason why it has become good practice to define "restoration objectives" (*Leitbild*) selecting target levels that should be obtained. The definition of the restoration objectives is usually a combination of different methods, as proposed in Jungwirth et al. (2002) or Sommerhäuser & Klausmeier (1999). Figure 3.7 schematically shows the relation between the natural condition of a river system, the reference condition, the restoration potential and the actual state.

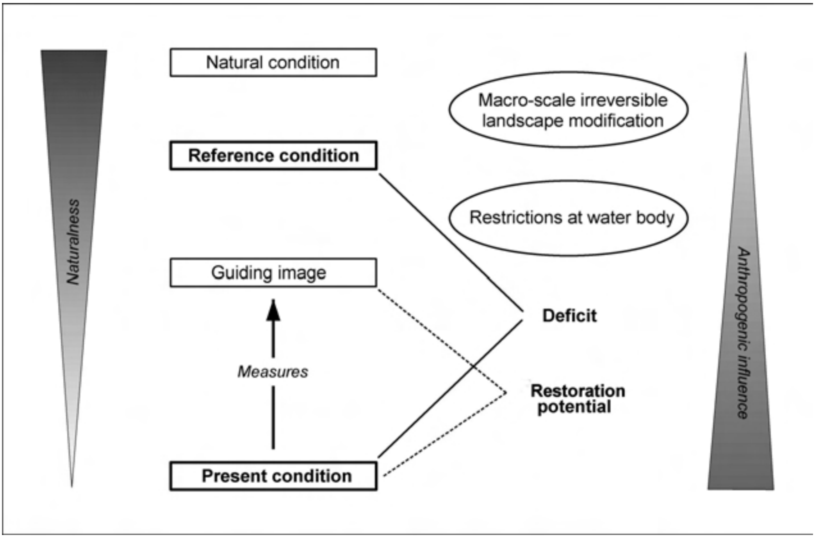


Figure 3.7 Reference condition in relation to the natural condition (pristine status), present condition and restoration potential (BAFU, 2006)

3.7 Methods for stream assessment

Stream assessment is an important tool for river managers. Physical, chemical and biological properties usually are assessed separately. There are two currently favored approaches to stream assessment (Milner & Oswood, 2000; Buffagni et al., 2004):

multimetric and multivariate approaches. Multimetric indices for habitat quality assessment incorporate a variety of abiotic variables that typically include characteristics of both morphological (channel, bank, floodplain) and hydraulic, i.e. flow-related, properties. By means of a scoring system, the hydromorphological status of a stream is then evaluated and, preferably, the scores are subdivided into different classes (Clausen et al., 2004). Variables are qualified using simplified techniques such as visual assessment and overall estimation, rather than quantitative techniques such as surveying, replicated sedimentological particle size analysis and historical interpretation (Parsons et al., 2002).

A vast number of methods are in use in different countries to assess the ecomorphological status of streams: the River Habitat Survey in UK (Raven et al., 2000), the Modular Stepwise Procedure in Switzerland (BUWAL, 1998), the Overview Survey for large rivers and the On-Site Survey focusing on small and medium rivers in Germany (LAWA, 1999; LAWA, 2000a; LAWA, 2000b, Fleischhacker & Kern, 2002), the SEQ Physique in France (Agences de l'Eau & Ministère de l'Environnement, 1998), the Riparian, Channel and Environmental inventory in Sweden (Petersen, 1992), the Index of Fluvial Functioning in Italy (Siligardi et al., 2000), the Australian River Assessment System in Australia (Parsons et al., 2002a, Parson et al., 2002b) and the Qualitative Habitat Evaluation Index (Rankin, 1995) or Bioassessment Protocols in USA (Barbour et al., 1999).

Two important biotic assessment indices to biological monitoring are the river invertebrate prediction and classification system (RIVPACS) (Wright et al., 1991) and the index of biological integrity (IBI) (Karr, 1981). They are described and compared in Karr & Chu (2000). In the European Union the project AQEM, which was carried out from 2000 to 2002, aimed at developing a framework for assessing streams in Europe with benthic macroinvertebrates, thus contributing to fulfilling the requirements of the EU WFD (Hering et al., 2004).

3.8 Assessment of success in river restoration

To know the effects of river restoration projects, to eventually detect shortcomings and errors and to improve constantly the expertise in this discipline post-project appraisal are warmly recommended (Palmer et al., 2010). Assessments of river restoration have observed large numbers of projects, but many lack explicit monitoring goals (Bernhardt et al. 2005). Nevertheless, there is growing body of studies that, based on fish response or macroinvertebrate assessment investigate pre- and post-projects and, in part comparing it to control sites, evaluate the ecological success of stream restoration projects.

Several studies in the last decade (Larson et al., 2001; Negishi & Richardson, 2003; Moerke et al., 2004; Lepori et al., 2005; Jähnig et al., 2009; Palmer et al., 2010) demonstrate that restoring physical heterogeneity alone might be insufficient for recovering biotic quality. Some site-specific studies report significant success (Zauner, 1993), others partial success (Roni et al., 2006), after the placement of instream structures such as large wood or boulders. By identifying 53 peer-reviewed studies and carrying out meta-analysis for 24 of them, Miller et al. (2009) showed that increasing habitat heterogeneity had significant, positive effects on macroinvertebrate richness, although density increases were negligible. Large woody debris additions produced the largest and most consistent responses, whereas responses to boulder additions and channel reconfigurations were positive, yet highly variable.

3.9 Prediction of habitat: simulation models and integrated approaches

Important tools to predict consequences of hydromorphological modifications on aquatic biota are habitat simulation models. These models were originally developed when anthropogenic changes in flow regime (mainly water withdrawal for hydropower generation) are suspected to affect biota. An increasing use to predict changes in habitat due to morphological modifications within the frame of river restoration project can be observed.

An exhaustive overview of current habitat simulation models is given in Conallin et al. (2010). The models mostly applied are:

- Habitat suitability models (Stalnaker et al., 1995; Bovee et al., 1998): At the base of these methods lie species-specific preference curves (see Chapter 3.5.3) in relation to single habitat-related factors such as ranges in flow velocity, water depth, substrate or near bed-conditions. By combining these preference curves with a hydraulic model habitat suitability indices (HSI) and weighted usable areas (WUA) can be derived and recommendations for residual flow allocations or a specific morphological design given.
- Fuzzy rule-based modelling: Instead of using preference curves fuzzy rule-based modelling uses “If-Then” rules that are more flexible with biota suitability. In

Central Europe, the fuzzy-based model Casimir (Jorde et al., 2000) in the last years finds more and more application.

- Generalized habitat models are also proposed as alternative to conventional hydraulic-habitat modelling approaches (Lamouroux & Jowett, 2005). These models obtain reach scale habitat values based on a limited number of field measurements and are particularly valuable for large-scale assessments or when only few reach data are available (Conallin et al., 2010).
- MesoHabSim (Parasiewicz, 2001, Parasiewicz, 2007a, Parasiewicz, 2007b) is a habitat simulation model that changes the scale of physical parameters and biological response assessment from micro- to meso-scale. Microhabitat surveys are replaced by mesohabitat mapping of whole-river sections and therefore it matches the scale of restoration measures. Furthermore, logistic regression instead of preference curves is applied to describe fish habitat use in relation to the environmental attributes, whereby aquatic biota is represented rather by community than by single species.
- The conceptual mesohabitat evaluation model (Hauer et al., 2009) considers bioenergetic phenomena by including drift-feeding processes into numerical microhabitat modeling by deriving a new suitability parameter for drift feeding using relationships of sources and sinks for benthic drift.

Some further developments, such as the Lotic-Invertebrate Index for Flow Evaluation LIFE (Extence et al., 1999; Dunbar et al., 2010), attempt to deliver an integrated vision of hydrological and morphological modifications. However, these methods also are primarily focused on the hydrology of streams and therefore best applicable for studies of altered flow regimes.

3.10 Classification of HMID within fluvial sciences

The Hydro-Morphological Index of Diversity (HMID) aims at filling a gap in the row of already available methodologies applied at different stages of restoration projects: from assessing the initial condition of a degraded stream to planning the measures most adequate for the system and finally evaluating the success of the conducted restoration (see Figure 3.1 and Figure 5.1). At a first glance it might seem a competitor to habitat simulation models. However, Chapters 5 to 7 expose in detail the scopes, purpose and aims of the HMID.

4 Project approach

4.1 In general

The basic idea for the project was that observing streams with contrasting morphology, patterns in hydromorphological variables could be detected which, molded in the correct mathematical formula representing an Hydro-Morphological Index of Diversity (HMID), are able to characterize hydromorphological heterogeneity of stream reaches. Inverting the argument, such an index could constitute a tool for ecologically successful habitat rehabilitation in river engineering projects. To know the differences in hydromorphological variables between morphologically contrasting sites, three gravel bed rivers in Switzerland were chosen where the hydrological regime is unaltered and also the sediment regime seems to be in a quasi-equilibrium state. Therefore, confounding effects due to a strongly modified hydrological or sedimentological regime could be excluded.

The selected streams were the river Bünz, the river Venoge and the river Sense. At each stream morphologically contrasting reaches were chosen to be studied. Whereas at river Bünz and Venoge the investigations are distinguished more by a “pilot”-character, river Sense was the main object of the study. However, also data collected at river Bünz and Venoge were useful for the development of the HMID. The following sections describe briefly the working steps that have been conducted for the present project.

4.2 Field work

At river Bünz (see photos in Appendix A) four sites with the following characteristics have been chosen with numbering order in flow direction (for key data see Table 5.1):

- B1: a channelized reach with a slight curvature that has been restored in the last decade over a length of 1.5 km. Woody debris and logs have been introduced as instream structures to diversify habitat heterogeneity. The slope of the left bank has been reduced and the riparian strip enlarged.
- B2: a straight trapezoidal channel having steep regular banks with the same slope on both sides. The river bed is stabilized with the so-called Turnherr system, which are transversal concrete sills placed in a regular distance of about 20 m. The bank toe is protected by a strip of concrete with a height of around 20 cm.

- B3: a natural stream reach with the exception of some local river training works carried out in the 1930s for bank stabilization. The reach is slightly meandering with a wide spectrum of hydromorphologic units (riffles, pools, runs, backwater areas).
- B4: This stream reach shows a braided morphological pattern with gravel banks being active parts of channel avulsion processes occurring at flood events. River banks are varied ranging from steep undercut banks held by cohesive material to flat gravel banks. The reach has been built destroying an engineered reach during a major flood in 1999.

Also at river Venoge four sites have been chosen to be investigated:

- V1: a naturally straight channel, where hydraulic variability is high due to step-pool respectively riffle-pool sequences. The river bank is naturally steep with frequent undercut banks, flanked by a small riparian vegetative buffer on both sides.
- V2: a straight channelized channel with a trapezoidal profile. Hydraulic variability is very low as flow is approximately uniform.
- V3: also this reach is channelized. However, hydraulic variability is slightly more pronounced than at V2 as the river bed exhibits some irregularities.
- V4: a natural reach with flat slope meandering through an alluvial forest, showing typical hydromorphologic units for meandering reaches (deep pools with undercut banks on the outer banks, flat slopes with deposits of fine material at the inner banks). Pools are connected by riffles, thus hydraulic variability is evidently high.

At river Sense 5 sites have been selected for the study:

- S1 is characterized by a braided system with a distinct main channel and several secondary channels. Mid channel and side bars with distinct elevations give home to a diverse terrestrial flora and fauna. The complete spectrum of common hydromorphologic units such as pools, riffles, runs, glides and backwater zones offering a huge range of flow depths and velocities and diverse combinations of them can be observed.
- S2 is situated in an incised limestone bedrock gorge where the river Sense is flowing as a single thread channel with locally limited braiding patterns and sharp flow direction changes. Cut-off channels present along the intersection between the active flood plain and the side walls demonstrate that geomorphic activity is hindered by the naturally present lateral confinements. At mean flow stage the diversity of aquatic habitats is high with a continuous succession of riffles and pools as well as

the presence of backwater areas and side channels with low flow velocity and shallow water depth.

- S3 is similar to site S1: diversity and abundance of terrestrial and aquatic patches is high. However, at the upstream end of the site a large road bridge is situated. It doesn't span over the entire width of the valley thus the abutments of the bridge cause a bottleneck for the river. Moreover, at this site the right bank is protected by a row of large natural or artificially produced boulders. Consequently, site S3 is to be interpreted as a minimally altered natural site.
- At S4 river Sense has been trained with a protection of the right bank by a rip-rap consisting of concrete cuboids. At mean flow stages sparsely vegetated alternating gravel bars are present, during flood events the migration of the gravel bars and the main channel can be observed. Runs and glides are the prevalent hydromorphologic unit, diversity of habitats is limited to the local occurrence of riffles and pools.
- S5 is a characterized by a trapezoidal profile with steep river banks on both sides formed either by gabions or rip-rap. Gravel bars are almost absent, at mean flow the whole river bed is wetted. Flow is almost uniform with runs as the solely hydromorphologic unit present, with the exception of three block ramps where flow is highly non uniform with fast flow velocity in the central area of the ramp, slow velocity at the side and a deep pool present at the toe of the ramp.

At all three study sites during mean flow stages at predefined transects flow velocity and water depth were measured in wadeable conditions. Spacing between each survey point varied between 50 and 200 cm. The distance between transects was between 5 and 100 m depending on site morphology (Table 5.1). The location of transects was chosen to comprise all the hydromorphologic units present at a site, thus the total number of transects, with a minimum of 7 and a maximum of 19, varied depending on the degree of alteration of each site. Flow velocity was obtained by measuring the velocity at six-tenths of depth using either an acoustic Doppler velocity meter (SonTek FlowTracker Handheld ADV) or an electromagnetic flow meter (Ott Nautilus Flow Sensor C2000).

Moreover, at river Sense the following abiotic data have been collected (see also Appendix B):

- A thalweg survey;

- Substrate sampling along each cross section, according to the pebble count method (Wolman, 1954);
- Records of bankfull height on both banks by means of a measuring rod;
- Investigation of large woody debris (LWD) volumes by measuring the circumference and height of LWD accumulations;
- A detailed temperature measuring campaign along the transects to analyze spatial variability at two different stages of the season;
- Finally, a detailed topographic survey using either a theodolite or a first order GPS station was conducted. Along the transects the survey comprised the whole river bed and its banks, including parts that were not wetted, in order to determine river bed elevation, wetted width, top and bottom of channel banks, bankfull stage, terrace elevations and any additional visual breaks along the cross sections. Additionally, to provide a dense and reliable terrain data cloud for the numerical modelling the topographical survey was completed by surveying perimeters, break lines and extreme elevations of gravel banks, islands, large woody debris accumulations and other distinctive features.

For each point at river Sense with records of hydraulic variables, Reynolds and Froude numbers as well as bottom shear stress were calculated.

In parallel to the present work and within the frame of the “Integrated River Management” project, biotic characteristics were recorded by means of macroinvertebrates sampling (see chapter 5). Moreover, at S3 of river Sense a digital photocamera, overviewing around 50 % of the whole site length takes at an hourly frequence an image creating a photo series showing modifications of river bed morphology. The camera has been installed by VAW (ETH Zürich) by April 2009 and is still in operation.

4.3 Statistical elaboration and formulation of HMID

Based on the data of the river Sense, statistical analysis with R 2.11.1 (R Development Core Team, 2010) were conducted to test correlations between hydraulic and geomorphic variables and reduce their number to a minimum sufficient to describe the reach condition in terms of hydromorphology. The HMID was then formulated by combining the identified key variables that best describe hydromorphological condition of a given site. Based on correlation analysis, flow velocity and water depth were identified as key variables sufficient for describing the hydromorphological heterogeneity of a stream reach.

Moreover, also a correlation test between the HMID and a visual habitat assessment method (RBP, Barbour et al., 1999) was conducted. In addition, relationships between HMID and biotic diversity indices were tested (see Chapter 5).

4.4 Numerical modelling

For the study reaches at river Sense (see Chapter 6 and Chapter 8) and for the applicative case (see Chapter 7) numerical modelling was carried out. The purpose of numerical modelling was twofold:

- A field survey is like a snapshot and reflects the record for a determined discharge. Numerical modelling allows to investigate the patterns of hydraulic variables for any desired discharge and therefore to analyze temporal variability without a gigantic effort that would be necessary for field records.
- Numerical models, if elaborated in a thorough manner, nowadays are able to generate accurate results. They also reflect the physical reality more reliably as they see the stream more as a continuum, whereas field works are more transect-orientated and therefore rather one-dimensional.

4.5 Application of HMID

To test the applicability of the HMID in practice, a case study based on a real situation has been carried out (Chapter 7). The case study starts from a present, morphologically heavily degraded status and defines three distinct project alternatives for habitat enhancement. A numerical 2D-model allows to obtain the hydraulic variables flow velocity and water depth for each grid cell of the computing domain. By running the model for different flows and calculating the HMID spatial and temporal variability of hydraulic habitats are shown for the different project alternatives.

The case study demonstrates that the HMID can be a valuable tool in river engineering projects when enhancement of habitat heterogeneity is one of the project targets. However, for sustainability and long-term successful projects it is essential to properly evaluate geomorphic processes at the watershed scale.

5 The hydro-morphological index of diversity: a predictive tool for habitat heterogeneity in river engineering projects

Abstract: A new Hydro-Morphological Index of Diversity (HMID), a predictive tool aimed for use in river engineering projects, is presented. For the development of the index, field work with extensive data collection was carried out, correlation analysis with hydromorphological variables conducted, the HMID formulated and the correlation between HMID and a visual habitat assessment method as well as biotic metrics analyzed. Using the variability of flow velocity and water depth allows one to sufficiently represent the hydromorphological heterogeneity of a stream site. Based on numerical modeling, the HMID can easily be calculated for comparison of different alternatives in river engineering projects and thus achieves predictive power for design decisions. HMID can be applied in engineering programs involving geomorphic measures that aim at the enhancement of habitat heterogeneity of a stream.

Keywords: Hydromorphology, physical heterogeneity, gravel bed rivers, predictive tools, benthic diversity

5.1 Introduction

Riverine landscapes are acknowledged hotspots of biodiversity (Allan & Castillo 2007) that not only fulfill a number of important ecological functions, but are also of high relevance at economic and social scales. However, extensive anthropogenic exploitation of streams for water use and waste disposal, altered land-use in their watersheds as well as modification of stream morphology using traditional engineering methods, exert a multitude of pressures on stream ecosystems. In particular, river channelization has pronounced negative effects on river biota, while frequently failing to reach the initial goal of flood protection. The resulting major degradation of many streams today poses a significant threat to stream ecosystem health and stability (Malmqvist & Rundle, 2002; Jungwirth et al., 2003;Vörösmarty et al., 2010).

Policy makers have recognized the need for both sustainable flood protection management and the recovery of lost biodiversity in streams. In the European Union, the Flood Risks Directive (FRD), on the one hand, indicates a clear paradigm shift by defining flood risk management plans with a view to giving rivers more space by considering the maintenance and restoration of floodplains (European Commission, 2007). On the other hand, the Water Framework Directive (WFD) urges the member states to protect, enhance and restore all surface water bodies, with the aim of achieving good ecological status (European Commission, 2000). A comprehensive vision of these two landmark directives implies that in today's river engineering projects not only flood protection measures must be designed in a proper way, but also the potential for ecological improvement should be identified and appropriate measures defined to best obtain this target.

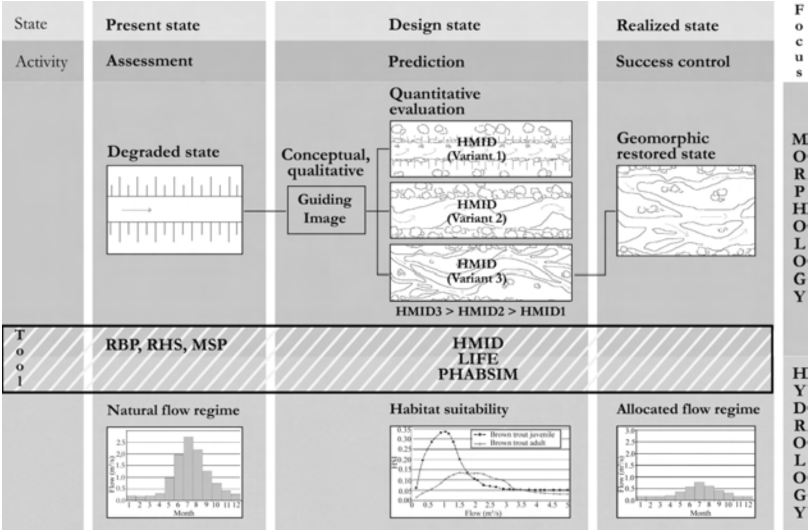


Figure 5.1 Reach-related process flow diagram of thematic and temporal actions in river restoration with indication of methods and tools currently applied.
Note that PHABSIM here stands for hydraulic habitat simulation tools that casually are also used for the same purpose as HMID. RHS (river habitat survey), RBP (rapid bioassessment protocol) and MSP (modular stepwise procedure) are indicated as examples for visual habitat assessment). LIFE (Lotic Invertebrate Index for Flow Evaluation) stands for methods aiming at a comprehensive vision integrating hydrological and morphological traits.

As homogenization of physical habitat is widely assumed to be the most significant threat to biodiversity and ecosystem functioning (Allan & Castillo, 2007), rehabilitation of hydromorphological diversity, in combination with flood protection measures, is now one of the key topics in the field of river restoration. Hence, the impacts of habitat degradation on river biota are receiving increasing attention (Vaughan et al., 2009; Armanini et al., 2010; Dunbar et al., 2010), whereas the majority of river restoration projects are conducted under the assumption that restoring physical habitat will increase biodiversity (Miller et al., 2009). Nevertheless, numerous studies in the last decade (Larson et al., 2001; Negishi & Richardson, 2003; Moerke et al., 2004; Lepori et al., 2005; Jähnig et al., 2009; Palmer et al., 2010) demonstrate that restoring physical heterogeneity alone might be insufficient for recovering biotic quality. These failures occasionally are attributed to other factors, thereby overwhelming hydromorphological diversity. However, the knowledge for planning of hydromorphological measures in an appropriate way to enhance the ecological potential of a stream reach still offers large room for improvement.

Therefore, adequate and easy-to-use tools are needed to design projects in a way to provide the best possible potential for ecological recovery. The Hydro-Morphological Index of Diversity (HMID) offers such a tool, aiming at filling a gap in the row of already available methodologies applied at different stages of restoration projects: from assessing the initial condition of a degraded stream to planning the measures most adequate for the system and finally evaluating the success of the conducted restoration (see Figure 5.1).

A vast number of methods are in use in different countries to assess the ecomorphological status of streams: the River Habitat Survey in UK (Raven et al., 2000), the Modular Stepwise Procedure in Switzerland (BUWAL, 1998), the Overview Survey for large rivers and the On-Site Survey focusing on small and medium rivers in Germany (LAWA, 1999; LAWA, 2000a; LAWA, 2000b, Fleischhacker & Kern, 2002), the SEQ Physique in France (Agences de l'Eau & Ministère de l'Environnement, 1998), the Riparian, Channel and Environmental inventory in Sweden (Petersen, 1992), the Index of Fluvial Functioning in Italy (Siligardi et al., 2000), the Australian River Assessment System in Australia (Parsons et al., 2002a, Parson et al., 2002b) and the Qualitative Habitat Evaluation Index (Rankin, 1995) or Bioassessment Protocols in USA (Barbour et al., 1999). Frequently these methods use standardized multimetric indices that incorporate a variety of abiotic variables. These typically characterize both geomorphic (usually including channel, bank and floodplain) and hydraulic properties, and thus allow the highly multivariate nature of riverine physical habitat to be assessed, quantified and summarized (Dunbar et al., 2010). Often the variables are classified using simplified techniques such as visual assessment and overall estimation, rather than quantitative techniques (Parsons et al., 2002a). Indices based on such qualitative assessment have no predictive ability, their objective being to assess the present physical status of streams. These assessment methods are also applied to evaluate the hydromorphological success of rehabilitation measures by comparing the physical status before and after project execution (e.g. Woolsey et al., 2007).

At the design stage of river engineering projects, the step after the assessment of the initial condition of a stream and where a strictly perceived hypothetical target status is imagined, a “guiding image” (Kern, 1992b) is normally formulated describing a dynamic, ecologically healthy river that could exist at a given site (Palmer et al., 2005). The guiding image should consider the range of the key system variables and recognize human-induced changes to the system (Jungwirth et al., 2002) in order to define a potential for restoration that realistically can be achieved. However, a guiding image represents primarily a conceptual and therefore rather qualitative framework upon which project outlines, frequently oriented by a reference status with the focus on an achievable geomorphic form, can be defined and rehabilitation measures put into practice (Jungwirth et al., 2003).

In lotic research, many previous efforts have been put into the development of predictive methods aiming at modelling freshwater biota response to modification of the hydrological regime. Hydraulic-habitat models, e.g. PHABSIM (Bovee et al., 1998), CASIMIR (Jorde et al., 2000) or MesoHabSim (Parasiewicz, 2001), are mostly used (Conallin et al., 2010) when anthropogenic changes in flow regime (e.g. hydropower, water abstraction) are suspected to affect biota (Gibbins & Acornley, 2000). At the base of these methods lie species-specific preference curves in relation to single habitat-related factors such as ranges in flow velocity, water depth, substrate or near bed-conditions (Statzner et al., 1991; Schmedtje, 1996; Jowett, 1997; Zappia & Hayes, 1998; Lamouroux et al., 1998; Armstrong et al., 2003; Lamouroux & Jowett, 2005). By calculating habitat suitability indices for target species under different scenarios of flow regime management, ecologically acceptable instream flow allocations can be negotiated and prescribed. These hydraulic-habitat models are sometimes also applied in cases when modifications of morphological conditions are planned and the change of the flow regime is not the focus (Alfredsen et al., 2004; Boavida et al., 2011). However, these models are rather time consuming and their predictive power strongly dependent on the use of appropriate preference curves (Conallin et al., 2010). Some further developments, such as the Lotic-Invertebrate Index for Flow Evaluation LIFE (Extence et al., 1999; Dunbar et al., 2010), make an attempt to deliver an integrated vision of hydrological and morphological modifications. However, these methods also are primarily focused on the hydrology of streams and therefore best applicable for studies of altered flow regimes (Monk et al., 2008; Buffagni et al., 2009; Armanini et al., 2010).

The intention of the presented Hydro-Morphological Index of Diversity (HMID) is not to replace already proven approaches and methods. As it will be demonstrated, the approach is distinguished from other methods by the following characteristics:

- as a predictive tool, it can be used during the design to evaluate and compare the effects of different river engineering project alternatives, whereas ecomorphological assessment methods have been developed to appraise a physically existing status;
- it allows a quantitative statement concerning the improvement of physical heterogeneity of studied project alternatives and can therefore be a valuable supplement for the execution of measures defined within the frame of a qualitative guiding image;
- its focus is on geomorphic measures aiming at enhancing physical diversity, in contrast to hydraulic-habitat models that prevalently evaluate anthropogenic changes of flow regime in order to allocate instream flow;
- in contrast to habitat simulation models, which are often complex and time-consuming, HMID, based on numerical modelling, is straightforward and delivers clear quantitative statements, while requiring rather low effort.

Many researchers have stressed the importance of variance for ecological processes (Palmer et al., 1997). HMID was developed for river restoration projects in which increasing variance of the hydromorphological mosaic framework for spatial complexity, is a key target. A growing body of research suggests that spatial complexity of the channel and river corridor is critical for ecosystem integrity at different scales (Thoms, 2006; Elosegi et al., 2010) and that diversity and productivity of stream food webs are related to habitat heterogeneity (Negishi & Richardson, 2003). The riverine ecosystem synthesis concept (RES, Thorp et al., 2006) predicts that biodiversity, system metabolism, and many other functional processes are enhanced by habitat complexity and that biocomplexity should be greater in functional process zones that are more hydrogeomorphically complex than in simpler river segments (Thorp et al., 2010).

This article describes how the HMID was developed. An extensive field campaign on three pre-alpine gravel bed rivers in Switzerland was conducted, and correlations between hydromorphological variables were analyzed. It was also tested if the HMID approach and other visual ecomorphological assessment methods lead to similar results at the same study sites. Additionally, to test for a direct link between hydromorphological and biotic characteristics, we investigated the relationship between HMID and zoobenthic diversity at the study sites was investigated; zoobenthos being an organism group typically used as an indicator for ecosystem health in stream assessment.

5.2 Methods

5.2.1 Site selection and description

We selected three Swiss pre-alpine streams for collecting data to develop the HMID (Figure 5.2, Table 5.1). Buenz, Venoge and Sense are gravel-bed alluvial streams characterized by a pluvial to nivo-pluvial hydrological regime. The hydrological regime of all study streams is mostly unaltered. The exception is a minor water withdrawal at the Venoge upstream of the V1 site. Also, a small run-of-the-river hydropower station, situated downstream of the B1 site in the Buenz, with a length of the residual reach of around 100 m, causes occasional unnatural fluctuations of discharge due to flushing of the reservoir on average once per year. A high variability of morphological conditions is present along each stream, ranging from braided, near-natural meandering or straight to partially or totally channelized as well as to partially restored reaches.

Figure 5.2 Location of the study rivers.

River Buenz		**B1**	**B2**	**B3**	**B4**
Morphological identification		restored, previously channelized	channelized	natural, gently meandering	braided, emerged after a flood
Elevation	(m)	407	387	384	373
Gradient	(%)	0.15	0.3	0.75	1.5
Site length	(m)	140	55	115	150
No. of transects		10	7	12	15
Mean spacing between transects	(m)	16	9	10	11
Surveyed points		177	66	209	436
Mean wetted width	(m)	8.7	5.2	9.7	15.1
Survey discharge	(m³/s)	0.68	0.84	0.84	0.98
Survey specific discharge	(l/s,km²)	7.5	7.5	7.5	7.5

River Venoge		**V1**	**V2**	**V3**	**V4**
Morphological identification		naturally straight	channelized	channelized	naturally meandering
Elevation	(m)	621	465	440	395
Gradient	(%)	NA	NA	NA	NA
Site length	(m)	60	40	80	120
No. of transects		12	8	8	12
Mean spacing between transects	(m)	5	5	10	10
Surveyed points		112	152	113	167
Mean wetted width	(m)	4.6	9.6	7.0	13.5
Survey discharge	(m³/s)	0.69	2.41	2.69	3.99
Survey specific discharge	(l/s,km²)	19.0	19.0	19.0	19.0

River Sense		**S1**	**S2**	**S3**	**S4**	**S5**
Morphological identification		naturally braided	naturally meandering in a gorge	naturally braided, right bank protected	partially trained, rip-rap on right bank	Channe-lized
Elevation	(m)	827	760	646	558	531
Gradient	(%)	1.8	1.3	1.2	0.5	0.7
Site length	(m)	1850	770	620	685	940
No. of transects		19	17	19	14	14
Mean spacing between transects	(m)	100	48	25	53	72
Mean wetted width	(m)	21.2	16.1	24.8	15.6	24.9
Mean bankf. width	(m)	127.3	65.6	103.4	40.9	29.0
Surveyed points		310	202	249	135	216
Survey discharge	(m³/s)	2.30	2.93	3.19	5.65	5.81
Survey specific discharge	(l/s,km²)	19.5	19.5	18.2	17.6	16.3

Table 5.1 Characteristics of study sites.

The River Buenz is a 3rd order pre-alpine river with a catchment area of 111 km² that flows into the River Aare (Rhine drainage). It was channelized to a different extent along most of its length in the 1930s and flows mainly through agricultural areas. Several restoration projects have been conducted at the Buenz in the last two decades.

The River Venoge is a 3rd order river with a catchment area of 238 km^2 and flows directly into Lake Geneva (Rhone drainage). In its headwaters, the River Venoge flows through relatively steep agricultural areas, being a naturally straight channel. Along the middle course, crossing a highly urbanized and industrialized area, it has been channelized to a high degree, whereas in its downstream part it runs as a meandering river through a flat alluvial forest.

The River Sense is a 4th order river draining a watershed of 432 km^2 and is a tributary of the River Saane (Rhine drainage). For its prevailing part, the River Sense is unregulated: around 23 km of the total 35 km of the main stem length of the River Sense are mostly in a morphologically pristine status. Moreover, the riparian corridor provides home to the longest alluvial forest conserved in the country. For most of its length, the river flows through agricultural landscape, with the exception of the headwaters being characterized by a natural mountainous setting. Being the least affected by other human-induced stressors, Sense had the highest potential for revealing relationships between benthic diversity and morphological heterogeneity.

5.2.2 Measurement of hydromorphological variables

At each stream, sites of contrasting morphology for hydromorphological measurements and benthic sampling (Figure 5.3 and Figure 5.4) were selected, and data collection carried out at predefined transects during mean flow stages. The distance between transects was between 5 and 100 m depending on site morphology (Table 1). The location of transects was chosen to comprise all the hydromorphological units present at a site, thus the total number of transects, with a minimum of 7 and a maximum of 19, varied depending on the degree of alteration of each site. Spacing between survey points along each transect varied between 50 and 200 cm. At each survey point, water depth and mean flow velocity were measured. The latter was obtained by measuring the velocity at six-tenths of depth using either an acoustic Doppler velocity meter (SonTek FlowTracker Handheld ADV) or an electromagnetic flow meter (Ott Nautilus Flow Sensor C2000). Moreover, at the River Sense, a thalweg survey and surface substrate sampling along each cross section was carried out, the latter according to the pebble count method (Wolman, 1954). Finally, along the transects a detailed topographical survey over the whole river bed comprising the banks was conducted, using either a theodolite or a first order GPS station, that allowed determination of river bed elevation, wetted width and width at bankfull depth.

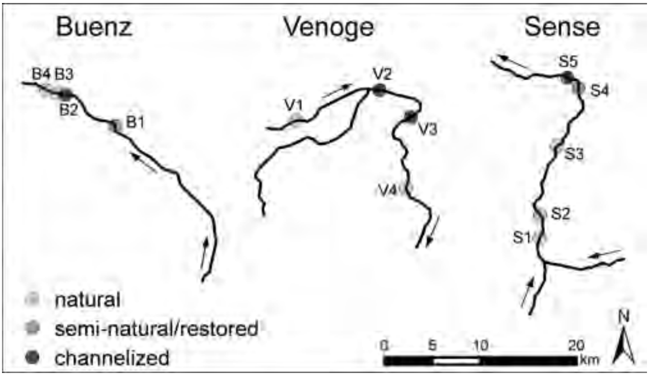


Figure 5.3 Location and morphology of study sites.

Figure 5.4 Examples of the study sites. Left: Channelized study site at river Buenz (B2). Right: Braided and morphologically pristine study site at river Sense (S1).

For each survey point, also Reynolds and Froude numbers that have been used in different studies as descriptors in preference curves for fishes (Heede & Rinne, 1991; Bisson et al., 1998; Bates, 2000) were calculated. Reynolds number in its simplified form writes

$$\mathrm{Re} = \frac{\mathrm{v} \cdot 4 \cdot \mathrm{h}}{\nu} \tag{5.1}$$

with v = mean column flow velocity, h = water depth, ν = cinematic viscosity of water (usually set at $1.3 \cdot 10^{-6}$ m²/s), whereas Froude number is expressed as

$$Fr = \frac{v}{\sqrt{g \cdot h}} \tag{5.2}$$

where v = flow velocity, h = water depth, g = gravitational acceleration. Moreover, bottom shear stress that represents near-bed conditions which is considered a key hydraulic factor for river benthos (Minshall, 1984; Statzner et al., 1988) was calculated. Point bottom shear stress was calculated using

$$\tau = \left(\frac{v}{5.75 \cdot \log\left(\frac{12 \cdot h}{k_s} \right)} \right)^2 \cdot \rho \tag{5.3}$$

where v = mean column flow velocity, h = water depth, k_s = equivalent sand roughness, ρ = specific weight of water. This formula represents the approach of Nikuradse (1923), with equivalent sand roughness expressed as $k_s = 2 \cdot D_{65}$ (proposed by Engelund & Hansen, 1966), where D_{65} = diameter for which 65% of sediment by weight is smaller.

5.2.3 Benthic sampling

We used a standard semi-quantitative method for sampling zoobenthos at rivers Sense and Buenz (BUWAL, 2005; Stucki, 2010). The data from Venoge (collecting following the same methodology) was kindly provided by the local authorities. At each site, macroinvertebrates were collected by kick-sampling during 4-5 min, whereby the sampling time was distributed between different mesohabitats proportionately to their respective surface ratio in the stream stretch. To exclude the effect of seasonal fluctuations in benthic composition, the sampling was conducted at least 2 times at each site: in spring and early summer at the Rivers Buenz and Venoge and in late summer at the River Sense. Macroinvertebrates were stored in 70% ethanol, then handpicked from each sample using a dissecting microscope at 10x magnification, identified to lowest practical taxonomic unit (usually genus or family), and counted.

5.2.4 Correlation analysis of hydromorphological data to select variables for HMID

Physical descriptors of the abiotic environment in riverine landscapes are highly interdependent and characterized by complex and not yet fully understood cross-correlations and confounding effects at different spatial scales (Graham, 2003). However, it is known that channel form and flow are inseparably associated (Elosegi et al., 2010) and that a combination of these two factors produces the physical habitat for instream biota (Maddock, 1999). Based on the data of the river Sense, statistical analysis with R 2.11.1 (R Development Core Team, 2010) was carried out to test for the correlations between hydraulic and geomorphic variables and reduce their number to a minimum sufficient to describe the reach condition in terms of hydromorphology. The HMID was then formulated by combining the identified key variables that best describe hydromorphological condition of a given site.

For the correlation analysis, various metrics were considered at two different levels. The first one, hence denoted as point-related, concerned correlation analysis of variables measured or calculated for single survey points. This approach was applied to the hydraulic variables flow velocity, water depth, shear stress, Froude and Reynolds number. The second level, referred to as reach-related, was applied for geomorphic and hydraulic variables that express overall diversity at a reach scale. For describing the reach-scale spatial diversity of flow velocity, water depth and of substrate characteristics, the coefficient of variation (CV = standard deviation σ /mean μ) was used. It adjusts the sample variance by the mean and thus is a better comparative measure of variability than variance alone (Schneider, 1994). The statistical parameters μ, σ and CV of flow velocity, water depth and grain size distribution were calculated out of a single data set per site and per variable, where the data recorded along the transects were pooled.

The reach-related spatial diversity of the geomorphic conditions was characterized by determining diversity on the longitudinal axis by analyzing the thalweg profile (thalweg diversity TWD) and on the transversal axis along the transects (Cross section diversity CSD). In a more natural reach, slopes are expected to continuously change along the thalweg profile are due to the presence of riffle-pool sequences and thus result in a higher thalweg diversity, whereas in a channelized reach, slope along the thalweg profile is relatively uniform. TWD was determined by equation

$$\mathrm{TWD} = \frac{\sum\limits_{i=2}^{n} |\Delta Z_i|}{\sum\limits_{i=1}^{n-1} W_i} \tag{5.4}$$

with

$$\Delta Z_i = Z_{i-1} - (S_{i-2} \cdot W_i) - Z_i \tag{5.5}$$

where ΔZ_i = height difference between the survey point height and the theoretical height calculated as if the slope from the thalweg differential immediately upstream would remain equal, S_i = Slope of the i-th thalweg differential element, Z_i = heigth of the i-th thalweg point record, W_i = distance between i-th and following point record. For each survey point the height difference between the real point height and the theoretical height calculated as if the slope from the thalweg differential immediately upstream remained equal (see McCormick, 1994; Beck, 1998) was defined (Figure 5.5). TWD represents a normalization as the absolute values of the single height differences were summed and divided through the total length of the thalweg profile.

CSD of each study site was calculated similarly to thalweg diversity using the equation

$$\mathrm{CSD} = \frac{\sum\limits_{i=2}^{n} |\Delta Y_i|}{\sum\limits_{i=1}^{n-1} X_i} \tag{5.6}$$

with

$$\Delta Y_i = Y_{i-1} - Y_i \tag{5.7}$$

where ΔY_i = height difference between two consecutive point records along the transect, X_i = distance between i-th and following point record along the transect (Figure 5.5). Also CSD represents a normalization as the height differences between the recorded points along the transects were summed up and divided by the total length of the considered part of the transect. Two types of CSD were calculated: the CSD related only to the wetted part of the transect and the CSD related to the active river bed omitting the river banks as they might be strongly artificial and therefore distort the calculation.

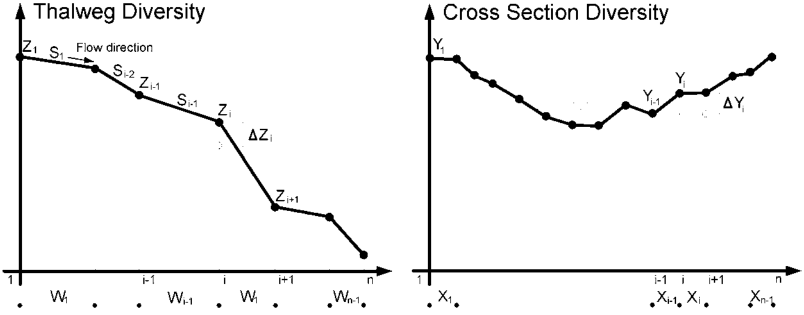


Figure 5.5 Explaining figure for calculation of thalweg and cross-section diversity

An additional geomorphic measure was introduced for the width of each study site by calculating the mean ratio between the wetted width and width at bankfull depth.

Point-related metrics revealed that within hydraulic variables there is a strong correlation of flow velocity with more complex hydraulic metrics such as shear stress, Froude and Reynolds number (Table 5.2). In contrast, correlation between flow velocity and water depth was weak. High velocity in fact could be found at both low water depth (e.g. in riffles) and in medium to high water depth areas (e.g. in runs). Low flow velocity, on the other hand, was generally present in areas with high water depth (e.g. in pools), but also appeared in shallow backwater zones.

Reach-related analysis generally revealed strong correlations between geomorphic and hydraulic diversity (Table 5.3). CV of flow velocity showed strong and significant correlation to each of the applied geomorphic metrics, except to CSD limited only to the wetted part of the transect. Water depth diversity behaved similarly, though showing slightly weaker correlations than flow velocity with the other variables. Moreover, correlation within geomorphic measures also was strong, again with the sole exception of the CSD limited to the wetted part, which therefore might be not a good measure for geomorphic diversity. This can be attributed to the fact that even at natural sites with large river beds, the wetted part at certain locations might periodically consist of a single channel where flow during ordinary flow stages shapes the channel to a quite regular section, whereas cross section diversity in its whole remains high due to irregularities at secondary channels formed during bed reshaping events, gravel bars and other geomorphic features. The latter thus is considered a more reliable descriptor of stream-bed diversity.

Strong correlation was found between the reach-related diversity of bed sediment and flow velocity (Table 5.3): at natural sites the substrate mosaic was much more variable than at channelized sites. Fine sediments are to be found in areas with relatively low conveyance, e.g. in the stream shadow of vegetation, large woody debris or boulder clusters or at different locations in pools. In contrast, cobbles of large diameter were associated with riffle zones. At channelized sites where diversity of flow velocity was low, the heterogeneity of bed sediments was restricted, characterized by a complete absence of clay and silt.

Finally, streams with high geomorphic and hydraulic diversity were characterized by a low ratio between wetted width during mean flow stage and wetted width at bankfull flow – an indication of importance of active parafluvial zones (sensu Lorang & Hauer, 2006) for streams with natural morphology. This metric was also significantly correlated with the diversity of flow velocity (Table 5.3).

Consequently, based on correlation analysis, flow velocity and water depth were identified as key variables sufficient for describing the hydromorphological heterogeneity of a stream reach.

		v	**τ**	**Fr**	**Re**
Water depth (h)	1.00				
Flow velocity (v)	**0.45**	1.00			
Shear stress (τ)	**0.14**	**0.84**	1.00		
Froude number (Fr)	**0.13**	**0.89**	**0.92**	1.00	
Reynolds number (Re)	**0.74**	**0.84**	**0.56**	**0.54**	1.00

Table 5.2 Correlation matrix of point related metrics.
Indicates r-values from Pearson Product Momentum correlation, with significant results ($p<0.05$, n=1102) in bold

	CVv	**CVh**	**CVs**	**CSDw**	**CSDb**	**TWD**	**Bw/Bbf**
CV flow velocity (CVv)	1.00						
CV water depth (CVh)	**0.91**	1.00					
CV substrate (CVs)	**0.96**	**0.98**	1.00				
CSD wetted (CSDw)	0.36	0.23	0.22	1.00			
CSD river bed (CSDb)	**0.94**	0.82	**0.90**	0.52	1.00		
Thalweg diversity (TWD)	**0.93**	0.76	0.87	0.43	**0.98**	1.00	
$\mu(B_{wetted}/B_{bankfull})$ (Bw/Bbf)	**-0.92**	-0.76	-0.87	-0.38	**-0.98**	**-0.99**	1.00

Table 5.3 Correlation matrix of reach related metrics.
Indicates r-values from Pearson Product Momentum correlation, with significant results ($p<0.05$, n=5) in bold. Note that CSD is the cross-section diversity, CSD wetted is related to the wetted part of the transect, whereas CSD river bed is related to that part of the transect belonging to the river bed, including gravel bars, islands, secondary channels without flowing water, but excluding river banks.

5.2.5 Formulation of HMID

The HMID is based on the coefficient of variation CV of flow velocity and water depth. Partial diversity V(i) of each variable is expressed as:

$$V(i) = (1 + CV_i) = (1 + \frac{\sigma_i}{\mu_i}) \qquad (5.8)$$

The HMID of a site was formulated by multiplying the partial diversity of the hydraulic variables flow velocity (v) and water depth (h). Thus the HMID for a site, becoming a single metric to describe the physical heterogeneity, is written as

$$\mathrm{HMID}_{\mathrm{Site}} = \prod_i \mathrm{V(i)}^2 = \mathrm{V(v)}^2 \cdot \mathrm{V(h)}^2 = \left(1+\frac{\sigma_v}{\mu_v}\right)^2 \cdot \left(1+\frac{\sigma_h}{\mu_h}\right)^2 \tag{5.9}$$

Using squared values of partial diversity and multiplication of squared values of partial diversity instead of building the sum (Schleiss, 2005) spreads out the range of HMID values and thus makes the index more sensitive to smaller differences in hydromorphology.

5.2.6 Comparison of HMID with a habitat assessment method

Assuming that HMID is able to reliably describe the physical environment of a stream, a correlation between scores obtained by applying visual assessment methods and the calculated value of HMID was expected. To test this hypothesis, rapid bioassessment protocols (RBP; Plafkin et al, 1989; Barbour et al., 1999) were applied to the study sites at each river. RBP is a visually-based habitat assessment that evaluates the structure of the physical river habitat (Barbour et al., 1999). It includes 10 variables that characterize stream habitat at the micro- and mesohabitat scale (embeddedness, epifaunal substrate cover, velocity/depth regime, sediment deposition, frequency of riffles) as well as at the reach scale (channel flow status, channel alteration). Further factors, such as riparian and bank structure, that influence these micro- and macroscale features are also assessed (Barbour & Stribling, 1991; Barbour et al., 1999). At each site, individual parameters are rated according to a continuum of scores that represent optimal, sub-optimal, marginal or poor condition, and that ranges between a low value of 1 and a high value of 20. A total score out of a maximum score of 200 is obtained for each site and is used to assess the quality of instream and riparian habitat at a stream site (Parsons et al., 2002b).

5.2.7 Analysis of biotic data

Benthic data with a taxonomic resolution of family-level was used for statistical analysis. Several standard measures characterizing the structure of the benthic community in terms of richness and dominance were calculated: overall taxonomic richness (total number of families), EPT - Richness (number of Ephemeroptera, Plecoptera and Trichoptera families), Shannon-Wiener diversity index (see appendix), and Berger-Parker dominance (relative proportion of the dominant taxon). To test for the relationship between HMID and single diversity indices, linear regression analysis was conducted with R 2.11.1 (R Development Core Team, 2010). Model assumptions were checked using diagnostic plots.

Being aware that family is a relatively rough taxonomic level and some patterns might remain undetected for this reason, additional correlation analysis was conducted with richness of EPT taxa which had been consistently determined to the genus level within each stream (EPT in Buenz and EP in Venoge).

5.3 Results

5.3.1 Hydraulic variability

The range of flow velocities and water depths was narrow in channelized sites (B2, V2, C3, S5). Mean flow velocity in these sites was remarkably higher than in more natural sites with runs being the prevalent habitat (Figure 5.6). The range of flow velocities and water depths was widest at sites with natural morphology (B3, B4, V1, V4, S1, S2 and S3), where a wide variety of habitats from riffles, runs and glides to pools, as well as backwater areas was present.

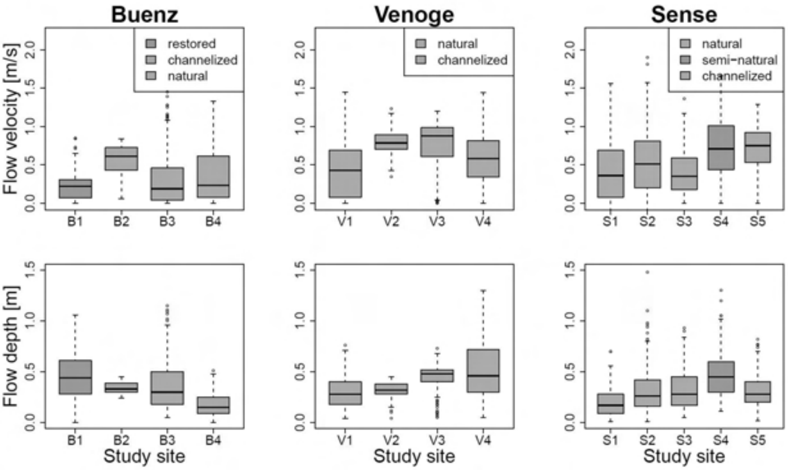


Figure 5.6 Boxplots of the hydraulic variables flow velocity and flow depth for the investigated sites at rivers Buenz, Venoge and Sense.

Hydraulic variability was generally lower in channelized sites (B2, V2, V3, and S5) than in less modified ones (Table 5.4). In fact, between the study sites within each stream, the coefficient of variation was always lowest in channelized sites. In restored sites (B1) or in partially channelized sites (S4), the coefficient of variation was somewhat higher, whereas the highest coefficients of variation were found in the most natural sites (B3, B4, V1, V4, S1, S2 and S3). Summarizing, CV values for water depth were found to be in the range of 0.2 – 0.5 for channelized sites and in the range of 0.6 – 0.7 for natural sites, whereas CV for flow velocity covered the region between 0.2 - 0.6 for channelized and 0.7 – 1.1 for natural sites. The difference of CV between flow velocity and water depths was highest at less modified sites, with a maximum ratio of almost 2 at the most natural sites. On the contrary, at channelized sites CV of water depth might be higher than CV of flow velocity.

The observed variability patterns were reflected in HMID values. In all of the streams, the channelized sites (B2, V2, V3 and S5) showed the lowest HMID (Table 4). Partially trained or restored sites (e.g. S4 and B1) had a higher HMID than respective channelized sites. Highest values for HMID were obtained for river sites with a natural physical environment, as found at B3, B4, V1, V3, S1, S2 and S3.

In the study reaches with examples of contrasting morphological conditions, HMID values spanned a range of values from 2 to 12; higher HMID values corresponding to higher hydromorphological heterogeneity. Overall, the following categories, generally valid for gravel bed rivers, could be defined respectively to ranges in HMID values:

- **Low range of HMID (HMID < 5):** channelized and morphologically heavily altered sites with uniform cross-sections and longitudinal slope. The theoretical lowest HMID value of 1 would be obtained by a completely regular channel without any variability in the hydraulic variables ($\sigma = 0$), whereas an HMID close to 5 corresponds to a channelized river with minor geomorphic patches as, for example, a thalweg line continuously shifting between the two bank toes.
- **Medium range of HMID (5 < HMID < 9):** Stream sites at the lower end of this range were less severely modified than those of the previous category, but still showing a limited variability of hydraulic units (V4, B1). In these sites, variability of hydraulic units was present to a certain extent, but hydromorphological patches typical to intact natural state were not developed yet. At the upper end of this range, sites were found that in hydromorphological terms were approaching sites with natural morphology (V1, S3).
- **High range of HMID (HMID > 9):** Morphologically pristine sites where gravel bed streams fully develop their spatial dynamics showing the complete range of hydraulic habitats found in this range (B3, B4, S1 and S2). For river engineering projects, these sites could be classified as reference sites. HMID values in this range

should be taken as a guiding measure for geomorphic re-styling of pre-alpine gravel bed rivers.

River Buenz			**B1**	**B2**	**B3**	**B4**
v	(m/s)	μ	0.20	0.56	0.32	0.37
		σ	0.15	0.21	0.35	0.34
		CV	0.75	0.38	1.09	0.92
		V(v)	1.75	1.38	2.09	1.92
h	(m)	μ	0.46	0.34	0.38	0.18
		σ	0.22	0.06	0.26	0.11
		CV	0.48	0.18	0.68	0.61
		V(h)	1.48	1.18	1.68	1.61
		HMID	**6.69**	**2.62**	**12.43**	**9.56**

River Venoge			**V1**	**V2**	**V3**	**V4**
v	(m/s)	μ	0.45	0.79	0.77	0.57
		σ	0.38	0.16	0.31	0.34
		CV	0.84	0.20	0.40	0.60
		V(v)	1.84	1.20	1.40	1.60
h	(m)	μ	0.30	0.32	0.44	0.49
		σ	0.16	0.08	0.14	0.26
		CV	0.53	0.25	0.32	0.53
		V(h)	1.53	1.25	1.32	1.53
		HMID	**8.00**	**2.26**	**3.42**	**5.97**

River Sense			**S1**	**S2**	**S3**	**S4**	**S5**
h	(m/s)	μ	0.44	0.56	0.39	0.72	0.71
		σ	0.41	0.45	0.27	0.42	0.29
		CV	0.93	0.80	0.69	0.58	0.41
		V(v)	1.93	1.80	1.69	1.58	1.41
d	(m)	μ	0.20	0.32	0.31	0.46	0.31
		σ	0.13	0.22	0.18	0.22	0.15
		CV	0.65	0.69	0.58	0.48	0.48
		V(h)	1.65	1.69	1.58	1.48	1.48
		HMID	**10.16**	**9.26**	**7.16**	**5.48**	**4.37**

Table 5.4 Mean value (μ), standard deviation (σ), coefficient of variation (CV) and partial diversity (V) of flow velocity (v) and water depth (h) as well as HMID values at the study sites.

5.3.2 Correlation with RBP

We found a strong correlation between HMID and RBP in each of the study rivers ($R^2=0.91-0.98$; Figure 5.7a). Analysis of pooled normalized values for all three rivers also showed a high correlation between the two indices ($R^2=0.86$, $p=5.6 \cdot 10^{-6}$; Figure 5.7b).

5.3.3 Benthic diversity and its correlation with hydromorphology

Strong differences between streams were found in the relationship of benthic and hydromorphological diversity (Figure 5.7c-f). In Venoge and Buenz, no correlation of HMID and local benthic diversity was found at the investigated taxonomic level (Table 5.5). In contrast, some patterns were detected in this respect at the Sense. Total taxonomic richness at the river Sense increased with increasing hydromorphological diversity (R^2=0.93; p<0.01; Figure 5.7c). Berger-Parker index also showed a significant effect of hydromorphological heterogeneity on the dominance structure of the benthic community (R^2=0.80; p=0.04; Table 5.5, Figure 5.7f). Sense sites with lower hydromorphological diversity had a stronger expressed prevalence of the dominant taxon, the mayfly family Baetidae.

	Buenz	**Venoge**	**Sense**
RBP			
R^2	**0.957**	**0.978**	**0.912**
Slope	**9.029**	**15.969**	**7.583**
p-value	**0.022**	**0.011**	**0.011**
Total taxonomic richness			
R^2	0.123	0.580	**0.928**
Slope	-0.481	-0.283	**0.647**
p-value	0.649	0.238	**0.008**
EPT richness			
R^2	0.743	0.189	0.711
Slope	-0.351	-0.351	0.488
p-value	0.138	0.566	0.073
Shannon-Wiener Index			
R^2	0.157	0.228	0.587
Slope	-0.010	-0.026	0.013
p-value	0.604	0.522	0.131
Berger-Parker Dominance			
R^2	0.163	0.049	**0.801**
Slope	0.007	0.010	**0.022**
p-value	0.596	0.779	**0.040**

Table 5.5 Correlation of HMID with visual habitat assessment metric (RBP) and diversity of benthic community. Significant correlations are represented in bold (p<0.05).

No difference in patterns were found when EPT taxa richness determined to genus-level was included into the correlation analysis (Table 5.6).

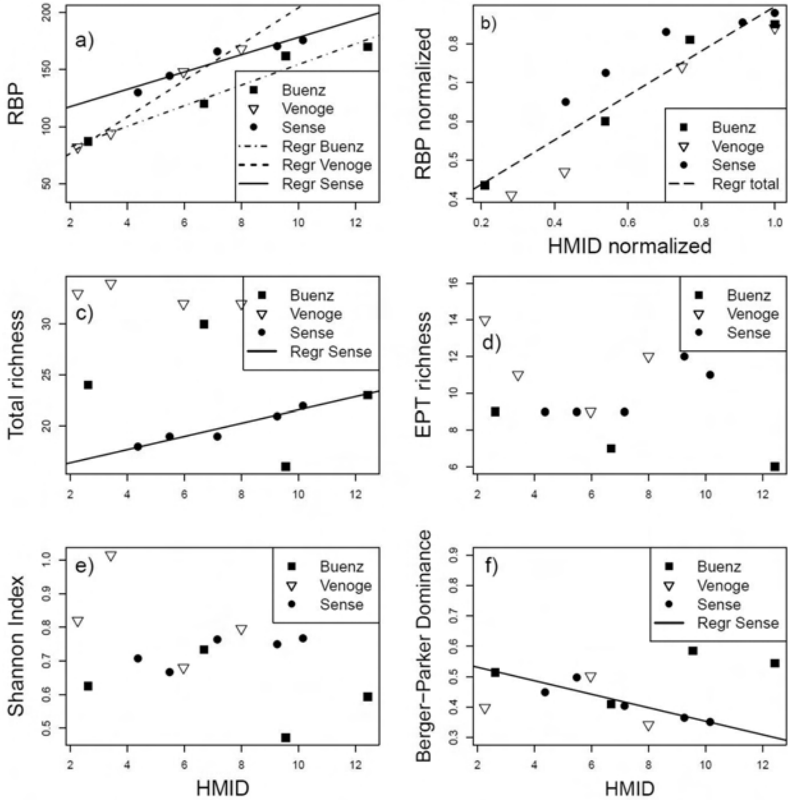


Figure 5.7 Relation of HMID to visual habitat assessment metric (RBP) and diversity of benthic community.
Regression lines are shown where a correlation was significant.

	Buenz	Venoge
EPT richness	EPT	EP
R^2	0.1401	0.05685
Slope	-0.5424	-0.3258
p-value	0.6258	0.762

Table 5.6 Correlation of HMID with richness of EPT taxa (on genus level)

5.4 Discussion

While identifying a gap in the range of existing planning tools for river restoration projects, a solution is offered by presenting a hydro-morphological index which could fill this gap. The steps of development of the HMID and the conducted analyses to test its performance and validity are described. The intent of this work was to provide the practitioner with a simple-to-use and straightforward tool to be applied in river engineering projects.

5.4.1 Hydraulic variables: representative descriptors of stream condition

Preliminary field survey assessing a range of geomorphic and hydraulic variables at both point and reach level, lead us to the conclusion that most of these variables are strongly correlated. Diversity of all variables decreased with the level of reach channelization and, interestingly, the direction in which geomorphic diversity was considered did not play an important role. Altogether, it can confidently be concluded that at the considered spatial scale, most geomorphic and hydraulic variables are interchangeable and few variables can reliably describe hydromorphological variability of a stream reach.

Elsewhere it has in fact already been argued that morphology accurately reflects the range of flows that move through the channel (Emery et al., 2003) and can be used as a surrogate of the flow condition (Bartley & Rutherford, 2005). In other works, hydraulic variables were defined as a result of the combination between flow and morphology (Maddock, 1999) and were thus stated to characterize the hydromorphological template of a stream at an ecologically relevant scale (Wallis et al., 2010). In concordance with the latter, focusing directly on the hydraulic variables in lieu of studying morphological characteristics of a stream is a valid approach, as hydraulic variables reflect not only the hydrological framework of a stream but also its geomorphic template. Furthermore, I could be shown that complex hydraulic variables at both the reach and point level are closely correlated with basic variables such as flow velocity and water depth. Therefore, the description of hydromorphological template is basied on the latter, as they are easier to measure, calculate and to interpret.

5.4.2 The HMID approach: using variance to describe diversity

The proposed HMID uses the coefficient of variation as a measure of diversity of hydraulic variables. CV is a useful measure in statistics (Rossi et al., 1992) and already found to be an appropriate metric for investigation of hydromorphological diversity. The patterns found by Jähnig et al (2008) showed that CV was generally higher at multiple-channel than at single-channel reaches, with CV for flow velocity generally being higher than CV for water depth, being in a similar range to the results of our study (Table 4). Other studies (Simonson et al., 1994; Negishi & Richardson, 2003) also use the CV to evaluate diversity of hydraulic variables, stating, for example (Simonson et al., 1994), CV of flow velocity to be twice as high as for other variables.

Our results confirmed these findings. The range of values found for CV of flow velocity and depth were similar to those reported by Jähnig et al. (2008). Elevated CV of flow velocity were found at natural sites, whereas at more modified sites the difference of CV for flow velocity and water depth mostly became smaller. Overall the study confirmed the sensitivity of CV to hydromorphological diversity patterns and therefore confidence to develop the HMID based on this statistical metric is justified.

5.4.3 Application of HMID

Comparing HMID with a visual assessment metric (RBP), it was showed that the proposed HMID is in fact able to reliably characterize the physical heterogeneity of a stream. Despite fundamentally different approaches behind the two measures, the correlation with RBP was strong. This correlation with a widely applied metric confirms the validity of HMID but does not mean that the two indices can substitute each other, as HMID and RBP were formulated for different applications and differ in some characteristics. Thus in contrast to HMID, based on predictable statistical parameters of hydraulic variables, the RBP acquired with visual assessment methods cannot be used as a predictive tool.

The possibility of being used as a predictive tool to evaluate geomorphic measures in river engineering projects from a ecomorphological perspective is the key added value of HMID. Our index is particularly suitable for application within the framework of river basin management plans that aim at both sustainable flood protection and enhancement of ecological status. In such projects, two-dimensional (2D) numerical models have become a standard for engineers for evaluation of flood protection works (see e.g. River2D, Steffler & Blackburn, 2002; BASEMENT, Faeh et al., 2006-2011). If elaborated in a thorough manner, numerical models are able to represent the physical reality in a more reliable way than field measurements. Field measurements correspond to a single snapshot in time and are traditionally characterized by the one dimensionality of measurements because they are carried out along transects and are affected by operator variability (Wallis et al., 2010).

Numerical 2D-models do not view the stream as a number of transects, but rather as a continuum (Ghanem et al., 1996) represented by a digital terrain model which is defined upon a topographical field survey containing information about altitude and roughness. In projects where a 2D-model has been implemented, a very small surplus of time is needed to calculate the HMID for the different project alternatives in order to determine the design alternative preferable from an ecomorphological point of view. The procedure to determine the HMID based on numerical modeling would start with running a steady 2D-simulation with the topography of the project variants and the mean flow as input. Mean flow is usually defined based upon a flow duration curve specific for the study site. From the model output, the values of flow velocities and water depth for each grid cell of the modeling domain would be read out, then the statistical parameters μ and □ for the pooled data set computed, and finally the HMID for the site calculated. For an engineer with the expertise in application of 2D-models, the time needed to determine the HMID for a project alternative would be no more than a few hours.

5.4.4 Constraints in terms of ecological effects

HMID has been developed to characterize river segments at the reach scale - the scale at which river rehabilitation measures are typically designed and implemented (Brierley & Fryirs, 2005). Therefore it can be expected to be of great assistance for the design of rehabilitation projects as it offers a quantitative evaluation tool of different project variants and thus can complement the guiding image concept where usually a qualitative geomorphic reference condition is defined. However, what happens at the reach scale is also influenced by larger scale processes (Thoms, 2006). For designing ecologically successful restoration projects, the use of reach-scale tools like HMID has necessarily to be combined with consideration of processes at the watershed and ecoregion scales (Palmer et al., 2005; Brierley & Fryirs, 2008; Fryirs & Brierley, 2008).

In particular, it should be kept in mind that physical heterogeneity alone does not make a healthy river. Our results on benthic diversity in the study streams lie in line with other published work, suggesting that one should be careful with the assumption that enhanced hydromorphological diversity automatically enhances biodiversity (Jähnig et al, 2010; Palmer et al., 2010). Only in the Sense, the stream with the least impacted catchment (in terms of non-hydromorphology-related stressors), was a positive correlation of two benthic diversity measures with physical diversity expressed as HMID found. The fact of no such relationships being detected in the other streams could have been caused by further factors such as modified hydrology, intense sediment flushing activities or pollution history (which might have exterminated sensitive species in the whole catchment), and especially by the relative position of the sites of different biotic quality within the stream landscape. Thus biota in downstream sites are probably influenced not only by local factors such as hydromorphology, but actually integrate the positive and negative effects of the whole catchment and, in particular, sites and tributaries closest upstream. An example where similar explanation are suspected is the utmost downstream site V4 in the river Venoge, which shows low benthic diversity in spite of high hydromorphological variability. Here benthic diversity seems to reflect the effects of the upstream degraded sites and tributaries, as well as suspected input of poorly purified waste waters from an industrial area rather than the local hydromorphological condition of the study site.

5.4.5 Generality of HMID and outlook

The HMID was developed at pre-alpine gravel bed rivers with specific geomorphic properties characterized by relatively steep slopes where riffles, runs and pools are the typical hydromorphological units in natural conditions, whereas glides occur in channelized sites. However, improvement of spatial variability to offer a variety of habitats is a common principle in river rehabilitation that is valid for different river types. Thus, the HMID could also be applied for a much wider range of cases, although thresholds as described in the results between different classes will be different at other river types.

The described development of HMID was based on spatial diversity achieved from field surveys that represent a single snapshot in the year. As the interaction between spatial variability and temporal dynamism is crucial for aquatic ecology, a further study is being carried out to enlighten this topic giving the index further descriptive and predictive power. Future activities will moreover include the elaboration of application guidelines for the HMID in order to move from the research arena into practical application as stimulated in other publications (Dunbar et al., 2010).

Even if enhancement of habitat heterogeneity cannot always be a guarantee of ecological success (Palmer et al., 2010), in the future it will doubtlessly remain one of the key measures in river restoration. The HMID can become a valuable tool on its own for predicting the change in local hydromorphology for different engineering scenarios. It will, however, need to be combined with predictions for other catchment-scale parameters when estimating the probability of actual change in biotic quality is the goal.

6 Spatial and temporal hydraulic variability in an Alpine gravel bed stream with morphologically contrasting sites based on the Hydro-Morphological Index of Diversity (HMID)

Abstract: The investigation of physical heterogeneity is a major topic in river sciences as it is known to be a key factor for ecological integrity. In this chapter, a study on the spatial and temporal variability in an Alpine gravel bed stream based upon an extensive analysis of hydraulic variables at morphologically contrasting sites is presented. Descriptive statistics of hydraulic variables and a recently proposed hydromorphological index of diversity are adopted to demonstrate that spatial and temporal variability show an inverse behaviour. Spatial diversity is more distinct at natural than at channelized sites, whereas temporal variability generally is higher at channelized sites. This gives new insight in habitat diversity theories: natural streams are not only characterized by high spatial variability, but also by a durable temporal stability unless threshold events occur. Therefore in river engineering projects aiming at enhancing the diversity of the physical template not only the creation of a diverse habitat mosaic should be a main target. Temporally stable habitats should assume at least an equal importance in the restoration goals.

Keywords: hydromorphological units, hydraulic variables, spatial and temporal variability, numerical modelling, duration curves

6.1 Introduction

Riverine landscapes are hotspots of biodiversity (Allan and Castill, 2007) that fulfil a number of important ecological, economic and social functions. However, extensive anthropogenic exploitation of streams for water use and waste disposal, altered land-use in their watersheds and, particularly, alteration of stream morphology using traditional engineering methods have caused strong alterations of streams in the last centuries. As a result, many streams today are heavily degraded, posing a significant threat to stream ecosystem health and stability (Malmqvist and Rundle, 2002; Jungwirth et al., 2003; Vörösmarty et al., 2010). To re-establish the ecological integrity of streams water policies (f.i. European Commission, 2000) address river restoration as an important task of our and future generations, making it a main challenge for water authorities and managers. The majority of river restoration projects are conducted under the predominant paradigma that increasing habitat heterogeneity promotes restoration of biodiversity (Miller et al., 2009; Palmer et al., 2010), and as result of lack of information linking descriptors of physical habitat to biotic responses, geodiversity habitually is considered equivalent with biodiversity (Newson & Large, 2006). However, success control campaigns demonstrate that restoration targets frequently are not obtained (Brooks et al., 2002; Pretty et al., 2003, Lepor et al., 2005; Jähnig et al., 2009; Palmer et al., 2010). Thus, for ecologically successful river restoration projects it is of outmost importance to better understand the processes at the interface between the abiotic environment and the ecological functioning of streams (Vaughan et al., 2009; Wallis et al., 2010).

At the physical scale, the disciplines are commonly gathered under the term of hydromorphology since it captures the main contributory disciplines geomorphology and hydrology, their interactions and their arrangement and variability in space and time (Vaughan et al., 2009). Many studies so far have concentrated on the variability either of morphology (Buhman et al., 2002, Thoms et al., 2006a; Alber & Piégay, 2010) respectively hydrology (Junk et al., 1999; Petts et al., 1995, Poff, 1996; Thoms & Parsons, 2003; Petts et al., 2006; Larned et al., 2010) or on the interactions between hydrology and morphology (Poff et al., 1997) with the focus on streams that are morphologically not altered by human interventions.

However, to evaluate the physical environment the hydromorphological conditions should be characterized at an ecologically relevant scale and spaced together with its variance (Palmer et al., 1997; Wallis et al., 2010). For the understanding of the links between hydromorphology and biotic quality previous work (Inoue & Nakano, 1999; Emery et al., 2003) has demonstrated the advantage to investigate directly the hydraulic variables instead of focussing on hydrology or morphology. Other studies have highlighted the separate importance of geomorphic (Bartley & Rutherford, 2005; Yarnell et al., 2006) and hydraulic diversity (Thoms et al., 2006b). However, it has been suggested that they represent closely related aspects of physical heterogeneity (Wallis et al., 2010). In fact, spatial variability of hydraulic variables is a consequence of morphology, whereas temporal variability is caused by the hydrological processes occurring in a stream. In addition, temporal variability of hydraulic variables is driven by the geomorphic template as it will be shown in this chapter. Thus, the patterns of hydraulic variables are a direct response on the hydromorphological conditions (Maddock, 1999; Wallis et al., 2010) and their study merits wider application (Newson & Newson, 2000). Moreover, the direct link between the abiotic environment and biotic response is delivered by hydraulic variables, as they shape the characteristics of aquatic habitats and therefore directly condition river biota as often demonstrated in the past (Ulfstrand, 1967; Minshall, 1984; Statzner et al., 1988; Weber et al., 2009).

This chapter presents a study where spatial and temporal variability of hydraulic variables has been investigated. At the beginning of the study the hypothesis was postulated that spatial variability of hydraulic variables is directly correlated to the geomorphic diversity of a stream, but also that a geomorphic more diverse stream guarantees a greater temporal stability, in other words, a reduced temporal variability of hydraulic variables. The hypothesis further suggests that vice versa at streams with a strongly modified morphology, i.e. at channelized or resectioned river sites, spatial variability is reduced and temporal variability increased with a resulting instability of hydraulic habitats. As a consequence the attempt is made to capture the inverse behaviour between spatial and temporal variability. Such patterns have already been discovered in other studies, though they haven't been analyzed in detail (Parasiewicz, 2005; Ballesterro et al., 2006).

For the demonstration of this hypothesis an investigation was conducted analyzing in detail five study sites at the river Sense, a gravel bed stream in Switzerland with an unaltered hydrological and sedimentological regime on one hand and sites with contrasting geomorphic characteristics, ranging from almost pristine to totally channelized, on the other hand. The study has been carried out by means of numerical modelling which results have been used to analyze spatial and temporal variability based on statistical parameters of the hydraulic variables as well as on the recently proposed hydro-morphological index of diversity HMID (Gostner et al., 2012).

6.2 Methods

6.2.1 Study sites

The river Sense is a fourth order watercourse in a 432 km^2 watershed situated in the cantons of Fribourg and Bern, Switzerland (Figure 6.1). For its prevailing part, the river is an unregulated gravel bed stream: around 23 km out of the total 35 km of the main stem length are almost in their morphologically pristine status, moreover, the riparian corridor provides home to the longest alluvial forest conserved in the country. For most of its length, the river flows through agricultural landscape, with the exception of the upmost headwaters characterized by a natural mountainous setting. Their aren't any water impoundments or withdrawals along the main course and its main tributaries, also the urbanization of the watershed is very limited, thus the hydrological regime of the stream is nearly unaltered in comparison to its natural behaviour. Also gravel extraction or addition activities are practically non-existent. Consequently, along its morphologically unaltered part the river Sense represents a water course in its reference status. However, prior to confluencing with the river Saane, the River Sense has undergone river training works of different degree over the past decades, resulting in a trapezoidal channel that has been protected by rip-rap partially on one and partially on both banks.

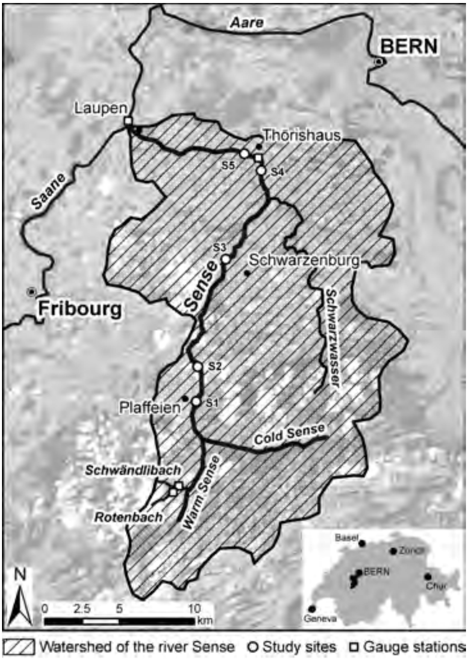


Figure 6.1 River Sense site location map

Five sites with contrasting morphology and numbering order in flow direction were selected (Figure 6.1). Site S1 (Figure 6.2) is situated immediately downstream of the confluence of the two main headwaters, the cold and the warm Sense. The site is characterized by a braided system with a distinct main channel, which carries the main portion of discharge and several secondary channels characterized by minor discharges. Sediment transport capacity at this site is high, causing frequent channel avulsion processes with a complete habitat turnover at each major flood event and possible relocation of the main channel from the left to the right site of the parafluvial zone (*sensu* Lorang & Hauer, 2006). Over the length of the study site the main channel covers approximately two wave lengths changing its location twice from the left to right bank. Mid channel and side bars with distinct elevations give home to a diverse terrestrial flora and fauna. *Chorthippus pullus* (gravel grashopper) and *Myricaria Germanica* (German Tamarisk) present on gravel bars with an inundation frequency of around 5 years (Gostner et al., 2010) are indicators for high biotic integrity (Werth & Scheidegger, 2011; Werth et al., 2011). From a hydraulic point of view, the complete spectrum of common hydromorphologic units (Parasiewicz 2001, Parasiewicz 2007a) such as pools, riffles, runs, glides and backwater zones offering a huge range of flow depths and velocities and diverse combinations of them can be observed.

Figure 6.2 Example of study sites (Site S1 and site S5 respectively)

Site S2 is situated in an incised limestone bedrock gorge where the river Sense is flowing as a single thread channel with locally limited braiding patterns and sharp flow direction changes. Although there isn't any human interference at this site, cut-off channels present along the intersection between the active flood plain and the side walls demonstrate that geomorphic activity is hindered by the naturally present lateral confinements. Nonetheless also at this site highly diverse geomorphic patterns can be observed with gravel bars of varying elevation occupied by different vegetation. In addition, at mean flow stage the diversity of aquatic habitats is high with a continuous succession of riffles and pools as well as the presence of backwater areas and side channels with low flow velocity and shallow water depth.

At site S3 the river Sense, after having left the natural gorge, is located, similar to site S1, again in a large floodplain. From a geomorphic and hydraulic point of view, site S3 is similar to site S1: diversity and abundance of terrestrial and aquatic patches is high.

However, at the upstream end of the site a large road bridge is situated. It doesn’t span over the entire width of the valley thus the abutments of the bridge cause a bottleneck for the river. Moreover, at this site the right bank is protected by a row of large natural or artificially produced boulders to provide space for a military training area along the right strip of the floodplain originally occupied by the stream activity. Consequently, site S3 is to be interpreted as a minimally altered natural site.

Sites S4 and S5 (Figure 6.2) are flowing through a more densely urbanized setting. For that reason, there the river Sense has been trained in the past to a notably altered single-thread channel. At site S4 only the right bank is protected by a rip-rap consisting of concrete cuboids. At mean flow stages sparsely vegetated alternating gravel bars are present, during flood events the migration of the gravel bars and the main channel can be observed. Runs and glides are the prevalent hydromorphologic unit, diversity of habitats is limited to the local occurrence of riffles and pools. Site S5 is a characterized by a trapezoidal profile with steep river banks on both sides formed either by gabions or rip-rap. Gravel bars are almost absent, at mean flow the whole river bed is wetted. Flow is almost uniform with constant flow velocity and flow depth in the longitudinal and transversal direction and runs as the solely hydromorphological unit present, with the exception of three block ramps present at the site to stabilize the river bed and placed in lieu of formerly present concrete check weirs. Over the block ramps flow is highly non uniform with fast flow velocity in the central area of the ramp, slow velocity at the side and a deep pool present at the toe of the ramp.

6.2.2 Field data collection

Data collected in the field served for the development and calibration of the numerical modelling subsequently conducted. The field campaign was carried out during a mean annual flow stage (Table 6.1) in wadeable conditions. Along predefined cross sections water depth and mean column flow velocity with a spacing between survey points of 50 to 200 cm was measured. The latter was obtained via the six-tenths depth method using either an acoustic Doppler velocity meter (SonTek FlowTracker Handheld ADV) or an electromagnetic flow meter (Ott Nautilus Flow Sensor C2000). The distance between transects was between 25 and 100 m depending on the site morphology (Table 6.1). The location of transects was chosen to comprise all the hydromorphologic units present at a site (Simonson et al., 1994), whereas the total number of transects varied depending on the degree of alteration of each site.

Site	**S1**	**S2**	**S3**	**S4**	**S5**
Geomorphic characteristis					
Valley gradient (%)	1.94	1.33	1.20	0.73	0.66
Channel gradient (%)	1.82	1.29	1.15	0.53	0.68
Mean bankfull width	131.0	62.12	105.8	40.43	29.00
Mean wetted width at mean flow	21.79	16.14	24.77	15.59	24.95
Thalweg length/valley length	1.086	1.142	1.125	1.015	1.018
Hydrologic characteristis					
Watershed area (km^2)	118	150	174.9	321.8	355.8
Hydrology Correction factor	1.40	1.28	1.21	0.98	0.94
Specific flow at Q180 (l/s,km^2)	22.54	20.00	19.04	15.54	16.86
Q330 (m^3/s)	1.20	1.50	1.50	2.33	2.50
Q200 (m^3/s)	2.33	2.75	3.00	4.50	5.00
Q180 (m^3/s) (median annual flow)	2.66	3.00	3.33	5.00	6.00
Q90 (m^3/s)	5.00	5.00	6.00	8.00	10.00
Q30 (m^3/s)	11.00	12.00	12.00	17.00	19.00
HQ1 (m^3/s)	86.00	101.0	111.0	152.0	159.0
HQ3 (m^3/s)	145.0	169.0	185.0	255.0	267.0
HQ5 (m^3/s)	172.0	200.0	220.0	303.0	315.0
HQ10 (m^3/s)	208.0	242.0	266.0	368.0	385.0
Field work features					
Reach survey length (m)	1’850	770	620	685	940
No. of transects	19	17	19	14	14
Mean spacing between transects (m)	100	48	25	53	72
No. of points with recorded v and d	310	202	249	135	216
Survey discharge (m^3/s)	2.30	2.93	3.19	5.65	5.81
Specific discharge (l/s, km^2)	19.5	19.5	18.2	17.6	16.3
Characteristics of numerical hydraulic model					
Computational area (m^2)	245’268	61’243	58’510	38’643	35’248
Number of surveyed points	3’611	1’413	954	517	551
Density of surveyed points (m^2/points)	67.92	43.34	61.33	74.74	63.97
Number of grid cells	32’591	13’216	12’524	7’147	5’911
Average size of cells (m^2)	7.53	4.63	4.67	5.41	5.96
Maximum size of cells (m^2)	38.43	15.36	15.75	21.02	16.02
Minimum size of cells (m^2)	0.30	0.37	0.87	0.28	0.77

Table 6.1 Characteristics of study sites.

Along the cross sections a topographical survey was carried out using both a theodolite or a first order GPS station that allowed determination of geomorphic features such as the river bed elevation, the channel thalweg, top and bottom of channel banks, bankfull stage, terrace elevations and any additional visual breaks along the cross sections. Additionally, to provide a dense and reliable terrain data cloud for the numerical modelling the topographical survey was completed by surveying perimeters, break lines and extreme elevations of gravel banks, islands, large woody debris accumulations and other distinctive features. Moreover, substrate sampling along the cross sections was carried out according to the well-known pebble count method (Wolman, 1954).

6.2.3 Numerical modelling

The use of numerical two-dimensional (2D) models is a today's standard in river engineering projects, whether for flood protection measures or for instream habitat modelling. A 2D-model offers the benefit of achieving superior results with comparable amounts of field data, as the stream is not seen as number of transects, but rather as a continuum (Ghanem et al., 1996). Additionally, a numerical hydraulic model allows to simulate any desired state in terms of topography and discharge, facilitating the interpretation of temporal variability which in ecological science frequently has been conducted adopting the space-for-time substitution (Pickett, 1989; Travis & Hester, 2005; Kappes et al., 2009; Dunbar et al., 2010a) concept as auxiliary tool.

6.2.3.1 Data basis

Based on already available or ad hoc collected field data and on additional calculations the basis of data described henceforward has been defined for the implementation of the numerical 2d-model.

- Topography: The digital terrain model (DTM) for the study sites was built using the topographical data collected in the field. A reliable DTM is an essential prerequisite to reflect the physical reality, therefore special attention was necessary during the analysis and pre-processing of the topographical data conducted for properly depicting the thalweg, break lines and special features within the model domain.
- Rugosity: Hydraulic roughness within the bankfull channel was primary estimated from the results of the Wolman Pebble count using the Manning-Strickler equation of the form (Strickler, 1923):

  $$k_{St} = \frac{21.1}{D_m^{1/6}} = \frac{1}{n} \tag{6.1}$$

  where k_{St} is the Strickler value, n is the Manning's roughness coefficient and D_m is the mean diameter of the substrate material.

- Hydrology: For each study site a discharge duration curve was defined based upon available discharge records at gauge stations in the proximity of the study sites. Two gauge stations are located upstream (approximately 7 km) of site S1 on two tributaries (Rotenbach, Schwändlibach), one gauge located at Thörishaus in the vicinity of site S4 and a fourth gauge on the River Saane at Laupen downstream of the confluence with the River Sense (Figure 6.1).

  For ordinary discharges a flow duration curve, based on a daily mean flow time series valid from 1993 to 2008, at the Thörishaus gauge station was elaborated. Afterwards mean annual specific flow of gauge stations at Rotenbach, Schwändlibach, Sense and Saane were taken to define a regression line that relates specific flow to watershed area. Subsequently a correction factor (indicated in Table 6.1), defined as the ratio between mean annual specific flow for the watershed area at the study sites and the gauge station at Thörishaus was calculated. For each study site, a discharge duration curve was then assigned by multiplying the discharges at the Thörishaus gauge station with the mentioned correction factor and the ratio between the watersheds at the study site and the Thörishaus gauge station.

  Also for flood discharges with return periods of more than 1 year a regression curve, elaborated by means of flood peak discharges given by the official data for the gauge stations, was constructed and flood peak discharges for the study sites calculated.

6.2.3.2 Modelling approach

For the present study, the software BASEMENT (Faeh et al., 2006-2011) was used. The software uses the finite volume method for spatial discretization and the explicit Euler scheme to solve the 2-dimensional shallow water equations.

The river bed was assumed to be stable. For the majority of ordinary discharges where sediment transport is almost non-existent the assumption of a static river bed comes close to reality, whereas for flood discharges this is a simplification, mainly for the less modified study sites. However, as the purpose of the present study was to investigate the variability of hydraulic variables for differing discharges, but at steady flow conditions, the model can be assumed to be sufficiently accurate also for flood conditions.

For each study site 20 – 25 typical discharges chosen from the duration curve and shown as items in Figure 6.3 were modelled. The hydraulic modelling was conducted under the assumption of steady flow conditions, which in reality is certainly a good approximation for ordinary flow conditions, whereas floods are characterized, especially in rather small watersheds, by their highly unsteady behaviour. On the other hand, the focus of the present study was to investigate spatial hydraulic variability for differing flow stages and to build time series of the investigated variability a posteriori and beyond single flood events, therefore it was adequate to conduct the hydraulic modelling under steady flow conditions.

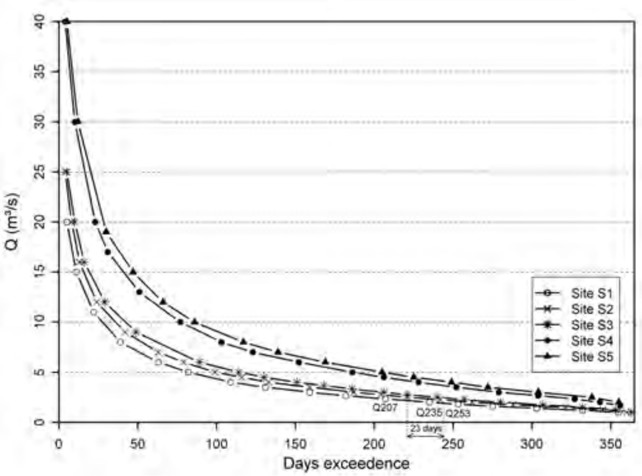


Figure 6.3 Discharge duration curves for the study sites.
Discharges used for numerical modelling are indicated as items. Flood discharges occuring less than at 5 days per year and up to return frequencies of 10 years are not represented in the graph, yet modelled and reported partially in Table 6.1.

6.2.3.3 Calibration of numerical model

Calibration of the model was conducted in a threefold manner. First of all, for each site the numerical model was run with the discharge that occurred during the field campaign. By comparing the measured water depths and flow velocities with the calculated ones along the field transects the reliability of the model was evaluated. In cases where results were not satisfying, the primary adopted roughness factor was adjusted accordingly in order to take into account local friction elements responsible for increased roughness and reduced flow velocities.

Secondly, statistical parameters such as mean value μ and standard deviation σ were calculated for both measured and modelled hydraulic variables and compared. Diverging results were the impulse to verify and further improve the input structure of the numerical model until reaching conformity between field records and values resulting from numerical modelling.

Third, an additional verification was possible by comparing the water depth of the presumable bankfull discharge with bankfull height measured in the field.

6.2.4 Analysis of spatial and temporal variability

To analyse spatial and temporal variability within and between the study sites mean values and the coefficient of variation (CV) of the hydraulic variables considered were chosen. Coefficient of variation CV is an adjusted measure for standard deviation, therefore a better comparative measure of variability (Schneider, 1994) and commonly used in temporal and spatial analysis of ecological patterns (Rossi et al., 1992; Simonson et al., 1994; Gubala et al., 1996, Palmer et al., 1997; Thoms, 2006c).

Coefficient of variation is also the basic input variable to calculate a recently proposed hydro-morphological index of diversity HMID (Gostner et al., 2012) which has been shown to properly represent the physical heterogeneity, i.e. the spatial variability, of a stream. The HMID of a site is given by

$$\mathrm{HMID}_{\mathrm{Site}} = \prod_i \mathrm{V(i)} = \mathrm{V(v)} \cdot \mathrm{V(h)} \tag{6.2}$$

where V(v) is the partial diversity of flow velocity v and V(h) is the partial diversity of water depth h. Partial diversity V(i) of a variable is calculated by

$$\mathrm{V(i)} = (1 + \mathrm{CV_i})^2 = (1 + \frac{\sigma_i}{\mu_i})^2 \tag{6.3}$$

where $\mathrm{CV_i}$ is the coefficient of variation of a variable, expressed by the quotient of standard deviation σ and mean value μ of the spatial distribution of a single variable i (either flow velocity v or water depth h) at a determined discharge.

In addition, CV is used not only to analyze spatial variability, but also to evaluate temporal variability of the hydraulic variables and of HMID.

6.3 Results

6.3.1 Hydraulic numerical model

Computational domains for each of the study sites were defined according to the length and width of the field sites. Computational areas had differing surfaces: the domain of S1 for example covers an area of around 245’000 m², whereas the domain of S5 has an area of around 35’000 m².

The model grid was elaborated as an unstructured triangular network with differing sizes of the single cells. In areas closed to topographically accentuated changes cell size was diminished, whereas in other cases with a near plane topography cell size was greater in order to speed up computing velocity. The average size of grid cells was around 5 - 7 m², whereby for a number of 5'900 (S5) to 32'500 (S1) cells flow velocity and water depth were obtained. The values for the hydraulic variables were in typical range for gravel bed streams where slope and therefore flow velocity is relatively high and water depth is rather low.

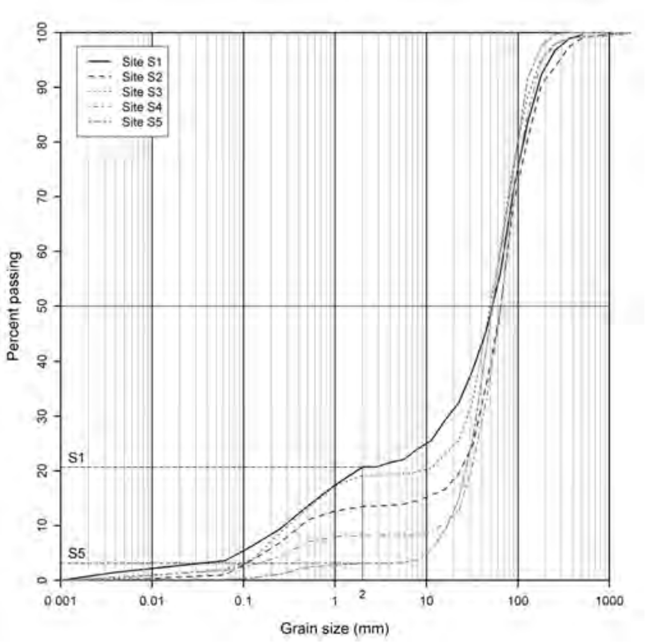


Figure 6.4 Grain size distribution curves for the study sites.
D_{50} covers the range between 50 mm (S3) and 65 mm (S2 resp. S4). The portion for the fraction < 2 mm (clay-silt-sand) varies between 20.7 % for S1 and 3.1 % for S5.

6.3.2 Grain size distribution and rugosity

Grain size curves (Figure 6.4) show typical diameters for a gravel bed river with a d_{50} ranging between 50 mm and 65 mm. In the medium to coarse sand range there is usually a plateau as the fines are washed away due to the high stream power. At natural sites the substrate mosaic is more diverse with zones in the stream power shadow, frequently to be found downstream of boulders or woody debris, where fines during the falling limb of the hydrograph after a flood has passed settle down. Thus at the more natural sites the fraction of fines < 2 mm reaches quotas of > 20 %, whereas at the less natural sites the silt and clay fraction is almost completely missing with a quota of less than 10 %.

By adopting equation (6.1) bed rugosity expressed in terms of Manning's roughness coefficient n and used as input data for hydraulic modelling was set in the range of $0.035 < n < 0.033$. Roughness beyond the limits of the active flood plain with riparian vegetation and mature tree stands on islands, respectively, zones with bushes were estimated in the range of $0.05 < n < 0.10$ and associated with the density and calliper of vegetative communities as suggested by Chow (1959). On the contrary, for nude rocky parts and rip-rap roughness was set to be in the range of $0.033 < n < 0.025$.

6.3.3 Hydrology

The duration curves (Figure 6.3) show that discharge between the most downstream site S5 and the most upstream site S1 differs by a factor of approximately 2. Specific flow is higher at site S1 (Table 6.1) as the mean annual precipitation of a watershed is increasing with its mean altitude.

Within sites discharge is doubling for approximately each 100 days of exceedence, thus on a logarithmic scale discharge and days exceedence are linearly correlated. At site S1 for example the flow exceeded for 300 days a year (Q_{300}) is around 1.4 m³/s, the Q_{200} around 2.6 m³/s and the Q_{100} is around 5 m³/s. For flood discharges the duration curves show a usual behaviour with an almost linear correlation between the logarithm of return frequency and discharge.

6.3.4 Spatial variability of hydraulic variables

To investigate spatial variability the conditions at discharge that is exceeded for 50 % of the season (Q180) have been analysed (Figure 6.5, a-b). This is a single observation in time, nontheless representative for most of the discharges occurring troughout a season except for the extreme ends of the discharge duration curve. The values for the hydraulic variables, derived from numerical 2D-modelling, were in typical range for gravel bed streams where slope and therefore flow velocity is relatively high and water depth is rather low.

Mean values (Table 6.2), calculated from the values obtained for each wetted cell of the numerical model, indicate that at channelized sites as expected mean flow velocity is generally higher than at natural sites. In fact, at site S1 mean flow velocity for a Q180 is 0.42 m/s, whereas at site S5 it is almost double (0.76 m/s). For water depth this linearity between mean value and degree of regulation is less clear, though it can be observed that at sites without lateral limitations (Site S1 and Site S3) water depth is generally lower than at sites with partial or complete lateral confinement.

Site	S1	S2	S3	S4	S5
μ,v	0.42	0.70	0.52	0.67	0.76
μ, h	0.14	0.24	0.17	0.34	0.24
CV,v	0.96	0.68	0.72	0.66	0.47
CV,h	0.74	0.75	0.74	0.71	0.61
HMID	11.64	8.64	8.96	8.08	5.57

Table 6.2 Mean values, coefficient of variation CV and HMID for the median discharge (Q180).

When looking at variance instead of mean values, for flow velocity (Figure 6.5a) a difference in spatial diversity can clearly be observed as the range of values is obviously lower at the channelized site S5 than at the other sites. A Kruskal-Wallis rank sum test (using the software R, R Development Core Team, 2010) which has to be performed for non-normality of distributions (McDonald, 2008) being obviously the case revealed a significant effect between sites ($p<0.01$). A post-hoc test using pairwise Mann-Whitney tests with Bonferroni correction showed the significant difference between the sites, with the only exception observed between site S2 and site S4 ($p=0.21$).

For water depth (Figure 6.5b) at each site a certain variety of water depths at a mean flow stage exists. At site S5 for example at the crest of the block ramps there is supercritical flow with low water depths, whereas at the toe of the ramps where the hydraulic jump occurs there are scours with relatively high water depths. In this way also at site S5, even if diversity of hydromorpholical units is rather poor, a spatial diversity of water depths exists. However, the differences between each site (using pairwise Mann-Whitney tests) are confirmed to be significant ($p<0.01$).

Looking at coefficient of variation CV (Figure 6.5 a-b) and the HMID differences in spatial diversity of hydraulic variables between sites become evident (Table 6.2). Coefficient of variation for flow velocity and water depth is highest at natural sites. For flow velocity CV there is approximating values close to 1, which means that standard deviation is almost as high as mean value, and is continuously decreasing with the degree of modification. At the most regulated site S5 the value of CV (0.47) for velocity is approximately half of the CV at the most natural site S1 (0.96). Also for water depth the observation is similar: for natural sites CV assumes the highest values, although the differences are not so accentuated.

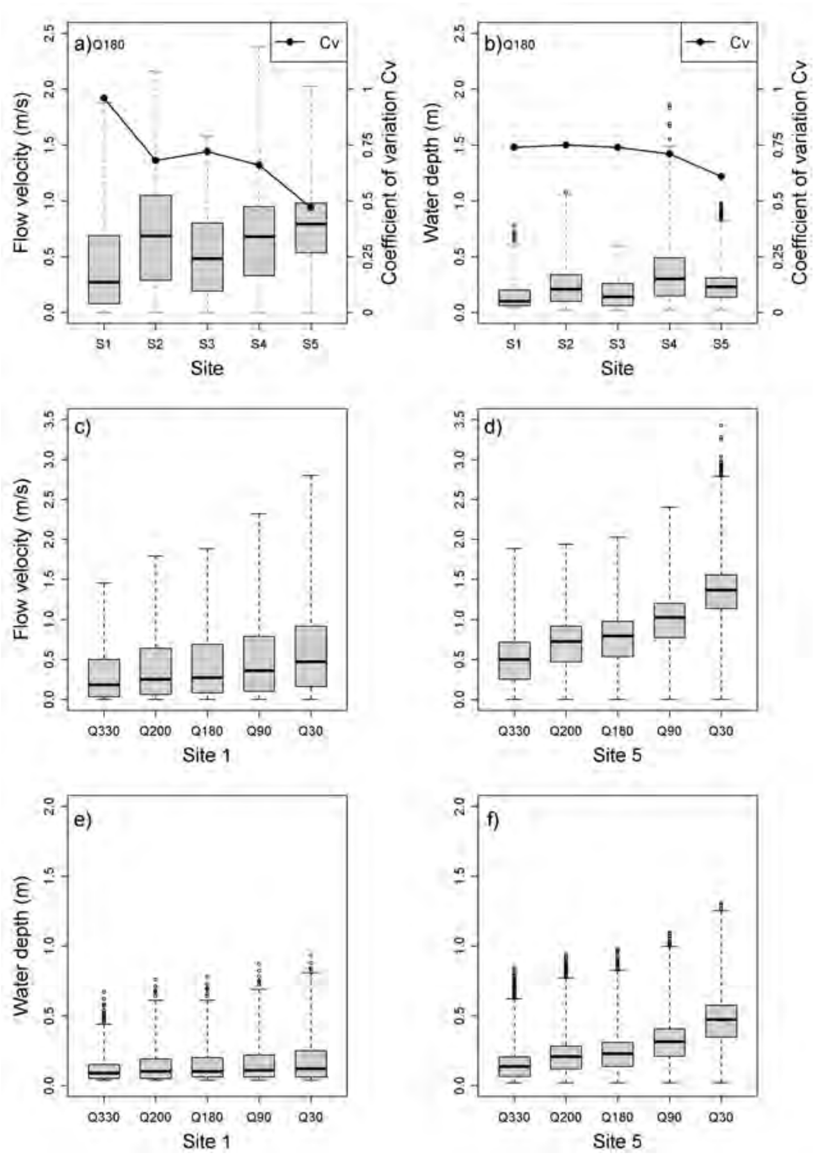


Figure 6.5 Boxplot representation of spatial variability.
a-b) Boxplots of the hydraulic variables flow velocity (a) and water depth (b) for a Q180. Black continuous lines linking points indicate the coefficient of variation CV. c-f) Box plots of velocity (c-d) and depth (e-f) at site S1 and S5 for a typical low discharge (Q330), two mean discharges (Q200 resp. Q180), slightly above mean discharge (Q90) and high discharge (Q30).

HMID is highest at the entirely natural site S1. At site S2 which is naturally confined by the limestock walls of the gorge and at site S3 which on the right bank is slightly fixed by a row of large bouldes, HMID values are lower than at site S1. At the site S4 whose right bank is protected by rip-rap, but where a certain diversity of hydromorphologic units has been observed in the field, HMID in turn is slightly lower than at sites S2 and S3. The lowest HMID value is observed at the completely channelized site S5.

6.3.5 Temporal variability

By comparing the distribution of hydraulic variables at five selected flow stages for the two morphologically most contrasting sites (Figure 6.5 c-f), it can be observed that at the natural site S1 median values of variables are remaining approximately in the same region for the majority of the flows. Only at high discharges (> 30 days exceedence) there is a sensitive increase of values, with flow velocity showing a stronger tendency of increase than water depth. Infact, pairwise performed Mann-Whitney tests with Bonferroni correction partially are showing non significant differences for water depth (f.i. $p=0.535$ for Q180 against Q200).

On the contrary, at the channelized site S5 median values for velocity and depth are constantly increasing with discharge with significant differences between each flow stage ($p<0.01$). Thus, ratios between flow velocity and water depth means for different flow stages are higher at the channelized site S5 than at the natural site S1 (Table 6.3), with water depths showing a greater temporal variability than flow velocity. At site S5 for example mean water depth at a Q90 flow is double of the water depth at a Q330 flow, whereas at site S1 the Q90 flow shows an increment in water depth in comparison to the Q330 of only 36 %, whereby the Q90 discharge is the fourfold of the Q330 discharge (Figure 6.3).

Site	**S1**	**S5**	**S1**	**S5**
	Flow velocity		Water depth	
Q200/Q330	1.34	1.40	1.18	1.38
Q180/Q330	1.45	1.52	1.25	1.50
Q90/Q330	1.72	1.96	1.36	2.00
Q30/Q330	2.34	2.62	1.73	2.94

Table 6.3 Ratios between mean values of flow velocity and water depth for different flow stages, shown at site S1 and site S5.

An analysis of the numerical modelling reveals that temporal variability is inverse to spatial variability (Table 6.4). In fact, temporal variability expressed as CV, is tendentially lower at natural sites than at channelized sites. At site S5 CV is highest for both flow velocity and water depth revealing that temporal stability of hydraulic variables is significantly lower than at more natural sites.

Site	S1	S2	S3	S4	S5
Flow velocity (m/s)					
μ	0.43	0.76	0.54	0.71	0.81
σ	0.12	0.19	0.13	0.22	0.29
CV	0.28	0.25	0.23	0.31	0.36
Flow depth (m)					
μ	0.14	0.26	0.18	0.36	0.27
σ	0.03	0.07	0.04	0.10	0.12
CV	0.19	0.26	0.26	0.27	0.44
HMID					
μ	11.66	8.64	9.11	8.22	6.06
σ	0.40	0.48	0.29	0.79	1.65
CV	0.03	0.06	0.03	0.10	0.27

Table 6.4 Weighted average and weighted standard deviation of mean values for the modelled discharges on the duration curve[1].
Coefficient of variation CV (=σ/μ) indicates temporal variability of hydraulic variables and HMID.

Duration curves of HMID (Figure 6.6) graphically represent these observations showing several features:

- At natural sites S1, S2 and S3 HMID remains constant for most part of the year, confirmed by the low coefficient of variation CV for temporal variability (Table 6.4).
- At partially or complete regulated sites (S4, S5) HMID decreases continuously with increasing discharge. This tendency is stronger at sites with a higher degree of channelization. In fact, the slope of the HMID duration curve is higher at site S5 than at site S4.

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[1] Mean values of hydraulic variables, obtained for the discharges chosen from the duration curve (Figure 6.3) and numerically modelled have been weighted discretising the duration curve and assigning to each discharge the number of days for whose the discharge is representative. The Q_{235} of the site S1 for example has been defined to be representative for 23 days as the sum of 9 days, which is half of the 18 days between Q_{253} and Q_{235}) and 14 days, which is half of the 28 days between Q_{235} and Q_{207}. Flood discharges (Q_1 and less frequent events) have not been included in this analysis in order to exclude phenomena equaling catastrophic events

- At small discharges HMID values are close one to each other, whereas at mean flow stages (100 – 250 days exceedence) the HMID represents differences in physical heterogeneity at best. At higher discharges occurring with an exceedence of 10 – 100 days differences in HMID are large showing clear contrasts depending on the degree of modification.
- At discharges exceeded 1 – 2 times per year, HMID decreases strongly (Detail of Figure 6.6 on the right) at natural sites. For floods with a return period of >1 year HMID values are approaching one to each other, demonstrating that during flood events spatial variability results to be reduced also at each site, independent of the gemorphic template.

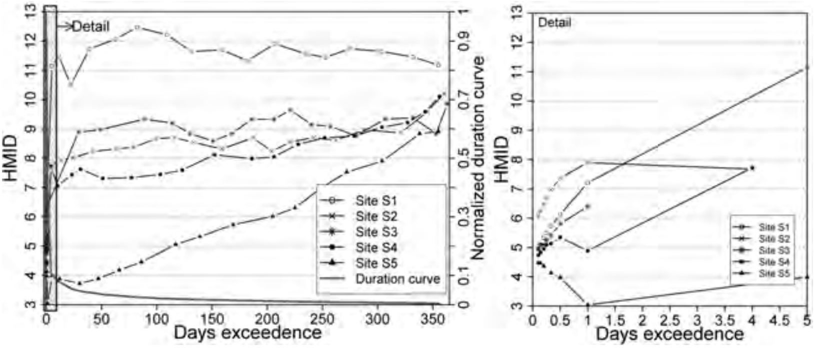

Figure 6.6 Duration curves of HMID at the study sites of river Sense.
The figure on the left shows the behaviour during the whole season, whereas the figure on the right shows a zoom of the HMID values for discharges exceeded < 5 days/year, i.e. for flood discharges with return frequencies up to 10 years (0.1 days exceedence).

6.4 Discussion

Hydraulic variables are key elements of the physical environment directly affecting biota at an ecologically relevant scale. Therefore it is a straightforward approach to study them directly in lieu of focussing on hydrological behaviour or morphological characteristics of a stream, where both of them hydrology and morphology are intertwined in hydraulic variables.

The values for the hydraulic variables, obtained in the present study by means of numerical hydraulic modelling and confirmed by former field observations (Gostner et al., 2012), were in the typical range for gravel bed streams where slope and therefore flow velocity is relatively high and water depth is rather low. Although at naturally braided sites S1 and S3 valley slope is higher than at the partially or totally channelized sites S4 and S5 (Table 6.1), mean flow velocity is remarkably lower. Velocity thus reflects morphological traits at the single sites, with natural riffle-pool sequences and strong bidimensional flow behaviour characterizing natural sites, while at laterally confined sites morphology is conditioned to a certain extent with a notable presence of hydromorphological units such as runs and glides where flow direction is unidirectional and relatively high. This demonstrates that at natural sites energy dissipation is occurring continuously, whereas at laterally confined sites conveyance and therefore shear stress is high, resulting in difficult life conditions for benthic invertebrates living on the stream bed on one hand and reduced hydraulic habitat diversity for fish species on the other hand.

Variance is seen as an aspect of nature that has ecological relevance (Palmer et al., 1997), therefore the results of the present study in relation to variability of hydraulic variables are of particular interest. For an integrated view of the topic both spatial and temporal patterns and their interactions have been enlightened. The study of the five, morphologically contrasting sites at river Sense has revealed that spatial and temporal diversity in streams with a natural hydrological regime have an inverse behaviour.

At natural sites the spatial diversity is greater, with the most pristine site S1 showing the greatest diversity. Site S1 is characterized by its geomorphic uniqueness with a parafluvial zone where lateral constrictions are absent and fluvial geomorphic activity can occur in a totally unhindered manner. Already small disturbances of the physical equilibrium such as a lateral confinement, even if naturally given by a gorge (site S2), or a slight artificial protection of a river bank (site S3) may cause a reduced spatial variability. In channelized sites spatial and therefore hydraulic habitat diversity results to be even more reduced. On the contrary, temporal variability is lowest at natural sites, demonstrating that there hydraulic habitats which are formed by flow velocity and water depth show more temporal stability, whereas at channelized sites hydraulic habitats are undergoing a temporal variation always when a change in discharge occurs. Therefore at channelized sites there is not solely a reduction of hydraulic habitat diversity in comparison to natural sites, but also a reduced temporal stability of these habitats. As a consequence, aquatic fauna in channelized sites not only finds a reduced habitat availability, but also suffers a major stress from a continuous change of life conditions, whereas at natural sites life conditions within hydromorphological units remain approximately constant troughout most part of the season. As already stated elsewhere and confirmed by the present study, less modified channels maintain greater habitat diversity and provide more refugia for invertebrates even at high and low flows (Dunbar et al., 2010b). Thus, it has to be expected that habitat bottlenecks (Bovee et al., 1994; Bovee et al., 1998) are less frequent both in space and time at natural than at channelized sites.

However, catastrophy theories, a key element of ecological science with regard to temporal evolvement of ecosystems, find perfect accomplishment at natural stream sites. By applying the HMID the study has shown that temporal stability of hydraulic patches is high until the occurring of a threshold event, to identify in a flood with a return period of approximately 1 year. During flood events diversity of hydraulic habitats is strongly decreasing also at natural sites. As the active parafluvial zone is filled up with water, flow becomes uniform, bed forms and thalweg diversity are not more relevant and hydromorphological units such as pools and riffles are disappearing. During these floods channel avulsion processes take place with a shift of the habitat mosaic (Lorang & Hauer, 2006) causing a partial or complete turnover of hydraulic habitats (Arscott et al., 2002). These events are also referred to as bed preparation functional flows (Escobar Arias & Pasternack, 2009). They rework the bed and provide the bed conditions for the next spawning cycle (Groot & Margolis, 1991) and reshape the subsurface layer providing the cavities that are important for benthic species living on the interface between the river bed and the hyporheic zone. In residual flow reaches downstream of large reservoirs in recent years artificial floods to initiate these processes have been applied with major success (Robinson et al., 2003; Robinson & Uehlinger, 2008) demonstrating that bed reshaping processes, similar to purifying storms in meteorological cycles, are essential for the ecological functionality of streams.

Thus, temporal stability is also a matter of time scaling. Natural streams show strong temporal stability as long as threshold events don’t occur, beyond threshold events natural streams are highly dynamic with intense geomorphic activity. Therefore on the long term natural sites seem much more dynamic and variable than channelized sites. At channelized sites there is no evident distinction of treshold events, habitat variables are suffering a constant pressure with a gradual decreasing of hydraulic diversity and a creeping transition from ordinary to catastrophic scenarios. At river Sense for example, in the 3-years period from 2009 to 2011 at site S1 at least two extreme events occurred with a total shift of habitats as the main channel of the braided system at the upstream end of the study area displaced completely its course from the right to the left side of the valley and than back again. Also at sites S2 and S3 major channel avulsion processes with a turnover of habitats were observed in the same period. Site S4 in a reduced manner also underwent some geomorphic changes, whereas at site S5 the geomorphic aspect remained stable.

The investigation of hydraulic variability at spatial and temporal scales has been conducted based on statistical parameters of hydraulic variables as well as on the application of the HMID. The present study has demonstrated that the HMID is an appropriate tool for research on physical hetergeneity. Considering variability of either flow velocity or water depth in their singularity, some non-linear behaviour between variability and degree of modification can appear. For example, at a stream site such as site S4 at river Sense that is partially trained, but nevertheless offers a good range of hydraulic habitats at a mean flow stage, water depth might be more variable than at a natural site similar to site S1. The HMID gathers variability of flow velocity and water depth in a single metric and has shown to override non-linear behaviour of single variables clearly establishing a strong correlation between the physical heterogeneity of a site and its HMID value.

Besides field measurements the study has been carried out with the help of a numerical hydraulic 2D-model. After a thorough calibration process, that field data are needed for, the applied software has shown to properly reflect physical reality. For practical applications the use of a numerical model is appropriate as it allows to obtain much more data in less time than by means of field work. Moreover, a numerical model is certainly more objective as it avoids bias happening in field work when transects and point records are chosen in a somewhat arbitrary way. It also represents physical reality in a more correct manner, as it reflects the bidimensional reality of the hydraulic environment instead of a one-dimensional representation of transects that is usually the case for field records.

6.5 Conclusions

The abiotic environment of a stream is a system of complex interactions between different factors that are highly cross-correlated and interdependent. The present study has focused on the hydraulics of flowing water as one of the key elements forming the physical template for the ecological functions of a stream, other key elements being water temperature and substrate characteristics (Jungwirth et al., 2003; Allan & Castillo, 2007). Hydraulic variables form hydraulic habitats and therefore directly affect the aquatic fauna. Hydraulic variables at the same time are direct consequences of both geomorphologic and hydrological traits of a stream. Whereas geomorphic diversity is transferred in spatial diversity of hydraulic variables, hydrology provides the template for temporal variability that has been demonstrated to be inverse proportional to spatial variability and positively correlated to degree of modification providing less stability of habitats at channelized sites than at natural sites.

A recently proposed hydro-morphological index of diversity (HMID) has been used to investigate spatial and temporal variability of hydraulic variables. It properly reflects diversity of hydraulic variables and is therefore suitable for broader use in practical applications. The main application field for the HMID are river engineering projects having the aim of flood protection, river restoration, realignment of river courses or other purposes. With the help of numerical hydraulic models hypothetical project designs being discussed in variant studies can be investigated. Comparing the HMID value for the different project proposals upon modelling of a mean flow allows a ranking of the project variants in relation to the expected variability of the hydraulic environment. Additionally, by means of the HMID value it can be estimated how close the project proposals will come to a reference status. Modelling different discharges occurring throughout the season is further necessary for deeper understanding the temporal stability of hydraulic variables that is a feature with at least the same importance for the aquatic fauna as the spatial diversity.

The study has confirmed the initial hypothesis of greater spatial diversity at natural sites and greater temporal variability with less stable aquatic habitats at channelized sites. Since the variability and dynamics of river environments is seen as a serious research challenge (Vaughan et al., 2009), and yet needs to be understood for successful river management (Thoms, 2006a), this study delivers a scientific progress at the interface of hydromorphological and biological interactions and is certainly applicable across regional scales (Armanini et al., 2010).

7 The hydromorphological index of diversity and its application in river engineering projects

Abstract: River restoration has become one of the most important disciplines in the management of freshwaters. Due to economic and societal constraints a historic reference condition frequently is not achievable. Thus, water management authorities need tools to plan and realize river restoration measures that deliver the best possible ecological potential in the specific case. Measures providing streams with a dynamic equilibrium where maintenance costs are small seem the most prone for sustainability. This chapter presents an applicative case study where by means of a recently developed Hydro-Morphological Index of Diversity (HMID) different project alternatives for a river restoration project are quantitatively compared. Further checks allow verifying the hydromorphological improvement of the investigated alternatives. Application of the HMID allows establishing an ecomorphologically oriented decision base to water authorities for the definition of the preferred project alternative to realize.

Keywords: river restoration, quantitative evaluation tools, numerical 2D-models, habitat heterogeneity, dynamic equilibrium, disturbance concepts

7.1 Introduction

Streams are a manifestation of the landscapes that they drain (Hynes, 1975) and contribute strongly to the geodiversity of our globe (Gray, 2004). Water flowing down to the sea and immediately beneath the land surface is the dominant agent of landscape alteration (Bloom, 1998). In their natural status streams form a continuum (Vannote et al., 1980) with connectivity working in the three spatial dimensions (Kondolf, 2006; Elosegi et al., 2010) respectively by adding the temporal scale in four dimensions (Amoros et al., 1987; Ward, 1989). Streams are not to see as elements that are isolated by clear separation marks from their surrounding terrestrial landscape, they rather form a ecosystems strongly influenced by their surroundings (Wiens, 2002; Allan, 2004), with gradual transitions from terrestrial to aquatic habitats. Therefore they are able to fulfill important ecological functions also in a major context. Upstream migration of salmon for example (Elosegi et al., 2010) carries energy and nutrients from the ocean into reaches where carcasses fertilize the stream and, mediated by predation and lateral transport by bears, provide N influx to riparian forests (Helfield & Naiman, 2006, Quinn, et al., 2009).

Despite covering only about 0.8 % of the earth's surface (Gleick, 1996) streams are home to around 6 % (Dudgeon et al., 2006) of the species community. Thus, they are acknowledged hotspots of biodiversity being home to a multifarious flora and fauna with at least 100'000 known species worldwide (Hawksworth & Kalin-Arroyo, 1995), including 10'000 freshwater fishes and 90'000 invertebrates (Allan & Castillo, 2007). Nevertheless, due to human interferences of different type throughout civilization and at varying scales rivers today are heavily degraded. The range of stream conditions from pristine to profoundly impacted reflects the system's integrated response to various human disturbances (Allan, 2004). Many aquatic species are already extinct or strongly reduced in biomass and abundance with restricted distributions compared with historical occurrences (Dudgeon et al., 2006; Allan & Castillo, 2007; Vörösmarty et al., 2010). At the heavily degraded river Inn in Austria for example around 1920 fish stock surveys indicated at range of more than 24 species (Jungwirth et al., 1989), whereas today the only indigenous and reproducing species are grayling (*Thymallus thymallus*) and the brown trout (*Salmo trutta fario, L.*) (Muhar et al., 1995).

To counteract threatening impacts to aquatic ecosystems, the discipline of river restoration in the last decades has become a main task for decision makers of freshwater systems aiming at recovering natural patterns and processes within the fluvial landscape (Benda et al., 2011). The major part of western countries has released directives and laws challenging water authorities to improve the ecological status of their running waters. The Water Framework Directive (WFD) of the European Union for example urges the member states to protect, enhance and restore all surface water bodies, with the aim of achieving good ecological status (European Commission, 2000). In Switzerland the Water Protection Ordinance obliges the Cantons to restore 4'000 km of modified streams within the next 20 years (Bundesrat, 2011).

Stream restoration is a relatively recent discipline in the management of running waters, nonetheless it is accepted as an essential complement to conservation and natural resource management (Wohl et al., 2005). The term "stream restoration" is used for a large number and jsometimes contrasting variety of activities. Commonly "restoration" refers to the return of a degraded ecosystem to an approximation of its remaining natural potential, although the more properly term for it would be "rehabilitation" (Shields et al., 2003). From its very beginnings in the 1930s when the USDA Forest service started undertaking "stream improvement" with intent of increasing salmonid production (Everset & Sedell, 1984), over its broad implementation from the late 1970s (Sear, 1994) stream restoration has gained enormously in popularity (Wheaton, 2004) accomplishing important steps. Accompanied by an improved understanding of ecological, hydrological and geomorphologic processes providing insight into the functional and structural characteristics of stream systems (Allan, 2004), water authorities recognized the more and more the need of turning away from piecemeal, on-off local projects (Wheaton, 2004) towards the implementation of more comprehensive approaches. Despite the fact that resolving resource management issues across entire river basins and resolving conflicting interests among stakeholders requires degrees of coordination and cooperation rarely achieved in human society (Naiman, 1992), in various countries efforts are undertaken to define projects that include entire watersheds. Integrated river basin management plans are aimed at providing both flood protection and ecological improvement (European Commission, 2007; Chaix et al., 2011; Nikowitz & Ernst, 2011), pursuing possibly a multivariate approach to examine in detail cause-effect relationship for the ecological integrity of the concerned streams, having strong participative character involving the whole field of stakeholders (Koehn et al., 2001; Hostmann et al., 2005), engaging experts from different disciplines and being outlined preferably at a large scale (see for example Annable et al., 2002, Jungwirth et al., 2002).

Nine common types for river restoration have been identified (Wheaton, 2005), with enhancement of habitat heterogeneity being a cardinal element, as alteration of habitat is recognized to be likely the single most significant threat to freshwater biota (Allan & Castillo, 2007). Habitat targeted measures cover a wide range of measures with different spatial scales and complexities, from the simple placement of boulders up to the most visually striking types which are channel reconstructions that involve the creation of a new channel, often in a new alignment and generally with a form and dimensions that are different from those of the preproject channel (Kondolf, 2006). The literature concerning the appropriate design of channels from a geomorphic point of view is vast and has developed over many decades (Lane; 1953; Leopold et al., 1964; Schumm, 1977; Rosgen, 1996; Kondolf et al., 2003; Sear et al., 2003; Shields et al., 2003; Brierley & Fryirs, 2005; Piégay et al., 2005; Shields & Copeland, 2006; Schweizer et al., 2007; Nardini & Pavan, 2012). On the other hand, for a predictive and quantitative evaluation of river restoration project alternatives that address ecomorphological measures aiming at the enhancement of habitat heterogeneity in order to re-establish ecological functions, scientific approaches to be found in literature are remarkably rarer. Thus, in this specific field there is still large room for appropriate tools to be developed and applied.

In the following the application of a recently proposed Hydro-Morphological Index of Diversity (HMID) is discussed. The HMID aims at delivering a contribution in the field of ecomorphological proper design of river engineering projects. It is shown how the HMID can be used in river engineering projects to compare project alternatives from an ecomorphological perspective. By means of a case study different project alternatives, driven by commonly applied approaches for the enhancement of habitat heterogeneity, are evaluated calculating the HMID by means of numerical modelling. Further checks allow to verify tendencies acquired by calculating the mean flow based HMID. As a result, recommendations for a prioritization of project alternatives can be given to the decision makers.

7.2 Methods

7.2.1 The Hydro-Morphological Index of Diversity (HMID)

The HMID has been developed (Gostner et al., 2012a) by investigating pre-alpine gravel-bed streams, where geomorphic pristine situations, but also strongly modified reaches exist. Comparing hydromorphological properties between the study reaches and conducting correlation analysis for hydraulic and geomorphic metrics within reaches the hydraulic variables flow velocity (v) and water depth (h), by means on the following formulation, were found to represent exhaustively hydromorphological variability of a stream reach.

The HMID is based on the coefficient of variation CV. Partial diversity V(i) of a variable is expressed as:

$$V(i) = (1 + CV_i)^2 = (1 + \frac{\sigma_i}{\mu_i})^2 \tag{7.1}$$

By multiplying the partial diversity of the hydraulic variables flow velocity and water depth the HMID is obtained. The HMID becomes a single metric to describe the physical heterogeneity of a site and is written as

$$HMID_{Site} = \prod_i V(i) = V(v) \cdot V(h) = \left(1 + \frac{\sigma_v}{\mu_v}\right)^2 \cdot \left(1 + \frac{\sigma_h}{\mu_h}\right)^2 \tag{7.2}$$

The HMID was developed based on data acquired by means of extensive field surveys carried out at mean flow stage. In a further study (Gostner et al., 2012b) the temporal variability of the hydromorphological template was tested by means of numerical modelling. The HMID has been demonstrated to properly describe the aquatic environment also in its temporal variability, which is strongly driven by the geomorphic template.

7.2.2 The project frame and study site

The stream under study is the Etsch, whose watershed is situated in the North of Italy (Figure 7.1). Its source is on the main chain of the Alps closed to the boarder between Italy and Austria and, in terms of length (~410 km), it is the second longest, and, in terms of watershed surface (~12’200 km²), the third largest river in Italy.

In its upper course the Etsch runs through a U-shaped, glacier formed valley that, at the study site, spans over a width of around 1.8 km. The two largest debris fans of the Alps (Malser Haide and Gadria), formed by lateral tributaries draining highly erodible watersheds, are at the upstream and the downstream end of the project area. These ends are characterized by two marking changes of gradient, whereas in the project area itself the slope of the valley is moderate and relatively constant with the debris fan at the downstream end representing a non erodible altitude fix point.

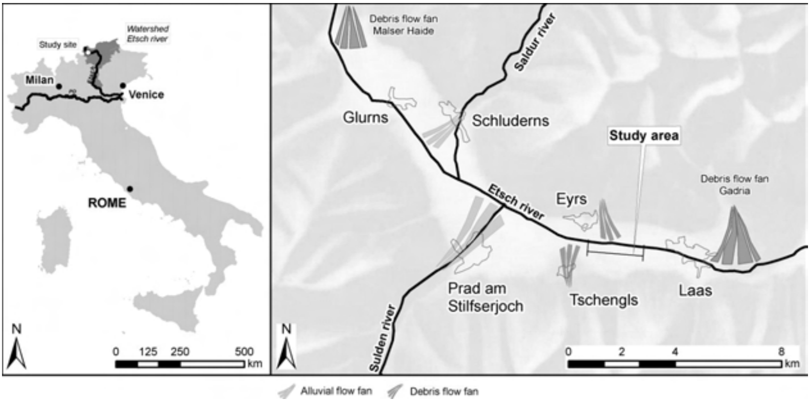

Figure 7.1 Watershed of the Etsch river (left) and overview of the project area with study site location.

In the project area the Etsch river at present covers a length of approximately 13 km. Historically the Etsch river was a braided stream in its steeper parts at the upper end of the project area, whereas in its middle part and at the lower end of the area the stream was meandering through the valley (Figure 7.2), being extended over a length of 16.2 km. The valley was occupied mostly by alluvial forests forming a large active floodplain that could be freely occupied by the fluvial activity of the Etsch river. To gain arable land and to improve flood safety for the settlements, situated slightly elevated on alluvial fans on the sides of the valley, in the years between 1819 and 1825 the Etsch river was constricted into a single-thread, trapezoidal channel positioned approximately on the thalweg of the valley dictated by the lateral fans. These stream training works were the first major channelization projects at the whole Etsch river.

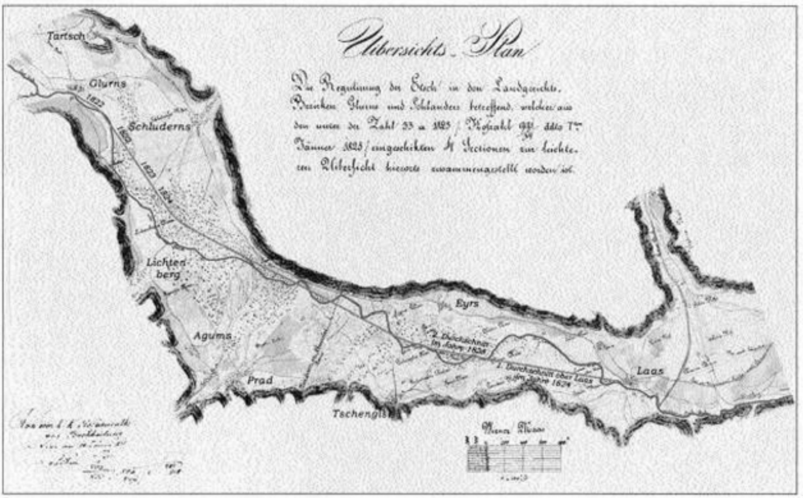

Figure 7.2 Historical map of the Etsch river in the project area (1825).
The dark blue line indicates the original alignment, and the light blue line shows the new alignment after the channelization between 1819 and 1925.

In aerial photographs there is still clear evidence of the ancient river bed, however, the large part of the former parafluvial area nowadays is occupied by agricultural land with apple orchards being the main culture (Figure 7.3). There are some reminiscent alluvial forests, however, they are entirely disconnected from the Etsch river and therefore not more able to fulfill their pristine functions. River channelization resulted in severe habitat degradation which most probably is a main cause for the impoverished biodiversity in the Etsch river with an overall scarce biotic quality.

As the issues in the study area are not only limited to biodiversity impairment, but also to flood protection and other topics, in 2008 an integrated river basin management plan was launched with the participation of the concerned stakeholders (Autonome Provinz Bozen, 2009). In regular workshops detailed information about ongoing studies was given as a base for working groups where directives for a guiding image were elaborated. A hazard assessment study, conducted within the frame of this project, has revealed that the village of Laas, situated at the downstream end of the project area, in case of major floods on the Etsch river is threatened by severe inundations. The guiding image defined several sub-projects to be studied and appropriate measures to be planned in detail.

One sub-project addresses the aforementioned questions. On the one hand, flood protection measures for the village of Laas are to be planned and on the other hand, according to the EU WFD, the ecological status of the stream site in question has to be improved. Amongst others, to enhance habitat diversity has been defined to be one of the key activities.

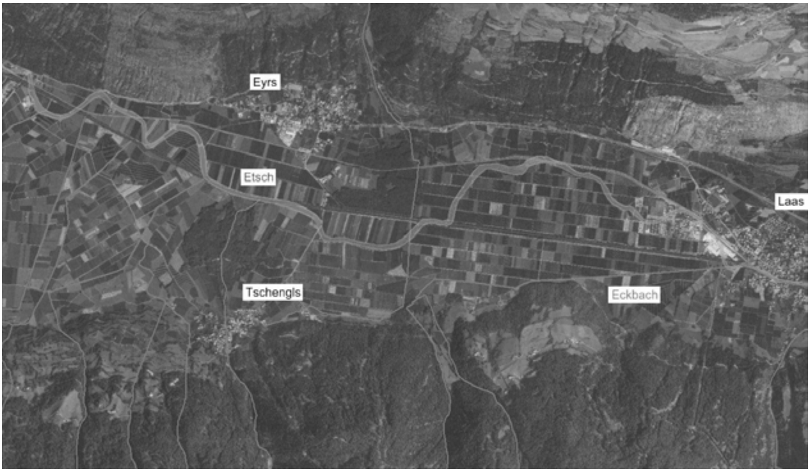

Figure 7.3 Aerial photograph with identification of the ancient river bed and the lower part of the project area.

The case study presented herein is intended as part of this sub-project assuming rather a pilot character, as it is the first real case application of the HMID that has also the aim to individuate eventual critical aspects in its use. The selected study site is situated along one of the reminiscent alluvial forests (Figure 7.4) which, by connecting it hydraulically to the Etsch river, could eventually be destined as flood retention area to improve flood safety for the downstream village. In combination with the improvement of the hydromorphological conditions in the Etsch river the great chance arises that the alluvial forest together with stream in the future could fulfill again, at least partially, his doubtless ecological importance (see e.g. Roberts & Angermeier, 2007; Schmutz et al., 2008; Elosegi et al., 2010) as a riparian corridor.

The study site situated along the riparian forest has a length of 1’900 m and at present a slope of 0.26 % and is characterized by the straight alignment and its monotonous trapezoidal profile with a river bed width of around 15 m (Figure 7.5). The river banks are characterized by rip-rap protection, with a relatively dense vegetation cover consisting of willows, alders and similar plants.

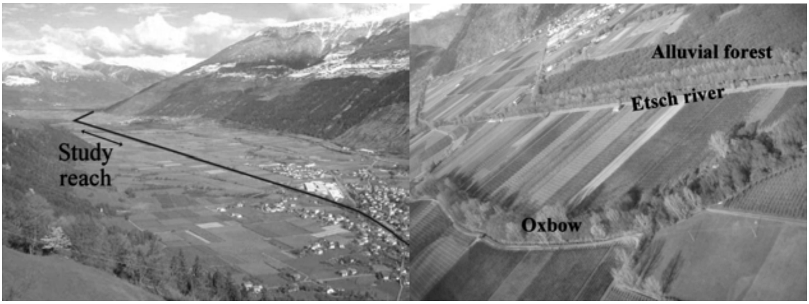

Figure 7.4 Project area with the channel of the Etsch river (left) and study site (right) with view in the upstream direction.
On the left floodplain in flow direction the reminiscent alluvial forest is situated and on the right plain an oxbow is present. The photograph evidentiates the intense agricultural activity with apple orchards occupying most of the available land.

Figure 7.5 View in the downstream direction of the study site (picture by Gostner, 2012).

A qualitative comparison with cross sections from 1997 revealed that the channel is in a quite stable situation without particular aggradation neither erosion. The river bed in fact is characterized by a pavement layer (sensu Sutherland, 1987; Bunte & Steven, 2001) showing a rather narrow spectrum of grain sizes in the gravel fraction with a D_{50} of 12.7 cm and a heterogeneity factor D_{90}/D_{40} (Schwoerbel, 1961) of 5 which has to be judged as a rather low heterogeneity (Williams, 1980). At the upstream end of the study site (Figure 7.1) a lateral tributary with a relatively frequent debris flow activity (Gostner et al., 2003) feds the Etsch river with sediments that favors the stability of the channel under study.

7.2.3 Definition of projects variants to enhance habitat heterogeneity

7.2.3.1 On the way to the reference condition

As suggested in the legal frameworks, targets in restoration projects should be derived from a reference condition (see e.g. Muhar et al., 1995; Stoddard et al., 2006; Nestler et al., 2010), whereby this may be based either on historical or geographical comparisons or on modelling (van Looy, 2006). However, as in our highly urbanized and multiple-pressure affected watersheds many human interventions result to be irreversible and an original reference status usually can not be achieved, frequently a restoration potential is defined which deviates from a complete return to a pristine status (Jungwirth at al., 2002). These conceptual frameworks focus on re-establishing important ecological functions. Many of these functions are related to the availability of specific physical habitats. Fishes for example need a variety of habitats satisfying their requirements during different life stages and for differing activities (feeding, resting, refuging, spawning, etc.). Therefore, for re-establishing ecological functions to enhance habitat heterogeneity is a common base activity.

Habitat enhancement techniques are based mainly on observation of conditions and patterns to be found in natural streams and aim at emulating the physical characteristics of streams situated in similar geographical regions and less affected by habitat degradation. However, there is a huge variety of habitat enhancement techniques (Raven et al., 1998), ranging from localized instream measures at a micro-scale level such as placement of boulders or wood, over meso-scale approaches such as the creation of gravel bars to mimic riffles, realization of deflector groynes to generally diversify flow or bank reprofiling to create more gentle slopes up to measures at a reach scale level, for example the total removal of river banks, the complete realignment or reshaping of entire stream reaches.

For the present case three different project alternatives have been defined that span over different spatial scales. As this study is rather a pilot study to verify the suitability of the HMID for application, strongly contrasting variants have been selected. By this choice the range of hypothetical HMID scores and the advance of each project alternative in comparison to the present condition can be shown.

7.2.3.2 Project alternative 1: Instream habitat enhancement by placement of boulders.

The placement of single boulders or of boulder clusters is a very popular technique (see e.g. Negishi & Richardson, 2003; Roni et al., 2006). It is applied more on a local scale and prevalently used in cases where there is no possibility to remove or redesign the river banks. The placement of boulders is seen as a means to actively restore habitat heterogeneity and geomorphic channel form at a relatively small spatial scale (Negishi & Richardson, 2003). Boulder placement not only enhance habitat heterogeneity for fish, it also offers macroinvertebrates a possibility for oviposition which is especially important in stream reaches where the entire river bed already at low to mean flow conditions is wetted and locations for oviposition are lacking (Alp et al., 2011). Alternatively, instead of boulder placement also large wood is placed (see e.g. Larson et al., 2001; Angermeier & Karr, 1984; He & Shields, 2009; Floyd & Taylor, 2009) to enhance instream structures. At the first glance this seems to be a problem for flood safety, as wood transported downstream during flood events might clog bridges and provoke a raise of the water level in critical zones with subsequent floodplain inundations (Lange & Bezzola, 2006; Schmocker & Hager, 2011). However, a correct interpretation allows the conclusion that the placement of wood not only increases habitat heterogeneity and nutrient retention, but also improves channel stability (Elosegi et al., 2010).

The effects of boulder or wood placement on an ecological scale are contradictory. By identifying 53 peer-reviewed studies, and carrying out meta-analysis for 24 of them Miller et al. (2009) showed that increasing habitat heterogeneity had significant, positive effects on macroinvertebrate richness, although density increases were negligible. However, also in the future these small-scale techniques will be widely applied measures: on the one hand they are not cost intense and do not require long bureaucratic procedures for approval. On the other hand in many cases due to an highly urbanized context or to an insuperable obstruction of adjacent land owners the space for river restoration will not increase.

The design of this project alternative was based on several empirical approaches and guidelines. Boulders should occupy less than 10 % of flow area at bank-full flow (Fischenich & Seal, 1999). Groups of three to five boulders in a triangular configuration should be placed in or near the channel thalweg to ensure habitat availability during low flow. Moreover, boulders should be well-spaced, each one in the periphery of the wake of upstream boulders, as those placed in the wake of an upstream boulder have in fact minimal benefits. Boulders with diameter between 0.5 and 1 m to form clusters (Sartorelli & Puzzi, 2012) should be used, and the clusters should not be submerged for low flows. In the present case study, boulder clusters with a minimum diameter of the base area of around 2 m were chosen. The height of each cluster is 1.5 m, and the spacing between clusters is about 13 m, to avoid interference between the wakes of each cluster.

7.2.3.3 Project alternative 2: Creation of alternating gravel bars.

In locations where the space required to restore a meandering or multi-thread pattern is impractical, by creating riffle-pool sequences a single thread channel with alternating gravel bars can be expected (da Silva, 1991; Schweizer et al., 2007).

This project alternative represents a scenario which is very likely to occur in the present case. Intense agricultural activity which is a main business in the region has led to the advance of apple orchards right up to the toe of the river banks. Probability is high that land owners will only accept a compromise with a limited amount of land made available for the river restoration project. Alternating gravel bars guarantee channel slope to be diversified and the development of riffle-pool sequences with a subsequent increase of habitat heterogeneity. However, the full range of hydromorphologic units (Parasiewicz 2001) will hardly be achieved, as features such as undercut banks, side arms and backwater areas usually are missing in reaches with alternating gravel bars.

For the layout of this project alternative regression estimates (Schweizer et al., 2007) of bed width as a function of discharge, valley slope and gravel size that allow to predict the channel morphology have been applied. A bankfull width of around 40 m is the condition for a single thread channel with alternating gravel bars to develop (Figure 7.6). For the definition of the planar bars and pools sequence, and for an estimation of the maximum pool depth and the maximum bar height, the expressions proposed by Ikeda (1984) and Colombini et al. (1987) were used. A wavelength of the bars of around 350 m, a maximum pool depth of 1.3 m and a maximum bar height of 1 m was derived.

7.2.3.4 Project alternative 3: Creation of a multi-thread channel.

Historical material demonstrates that in the study site the Etsch river originally was a meandering stream (Figure 7.2) taking advantage of the relatively wide valley to displace its course from one valley side to the other. To achieve this status quo ante is a non achievable goal. It will even be difficult to obtain land allowing to re-establish a sort of meandering stream. Therefore each river restoration measure at the Etsch river in the project area will be rather a remediation activity that recognizes the stream has changed so much that the original condition is no longer relevant and an entirely new condition has to be aimed at (Walsh & Breen, 1999).

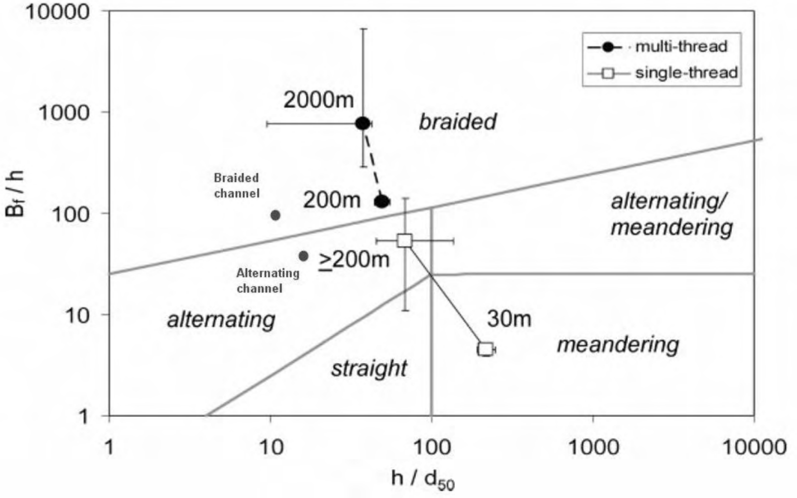

Figure 7.6. Expected channel morphological patterns for project alternative n°2 (alternating gravel bars) and n°3 (braided channel), based on the pattern diagram of da Silva (1991).

In other words, as in the present case the historical reference status cannot be set as a geomorphological achievable target and river widening depends strongly on available land and space, the project has to focus on recovering important ecological functions of the stream. Assumed that land owners, against all predictions, are willing to cede more surface than expected, the creation of a multi-thread channel can be envisaged. By means of this new geomorphic pattern several ecological functions might be re-established. The full range of hydromorphologic units will be delivered, providing to aquatic biota a variety of habitats needed for different activities and life stages. Sediment transport activity will be more dynamic with the chance that functional flows (Escobar-Arias & Pasternack, 2009) will prepare the bed in order to allow spawning activity, to deliver porosities and thus refuge for macroinvertebrates in the hyporheic zone and to re-establish vertical connectivity (Schälchli, 1992). Bed sediments will be more diverse, with clusters of varying sediment sizes including patches of fine sediment deposits offering habitats for certain vegetational species and sinks for nutrient retention which is a an essential function of stream ecosystems (Fisher, 1997). The reconnection of the stream with the reminiscent alluvial forests will reinstall many ecological functions, as for example increasing the chances of finding refuge during disturbances, creating preferential paths for organisms or regulating the transport of nutrients and organic matter between floodplain and channel (Elosegi et al., 2010), favoring a general improvement of biodiversity at the floodplain scale (Ward & Tockner, 2001). Additionally, where spatial diversity is higher habitats between disturbance events will be more persistent (Gostner et al., 2012b), which acts as selective force for the kinds of ecological strategies possible in a particular location (Fisher et al., 2007), favoring better conditions for less specialized species.

For this study case morphological considerations (according to Schweizer et al., 2007) predict that a braided channel will develop for bed widths greater than 50 m. A river bed width of 70 m was defined, which seems for the most optimistic previsions to be the maximum space available (Figure 7.6). Several intersecting channels were created, with different width, depth and curvature radius, and many bars with different height and planar dimensions in a way that they can be submerged for flows with varying return time as it has been investigated for natural braided channels (Gurnell et al., 2001; Gostner et al., 2010). Moreover, pool-riffle sequences for the wetted channels were defined according to investigations of natural channels (Richards, 1976; Sear & Newson, 2004; Neff et al., 2010).

7.2.4 The numerical 2D-modelling approach for the project

7.2.4.1 The diffusion of numerical 2D-models

In flood protection projects the employment of numerical 2D-models is a nowadays standard. Therefore, to calculate the HMID for the design alternative under study in order to deduce an ecomorphological evaluation, signifies a limited additional effort, as the 2D-model has to be run with some supplementary discharges corresponding to flows being smaller than flood discharges.

In the present case the software system BASEMENT (Faeh et al., 2006-2011) has been used. BASEMENT is a 1D-2D numerical simulation model, and it allows by means of a two-phase system both hydrodynamic and morphological simulations. Concerning the computational grid, the software allows the use of both structured and unstructured grids. The mathematical models are based on the 1D Saint-Venant equations and on the

2-dimensional shallow water equations (derived from the Navier-Stokes approach) for hydrodynamic simulations, while for sediment transport (bed load, suspended sediment load and pollutant transport) empirical formulae are used. Numerical models used consist mainly in the finite volume method for spatial discretization (in the hydrodynamic model the Riemann solver is used for flux estimation) and in the explicit Euler schema for time discretization (in 1D simulations an implicit calculation method is also available).

To run a 2D-model, the necessary field work to carry out is a detailed topographical survey of the present state and to make records or evaluations of channel roughness. Moreover, for long-term successful projects also grain size characteristics should be known to evaluate qualitatively or quantitatively the long term evolvement of the river bed and to verify whether a dynamic equilibrium can be reached or not. However, in the frame of the presented project these measurements were previously carried out for implementing the 2D-model for the calculation of the discharge performance of channel in flood conditions.

If elaborated in a thorough manner, numerical models are able to represent the physical reality in a more reliable way. Firstly, numerical 2D-models do not view the stream as a number of transects, but rather as a continuum (Ghanem et al., 1996) represented by a digital terrain model (DTM) which is defined upon the topographical survey containing information about altitude and roughness. Secondly, field measurements that traditionally are characterized by the one-dimensionality of measurements because carried out along transects are affected by operator bias (Wallis et al., 2010). Thirdly, field measurements correspond to a single snapshot in time, whereas in numerical models each desired discharge can be modelled, therefore allowing a space-for-time substitution (Dunbar et al., 2010).

7.2.4.2 Hydrological input for the numerical 2D-model

The watershed area in correspondence of the study site has an area of 660 km². The highest elevation point in the watershed is at 3’900 m a.s.l., whereas the study site itself is at a height of approximately 870 m a.s.l. Being situated immediately at the southern flanks of the main chain of the Alps, the watershed is characterized by the presence of numerous glaciers. Thus, from a hydrological point of view, many tributaries are characterized, according to Pardé (1920), by an accentuated glacio-nival regime, whereas the Etsch river itself, draining the main valley where also snow melt is an important flow generating factor, without the glacier fed tributaries would have rather a nival-meridional hydrological regime. Flood events in the Etsch river occur mainly between late spring and autumn in correspondence to intense precipitations with a duration of 1 – 3 days.

In this context, as ordinary discharges flows below a certain threshold corresponding to the initiation of major sediment transport are defined, whereas extraordinary discharges are flows where major channel avulsion processes with bed reshaping and habitat turnover take place.

7.2.4.3 The 2D-model

Alternative	**0**	**1**	**2**	**3**
Verbal description	Present state	Boulder placement	Alternating gravel bars	Multi-thread channel
Study length (m)	500	500	1’300	1’550
River bed width (m)	15	15	40	70
River bed rugosity k_s ($m^{1/3}/s$)	29	29	29	29
River bank rugosity k_s ($m^{1/3}/s$)	13	13	13	13
Computational area (m²)	16’400	16’400	72’500	124’200
Number of grid cells	18’997	18’997	30’746	69’816
Average size of cells (m²)	0.86	0.86	2.36	1.78
Maximum size of cells (m²)	1.80	1.80	6.92	3.43
Minimum size of cells (m²)	0.29	0.29	0.81	0.23

Table 7.1 Characteristics of numerical hydraulic models.

Computational domains for each of the project alternatives were defined according to the complexity of the solution (Table 7.1). For simpler designs model area was reduced. The model grid was elaborated as an unstructured triangular network with differing sizes of the single cells. In areas closed to topographically accentuated changes cell size was diminished, whereas in other cases with a near plane topography cell size was greater in order to speed up computing velocity.

Due to lack of particular instream features such as gravel bars, main and secondary channels, intermediate break lines etc. for the definition of the DTM it was sufficient to interpolate the cross section data available from a cross section survey carried out in 2007.

Hydraulic roughness k_{St} within the bankfull channel was estimated using the Manning-Strickler equation of the form (Strickler, 1923):

$$k_{St} = \frac{21.1}{D_m^{1/6}} = \frac{1}{n} \qquad (7.3)$$

where n is the Manning's roughness coefficient and D_m is the mean diameter of the substrate material.

The average size of grid cells was around 1 - 2 m², whereby for a number of 19'000 (project alternative n°1) to 70'000 (project alternative n°3) cells flow velocity and water depth were obtained. The values for the hydraulic variables were in the typical range for gravel bed streams with relatively low slope. HMID rankings were calculated exclusively for the river bed, with the confining node corresponding to the intersect between river bed and bank. Especially for the present state and for project alternative n°1 where the stream is confined by steep, engineered slopes to include hydraulic variables valid for the slopes would fake a non-existent habitat heterogeneity. Therefore, decreased flow velocity and water depth along the slopes were not considered.

7.2.4.4 Model runs and further checks

The numerical 2D-model is run for the present status and for the defined project alternatives. To calculate the base HMID the median discharge on the flow duration curve Q_{180}, which corresponds to the flow that is exceeded for the half of the days during a hydrological average year, was used. However, further checks are necessary to strengthen the quantitative statement given by the base HMID.

In reaches where habitat heterogeneity and thus HMID is rather high, also temporal stability is expected to be higher as long as major discharges do not occur (Gostner et al., 2012b). Thus, to consider besides of spatial also temporal considerations which is fundamental to river science (Wohl et al., 2005) HMID is calculated also for discharges deviating from a mean discharge. This serves also to verify if marked disturbance events, which correspond to floods with a sharp decrease of HMID, occur for the designed project alternatives. Disturbances are considered the dominant factor organizing stream ecology (Resh et al., 1988) being responsible for maintaining of several ecological functions, therefore it is essential that disturbance events are able to behave as that.

Additionally, an increased habitat heterogeneity alone might not be sufficient to deliver the best possible abiotic conditions necessary to re-establish biotic integrity. Care has to be taken of habitat bottlenecks (Bovee et al., 1994) as an absence of key habitats can decrease fish population, with effects cascading through the food webs (Katano et al., 2006). For the present case as an example it is verified, if hydraulic habitats with water depths >55 cm and flow velocity <70 cm/s are present and to which percentage. Derived from brown trout preference curves, based on polynomial regression and valid for gravel bed streams on the southern part of the Alps (Vismara et al., 2001), this properties are characteristic for pools and offer brown trouts a habitat suitability of at least 0.5 for adults and 0.85 for juveniles.

7.3 Results

7.3.1 Hydrology

Flows in the Etsch river are driven by the seasonal change between winter, when precipitation is mainly falling as snow and thus flows are small with a minimum in the month of February, and summer when snow and glacier melt events concur to generate major discharges. Due to their glacio-nival regime two tributaries of the Etsch river, the Saldur river and Sulden river (Figure 7.1), having a watershed area of 100 km² and 161 km² respectively, achieve a sharp flow peak in July. They influence the hydrological regime at the study site in a way to generate almost an equal average discharge of around 35 m³/s in June, when nival regimes usually have their peak, and July (Table 7.2). On the flow duration curve (Figure 7.7) therefore flow of around 30 m³/s is exceeded for about 60 days of the year. Flow in general is doubling for approximately each 100 days of exceedence. The flow exceeded for 300 days a year (Q_{300}) for example is around 5.0 m³/s, the Q_{200} around 11 m³/s and the Q_{100} is around 21.5 m³/s.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Q (m³/s)	5.74	5.21	5.27	7.26	18.06	35.56	34.13	26.13	15.64	13.14	9.94	7.17
q (l/s,km)	8.70	7.90	7.99	11.01	27.37	53.87	51.72	39.59	23.70	19.91	15.06	10.86

Table 7.2 Average monthly flow discharge and specific flow for the study site.

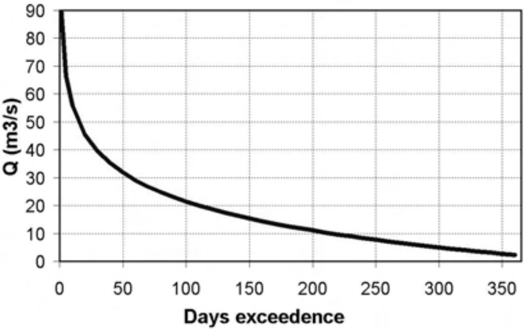

Figure 7.7 Flow duration curve for the study site.

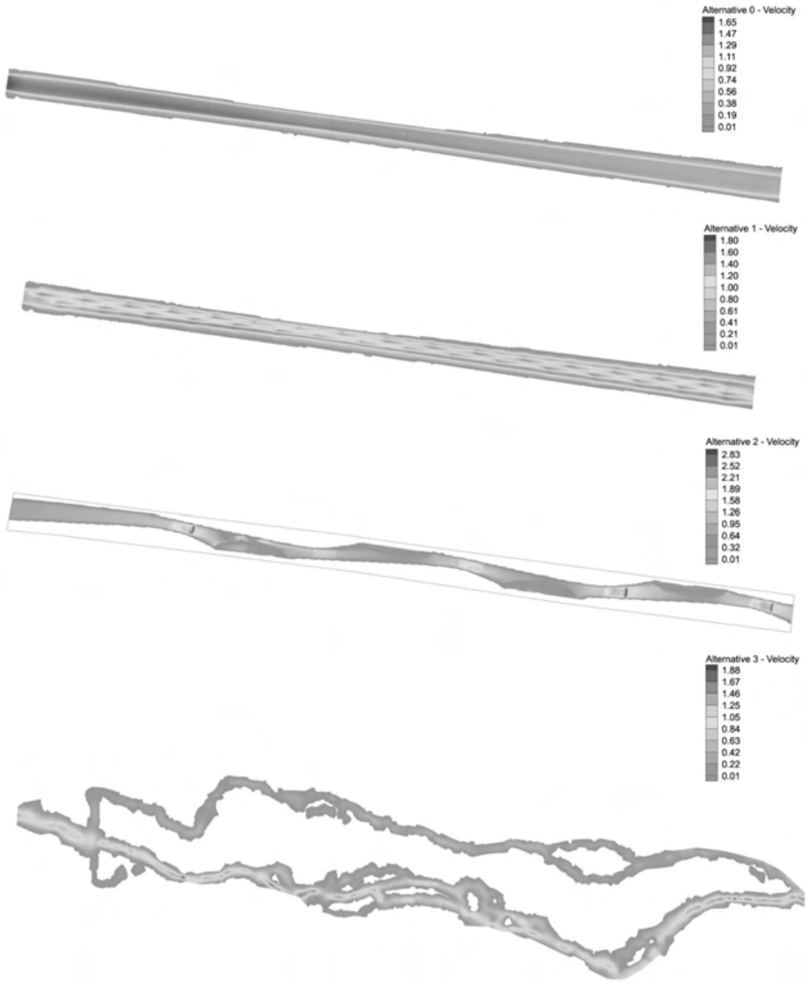

Figure 7.8 BASEMENT output indicating flow velocity ranges of Q_{180} for the studied project alternatives ("0": present condition, "1": boulder placement, "2": alternating bars, "3": multi-thread channel)

7.3.2 HMID for median flow stages and temporal variability

The numerical 2D-model was run under the assumption of steady conditions and stable bed (Figure 7.8). HMID calculations for the median discharge Q_{180} (henceforward also referred to as "Base HMID") which is the daily mean discharge that is exceeded for 180 days of the year, i.e. for 50 % of the year, revealed that HMID is lowest for the present state (Table 7.3). Due to boulder placement hydraulic variability slightly increases with a resulting higher HMID.

For project alternative n°2 (alternating bars) and n°3 (multi-thread) HMID is remarkably higher, stating that hydraulic variability is the highest for alternative n°3. The results are in line with recent observations (Gostner et al., 2012) where HMID levels have been classified into three categories. An HMID <5 reveals a channelized and morphologically heavily altered site, however a HMID close to 5 gives evidence for a minor variability in geomorphic patterns. An HMID between 5 and 9 corresponds to a medium range where on the upper end stream reaches approach a natural morphology. A HMID >9 reveals a geomorphic almost pristine site where hydraulic variability and therefore also habitat heterogeneity is high and close to a reference status.

Project alternative			**Present state**	**Boulders**	**Alternating bars**	**Multi-thread**
v	**(m/s)**	**μ**	1.13	0.97	0.62	0.56
		σ	0.21	0.26	0.37	0.45
		CV	0.18	0.27	0.59	0.80
		V(v)	1.40	1.61	2.54	3.25
h	**(m)**	**μ**	0.83	0.96	0.73	0.63
		σ	0.14	0.16	0.48	0.51
		CV	0.16	0.17	0.66	0.81
		V(h)	1.36	1.36	2.77	3.27
		HMID	1.90	2.19	7.02	10.65

Table 7.3 Mean value (μ), standard deviation (σ), coefficient of variation (CV) and partial diversity (V) of flow velocity (v) and water depth (h) as well as HMID scores for the Q_{180}.

7.3.3 Further checks: temporal variability and availability of key habitats

7.3.3.1 Temporal variability

When looking at temporal variability (Figure 7.9) it is confirmed that the HMID is less variable for alternatives where habitat heterogeneity is higher. At a channelized site flow velocity and water depths increments for changing discharges are larger than at more natural reaches. Due to the confined river bed water depth and therefore also flow velocity are increasing faster than in wider river beds where an increasing discharge primary causes the lateral expansion of the flowing water until the entire river bottom is wetted. Therefore for discharges below a threshold value which corresponds to the wetting of the whole river bed temporal variability of habitats in more natural sites is lower than at channelized sites where the phase of river bed wettening is almost non-existent but for very low flows.

However, for extraordinary discharges corresponding to a flood where at natural sites channel avulsion processes with bed reshaping processes take place the HMID is sharply decreasing also at natural reaches. At a channelized reach this sharp edge in the HMID duration curve usually doesn't occur.

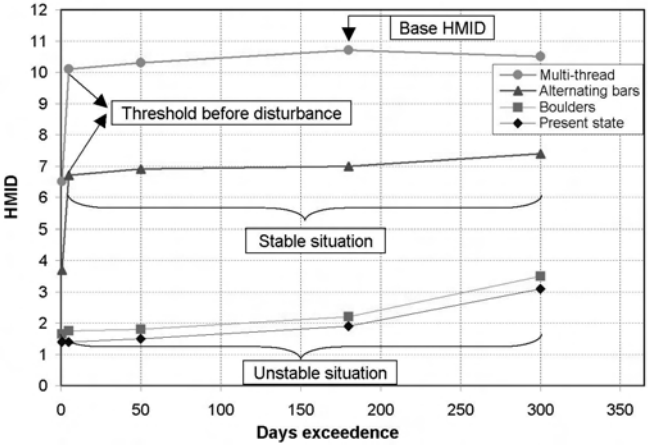

Figure 7.9 Temporal variability of HMID for the project alternatives.

7.3.3.2 Availability of key habitats

The availability of a key habitat such as pools which are essential for the brown trout is strongly related to the morphological characteristics of the project alternatives (Table 7.4). For the present state in the entire study area the unique available habitat are glides, pools are almost non-existent. By placing boulder local scour downstream of the structures with the subsequent forming of slow-flow habitats occurs and the percentage of pools increases. For project alternative n°2 and n°3 the percentage of pools is further increasing guaranteeing that brown trout will dispose of its preferred habitat in the study site.

Alternative	Pool percentage
Present status	2 %
Boulders	10 %
Alternating bars	22 %
Multi-thread	24 %

Table 7.4 Pool percentage of wetted surface for Q_{180}. Pools are defined as such if $v < 70$ cm/s and $h > 55$ cm.

7.4 Discussion

In the last 20 years leading researchers over and over have advocated that river restoration is not sustainable without incorporating processes at a watershed scale (Boon et al., 1991; Sear, 1994; Muhar et al., 1995; Kondolf et al., 2001; Palmer et al., 2005; Wohl et al., 2005; Fryirs & Brierley, 2008; Benda et al., 2011). Thus river restoration projects have to take place at different spatial scales (Wiens, 2002), according to different spatial hierarchies (Frissell et al., 1986) governing fluvial processes. River basin management plans nowadays follow these tracks and frequently come along with integrated, watershed oriented and long term driven guiding images characterized by a quite innovative spirit. However, financial constraints, bureaucratic obstacles where administrative bodies are not ready to act from an overall point of view (Mellquist, 1992) respectively to abandon dogmatic patterns of practice (Gillilan et al., 2005) or political groups holding the voice for adjacent land owners not willing to dispose of their properties are examples which impede large scale measures to be realized at once. Nonetheless, such obstacles should not discourage water authorities to initiate sub-projects. A step-by-step philosophy sometimes is more likely to yield results than to spend energies and money for large-dimensioned projects where one critical project issue might be the cause for a project to faile at all. Therefore, measures to be realized at a reach scale will also henceforward constitute an essential component in river restoration projects.

The HMID is a tool to be applied for reach scale habitat enhancement measures. Despite having pilot character to demonstrate how the proposed HMID could be applied, the study presented herein is based on a real case and can therefore also be used as a guideline for practitioners in similar projects.

By application of the HMID it is possible to bring into a practical arena (Dunbar et al., 2010) several postulates from river restoration research. First of all, in virtually all cases the historical reference condition can not more be set at as a target (Nestler et al., 2010). Therefore a potential for restoration that realistically can be achieved has to be defined (Jungwirth et al., 2002). However, in practice due to external boundary conditions curtailments have usually to be made also concerning the full achievement of the restoration potential. The HMID allows a quantitative evaluation of different project alternatives with an affirmation how close the alternatives come to an ideal restoration potential. The alternatives shown in the present case study for example reveal that the placement of boulders does not improve habitat heterogeneity arising strong doubts if essential ecological functions will be re-established. On the other hand, widening of the river bed to a limited extent with creation of alternating gravel bars allows a relatively high habitat heterogeneity to be obtained coming close a hydromorphological status represented by alternative n°3 which is the best possible potential under the given circumstances.

Additionally, the HMID doesn't evaluate enhancement of habitat heterogeneity from a static viewpoint. Sound river restoration shouldn't aim at creating a static endpoint (Wohl et al., 2005), as these project have commonly proven to fail (Kondolf et al., 2001, Palmer, 2008). Habitat simulation such as PHABSIM (Bovee et al., 1998) for river restoration projects usually define a hypothetical layout and predict habitat suitability for target species with exact localization of different habitats, therefore assuming a static form of the redesigned stream reach. Moreover, the traditional, narrow application of these tools toward management of single species has been viewed as inadequate in the context of growing concerns over ecosystem integrity (Parasiewicz et al., 2011). The HMID is an alternative to such models, as it rather looks at general hydraulic diversity, not at a specific diversity for target species. The approach implies that if overall diversity is high, an acceptable range of variability of process is likely to succeed (Wohl et al., 2005) with different habitats present, offering the chance that aquatic species find their preferred habitats at different life stages. Moreover, the approach trusts in the self regulatory capacity of natural or near-natural streams, where the hydromorphological template after disturbances, even if during the events major bed reshaping processes with migration of the river channels takes place, will be similar as before (see Arscott et al., 2002).

Finally, the HMID intrinsically incorporates the requirement for a dynamic equilibrium where basic ecological functions are guaranteed also at the long term and allow the targeted river to be self-sustainable in its new context (Palmer et al., 2005; Elosegi et al., 2010). Due to the HMID scores for different flows which demonstrate that there are distinct differences in temporal variability of habitat heterogeneity conditioned by stream morphology (Figure 7.9) the term "dynamic equilibrium" can be used in a slightly modified manner than it is originally meant for. Dynamic equilibrium hitherto referred mainly to a geomorphological state. However, as the present case demonstrates, the dynamic equilibrium concept might also be applied to the temporal conditions of physical habitat aquatic biota undergo. In a stream with a natural or near-natural morphology the point localized situation in terms of hydraulic variables respectively of aquatic habitat is temporally rather stable for ordinary discharges, with a temporal equilibrium for aquatic species occupying a specific area. If extraordinary discharges occur, disturbances take place which have an important and continuing effect on river morphology and biological communities (Poff, 1997). These disturbances represent in fact the dynamism in riverine landscapes and correspond to major bedforming events which are represented by bankfull discharges occurring with a return period of 1.5 – 5 years (Williams, 1978). Bankfull discharges are characterized by an intermediate frequency what has been hypothesized to lead to the highest diversity resulting in a hump-shaped diversity-disturbance curve (Hildrew & Townsend, 1987; Johst & Huth, 2005). The HMID demonstrates to well reflect this change between stability (equilibrium) and disturbance (dynamism) (Figure 7.9). In similar environments bed reshaping processes with strong habitat turnover (Arscott et al., 2002) and a cycle of formation, growth and decay of islands has been observed (Bertoldi et al., 2011), confirming high biodiversity in environments where intermediate disturbances occur. On the other hand, in channelized reaches a clear distinction between stability and disturbance can not be observed, as the HMID continuously decreases with an increase in discharges even if remaining in the range of ordinary flows. For the aquatic biota this results in a sort of stress, whereas intermediate disturbances are missing and important ecological functions (e.g. spawning, nutrient retention, vertical flux, etc.) therefore are not able to be maintained. From a geomorphological point of view, it is confirmed that in a channelized reach bankfull discharges are achieved only for very rare events. Due to the coarse pavement bed reshaping processes do not occur with intermediate frequency, only floods with major return period are able to remove the pavement. In these cases the river bed basically is not able to provide the physical template necessary for example for spawning activity or for marcoinvertebrate refuge during floods which is the case if alternative n°2 or n°3 are realized as merely a movable armoring layer, instead of a pavement, in the wetted parts and an overall diverse substrate mosaic will be created.

Nonetheless, a dynamic equilibrium has to be achieved also in the geomorphic sense. Balancing sediment supply and transport is a key consideration (Shields et al., 2003) and to understand watershed processes in terms of morphology is essential (Kondolf et al., 2001; Kondolf et al., 2007). A lack of sediment input from upstream may lead to an incision of the river bed where sooner or later a single thread channel, even in a widened stream reach, will again be the case with a subsequent degradation of habitats. If sediment yield is excessive or contains a high percentage of fines, risk that key habitats (for example spawning areas) will be siltated is high. 2D-models with mobile bed modules could be of great help in this sense, as the long term behaviour of the river bed can be modeled, enabling also quantitative comparisons of the hydromorphological condition before and after flood events with intense sediment transport. However, if projects from an ecomorphological point of view are successful, ecological success can nevertheless be small as there are many other factors that might overrule a heterogeneous and natural habitat mosaic. Watershed processes are to be considered also in biological (are recolonization pools available) or chemical (is there sources of pollution) terms. Moreover, other hydromorphological issues, for example river fragmentation in the longitudinal or lateral direction with lack of a riparian buffer or a strongly altered flow regime, could also play a primordial role in impeding ecological successful river restoration. Additionally, one has to be aware the temporal scales of ecological response and river restoration might not match with delayed biodiversity recover (Gregory et al., 2007)

7.5 Conclusions

In the present case study the application of a recently developed Hydro-Morphological Index of Diversity (HMID) has been demonstrated. The HMID is a new tool enabling quantitative judgments of river restoration projects on an ecologically relevant scale. As the HMID is able to reflect spatial and temporal variability in relation to morphological characteristics, it can be a valuable answer to what has been postulated as the need to develop means of quantifying predictions relevant to restoration, including channel response to physical changes (Wohl et al., 2005). The HMID was developed as a straightforward tool that could contribute to conducting river restoration projects in a way to re-establish important ecological functions and services (Covich et al., 2004) sustained by a dynamic equilibrium (Elosegi et al., 2010) which is characterized by an environment where periodical disturbances help to maintain a healthy biotic river community.

8 Gravel bar inundation frequency: an indicator for the ecological potential of a river in context with presence of target species such as German Tamarisk or Chorthippus pullus

Abstract: In braiding river systems, gravel bars fulfill important ecological functions. At the River Sense, one of the last unregulated rivers in Switzerland, the frequency of gravel bar inundation of a 2 km long site maintaining indicator species such as *Myricaria Germanica* (German Tamarisk) and *Chorthippus pullus* (Gravel Grashopper) was studied. Based upon both detailed data collected in the field and a hydrological analysis of the site, a numerical two-dimensional model of the site was developed to investigate the inundation area and frequency of the parafluvial zone for a range in flow regimes. Results show that the free surface of the parafluvial zone is reduced significantly only when floods with a return period greater than one year occur. Three types of gravel bars were distinguished: gravel bars devoid of vegetation occur for return periods less than two years. The elevation of gravel bars that support *Myricaria Germanica* and *Chorthippus pullus* are at higher discharge elevations that coincide with discharge return frequencies between 2 to 5 years. Densely vegetated overstory and understory communities occur at floods greater than the bankfull return period of five years which also coincide with the floods principally responsible for altering the riverscape. Findings correlate well with the hypothesis that the sustainability of *Myricaria Germanica* and *Chorthippus pullus* is largely dependent upon a specific frequency and duration of intermittent flood inundations.

Keywords: Ecological Potential, Numerical Models, Gravel Bars, Flood Frequency, Inundation

8.1 Introduction

Riparian corridors are a nexus between biotic and abiotic environments which change spatially and temporally due to fluvial processes driven by hydrographic events, droughts, water quality, disease, ecological spiraling and dispersion, and anthropogenic influences, amongst many other factors. At the reach scale, the physical riverscape is mostly defined by erosion and depositional processes during flood events when sediment transport capacity and particle entrainment are high. During such discharge events, depositional features (such as point bars and central bars) and floodplains are inundated and their frequency and duration of inundation are directly linked to the intensity and duration of precipitation and snowmelt events.

Tockner and Stanford (2002) have identified floodplain riparian zones as some of the most geomorphologically active and endangered landscapes in the world. Terrestrial vegetation along river banks is frequently eroded and incorporated into flood events resulting in woody debris deposits with receding flows. Correspondingly, the colonization success of successional species which populate point bars, central bars and other mid-channel depositional features between large hydrographic events are also directly coupled to the frequency and duration of hydrographic events. However, the frequency and duration of hydrographic events defining river form may not be commensurate with those which sustain terrestrial growth and colonization. A feedback mechanism may also occur whereby mature terrestrial vegetation can increase the tensile shear strength of bank material leading to reduced rates of bank erosion (Wolman and Gerson, 1978; Thorne, 1990; Knighton, 1998) thus changing the frequency and duration of events where fluvial processes change the riverscape.

In the 21st century, considerable emphasis is being placed on the restoration of riparian corridors as an essential means to enhance the dynamic stability of rivers while correspondingly improving habitat diversity and variability and lowering long-term maintenance expenditures (EU WFD, 2000; FISRWG, 1998). Riparian corridor restoration may involve the removal of river training measures to allow fluvial processes to become re-established within riparian corridors, the physical restoration of channel morphologies through construction measures, removal of levees, bioengineering, terrestrial grooming and enhanced planting, and the protection and preservation of wild areas.

In many countries, there is an added level of complexity in riparian corridor restoration resulting from hydropower schemes which require controlled artificial flood durations and events to produce hydro-electricity. In many cases, the power scheme events can be altered to assist riparian corridor restoration. However, little is currently known about the frequency and duration of inundation of floodplains and mid-channel depositional features and the resulting success of terrestrial species. The aim of this study is to investigate the frequency and duration of flows in a braided river reach where native successional species are known to exist under relatively natural (unregulated) flow conditions. The information arising from this study can then provide power scheme design information on how to best regulate anthropogenic flow regimes to improve and enhance downstream riparian corridors.

8.2 The river Sense

The River Sense is a fourth order watercourse in a 432 km^2 watershed situated in the cantons of Fribourg and Bern, Switzerland (Figure 8.1). The watershed is one of the last unregulated rivers in Switzerland where hydrographic events are driven by snowmelt and precipitation events without any power schemes or major flow diversion works. Downstream from the confluence of several headwater streams (near Plaffeien – Figure 1), the main stem of the river flows for 35 km before confluencing with the River Saane.

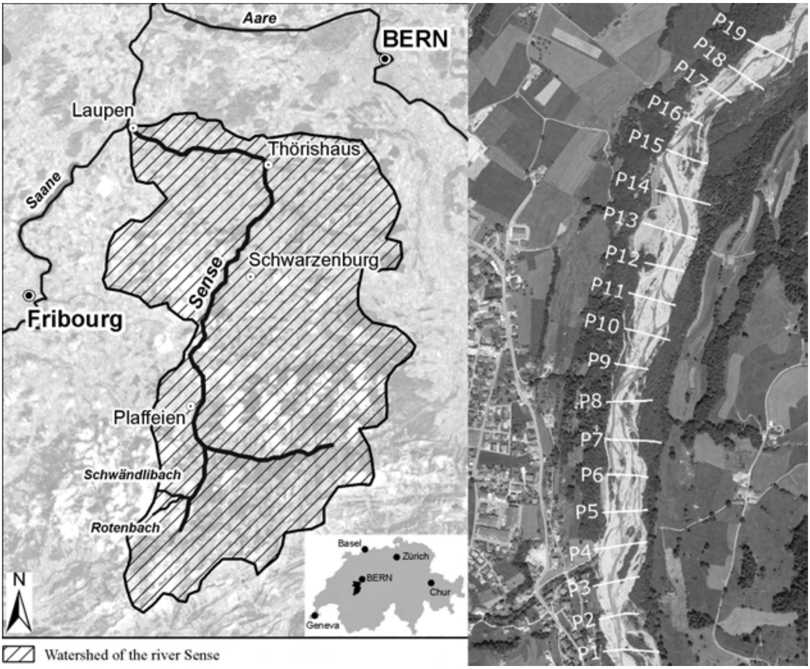

Figure 8.1 River Sense site location map (left) and study site with cross sections (right).

A braided river channel exists in a glacial trough valley near Plaffeien below the mountain headwaters where the sediment transport capacity is high. As the river progresses downstream, the channel enters into a single-thread incised limestone bedrock gorge and then progresses into a single-thread riffle-pool dominated channel morphology. Prior to confluencing with the River Saane, the River Sense is a single-thread plane-bed channel morphology (Montgomery and Buffington, 1997) that has undergone river training over the past several decades.

In the braided parafluvial zones of the river, the morphology is dominated by frequent channel avulsions, mid channel and side channel bars resulting in a highly diverse habitat environment (Lorang and Hauer, 2006) with frequent bank retreats, tree losses, woody debris, emergent vegetation and successional terrestrial species. The return frequency of inundation varies widely between mid and side channel bars, floodplains and terraces. Conversely in the single-thread orthofluvial zones (in particular where river training works have been employed), point bars and side channel bars are inundated much more frequently than the untrained braided reaches.

Within the riparian corridor of the River Sense, *Chorthippus pullus* and *Myricaria Germanica* are frequently observed in mid channel and side channel bars which are indicators of high biotic integrity. These species are particularly abundant in the braided reaches where it is expected that the more heterogeneous fluvial environment supports a more diverse aquatic and terrestrial environment (Stanford et al., 2005). Further, the braided channel reaches have highly varied elevations of mid and side channel bars, floodplains and terraces resulting in disparate inundation frequencies allowing several terrestrial species to become established.

In the single thread reaches, there is an observed absence or reduction in *Myricaria Germanica* and *Chorthippus pullus*. The reduction is believed to result from the increased frequency in inundation of the depositional features at similar elevations limiting rooting establishment and hindering the terrestrial community development. On the other hand, floodplain abandonment resulting from reduced upstream sediment supply or headcutting may contribute to the pervasiveness of terrestrial species by changing the frequency of inundation and proximity to the water table. Completely abandoned floodplains are inundated on a less frequent basis and have a reduced susceptibility to erosion which may then contribute less to the destruction of more aggressive species and colonization of more biologically diverse indigenous species.

8.3 Methods and analysis

8.3.1 Study site

The inundation frequency of a braided reach near Plaffeien (Figure 8.1) is investigated to determine the frequency and duration of discharge events which are considered biologically optimal for the colonization of *Chorthippus pullus* and *Myricaria*

Germanica. *Chorthippus pullus* and *Myricaria Germanica* are found in the study reach, however, there are a series of mid channel bars also devoid of the species of interest. Other gravel bars at higher elevations are densely vegetated islands with tree heights approaching 15 meters and absence of *Myricaria Germanica*.

The study site is approximately 2 km in length (Figure 8.1) with an average bankfull width of 150 m and an effective catchment area of 118 km^2. The area of study is approximately 25 hectares.

8.3.2 Field data collection

Nineteen cross sections and a longitudinal thalweg profile of the channel were surveyed using a first-order differential GPS. Transects were spaced at approximate 100m even intervals perpendicular to the mean channel flow direction to characterize the geomorphic features which included: the channel thalweg, top and bottom of channel banks, bankfull stage, terrace elevations and any additional visual breaks in cross sectional slope. The limits of islands and depositional features were surveyed in addition to the maximum elevation of each feature and the location of woody debris piles.

Substrate size and distribution were characterized using the Wolman pebble count method (Wolman, 1954) at each cross section within the bankfull limits of the channel. Grain size distribution plots were generated for each cross section and the median particle diameters of log-normal distribution plots used to determine the median grain size diameter (D_{50}) as illustrated in Figure 8.2. The median reach particle diameter was found to be 53 mm which relates to a very coarse gravel substrate.

Hydraulic roughness (k_{St}) was estimated from the results of the Woman Pebble count using the Strickler equation of the form (Strickler, 1923):

$$k_{St} = \frac{21.1}{D_m^{1/6}} = \frac{1}{n} \tag{8.1}$$

where n is the Manning's roughness coefficient. An average value of $k_{St} = 34 m^{1/3} s^{-1}$ was obtained for the entire study reach. An average reach roughness coefficient was used rather than discrete values obtained at each cross section since at discharges approaching mid channel bar inundation, there is significant course grain sediment transport leading to a redistribution in the bed material that cannot be adequately quantified in addition to changes in the wetted perimeter resulting from scour and deposition.

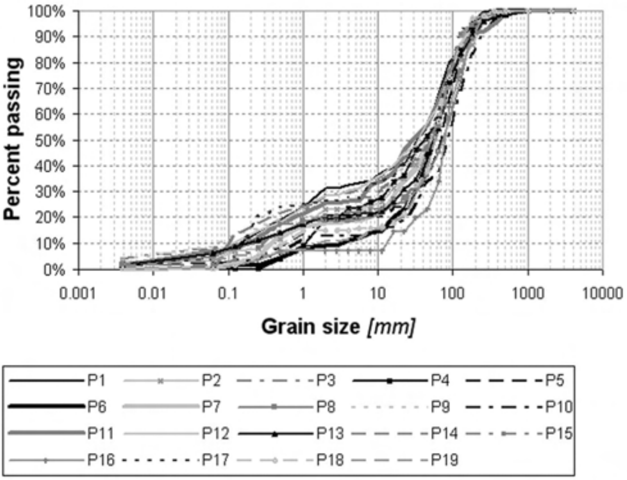

Figure 8.2 Grain size distribution curves at each transect

Discharge velocities were obtained within the flowing sections of each cross section using the six-tenths velocity method in addition to velocities being measured 0.05m above the channel bed. Velocities obtained at 0.05m were considered to relate to the nose running depth of fish that would occupy the lotic environments. Discharge velocities were obtained using a Sontek Flow Tracker® acoustic Doppler velocity meter and their specific locations surveyed using a GPS.

The spatial location of the terrestrial species of interest were acquired from a parallel biological inventory using a hand held GPS. Ground elevations at each plant location were related to ground elevations obtained in the first order differential transect surveys.

8.3.3 Hydrology

A hydrometric monitoring gauge station was not available at the study site proper. However, two gauge stations are located upstream (approximately 7 km) located on two tributaries at Rotenbach and Schwändlibach, one gauge located 15 km downstream at Thörishaus and a fourth gauge on the River Saane at Laupen immediately downstream of the confluence with the River Sense (Figure 8.1). Flow duration curves were developed for each of the four gauge stations and a watershed scaled flow duration curve developed for the study site (Figure 8.3) using the Swiss regionalized model developed by Pfaundler & Zappa (2006) which is based upon ordinal datasets between 1981 and

2000. The model assumes there is a contiguous logarithmic function between watershed area and discharge.

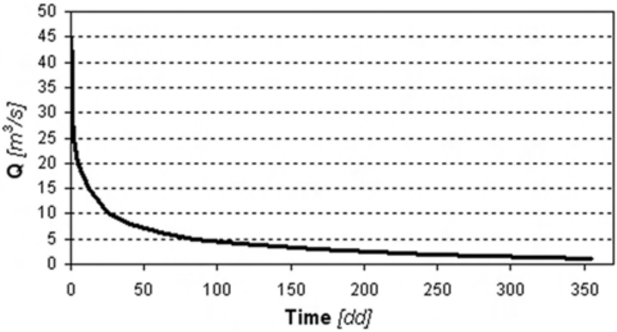

Figure 8.3 Study site flow duration curve.

At the Thörishaus gauge station 15 km downstream, the mean annual discharge was calculated to be 8.7 m^3/s and using a logarithmic discharge scaling factor of 0.66 for the study site at Plaffeien, a mean annual discharge was estimated as 4.2 m^3/s. Validation of the scaling factor was achieved using the calculated discharge from velocity measurements during field inventories and compared to those of the Thörishaus gauge station during the same days of observation. On the day of field measurement, the average daily discharge at Thörishaus was 4.8 m^3/s. Using the logarithmic model, a predicted discharge at Plaffeien was 2.8 m^3/s whereas a field measured discharge of 2.3 m^3/s was calculated. It is important to note that on the day of flow measurement, discharge varied slightly during the day of measurement between cross sections. The average discharge from all 19 cross section velocity measurements and discharge calculations were used. Given the small error between the observed average daily discharge and that predicted using the logarithmic model, it is assumed that the flow duration curve developed at the Thörishaus gauge could be extrapolated with reasonable certainty to the study site.

Return period (ys.)	Q (m^3/s)
2	124
5	172
10	208
30	266
50	296

Table 8.1 Return frequencies and extrapolated discharges.

Flow frequency analysis using the Log Pearson III analysis method were conducted for a series of return periods between 2 to 50 years for the four gauge stations over each period of record. The return periods were extrapolated for the Plaffeien study site using the same logarithmic scaling factor (Figure 8.4). Table 8.1 lists the return periods and associated flows extrapolated for the Plaffeien site.

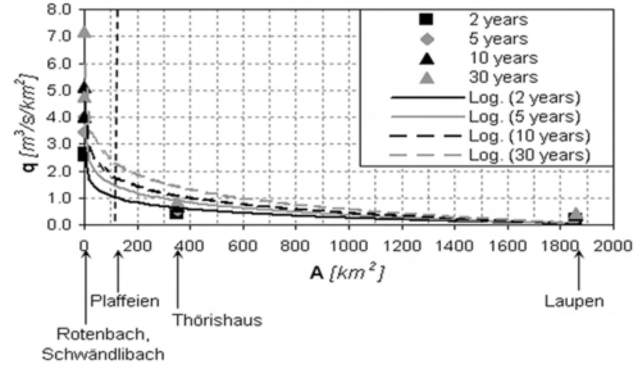

Figure 8.4 Interpolation of specific discharges between the available gauges by means of a logarithmic law.

8.3.4 Numerical model development

The numerical model FLUMEN (FLUvial Modelling ENgine) was used to investigate the spatial distribution and inundation frequency of depositional features of the study site. FLUMEN is a two-dimensional surface water model which can be used to investigate hydraulic behavior of rivers and coastal waters in a myriad of discharge conditions. The solution method is solved using depth-averaged shallow water flow equations on a cell-centered unstructured mesh that allows for wet and dry domains, sub- and supercritical flow conditions, and the specification of variable bed topography (Beffa, 2004).

In the current study, the river bed was assumed to be stable. It is recognized that a static river bed is an over-simplification of the braided river reach of study, however, the modeling domain cannot accommodate a dynamically changing grid configuration which would be consistent with a braided river reach under various high flow conditions. Nevertheless, for an initial investigation in determining the frequency and duration of depositional features and how these temporal metrics relate to terrestrial colonization, the proposed model should provide sufficient accuracy.

Nineteen cross sections, additional survey points, and surrounding upland data extracted from digital terrain were used to define the modeling domain of the River Sense at Plaffeien which is illustrated in Figure 2. An average Manning's roughness value of 0.03 was used for the bankfull channel (Equation 8.1) using the results of the pebble count analysis. Flood plain roughness beyond the limits of the bankfull channel and mature tree stands on islands were estimated in the range of $0.05 < n \leq 0.10$ and associated with the density and calliper of vegetative communities as suggested by Chow (1959).

8.3.5 Calibration of model

Model calibration was conducted using field measured velocities and the calculated discharge for the observed flow condition of 2.4 m^3/s where measured versus estimated flow depths were compared.) Further, flow depths were only compared at cross sections where the total flow occurred in a single channel, rather than multiple flow paths. The single flow path sites were selected as they offered greater flow depths and decreased cross sectional variability leading to better comparison between observed and predicted flow depths. The most upstream and downstream cross sections were also eliminated from the comparison arising from boundary condition limitations in the numerical model.

Figure 8.5 shows the geodetic elevations of the thalweg profile (bed elevation) and of the calculated and measured water level along a segment of the modeled reach. Simulated average flow depths, calculated as difference between thalweg and water level elevation, correlate very well with field observations.

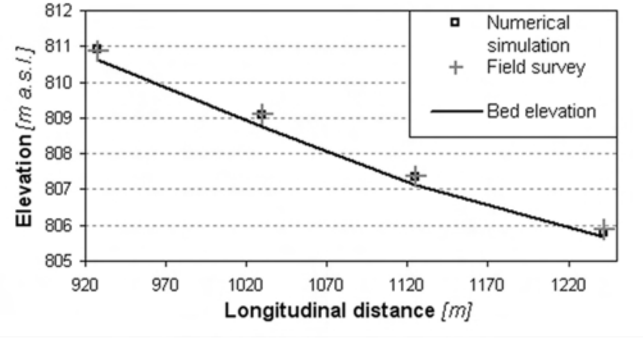

Figure 8.5 Comparison between measured and predicted water elevations for 4.3m^3/s.

The bankfull discharge frequency was also calculated as a qualitative metric to evaluate the accuracy of the model to the flow regime commensurate with initial flooding of the floodplain regions. Kellerhals et al. (1972) observed that the return frequency of bankfull discharge in braided rivers of western Canada ranged between 2 years and 7 years. Williams (1978) studying both braided and single thread channels observed bankfull return frequencies ranging between 1.1years and 25 years but did not stratify his data into specific channel morphologies. A series of simulations were conducted with varying discharges to determine what discharge (and associated return period) correlated best with the field observed bankfull discharge and associated depth along the longitudinal profile of the channel. A discharge of 172 m^3/s (relating to a 5-year return period) best correlated with observed flow depth conditions (Figure 8.6). The return period coincides with the range of previously observed discharge return periods in other braided river systems which provides additional confidence in the predictability of the model.

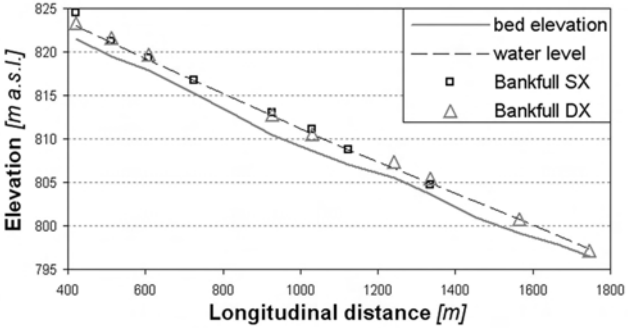

Figure 8.6 Comparison between bankfull height and water level for 172 m^3/s.

8.4 Results

8.4.1 Overall study site

Six inundation simulations were conducted between low flow conditions and the 10-year discharge ranging between 2 m³/s and 220 m³/s. The spatial distribution of inundation of the study reach is illustrated in Figure 8. The results illustrate that with increasing discharge, an increasing proportion of the river bed is inundated which increases the number of isolated regions (pseudo islands) up to a flow of approximately 57 m3/s (which relates to a 0.5 year discharge return frequency) followed by a decrease in isolated regions until the majority of the channel is inundated at 200 m3/s. The remaining dry regions correlate with islands identified from field investigations were mature and well established tree stands exist.

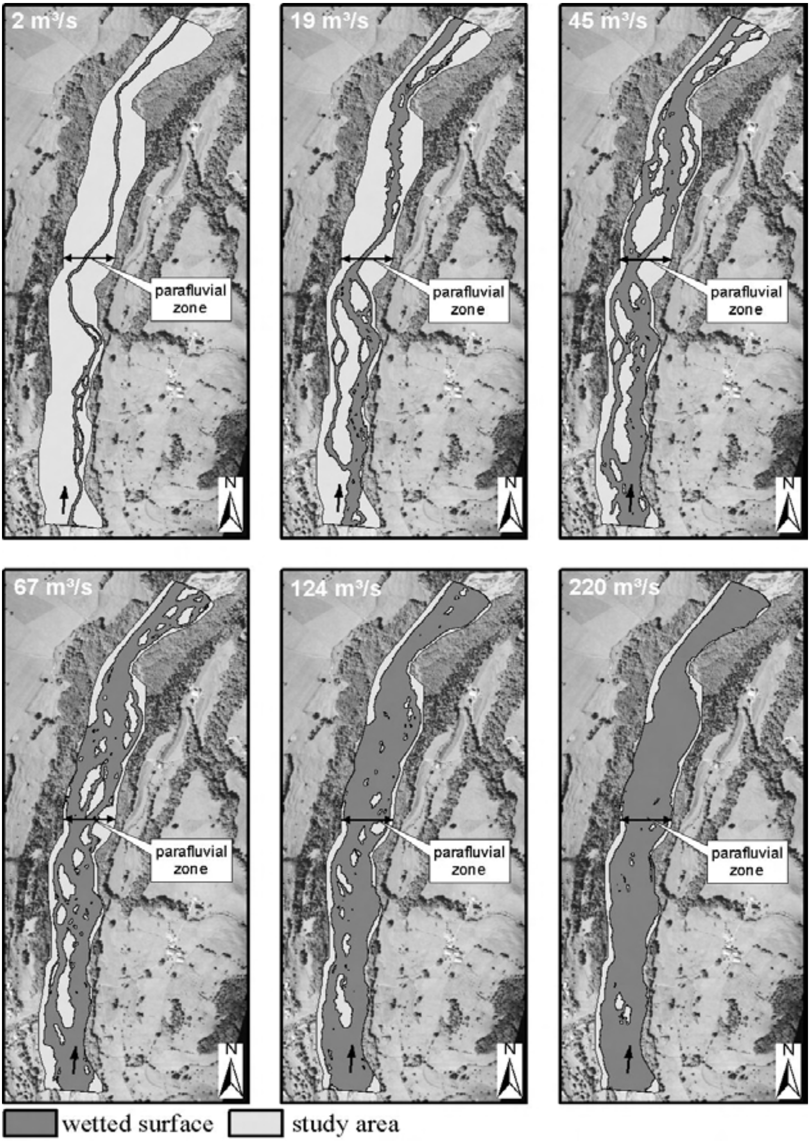

Figure 8.7 Parafluvial zone inundation with varying flow regimes.

Based upon the two-dimensional hydraulic analysis, a relationship was derived between the exposed (dry) surface area of the study reach and the annual duration of exposure (Figure 8.8). The relationship shows that at base flow conditions (2 m^3/s), 20’000 m^2 of the parafluvial zone is inundated and that the inundation trend follows a logarithmic profile with decreasing annual duration (increasing discharge). At the annual average maximum discharge, approximately 140’000 m^2 of the study reach is inundated which relates to 56 % of the total parafluvial zone. Further, for over half of a year in an average discharge year, only 10 % of the total parafluvial zone is inundated while 20 % of the parafluvial zone is inundated for 25 days/year or less.

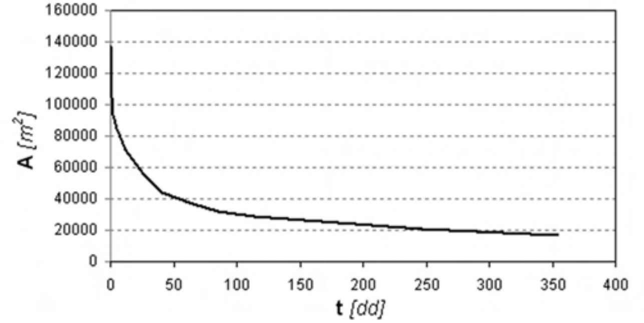

Figure 8.8 Wetted parafluvial zone area versus annual duration.

Relative percentages of inundated (wet) and exposed (dry) parafluvial zones were calculated for a series of discharge simulations related to specific frequency return periods and a relationship developed between relative area wet/dry percentages and discharge return frequency (Figure 8.9). A rapid increase in inundation area occurs within the parafluvial zone up to approximately the 2-year return period (approximately 85% wetted surface area). With increasing discharge return frequencies the relative areal increase in inundation significantly decreases. The rapid increase in parafluvial zone inundation relates to the range in discharges that are filling the bankfull channel in which all of the mid-channel and side channel bars exists. Beyond the two-year return period, only the highest elevation island remain above the water surface and correlate with the locations of well established island vegetative communities. A small percentage of the parafluvial zone remains above the water table at the 30-year return period, these elevations relate to an abandoned terrace elevation that has persisted over several decades.

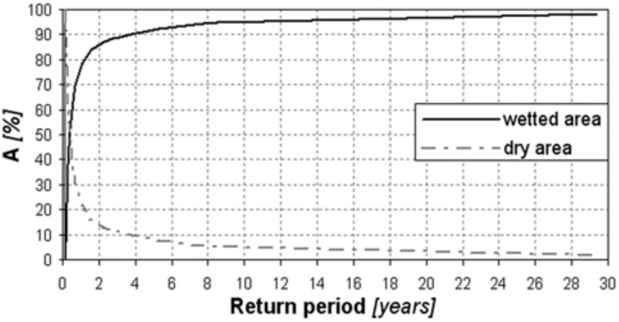

Figure 8.9 Trend of wetted and dry area in the entire floodplain for floods with different return period.

8.4.2 Special area of interest

A particular sub-reach of the study area was evaluated in closer detail between cross sections 3 and 9 (Figure 8.1). The sub-reach is of particular interest as the area has several gravel bar deposits of varying elevations where some bars support *Myricaria Germanica* and *Chorthippus pullus*, some support tree stands and some have an absence of either. The surface area of the parafluvial zone is 39040 m^2 and has a longitudinal distance of 600m and an average bankfull with of 130 m.

Rather than evaluating areal percentage of parafluvial inundation as it relates to pre-determined discharge frequency, here the discharge related to the water surface elevation when the elevation of specific gravel bars and island became inundated was determined. A relationship could therefore be developed between exposed (dry) percent parafluvial zone and discharge at vertical stages or “thresholds” when inundation significantly changes. The discharge thresholds were determined by evaluating a series of simulations and identifying inflection points in the relationship between the change in exposed parafluvial area (dA) and change in discharge (dQ) as a function of discharge. Evaluating local maxima or minima in the rate of change of dA/dQ identifies the threshold discharges where significant changes in exposed surface area (relating to the inundation of gravel bars) occur. The objective of this analysis was to correlate particular discharges and their return frequencies to the success in migration of *Chorthippus pullus* and colonization of *Myricaria Germanica* at certain gravel bar sites.

Figure 8.10 identifies the thresholds values in dA/dQ as a function of discharge over a broad range in simulated discharge values and return frequencies. Seven threshold discharges were identified: 10, 19, 32, 75, and 195 m^3/s which then relate to water surface elevations where there are significant changes in parafluvial inundation.

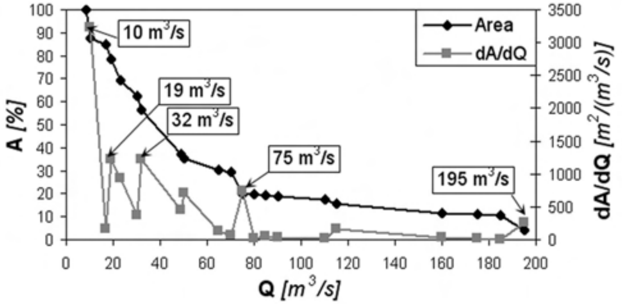

Figure 8.10 Decreasing of gravel bar continuous dry area due to the growth of discharge.

Figure 8.11 illustrates the spatial distribution of dry and wet zones for the sub-study reach. It is noted that an additional base case of 8.5 m^3/s is also illustrated: which is the lowest discharge when two flowing channels begin to form in the parafluvial zone. The dashed regions in Figure 8.11 depict the dry surfaces in the area of interest, while the darker solid shading identifies the inundated regions. As illustrated in Figure 8.11, at a discharge of 10 m^3/s a new flow path emerges on the left hand side of the channel forming an island. By 19 m^3/s, an additional bifurcation in flow occurs on the right hand side of the channel leading to an additional island. The formation of branches that evulse the principle dry zone from left to right occur between discharges of 32 m^3/s and 75 m^3/s. A discharge of 75 m^3/s relates to a return period of around 1.3 years. At the flow stage related to 75 m^3/s, the majority of the gravel bars devoid of vegetation are submerged, while the bars with *Myricaria Germanica* are still above the water surface. In the discharge range between the 4 and 5 year return frequency (just below bankfull discharge), areas populated by *Myricaria Germanica* are completely inundated.

Beyond 75 m^3/s, no significant change in inundated surface area occurs until a discharge of 195 m^3/s (7-year return period) is achieved which is above the bankfull stage (a discharge of 172 m^3/s and a five-year return period).

At a discharge of 195 m^3/s the adjacent floodplains will also be inundated and this final inundation elevation relates to a low terrace elevation. The remaining island surface elevation above the water level coincides with the mature tree stand, which has a surface of 1530 m^2 relating to 4 % of the total parafluvial zone. For discharges with return periods greater than 20 years, the entirety of the parafluvial zone is inundated.

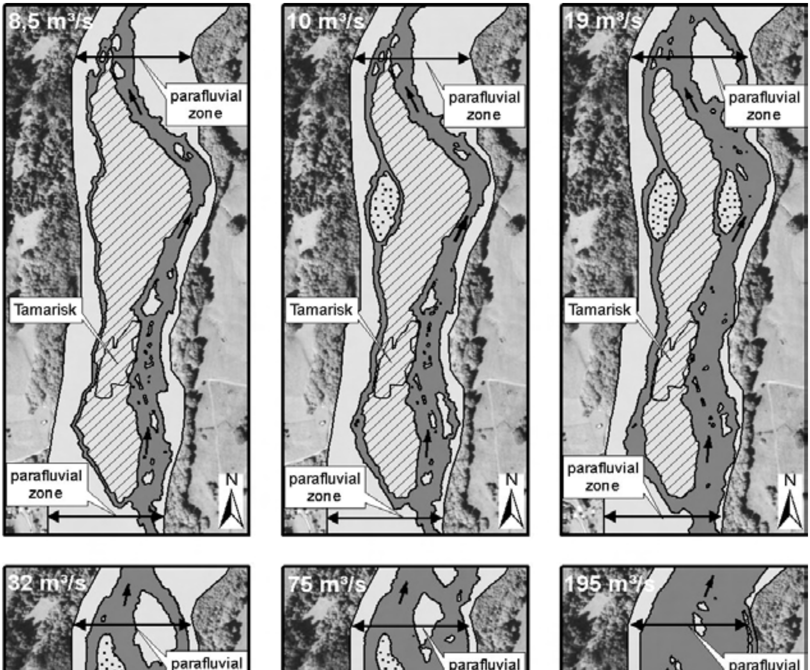

Figure 8.11 Wetted and dry areas with changing discharges.

8.5 Conclusions

A two-dimensional surface water model of a braided river reach of the River Sense in Switzerland was developed to investigate the persistence of terrestrial species with specific habitat requirements. Three dominant types of depositional features exist within the parafluvial zone. Depositional features devoid of vegetation are typically inundated in flows less than a two-year return period. Depositional features where *Chorthippus pullus* and *Myricaria Germanica* persist were found to become inundated at discharge return frequencies ranging between 4 years and 5 years. Depositional features, floodplains and abandoned island terraces where mature overstory and understory tree stands persist were found to be flooded at discharge return frequencies greater than 5 years. All parafluvial features were inundated when discharges exceeded a 20 years return period.

In single thread unregulated gravel-bed river channels, bankfull discharge is often correlated with a 1.5 year – 2 years return period (Leopold et al., 1964) and also maintains a relatively homogeneous wetted perimeter (relative to a braided channel). The absence of *Chorthippus pullus* and *Myricaria Germanica* in single thread channels may be related to the channel morphology or the frequency of orthofluvial inundation.

The results presented here provide initial insights into methods for linking the persistence of terrestrial species of interest with hydrologic and hydraulic tools. With sufficient coupled investigation of biotic and abiotic characteristics in a myriad of channel morphologies under a range in flow regimes, it is expected that flow regulation guidelines can be developed to optimize channel flow for both hydro-electric demands while enhancing terrestrial community restoration.

9 Temperature regime in a braided river system: an indicator of morphological heterogeneity and ecological potential

Abstract: Water temperature is one of the most important abiotic variables in streams and strongly influences the distribution and abundance of freshwater organisms. It might be assumed that in natural streams home to heterogenous habitats also a wide range of thermal habitats exist, whereas in altered and channelized streamms variability in water temperatures will be less pronounced. In order to test this hypothesis a case study at river Sense in Switzerland was carried out. At five river reaches characterized by different morphological patterns variability of water temperature was analysed. Temporal variability could be investigated by means of temperature loggers, whereas detailed temperature measurements in each water body along predefined transects served to elaborate spatial variability. As a key result if could be shown that there is an evident correlation between morphological characteristics and spatial variability of water temperatures.

Keywords: water temperature, river morphology, abiotic variables, biodiversity, ecological potential

9.1 Introduction

9.1.1 Role of water temperature in freshwaters

The distribution and abundance of organisms in freshwaters are conditioned by their abiotic environment. The most important variables in fluvial environments are most often current, substrate and temperature (Allan & Castillo, 2007). Temperature has been repeatedly recognized as a key environmental variable (Arscott et al., 2001) structuring both aquatic invertebrates (Vannote & Sweeney, 1980, Ward & Stanford, 1982, Hawkins et al, 1997) and fish (Illies, 1961, Welcomme, 1979, Torgersen et al, 1999).

Stream temperature usually varies on seasonal and daily timescales, but it also shows spatial patterns depending upon morphological characteristics and exchange with the groundwater. In addition tributaries have a substantial impact on the temperature of the main river. Therefore temperature depends strongly by groundwater inflows, nevertheless in the majority of cases it increases from the spring to the mouth, allowing the distinction of cold and warm water regions along a stream. As every species is restricted to some temperature range also its geographic distribution is related to a certain range of latitude and elevation (Allan & Castillo, 2007).

The hypothesis that alteration and homogenization of physical habitat is the most significant threat to biodiversity and ecosystem functioning leading to biodiversity decline (Allan and Castillo, 2007) is widely accepted. Consequently, the assumption that restoring physical habitat heterogeneity will increase biodiversity underlies many river restoration projects (Miller et al, 2009). By delivering heterogeneous physical habitats it might be assumed that also a wide range of thermal habitats are created favoring greater biodiversity as well as provide unique thermal niches for endemic taxa (Milner et al, 2001).

Spatial and temporal temperature heterogeneity are important characteristics of natural and near-natural rivers. Thus, the hypothesis can be established that at river reaches with a natural morphology spatial variability of temperature will be higher than at reaches with a highly altered morphology, with stream temperature being variable between habitats only a few meters apart (Hauer & Hill, 2006). In order to verify this hypothesis at river Sense in Switzerland an extensive temperature measurement campaign was carried out. In this chapter the objects, methods and analysis of the campaign are presented.

9.1.2 The river Sense

The River Sense is a fourth order watercourse in a 432 km^2 watershed situated in the cantons of Fribourg and Bern, Switzerland (Figure 9.1). Downstream from the confluence of several headwater streams (near Plaffeien – Figure 9.1), the main stem of the river flows for 35 km before confluencing with the River Saane. The watershed is one of the last unregulated rivers in Switzerland where hydrographic events are driven by snowmelt and precipitation events without any power schemes or major flow diversion works.

Moreover, between Plaffeien and Thörishaus for an overall length of around 20 km the river Sense results to be morphologically almost unaltered. Near Plaffeien the morphology of the river is characterized by a braided river pattern where sediment transport capacity is high. As the river progresses downstream, the channel enters into a single-thread incised limestone bedrock gorge and then progresses again into a braided river system. More downstream it enters into a semi-trained, single-thread riffle-pool dominated channel morphology. Prior to confluencing with the River Saane, the River

Sense, having undergone river training over the past several decades, results to be in a channelized state with a trapezoidal sections where both river banks are shaped by a rip-rap protection.

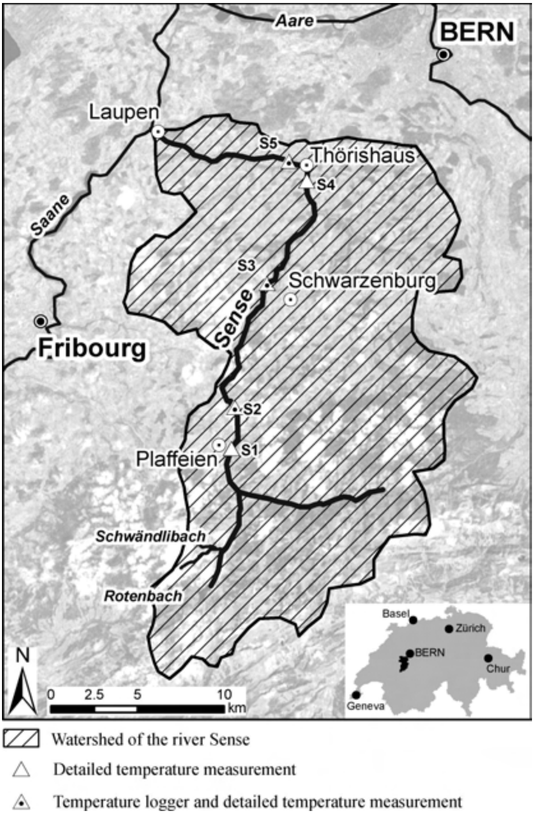

Figure 9.1 River Sense site location map.

In the braided parafluvial zones of the river, the morphology is dominated by frequent channel avulsions, mid channel and side channel bars resulting in a highly diverse habitat environment (Lorang & Hauer, 2006) with frequent bank retreats, tree losses, woody debris, emergent vegetation and successional terrestrial species. In the main and secondary channels fast flowing (riffles) and low velocity reaches (pools) are following one each other creating locally backwater areas, too, whereas in more remote areas stagnant water zones are to be found. Mid and side channel bars, floodplains and terraces are inundated with varying frequencies. Therefore, river dynamics in these areas are very high.

Conversely in the single-thread orthofluvial zones (in particular where river training works have been employed), usually the whole river bed is filled with water reaching the base of both river banks. Therefore, the variability of water depths and flow velocities is strongly limited, resulting in a quite uniform distribution of hydraulic habitats.

9.1.3 Objects of the study

The object of the present study is to verify the hypothesis that a more natural morphology delivers also a greater variability to the temperature regime of a stream. To pursue this object at river Sense several temperature loggers were installed where temperature was measured continuously for at last one year. Additionally, in order to get a picture of spatial temperature variations at a meso-scale level at five distinct river sites detailed temperature measurements were carried out along predefined cross sections. The measurements were carried out in summer and late fall when the temperature of surface water and groundwater are distinctly different.

The following questions to be answered were defined:

(i) What are the characteristics of temporal temperature variability? Can temperature be related to season and local meteorological conditions?

(ii) What are the characteristics of spatial temperature variability? Does water temperature change along the water course?

(iii)Can temperature variability at the meso-habitat scale be related to the morphological patterns?

9.2 Field data collection

9.2.1 Location of temperature loggers and detailed temperature measurements

To test the hypothesis that greater morphological variability delivers more diverse temperature patterns 5 sites with different morphological characteristics have been defined They are numbered from upstream to downstream (S1 – S5, see also appendix A). In Figure 9.1 the location of the sites is represented, in Appendix A images of the sites are shown. The reaches have a length between 620 and 1’850 meters and have been divided by minimum number of 14 and a maximum number of 19 regularly spaced transects. The transects were defined in a way to cover all the available meso-habitats that are to be found in a site.

9.2.2 Measurement of temporal variability

At all sites temperature loggers with hourly registration were installed in May 2009. At some sites temperature loggers after some time had got lost or they were not more concerned by the water due to a shift of the channel system. Comparable data are only available for S2, S3, and S5.

9.2.3 Measurement of spatial variability

Moreover, along the predefined transects in 2010 two series of detailed temperature measurements have been performed. The first time series was carried out by end of August (henceforward called series 08/10) and the second time series at the beginning of November (henceforward called series 11/10).

Advancing along the transects temperature measurements have been carried out at each location where water came across. In the braided river system for each channel with flowing water temperature was recorded at the left and right boarder and in the center of the channel where the maximum water depth was reached. In stagnant water zones and backwaters a singular temperature measurement in the center of the zone was executed. Moreover, each single temperature measurement was correlated to qualitative classification of water depth and flow velocity at the measured point as well as to a air temperature record.

By comparing mean temperature during the measurement campaigns to overall mean temperatures calculated by means of the temperature logger data at investigation, it can be concluded that series 08/10 reflects the situation when water temperature is slightly above the mean, whereas series 11/10 represents a situation with water temperatures are at a level between the overall mean and the overall minimum.

9.3 Analysis and results

9.3.1 Temporal variability

The records at the temperature loggers are able to deliver a good picture of temporal variability. For fishes average July temperature and maximum July temperature are relevant. In July 2009 at S2 an average temperature of 15.0° C (maximum temperature 21.6° C), at S3 an average temperature of 16.7° C (maximum temperature 26.4° C), and at S5 an average temperature of 17.0° C (maximum temperature of 23.4° C) was measured. The average temperature is increasing in the downstream direction. However, the maximum temperature in July (26.4 C) was measured at S3. Temperatures > 19° C cause thermal stress for the brown trout (Elliott 1994) and the tolerance zone or death is a question of exposure time. The observed 26.4° C in S3 are very critical and trout will move to thermal refugia (cold water patches) if they are available. The observed summer temperatures are also in a critical range for bullhead (Cottus gobio). Bullhead prefer summer temperatures that are distinctly less than 20° C. The survival of both species in summer time highly depends on the observed thermal refugia in S3. In S5 summer maximum temperature was lower probably because of the effect of tributaries with colder water.

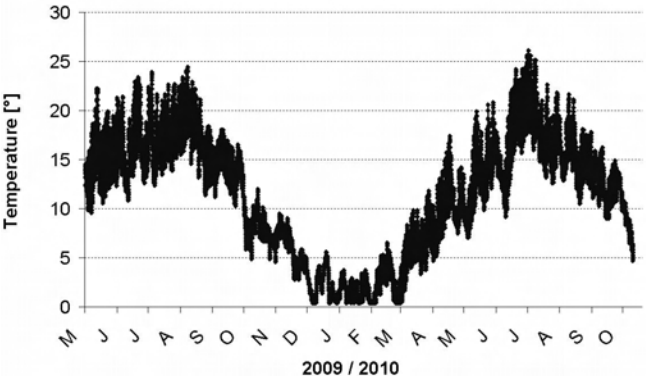

Figure 9.2 Temperature graph at site S5 from May 2009 to October 2010.

Comparable January temperatures are available for January 2010 at sites S3 and S5. At S3 the average January temperature was 1.1° C (minimum temperature of 0° C) and at S5 average January temperature was 1.6° C (minimum temperature 0.4° C).

Figure 9.2 shows the temperature graph resulting from the hourly measurements at the temperature logger of site S5. The maximum of the period was reached in August 2010 with 26.1° C, the minimum several times between January and March with 0.4° C. It can be observed that daily fluctuations in sunny days in summer can be around 10° C, whereas in winter the difference between daily maximum and minimum temperatures is not more than 3 – 4° C.

9.3.2 Spatial variability

As weather conditions were not stable during the measurement campaigns, mean air temperature and therefore also mean water temperature amongst investigation sites varied. Figure 9.3 states that there is a strong correlation between these variables. However, the clear distinction between series 08/10 and series 11/10 confirms that water temperature experiences both annual fluctuation. In fact, the water temperature regime in November (series 11/10) is much lower than in august (series 08/10), therefore at days with relatively high mean air temperatures for November (the three points on the right on the lower line in Figure 9.3) mean water temperature nevertheless was remarkably lower than on days with similar air temperatures in August (series 08/10). From Figure 9.3 it can be confirmed, too, that stream temperature varies much more narrowly than air temperatures (Hauer & Hill, 2006).

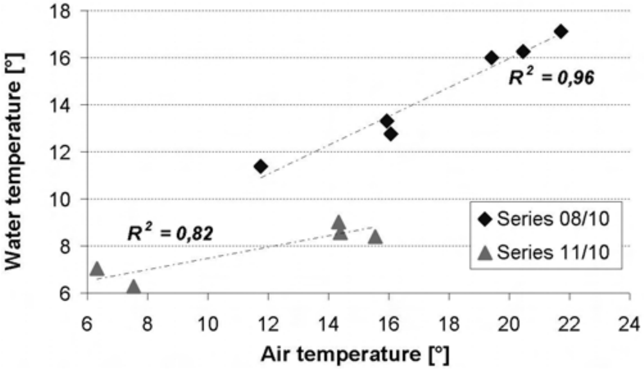

Figure 9.3 Correlation between mean air temperature and mean water temperature during the measurement campaigns of 2010.

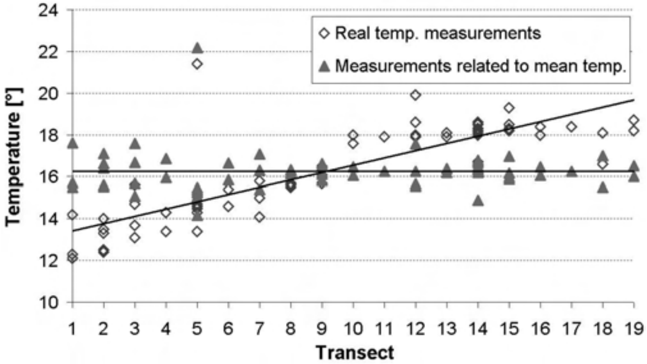

Figure 9.4 Real temperature measurements and adjustment to overall mean water temperature during data collection (Site S1 and series 08/10).

In order to eliminate noise due to temporal temperature flux during measurements and to determine spatial variability in a statistically correct way, adjustment of data was necessary. In fact, the time frame needed for data collection varied between one hour at the channelized site (S5) and 4 hours at the natural sites S1 and S3. As a consequence, due to the daily temperature flux air and water temperature varied during the measurement. Thus, progressing from one transect to the next, mean water temperature per transect changed not due to spatial variability, but to temporal variability. To calculate spatial variability of water temperature for each transect the difference between the overall mean water temperature of the investigation site and the mean water temperature of the transect was calculated and then at each transect this difference was added to the single temperature measurements at the transect. Figure 9.4 shows a graphical example of this approach.

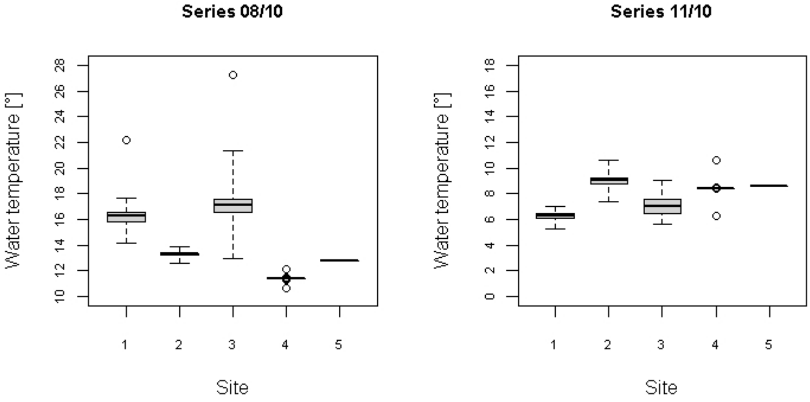

Figure 9.5 Boxplots with median, interquartiles, whiskers (to data points corresponding four times the interquartile range) and extreme outliers.

Figure 9.5 shows boxplots of the temperature data (adjusted to the overall mean as explained above). Different observations can be made:

- As there aren’t any secondary channels, backwater or stagnant water zones, at site S5 spatial variability was non-existent neither in August nor in November. Therefore it can be assumed that throughout the whole year spatial variability at channelized sites is non-existent.
- At the semi-channelized site S4 there are some stagnant water zones (represented by the outliers in the figure), that are cut off from the main channel after events with major discharges and where water temperature can reach relatively high values. However, due to evaporation this zones tend to disappear after a while and their

ecological value is questionable. In the area concerned by flowing water also at site S4 spatial variability of water temperature is almost non-existent.

- Also at sites S1 and S3 cut-off zones with high temperatures were observed during the measurement campaign 08/10. In the series 11/10 this measurements doen't appear anymore, a sign that these zones are to be interpreted rather as puddles and might have disappeared shortly after the measurement campaign.
- Omitting the outliers, statistical parameters of spatial temperature variability have been calculated (Table 9.1). At the braided sites S1 and S3 and, with some restrictions, at the naturally meandering site S2 spatial variability, represented by the standard deviation, is much higher than in the semi-channelized site S4 or in the channelized site S5. When referring to the coefficient of variation CV which is the quotient of mean and standard deviation and is a better comparative measure (Schneider, 1994), it becomes evident that at natural sites variability remains in a similar range throughout the season with generally smaller temperature ranges when temperature is lower. Site S3, due do its several backwater zones at laterally flowing secondary channels shows a particularly interesting water temperature pattern.

	Series 08/10			**Series 11/10**		
Site	μ	σ	CV	μ	σ	CV
S1	16.2	0.62	0.039	6.3	0.36	0.058
S2	13.3	0.26	0.019	9.0	0.57	0.063
S3	16.9	1.36	0.081	7.1	0.86	0.122
S4	11.4	0.04	0.004	8.4	0.02	0.002
S5	12.7	0.00	0.000	8.6	0.00	0.000

Table 9.1 Mean, standard deviation and coefficient of variation for water temperature measurements at the investigations sites for two measurement series.

9.4 Conclusions

Water temperature strongly influences life conditions for freshwater taxa. In streams water temperature strongly depends on the geographical position, but also on groundwater and tributary inflows. Water temperature generally increases with the distance of a stream from its source influencing the distribution and abundance of aquatic organisms.

At river Sense in Switzerland measurements have been carried out in order to analyse temporal and spatial variability of water temperature.

By means of temperature loggers installed at different sites of the river it could be shown that there are seasonal and daily fluctuations. In summer maximum temperatures of around 26° C were measured, whereas minimum temperatures in winter are at the freezing point. Daily fluctuations in summer are in average around 10° C in summer and 5° C in winter.

In order to analyze spatial variability detailed temperature analysis have been carried out at five morphologically different investigation sites. At the semi-trained and channelized sites spatial variability was almost non-existent, whereas at the natural sites that are characterized by a braided river pattern thermal variability is quite high. Therefore, it can be concluded that in reaches with heterogeneous physical habitats also temperature variability is higher favoring greater biodiversity as well as provide unique thermal niches for endemic taxa.

This is particularly important for the most abundant fish species in the Sense River that are brown trout and bullhead. Both are negatively affected by high temperatures (> 20° C) and depend on cold water refugia. The chance that in morphologically pristine river reaches, where riparian vegetation is present providing shading and preventing streams for heating up, such refugia are available is higher than in channelized reaches where temperature variability is non-existent. Thus, spatial temperature variability can be seen as an indicator for a good ecological potential as it is correlated intrinsically to a heterogeneous physical environment. Especially if the general water temperature level in streams is raising due to climate change the presence of cold water refugia can become essential for aquatic species to survive.

10 General conclusions and outlook

In this work, a new approach to describe hydromorphological variability of streams at a reach scale has been presented. The aim was to develop a straightforward, useful and simple-to-use tool for the practitioner engaged in river engineering projects.

During the field campaigns a huge variety data was recorded. Realizing, especially at the river Sense, that the fluvial environment is rather complex, the present work aimed at simplifying the hydromorphological template as much as possible. Wading along the transects and manually writing down flow velocities and water depths on a sheet, the site-related differences in spatial variability of these hydraulic variables became evident. Absorbing at the same time the geomorphic condition of the riverine landscape, correlations between geomorphic and hydraulic diversity could intuitively be perceived. Therefore, confidence that the proposed formula for the HMID despite its disarming simpleness depicts the diversity of the hydromorphological template quite reliably is justifiable.

The present work has confirmed both the initial formulated hypotheses (Chapter 1.2) and the intuitive perception of strong cross-correlations between geomorphic and hydraulic variables.

Picking up the initial hypotheses the present work delivered the following important results:

- The hydromorphological variability of a stream reach can be described by using the coefficient of variation CV of the hydraulic variables water depth and flow velocity.
- Correlation analysis were conducted within hydraulic variables at a micro-scale level (point related) and between geomorphic and hydraulic variables at a reach-scale level. The analysis revealed strong correlations between simple hydraulic variables and complex hydraulic variables as well as between variability of the simple hydraulic variables water depth and flow velocity and gemorphic variability, described by substrate variability, cross-section and thalweg diversity and mean ration of wetted to bankfull width.
- The proposed formula of the HMID has been demonstrated, by correlation analysis with a visual habitat assessment method, to properly represent the hydromorphological diversity of a stream reach.

- By means of numerical modelling temporal variability of hydraulic variables and of HMID was investigated. If could be demonstrated that in a natural stream greater temporal stability is maintained as hydraulic variables show less temporal variabilty. Vice versa, at streams with a strongly modified morphology, i.e. at channelized reaches, spatial variability is reduced and temporal variability increased with a resulting instability of hydraulic habitats.

  However, when discharges approaches bankfull, at natural streams habitats lose their stability due to occurring bed reshaping events. These events represent intermediate disturbance events which are important to maintain ecological functions of the river bed.
- The HMID can be used as a planning tool in river restoration projects. By means of a case study the applicability of the HMID could be shown. Apart from the fact that river restoration projects must consider also macro-scale effects and include interdisciplinary approaches, the HMID is a useful tool to compare habitat enhancement for different project alternatives, to evaluate the improvement of a project alternative in relation to the present condition and to which extent the project alternatives approach hydromorphological reference conditions.
- By investigating the inundation frequency of gravel bars at the naturally braided site S1 at river Sense, the importance of intermediate disturbance events could again be demonstrated. The *German Tamarisk*, an indicator for a high biotic quality of a stream, is maintained only it gravel bars exist which are flooded and reshaped with a return frequency of 5 – 6 years. These events correspond to bankfull flow at S1 of river Sense. On more frequently flooded gravel bars the plant is not able to fully develop whereas on gravel bars which are not concerned by these intermediate disturbance events the plant is ruled out by stronger species.
- A water temperature measurement campaign revealed that spatial variability of water temperature is higher at natural than at channelized reaches. Whereas at channelized reaches spatial variability of temperature is almost non-existent, at natural reaches areas with higher or lower temperature exist which might deliver refugia for aquatic biota. This aspect might become especially if climate change causes a general raise of water temperature in streams

The presented work can be at the beginning for further research activities helping to verify the approach, extend it to other realities apart from gravel bed pre-alpine streams and improve its applicability:

- To render the correlation tests between geomorphic and hydraulic variables statistically more valid the data set should be extended to more sites. At river Sense the correlations, especially between hydraulic diversity and geomorphic metrics such as thalweg or cross section diversity as well as the ratio between width at mean flow and at bankfull flow were found to be strikingly high (see Chapter 5). Investigating these interlinkages at more sites and possibly at other streams could be a useful option to verify the analyses of this work.
- For the sites at river Sense several topographical data from the last years are available. The topographical survey conducted for this work in June and July 2010 is very detailed, moreover a LiDAR flight has been carried out after a major flood in 2010 that has caused the complete migration of the main channel at site n°1. Carrying out a new topographical survey and field campaign where hydraulic data are collected, hypothesis of similar composition of hydraulic habitats before and after habitat turnover events (Arscott, 2002) could be tested.
- At site n°3 a camera has been installed at the bridge situated at the upstream end of the site. Since around 2 years each hour a photo is taken of the first section of this study site. At site n°3, similar to site n°2, characterized by its dynamism several bed reshaping processes have occurred. Therefore an elaboration of the available photos and an analysis of the interlinkages between dynamism, bed reshaping and the shifting of habitats, at site n°3 would be a valuable exercise.
- The river Sense, due to its natural condition, is a candidate to carry out more studies in the context of geomorphology and sedimentological regime. At site n°1 detailed sieve analysis have already been made within this work. The available data could be used to test the performing ability of the software BASEMENT to calculate flood events with intense solid transport and bed reshaping processes.
- The set up for the temperature measurement campaign was rather rough and not very sophisticated (Chapter 9). Nonetheless, an idea about spatial variability of water temperature in relation to the geomorphic conditions was obtained. The river Sense is certainly an appropriate stream to conduct a scientifically more valuable temperature measurement campaign. Especially in the light of climatic change the

consequences of elongated high air temperature periods on the water temperature could be surveyed. As it has been shown within the campaign of this work, there is a real risk that in areas where shading is poor, for example at site n°3, threshold values for temperature are exceeded which might be tipping points with severe consequences for the aquatic biota.

- The HMID was developed at gravel bed streams characterized by a specific range of discharges and slopes. It has been possible to fix categories for the HMID which reflect the hydromorphological conditions (Chapter 5). The work could be extended to other stream types (for example to steeper alpine torrents where step-pool sequences are the main hydromorphological template or to meandering streams where slopes diminishes and flow augments) in order to define a broader framework for HMID scores.
- Chapter 6 revealed interesting insights into the differences between spatial and temporal variability of hydraulic habitats, driven by the geomorphic conditions. Parasiewicz (2007) stressed the concept of uniform continuous above threshold (UCAT) which investigates duration curves of mesohabitats relevant for target species. Moreover, the MesoHabSim model (Parasiewicz, 2001) includes field surveys for habitat mapping under different flow conditions. Numerical 2D-models and calculations of HMID scores for different flows with subsequent elaboration of HMID duration curves could be overlapped with the methods of MesoHabSim and the UCAT-approaches. This opens the chance for synergies and for the creation of a comprehensive model appropriate for planning river restoration projects comprising habitat enhancement in an ecologically sound and long-term oriented way.
- The present work didn’t take into account that in many cases the hydrological regime is strongly modified due to water withdrawal for hydropower or due to hydropeaking of hydropower plants. The HMID could also be used to establish residual flow allocations or maximum flow ratios between peak and base flow able to maintain basic ecological functions of the affected streams. However, for this aim the formulation of the HMID is not appropriate yet, as it doesn’t detect threshold flows under which key habitats are not more available.
- Swiss water authorities are enforced to define and carry out a multitude of river restoration projects in the next years. Applying the HMID in selected projects, a win-win situation for both sides could be created. On the one hand to water

authorities a quantitative decision base for discussing project alternatives can be delivered, on the other hand the suitability of the HMID for application can undergo further tests, besides of the case study presented in Chapter 7.

- The application of the HMID is appropriate if a numerical 2D-model of the stream reach under study is already implemented. 2D-models for the model output usually create files in text format that can be imported in a spreadsheet software, where statistical parameters and therefore HMID scores can easily be calculated. However, to define a sub-routine in a 2D-software that automatically generates HMID scores would further facilitate the application of the HMID.

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Appendix

A. Photos of the study sites at rivers Bünz, Venoge and Sense

River Bünz

Site B1: Restored site with removal of left bank, insertion of instream structures such as logs and large boulders

Site B2: Totally channelized, river bed is stabilized with concrete sills in regular distance (System Turnherr)

Site B3: Near-pristine site, without river banks and high spatial diversity

Site B4: Braided site, naturally formed by a major flood in 1999

**Left: Impoundment for run-of-river plant at Tieffurtmühle (downstream of site n°1).
Right: Interruption of longitudinal connectivity due to steep bed stabilizing ramp**

River Venoge

Site V1: straight natural channel with step-pool resp. riffle-pool sequences (left). Site V2: Trapezoidal artificial channel with uniform flow conditions (right)

Site V3: Trapezoidal artificial channel with minor structures at river bed (left). Site V4: meandering channel through an alluvial forest (right)

River Sense

Site S1: Parafluvial floodplain at river sense with pristine morphology and a highly variable hydromorphological template

Site S2: Natural site confined by a gorge formed by limestone walls with a meandering feature of the stream and locally braided patterns

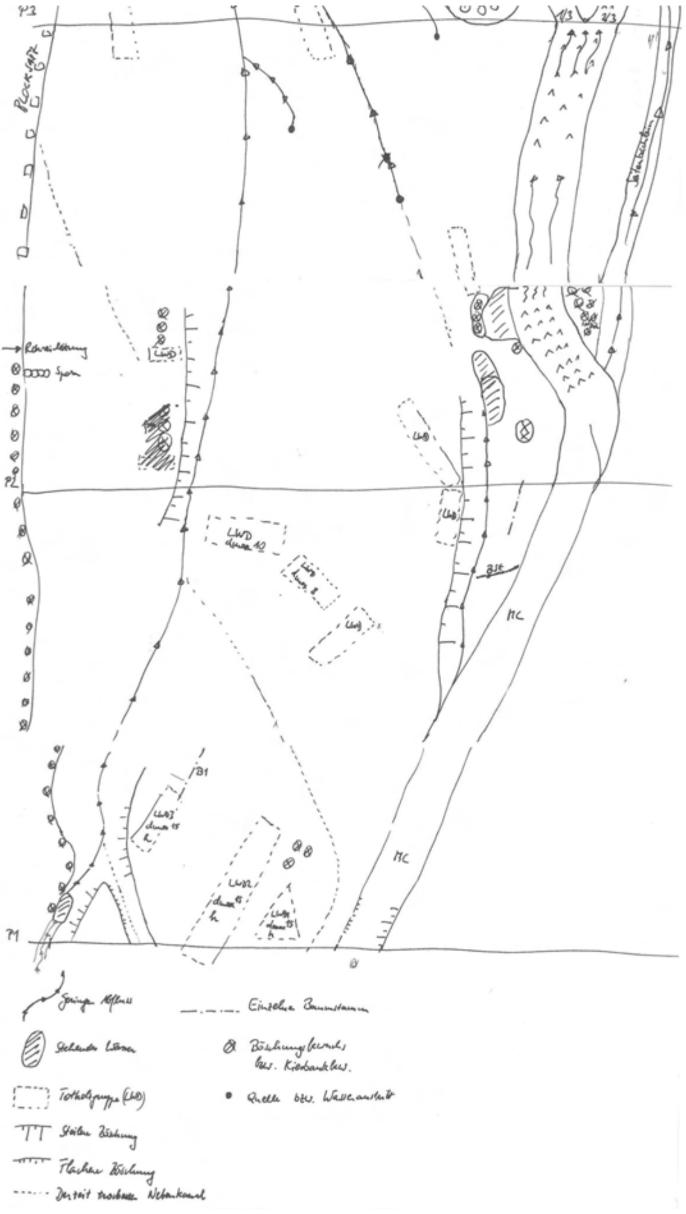
Site S3: Braided site with local protections of the right bank. In the wake of large wood deep pools are forming (right).

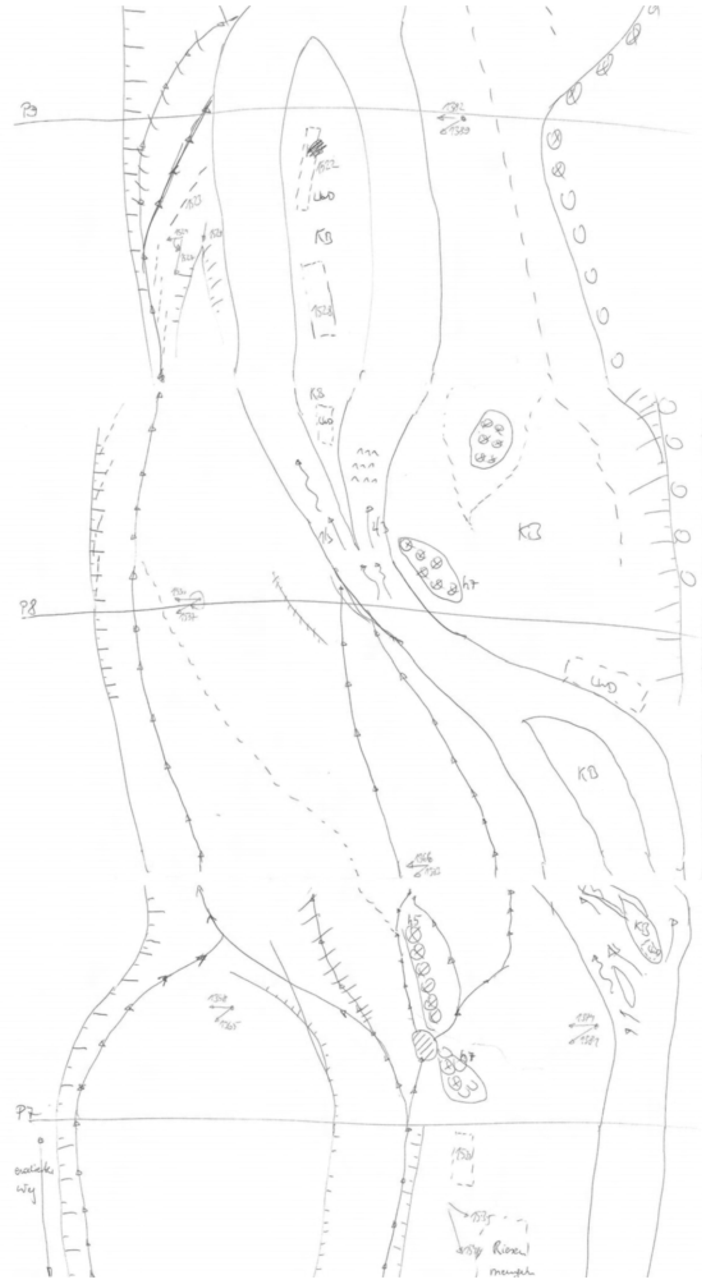
Site S4: site with rip-rap protection of right bank and leisure activities on gravel bars ("Sense beach")

Site S5: Channelized reach with rip-rap on both banks and a degraded hydromorphological template

B. Graphical representations of river Sense

Example of manual field habitat mapping

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1389
1522
LwD
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1528
KB
LwD
h3
h7
KB
P8
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KB
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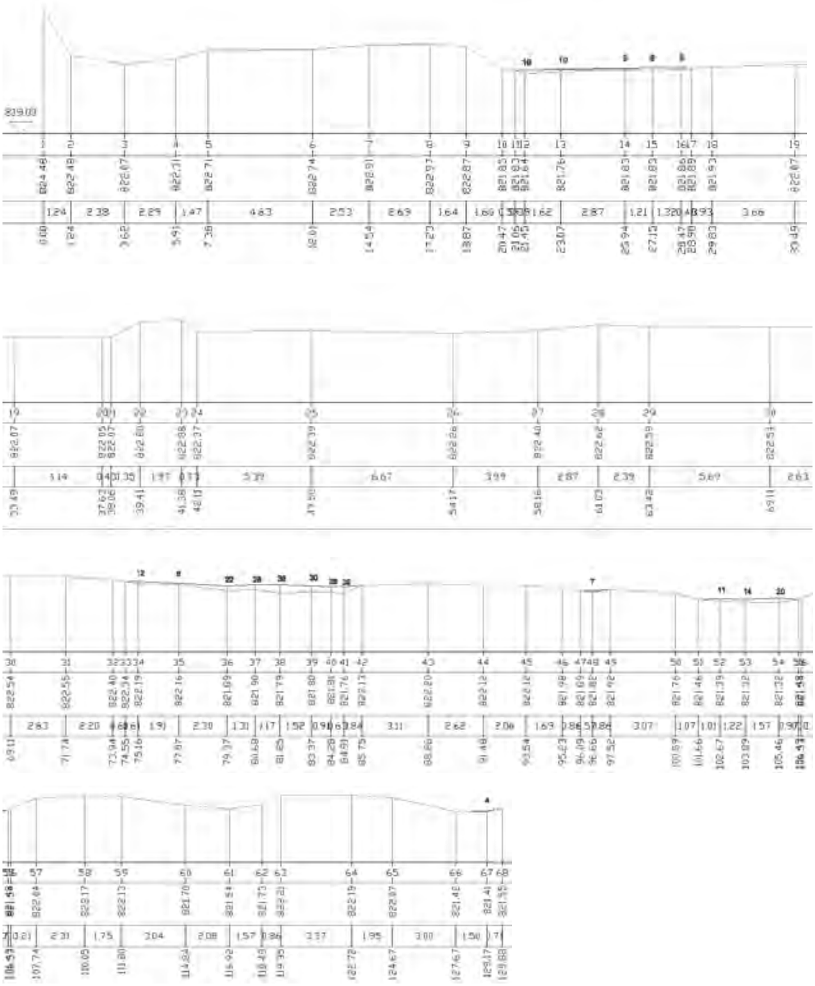
Examples of transects at river Sense[3]



Transect P5 at Site S1

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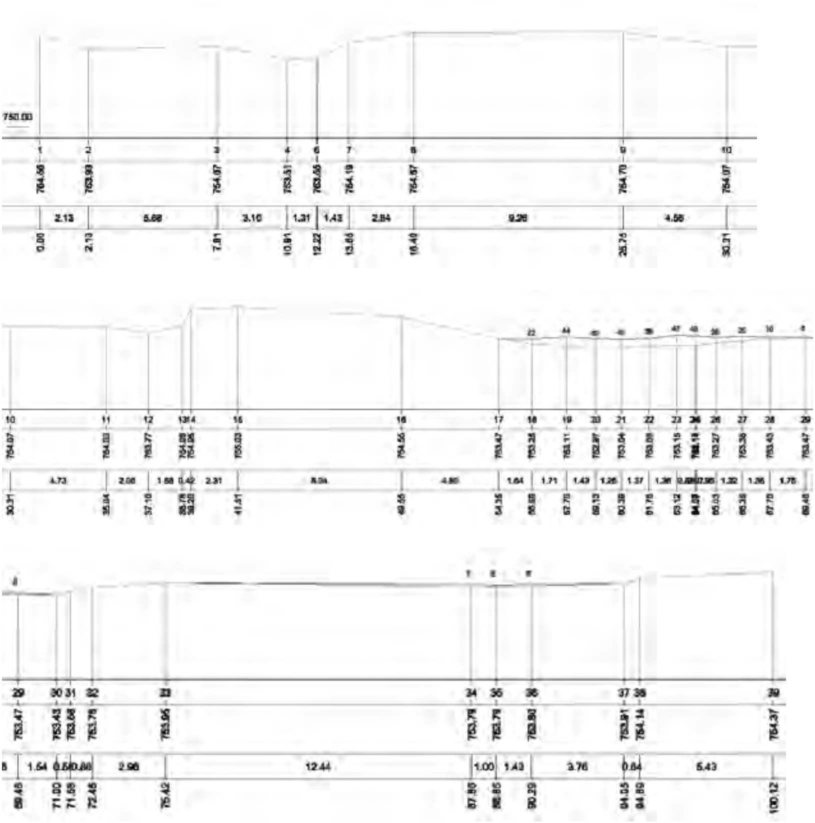
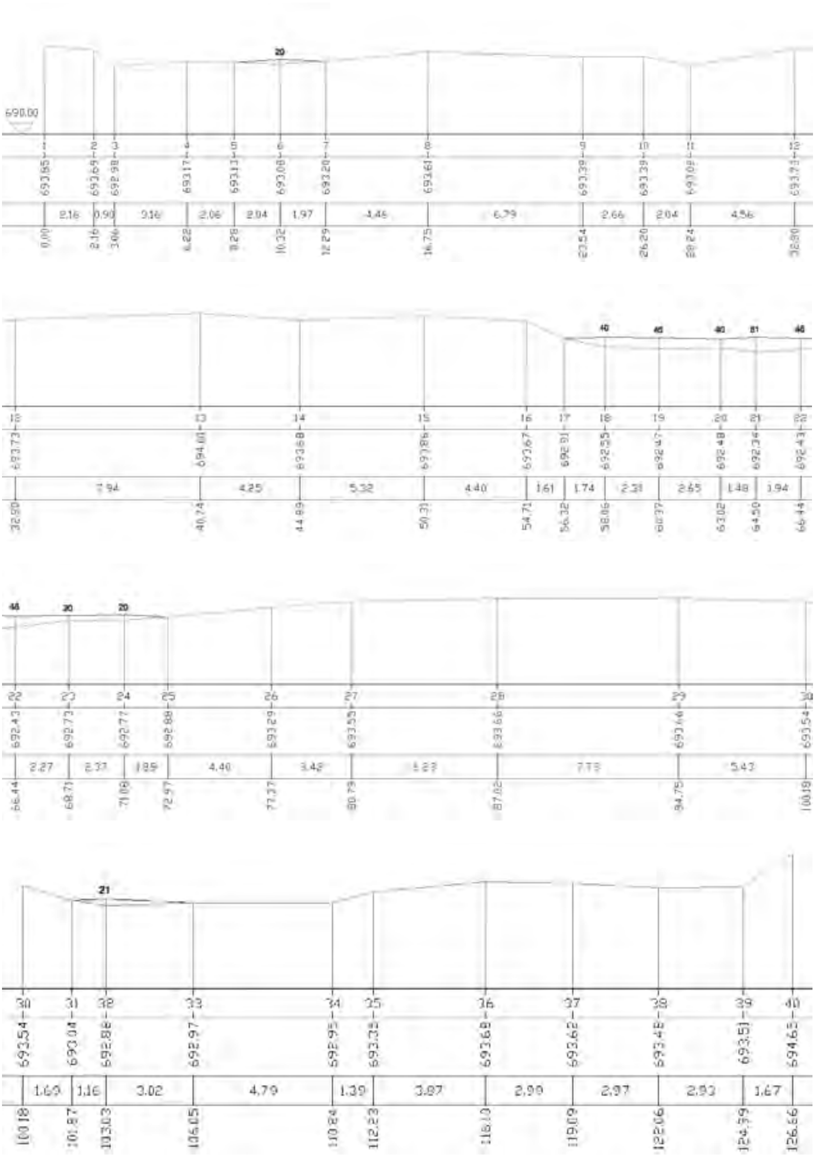
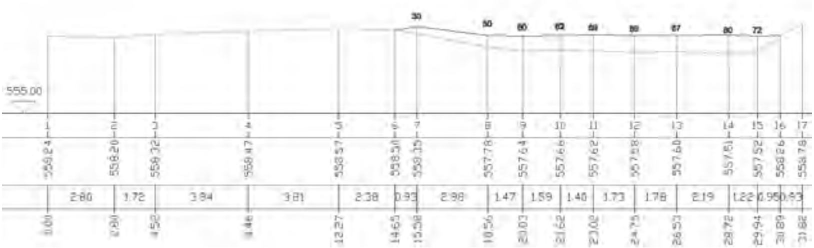
[3] Where necessary transects have been splitted in more rows in order to make them more readable



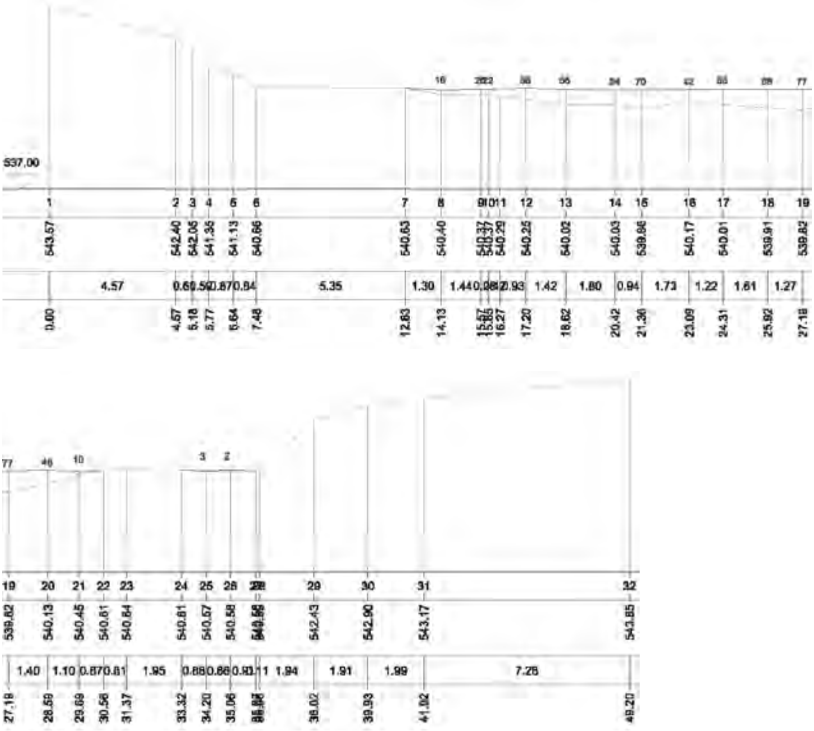
Transect P9 at Site S2



Transect P7 at Site S3

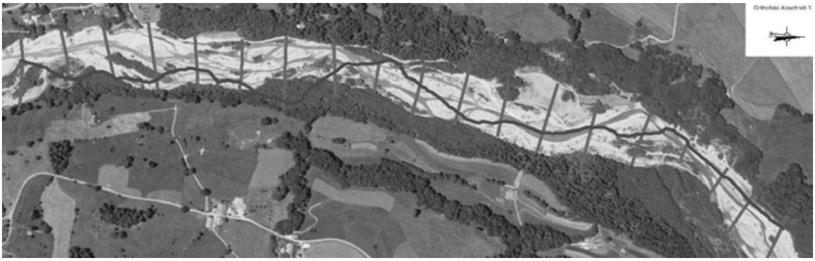


Transect P4 at Site S4

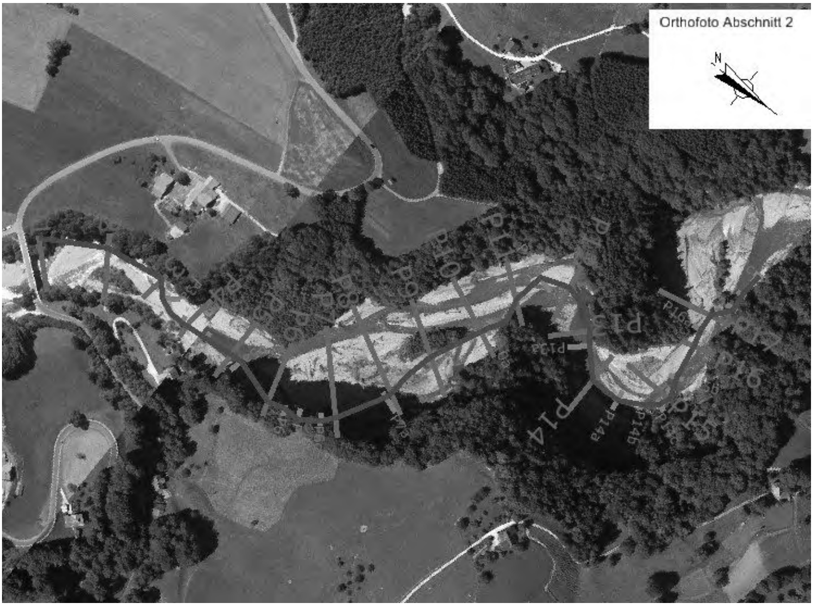


Transect P7 at Site S5

Aerial photographs with illustration of thalweg



Site S1



Site S2

Site S3

Site S4

Site S5

C. Data set for statistical analysis

Abbreviations:

ID	…	identification number of point	
Site	…	number of site	
Trans	…	transect number	
Ch	…	number of channel along transect	
Nfield	..	GPS Identification number of point	
Hbed	…	topographical height of river bed	(m)
DY	…	distance from point river bed to lowest point in the same channel along transect	(m)
h	…	water depth	(cm)
hm	…	water depth	(m)
Hwater	…	topographical height water level	(m)
v1	…	mean velocity (6/10 depth)	(m/s)
v2	…	nose velocity (5cm depth)	(m/s)
dm	…	median diameter of substrate resulting form pebble count (=D_{50})	(mm)
kst	…	Strickler value calculated based on dm	
d65	…	D_{65} of substrate	(mm)
tau	…	shear stress	(N/m^2)
Fr	…	Froude number	
Re	…	Reynolds number	

V1cvSite	…	CV of flow velocity
hmcvSite	…	CV of water depth
dcvSite	…	Cv of substrate
HdiffnormSite	…	Cross section diversity (only wetted part)
HdiffSohlenormSite	…	Cross section diversity (over the entire transect)
Thalwegdiv	…	Thalweg diversity
Bw_Bb	…	mean of wetted width to bankfull width

Point related records and calculated variables

ID	Site	Trans	Ch	Nfield	Hbed	DY	h	hm	Hwater	v1	v2	dm	kst	d65	tau	Fr	Re
1	1	P1	1	103	829.460	0.000	6	0.06	829.52	0.050	NA	34.2	37.0	59.6	0.124	0.065	2308
2	1	P1	1	104	829.490	0.030	4	0.04	829.53	0.005	NA	34.2	37.0	59.6	0.002	0.008	154
3	1	P1	2	107	830.320	0.210	20	0.20	830.52	0.060	0.114	34.2	37.0	59.6	0.064	0.043	9231
4	1	P1	2	108	830.110	0.000	42	0.42	830.53	0.630	0.470	34.2	37.0	59.6	4.540	0.310	203538
5	1	P1	2	109	830.200	0.090	36	0.36	830.56	1.140	0.790	34.2	37.0	59.6	16.171	0.607	315692
6	1	P1	2	110	830.180	0.070	36	0.36	830.54	0.690	0.230	34.2	37.0	59.6	5.924	0.367	191077
7	1	P1	2	111	830.140	0.030	30	0.30	830.44	0.360	0.390	34.2	37.0	59.6	1.790	0.210	83077
8	1	P1	2	112	830.160	0.050	26	0.26	830.42	0.270	0.460	34.2	37.0	59.6	1.097	0.169	54000
9	1	P1	2	113	830.260	0.150	14	0.14	830.40	0.520	NA	34.2	37.0	59.6	6.196	0.444	56000
10	1	P1	2	114	830.290	0.180	15	0.15	830.44	0.030	NA	34.2	37.0	59.6	0.020	0.025	3462
11	1	P1	2	115	830.300	0.190	16	0.16	830.46	0.410	NA	34.2	37.0	59.6	3.491	0.327	50462
12	1	P1	2	116	830.400	0.290	8	0.08	830.48	0.610	NA	34.2	37.0	59.6	13.716	0.689	37538
13	1	P1	3	120	830.000	0.000	5	0.05	830.05	0.100	NA	34.2	37.0	59.6	0.614	0.143	3846
14	1	P1	4	121	830.110	0.000	4	0.04	830.15	0.030	NA	34.2	37.0	59.6	0.074	0.048	923
15	1	P1	5	124	831.110	0.140	6	0.06	831.17	0.002	NA	34.2	37.0	59.6	0.000	0.003	92
16	1	P1	5	125	830.970	0.000	18	0.18	831.15	0.020	NA	34.2	37.0	59.6	0.008	0.015	2769
17	1	P1	5	126	831.080	0.110	9	0.09	831.17	0.010	NA	34.2	37.0	59.6	0.003	0.011	692
18	1	P1	5	127	831.070	0.100	7	0.07	831.14	0.004	NA	34.2	37.0	59.6	0.001	0.005	215
19	1	P2	3	202	827.900	0.500	20	0.20	828.10	0.390	0.220	43.9	35.5	78.4	3.277	0.278	60000
20	1	P2	3	203	827.670	0.270	43	0.43	828.10	0.730	0.370	43.9	35.5	78.4	7.001	0.355	241462
21	1	P2	3	204	827.420	0.020	56	0.56	827.98	0.380	0.120	43.9	35.5	78.4	1.640	0.162	163692
22	1	P2	3	205	827.400	0.000	54	0.54	827.94	1.490	0.480	43.9	35.5	78.4	25.706	0.647	618923
23	1	P2	3	206	827.620	0.220	45	0.45	828.07	0.720	0.360	43.9	35.5	78.4	6.637	0.343	249231
24	1	P2	3	207	827.780	0.380	28	0.28	828.06	0.780	0.640	43.9	35.5	78.4	10.387	0.471	168000
25	1	P2	3	208	827.850	0.450	22	0.22	828.07	0.660	0.490	43.9	35.5	78.4	8.762	0.449	111692
26	1	P2	3	209	827.960	0.560	10	0.10	828.06	0.230	NA	43.9	35.5	78.4	2.048	0.232	17692
27	1	P2	2	212	827.800	0.000	12	0.12	827.92	0.010	NA	43.9	35.5	78.4	0.003	0.009	923
28	1	P2	2	213	827.900	0.100	4	0.04	827.94	0.004	NA	43.9	35.5	78.4	0.002	0.006	123
29	1	P2	1	216	827.860	0.050	12	0.12	827.98	0.007	NA	43.9	35.5	78.4	0.002	0.006	646
30	1	P2	1	217	827.880	0.070	12	0.12	828.00	0.032	NA	43.9	35.5	78.4	0.033	0.029	2954
31	1	P2	1	218	827.810	0.000	16	0.16	827.97	0.040	NA	43.9	35.5	78.4	0.041	0.032	4923
32	1	P3	1	302	826.430	0.020	9	0.09	826.52	0.002	NA	46.3	35.2	85.4	0.000	0.002	138
33	1	P3	1	303	826.410	0.000	8	0.08	826.49	0.003	NA	46.3	35.2	85.4	0.000	0.003	185
34	1	P3	2	306	825.700	0.070	4	0.04	825.74	0.080	NA	46.3	35.2	85.4	0.962	0.128	2462
35	1	P3	2	307	825.630	0.000	9	0.09	825.72	0.160	NA	46.3	35.2	85.4	1.208	0.170	11077
36	1	P3	2	308	825.670	0.040	6	0.06	825.73	0.080	NA	46.3	35.2	85.4	0.496	0.104	3692
37	1	P3	3	311	826.050	0.000	4	0.04	826.09	0.030	NA	46.3	35.2	85.4	0.135	0.048	923
38	1	P3	3	312	826.070	0.020	4	0.04	826.11	0.010	NA	46.3	35.2	85.4	0.015	0.016	308
39	1	P3	4	315	826.130	0.040	12	0.12	826.25	0.450	NA	46.3	35.2	85.4	7.149	0.415	41538
40	1	P3	4	316	826.090	0.000	12	0.12	826.21	0.080	NA	46.3	35.2	85.4	0.226	0.074	7385
41	1	P3	4	317	826.130	0.040	14	0.14	826.27	0.870	NA	46.3	35.2	85.4	23.237	0.742	93692
42	1	P3	4	318	826.190	0.100	12	0.12	826.31	0.540	NA	46.3	35.2	85.4	10.294	0.498	49846
43	1	P3	4	319	826.200	0.110	7	0.07	826.27	0.880	NA	46.3	35.2	85.4	48.977	1.062	47385
44	1	P3	5	322	825.860	0.210	20	0.20	826.06	0.330	0.270	46.3	35.2	85.4	2.502	0.236	50769
45	1	P3	5	323	825.690	0.040	40	0.40	826.09	0.530	0.340	46.3	35.2	85.4	4.049	0.268	163077
46	1	P3	5	324	825.650	0.000	46	0.46	826.11	1.310	0.980	46.3	35.2	85.4	22.788	0.617	463538
47	1	P3	5	330	825.710	0.060	37	0.37	826.08	0.540	0.140	46.3	35.2	85.4	4.407	0.283	153692
48	1	P3	5	331	825.800	0.150	28	0.28	826.08	1.530	1.070	46.3	35.2	85.4	42.310	0.923	329538
49	1	P3	5	332	825.770	0.120	20	0.20	825.97	1.150	0.970	46.3	35.2	85.4	30.379	0.821	176923
50	1	P3	5	333	825.840	0.190	12	0.12	825.96	0.460	NA	46.3	35.2	85.4	7.470	0.424	42462
51	1	P3	5	334	825.780	0.130	16	0.16	825.94	0.430	NA	46.3	35.2	85.4	5.067	0.343	52923
52	1	P3	5	335	825.780	0.130	15	0.15	825.93	0.200	NA	46.3	35.2	85.4	1.157	0.165	23077
53	1	P4	5	402	823.310	0.040	8	0.08	823.39	0.090	NA	42.0	35.8	77.0	0.388	0.102	5538
54	1	P4	5	403	823.270	0.000	8	0.08	823.35	0.180	NA	42.0	35.8	77.0	1.552	0.203	11077
55	1	P4	5	404	823.360	0.090	7	0.07	823.43	0.010	NA	42.0	35.8	77.0	0.006	0.012	538
56	1	P4	4	408	823.780	0.250	24	0.24	824.02	1.410	0.350	42.0	35.8	77.0	37.177	0.919	260308

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57    1   P4   4   409   823.540 0.010   43   0.43   823.97  1.350   1.040   42.0   35.8   77.0   23.701  0.657   446538
58    1   P4   4   410   823.530 0.000   40   0.40   823.93  1.290   0.650   42.0   35.8   77.0   22.561  0.651   396923
59    1   P4   4   411   823.640 0.110   34   0.34   823.98  0.510   0.220   42.0   35.8   77.0   3.885   0.279   133385
60    1   P4   4   413   823.660 0.130   30   0.30   823.96  0.640   0.180   42.0   35.8   77.0   6.613   0.373   147692
61    1   P4   4   414   823.610 0.080   18   0.18   823.79  0.840   NA      42.0   35.8   77.0   16.226  0.632   116308
62    1   P4   4   415   823.850 0.320   12   0.12   823.97  -0.300  NA      42.0   35.8   77.0   2.889   0.277   27692
63    1   P4   4   416   823.850 0.320   14   0.14   823.99  -0.010  NA      42.0   35.8   77.0   0.003   0.009   1077
64    1   P4   3   419   823.960 0.490   4    0.04   824.00  0.170   NA      42.0   35.8   77.0   3.587   0.271   5231
65    1   P4   3   420   823.890 0.420   13   0.13   824.02  0.240   NA      42.0   35.8   77.0   1.723   0.213   24000
66    1   P4   3   421   823.750 0.280   24   0.24   823.99  0.270   0.230   42.0   35.8   77.0   1.363   0.176   49846
67    1   P4   3   422   823.470 0.000   52   0.52   823.99  -0.030  -0.030  42.0   35.8   77.0   0.011   0.013   12000
68    1   P4   3   423   823.640 0.170   38   0.38   824.02  0.009   0.004   42.0   35.8   77.0   0.001   0.005   2631
69    1   P4   3   424   823.630 0.160   38   0.38   824.01  0.002   0.003   42.0   35.8   77.0   0.000   0.001   585
70    1   P4   3   425   823.810 0.340   18   0.18   823.99  0.190   NA      42.0   35.8   77.0   0.830   0.143   26308
71    1   P4   3   426   823.870 0.400   16   0.16   824.03  0.150   NA      42.0   35.8   77.0   0.567   0.120   18462
72    1   P4   2   429   823.850 0.040   4    0.04   823.89  0.080   NA      42.0   35.8   77.0   0.794   0.128   2462
73    1   P4   2   430   823.810 0.000   11   0.11   823.92  1.040   NA      42.0   35.8   77.0   37.584  1.001   88000
74    1   P4   1   433   823.740 0.000   12   0.12   823.86  1.260   NA      42.0   35.8   77.0   50.955  1.161   116308
75    1   P4   1   434   823.830 0.090   9    0.09   823.92  1.090   NA      42.0   35.8   77.0   50.231  1.160   75462
76    1   P4   1   435   823.810 0.070   4    0.04   823.85  0.070   NA      42.0   35.8   77.0   0.608   0.112   2154
77    1   P5   1   502   821.640 0.000   16   0.16   821.80  0.170   NA      68.8   33.0   88.6   0.817   0.136   20923
78    1   P5   1   503   821.760 0.120   10   0.10   821.86  0.240   NA      68.8   33.0   88.6   2.526   0.242   18462
79    1   P5   1   504   821.830 0.190   5    0.05   821.88  0.190   NA      68.8   33.0   88.6   3.895   0.271   7308
80    1   P5   1   505   821.830 0.190   8    0.08   821.91  0.050   NA      68.8   33.0   88.6   0.141   0.056   3077
81    1   P5   1   506   821.860 0.220   6    0.06   821.92  0.070   NA      68.8   33.0   88.6   0.400   0.091   3231
82    1   P5   2   509   822.190 0.430   12   0.12   822.31  0.310   NA      68.8   33.0   88.6   3.512   0.286   28615
83    1   P5   2   510   822.160 0.400   8    0.08   822.24  0.005   NA      68.8   33.0   88.6   0.001   0.006   308
84    1   P5   2   511   821.890 0.130   22   0.22   822.11  0.160   0.200   68.8   33.0   88.6   0.563   0.109   27077
85    1   P5   2   512   821.900 0.140   28   0.28   822.18  1.120   0.840   68.8   33.0   88.6   23.242  0.676   241231
86    1   P5   2   513   821.790 0.030   38   0.38   822.17  1.060   0.840   68.8   33.0   88.6   17.087  0.549   309846
87    1   P5   2   514   821.810 0.050   30   0.30   822.11  0.570   0.410   68.8   33.0   88.6   5.747   0.332   131538
88    1   P5   2   515   821.810 0.050   26   0.26   822.07  1.310   1.010   68.8   33.0   88.6   33.461  0.820   262000
89    1   P5   2   516   821.760 0.000   32   0.32   822.08  1.470   0.720   68.8   33.0   88.6   36.637  0.830   361846
90    1   P5   3   519   821.820 0.000   7    0.07   821.89  0.007   NA      68.8   33.0   88.6   0.003   0.008   377
91    1   P5   4   522   821.390 0.070   11   0.11   821.50  0.090   NA      68.8   33.0   88.6   0.322   0.087   7615
92    1   P5   4   523   821.320 0.000   14   0.14   821.46  0.240   NA      68.8   33.0   88.6   1.827   0.205   25846
93    1   P5   4   524   821.320 0.000   20   0.20   821.52  0.280   0.240   68.8   33.0   88.6   1.852   0.200   43077
94    1   P5   5   527   821.410 0.000   4    0.04   821.45  0.020   NA      68.8   33.0   88.6   0.065   0.032   615
95    1   P6   5   602   819.800 0.160   22   0.22   820.02  0.250   0.190   55.2   34.2   75.4   1.224   0.170   42308
96    1   P6   5   603   819.640 0.000   36   0.36   820.00  1.220   0.750   55.2   34.2   75.4   21.210  0.649   337846
97    1   P6   5   604   819.760 0.120   26   0.26   820.02  0.540   0.230   55.2   34.2   75.4   5.096   0.338   108000
98    1   P6   5   605   819.990 0.350   8    0.08   820.07  0.250   NA      55.2   34.2   75.4   2.927   0.282   15385
99    1   P6   5   606   820.060 0.420   4    0.04   820.10  0.050   NA      55.2   34.2   75.4   0.299   0.080   1538
100   1   P6   4   609   819.810 0.000   4    0.04   819.85  0.005   NA      55.2   34.2   75.4   0.003   0.008   154
101   1   P6   3   612   819.800 0.600   10   0.10   819.90  0.160   NA      55.2   34.2   75.4   0.955   0.162   12308
102   1   P6   3   613   819.360 0.160   48   0.48   819.84  0.350   0.270   55.2   34.2   75.4   1.481   0.161   129231
103   1   P6   3   614   819.200 0.000   70   0.70   819.90  0.570   0.510   55.2   34.2   75.4   3.225   0.218   306923
104   1   P6   3   615   819.250 0.050   70   0.70   819.95  0.230   0.040   55.2   34.2   75.4   0.525   0.088   123846
105   1   P6   3   617   819.550 0.350   36   0.36   819.91  0.260   0.010   55.2   34.2   75.4   0.963   0.138   72000
106   1   P6   3   618   819.970 0.770   14   0.14   820.11  0.390   NA      55.2   34.2   75.4   4.199   0.333   42000
107   1   P6   3   619   819.930 0.730   20   0.20   820.13  0.660   NA      55.2   34.2   75.4   9.125   0.471   101538
108   1   P6   3   620   819.930 0.730   20   0.20   820.13  0.830   NA      55.2   34.2   75.4   14.431  0.593   127692
109   1   P6   3   621   820.110 0.910   12   0.12   820.23  0.390   NA      55.2   34.2   75.4   4.793   0.359   36000
110   1   P6   3   622   820.070 0.870   12   0.12   820.19  0.140   NA      55.2   34.2   75.4   0.618   0.129   12923
111   1   P6   3   623   820.130 0.930   6    0.06   820.19  0.370   NA      55.2   34.2   75.4   8.989   0.482   17077
112   1   P6   3   624   820.020 0.820   10   0.10   820.12  1.140   NA      55.2   34.2   75.4   48.466  1.151   87692
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113	1	P6	3	625	819.960	0.760	20	0.20	820.16	0.210	NA	55.2	34.2	75.4	0.924	0.150	32308
114	1	P6	2	628	819.810	0.050	3	0.03	819.84	0.002	NA	55.2	34.2	75.4	0.001	0.004	46
115	1	P6	2	629	819.770	0.010	6	0.06	819.83	0.230	NA	55.2	34.2	75.4	3.473	0.300	10615
116	1	P6	2	630	819.760	0.000	6	0.06	819.82	0.090	NA	55.2	34.2	75.4	0.532	0.117	4154
117	1	P6	2	631	819.770	0.010	4	0.04	819.81	0.017	NA	55.2	34.2	75.4	0.035	0.027	523
118	1	P6	1	634	819.630	0.000	20	0.20	819.83	0.160	NA	55.2	34.2	75.4	0.536	0.114	24615
119	1	P7	1	702	817.750	0.000	10	0.10	817.85	0.012	NA	51.8	34.6	75.0	0.005	0.012	923
120	1	P7	1	703	817.850	0.100	4	0.04	817.89	0.080	NA	51.8	34.6	75.0	0.758	0.128	2462
121	1	P7	1	704	817.780	0.030	9	0.09	817.87	1.130	NA	51.8	34.6	75.0	52.534	1.203	78231
122	1	P7	1	705	817.890	0.140	5	0.05	817.94	0.050	NA	51.8	34.6	75.0	0.209	0.071	1923
123	1	P7	2	708	817.740	0.000	3	0.03	817.77	0.120	NA	51.8	34.6	75.0	3.012	0.221	2769
124	1	P7	2	709	817.800	0.060	4	0.04	817.84	0.050	NA	51.8	34.6	75.0	0.296	0.080	1538
125	1	P7	2	710	817.960	0.220	1	0.01	817.97	0.010	NA	51.8	34.6	75.0	0.323	0.032	77
126	1	P7	2	711	818.130	0.390	1	0.01	818.14	0.010	NA	51.8	34.6	75.0	0.323	0.032	77
127	1	P7	3	712	818.160	0.000	1	0.01	818.17	0.010	NA	51.8	34.6	75.0	0.323	0.032	77
128	1	P7	4	713	818.190	0.010	8	0.08	818.27	0.090	NA	51.8	34.6	75.0	0.377	0.102	5538
129	1	P7	4	714	818.180	0.000	10	0.10	818.28	0.030	NA	51.8	34.6	75.0	0.033	0.030	2308
130	1	P7	5	717	818.190	0.230	14	0.14	818.33	0.320	NA	51.8	34.6	75.0	2.813	0.273	34462
131	1	P7	5	718	818.030	0.070	34	0.34	818.37	0.450	0.160	51.8	34.6	75.0	2.976	0.246	117692
132	1	P7	5	719	817.960	0.000	38	0.38	818.34	0.710	0.450	51.8	34.6	75.0	6.933	0.368	207538
133	1	P7	5	720	817.960	0.000	38	0.38	818.34	0.620	0.460	51.8	34.6	75.0	5.287	0.321	181231
134	1	P7	5	721	817.990	0.030	36	0.36	818.35	0.520	0.470	51.8	34.6	75.0	3.840	0.277	144000
135	1	P7	5	722	818.010	0.050	32	0.32	818.33	0.690	0.510	51.8	34.6	75.0	7.260	0.389	169846
136	1	P7	5	723	818.170	0.210	18	0.18	818.35	0.380	NA	51.8	34.6	75.0	3.254	0.286	52615
137	1	P7	5	724	818.280	0.320	4	0.04	818.32	0.110	NA	51.8	34.6	75.0	1.434	0.176	3385
138	1	P7	5	725	818.250	0.290	6	0.06	818.31	0.110	NA	51.8	34.6	75.0	0.788	0.143	5077
139	1	P7	5	726	818.180	0.220	14	0.14	818.32	0.460	NA	51.8	34.6	75.0	5.813	0.393	49538
140	1	P8	5	802	815.480	0.380	22	0.22	815.70	0.570	0.410	73.9	32.6	107.5	8.282	0.388	96462
141	1	P8	5	803	815.330	0.230	36	0.36	815.69	0.860	0.620	73.9	32.6	107.5	13.173	0.458	238154
142	1	P8	5	804	815.340	0.240	34	0.34	815.68	0.810	0.380	73.9	32.6	107.5	12.144	0.444	211846
143	1	P8	5	805	815.340	0.240	34	0.34	815.68	0.620	0.380	73.9	32.6	107.5	7.115	0.339	162154
144	1	P8	5	806	815.400	0.300	32	0.32	815.72	0.670	0.450	73.9	32.6	107.5	8.662	0.378	164923
145	1	P8	5	807	815.520	0.420	12	0.12	815.64	0.360	NA	73.9	32.6	107.5	5.745	0.332	33231
146	1	P8	5	808	815.430	0.330	15	0.15	815.58	0.330	NA	73.9	32.6	107.5	3.867	0.272	38077
147	1	P8	5	809	815.410	0.310	16	0.16	815.57	0.440	NA	73.9	32.6	107.5	6.475	0.351	54154
148	1	P8	5	810	815.330	0.230	12	0.12	815.45	0.170	NA	73.9	32.6	107.5	1.281	0.157	15692
149	1	P8	5	811	815.310	0.210	10	0.10	815.41	1.030	NA	73.9	32.6	107.5	57.527	1.040	79231
150	1	P8	5	812	815.100	0.000	26	0.26	815.36	0.710	0.620	73.9	32.6	107.5	11.295	0.445	142000
151	1	P8	5	813	815.140	0.040	16	0.16	815.30	0.110	NA	73.9	32.6	107.5	0.405	0.088	13538
152	1	P8	4	816	816.150	0.020	10	0.10	816.25	0.030	NA	73.9	32.6	107.5	0.049	0.030	2308
153	1	P8	4	817	816.130	0.000	14	0.14	816.27	0.180	NA	73.9	32.6	107.5	1.229	0.154	19385
154	1	P8	4	818	816.160	0.030	4	0.04	816.20	0.010	NA	73.9	32.6	107.5	0.025	0.016	308
155	1	P8	3	821	815.540	0.000	1	0.01	815.55	0.010	NA	73.9	32.6	107.5	0.047	0.032	77
156	1	P8	2	823	815.240	0.000	8	0.08	815.32	0.120	NA	73.9	32.6	107.5	1.031	0.135	7385
157	1	P8	1	825	815.030	0.050	8	0.08	815.11	0.160	NA	73.9	32.6	107.5	1.833	0.181	9846
158	1	P8	1	826	815.040	0.060	5	0.05	815.09	0.240	NA	73.9	32.6	107.5	8.765	0.343	9231
159	1	P8	1	827	815.030	0.050	5	0.05	815.08	0.020	NA	73.9	32.6	107.5	0.061	0.029	769
160	1	P8	1	828	815.030	0.050	5	0.05	815.08	0.340	NA	73.9	32.6	107.5	17.592	0.485	13077
161	1	P8	1	829	814.980	0.000	14	0.14	815.12	0.850	NA	73.9	32.6	107.5	27.404	0.725	91538
162	1	P9	1	902	813.250	0.170	13	0.13	813.38	0.110	NA	45.3	35.3	74.6	0.352	0.097	11000
163	1	P9	1	903	813.220	0.140	14	0.14	813.36	0.370	NA	45.3	35.3	74.6	3.745	0.316	39846
164	1	P9	1	904	813.310	0.230	8	0.08	813.39	0.290	NA	45.3	35.3	74.6	3.891	0.327	17846
165	1	P9	1	905	813.270	0.190	8	0.08	813.35	0.590	NA	45.3	35.3	74.6	16.107	0.666	36308
166	1	P9	1	906	813.080	0.000	22	0.22	813.30	1.240	1.260	45.3	35.3	74.6	29.867	0.844	209846
167	1	P9	1	907	813.160	0.080	22	0.22	813.38	0.590	0.630	45.3	35.3	74.6	6.762	0.402	99846
168	1	P9	1	909	813.250	0.170	14	0.14	813.39	0.030	NA	45.3	35.3	74.6	0.025	0.026	3231
169	1	P9	1	910	813.280	0.200	10	0.10	813.38	0.120	NA	45.3	35.3	74.6	0.531	0.121	9231

170	1	P9	1	911	813.350	0.270	10	0.10	813.45	0.110	NA	45.3	35.3	74.6	0.446	0.111	8462
171	1	P9	2	914	813.200	0.220	15	0.15	813.35	0.330	NA	45.3	35.3	74.6	2.816	0.272	38077
172	1	P9	2	915	813.230	0.250	8	0.08	813.31	0.120	NA	45.3	35.3	74.6	0.666	0.135	7385
173	1	P9	2	916	813.180	0.200	16	0.16	813.34	0.150	NA	45.3	35.3	74.6	0.553	0.120	18462
174	1	P9	2	917	813.070	0.090	24	0.24	813.31	0.430	0.430	45.3	35.3	74.6	3.384	0.280	79385
175	1	P9	2	918	813.140	0.160	26	0.26	813.40	0.730	0.740	45.3	35.3	74.6	9.245	0.457	146000
176	1	P9	2	919	813.010	0.030	16	0.16	813.17	1.100	NA	45.3	35.3	74.6	29.728	0.878	135385
177	1	P9	2	920	813.070	0.090	30	0.30	813.37	1.110	0.600	45.3	35.3	74.6	19.497	0.647	256154
178	1	P9	2	921	812.980	0.000	30	0.30	813.28	0.950	0.520	45.3	35.3	74.6	14.281	0.554	219231
179	1	P9	2	922	813.200	0.220	18	0.18	813.38	0.530	NA	45.3	35.3	74.6	6.306	0.399	73385
180	1	P9	2	923	813.110	0.130	26	0.26	813.37	0.410	0.210	45.3	35.3	74.6	2.916	0.257	82000
181	1	P9	2	924	813.220	0.240	12	0.12	813.34	0.490	NA	45.3	35.3	74.6	7.491	0.452	45231
182	1	P10	1	1002	810.650	0.260	15	0.15	810.80	0.300	NA	85.8	31. Aug	118.6	3.515	0.247	34615
183	1	P10	1	1003	810.630	0.240	26	0.26	810.89	0.670	0.790	85.8	31. Aug	118.6	10.844	0.420	134000
184	1	P10	1	1004	810.430	0.040	48	0.48	810.91	0.790	0.090	85.8	31. Aug	118.6	9.837	0.364	291692
185	1	P10	1	1005	810.390	0.000	50	0.50	810.89	1.020	0.630	85.8	31. Aug	118.6	15.988	0.461	392308
186	1	P10	1	1006	810.430	0.040	48	0.48	810.91	0.740	0.340	85.8	31. Aug	118.6	8.632	0.341	273231
187	1	P10	1	1007	810.490	0.100	28	0.28	810.77	0.590	-0.050	85.8	31. Aug	118.6	7.945	0.356	127077
188	1	P10	1	1008	810.520	0.130	28	0.28	810.80	1.110	0.930	85.8	31. Aug	118.6	28.123	0.670	239077
190	1	P10	1	1010	810.630	0.240	16	0.16	810.79	0.390	NA	85.8	31. Aug	118.6	5.579	0.311	48000
191	1	P10	1	1011	810.640	0.250	20	0.20	810.84	0.260	NA	85.8	31. Aug	118.6	2.024	0.186	40000
192	1	P10	1	1012	810.810	0.420	4	0.04	810.85	0.010	NA	85.8	31. Aug	118.6	0.032	0.016	308
193	1	P10	1	1013	810.800	0.410	6	0.06	810.86	0.001	NA	85.8	31. Aug	118.6	0.000	0.001	46
194	1	P11	1	1102	808.750	0.210	34	0.34	809.09	0.260	0.030	29. Jul	37.9	62.5	0.892	0.142	68000
195	1	P11	1	1104	808.540	0.000	50	0.50	809.04	0.850	0.360	29. Jul	37.9	62.5	7.732	0.384	326923
196	1	P11	1	1105	808.590	0.050	46	0.46	809.05	0.640	0.750	29. Jul	37.9	62.5	4.579	0.301	226462
197	1	P11	1	1106	808.730	0.190	30	0.30	809.03	0.590	0.420	29. Jul	37.9	62.5	4.944	0.344	136154
198	1	P11	1	1107	808.640	0.100	38	0.38	809.02	1.280	0.020	29. Jul	37.9	62.5	20.313	0.663	374154
199	1	P11	1	1109	808.660	0.120	46	0.46	809.12	0.640	0.430	29. Jul	37.9	62.5	4.579	0.301	226462
200	1	P11	1	1110	808.720	0.180	34	0.34	809.06	0.550	-0.100	29. Jul	37.9	62.5	3.994	0.301	143846
201	1	P11	1	1111	808.680	0.140	32	0.32	809.00	0.390	0.480	29. Jul	37.9	62.5	2.080	0.220	96000
202	1	P11	1	1112	808.880	0.340	17	0.17	809.05	0.190	NA	29. Jul	37.9	62.5	0.743	0.147	24846
203	1	P12	1	1202	807.200	0.200	14	0.14	807.34	0.009	NA	35.3	36.8	67.3	0.002	0.008	969
204	1	P12	1	1203	807.140	0.140	28	0.28	807.42	0.320	0.050	35.3	36.8	67.3	1.586	0.193	68923
205	1	P12	1	1204	807.200	0.200	22	0.22	807.42	0.430	0.800	35.3	36.8	67.3	3.346	0.293	72769
206	1	P12	1	1205	807.090	0.090	24	0.24	807.33	0.940	1.150	35.3	36.8	67.3	15.097	0.613	173538
207	1	P12	1	1206	807.130	0.130	20	0.20	807.33	0.680	NA	35.3	36.8	67.3	8.932	0.485	104615
208	1	P12	1	1207	807.100	0.100	28	0.28	807.38	0.730	0.670	35.3	36.8	67.3	8.253	0.440	157231
209	1	P12	1	1208	807.120	0.120	22	0.22	807.34	1.010	0.980	35.3	36.8	67.3	18.463	0.688	170923
210	1	P12	1	1209	807.030	0.030	30	0.30	807.33	0.890	0.720	35.3	36.8	67.3	11.758	0.519	205385
211	1	P12	1	1210	807.050	0.050	31	0.31	807.36	0.740	0.650	35.3	36.8	67.3	7.969	0.424	176462
212	1	P12	1	1212	807.000	0.000	30	0.30	807.30	0.740	0.770	35.3	36.8	67.3	8.129	0.431	170769
213	1	P12	1	1213	807.060	0.060	26	0.26	807.32	0.860	0.570	35.3	36.8	67.3	12.001	0.538	172000
214	1	P12	1	1214	807.180	0.180	18	0.18	807.36	0.420	NA	35.3	36.8	67.3	3.671	0.316	58154
215	1	P13	1	1302	805.650	0.240	18	0.18	805.83	0.390	NA	55.4	34.2	78.4	3.544	0.293	54000
216	1	P13	1	1303	805.630	0.220	18	0.18	805.81	0.560	NA	55.4	34.2	78.4	7.307	0.421	77538
217	1	P13	1	1304	805.530	0.120	24	0.24	805.77	1.150	0.940	55.4	34.2	78.4	25.026	0.749	212308
218	1	P13	1	1305	805.510	0.100	22	0.22	805.73	0.610	0.610	55.4	34.2	78.4	7.482	0.415	103231
219	1	P13	1	1306	805.530	0.120	32	0.32	805.85	0.670	0.570	55.4	34.2	78.4	7.035	0.378	164923
220	1	P13	1	1307	805.650	0.240	17	0.17	805.82	0.130	NA	55.4	34.2	78.4	0.412	0.101	17000
221	1	P13	1	1308	805.700	0.290	8	0.08	805.78	0.270	NA	55.4	34.2	78.4	3.559	0.305	16615
222	1	P13	1	1309	805.640	0.230	20	0.20	805.84	0.750	NA	55.4	34.2	78.4	12.114	0.535	115385
223	1	P13	1	1310	805.410	0.000	44	0.44	805.85	1.080	0.360	55.4	34.2	78.4	15.120	0.520	365538
224	1	P13	1	1311	805.450	0.040	46	0.46	805.91	1.130	0.840	55.4	34.2	78.4	16.142	0.532	399846
225	1	P13	1	1313	805.640	0.230	20	0.20	805.84	0.490	NA	55.4	34.2	78.4	5.171	0.350	75385
226	1	P13	1	1314	805.690	0.280	22	0.22	805.91	0.540	0.510	55.4	34.2	78.4	5.863	0.368	91385

227	1	P13	1	1315	805.750	0.340	18	0.18	805.93	0.270	NA	55.4	34.2	78.4	1.699	0.203	37385
228	1	P13	1	1316	805.950	0.540	4	0.04	805.99	0.028	NA	55.4	34.2	78.4	0.100	0.045	862
229	1	P14	4	1402	803.910	0.370	4	0.04	803.95	0.015	NA	50.0	34.8	75.2	0.027	0.024	462
230	1	P14	4	1403	803.810	0.270	16	0.16	803.97	0.080	NA	50.0	34.8	75.2	0.158	0.064	9846
231	1	P14	4	1404	803.680	0.140	28	0.28	803.96	0.540	0.340	50.0	34.8	75.2	4.847	0.326	116308
232	1	P14	4	1405	803.690	0.150	26	0.26	803.95	0.510	0.460	50.0	34.8	75.2	4.538	0.319	102000
233	1	P14	4	1406	803.790	0.250	17	0.17	803.96	0.630	NA	50.0	34.8	75.2	9.365	0.488	82385
234	1	P14	4	1407	803.810	0.270	17	0.17	803.98	0.530	NA	50.0	34.8	75.2	6.628	0.410	69308
235	1	P14	4	1408	803.750	0.210	20	0.20	803.95	0.450	NA	50.0	34.8	75.2	4.234	0.321	69231
236	1	P14	4	1409	803.740	0.200	15	0.15	803.89	0.710	NA	50.0	34.8	75.2	13.124	0.585	81923
237	1	P14	4	1410	803.580	0.040	34	0.34	803.92	0.910	0.740	50.0	34.8	75.2	12.193	0.498	238000
238	1	P14	4	1411	803.630	0.090	24	0.24	803.87	0.290	0.560	50.0	34.8	75.2	1.548	0.189	53538
239	1	P14	4	1412	803.630	0.090	22	0.22	803.85	1.200	0.960	50.0	34.8	75.2	28.137	0.817	203077
240	1	P14	4	1413	803.540	0.000	36	0.36	803.90	1.070	0.460	50.0	34.8	75.2	16.289	0.569	296308
241	1	P14	4	1414	803.620	0.080	22	0.22	803.84	0.400	0.250	50.0	34.8	75.2	3.126	0.272	67692
242	1	P14	4	1415	803.740	0.200	4	0.04	803.78	-0.030	NA	50.0	34.8	75.2	0.107	0.048	923
243	1	P14	3	1418	803.770	0.000	1	0.01	803.78	0.010	NA	50.0	34.8	75.2	0.313	0.032	77
244	1	P14	2	1421	803.560	0.040	4	0.04	803.60	0.050	NA	50.0	34.8	75.2	0.298	0.080	1538
245	1	P14	2	1422	803.520	0.000	6	0.06	803.58	0.003	NA	50.0	34.8	75.2	0.001	0.004	138
246	1	P14	1	1424	803.500	0.040	5	0.05	803.55	0.013	NA	50.0	34.8	75.2	0.014	0.019	500
247	1	P14	1	1426	803.460	0.000	16	0.16	803.62	0.026	NA	50.0	34.8	75.2	0.017	0.021	3200
248	1	P14	1	1427	803.610	0.150	2	0.02	803.63	-0.011	NA	50.0	34.8	75.2	0.089	0.025	169
249	1	P15	1	1502	801.270	0.000	16	0.16	801.43	0.001	NA	53.7	34.4	76.3	0.000	0.001	123
250	1	P15	1	1503	801.390	0.120	6	0.06	801.45	0.030	NA	53.7	34.4	76.3	0.060	0.039	1385
251	1	P15	1	1504	801.330	0.060	9	0.09	801.42	0.014	NA	53.7	34.4	76.3	0.008	0.015	969
252	1	P15	1	1505	801.280	0.010	12	0.12	801.40	0.002	NA	53.7	34.4	76.3	0.000	0.002	185
253	1	P15	1	1507	801.280	0.010	10	0.10	801.38	0.120	NA	53.7	34.4	76.3	0.543	0.121	9231
254	1	P15	1	1508	801.270	0.000	14	0.14	801.41	0.090	NA	53.7	34.4	76.3	0.226	0.077	9692
255	1	P15	2	1511	800.850	0.140	20	0.20	801.05	0.430	NA	53.7	34.4	76.3	3.906	0.307	66154
256	1	P15	2	1512	800.790	0.080	36	0.36	801.15	0.860	0.970	53.7	34.4	76.3	10.612	0.458	238154
257	1	P15	2	1513	800.740	0.030	32	0.32	801.06	0.370	0.760	53.7	34.4	76.3	2.110	0.209	91077
258	1	P15	2	1514	800.710	0.000	40	0.40	801.11	1.160	0.820	53.7	34.4	76.3	18.146	0.586	356923
259	1	P15	2	1515	800.720	0.010	44	0.44	801.16	1.490	1.030	53.7	34.4	76.3	28.350	0.717	504308
260	1	P15	2	1516	800.840	0.130	30	0.30	801.14	1.510	0.980	53.7	34.4	76.3	36.600	0.880	348462
261	1	P15	2	1517	800.980	0.270	20	0.20	801.18	0.870	0.540	53.7	34.4	76.3	15.989	0.621	133846
262	1	P15	2	1518	800.960	0.250	24	0.24	801.20	0.180	0.210	53.7	34.4	76.3	0.602	0.117	33231
263	1	P15	2	1519	800.970	0.260	22	0.22	801.19	0.240	0.060	53.7	34.4	76.3	1.137	0.163	40615
264	1	P15	3	1522	801.620	0.000	1	0.01	801.63	0.010	NA	53.7	34.4	76.3	0.277	0.032	77
265	1	P16	1	1602	799.690	0.000	16	0.16	799.85	0.010	NA	78.9	32.2	97.1	0.003	0.008	1231
266	1	P16	1	1603	799.780	0.090	8	0.08	799.86	0.011	NA	78.9	32.2	97.1	0.008	0.012	677
267	1	P16	2	1606	799.190	0.100	22	0.22	799.41	0.330	0.360	78.9	32.2	97.1	2.563	0.225	55846
268	1	P16	2	1607	799.250	0.160	26	0.26	799.51	1.320	0.120	78.9	32.2	97.1	36.230	0.827	264000
269	1	P16	2	1608	799.090	0.000	42	0.42	799.51	0.850	0.790	78.9	32.2	97.1	10.924	0.419	274615
270	1	P16	2	1609	799.170	0.080	34	0.34	799.51	0.280	0.380	78.9	32.2	97.1	1.356	0.153	73231
271	1	P16	2	1610	799.320	0.230	20	0.20	799.52	1.270	NA	78.9	32.2	97.1	40.900	0.907	195385
272	1	P16	2	1611	799.250	0.160	30	0.30	799.55	0.580	0.450	78.9	32.2	97.1	6.326	0.338	133846
273	1	P16	2	1612	799.260	0.170	30	0.30	799.56	0.920	0.740	78.9	32.2	97.1	15.917	0.536	212308
274	1	P16	2	1613	799.380	0.290	22	0.22	799.60	0.480	0.400	78.9	32.2	97.1	5.424	0.327	81231
275	1	P16	2	1614	799.390	0.300	19	0.19	799.58	0.310	NA	78.9	32.2	97.1	2.539	0.227	45308
276	1	P16	2	1615	799.320	0.230	15	0.15	799.47	0.270	NA	78.9	32.2	97.1	2.357	0.223	31154
277	1	P17	1	1702	797.920	0.180	17	0.17	798.09	0.180	NA	45.3	35.3	70.6	0.729	0.139	23538
278	1	P17	1	1703	797.780	0.040	30	0.30	798.08	0.700	0.310	45.3	35.3	70.6	7.494	0.408	161538
279	1	P17	1	1704	797.810	0.070	24	0.24	798.05	0.760	0.620	45.3	35.3	70.6	10.189	0.495	140308
280	1	P17	1	1705	797.840	0.100	24	0.24	798.08	0.280	0.180	45.3	35.3	70.6	1.383	0.182	51692
281	1	P17	1	1706	797.820	0.080	24	0.24	798.06	0.560	0.400	45.3	35.3	70.6	5.532	0.365	103385
282	1	P17	1	1707	797.860	0.120	22	0.22	798.08	0.610	0.590	45.3	35.3	70.6	6.960	0.415	103231
283	1	P17	1	1708	797.840	0.100	28	0.28	798.12	0.580	0.250	45.3	35.3	70.6	5.371	0.350	124923

284	1	P17	1	1709	797.740	0.000	24	0.24	797.98	0.840	0.730	45.3	35.3	70.6	12.447	0.547	155077
285	1	P17	1	1710	797.750	0.010	27	0.27	798.02	0.550	0.550	45.3	35.3	70.6	4.943	0.338	114231
286	1	P18	1	1802	796.940	0.570	6	0.06	797.00	0.050	NA	56.9	34.0	76.1	0.166	0.065	2308
287	1	P18	1	1803	796.920	0.550	8	0.08	797.00	0.160	NA	56.9	34.0	76.1	1.210	0.181	9846
288	1	P18	1	1804	796.930	0.560	6	0.06	796.99	0.006	NA	56.9	34.0	76.1	0.002	0.008	277
289	1	P18	1	1805	796.950	0.580	8	0.08	797.03	0.020	NA	56.9	34.0	76.1	0.019	0.023	1231
290	1	P18	1	1806	796.920	0.550	5	0.05	796.97	0.086	NA	56.9	34.0	76.1	0.630	0.123	3308
291	1	P18	1	1807	796.810	0.440	4	0.04	796.85	0.018	NA	56.9	34.0	76.1	0.039	0.029	554
292	1	P18	1	1808	796.780	0.410	7	0.07	796.85	0.080	NA	56.9	34.0	76.1	0.352	0.097	4308
293	1	P18	1	1809	796.620	0.250	16	0.16	796.78	0.440	NA	56.9	34.0	76.1	4.830	0.351	54154
294	1	P18	1	1810	796.550	0.180	30	0.30	796.85	1.020	0.930	56.9	34.0	76.1	16.667	0.595	235385
295	1	P18	1	1811	796.560	0.190	20	0.20	796.76	1.390	NA	56.9	34.0	76.1	40.720	0.992	213846
296	1	P18	1	1812	796.380	0.010	34	0.34	796.72	1.150	0.680	56.9	34.0	76.1	19.605	0.630	300769
297	1	P18	1	1813	796.370	0.000	44	0.44	796.81	1.360	0.480	56.9	34.0	76.1	23.577	0.655	460308
298	1	P18	1	1814	796.410	0.040	46	0.46	796.87	0.620	0.510	56.9	34.0	76.1	4.779	0.292	219385
299	1	P18	1	1815	796.530	0.160	26	0.26	796.79	0.340	0.060	56.9	34.0	76.1	2.032	0.213	68000
300	1	P18	1	1816	796.630	0.260	16	0.16	796.79	0.009	NA	56.9	34.0	76.1	0.002	0.007	1108
301	1	P19	1	1902	795.450	0.300	5	0.05	795.50	0.040	NA	58.7	33.8	77.7	0.141	0.057	1538
302	1	P19	1	1903	795.420	0.270	10	0.10	795.52	0.350	NA	58.7	33.8	77.7	4.704	0.353	26923
303	1	P19	1	1904	795.390	0.240	18	0.18	795.57	0.460	NA	58.7	33.8	77.7	4.901	0.346	63692
304	1	P19	1	1905	795.340	0.190	24	0.24	795.58	0.430	NA	58.7	33.8	77.7	3.480	0.280	79385
305	1	P19	1	1906	795.440	0.290	14	0.14	795.58	0.120	NA	58.7	33.8	77.7	0.408	0.102	12923
306	1	P19	1	1907	795.330	0.180	20	0.20	795.53	1.560	NA	58.7	33.8	77.7	52.109	1.114	240000
307	1	P19	1	1908	795.260	0.110	30	0.30	795.56	1.530	NA	58.7	33.8	77.7	38.023	0.892	353077
308	1	P19	1	1909	795.240	0.090	28	0.28	795.52	0.630	NA	58.7	33.8	77.7	6.739	0.380	135692
309	1	P19	1	1911	795.150	0.000	36	0.36	795.51	0.770	NA	58.7	33.8	77.7	8.603	0.410	213231
310	2	P1	3	167	759.580	0.000	36	0.36	759.94	0.430	NA	64.0	33.4	83.9	2.810	0.229	119077
311	2	P1	3	168	759.643	0.063	21	0.21	759.85	0.000	NA	64.0	33.4	83.9	0.000	0.000	0
312	2	P1	3	169	759.809	0.229	10	0.10	759.91	0.000	NA	64.0	33.4	83.9	0.000	0.000	0
313	2	P1	2	170	759.416	0.226	8	0.08	759.50	0.200	NA	64.0	33.4	83.9	2.108	0.226	12308
314	2	P1	2	171	759.256	0.066	20	0.20	759.46	0.160	NA	64.0	33.4	83.9	0.580	0.114	24615
315	2	P1	2	172	759.351	0.161	12	0.12	759.47	0.380	NA	64.0	33.4	83.9	5.010	0.350	35077
316	2	P1	2	173	759.312	0.122	12	0.12	759.43	0.540	NA	64.0	33.4	83.9	10.117	0.498	49846
317	2	P1	2	174	759.190	0.000	26	0.26	759.45	0.470	NA	64.0	33.4	83.9	4.146	0.294	94000
318	2	P1	2	175	759.245	0.055	24	0.24	759.49	0.210	NA	64.0	33.4	83.9	0.875	0.137	38769
319	2	P1	2	176	759.345	0.155	12	0.12	759.47	0.150	NA	64.0	33.4	83.9	0.781	0.138	13846
320	2	P1	1	177	758.750	0.537	46	0.46	759.21	-0.040	-0.800	64.0	33.4	83.9	0.021	0.019	14154
321	2	P1	1	178	758.213	0.000	98	0.98	759.19	-0.300	-0.100	64.0	33.4	83.9	0.799	0.097	226154
322	2	P1	1	179	758.395	0.182	82	0.82	759.22	0.670	0.850	64.0	33.4	83.9	4.342	0.236	422615
323	2	P1	1	180	758.576	0.363	68	0.68	759.26	1.900	1.500	64.0	33.4	83.9	38.364	0.736	993846
324	2	P1	1	181	758.749	0.536	40	0.40	759.15	1.250	1.550	64.0	33.4	83.9	22.275	0.631	384615
325	2	P1	1	182	759.065	0.852	20	0.20	759.27	0.230	0.260	64.0	33.4	83.9	1.198	0.164	35385
326	2	P2	2	186	758.152	0.000	18	0.18	758.33	0.000	NA	34.5	37.0	62.0	0.000	0.000	0
327	2	P2	2	188	758.167	0.015	18	0.18	758.35	0.450	NA	34.5	37.0	62.0	3.977	0.339	62308
328	2	P2	2	189	758.156	0.004	18	0.18	758.34	0.200	NA	34.5	37.0	62.0	0.785	0.151	27692
329	2	P2	2	191	758.256	0.104	6	0.06	758.32	0.010	NA	34.5	37.0	62.0	0.005	0.013	462
330	2	P2	1	193	758.357	0.320	22	0.22	758.58	0.480	NA	34.5	37.0	62.0	3.950	0.327	81231
331	2	P2	1	196	758.290	0.253	26	0.26	758.55	0.560	0.320	34.5	37.0	62.0	4.834	0.351	112000
332	2	P2	1	200	758.188	0.151	36	0.36	758.55	0.650	0.550	34.5	37.0	62.0	5.374	0.346	180000
333	2	P2	1	202	758.080	0.043	50	0.50	758.58	0.920	0.550	34.5	37.0	62.0	9.019	0.415	353846
334	2	P2	1	205	758.037	0.000	52	0.52	758.56	0.950	0.420	34.5	37.0	62.0	9.425	0.421	380000
335	2	P2	1	208	758.144	0.107	42	0.42	758.56	0.690	0.370	34.5	37.0	62.0	5.562	0.340	222923
336	2	P2	1	209	758.167	0.130	40	0.40	758.57	0.600	0.400	34.5	37.0	62.0	4.319	0.303	184615
337	2	P2	1	213	758.155	0.118	38	0.38	758.54	0.260	0.170	34.5	37.0	62.0	0.834	0.135	76000
338	2	P2	1	215	758.367	0.330	20	0.20	758.57	0.110	0.130	34.5	37.0	62.0	0.221	0.079	16923
339	2	P3	2	305	757.739	0.009	8	0.08	757.82	0.350	NA	56.5	34.1	70.9	5.370	0.395	21538

340	2	P3	2	307	757.735	0.005	6	0.06	757.80	0.110	NA	56.5	34.1	70.9	0.735	0.143	5077
341	2	P3	2	309	757.737	0.007	6	0.06	757.80	0.030	NA	56.5	34.1	70.9	0.055	0.039	1385
342	2	P3	2	312	757.730	0.000	2	0.02	757.75	0.080	NA	56.5	34.1	70.9	3.704	0.181	1231
343	2	P3	2	313	757.771	0.041	2	0.02	757.79	0.080	NA	56.5	34.1	70.9	3.704	0.181	1231
344	2	P3	1	315	757.978	0.375	11	0.11	758.09	0.360	NA	56.5	34.1	70.9	4.175	0.347	30462
345	2	P3	1	318	757.908	0.305	16	0.16	758.07	0.320	NA	56.5	34.1	70.9	2.418	0.255	39385
346	2	P3	1	321	757.821	0.218	26	0.26	758.08	0.970	0.720	56.5	34.1	70.9	15.789	0.607	194000
347	2	P3	1	323	757.798	0.195	28	0.28	758.08	1.000	0.830	56.5	34.1	70.9	16.004	0.603	215385
348	2	P3	1	324	757.741	0.138	36	0.36	758.10	1.080	0.430	56.5	34.1	70.9	16.022	0.575	299077
349	2	P3	1	326	757.700	0.097	38	0.38	758.08	1.420	0.390	56.5	34.1	70.9	26.842	0.735	415077
350	2	P3	1	329	757.603	0.000	50	0.50	758.10	1.270	0.720	56.5	34.1	70.9	18.439	0.573	488462
351	2	P3	1	332	757.672	0.069	40	0.40	758.07	0.580	0.380	56.5	34.1	70.9	4.349	0.293	178462
352	2	P3	1	334	757.791	0.188	16	0.16	757.95	0.810	NA	56.5	34.1	70.9	15.495	0.647	99692
353	2	P3	1	336	757.951	0.348	8	0.08	758.03	0.180	NA	56.5	34.1	70.9	1.420	0.203	11077
354	2	P4	1	401	756.694	0.430	12	0.12	756.81	0.400	NA	68.7	33.0	91.4	6.025	0.369	36923
355	2	P4	1	402	756.613	0.349	20	0.20	756.81	0.920	NA	68.7	33.0	91.4	20.479	0.657	141538
356	2	P4	1	407	756.572	0.308	26	0.26	756.83	1.100	0.040	68.7	33.0	91.4	24.112	0.689	220000
357	2	P4	1	413	756.580	0.316	24	0.24	756.82	1.040	1.040	68.7	33.0	91.4	22.823	0.678	192000
358	2	P4	1	418	756.507	0.243	28	0.28	756.79	0.920	0.320	68.7	33.0	91.4	16.018	0.555	198154
359	2	P4	1	422	756.403	0.139	42	0.42	756.82	1.190	0.370	68.7	33.0	91.4	20.647	0.586	384462
360	2	P4	1	426	756.289	0.025	50	0.50	756.79	1.310	0.250	68.7	33.0	91.4	22.584	0.591	503846
361	2	P4	1	434	756.264	0.000	40	0.40	756.66	1.420	1.340	68.7	33.0	91.4	30.285	0.717	436923
362	2	P4	1	439	756.491	0.227	42	0.42	756.91	1.280	0.410	68.7	33.0	91.4	23.889	0.631	413538
363	2	P4	1	444	756.575	0.311	10	0.10	756.68	0.490	NA	68.7	33.0	91.4	10.879	0.495	37692
364	2	P5	1	504	756.295	0.274	10	0.10	756.40	0.230	NA	71.0	32.8	88.6	2.317	0.232	17692
365	2	P5	1	506	756.254	0.233	20	0.20	756.45	0.030	NA	71.0	32.8	88.6	0.021	0.021	4615
366	2	P5	1	510	756.202	0.181	26	0.26	756.46	0.610	0.530	71.0	32.8	88.6	7.250	0.382	122000
367	2	P5	1	514	756.172	0.151	35	0.35	756.52	0.570	0.850	71.0	32.8	88.6	5.197	0.308	153462
368	2	P5	1	518	756.150	0.129	28	0.28	756.43	0.660	0.560	71.0	32.8	88.6	8.065	0.398	142154
369	2	P5	1	521	756.194	0.173	30	0.30	756.49	0.920	0.530	71.0	32.8	88.6	14.961	0.536	212308
370	2	P5	1	526	756.074	0.053	44	0.44	756.51	0.710	0.300	71.0	32.8	88.6	7.014	0.342	240308
371	2	P5	1	530	756.047	0.026	42	0.42	756.47	0.810	0.720	71.0	32.8	88.6	9.384	0.399	261692
372	2	P5	1	533	756.066	0.045	37	0.37	756.44	0.740	0.680	71.0	32.8	88.6	8.460	0.388	210615
373	2	P5	1	537	756.021	0.000	45	0.45	756.47	0.700	0.410	71.0	32.8	88.6	6.728	0.333	242308
374	2	P5	1	542	756.073	0.052	48	0.48	756.55	0.680	0.110	71.0	32.8	88.6	6.116	0.313	251077
375	2	P5	1	547	756.057	0.036	40	0.40	756.46	0.410	0.370	71.0	32.8	88.6	2.476	0.207	126154
376	2	P6	1	601	755.418	0.277	10	0.10	755.52	0.220	NA	77.3	32.3	109.5	2.682	0.222	16923
377	2	P6	1	606	755.376	0.235	22	0.22	755.60	0.210	0.230	77.3	32.3	109.5	1.141	0.143	35538
378	2	P6	1	609	755.207	0.066	42	0.42	755.63	0.830	0.800	77.3	32.3	109.5	11.231	0.409	268154
379	2	P6	1	612	755.213	0.072	40	0.40	755.61	1.250	0.460	77.3	32.3	109.5	26.286	0.631	384615
380	2	P6	1	616	755.260	0.119	40	0.40	755.66	1.480	1.020	77.3	32.3	109.5	36.849	0.747	455385
381	2	P6	1	622	755.141	0.000	40	0.40	755.54	1.340	1.000	77.3	32.3	109.5	30.207	0.676	412308
382	2	P6	1	624	755.218	0.077	30	0.30	755.52	1.030	0.900	77.3	32.3	109.5	21.703	0.600	237692
383	2	P6	1	628	755.150	0.009	42	0.42	755.57	0.600	0.230	77.3	32.3	109.5	5.869	0.296	193846
384	2	P6	1	634	755.349	0.208	24	0.24	755.59	0.910	0.610	77.3	32.3	109.5	20.002	0.593	168000
385	2	P6	1	640	755.150	0.009	42	0.42	755.57	0.310	0.020	77.3	32.3	109.5	1.567	0.153	100154
386	2	P6	1	642	755.319	0.178	20	0.20	755.52	0.124	0.180	77.3	32.3	109.5	0.430	0.089	19077
387	2	P7	1	732	754.369	0.940	16	0.16	754.53	0.380	NA	69.7	32.9	89.6	4.115	0.303	46769
388	2	P7	1	733	753.990	0.561	54	0.54	754.53	0.450	0.080	69.7	32.9	89.6	2.522	0.196	186923
389	2	P7	1	736	753.686	0.257	82	0.82	754.51	0.760	0.360	69.7	32.9	89.6	5.771	0.268	479385
390	2	P7	1	738	753.635	0.206	88	0.88	754.52	0.710	0.360	69.7	32.9	89.6	4.864	0.242	480615
391	2	P7	1	741	753.429	0.000	110	01. Okt	754.53	0.540	0.070	69.7	32.9	89.6	2.529	0.164	456923
392	2	P7	1	746	753.553	0.124	96	0.96	754.51	0.220	0.220	69.7	32.9	89.6	0.448	0.072	162462
393	2	P7	1	752	753.840	0.411	66	0.66	754.50	-0.010	0.010	69.7	32.9	89.6	0.001	0.004	5077
394	2	P7	1	756	753.980	0.551	50	0.50	754.48	-0.052	0.070	69.7	32.9	89.6	0.035	0.023	20000
395	2	P7	1	761	753.796	0.367	68	0.68	754.48	-0.100	-0.090	69.7	32.9	89.6	0.110	0.039	52308
396	2	P7	1	765	753.974	0.545	62	0.62	754.59	-0.100	-0.090	69.7	32.9	89.6	0.115	0.041	47692

397	2	P8	1	773	753.909	0.373	10	0.10	754.01	0.630	NA	92.7	31.4	116.5	23.699	0.636	48462
398	2	P8	1	776	753.752	0.216	36	0.36	754.11	0.530	0.566	92.7	31.4	116.5	5.284	0.282	146769
399	2	P8	1	781	753.678	0.142	36	0.36	754.04	0.520	0.330	92.7	31.4	116.5	5.087	0.277	144000
400	2	P8	1	784	753.573	0.037	48	0.48	754.05	1.230	0.890	92.7	31.4	116.5	23.583	0.567	454154
401	2	P8	1	785	753.536	0.000	54	0.54	754.08	1.405	1.400	92.7	31.4	116.5	28.630	0.610	583615
402	2	P8	1	801	753.702	0.166	38	0.38	754.08	0.120	0.110	92.7	31.4	116.5	0.261	0.062	35077
403	2	P8	1	803	754.019	0.483	10	0.10	754.12	0.070	0.170	92.7	31.4	116.5	0.293	0.071	5385
404	2	P8	1	805	754.281	0.745	6	0.06	754.34	0.130	NA	92.7	31.4	116.5	2.130	0.169	6000
405	2	P8	2	811	754.369	0.131	10	0.10	754.47	0.080	NA	92.7	31.4	116.5	0.382	0.081	6154
406	2	P8	2	814	754.334	0.096	14	0.14	754.47	0.030	NA	92.7	31.4	116.5	0.037	0.026	3231
407	2	P8	2	816	754.238	0.000	16	0.16	754.40	0.040	NA	92.7	31.4	116.5	0.058	0.032	4923
408	2	P9	2	822	753.799	0.013	6	0.06	753.86	0.030	NA	73.0	32.6	86.2	0.071	0.039	1385
409	2	P9	2	824	753.790	0.004	5	0.05	753.84	0.018	NA	73.0	32.6	86.2	0.033	0.026	692
410	2	P9	2	827	753.786	0.000	7	0.07	753.86	0.060	NA	73.0	32.6	86.2	0.230	0.072	3231
411	2	P9	1	833	753.468	0.501	8	0.08	753.55	0.060	NA	73.0	32.6	86.2	0.196	0.068	3692
412	2	P9	1	835	753.433	0.466	10	0.10	753.53	0.090	NA	73.0	32.6	86.2	0.345	0.091	6923
413	2	P9	1	837	753.363	0.396	20	0.20	753.56	0.050	0.210	73.0	32.6	86.2	0.058	0.036	7692
414	2	P9	1	840	753.274	0.307	26	0.26	753.53	0.590	0.520	73.0	32.6	86.2	6.657	0.369	118000
415	2	P9	1	848	753.133	0.166	48	0.48	753.61	0.910	0.660	73.0	32.6	86.2	10.785	0.419	336000
416	2	P9	1	851	753.154	0.187	47	0.47	753.62	0.760	0.510	73.0	32.6	86.2	7.614	0.354	274769
417	2	P9	1	854	753.093	0.126	38	0.38	753.47	0.530	0.480	73.0	32.6	86.2	4.199	0.275	154923
418	2	P9	1	865	753.039	0.072	40	0.40	753.44	0.440	0.200	73.0	32.6	86.2	2.805	0.222	135385
419	2	P9	1	867	752.967	0.000	50	0.50	753.47	0.740	0.390	73.0	32.6	86.2	6.969	0.334	284615
420	2	P9	1	872	753.114	0.147	44	0.44	753.55	0.470	1.320	73.0	32.6	86.2	3.025	0.226	159077
421	2	P9	1	874	753.252	0.285	22	0.22	753.47	0.120	NA	73.0	32.6	86.2	0.310	0.082	20308
422	2	P10	1	1001	752.613	0.348	20	0.20	752.81	0.780	0.720	56.5	34.1	76.6	12.882	0.557	120000
423	2	P10	1	1004	752.420	0.155	47	0.47	752.89	0.540	0.370	56.5	34.1	76.6	3.595	0.251	195231
424	2	P10	1	1010	752.424	0.159	62	0.62	753.04	1.120	0.860	56.5	34.1	76.6	13.339	0.454	534154
425	2	P10	1	1014	752.265	0.000	48	0.48	752.75	0.900	0.410	56.5	34.1	76.6	9.871	0.415	332308
426	2	P10	1	1015	752.371	0.106	46	0.46	752.83	0.460	0.260	56.5	34.1	76.6	2.640	0.217	162769
427	2	P10	1	1020	752.386	0.121	42	0.42	752.81	0.690	0.160	56.5	34.1	76.6	6.254	0.340	222923
428	2	P10	1	1024	752.497	0.232	36	0.36	752.86	0.660	0.470	56.5	34.1	76.6	6.263	0.351	182769
429	2	P10	1	1029	752.593	0.328	26	0.26	752.85	0.490	0.430	56.5	34.1	76.6	4.237	0.307	98000
430	2	P10	1	1032	752.680	0.415	12	0.12	752.80	0.120	NA	56.5	34.1	76.6	0.460	0.111	11077
432	2	P10	1	1038	752.621	0.356	8	0.08	752.70	0.180	NA	56.5	34.1	76.6	1.542	0.203	11077
433	2	P10	1	1041	752.640	0.375	10	0.10	752.74	0.240	NA	56.5	34.1	76.6	2.179	0.242	18462
434	2	P11	1	1101	751.914	0.654	13	0.13	752.04	0.010	NA	70.6	32.8	96.1	0.004	0.009	1000
435	2	P11	1	1104	751.728	0.468	36	0.36	752.09	0.210	0.170	70.6	32.8	96.1	0.730	0.112	58154
436	2	P11	1	1111	751.582	0.322	54	0.54	752.12	0.320	0.120	70.6	32.8	96.1	1.327	0.139	132923
437	2	P11	1	1114	751.508	0.248	60	0.60	752.11	0.630	0.350	70.6	32.8	96.1	4.849	0.260	290769
438	2	P11	1	1121	751.260	0.000	64	0.64	751.90	0.670	0.460	70.6	32.8	96.1	5.294	0.267	329846
439	2	P11	1	1124	751.290	0.030	80	0.80	752.09	0.690	0.460	70.6	32.8	96.1	4.992	0.246	424615
440	2	P11	1	1129	751.503	0.243	59	0.59	752.09	0.630	0.395	70.6	32.8	96.1	4.894	0.262	285923
441	2	P11	1	1135	751.596	0.336	64	0.64	752.24	0.081	0.058	70.6	32.8	96.1	0.077	0.032	39877
442	2	P11	1	1140	751.747	0.487	40	0.40	752.15	-0.030	0.030	70.6	32.8	96.1	0.014	0.015	9231
443	2	P12	2	1201	751.418	0.109	8	0.08	751.50	-0.020	NA	71.4	32.8	86.8	0.022	0.023	1231
444	2	P12	2	1205	751.364	0.055	14	0.14	751.50	0.510	NA	71.4	32.8	86.8	8.097	0.435	54923
445	2	P12	2	1210	751.309	0.000	22	0.22	751.53	0.450	0.470	71.4	32.8	86.8	4.384	0.306	76154
446	2	P12	2	1215	751.352	0.043	16	0.16	751.51	0.490	NA	71.4	32.8	86.8	6.667	0.391	60308
447	2	P12	2	1219	751.329	0.020	18	0.18	751.51	0.450	0.290	71.4	32.8	86.8	5.110	0.339	62308
448	2	P12	2	1222	751.347	0.038	12	0.12	751.47	0.890	NA	71.4	32.8	86.8	28.385	0.820	82154
449	2	P12	2	1223	751.440	0.131	6	0.06	751.50	0.260	NA	71.4	32.8	86.8	5.359	0.339	12000
450	2	P12	1	1228	750.931	0.750	22	0.22	751.15	0.048	0.206	71.4	32.8	86.8	0.050	0.033	8123
451	2	P12	1	1229	750.738	0.557	32	0.32	751.06	0.410	0.240	71.4	32.8	86.8	2.812	0.231	100923
452	2	P12	1	1230	750.738	0.557	42	0.42	751.16	0.720	0.610	71.4	32.8	86.8	7.328	0.355	232615
453	2	P12	1	1235	750.230	0.049	74	0.74	750.97	1.400	0.410	71.4	32.8	86.8	20.303	0.520	796923

455	2	P13	1	1321	750.919	0.361	6	0.06	750.98	0.290	NA	50.0	34.8	71.6	5.175	0.378	13385
456	2	P13	1	1325	750.558	0.000	48	0.48	751.04	0.430	-0.120	50.0	34.8	71.6	2.173	0.198	158769
457	2	P13	1	1328	750.795	0.237	24	0.24	751.04	0.450	0.400	50.0	34.8	71.6	3.606	0.293	83077
458	2	P13	1	1330	750.892	0.334	16	0.16	751.05	0.290	NA	50.0	34.8	71.6	2.002	0.231	35692
459	2	P13	1	1333	750.900	0.342	16	0.16	751.06	0.280	NA	50.0	34.8	71.6	1.867	0.223	34462
460	2	P13	1	1337	750.858	0.300	16	0.16	751.02	0.430	NA	50.0	34.8	71.6	4.402	0.343	52923
461	2	P13	1	1341	750.916	0.358	12	0.12	751.04	0.440	NA	50.0	34.8	71.6	5.830	0.406	40615
462	2	P13	1	1343	750.832	0.274	24	0.24	751.07	0.520	NA	50.0	34.8	71.6	4.816	0.339	96000
463	2	P13	1	1350	750.867	0.309	24	0.24	751.11	0.520	NA	50.0	34.8	71.6	4.816	0.339	96000
464	2	P13	1	1351	750.837	0.279	28	0.28	751.12	0.550	NA	50.0	34.8	71.6	4.874	0.332	118462
465	2	P13	1	1361	750.722	0.164	36	0.36	751.08	0.590	0.430	50.0	34.8	71.6	4.811	0.314	163385
466	2	P13	1	1362	750.640	0.082	42	0.42	751.06	0.540	0.340	50.0	34.8	71.6	3.689	0.266	174462
467	2	P13	1	1369	750.616	0.058	48	0.48	751.10	0.444	0.253	50.0	34.8	71.6	2.317	0.205	163938
468	2	P13	1	1370	750.658	0.100	46	0.46	751.12	0.700	0.320	50.0	34.8	71.6	5.894	0.330	247692
469	2	P14	1	1401	750.189	0.433	13	0.13	750.32	0.300	NA	64.0	33.4	76.3	2.671	0.266	30000
470	2	P14	1	1402	749.994	0.238	28	0.28	750.27	0.740	NA	64.0	33.4	76.3	9.187	0.446	159385
471	2	P14	1	1409	749.804	0.048	40	0.40	750.20	1.370	0.800	64.0	33.4	76.3	25.310	0.692	421538
472	2	P14	1	1410	749.756	0.000	54	0.54	750.30	1.180	2.450	64.0	33.4	76.3	15.891	0.513	490154
473	2	P14	1	1418	750.032	0.276	26	0.26	750.29	1.150	1.030	64.0	33.4	76.3	23.289	0.720	230000
474	2	P14	1	1419	749.854	0.098	44	0.44	750.29	0.640	NA	64.0	33.4	76.3	5.230	0.308	216615
475	2	P14	1	1423	749.998	0.242	22	0.22	750.22	0.110	0.020	64.0	33.4	76.3	0.239	0.075	18615
476	2	P14	1	1424	750.002	0.246	26	0.26	750.26	0.040	NA	64.0	33.4	76.3	0.028	0.025	8000
477	2	P14	1	1431	750.020	0.264	22	0.22	750.24	0.580	0.470	64.0	33.4	76.3	6.639	0.395	98154
478	2	P14	1	1432	750.251	0.495	12	0.12	750.37	0.220	NA	64.0	33.4	76.3	1.541	0.203	20308
479	2	P14	1	1433	750.206	0.450	8	0.08	750.29	0.008	NA	64.0	33.4	76.3	0.003	0.009	492
480	2	P15	1	1501	748.652	0.842	8	0.08	748.73	0.523	NA	40.8	36.0	60.4	10.201	0.590	32185
481	2	P15	1	1502	748.488	0.678	24	0.24	748.73	1.410	1.000	40.8	36.0	60.4	31.682	0.919	260308
482	2	P15	1	1506	748.445	0.635	36	0.36	748.81	1.110	0.920	40.8	36.0	60.4	15.436	0.591	307385
483	2	P15	1	1509	748.152	0.342	52	0.52	748.67	0.820	0.010	40.8	36.0	60.4	6.927	0.363	328000
484	2	P15	1	1514	748.135	0.325	60	0.60	748.74	1.520	0.840	40.8	36.0	60.4	22.165	0.627	701538
485	2	P15	1	1515	747.945	0.135	70	0.70	748.65	0.110	0.110	40.8	36.0	60.4	0.108	0.042	59231
486	2	P15	1	1516	747.979	0.169	94	0.94	748.92	0.270	0.080	40.8	36.0	60.4	0.568	0.089	195231
488	2	P16	1	1601	748.053	0.372	8	0.08	748.13	0.260	NA	76.4	32.4	99.0	4.351	0.293	16000
489	2	P16	1	1602	747.931	0.250	16	0.16	748.09	0.080	0.200	76.4	32.4	99.0	0.199	0.064	9846
490	2	P16	1	1603	747.829	0.148	26	0.26	748.09	0.990	0.880	76.4	32.4	99.0	20.676	0.620	198000
491	2	P16	1	1604	747.814	0.133	22	0.22	748.03	1.290	1.330	76.4	32.4	99.0	39.780	0.878	218308
492	2	P16	1	1607	747.809	0.128	26	0.26	748.07	1.360	1.140	76.4	32.4	99.0	39.019	0.852	272000
493	2	P16	1	1608	747.920	0.239	24	0.24	748.16	0.610	0.460	76.4	32.4	99.0	8.326	0.398	112615
494	2	P16	1	1609	747.844	0.163	44	0.44	748.28	0.990	0.660	76.4	32.4	99.0	14.581	0.477	335077
495	2	P16	1	1610	747.786	0.105	38	0.38	748.17	0.720	0.460	76.4	32.4	99.0	8.450	0.373	210462
496	2	P16	1	1611	747.682	0.001	36	0.36	748.04	0.810	0.620	76.4	32.4	99.0	11.073	0.431	224308
497	2	P16	1	1612	747.681	0.000	44	0.44	748.12	0.770	0.390	76.4	32.4	99.0	8.820	0.371	260615
498	2	P16	1	1613	748.080	0.399	8	0.08	748.16	0.160	NA	76.4	32.4	99.0	1.648	0.181	9846
499	2	P16	1	1614	748.067	0.386	8	0.08	748.15	0.290	NA	76.4	32.4	99.0	5.413	0.327	17846
500	2	P16	1	1615	748.035	0.354	10	0.10	748.14	0.240	NA	76.4	32.4	99.0	2.846	0.242	18462
501	2	P17	1	1616	746.945	0.223	10	0.10	747.05	0.010	NA	72.6	32.7	94.9	0.005	0.010	769
502	2	P17	1	1617	746.895	0.173	20	0.20	747.10	0.420	NA	72.6	32.7	94.9	4.393	0.300	64615
503	2	P17	1	1618	746.802	0.080	24	0.24	747.04	1.460	1.420	72.6	32.7	94.9	46.208	0.952	269538
504	2	P17	1	1619	746.849	0.127	12	0.12	746.97	1.260	NA	72.6	32.7	94.9	61.981	1.161	116308
505	2	P17	1	1620	746.817	0.095	30	0.30	747.12	1.400	1.400	72.6	32.7	94.9	36.289	0.816	323077
506	2	P17	1	1621	746.722	0.000	36	0.36	747.08	1.420	0.890	72.6	32.7	94.9	33.105	0.756	393231
507	2	P17	1	1622	746.896	0.174	18	0.18	747.38	1.810	0.480	72.6	32.7	94.9	45.101	0.834	668308
508	2	P17	1	1623	746.907	0.185	16	0.16	747.07	1.270	1.130	72.6	32.7	94.9	48.288	1.014	156308
509	2	P17	1	1624	746.869	0.147	26	0.26	747.13	1.570	0.680	72.6	32.7	94.9	50.422	0.983	314000
510	2	P17	1	1625	747.000	0.278	12	0.12	747.12	0.340	NA	72.6	32.7	94.9	4.513	0.313	31385
511	3	P1	1	107	696.040	0.630	11	0.11	696.15	0.130	NA	53.5	34.4	71.0	0.562	0.127	11169

512	3	P1	1	108	695.840	0.430	18	0.18	696.02	0.320	NA	53.5	34.4	71.0	2.272	0.244	44862
513	3	P1	1	109	695.740	0.330	8	0.08	695.82	0.330	NA	53.5	34.4	71.0	4.781	0.373	20308
514	3	P1	1	110	695.650	0.240	19	0.19	695.84	0.230	NA	53.5	34.4	71.0	1.139	0.171	34200
515	3	P1	1	111	695.510	0.100	37	0.37	695.88	0.320	0.370	53.5	34.4	71.0	1.368	0.167	90508
516	3	P1	1	112	695.440	0.030	48	0.48	695.92	0.410	0.330	53.5	34.4	71.0	1.947	0.188	150646
517	3	P1	1	113	695.460	0.050	48	0.48	695.94	0.750	0.500	53.5	34.4	71.0	6.579	0.346	276923
518	3	P1	1	114	695.410	0.000	53	0.53	695.94	0.830	0.800	53.5	34.4	71.0	7.606	0.363	337569
519	3	P1	1	115	695.450	0.040	45	0.45	695.90	0.650	0.700	53.5	34.4	71.0	5.087	0.308	224308
520	3	P1	1	116	695.650	0.240	25	0.25	695.90	0.500	0.620	53.5	34.4	71.0	4.377	0.322	96923
521	3	P1	1	117	695.690	0.280	17	0.17	695.86	0.310	NA	53.5	34.4	71.0	2.114	0.237	40015
522	3	P1	1	118	695.780	0.370	11	0.11	695.89	0.180	NA	53.5	34.4	71.0	1.045	0.173	15231
523	3	P1	1	119	695.780	0.370	16	0.16	695.94	0.250	NA	53.5	34.4	71.0	1.502	0.201	31015
524	3	P1	1	120	695.830	0.420	10	0.10	695.93	0.220	NA	53.5	34.4	71.0	1.643	0.218	16615
525	3	P1	1	121	695.810	0.400	9	0.09	695.90	0.120	NA	53.5	34.4	71.0	0.561	0.128	8308
526	3	P1	2	129	695.220	0.000	12	0.12	695.34	0.020	NA	53.5	34.4	71.0	0.017	0.022	2215
527	3	P1	3	133	695.410	0.000	5	0.05	695.46	0.020	NA	53.5	34.4	71.0	0.034	0.030	808
528	3	P2	1	203	695.430	0.000	12	0.12	695.55	0.020	NA	34.6	37.0	44.7	0.008	0.018	1772
529	3	P2	1	204	695.470	0.040	9	0.09	695.56	0.030	NA	34.6	37.0	44.7	0.022	0.031	2035
530	3	P2	2	212	695.170	0.070	30	0.30	695.47	0.470	0.510	34.6	37.0	44.7	2.572	0.273	108000
531	3	P2	2	213	695.100	0.000	55	0.55	695.65	0.860	0.650	34.6	37.0	44.7	6.380	0.369	363000
532	3	P2	2	214	695.100	0.000	40	0.40	695.50	0.660	0.950	34.6	37.0	44.7	4.403	0.333	203077
533	3	P2	2	215	695.430	0.330	10	0.10	695.53	0.270	NA	34.6	37.0	44.7	1.733	0.273	20769
534	3	P2	2	216	695.300	0.200	20	0.20	695.50	0.460	NA	34.6	37.0	44.7	3.162	0.330	71077
535	3	P2	2	217	695.180	0.080	40	0.40	695.58	0.750	1.050	34.6	37.0	44.7	5.685	0.379	230769
536	3	P2	2	218	695.230	0.130	38	0.38	695.61	0.530	0.620	34.6	37.0	44.7	2.892	0.273	154338
537	3	P2	2	219	695.350	0.250	16	0.16	695.51	0.390	NA	34.6	37.0	44.7	2.593	0.311	48000
538	3	P2	2	220	695.490	0.390	14	0.14	695.63	0.190	NA	34.6	37.0	44.7	0.645	0.159	20031
539	3	P2	3	225	695.300	0.050	20	0.20	695.50	0.710	NA	34.6	37.0	44.7	7.426	0.505	108923
540	3	P2	3	226	695.250	0.000	36	0.36	695.61	0.590	0.790	34.6	37.0	44.7	3.687	0.313	162831
541	3	P2	3	227	695.300	0.050	19	0.19	695.49	0.700	NA	34.6	37.0	44.7	7.534	0.514	102600
542	3	P2	3	228	695.360	0.110	18	0.18	695.54	0.270	NA	34.6	37.0	44.7	1.153	0.203	37385
543	3	P2	4	231	695.370	0.020	19	0.19	695.56	0.290	NA	34.6	37.0	44.7	1.268	0.211	42092
544	3	P2	4	232	695.350	0.000	20	0.20	695.55	0.350	NA	34.6	37.0	44.7	1.794	0.248	53538
545	3	P2	4	233	695.430	0.080	10	0.10	695.53	0.220	NA	34.6	37.0	44.7	1.172	0.224	17077
546	3	P2	5	238	695.530	0.000	10	0.10	695.63	0.220	NA	34.6	37.0	44.7	1.172	0.224	17077
547	3	P2	6	249	694.870	0.000	8	0.08	694.95	0.000	NA	34.6	37.0	44.7	0.000	0.003	185
548	3	P3	1	301	694.880	0.000	14	0.14	695.02	0.060	NA	54.7	34.3	79.4	0.104	0.051	6462
549	3	P3	2	309	694.570	0.170	44	0.44	695.01	0.520	0.370	54.7	34.3	79.4	3.477	0.248	174646
550	3	P3	2	310	694.400	0.000	60	0.60	695.00	0.780	0.550	54.7	34.3	79.4	6.706	0.322	360000
551	3	P3	2	311	694.490	0.090	55	0.55	695.04	0.800	0.600	54.7	34.3	79.4	7.351	0.344	337615
552	3	P3	2	312	694.530	0.130	50	0.50	695.03	0.620	0.800	54.7	34.3	79.4	4.643	0.279	237692
553	3	P3	2	313	694.710	0.310	28	0.28	694.99	0.510	0.440	54.7	34.3	79.4	4.478	0.308	109846
554	3	P3	2	314	694.880	0.480	9	0.09	694.97	0.110	NA	54.7	34.3	79.4	0.567	0.121	7892
555	3	P3	3	318	694.840	0.000	12	0.12	694.96	0.160	NA	54.7	34.3	79.4	0.834	0.147	14677
556	3	P3	4	326	694.380	0.180	24	0.24	694.62	0.310	0.150	54.7	34.3	79.4	1.859	0.203	57600
557	3	P3	4	327	694.290	0.090	37	0.37	694.66	0.180	0.250	54.7	34.3	79.4	0.468	0.094	51231
558	3	P3	4	328	694.200	0.000	42	0.42	694.62	0.480	0.550	54.7	34.3	79.4	3.091	0.236	155077
559	3	P3	4	329	694.200	0.000	44	0.44	694.64	0.420	0.560	54.7	34.3	79.4	2.304	0.202	142154
560	3	P3	4	330	694.450	0.250	17	0.17	694.62	0.230	NA	54.7	34.3	79.4	1.347	0.181	30600
561	3	P3	5	334	694.740	0.050	10	0.10	694.84	0.160	NA	54.7	34.3	79.4	1.029	0.164	12462
562	3	P3	5	335	694.730	0.040	13	0.13	694.86	0.390	NA	54.7	34.3	79.4	4.672	0.345	39000
563	3	P3	5	336	694.690	0.000	18	0.18	694.87	0.080	NA	54.7	34.3	79.4	0.143	0.059	10800
564	3	P3	5	337	694.840	0.150	9	0.09	694.93	0.100	NA	54.7	34.3	79.4	0.402	0.102	6646
565	3	P3	6	347	695.040	0.000	11	0.11	695.15	0.170	NA	54.7	34.3	79.4	1.083	0.168	14723
566	3	P3	7	354	694.340	0.000	10	0.10	694.44	0.170	NA	54.7	34.3	79.4	1.187	0.176	13385
567	3	P4	1	403	694.620	0.000	11	0.11	694.73	0.040	NA	52.2	34.5	67.5	0.054	0.040	3554
568	3	P4	1	404	694.690	0.070	9	0.09	694.78	0.190	NA	52.2	34.5	67.5	1.367	0.204	13292

569	3	P4	1	405	694.650	0.030	10	0.10	694.75	0.300	NA	52.2	34.5	67.5	3.024	0.303	23077
570	3	P4	2	412	694.190	0.000	60	0.60	694.79	0.670	0.350	52.2	34.5	67.5	4.580	0.277	310154
571	3	P4	2	413	694.350	0.160	30	0.30	694.65	0.540	0.300	52.2	34.5	67.5	4.337	0.315	124615
572	3	P4	2	414	694.490	0.300	14	0.14	694.63	0.180	NA	52.2	34.5	67.5	0.817	0.154	19385
573	3	P4	2	415	694.390	0.200	20	0.20	694.59	0.210	NA	52.2	34.5	67.5	0.854	0.150	32308
574	3	P4	3	416	694.370	0.000	30	0.30	694.67	0.500	0.250	52.2	34.5	67.5	3.689	0.290	114923
575	3	P4	3	417	694.430	0.060	20	0.20	694.63	0.300	NA	52.2	34.5	67.5	1.742	0.214	46154
576	3	P4	3	418	694.520	0.150	11	0.11	694.63	0.360	NA	52.2	34.5	67.5	3.997	0.347	30462
577	3	P4	3	420	694.550	0.180	10	0.10	694.65	0.000	NA	52.2	34.5	67.5	0.001	0.004	323
578	3	P4	4	425	694.090	0.410	11	0.11	694.20	0.230	NA	52.2	34.5	67.5	1.603	0.219	19292
579	3	P4	4	426	693.880	0.200	36	0.36	694.24	0.510	0.490	52.2	34.5	67.5	3.473	0.271	141231
580	3	P4	4	427	693.790	0.110	46	0.46	694.25	0.590	0.600	52.2	34.5	67.5	4.109	0.280	210185
581	3	P4	4	428	693.680	0.000	60	0.60	694.28	0.810	0.850	52.2	34.5	67.5	6.654	0.334	373846
582	3	P4	4	429	693.760	0.080	50	0.50	694.26	0.380	0.700	52.2	34.5	67.5	1.592	0.171	145385
583	3	P4	5	436	693.980	0.000	32	0.32	694.30	0.070	0.280	52.2	34.5	67.5	0.062	0.037	16246
584	3	P4	5	437	694.040	0.060	23	0.23	694.27	0.210	0.120	52.2	34.5	67.5	0.777	0.140	37154
585	3	P4	5	438	694.070	0.090	22	0.22	694.29	0.390	0.500	52.2	34.5	67.5	2.759	0.265	66000
586	3	P4	5	439	694.090	0.110	20	0.20	694.29	0.440	NA	52.2	34.5	67.5	3.817	0.317	68308
587	3	P4	5	440	694.020	0.040	29	0.29	694.31	0.490	0.750	52.2	34.5	67.5	3.587	0.288	108415
588	3	P4	5	441	694.120	0.140	16	0.16	694.28	0.080	NA	52.2	34.5	67.5	0.161	0.067	10338
589	3	P4	6	460	694.630	0.000	11	0.11	694.74	0.180	NA	52.2	34.5	67.5	0.999	0.173	15231
590	3	P4	7	466	694.100	0.000	9	0.09	694.19	0.060	NA	52.2	34.5	67.5	0.134	0.064	4154
591	3	P5	1	507	693.590	0.000	9	0.09	693.68	0.010	NA	42.2	35.8	72.3	0.006	0.013	831
592	3	P5	2	516	693.060	0.260	41	0.41	693.47	0.060	0.020	42.2	35.8	72.3	0.046	0.030	18923
593	3	P5	2	517	693.320	0.520	16	0.16	693.48	0.310	0.520	42.2	35.8	72.3	2.245	0.244	37662
594	3	P5	2	518	692.830	0.030	70	0.70	693.53	0.710	0.650	42.2	35.8	72.3	4.872	0.270	381231
595	3	P5	2	519	692.800	0.000	93	0.93	693.73	1.170	0.540	42.2	35.8	72.3	11.622	0.387	837000
596	3	P5	2	520	692.940	0.140	65	0.65	693.59	0.960	0.570	42.2	35.8	72.3	9.293	0.380	480000
597	3	P5	2	521	693.080	0.280	42	0.42	693.50	0.660	0.650	42.2	35.8	72.3	5.539	0.325	213231
598	3	P5	2	522	693.310	0.510	20	0.20	693.51	0.600	NA	42.2	35.8	72.3	7.315	0.428	92308
599	3	P5	2	523	693.380	0.580	20	0.20	693.58	0.670	NA	42.2	35.8	72.3	9.176	0.480	103385
600	3	P5	2	524	693.570	0.770	5	0.05	693.62	0.030	NA	42.2	35.8	72.3	0.071	0.043	1154
601	3	P5	3	538	693.920	0.000	25	0.25	694.17	0.110	0.030	42.2	35.8	72.3	0.203	0.069	20769
602	3	P5	4	544	693.820	0.000	10	0.10	693.92	0.040	NA	42.2	35.8	72.3	0.046	0.036	2769
603	3	P6	1	606	693.220	0.000	20	0.20	693.42	0.020	NA	43.3	35.6	65.5	0.005	0.011	2400
604	3	P6	2	616	692.800	0.160	40	0.40	693.20	0.330	0.300	43.3	35.6	65.5	1.347	0.167	101538
605	3	P6	2	617	692.640	0.000	57	0.57	693.21	0.630	0.060	43.3	35.6	65.5	4.068	0.266	276231
606	3	P6	2	618	692.640	0.000	55	0.55	693.19	1.020	0.250	43.3	35.6	65.5	10.859	0.439	431538
607	3	P6	2	619	692.680	0.040	51	0.51	693.19	0.620	0.850	43.3	35.6	65.5	4.225	0.279	244800
608	3	P6	2	620	692.820	0.180	35	0.35	693.17	0.630	0.630	43.3	35.6	65.5	5.293	0.340	169615
609	3	P6	2	621	692.880	0.240	28	0.28	693.16	0.590	0.570	43.3	35.6	65.5	5.267	0.355	126646
610	3	P6	2	622	692.850	0.210	30	0.30	693.15	0.340	0.500	43.3	35.6	65.5	1.708	0.199	78923
611	3	P6	3	632	693.210	0.000	20	0.20	693.41	0.030	NA	43.3	35.6	65.5	0.021	0.024	5077
612	3	P7	1	706	693.080	0.000	20	0.20	693.28	0.060	NA	62.7	33.5	85.2	0.083	0.043	9231
613	3	P7	2	718	692.560	0.220	40	0.40	692.96	0.820	0.760	62.7	33.5	85.2	9.723	0.415	252923
614	3	P7	2	719	692.470	0.130	45	0.45	692.92	1.040	1.030	62.7	33.5	85.2	14.633	0.497	361385
615	3	P7	2	720	692.480	0.140	40	0.40	692.88	0.830	1.075	62.7	33.5	85.2	9.866	0.418	254769
616	3	P7	2	721	692.340	0.000	61	0.61	692.95	0.790	0.760	62.7	33.5	85.2	7.007	0.321	368815
617	3	P7	2	722	692.430	0.090	48	0.48	692.91	0.760	0.520	62.7	33.5	85.2	7.513	0.351	281354
618	3	P7	2	723	692.730	0.390	20	0.20	692.93	0.350	NA	62.7	33.5	85.2	2.872	0.253	54462
619	3	P7	2	724	692.770	0.430	20	0.20	692.97	0.070	NA	62.7	33.5	85.2	0.100	0.047	10154
620	3	P7	3	732	692.880	0.000	21	0.21	693.09	0.000	NA	62.7	33.5	85.2	0.000	0.000	0
621	3	P8	1	804	692.060	0.000	27	0.27	692.33	0.290	0.170	57.0	34.0	81.5	1.551	0.181	61062
622	3	P8	2	830	691.860	0.160	45	0.45	692.31	0.320	0.410	57.0	34.0	81.5	1.323	0.151	110077
623	3	P8	2	831	691.700	0.000	60	0.60	692.30	0.910	0.900	57.0	34.0	81.5	9.295	0.376	420923
624	3	P8	2	832	691.730	0.030	62	0.62	692.35	0.730	0.520	57.0	34.0	81.5	5.790	0.294	346246
625	3	P8	2	833	691.820	0.120	55	0.55	692.37	0.680	0.250	57.0	34.0	81.5	5.381	0.292	286846

626	3	P8	2	834	691.860	0.160	45	0.45	692.31	0.720	0.820	57.0	34.0	81.5	6.785	0.343	249231
627	3	P8	2	835	692.030	0.330	28	0.28	692.31	0.580	1.020	57.0	34.0	81.5	5.932	0.351	125354
628	3	P8	2	836	691.970	0.270	41	0.41	692.38	0.430	0.140	57.0	34.0	81.5	2.507	0.212	134354
629	3	P8	3	842	692.060	0.050	11	0.11	692.17	0.000	NA	57.0	34.0	81.5	0.000	0.002	152
630	3	P8	3	843	692.010	0.000	15	0.15	692.16	0.060	NA	57.0	34.0	81.5	0.100	0.049	6923
631	3	P9	1	924	691.520	0.400	30	0.30	691.82	0.790	1.050	51.9	34.5	76.5	10.084	0.462	182769
632	3	P9	1	925	691.400	0.280	40	0.40	691.80	0.400	0.520	51.9	34.5	76.5	2.118	0.200	121846
633	3	P9	1	926	691.260	0.140	55	0.55	691.81	1.360	0.200	51.9	34.5	76.5	20.808	0.584	573692
634	3	P9	1	927	691.300	0.180	50	0.50	691.80	1.050	1.210	51.9	34.5	76.5	13.133	0.474	403846
635	3	P9	1	928	691.120	0.000	68	0.68	691.80	0.350	0.410	51.9	34.5	76.5	1.228	0.135	182031
636	3	P9	1	929	691.240	0.120	55	0.55	691.79	0.220	0.500	51.9	34.5	76.5	0.558	0.096	93923
637	3	P9	1	930	691.330	0.210	50	0.50	691.83	0.350	0.029	51.9	34.5	76.5	1.493	0.160	136154
638	3	P10	1	1005	691.700	0.000	10	0.10	691.80	0.050	NA	56.5	34.1	71.7	0.099	0.053	4062
639	3	P10	2	1029	691.240	0.390	23	0.23	691.47	0.240	0.310	56.5	34.1	71.7	1.056	0.160	42462
640	3	P10	2	1030	691.140	0.290	40	0.40	691.54	0.510	0.300	56.5	34.1	71.7	3.384	0.257	156923
641	3	P10	2	1031	691.020	0.170	51	0.51	691.53	0.640	0.260	56.5	34.1	71.7	4.604	0.284	249508
642	3	P10	2	1032	691.000	0.150	57	0.57	691.57	0.770	0.310	56.5	34.1	71.7	6.431	0.327	339369
643	3	P10	2	1033	690.960	0.110	62	0.62	691.58	0.740	0.780	56.5	34.1	71.7	5.692	0.302	354831
644	3	P10	2	1034	691.010	0.160	53	0.53	691.54	0.470	0.530	56.5	34.1	71.7	2.442	0.205	190800
645	3	P10	2	1035	690.850	0.000	78	0.78	691.63	0.200	0.060	56.5	34.1	71.7	0.382	0.074	122400
646	3	P11	1	1107	691.080	0.040	15	0.15	691.23	0.290	NA	44.6	35.4	70.0	2.039	0.237	33231
647	3	P11	1	1108	691.040	0.000	20	0.20	691.24	0.180	NA	44.6	35.4	70.0	0.643	0.129	27692
648	3	P11	1	1109	691.040	0.000	26	0.26	691.30	0.450	0.480	44.6	35.4	70.0	3.370	0.282	90000
649	3	P11	2	1130	691.180	0.400	20	0.20	691.38	0.220	NA	44.6	35.4	70.0	0.979	0.158	34154
650	3	P11	2	1131	690.990	0.210	38	0.38	691.37	0.430	0.360	44.6	35.4	70.0	2.398	0.221	124523
651	3	P11	2	1132	691.060	0.280	34	0.34	691.40	0.660	0.770	44.6	35.4	70.0	6.143	0.361	172615
652	3	P11	2	1133	691.040	0.260	28	0.28	691.32	0.560	0.780	44.6	35.4	70.0	5.050	0.340	121477
653	3	P11	2	1134	690.940	0.160	48	0.48	691.42	0.490	0.340	44.6	35.4	70.0	2.809	0.227	181662
654	3	P11	2	1135	690.890	0.110	50	0.50	691.39	0.690	0.730	44.6	35.4	70.0	5.406	0.312	265385
655	3	P11	2	1136	690.780	0.000	60	0.60	691.38	0.610	0.720	44.6	35.4	70.0	3.793	0.250	279692
656	3	P11	2	1137	690.900	0.120	50	0.50	691.40	0.160	-0.220	44.6	35.4	70.0	0.298	0.073	62308
657	3	P12	1	1206	690.990	0.090	9	0.09	691.08	0.110	NA	73.5	32.6	94.6	0.687	0.121	7892
658	3	P12	1	1207	690.900	0.000	20	0.20	691.10	0.280	NA	73.5	32.6	94.6	1.976	0.201	43385
659	3	P12	1	1208	690.910	0.010	19	0.19	691.10	0.260	NA	73.5	32.6	94.6	1.804	0.193	38585
660	3	P12	2	1227	690.740	0.040	42	0.42	691.16	0.110	0.140	73.5	32.6	94.6	0.174	0.053	34892
661	3	P12	2	1228	690.710	0.010	48	0.48	691.19	0.720	0.590	73.5	32.6	94.6	7.124	0.332	265846
662	3	P12	2	1229	690.700	0.000	53	0.53	691.23	0.850	1.080	73.5	32.6	94.6	9.289	0.371	344908
663	3	P12	2	1230	690.720	0.020	47	0.47	691.19	0.810	1.200	73.5	32.6	94.6	9.129	0.377	292846
664	3	P12	2	1231	690.830	0.130	37	0.37	691.20	0.600	0.340	73.5	32.6	94.6	5.797	0.315	170769
665	3	P12	2	1232	690.900	0.200	30	0.30	691.20	0.680	0.990	73.5	32.6	94.6	8.494	0.395	156462
666	3	P12	2	1233	690.810	0.110	38	0.38	691.19	0.520	0.450	73.5	32.6	94.6	4.315	0.270	152585
667	3	P12	2	1234	690.850	0.150	36	0.36	691.21	0.380	0.170	73.5	32.6	94.6	2.416	0.204	106338
668	3	P13	1	1314	690.570	0.000	20	0.20	690.77	0.360	NA	64.0	33.4	81.9	2.884	0.257	55385
669	3	P13	1	1315	690.640	0.070	15	0.15	690.79	0.190	NA	64.0	33.4	81.9	1.029	0.158	22154
670	3	P13	1	1316	690.650	0.080	8	0.08	690.73	0.060	NA	64.0	33.4	81.9	0.185	0.068	3692
671	3	P13	2	1326	690.560	0.000	6	0.06	690.62	0.090	NA	64.0	33.4	81.9	0.593	0.117	4154
672	3	P13	3	1334	690.670	0.190	28	0.28	690.95	0.370	0.200	64.0	33.4	81.9	2.431	0.224	80123
673	3	P13	3	1335	690.540	0.060	43	0.43	690.97	0.680	0.790	64.0	33.4	81.9	6.193	0.330	224262
674	3	P13	3	1336	690.520	0.040	46	0.46	690.98	0.700	0.780	64.0	33.4	81.9	6.278	0.328	246277
675	3	P13	3	1337	690.480	0.000	50	0.50	690.98	0.700	0.570	64.0	33.4	81.9	6.095	0.317	270000
676	3	P13	3	1338	690.600	0.120	37	0.37	690.97	0.850	0.730	64.0	33.4	81.9	10.541	0.444	240785
677	3	P13	3	1339	690.580	0.100	32	0.32	690.90	0.310	0.320	64.0	33.4	81.9	1.509	0.173	75323
678	3	P14	1	1408	690.310	0.000	20	0.20	690.51	0.200	NA	51.3	34.6	78.9	0.849	0.141	30462
679	3	P14	1	1409	690.340	0.030	16	0.16	690.50	0.230	NA	51.3	34.6	78.9	1.406	0.187	28800
680	3	P14	2	1419	690.080	0.060	20	0.20	690.28	0.010	NA	51.3	34.6	78.9	0.003	0.009	1846
681	3	P14	2	1420	690.020	0.000	32	0.32	690.34	0.010	0.007	51.3	34.6	78.9	0.003	0.008	3545

682	3	P14	3	1427	690.450	0.700	20	0.20	690.65	0.220	NA	51.3	34.6	78.9	1.010	0.154	33231
683	3	P14	3	1428	690.440	0.690	25	0.25	690.69	0.420	0.590	51.3	34.6	78.9	3.261	0.268	80769
684	3	P14	3	1429	690.470	0.720	20	0.20	690.67	0.260	NA	51.3	34.6	78.9	1.441	0.184	39692
685	3	P14	3	1430	690.500	0.750	20	0.20	690.70	0.430	NA	51.3	34.6	78.9	3.928	0.304	65538
686	3	P14	3	1431	690.380	0.630	35	0.35	690.73	0.530	0.690	51.3	34.6	78.9	4.246	0.288	143769
687	3	P14	3	1432	690.000	0.250	70	0.70	690.70	0.530	0.420	51.3	34.6	78.9	2.830	0.201	284308
688	3	P14	3	1433	689.750	0.000	90	0.90	690.65	0.860	1.370	51.3	34.6	78.9	6.610	0.289	594000
689	3	P15	1	1507	690.240	0.000	11	0.11	690.35	0.020	NA	33.5	37.2	51.0	0.012	0.021	1878
690	3	P15	2	1511	690.540	0.820	30	0.30	690.84	0.090	0.160	33.5	37.2	51.0	0.102	0.052	20769
691	3	P15	2	1512	690.240	0.520	25	0.25	690.49	0.250	0.350	33.5	37.2	51.0	0.891	0.161	48462
692	3	P15	2	1513	690.320	0.600	25	0.25	690.57	0.310	0.130	33.5	37.2	51.0	1.313	0.195	58846
693	3	P15	2	1514	690.340	0.620	29	0.29	690.63	0.230	0.070	33.5	37.2	51.0	0.705	0.139	52200
694	3	P15	2	1516	690.180	0.460	44	0.44	690.62	0.250	0.140	33.5	37.2	51.0	0.623	0.118	83262
695	3	P15	2	1517	690.040	0.320	58	0.58	690.62	0.500	0.290	33.5	37.2	51.0	2.284	0.211	224862
696	3	P15	2	1518	689.720	0.000	84	0.84	690.56	0.480	1.120	33.5	37.2	51.0	1.751	0.167	310154
697	3	P15	2	1519	689.760	0.040	70	0.70	690.46	0.080	0.230	33.5	37.2	51.0	0.058	0.032	45231
698	3	P15	2	1520	689.860	0.140	84	0.84	690.70	0.210	0.350	33.5	37.2	51.0	0.335	0.073	135692
699	3	P16	1	1601	690.160	0.000	12	0.12	690.28	0.010	NA	35.0	36.9	53.6	0.001	0.006	554
700	3	P16	2	1613	689.960	0.140	19	0.19	690.15	0.000	NA	35.0	36.9	53.6	0.000	0.001	263
701	3	P16	2	1614	689.840	0.020	20	0.20	690.04	0.090	NA	35.0	36.9	53.6	0.134	0.064	13846
702	3	P16	2	1615	689.820	0.000	20	0.20	690.02	0.130	NA	35.0	36.9	53.6	0.263	0.090	19385
703	3	P16	3	1620	690.020	0.000	20	0.20	690.22	0.320	NA	35.0	36.9	53.6	1.678	0.227	48923
704	3	P16	3	1621	690.030	0.010	20	0.20	690.23	0.500	NA	35.0	36.9	53.6	4.116	0.356	76615
705	3	P16	4	1626	690.400	0.600	9	0.09	690.49	0.050	NA	35.0	36.9	53.6	0.061	0.048	3115
706	3	P16	4	1627	690.320	0.520	17	0.17	690.49	0.310	NA	35.0	36.9	53.6	1.799	0.242	40800
707	3	P16	4	1628	690.260	0.460	25	0.25	690.51	0.410	0.570	35.0	36.9	53.6	2.405	0.261	78462
708	3	P16	4	1629	690.200	0.400	32	0.32	690.52	0.500	0.530	35.0	36.9	53.6	3.106	0.281	122585
709	3	P16	4	1630	690.070	0.270	48	0.48	690.55	0.470	0.370	35.0	36.9	53.6	2.213	0.216	172800
710	3	P16	4	1631	690.020	0.220	48	0.48	690.50	0.550	0.400	35.0	36.9	53.6	3.078	0.254	203815
711	3	P16	4	1632	690.170	0.370	39	0.39	690.56	0.530	0.630	35.0	36.9	53.6	3.135	0.270	158400
712	3	P16	4	1633	690.000	0.200	50	0.50	690.50	0.320	0.160	35.0	36.9	53.6	1.039	0.146	124615
713	3	P16	4	1634	689.800	0.000	70	0.70	690.50	0.230	0.220	35.0	36.9	53.6	0.438	0.087	122769
714	3	P16	4	1635	689.960	0.160	52	0.52	690.48	0.110	0.120	35.0	36.9	53.6	0.113	0.048	43200
715	3	P17	1	1707	689.680	0.020	26	0.26	689.94	0.090	0.110	53.6	34.4	71.7	0.137	0.056	18000
716	3	P17	1	1708	689.660	0.000	38	0.38	690.04	0.370	0.350	53.6	34.4	71.7	1.795	0.190	106985
717	3	P17	1	1709	689.780	0.120	17	0.17	689.95	0.220	NA	53.6	34.4	71.7	1.121	0.172	29031
718	3	P17	3	1713	689.870	0.000	32	0.32	690.19	0.670	0.970	53.6	34.4	71.7	6.700	0.379	165415
719	3	P17	3	1714	689.910	0.040	30	0.30	690.21	0.430	0.640	53.6	34.4	71.7	2.801	0.248	98308
720	3	P17	3	1715	689.930	0.060	35	0.35	690.28	0.650	0.620	53.6	34.4	71.7	5.904	0.350	174462
721	3	P17	3	1716	689.980	0.110	31	0.31	690.29	0.590	0.730	53.6	34.4	71.7	5.230	0.337	140215
722	3	P17	3	1717	689.980	0.110	29	0.29	690.27	0.620	0.150	53.6	34.4	71.7	6.139	0.370	139200
723	3	P17	3	1718	690.070	0.200	26	0.26	690.33	0.560	0.560	53.6	34.4	71.7	5.264	0.349	111600
724	3	P17	3	1719	690.120	0.250	20	0.20	690.32	0.300	NA	53.6	34.4	71.7	1.818	0.214	46154
725	3	P17	4	1724	690.130	0.340	20	0.20	690.33	0.300	NA	53.6	34.4	71.7	1.818	0.214	46154
726	3	P17	4	1725	689.830	0.040	53	0.53	690.36	0.590	0.280	53.6	34.4	71.7	3.855	0.258	239723
727	3	P17	4	1726	689.820	0.030	55	0.55	690.37	0.010	0.007	53.6	34.4	71.7	0.002	0.005	5077
728	3	P17	4	1727	689.790	0.000	52	0.52	690.31	0.460	0.007	53.6	34.4	71.7	2.342	0.202	182400
729	3	P18	1	1803	689.340	0.000	36	0.36	689.70	0.070	0.120	43.9	35.5	67.7	0.069	0.038	19938
730	3	P18	2	1809	689.440	0.260	30	0.30	689.74	0.670	0.470	43.9	35.5	67.7	6.610	0.388	153692
731	3	P18	2	1810	689.370	0.190	42	0.42	689.79	0.780	0.860	43.9	35.5	67.7	7.458	0.384	252000
732	3	P18	2	1811	689.180	0.000	65	0.65	689.83	0.790	1.020	43.9	35.5	67.7	6.029	0.311	393000
733	3	P18	2	1812	689.320	0.140	50	0.50	689.82	0.720	0.810	43.9	35.5	67.7	5.783	0.325	276923
734	3	P18	2	1813	689.410	0.230	35	0.35	689.76	0.480	0.620	43.9	35.5	67.7	3.132	0.259	129231
735	3	P18	2	1814	689.710	0.530	13	0.13	689.84	0.180	NA	43.9	35.5	67.7	0.870	0.159	18000
736	3	P18	2	1815	689.760	0.580	15	0.15	689.91	0.330	NA	43.9	35.5	67.7	2.609	0.272	38077
737	3	P18	2	1816	689.820	0.640	15	0.15	689.97	0.310	NA	43.9	35.5	67.7	2.332	0.257	36000
738	3	P18	2	1817	689.770	0.590	20	0.20	689.97	0.200	NA	43.9	35.5	67.7	0.761	0.141	30462

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739    3    P18   2    1818   689.920 0.740  20    0.20    690.12 0.310  NA     43.9  35.5  67.7   1.889  0.223  48000
740    3    P18   3    1825   689.900 0.000  32    0.32    690.22 0.470  0.290  43.9  35.5  67.7   3.139  0.264  115200
741    3    P18   3    1826   690.070 0.170  16    0.16    690.23 0.340  NA     43.9  35.5  67.7   2.574  0.268  41354
742    3    P18   3    1827   689.920 0.020  32    0.32    690.24 0.480  0.560  43.9  35.5  67.7   3.302  0.271  118154
743    3    P18   3    1828   690.090 0.190  5     0.05    690.14 0.150  NA     43.9  35.5  67.7   1.628  0.214  5769
744    3    P18   3    1829   689.990 0.090  20    0.20    690.19 0.110  NA     43.9  35.5  67.7   0.252  0.081  17538
745    3    P19   1    1901   689.080 0.070  43    0.43    689.51 0.410  0.060  47.0  35.1  60.0   1.943  0.202  136938
746    3    P19   1    1902   689.020 0.010  55    0.55    689.57 0.470  0.250  47.0  35.1  60.0   2.244  0.204  200538
747    3    P19   1    1903   689.010 0.000  55    0.55    689.56 0.540  0.460  47.0  35.1  60.0   2.912  0.232  228462
748    3    P19   1    1904   689.080 0.070  49    0.49    689.57 0.680  0.850  47.0  35.1  60.0   4.867  0.309  255554
749    3    P19   1    1905   689.160 0.150  40    0.40    689.56 0.570  0.880  47.0  35.1  60.0   3.829  0.288  175385
750    3    P19   1    1906   689.400 0.390  12    0.12    689.52 0.050  NA     47.0  35.1  60.0   0.060  0.044  4431
751    3    P19   1    1907   689.530 0.520  10    0.10    689.63 0.030  NA     47.0  35.1  60.0   0.027  0.030  2308
752    3    P19   1    1908   689.530 0.520  13    0.13    689.66 0.180  NA     47.0  35.1  60.0   0.790  0.159  18000
753    3    P19   2    1916   689.770 0.050  16    0.16    689.93 0.070  NA     47.0  35.1  60.0   0.108  0.057  8862
754    3    P19   2    1917   689.850 0.130  18    0.18    690.03 0.010  NA     47.0  35.1  60.0   0.001  0.005  831
755    3    P19   2    1918   689.860 0.140  17    0.17    690.03 0.200  NA     47.0  35.1  60.0   0.783  0.153  25892
756    3    P19   2    1919   689.830 0.110  20    0.20    690.03 0.400  NA     47.0  35.1  60.0   2.888  0.287  61846
757    3    P19   2    1920   689.720 0.000  28    0.28    690.00 0.360  0.540  47.0  35.1  60.0   1.872  0.217  77538
758    3    P19   2    1921   689.840 0.120  15    0.15    689.99 0.370  NA     47.0  35.1  60.0   2.929  0.302  42231
759    3    P19   2    1922   689.820 0.100  17    0.17    689.99 0.430  NA     47.0  35.1  60.0   3.728  0.335  56492
760    4    P1    1    112    558.200 0.660  52    0.52    558.72 0.000  NA     75.6  32.4  98.2   0.000  0.000  0
761    4    P1    1    113    558.290 0.750  43    0.43    558.72 0.000  NA     75.6  32.4  98.2   0.000  0.000  0
762    4    P1    1    114    557.930 0.390  78    0.78    558.71 0.040  0.150  75.6  32.4  98.2   0.017  0.014  24000
763    4    P1    1    115    557.680 0.140  105   01. Mai 558.73 0.670  0.260  75.6  32.4  98.2   4.156  0.209  541154
764    4    P1    1    116    557.540 0.000  120   Jan 20  558.74 1.100  0.620  75.6  32.4  98.2   10.517 0.321  1015385
766    4    P2    1    215    558.060 0.210  39    0.39    558.45 1.070  0.920  82.7  32.0  106.5  19.232 0.547  321000
767    4    P2    1    216    557.960 0.110  48    0.48    558.44 0.820  0.420  82.7  32.0  106.5  9.917  0.378  302769
768    4    P2    1    217    557.850 0.000  59    0.59    558.44 1.220  0.670  82.7  32.0  106.5  19.443 0.507  553692
769    4    P2    1    218    557.880 0.030  60    0.60    558.48 1.170  0.450  82.7  32.0  106.5  17.711 0.482  540000
770    4    P2    1    219    557.850 0.000  61    0.61    558.46 1.290  0.860  82.7  32.0  106.5  21.330 0.527  605308
771    4    P2    1    220    557.890 0.040  51    0.51    558.40 1.090  0.670  82.7  32.0  106.5  16.896 0.487  427615
772    4    P2    1    221    557.860 0.010  50    0.50    558.36 1.100  0.400  82.7  32.0  106.5  17.412 0.497  423077
773    4    P2    1    223    558.010 0.160  37    0.37    558.38 0.550  0.430  82.7  32.0  106.5  5.259  0.289  156538
774    4    P2    1    223    558.010 0.160  46    0.46    558.47 0.000  0.430  82.7  32.0  106.5  0.000  0.000  0
775    4    P3    1    311    558.130 0.570  14    0.14    558.27 0.150  NA     72.6  32.7  97.9   0.781  0.128  16154
776    4    P3    1    312    557.790 0.230  50    0.50    558.29 0.520  0.080  72.6  32.7  97.9   3.702  0.235  200000
777    4    P3    1    313    557.660 0.100  65    0.65    558.31 0.780  0.390  72.6  32.7  97.9   7.185  0.309  390000
778    4    P3    1    314    557.610 0.050  68    0.68    558.29 0.870  0.420  72.6  32.7  97.9   8.724  0.337  455077
779    4    P3    1    315    557.640 0.080  69    0.69    558.33 0.990  0.690  72.6  32.7  97.9   11.209 0.381  525462
780    4    P3    1    316    557.660 0.100  68    0.68    558.34 0.940  0.650  72.6  32.7  97.9   10.184 0.364  491692
781    4    P3    1    317    557.660 0.100  68    0.68    558.34 0.860  0.300  72.6  32.7  97.9   8.525  0.333  449846
782    4    P3    1    318    557.730 0.170  64    0.64    558.37 0.940  0.240  72.6  32.7  97.9   10.524 0.375  462769
783    4    P3    1    319    557.680 0.120  66    0.66    558.34 0.750  0.360  72.6  32.7  97.9   6.588  0.295  380769
784    4    P3    1    320    557.560 0.000  75    0.75    558.31 0.150  0.130  72.6  32.7  97.9   0.246  0.055  86538
785    4    P4    1    406    558.350 0.840  30    0.30    558.65 0.190  0.160  64.0  33.4  80.3   0.599  0.111  43846
786    4    P4    1    407    557.780 0.270  50    0.50    558.28 0.440  0.260  64.0  33.4  80.3   2.369  0.199  169231
787    4    P4    1    408    557.640 0.130  60    0.60    558.24 0.550  0.340  64.0  33.4  80.3   3.355  0.227  253846
788    4    P4    1    409    557.660 0.150  62    0.62    558.28 0.750  0.360  64.0  33.4  80.3   6.132  0.304  357692
789    4    P4    1    410    557.620 0.110  69    0.69    558.31 0.780  0.500  64.0  33.4  80.3   6.277  0.300  414000
790    4    P4    1    411    557.580 0.070  69    0.69    558.27 0.600  0.340  64.0  33.4  80.3   3.714  0.231  318462
791    4    P4    1    412    557.600 0.090  67    0.67    558.27 0.750  0.410  64.0  33.4  80.3   5.891  0.293  386538
792    4    P4    1    413    557.510 0.000  80    0.80    558.31 0.660  0.180  64.0  33.4  80.3   4.175  0.236  406154
793    4    P4    1    414    557.520 0.010  72    0.72    558.24 0.420  0.340  64.0  33.4  80.3   1.781  0.158  232615
794    4    P5    1    503    557.960 0.240  11    0.11    558.07 0.300  NA     68.4  33.0  81.8   3.311  0.289  25385
795    4    P5    1    504    557.980 0.260  12    0.12    558.10 0.210  NA     68.4  33.0  81.8   1.495  0.194  19385
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796	4	P5	1	506	557.860	0.140	26	0.26	558.12	0.440	0.290	68.4	33.0	81.8	3.572	0.276	88000
797	4	P5	1	507	557.780	0.060	38	0.38	558.16	0.920	0.690	68.4	33.0	81.8	12.259	0.476	268923
798	4	P5	1	508	557.750	0.030	39	0.39	558.14	0.900	0.410	68.4	33.0	81.8	11.550	0.460	270000
799	4	P5	1	509	557.780	0.060	34	0.34	558.12	0.620	0.390	68.4	33.0	81.8	5.959	0.339	162154
800	4	P5	1	510	557.860	0.140	29	0.29	558.15	0.900	0.780	68.4	33.0	81.8	13.897	0.534	200769
801	4	P5	1	513	557.780	0.060	35	0.35	558.13	0.940	0.710	68.4	33.0	81.8	13.454	0.507	253077
802	4	P5	1	514	557.810	0.090	33	0.33	558.14	0.950	0.510	68.4	33.0	81.8	14.254	0.528	241154
803	4	P5	1	515	557.830	0.110	37	0.37	558.20	1.110	0.730	68.4	33.0	81.8	18.134	0.583	315923
804	4	P5	1	516	557.820	0.100	36	0.36	558.18	1.120	0.920	68.4	33.0	81.8	18.773	0.596	310154
805	4	P5	1	517	557.770	0.050	37	0.37	558.14	0.990	0.660	68.4	33.0	81.8	14.425	0.520	281769
806	4	P5	1	518	557.720	0.000	45	0.45	558.17	0.810	0.220	68.4	33.0	81.8	8.606	0.386	280385
807	4	P5	1	519	558.030	0.310	15	0.15	558.18	0.440	NA	68.4	33.0	81.8	5.399	0.363	50769
808	4	P6	1	603	557.690	0.150	26	0.26	557.95	0.490	0.150	59.5	33.8	74.1	4.148	0.307	98000
809	4	P6	1	604	557.570	0.030	38	0.38	557.95	0.930	0.460	59.5	33.8	74.1	11.817	0.482	271846
810	4	P6	1	605	557.610	0.070	35	0.35	557.96	1.190	0.910	59.5	33.8	74.1	20.311	0.642	320385
811	4	P6	1	606	557.560	0.020	39	0.39	557.95	0.920	0.750	59.5	33.8	74.1	11.390	0.470	276000
812	4	P6	1	607	557.640	0.100	30	0.30	557.94	1.060	0.750	59.5	33.8	74.1	17.711	0.618	244615
813	4	P6	1	608	557.740	0.200	27	0.27	558.01	0.920	0.720	59.5	33.8	74.1	14.268	0.565	191077
814	4	P6	1	609	557.740	0.200	25	0.25	557.99	0.820	0.240	59.5	33.8	74.1	11.923	0.524	157692
815	4	P6	1	610	557.710	0.170	22	0.22	557.93	0.670	0.520	59.5	33.8	74.1	8.682	0.456	113385
816	4	P6	1	611	557.670	0.130	30	0.30	557.97	0.720	0.500	59.5	33.8	74.1	8.171	0.420	166154
817	4	P6	1	612	557.610	0.070	34	0.34	557.95	0.930	0.590	59.5	33.8	74.1	12.623	0.509	243231
818	4	P6	1	613	557.540	0.000	25	0.25	557.79	0.530	0.420	59.5	33.8	74.1	4.981	0.338	101923
819	4	P6	1	614	557.620	0.080	24	0.24	557.86	0.200	0.150	59.5	33.8	74.1	0.729	0.130	36923
820	4	P7	1	704	557.310	0.260	32	0.32	557.63	0.250	0.990	72.3	32.7	83.9	1.023	0.141	61538
821	4	P7	1	705	557.170	0.120	50	0.50	557.67	0.290	0.870	72.3	32.7	83.9	1.054	0.131	111538
822	4	P7	1	706	557.050	0.000	56	0.56	557.61	0.540	1.240	72.3	32.7	83.9	3.434	0.230	232615
823	4	P7	1	707	557.140	0.090	50	0.50	557.64	0.330	0.800	72.3	32.7	83.9	1.365	0.149	126923
824	4	P7	1	708	557.230	0.180	40	0.40	557.63	0.100	0.810	72.3	32.7	83.9	0.143	0.050	30769
825	4	P7	1	709	557.310	0.260	32	0.32	557.63	1.040	0.870	72.3	32.7	83.9	17.701	0.587	256000
826	4	P7	1	710	557.460	0.410	19	0.19	557.65	0.510	NA	72.3	32.7	83.9	6.128	0.374	74538
827	4	P7	1	711	557.550	0.500	11	0.11	557.66	0.290	NA	72.3	32.7	83.9	3.170	0.279	24538
828	4	P7	1	712	557.610	0.560	11	0.11	557.72	0.330	NA	72.3	32.7	83.9	4.105	0.318	27923
829	4	P7	2	716	557.560	0.000	29	0.29	557.85	0.330	0.140	72.3	32.7	83.9	1.900	0.196	73615
830	4	P7	2	717	557.710	0.150	14	0.14	557.85	0.050	NA	72.3	32.7	83.9	0.076	0.043	5385
831	4	P8	1	804	556.450	0.060	46	0.46	556.91	1.070	0.320	70.3	32.8	93.4	16.017	0.504	378615
832	4	P8	1	805	556.460	0.070	57	0.57	557.03	1.600	1.060	70.3	32.8	93.4	31.676	0.677	701538
833	4	P8	1	806	556.510	0.120	50	0.50	557.01	1.120	0.680	70.3	32.8	93.4	16.716	0.506	430769
834	4	P8	1	808	556.390	0.000	63	0.63	557.02	1.630	1.230	70.3	32.8	93.4	31.120	0.656	789923
835	4	P8	1	809	556.430	0.040	60	0.60	557.03	1.490	0.910	70.3	32.8	93.4	26.704	0.614	687692
836	4	P8	1	810	556.400	0.010	63	0.63	557.03	1.060	0.430	70.3	32.8	93.4	13.161	0.426	513692
837	4	P8	1	811	556.520	0.130	49	0.49	557.01	0.800	0.570	70.3	32.8	93.4	8.629	0.365	301538
838	4	P8	1	812	556.660	0.270	35	0.35	557.01	0.560	0.330	70.3	32.8	93.4	5.192	0.302	150769
839	4	P8	1	813	556.810	0.420	17	0.17	556.98	0.050	NA	70.3	32.8	93.4	0.070	0.039	6538
840	4	P9	1	901	556.560	1.100	20	0.20	556.76	0.610	NA	56.5	34.1	72.0	7.542	0.435	93846
841	4	P9	1	902	556.010	0.550	76	0.76	556.77	1.010	0.380	56.5	34.1	72.0	9.509	0.370	590462
842	4	P9	1	9021	555.760	0.300	102	01. Feb	556.78	1.250	0.190	56.5	34.1	72.0	12.699	0.395	980769
843	4	P9	1	9022	555.460	0.000	130	Jan 30	556.76	0.038	0.005	56.5	34.1	72.0	0.011	0.011	38000
844	4	P9	1	903	556.000	0.540	75	0.75	556.75	0.007	0.006	56.5	34.1	72.0	0.000	0.003	4038
845	4	P9	1	904	556.300	0.840	40	0.40	556.70	0.007	0.007	56.5	34.1	72.0	0.001	0.004	2154
846	4	P9	1	905	556.540	1.080	17	0.17	556.71	0.030	NA	56.5	34.1	72.0	0.021	0.023	3923
847	4	P10	1	1005	556.210	0.350	24	0.24	556.45	0.720	0.510	64.9	33.3	91.2	10.917	0.469	132923
848	4	P10	1	1006	556.090	0.230	32	0.32	556.41	1.220	0.660	64.9	33.3	91.2	25.706	0.689	300308
849	4	P10	1	1007	556.020	0.160	43	0.43	556.45	1.480	0.930	64.9	33.3	91.2	31.438	0.721	489538
850	4	P10	1	1008	555.920	0.060	57	0.57	556.49	1.500	1.240	64.9	33.3	91.2	27.466	0.634	657692
851	4	P10	1	1009	555.860	0.000	60	0.60	556.46	1.560	1.140	64.9	33.3	91.2	28.884	0.643	720000
852	4	P10	1	1010	556.040	0.180	45	0.45	556.49	1.320	0.760	64.9	33.3	91.2	24.341	0.628	456923

853	4	P10	1	1011	556.140	0.280	38	0.38	556.52	1.140	0.700	64.9	33.3	91.2	20.113	0.590	333231
854	4	P10	1	1012	556.330	0.470	18	0.18	556.51	0.240	NA	64.9	33.3	91.2	1.512	0.181	33231
855	4	P11	1	1102	555.440	0.000	75	0.75	556.19	0.060	0.030	58.1	33.9	81.3	0.036	0.022	34615
856	4	P11	1	1100	555.440	0.000	75	0.75	556.94	0.003	0.010	58.1	33.9	81.3	0.000	0.001	1731
857	4	P11	1	1103	555.700	0.260	45	0.45	556.15	0.760	0.490	58.1	33.9	81.3	7.549	0.362	263077
858	4	P11	1	1104	555.820	0.380	35	0.35	556.17	0.630	0.490	58.1	33.9	81.3	6.020	0.340	169615
859	4	P11	1	1105	555.730	0.290	43	0.43	556.16	1.150	0.740	58.1	33.9	81.3	17.743	0.560	380385
860	4	P11	1	1106	555.740	0.300	45	0.45	556.19	1.120	0.760	58.1	33.9	81.3	16.395	0.533	387692
861	4	P11	1	1107	555.570	0.130	61	0.61	556.18	1.450	0.560	58.1	33.9	81.3	23.263	0.593	680385
862	4	P11	1	1108	555.530	0.090	67	0.67	556.20	1.230	0.900	58.1	33.9	81.3	15.944	0.480	633923
863	4	P11	1	1109	555.650	0.210	50	0.50	556.15	0.560	0.070	58.1	33.9	81.3	3.863	0.253	215385
864	4	P11	1	1110	555.920	0.480	22	0.22	556.14	0.270	NA	58.1	33.9	81.3	1.505	0.184	45692
865	4	P12	1	1200	556.100	1.100	30	0.30	556.40	0.560	0.390	67.3	33.1	81.9	5.268	0.326	129231
866	4	P12	1	1202	555.470	0.470	64	0.64	556.52	0.550	0.350	67.3	33.1	81.9	2.573	0.171	444231
867	4	P12	1	1201	555.000	0.000	105	01. Mai	555.64	0.560	0.100	67.3	33.1	81.9	3.397	0.223	275692
868	4	P12	1	1203	555.610	0.610	50	0.50	556.11	0.520	0.270	67.3	33.1	81.9	3.345	0.235	200000
869	4	P12	1	1204	555.630	0.630	48	0.48	556.11	0.670	0.400	67.3	33.1	81.9	5.681	0.309	247385
870	4	P12	1	1205	555.600	0.600	52	0.52	556.12	0.690	0.620	67.3	33.1	81.9	5.763	0.306	276000
871	4	P12	1	1206	555.660	0.660	48	0.48	556.14	0.700	0.090	67.3	33.1	81.9	6.201	0.323	258462
872	4	P12	1	1207	555.640	0.640	45	0.45	556.09	0.620	0.300	67.3	33.1	81.9	5.046	0.295	214615
873	4	P12	1	1208	555.630	0.630	48	0.48	556.11	0.600	0.330	67.3	33.1	81.9	4.556	0.277	221538
874	4	P12	1	1209	555.660	0.660	45	0.45	556.11	0.490	0.370	67.3	33.1	81.9	3.152	0.233	169615
875	4	P12	1	1210	555.820	0.820	29	0.29	556.11	0.310	0.350	67.3	33.1	81.9	1.650	0.184	69154
876	4	P13	1	1300	555.540	0.280	38	0.38	555.92	1.660	0.700	51.1	34.6	69.1	36.160	0.860	485231
877	4	P13	1	1301	555.260	0.000	65	0.65	555.91	1.610	1.210	51.1	34.6	69.1	25.562	0.638	805000
878	4	P13	1	1302	555.380	0.120	55	0.55	555.93	1.170	0.550	51.1	34.6	69.1	14.691	0.504	495000
879	4	P13	1	1303	555.520	0.260	41	0.41	555.93	1.150	0.840	51.1	34.6	69.1	16.624	0.573	362692
880	4	P13	1	1304	555.580	0.320	30	0.30	555.88	1.010	0.900	51.1	34.6	69.1	15.398	0.589	233077
881	4	P13	1	1305	555.710	0.450	25	0.25	555.96	0.560	0.410	51.1	34.6	69.1	5.311	0.358	107692
882	4	P13	1	1306	555.710	0.450	20	0.20	555.91	0.480	NA	51.1	34.6	69.1	4.536	0.343	73846
883	4	P13	1	1307	555.800	0.540	11	0.11	555.91	0.280	NA	51.1	34.6	69.1	2.470	0.270	23692
884	4	P13	1	1308	555.790	0.530	13	0.13	555.92	0.130	NA	51.1	34.6	69.1	0.462	0.115	13000
885	4	P14	1	1404	555.330	0.130	45	0.45	555.78	0.360	0.250	56.2	34.1	74.3	1.610	0.171	124615
886	4	P14	1	1405	555.280	0.080	50	0.50	555.78	0.740	0.430	56.2	34.1	74.3	6.420	0.334	284615
887	4	P14	1	1406	555.200	0.000	58	0.58	555.78	0.870	0.570	56.2	34.1	74.3	8.203	0.365	388154
888	4	P14	1	1407	555.210	0.010	57	0.57	555.78	0.780	0.580	56.2	34.1	74.3	6.653	0.330	342000
889	4	P14	1	1408	555.200	0.000	55	0.55	555.75	0.900	0.530	56.2	34.1	74.3	9.026	0.387	380769
890	4	P14	1	1409	555.280	0.080	48	0.48	555.76	0.690	0.420	56.2	34.1	74.3	5.707	0.318	254769
891	4	P14	1	1410	555.360	0.160	40	0.40	555.76	0.680	0.290	56.2	34.1	74.3	6.140	0.343	209231
892	4	P14	1	1411	555.430	0.230	33	0.33	555.76	0.580	0.470	56.2	34.1	74.3	5.006	0.322	147231
893	4	P14	1	1412	555.490	0.290	23	0.23	555.72	0.430	0.400	56.2	34.1	74.3	3.473	0.286	76077
894	5	P1	1	101	543.400	0.050	32	0.32	543.72	0.920	0.760	58.2	33.9	79.6	13.397	0.519	226462
895	5	P1	1	102	543.350	0.000	38	0.38	543.73	1.090	0.710	58.2	33.9	79.6	16.928	0.565	318615
896	5	P1	1	103	543.380	0.030	32	0.32	543.70	0.810	0.680	58.2	33.9	79.6	10.385	0.457	199385
897	5	P1	1	106	543.380	0.030	34	0.34	543.72	0.990	0.690	58.2	33.9	79.6	14.938	0.542	258923
898	5	P1	1	110	543.470	0.120	28	0.28	543.75	0.810	0.680	58.2	33.9	79.6	11.314	0.489	174462
899	5	P1	1	112	543.460	0.110	26	0.26	543.72	1.000	0.780	58.2	33.9	79.6	18.114	0.626	200000
900	5	P1	1	115	543.450	0.100	28	0.28	543.73	0.900	0.590	58.2	33.9	79.6	13.968	0.543	193846
901	5	P1	1	117	543.500	0.150	26	0.26	543.76	0.780	0.620	58.2	33.9	79.6	11.021	0.488	156000
902	5	P1	1	118	543.410	0.060	30	0.30	543.71	0.770	0.420	58.2	33.9	79.6	9.777	0.449	177692
903	5	P1	1	121	543.400	0.050	33	0.33	543.73	0.850	0.630	58.2	33.9	79.6	11.218	0.472	215769
904	5	P1	1	124	543.510	0.160	30	0.30	543.81	0.440	0.400	58.2	33.9	79.6	3.192	0.256	101538
905	5	P2	1	208	543.140	0.110	25	0.25	543.39	0.650	0.650	45.3	35.3	63.7	6.786	0.415	125000
906	5	P2	1	212	543.110	0.080	28	0.28	543.39	0.850	0.410	45.3	35.3	63.7	10.815	0.513	183077
907	5	P2	1	215	543.110	0.080	27	0.27	543.48	0.860	0.550	45.3	35.3	63.7	9.402	0.451	244769
908	5	P2	1	217	543.100	0.070	28	0.28	543.38	0.870	0.660	45.3	35.3	63.7	11.330	0.525	187385

909	5	P2	1	219	543.090	0.060	28	0.28	543.37	0.730	0.650	45.3	35.3	63.7	7.977	0.440	157231
910	5	P2	1	222	543.120	0.090	29	0.29	543.41	0.810	0.570	45.3	35.3	63.7	9.614	0.480	180692
911	5	P2	1	225	543.110	0.080	30	0.30	543.41	0.900	0.700	45.3	35.3	63.7	11.630	0.525	207692
912	5	P2	1	228	543.040	0.010	32	0.32	543.36	0.750	0.310	45.3	35.3	63.7	7.773	0.423	184615
913	5	P2	1	230	543.030	0.000	36	0.36	543.39	0.910	0.590	45.3	35.3	63.7	10.691	0.484	252000
914	5	P2	1	232	543.040	0.010	38	0.38	543.42	1.010	0.530	45.3	35.3	63.7	12.775	0.523	295231
915	5	P2	1	233	543.100	0.070	34	0.34	543.44	0.920	0.720	45.3	35.3	63.7	11.291	0.504	240615
916	5	P2	1	236	543.030	0.000	38	0.38	543.41	0.980	0.770	45.3	35.3	63.7	12.028	0.508	286462
917	5	P2	1	239	543.190	0.160	27	0.27	543.56	0.610	0.470	45.3	35.3	63.7	4.730	0.320	173615
918	5	P3	1	303	542.350	0.270	25	0.25	542.60	0.710	0.460	43.5	35.6	65.7	8.263	0.453	136538
919	5	P3	1	307	542.240	0.160	34	0.34	542.58	0.760	0.530	43.5	35.6	65.7	7.849	0.416	198769
920	5	P3	1	310	542.270	0.190	28	0.28	542.55	0.860	0.630	43.5	35.6	65.7	11.290	0.519	185231
921	5	P3	1	313	542.200	0.120	49	0.49	542.69	0.850	0.660	43.5	35.6	65.7	8.020	0.388	320385
922	5	P3	1	317	542.160	0.080	40	0.40	542.56	0.820	0.610	43.5	35.6	65.7	8.330	0.414	252308
923	5	P3	1	320	542.300	0.220	24	0.24	542.54	0.790	0.710	43.5	35.6	65.7	10.502	0.515	145846
924	5	P3	1	338	542.230	0.150	32	0.32	542.55	0.860	0.770	43.5	35.6	65.7	10.414	0.485	211692
925	5	P3	1	335	542.180	0.100	43	0.43	542.61	0.830	0.600	43.5	35.6	65.7	8.202	0.404	274538
926	5	P3	1	336	542.080	0.000	50	0.50	542.58	0.780	0.580	43.5	35.6	65.7	6.683	0.352	300000
927	5	P3	1	337	542.140	0.060	44	0.44	542.58	0.750	0.620	43.5	35.6	65.7	6.614	0.361	253846
928	5	P3	1	338	542.230	0.150	38	0.38	542.61	0.980	0.770	43.5	35.6	65.7	12.245	0.508	286462
929	5	P3	1	341	542.220	0.140	37	0.37	542.59	0.950	0.780	43.5	35.6	65.7	11.682	0.499	270385
930	5	P3	1	343	542.230	0.150	36	0.36	542.59	1.050	0.720	43.5	35.6	65.7	14.495	0.559	290769
931	5	P3	1	346	542.160	0.080	42	0.42	542.58	1.070	1.010	43.5	35.6	65.7	13.807	0.527	345692
932	5	P3	1	348	542.220	0.140	36	0.36	542.58	0.880	0.620	43.5	35.6	65.7	10.181	0.468	243692
933	5	P3	1	349	542.360	0.280	18	0.18	542.54	0.550	NA	43.5	35.6	65.7	6.191	0.414	76154
934	5	P3	1	351	542.400	0.320	12	0.12	542.52	0.940	NA	43.5	35.6	65.7	24.727	0.866	86769
935	5	P3	1	352	542.330	0.250	18	0.18	542.51	0.490	NA	43.5	35.6	65.7	4.914	0.369	67846
936	5	P3	1	353	542.390	0.310	16	0.16	542.55	0.210	NA	43.5	35.6	65.7	0.984	0.168	25846
937	5	P4	1	401	541.900	0.090	28	0.28	542.18	0.460	0.480	52.6	34.5	75.1	3.513	0.278	99077
938	5	P4	1	402	541.850	0.040	36	0.36	542.21	0.870	0.720	52.6	34.5	75.1	10.757	0.463	240923
939	5	P4	1	403	541.930	0.120	27	0.27	542.20	0.830	0.690	52.6	34.5	75.1	11.711	0.510	172385
940	5	P4	1	404	541.950	0.140	28	0.28	542.23	0.840	0.660	52.6	34.5	75.1	11.715	0.507	180923
941	5	P4	1	405	541.990	0.180	22	0.22	542.21	0.620	0.580	52.6	34.5	75.1	7.501	0.422	104923
942	5	P4	1	406	542.000	0.190	22	0.22	542.22	0.550	0.480	52.6	34.5	75.1	5.903	0.374	93077
943	5	P4	1	403	541.930	0.120	25	0.25	542.18	0.680	0.690	52.6	34.5	75.1	8.270	0.434	130769
944	5	P4	1	431	541.950	0.140	24	0.24	542.19	0.620	0.420	52.6	34.5	75.1	7.066	0.404	114462
945	5	P4	1	432	541.930	0.120	32	0.32	542.25	0.800	0.410	52.6	34.5	75.1	9.769	0.452	196923
946	5	P4	1	433	541.920	0.110	30	0.30	542.22	0.930	0.380	52.6	34.5	75.1	13.743	0.542	214615
947	5	P4	1	434	541.880	0.070	36	0.36	542.24	0.810	0.220	52.6	34.5	75.1	9.324	0.431	224308
948	5	P4	1	435	541.810	0.000	42	0.42	542.23	1.100	0.800	52.6	34.5	75.1	15.721	0.542	355385
949	5	P4	1	438	541.810	0.000	40	0.40	542.21	0.960	0.750	52.6	34.5	75.1	12.313	0.485	295385
950	5	P4	1	441	541.870	0.060	32	0.32	542.19	0.900	0.620	52.6	34.5	75.1	12.364	0.508	221538
951	5	P4	1	444	541.980	0.170	22	0.22	542.20	0.560	0.290	52.6	34.5	75.1	6.120	0.381	94769
952	5	P5	1	522	541.550	0.160	21	0.21	541.76	0.280	0.250	67.3	33.1	105.7	2.047	0.195	45231
953	5	P5	1	521	541.490	0.100	30	0.30	541.79	0.730	0.620	67.3	33.1	105.7	10.631	0.426	168462
954	5	P5	1	520	541.510	0.120	31	0.31	541.82	1.070	0.770	67.3	33.1	105.7	22.320	0.614	255154
955	5	P5	1	519	541.470	0.080	37	0.37	541.84	1.020	0.800	67.3	33.1	105.7	17.994	0.535	290308
956	5	P5	1	516	541.390	0.000	41	0.41	541.80	0.880	0.630	67.3	33.1	105.7	12.534	0.439	277538
957	5	P5	1	512	541.530	0.140	34	0.34	541.87	0.970	0.660	67.3	33.1	105.7	17.216	0.531	253692
958	5	P5	1	509	541.510	0.120	34	0.34	541.85	0.920	0.720	67.3	33.1	105.7	15.487	0.504	240615
959	5	P5	1	505	541.480	0.090	33	0.33	541.81	0.930	0.630	67.3	33.1	105.7	16.150	0.517	236077
960	5	P5	1	504	541.530	0.140	29	0.29	541.82	0.730	0.480	67.3	33.1	105.7	10.890	0.433	162846
961	5	P5	1	503	541.570	0.180	26	0.26	541.83	0.610	0.410	67.3	33.1	105.7	8.233	0.382	122000
962	5	P5	1	502	541.570	0.180	24	0.24	541.81	0.730	0.390	67.3	33.1	105.7	12.525	0.476	134769
963	5	P5	1	501	541.560	0.170	28	0.28	541.84	0.810	0.790	67.3	33.1	105.7	13.750	0.489	174462
964	5	P5	1	531	541.510	0.120	32	0.32	541.83	0.680	0.550	67.3	33.1	105.7	8.818	0.384	167385
965	5	P5	1	529	541.510	0.120	20	0.20	541.71	0.690	0.490	67.3	33.1	105.7	12.932	0.493	106154

966	5	P5	1	527	541.610	0.220	22	0.22	541.83	0.620	0.520	67.3	33.1	105.7	9.668	0.422	104923
967	5	P6	1	606	540.970	0.000	50	0.50	541.47	0.450	0.290	43.6	35.6	55.1	2.033	0.203	173077
968	5	P6	1	608	541.050	0.080	40	0.40	541.45	0.890	0.370	43.6	35.6	55.1	8.922	0.449	273846
969	5	P6	1	610	541.030	0.060	45	0.45	541.48	0.960	0.610	43.6	35.6	55.1	9.762	0.457	332308
970	5	P6	1	612	541.020	0.050	46	0.46	541.48	1.060	0.540	43.6	35.6	55.1	11.768	0.499	375077
971	5	P6	1	613	541.120	0.150	46	0.46	541.58	0.960	0.680	43.6	35.6	55.1	9.652	0.452	339692
972	5	P6	1	616	541.120	0.150	34	0.34	541.46	0.790	0.560	43.6	35.6	55.1	7.677	0.433	206615
973	5	P6	1	618	541.230	0.260	25	0.25	541.48	0.840	0.570	43.6	35.6	55.1	10.370	0.536	161538
974	5	P6	1	621	541.290	0.320	18	0.18	541.47	0.580	0.510	43.6	35.6	55.1	6.096	0.436	80308
975	5	P6	1	623	541.370	0.400	16	0.16	541.53	0.450	NA	43.6	35.6	55.1	3.979	0.359	55385
976	5	P6	1	625	541.310	0.340	16	0.16	541.47	0.520	NA	43.6	35.6	55.1	5.313	0.415	64000
977	5	P6	1	627	541.320	0.350	18	0.18	541.50	0.680	NA	43.6	35.6	55.1	8.380	0.512	94154
978	5	P6	1	650	541.270	0.300	18	0.18	541.45	0.380	NA	43.6	35.6	55.1	2.617	0.286	52615
979	5	P6	1	651	541.360	0.390	8	0.08	541.44	0.370	NA	43.6	35.6	55.1	4.689	0.418	22769
980	5	P7	1	701	540.400	0.580	16	0.16	540.56	0.420	NA	48.4	35.0	61.5	3.747	0.335	51692
981	5	P7	1	702	540.370	0.550	20	0.20	540.57	0.620	NA	48.4	35.0	61.5	6.984	0.443	95385
982	5	P7	1	709	540.370	0.550	22	0.22	540.59	0.540	0.360	48.4	35.0	61.5	4.974	0.368	91385
983	5	P7	1	712	540.250	0.430	38	0.38	540.63	0.860	0.550	48.4	35.0	61.5	9.087	0.445	251385
984	5	P7	1	715	540.020	0.200	56	0.56	540.58	0.830	0.550	48.4	35.0	61.5	6.903	0.354	357538
985	5	P7	1	718	540.030	0.210	54	0.54	540.57	0.690	0.560	48.4	35.0	61.5	4.858	0.300	286615
986	5	P7	1	721	539.860	0.040	70	0.70	540.56	0.530	0.002	48.4	35.0	61.5	2.525	0.202	285385
987	5	P7	1	722	540.170	0.350	42	0.42	540.59	0.620	0.550	48.4	35.0	61.5	4.472	0.305	200308
988	5	P7	1	725	540.010	0.190	58	0.58	540.59	0.750	0.520	48.4	35.0	61.5	5.539	0.314	334615
989	5	P7	1	727	539.910	0.090	68	0.68	540.59	0.890	0.610	48.4	35.0	61.5	7.219	0.345	465538
990	5	P7	1	729	539.820	0.000	77	0.77	540.59	0.580	0.470	48.4	35.0	61.5	2.892	0.211	343538
991	5	P7	1	730	540.130	0.310	48	0.48	540.61	0.820	0.480	48.4	35.0	61.5	7.288	0.378	302769
992	5	P7	1	731	540.450	0.630	10	0.10	540.55	0.140	NA	48.4	35.0	61.5	0.606	0.141	10769
993	5	P7	2	735	540.570	0.000	3	0.03	540.60	0.210	NA	48.4	35.0	61.5	6.133	0.387	4846
994	5	P7	2	736	540.580	0.010	2	0.02	540.60	0.100	NA	48.4	35.0	61.5	3.590	0.226	1538
995	5	P8	1	805	539.970	0.100	34	0.34	540.31	0.510	0.350	61.5	33.6	79.1	3.949	0.279	133385
996	5	P8	1	806	539.940	0.070	40	0.40	540.34	0.930	0.350	61.5	33.6	79.1	11.910	0.469	286154
997	5	P8	1	808	539.950	0.080	45	0.45	540.40	1.260	0.880	61.5	33.6	79.1	20.428	0.600	436154
998	5	P8	1	811	539.870	0.000	45	0.45	540.32	0.970	0.230	61.5	33.6	79.1	12.107	0.462	335769
999	5	P8	1	813	539.950	0.080	38	0.38	540.33	0.780	0.490	61.5	33.6	79.1	8.636	0.404	228000
1000	5	P8	1	815	540.020	0.150	26	0.26	540.28	0.670	0.540	61.5	33.6	79.1	8.097	0.420	134000
1001	5	P8	1	817	540.100	0.230	18	0.18	540.28	0.540	NA	61.5	33.6	79.1	6.844	0.406	74769
1002	5	P8	1	818	540.120	0.250	20	0.20	540.32	0.430	NA	61.5	33.6	79.1	4.010	0.307	66154
1003	5	P8	1	819	540.120	0.250	16	0.16	540.28	0.700	NA	61.5	33.6	79.1	12.611	0.559	86154
1004	5	P8	1	823	540.090	0.220	22	0.22	540.31	0.620	0.590	61.5	33.6	79.1	7.781	0.422	104923
1005	5	P8	1	826	540.100	0.230	14	0.14	540.24	0.540	NA	61.5	33.6	79.1	8.377	0.461	58154
1006	5	P8	1	827	540.150	0.280	12	0.12	540.27	0.051	NA	61.5	33.6	79.1	0.086	0.047	4708
1007	5	P8	1	829	540.280	0.410	3	0.03	540.31	0.012	NA	61.5	33.6	79.1	0.034	0.022	277
1008	5	P9	1	904	539.620	0.380	16	0.16	539.78	0.390	NA	60.0	33.7	78.6	3.894	0.311	48000
1009	5	P9	1	906	539.670	0.430	13	0.13	539.80	0.510	NA	60.0	33.7	78.6	7.917	0.452	51000
1010	5	P9	1	907	539.680	0.440	10	0.10	539.78	0.560	NA	60.0	33.7	78.6	12.169	0.565	43077
1011	5	P9	1	909	539.680	0.440	11	0.11	539.79	0.430	NA	60.0	33.7	78.6	6.547	0.414	36385
1012	5	P9	1	911	539.700	0.460	8	0.08	539.78	0.540	NA	60.0	33.7	78.6	14.278	0.610	33231
1013	5	P9	1	913	539.690	0.450	10	0.10	539.79	0.610	NA	60.0	33.7	78.6	14.439	0.616	46923
1014	5	P9	1	915	539.640	0.400	18	0.18	539.82	0.490	NA	60.0	33.7	78.6	5.606	0.369	67846
1015	5	P9	1	917	539.660	0.420	14	0.14	539.80	0.930	NA	60.0	33.7	78.6	24.706	0.794	100154
1016	5	P9	1	918	539.640	0.400	14	0.14	539.78	0.920	NA	60.0	33.7	78.6	24.178	0.785	99077
1017	5	P9	1	920	539.490	0.250	26	0.26	539.75	0.760	0.620	60.0	33.7	78.6	10.372	0.476	152000
1018	5	P9	1	921	539.470	0.230	32	0.32	539.79	0.710	0.580	60.0	33.7	78.6	7.914	0.401	174769
1019	5	P9	1	922	539.400	0.160	46	0.46	539.86	0.830	0.670	60.0	33.7	78.6	8.722	0.391	293692
1020	5	P9	1	925	539.320	0.080	45	0.45	539.77	1.000	0.030	60.0	33.7	78.6	12.818	0.476	346154
1021	5	P9	1	929	539.310	0.070	50	0.50	539.81	0.990	0.590	60.0	33.7	78.6	11.847	0.447	380769

1022	5	P9	1	932	539.240	0.000	50	0.50	539.74	0.920	0.520	60.0	33.7	78.6	10.231	0.415	353846
1023	5	P9	1	935	539.260	0.020	55	0.55	539.81	0.930	0.140	60.0	33.7	78.6	9.928	0.400	393462
1024	5	P9	1	938	539.260	0.020	50	0.50	539.76	0.360	0.170	60.0	33.7	78.6	1.567	0.163	138462
1027	5	P10	1	1003	539.200	0.000	42	0.42	539.62	0.890	0.670	55.3	34.2	75.2	10.298	0.438	287538
1028	5	P10	1	1004	539.230	0.030	40	0.40	539.63	0.950	0.590	55.3	34.2	75.2	12.067	0.480	292308
1029	5	P10	1	1005	539.280	0.080	35	0.35	539.63	0.880	0.670	55.3	34.2	75.2	11.201	0.475	236923
1030	5	P10	1	1006	539.300	0.100	33	0.33	539.63	0.610	0.210	55.3	34.2	75.2	5.577	0.339	154846
1031	5	P10	1	1007	539.390	0.190	21	0.21	539.60	0.510	0.470	55.3	34.2	75.2	5.249	0.355	82385
1032	5	P10	1	1008	539.430	0.230	16	0.16	539.59	0.280	NA	55.3	34.2	75.2	1.938	0.223	34462
1033	5	P10	1	1009	539.500	0.300	8	0.08	539.58	0.950	NA	55.3	34.2	75.2	42.114	1.072	58462
1034	5	P10	1	1010	539.550	0.350	5	0.05	539.60	0.520	NA	55.3	34.2	75.2	22.645	0.742	20000
1035	5	P10	1	1011	539.480	0.280	14	0.14	539.62	0.630	NA	55.3	34.2	75.2	10.927	0.538	67846
1036	5	P10	1	1012	539.420	0.220	18	0.18	539.60	0.660	NA	55.3	34.2	75.2	9.837	0.497	91385
1037	5	P10	1	1013	539.260	0.060	32	0.32	539.58	0.410	0.300	55.3	34.2	75.2	2.568	0.231	100923
1038	5	P10	1	1014	539.510	0.310	12	0.12	539.63	0.250	NA	55.3	34.2	75.2	1.964	0.230	23077
1039	5	P10	1	1050	539.370	0.170	27	0.27	539.64	0.170	0.160	55.3	34.2	75.2	0.492	0.104	35308
1040	5	P10	1	1051	539.500	0.300	6	0.06	539.56	0.003	NA	55.3	34.2	75.2	0.001	0.004	138
1041	5	P11	1	1113	538.970	0.630	18	0.18	539.15	0.180	NA	56.7	34.0	70.7	0.699	0.135	24923
1042	5	P11	1	1114	538.900	0.560	19	0.19	539.09	0.770	NA	56.7	34.0	70.7	12.304	0.564	112538
1043	5	P11	1	1115	539.040	0.700	12	0.12	539.16	0.620	NA	56.7	34.0	70.7	11.450	0.571	57231
1044	5	P11	1	1116	539.040	0.700	10	0.10	539.14	0.030	NA	56.7	34.0	70.7	0.032	0.030	2308
1045	5	P11	1	1117	539.060	0.720	2	0.02	539.08	0.010	NA	56.7	34.0	70.7	0.057	0.023	154
1046	5	P11	1	1118	538.970	0.630	16	0.16	539.13	0.180	NA	56.7	34.0	70.7	0.764	0.144	22154
1047	5	P11	1	1119	538.600	0.260	50	0.50	539.10	0.850	0.620	56.7	34.0	70.7	8.250	0.384	326923
1048	5	P11	1	1120	538.340	0.000	82	0.82	539.16	1.130	0.670	56.7	34.0	70.7	11.379	0.398	712769
1049	5	P11	1	1121	538.360	0.020	76	0.76	539.12	0.580	0.530	56.7	34.0	70.7	3.108	0.212	339077
1050	5	P11	1	1122	538.340	0.000	74	0.74	539.08	1.280	0.580	56.7	34.0	70.7	15.333	0.475	728615
1051	5	P11	1	1123	538.460	0.120	64	0.64	539.10	1.290	0.750	56.7	34.0	70.7	16.726	0.515	635077
1052	5	P11	1	1124	538.630	0.290	54	0.54	539.17	1.090	0.640	56.7	34.0	70.7	13.026	0.474	452769
1053	5	P11	1	1125	538.650	0.310	48	0.48	539.13	0.280	0.160	56.7	34.0	70.7	0.915	0.129	103385
1054	5	P11	1	1126	538.570	0.230	55	0.55	539.12	0.450	0.320	56.7	34.0	70.7	2.199	0.194	190385
1055	5	P11	1	1127	538.780	0.440	20	0.20	538.98	0.010	NA	56.7	34.0	70.7	0.002	0.007	1538
1056	5	P11	1	1128	538.940	0.600	22	0.22	539.16	0.650	0.620	56.7	34.0	70.7	7.911	0.442	110000
1057	5	P11	1	1129	538.840	0.500	30	0.30	539.14	0.810	0.670	56.7	34.0	70.7	10.044	0.472	186923
1058	5	P11	1	1130	538.920	0.580	22	0.22	539.14	0.750	0.710	56.7	34.0	70.7	10.533	0.511	126923
1059	5	P12	1	1202	538.410	0.040	38	0.38	538.79	1.130	0.020	51.5	34.6	76.9	17.820	0.585	330308
1060	5	P12	1	1203	538.480	0.110	40	0.40	538.88	1.110	0.990	51.5	34.6	76.9	16.686	0.560	341538
1061	5	P12	1	1204	538.410	0.040	47	0.47	538.88	1.110	0.690	51.5	34.6	76.9	15.225	0.517	401308
1062	5	P12	1	1205	538.370	0.000	52	0.52	538.89	1.060	0.630	51.5	34.6	76.9	13.137	0.469	424000
1063	5	P12	1	1206	538.470	0.100	40	0.40	538.87	1.140	0.730	51.5	34.6	76.9	17.600	0.575	350769
1064	5	P12	1	1207	538.500	0.130	36	0.36	538.86	1.020	0.620	51.5	34.6	76.9	14.994	0.543	282462
1065	5	P12	1	1208	538.570	0.200	30	0.30	538.87	0.940	0.610	51.5	34.6	76.9	14.249	0.548	216923
1066	5	P12	1	1209	538.660	0.290	24	0.24	538.90	0.650	0.560	51.5	34.6	76.9	7.891	0.424	120000
1067	5	P12	1	1210	538.670	0.300	28	0.28	538.95	0.750	0.490	51.5	34.6	76.9	9.481	0.453	161538
1068	5	P12	1	1211	538.710	0.340	18	0.18	538.89	0.460	NA	51.5	34.6	76.9	4.859	0.346	63692
1069	5	P12	1	1212	538.700	0.330	18	0.18	538.88	0.590	NA	51.5	34.6	76.9	7.994	0.444	81692
1070	5	P12	1	1213	538.620	0.250	26	0.26	538.88	0.670	0.480	51.5	34.6	76.9	7.944	0.420	134000
1071	5	P12	1	1214	538.650	0.280	26	0.26	538.91	0.650	0.500	51.5	34.6	76.9	7.477	0.407	130000
1072	5	P12	1	1215	538.570	0.200	28	0.28	538.85	0.070	0.100	51.5	34.6	76.9	0.083	0.042	15077
1073	5	P12	1	1216	538.650	0.280	20	0.20	538.85	0.730	NA	51.5	34.6	76.9	11.317	0.521	112308
1074	5	P12	1	1217	538.710	0.340	14	0.14	538.85	0.340	NA	51.5	34.6	76.9	3.242	0.290	36615
1075	5	P12	1	1218	538.760	0.390	12	0.12	538.88	0.060	NA	51.5	34.6	76.9	0.115	0.055	5538
1076	5	P13	1	1302	538.370	0.420	16	0.16	538.53	0.330	NA	62.6	33.5	91.0	3.146	0.263	40615
1077	5	P13	1	1303	538.250	0.300	25	0.25	538.50	0.620	0.520	62.6	33.5	91.0	7.849	0.396	119231
1078	5	P13	1	1304	538.250	0.300	20	0.20	538.45	0.530	NA	62.6	33.5	91.0	6.771	0.378	81538

1079	5	P13	1	1305	538.210	0.260	26	0.26	538.47	0.680	0.430	62.6	33.5	91.0	9.183	0.426	136000
1080	5	P13	1	1306	538.280	0.330	21	0.21	538.49	0.480	0.430	62.6	33.5	91.0	5.350	0.334	77538
1081	5	P13	1	1307	538.260	0.310	22	0.22	538.48	0.690	0.580	62.6	33.5	91.0	10.673	0.470	116769
1082	5	P13	1	1308	538.350	0.400	12	0.12	538.47	0.480	NA	62.6	33.5	91.0	8.636	0.442	44308
1083	5	P13	1	1309	538.370	0.420	9	0.09	538.46	0.410	NA	62.6	33.5	91.0	8.501	0.436	28385
1084	5	P13	1	1310	538.280	0.330	24	0.24	538.52	0.860	0.750	62.6	33.5	91.0	15.552	0.560	158769
1085	5	P13	1	1311	538.150	0.200	40	0.40	538.55	1.070	0.720	62.6	33.5	91.0	17.145	0.540	329231
1086	5	P13	1	1312	538.050	0.100	42	0.42	538.47	1.250	0.970	62.6	33.5	91.0	22.716	0.616	403846
1087	5	P13	1	1313	537.950	0.000	52	0.52	538.47	1.120	0.690	62.6	33.5	91.0	16.100	0.496	448000
1088	5	P13	1	1314	537.960	0.010	50	0.50	538.46	0.930	0.450	62.6	33.5	91.0	11.351	0.420	357692
1089	5	P13	1	1315	538.050	0.100	46	0.46	538.51	1.060	0.660	62.6	33.5	91.0	15.476	0.499	375077
1090	5	P13	1	1316	538.220	0.270	28	0.28	538.50	0.470	0.420	62.6	33.5	91.0	4.167	0.284	101231
1091	5	P14	1	1402	538.100	0.450	8	0.08	538.18	0.450	NA	50.8	34.7	72.1	9.041	0.508	27692
1092	5	P14	1	1403	538.030	0.380	25	0.25	538.28	0.330	0.270	50.8	34.7	72.1	1.896	0.211	63462
1093	5	P14	1	1408	537.920	0.270	21	0.21	538.13	0.120	0.350	50.8	34.7	72.1	0.282	0.084	19385
1094	5	P14	1	1409	537.950	0.300	18	0.18	538.13	0.380	NA	50.8	34.7	72.1	3.162	0.286	52615
1095	5	P14	1	1410	538.000	0.350	13	0.13	538.13	0.700	NA	50.8	34.7	72.1	13.864	0.620	70000
1096	5	P14	1	1411	537.990	0.340	18	0.18	538.17	0.410	NA	50.8	34.7	72.1	3.681	0.309	56769
1097	5	P14	1	1412	537.970	0.320	18	0.18	538.15	0.690	NA	50.8	34.7	72.1	10.426	0.519	95538
1098	5	P14	1	1413	537.980	0.330	21	0.21	538.19	0.730	0.620	50.8	34.7	72.1	10.445	0.509	117923
1099	5	P14	1	1414	537.900	0.250	26	0.26	538.16	0.750	0.590	50.8	34.7	72.1	9.547	0.470	150000
1100	5	P14	1	1415	537.870	0.220	28	0.28	538.15	0.990	0.830	50.8	34.7	72.1	15.860	0.597	213231
1101	5	P14	1	1416	537.740	0.090	41	0.41	538.15	1.010	0.680	50.8	34.7	72.1	13.133	0.504	318538
1102	5	P14	1	1417	537.750	0.100	42	0.42	538.17	1.270	0.680	50.8	34.7	72.1	20.484	0.626	410308
1103	5	P14	1	1418	537.720	0.070	46	0.46	538.18	1.050	0.600	50.8	34.7	72.1	13.311	0.494	371538
1104	5	P14	1	1419	537.650	0.000	50	0.50	538.15	1.250	1.180	50.8	34.7	72.1	18.031	0.564	480769
1105	5	P14	1	1420	537.700	0.050	48	0.48	538.18	1.890	1.550	50.8	34.7	72.1	42.139	0.871	697846
1106	5	P14	1	1421	537.750	0.100	44	0.44	538.19	0.930	0.520	50.8	34.7	72.1	10.702	0.448	314769
1107	5	P14	1	1422	537.760	0.110	42	0.42	538.18	0.650	0.350	50.8	34.7	72.1	5.366	0.320	210000
1108	5	P14	1	1423	537.750	0.100	44	0.44	538.19	0.530	0.400	50.8	34.7	72.1	3.476	0.255	179385
1109	5	P14	1	1424	537.880	0.230	32	0.32	538.20	0.440	0.380	50.8	34.7	72.1	2.883	0.248	108308

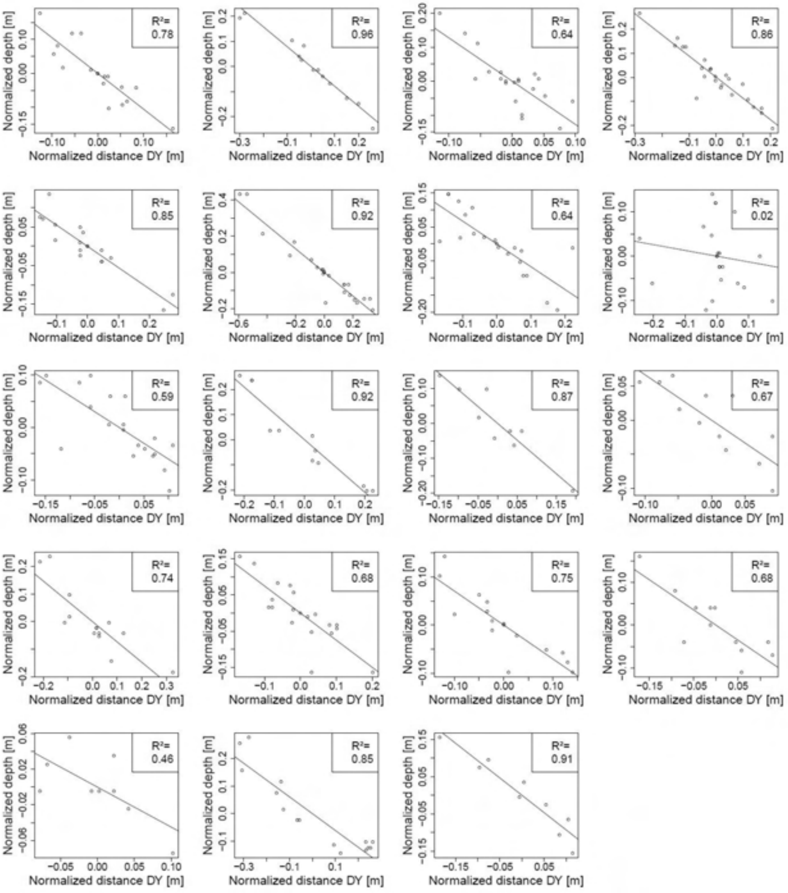
Reach related metrics

	Site	v1cvSite	hmcvSite	dcvSite	HMID	HdiffnormSite	HdiffSohlenormSite	Thalwegdiv	Bw_Bb
1	1	0.923	0.669	0.950	10.294	0.050	0.075	0.0254	0.1725789
2	2	0.793	0.662	0.912	8.879	0.068	0.075	0.0233	0.2710588
3	3	0.686	0.585	0.850	7.140	0.038	0.069	0.0226	0.2633684
4	4	0.580	0.474	0.672	5.424	0.063	0.065	0.0203	0.4295000
5	5	0.413	0.489	0.628	4.425	0.038	0.050	0.0117	0.8630714

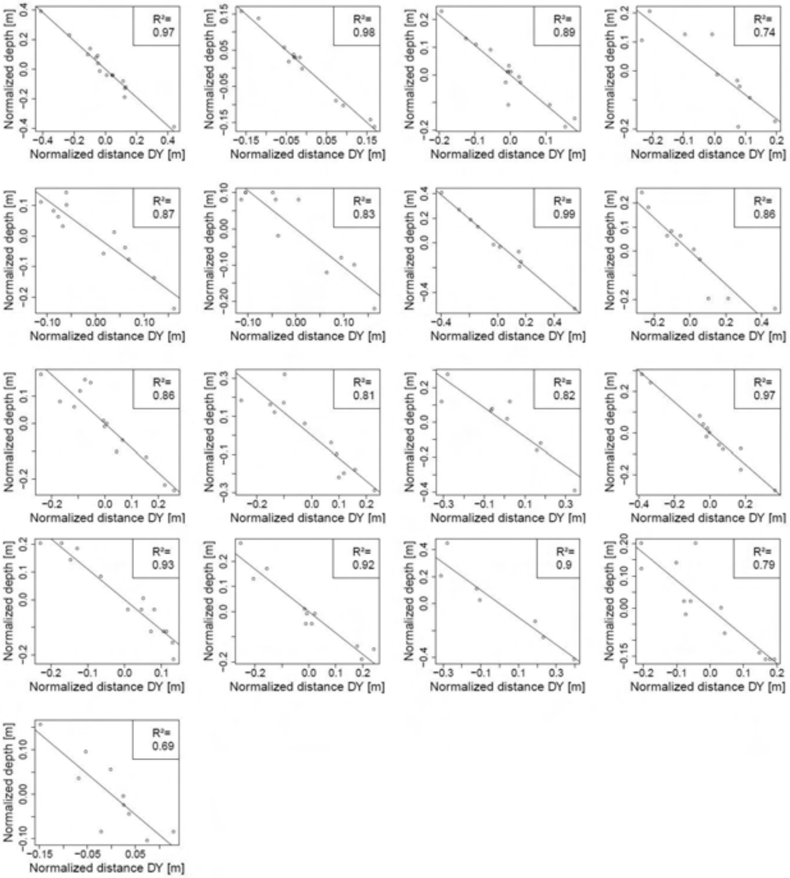
D. Correlations between hydro-morphological variables at river Sense

Correlation bottom elevation – water depth

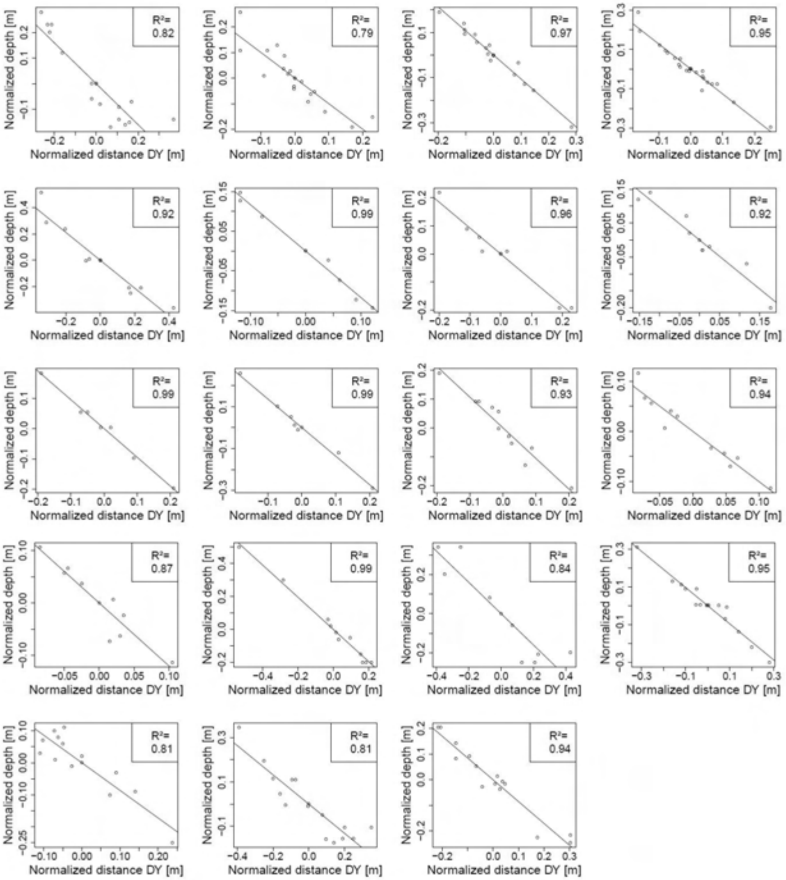
In the figures of this Chapter the correlation between bottom elevation DY, expressed as distance between the elevation of the recorded point and the thalweg elevation, and water depth at the same point is shown for each survey cross section. Values have been normalized by subtracting the mean values from the recorded values.



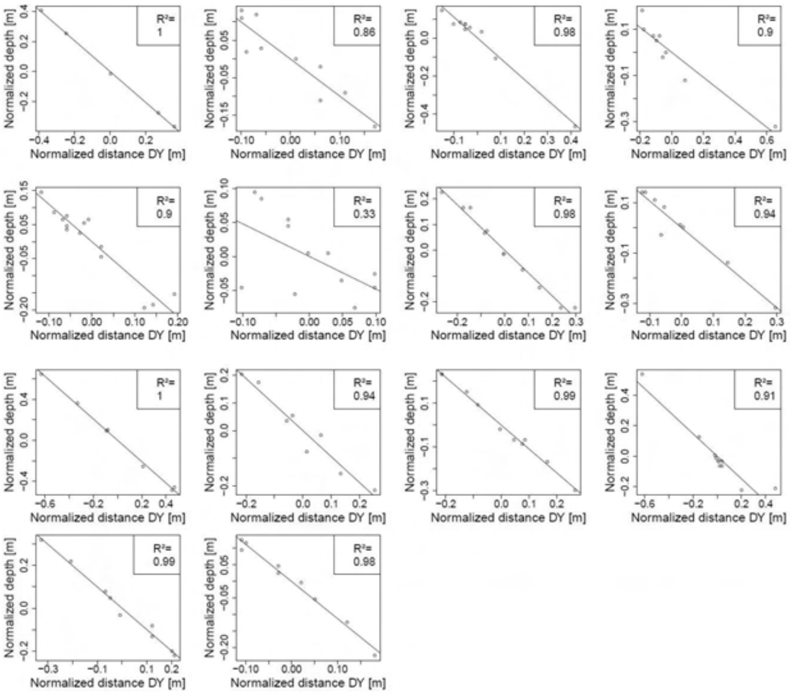
Site n°1 – separated by cross sections



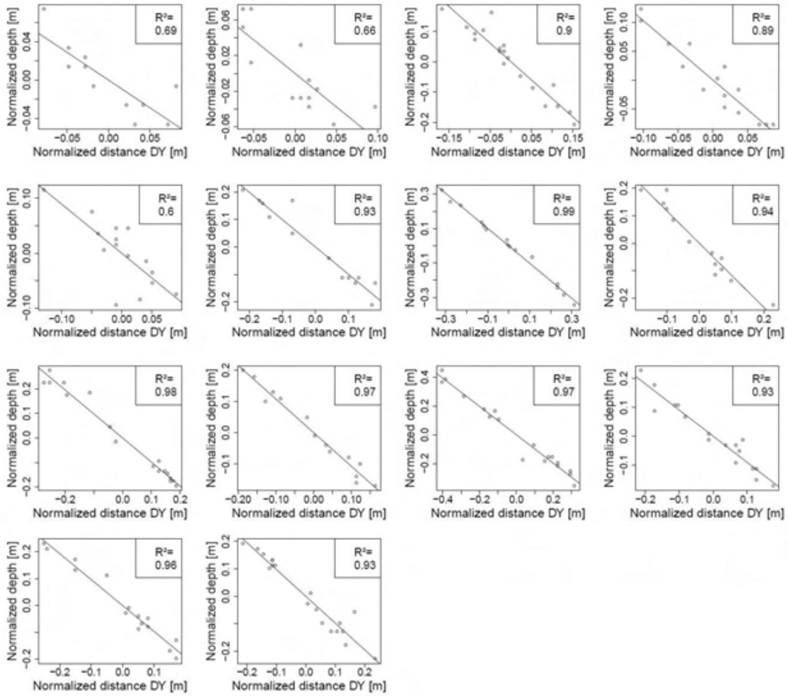
Site n°2 – separated by cross sections



Site n°3 – separated by cross sections



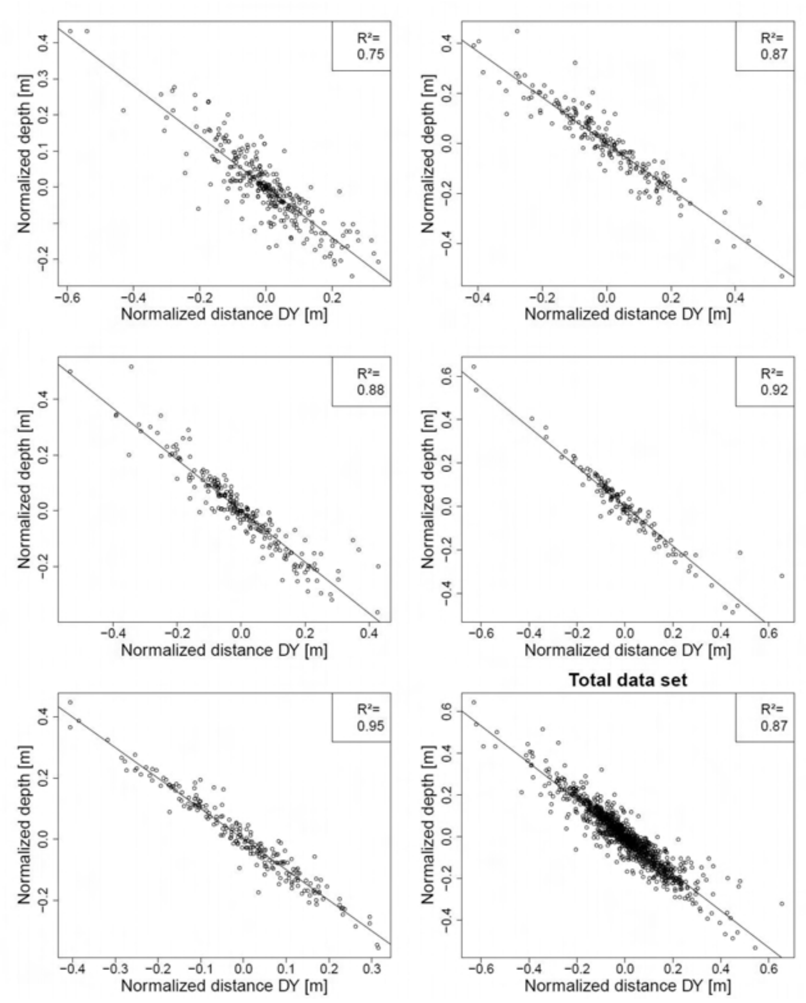
Site n°4 – separated by cross sections



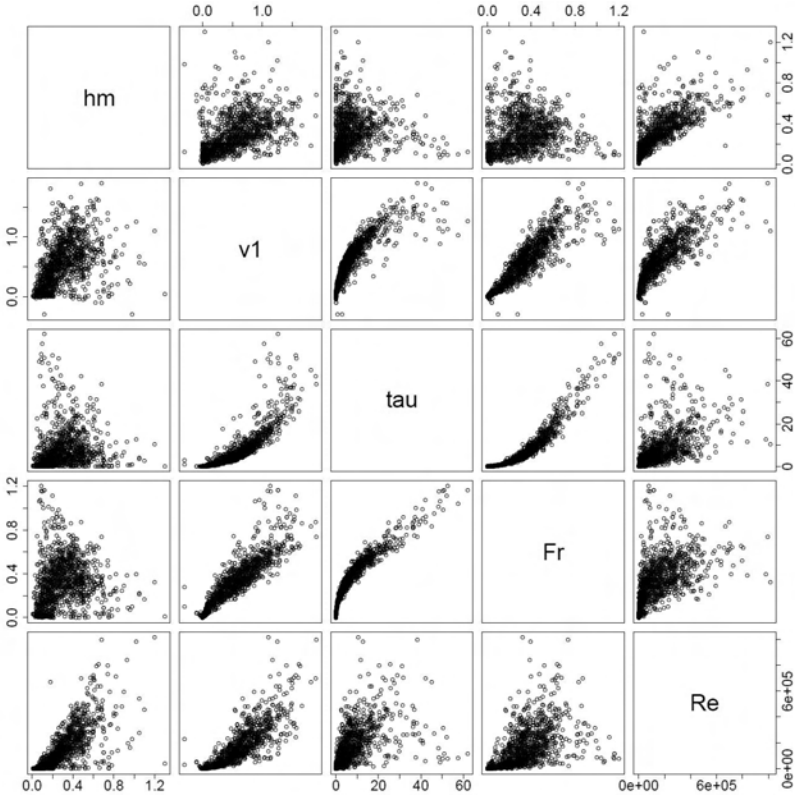
Site n°5 – separated by cross sections

Site n°1-n°5 – cumulative regression

The first 5 graphs of this figure show the correlation between bottom distance and water depth for the five study sites with the totality of the recorded points along the cross sections in a single graph, whereas at last graph reports the totality of the five sites together.

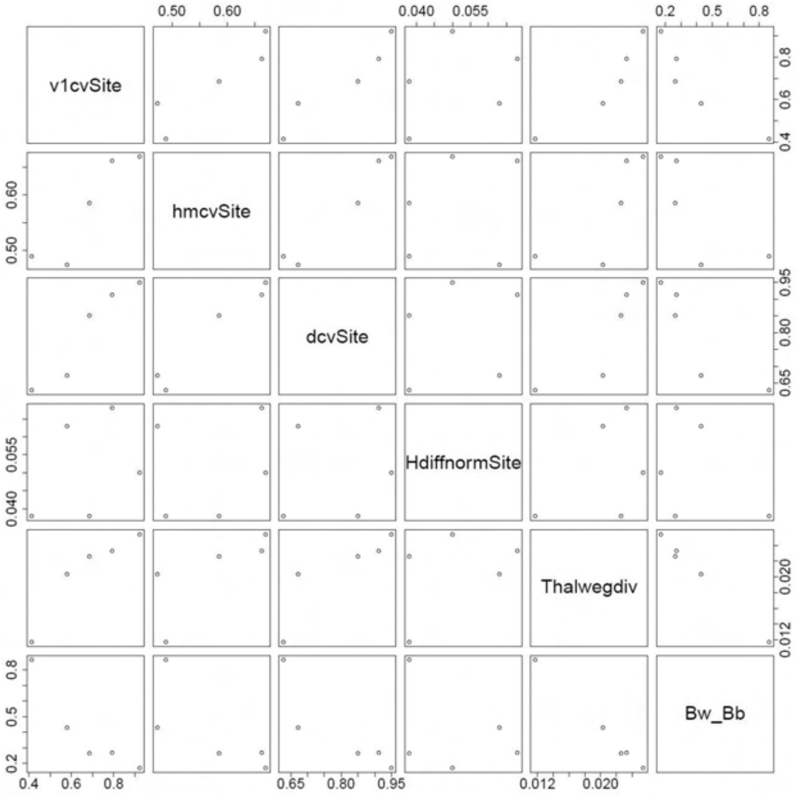


Scatterplots for hydraulic variables



Scatterplot of hydraulic variables water depth, mean column flow velocity, shear stress, Froude number and Reynolds number

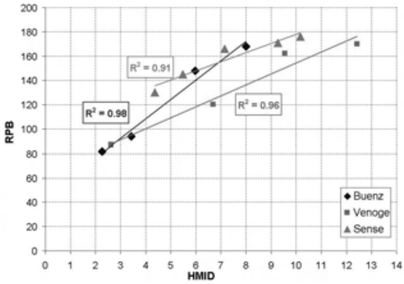
Scatterplots for geomorphic and hydraulic diversity metrics



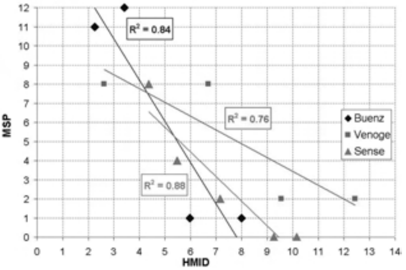
Scatterplot of CV for flow velocity, CV for water depth, CV for substrate grain size curve, cross section diversity over the entire transect, Thalweg diversity, ratio of mean wetted width and mean bankfull width

E. Correlation HMID, RPB and MSP[4]

Stream	Site	HMID	$HMID_{norm}$	RBP	RBP_{norm}	MSP	Total rich	EPT rich	Simp-son	Shannon	Eveness	Berger-Parker	Mean Abund
Buenz	B1	6.69	0.538	120	0.600	8	30	7	0.721	0.734	0.563	0.410	1030.3
Buenz	B2	2.62	0.210	87	0.435	8	24	9	0.644	0.625	0.848	0.514	1215.7
Buenz	B3	12.43	1.000	170	0.850	2	23	6	0.617	0.593	0.886	0.544	1044.7
Buenz	B4	9.56	0.769	162	0.810	2	16	5	0.542	0.472	0.420	0.585	1202.0
Venoge	V1	8.00	0.643	168	0.840	1	32	12	0.785	0.796	0.529	0.342	6042.0
Venoge	V2	2.26	0.182	82	0.410	11	33	14	0.760	0.820	0.540	0.398	3347.0
Venoge	V3	3.42	0.275	94	0.470	12	34	11	0.871	1.015	0.663	0.223	4813.0
Venoge	V4	5.97	0.480	148	0.740	1	32	9	0.666	0.680	0.451	0.502	4499.5
Sense	S1	10.16	0.817	176	0.880	0	22	11	0.769	0.768	0.248	0.352	2203.5
Sense	S2	9.26	0.745	171	0.855	0	21	12	0.773	0.750	0.246	0.365	2198.0
Sense	S3	7.16	0.575	166	0.830	2	19	9	0.756	0.764	0.260	0.405	1834.0
Sense	S4	5.48	0.441	145	0.725	4	19	9	0.659	0.668	0.227	0.498	2529.5
Sense	S5	4.37	0.351	130	0.650	8	18	9	0.721	0.708	0.245	0.450	1179.0



RPB vs. HMID (Left)



MSP vs. HMID (right)

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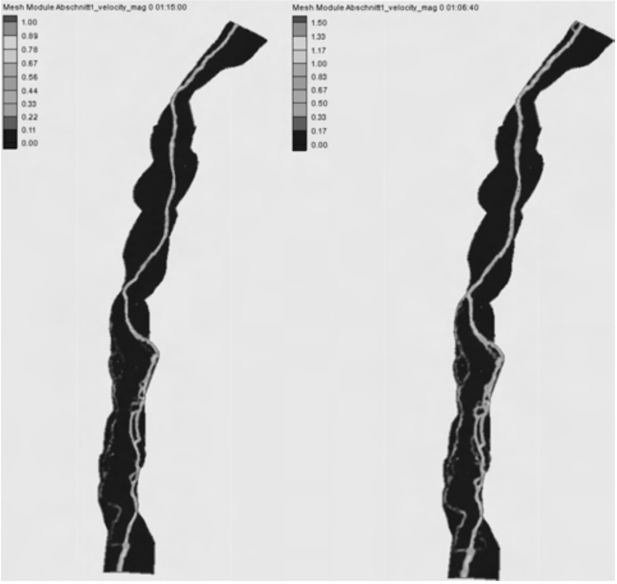
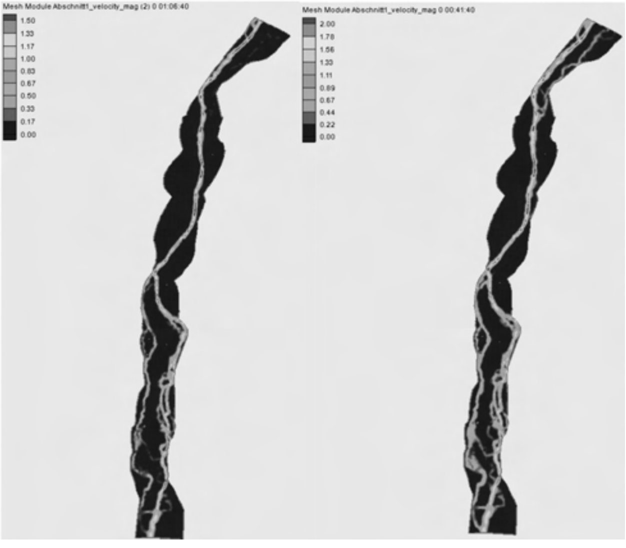
[4] MSP … modular stepwise procedure, modul ecomorphology (BUWAL, 1998)

F. Numerical modelling with BASEMENT: Visualization of flow field

Sense Site n°1

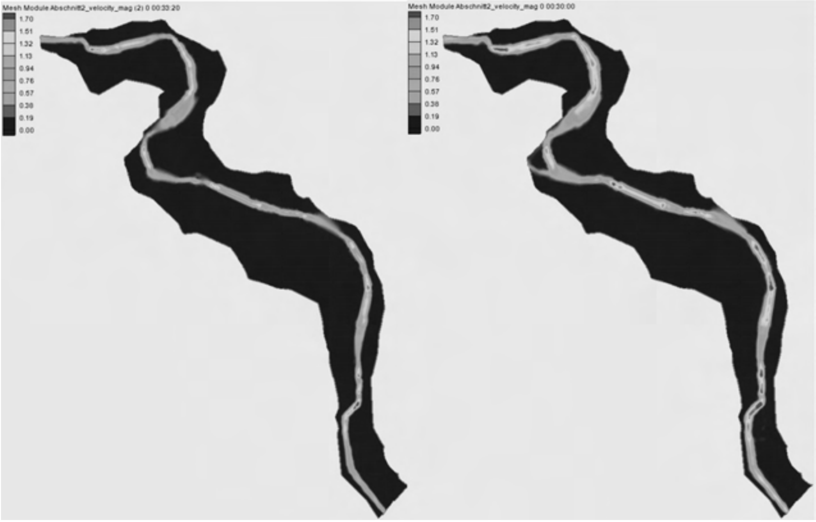


Q332 (left), Q182 (right)

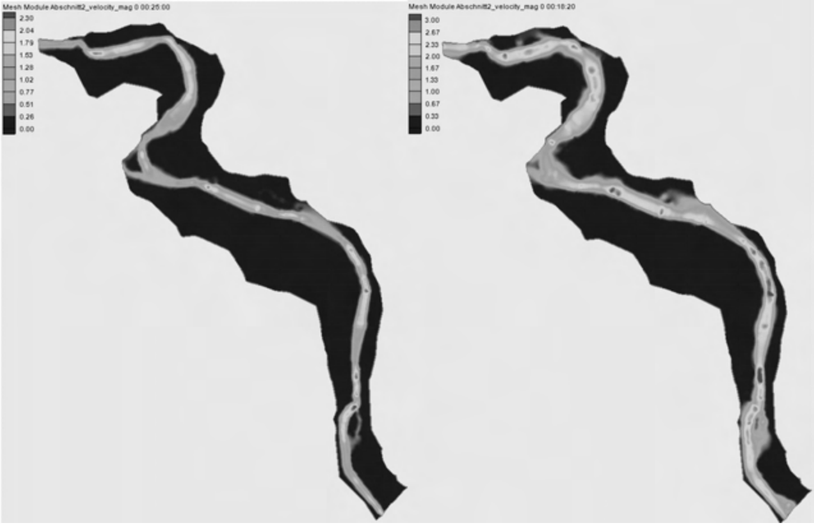


Q109 (left), Q39 (right)

Sense Site n°2

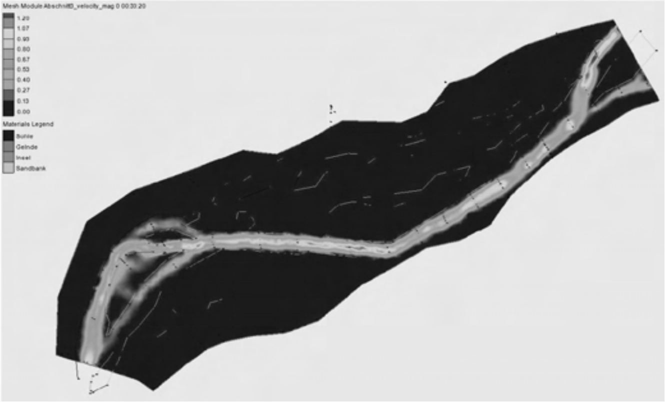


Q321 (left), Q187 (right)

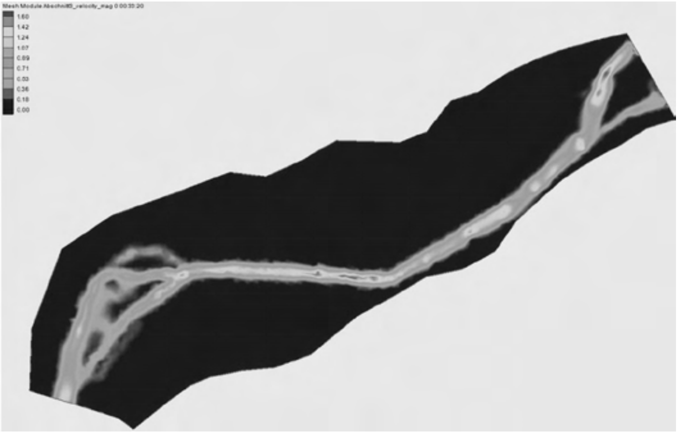


Q99 (left), Q8 (right)

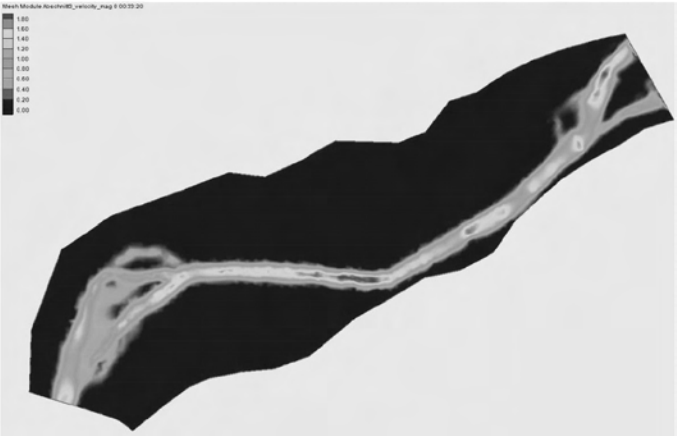
Sense Site n°3



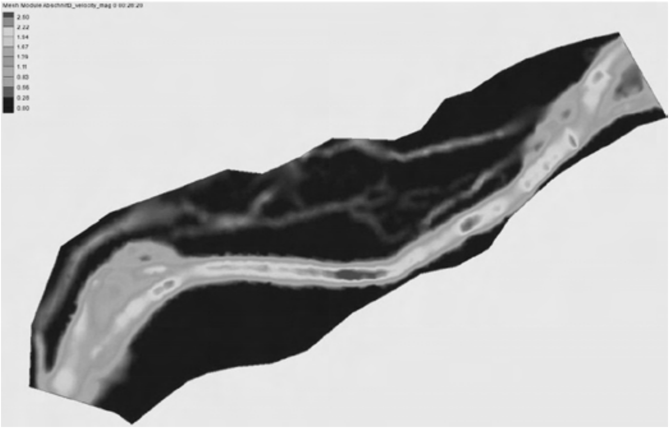
Q332



Q186

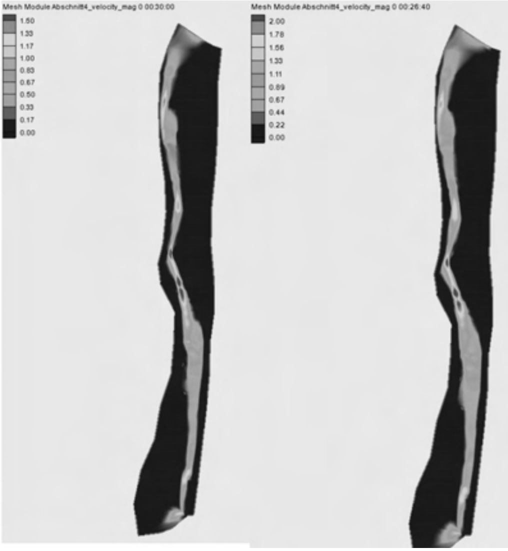

Mesh Module:Abschnitt3_velocity_mag 0 00:33:20
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00

Q89

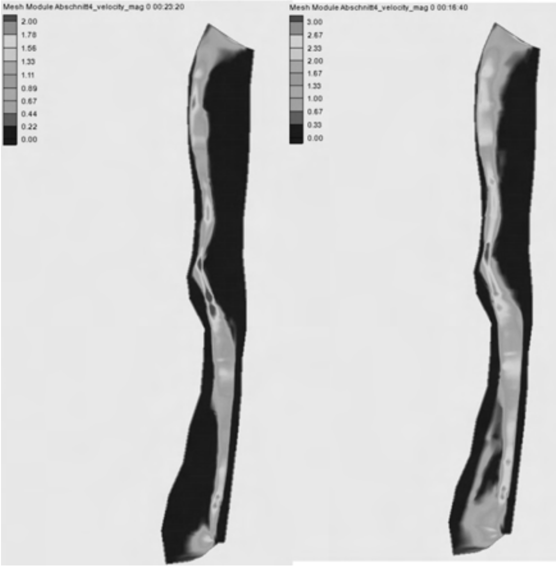

Mesh Module:Abschnitt3_velocity_mag 0 00:26:20
2.50
2.22
1.94
1.67
1.39
1.11
0.83
0.56
0.28
0.00

Q10

Sense Site n°4



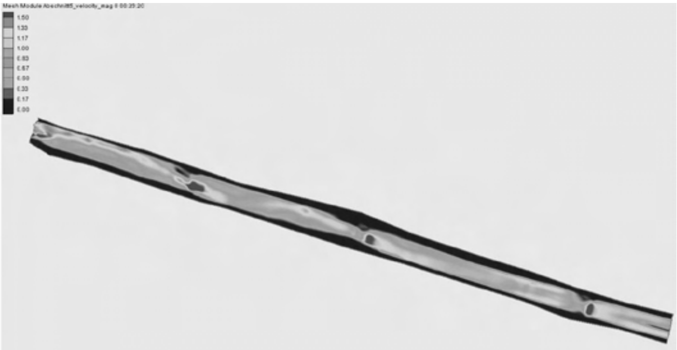
Q327 (left), Q186 (right)



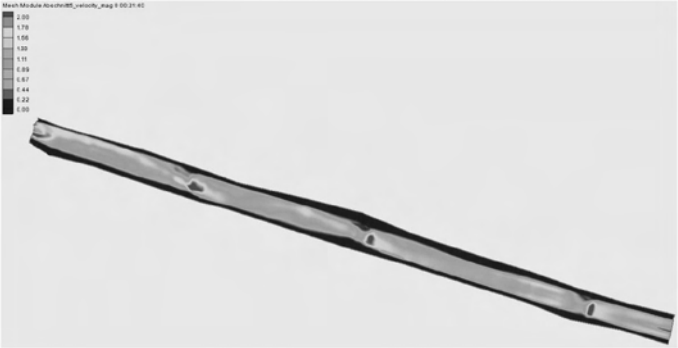
Q103 (left), Q10 (right)

Sense Site n°5

Q338



Q169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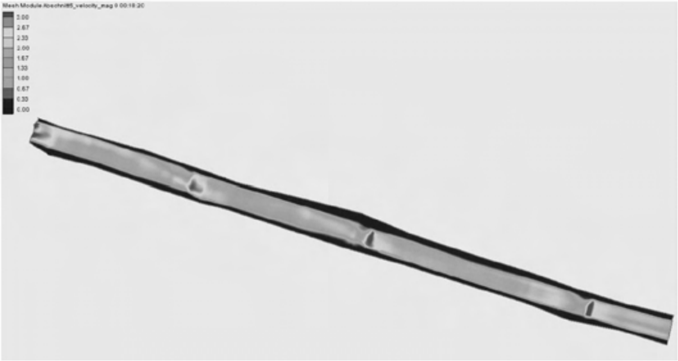
1.78
1.56
1.33
1.11
0.89
0.67
0.44
0.22
0.00

Q86


Mesh Module Abschnitt5_velocity_mag 0 00:18:20
3.00
2.67
2.33
2.00
1.67
1.33
1.00
0.67
0.33
0.00

Q12

G. Statistical parameters and HMID calculation from BASEMENT output

Q	Days exc	Flow velocity				Water depth				HMID
(m^3/s)		μ	σ	Cv	Vi	μ	σ	Cv	Vi	
1.00	355	0.27	0.27	1.00	4.00	0.11	0.07	0.67	2.80	11.18
1.20	332	0.29	0.29	1.00	4.00	0.11	0.08	0.69	2.86	11.46
1.40	303	0.31	0.31	1.00	4.00	0.12	0.08	0.71	2.91	11.65
1.60	275	0.33	0.33	1.00	4.00	0.12	0.09	0.71	2.93	11.74
1.80	253	0.35	0.34	0.97	3.89	0.13	0.09	0.72	2.95	11.45
2.00	235	0.37	0.36	0.97	3.89	0.13	0.09	0.72	2.97	11.56
2.33	207	0.39	0.38	0.99	3.95	0.13	0.10	0.74	3.02	11.91
2.66	182	0.42	0.40	0.95	3.81	0.14	0.10	0.72	2.97	11.33
3.00	159	0.43	0.41	0.95	3.82	0.14	0.11	0.75	3.07	11.70
3.50	131	0.46	0.43	0.93	3.74	0.14	0.11	0.76	3.11	11.65
4.00	109	0.47	0.45	0.96	3.83	0.15	0.11	0.79	3.19	12.22
5.00	82	0.50	0.48	0.96	3.84	0.15	0.12	0.80	3.25	12.47
6.00	63	0.54	0.50	0.93	3.71	0.16	0.13	0.80	3.25	12.07
8.00	39	0.60	0.54	0.90	3.61	0.18	0.14	0.80	3.25	11.73
11.00	22	0.68	0.54	0.79	3.22	0.19	0.16	0.81	3.26	10.51
15.00	11	0.74	0.64	0.86	3.48	0.22	0.18	0.82	3.31	11.49
20.00	5	0.81	0.68	0.84	3.38	0.24	0.20	0.82	3.29	11.15
86.00	1	1.45	0.83	0.57	2.47	0.46	0.33	0.71	2.92	7.21
124.00	0.50	1.70	0.85	0.50	2.26	0.55	0.36	0.65	2.72	6.13
145.00	0.33	1.82	0.87	0.48	2.18	0.60	0.37	0.62	2.63	5.73
160.00	0.25	1.90	0.88	0.46	2.14	0.64	0.38	0.60	2.57	5.50
172.00	0.20	1.97	0.89	0.45	2.10	0.66	0.39	0.59	2.53	5.33
190.00	0.14	2.06	0.89	0.43	2.06	0.70	0.40	0.57	2.47	5.09
208.00	0.10	2.14	0.91	0.43	2.03	0.74	0.42	0.56	2.44	4.96

Site S1

Q	Days exc	Flow velocity				Water depth				HMID
(m^3/s)		μ	σ	Cv	Vi	μ	σ	Cv	Vi	
1.00	360.00	0.47	0.35	0.75	3.07	0.17	0.14	0.82	3.33	10.20
1.25	345.00	0.52	0.38	0.73	3.00	0.19	0.15	0.79	3.20	9.59
1.50	321.00	0.57	0.40	0.70	2.90	0.20	0.15	0.75	3.06	8.87
1.75	288.00	0.60	0.42	0.70	2.89	0.21	0.16	0.76	3.10	8.97
2.00	262.00	0.63	0.44	0.70	2.88	0.22	0.16	0.73	2.98	8.61
2.25	242.00	0.66	0.46	0.70	2.88	0.23	0.17	0.74	3.02	8.71
2.50	221.00	0.66	0.45	0.68	2.83	0.23	0.17	0.74	3.02	8.56
2.75	204.00	0.72	0.49	0.68	2.82	0.25	0.18	0.71	2.92	8.24
3.00	187.00	0.70	0.48	0.69	2.84	0.24	0.18	0.75	3.06	8.70
3.50	159.00	0.78	0.52	0.67	2.78	0.26	0.19	0.73	3.00	8.32
4.00	133.00	0.81	0.55	0.68	2.82	0.27	0.20	0.74	3.03	8.54
4.50	116.00	0.83	0.57	0.69	2.85	0.28	0.21	0.75	3.06	8.71
5.00	99.00	0.82	0.56	0.68	2.83	0.28	0.21	0.75	3.06	8.67
6.00	79.00	0.88	0.59	0.67	2.79	0.30	0.22	0.73	3.00	8.38
7.00	63.00	0.93	0.61	0.66	2.74	0.31	0.23	0.74	3.03	8.32
9.00	42.00	1.01	0.66	0.65	2.73	0.34	0.25	0.74	3.01	8.23
12.00	24.00	1.11	0.72	0.65	2.72	0.39	0.28	0.72	2.95	8.02
16.00	13.00	1.21	0.79	0.65	2.73	0.44	0.31	0.70	2.91	7.94
20.00	8.00	1.29	0.84	0.65	2.73	0.49	0.34	0.69	2.87	7.82
25.00	4.00	1.38	0.89	0.64	2.71	0.54	0.37	0.69	2.84	7.68
101.00	1.00	1.77	1.15	0.65	2.72	0.95	0.67	0.70	2.90	7.90
145.00	0.50	1.94	1.22	0.63	2.65	1.14	0.76	0.67	2.78	7.37
169.00	0.33	2.07	1.25	0.60	2.57	1.27	0.82	0.65	2.71	6.97
187.00	0.25	2.15	1.27	0.59	2.53	1.37	0.86	0.63	2.65	6.70
200.00	0.20	2.20	1.26	0.57	2.47	1.44	0.89	0.62	2.62	6.48
221.00	0.14	2.28	1.29	0.57	2.45	1.56	0.93	0.60	2.55	6.25
242.00	0.10	2.36	1.31	0.56	2.42	1.67	0.98	0.59	2.52	6.09

Site S2

Q	Days exc	Flow velocity				Water depth				HMID
(m^3/s)		μ	σ	Cv	Vi	μ	σ	Cv	Vi	
1.00	363.00	0.33	0.27	0.82	3.31	0.11	0.08	0.73	2.98	9.86
1.25	353.00	0.37	0.29	0.78	3.18	0.12	0.08	0.67	2.78	8.84
1.50	332.00	0.40	0.30	0.75	3.06	0.12	0.09	0.75	3.06	9.38
1.75	307.00	0.42	0.31	0.74	3.02	0.13	0.10	0.76	3.09	9.34
2.00	280.00	0.44	0.32	0.73	2.98	0.14	0.10	0.71	2.94	8.77
2.25	257.00	0.46	0.34	0.74	3.02	0.15	0.11	0.73	3.00	9.09
2.50	240.00	0.47	0.35	0.74	3.04	0.15	0.11	0.73	3.00	9.15
2.75	221.00	0.49	0.38	0.78	3.15	0.16	0.12	0.75	3.06	9.65
3.00	206.00	0.51	0.38	0.75	3.05	0.16	0.12	0.75	3.06	9.33
3.33	186.00	0.52	0.38	0.73	3.00	0.17	0.13	0.76	3.11	9.33
3.66	168.00	0.55	0.40	0.73	2.98	0.18	0.13	0.72	2.97	8.85
4.00	151.00	0.57	0.40	0.70	2.90	0.18	0.13	0.72	2.97	8.59
4.50	130.00	0.59	0.42	0.71	2.93	0.19	0.14	0.74	3.02	8.84
5.00	114.00	0.60	0.44	0.73	3.00	0.20	0.15	0.75	3.06	9.20
6.00	89.00	0.64	0.47	0.73	3.01	0.21	0.16	0.76	3.10	9.34
9.00	49.00	0.74	0.52	0.70	2.90	0.25	0.19	0.76	3.10	8.98
12.00	29.00	0.81	0.57	0.70	2.90	0.28	0.21	0.75	3.06	8.89
111.00	1.00	1.48	0.82	0.55	2.41	0.65	0.41	0.63	2.65	6.40
159.00	0.50	1.68	0.91	0.54	2.38	0.78	0.44	0.56	2.45	5.81
185.00	0.33	1.80	0.93	0.52	2.30	0.86	0.46	0.53	2.36	5.42
205.00	0.25	1.88	0.95	0.51	2.27	0.92	0.48	0.52	2.32	5.25
220.00	0.20	1.94	0.96	0.49	2.23	0.96	0.49	0.51	2.28	5.10
243.00	0.14	2.02	1.02	0.50	2.26	1.02	0.51	0.50	2.25	5.10
266.00	0.10	2.09	1.03	0.49	2.23	1.08	0.53	0.49	2.22	4.95

Site S3

Q	Days exc	Flow velocity				Water depth				HMID
(m^3/s)		μ	σ	Cv	Vi	μ	σ	Cv	Vi	
1.66	356.00	0.40	0.31	0.78	3.15	0.24	0.19	0.79	3.21	10.11
2.00	343.00	0.44	0.33	0.75	3.06	0.26	0.20	0.77	3.13	9.59
2.33	327.00	0.47	0.35	0.74	3.04	0.27	0.20	0.74	3.03	9.22
2.66	304.00	0.50	0.36	0.72	2.96	0.28	0.21	0.75	3.06	9.06
3.00	279.00	0.53	0.38	0.72	2.95	0.29	0.21	0.72	2.97	8.76
3.50	252.00	0.57	0.40	0.70	2.90	0.30	0.22	0.73	3.00	8.70
4.00	228.00	0.61	0.41	0.67	2.80	0.31	0.23	0.74	3.03	8.48
4.50	206.00	0.64	0.43	0.67	2.80	0.33	0.23	0.70	2.88	8.05
5.00	186.00	0.67	0.44	0.66	2.74	0.34	0.24	0.71	2.91	7.99
6.00	152.00	0.71	0.47	0.66	2.76	0.35	0.25	0.71	2.94	8.12
7.00	123.00	0.77	0.49	0.64	2.68	0.38	0.26	0.68	2.84	7.60
8.00	103.00	0.81	0.51	0.63	2.66	0.40	0.27	0.68	2.81	7.45
10.00	77.00	0.89	0.55	0.62	2.62	0.43	0.29	0.67	2.80	7.34
13.00	51.00	0.97	0.61	0.63	2.65	0.47	0.31	0.66	2.75	7.31
17.00	31.00	1.05	0.67	0.64	2.68	0.51	0.35	0.69	2.84	7.63
20.00	23.00	1.11	0.70	0.63	2.66	0.55	0.37	0.67	2.80	7.44
30.00	10.00	1.27	0.78	0.61	2.61	0.65	0.42	0.65	2.71	7.06
40.00	4.00	1.31	0.85	0.65	2.72	0.70	0.48	0.69	2.84	7.73
152.00	1.00	2.19	1.03	0.47	2.16	1.44	0.73	0.50	2.26	4.89
217.00	0.50	2.33	1.22	0.52	2.32	1.62	0.84	0.52	2.31	5.35
255.00	0.33	2.46	1.26	0.51	2.29	1.77	0.88	0.50	2.24	5.13
282.00	0.25	2.54	1.30	0.51	2.29	1.87	0.92	0.49	2.23	5.09
303.00	0.20	2.61	1.31	0.50	2.26	1.95	0.94	0.48	2.20	4.95
335.00	0.14	2.71	1.35	0.50	2.24	2.07	0.97	0.47	2.16	4.84
368.00	0.10	2.79	1.38	0.49	2.23	2.19	1.00	0.46	2.12	4.74

Site S4

Q	Days exc	Flow velocity				Water depth				HMID
(m^3/s)		μ	σ	Cv	Vi	μ	σ	Cv	Vi	
2.00	355.00	0.46	0.30	0.65	2.73	0.15	0.12	0.81	3.27	8.92
2.50	338.00	0.50	0.32	0.64	2.69	0.16	0.13	0.81	3.29	8.84
3.00	304.00	0.54	0.32	0.59	2.54	0.17	0.13	0.76	3.11	7.90
3.50	272.00	0.59	0.35	0.59	2.54	0.18	0.13	0.72	2.97	7.53
4.00	249.00	0.63	0.35	0.56	2.42	0.20	0.14	0.70	2.89	6.99
4.50	225.00	0.67	0.34	0.51	2.27	0.21	0.14	0.67	2.78	6.31
5.00	205.00	0.70	0.35	0.50	2.25	0.22	0.14	0.64	2.68	6.02
6.00	169.00	0.76	0.36	0.47	2.17	0.24	0.15	0.63	2.64	5.73
7.00	139.00	0.82	0.38	0.46	2.14	0.26	0.15	0.58	2.49	5.33
8.00	117.00	0.88	0.38	0.43	2.05	0.28	0.16	0.57	2.47	5.06
10.00	86.00	0.98	0.40	0.41	1.98	0.32	0.16	0.50	2.25	4.46
12.00	66.00	1.08	0.42	0.39	1.93	0.36	0.17	0.47	2.17	4.18
15.00	47.00	1.19	0.44	0.37	1.88	0.41	0.18	0.44	2.07	3.89
19.00	30.00	1.31	0.49	0.37	1.89	0.47	0.19	0.40	1.97	3.72
30.00	12.00	1.55	0.62	0.40	1.96	0.59	0.24	0.41	1.98	3.88
40.00	5.00	1.71	0.72	0.42	2.02	0.69	0.28	0.41	1.98	3.99
159.00	1.00	3.06	1.08	0.35	1.83	1.59	0.46	0.29	1.66	3.04
227.00	0.50	3.26	1.46	0.45	2.10	1.78	0.67	0.38	1.89	3.97
267.00	0.33	3.43	1.58	0.46	2.13	1.92	0.75	0.39	1.93	4.13
315.00	0.20	3.61	1.74	0.48	2.20	2.08	0.85	0.41	1.98	4.36
350.00	0.14	3.71	1.83	0.49	2.23	2.17	0.90	0.41	2.00	4.46
385.00	0.10	3.83	1.89	0.49	2.23	2.28	0.95	0.42	2.01	4.48

Site S5

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