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MASTER THESIS

In partial fulfilment of the requirements for the degree of

Master of Science

INFLUENCE OF LATERAL GRAVEL BANK SLOPE AND TIME OF THE DAY ON DRIFT AND STRANDING OF LARVAL GRAYLING *(THYMALLUS THYMALLUS L.)* DUE TO HYDROPEAKING

submitted by:

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Affirmation

I certify, that the Master Thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Vienna, 23.01.2017 *Dessislava Alexandrova* *signature*

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Abstract

The present study is part of the MARS project (**M**anaging **A**quatic Ecosystems and Water **R**esources under Multiple **S**tress) funded by the European Union. The purpose of this thesis is to investigate the drift and stranding risk of larval grayling *(Thymallus thymallus,* L.*)* due to the fluctuating water levels from hydropower plants, so called hydropeaking. In Austria, hydropeaking affects approximately 965 km of river stretches. Hydropeaking rivers are inhabited by European grayling (*Thymallus thymallus, L.*), which are dominant species that has been listed as endangered species in Austria since 1997. The fish is very susceptible to high flow fluctuations, especially in the early life stages due to their preferred habitat and juveniles are rarely found in river sections with significant changes in flows. The ultimate objective of the present thesis is to investigate the influence of the lateral slope of gravel bars and the time of the day on drift and stranding behaviour of graylings due to hydropeaking. In a broader sense, the findings can be used for recommendations concerning rehabilitation as well as effective measures to mitigate damage caused by hydropeaking and to restore the ecological quality or functioning of the river. Experiments were conducted at the HyTEC (**Hy**dromorphological and **T**emperature **E**xperimental **C**hannels) facility in Lunz am See (Lower Austria). Hydropeaking simulations and reference experiments were performed during the day and night at 3.5 % and 11 % lateral gravel bar slope. The graylings used for the trials comprise hatched larvae originating from wild fish from the rivers Ybbs, Salza and Mur. Fish size was between 17.31 mm to 22.40 mm and the age from 4 to 29 days after hatching. The experiments were executed between 06.05.2016 to 23.06.2015. The results revealed that the time of the day has a significant influence on the stranding of larval graylings. During the night, more fish stranded compared to the day time. In terms to the lateral gravel bar slopes, more stranding occurred on the 3.5 % than on the 11 % slope, although the difference was not significant. Downstream displacement of larval graylings was not affected by the time of the day or the lateral slopes of gravel bars.

1. Introduction

Hydropower is one of the main sources for generation of renewable energy in the electricity sector. In the last decade, the global use of hydropower has strongly increased due to higher demand for electricity, economic development, climate change, and GHG mitigation policies (Kumar et al., 2011; IPCC, 2011). Hydropeaking caused by hydropower facilities is considered to have a negative impact on lotic ecosystems, particularly on the drift of macroinvertebrates, stranding of fish, and results in changes of their habitat (Moog, 1994; Parasiewicz et al., 1998). The frequency of the peak flows (periodicity) occur faster than the ability of the organisms to adapt to new conditions caused by peak flows. The sudden increase and decrease of the water volume leads to changes in the water depth, flow velocity, and wetted area (Charmasson et al., 2011; Parasiewicz et al., 1998).

The present study is part of the MARS project (Managing Aquatic Ecosystems and Water Resources under Multiple Stress). The ultimate goal of MARS is to investigate how multiple stressors affect rivers, lakes, and estuaries. The project operates at three scales: water body; river basin and European scale, and addresses the connection between the multiple stressors, ecological responses, and functions. MARS aims to support managers and policy makers in the implementation of the WFD, the Floods Directive, and the Blueprint to Safeguard Europe's Water Resources (Hering et al., 2015). The project addresses the most relevant stressor combinations that affect the European water bodies.

In the Alpine region the most relevant stressor combinations affecting the aquatic ecology are related to hydropower generation (Hering et al., 2015). In Austria, around 55 % of the current electricity demand is covered by hydroelectric power production (E-Control 2009). Hydropeaking occurs mainly in medium and large rivers in the grayling and trout region (Hyporhithral and Metarhithral). The most affected river stretches are in the Hyporhithral zone where the European grayling *(Thymallus thymallus, L.)* is the dominant species. In Austria, over the recent years the grayling has severely declined in population sizes (Uiblein et al., 2001) and has been listed as endangered species since 1997. The European graylings are extremely susceptible to peak flows mainly because the early life stages inhabit the hydropeaking zone (Nagrodski et al., 2012; Schmutz et al., 2013; Schmutz et al., 2014). The impact of hydropeaking on graylings has not been well studied. Most of the available studies on the effect of hydropeaking have focused on salmonid species such as salmon and trout. Little information is available for the vulnerable European grayling (Nagrodski et al., 2012; Schmutz et al., 2013; Schmutz et al., 2014). Furthermore, the information available in the literature on drift and stranding of grayling is not sufficient. There are contradictory results in terms of the time of the day when other factors such as the water temperature and the seasonal variability has been also considered (Bradford, 1997; Halleraker et al., 2003; Nagrodski et al., 2012; Saltveit et al., 2001). Some studies showed higher stranding rates during the day time and depending on the season, due to substrate concealment behaviour of the juvenile fish (Bradford et al., 1995; Bradford, 1997), whereas other research found more stranding during the night time (Hamilton and Buell, 1976). In terms of the channel morphology different authors concluded that more beach stranding occurs on gently sloping gravel bars, than on steeper banks slopes (Adams et al., 1999; Bradford et al., 1995; Hunter, 1992). However, stranding under natural conditions on steeper lateral gravel bar slopes > 5 % has not been widely investigated (Hunter, 1992). In addition, most of the field studies have been conducted in stream channels and little information is available on stranding in experimental channels (Schmutz et al., 2014).

This thesis is specifically concerned with the drift and stranding risk of larval grayling due to hydropeaking. Factors considered concerning stranding frequency include lateral gravel bar slope and time of the day. The experiments have been conducted at the research centre HyTEC (Hydromorphological and Temperature Experimental Channels) in Lunz am See (Lower Austria). Performing research in experimental channels provides more possibilities to investigate different parameters and conduct consistent replicates. Controlled hydropeaking and reference experiments have been performed repeatedly during the day and night at experimental channels with 3.5 % and 11 % lateral gravel bar slope. The thesis analyses the dependency of drift and stranding of fish on diurnal time and channel morphology.

2. Problems and objectives

In 2013, renewable energy has contributed approximately 19.1 % to the global energy production (Foley et al., 2015). Hydropower is the primary renewable energy source, providing 16 % of the world electricity supply and 70 % of the total renewable energy production. The generation of hydroelectricity is proven, reliable, and a cost-effective technology. Hydropower facilities require relatively high initial investments, but due to their long lifespan, low operational, and maintenance costs, they are economically competitive. Currently, hydropower facilities are used in over 160 countries worldwide (Kumar et al., 2011; Person, 2013; Seyboth, 2016). Hydroelectricity has a minimum contribution to CO_2 loads in the atmosphere and therefore is seen as a very attractive source in terms of GHG mitigation policies. Hydropower has a very high conversion efficiency amounting to approximately 90 % water to wire. Hydropower plants can provide incentives for socio-economic development by producing energy and providing water management services. The high head storage power plants can assure municipal and industrial water supply, mitigate water scarcity during drought periods and prevent against flooding (Kumar et al., 2011; Person, 2013). The hydroelectricity generation output can be operated with flexibility and provide power for base load and peak hours. The energy production can start and stop at a low cost, thus assuring reliable power source depending on the market needs and especially in times of changing demand and supply patterns (Kumar et al., 2011; Person, 2013).

While hydroelectric power production has many positive effects on a global level, it can cause significant impact on the environment on a local scale. Storage facilities may work periodically following energy consumption patterns, thus causing short-term fluctuations of flow in the receiving water body. Artificial discharge peaks caused by hydroelectric power plants are called hydropeaking. Moog (1993) has defined hydropeaking as the release of water retained in storage basins to generate electricity according to variations in market demand (Charmasson et al., 2011). The hydropeaking alters the amount of water in the river downstream and can have severe impact on local ecosystems and stream biodiversity. The flow magnitude of hydropeaks, as well as frequency and duration differ from natural discharge conditions. The sudden change in the water volume as water is released from dams results in changes in the flow velocity, water depth, wetted area, water temperature, channel morphology, and the composition of the suspended matter (Charmasson et al., 2011).

2.1. Hydropeaking in Austria

In Austria, approximately 965 km of river stretches including 122 water bodies are significantly affected by hydropeaking (Rahmen & Umwelt, 2015) (Figure 1.). The impact of the flow peaks in large rivers with catchment areas > 1000 km² is particularly high. The hydropeaking occurs mainly in medium to large Alpine rivers like Drau, Moell, Mull, Enns, Alpenrhein and Inn, which are primarily attributable to the lower trout region, the grayling region and the transition to the barbel region (Schmutz et al., 2013). Most of the Alpine rivers are channelized resulting in degraded condition for the fish. Due to hydropeaking the fish experience extensive additional stress and often cannot survive the artificial fluctuations in peak flow (Gostner et al., 2011; Schmutz et al., 2014).

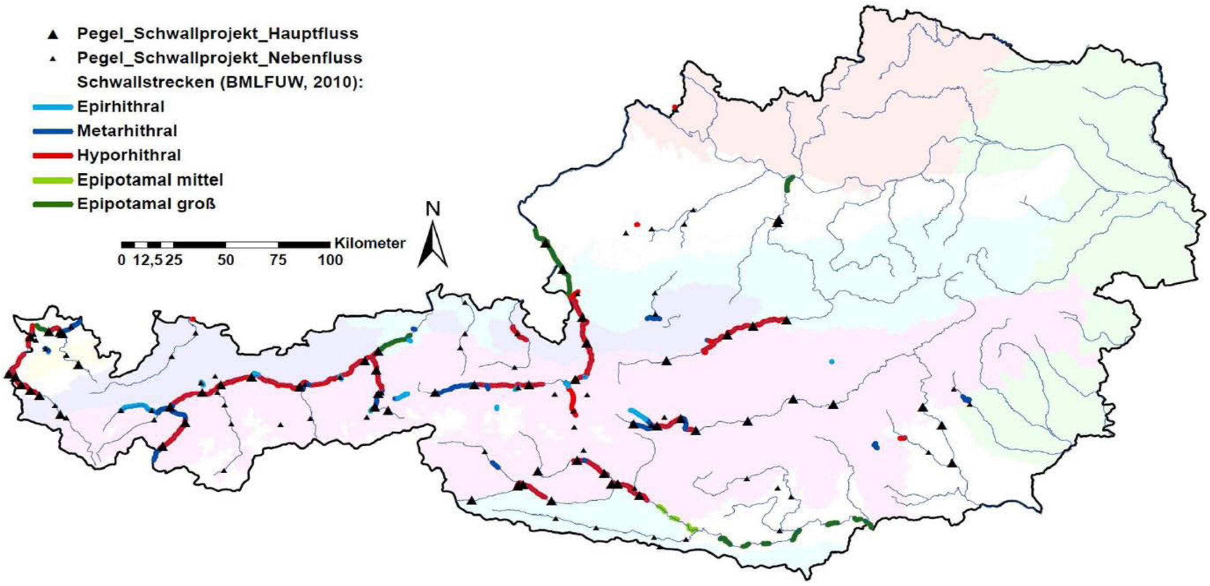

Figure 1. Austrian river stretches impacted by hydropeaking, fish zones and sampling sites (derived from Schmutz et al., 2015)

The artificial peak flows have the highest impact in the hyporhithral region, which is inhabited by with European grayling (Schmutz et al., 2013). This species is very susceptible to high fluctuations in flow. Juveniles are rarely found in river sections with significant changes in the peak flow (Schmutz et al., 2014). Over the past two decades, different studies reported a wide spread decline in the populations of the European grayling, primarily due to anthropogenic changes in biotic and abiotic conditions. In Austria, European grayling has been listed as endangered since 1997 (Spindler, 1997; Uiblein et al., 2001). The fish is also protected under Appendix III of the Bern Convention on the Conservation of European Wildlife and Natural Habitats (Ingram et al., 1999). Because graylings are significantly affected by the operation of power plants due to their distribution patterns and ecological requirements, it was chosen as indicator species for this study (Schmutz et al., 2013; Schmutz et al., 2014).

2.2. Characterization of hydropeaking

Hydropeaking is characterized with the changes in the discharge regime and water level for a period of time. Figure 2 shows the hydropeaking parameters affecting the hydrological regime of rivers.

Flow regime parameters

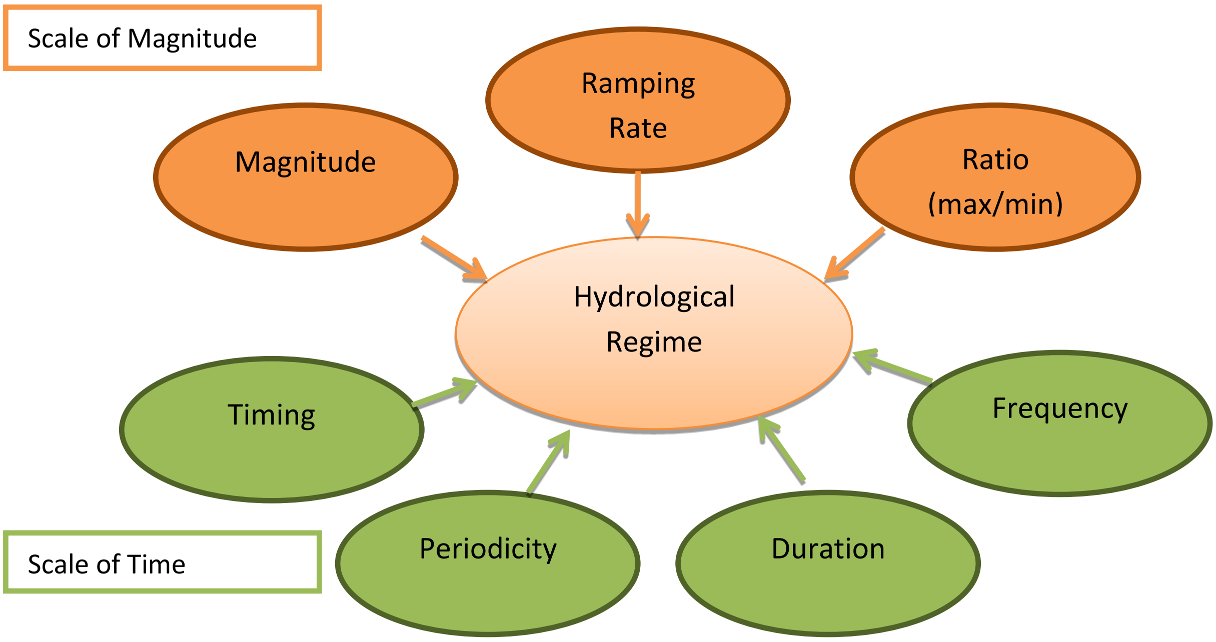

Figure 2. Hydropeaking parameters affecting the hydrological regime of rivers (adapted from Charmasson et al., 2011)

In **Table 1**. several key parameters measured from the hydrograph are taken into account in order to describe the hydropeaking regime:

- Q_{max}- maximum discharge value reached at the peak event
- Q_{min}- minimum discharge values before and after the peak event
- Q_{mean}- mean discharge values during the time period studied
- (Q_{max} - Q_{min})- discharge magnitude
- (Q_{max}/Q_{min})- discharge ratio, calculated for increase and decrease in water volume (Charmasson et al., 2011).

Table 1. Parameters and derived values for the characterisation of hydropeaking (Charmasson et al., 2011)

Type of parameter	**Measured parameters**	**Derived hydropeaking indicators**
Magnitude	Maximum discharge $\boldsymbol{Q_{max}}$ Minimum discharge $\boldsymbol{Q_{min}}$ Mean discharge $\boldsymbol{Q_{mean}}$	Discharge ratio: $\boldsymbol{Q_{max}} / \boldsymbol{Q_{min}}$ Discharge magnitude: $\boldsymbol{Q_{max}} - \boldsymbol{Q_{min}}$ $\Delta \boldsymbol{Q} / \boldsymbol{Q_{mean}}$ Rate of flow increase/decrease $\boldsymbol{dQ/dt}$
Time	Duration of the peak Time of start/end of the peak Duration between peaks Duration between low flows stage	Length Timing Periodicity Frequency

Except for the changes in discharge, flow fluctuations can be measured by changes of a given stage. The rate of flow increase or decrease is calculated in m^3/s per minute or per hour and refers to the rapid change in discharge during hydropeaking events (dQ/dt) (Baumann, 2003; Charmasson et al., 2011).

The observed parameters during the hydropeaking are shown on Figure 3.

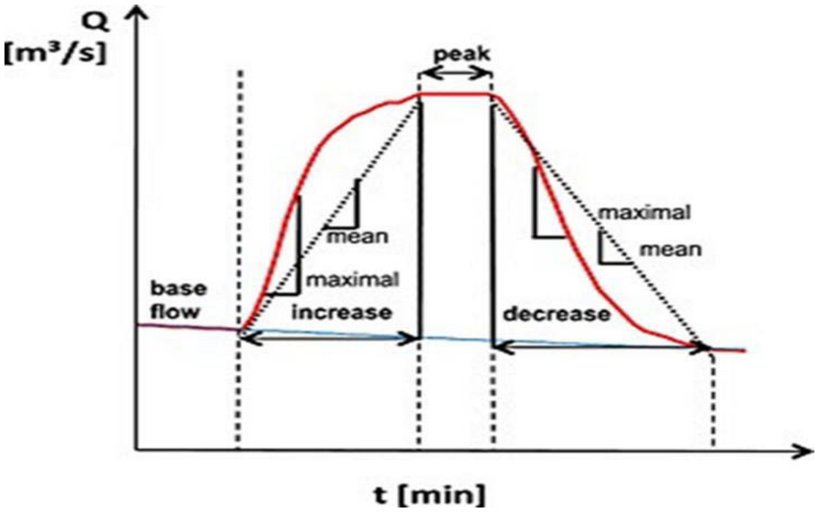

Figure 3. Hydrological variables derived from flow curves (Schmutz et al., 2014)

The following parameters for increase and decrease in the flow curve are described in Schmutz et al., 2014.

- Duration dt (min)
- Mean increase/decrease (m^3/s)
- Maximum increase/decrease (m^3/s)
- Total increase/decrease (m^3/s, per event)

2.3. Impact on river ecosystems and fish ecology

The river morphology and the abiotic processes determine the suitability of the habitat for the living organisms. Changes in the physical parameters have direct effects on the biological communities (Person, 2013, Young et al., 2011). The impact of hydropeaking on the river ecosystems and the fish population is shown on the flowchart in Figure 4.

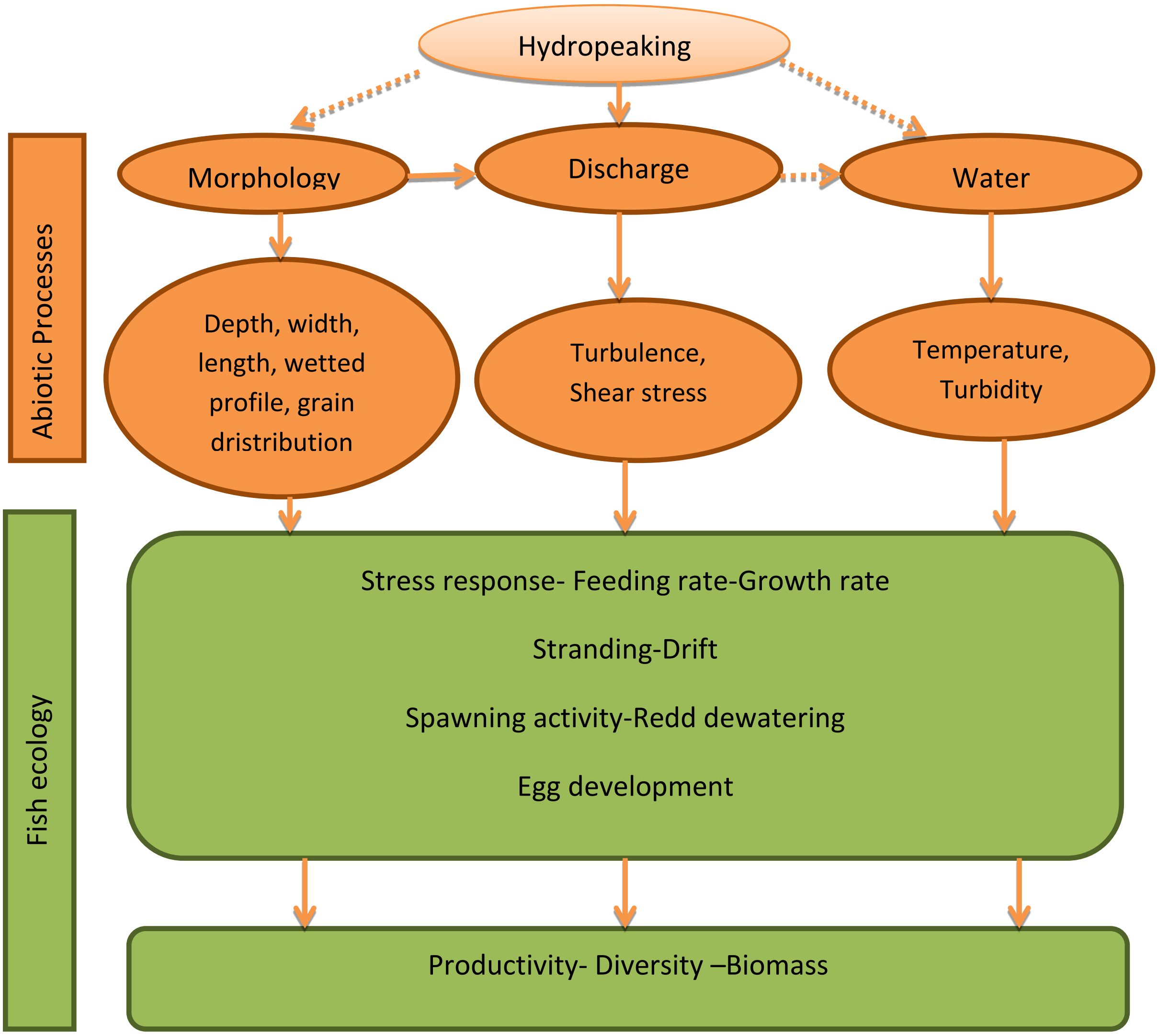

Figure 4. Abiotic processes influenced by hydropeaking and their impact on river streams and salmonids population (modified after Person, 2013)

The main impact caused by hydropeaking is the alteration of the hydrological characteristics downstream of the dam. The discharge regime which is an essential component for the ecological qualities of rivers is seriously affected. The thermal regime may also be altered as the temperature of the water released from the power plant outlet may be different from the temperature in the receiving river. This temperature hydropeaking, which is also known as thermopeaking, can severely impact the integrity of the freshwater ecosystems (Person, 2013).

Sediment transportation in lotic systems depends on different hydrological components such as lateral slope, water depth, and velocity. During peak flows, sediment is relocated and transported, and erosion is increased. During low flow, due to the low flow velocities, the sediment is redeposited and thus leading to river bed clogging (Person, 2013).

The abiotic factors and the morphological components define the physical habitat for stream biodiversity. Modification of the abiotic parameters due to pulse flows can have severe impacts on aquatic organisms. Different studies have focused on the negative consequences on fish, macroinvertebrates, and aquatic plants (Moog et al., 1994; Parasiewicz et al., 1998; Person, 2013; Young et al., 2011).

A simplified diagramme (Figure 5.) shows the impact of hydropeaking on fishes. The solid lines illustrate the direct effect on fish, whilst the dashed lines illustrate indirect consequences.

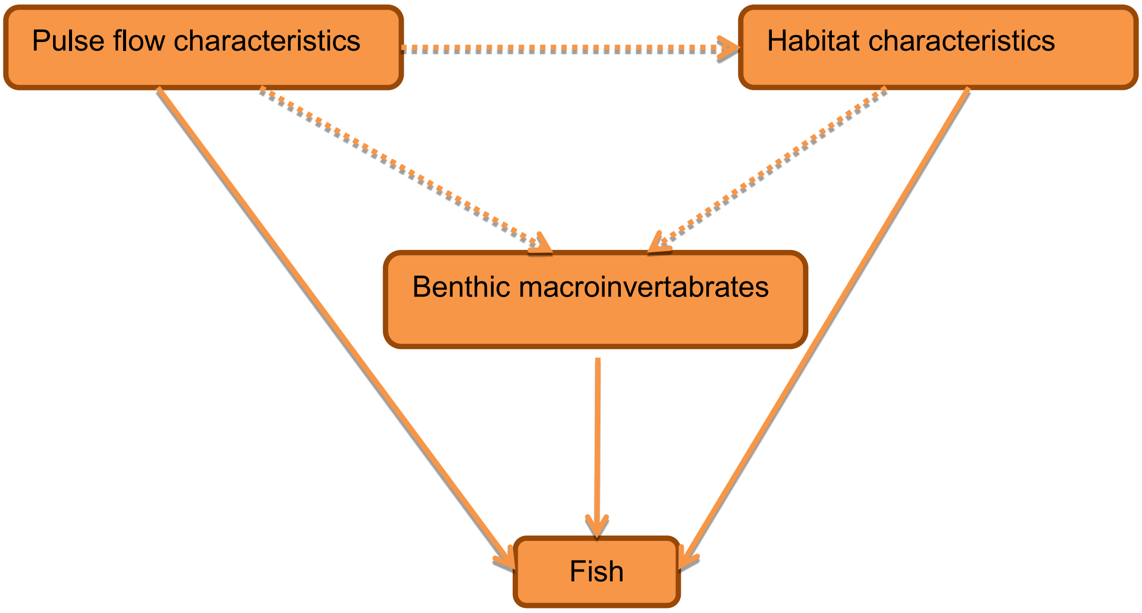

Figure 5. Simplified conceptual diagram of hydropeaking impact on fish (after Young et al., 2011).

The pulse flow characteristics may include seasonality (winter/spring vs. summer/fall), frequency (single or repeated), magnitude (small or large), duration (short or long), as well as photo phase (day or night) (Young et al., 2011).

Fish are good indicators of the ecological state of lotic ecosystem. Representative species (indicator species) are usually selected as target species to investigate the negative consequences resulting from hydropower operations. Often salmonid species are used in the studies because they occur in the upper part of the catchments, where the impact of hydropower is high, and the species are most severely impacted. The salmonids are very sensitive and more susceptible to the high flow fluctuations during their larvae stages in comparison to other species encountered in the same streams (Charmasson et al., 2011; Person, 2013; Young et al., 2011). In Austria, the zone experiencing most pressure from hydropeaking is the hyporhithral zone where the European grayling is a dominant species.

2.4. Characterization of drift and stranding

The most significant biological impact on fish caused by pulsed flows is stranding (Schmutz et al., 2014; Young et al., 2011).

Stranding is defined as the "separation of fish from the flowing surface water as a result of declining river stage" from rapid decreases in flow (downramping) (Hunter et al., 1992).

Fish can be stranded during the rapid flow decrease on the shifted side channels or on the low lateral bar slopes downstream of the power station (Young et al., 2011). The stranding can be distinguished between:

- beach stranding- the fish are out of the water and flounder out on the substrate
- entrapment in pockets of water- the fish are trapped in potholes and do not have access to the flowing water (Higgins et al., 1996; Young et al., 2011)

Due to stranding, fish can experience hypoxia, desiccation, temperature stress, predation, and mortality in different life stages, i.e. eggs, fry, juvenile, and adult fish (Young et al., 2011).

The photo on Figure 6 shows stranded larvae graylings after a hydropeaking experiment at the HyTEC experimental channels.

Figure 6. Stranded larval graylings after hydropeaking simulations at the HyTEC experimental channels (Auer, 2013)

Drift is another significant impact on fish caused by hydropeaking.

Drift is defined as the downstream displacement of the fish under current velocities (Hunter, 1992).

The following types of drift can be considered:

- passive drift- the downstream displacement in the direction of the current, due to changes in flow velocities
- active drift- the fish choose to swim with the current, against the current or not swim at all (Hogan et al., 2005)

Different factors such as the channel morphology, the downramping rate, the time of the day, as well as fish size, influence the incidence of drift (Young et al., 2011; Zitek et al., 2004). The discharge fluctuations from the hydropower facilities have highly disturbing effects, as according fluctuations may result in displacement and multiple drift of the fish larvae (Schmutz et al., 2014). With increased flow-rates during the rising limb of the hydropeaking wave the fish tend to drift. This applies particularly for the larvae in their early stages of life, since the swimming performances of such larvae are not sufficient to withstand the strong current (Adams et al., 1999; Fohler, 2013).

2.5. Factors influencing the fish drift and stranding

In general, the factors that determine the rates of fish stranding can differ. Many studies agree that reduced water flow, shallow shorelines, lower temperatures, decline in water quality and strongly structured shorelines and riverbeds increase the stranding of fish (Halleraker et al., 2003; Murchie et al., 2007; Nagrodski et al., 2012; Saltveit et al., 2001; Schmutz et al., 2013).

Fish stranding is mainly induced by the following biotic and abiotic factors that will be further discussed below: life stage, channel morphology, substrate composition, time of the day, downramping rate, and fish species. (Bradford, 1997; Halleraker et al., 2003; Hunter, 1992; Irvine et al., 2007; Nagrodski et al., 2012; Poff et al., 1997; Saltveit et al., 2001; Schmutz et al., 2014; Scruton et al., 2008; Young et al., 2011).

- Life stage

The habitat preferences of the larval grayling are in the hyporhithral region close to gravel banks. The species favours shallow waters with low flow velocities (Bardonnet et al., 1991; Ingram et al., 1999; Sempeski et al., 1995). As water levels rise during hydropeaking, the graylings stay closer to the marginal areas of the water shoreline where flow velocities are lower. When the water recedes during downramping the risk of stranding increases, which is more pronounced on the lower gradient slopes (Adams et al., 1999; Bardonnet et al., 1991; Bradford et al., 1995; Hunter, 1992; Sempeski & Gaudin, 1995).

With respect to life stages, salmonid fry and larvae are more susceptible to stranding in comparison to the adults. After emerging from the eggs in the substrate, the salmonids avoid deep waters and settle along the river margins. The larval fish are weak swimmers and seek shallow and quiet places near the shore in order to find a refuge mainly from currents and larger fish. For different species, the vulnerability is considerably lower after the fry has grown to a certain size. The sudden flow increase during hydropeaking results in drift and displacement of the larval fish but it is not a cause for the stranding. The latter occurs when the flow decrease is too sudden and the fish cannot manage to find habitats that remain water covered. Stranding can result in mortality due to desiccation, increased temperature, or predators (Hunter, 1992; Pacificorp, 2004).

- Lateral slope and channel morphology

The channel morphology has a significant influence on the risk of stranding. Rivers with side channels, low lateral bank slopes and potholes result in higher fish stranding rates compared to single channel rivers with steep slopes. The steeper lateral slopes however provide less suitable habitat conditions for the graylings, especially in their larvae stages (Nykanen et al., 2003; Sempeski et al., 1995).

In general, higher standing rates occurred in slopes < 5 % (Bauersfeld, 1978; Monk et al., 1989). Research with respect to lateral gravel bar slopes > 5 % has not been widely conducted (Hunter, 1992). River configurations with long side channels that have intermittent flow are well known for trapping fish in their fry stages. Juveniles of certain species chose such side channels for rearing habitats. Repeated controlled peak flows can trap significant numbers of juveniles and cause high mortality in such species (Olson et al., 1990, Hunter, 1992).

- Substrate composition

Different types of substrate composition induce different incidents and frequencies of stranding. Most of the research and observations have focused on gravel and cobble type substrates. However, stranding has also been observed in sand, mud and vegetation. Sandy areas with shallow depressions as well as large organic debris such as piles of leaves and roots can also lead to fish stranding (Hunter, 1992; Pacificorp, 2004).

- Time of Day

The vulnerability of fish to stranding during different times of the day has been investigated in different research papers. Results reported are contradictory. Some studies showed higher stranding rates during the day due to substrate concealment behaviour of the juvenile fish (Bradford et al., 1995; Bradford, 1997). Other research found more stranding during the night (Hamilton and Buell, 1976). A study conducted by Woodin (1984) found that juvenile chinook (*Oncorhynchus tshawytscha*) is using the substrate for cover only to a smaller degree at night, therefore these species are less likely to strand at night. Research on steelhead fry (*Oncorhynchus mykiss*) indicates that this species is less susceptible to stranding during the day, presumably because the fish feeds during this time (Olson et al., 1990).

In different studies stranding has been linked to time of the day in combination with temperature (Bradford et al., 1995; Halleraker et al., 2003; Bradford, 1997). In the Nidelva River (Norway) Saltveit et al., (2001) revealed that the season, time of the day and temperature are the main factors influencing stranding of juvenile salmonids (Atlantic salmon and brown trout). His study revealed higher stranding during lower temperatures in winter and at day time due to lower activity and substrate seeking behaviour. During the summer when water temperatures are higher, the trend was opposite with higher stranding rates for both species during the night (Saltveit et al., 2001; Schmutz et al., 2014).

Bradford et al., (1997) conducted an experimental study in artificial stream channels to investigate the effect of stranding of juvenile salmonids on gravel bars as flow rapidly decreases.

His study examined newly emerged chinook *(Oncorhynchus tshwytscha)* and coho salmon *(Oncorhynchus kisutch).* Factors such as downramping rate, time of the day and water temperature were varied. Six times more chinook salmon were stranded over a gravel bar at lower water temperature (6 °C compared to 12 °C) and the downramping rate was not seen as a significant factor. In the side channels built in the stream channel, however, rapid decrease of flow had a strong effect and more chinook and coho were trapped, with higher numbers of coho salmon trapped at night as compared to the daytime.

Bradford et al. (1995) focused on stranding of juvenile coho salmon and rainbow trout on river bars. The experiments were conducted in an artificial stream channels with gravel bar substrate and winter water temperatures <4°C. During the day, the incidence of stranding was higher because the fish were concealed in the interstitial areas of the substrate and hesitated to leave when water levels receded. During the night, less stranding occurred, as the fish were more active. The research results suggested that less stranding will occur during winter conditions, at night and at slow rates of flow reduction (Bradford et al., 1995).

Halleraker (2003) performed experiments with brown trout (Salmo trutta) in artificial stream channels. He varied the downramping rates, time of the day and water temperature. Based on his results and in order to reduce the stranding of salmonids, he recommend dewatering during darkness at all times of year as well as slow downramping rates <10 cm h^{-1}.

- Downramping rate

Downramping can be defined as the decline of the water flow or river stage per hour. Rapid downramping is seen as one of the prime causes for fish stranding. More fish are likely to be stranded with increased downramping. Different studies revealed that with reduction of the downramping rate, the potential of fish stranding decreases (Bradford, 1997; Halleraker et al., 2003; Hunter, 1992). While management of the down-ramping rates could decrease the probability of beach stranding, in terms of side channel and pothole entrapment such measures would be less effective (Hunter, 1992; Pacificorp, 2004; Young et al., 2011).

- Fish species

The vulnerability to stranding is associated to the behavioural response of the fish to reduced water levels. Species inhabiting littoral and backwater regions, that passively drift or swim with the flow show lower stranding potential in comparison to the young living in the main channel. During hydropeaking, these fish may drift or swim into newly flooded areas or will drift or swim back to the main channel during the lowering of the water levels. On the contrary, the young of the main channel fish that are positively rheotaxic are more likely to swim against the flow of the receding water and therefore more likely to be stranded (Adams et al., 1999; Young et al., 2011).

Most of the available research has concentrated on salmonid species, because their larval stages show higher stranding potential in comparison to other fish found in the same streams. After emerging from the gravel, the salmonid fry tends to search shallow areas near the shoreline thereby increasing the potential of stranding during high flow fluctuations. According to a review by Hunter (1992) chinook salmon and steelhead fry show higher stranding rates in comparison to pink salmon fry and chum salmon. This could be related to the comparatively longer residence times in streams. The chinook salmon and steelhead inhabit the river channel for months to years, whereas the pink salmon fry and Chum salmon move to salt water after emergence from the substrate (Hunter, 1992). The coho salmon shows rather low potential to gravel bar stranding in the available research. This could be related to the fact that most studies have been conducted in rivers of large and medium size, whereas the spawning and rearing of the coho salmon generally occurs in headwater streams and small tributaries. The coho salmon rears in fresh water for a whole year and therefore it can be suggested that the stranding rates of the coho juveniles should be comparable to the chinook salmon and the steelhead (Hunter, 1992; Pacificorp, 2004).

3. Research questions and hypotheses

The present research aims at investigating the relationship between the impact of the morphological and hydrological changes in the abiotic conditions of the water bodies and the occurring ecological consequences on the fish. The substantially higher flows and stronger flow fluctuations during the periods for power demand, together with the morphological changes of the rivers could have severe consequences on the aquatic organisms particularly related to drift and stranding of fish. As previously mentioned, in the Alpine region the most relevant drivers and stressor combinations are related to the hydropower generation. Most of the medium size and large rivers in Austria are channelized and influenced by hydropeaking. The most affected river stretches are in the Hyporhithral zone where the European Graylings are dominant species; therefore, the latter has been selected as a target species in this study. In the recent years, the fish has severely declined in population as a result of the hydropower operations and has been listed as endangered in Austria as well as in a different European Directives (Ingram et al., 1999; Uiblein et al., 2001).

Based on the literature review it can be expected that the time of the day and the channel morphology have a great influence on the drift and stranding of fish during hydropeaking. However, the available knowledge concerning the graylings, especially in their larvae stages is still fragmentary or contradicting as most of the research have focused mainly on salmonid species such as salmon and trout (Bradford, 1997; Halleraker et al., 2003; Nagrodski et al., 2012; Schmutz et al., 2013; Schmutz et al., 2014). The literature triggering research in experimental channels has been also insufficient as most of the experimental studies have been conducted in freshwater ecosystems (Schmutz et al., 2014). The advantage of performing simulations in experimental channels is the possibilities to investigate different parameters and conduct consistent replicates. The purpose of the experiments performed at the HyTECH facility is to obtain advanced knowledge of the impact of hydropeaking and investigate whether the lateral gravel bank slope and the time of the day has an influence on the drift and stranding risk of larval graylings.

The following research questions (RQ) and hypotheses (H) have been examined:

RQ_1: Does the lateral slope have an effect on drift of larval graylings during hydropeaking?

$H_{1.0}$. The lateral slope does not affect the drift of larvae grayling during hydropeaking.

RQ_2: Does the time of the day have an effect on drift of larval graylings during hydropeaking ?

$H_{2.0}$. The time of the day does not affect the drift of larvae grayling during hydropeaking.

RQ_3: Does the lateral slope have an effect on stranding of larval graylings during hydropeaking?

$H_{3.0}$. The lateral slope does not affect the stranding risk of larvae grayling during hydropeaking.

RQ_4: Does the time of the day have an effect on stranding of larval graylings during hydropeaking?

$H_{4.0}$. The time of the day does not affect the stranding risk of larvae grayling during hydropeaking.

To test these research questions and hypotheses, experiments have been conducted at the HyTEC facility at Lunz am See. The research has been focused on the drift and stranding of the fish depending on the lateral gravel bar slope (3.5 % or 11 %) and the time of the day (day or night). Comparison between reference and hydropeaking experiments has been conducted to analyse whether the hydropeaking increase the drift and the stranding rates.

4. Materials and Methods

4.1. „HyTEC“ Facility

The „HyTEC“ (**Hy**dromorphological and **T**emperature **E**xperimental **C**hannel) facility is located in Lunz am See, district of Scheibbs (Lower Austria) at approximately 600 meters above sea level (Figure 7).

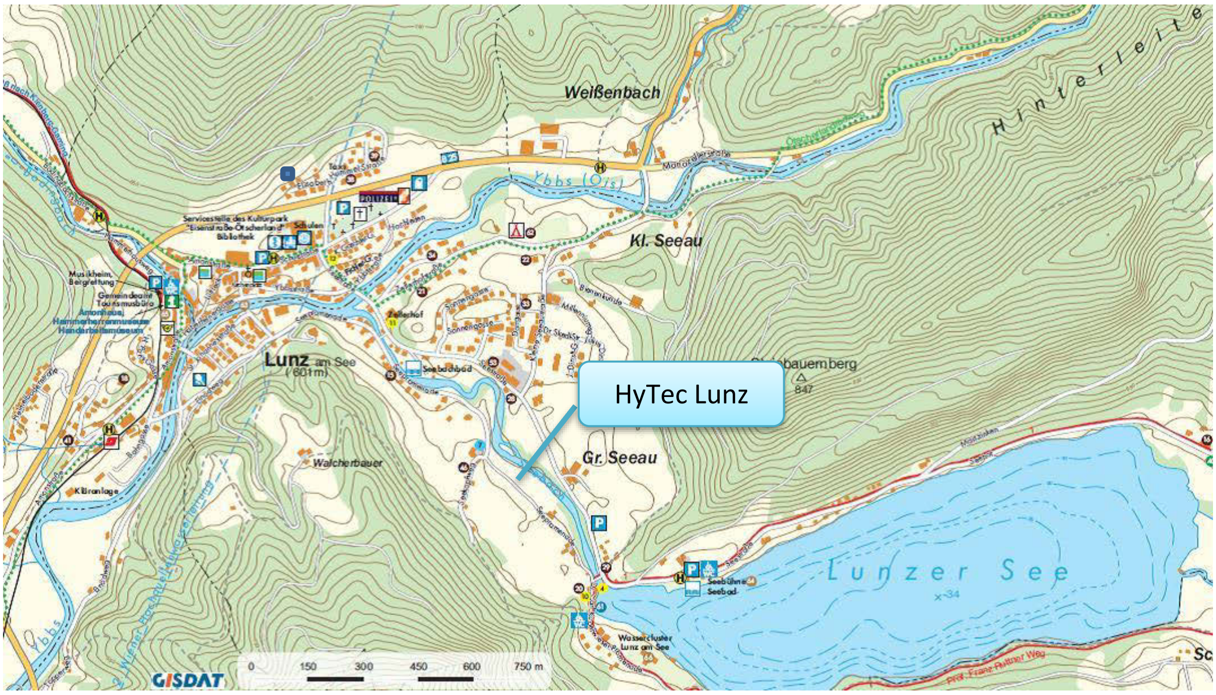

Figure 7. Location of the HyTEC facility plant at Lunz Am See (available at http://www.lunz.at/tourismus/ortsplan2013.pdf, Accessed on: 15.12.2015)

The „HyTEC“ experimental plant has been established within the frame of the project "*Schwallproblematik an Österreichs Fließgewässern – Ökologische Folgen und Sanierungsmöglichkeiten*". It was inaugurated in September 2011, under the patronage of the Institute of Hydrobiology and Aquatic Ecosystem Management (IHG) at the University of Natural Resources and Life Sciences (BOKU), Vienna. The main objective of the investigations conducted at the experimental plant is to examine the response of aquatic organisms to pulse-released flows caused by hydropower plants. The „HyTEC”- facility consists of two identic parallel nature-like channels with the following characteristics: 40 meters length, 6 meters width, and 1.4 meters depth. The water supply for the channels is managed through pipelines extracting the water directly from Lake Lunz located at about 400 meters upstream. The altitude difference between the water level of the lake and the channel’s inlet is about 7.15 meters. Two independent pipelines with maximum capacity of 300 l/s each, lead the water from the lake to the plant on an average gradient of 13 ‰ (Auer, 2013; Schmutz et al., 2013). The schematic diagram on Figure 8 illustrates the "HyTEC" facility.

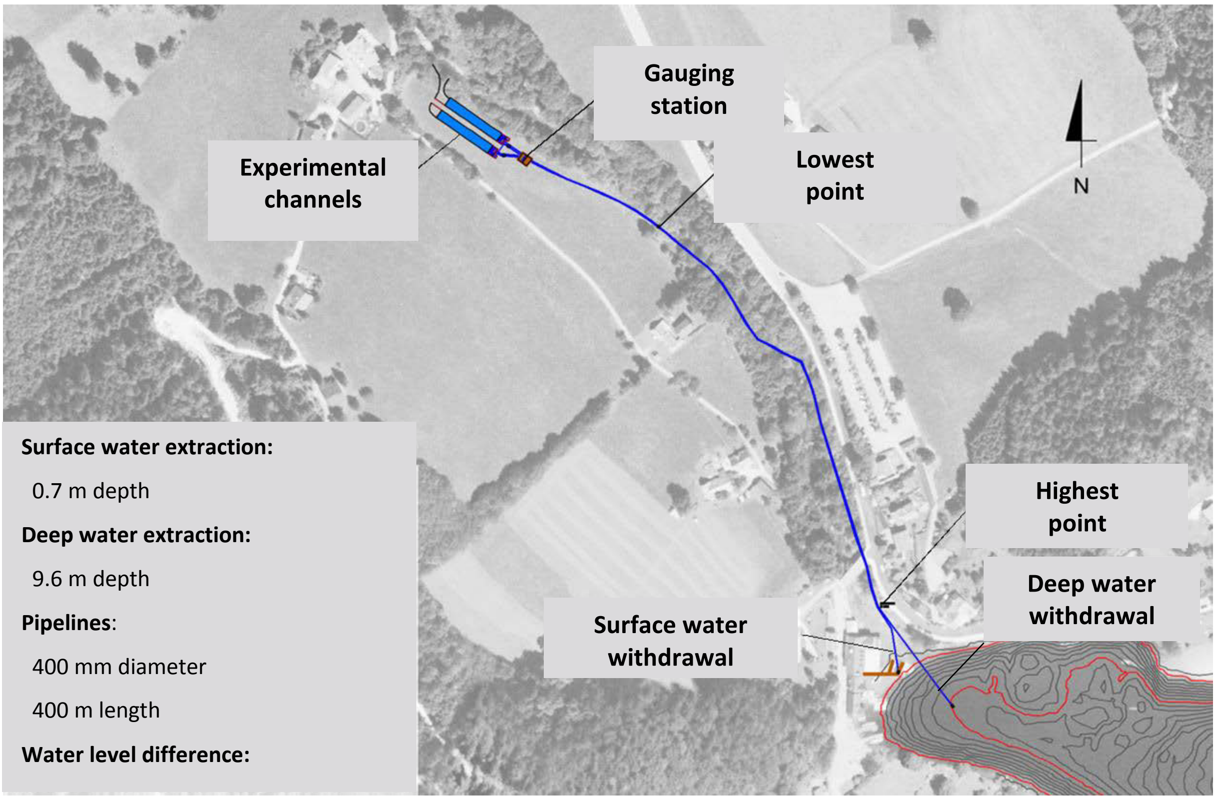

Figure 8. Schematic figure of the „HyTEC" facility plant at Lunz am See (Schmutz et al., 2013).

The gauging station is located in close proximity to the experimental channels and has an area of 4 x 5 meters. The two experimental channels start with a mixing basin where the inflowing water from the surface and deep water withdraw is mixed before entering the channels. The homogenisation stretch of the channels is used for research purposes with macrozoobenthos and algae. The lower part of the channels is used for fish experiments. An overview of the „HyTEC "research plant and experimental channels is provided in Figure 9 and Figure 10.

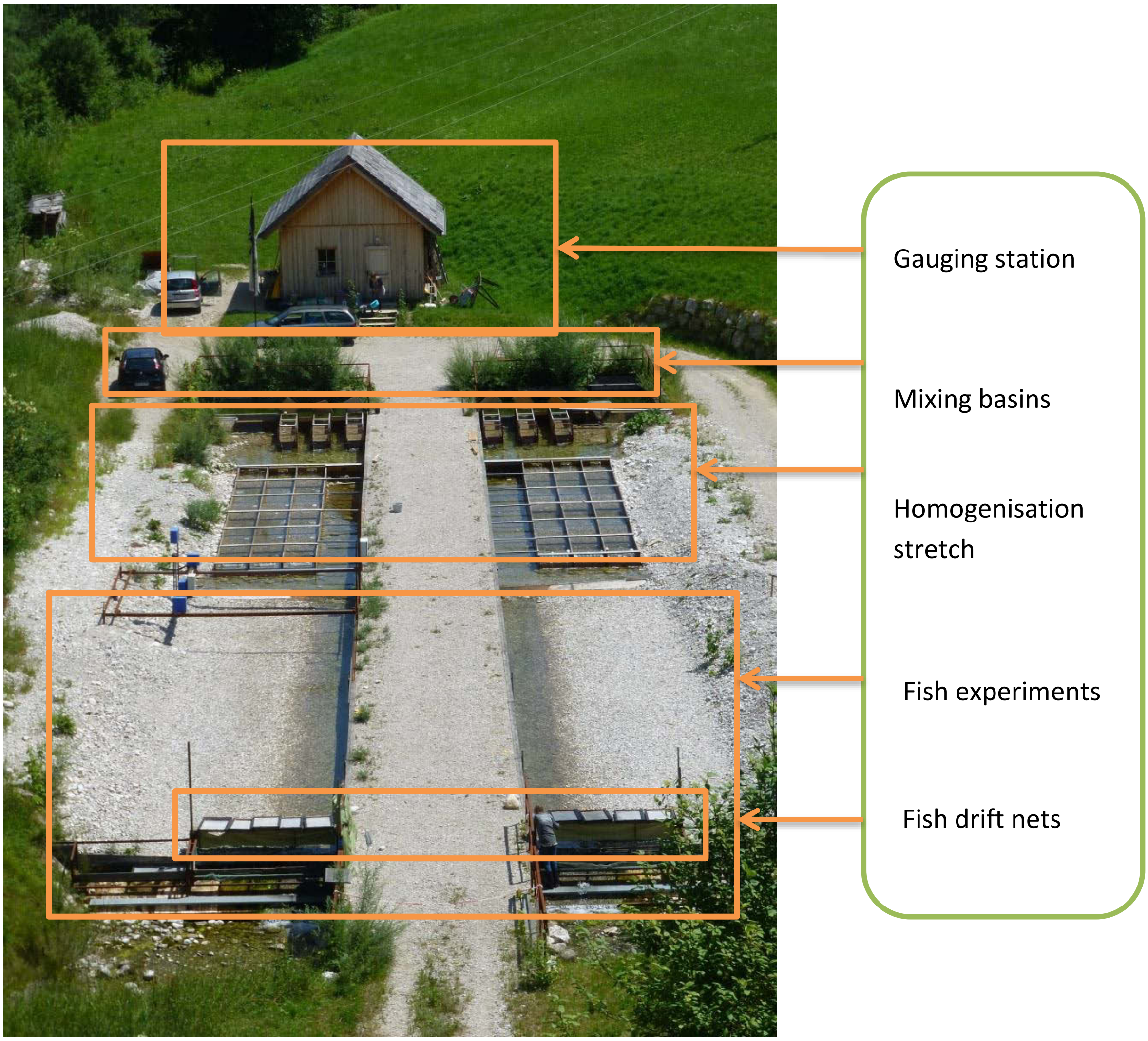

Figure 9. Overview of the HyTEC experimental and research plant

Figure 10. HyTEC experimental channels (Auer, 2011)

Technical description

The “HyTEC” facility can be subdivided into four main parts (Schmutz et al., 2013; Schmutz et al., 2014):

- Water withdraw (surface and groundwater)
- Water transportation
- Gauging station and valve chamber
- Experimental channels

Water withdraw (surface and groundwater)

The water withdraw is managed through two independent pressure pipelines DN400. One of the pipelines known as the “cold water pipeline” extracts ground water from approximately 10 meters depth, whereas the other pipeline (“warm water pipeline”) obtains surface water from the lake. In order to minimize the risk for recreational purposes such as swimming and diving, both pressure pipelines are protected with a steel wire mesh (Auer, 2013; Schmutz et al., 2013; Schmutz et al., 2014).

Water transportation

The two pipelines DN 400 have a maximum capacity of 300 l/s each and can reach a flow velocity of 2.3 m/s. The average slope of the pipes has been set to approximately 1.3 % due to the difference in the water level between the lake and the power plant and in order to reach the most favorable hydraulic conditions.

The pipelines have the following characteristics:

- Pipeline 1 - cold water, length 490 m, material GF-UP (unsaturated polyester - glass fibre reinforced) and steel DN 400mm
- Pipeline 2 - warm water, length 456 m, material GF-UP (unsaturated polyester - glass fibre reinforced) and steel DN 400mm

Pipeline 1 extracts the water from a depth of 9.6 m and pipeline 2 obtains the water from the surface. Both pipelines pass under the research station into a valve chamber (Auer, 2013; Schmutz et al., 2013; Schmutz et al., 2014).

Valve chamber

The valve installation is located below the gauging station where the cold and warm water pipelines are divided into two additional pipelines per flow channel, each provided with motorized gate valves to regulate the flow. A sensor detects the water temperature. The flow rate is measured with ultrasonic device with the following characteristics: 1-path measurement; Model Rittmeyer RISONIC 2000, sensors type A, located in a shaft near the valve chamber. The discharge is regulated from the gauging station through devices with the following components: RISONIC controller and RISONIC ultrasonic transit time units. Flow scenarios with different duration, discharge, up-and downramping rates, and temperature can be set and performed in respect to the experimental design. The data concerning the flow rates and the water temperature is displayed in real-time on a screen and stored every five minutes (Auer, 2013; Schmutz et al., 2013; Schmutz et al., 2014). Figure 11 illustrates the technical overview of the valve installation.

Figure 11. Technical overview- 1) knife gate valve; 2) water outtake for the three round basin, 3) temperature sensors (Auer, 2013)

Experimental channels

The experimental channels are parallel, geometrically identical and constructed as a mirror image. Each channel starts with a rectangular mixing basin where inflowing water from the cold and warm pipelines is mixed before entering the channel. In order to smooth the flow, an inflow wooden baffle is attached near the pipeline outlet. The flow rate for each channel can vary between 0 and 600 l/s depending on the experimental design. The water temperature is regulated through the ratio of cold and warm water from the pipelines. The ratio of both water volumes can be controlled via a touch screen; either manually or with predefined programmes on the controller devices located in the gauging station (Auer, 2013; Schmutz et al., 2013; Schmutz et al., 2014). The two channels are divided into five successive segments each 4 meters long (Figure 12). These sections are separated only in visual way, hence marked by transverse steel and wood structures on the sidewalls and do not have effect on the fish (Auer, 2013; Schmutz et al., 2013; Schmutz et al., 2014).

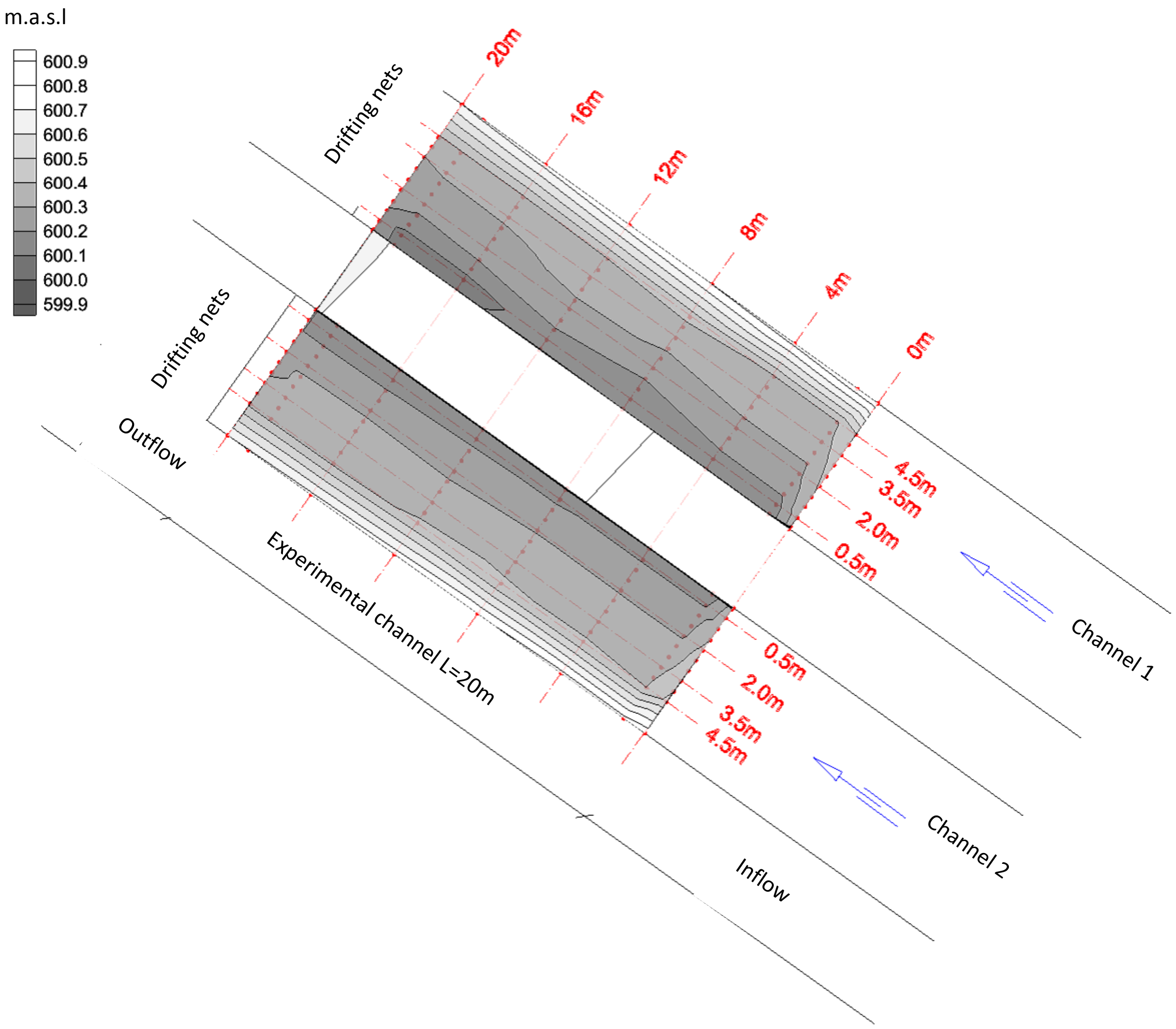

Figure 12. Schematic figure of experimental channels (Schmutz et al., 2013).

The bottom of each channel is sealed against infiltration with a geotextile bentonite waterproof membrane. On top of the membrane, river gravel from river Ybbs is spread. The channels banks are flat and composed of gravel that is shaped and formed to the appropriate lateral slope inclination, namely 3.5 % (channel 1) and 11% (channel 2). At the lower end of the experimental channels, a steel ramp structure with wooden beams and drift nets is installed to retain the drifted fish (Figure 13) (Auer, 2013; Schmutz et.al, 2013).

Figure 13. Drift nets at the end of each channel (Own photo)

4.2. European grayling (Thymallus thymallus L.)

Figure 14. European grayling (*Thymallus Thymallus*), Photo: Ludwig S., Vorsfelde, Available at: http://www.fischfauna-online.de, Accessed (13.05.2016)

The European grayling belongs to the Salmonidae family. The name *thymallus* originates from the typical strong smell of the wild thyme herb that emanates from the flesh of the fish. The European grayling inhabit mainly rivers and rapid flowing streams but some populations are also found in lakes, such as the Gouthwaite Reservoir (Yorkshire, UK) and Llyn Tegid (Wales). The grayling is a freshwater fish; nevertheless, it also occurs in marine environments with low salt content. The fish is native to Europe, the Black Sea, the Mediterranean Sea, the Northeastern Atlantic and the former USSR inland waters. *Thymallus thymallus* are widely distributed from England throughout Europe and up to the White See in Northeastern Russia. The fish occurs at 40° - 70° N in the Northern Hemisphere and at altitudes approximately 500 meters in the Alps and up to 1000 meters in the Carpathians (Ingram et al., 1999).

Thymallus thymallus favour cold, clean, and well-oxygenated water. The body length of the adult is typically around 30 cm but can reach maximum sizes of 60 cm and weight of 6.7 kg. The fish is covered with small scales, has a slightly flat-sided body, small head, and small pointed mouth. The upper jaw projects somewhat beyond the lower jaw. The fish is omnivorous and feeds mainly on drifting zoo- and phytoplankton, terrestrial invertebrates, vegetable matter, insects, and crustaceans (Nygård, n.d.). Larval graylings feed on drift in the surface water of the river. With increasing size, the juvenile fish catch drifting invertebrates and feed within 5 cm of the upper water layers. The bottom feeding starts in the older stages, although the fish is seen regularly ascending to the water surface to catch floating prey. The European grayling feeds mainly at dawn, dusk and during the day, and no feeding activity is seen during the night. Juveniles prefer pray such as chironomid larvae and microcrustacea, i.e. copepods, whereas adults consume a wider variety of prey items and feed mainly on chironomid pupae, trichoptera, simulidae and ephemeroptera (Ingram et al., 1999).

Thymallus thymallus are distinguished by their high dorsal fin, which is very colourful and longer in the male. It has four or five rows of red, orange, or black colour spots. The body is also multi-coloured; the juveniles have more smattering of small dark silver grey to light green sports with bluish dots along the flanks. The adults have a grey to green back, white belly and green sides. The existence of the adipose fin taxonomically relates the grayling with the salmonids (Ingram et al., 1999). The European grayling have 5 to 8 dorsal spines and 3 to 4 anal spines, which makes it easier to distinguish them from the other species. The dorsal soft rays are 12 to 17, the anal soft rays 9 to 10 and vertebrae 57 to 61. The European grayling is very sensitive to changes in the water quality. They have a small liver indicating that they do not tolerate polluted water and can be considered as indicator species. The fish has economic importance; it is valued as food and commercially raised and used as a game fish.

Habitat requirements

The European grayling is found in river reaches with maximum temperatures of 22.5 °C and maximum altitude of up to 1000 m above the sea level (Uiblein et al., 2001, Schmutz et al., 2000). The suitable habitat conditions for the fish are clean, cool and well oxygenated river reaches with gentle slopes and hard sand or stone bottom. The oxygen requirements are minimum 5-7 ppm and the temperature is in the range of 0-4 °C as lower critical and 18-25°C as upper critical level (Ingram et al., 1999). Table 2 below indicates the critical temperatures, the preferred water depth, and substrate type for the European grayling.

Table 2. Critical temperatures (°C) for European grayling in Europe (Ingram et al., 1999)

Range	**Temperature °C**
Lower critical	0-4 °C
Upper critical	>18 °C
Optimum	4-18 °C

Larval graylings habitat is characterized with water depth <20 cm and water velocity < 10 cm/s. They inhabit shallow and calm waters, not more than 20 cm from the gravel bank. The substrate in these areas is more homogeneous composed of sand and silt, however fine pebbles and gravel occur in smaller quantities (Bardonnet et al., 1991; Fohler., 2013; Ingram et al., 1999; Sempeski & Gaudin, 1995).

Emergence

Fertilized grayling eggs hatch after 177 degree-day or 22 days at a temperature of 8.05 °C. The hatching time depends on temperature. Therefore, with higher temperatures, development time decreases. For *Thymallus thymallus* the optimum temperature range for development is between 7-11°C. The mortality at hatching is found to be approximately 10 %, but it has to be considered that this varies between different years and sites and is dependent on certain biotic and abiotic factors (Ingram et al., 1999).

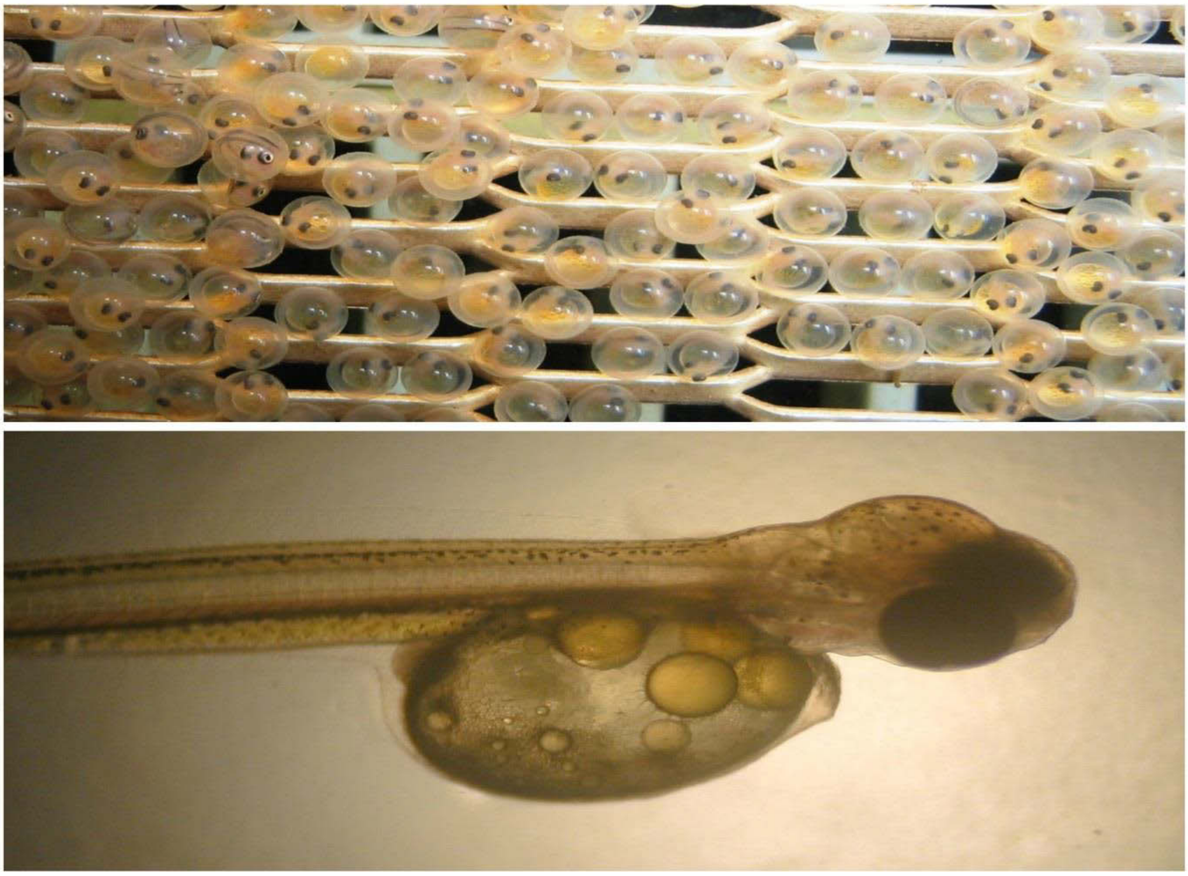

Figure 15. European grayling eggs and larvae emerge with a yolk sac, Available at: http://www.graylingresearch.org, Accessed (13.05.2016)

The emergence from the substrate occurs after 4 to 5 days in the gravel and feeding on the yolk sac. This time is needed for the embryos to manage with the current before they reach their fry swimming stage. The fry feed closely to the water surface prior to the full resorption of the yolk sac. The full yolk resorption is accomplished after 156 degree days (12 days). Bardonnet & Gaudin (1991) revealed that the larvae emerge from the gravel and swim-up after 276-320° days of incubation or approximately 10 days of post-hatching. Upon emergence graylings measure approx. 15-19 mm. Larvae reach a size up to 3 cm by the end of the first month and again double their size after two months. In the first year the fish can grow up to 18 cm (Ingram et al., 1999). In comparison to other salmonids, *Thymallus thymallus* emerge diurnally with a peak at dawn. The downstream displacement occurs at night and could be interpreted as a strategy to avoid predators. Bardonnet & Gaudin (1990) suggested that the diurnal activity helps the acclimation of the fry to their surroundings. The high activity in the colder hours is opposite to the expected trend that activities of the individuals increase with higher temperature (Ingram et al., 1999).

Habitat requirements of different developmental stages

The European graylings require certain habitat types during their different development stages. In terms of habitat suitability, streams can be subdivided into three groups (Ingram et al., 1999).

- *Dead zone*- the marginal areas of the stream, slow flow rates
- *Transition zone*- between the dead zone and main channel, medium flow rates
- *Main channel*- middle part of the stream, fast flow rates

The distribution of the graylings is strongly related to current velocity. The juveniles are mainly found in areas with current velocity that equals around 50 % of their swimming capacity. With increasing size, the graylings are capable to occupy regions with higher current velocity and to inhabit broader habitat spectrums. The increased body size and mouth of the fish allows them to swim faster and to find and catch prays. Thus, the fish energy expenditure can be minimized and the optimal fitness maximized. The shift in habitats from dead zone, to transition and then main channel favours the foraging behaviour and predator avoidance of the fish (Ingram et al., 1999).

After emergence from the substrate, the larval graylings are poor swimmers and tend to inhabit shallow marginal habitats, avoiding steep banks and deep water. Since the yolk sac is nearly consumed, the larvae should learn fast how to allocate their food, generally drifting food particles. The dead zone with the slowest flow rates provides vital habitat for the just emerged larvae. The slow current decreases the energy costs and swimming activity and the shallow waters reduces the potential of larger fish that usually inhabits deeper depths (Ingram et al., 1999).

Habitat use of the European grayling differs between day and night. As the juveniles increase in size they move from the dead zone to the main channel during the day. When the fish reach > 60 mm, they move away from the shallow habitats (Ingram et al., 1999). During the night it has been observed that all size classes inhabit marginal areas making the fish more susceptible to stranding (Schmutz et al., 2014). The behaviour of the graylings is also different during the day and the night. During the day the fish feed in the water column and rarely on the bottom, whereas at night the graylings rest on the bottom of the channel (Ingram et al., 1999).

Fish used in the experiments

European grayling larvae from the rivers Mur, Salza and Ybbs have been used for the experiments (Figure 16). The eggs from the wild mother fish were reared either at the facility or in a local fish farm and delivered in 3 different charges to provide fish of the same age for more experiments.

Figure 16. Larvae graylings used in the experiments (Own photo).

The experiments were conducted with larval grayling (body length between 17.31 mm to 22.40 mm) age 4 to 29 days after stand up. Table 3 below provides information about the fish including the river origin, the time during the fish was used, fish body length and age after stand up (in days).

Table 3. Fish used in the experiments

Charge N:	River	Time Span	Age [days after stand-up]	Fish length [mm]
1	Ybbs	06.05.-21.05.15	4-19	17.31-20.10
2	Salsa	20.05.-04.06.15	8-23	18.20-19.58
3	Mur	10.06.-23.06.15	16-29	18.71-22.40

The grayling larvae were kept in three circular tanks in the storage compartment behind the research station (Figure 17).

Figure 17. Experimental fish kept in circular tanks (Own photos).

The water for the tanks was supplied through the same pipelines as for the two experimental channels, thus providing the same water temperature and assuring adequate water conditions. The fish larvae were initially fed with plankton obtained from nets (Figure 18) mounted at the outlet of the mixing tanks in the two experimental channels. The three circular thanks were cleaned daily and uneaten food (zooplankton and phytoplankton) and faeces were removed by flushing the tank sinks.

Figure 18. Mixing basin with plankton nets for collection of zoo- and phytoplankton (Fischer, 2013)

At a later stage the fish were fed with *Artemia salina* (brine shrimps) – aquatic crustaceans closely related to the Triops and cladocerans. *Artemia salina* was reared in 1.5 l plastic bottles (Figure 19). Equal parts of brine shrimp eggs and salt (around 2 table spoons) were placed at the bottom of the plastic bottles and filled with warm water (32 °C). Under constant water temperature the bottles were aerated for 24 hours until the brine shrimps hatch. The empty shells of *Artemia salina* were carefully removed before feeding.

Figure 19. Rearing of *Artemia salina* (Own photo).

The grayling larvae were weighed and measured on a weekly basis to determine the development (Figure 20). For the measurement 25-30 fish were randomly selected and calmed in a bucket of water with few drops of clove oil. The fish were measured, weighed, and returned to a separate basin, thus no longer used for the experiments. Experimental fish were only used once and stored in different tanks thereafter.

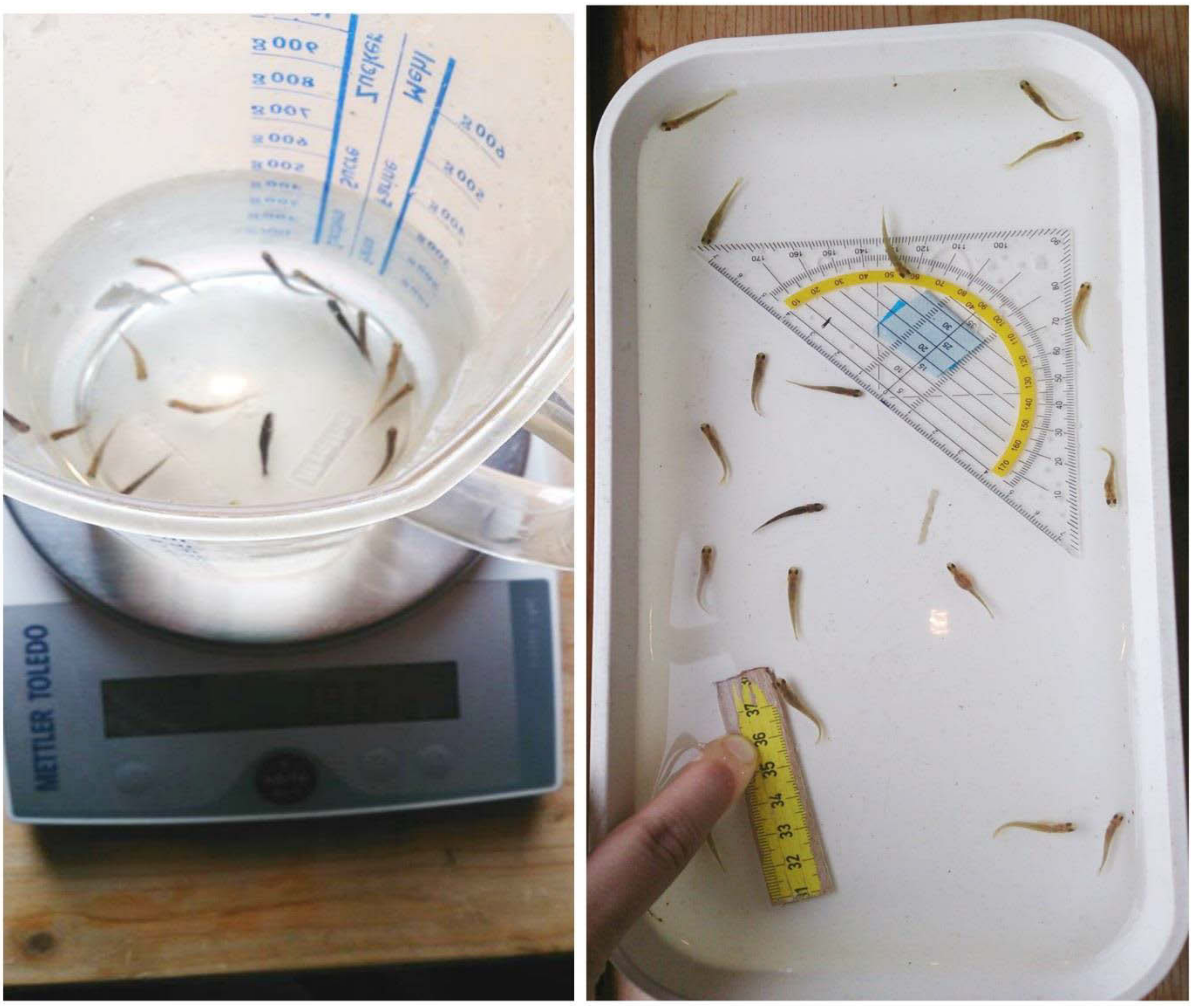

Figure 20. Measurement of the experimental fish (Own photos).

4.3. General description of the experiments

The research took place from 06.05.2016 to 23.06.2015. Reference and peak experiments were performed during the day and at night on different lateral gravel bar slopes. For the experimental design, the two channels were equipped with homogeneous gravel. Channel one (orographic right) exhibited 3.5 % lateral slope and channel two (orographic left) 11 %. For the experimental setup, only the lower part of the channels was used, which extends over the length of 20 m. The research section was divided into 5 sub-segments each 4 m long, which were separated from each other only in visual and not in a constructive way. The red outline in Figure 21 shows the experimental sections of the channels in which simulations of peak and reference experiments with grayling larvae were performed. In the middle of the channel, marked with orange bars, is the separation ramp that prevented fish swim to the upstream part where controlled experiments not related to our trials were performed with algae and other mesocosms. The continuous blue line indicate the water stop line at base flow of 25 l/s. The short dashed blue line indicate the water stop line during hydropeaking with flow of 125 l/s. The pink circles indicate the starting position for measurment of the flow velocity rates via flow velocity sensors.

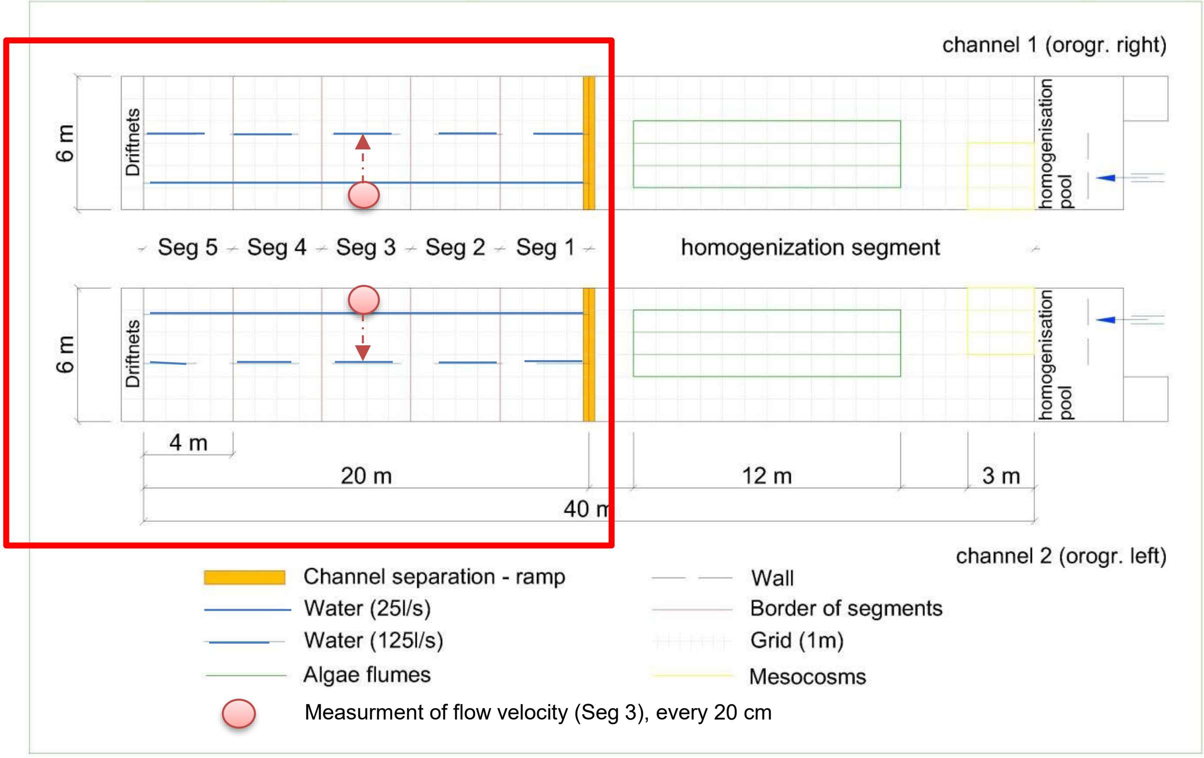

Figure 21. Schematic channel overview with red outline indicating the experimental sections for simulation of peak and reference experiments (after Schmutz et al., 2013)

Flow velocity

Flow velocity during the reference and peak experiments was measured at 10 m of the longitudinal profile of the channel. A flow velocity sensors “Flo-Mate 2000” manufactured by March McBirney Inc. was used to create cross-sectional profiles of flow velocity distributions (Figure 23 & 24). The device measures the flow velocity with the help of electromagnetic induction as per the law of Faraday. The electromagnetic field is deflected by the current and detects the water velocity (Bittner & Schmalfuß, 2016).

The flow velocity rates in both channels have a maximum value from 0.29 to 0.57 m/s depending on the type of flow, whether it is a base flow of 25 l/s or peak flow of 125 l/s. The variations of up to 0.28 m/s shows approximately two times higher flow velocity rate during the peak flow, which is a wide range for the grayling, especially in their larvae stages (Bittner & Schmalfuß, 2016; Ingram et al., 1999).

Channel 1 (3.5 %)

- longitudinal profile stationing: 10m (experimental section)
- longitudinal profile stationing: 30m (total channel)
- lateral slope: 3.5 %
- longitudinal slope: 0.5 %
- base flow: 25 l/s
- peak flow: 125 l/s
- downramping rate: 0.5 cm/m
- Δ water level (= Δh): 6.6 cm
- transition zone: 1.83 m

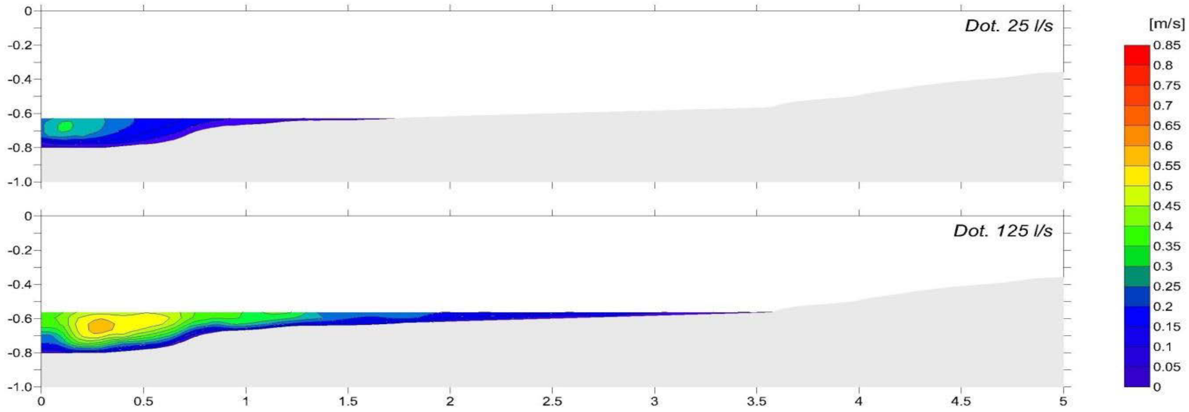

Figure 22. Flow velocity distribution in channel 1 (3,5 % lateral slope), at 25 l/s (base flow) and at 125 l/s (peak flow)

Channel 1 (3.5 %) had a maximum flow velocity of 0.29 m/s during base flow, which is increased to 0.53 m/s during peak flow as shown in Figure 22. Channel 2 (11%) had a maximum flow velocity of 0.29 m/s during base flow, which is increased to 0.57 m/s during peak flow as shown in Figure 23.

Channel 2 (11%)

- longitudinal profile stationing 10 m (experimental section)
- longitudinal profile stationing 30 m (total channel)
- lateral slope 11 %
- base flow 25 l/s
- hydropeaking flow 125 l/s
- downramping 0.5 cm/m
- Δ water level (= Δh) 10 cm
- transition zone 0.93 m

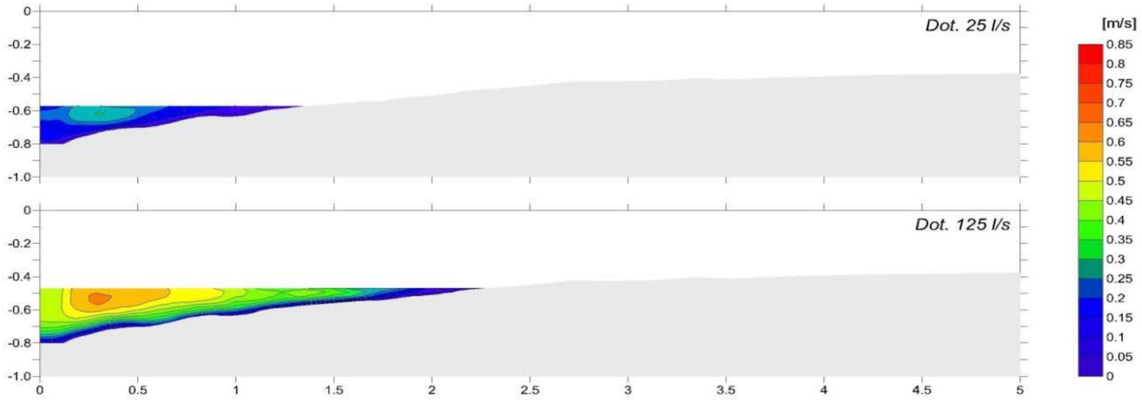

Figure 23. Flow velocity distribution in channel 2 (11% lateral slope), at 25 l/s (base flow) and at 125 l/s (peak flow)

Substrate composition

The structure and composition of the riverbed substrate is an important factor for providing suitable habitat for the fish. To assure adequate physical and chemical conditions for the graylings, the substrate for the experiments has been taken from a downstream quarry at river Ybbs. The measurement of the grain size distribution of the used substrate was conducted in the period between 14th of April and 19th of May 2015 as part of a bachelor thesis (Bittner & Schmalfuß, 2016).

Figure 24 shows a schematic representation of the experimental sections of the channels, including labeling of the segments in which the sampling for the grain size distribution has been performed.

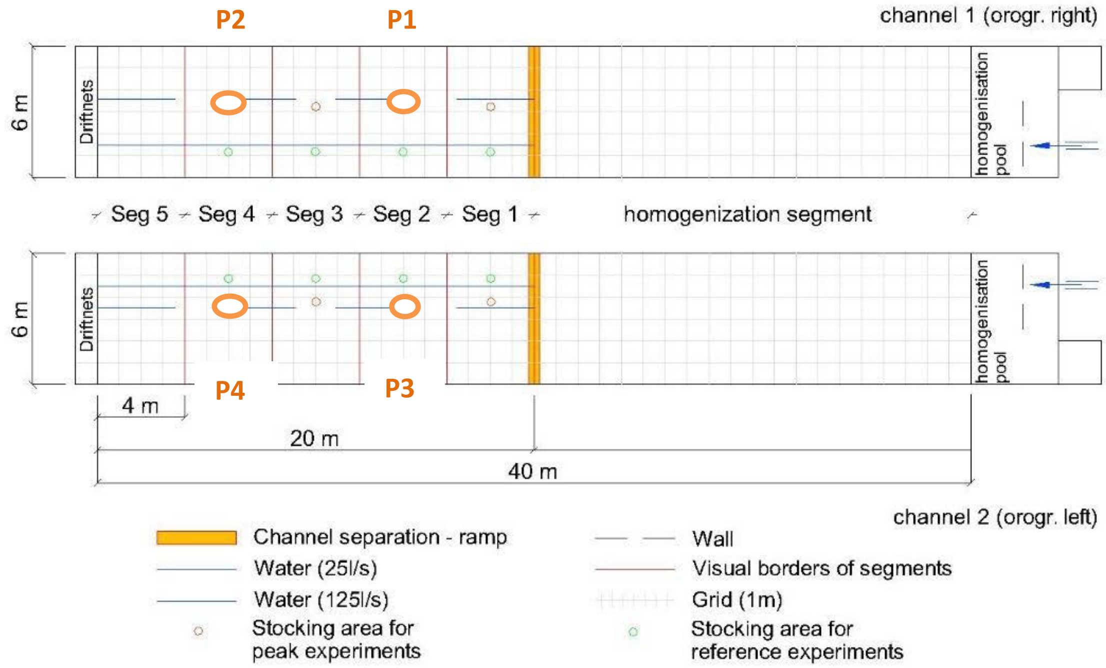

Figure 24. Schematic outline of the experimental channels with identification of the positions 1 - 4 (P1 –P4) for sampling of the substrate composition **(Bittner & Schmalfuß, 2016).**

The four sampling positions were located as follows:

- P1- 2nd segment of the orographic right channel (Channel 1) with lateral slope of 3.5 %.
- P2 - 4th segment of the orographic right channel (Channel 1) with lateral slope of 3.5 %.
- P3 - 2nd segment of the orographic left channel (Channel 2) with lateral slope of 11 %.
- P4 - 4th segment of the orographic left channel (Channel 2) with lateral slope of 11 %.

The determination of particle size distribution of the gravel was accomplished through Line number analysis, which is a proven method for qualification of grain size distribution using manual measuring of the substrate stones with a conventional measuring tape. Since this procedure takes only the top substrate layer into consideration and in order to include the smaller particles from the sub-layer, the method was calculated according to Fuller and Fehr using formulas (Bittner & Schmalfuß, 2016).

Referring to these methods the results are divided into groups depending on different grain size classes. Approximately 90 % of the substrates were in the range between 8-32 mm which belongs to the medium and coarse gravel classes. A small proportion of the substrate was characterized as fine gravel (size class 4-8 mm) or very coarse gravel (size class 32-64 mm) (Bittner & Schmalfuß, 2016).

Fish stocking

For each replicate a total of 100 grayling larvae were taken from the circular tanks and placed into 4 buckets with 25 fish each. The fish were then released in the centre of segments 1, 2, 3, and 4 (Figure 25). During the peak experiment the fish were released at 125 l/s discharge which mimics the peak flow of a hydropeaking event, whereas during the reference experiment the fish were released at constant flow of 25 l/s. For both experimental setups fish were stocked very carefully at areas with flow velocities always lower than 0.1 m/sec to provide natural dispersal within the channels.

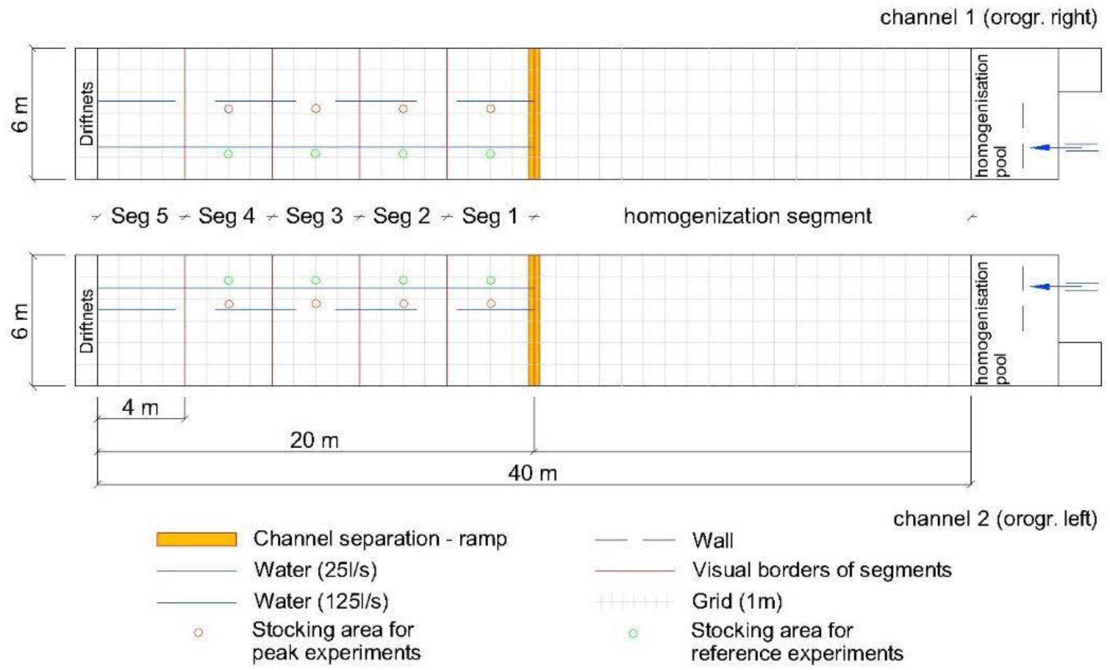

Figure 25. Channel overview (adapted from Schmutz et al., 2013)

4.4. Experimental setup

Hydropeaking events in nature include an increase of flow (up ramping), peak flow and decrease of the flow (downramping). Previous experience with hydropeaking simulations conducted at the HyTEC facility plant has shown that for estimation of the drift and stranding of fish it is sufficient to perform experiments focused only on the peak and downramping phase of the peak events. The reason is that during the rising limb no stranding can occur as the water level is increased. Stranding can only happen during the downramping phase because the water level and the wetted width are suddenly reduced. Based on this, the current experimental setup has focused only on the peak phase and downramping phase of the peak event. These experiments simulate the situation after a downstream displacement caused by up ramping and inhabiting a new habitat further downstream.

The reference experiments with base flow of 25 l/s were performed to make a comparison between the two different conditions - reference and hydropeaking. These experiments were indispensable to assess possible differences of drift and stranding for peak experiments.

Figure 26 shows a schematic overview of a complete hydropeaking event with red line indicating the experimental design for this thesis.

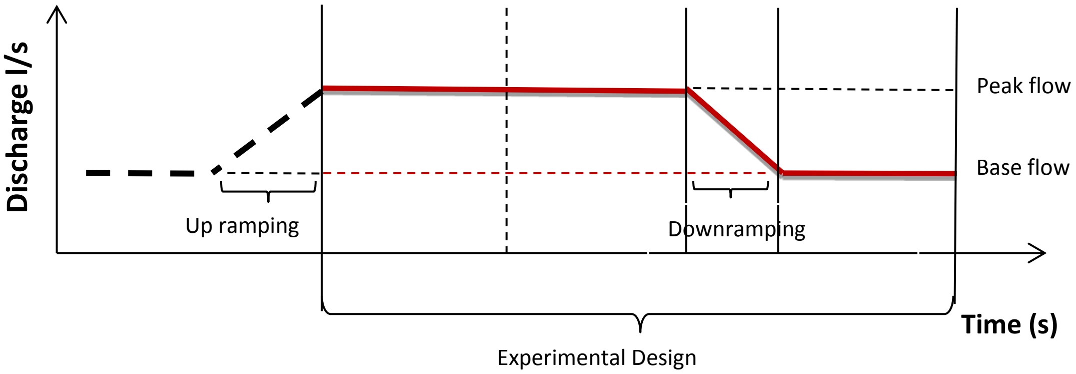

Figure 26. Schematic overview of a complete hydropeaking event. Red line indicating the experimental design for this thesis.

Each experimental procedure was divided into 3 phases characterized by different flow conditions: adaptation-, downramping- and clearing phase. This applies for both, peak experiment, and reference experiment (Figure 27).

The first phase is the „adaptation phase“ which lasts 30 min. Former experiments showed that 30 min is an adequate time for the fish to orient themselves in the new environment, disperse and find adequate habitats. At the beginning of the adaptation phase, fish were placed in the channel, into segment 1 to 4 (Figure 25). In order to accurately detect the drifted graylings for each of the time steps, the adaptation phase has been divided into two equal parts, namely middle adaptation (MA) and after adaptation (AA) each lasting for 15 min. The flow during MA and AA for the control experiment is set to 25 l/s, whereas the flow during the peak experiment starts with 125 l/s. Therefore, the MA during peak scenario is referred to Half Peak (HP) and the AA to the Full Peak (FP). The larval fish that is drifted in the nets were manually counted and recorded at each of the time steps.

The second phase is the „downramping phase“ and refers to the vertical change of the water level in the profile per unit of time and is measured in cm/min. During this phase starts reduction of the flow rate for the peak experiment with 0.5 cm/min until base flow of 25 l/s is reached. The duration of the downramping is 14 min for channel 1 with the 3.5 % slope or 20 min for channel 2 with 11 % lateral slope. The difference in the duration is related to the requirements to provide the same downramping velocity of 0.5 cm/min for both channels. Due to the different slope inclination, it takes less time on the lower inclined slopes and longer time on the steeper slopes to return to base flow of 25 l/s. For the reference experiment, the flow has a constant rate of 25 l/s and during this phase there is no reduction of the water level. After the downramping phase the proportion of stranded fish was calculated with formulas for accuracy, whereas the drift was collected from the drift nets, counted, and recorded.

The third phase is called “clearing phase” and describes the process when the graylings remaining in the channel are removed manually with fish nets or with electrofishing. The electrofishing device SAMUS 725G is a tool that allows the capture of fish through impulse voltage within the water. The electric impulses cause an effect called electro taxis which forces the fish to swim actively to the direction of the positive pole where they can be collected unharmed with fish nets. The standardised clearing procedure was performed at least 2 times per channel until no fish was detectable in the channel. The fish were collected in buckets, counted, and recorded.

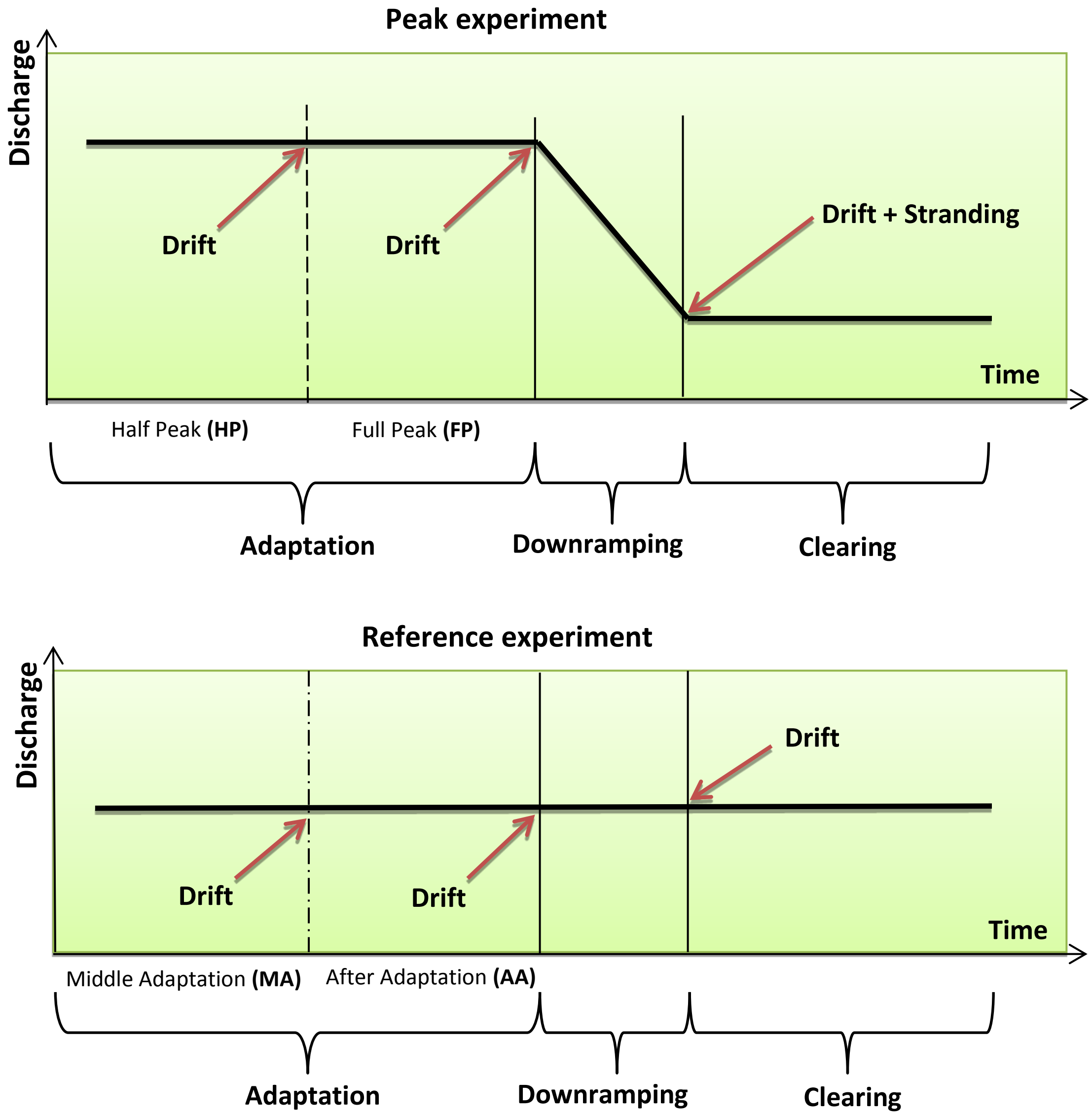

Figure 27. Overview and comparison of the different experimental phases (adaptation, downramping and clearing) for both peak and reference experiment

4.4.1. Peak experiment

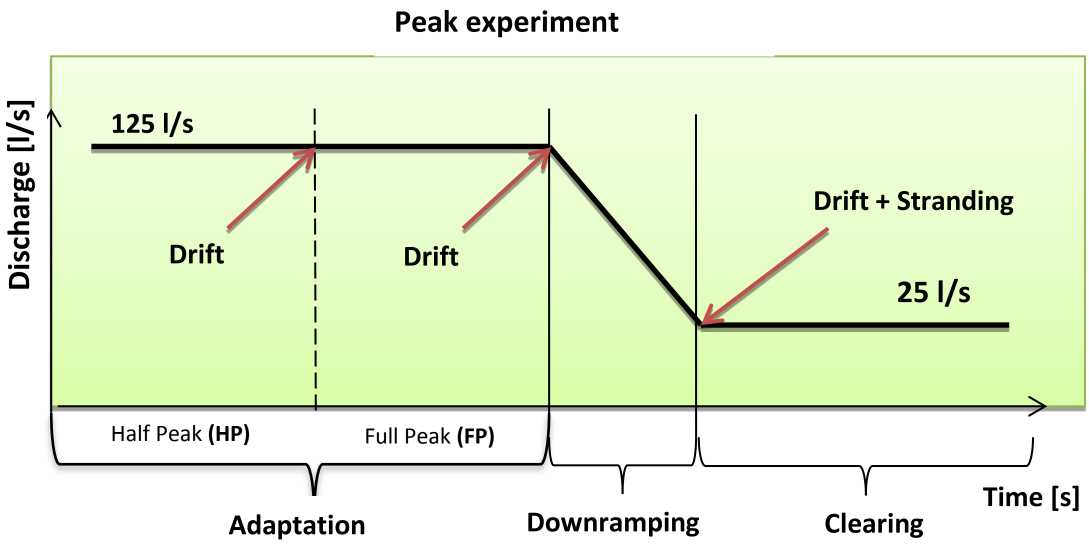

Figure 28. Schematic overview of the peak experiment

As mentioned in subchapter 4.4, the first part of the experiment is called adaptation phase. During peak experiments, the discharge starts with 125 l/s for 30 min. The fish were stocked at 125 l/s discharge and had 30 min time to adapt (Figure 29). The drift was counted at Half Peak and Full Peak. Grayling larvae in the drift were carefully collected from the drift nets, counted and recorded.

During downramping phase, discharge was reduced from 125 l/s to 25 l/s by 0.5 cm/min of vertical water level decrease. In order to provide the same reduction of the flow rate, namely 0.5 cm/min, the downramping time differed between the two channels due to the different slope inclination. Channel 1 with the 3.5 % slope required 14 min, whereas channel 2 with 11 % lateral slope required 20 min of downramping. During this phase of receding water level, the fish run the risk to get stranded on the gravel bank. After the downramping phase the stranding of the fish was calculated with formulas for accuracy and drifted collections in the nets were counted.

Clearing was performed after the discharge reached 25 l/s. Fish remaining in the channel were manually removed with fishnets or by electrofishing until no more fish were found in the channel. The total number of fish collected from the clearing was counted and recorded. Table 4 provides an overview of the peak experiment.

Table 4. Overview of the peak experiment

Time	
Adaptation (HP and FP)	30 min at 125 l/s flow
Downramping	14 min (3.5 % slope) or 20 min (11% slope)
Downramping rate	0.5 cm/min until base flow 25 l/s
Drift observations	HP, FP, after downramping
Stranding observations	calculated with formulas
Clearing	w/w.o electrofishing (at least 2 times)

4.4.2. Reference experiment

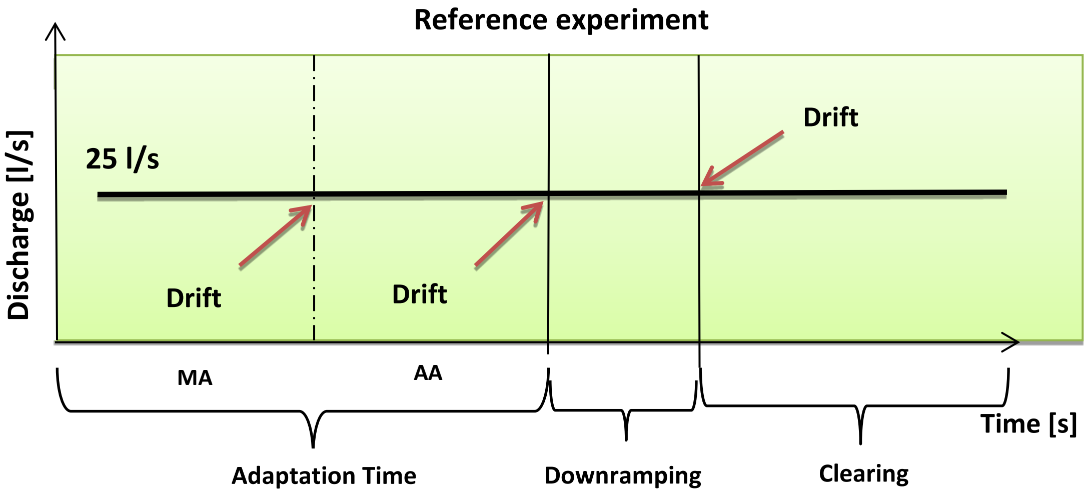

Figure 29. Schematic overview of the reference experiment

In the reference experiment, the flow was set to 25 l/s for the whole experiment. The fish were stocked at 25 l/s discharge and the drift was counted at middle adaptation (MA), after adaptation (AA), and an equivalent period for downramping (DR). The drifted fish larvae were counted and recorded. Although stranding is not possible during a static discharge, stranding risk was calculated the same way as for the peak experiments. This enabled us a direct comparison of stranding values. Clearing was performed after the end of the experiment minimum 2 times until no more fish was found in the channel. Table 5 provides an overview of the reference experiment.

Table 5. Overview of the reference experiment

Time	
Adaptation	30 min at 25 l/s flow
Downramping	14 min (3.5 % slope) or 20 min (11% slope)
Downramping rate	constant base flow 25 l/s
Drift observations	MA, AA, after downramping
Clearing	w/w.o electrofishing (at least 2 times)

4.5. Overview of both experimental designs

Both reference and peak experiments were performed during the day and at night. The weather conditions, the air and water temperature were recorded during each experiment. Under heavy weather conditions such as rain or storm, no experiments were conducted. The diurnal scenarios were performed only at full day light; the night experiments were conducted only when it was completely dark. During the night experiments, streetlights surrounding the facility were covered to avoid casting shadows into the channels. The stocking of the graylings was done at complete darkness and only when needed red infrared light was used.

Figure 30 below pictures the reference experiment with a base flow of 25 l/s and the peak experiment with flow rate of 125 l/s.

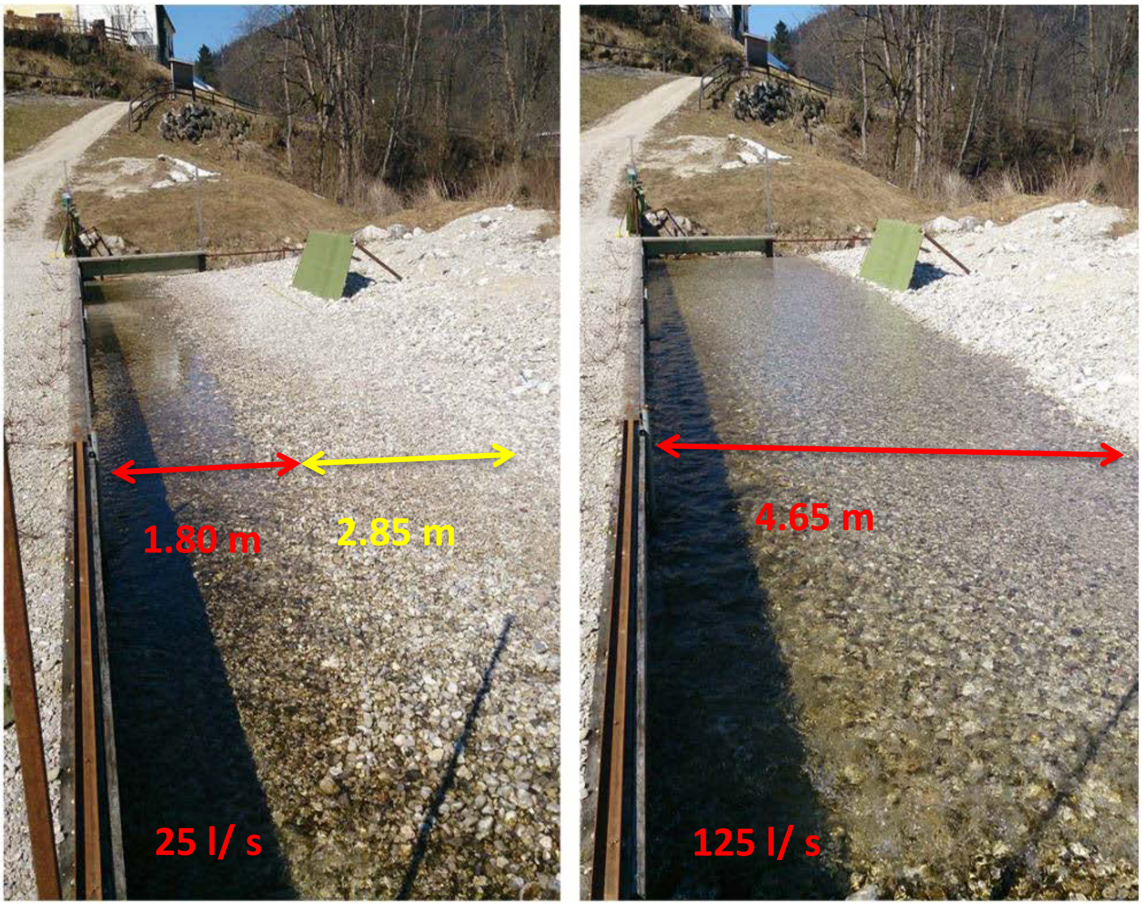

Figure 30. Flow during reference (left) and peak experiment (right) on 11% lateral gravel bar slope. The picture on the left side shows flow rate of 25 l/s and wetted width 1.8 m, and on the right side flow rate of 125 l/s and wetted width 3.65 m.

The collection of the drifted fish is illustrated on Figure 31.

Figure 31. Collection of drift during peak experiment

The clearing was conducted using dim light or red infrared light. The pictures on Figure 32 show clearing with electrofishing during day experiment on the left side and during night experiment on the right.

Figure 32. Clearing with electrofishing during day time (left) and night time (night)

Table 6 provides an overview of the performed experiments in terms of the type of the experiment, number of conducted experiment on 3.5 % or 11 % lateral slope, time span, age and size of the fish.

Table 6. Overview of the performed experiments

Experiment Type	N: Exp.3.5 % Slope	Time Span	Age [days after stand-up]	N: Exp.11 % Slope	Time Span	Age [days after stand-up]	Fish length [mm]
Peak day	8	14.05.-10.06.15	08-27	9	07.05.-10.06.15	05-27	17.3-20.10
Peak night	5	18.05.-08.06.15	13-27	6	11.05.-08.06.15	09-27	17.3-20.10
Reference day	6	11.05.-23.06.15	09-29	6	06.05.-25.05.15	04-19	17.3-22.4
Reference night	5	13.05.-23.06.15	11-29	6	18.05.-23.06.15	15-29	17.3-22.4

4.6. Calculating methods

Various essential indicators were used to estimate the drift and stranding of grayling larvae during the peak and reference experiments (**Table 7**). Based on these indicators the relative drift during the different flow stages as well as the relative stranding could be calculated. **Figure 33** shows the peak experiment and the corresponding indicators. The phases with peak flow are shown in red and with base flow in blue.

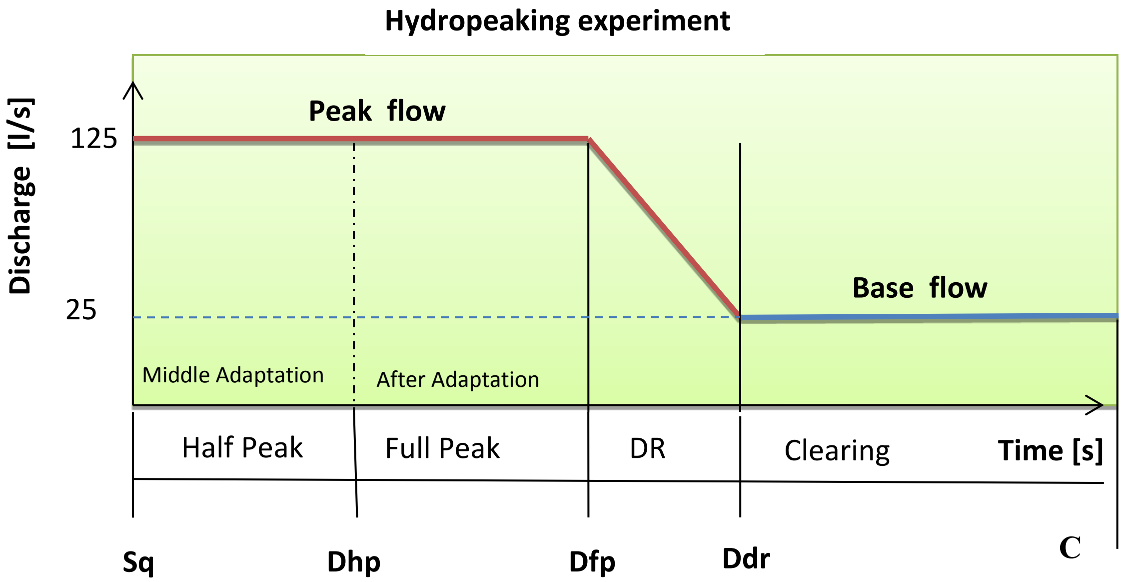

Figure 33. Schematic overview of the peak experiment with different phases and indicator

Table 7. Indicators calculated

Sq	*Stocking quantity*. Number of stocked fish at beginning of the experiment (100 individuals)
Dhp	*Drift after half peak*. Number of drifted fish at 0- 15 min of the peak and reference experiment
Dfp	*Drift after full peak*. Number of drifted fish at 16-30 min of the peak experiment
Ddr	*Drift after downramping. Number of drifted fish at 31- 44 min (3.5 % Slope)* *or 31- 50 min (11 % Slope) of the peak experiment*
C	*Clearing*. Number of fish taken out of the channel after the end of the experiment
R	*Rest.* Fish remaining in the channel after the end of the peak phases
Str_{calc}	*Stranding* calculated
Str_{rel}	*Stranding* relative in %
Dt	*Drift total*. Sum of the drift at half peak, drift at full peak and drift at downramping
Dt_{rel}	*Relative drift total* in %
Dhp_{rel}	*Relative drift at half peak* in %
Dfp_{rel}	*Relative drift at full peak* relative in %
Ddr_rel	*Relative drift at downramping* relative in %

For calculations, the following formula were used:

$$(\mathbf{Dhp_{rel}}) = \frac{\boldsymbol{Dhp}}{\boldsymbol{Sq}}\times\mathbf{100}\ [\%]$$

Dhp_{rel} indicates the relative number of drifted fish during the first 15 min of the peak and reference experiment. Dhp_{rel} is calculated relative to the number of grayling larvae stocked at beginning of the experiment (Sq) and is presented in as percentage.

$$(\mathbf{Dfp_{rel}}) = \frac{\boldsymbol{Dfp}}{(\boldsymbol{Sq - Dhp})}\times\mathbf{100}\ (\%)$$

$\mathrm{Dfp_{rel}}$indicates the relative number of drifted fish after the 30 min of the peak experiment. Dfp is calculated in relation to the number of grayling larvae stocked at beginning of the experiment (Sq) minus Dhp.

$$(\mathbf{Ddr_{rel}}) = \frac{\boldsymbol{Ddr}}{(\boldsymbol{Sq - Dhp - Dfp})}\times\mathbf{100}\ (\%)$$

$\mathrm{Ddr_{rel}}$indicates the relative number of drifted fish after the 44 min (3.5 % lateral slope) or 50 min (11% lateral slope) of the peak experiment. Ddr is calculated relative to the number of larvae graylings stocked at beginning of the experiment (Sq) minus Dhp and Dfp.

$$\mathbf{Dt} = \boldsymbol{Dhp} + \boldsymbol{Dfp} + \boldsymbol{Ddr}$$

Dt indicates the total number of fish drift from the beginning of the peak phase until the end of the downramping phase. It is calculated summing up the drift of the three phases, namely the Drift half peak (Dhp), Drift full peak (Dfp), and Drift dowramping (Ddr).

$$(\mathbf{Dt_{rel}}) = \frac{\boldsymbol{Dt}}{\boldsymbol{Sq}}\times\mathbf{100}\ [\%]$$

$\mathrm{Dt_{rel}}$indicates the total number of drifted fish from the beginning of the peak phase until the end of the downramping phase. It is calculated relative to the number of grayling larvae stocked at beginning of the experiment (Sq) and is presented in as percentage.

$$\mathbf{R} = \boldsymbol{Sq} - \boldsymbol{Dt}$$

R indicates the number of fish remaining in the channel after the peak phase of the experiment. It is calculated by subtracting the total drift from all three drifting phases (Dt) during the peak experiment from the number of graylings stocked at beginning of the experiment (Sq).

$$\mathbf{Str_{calc}} = \boldsymbol{R} - \boldsymbol{C}$$

$\mathrm{Str}_{\mathrm{calc}}$is calculated by subtracting the number of grayling recorded during the clearing (C) from the number of fish remaining in the channel after the peak phase of the experiment. In order to avoid methodological errors, the calculations were also performed for the reference experiments.

$$(\mathbf{Str_{rel}}) = \frac{\boldsymbol{Str_{calc}}}{\boldsymbol{Sq} - (\boldsymbol{Dt} - \boldsymbol{Ddr})} \times \mathbf{100}\ (\%)$$

The relative stranding is calculated by setting the value of the calculated stranding in relation to the number of grayling larvae stocked at beginning of the experiment (Sq) subtracted from the total number of drifted fish (Dt) and the drifted fish after the downramping phase (Ddr) of the peak experiment.

4.7. Statistical test methods

For the statistical analysis IBM SPSS Statistics 21 software was used. Non-parametric statistical tests were chosen to test the hypotheses. The non-parametric test makes few or no assumptions about the distribution of the data. Non-parametric tests are based on ranks and can be used on ordinal data. Non-parametric tests reduce the effect of the outliers and the heterogeneity of the variance (Zaiontz C., 2016). These statistical tests are used when the number of replicates is small while variation in the data is comparatively high and the exact data distribution is unknown (Ramon L., 2004). The two tests used for the analysis were the Median Test and Mann–Whitney U Test.

The Median Test is a quick test for the initial orientation. It is used to compare the equality of medians of a quantitative variable from two or more groups. The test is robust against outliers and it is performed when the sample size is small, the dependant variable is ordinal, and the data is non-normally distributed. The null hypothesis (H_0) suggests that the expected values of the medians of the samples do not differ from the median of the total population (Bortz et al., 2008). This test has a low efficiency and is usually used when information about the data distribution is unsure (Siegel et al., 1957).

The Mann- Whitney U Test is a statistical hypothesis test used to compare the medians of two not normally distributed populations. It is based on the comparison of pairs of observations. The assumption is that the variable is ordinal, the sample data is representative and unbiased and the two populations are not dependant on each other. The median is the better description of the centre of the distribution in a non-normal distribution. The null hypothesis (H_0) suggests that the expectation values of the medians are equal, and the alternative hypothesis (H_1) is that they are not equal (Coleman, 2015). The significance level of $\alpha=0.05$ is referred to the maximum exposure of the test to mistakenly reject the H_0 hypothesis. The Mann- Whitney U Test is robust for populations that are non-normally distributed and can be used when the shapes of the distributions are different (Coleman, 2015).

5. Results

5.1. Results related to drift

Drift at reference experiment

The number of experiments per scenario is ranging from 5-6. The Box-plot Diagrams indicate that during day and night and the total drift on the two different slopes is almost identical (Figure 35). Medians are all approx. 30 %.

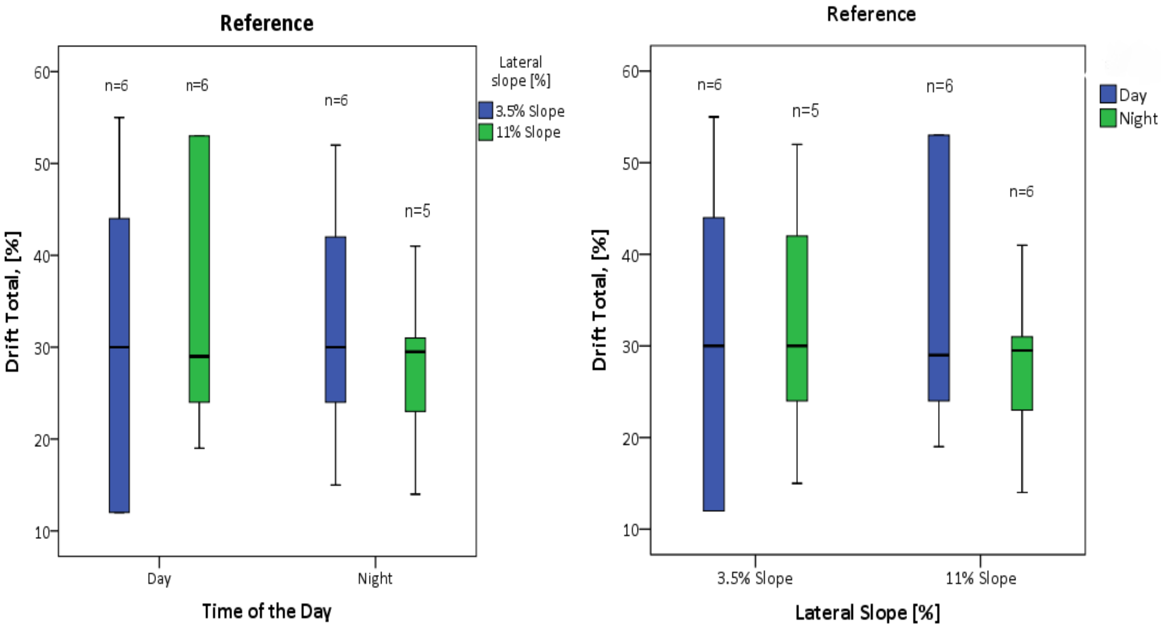

Figure 34. Total drift at reference experiment during day and night (left) and 3.5 % and 11 % lateral slope (right)

Drift at peak experiment

There is no specific trend in the drift of larval grayling in the peak scenario, neither during the day and night, nor on the different gravel bar slopes (Figure 36). The medians for the total drift during peak experiment are at 56.5 %.

The total drift during peak scenario with 125 l/s is shown in Figure 35.

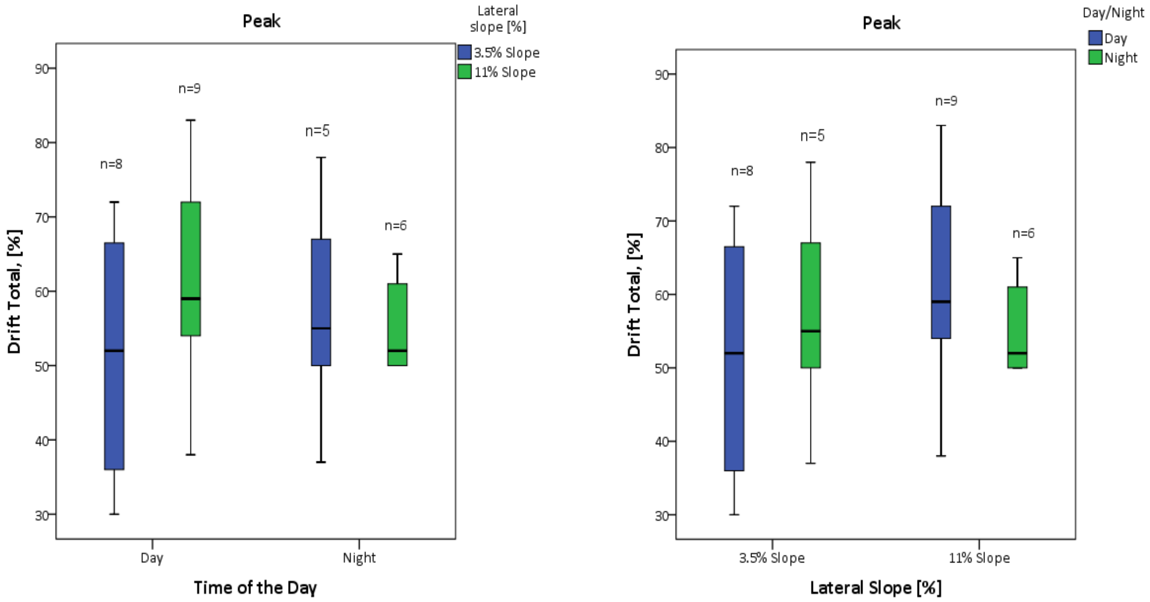

Figure 35. Total drift at peak experiment during day and night (left) and 3.5 % and 11 % lateral slope (right)

Influence of hydropeaking

The medians of the drift rates during the peak experiments for both slopes during the day and night are always higher in comparison to the reference experiment (Figure 37). This implicates that hydropeaking causes higher drift of larval graylings in comparison to base flow conditions.

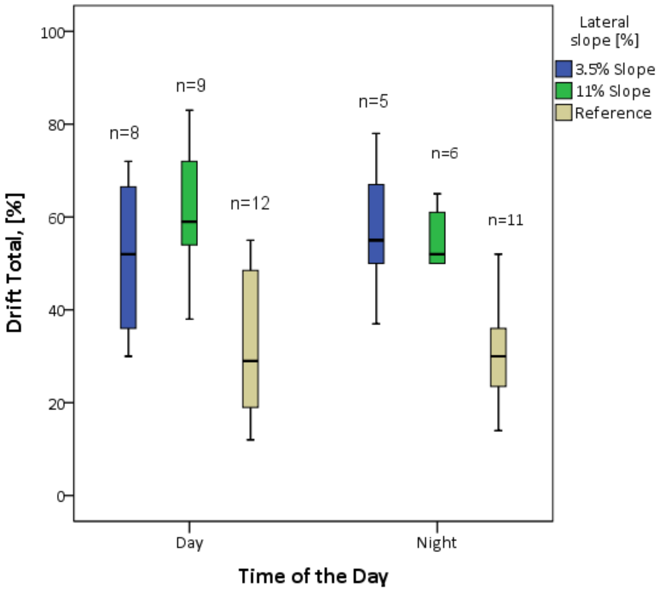

Figure 36. Total drift rates during the day and night, depending on the different lateral gravel bar slopes. Comparison between peak and reference experiment. Results from reference experiments for both slope scenarios combined.

Influence of time of the day on drift

Hypotheses:

$H_{1.0}$ The time of the day does not affect the drift of larval grayling during hydropeaking.

Drift rates at different phases of the experiment are illustrated in Figure 37.

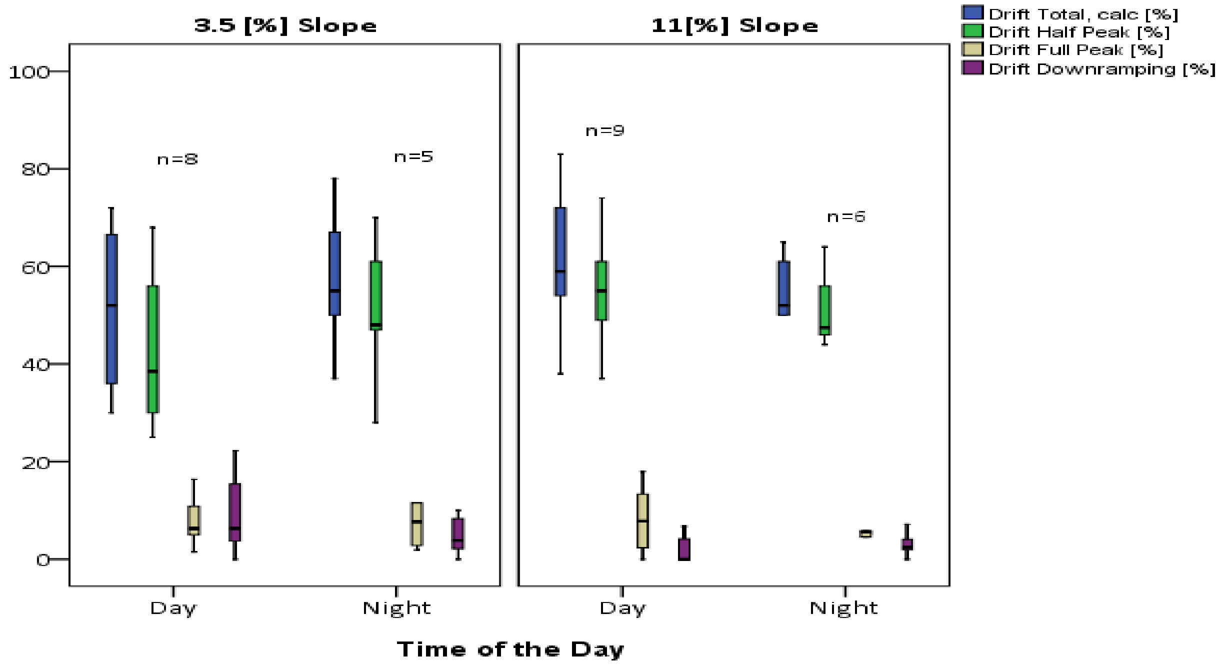

Figure 37. Drift rates at peak experiment during the day and night depending on the different slopes.

Total Drift

There is no statistical difference in the total drift of grayling depending on the different lateral gravel bar slopes. Mann-Whitney U Test with a significance level of α=0.05 show non-significant difference. The asymptotic significance of p=0.524 at the 3.5 % and p=0.224 at the 11 % lateral gravel bar slope. The results for the Median Test are respectively p=1.000 for the 3.5 % and p=0.608 for the 11 % lateral gravel bar slope. The hypothesis is accepted.

Drift Half Peak

The drift of graylings during the Half peak is highest in comparison to the other two phases, namely Full peak and Downramping. This indicates that most of the larval fish drift during the first 15 min of the experimental design. The median of the drift during Half Peak for the 3.5 % slope is 48 % and 52 % for the 11 % slope. Mann-Whitney U Test shows an asymptotic significance of p=0.354 at the 3.5 % and p=0.224 at the 11% lateral gravel bar slope. The results for the Median

Test are p=0.592 at the 3.5% and p=0.608 at the 11 % lateral gravel bar slope. The results indicate no statistical difference during the day and night on the different lateral gravel bar slopes. There is no specific drift trend during the diurnal time. Referring to the lateral slope, the drift rate is a little bit higher on the steeper slope, although not statistically significant.

Drift Full Peak

During Full Peak, the drift rate is much lower in comparison to the Half peak. Comparing the drift rate during the day and night is almost the same. The medians of the drift during Full Peak for the 3.5 % slope are 6.2 % whereas on the 11 % lateral gravel bar slope are 5.6 %. Mann-Whitney U Test shows an asymptotic significance of p=0.833 at 3.5% and p=0.529 at the 11 % lateral gravel bar slope. The results for the Median Test are p=0.592 at the 3.5 % and p=0.608 at the 11 % slope. The results for the drift at full peak indicate no statistical difference during the day and night on the different lateral gravel bar slopes (Mann Whitney U-Test, $p > 0.05$).

Drift Downramping

The drift of graylings during Downramping is lowest in comparison to Half peak and Full peak. Medians of the downramping drift for the 3.5 % slope is 4.1 % whereas on the steeper slope are 2.7 %. Mann-Whitney U Test shows an asymptotic significance of p=0.354 at 3.5 % and p=0.529 at the 11 % lateral gravel bar slope. Median Test shows p=1.000 at the lower inclined slope and p=1.000 at the steeper slope. The results for the drift at downramping indicate no statistical difference during diurnal and nocturnal time on the different lateral gravel bar slopes.

Influence of the lateral slope on drift

Hypotheses:

$H_{2.0}$ The lateral slope does not affect the drift of larval grayling during hydropeaking.

The drift during the different phases of the peak scenarios is represented on Figure 38. The Box-plot diagram below shows the total drift, the drift at Half Peak, at Full Peak and the drift at Downramping on different slopes and depending on the time of the day. The number of experiments per scenario is ranging from 8-9 during the day and 5-6 during the night.

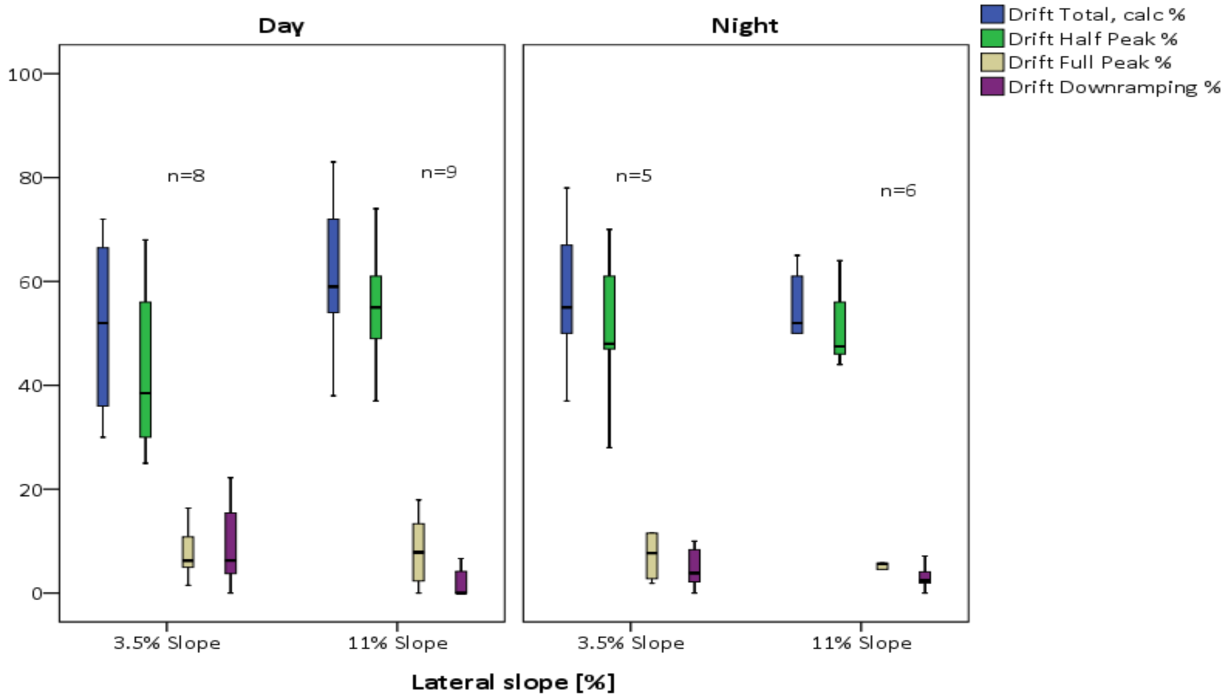

Figure 38. Drift rates at peak experiment at 3,5 % and 11 % lateral gravel bar slope depending on the time of the day.

Total Drift

There is no statistical difference of the total drift of grayling at the 3.5 % and 11 % lateral gravel bar slopes depending on the time of the day. Mann-Whitney U Test shows an asymptotic significance of p=0.321 during diurnal and p=0.792 during the nocturnal time. The results for the Median Test are respectively p=1.000 during the day and p=0.567 during the night. The hypothesis is accepted.

Drift Half Peak

The drift of graylings during the Half peak is the highest in comparison to the other two phases, namely Full peak and Downramping. That means that the most drifted grayling larvae is during the first 15 min of the hydropeaking experiment. Mann-Whitney U Test shows an asymptotic significance of p=0.074 during the day and p=0.792 during the night. The results for the Median Test are p=0.074 during the day time and p=1.000 during the night. The results do not indicate specific drift trend at the different lateral gravel bar slopes. Referring to the slope, the drift rate is a little bit higher on the steeper slope, although not statistically significant. The medians of the drift during diurnal time are 52 % whereas during nocturnal time are 48 %.

Drift Full Peak

During Full Peak the drift is lower and the drift rates at the 3.5 % and 11 % lateral gravel bar slope are almost the same. Mann-Whitney U Test shows an asymptotic significance of p=0.963 during the day and p=0.537 during the night. The results for the Median Test are p=0.637 during diurnal and p=0.567 during nocturnal time. The medians of the drift during Full Peak for the day time are 6.2 % whereas at night time are 5.6 %. The results for the drift at Full peak indicate no statistical difference at the different lateral gravel bar slopes during the day and night.

Drift Downramping

The downstream displacement during downramping is the lowest in comparison to the Half peak and the Full peak and does not show specific trend on the different slopes depending on the diurnal time. The results for the drift during the day at the different lateral gravel bars is close to the significance level $\alpha=0.05$. Mann-Whitney U Test shows an asymptotic significance p=0.046 which is statistically significant and the Median Test p=0.057 not statistically significant. During the night Mann-Whitney U Test indicates p=0.429 and Median Test p=0.567, both not statistically significant. The medians of the downramping drift during the day are 4.1 % whereas for the night time are 2.7 %.

5.2. Results related to stranding

Stranding at reference experiment

The Box-plot Diagram on Figure 39 indicates the stranding rate during reference experiment with base flow of 25 l/s. It aims to estimate the potential stranding error, or with other words the respective clearing efficiency, hence how many fish could not be taken out of the channel through clearing during base flow. The number of experiments per scenario during the day and night and on the different lateral slopes is ranging from 5 – 6.

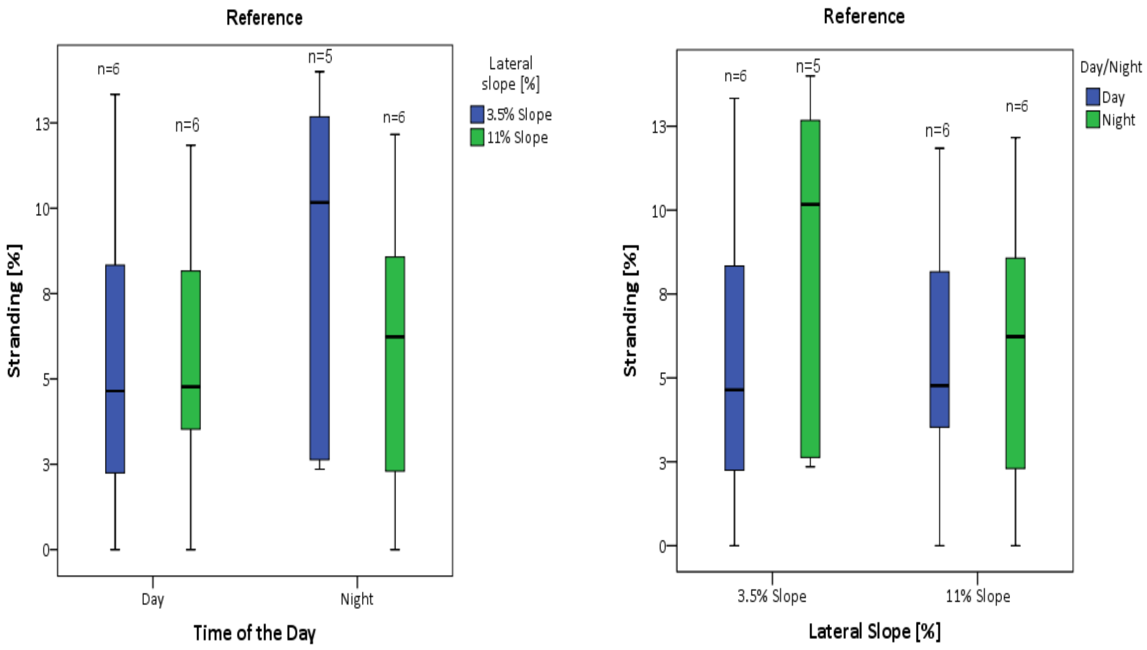

Figure 39.Total stranding rates at reference experiment during day and night (left) and 3.5 % and 11 % lateral slope (right).

Figure 39 shows reference scenario with no visible difference in the stranding of grayling larvae during the day time on the different slopes. For the 3.5 % and 11 % lateral gravel bar slope the stranding rate during the day is approximately 4 %. The stranding during the night is higher and more pronounced on the smaller slope. The results indicate stranding of approximately 10 % on the 3.5 % slope and 6 % on the 11 % slope. The statistical analysis does not indicate significant difference between day and night stranding of larval grayling. Mann-Whitney U test shows an asymptotic significance of p=1.000 for day time and p=0.329 for the night time, as well as p=0.247 for the 3.5 % slope and p=0.699 for the 11 % slope, all not statistically significant. The results for the Median test are p=0.567 for the 3.5 % slope and 0.567 for the 11 % slope, as well as p=1.000 for diurnal and 0.567 for nocturnal time.

Stranding at peak experiment

The total stranding at peak scenario with 125 l/s during day and night (left) and 3.5 % and 11 % lateral slope (right) has been shown on Figure 40.

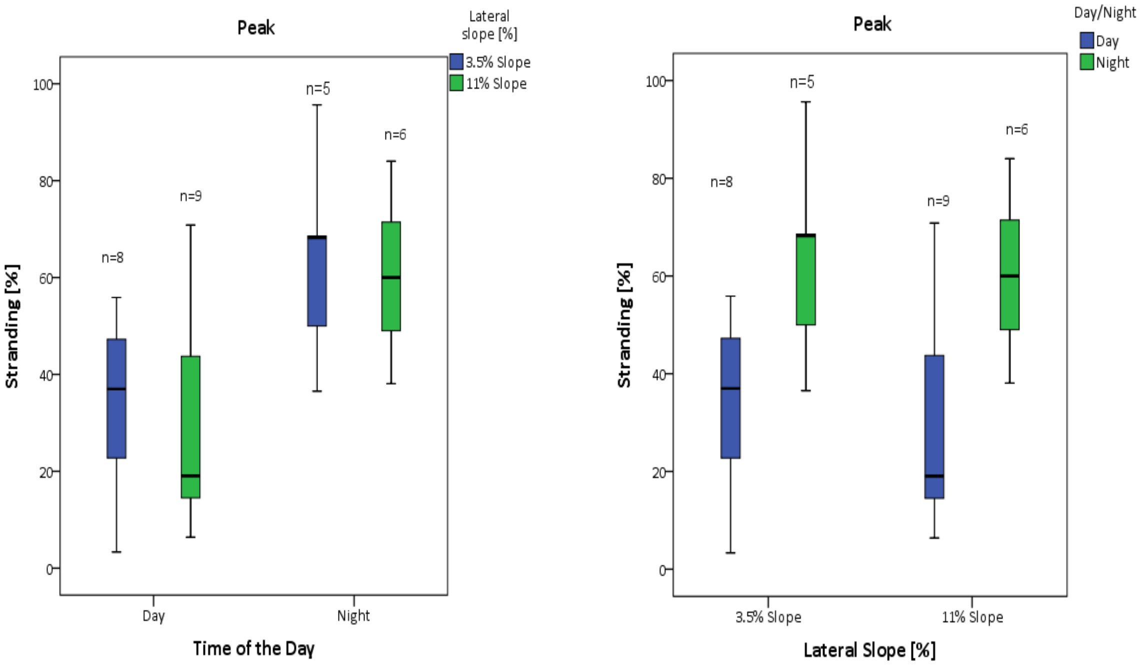

Figure 40. Total Stranding at peak experiment during day and night (left) and 3.5 % and 11 % lateral slope (right)

Figure 40 on the left shows the total stranding during diurnal and nocturnal time depending on the different slopes. The number of peak experiments is ranging from 8-9 during the day and 5-6 during the night. It is visible that there is higher stranding during the night time. The statistical tests Mann-Whitney U Test and Median Test with a significance level of α = 0.05 shows statistically significant difference between the day and night stranding during peak event and depending on the different lateral gravel bar slopes. Mann-Whitney U Test shows an asymptotic significance of p=0.030 at 3.5 % lateral slope and p=0.026 at 11 % lateral slope. The results for the Median Test are p=0.103 at 3.5 % lateral slope and p=0.041 at 11 % lateral slope.

Influence of time of the day on stranding

Hypotheses:

$H_{3.0}$ The time of the day does not affect the stranding risk of larval grayling during hydropeaking.

Comparison between the stranding rates at peak and reference scenario during day and night and depending on the lateral gravel bar slopes has been shown on Figure 41. The number of peak experiments is ranging from 8-9 during the day and 5-6 during the night. The reference experiments are amounting to 5-6 during the day and 6 during the night.

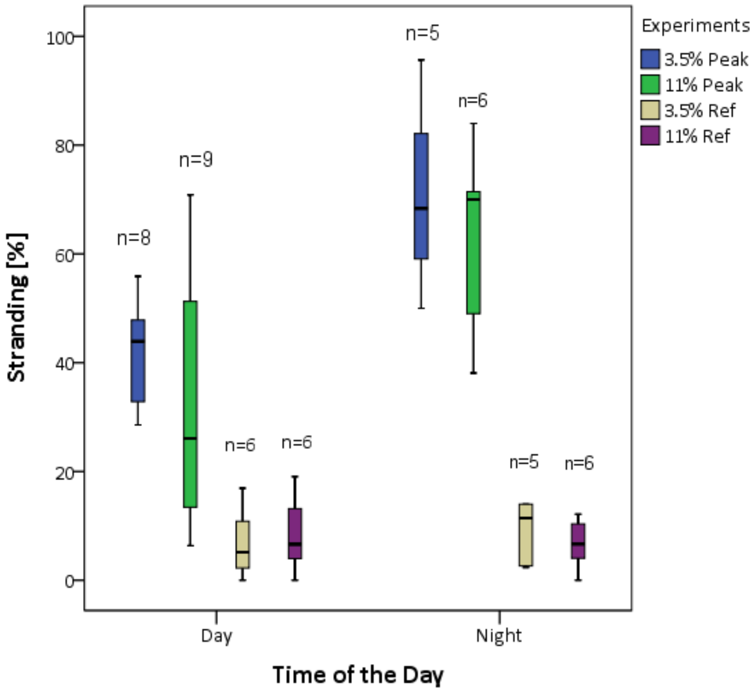

Figure 41.Total stranding rates at peak and reference experiment during different time of the day and depending on the lateral gravel bar slopes.

The statistical tests Mann-Whitney U Test and Median Test with a significance level of α=0.05 shows statistically significant difference between the day and night stranding during peak event and depending on the different lateral gravel bar slopes. Figure 41 clearly shows that during peak event there is a significant difference of the stranding rate between diurnal and nocturnal time depending on the different slopes. The stranding during the day occurs in smaller dimensions comparing to the night time. In addition, higher stranding is shown at the 3.5 % compared to the 11 % lateral gravel bar slope. The statistical analyses are also significant. Mann-Whitney U Test shows an asymptotic significance of p=0.030 at 3.5 % lateral slope and p=0.026 at 11 % lateral slope. The results for the Median Test are p=0.103 at 3.5 % lateral slope and p=0.041 at 11%

lateral slope. The hypothesis is rejected indicating that the time of the day does affect the stranding risk of larvae grayling during hydropeaking.

Influence of lateral slope on stranding

Hypotheses:

$H_{4.0}$ The lateral slope does not affect the stranding risk of larval grayling during hydropeaking.

The Box plots diagram on Figure 42 shows the total stranding rates during peak and reference scenario on different lateral gravel bar slopes. The number of peak experiments is ranging from 5-8 on 3.5 % lateral slope and 6-9 on the 11 % lateral slope. The reference experiments are in the range of 5-6 on 3.5 % slope and 6 on the 11 % lateral gravel bar slope.

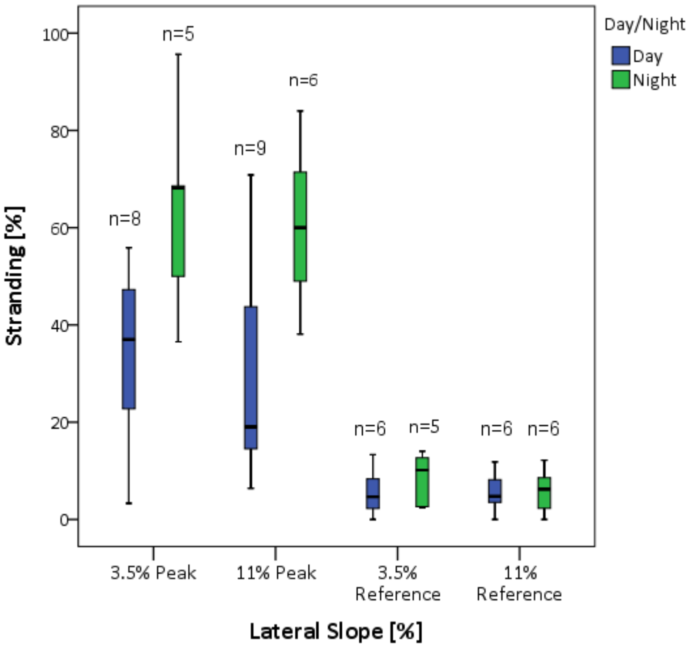

Figure 42. Total Stranding rates at different lateral gravel bar slopes during peak and reference experiment.

The statistical tests Mann-Whitney U Test and Median Test with a significance level of α=0.05 shows no statistically significant difference between the stranding at the different lateral gravel bar slopes depending on the time of the day for the peak experiment. The stranding rates during the peak scenarios are higher at night time, more obvious on the 3.5 % lateral gravel bar slope. Mann-Whitney U Test shows an asymptotic significance of p=0.606 during the day and p=1.000 during the night. The results for the Median Test are p=0.347 during the day time and p=1.000 during the night. The results indicate no statistically significant difference at the different lateral gravel bar slopes during the day and night. The stranding during base flow are also more pronounced at night time and slightly higher on the lower slope approximately 10 % compared to 6 % on the steeper slope, although not statistically significant. The hypothesis is accepted.

6. Discussion

Drift

High drift of grayling larvae has been observed during both scenarios, reference, and hydropeaking. Since the flow during the reference experiment is constant, the downstream displacement cannot be associated to changes in the flow rate, but to the natural behaviour of the graylings. According to Bardonnet et al. (1991), *Thymallus thymallus L.* move into their first feeding habitat after emergence from the gravel. The grayling larvae chose surface waters with low current velocities and then move to the benthic zones. The fish actively enter in the drift in search of their suitable larval habitats. Generally, the grayling larvae remain within the upper part of the water column. The drift usually occurs close to the shoreline areas with low current velocities (Bardonnet et al.,1991; Schmutz et al., 2014). The results of the downstream displacement showed almost two times higher drift during the peak experiment in comparison to the reference conditions with low flow. This result implicates that hydropeaking causes higher drift of larval graylings in comparison to base flow conditions. The influence of hydropeaking to higher drift rates of salmonid species have also been reported by Baumann (2003), Grimardias et al. (2004), Limnex AG, (2004) and Young et al. (2011).

Studies by Vehanen et al. 2000, conducted in artificial channels with brown trout have also confirmed higher drift rates because of hydropeaking. He found that as runoff increases, the number of animals in the drift is also significantly higher. This is supported by Thompson et al. (2011). Their study on young and juvenile rainbow trout and brown trout showed that during the pulse flow, smaller fish are more susceptible and likely to be drifted than adult trout. This may be a result of the poor swimming performance of the young in comparison to that of larger fish. Heggenes and Traaen (1988) also found that smaller fish were more likely to be displaced downstream by the increased discharge in comparison with the larger individuals.

Research by Heggenes et al., (1988) found higher drift rates of brook trout during high runoff at night. They suggest that this could be related to the salmonids behaviour to migrate and disperse in the dark.

The results from this work did not show specific trends in the drift of larval grayling depending on the time of the day or on the different lateral gravel bar slopes. The highest drift was observed at half peak during the first 15 min of the experiment. Approximately 50 % of the grayling larvae were displaced downstream during the day or night in both channels. The reason for such a high drift during the initial phase could be related to the fact that the graylings swim in group. Therefore, during hydropeaking a high percentage of the larvae are drifted away with the flow (Ingram et al., 1999). Other possible explanation could be the swimming performances of the fish. The graylings which at the beginning of the phase were not able to endure to the high flow rates could drift away, while the rest managed to swim in a position against the current or found suitable habitats. These increased drift rates during the peak phase are consistent with the findings from previous experiments conducted at the HyTEC facility with a similar experimental setup (Auer et al., 2013; Fohler, 2013; Rauch, 2014).

During the Full peak drift rates fall to very low levels. The downstream displacement for both lateral gravel bar slopes was almost the same during the day and at night. The decreased drift during this phase could mean that the fish has already adapted to the flow conditions. Another possibility could be that the fish with better swimming performances has already been able to find a refuge habitat and avoid stressful conditions.

The downstream displacement during the downramping phase is the lowest, in comparison to the other two drift phases. The drift does not indicate specific trends related to the different slopes and time of the day. Possible reasons include that the fish have already found refuge habitats and are less susceptible to downstream displacement.

Stranding

Stranding results have been calculated from other parameters as stranded fish is not easy to find, especially in their larvae stages. Due to their colour and small body size, stranded fish are difficult to be detected on the gravel. In addition, the grayling larvae can also escape deeper into the substrate (Schmutz et al., 2014). Difficulties related to the estimation of stranding rates have been mentioned in different studies (Halleraker et al., 2003; Irvine et al., 2009). In a field research performed by Saltveit et al. (2001) on Nidelva River (Norway) it was indicated that detection of stranding based on counting could lead to underestimation of the actual stranding rates.

The natural habitat of the grayling larvae is in waters of the hyporhithral region close to the gravel banks. The favourable conditions are shallow waters with low flow velocities (Ingram et al., 1999; Sempeski & Gaudin, 1995). During rising water levels, graylings stay closer to the water line where the current velocities are lower. Stranding occurs when the water levels recede during downramping and is more pronounced on the lower gradient slopes, as the lateral part of the water decrease is faster, thus leading to higher stranding potential.

The results from this work showed higher stranding rates, although not significant, on the 3.5 % lateral gravel bar slope and more pronounced at night time. A possible explanation could be that with the same downramping rates, on the lower gradient it takes less time for the water near the water surface line to decrease, and therefore the stranding potential is higher. The steeper lateral slopes could have lower stranding risk, however these conditions provide less suitable habitat for the graylings, especially in their larval stages as well as during the spawning period (Nykanen et al., 2003; Sempeski & Gaudin, 1995).

According to Hunter et al., river configurations with low gradient slopes, side channels and potholes has significantly higher stranding risk in comparison to rivers confined to a single channel with steeper slopes. Different authors concluded that more beach stranding occurs on gently sloping gravel bars, than on steeper banks slopes (Adams et al., 1999; Bradford et al., 1995; Hunter, 1992). Generally, higher standing rates occurred in slopes < 5% (Bauersfeld, 1978; Beck Assoc.,1989; Monk, 1989).

Bauersfeld 1978, investigated the stranding of chinook salmon fry on 6 different gravel bars in the Cowlitz River (California USA). The transect gradient slopes were in the range from 0.57 % to 4.8 %. He concluded that most of the stranding occurred on lateral gravel bar slopes < 2 %. His observation indicated that stranding is greatly reduced on river bars with a slope greater than 4 %. Bell et al. (2008) conducted a study in Trail Bridge Reservoir, Oregon with bull trout (*Salvelinus confluentus*) and chinook salmon. They found that more stranding occurred at the < 6 % slopes in comparison to the 10 % slopes. The stranded salmonids were mainly found in interstitial spaces among cobbles and in potholes.

In the available literature stranding in natural conditions on steeper lateral gravel bar slopes > 5 % has not been widely investigated (Hunter, 1992). Stranding of salmonids on slopes greater than 5 % has been observed in laboratory experiments. Monk 1989 concluded that more chinook salmon fry were stranded on 1.8 % slopes than on 5.1 % slopes.

In the available literature, in terms to the time of the day, some studies showed higher stranding rates during diurnal time due to substrate concealment behaviour of the juvenile fish (Bradford et al., 1995; Bradford, 1997). Other research found more stranding during the night time (Hamilton and Buell, 1976). The experiments by Irvine et al. (2009) indicate no effect of the time of the day for stranding. Although the authors suggest that this could be related to fewer experimental trials at night and therefore unbalanced data in favour to the experiments conducted during the day time. Moreover, the contradictory in the results from the different studies could be related to the fact that some of the research has also investigated additional factors such as the water temperature and the seasonal variability (Irvine et al., 2009; Schmutz et al., 2014).

The results of my work show that the time of the day significantly affects the stranding risk of grayling larvae. Higher stranding is observed during the night than during the day. This can be related to the habitat preferences of the fish. During the day the grayling inhabit sectors with higher flow rates and greater depths in comparison to the night. At night the larval fish move to shallower habitats with calm water near the shoreline where the stranding risk is higher (Sempeski & Gaudin, 1995; Gaudin & Sempeski, 2001; Schmutz et al., 2014). Another reason for the higher stranding at night could be associated with the optical orientation of the fish. During the night, it is possible that graylings close to the water surface line could have difficulties in their orientation and loose visual contact with the substrate. In addition, the swimming performances of the fish during the day are better. The increased stranding rates during hydropeaking at night time are consistent with findings from previous experiments conducted at the HyTec facility with similar experimental setup (Auer et al., 2014; Fohler, 2013).

Findings from the other studies contradict these results. Bradford et al. (1995) focused on stranding of juvenile coho salmon and rainbow trout on river bars. The experiments were conducted in artificial stream channels with gravel bar substrate and at winter conditions. During the day, the incidence of stranding was higher because the fish was concealed in the interstitial areas of the substrate and was hesitating to leave when water levels receded. During night time, less stranding occurred, as the fish were more active. The research results suggested that in winter less stranding will occur at night and at slow rates of flow reduction (Bradford et al., 1995)

The vulnerability of fish to stranding depending on the time of the day has also been investigated by Woodin (1984). He inferred that juvenile chinook is using the substrate for cover at night only to a smaller degree, therefore these species are less likely to strand at night. Research on steelhead fry showed that the fish is less susceptible to stranding during the day, presumably because the fish feeds during this time (Olson, 1990). Experiments with steelhead trout fry concluded that there is no significant difference in fish stranding during the day or night (Beck Assoc., 1989, Monk, 1989, Olson, 1990)

7. Conclusion

The results related to the drift indicated that there is higher downstream displacement during the peak experiments, although not significant. The mean values of total drift during hydropeaking were 56.5 %, as compared to 30 % in the reference experiment. Drift was more obvious during the first 15 min of the adaptation phase at Half peak, when approximately 50 % of the fish drifted. The results did not indicate a specific preference for drift comparing the day or night, or comparing different slopes of lateral gravel bars. The increased drift rates during hydropeaking are also consistent with findings from previous experiments conducted at the HyTEC facility with similar experimental setup (Auer et al., 2013; Fohler, 2013; Rauch, 2014).

The results related to the stranding of grayling larvae indicate that the time of the day has a significant influence on the stranding caused by hydropeaking. During the night, stranding rates are higher, which is more obvious with the 3.5 % lateral gravel bar slope. This can be linked to the habitat preferences of the fish. During the day, the grayling inhabit sectors with higher flow rates and greater depths. At night, the fish change the preferred locations to shallower and slower flowing areas closer to the shoreline, where the risk of stranding is higher. Greater fish stranding during hydropeaking at night time was also confirmed in findings from previous experiments conducted at the HyTEC facility plant (Auer et al., 2013; Fohler, 2013).

The experiments showed that the time of the day has a greater impact on the drift and stranding of the fish, than the lateral gravel bar slope. However, at the 3.5 % slope the stranding was higher in comparison to the 11 % slope, although not significant. These results suggest that the lower slopes have increased negative effects of hydropeaking on grayling populations in comparison to the steeper slopes. The natural rivers with shallow lateral banks provide perfect habitat for the larvae and juvenile grayling. However these otherwise ideal habitats exhibit a large stranding risk whereas the steeper lateral gravel banks have lower stranding potential, but provide less suitable habitat for the graylings, especially in their larval stages (Nykanen et al., 2003; Sempeski & Gaudin, 1995).

From the performed experiments, it can be asserted that the rapid lowering of the water level during night time as a result of hydropeaking represents an extreme danger to the grayling in their larval stages. The results obtained in this research should contribute to future investigations in this area. To develop suitable mitigation measures, more aspects must be investigated especially in combination between morphology, substrate, hydrology, temporal and seasonal influences, and water temperature.

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Appendix

No	Experiment	Date	Time	Day/ Night	Reference ID	Channel	Slope [%]	Reference / Peak	Duration (min)	Weather	Air t (°C)	Water t (°C)	Fish type	Age (stand up days)	from Tank No	to Tank No	Origin	Stocking No (B)	Stranding %	Drift HP	Drift FP	Drift DP	Drift total	Clearing	Total sum	% Drift atHP	% Drift at FP	% Drift DP
1	BVT1_Ref	06/05/15	18:48	D	25 (1:1)	2	11	R	30	cloudy	N/A	N/A	Grayling	4	2	4	Ybbs	100	8.2	44	7	2	53	43	96	44	12.5	4.1
2	BVT2_Ref	07/05/15	18:48	D	25 (1:1)	1	3.5	R	30	sunny	19	9.4	Grayling	9	2	4	Ybbs	100	13.3	54	1	0	55	39	94	54	2.2	0.0
3	BVT3_Ref	08/05/15	11:32	D	25 (1:1)	2	11	R	30	y, slightly	20	9.6	Grayling	11	2	4	Ybbs	100	0.0	41	9	3	53	47	100	41	15.3	6.0
4	BVT4_Ref	09/05/15	11:32	D	25 (1:1)	1	3.5	R	30	y, slightly	20	9.6	Grayling	11	2	4	Ybbs	100	7.0	41	2	1	44	52	96	41	3.4	1.8
5	BVN1_Ref	10/05/15	10:12	N	25 (1:1)	1	3.5	R	30	cloudy	16	10	Grayling	11	2	4	Ybbs	100	20.0	10	0	0	10	72	82	10	0.0	0.0
6	BVT5_Ref	11/05/15	14:42	D	25 (1:1)	2	11	R	30	sunny	24	11	Grayling	16	2	3	Ybbs	100	5.1	21	1	2	24	72	96	21	1.3	2.6
7	BVN2_Ref	12/05/15	22:33	N	25 (1:1)	2	11	R	30	clear	12	10	Grayling	16	2	3	Ybbs	100	8.6	26	4	0	30	64	94	26	5.4	0.0
8	BVT6_Ref	13/05/15	14:03	D	25 (1:1)	1	3.5	R	30	raining	12	11	Grayling	17	2	3	Ybbs	100	2.3	11	1	0	12	86	98	11	1.1	0.0
9	BVN03_Ref	14/05/15	22:45	N	25 (1:1)	2	11	R	30	cloudy	14	10	Grayling	17	2	3	Ybbs	100	2.3	10	3	1	14	84	98	10	3.3	1.1
10	BVT7_Ref	15/05/15	15:32	D	25 (1:1)	2	11	R	30	raining	10	9.3	Grayling	18	2	3	Ybbs	100	3.5	13	2	4	19	78	97	13	2.3	4.7
11	BVN4_Ref	16/05/15	22:19	N	25 (1:1)	1	3.5	R	30	raining	8	9.2	Grayling	18	2	3	Ybbs	100	2.6	22	2	0	24	74	98	22	2.6	0.0
12	BVT8_Ref	17/05/15	11:35	D	25 (1:1)	1	3.5	R	30	cloudy	9	10	Grayling	9	1	3	Salza	100	0.0	18	1	0	19	81	100	18	1.2	0.0
13	BVT9_Ref	18/05/15	14:40	D	25 (1:1)	2	11	R	30	cloudy	10	11	Grayling	19	2	3	Ybbs	100	11.8	22	2	1	25	66	91	22	2.6	1.3
14	BVT10_Ref	19/05/15	19:23	D	25 (1:1)	2	11	R	30	cloudy	14	8.9	Grayling	14	1	3	Salza	100	4.4	30	2	1	33	64	97	30	2.9	1.5
15	BVN5_Ref	20/05/15	22:05	N	25 (1:1)	1	3.5	R	30	cloudy	8	8.5	Grayling	15	1	3	Salza	100	10.2	40	1	1	42	52	94	40	1.7	1.7
16	BVN6_Ref	21/05/15	22:05	N	25 (1:1)	2	11	R	30	cloudy	8	8.5	Grayling	15	1	3	Salza	100	5.8	29	2	0	31	65	96	29	2.8	0.0
17	BVN7_Ref	22/05/15	00:51	N	25 (1:1)	1	3.5	R	30	cloudy	7	8.5	Grayling	15	1	3	Salza	100	14.0	49	1	2	52	41	93	49	2.0	4.0
18	BVN8_Ref	23/05/15	00:51	N	25 (1:1)	2	11	R	30	cloudy	7	8.5	Grayling	15	1	3	Salza	100	6.7	34	6	1	41	55	96	34	9.1	1.7
19	BVN9_Ref	24/05/15	22:32	N	25 (1:1)	2	11	R	30	, visible r	8.5	8.9	Grayling	16	1	3	Salza	100	12.2	26	0	3	29	62	91	26	0.0	4.1
20	BVN10_Ref	25/05/15	22:41	N	25 (1:1)	1	3.5	R	30	, visible r	8.5	8.9	Grayling	16	1	3	Salza	100	12.7	26	3	1	30	61	91	26	4.1	1.4
21	BVT11_Ref	26/05/15	13:31	D	25 (1:1)	1	3.5	R	30	sunny, hot	27	14	Grayling	23	1		Salza	100	8.3	36	4	1	41	54	95	36	6.3	1.7
22	BVN11_Ref	27/05/15	23:10	N	25 (1:1)	2	11	R	30	dy, no vis r	18	15	Grayling	16	3	3	Mur	100	57.6	62	5	3	70	11	81	62	13.2	9.1
23	BVN12_Ref	28/05/15	00:32	N	25 (1:1)	1	3.5	R	30	dy, no vis r	18	15	Grayling	16	3	3	Mur	100	65.5	58	13	3	74	7	81	58	31.0	10.3
24	BVN13_Ref	29/05/15	22:32	N	25 (1:1)	1	3.5	R	30	cloudy	18	15	Grayling	17	3		Mur	100	60.5	49	13	4	66	11	77	49	25.5	10.5
25	BVT12_Ref	30/05/15	14:23	D	25 (1:1)	1	3.5	R	30	cloudy	15	11	Grayling	29	1		Mur	100	2.2	11	0	1	12	86	98	11	0.0	1.1
26	BVN14_Ref	31/05/15	22:40	N	25 (1:1)	1	3.5	R	30	cloudy	11	11	Grayling	29	1		Mur	100	2.4	14	1	0	15	83	98	14	1.2	0.0
27	BVN15_Ref	01/06/15	22:42	N	25 (1:1)	2	11	R	30	cloudy	11	11	Grayling	29	1		Mur	100	0.0	19	1	3	23	77	100	19	1.2	3.8

0	Experiment ID	Date	Time	Day/Night	Peak-ID	Mixing ratio (T:O)	Channel N:	Slope [%]	DR(cm/min)	Reference / Pea	Duration peak (min)	Weather	Air t (°C)	Water t (°C)	Fish type	Age (St.up days	from Tank No	to Tank No	Origin	Stocking No (B)	Stranding %	Drift HP	Drift FP	Drift DR	Drift total	Clearing	Total sum	% Drift HP	% Drift FP	% Drift DR
1	BVT1_Peak	07/05/15	14:30	N	ISH_125_0.5	1:1	2	11	0.5	P	30	bright	17	9	Graylng	5	2	4	Ybbs	100	58.8	80	3	0	83	7	90	80	15.0	0.0
2	BVT2_Peak	08/05/15	16:37	N	ISH_125_0.5	1:1	2	11	0.5	P	30	sunny	20	9.6	Graylng	9	2	4	Ybbs	100	43.8	61	7	4	72	14	86	61	17.9	12.5
3	BVN1_Peak	09/05/15	23:38	N	ISH_125_0.5	1:1	2	11	0.5	P	30	clear	7.5	10	Graylng	9	2	4	Ybbs	100	84.0	47	3	0	50	8	58	47	5.7	0.0
4	BVT3_Peak	10/05/15	17:31	N	ISH_125_0.5	1:1	2	11	0.5	P	30	bright	23	9.3	Graylng	11	2	4	Ybbs	100	17.9	55	6	0	61	32	93	55	13.3	0.0
5	BVN2_Peak	11/05/15	22:21	N	ISH_125_0.5	1:1	2	11	0.5	P	30	cloudy	16	10	Graylng	11	2	4	Ybbs	100	38.1	56	2	3	61	23	84	56	4.5	7.1
6	BVT4_Peak	12/05/15	17:19	N	ISH_125_0.5	1:1	2	11	0.5	P	30	cloudy	15	10	Graylng	12	2	3	Ybbs	100	6.4	49	4	0	53	44	97	49	7.8	0.0
7	BVT5_Peak	13/05/15	17:20	N	_FISH_125_	1:1	1	3.5	0.5	P	30	cloudy	15	10	Graylng	12	2	3	Ybbs	100	41.2	28	4	3	35	37	72	28	5.6	4.4
8	BVT6_Peak	14/05/15	14:56	N	_FISH_125_	1:1	1	3.5	0.5	P	30	sunny	23.5	11	Graylng	16	2	3	Ybbs	100	28.6	25	5	0	30	50	80	25	6.7	0.0
9	BVN3_Peak	15/05/15	22:54	N	_FISH_125_	1:1	1	3.5	0.5	P	30	clear	12	10	Graylng	16	2	3	Ybbs	100	95.7	48	6	1	55	1	56	48	11.5	2.2
10	BVT7_Peak	16/05/15	17:00	D	ISH_125_0.5	1:1	2	11	0.5	P	30	unny, clou	19	10	Graylng	17	2	3	Ybbs	100	8.9	49	6	3	58	38	96	49	11.8	6.7
11	BVN4_Peak	17/05/15	23:04	N	_FISH_125_	1:1	1	3.5	0.5	P	30	cloudy	14	10	Graylng	17	2	3	Ybbs	100	50.0	61	3	3	67	15	82	61	7.7	8.3
12	BVT8_Peak	18/05/15	15:43	D	_FISH_125_	1:1	1	3.5	0.5	P	30	raining	10	9.3	Graylng	8	1	3	Salza	100	55.9	60	6	2	68	13	81	60	15.0	5.9
13	BVN5_Peak	19/05/15	22:20	D	ISH_125_0.5	1:1	2	11	0.5	P	30	raining	8	9.3	Graylng	18	2	3	Ybbs	100	71.4	48	3	2	53	12	65	48	5.8	4.1
14	BVT9_Peak	20/05/15	11:38	D	ISH_125_0.5	1:1	2	11	0.5	P	30	cloudy	9	11	Graylng	19	2	3	Ybbs	100	26.1	52	2	0	54	34	88	52	4.2	0.0
15	VT10_Peak	21/05/15	14:40	D	_FISH_125_	1:1	1	3.5	0.5	P	30	cloudy	10	11	Graylng	19	2	3	Ybbs	100	47.8	45	9	8	62	16	78	45	16.4	17.4
16	VT11_Peak	22/05/15	19:21	D	_FISH_125_	1:1	1	3.5	0.5	P	30	cloudy	14	8.9	Graylng	13	1	3	Salza	100	32.8	32	1	9	42	36	78	32	1.5	13.4
17	BVN6_Peak	23/05/15	22:05	D	_FISH_125_	1:1	1	3.5	0.5	P	30	artly cloud	12	8.7	Graylng	13	1	3	Salza	100	68.6	28	2	7	37	15	52	28	2.8	10.0
18	BVN7_Peak	24/05/15	22:08	D	ISH_125_0.5	1:1	2	11	0.5	P	30	artly cloud	12	8.7	Graylng	13	1	3	Salza	100	49.0	46	3	1	50	25	75	46	5.6	2.0
19	BVN8_Peak	25/05/15	22:24	D	ISH_125_0.5	1:1	2	11	0.5	P	30	cloudy	9.5	8.3	Graylng	14	1	3	Salza	100	70.0	44	6	1	51	14	65	44	10.7	2.0
20	BVN9_Peak	26/05/15	22:20	D	_FISH_125_	1:1	1	3.5	0.5	P	30	cloudy	9.5	8.3	Graylng	14	1	3	Salza	100	68.2	70	8	0	78	7	85	70	26.7	0.0
21	BVT12_Peak	27/05/15	16:00	D	_FISH_125_	1:1	1	3.5	0.5	P	30	sunny	18	8.5	Graylng	16	1	3	Salza	100	46.7	52	3	10	65	14	79	52	6.3	22.2
22	BVT13_Peak	28/05/15	16:00	D	ISH_125_0.5	1:1	2	11	0.5	P	30	sunny	18	8.5	Graylng	16	1	3	Salza	98	70.8	74	0	1	75	6	81	74	0.0	4.2
23	VT_14_Peak	29/05/15	13:02	D	ISH_125_0.5	1:1	2	11	0.5	P	30	ly very clo	24	13	Graylng	27	1	3	Salza	100	14.5	37	1		38	53	91	37	1.6	0.0
24	VT_15_Pea	30/05/15	12:56	D	ISH_125_0.5	1:1	1	3.5	0.5	P	30	ly very clo	24	13	Graylng	27	1	3	Salza	100	3.3	68	2	2	72	27	99	68	6.3	6.7
25	VN_10_Pea	31/05/15	22:56	D	ISH_125_0.5	1:1	2	11	0.5	P	30	udy and wi	18.5	15	Graylng	27	1	3	Salza	100	50.0	64	0	1	65	17	82	64	0.0	2.8
26	VN_11_Pea	01/06/15	22:55	D	ISH_125_0.5	1:1	1	3.5	0.5	P	30	udy and wi	18.5	15	Graylng	27	1	3	Salza	100	36.5	47	1	2	50	31	81	47	1.9	3.8
27	VT_16_Pea	02/06/15	10:26	D	ISH_125_0.5	1:1	2	11	0.5	P	30	cloudy	20	14	Graylng	16	3	3	Mur	100	19.0	57	1	1	59	33	92	57	2.3	2.4
28	VT_17_Pea	03/06/15	10:38	D	ISH_125_0.5	1:1	1	3.5	0.5	P	30	cloudy	20	14	Graylng	16	3	3	Mur	100	16.9	32	3	2	37	52	89	32	4.4	3.1