ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

EVALUATION OF FISH PASSAGE DESIGN: A CASE STUDY IN VEREINIGTE WEIßERITZ RIVER

M.Sc. THESIS

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Department of Civil Engineering

Hydraulics and Water Resources Engineering Programme

JANUARY 2015

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

BALIK GEÇİDİ TASARIM DEĞERLENDİRMESİ: VEREINIGTE WEIßERITZ NEHRİ ÖRNEK ÇALIŞMASI

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10 ARALIK 2014

Meliha Gamze Ekren, a **M.Sc.** student of ITU **Institute of Science and Technology** student ID 501121515, successfully defended the **thesis/dissertation** entitled "**EVALUATION OF FISH PASSAGE DESIGN: A CASE STUDY IN VEREINIGTE WEIßERITZ RIVER"** which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : December 10 2014
Date of Defense : January 19 2015

To my family and my colleagues,

FOREWORD

I am very grateful to be supervised by Prof. Necati Ağıralioğlu and Prof. Hilal Gonca Coşkun in Istanbul Technical University. I really appreciate the support they provided me and the trust they put in me and the study itself. Whenever I have questions, they dealed with them meticulously.

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December 10 Meliha Gamze EKREN
Environmental Engineer

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ABBREVIATIONS

OPAQUE: Operationelle Abfluss-und Hochwasservorhersage in Quellgebieten (Operational runoff and flood forecasting in source areas)
LTV: Landestallsperrenverwaltung des Freistaates Sachsen (Dam Authority of Saxony)
SMUL: Sachsisches Staatsministerium für Umwelt und Landwirtschaft (Saxon State Ministry for Environment and Agriculture)
LAWA: Bund/Lander-Arbeitgemeinschaft Wasser (Federal/ State Working Group on Water)
LfUG: Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (Saxon State Office for Environment, Agriculture and Geology)
DWA: Deutsche Vereinigung für Wasserwirtschaft (German Association for Water, Wastewater and Waste)
DVWK: Deutsch Verband für Wasserwirtschaft und Kulturbau **(**German Association for Water Resources and Land Improvement)
BfG: Bundesanstalt für Gewasserkunde (Federal Institute of Hydrology)
BAW: Bundesanstalt für Wasserbau (Federal Waterways Engineering and Research Institute)
WFD: Water Framework Directive
BMWI: Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
WSV: Wasser und Schifffahrtsverwaltung des Bundes **(**Federal Waterways and Shipping Administration)
REA: German Renewable Energy Sources Act

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EVALUATION OF FISH PASSAGE DESIGN: A CASE STUDY IN VEREINIGTE WEIßERITZ RIVER

SUMMARY

The fish passage issue is an essential element in the environmental impact assessment of small hydropower projects. These projects not only create a barrier for upstream movement, but they can also induce mortality to fish population by passage through turbines. Downstream fish passage at hydropower stations is a relatively recent issue, and devices to safely transit fish downstream of turbines are still under development. Most of the devices that were installed were on existing generating stations, and so, owners usually did not have much flexibility in the type of device that was installed. Three types of devices are usually found at hydroelectric sites, bypass channels, physical barriers (i.e. screens), and physiological barriers (louvers, lights, sound, etc.). The efficiency for downstream migration devices varies according to site configuration and species present. Even though high efficiencies were found for certain salmonids such as Atlantic salmon, no single device has attained 100% efficiency. The use of certain devices such as fine mesh screens has direct impact on generating station operation because of high maintenance needs, and headloss through the screens which lowers power production. Upstream fish passage is as the most investigated type of fishways that are in place have been so for a long time. Consequently, these systems are well standardised and many authors have presented guidelines for their design. The most common fishway is the pool and weir which is found in many countries around the world. Finally, the monitoring of fish passages at hydropower sites should be an integral part of the project. This activity is frequently left aside, but needs to be carried out to evaluate the efficiency of systems that are built for fish passage. Mark-recapture techniques or telemetry are tools that can be used for such a purpose.

In this thesis, the fish passage nearby WKA Bienertmühle weir was investigated onsite and novel fish passage design is proposed. Fish passage instructions, fish passage design principles, background of the case study area: geography, population and socio-economy, topography, meteorology, hydrology, river properties: ecohydrology, hydromorphology, hydrobiology, hydrochemistry, ecohydraulics, materials and methods: status quo of Vereinigte Weißeritz River, fish passage location and design,

methods of approach: conventional and ecohydraulics, evaluations and discussions: practical solutions: optimum fish passage concept: legislation, proposed design: operation criteria and novel fish passage design are given respectively.

The existing fish passage is one vertical slot type of fish passage and a small hydro power plant is located nearby WKA Bienertmühle weir. Small hydropower project development has been, for the last decade, one of the sectors in the energy field that has been very active. Where the preceding decades saw a fair number of large hydroelectric developments, the last decade was almost exclusively made up of smaller projects that were essentially developed by private producers. One of the main environmental challenges of small hydropower development is related to fish passage both upstream and downstream. These migrations are ecological imperatives for populations of anadromous fish. Entire populations of these migratory species can be eliminated if either up or downstream migrations are blocked. Small scale hydro developments are often an impediment to these migrations. Efficient fish passage is required under many jurisdictions in order for regulating agencies to approve hydropower projects, whether they be new developments or under relicensing. Hydroelectric dams can also cause other impacts apart from blocking fish migrations. For instance, dams can have effects on water temperature, flow regimes, dissolved gas content, species diversity, and other ecological parameters that may have direct or indirect effects on fish. Additionally, climate change alters the fish assemblage structure and function distribution in Europe. For this reason, a relatively new field called ecohydraulics that is a subdiscipline of hydraulics that deals with fish passage facilities is proposed. This field constitues links between biological (swimming performance, behavioural responses of fish) and physical (hydraulic, hydrologic) features of aquatic systems.

The result of this thesis showed that the fish passage nearby WKA Bienertmühle weir was found to be not functional. Therefore, a novel fish passage design that is comprised of two fish passage facilities (serves both upstream and downstream migration) and operational system was proposed. This novel design is retrofitted design of the existing fish passage with new design for downstream fish migration.

BALIK GEÇİDİ TASARIM DEĞERLENDİRMESİ: VEREINIGTE WEIßERITZ NEHRİ ÖRNEK ÇALIŞMASI

ÖZET

Barajlar, akarsu sistemindeki akım şartlarını değiştirerek oluşturdukları göllerle yeni bir hayat ortamı (habitat) sağlayarak balıklar üzerinde olumlu etki yaparken, balık geçişlerini engelledikleri için balık türleri üzerinde, balıkların nesillerinin tükenmesine kadar varan çok ciddi olumsuz etkileri de bulunmaktadır. Ayrıca dolu savaklar, su alma ağızları, hidroelektrik santral ve dip savaklardan geçen balıklar ciddi şekilde yaralanabilir, hatta ölebilirler. Bu olumsuz etkileri azaltmak için genellikle baraj ve bağlamalarda balık geçitleri ve ızgara tesisleri planlanır. Balık geçitleri ve ızgara tasarımına, hukuk, topografya, zemin durumu, balık biyolojisi, hidroloji, hidrolik ve çevre faktörleri gibi çeşitli etkenler etki eder. Bunun için bunların tasarımı farklı disiplinlerdeki uzmanların bir arada çalışması ile gerçekleştirilebilir.

Balık göçü, doğal ve genellikle mevsimlik hayat devresinin bir fonksiyonudur. Bu göçte, çok sayıda balık, bir hayat ortamından diğerine yumurtlamak, beslenmek, büyümek veya yırtıcı hayvanlardan korunma yeri aramak için hareket eder. Hukuki düzenlemelerde, geçiş engellerinin aşılması ve su almalarda veya su çevirmelerde balık girişlerinin azaltılması istenir. Gelişmiş ülkelerin pek çoğunda, balık geçitleri için önemli ve pek çok sayıda araştırmalar yapılmakta ve uygulama projeleri gerçekleştirilmektedir. Türkiye'de bu hususa yeterli ve gerekli önem henüz verilmemiştir. Halbuki Türkiye'de bugüne kadar yüzlerce baraj ve binlerce bağlama yapılmıştır ve yapılmaya devam etmektedir. Bu yapılan tesislerin pek azında balık geçidi vardır. Türkiye'de bu konudaki yasal düzenlemeler sırasıyla aşağıda verilmiştir. Su Ürünleri Kanunu (22 Mart, 1971) Madde 22 şöyledir: Madde 22- "İlgili bakanlık izni alınmadan su ürünlerinin geçişine ve yetişmesine engel yapıların yapılması yasaklanmış, su ürünlerinin geçmesine olanak sağlayan balık geçidi yapılarının yapılması ve bunların devamlı işler durumda bulundurulması mecburiyeti getirilmiştir." Su Ürünleri Yönetmeliği (10 Mart 1995) Madde 8 şöyledir: Madde 8- "Baraj gölü, gölet, set gibi tesisler yapılırken balık geçitleri, balık perdeleri, asansörleri yapılması zorunlu kılınmıştır." Elektrik Piyasasında Üretim Faaliyetinde Bulunmak Üzere Su Kullanım Hakkı Anlaşması İmzalanmasına İlişkin Usul ve Esaslar Hakkında Yönetmelik (26 Haziran 2003) Madde 9/Ek fıkra şöyledir: Madde 9/Ek fıkra-"

Depolama ve çevirme (regülatör) yapılarında yapısal ve işlevsel balık geçiş yapılarının tesis edilmesi gerektiğini, tesis eden şirketin balık geçitlerinin çalışmasını izlemesini ve bakımını yapmakla hükümlü kılmıştır."

Balık geçitleri, arazi, akarsu, yapı ve canlı dengesine dayanarak planlanmalıdır. Bu karmaşık yapılarından dolayı planlanmaları kolay değildir. Planlama ve tasarımda, balık biyolojisi uzmanları dâhil, farklı disiplinlerde uzmanlar, beraber çalışmalıdır. Balık geçitleri çevre ve ekoloji açısından olduğu kadar ülke ekonomisi için de önemlidir. Bunların özellikle tatlı su balıkçılığına olumlu etkileri büyüktür. Barajlarda sular altında kalan tarım topraklarından kaybedilen gıda ürünleri yerine su ürünleri geliştirilerek gıda güvenliği ve çeşitliliği sağlanabilir. Balık geçitlerinin ise su ürünlerinin üzerinde hayati bir etkisi vardır.

Pek çok balık geçidi, balığın engellerin etrafından yüzecek veya küçük basamaklarla öteki tarafa sıçrayacak şekilde yapılır. Basamaklar üzerinden düşen suyun hızı balıkları merdivene çekecek seviyede olmalıdır. Fakat balıkları tekrar aşağı itecek kadar veya onların yukarıya doğru hareketini sürdüremeyecek şekilde uzak bir noktaya düşürecek kadar fazla büyük olmamalıdır.

Bu tez çalışmasında WKA Bienertmühle savağında bulunan balık geçidi (Dresden, Almanya) yerinde saha çalışması yapılarak incelenerek Türkiye'de çalışmayan balık geçitleri için bir örnek teşkil etmesi amaçlanmıştır. Balık geçidi bilgileri, balık geçidi tasarım ilkeleri, saha alanı: coğrafya, nüfus ve sosyo-ekonomi, topografya, meteoroloji, hidroloji, nehir özellikleri: ekohidroloji, hidromorfoloji, hidrobiyoloji, hidrokimya, ekohidrolik, malzeme ve yöntemler: Vereinigte Weißeritz Nehri, balık geçidi konumu ve tasarımı, yaklaşım yöntemleri: konvansiyonel ve ekohidrolik, değerlendirmeler ve tartışmalar: pratik çözümler: optimum balık geçidi konsepti: mevzuat, önerilen tasarım: işletme kriterleri, yeni balık geçidi tasarımı sırasıyla verilmiştir.

Balık geçidi tasarımını yapan mimarla görüşülmüş ve balık geçidiyle ilgili plan, enkesit gibi çizimler elde edilmiştir. Ayrıca, Saksonya eyaletinin barajlardan sorumlu kişisinden yeni tasarım kılavuzu hakkında bilgi alınmış ve TU Dresden'de ekoloji anabilim dalında görev yapan profesörden bölgede varolan diğer baraj ve balık geçidi yapılarına gezi düzenlenmiştir. Varolan balık geçidi istenilen fonksiyonu gerçekleştirememekte olup yerine hem membe hem mansap balık göçüne izin veren yeni bir balık geçidi planlanması uygun görülmüştür.

Bu tez çalışması Almanya'da yer alan balık geçidinin değerlendirilmesiyle Türkiye'deki çalışmayan balık geçitlerine bir örnek teşkil etmesi açısından önem taşımaktadır. Sonuç olarak bu çalışma ile Elbe Nehri'nin bir kolu olan Vereinigte Weißeritz Nehri'nde değerlendirmeye alınan tek yönlü balık göçüne (yukarı göç) izin veren bir adet düşey yarıklı balık geçidinin yerine iki yönlü (aşağı ve yukarı göç) balık göçüne izin veren iki adet düşey yarıklı balık geçidi yapılmasına karar verilmiştir. Ayrıca, var olan dört adet balık geçidi havuz yapısının sol tarafa alınması ve yerine aşağı göçe izin veren düşey yarıklı balık geçidi yapılması uygun bulunmuştur. Bölgede yapılacak olan izleme ve değerlendirme, bakım programları balık geçidinin işletim kriterlerinden gerekli oranda verim alınmasını sağlayacaktır.

1. INTRODUCTION

Introduction part express purpose, objective and scope of the thesis titled evaluation of fish passage design: a case study in Vereinigte Weißeritz River.

1.1 Purpose of the Thesis

Fish passage is considered a necessity where a dam separates a target species from needed habitat. Fish are generally unable to pass upstream of a hydropower dam unless some fish passage facility is present. Downstream passage facilities may not always be necessary if the fish can safely pass through turbines, spillways, or sluiceways, though there is significant debate about the adequacy of these latter two passage methods. Decisions about the need for fish protection measures at dams are often based on the perceived or measured impacts on one or more species at the site. Fish populations may be adversely affected by hydropower facilities and many other activities and facilities (e.g., multiple use, flood control, and water supply dams; land use practices like grazing and forestry; and facilities like coal-fired power plants that cause acid rain). Migrations and other important fish movements can be blocked or delayed. The quantity, quality, and accessibility of up and downstream fish habitat, which can play an important role in population sustainability, can be affected. Fish that pass through power generating turbines can be injured or killed. Increased predation on migratory fish has also been indirectly linked to hydropower dams (e.g., due to migration delays, fish being concentrated in one place, or increased habitat for predatory species). The thesis seeks a consideration for the functionless fish passage near small hydropower plants.

1.2 Objective of the Thesis

Fish passage can be defined as any form of conduit, channel, lift, other device or structure which facilitates the free passage of migrating fish over, through or around any dam or other obstruction, whether natural or man-made, in either an upstream or a downstream direction.

In the past, the provision of fish passes has usually only been concerned with the upstream migration of the diadromous (sea to freshwater cycle or vice versa) migratory salmonid species. In recent years, interest has widened to include the potadromous (within freshwater) coarse fish species, and other diadromous species such as eels and shad. The objective of this thesis was to propose a novel fish passage design that serves both upstream and downstream migration for existing fish passage facility in Vereinigte Weißeritz River.

1.3 Scope of the Thesis

The scope of the thesis involves introduction, instructions and principles of fish passage, background of study area, materials and methods for the study area, evaluations and discussions of fish passage, conclusions that were put forward at the end of the thesis. As a conclusion, after the comparison of design manuals of 1996 and 2014, a retrofitted existing fish passage design and operation in lieu of existing fish passage that is constructed in 2000 is proposed. In addition, novel fish passage design is proposed according to the new design manual that was published in 2014.

2. FISH PASSAGE INSTRUCTIONS

In this section literature review, fish migration types, river continuum concept, fish passage and evaluation of some fish passage facilities are explained respectively.

2.1 Literature Review

Important researches and publications about fish passage (fishway, fish steps) up to now is stated below in chronological order.

- In 17th century, France and North America: First research studies
- 1837, R. McFarlan, Canada: Patent of fish passage in a reservoir
- 1852-1854, Ireland: Ballisodare fish passage in County Sligo for salmons
- 1880, United States of America: Fish steps in Pawtuxet Falls reservoir in Rhode Island
- 1909, G. Denil, Belgium: Denil fish passage
- 1914, Royal Roads University, Canada: Japon garden fish steps in Esquimalt Lagoon
- 1908, H. Von Bayer, C.E.: “Fishways”, United States Bureau of Fisheries
- 1941, A.M.McLoed ve P.Nemenyi: “An Investigation of Fishways”
- 1992, C.Katopodis: “Introduction to Fishway Design”
- 1995, C.H.Clay: “Design of Fishways and Other Fish Facilities”
- 1995, Congress of U.S. Office of Technology Assessment: “Fish Passage Technologies: Protection at Hydropower Facilities”
- 1996, DVWK (DWA): “Fish Passes: Design, Dimensions and Monitoring”
- 2000, IEA Hydropower Agreement: “IEA Technical Report”
- 2010, EA UK: “Fish Pass Manual”

- 2014, DWA: “Fish Passage Structures: Design and Quality Assurance”

2.2 Fish Migration Types

Rheotaxis is a form of taxis seen in many aquatic organisms, e.g., fish, whereby they will (generally) turn to face into an oncoming current. Some fish will exhibit negative rheotaxis where they will avoid currents. Chemical, mechanical, electric and magnetic stimuli also affect the form of taxis. There are three types of fish migration: potamodromous, diadromous and oceanodromous migration.

2.2.1 Potamodromous migration

Some of the riverine fish may display spawning migrations between lakes and rivers, or from one area of a river to another. This migratory pattern is referred to as potamodromy. Some common examples of fish that engage in potamodromous migrations include trout, sauger, mooneye, some redhorse, some suckers, some sturgeon, some lamprey, etc. Following figure shows life cycle of potamodromous fish (Figure 2.1).

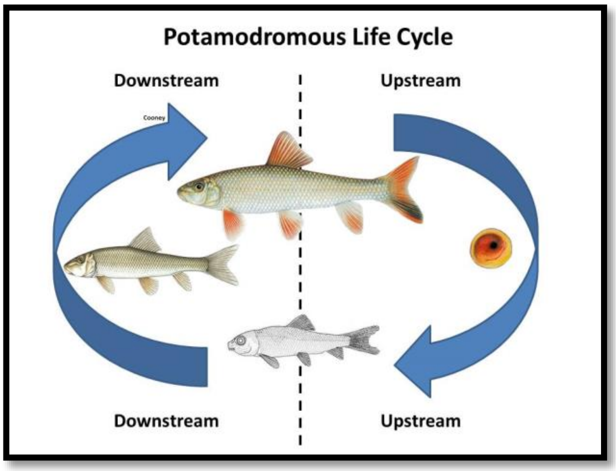


Figure 2.1: Potamodromous life cycle (Fisheries Blog, 2013).

2.2.2 Diadromous migration

Some fish display specialized migratory patterns involving regular, seasonal, more or less obligatory movements between fresh and marine waters. This strategy is generally referred to as diadromy, and there are three distinct forms. First, in some species, sexually mature adults migrate from the sea to spawn in freshwater streams/rivers and associated lakes. This migratory pattern is called anadromy. Examples of fish that engage in anadromous migrations are Pacific and Atlantic salmon, American and Hickory shad, Atlantic sturgeon, alewife, searun lamprey, etc. Life cycle of anadromous fish is shown in Figure 2.2.

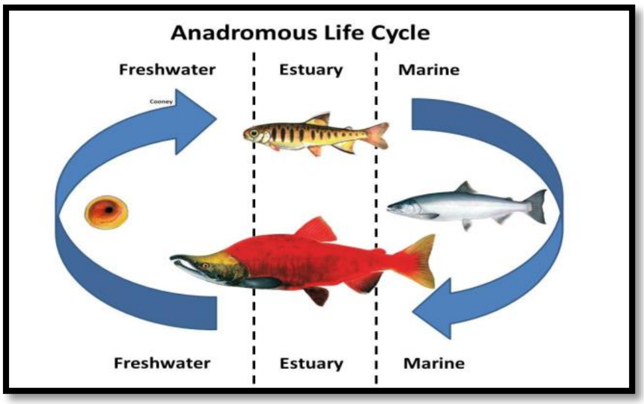


Figure 2.2: Anadromous life cycle (Fisheries Blog, 2013).

Second, sexually mature adults of some species migrate from freshwater streams/rivers and associated lakes to spawn in the sea. This migratory pattern is called catadromy. The most notable example of species that make catadromous migrations is the American eel. The following figure shows life cycle of catadromous fish (Figure 2.3).

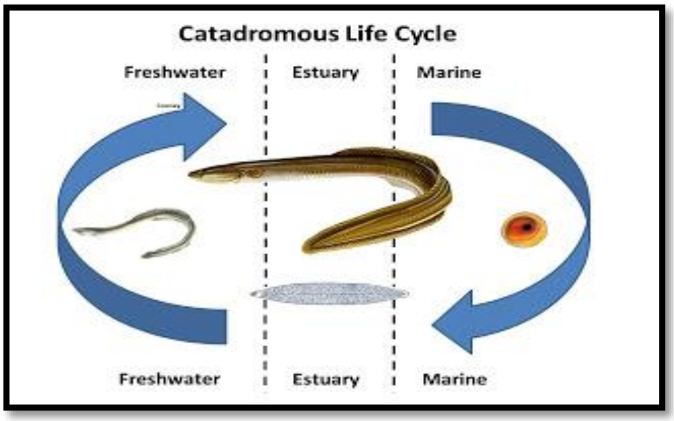


Figure 2.3: Catadromous life cycle (Fisheries Blog, 2013).

Third, some species make seasonal movements between estuaries and coastal rivers and streams. This migratory pattern is called amphidromy and is typically associated with the search for food and/or refuge rather than reproduction. Examples of fish that engage in amphidromous movements include striped mullet and tarpon. Life cycle of amphidromous fish is shown in Figure 2.4.

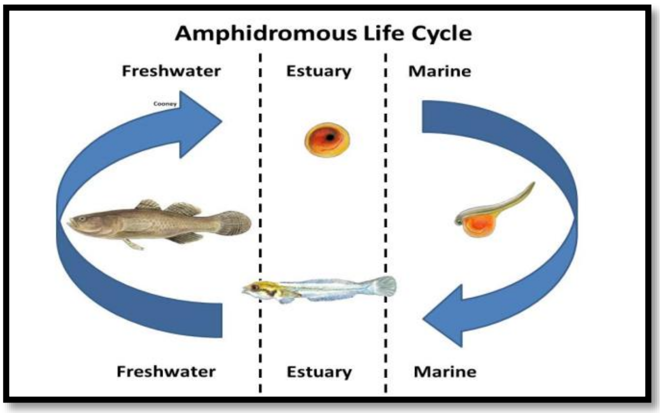


Figure 2.4: Amphidromous life cycle (Fisheries Blog, 2013).

2.2.3 Oceanodromous migration

Some fish display specialized migratory patterns involving regular, seasonal, more or less obligatory movements between fresh and marine waters. Life cycle of oceanodromous fish is shown in Figure 2.5.

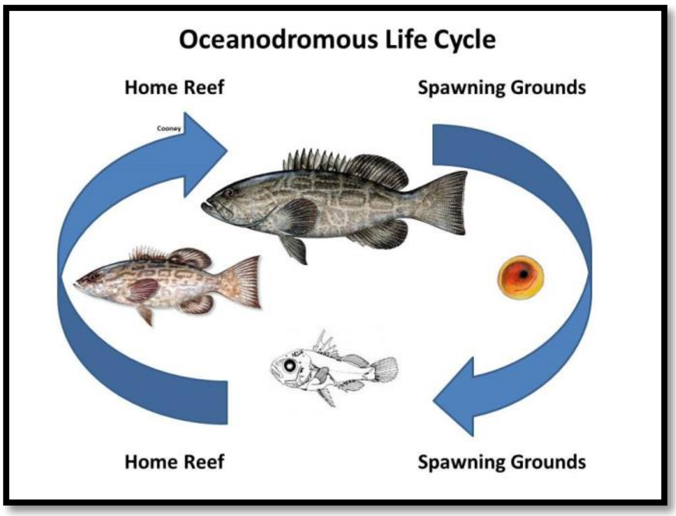


Figure 2.5: Oceanodromous life cycle (Fisheries Blog, 2013).

2.3 River Continuum Concept

For hundreds of years, throughout the history of human development, rivers have been diverted for irrigation, hydropower, navigation, provision of drinking water, removal of wastewater, etc. A report by the World Commission on Dams (2000) and a recent review by Kingsford (2011) suggested that modification of the river flow regime as a result of regulation by creating barriers, impoundment and overabstraction, the spread of invasive species, overharvesting and the effects of water pollution were the main threats to the world's river and wetlands and these effects could be compounded by future climate change. The impacts of dam construction, river regulation and channelisation have significantly reduced the natural variability of the flow regime and channel morphology. This results in degradation, fragmentation and loss of habitat structure and availability with subsequent reductions in aquatic biodiversity. The EU Water Framework Directive requires the achievement of 'good ecological status' in all water bodies across EU member states by 2015. This, in turn, has required the development of methods and techniques to assess the current status of chemical and biological water quality, hydromorphology and flow regime variability, and identify ways of mitigating impacts and restoring river channels and flow regimes where they are an impediment to the improvement of river health. According to the European Water Framework Directive (WFD), preservation and establishment of fish spawning habitats should be considered as one of the major aims in successful river restoration. River dynamic processes such as flow alteration, sediment transport and seasonal flow events lead to mobilization of channel bed sediments and provide renewal of substrate conditions. But, they can also affect early fish life stages or even destroy an entire generation. Intrusion of fines or embeddedness contributes to a decrease in substrate permeability in the hyporheic interstitial and negatively impacts the development of early life stages. It may inhibit the emergence of fry from interstitial spaces to the dree water column and reduce the supply of dissolved oxygen and the transport of metabolic waste during egg incubation. The significance of substrate characteristics is essential for the ecological assessment of spawning habitats. In particular, high flow events, their frequency and intensity, are crucial in maintaining spawning habitats as these periodical events remove fine sediments and avoid clogging of interstitial spaces in suitable spawning habitats in a gravel bed.

Ecohydraulics as well as ecohydrology, hydromorphology and hydrodynamics of aquatic ecosystems is rooted in the river continuum concept, which establishes a connection between abiotic processes and the biotic environment. They stem from the principle that the structure and function of biological communities, which define aquatic ecosytems, depend on interplay between biological, physical and chemical processes in aquatic environments, such as rivers, lakes, estuariees and seas. Developments in river science reflect this overall pattern, with the emergence of ecohydrology at the interface of hydrology and ecology and hydromorphology, which reflects the interaction of the channel morphology and flow regime (hydrology and hydraulics) in creating 'physical habitat'.

2.4 Fish Passage

There are two types of fish passage which are close-to-nature type fish passage and technical fish passage and explained below.

2.4.1 Close-to-nature type fish passage

The "close-to-nature style" of construction of sills and fish passes, such as rock ramps, imitates as closely as possible natural river rapids or brooks with steep gradients. Following constructions are defined as "close-to-nature types" of fish passes (Figure 2.6): a) Bottom ramps and slopes: A sill having a rough surface and extending over the entire river width with as shallow a slope as possible, to overcome a level difference of the river bottom. This category also includes stabilizing structures (e.g. stabilizing weirs), if the body of the weir has a shallow slope similar to the slope of a ramp or slide and is of loose construction, b) Bypass channels: A fish pass with features similar to those of a natural stream, bypassing a dam. As the dam is preserved unchanged, its functions are not negatively affected. The whole impounded section of the river can thus be bypassed and c) Fish ramps: A construction that is integrated into the weir and covers only a part of the river width, with as gentle slope as possible to ensure that fish can ascend. Independent of their slope, they are all called ramps. In general, the incorporation of perturbation boulders or boulder sills is required to reduce flow velocity.

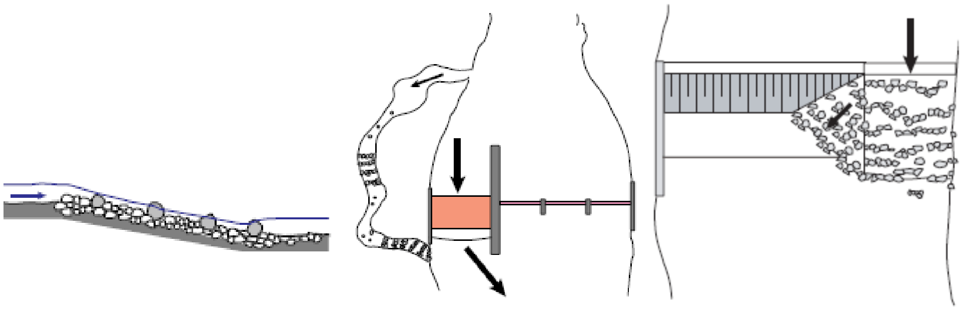
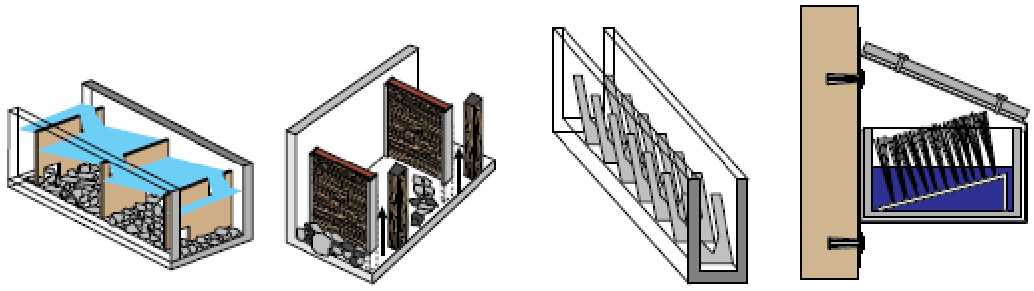


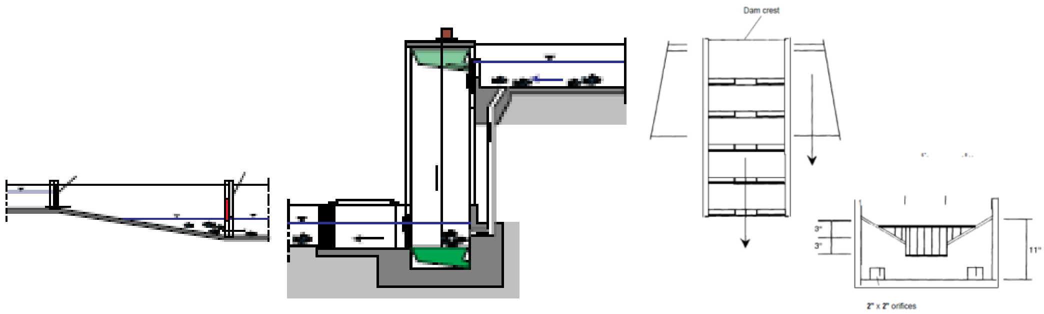
Figure 2.6: Close to nature type fish passage types a) Bottom ramps and slopes, b) Bypass channels, c) Fish ramps.

2.4.2 Technical fish passage

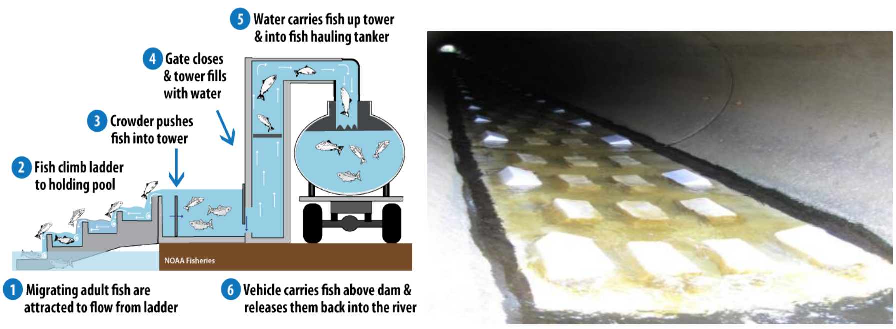
Technical fish passes include the following fish passage types: pool passes (e.g. center weir, centre overflow and orifice, side overflow weir, full overflow, notched, submerged orifice, sloped arpon, ice harbor), vertical slot passes (e.g. one or two slot, Denil passes (e.g. Alaska steeppass,), eel ladders, fish locks, fish lifts, hybrid (pool and chute), trap and haul systems, culverts (e.g. baffle array: slotted weir baffle, offset baffle, spoiler baffle, weir baffle, fish- weir). Below figures represents aforementioned technical fish passages (Figure 2.7).



a) Pool pass   b) Slot pass   c) Denil pass   d) Eel ladder



e) Fish lock   f) Fish lift   g) Pool and chute (Hybrid)



h)Trap and haul   i) Culvert (Spoiled baffle)

Figure 2.7: Technical fish passage types (DVWK, 1996; Aprahamian, M.W. et al., 2010).

Slot passes (vertical slot passes) are well suited to guarantee ascent by both fish species that are weak swimmers and small fishes. Relatively high discharges can be sent through, thus good attraction currents can compose. They are more reliable than conventional pool passes because of the lower risk of clogging of the slots. Vertical apertures that stretch over the whole height of the cross-walls are suited to the swimming behaviour of both bottom-living and open-water fish. Reduction in flow velocities near the bottom of the slots also allows low performance fish to ascend. A prerequisite for this is the installation of a bottom substrate with some larger perturbation boulders. They are suitable for use even with varying headwater levels. and not sensitive to varying tailwater levels. Benthic invertebrate fauna can also migrate if the bottom substrate has continuous interstitial spaces. Because, the orifices extend vertically over the total height of the cross-walls the slot pass is less susceptible to clogging than traditional fish pass designs. Partial clogging of the discharge cross-section does not cause complete loss of function. This type of construction is suitable both for use in small streams with low discharge and for use in larger rivers. Slot passes can cope with discharges from just over 100 l/s to several m^3/s. They are currently the best type of technical fish pass, being suitable for all species of fish and are passable for invertebrates if a continuous bottom substrate is built in. Other advantages are; i) ascent of the fishway is possible at any depth the fish chooses, ii) the path of a fish ascending the fishway is not tortuous, iii) conditions for resting in the pools are satisfactory, if required. Also, it can tolerate reasonably large upper and lower water level fluctuations. One reason for this lies in their hydraulic function: flow patterns inside inside the pools and water velocities in the slots are almost independent on the water depth in the fishway. Velocity distribution in the slots is even, and the same velocity prevails from bottom of the slot to the water surface. Present knowledge points out that slot passes should be given preference over other technical fish passes. As an illustration, vertical slot fish passages in Saxony are shown in Figure 2.8.

Figure 2.8: Vertical slot fish passage, from left to right: Rochsburg, Poppenwald, Rochlitz (Saxony Dam Administration, 2014).

2.5 Evaluation of Fish Passage Facilities

Three of the case studies (i.e. culvert, vertical slot and pool and weir type of fish passage) were researched and are placed in this section.

A case study in Alaska is specified as an evaluation of the fish passage facilities. In the article, hydraulic evaluation of fish passage through roadway culverts in Alaska is mentioned (Figure 2.9). Culverts are very simple hydraulic structure. However, because the engineer must design for peak flows passing through the culvert while fish are trying to move upstream, serious problems arise. The two major hydraulic problems in regard to fish passage were high velocities and perching; inlet drops caused by deposited sediment, aufeis, alignment of culvert with stream, and non-uniform culvert slopes are some of the other fish passage deterrents that were observed. Also, all known baffled structures were evaluated. Numerous recommendations were made that should improve the hydraulic conditions that exist at a culvert relative to fish passage. In addition, it is recommended that further studies be carried out to evaluate the swimming performance of the native fish. Present design criteria are based on very limited studies. Lastly, it is recommended that the concept of the velocity in the occupied zone (area in culvert where fish swim) be considered as the culvert design velocity for fish passage in place of the presently used average cross-sectional velocity.

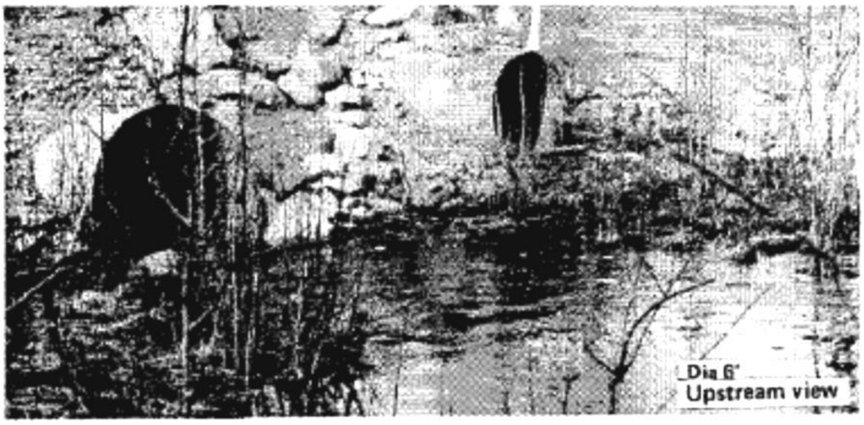


Figure 2.9: Upstream view of roadway culverts in Alaska (Kane and Wellen, 1985).

A case study: The Schuylkill River in Southeastern Pennsylvania once supported massive spring runs of anadromous fishes until the construction of dams in the early 1800's. The dam served as a physical barrier to migratory fishes, completely blocking upstream movement and access to critical spawning grounds. In 1979, a vertical slot fish passage facility (Figure 2.10) was constructed on the west side of Fairmount Dam. However, very few anadromous species were utilizing the passage and the fishway was abandoned by 1984. No fish counts were conducted from 1984 to 2004, until Philadelphia Water Department biologists took responsibility for maintenance and operation of the fishway and developed a digital video monitoring system to record fish passage. An underwater viewing room and window allows direct observation of fishes swimming through the fishway and is the primary means for evaluating fish passage. In 2004, there were 6,438 fish of 23 species that ascended Fairmount fishway, including 91 American shad, 161 striped bass, and 2 river herring. A total of 8,017 fishes representing 25 species were counted passing through the fishway in 2005, including 41 American shad, 127 striped bass, and 5 river herring. In 2006, a total of 16,850 fishes representing 26 species were counted passing through the fishway including 345 American shad, 9 hickory shad, 61 striped bass, and 7 river herring, marking an astonishing 279% increase in American shad passage from 2004 to 2006. The interannual trend in relative abundance of American shad below Fairmount Dam increased, as did overall shad passage trends in the fishway. Continued monitoring of fish passage will be a critical component in assessing anadromous fish restoration efforts on the Schuylkill River.

Figure 2.10: Overhead view of Fairmount fishway (Perillo, 2006).

Rio Paraopeba, a tributary of Rio São Francisco, has a six-meter high dam, built in 1978 to divert water to the Igarapé Thermal Power Plant. In 1994, a fish ladder (Figure

2.11) was built at this dam. The results of a marking and recapture program carried out along rio Paraopeba between 1997 and 2001 are described, using information from fish community studies conducted at ten sampling stations between 1994 and 1997. During four rainy seasons between 1997 and 2000, fish were caught downstream of the dam, marked with external plastic tags, and immediately released at the same site. The objective was to evaluate fish passage through the ladder, based on recapture information from artisanal and sport fishermen. A total of 3,642 specimens were marked, adding up to a biomass of approximately 1.33 tons. Twenty-six species were used, representing 28.5% of the total recorded richness (91 species). Maximum recorded tag retention time was 10 months. Total recapture rate was 4.37% in four years, reaching 5.75% in the last period (2000-2001). Of all recaptured specimens, 14.0% were caught upstream of the dam, evidencing passage through the ladder. The main result of the present program is the evidence of passage through the ladder by three migratory species of Rio Paraopeba (P. costatus, L. obtusidens and P. maculatus), which represented 90% of all marked species. With regard to the other species studied, too few specimens were marked and recaptured to allow an evaluation of the capacity of these other species to pass through the ladder and the extent to which they are affected by hydraulic and water velocity limitations.

Figure 2.11: View of a fish ladder (pool and weir system) in Rio Paraopeba (Alves, 2007).

3. FISH PASSAGE DESIGN PRINCIPLES

This section involves preparation of fish passage design, fish passage design and operating system design of fish passage.

3.1 Preparation of Fish Passage Design

For the preparation of fish passage design, physical and biological data must be analysed before the designing phase.

3.1.1 Physical data analysis

The following physical data are required: water quality of the tributary and mainstream of the river, key curve of tailwater, detailed plans of any existing structure (if none are available, then a topographical survey may be required), monthly flow duration curve of spillway, bottom outlet and water passing through turbines, water surface level at operational flow rates, monthly flow duration curve of reservoir, operational data of the reservoirs, ice-covered periods right before the project had started, water temperature data for during the phase of particularly during key migration periods, range of water levels upstream and downstream of the barrier over a range of river discharges corresponding with the hydrograph, air temperature (max., avg., min.), sediment knowledge, river morphology, geological maps and boreholes, topographic maps, present reservoir drawings (plan, section, altitude), summary of the project (turbine properties), head difference over the barrier, station operation conditions, access road for reservoirs, hydrograph at the site - preferably over a period of years including typically dry and wet years, existence of electricity, floating waste material in upstream and downstream of the reservoir.

3.1.2 Biological data analysis

Biological data must include target fish species that are expected to pass through the fish passage, other aquatic organisms, life stages of fish species, fish migration properties (route, season, migration period), quantity and size of fish species that migrate upstream or downstream, fish species features (size, migration type, swimming performance), abundance of fish species of each section of the river, predators for the fish species, present ecosystem conditions and light, sound, current effects of that river.

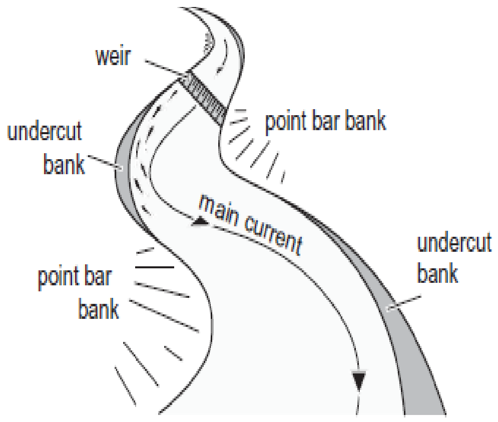
3.2 Fish Passage Design

Fish passage design is explained as optimum fish passage location. In this sense, fish passage entrance, exit and body are clarified respectively.

3.2.1 Optimum fish passage location

While in rivers that have not been dammed, the whole width of the channel is available for the migration of aquatic organisms, fish passes at weirs and dams usually confine migrating organisms to a small part of the cross section of the channel. Fish passes are usually only relatively small structures and, therefore, have the characteristics of the eye of a needle, particularly in rivers and large rivers. In practice, the possible dimensions of any fishway are usually severely limited by engineering, hydraulic and economic constraints, particularly in larger rivers. Thus the position of a fishway at the dam is of critical importance. Fish and aquatic invertebrates usually migrate upstream in, or along, the main current. Fish swimming in or along the main current will arrive at the weir along the side of undercut bank. Consequently, a fish pass should be positioned as closely as possible to the point where the fish meet the obstacle (Figure 3.1a). Fish migrating upstream are guided by main current and swim up to the zone of highest turbulence in the tailwater directly below the dam ot the turbine outlet. In the vicinity of the bank, fish seek a way to continue to move upstream. Most importantly, it must be ensured that fish can pass the bottom still of the stilling basin (Figure 3.1b and Figure 3.1c).

For the entrance of a fishway to be detected by the majority of upstream migrating organisms, it must be positioned at the bank of the river where the current is highest. This has the added advantage that, with a position near the bank, the fish pass can be more easily linked to the bottom or bank substrate. The most suitable position for a fish pass at hydroelectric power stations is also usually on the same side of the river as the powerhouse. The water outlet of (i.e. the entrance to) the fish pass should be placed as close as possible to the dam or turbine outlet. Placing the outflow of the fish pass (and thus its entrance) in the immediate vicinity of the dam or weir minimizes the formation of a dead zone between the obstruction and the fish pass entrance. This is important as fish swimming upstream can easily miss the entrance and remain trapped in the dead zone. A fish pass that extends far into the tailwaters below the dam considerably limits the possibility that fish find the entrance, a design fault that has been responsible for the failure of many fish passes. Where dams or weirs are placed diagonally across the river and overflow along their entire crest, upstream migrating fish usually concentrate at the upstream, narrow angle between weir and bank (Figure 3.2).



a)

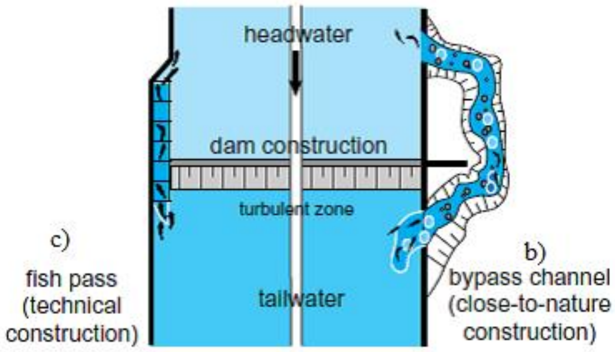


Figure 3.1: Left- Flow pattern in a river with undercut banks and point bar banks, Right- a) Diagram showing the flow pattern in a river with undercut banks and point bar racks b) Optimum position of a bypass channel and c) optimum position of a technical fish pass (DVWK, 1996).

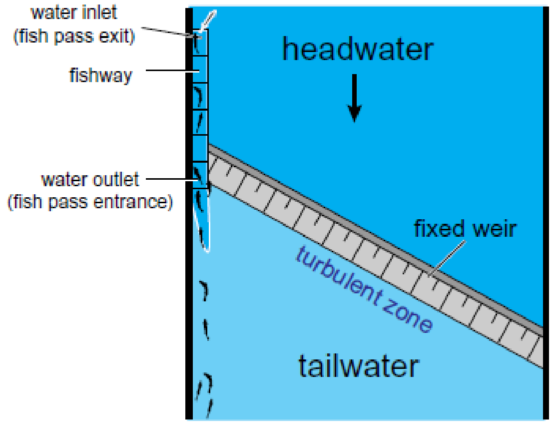


Figure 3.2: Suitable location for the construction of a fish pass (DVWK, 1996).

Therefore, the fish pass should clearly be situated in this area. As regards bypass hydroelectric power stations, there are two options for positioning the fish pass to ensure longitudinal connectivity. Firstly, the fish pass can be built at the power station, providing a link between the tailwater channel and the headwater channel. Secondly, it can be constructed at the weir, acting as a link between the original natural main channel and the headwater of the impoundment. Usually a fish pass is constructed at only one of these locations. Since the fish generally follow the strongest current, they tend to swim up the tailwater channel to the turbine outlet rather than entering the old main channel through which the discharge is usually lower. Construction of a fish pass from the tailwater channel to the headwater channel is, therefore, needed in such cases. However, when the turbine capacity of the power plant is exceeded, excess water is spilling over the dam into the old main channel andso, it is also advisable to install a fish pass at the barrage. The water from this second fish pass can also be used to provide minimum environmental flows in the old channel so that running water conditions are maintained there, provided that the discharge is sufficiently high. From an ecological point of view, it is, therefore, highly advisable in such cases to construct two fish passes, one at the hydropower plant and one at the barrage (Figure 3.3).

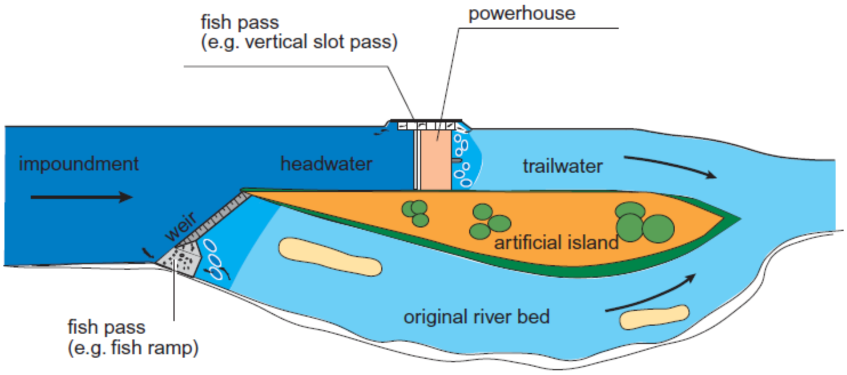


Figure 3.3: Ensuring longitudinal connectivity at a bypass hydroelectric power station through construction of two fish passes, i.e., one directly at the hydropower plant and the other at the weir (DVWK, 1996).

3.2.1.1 Fish passage entrance

The entrance of the fish pass must be positioned where fish concentrate while moving upstream. The characteristics of the tailwater currents and the structural details of the hydropower station determine the area of concentration. In many cases, this is directly below the weir or dam, at the foot of the barrage or at the turbine outlets. Therefore, any current to attract fish must be directed from the entrance to the pass towards the area of concentration in such a way that fish, in following the current, will be drawn to the entrance of the pass and thus enter the fishway.

A critical problem is how to construct the fish pass entrance so that fish can swim into the fishway even at low water levels. Entry into the fishpass can be eased, even for bottom-living fish species and macrozoobenthos, by linking the fish pass to the natural river bottom. This can be done with a ramp with a maximum slope of 1:2. Some existing fish passes have their entrances oriented towards the weir and thus at an angle of 180º relative to the river current. In such cases, the entrance is unsuitable in that it can not establish an attracting current to enable the fish to find the entrance to the fishway.

Since diurnal fish avoid swimming into dark channels the fish pass should be in daylight and thus not covered over. If this is not possible the fishway should be lit artificially in such a way that the lighting is as close as possible to natural light.

3.2.1.2 Fish passage exit

Where the fish pass is installed at a hydroelectric power station, its water inlet (exit into the headwater) must be located far enough from the weir or turbine intake so that fish coming out of the pass are not swept into the turbine by the current. A minimum distance of 5 m should be maintained between the fish pass exit and the turbine intake or the trash rack. If the current velocity of the headwater is greater than 0.5 m/s, the exit area of the fish pass has to be prolonged into the headwater by a partition wall. In general, if the headwater level of the impoundment is constant, the design of the water inlet does not present a problem.

However, special provisions have to be made at dams where the headwater level varies. Here, the fish pass either has to be of such a type that its functioning is only slightly affected by varying headwater levels, or relevant structural adaptations of its water inlet area must be incorporated. A vertical slot exit has proved appropriate for technical fish passes if the variations in headwater level are at maximum between 0.5 to 1.0 m. Where variations in level exceed one metre, several exits must be constructed at different levels for the fishway to remain functional. With certain types of fish pass, mechanical regulation of the flow-through discharge may be necessary for the pass to continue to function. Simple aperture controls at the exit (i.e. the water intake) may be suitable. When the impoundment shows greater variations in level, more complex structures with control systems or barrier devices may be necessary. Unfortunately, such devices are liable to malfunction or, alternatively, the staff may operate the control systems improperly causing a lessening in the efficiency of the fish pass. Strong turbulence and current velocities over 2.0 m/s must be avoided at the exit area of the fish pass so that fish leave the pass for the headwaters more easily. Furthermore, linking the exit of the fishway with the natural bottom or bank substrate by means of a ramp facilitates the movement of migrant benthic organisms from the fish pass into the headwater. The water intake of the fishway should be protected from debris by a floating beam. Structural provisions should be made so that a control device (e.g. a trap) can be installed at the exit of the fishway to monitor its effectiveness. These could be footings for a fish trap and an adjacent lifting device for instance. It should also be possible to shut down the flow through the fishpass, e.g. for control and maintenance work.

3.2.1.3 Fish passage body

Discharge and current conditions in the fish pass

The discharge required to ensure optimum hydraulic conditions for fish within the pass is generally less than that needed to form an attracting current. However, the total discharge available should be put through the fish pass to allow unhindered passage of migrants, especially during periods of low water. This is particularly advisable for dams that are not used for hydropower generation. If more water is available to supply the fishway than is needed for the hydraulically-sound functioning of the existing or planned fish pass, alternative designs should be envisaged, e.g. the construction of a rocky ramp that should be as wide as possible. In some cases, a structural adaptation of the fishway's exit area may be necessary to limit the discharge through the fish pass, e.g. during floods, in the interest of efficient functioning. Using supplementary water to increase flows that does not originate from the river on which the fish pass is situated, such as discharge from water diversions or sewage treatment plants, should be avoided. The mixing of waters of different physical-chemical properties disturbs the sensitive olfactory orientation capability of the fish and thus reduces their urge to continue migration. The turbulence of the flow through the fishway should be as low as possible so that all aquatic organisms can migrate through the pass independently of their swimming ability. Larinier (1992b) recommends that the volumetric energy dissipation in each pool of a pool pass should not exceed 150 to 200 W per cubic meter of pool volume. In general, current velocity in fishways should not exceed 2.0 m/s at any narrow point such as in orifices or slots and this limit to velocity should be assured by the appropriate design of the pass. The average current velocity in the fishway must be significantly lower than this value, however. The pass should incorporate structures that form sufficient resting zones to allow weak swimming fish to rest during their upstream migration. Furthermore, the current velocity near the bottom is reduced if the bottom of the fish pass is rough. As a rule, there should be laminar flow through the fish pass as plunging (turbulent) flow can only be accepted under specific local conditions, such as over boulder sills.

Lengths, slopes and resting pools

Instructions for the correct dimensions of fishways include information on such features as slope, width, length and water depth as well as the dimensions of orifices and resting pools. These instructions depend mainly on the particular type of fish pass to be built as well as on the available discharge. Type-specific instructions are to be found in the relevant sections of these guidelines that deal with the different types of fish passes. All instructions given in these guidelines are minimum requirements. The body length of the biggest fish species that occurs or could be expected to occur (in accordance with the concept of the potential natural fish fauna) is an important consideration in determining the dimensions of fish passes. The fact that fish can grow throughout their whole lives must be taken into account when gathering information on the potential fish sizes. The average body length of the largest fish species expected in the river as well as the permissible difference in water level must be considered in defining the dimensions of a fish pass. Since a difference in water level of only h = 0.2 m entails a maximum current velocity of 2.0 m/s for instance at orifices and crosswalls, it is recommended that the water level difference between pools in a fishway be also kept below 0.2 m. Such a maximum difference in water level leads to a current velocity in the layer just above the rough bottom that allows even fish that have a weak swimming performance to pass. Waterfalls and drops where aerated jets would form must be avoided. For more technical constructions, the maximum permissible slope ranges from 1:5 to 1:10, depending on the construction principle chosen, while close-to-nature constructions should show maximum slopes less than 1:15 corresponding to the natural form of rapids. It is, however, acceptable for the slope of a natural-looking fish pass to not correspond to the natural slope of the river at this very location. The swimming ability of the fish species of the potential natural fish fauna and all its life stages has to be considered in setting the length of a fishway. However, data on the swimming velocity of fish is not listed here since the values determined in different investigations differ markedly from one another or is even contradictory (Geitner & Drewes, 1990; Jens, 1982; Peckmann and Stahlberg, 1986; Pavlov, 1989). In any case, the requirements of the weakest species, or of the weakest life stages, must be considered when defining the dimensions of a pass. Resting zones or resting pools should be provided in fishways. Here, fish can interrupt their ascent and recover from the effort. In some types of pass, such as slot or pool passes, resting zones are inherent to the design. In others, such as rock ramps, they can easily be created. Resting pools where turbulence is minimal should be inserted at intermediate locations into types of fishways that have normally no provision for resting zones due to their design. The dimensions of a resting pool should be set so that the volumetric power dissipation must not exceed 50 W/m^3 of pool volume. Valid data on the maximum permissible length of fish passes are not generally available. However, for types of pass without rest zones and of a length that is excessive for fish to negotiate in a single effort, it is recommended that resting pools are placed at intervals of such lengths as defined by the difference in level of not more than 2.0 m between pools. Denil passes must be broken up by resting pools at least after every 10-m-stretch of linear distance for salmonids, and at least after every 6 to 8 m for cyprinids.

Design of the bottom

The bottom of a fish pass should be covered along its whole length with a layer at least 0.2 m thick of a coarse substrate. Ideally, the substrate should be typical for the river. From the hydraulic engineering point of view, a coarse substrate is necessary for the creation of an erosion-resistant bottom. However, the bottom material used for this should be as close to natural as possible and should form a mosaic of interstices with a variety of differently sized and shaped gaps due to the varied grain size. Small fish, young fish, and particularly benthic invertebrates can retreat into such gaps where the current is low and can then ascend almost completely protected from the current. The creation of a rough bottom usually presents few problems in close-to-nature types of fishways. The rough bottom must be continuous up to and including the exit area of the fish pass, as well as at the slots and orifices. In some more technical types of construction, such as Denil passes, the creation of a rough bottom is not possible. This means that benthic invertebrates cannot pass through them and thus these constructions do not fulfil one of the essential ecological requirements for fish passes.

Operating times

The migrations of our indigenous fish take place at different times of the year. While many cyprinid species (Cyprinidae) migrate mainly in spring and summer, the spawning migrations of salmonid species (Salmonidae) occur mainly in autumn and winter. The migratory movements of benthic invertebrates probably occur during the entire vegetative period. The time of the day at which aquatic organisms move in rivers also differs for the different groups. Thus, numerous benthic invertebrates are mainly active at twilight and at night, while the time of maximum activity of the different fish species varies considerably and can, in fact, even alter during the year (Müller, 1968). Because of this variability in the timing of migrations, fish passes must operate throughout the year. Limited operation can be tolerated only during extreme low and high water periods (i.e. for the 30 lowest days and the 30 highest days in one year), since at such times fish usually show a decrease in migratory activity. Continuous 24 hour operation must be guaranteed since, once they have entered the fish pass, invertebrates that are little mobile would be unable to escape even a short drying out of the pass and inevitably die if the pass is only operating periodically.

3.3 Fish Passage Operating System Design

Operating system design of fish passage comprise of monitoring, evaluation program and maintenance plan.

3.3.1 Monitoring program

The objective of monitoring is to prove explicitly that the fish pass entrance can be found and the fish pass negotiated by fish. Monitoring goes beyond checking the construction against the planning directives and construction certification, as well as beyond the obligatory trial run, which is required particularly for the more natural looking constructions. It also goes beyond routine maintenance. Monitoring is also recommended for newly built fish passes when there is no, or only inadequate, experience with the operation of the (new) type of construction chosen, or if the pass is unique because of its dimensions (e.g. very high water discharges or fall heads).

Hydraulic and biological performance: A full monitoring programme would demonstrate that the fish pass is functioning as anticipated both hydraulically and biologically. The use of gauge boards upstream & downstream of the pass to help establish that the pass is operating within the expected range of head levels is highly recommended as part of the physical monitoring of the pass. Biological monitoring should aim to demonstrate that the target fish species use the pass effectively and efficiently.

While sufficiently tested methods for monitoring upstream migration of fish exist, it is generally very difficult to prove the efficiency of upstream migration of benthic invertebrates in fish passes. The invertebrates' differing colonisation strategies mean that proof of their migration has usually to be restricted to recording colonisation within the fish pass itself. Present knowledge indicates that the existence of continuous bottom substrate alone can be invoked as an indicator of the possibility of upstream migration of invertebrates. Most fisheries laws prohibit catching fish in fish passes. If research necessitates the capture of fish from a fish pass, an exemption permit must be requested prior to fishing. Granting of this permit is only possible if the owner of the fishery is in agreement prior to any fishing action. Usually the management of monitoring should be entrusted to fisheries experts. The timing and duration of testing are of great significance to the reliability of any control of functioning. This should preferably take place during the main migration periods, which can differ regionally due to local particularities and weather conditions. The following biological and technical elements should be considered when drafting a monitoring strategy and later when assessing the functioning of the fish pass: The potential natural fish fauna of the watercourse and the actual qualitative and quantitative composition of fish stocks in the headwater and tailwater of each dam. In addition, similar assessments should be made of the benthic invertebrate fauna, the unrestricted ascent of all migratory developmental stages of the relevant fish species, the current state of connectivity of the water system and the general requirements for planning and construction of the fish pass as set out in these Guidelines. If necessary, proposals for optimising the fish pass should be made. Control of the functioning of the fish pass requires not only the obligatory counting of all fish that have negotiated the fishway but also the assessment of a number of other parameters and baseline conditions. These data are used to appraise the efficiency of the pass by comparing the monitoring results with the natural migratory activity of the fish fauna in the stretch of water being investigated. The additional data include counting ascending fish classified by species and size groups, data on sexual maturity, data on water level and discharge trends (increasing or decreasing water discharges), weather, turbidity of the water or degree of transparency, details of lunar phase with reference to the migratory activity of the fish, particularly during eel migration, measurement of current velocities and discharge in the fish pass, measuring oxygen content and water temperature, determining fish stocks in the headwater and tailwater taking into account stocking measures in each of the stretches of water; noting other relevant details of the fish such as disease or injury. Assessing the overall condition of the fish pass and its level of maintenance and recording any modifications of the environmental conditions of the river and recording particular events such as maintenance measures, fish mortalities etc, that may have bearings on the migratory activity in the fish pass are the two procedure that need to be done during monitoring. It is recommended that, already during construction of the pass, provision should be made for built-in trapping chambers or at least lifting devices for the use of mobile fish traps to be installed directly at the outlet of the pass. This is particularly necessary in technical passes to test ascent of fish in the pass. The methods for controlling the functioning of the pass should be appropriate to the type of pass. If necessary, several methods may have to be combined to balance out the different disadvantages of the individual methods. Various traditional methods are listed below, which, when used in the appropriate manner, can help to provide reliable data on the functioning of the fish pass.

Fish traps

The standard method for testing both natural looking and technical passes is trapping the fish. Traps can be used provided that the cross section of the pass can be completely blocked off by the fish trap and that there is a tight connection to the bottom. The fish trap should be installed immediately at the water intake of the pass and can be built as a box, pedestal or special fish trap according to local circumstances. Box traps are the most appropriate for use in pool or slot passes, their size being determined by the dimension of the pools. The traps should be set in the uppermost pool. Control traps, which are, for example, set in resting pools or which are not set immediately at the water intake do not give any definite proof that fish can negotiate the total length of the pass. The fish trap should be made of robust, dark, plastic yarn with maximum mesh size of 10 – 12 mm to allow the catch of young fish during the control. Box traps consist of a light aluminium frame, whose sides are filled with either plastic netting or coated wire mesh. Control tests with traps require intensive care by trained staff. Fish may be injured as a result of high density in the trap, particularly in times of increased migratory activity. Frequent emptying can prevent this. The fish are removed from the trap, measured and their parameters recorded according to the defined programme, and released into the headwater. Since the trap, in the way it is set, prevents migration downstream from the headwater into the fish pass, this method provides reliable data on upstream movement.

Blocking method

This method involves blocking-off the water intake of the fish pass (i.e. fish pass exit) with a net or grid to prevent fish swimming in from the headwater. All fish are then removed from the fishway, either by electro-fishing or by drying the pass. Control fishing, which is carried out after a certain time, reveals the fish that have entered the fish pass from the tailwater. This method can be applied at all passes that provide places for the fish to rest. It is, therefore, not suitable for Denil passes. Problems arise particularly from clogging of the blocking device by debris and floating solids. Test fishing in a fish pass using conventional methods or electro-fishing is not suitable as a function control unless the water intake of the fish pass (i.e. the fish pass exit) is first blocked off. It is otherwise, impossible to determine from which direction the fish migrated into the pass, i.e. whether they came from the tailwater or headwater.

Marking

Marking of fish can be used to control the functioning of the more natural fish passes and is often used to study migrations in aquatic systems. Marking of fish must be reported to, or approved by, the appropriate authorities. There are different methods for marking fish, such as the use of coded marks (tags) or dye injections, each of which has distinct advantages and disadvantages. When using this method autochthonous fish, that is caught in the relevant waterbody, is marked and released into the tailwater of the dam being investigated. Control of the functioning of the fish pass then consists of proving the presence of marked fish in the water intake area (fish exit area) of the pass or in the headwater. Information about the recapture of the marked fish can be gained either directly by using conventional methods, such as fish traps or electro-fishing, or through the notification by anglers of any marked fish caught. Since the recapture rate is generally low, large numbers of various species and sizes must be marked for release into the tailwater. The relationship between the total number of all fish marked and the number recaptured must be taken into account when assessing the results.

Electro fishing

Electro-fishing is frequently used for qualitative and quantitative investigation of fish stocks. Under the influence of an electric field in the water, any fish present first swim towards the anode (galvanotaxis) and are then anaesthetised for a short period (galvanonarcosis), which forces them to be captured. The fish can then be investigated as to species, size category etc.. If the electro-fishing equipment is used correctly, the fish are not injured. Electro-fishing (in Germany) must only be carried out by specially trained persons and requires the approval of the relevant authority and the agreement of the holder of the fishing rights. Electro-fishing gives qualitative and semiquantitative estimates of the fish stock in the headwater and tailwater of dams. The determination of stock size can be used to assess the ascent activity of the fish fauna at the time of monitoring and also constitutes the basis for estimating the functionality of the fish pass. In combination with other methods, such as blocking the water inlet to the fish pass or marking, electrofishing gives the possibility of proving that fish manage to negotiate the pass.

Automatic counting equipment

Automatic counting equipment allows the ascending fish to be observed without disturbing them. The various methods are based on different principles, including movement sensors, light barriers or video control, and many are still largely in the exploratory stage. Optical systems can only be applied if there is sufficient viewing depth. Light barriers and movement sensors only allow the fish to be counted without distinguishing species or size. A more sophisticated combination of video monitoring and image processing systems allows a differential assessment of the functionality of the fish pass (Larinier and Travade, 1992). In most cases, the application of automatic counting equipment presupposes separate observation chambers, devices or installations mostly at the water intake (fish exit) of the pass. If these methods are to be used, provision must be made at an early stage in planning before building the fish pass. Expenditure on regular checks and maintenance of automatic counting equipment is high.

3.3.2 Evaluation program

The assessment of the results of controls of the functioning of fish passes presupposes detailed recording of data. In addition to locality-specific data for the river stretch and other factors that may influence the test results, data on the methodology used, including the duration of exposure of the fish traps or the cycle of emptying these traps, are required for correct assessment. Unrestricted functioning and complete failure of a fish pass are both easy to demonstrate, but proof of restricted or selective functioning for specific species or sizes is considerably more difficult. Proof of the full functioning of a pass by the analysis and assessment of fish ascent figures should be carried out using the following criteria. i) Results of monitoring are to be assessed in relation to the main periods of migration that are specific to species and waterbody. Here, concomitant factors such as discharge conditions, temperature, moon phase etc, should be considered. ii) Fish migrating through the fish pass are to be assessed in relation to the stock densities in the headwater and tailwater of the dam. This can be done by comparing the results of the fish pass monitoring with the natural dominance relationships (as percentage data) and the size range of the species actually present in the water. According to the general requirements, a fish pass can be recognised as functional if all species of the potential natural fish fauna, in the different stages of development and in numbers that reflect their relative abundance in the watercourse, can find the fish pass entrance and negotiate the pass. However, this frequently presents methodological problems. This is because, usually, not all species of the potential natural fish fauna are represented in the water and, in particular, the presence of small fish species is difficult to prove with traditional methods such as fish traps. In addition, species that are extremely rare in the river may not be detected during monitoring, although these species may, in principle, be able to negotiate the pass. Therefore, it isnow allowed to believe that a fish pass functions well if it can be proved that all fish species actually present in the affected river stretch, in their different stages and relative abundance, can find the entrance and negotiate the pass. The pass can be considered functional even for extremely rare species or species that are not recorded because of the methodological difficulty to catch them. If other species with the same ratio of body size to pass dimensions and similar swimming performance are able to negotiate the pass, the plausibility that the fish pass entrance can be detected and the pass be negotiated must also be given for species of fish of the potential natural fish fauna that are currently not represented in the population of the watercourse.

3.3.3 Maintenance plan

The need for regular maintenance must be considered from the start of planning a fish pass as poor maintenance is the chief cause of functional failure in fishways. Obstruction of the exit of the pass (i.e. the water inlet) and of the orifices, damage to the fish pass structure or defective flow control devices are not rare but can be overcome through regular maintenance. There must be unhindered and safe access to the pass so that maintenance can be assured. Close-to-nature types of construction such as rock ramps are easier to maintain than highly technical structures because obstruction with debris of the water inlet area or the boulder bars is rarely total and does not immediately halt operations. Highly technical structures, therefore, require more frequent maintenance. A maintenance schedule can be drawn up or adjusted on the basis of operational experience of the type and frequency of malfunction of the fish pass in question. Maintenance must always be carried out after floods, however.

Structural and operational maintenance

It is an offence not to maintain the pass in an effective and efficient state. Following questions must be asked for the maintenance: How often will the structural integrity of the pass be checked, and by whom? How often will the pass be checked to ensure that it is operating correctly and is not compromised by debris collection, and who will be responsible?

3.4 Project Phases

Project phases of fish passage design includes preliminary project, feasibility and final project reports.

3.4.1 Preliminary project report

In this stage, the whole data about the suitable site such as biological, physical and economical are gathered. All the various fishway designs of conceptual design alternatives that may meet fish passage objectives at the project site are identified and issues raised throughout the first elimination process among alternatives. To summarize, preliminary project report consists of examination of various design alternatives and preparation of feasible options by considering site conditions and dam, weir, culvert characteristics, fish species and sizes, water levels and flows, fish behaviour and stamina, debris and ice, bank protection and stream scour or sedimentation. It gives clear picture of the type of project envisaged, legal clearence for construction from various agencies and individuals whose property rights might be involved and provides initial list of alternative conceptual designs for a detailed feasibility study.

3.4.2 Feasibility report

Feasibility includes the detailed appraisal of the options and identification of the best solution. This phase is an "evaluation of conceptual design alternatives" which includes a more detailed examination of site characteristics, conceptual design details and limitations, and estimated costs for each design. The feasibility study supports selection of the prefered alternative design. At the feasibility stage the expediency of using any of the practical options identified at the concept stage is investigated in depth, and outline design is prepared for the recommended option(s) chosen for final detailed design. Feasibility assessment report comprise of six sections such as introduction, existing obstruction, constraints, feasibility options, conclusion and appendices.

Introduction section includes brief, site, fish species, data sources, river flows, consultations. Existing obstruction section includes history, type & construction (including plans), use & operation, visual inspection & condition, external influences, hydraulic assessment. Constraints section includes topography of existing obstruction, structural condition of existing construction, upstream & downstream water levels, access & working, environment, ownership, conservation matters, planning matters, utilities. Feasibility options section includes required operating range, option types, assessment of options (1 to nn), recommended option(s), budget cost estimate(s), outstanding & miscellaneous issues. And finally, conclusions and appendices sections take part in as a final stage in feasibility assessment report.

3.4.3 Final project report

Final project report is the ultimate report of the fish passage design. This phase builds on the preliminary design and incorporates review comments, recommendations and the results of modeling. Final project report involves i) project summary, ii) introduction, iii) location, purpose and authority, iv) biological considerations, assessments, and benefits of fish passage, v) plan formulation, vi) proposed fish passage facilities, vii) construction cost estimates and schedule, viii) economic evaluation, ix) environmental compliance. The end product of this phase is the final or functional design and specifications in preparation for the bid process.

4. DESCRIPTION OF THE CASE STUDY AREA: VEREINIGTE WEIßERITZ RIVER

4.1 Background of Study Area

4.1.1 Geography

The Weißeritz River catchment is situated in the eastern part of the Ore Mountains, East Germany, between 50°40' and 50°49' N (northern latitude) and 13°35' and 13°45' E (eastern longitude). Weißeritz River catchment (Figure 4.1) belongs to Elbe River basin district (Upper Elbe River basin) and subdivided into Rote (Red), Wilde (Wild), and (Vereinigte) (United) Weißeritz River. The Weißeritz River catchment flows through the eastern part of the Ore Mountains. The drainage area covers about 384 km^2 with a total river (including Vereinigte, Rote and Wilde Weißeritz River) length 102 km. Length and area data concerning the rivers mentioned above are summarized in Table 4.1. It should be noted that the River Wilde Weißeritz flows through both in Federal Republic of Germany and Czech Republic while others (Wilde and Vereinigte Weißeritz River) flows through only in Federal Republic of Germany.

Table 4.1: Main data of the River Weißeritz catchment (Landeshauptstadt Dresden Die Oberburgermeisterin, Umweltamt, 2010).

River	Length, km	Area, km^2
Wilde (Wild)	Germany, 47	Germany, 150.3
	Czech Republic, 6.3	Czech Republic, 12.3
Rote (Red)	35.4	154.3
Vereinigte (United)	14.2	66.7
Total	102.5	383.6 ~ 384

Vereinigte Weißeritz River is formed by the confluence of the Wilde (Wild) Weißeritz River and Rote (Red) Weißeritz River at the town of Freital between 50° 58' 54" N (northern latitude) and 13° 37' 46" E (eastern longitude). Vereinigte Weißeritz River also named as United Weißeritz or Weißeritz River, which is a confluence river of Weißeritz River catchment (Figure 4.1), is a 14.2 km short left tributary of the River Elbe which flows through 5.5 km in Freital (District: Sachsishe Schweiz-Osterzgerbirge), 8.7 km in Dresden (District: Dresden, Stadt) and opens up to Elbe River (61.5th km of the River Elbe) in Cotta-Dresden between 51° 3' 48" N (northern latitude) and 13° 41' 12" E (eastern longitude). In detail, it flows through (upstream to downstream) Freital-Hainsberg, Plauenscher Grund, Stadtgrenze Dresden, Plauen, Cotta respectively. The River Vereinigte Weißeritz has 66.7 km^2 catchment area in Federal Republic of Germany. Aerial view of Vereinigte Weißeritz River is given in Figure 4.2.

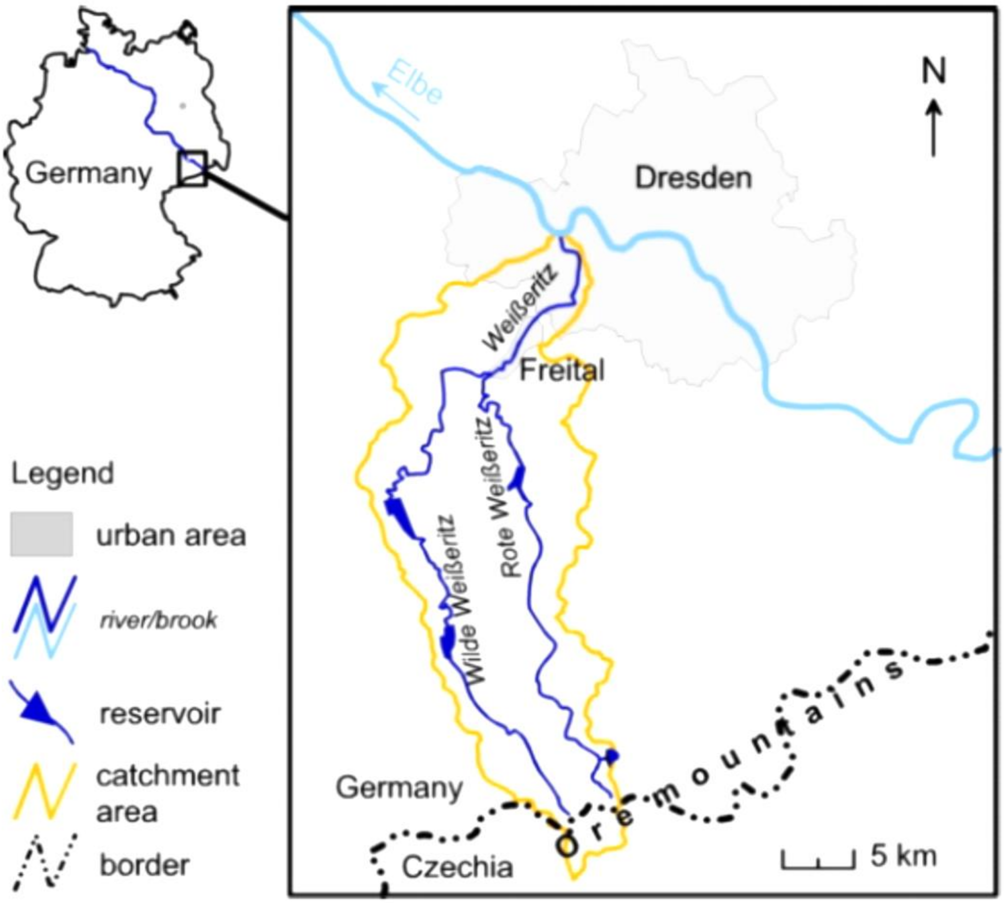


Figure 4.1: Catchment area of the case study (Bornschein and Pohl, 2011).

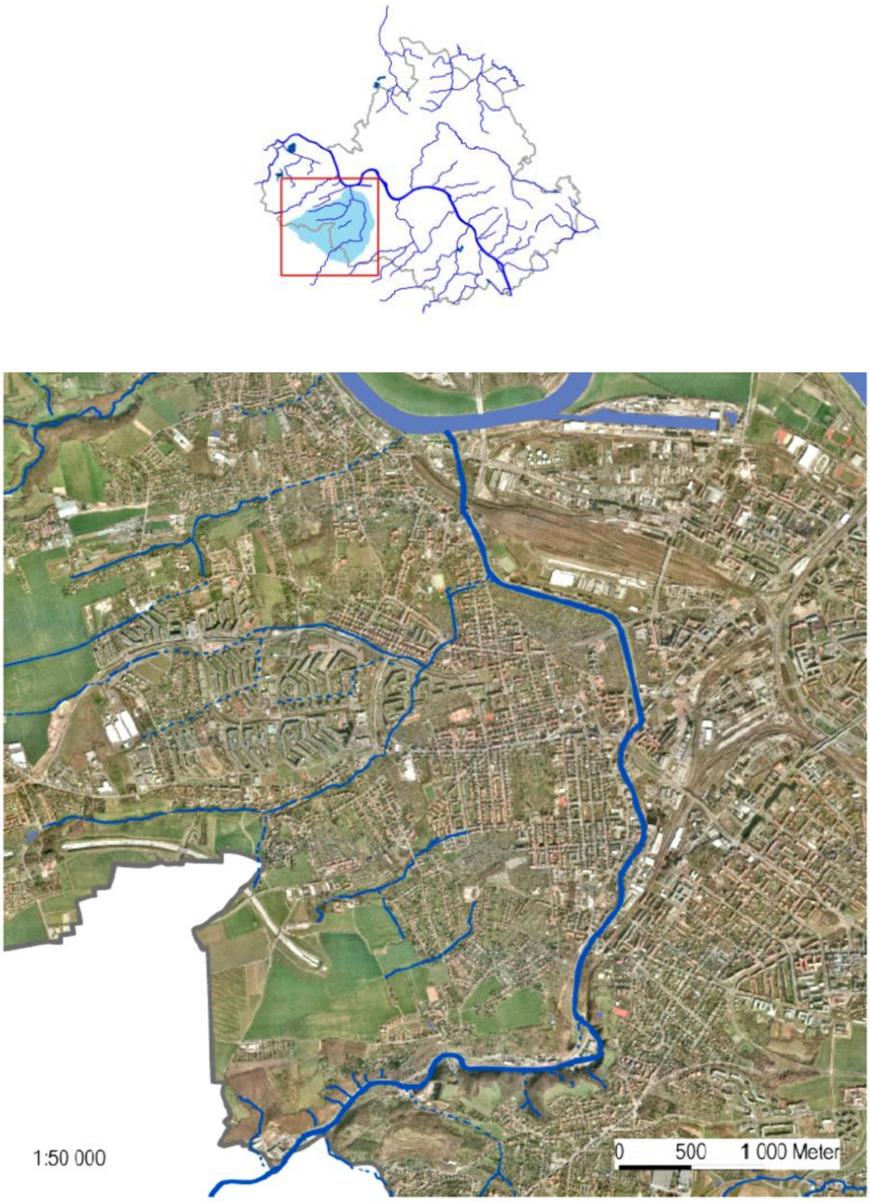


Figure 4.2: Aerial view of Vereinigte Weißeritz River (Landeshauptstadt Dresden Die Oberburgermeisterin, Umweltamt, 2010).

It has approximately ten small inflows such as Plauen Grund valley and Weidigtbach. In urban area, there are seven water sources in the Plauen Grund valley. Other important tributaries outside of Dresden are Wiederitz, Posenbach, Rote Weißeritz, Schloizbach, Höckenbach, Seerenbach, Hennersdorferbach, Hermsdorferbach (Landeshauptstadt Dresden Die Oberburgermeisterin, Umweltamt, 2010).

Catchment areas regarding each river, i.e., Vereinigte, Rote and Wilde Weißeritz River with stream gauge stations and dams are illustrated (Figure 4.3). The following configuration displays stream gauge stations in Rote Weißeritz and Wilde Weißeritz

Rivers measuring water level or depth. There are additional three main stream gauge stations in Vereinigte Weißeritz River which are not shown in figure below: Hainsberg 6 (after 2005, replacement of Hainsberg 4) and Plauen (2012) (Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 2012).

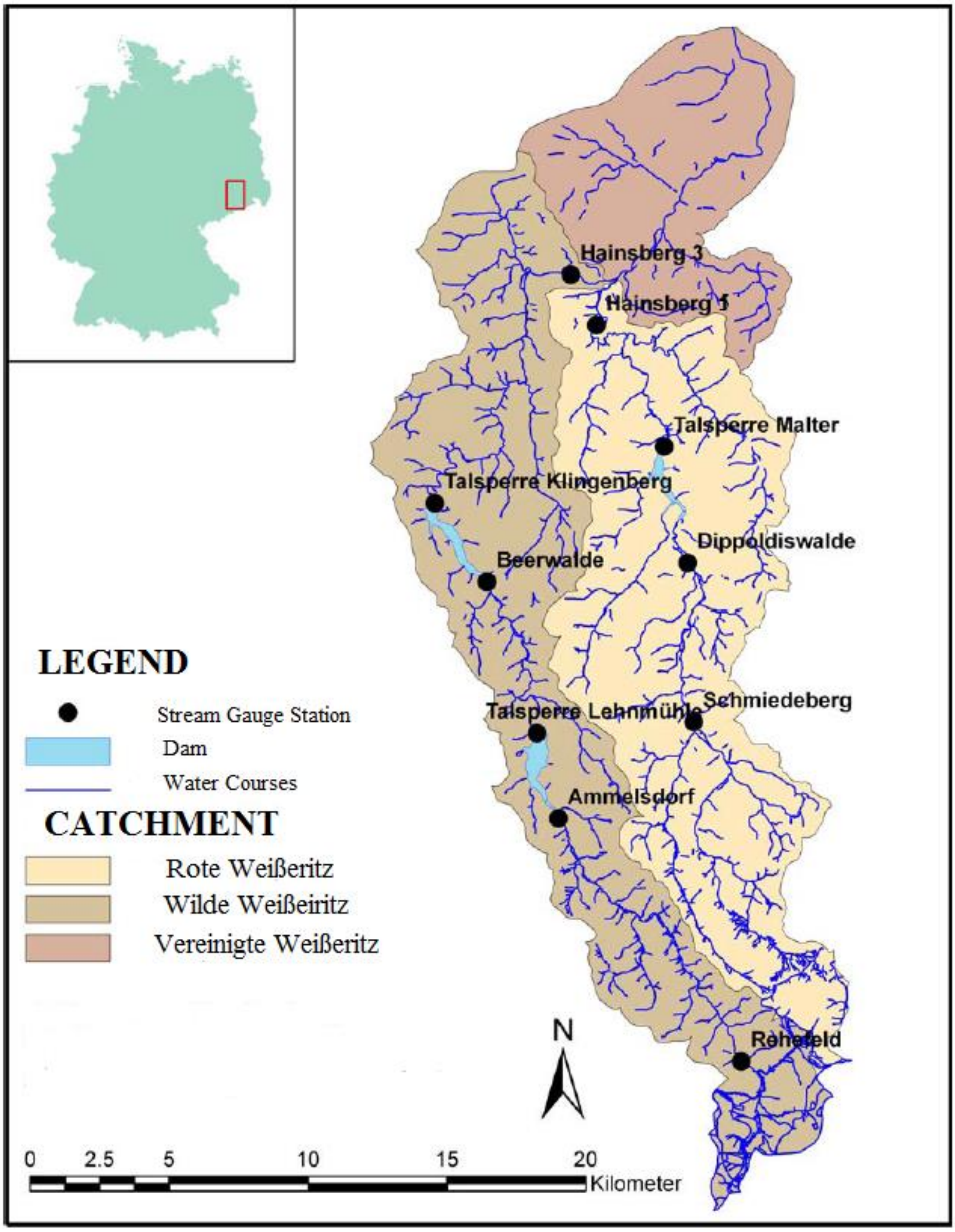


Figure 4.3: Vereinigte, Rote and Wilde Weißeritz River catchment (Pöhler, 2006).

The Wilde Weißeritz River arises in Czechia near Nove Město, between 50° 42' 0'' N (northern latitude) and 13° 40' 55'' E (eastern longitude), forms the Czech-German border along 1 km and flows through 47 km in Federal Republic of Germany (Free State of Saxony- Sachsische Schweiz District) until it joins the Rote Weißeritz River to form Vereinigte Weißeritz River at the town of Freital between 50° 58' 54" N (northern latitude) and 13° 37' 46" E (eastern longitude). In detail, it flows through (upstream to downstream) Nove Město, Rehefeld, Klingenberg, Dorfhain, Edle Krone, Tharandt, Freital-Hainsberg respectively. The River Wilde Weißeritz has 12.3 km^2 upper catchment area in Czech Republic and 150.3 km^2 catchment area in Federal Republic of Germany.

The source of the Rote Weisseritz River lies close to the towns of Altenberg and Zinnwald-Georgenfeld (Cinovec) at the Czech-German border, between 50° 45' 42" N (northern latitude) and 13° 44' 13" E (eastern longitude) and flows through 35 km in Federal Republic of Germany (Free State of Saxony- Sachsische Schweiz District) until it joins the Wilde Weißeritz River to form Vereinigte Weißeritz River at the town of Freital between 50° 58' 54" N (northern latitude) and 13° 37' 46" E (eastern longitude). In detail, it flows through (upstream to downstream) Altenberg, Waldbarenburg, Kurort, Kipsdorf, Schmiedeberg, Obercarsdorf, Ulberndorf, Dippoldiswalde, Freital-Hainsberg respectively. The River Rote Weißeritz has 154.3 km^2 catchment area in Federal Republic of Germany.

4.1.2 Population and socio-economy

Population has an impact on water in direct and indirect ways. The former consists in modifications to the circulation of water and its quality by withdrawals, waste water disposal, river regulation etc. The latter consists in modifications of vegetation and soil cover: deforestation and compaction reduce the absorptive capacity of the soil and accelerate water runoff; this causes floods and deficits of recharge of aquifers; the loss of soil protection accelerates erosion and leaching, increasing water pollution; finally, air pollution affects the chemical properties of water through precipitations (viz. acid rains) (Population Information Network (POPIN) Gopher of the United Nations Population Division Department for Economic and Social Information and Policy Analysis contrib. by FAO, 1994)

In order to perceive the population in the natural boundaries of the catchment area, population density in regional boundaries are introduced in Table 4.2. Study area (Weißeritz River catchment) consists of part of the Dresden, Stadt, Sacsische Schweiz

(After 2008, Weißeritzkreis and Sachsische Schweiz districts are combined and named as Sacsische Schweiz) in Federal Republic of Germany and Karlovarský kraj in Czech Republic districts. According to the population and area on 31 December 2012 by district free cities and counties of Free State of Saxony (Table 4.2), population densities of the districts that is mentioned below are 1599 and 149 capita per square km, respectively. Based on the values that is shown in Table 4.1, it can be interpreted that the Weißeritz River catchment area densely is populated in the city centre of Dresden whereas less inhabitants settled in Sachsische Schweiz as compared to Dresden, Stadt. Population estimates of Weißeritz River Catchment is outside of the scope of the thesis, therefore the population of the investigaton area is not included here. With regard to basis population in Dresden, Stadt within the borders of the Weißeritz catchment area, Bornschein and Pohl (2011) stated that about 4700 (%0,9 of Dresden, Stadt population) inhabitants live within the possible inundation area of a 100-year flood of the River Vereinigte Weißeritz in Dresden.

Table 4.2: The population and area of interested districts in Federal Republic Germany (Statistics of Free State of Saxony, 2012).

District	Municipality	Population	Area (km)	Population Density (capita/km^2)
Dresden, Stadt	1	525105	328	1599
Sachsische Schweiz-Osterzgerbirge	36	245927	1654	149

The Weißeritz River is part of a heterogeneous area with economic and social development below average. In summary, it can be stated that the area suffers due to its heterogeneous structure from an accumulation of environmental, economic and social problems in addition to those of urban structure (Egermann et al., 2006).

4.1.3 Topography

The Weißeritz catchment is located in the Eastern Ore Mountains and extends from the crests at the German-Czech border over middle and lower mountain region as well as the hilly country down to the lowland of the Elbe valley. It extends from Czechia in the south about 909 metre above sea level to the Elbe River at the city of Dresden in the north 107 metre above sea level (Matouskova et al., 2010). There is approximately 800 m elevation difference between the maximum headwater elevation level of the River Rote Weißeritz and Wilde Weißeritz at about 900 m above sea level (ASL) and the confluence of the Vereinigte Weißeritz River with the Elbe River near Dresden at 100 m above sea level (ASL). As it can be seen from the Figure 4.4, Vereinigte Weißeritz River is located in the region (Vereinigte Weißeritz catchment) where altitude (ASL: above sea level) changes between the range of 0 to 400 m. Upstream of the River Vereinigte Weißeritz is at 100-200 m altitude whereas downstream of the river is at 0-100 m altitude before uniting with River Elbe (Bernhofer and Franke, 2009). Altitudes at the source of the River Vereinigte Weißeritz, Wilde Weißeritz and Rote Weißeritz are 183, 860, 905 m above sea level (ASL) and at the mouth of the River Vereinigte Weißeritz, Wilde Weißeritz and Rote Weißeritz are 107, 183, 183 m above sea level (ASL) respectively (Table 4.3) (Bernatowicz et al. 2008). Slopes in the study area (Weißeritz River catchment) changes between 0° to 30° is presented in Figure 4.6c. Slopes of the Rote and Wilde Weißeritz are steeper than Vereinigte Weißeritz River (Table 4.3).

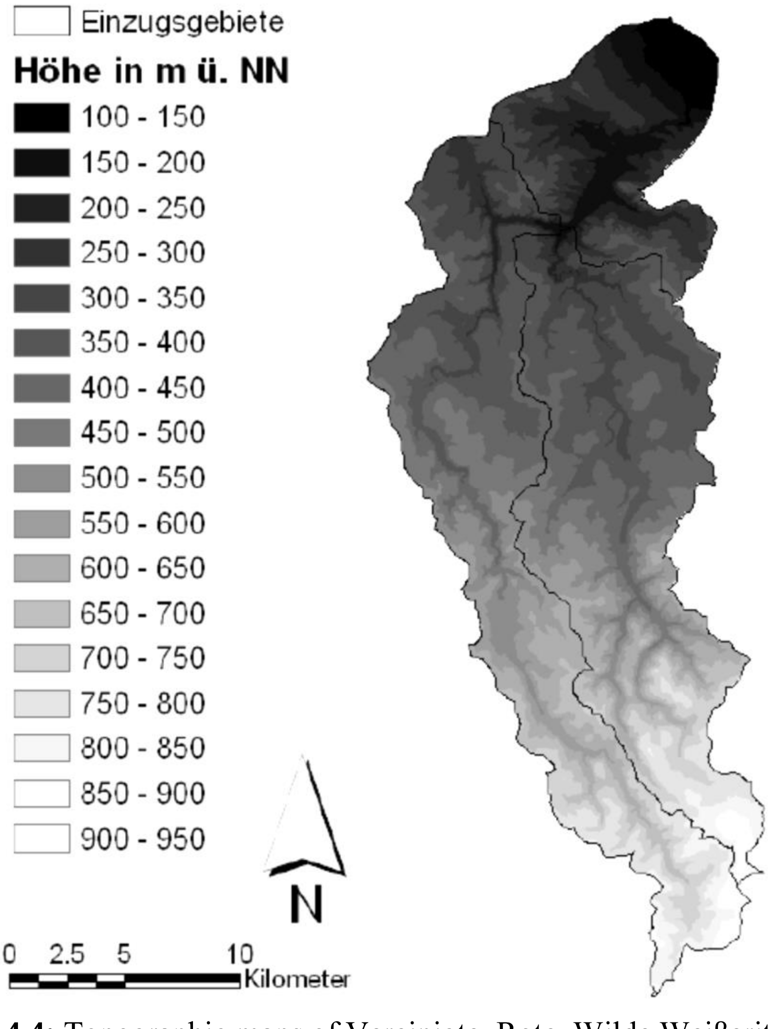


Figure 4.4: Topographic maps of Vereinigte, Rote, Wilde Weißeritz River catchments (20 m raster data, ATKIS-DGM25) (Pöhler, 2006).

Table 4.3: Altitudes above sea level of Weißeritz Rivers (Bernatowicz et al., 2008).

River	ASL at Source (m)	ASL at Mouth (m)	Difference from source to mouth (m)	Slope (%)
Wilde Weißeritz	860	183	677	1.0-3.1
Rote Weißeritz	905	183	722	1.1-3.0
Vereinigte Weißeritz	183	104	79	0.58

4.1.4 Meteorology

The River Vereinigte Weißeritz has its sources in the Erzgebirge (Ore Mountains) which is prone to very intense rainfall events. The eastern Ore Mountains have a moderate climate. Three climatic zones can be distinguished in the catchment of the River Vereinigte Weißeritz: 1) Above 650 m a cool mountain climate is prevalent, 2) Below 650 m the lower Ore Mountains have a moderate mountain climate 3) The valley of the River Elbe around Dresden has a mild climate.

The raise of the mountain range from north west to south east results in orographic rain. Therefore, long lasting rainfall occurs during west and northwest wind weather and the Ore Mountains obtain twice as much rain than the closeby plain. The flood in July 1987 and August 2002 in the Vereinigte Weißeritz River was caused by increased rainfall due to orographic effects on the southern slopes during a Vb (Five B) weather pattern[1], which is identified by Bebber (1882), also known as a subclass of storm trajectory V of five weather pattern (OPAQUE, 2006). OPAQUE (2006) classified climatic zones into three zones as illustrated in Table 5.1.

Table 4.4: Climatic zones of Weißeritz River catchment (OPAQUE, 2006).

Climatic Zone	Mean Annual Temperature (°C)	Annual Rainfall (mm/yr)
Upper Eastern Ore Mountains	4-5.5° C	950-1050
Lower Eastern Ore Mountains	6.1-7° C	730-1000
Elbe River Valley	9.1° C	600-640

[1] Low pressure trajectories: from the Middle Atlantic southeastward across Biscay to the Mediterranean area (Va), and from there to north-east (Vb), to Eastern (Vc) or to southeast (Vd).

Between the years 1961-1990, Tharandt meteorological station recorded annual mean temperature as 7.9 °C, annual mean precipitation as 738 mm, monthly mean temperature as -1.2 °C (min: January) and 16 °C (max: July), mothly mean precipitation as 46 mm (min: February) and 82 mm (max: August) (Bianchin et al., 2007).

4.1.5 Hydrology

Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall event, i.e. intensity, duration and distribution and other site specific factors such as soil type, vegetation, slope and catchment size (Critchley and Siegert, 1991). Within the middle and lower regions of the Weißeritz catchment, runoff generation processes from arable land areas also called as extensively used grasslands or agricultural areas with loess (silty) soil show potential overland flow[2] (corresponds to 21% of Weißeritz catchment) with bad infiltration conditions. The quick interflow[3] (corresponds to 33% of Weißeritz catchment) occurs particularly on steeper slopes (Figure 4.6c) and forested (spruce) shallow soils (Figure 4.6b). The delayed interflow[3] (corresponds to 17% of Weißeritz catchment) particulary originates from areas with minor slopes (Figure 4.6c) and loess or deep soils below extensively used grassland (Figure 4.6b). Overland flow sealed urban areas (Figure 4.5c) due to densely populated settlement areas (Figure 4.6b) and overland flow areas with small infiltration (Figure 4.5c) due to loess (silty) soil types (Figure 4.6a) is generated in the lower part of the Vereinigte Weißeritz River catchment. Overland flow sealed urban areas dominate throughout the towns in the upper parts of the Vereinigte Weißeritz catchment. Because of the slope differences (Figure 4.6c), both quick and delayed interflow is generated in the Vereinigte Weißeritz catchment (Figure 4.5c).

[2] Overland flow (surface runoff) is the flow of water that occurs when excess water from rain, meltwater, or other sources flows over the earth's surface. [3] Interflow is the lateral movement of water in the unsaturated zone, or vadose zone, that first returns to the surface or enters a stream prior to becoming groundwater. Quick interflow = Direct runoff – Surface runoff (Overland flow), Delayed interflow = Baseflow – Groundwater runoff.

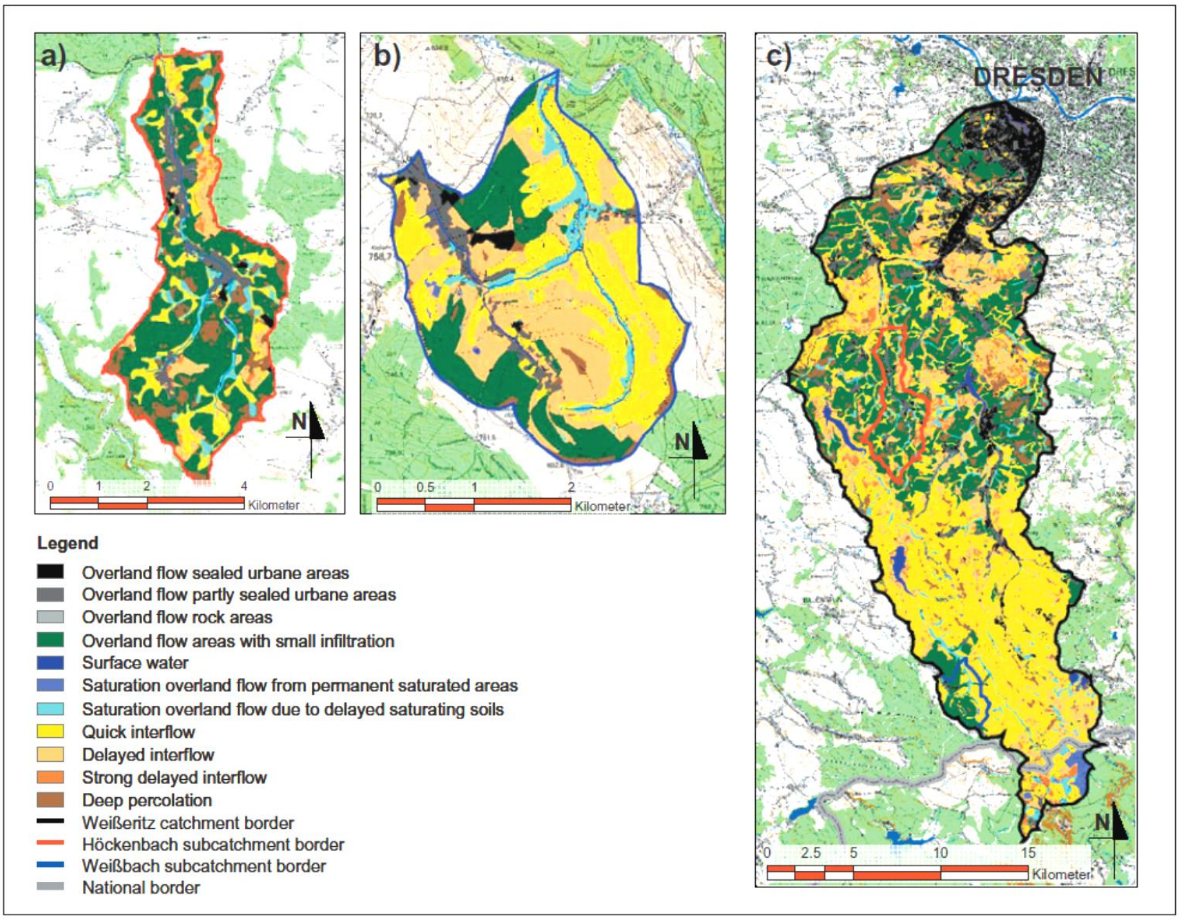


Figure 4.5: Spatial distribution of runoff generation processes resulting from the application of the Expert system FLAB: actual state. (a) Höckenbach subcatchment. (b) Weißbach subcatchment. (c) Weißeritz catchment (Bianchin et al., 2007).

4.1.6 Geology and hydrogeology

Weißeritz River catchment is part of European ecoregion 9[4] (Central highlands/ bio-coenotically relevant siliceous highland streams and rivers) and its lithology is dominated by by gneissic, granitic and porphyric bedrock (Pottgiesser and Sommerhauser, 2004). The area of today's prevailing Proterozoic rock formations initially between the Ore Mountains were intensely folded during the Variscan orogeny in the Carboniferous and shaped to metamorphic rocks (mainly gneiss). In the late phase of the Variscan orogeny (Upper Carboniferous), granitic magma intruded into the metamorphic rocks and led to the formation of veins that were used by mining from the 10th century (Wagenbreth, 1982).

[4]Subecoregions: the piedmont along the Danube west of Vienna and the granit-gneiss mountains contains of Bohemian Massif extending north to the borders of Germany and Czech Republic.

They are in the middle layers of the Ore Mountains in SW-NE direction as quartz and long granite porphyry (rhyolite), in the region of Tharandter forest and in the southeastern region of the Ore Mountains as fluffy quartz porphyries. During the Cretaceous period, rivers with wide floodplains formed the landscape. In northeastern outskirts, small and powerful sandstones occurred on the beach Ore gneiss and line of the Cretaceous sea, and thus serve as a boundary for Elbe Valley zone. Tertiary period lifted the Ore Mountains and in the end Cheb hills was formed. This process was accompanied by basalt volcanism along the fault zone. Deep erosion occurred in the river caused the emergence of the existing today's high surface. Finally, Quaternary period formed Ore loess soils from north western area to the partial south insular (Wagenbreth, 1982). The Ore Mountains is slightly permeable along with the fractures, fault zones, weathered zones and sandstones that have good ground water conductivity occurred in the period of Cretaceous. The hypodermic flow[5] is dominant in the region. For the entire study area, low well yield of less than 1 l/s with mostly scree sources which have a strong connection to downpours was specified (Lauterbach, 2000). Jordan and Weder (1995) indicated that the above and underground hydrogeological characteristics in the study area of Weißeritz River catchment are largely identical. However, the local flow conditions can be greatly affected by mining activities. Hydrogeology map (Figure A.1) depicted by LfUG pointed out that Vereinigte Weißeritz River catchment is composed of areas disturbed by underground mining, hydraulically effective (pore fraction of minor and high importance for the flow events, areas with groundwater management in rocks with mostly low to moderate or locally strong varying permeabilities, areas with silt and sands of terminal moraines with very changeable hydrodynamic condition, areas with rand pleistocene of local importance as the main area of high surfaces and thalers predominantly lax (downstream region) and silts and salts of the terminal moraines with very changeable hydrodynamic condition (downstream region).

[5] Also called as subsurface flow, is the flow of water beneath earth's surface as part of the water cycle.

4.1.7 Soil types

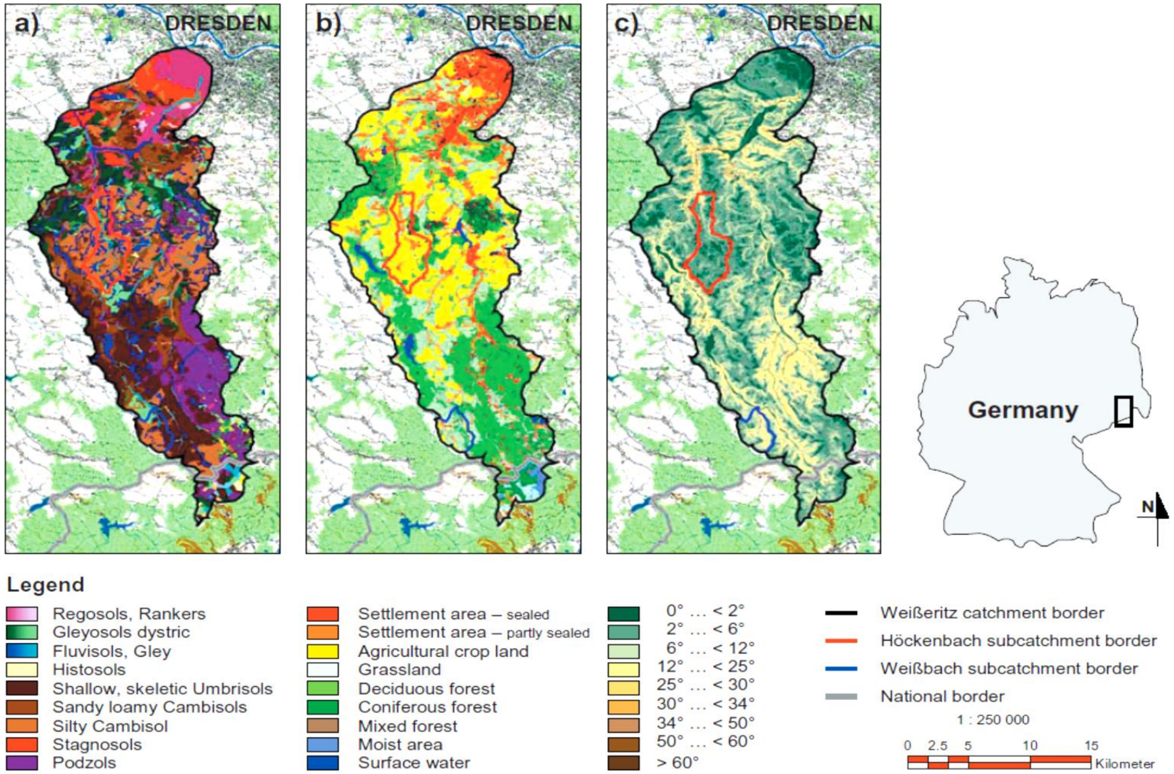


Figure 4.6: Weißeritz Catchment a) Soil types 1:200000 b) Land use (Color Infrared (CIR) Imagery Biotope Type and Land Use Mapping) c) Slope- DGM 20 (Bianchin et al., 2007).

Soils in the catchment area were mainly formed on periglacial debris. Therefore, the soils, especially in the upper areas, are shallow and skeleton rich. According to the geological initial situation, sandy loamy Cambisols are widespread in the study area (Figure 4.6a).

In the upper areas, poor Podzols and shallow skeletic Umbrisols are dominating on loess silty Cambisols and Stagnosols. The valleys are usually characterised of holocene sediments. Only in the upper mountain region in the south of the Weißeritz catchment few Fibric Histosols can be found (Mannsfeld and Richter, 1995). With regard to Figure 4.6a, Regosols, Rankers and Stagnosols formation is prevalent in the downstream reaches while sandy loamy Cambisols is dominant in upstream of the Vereinigte Weißeritz River. World Reference Base for Soil Resources by IUSS (2007) classified Regosol as soils with no significant profile development, Cambisols as moderately developed soils under relatively young soils or soils with little or no profile development (Group 10), Stagnosols as structural or moderate textural discontinuity under soils with stagnating water (Group 6).

4.1.8 Land use

In reference to Figure 4.6b, a third of the Weißeritz catchment is covered by forests, which stands mainly consist of spruce. Pinewood forests also share great parts of the area. Only some small woodlands consist of deciduous tree communities. Almost half of the area is used for agricultur, with considerably more agricultural crop land than grassland. Agriculture dominates in the lower and middle regions. The northern part of the catchment is particularly marked by the settlement areas such as town of Freital and city of Dresden (Mannsfeld and Richter, 1995).

Deciduous forests are major component of the upstream reaches of Rote Weißeritz River. Along the watercourse, agricultural crop land areas dominate the reaches with few grassland and settlement areas. Matouskova et al. (2010) articulated that only the upper reaches of Rote Weißeritz River downstream from the Altenberg reservoir, and the lower reaches between the Malter dam and the town of Freital remain largely uninfluenced by human activities (nature conservation areas).

Deciduous forests with agricultural crop land and grassland areas are primary fields of the upstream reaches of Rote Weißeritz River. Compared to the Rote Weißeritz River, the immediate vicinity of the River Wilde Weißeritz is almost uninhabited, except for the towns of Tharandt and Freital. Smaller settlements are located in side valleys or on the valley slopes and affect the river only locally (Matouskova et al., 2010).

Few forest, agricultural and grassland areas are located in the upstream reaches of the Vereinite Weißeritz River whereas densely populated urban settlement areas characterise the downstream. Figure 4.7 demonstrates the regional boundaries[6] and natural boundaries of study area. The land cover of Weißeritz River catchment recorded by CORINE Land Cover (1997) is given in Figure 4.7. In reference to Figure 4.7, Vereinigte Weißeritz River is covered mostly by settlement area in downstream and upstream reaches where few agricultural, forest and natural areas is observed in its surroundings.

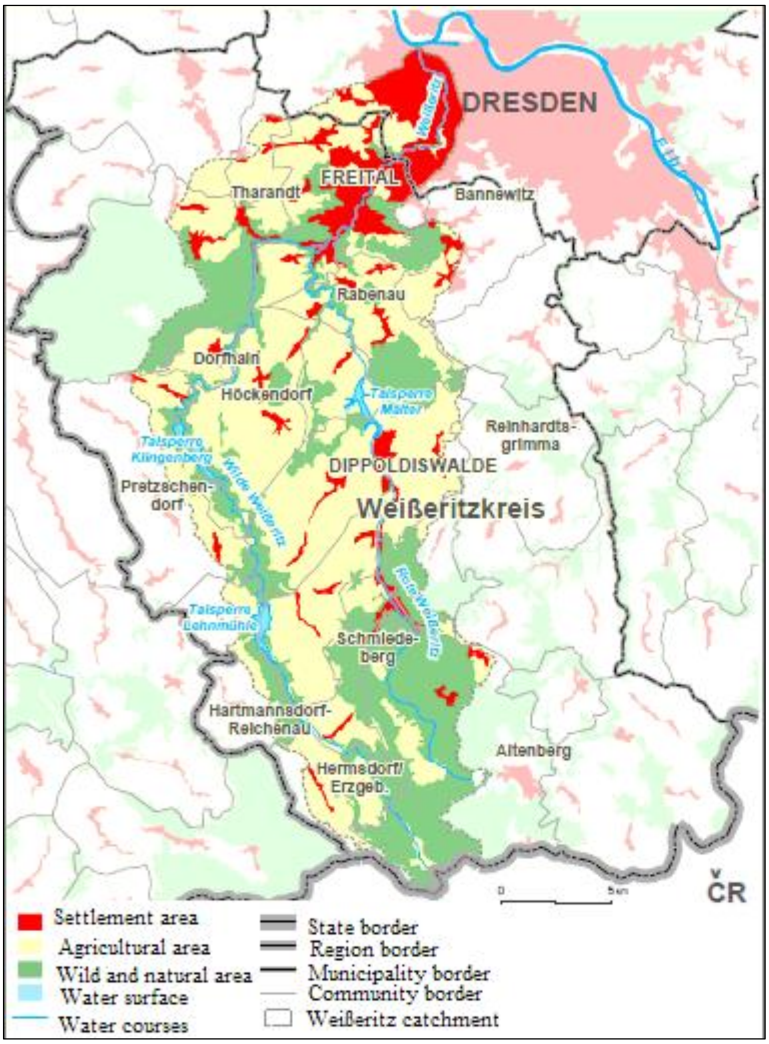


Figure 4.7: Weißeritz river catchment land cover in Federal Republic of Germany (Merta et al., 2007).

[6] Weißeritzkreis district joined Sachsische Schweiz district in 2008 and named as Sachsische Schweiz district ultimately.

LfUG (2004) stated that about 60% of the catchment is dominated by spruce stands, deciduous species and mixed type of forests; some 20% grassland, 10% arable land, 4% swamps and 6% settlements characterize the remaining parts of the catchment. More up-to-date study that is carried out by Foltyn (2006) indicates that the catchment area is composed of 34% of forest and afforestation areas, 26% of agricultural crop land and horticulture, 24% of grassland, bushes and moorland, 15% of settlement areas, industry and infrastructure, 1% of surface water, less than 0.1% of hedges, groves, tree rows, less than 0.5% of other areas (Table 4.5).

Table 4.5 Actual Land Use in Weißeritz Catchment (Color-Infrared (CIR) Imagery Biotope Type and Land Use Mapping) and in Weißbach subcatchment and Höckenbach subcatchment (Foltyn, 2006).

Land Use	Weißeritz Catchment	Höckenbach Subcatchment	Weißbach Subcatchment
	Proportion Of Area (%)		
Forest	34	12	16
Afforestation Areas		< 0.5	8
Hedges, Groves, Tree Rows	< 0.1	1.5	1.5
Grassland, Bushes, Moorland	24	7	44
Agricultural crop land, horticulture	26	69	21
Surface water	1	< 0.5	< 0.5
Settlement areas, industry, infrastructure	15	9	9
Other areas	< 0.5	< 0.5	< 0.5

4.2 River Properties

River properties are investigated in terms of ecohydrology (hydromorphology, hydrobiology and hydrochemistry) and ecohydraulics.

4.2.1 Ecohydrology

Ecohydrology is an interdisciplinary field that interacts water and its ecosystems. The field consists of hydromorphology, hydrobiology, hydrochemistry and ecohydraulics.

4.2.1.2 Hydromorphology

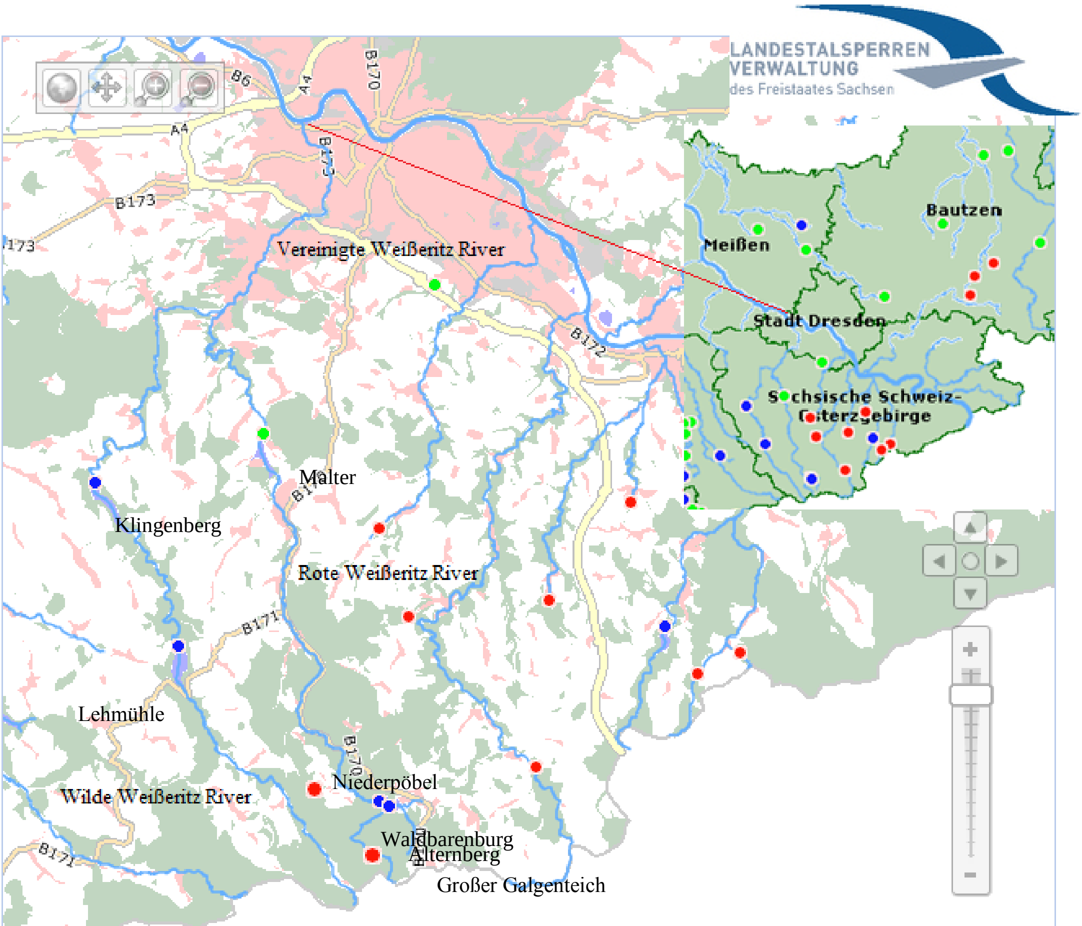
1) River continuity (Linear or longitudinal connectivity)

River continuity is evaluated by the number of impassable artificial or physical barriers (weirs, sluice, crossings, barrage or dams, etc.) that disturb the migration of aquatic organisms and sediment transport. Fish rely on migrations to satisfy their requirements with regard to the structure of the biotope during their different life stages. Longitudinal connectivity of rivers thus has an extremely important role to play with regard to reproductive exchange as well as to the spreading of populations and the recolonization of depopulated stretches of river (DVWK, 1996).

The Vereinigte Weißeritz River was the first Saxony River, for its management due to perennial water measurements, a water management plan was drawn up, which aimed in particular to the flow regulation by dams. Recorded flood in 1897, which had devastating effects of the reaches of Vereinigte Weißeritz River, paved the way for the construction of the dams in the 20th century. Dams influence fish migration by altering the flow of river systems as well as by presenting physical obstacles. The impoundment of a stream coverts flowing water into water that is essentially still. This may slow or disorient downstream migrants that depend on the flow of the stream to carry them to their destination and/or on the direction of flow as an orienting cue to direct their movement. One might expect that the reduction in water flow above a dam would facilitate upstream movement of fish through the impoundment by reducing the velocity that they have to counteract by swimming. If the stream flow itself is an important directional cue, however, migrants may become disoriented in the quiet water above a dam.

The River Wilde Weißeritz was dammed by two reservoirs Lehnmühle (upstream) completed in 1931 and Klingenberg (downstream) completed in 1914 with its pre-dam structure completed in 1954 in German territory which is represented as blue circles in Figure 4.8. Both supply drinking water for Dresden and Freital, serve flood protection and hydro-power plant. There are fifteen impassable artifical barriers (68,18%) together with six fish passage structures (27.27%) out of twenty two hydraulic structures along the River Wilde Weißeritz. Four fish passage structures (66.67%) out of six are in operation and only two of them (33.33%) are partially operated (SMUL, n.d.).

The River of Rote Weißeritz was dammed by the Malter reservoir (downstream) with its pre-dam structure completed in 1913, which is represented as green circle in Figure 4.8, is serving flood protection, industrial water supply, hydro-power plant, and local recreation. And in the upstream, there are two artificial lake bodies (storage structures) named Altenberg (completed in 1993) and Großer Galgenteich (completed in 1553 and reconditioned in 1942 and 1997). These lakes are represented as blue circle in Figure 4.8, and they supply drinking water and serves flood protection. Lange and Meltz (2012) denoted that Niederpöbel (construction on-going since 2014 until 2018) and Waldbarenburg (planning on-going) retention basins were going to be built for the purpose of flood protection between Malter reservoir and Altenberg, Großer Galgenteich lake bodies (storage structures) close by upstream of Rote Weißeritz River. These two flood retention basins in the River Rote Weißeritz are represented as red circles in Figure 4.8. There are nine impassable artifical barriers (36.0%) together with four fish passage structures (16.0%) out of twenty five hydraulic structures along the River Wilde Weißeritz. Three fish passage structures (75.0%) out of four are in operation and one of them (25.0%) is partially operated (SMUL, n.d.).



Legend: Dams used as drinking water reservoir or storage, with flood protection
Dams used as process water reservoir or storage, with flood protection
Flood retention basins

Figure 4.8: Dams of Vereinigte, Rote, Wilde Weißeritz River (LfUG, n.d.).

Both Wilde and Rote Weißeritz have no fish passage structure near to their dams and hydropower plants. Construction of the fish passage structures on the Rote Weißeritz River near to its flood retention basins is not essential because of the seasonal fluctuation of water level in the basin.

LAWA field survey method which took place between 2003 and 2005, detected 51 impassable cross-structures (smooth slide/ramp, high/very high fall/slope, rough slide/ramp depending on slope, height and length) higher than 0.3 m that restrict river continuity in Weißeritz River catchment. The number of structures for each monitoring section of rivers are: 10 impassable structures on Wilde Weißeritz River up to Lehnmühle reservoir (W-1), 5 impassable structures on Wilde Weißeritz River between reservoirs Lehnmühle and Klingenberg (W-2), 11 impassable structures on Wilde Weißeritz River up to confluence with Rote Weißeritz and Vereinigte Weißeritz River up to confluence with Elbe River (W-3), 17 impassable sturctures on Rote Weißeritz River up to confluence with reservoir Malter (RW-1), 8 impassable structures on Rote Weißeritz River up to confluence with Wilde Weißeritz River (RW-2) (Matouskova, 2010).

Altough there are no dam structures along the water course of the River Vereinigte Weißeritz (Figure 4.8), there are numerous artifical barriers. Nine hydraulic structures were detected along the River Vereinigte Weißeritz and are summarized in Table 4.6. There were two more weirs called Coschütz/Begerburg at 7.24 km and Albert/Schweizer Straße at 11.090 km from the mouth of Vereinigte Weißeritz River which are decommisioned in 2007 (SMUL, n.d.).

2) Hydrological regime

Quantity and dynamics of water flow

Daily discharge measurements at the Vereinigte Weißeritz River in Dresden has been carried out since July, 1882. Outflow record (flood) in the past recorded was 300 m^3/s at the Plauen district in July, 1897. On the Vereinigte Weißeritz River, high flow rates (discharge) recorded in the past at the former stream gauge station (Dölzschen (1927-2000)) were 108 m^3/s and 230 m^3/s in July, 1954 and in July, 1958, respectively.

In accordance with LfUG, from upstream to downstream, there are two stream gauge (gauging) stations which are established recently: Hainsberg 6 (water depth level with remote data transmission without flood warning function) and Plauen (water depth level with remote data transmission with high water alarm function at 190, 220, 250, 280 cm) on Vereinigte Weißeritz River (Figure 4.9). Average flow velocities were between 0.4-0.6 m/s in the Weißeritz River catchment (Matouskova et al., 2010).

Table 4.6 : Barrier structures on Vereinigte Weißeritz River (SMUL, n.d.)

Name	Location	Distance from mouth (km)
Elbe estuary	4618388.00-5659954.00	0.095
Hamburger Straße	4618412.00-5659868.00	0.171
Sohlgleite Flügelwegbrücke	4618520.00-5659396.00	0.677
Sohlabsturz Freiberger Straße	4619655.00-5657866.00	3.640
WKA Bienertmühle	4619432.00-5655826.00	5.930
Wehrschwelle Plauenscher Grund	4617764.00-5655020.00	8.352
Wehr Hofemühle Potschappel	4616737.00-5653978.00	9.990
Mühle Freital Deuben	4615725.00-5651868.00	12.710
Wehr Papierfabrik Hainsberg	4615050.00-5651194.00	13.060

Legend:
Water depth level with remote data transmission without flood warning function
Water depth level with remote data transmission with high water alarm function
No data available
Below mean minimum water flow rate

Figure 4.9: Stream gauge stations of Upper Elbe River basin (LfUG, 2014).

Additional stream gauge (gauging) station called Cotta (operated between 1999 and 2012) is situated at 112.03 m elevation in Dresden, Stadt, 1.2 km right from the mouth (downstream) of Vereinigte Weißeritz River, 373.94 km^2 of the Weißeritz River catchment. The following table (Table 4.7) presents flow rates (minimum, average, maximum) for each month that were measured by stream gauge (gauging) station Cotta between the years 1999-2010. Average flow rates were obtained by calculating arithmetic mean of eleven years (1999-2010) of mean flow rate (discharge) data (Table 4.7) for each month.

Table 4.7 Minimum, average and maximum flow rates at stream gauge station Cotta (m^3/s).

Flow rate	Jan.	Feb.	Mar.	Apr.	Ma.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Minimum	0.371	0.682	0.978	0.699	0.518	0.336	0.244	0.257	0.068	0.14	0.371	0.371
Average	4.248	6.155	8.098	4.442	1.691	1.645	1.395	3.513	1.965	2.077	3.693	3.188
Maximum	37.3	25.7	42.7	34.7	37.6	27.2	24.4	300	47	37.2	36	28.4

By making use of the data in Table 4.7, the following figure are introduced. Secondary axis was placed to show maximum flow rates. At stream gauge station Cotta located on the Vereinigte Weißeritz River, the lowest flow rate recorded was 0.068 m^3/s in September, 2009 whereas the highest flow rate recorded was 300 m^3/s in August, 2002 (Figure 4.10).

Starting from 1999, eleven years of measurements of minimum, mean and maximum flow rates had been taken at stream gauge station Cotta until 2010 (LfUG, 2012) and are given in Appendix B.1, Appendix B.2, Appendix B.3, respectively. Taking the minimum flow rate records (Appendix B.1), a flow rate of 8.73 m^3/s was found to be the highest minimum discharge recorded in the year 2009 and a flow rate of 0.068 m^3/s was found to be the lowest minimum discharge recorded in the year 2009. The mean flow rate data (Appendix B.2) show that 23.9 m^3/s flow rate was the highest mean discharge recorded in the year 2003 and 0.324 m^3/s was found to be the lowest mean discharge recorded in the year 2002. It was observed in the maximum flow rate data (Appendix B.3) that the highest maximum (peak) discharge was 300 m^3/s and it was recorded in the year 2002. In addition, the the lowest maximum discharge observed in the same category was 1.06 m^3/s and it was recorded in the year of 2004.

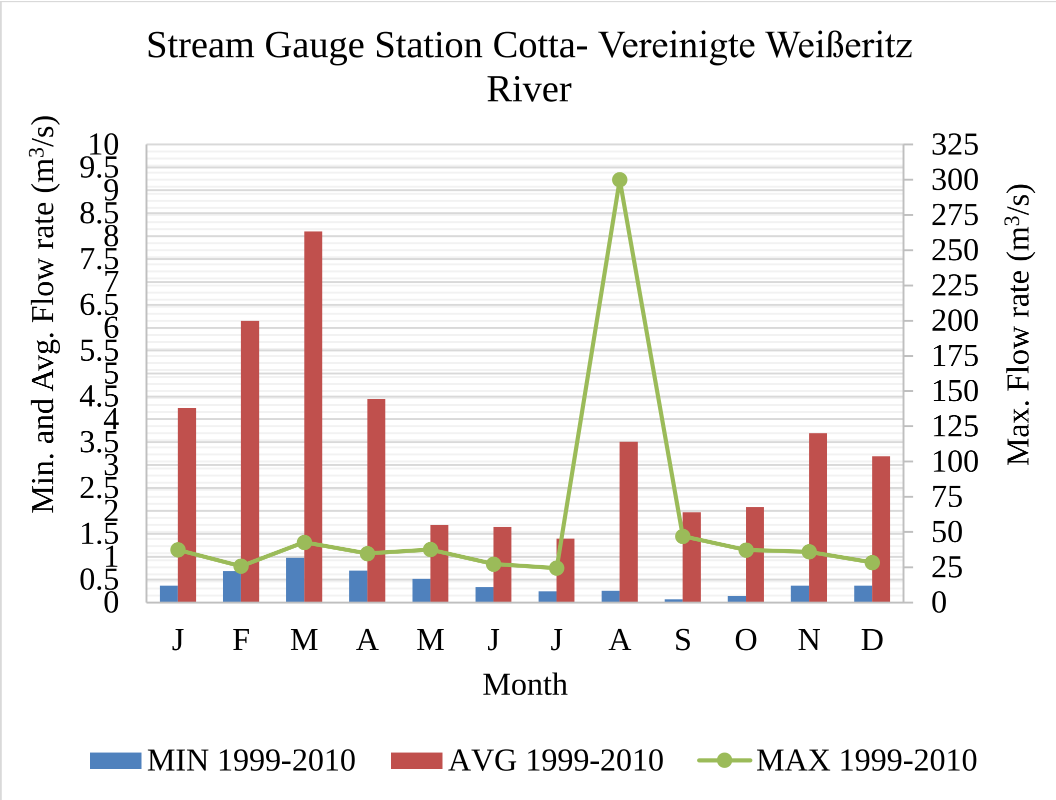


Figure 4.10: Flow rate measures of stream gauge station Cotta -Vereinigte Weißeritz River between years 1999 and 2010.

The last three columns (winter, summer, year) of Appendix B.1, Appendix B.2 and Appendix B.3 are depicted in Figure 4.11, Figure 4.12 and Figure 4.13, respectively. Minimum flow rate in a year is determined with respect to summer season. The lowest minimum discharge record occurred in the summer of 2009 (Figure 4.11). Mean flow rate in a year was determined based on mean flow rates in two seasons. The lowest mean discharge record occurred in 2004 whereas the highest mean discharge occurred in 2010 (Figure 4.12). And finally, maximum flow rate in a year was determined with respect to winter and summer seasons. The highest maximum (peak) discharge record occurred in the summer of 2002 (Figure 4.13).

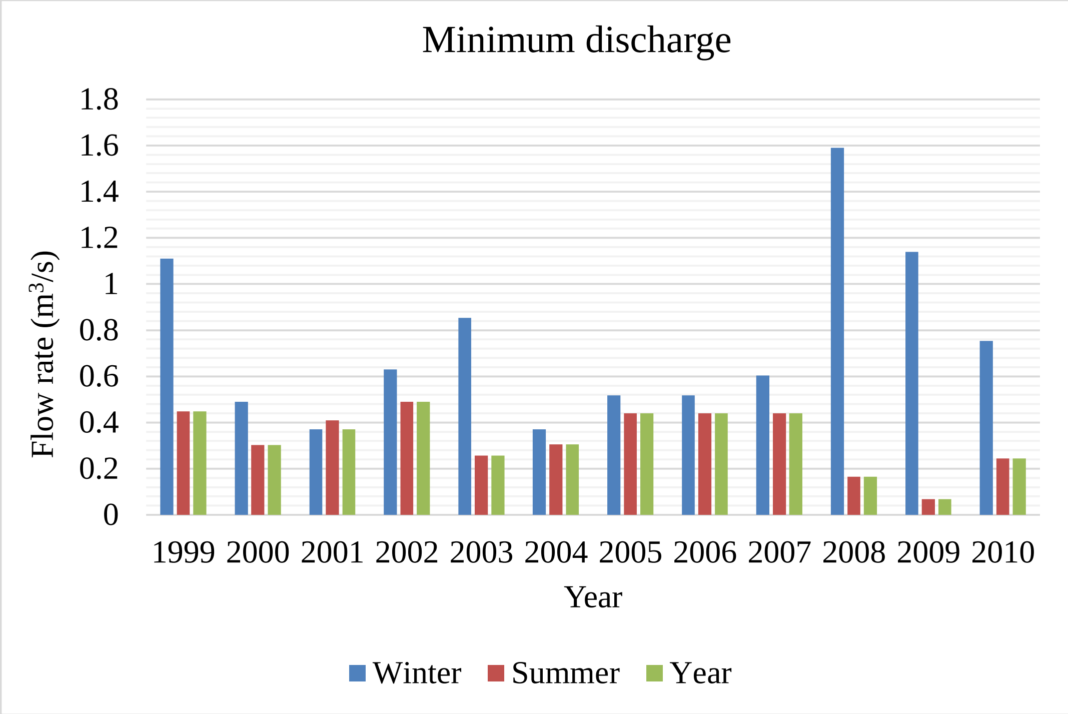


Figure 4.11: Minimum discharge by seasons and year at stream gauge station Cotta.

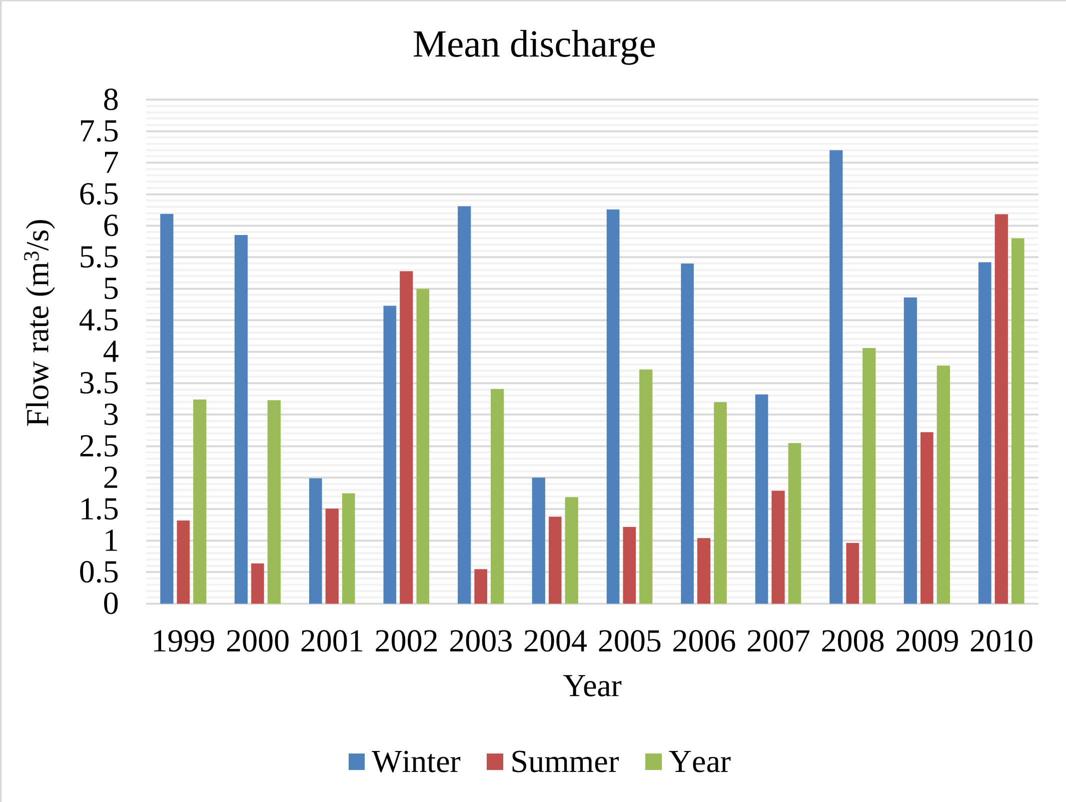


Figure 4.12 : Mean discharge by seasons and year at stream gauge station Cotta.

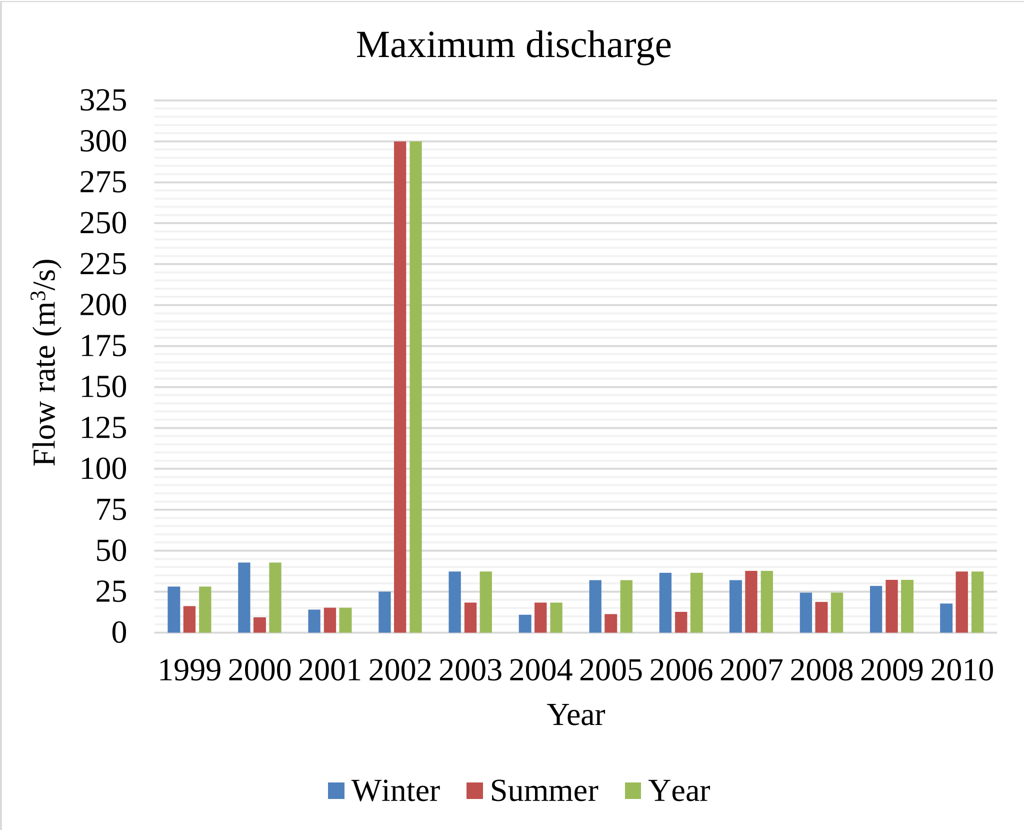


Figure 4.13: Maximum discharge by seasons and year at stream gauge station Cotta.

The relief and the geomorphology of the Weißeritz River catchment area cause high precipitations in the upper part of the catchment (Eastern Ore Mountains- Vb weather pattern) and a high surface run-off. Run-off characteristics are strongly influenced by precipitation storage as snow and by snow melt and summer rains. The related discharge regime was characterized by flood events in winter and spring, with peaks between February and April (Appendix B.3). A secondary peak was observed in July/August and corresponded to extreme precipitation events and thunder storms such as flash flood, e.g., the major flood event in August, 2002 (Table B.3).

In August 2002, Dresden was hit by floods of the River Elbe and its tributaries Vereinigte Weißeritz and Lockwitzbach (one week before the river Elbe flooded the city- flood propagation time between Freital and Dresden city is about 3 hours) which discharge into the River Elbe within the city area of Dresden. The flood of the Vereinigte Weißeritz in August, 2002, with a discharge of 450 m^3/s, had a return period of 400–500 years (Umweltamt Dresden, personal communication). At the same time extreme precipitation values up to 200 mm/day were measured in Dresden.

Normally, the annual mean water level of the River Elbe at the stream gauge station Dresden is 1.98 m. On August 17, 2002, the Elbe River rose up to a level of 9.40 m (the maximum water level at the stream gauge station Dresden (BfG, 2002). All stations in the catchment area of the River Vereinigte Weißeritz recorded new all-time records.

Rainfall-runoff diagram of the major flood event that took place in August, 2002 is given in Figure 4.14. Grey bars and values on the right axis, and colourful lines and values on the left axis show precipitation in depth and discharge, respectively. Wilde Weißeritz River is represented by blue line and is a source of the confluence point of Rote and Wilde Weißeritz Rivers. The highest flow rate recorded was around 220 m^3/s on the source of the confluence point on August 13, 2002.

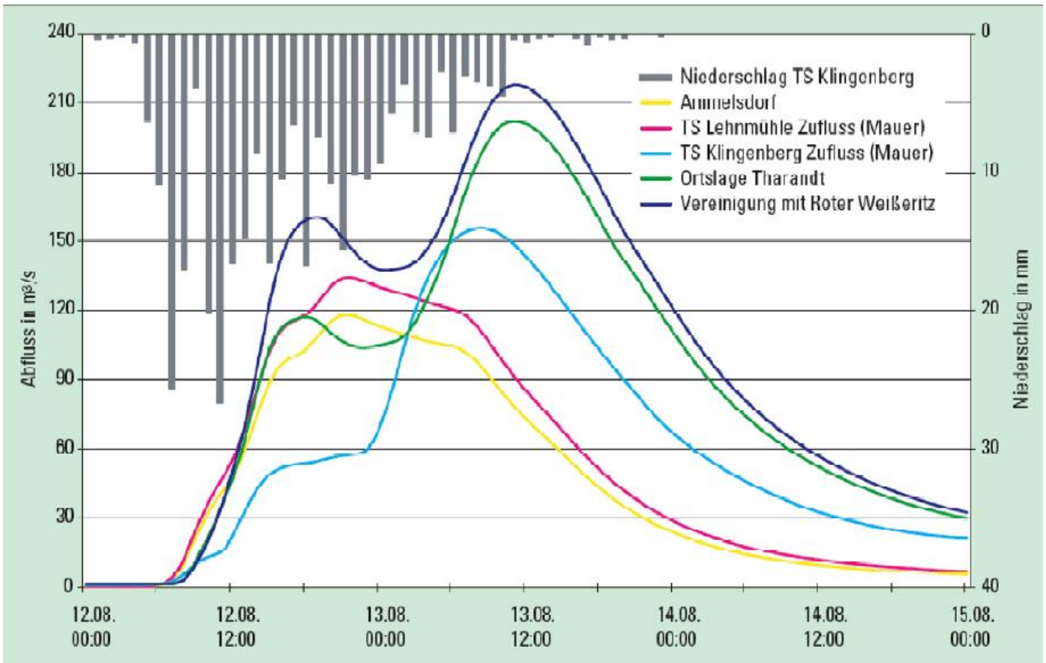


Figure 4.14: Simulation of rainfall-runoff model in Wilde Weißeritz River in August, 2012 (TS: Dam) (Landeshauptstadt Dresden Die Oberburgermeisterin, Umweltamt, 2010).

Between 12 and 14 August 2002, the region of eastern Ore Mountains (Saxony/Eastern Germany) was affected by the heaviest rainfall event recorded since beginning of the measuring period in 1882. This value is close to the maximum physically possible rainfall. The intensive rainfall in the catchments of Rote Weisseritz and Wilde Weisseritz led to unexperienced heavy flash floods with large material transport and flow damages. The resulting flood demonstrated the limits of retention capacity in the existing dams. The buffer effect of the existing dam systems (Klingenberg and Lehnmühle dams) was comparatively small because the reserved retaining capacity for flood protection was only about 15 % of the total capacity. Since the dams were very limited in their ability to hold extremely large amounts of water back, its effect was less in a reduction, but in a delay of the flood peak. This delay of the flood crest in the Wilde Weißeritz River by the dams Klingenberg and Lehnmühle was preventing the flood peaks of the Wilde and Red Weißeritz River in Freital-Hainsberg 4 (1927-2008) which arrived at the same time. If the vertices would be met, the peak flow in Freital would have been approximately 500 m³/s. Alternatively, the reservoirs filled quickly due to the very high maximum inflow of about 150 m^3/s. So, a long-time overflow of the dam system occurred with a maximum of about 300 m³/s at the Vereinigte Weißeritz River through the cities of Freital and Dresden (This situation led, e.g., to the flooding of central railway station in Dresden). This water flow is comparable with a medium flow rate of the River Elbe in Dresden, and it is about 300 times higher than the normal drain of the River Vereinigte Weißeritz in Freital (Bernhofer et al., 2002). Thus, the highest (peak) discharge record was able to reach around 450 m^3/s (Figure 4.15).

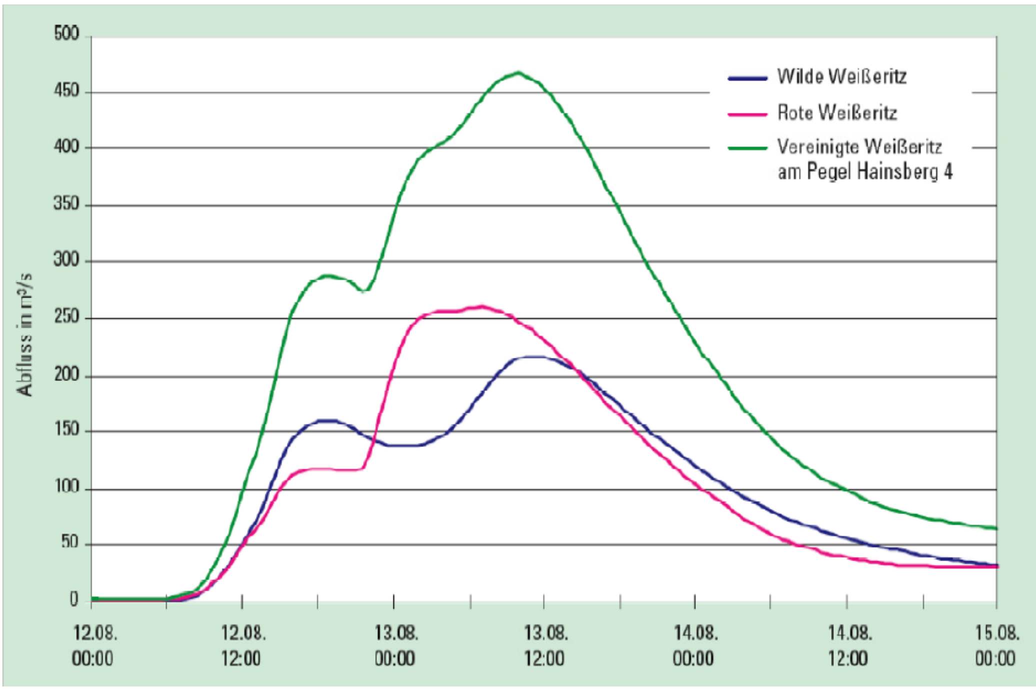


Figure 4.15: Highest flow rate (peak discharge) in Wilde, Rote and Vereinigte Weißeritz River in August, 2002 (Landeshauptstadt Dresden Die Oberburgermeisterin, Umweltamt, 2010).

The highest (peak) discharge recorded was around 450 m^3/s on the former stream gauge station called Hainsberg 4 (operated between 1927 and 2008) in the Vereinigte Weißeritz River on August 13, 2002. This is depicted by green line in Figure 4.15. The highest (peak) discharge record consists of discharge recorded at gauging station Cotta (300 m^3/s) and the amount that flowed through the city center of Dresden (approximately 150 m^3/s) (Bernatowicz et al. 2008).

The highest flow rates (peak discharges) that are recorded by stream gauge stations Hainsberg 4 (at 321 km^2 of the Weißeritz catchment) and Cotta (at 374,1 km^2 of the Weißeritz catchment) for floods with return periods of 20 years, 50 years, 100 years and 200 years and 400-500 years (extreme flood: 2002) occurred in Vereinigte Weißeritz River are summarized in Table 4.8.

Table 4.8 : Peak discharges recorded floods having a return period of 20,50, 100, 200 years and 400-500 years (extreme flood 2002) (LTV, 2004).

Stream Gauge Station	HQ_{20}	HQ_{50}	HQ_{100}	HQ_{200}	EHQ ($HQ_{400,500}$-2002)
Hainsberg 4	111	158	189	211	467
Cotta	133	194	234	263	495

Connection to groundwater bodies

Ten groundwater bodies near to the River Vereinigte Weißeritz are found at Löbtauerstraße, Freibergerstraße, Bünaustraße, Verlagsh-Tharandterstraße, Tharandterstraße, Pesterwitz, Freital Wurgwitz, Kesseldorf, Gittlersee Schulstraße, Hainsberg (Figure 4.16).

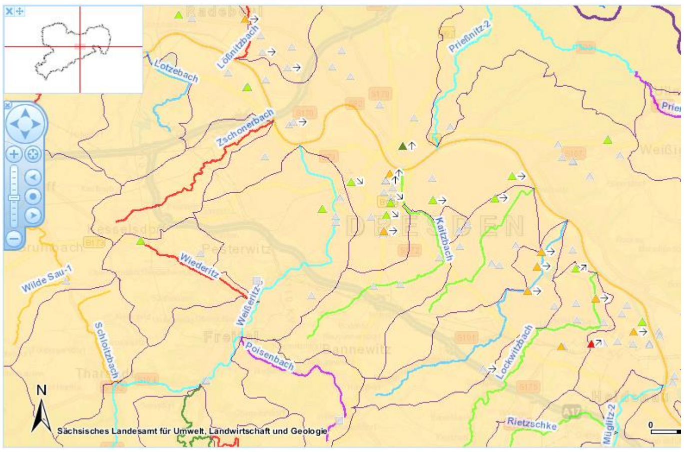


Figure 4.16: Groundwater resources in the Vereinigte Weißeritz catchment (Scale: 1:125000, with catchment and subcatchment boundaries) (LfUG, n.d.).

In August, 2002, area that is inundated by the Elbe River in Dresden (Figure 4.17d) has shown that groundwater bodies located near the Vereinigte Weißeritz River has been outflowed by the 2002 flood. Groundwater in some parts of the city including downstream reaches of the Vereinigte Weißeritz River rose to the surface and stayed at very high level for many months.

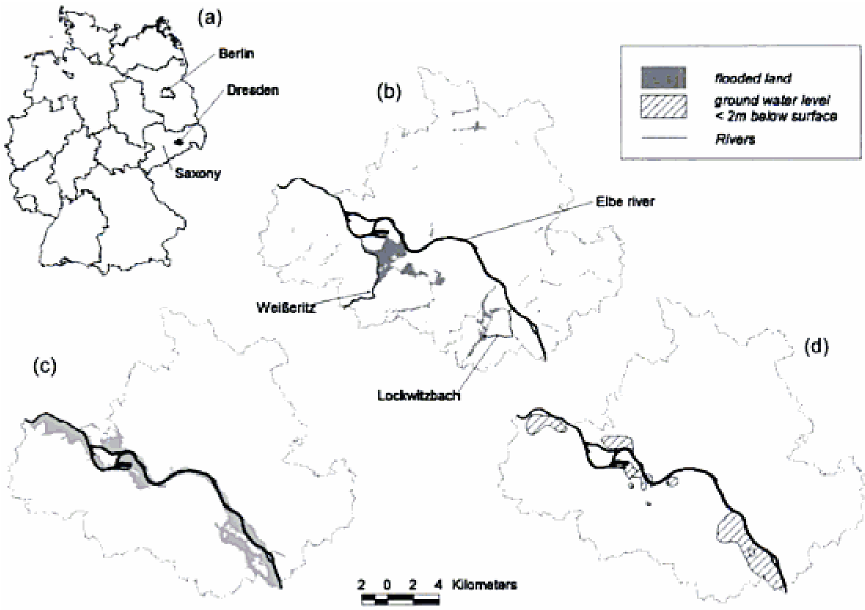


Figure 4.17: Location of the research area Dresden, Saxony, Germany (a) and (b) Areas inundated by streams and by the Weißeritz and Lockwitzbach in Dresden (c) Area inundated by the Elbe River in Dresden (d) Areas of high groundwater level in Dresden (Kreibich et al, 2005).

Groundwater depths at a flowrate of 100 year-flood (return period: 100 years) change between 1-3 m of water level (Landehauptstadt Dresden, Geschaftsbereich Wirtschaft, Umweltamt, 2011).

3) Morphological conditions

River depth and width variation

Water depths that were measured in 2007 at stream gauge station Cotta are given as an illustration (Figure 4.18). Based upon the figure below, highest water level were achieved in May and November. Appendix B.4 presents water depths for each month that were measured by stream gauge (gauging) station Cotta between the years 2001-2010. Briefly, the lowest water level (LWL), mean low water level (MLWL), mean water level (MWL), mean high water level (MHWL), and high water level (HWL) recorded were 13 (2004-2010), 19 (2004-2010), 38 (2004-2010), 151 (2004-2010), 430 (2002) cm, respectively. The highest water level was recorded in August, 2002 and it was 430 cm, whereas the lowest water level was recorded in August, 2004-2010 and it was found to be 13 cm.

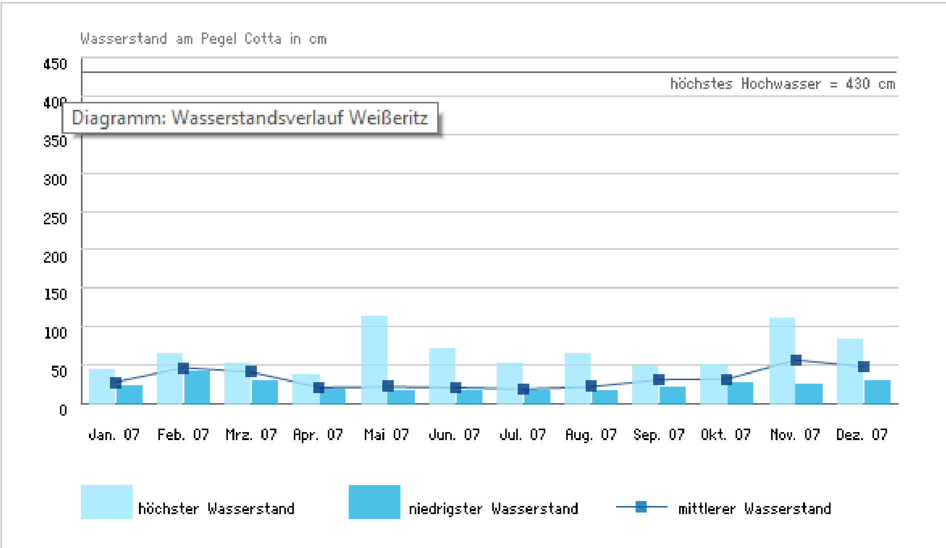


Figure 4.18: Water depths in 2007 at stream gauge station Cotta (Landehauptstadt Dresden, n.d.).

Current water depth measurements that are being undertaken at stream gauge station Hainsberg 6 varied between 40-50 cm in August and 50-60 cm in September. Water depths that are gathered from website in September are shown in Figure 4.19.

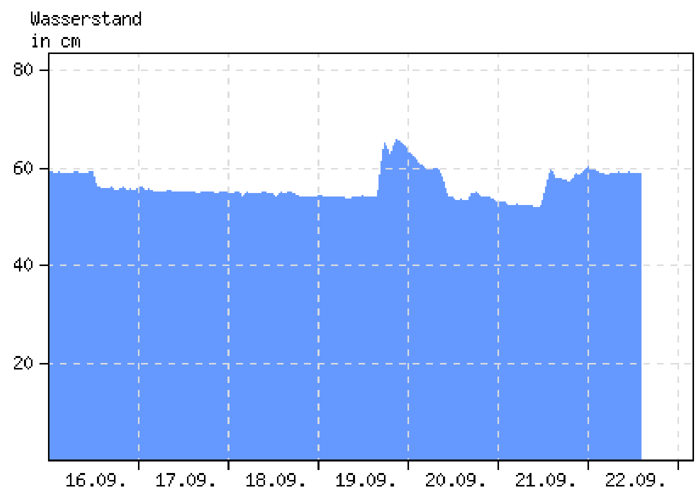


Figure 4.19: Water depth of Vereinigte Weißeritz River on six days in September (Umwelt Sachsen, 2014).

Width scale of the River Vereinigte Weißeritz changes between 3-25 m. Elevation of water level along the Vereinigte Weißeritz river changes between 100-192 m (Google Earth, 2012). Vereinigte Weißeritz River has average flow gradient about 0.3% below the Weißeritz kink (2.8th km of the river) and 0.7% above the Weißeritz kink approximately.

Structure and substrate of the riverbed

Vereinigte Weißeritz River flows, since the realized 1891-1893 laying and channeling, along the Emerich-Ambros-shore link side at the 61.5th km of the Elbe River. Previously, it led towards the site of present-day Marie Bridge (Weißeritzstraße) on the eastern edge of the Great Ostragehege into the Elbe River which is outside of the city centre (Landeshauptstadt Dresden Die Oberburgermeisterin, Umweltamt, 2010). The river has been displaced in an old sidearm in Dresden for flood protection reasons and therefore canalised (Egermann et al., 2006). In the 19th century, its estuary had been shifted by 3 km down the River Elbe in order to gain the areas require for the railway connection between Dresden main station and the railway station Dresden-Neustadt.

In August 2002, Dresden became a disaster area because masses of water from the rivers Vereinigte Weißeritz and Elbe flooded territories of the city. The Weißeritz River caused heavy damages during the 2002 European floods in Dresden and Freital. The river left its canalised bed near the inner city and went through its old riverbed (replaced in the 19th century) directly towards the Elbe river. The river reached Dresden Hauptbahnhof as well as the Zwinger and flooded some districts of the inner city. During the 2002 flood, the Vereinigte Weißeritz River in Dresden sought their old riverbed through Weißeritzstraße and flooded the neighborhoods Plauen, Loebtau, which lies between the channel and the same Friedrichstadt, the historic old town and the main railway station. The floods of Weißeritz were not confined to the lower reaches (Egermann et al., 2006). On the whole term of the Red Weißeritz of Altenberg on Kipsdorf, Dippoldiswalde, the Malter Dam to Freital, at the Wilde Weißeritz in Tharandt and Freital as well as at the Vereinigte (United) Weißeritz of Freital to Dresden flood caused great damage to homes, roads and railways. Particularly affected were the Dresden-Chemnitz, especially Tharandt and the Hauptbahnhof Dresden, and the Weißeritztalbahn

(Wikipedia, 2014). The water in the Weißeritz River flooded and spread to the area of its former riverbed in 2002 flood that happened on Elbe River owing to displacement of its estuary. Actual flooding areas of the River Elbe and Vereinigte Weißeritz in the year of 2002 are given in Figure 4.20.

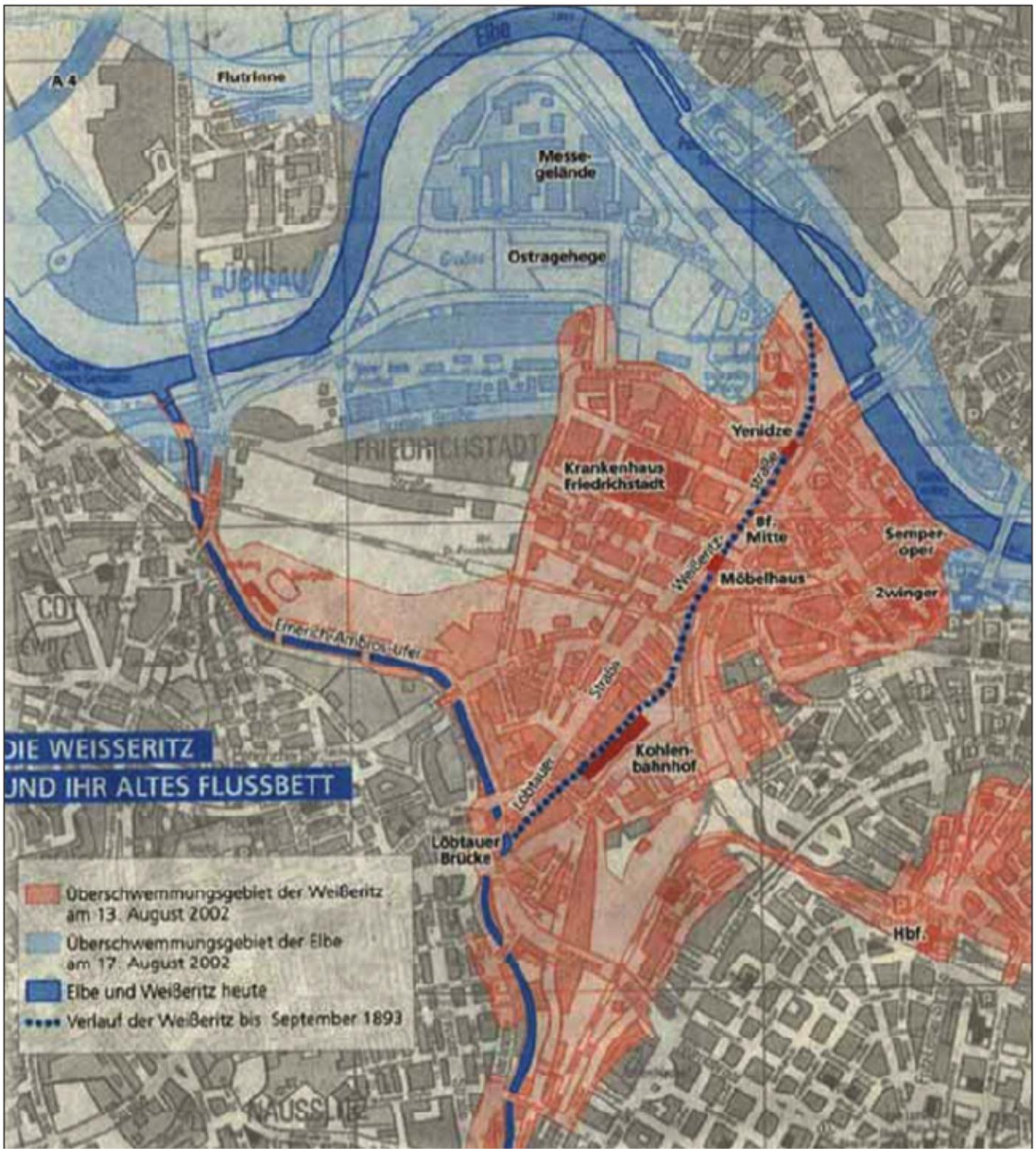


Figure 4.20: Actual flooding areas of the River Vereinigte Weißeritz and Elbe in August, 2002 (Landeshauptstadt Dresden Die Oberburgermeisterin, Umweltamt, 2010).

In 2002, the urgent challenge was to remove flood damages and to improve flood protection. In view of the flood expriences, the city of Dresden decided to gear the protection measures towards a flood event happening once in 200 years.

The new flood protection concept is realised by the city in cooperation with the dam administration of the Free State of Saxony. Apart from reactivating and expanding protective facilities along the River Vereinigte Weißeritz, the riverbed was cleared away and deepened on a section of 1 km in order to achieve superior drainage capacity for the river. The River Vereinigte Weißeritz received a new riverbed out of quarrystones and rough sett paving stabilising riverbed and slope toe. Breakwater stones were furthermore added creating rest areas for creatures living in the river and areas with different stream velocities (Werkstattstadt, 2013). After the flood in 2002, riverbed has been excavated between Bienertmühlweir and Dresden city center for the protection measures of 200-year flood. In accordance with the excavation of the riverbed, still and fluvial sections occurred along the river this sentence is not clear. I could not understand what u wanted to say. Additionally, refurbishment of the river bed between the bridge and the Altplauen Bienertmühlweir was implemented in 2002 for the protection measures of 200-year flood. 1.60 km excavation has been done every year since 2002 (Gloger, 2014).

Other improvements of the riverbed can be listed as (Landehauptstadt Dresden, Geschaftsbereich Wirtschaft, Umweltamt, 2011) deepening the riverbed, plant a parapet wall on the right bank, construction of a new section on the river wall of the entrance to Dresden above the bridge Altplauen and these improvements were implemented between 2009-2010. Expansion of the overall course to improve drainage conditions include 1) stretching and expansion of the Weißeritz Knicks, 2) depression of the riverbed between the bridges Freiberger Straße and Oederaner road, 3) rehabilitation of the river bed and plant an embankment on the right bank ("New Sorge") between the bridge and the access road Oederaner and machine steel construction in Dresden are planned and will be implemented from 2014 onwards.

The overall morphological status was moderate for the water body W-3 (Wilde Weißeritz River up to confluence with Rote Weißeritz and Vereinigte Weißeritz River up to confluence with Elbe River) (Figure 4.21) (Matouskova et al., 2010). Anthropogenic impacts on morphology is the highest for the Vereinigte Weißeritz River among other rivers in Weißeritz River catchment. Strongly to completely changed river sections are mainly detected at the Vereinigte Weißeritz River due to higher influence by bank impairments, land-use, and migration barriers. Nearly the entire river channel is significantly modified at the Vereinigte Weisseritz between Freital and Dresden by bank fixation, river straightening and maintenance, and human impairments in the floodplain (Bernatowicz et al., 2008). According to LfUG (2009) Vereinigte Weißeritz River is classified as significantly changed water body.The water falls under the German bio-coenotically relevant siliceous highland streams and rivers (Pottgiesser and Sommerhauser 2004). Riverbed of the Vereinigte Weißeritz is mostly composed of granit stones (Graeber and Sitte, 2014). With respect to LfUG (2009), Vereinigte Weißeritz River is classified as siliceous fine to coarse material rich upland river.

Structure of the riparian zone

The flood events of August 2002 resulted in several bank overflows on the River Vereinigte Weißeritz, which caused the flooding and the damage of significant parts of Dresden, the capital city of the Federal State Saxony. The dam authority of Saxony (LTV) then developed a flood protection concept in co-operation and coordination with the municipal authorities of Dresden. This concept constitutes the basis for all further planning. Along the Vereinigte Weißeritz River, two sides of the water body is structured with concrete wall. The project aims at heightening of the existing revetment wall by about 1,5 m (FICHTNER, 2014). For 500-year flood following the protection measures was implemented and are hereby given in a chronological order (Landehauptstadt Dresden, Geschaftsbereich Wirtschaft, Umweltamt, 2011): demolition and replacement construction of the bridge in the course of Werner road between 2005-2006, construction of the river wall destroyed as early performance of river development downstream left side of the road bridge Oederaner demolition and replacement construction of the bridge Altplauen and demolition and in the course of Löbtauer road between 2006-2007, expansion, renovation and reconstruction of the bridge in Course of Bienertstraße between 2007-2008, construction of the river wall destroyed as early performance of the downstream river development on the right side of the road bridge Oederaner between 2008-2009.

Both upstream and downstream, along the Vereinigte Weißeritz River are densely settled reaches, which mostly surrounded by oak trees. Thus, the aquatic flora of the

Vereinigte Weißeritz highly affected by the construction of wall bodies and thereby the condition of flora along the river is not ecologically sound (Paul and Peters, 2014).

4.2.2.2 Hydrobiology

Fish species

According to the information that is acquired from the authorized person (Peters and Paul), fish community in the River Vereinigte Weißeritz comprises of thirteen different types of fish species. These fish are listed in alphabetical order as: i) Brown/Sea trout (Salmo trutta fario), ii) Dace (Leuciscus leuciscus), iii) European brook lamprey (Lampetra planeri), iv) European bullhead (Cottus gobio), v) European chub (Squalius cephalus), vi) European river lamprey (Lampetra fluviatilis), vii) European grayling (Thymallus thymallus), viii) Gudgeon (Gobio gobio), ix) Minnow (Phoxinus phoxinus), x) Perch (Perca fluviatilis), xi) Pike (Esox lucius), xii) Roach (Rutilus rutilus), xiii) Stone loach (Barbatula barbatula) xiv) Three-spined stickleback (Gasterosteus aculeatus). Their representations, scientific classifications (System Of Nature, 1758) (Table 4.9 and Table 4.10) and characteristrics (Table 4.11) are given for each fish species.

Characteristics of the fish species listed as in Table 4.11 are: 1) Length, 2) Mass, 3) Swimming behaviour (Sustained: the speed is defined as the increased speed maintained by a fish during channel riffle, run, or a series of fishway pools, Burst: the speed is defined as the maximum speed capability demonstrated by fish during a short upstream movement challenge, such as escape from a predator, or a short high velocity current, Prolonged or Cruising: refers to the normal “over the ground” swimming speed utilized by a fish species during upstream migration through natural river and stream channel conditions), 4) Living depth, 5) Spawning season, 6) Age at sexual or reproductive maturity, 7) Type of migration, 8) Migration period and time, 9) Life span, 10) Temperature of aquatic ecosystem, 11) IUCN Red List Status.

Native (resident) species of the Vereinigte Weißeritz River are mostly European grayling (Thymallus thymallus) fish species (Appendix C.2). Therefore, European

Table 4.9: Taxonomic hierarchy of fish species in Vereinigte Weißeritz River.

Taxonomic Hierarchy	Brown trout (Salmo trutta fario)	Dace (Leuciscus leuciscus)	European brook lamprey (Lampetra planeri)	European bullhead (Cottus gobio)	European chub (Squalius cephalus)	European grayling (Thymallus thymallus)	European river lamprey (Lampetra fluviatilis)
Kingdom	Animalia	Animalia	Animalia	Animalia	Animalia	Animalia	Animalia
Subkingdom	Bilateria	Bilateria	Bilateria	Bilateria	-	Bilateria	Bilateria
Infrakingdom	Deuterostomia	Deuterostomia	Deuterostomia	Deuterostomia	-	Deuterostomia	Deuterostomia
Phylum	Chordata	Chordata	Chordata	Chordata	Chordata	Chordata	Chordata
Subphylum	Vertebrata	Vertebrata	Vertebrata	Vertebrata	-	Vertebrata	Vertebrata
Infraphylum	Gnathostomata	Gnathostomata	Agnatha	Gnathostomata	-	Gnathostomata	Agnatha
Superclass	Osteichthyes	Osteichthyes	Cephalaspidomorphi	Osteichthyes	-	Osteichthyes	-
Class	Actinopterygii	Actinopterygii	Cephalaspidomorphi	Actinopterygii	Actinopterygii	Actinopterygii	Cephalaspidomorphi
Subclass	Neopterygii	Neopterygii	Neopterygii	Neopterygii	-	Neopterygii	-
Infraclass	Teleostei	Teleostei	-	Teleostei	-	Teleostei	-
Superorder	Protacanthopterygii	Ostariophysi	-	Acanthopterygii	-	Protocanthopterygii	-
Order	Salmoniformes	Cypriniformes	Petromyzontiformes	Scorpaeniformes	Cypriniformes	Salmoniformes	Petromyzontiformes
Suborder	-	-	-	Cottoidei	-	-	-
Superfamily	-	Cyprinoidea	-	Cottoidea	-	-	-
Family	Salmonidae	Cyprinidae	Petromyzontidae	Cottidae	Cyprinidae	Salmonidae	Petromyzontidae
Subfamily	Salmoninae	-	-	-	-	Thymallinae	-
Genus	Salmo	Leuciscus	Lampetra	Cottus	Squalius	Thymallus	Lampetra
Species	Salmo trutta	Leuciscus leuciscus	Lampetra planeri	Cottus gobio	S.cephalus	Thymallus thymallus	Lampetra fluviatilis

Table 4.10: Taxonomic hierarchy of fish species in Vereinigte Weißeritz River.

Taxonomic Hierarchy	Gudgeon (Gobio gobio)	Minnow (Phoxinus phoxinus)	Perch (Perca fluviatilis)	Pike (Esox lucius)	Roach (Rutilus rutilus)	Stone loach (Barbatula barbatula)	Three-spined stickleback (Gasterosteus aculeatus)
Kingdom	Animalia	Animalia	Animalia	Animalia	Animalia	Animalia	Animalia
Subkingdom	Bilateria	Bilateria	Bilateria	Bilateria	Bilateria	Bilateria	Bilateria
Infrakingdom	Deuterostomia	Deuterostomia	Deuterostomia	Deuterostomia	Deuterostomia	Deuterostomia	Deuterostomia
Phylum	Chordata	Chordata	Chordata	Chordata	Chordata	Chordata	Chordata
Subphylum	Vertebrata	Vertebrata	Vertebrata	Vertebrata	Vertebrata	Vertebrata	Vertebrata
Infraphylum	Gnathostomata	Gnathostomata	Gnathostomata	Gnathostomata	Gnathostomata	Gnathostomata	Gnathostomata
Superclass	Osteichtyes	Osteichthyes	Osteichtyes	Osteichthyes	Osteichthyes	Osteichthyes	Osteichtyes
Class	Actinopterygii	Actinopterygii	Actinopterygii	Actinopterygii	Actinopterygii	Actinopterygii	Actinopterygii
Subclass	Neopterygii	Neopterygii	Neopterygii	Neopterygii	Neopterygii	Neopterygii	Neopterygii
Infraclass	Teleostei	Teleostei	Teleostei	Teleostei	Teleostei	Teleostei	Teleostei
Superorder	Ostariophysi	Ostariophysi	Acanthopterygii	Protocanthopterygii	Ostariophysi	Ostariophysi	Acanthopterygii
Order	Cypriniformes	Cypriniformes	Perciformes	Esociformes	Cypriniformes	Cypriniformes	Gasterosteiformes
Suborder	-	-	Percoidei	-	-	-	Gasterosteoidei
Superfamily	Cyprinoidea	Cyprinoidea	-	-	Cyprinoidea	Cobitoidea	-
Family	Cyprinidae	Cyprinidae	Percidae	Esocidae	Cyprinidae	Balitoridae	Gasterosteidae
Subfamily	-	-	-	-	-	Nemacheilinae	-
Genus	Gobio	Phoxinus	Perca	Esox	Rutilus	Barbatula	Gasterosteus
Species	Gobio gobio	Phoxinus phoxinus	Perca fluviatilis	Esox lucius	Rutilus rutilus	Barbatula barbatula	Gasterosteus aculeatus

Table 4.11: Characteristics of fish species in the Vereinigte Weißeritz River (*:sustained speed, **:burst speed, ***: prolonged speed).

	Salmo trutta fario	Leuciscus leuciscus	Lampetra planeri	Cottus gobio	Squalius cephalus	Thymallus thymallus	Lampetra fluviatilis
Characteristics	Brown trout	Dace	European brook lamprey	European bullhead	European chub	European grayling	European river lamprey
Length (cm)	18-56	15-40	5-16	10-18	30-60	30- 60 (Avg.: 0.5 m)	35-50
Mass (kg)	0.5-24	1	-	1.8	8 (max.)	-	0.150
Swimming behaviour (m/s)	0.92*, 3.26**	0.73*, 2**	0.08*, 1.4**, 4***	-	-	-	-
Living depth (m)	0.03-1.22 (Avg.:0.65)	1.1	0.8	2	-	0.45-1.8	10-
Spawning season	October-March	March-May	March-June	March-April	April-June	March-June	March-June
Age at sexual or reproductive maturity	1-10 years	-	-	-	-	-	-
Type of migration	Anadromous	Potamodromous	Potamodromous	Potamodromous	Potamodromous	Non-migratory	Anadromous
Migration time	After 18 months	-	-	-	-	-	-
Life span	Av.: 10 years	Max: 16 years	Av.: 6 years	Max: 10 years	Max: 22 years	Max: 14 years	Max: 10 years
Temperature of aquatic ecosystem	Toleration: 1-27 °C	-	1- 15 °C	1- 16 °C	4-20 °C	6- 18 °C	5-18 °C
IUCN Red List Status	Least Concern	Least Concern	Least Concern	Least Concern	Least Concern	Least Concern	Least Concern

Table 4.12: Characteristics of fish species in the Vereinigte Weißeritz River (*: sustained speed, **: burst speed, ***: prolonged speed).

	Gobio gobio	Phoxinus phoxinus	Perca fluviatilis	Esox lucius	Rutilus rutilus	Barbatula barbatula	Gasterosteus aculeatus
Characteristics	Gudgeon	Minnow	Perch	Pike	Roach	Stone loach	Three-spined stickleback
Length (cm)	12-20	7-14	25-60	40-137 (Avg.: 1.2 m)	25-50	12-21	-
Mass (kg)	0.220 (max.)	-	4.8	0.5-1.4	1.8	0.200 (max.)	-
Swimming behaviour (m/s)	-	-	0.66*, 1.3**	1.44*, 2.86**	-	-	-
Living depth (m)	-	-	-	1- 5	-	-	0-100
Spawning season	April-June	April-July	April-June	February-June	April-May	February-May	March-July
Age at sexual or reproductive maturity	-	-	-	2- 3 years	-	-	-
Type of migration	Potamodromous	Potamodromous	Anadromous	Potamodromous	Potamodromous	Potamodromous	Anadromous
Migration period and time							
Life span	Max: 8 years	Max: 11 years	Max: 22 years	Av.: 10 years	Max: 14 years	Max: 7 years	Max: 8 years
Temperature of aquatic ecosystem	2-18 °C	2-20 °C	10-22 °C	10- 28 °C	10-20 °C	-	4-20 °C
IUCN Red List Status	Least Concern	Least Concern	Least Concern	Least Concern	Least Concern	Least Concern	Least Concern

grayling must be taken as a target fish species for the design of the fish passage. Improved water quality status in the river shows the abundance of European brook lamprey in the river. However, because of the past moderate ecological status of the river, salmons do not appear. Salmons are planned to be introduced in the future.

Composition and abundance of benthic invertebrate fauna

Official German system method AQEM software Version 2.5 (The AQEM) was applied to estimate the effects of the stressors organic pollution, acidification and general degradation on benthic macroinvertebrates, and to describe the benthic community by taxonomic composition, number of data and abundance. Based on the monitored hydrobiological data in 2001, taxonomic groups in W-3 (Wilde Weißeritz River up to confluence with Rote Weißeritz and Vereinigte Weißeritz River up to confluence with Elbe River) (Figure 4.21) are dominated by insecta (ca. 90%) with 25 number of species which compose of 32% mayfly (Ephemeroptera), 4% stonefly (Plecoptera), 24% caddisfly (Tricoptera), 18% true flu (Diptera), 9% beetle (Coleoptera), 5% crustaceans (Crustacea), 4% snails and snugs (Gastropoda), 4% leech (Hirudinea) (LfUG correspondence with Biemelt, 2003). In addition to that, crayfish (Parastacoidea) and european otter (Lutra lutra) are other observed species in the Vereinigte Weißeritz River (Gloger, 2014). The status of the biological component benthic macroinvertebrates was evaluated to be not good in W-3 together with other four points, apart from W-1 water body that is shown in Figure 4.21 (Matouskova et al., 2010). Regarding to the samples that are measured by AQEM software Version 2.5 in 2001, quality classifications listed based on benthic invertebrate fauna are given as follows: organic pollution is in good quality, acidification is not relevant, general degradation[8] (morphological degradation and land use) is in moderate quality. And, thus, overall ecological quality class signified as moderate quality (LfUG, 2003). Benthic invertebrate fauna is characterized by reduction in species composition and abundance in downstream regions of the Weißeritz River catchment.

[8] It can be a result of hydrological regimes by off-takes, releases from dams, and backwater (e.g. artifical barriers, weirs, water transfer) or chemical pollutants.

4.2.1.3 Hydrochemistry

Harnapp and Küchler (2004) reported that overall water quality of the Vereinigte Weißeritz River is moderately polluted (Class II) and emphasized as no new pollution sources have been added, including a change in the other state is not expected in the near future. LAWA (2003) classified[9] moderately polluted waters (Class II) as water with moderate pollution and good oxygenation; very high biodiversity and population density of algea, snails, small crabs, larvae; covered areas with largely aquatic plant stocks; rich in fish species. These include water sections, especially in the middle and lower reaches of major rivers and the warm summer inherently streams of the lowlands.

According to LAWA (2003), Class II water has the following characteristics: saprobic index changes between 1.8 to 2.3, oxygen content (deficits and saturations) is due to wastewater pollution and algae growth is so high that fish death do not occur, i.e. consistently above 6 mg/l, BOD_5 is often between 2 to 6 mg/l and NH_4-N is typically less than 0.3 mg/l. LfUG (2003) indicated that the class of water quality in Vereinigte Weißeritz River falls in Class II, which is moderately polluted (Appendix A.2).

Recent monitoring data was supplied by LfUG, based on co-operation agreement within the interdisciplinary EMTAL-project (Matschullat et al. 2005; Weis et al. 2003). This project ran between 2002 and 2007, focussing on water quality related issues from 1992 to 2003 (Bernatowicz et al. 2008). The year 2001 monitoring and selected six points results which had been started monitoring since 2006 in the project period represent the five Weisseritz water bodies (W-1, W-2, W-3, RW-1, RW-2) (Table 4.8). These six points are: 1) W-1 (F0980: Stream type-5) Wilde Weißeritz River at Czech-German border, 2) W-1 (F1000: Stream type-5) Wilde Weißeritz River up to Lehnmühle reservoir, 3) W-2 (F1010: Stream type-5) Wilde Weißeritz River between reservoirs Lehnmühle and Klingenberg, 4) W-3 (F1130: Stream type-9) Wilde Weißeritz River up to confluence with Rote Weißeritz and Vereinigte Weißeritz River up to confluence with Elbe River, 5) RW-1 (F1090: Stream type-5) Rote Weißeritz River up to confluence with reservoir Malter, 6) RW-2 (F1110: Stream type-9) Rote Weißeritz River up to confluence with Wilde Weißeritz River (Figure 4.21).

[9] I: unpolluted or very low polluted , I-II: lightly polluted, II: moderately polluted, II-III: critically loaded, III: heavily polluted, III-IV: highly polluted, IV: excessively polluted (LAWA classification).

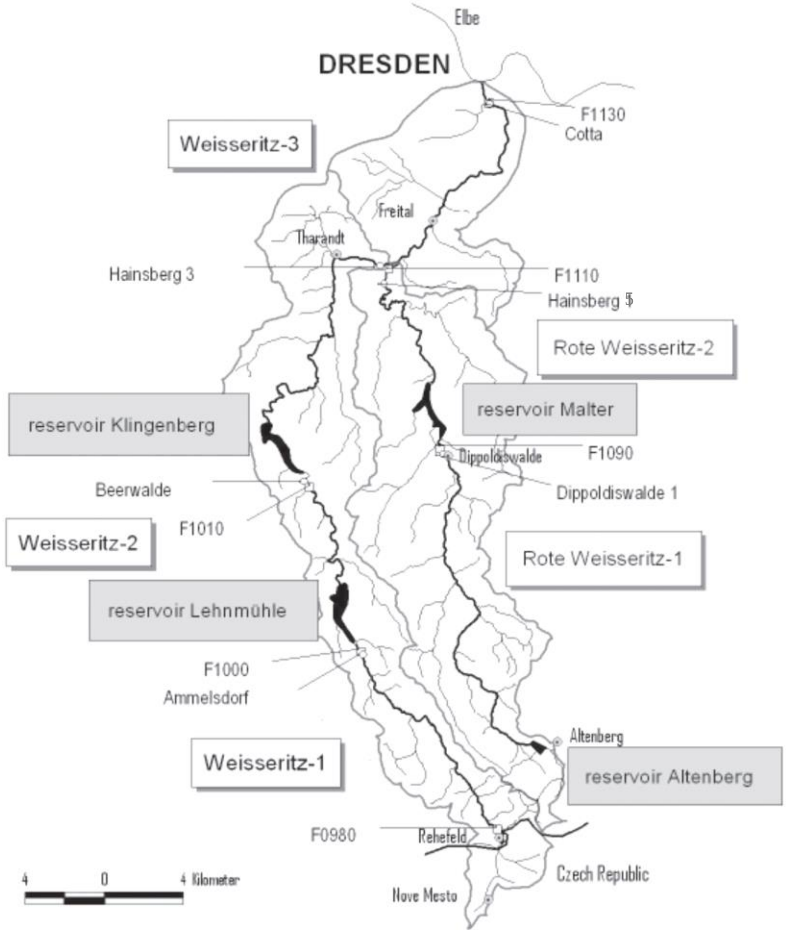


Figure 4.21: Monitoring stations in the Weißeritz River catchment (Matouskova et al., 2010).

Stream type specific background values make contribution to ascertain the physico-chemical conditions as compared with the physico-chemical reference status. These background values were published by LAWA (2007) to define the threshold value of reference conditions (limit between high and good status), and are based on maximum/minimum and mean values (Table 4.8). The LAWA (2007) preliminary specification uses the following statistical values: mean for TOC, BOD_5, chloride, P_{tot}, o-PO_4-P, NH_4-N, seasonal variability for temperature and dissolved oxygen, and minimum and maximum for pH-value.

Table 4.13: Background and orientation values for the common stream types 5 and 9 in siliceous highlands (preliminary specification by LAWA 2007: * depends on fish region, increase in temperature caused by discharge: type 5 max. 1,5 Kelvin, type 9 max. 3 Kelvin; BOD_5 uninhibited, **background values are not useful for pH value).

Temperature °C	Oxygen mg/l	Chloride mg/l	Ptot mg/l	o-PO_4-P mg/l	NH_4-N mg/l	TOC mg/l	BOD_5 mg/l	pH-value
seasonal variability	seasonal variability	mean	mean	mean	mean	mean	mean	min-max
Background values								
<18- 25 *	>9	50	0.05	0.02	0.04	5	2	**
Orientation values								
<20- 28 *	>9	<200	<0.1	<0.07	<0.3	<7	<4	6.5-8.5

Hydrochemical monitoring involves basic physico-chemical parameters such as temperature, dissolved oxygen, chloride, P_{tot}, o-PO_4-P, NH_4-N, NO_3-N, pH value, COD, conductivity, acidity and alkalinity. In 2001, temperature, oxygen, chloride, NH_4-N and TOC corresponded to the orientation values at all points (Table 4.13). These values were exceeded by P_{tot} and o-PO_4-P (Table 4.14) in the lower reaches of Vereinigte Weisseritz (W-3). Therefore, the parameters P_{tot} and o-PO_4-P can be identified to represent possible pressures for the Vereinigte Weißeritz River. BOD_5 was not detected in the hydrochemical monitoring.

Table 4.14: Hydrochemical status estimation of the Weißeritz Rivers based on the parameters of the LAWA background and orientation values (LAWA 2007) and other common parameters (LfUG, correspondence with Ziegler, K., 2004; Year: 2001 italic- differs from background values, bold italic- differs from orientation values).

Parameters	Units	Statistic value	F0980 (W-1)	F1000 (W-1)	F1010 (W-2)	F1130 (W-3)	F1090 (RW-1)	F1110 (RW-2)
Temperature	°C	min-max	0.3-12.8	0.1-13.4	0.1-11.0	1.3-16.7	-0.1-15.1	1.5-15.1
Oxygen (at temperature, °C)	mg/l	min-max	9.5 (12.8) -12.7 (2.3)	9.3 (13.4)-12.7 (0.1;3.0)	10.1 (10.7)-13.3 (0.1)	9.4 (16.7)-12.7 (4.1)	9.2 (15.1)-13.8 (-0.1)	9.2 (14.0)-12.9 (1.5)
Chloride	mg/l	mean	3.2	7.5	8.3	41	20	23
Ptot	mg/l	mean	0.023	*0.052*	0.026	***0.18***	*0.063*	***0.16***
$o\text{-}PO_4\text{-}P$	mg/l	mean	0.018	0.018	0.018	***0.12***	*0.027*	***0.12***
$NH_4\text{-}N$	mg/l	mean	*0.043*	*0.051*	*0.055*	*0.14*	*0.15*	*0.18*
TOC	mg/l	mean	*5.9*	4	3.2	4.8	4.4	4.8
pH value		min-max	***5.3-6.7***	***6.4-7.0***	***6.4-6.9***	*7.0-7.8*	***6.2-7.0***	*6.8-7.3*
Other common parameters								
Conductivity (25°C)	µS/cm	min-max	50-102	82-164	93-203	251-870	158-256	195-460
Conductivity (20°C)	µS/cm	min-max	45-91	73-147	83-182	225-780	142-229	175-412
COD	mg/l	mean	13	9	7	13	9	11
$NO_3\text{-}N$	mg/l	mean	1.0	2.3	3.6	3.9	5.1	5.9
Acidity (4.3)	mol/l	mean	0.13	0.31	0.27	0.26	0.59	1.2
Alkalinity (8.2)	mmol/l	mean	0.047	0.034	0.029	0.036	0.029	0.027

Highest salinity results were measured in Vereinigte among other Weißeritz rivers which is caused by dissolving minerals and pollutant supply (winter road salting). Salinity, represented by conductivity, and anions such as sulfate (SO_4^{-3}) and chloride (Cl^-), is classified and regarded as I to I-II for chloride and I-II to II-III for sulfate (Bernatowicz et al., 2008). Current status of water quality in the River Vereinigte Weißeritz was specified by LfUG (Table 4.14) in terms of ecological and chemical characteristics. According to Water Framework Directive classification[10], overall

[10] 1) Ecological status classification: high (I), good (II), moderate (III), poor (IV), bad (V). 2) Chemical status classification: good (I,II), bad (III, IV) (WFD, 2000).

chemical status and ecological status was regarded as poor and moderate status, respectively (Table 4.15).

Table 4.15: Water quality status of Vereinigte Weißeritz River (LfUG, n.d.).

Characteristics	Status	Status Classification
Nitrate	2	Good
Pesticides	1	High
Industrial chemicals	4	Poor
Heavy metals	1	High
Other pollutants	4	Poor
Chemical	4	Poor
Ecological	3	Moderate

Because of the ecological and chemical quality of Vereinigte Weißeritz River (LfUG, 2009), desired ‘good ecological and chemical status’, which is dictated as surface water status by WFD (2000), will be achieved after the year 2015 in the Vereinigte Weißeritz River. In order to improve the ecological status of the river in the targeted year, the aquatic flora must be improved. Due to poor chemical status of the river in the past years, industries were being removed to achieve good chemical status in the targeted year.

4.2.1.4 Ecohydraulics

Only four of the barrier structures on Vereinigte Weißeritz River which are given in Table 4.16 have fish passage structure. 2.6 m height of Elbe estuary weir is located at 0.095 km from the mouth of Vereinigte Weißeritz River. Hamburger Straße weir is positioned at 0.171 km from the mouth of Vereinigte Weißeritz River and its height is identical to Elbe estuary weir. Sohgleite Flügelwegbrücke weir is situated at 0.677 km from the mouth of Vereinigte Weißeritz River and has a 1.40 m height. WKA Bienertmühle weir has a height of 0.90 m and is at 5.93 km from the mouth of Vereinigte Weißeritz River.

Existing types of fish passage along the River Vereinigte Weißeritz are close-to-nature and technical. Close-to-nature type of fish passage called bottom ramp and slope is situated at headwater of Elbe estuary weir and Sohlgleite Flügelwegbrücke to overcome the level difference of the river bottom (Appendix A.1a, Appendix A.1e). Close-to- nature type of fish passage called fish ramp (i.e., in this case combines both natural and technical (one vertical slot fish passage structure) (Appendix A.1c)) is integrated near to the Hamburger Straße weir (Appendix A.1b, Appendix A.1d). Fish ramp type of fish passage at the Hamburger Straße weir is not functional in terms of fish migration in reference to its wrong selection of slot width. High height differences can restrict the movements of fish species different than salmons which actually the situation of fish species in the River Vereinigte Weißeritz. After the reconstruction of the weirs along the river, weir heights were lowered to a point where fish can move easily. According to the Table 4.16, fish species can naturally pass through the weir structures with low height difference that have no fish passage nearby.

Table 4.16: Weir and fish passage structures on Vereinigte Weißeritz River (SMUL, n.d.).

Name	Location	Distance from mouth (km)	Height (m)	Width (m)	Fish passage
Elbe estuary	4618388.00-5659954.00	0.095	2.6	27	Bottom ramp and slope
Hamburger Straße	4618412.00-5659868.00	0.171	2.6	28	Fish ramp
Sohlgleite Flügelwegbrücke	4618520.00-5659396.00	0.677	1.40	N.A.	Bottom ramp and slope
Sohlabsturz Freiberger Straße	4619655.00-5657866.00	3.640	0.90	N.A.	None
WKA Bienertmühle	4619432.00-5655826.00	5.930	4.50	48	Vertical slot
Wehrschwelle Plauenscher Grund	4617764.00-5655020.00	8.352	1.50	N.A.	None
Wehr Hofemühle Potschappel	4616737.00-5653978.00	9.990	1.70	32	None
Mühle Freital Deuben	4615725.00-5651868.00	12.710	0.10	18	None
Wehr Papierfabrik Hainsberg	4615050.00-5651194.00	13.060	1.30	N.A.	None

Technical type of fish passage called vertical slot fish passage (Appendix A.1f) is situated at near WKA Bienertmühle weir to serve a migration route for fish species in the aquatic environment. Due to old design of technical fish passage structure, it is not functional with regard to fish migration. Moreover, vertical slot fish passage at WKA Bienertmühle weir is susceptible to flood events (Figure 4.22).

Figure 4.22: Flood event in June, 2013 on Vereinigte Weißeritz River (Category Weißeritz, n.d.).

In the event of flood, which is an extreme occurrence in the Vereinigte Weißeritz River, that took place in 2013, fish species will be washed out immediately from the fish passage. Ultimately, fish passage will be inactive for the flood period and fish species will not be able to migrate from one place to another.

5. MATERIALS AND METHODS

This section involves information about fish passage and methods for evaluation of fish passage.

5.1 Status Quo: Vereinigte Weißeritz River

Current location of fish passage at WKA Bienertmühle weir along the River Vereinigte Weißeritz is given.

5.1.1 Fish passage location

WKA Bienertmühle weir is located under Hege Reiter Bridge in Plauen Grund valley towards the direction of the town Freital. WKA Bienertmühle weir has small hydro power plant and fish passage structure adjacent to its location. Vertical slot fish passage of WKA Bienertmühle weir on Vereinigte Weißeritz River is chosen as a study area of this thesis. Satellite views (Image Landsat, Image IBCAO) of fish passage location near WKA Bienertmühle weir by Google Earth (2012) is given in Figure 5.1 and Figure 5.2.

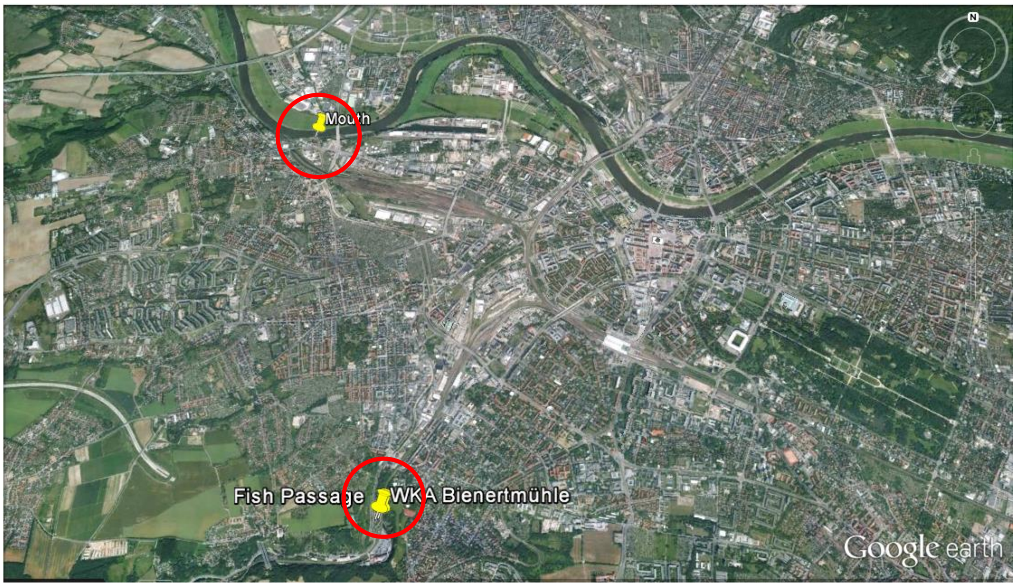


Figure 5.1 : Satellite view of fish passage near WKA Bienertmühle weir at 7.53 km eye elevation (Google Earth, 2012).

Figure 5.2 : Satellite view of fish passage near WKA Bienertmühle weir at 307 m eye elevation (Google Earth, 2012).

5.1.2 Fish passage design

One vertical slot type of fish passage and small hydro power plant with intake screen were constructed between the years of 1998 and 2000 near WKA Bienertmühle (Figure 5.3). 6% of the fish passage pass consists of C20/25 concrete whereas 94% of the fish passage comprises of durable wood which has a service life of 15 to 25 years. Flow rates which were observed in the river at WKA Bienertmühle are 0.36 m^3/s as a lowest flow rate, 2.0 m^3/s as a mean flow rate and 100-160 m^3/s as highest flow rate so far (Gloger, 2014). The waterbodies that move forward to tailwater of WKA Bienertmühle weir structure can be summarized as follows: a flow rate of 0.34 m^3/s directly flows through weir structure and reaches downstream of the river, a flow rate of 0.19 m^3/s flows within the fish passage, a flow rate of 16 m^3/s is directly bypassed and 1-4.4 m^3/s is given by hydro power plant to downstream of the river (Gloger, 2014). A plan view of typical one vertical slot fish passage (Figure 5.4) is designed to guarantee upstream fish migration. In order to deter the fish species entering to the turbines of hydro power plant while downstream migration, 18 mm bar spaced intake screen was located in front of the entrance of the hydro power plant (Figure 5.5).

Figure 5.3 : WKA Bienertmühle weir, fish passage and hydro power plant (July, 2014).

Figure 5.4 : Vertical slot fish passage structure next to WKA Bienertmühle weir (July, 2014).

Figure 5.5 : Intake screen in front of the turbines of hydro power plant next to WKA Bienertmühle weir (July, 2014).

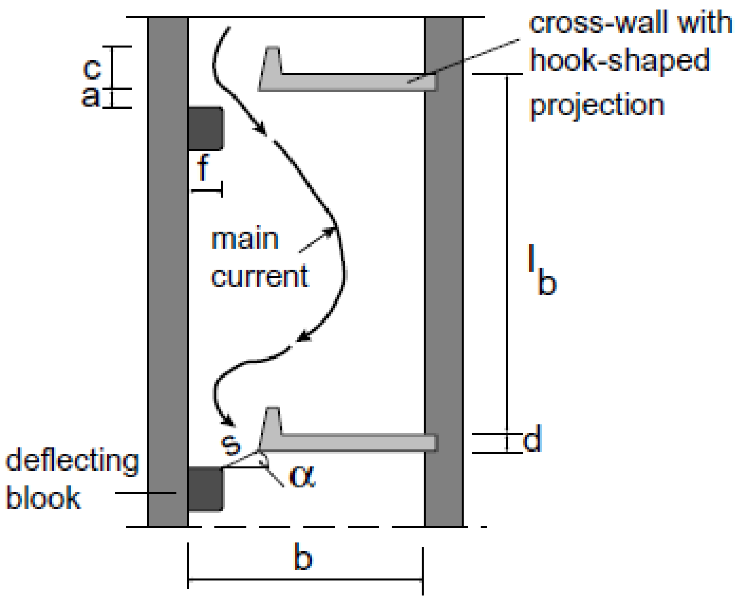


Figure 5.6 : Dimensions and terminology for slot passes with one slot only (Plan view) (DVWK, 1996).

Specifications of one vertical slot fish passage are given in Table 5.1 and Table 5.2. Gebler (1991) and Larinier (1992a) remarked pool dimension features for specific type of fish in Table 5.1.

Table 5.1 : Pool dimensions of fish passage (Gebler, 1991; Larinier, 1992a: *Fish fauna to be considered: Grayling, bream, chub, others (includes Brown trout, salmon, sea trout, huchen)).

Dimension	*Range or Number (m)	Given value (m)
Slot width (s)	0.15-0.30	0.18
Pool width (b)	1.20-1.80	2
Pool length (l_b)	1.90-3.00	1.8
Length of projection (c)	0.16-0.18	0.16
Stagger distance (a)	0.06-0.14	0.08
Width of deflecting block (f)	0.16-0.40	0.16
Thickness of wall in slot pass (d)	0.1	0.1
Minimum thickness of substrate	0.2	0.2
Water level difference (Δh)	0.2	0.233
Water depth below a cross-wall (h_u,h_{min})	0.50-0.75	0.6
Water depth above a cross-wall (h_o)	> 0.5	0.74

Table 5.2 : Water elevations in the fish passage (Gloger, 2014).

Water elevations	Given value (m)
Max. headwater level	134.94
Min. headwater level	134.64
Tailwater level	129.74
Level of water inlet (z_e, substrate)	134.107
Level of fish pass bottom (z_e, bottom)	133.97

The maximum difference (max h_{tot}) between headwater level (134.94 m) and tailwater level (129.74 m) in the fish passage is 5.20 m. The minimum difference (min h_{tot}) between headwater level (134.64 m) and tailwater level (129.74 m) in the fish passage is 4.90 m. Level of water inlet (z_e, substrate) is determined by maximum headwater level (134.94 m) minus ($\Delta h + h_u = 0.6 + 0.233$). Level of fish pass bottom (z_e, bottom) is determined by level of water inlet (z_e, substrate) minus minimum thickness of substrate (0.2). Figure 5.7 shows schematic longtidunal section of the vertical slot fish passage where water depth in all pools in the vertical slot fish passage must be higher than 0.5 m, substrate must be placed at the bottom and have at leat 0.2 m thickness and slope of the structure must be lower than 0.1.

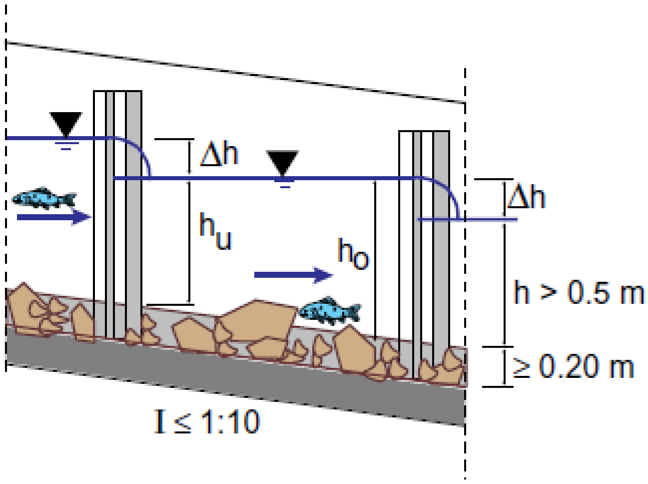


Figure 5.7: Detail of vertical slot pass (schematic longitudinal section) (DVWK, 1996).

Number of pools and cross walls are calculated from Equation **(5.1)**.

$$n = \frac{min,htot}{\Delta h} - 1 = 4.9/0.273 - 1 = 20 \qquad \textbf{(5.1)}$$

Sixteen of the pools are on one side while four of them on the other side of the one slot vertical fish passage (Figure 5.4). Total length of the one vertical slot fish passage is calculated as 1.8* (20-4)= 28.8 m. However, with additional distances, the total length of the fish passage equals to 31.8 m. For vertical slot passes water depth, discharges, flow velocities in the slot (critical velocities), and power density for the volumetric power dissipation in the pools should be monitored under all operating conditions (DVWK, 1996).

To achieve the same flow regimes in all pools e.g., headwater levels (h_u), tailwater levels (h_o), water level differences (Δh) between two succesive pools must be designed as same for all pools in the fish pass. μ_r (discharge coefficient) is a function of h_u/h_o ratio ($f(h_u/h_o)$) and relation between h_u/h_o ratio and μ_r (discharge coefficient) is shown in Figure 5.8. After interpolation process, the corresponding value for 0.81 (=0.6/0.74 (h_u/h_o)) is found as 0.49 (μ_r). Required discharge (m^3/s) is calculated using Equation **(5.2)** as 0.169 $m^3/s > Q_{cr} = 0.160$ m^3/s.

$$Q = \frac{2}{3} * s * \mu_r * \sqrt{2 * g} * h_o^{(3/2)} \qquad \textbf{(5.2)}$$

Flow velocity (m/s) in the slot is calculated using Equation **(5.3)** as 2.14 m/s > V_{cr} = 2 m/s.

$$V = \sqrt{2 * g * \Delta h} \quad \textbf{(5.3)}$$

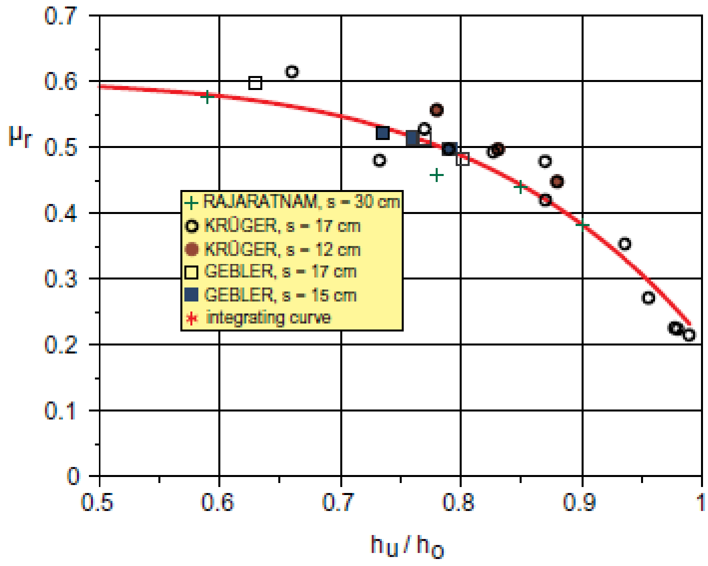


Figure 5.8 : Discharge coefficient μr= f(hu/ho) in Equation 5.2 for sharp-edged slope boundaries.

Mean water depth is calculated using Equation 5.4 as 0.7165 m . Power density for the volumetric power dissipation (W/m^3) is calculated using Equation **(5.5)** as 155 W/m^3 < E_{cr} = 200 W/m^3.

$$h_m = h_u + \Delta h/2 = 0{,}6 + 0{,}233/2 = 0{,}7165 \quad \textbf{(5.4)}$$

$$E = \frac{\rho\,(1000\ kg/m3) * g * \Delta h * Q)}{(b * hm * (lb - d))} = \frac{1000*9.81*0.233*0.169}{2*0.74*(1.8-0.1)} = 155\ W/m^3 \quad \textbf{(5.5)}$$

Drawings of the fish passage plan and sections are given in Figure A.2 and Table A.3, respectively.

A horizontally mounted Kaplan turbine, levied in October, 1999 from the Czech manufacturer KD Turbo Technics with a 180-ton crane in the prepared foundation and then welded, adjusted and cemented, can achieve a nominal power of 200 kW. The energy (0.5-1 MW/year) delivered is sufficient for the power supply of about 200 households with a total investment of 460,163 Euro, and additional costs for the fish passage that is constructed for living fish in the Vereinigte Weißeritz River and the backup of the weir. Related data about elevation and water depth above and below of hydropower plant and its turbine and generator properties are given in Table 5.3 and Table 5.4.

Table 5.3 : Elevation and water depth above and below of hydropower plant location next to the one vertical slot fish passage (Gloger, L., 2014).

	Headwater level	Tailwater level
Elevation (m)	134.64	129.14
Water depth (m)	0.3	0.7

Table 5.4 : Turbine and generator properties of the hydropower plant next to the one vertical slot fish passage (Gloger, L., 2014).

Turbine	Properties	Generator	Properties
Manufacturer	CKD Turbo Technics s.r.o. Brno	Manufacturer	M.L.S. Holice, spol.s.r.o.
Description	Horizontal Kaplan Turbine	Description	Type GB 355 LX8
Arrangement	Double regulated	Internal frequency	365A, 50 Hz
Falling height	5-5.5 m	Revolution	760 r/min (rpm)
Performance	Min. 28 kW-Max. 200 kW	Pole	8
Flow rate	0.9-4.70 m^3/s	Power factor	0.80
Revolution	346 r/min (rpm)	Voltage	400 V
Speed	872 r/min	Performance	200 kW
Lubrication	Central lubrication with oil separator	Cooling	Fan system
Control	Computer control system (water height sensor, quick lock with emergency stop)	Weight	1850 kg

5.2 Methods of Approach

In this section, methods of approach which are conventional and ecohydraulics will be discussed. Ecohydraulics approach should be taken as basis for the proposed design of fish passage.

5.2.1 Conventional approach

The traditional approach to developing fish passage criteria has been biased towards forced swimming experiments conducted under controlled and uniform hydraulic conditions. Measures of fish swimming ability obtained from forced swimming experiments have received criticism from forced swimming experiments have received criticism for their universal application to multispecies fish passage design (Castro Santos and Haro, 2006; Kemp et al., 2011). In part, this is because fish passage design is considered to be biased towards upstream movements of anadromous salmonids, but also because swim chambers generate unnatural hydraulic conditions (Enders et al., 2003) and prevent fish from expressing natural, performance enhancing behaviours (Peake and Farrell, 2006; Russon and Kemp, 2011).

Turbulence flow conditions, turbulent scale, vorticity (angular velocity) and eddy orientation can also negatively impact swimming performance and stability. Within the fluvial environment, turbulence has the potential to influence habitat selection, station holding and migratory abilities of fishes (Smith et al., 2005; Cotel et al., 2006). Yet, for fish passes, turbulence is necessary to dissipate energy so that water velocity is reduced to suitable levels relative to fish swimming capabilities, creating contradictory pressures for those designing such structures. As such, turbulence is a key hydraulic component that requires quantification and consideration during fish pass design, a factor overlooked during traditional swim chamber experiments. In natural rivers, eddy shedding is often unpredictable and variable in scale, vorticity and orientation, unlike the controlled laboratory conditions (Tritico, 2009). Despite this, the potential to apply this knowledge to fish pass design (i.e. modify turbulent characteristics in an unnatural channel located in the field to facilitate more efficient passage) presents an interesting avenue for the future research.

Traditional swim chambers confined fish in areas of limited size as necessity for researchers aiming to manipulate test conditions (velocity) while controlling for confounding variables (e.g. temperature, oxygen, turbulence).

Fish swimming capabilities determined using swim chambers (e.g. Brett, 1964) and endurance models based on unrealistic assumptions (e.g. Beach, 1984) have formed the main biological information used in fish pass design, and are still widely used where velocity criteria are required (e.g. Santos et al., 2007). However, these traditional approaches can underestimate the locomotory capacity of fish volitionally swimming under more natural conditions (Castro-Santos, 2005, 2006; Peake and Farrell, 2006; Russon and Kemp, 2011). Further, the unidirectional flows generated within swim chambers rarely occur in nature, where flows are characterized by varying levels of turbulence, which affects habitat selection, station holding and migratory abilities of fish. Due to these limitations, we recommend that future research should be based on an interdisciplinary approach to advance fish passage through the development of realistic, multi-species and multi-life stage design criteria.

5.2.2 Ecohydraulics approach

The need for interdisciplinary research and collaborative teams to address research questions that span traditional subject boundaries to address these issues has been increasingly recognized and has resulted in the emergence of new ‘sub-disciplines’ to tackle these questions.

Ecohydraulics is one of these emerging fields of research that has drawn together biologists, ecologists, fluvial geomorphologists, sedimentologists, hydrologists, hydraulic and river engineers and water resource managers to address fundamental research questions that will advance science and key management issues to sustain both natural ecosystems and the demands placed on them by contemporary society.

Linking biological and physical features of aquatic systems necessitates an interdisciplinary research approach (Lancaster and Downes, 2010). In modern river management, the importance of this is increasingly acknowledged with ‘ecohydraulics’, a sub-discipline of ecohydrology, gaining popularity (Wood et al., 2008; Rice et al., 2010; Towler et al. 2010). Adopting an ecohydraulics to fish passage research would advance the methods used to define suitable design criteria, and could be used to identify, quantify and understand responses of fish to the hydraulic environment relevant scales (Roy et al., 2010). Though ecohydraulics, the development of fish passes can be approached in a more hollistic and interdisciplinary way.

Ecohydraulics aims to link the physical properties of flowing water with biological and ecological processes (Lancaster and Downes, 2010). For fish passage, ecohydraulics allows hydraulic features of interest to be quantified and linked to the swimming performance and behavioural response of fish. Research should continue to adopt an ecohydraulics approach and conduct studies across a range of spatial scales and combine the advantages of both laboratory and field-based techniques. Technological developments in telemetry and hydraulic profilling allow this to take place in the field, while the ever-advancing techniques employed within flumes enable the direct observation and quantification of behaviour and hydraulic parameters at much finer scales, under conditions in which test variable are manipulated while founding factors are controlled.

Understanding the fundamental reasons why fish reject or progress through fish passes, be it due to physiological ability or behaviour, will greatly improve our capacity to facilitate more efficient passage or to deter fish from entering potentially hazardous locations. With this in mind, ecohydraulics must not be constrained to linking hydraulic and ecological processes, but should focus on bridging gaps between disciplines. For fish passage, physchometric theories could advance the understanding of mechanicsms governing migrant behaviour (Kemp et al., 2012), while other environmental stimuli may also be influential (e.g. Vowles and Kemp, 2012). Interdisciplinary interactions will likely benefit fish passage and other areas of river science in tackling unanswered questions. Adopting and ecohydraulics approach throughout all aspects of river management should, therefore, be encouraged.

6. EVALUATIONS AND DISCUSSIONS

In this section, evaluations of legislations in Germany and proposed novel fish passage design will be given. Existing inaccurate data about fish passage will be discussed and finally an accurate data presented.

6.1 Practical Solutions: Optimum Fish Passage Concept

Fish passage must be built in a way that balances terrain, river and structure. Optimum fish passage concept must be shaped based upon the current regulations. Fish passage studies should attempt to assess how and to what extent fishes use different types of spatial information for orientation based on a detailed understanding of the habitat selection and movement challenges likely to be encountered by fishes in their natural habitats. Therefore, optimum fish passage location and design is extremely important.

6.1.1 Legislation in Germany

European environment standards, such as the Water Framework Directive (WFD), the Fauna-Flora Habitat Directive and the Eel Regulation call for the restoration of the ecological connectivity of the waterways and the protection and nurturing of their fauna and flora. In Germany, Section 34 of the Federal Water Act (WHG) from the year 2010 requires that the Federal Waterways and Shipping Administration (WSV) implement the necessary measures for the restoration of the ecological connectivity on federal waterways at the barrages that it has constructed or that it operates. In the planning of this procedure, the Federal Waterways Engineering and Research Institute (BAW), in association with the Federal Institute of Hydrology (BfG), is acting on behalf of the Federal Ministry for Economic Affairs and Energy (BMVI) in an advisory capacity to the Federal Waterways and Shipping Administration (WSV). Furthermore, German Renewable Energy Sources Act (REA), was published in 1991 and lattermost revisioned in 2014, is the most important incentive for fish facility installations and funding mechanicsm. According to the WFD, regardless of the dam's purpose, the reservoir has to achieve the 'good ecological potential'. To achieve the ‘good ecological status’ as dictated in WFD, reduction/relinquishment of hydro-peaking, restoration of fish passage (upstream & downstream), minimum environmental flows, restoration/improvement of sediment transport, and restoration/improvement of riverine environment (hydromorphology) are vital. In relation to this requirement, dams are to be considered as an integrated part of the belonging catchment area. Thus, it focuses on construction/retrofitting of fish passes and the minimum amount of water flow rate that must be operated in fish passage. Fish passes Design, dimensions and monitoring (DVWK-Merkblatt 232/1996) was published in 1996 by German Association for Water Resources and Land Improvement (DVWK). Guideline for Fish Protection Technologies and Downstream Fishways was published in 2005 by German Association for Water, Wastewater and Waste (DWA). Screening criteria in downstrean migration are included in State Fisheries Regulations Guideline. Upstream Fishways on German Federal Waterways was published in 2011 by the Federal Waterways Engineering and Research Institute (BAW), in association with the Federal Institute of Hydrology (BfG). Recently, Fishways and fish passage structures- Design, dimensions, quality assurance (DWA-Merkblatt DWA-M 509) was published in 2014 by German Association for Water, Wastewater and Waste (DWA).

6.1.2 Proposed design

Proposal of new design for existing fish passage at WKA Bienertmühle weir should be based upon operation criteria which are explained in 2014 design manual. Fish passage must be redesigned for the parameters that are chosen incorrectly.

6.1.2.1 Operation criteria

Pool fish passes with vertical slots are based on the principle of dividing the height to be passed into several small drops forming a series of pools. The passage of water from one pool to another is provided via a deep slot located in the cross-wall separating two pools. The water flow forms a jet at the slot and the energy of the jet is dissipated by mixing in the pool. To improve fish passage, the first priority is, thus, to reduce the maximum velocity (i.e. the drop between pools) which will both make fish passage through slots easier and reduce turbulence intensity both within the jet and in the zones which are potential resting areas. This reduction of the maximum velocity will in turn result in lower values in the volumetric dissipated power, insofar as the length of the pools (L/l_b -which in return make it possible to increase the slope significantly) and the shape factors (B/l_b) that ensure acceptable flow patterns in the pools are maintained. Reducing the dissipated power by adjusting only the volume of pools without reducing velocities will not necessarily improve flow conditions in the pools and, therefore, the ability of fish to clear the pass. Important considerations are whether diadromous fish are adversely impacted by project structures and operations that block or impair fish movements and whether the specific fish passage design will provide for the efficient, effective, timely and safely upstream and downstream passage to fish to mitigate this impact. For the operation of the fish passage, these following four criteria must be investigated: i) efficiency, ii) effectiveness, iii) timely, iv) safely.

i) Efficiency (quantitative concept): To enhance the efficiency of the fish passage for multiple species, there is a need to quantify swimming performance and behaviour under realistic hydraulic conditions for a range of locomotory guilds. To achieve this, there is a need to: (1) create and quantify hydraulic conditions at biologically relevant scales, (2) quantify swimming performance under conditions where natural behaviours can be expressed, using appropriate metrics.

Quantifying the hydraulic environment at biologically relevant scales remains a key challenge. Advances in measuring hydraulic conditions at biologically relevant scales were made through the use of ADVs (Acoustic Doppler Velocimetry). However, ADVs can perform poorly during conditions of high turbulence and where air is entrained in the water column in such instances flow visualization methods may be appropriate. Particle image velocimetry (PIV) uses small seeding particles to visualise the hydraulic environment. Typically, multiple photographic or high-speed video methods record the particles as they pass through a laser sheet (laser PIV) that illuminates the hydraulic area of interest. However, the financial costs of using this technique can be substantially greater than those accrued using ADVs. Links between fluid dynamics and fish swimming performance, stability and behaviour are starting to emerge through the adoption of techniques that allow accurate quantification of hydraulics. The intensity, periodicity, orientation and scale of turbulence are all considered to be biologically relevant. However, it is not clear which metrics researchers should measure, as several have been proposed (e.g. turbulence intensity; turbulent kinetic energy; shear stress; eddy size; eddy orientation and vorticity). Frameworks that help shape which hydraulic parameters are quantified and integrate laboratory and field research have been developed, which should aid the application of an ecohydraulics approach to fish passage research.

The use of large, open-channel flumes enables the study of volitional fish movement and performance-enhancing behaviours in response to conditions relevant to fish passage. Direct observation of fine-scale behaviours using filming techniques and tracking software allows analysis and quantification of spatial distributions, trajectories and speed of movement and interactions between fish, and for this information to be linked to empirical maps or models (e.g. Computational Fluid Dynamic simulations) of the hydraulic environment. Integrating techniques across disciplines via the ecohydraulics approach yields benefits to fish passage research. Until recently, those attempting to improve the efficiency of fish passes or screens, and who were enlightened enough to consider behaviour, often simplistic metrics such as the proportion of a population that shows avoidance or attraction to a particular stimulus (e.g. accelerating velocity). Such an approach ignores the bias exhibited by individuals, in which some fish may not respond to stimuli they detect, while others will.

ii) Effectiveness (qualitative concept): It consists checking that the pass is capable of letting all target species pass through within the range of environmental conditions observed during the migration period. As a rule, it is not possible to use a fishway for upstream and downstream migration simultaneously as fish behave differently depending on whether they migrate upstream or downstream. Nevertheless, when planning a fishway the basic principles and side constraints applying to fish downstream migration must be taken into account to ensure that the project does not create obstacles to a potential construction of a fishway for downstream migration at a later stage and/or that some synergistic effects are produced. This is particularly relevant with regard to the space available in relation to the space required for a fishway for upstream migration aid and a fishway for downstream migration aid as well as the possibility of one common auxiliary water to extend the area of intensity of velocity of outflow from the fish entrances to attract more fish and provide velocities in fish transportation channels of sufficient magnitude to encourage the migrating fish to keep moving in the required upstream or downstream direction conduit for both facilities.

iii) Timely: Avoiding eddy flow is extremely important within the fish passage to have timely fish passage conditions. The cause of eddy is usually the difference in static head between normal tailwater elevation near the shore and the lower water-surface elevation at the upstream end of the hydraulic jump at the base of the spillway. This difference in elevation causes a velocity from the shore toward the base of the spillway, where the water is at its lowest level. If the eddy can be eliminated or damped to a point where velocities in it are not high enough to give fish a directional stimulus, then the downstream velocity of water leaving the fishway entrance will be the chief attraction to fish reaching this area, and there will be no delay in entering fishway.

iv) Safely: Downstream migrants swept through hydroelectric plants will face similar risk of mechanical damage. In order to have a safe fish passage, several methods have been attemped for diverting fish away from the entrances to power plants or turbines. Physical barriers to migration may be effective in situations where behavioural barriers are ineffective. Screens and similar physical barriers represent a compromise between interference with water flow and the blocking of fish entry. The more complete the barrier to fish the greater the loss of flow. Simple bar screens consists of vertical slots or bars like a trash rack, spaced sufficiently close to prevent the fish from entering. It has been useful for preventing entry of larger fish, because the close spacing for smaller fish led to problems of intake foulling by debris and algae; in addition, the narrow spacing restricted the flow into the intake unacceptably. For those reasons simple bar screens have been largely abandoned for modern intakes. Woven mesh screen is usually made from wire, and it has square openings between meshes. The sizes of mesh and of mesh material have to be adapted to the species to be excluded and to the conditions obtaining in the lake or river such as temperature, currents, etc. For an intake on a flowing stream or canal, a wire mesh screen is normally used. Instead of conventional turbines, an improved turbine design (environmental friendly turbines) which has redesigned gates with rounded edges & fewer gaps, curved walls reduced places where fish may be pinched and blade, hub and outlet designs work together to reduce the turbulence in order to reduce injury and mortality. Throughout the operation of fish passage, monitoring & evaluation and maintenance plans must be constituted in order to provide and maintain those aforementioned criteria.

v) Monitoring & evaluation: Future fish passage research that adopts the ecohydraulic approach should not be based only on advances in novel technology that enable the complexity of the fluid environment to be determined at ever finer resolution, but must also strive to improve methods by which animal behaviour is appropriately described. Historically, the field-based application of the ecohydraulics approach has been restricted by the resolution, accuracy and frequency at which both fish movements and complex hydraulic environments can be measured. Recording system (monitoring and assessment) of how many fish species are getting inside or outside of that particular passage will show the precise data about efficiency of the fish passage. Altough it requires capital and labor work, observation of the fish species is crucial with regard to their own migration patterns. It is recommended that already during construction of the pass provision be made for built-in trapping chambers or at least lifting devices for the use of mobile fish traps to be installed directly at the outlet of the pass. This is particularly necessary in technical passes to test ascent of fish in the pass.

Conventional fish-tracking techniques are best suited to reach-scale studies of movements, quantifying the location of tagged individuals within a general area rather than their absolute position, or confirmed passage at a fixed point, e.g. dam, weir or associated fish pass. Passive Integrated Electromagnetic Transmitter (PIT) tag detection system can be implemented inside of the fish species to monitor movements and survival of fish at the site. Whilst, offering insight into rates and timings of movements, life-history strategies and physical capabilities of many species, in addition to quantitative evaluation of fish passage efficieny, such studies arguably result in subjective interpretation of behaviours and correlative factors. Recent advances in acoustic telemetry now provide the potential for 2-D or 3-D fish movements to be tracked at near-continuous, sub-metre resolution. Movement trajectories are obtained from calculated positions of tagged fish, based on the differences in arrival times of transmitted signals at multiple hydrophones, which are typically positioned around the perimeter of the study site.

vi) Maintenance: Optimum operation time for fish passage must be 300 days in a year. According to the seasonal changes of the weather, different hydrodynamic conditions will occur. Both extreme conditions of dry and wet seasons (e.g flood events) will adversely affect the fish passage operation. Consequently, operation of the fish passage during the extreme conditions would be very limited and, therefore, care must be taken into account to quantify and qualify the effect of these extreme conditions. Highly technical structures, therefore, require more frequent maintenance. A maintenance schedule can be drawn up or adjusted on the basis of operational experience of the type and frequency of malfunction of the fish pass in question. Maintenance must always be carried out after floods, however.

6.1.2.2 Novel fish passage design

Existing fish passage design connoted that (Section 5.1.1.2) flow rate (Q), velocity (V) and water level difference (Δh) in the pools are above of critical values. Furthermore, the selection of pool length and width was not chosen within the range (Table 4.11). Hence, implementation of more up-to-date design for optimising the existing fish passage must be considered based on the new design manual that was released by DWA in 2014 for both upstream and downstream migration. Since it was constructed in the year of 2000, it must be retrofitted in such a way that it would provide an improvement in terms of operation criteria at the one vertical slot fish passage. According to the new design manual (WKA-M509), design flowrates must be based on 300 operational days and $Q_{30} = Q_{min}$ (average annual minimum flowrate) and $Q_{330} = 1.5 * Q_{mean}$ (average annual mean flowrate) (see Figure 4.10 and Figure 4.12) flowrates must be used in the designing phase. In addition, screens must have a sufficiently small spacing or mesh dimension to physically prevent fish from passing. Sufficient screen area is much smaller than the determined value (i.e. 15 mm, Fisheries Law). Design parameters that were given in design manual 1996 and 2014 are given in Table 6.1. Fish passage nearby WKA Bienertmühle weir was constructed in 2000 and designed based on the design manual in 1996. To determine the optimum location of a fishway within a barrage structure that may consist of several functional units (weir, power plant, lock (s), upstream and downstream fishways, boat channel, etc.) it is important to take account of the power plant and weir operation strategies, flow patterns and discharge distributions in the downstream area. Pool length and pool width values are not in the range of given values. Thus, pool geometry was chosen wrongly. Based upon the new design manual in 2014, pool length and slot width must be retrofitted in the novel fish passage design. Fish transport relies on water velocities not exceeding the swimming abilities of migrating species. Water level difference, velocity must be calculated and flow rate at the weir must be chosen again in accordance with the new design manual in 2014.

Table 6.1: Comparison of design parameters.

Parameter	Symbol	1996 (Manual)	2000 (Design)	2014 (Manual)
Pool length (m)	l_b	1.90-3.00	1.8	1.95-3.00
Pool width (m)	b	1.20-1.80	2	1.50-2.25
Slot width (m)	s	0.15-0.30	0.18	0.20-0.35
Water depth below a cross-wall (m)	h_{min}	0.50-0.75	0.6	0.50-0.80
Water level difference (m)	Δh	0.2	0.233	< 0.15
Velocity (m/s)	V (V_{min}, V_{max})	2	2.14	0.3-1.9
Flow rate at WKA (m^3/s)	Q_{30}, Q_{330}	160	169	150,180

Comparison of impacts for fish passage alternatives is discussed before retrofitting the existing fish passage. Dam removal, nature-like fishway, fish ladder, trap and haul and walk away are preferences of a fish passage. At the end of the discussion, one vertical slot fish passage (technical type of fish passage) is determined upon personal communication with Reservoir Adminstrator of Saxony State. As understood from Figure 6.1, the right side of the fish passage must be relocated near the turbine. A new fish passage on the side of the power station (to use the turbine's leading current) must be implemented. This new design of fish passage that is demonstrated in Figure 6.1 and Figure 6.2, at the recent site with the inflow must be located towards the middle of the weir and the entry at the turbine's mouth.

Figure 6.1 : Plan view of existing fish passage at WKA Bienertmühle weir (2014).

Figure 6.2: Plan view of novel fish passage at WKA Bienertmühle weir (2014).

Completely new construction of vertical slot fish passage left of the power station that has downstream fish passage must be considered in design (Figure 6.3).

Figure 6.3: Close-up view of fish passage at WKA Bienertmühle weir (2014).

In order to extend the area of intensity of velocity of outflow from the fish entrances to attract more fish and provide velocities in fish transportation channels of sufficient magnitude to encourage the migrating fish to keep moving in the required upstream and downstream direction, attraction (or if it is needed auxiliary) water must be implemented.

The geometry of the facility is defined by the largest species and the maximum flow speed by the weakest swimmers. Upstream migration must be based on the fact that migration capability of the fish (i.e. adults of anadromous species, juveniles of catadromous species) that is considered when designing a fish passage at WKA Bienertmühle weir. Because of much less advanced than that for upstream fish passage facilities, attention should be drawn to downstream fish passage facilities. For the downstream migration, fish (i.e. juveniles of anadromous species, adults of catadromous species) passing through hydraulic turbines are subject to various forms of stress likely to cause high mortality.

Since there is no monitoring and evaluation system which includes both biological and hydraulic parameters in the river, DART (Data Access Real Time) system must be set up or developed in order to count fish species daily, monthly and on annual basis, fish migration periods, fish species count for each fish passage, fish behaviour monitoring and timing of migration peaks, spawning location, estimated timing of each life stage, estimated periods of upstream and downstream migration, predator species expected to be present. Also, flow frequency analysis, discharge rating curve, characteristic velocity profile should be performed and low, average, high flows (therefore water levels for each situation) must be specified for the fish passage. And, design passage flows for upstream and downstream passage for each target species across life stages during both high and low flow conditions are needed. In order to apply DART system PIT tags can be tagged for each target species.

To control the fish passage facility in flood seasons, upstream flood control structures can be built in order to sustain progression of the system. Hence, a regular maintenance program should be provided for the river. In addition, fishery management plans or comprehensive water resources plans and security plans and facility features to guard against unauthorized human activity, poaching, vandalism, etc must be proposed. Structurally, all components of the fish passage must be designed accounting for all possible external, internal and superimposed loads and pressures. External loads include soil and hydraulic pressure, hydraulic uplift, impact from flowing water or submerged & floating objects and surcharges such as equipment and vehicles. Internal loading is normally hydraulic pressure depending on differences in outside and inside water levels or full hydraulic head, e.g., plugged baffle slot(s). Various combinations of these forces can occur and each structure must be analyzed accordingly. This requires extensive knowledge of engineering and hydraulic principles as well as experience in the design and construction of fishway or fish passage structures. The safety of the general public and protection of the environment must be paramount in implementation of works. All structural design must be in accordance with current codes and standards and be carried out by professional engineers.

7. CONCLUSIONS

In this study, fish passage design principles were evaluated. Upstream and downstream fish migration were investigated. In-situ evaluation of fish passage nearby WKA (Windkraftanlage: Wind turbine) Bienertmühle weir was executed and project criteria were evaluated.

While river infrastructure such as dams, road crossings (e.g. culverts), flood control barriers (e.g. levees, weirs and tide gates), are important in providing a range of socioeconomic goods and services (e.g. water supply, transportation, renewable hydropower and flood control), they are well known for having considerable negative impacts on freshwater ecosystems and the hydrologic processes which sustain them. The development of waterways for hydropower and other industrial uses has substantially altered many of the freshwater habitats of the planet and this has considerable impact upon aquatic organisms. Fish passage design is historically biased. Early fish passes were intended to facilitate the upstream migration of economically significant species, primarily salmonids, while the fate of downstream migrating life stages and species of lower commercial value were often ignored. Therefore, it is extremely important to examine to fish passage function for the target fish species which migrate upstream or downstream of the study site.

The entrance and exit of the fish passage have great importance to cope with the assessment. The fish entrance and exit ends of the fish passages must be located and aligned to allow attraction of migrating fish to enter and swim through the structure and then move safely upstream from the exit. This requires extensive on-site observations of migrant fish at all concerned river stages, with documentation of resting & holding areas and difficult swimming sites. The resulting data are important in planning the most logical entrance and exit locations. As a result, retrofitting of the current fish passage is considered in a way that allows fish migration for both sides that is upstream and downstream migration.

Therefore, professionals in fisheries engineering must be employed to implement extensive investigation and planning of fishways to ensure adequate fish passage. This requires conducting detailed engineering and hydraulic surveys to document shoreline topography, water surface profiles and flow patterns in the river section to considered for fish passages, obtaining water surface profiles for the operational design range of the fishway(s) in level intervals of about 0.5 m; and carrying out model testing to verify the maintenance of the original hydraulic river characteristics for the structures in place.

In this study, to determine whether the fish passage is appropriate or not, WKA (Windkraftanlage: Wind turbine) Bienertmühle weir fish passage had been taken as a basis. In this purpose, evaluation of fish passage design principles, case study area (Vereinigte Weißeritz River) features and project criteria were researched in the first place and after that study site was observed and investigated. The River Vereinigte Weißeritz has nine hydraulic structures and one of them is WKA (Windkraftanlage: Wind turbine) Bienertmühle weir. Maximum water level difference is 5.20 m whereas minimum water level difference is 4.90 m at WKA (Windkraftanlage: Wind turbine) Bienertmühle weir. Native (resident) species of the Vereinigte Weißeritz River are mostly European grayling (Thymallus thymallus) fish species. The Vereinigte Weißeritz River is classified as moderately pollutant river which in chemically poor condition and ecologically moderate condition.

Ecohydraulics approach must be applied in order to retrofit the existing fish passage. This field is interdisciplinary, that needs hollistic research and collaborative work, and has suitable design criteria (identify, quantify and understand responses of fish), linkage between biological (swimming performance, behavioral responses of fish) and physical (hydraulic) features of aquatic systems. It also combines laboratory and field based techniques to investigate applicability of fish passage. In the field of ecohydraulics, existing fish passage was evaluated as non functional. Therefore, novel fish passage design that serves two types of migration (upstream and downstream) is found as more appropriate design for the fish passage at WKA (Windkraftanlage: Wind turbine) Bienertmühle weir. As a rule, it is not possible to use a fishway for upstream and downstream migraton, simultaneously, as fish behave differently depending on whether they migrate upstream or downstream. Nevertheless, when planning a fishway, the basic principles and site constraints applying to fish downstream migration must be taken into account to ensure that the project does not create obstacles to a potential construction of a fishway for downstream migration at a later stage and/or that some synergistic effects are produced. This is particularly relevant with regard to the space available in relation to the space required for a fishway for upstream migration aid and a fishway for downstream migration aid as well as the possibility of one common auxiliary conduit for both facilities.

WKA (Windkraftanlage: Wind turbine) Bienertmühle weir was constructed between the years of 1998 and 2000 in accordance with the 1996 design manual. Observations made during onsite inspections and investigations and evaluations of world standard in the literature, and especially the authority and responsibility statements and opinions over the thesis were evaluated based on the criteria of the project. The project was examined and evaluated in accordance with the fish passage standards issued in 2014. In accordance with the new standards in 2014, slot width, pool length, water level difference, velocity and flow rate must be selected again. Downstream fish passage facility (i.e. one vertical slot) must be located near upstream fish passage facility (i.e. one vertical slot) as a second fish passage. In the light of this examination, for the entrance of the fish passage i) physical (e.g. auxiliary flow, velocity, depth) ii) behavioural (e.g. light, sound, etc.), iii) chemical (e.g. temperature, DO, etc.), iv) location (e.g. upstream abstraction) must be taken into account in order to provide fish migration and comply with the new standards that was published in 2014 (Merkblatt DWA-M 509). In order to eliminate unfavorableness of the fish passage, the aforementioned precautions must be followed.

In conclusion, this case study is a sample model for the existing non functional Turkish fish passage facilities. Having a better future of ecosystems sustainability is extremely prominent, especially when dealing with such biased facilities in the history. Before construction, environmental impact assessment must be conducted. Compatible fish passage structures for site specific fish species and river hydrodynamic conditions should be designed by placing emphasis on terrain, river species equilibrium. Fish passage location, entrance and exit are extremely important for the operation of fish passage. Monitoring and computer aided sytems maintenance and control programs should be set up in order to provide longevity of the fish passage facility. The fish passage design process for upstream and downstream migrating fish provides an opportunity to develop safe, timely and effective fish passage facilities appropriate for the site specific and target species. Constructing a efficient, effective, safely, timely fish passage at a barrier or impedement has been challenging because the natural ecological flow and passage characteristics of a site are greatly altered by barrier. Identifying the most appropriate and cost effective fishway design to achieve this goal will help in meeting fishery management objectives, including minimizing injury, stress and migration delays, restoration and sustainable diadromous fish populations in the future.

REFERENCES

Alves, C. B. M. (2007). Evaluation of fish passage through Igarape Dam fish ladder using marking and recapture. *Neotropical Ichthyology. 5(2)*:233-236, 2007. Sociedade Brasileira de Ictiologia.

Anderson, J. J., Kemp, P. S., and Vowles, A. S. (2011). Quantifying behavior of migratory fish: Application of signal detection theory to fisheries engineering. *Ecological Engineering*, *41*, 22-31.

Aprahamian, M. W. et al. (2010). Environment Agency Fish Pass Manual: Guidance Notes on The Legislation, Selection and Approval of Fish Passes In England and Wales.

Baras, E., Duncan A., Lucas, M. C., Slavik, O., Thom, T. J. (2001). Migration of Freshwater Fishes, Blackwell Science, 440.

Beach, M.H. (1984). Fish Pass Designs: Criteria for the Design and Approval of Fish Passes and Other Structures to Facilitate the Passage of Migratory Fish in Rivers. *Fisheries Research Technical Report*, Lowestoft, England, No.78.

Bernatowicz, W., Weiß, A. and Matschullat, J. (2008). Linking biological and physicochemical water quality. *Environmental Monitoring and Assessment*. Published online: 06.12.2008. DOI: 10.1007/s10661-008-0631-9.

Bernhofer, C., Franke, J. (2009). A method for deriving a future temporal spectrum of heavy precipitation on the basis of weather patterns in low mountain ranges. Meteorol. Appl. *16*, 513-522.

Bernhofer, C., Eichelmann, U., Goldberg, V., Prasse, H. (n.d.). The flash flood event in the catchment of the river Weißeritz (eastern Ore Mountains) from August 12- 14, 2002: meteorological and hydrological reasons, damage assessment and disaster management.

BfG. (2002). Das Augusthochwasser 2002 im Elbegebiet, Bundesamt fur Gewasserkunde. Date retrieved: 25.07.2014, address: http://elise.bafg.de/servlet/is/3967/.

Bianchin, S., Merta, M., Richert, E. and Seidler, C. (2007). Analysis of land use change in the eastern Ore Mountains regarding both nature protection and flood prevention, *International Scientific Conference: Bioclimatology and Natural Hazards.* Polana nad Detvou, Slovakia.

Bianchin, S. et al. (2007). Endbericht-Hochwasser und Naturschutz im Weißeritzkreis. *Hochnatur*. Aktenzeichen DBU: 21278.

Bornschein, A. and Pohl, R. (2011). ERA-NET CRUE Research Funding Initiative Flood Resilient Communities- managing the consequences of flooding. *CRUE Final Report Case Studies: Dresden, Germany.* (ch. 4).

Brett, J. R. (1964). The respiratory metabolism and swimming performance of young sockeye salmon. *Journal of Fisheries Research Board of Canada*, *21*: 1183-1226.

Castro-Santos, T. (2005). Optimal swim speeds for traversing velocity barriers: an analysis of volitional high-speed swimming behavior of migratory fishes. *The Journal of Experimental Biology*, *208*, 421-432.

Castro-Santos, T. (2006). Modeling the effect of varying swim speeds on fish passage through velocity barriers. *Transactions of the American Fisheries Society*, *135*, 1230-1237.

Castro-Santos, T. and Haro, A. (2006). Biomechanics and fisheries conservation. In Shadwick, R.E. and Lauder, G.V. (eds) *Fish Physiology*, Volume 23, Fish Biomechanics, Academic Press, New York, 469-523.

Category Weißeritz (n.d.). In *Wikipedia*. Date retrieved: 01.08.2014, address: http://commons.wikimedia.org/wiki/Category:Wei%C3%9Feritz?uselang=de#mediaviewer/File:Wei%C3%9Feritzhochwasser_Juni_2013,_2.JPG.

Cotel, A. J., Webb, P. W. and Tritico, H. (2006). Do brown trout choose locations with reduced turbulence? *Transactions of the American Fisheries Society*, *135*, 610-619.

Critchley, W., Siegert, K. (1991). A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. *FAO of United Nations*, (ch. 3).

Deutscher Verband für Wasserwirtschaft und Kulturbau e.V., DVWK (German Association for Water Resources and Land Improvement). (1996). DVWK-Merkblatt 232/1996: Fischaufstiegsanlagen – Bemessung, Gestaltung, Funktionskontrolle.

Drewes, U., Geitner, V. (1990). Entwicklung eines neuartigen Pfahlfischpass. – Wasser und Boden 42, 604-607.

Educational Technology Clearinghouse. (2014). Representations of fish species along the Vereinigte Weißeritz River. Date retrieved: 15.08.2014, address: http://etc.usf.edu/.

Egermann, M., Küttner, L. and Reichel, W. (2006). Report Case Study Area Dresden-Weißeritz. *LUDA Project: Improving the quality of life in Large Urban Distressed Areas*, Liebniz Instiute of Ecological And Regional Development, Dresden.

FICHTNER Water&Transportation. (n.d.). Hydraulic engineering: Extension of the river Vereinigte Weißeritz/ Germany. Date retrieved: 07.06.2014, address:http://www.fwt.fichtner.de/php/main/page/php/referenzen.php/ukat_id/9/kat_id/3/idc1/102/z1/4/map/1/sprache/e/li/0re_w.

Foltyn, M. (2006). Landschaftsökologische Analyse des Einzugsgebietes des Höckenbachs (Erzgebirge) auf Grundlage einer Biotoptypenkartierung. Studienarbeit, AG Biologie/Ökologie der TU Freiberg.

Free State of Saxony. (2012). Statistik-Bevölkerungsbestand: Belvölkerung und Flache am 31.Dezember 2012 nach Kreisfreien Stadten und Landkreisen.

Gebler, R. J. (1991). Naturgemäße Bauweisen von Sohlenbauwerken und Fischaufstiegen zur Vernetzung der Fließgewässer. – Diss. Univ. Karlsruhe, Mitteilungen des Institutes für Wasserbau und Kulturtechnik, Nr. 181.

Gloger, L. (2014). Personal communication.

Google Earth. (2012). Satellite view of fish passage near WKA Bienertmühle at different eye elevations.

Google Earth. (2012). Width measurement of Vereinigte Weißeritz River.

Graeber, P. W., Sitte, J. (2014). Personal communication.

Harnapp, S., Küchler, L. (2003). Gewassergütebericht: Biologische der Gewassergüte Sachsischer Fließgewasser mit Gewassergütekarte. Landesamt für Umwelt und GeologieReferat Oberirdische Gewasser, Flussgebietsmanagement, Abteilung Wasser, Abfall.

IUSS Working Group WRB. (2007). World Reference Base for Soil Resources 2006, first update 2007. World Soil Resources Reports No. 103. FAO, Rome.

Jens, G. (1982). Der Bau von Fischwegen. –Hamburg, Berlin (Verlag Paul Parey), 93 S.

Jordan, H., Weder, H. J. (1995). Hydrogeologie: Grundlagen und Methoden; Regionale Hydrogeologie: Mecklenburg-Vorpommern, Brandenburg und Berlin, Sachsen-Anhalt, Sachsen, Thüringen. 2. Auflage, Stuttgart, Enke-Verlag.

Kane, D. L., Wellen, P. M. (1985). A Hydraulic Evaluation of Fish Passage Through Culverts in Alaska Data Report. Institue of Water Resources/Engineering.

Kaulfuß, W., Kramer, M. (2002). Naturlandschaften und Nutzungpotentiale Sachsens. In Kowalke H (Hrsg.) Sachsen. Perthes Landerprofile. Klett-Perthes-Verlag Gotha, 71-73.

Kemp, P. S., Lucas, M. C., Russon, I. J. and Vowles, A. S. (2011). The influence of discharge and temperature on the ability of upstream migrant adult river lamprey (Lampetra fluviatilis) to pass experimental overshot and undershot weirs. *River Research and Applications*, *28*, 488-498.

Kemp, P. S. and Russon, I. J. (2011). Experimental quantification of the swimming performance and behavior of spawning run river lamprey Lampetra fluvialitis and European eel Anguilla Anguilla. Journal of Fish Biology, *78*, 1965-1975.

Kreibich, H., Merz, B., Müller, M., Petrow, T. and Thieken, A. H. (2005). Consequences of extreme flood event of August 2002 in the city of Dresden, Germany. *Sustainable Water Management Solutions for Large Cities*. IAHS Publ., 293.

Lancaster, J. and Downes, B. J. (2010). Linking the hydraulic world of individual organisms to ecological processes: putting ecology into ecohydraulics. *River Research and Applications, 26,* 31-44.

Landeshauptstadt Dresden Die Oberburgermeisterin, Umweltamt. (2010). Plan Hochwasservorsorge, Dresden: Gewassersteckbrief-Vereinigte Weißeritz.

Landehauptstadt Dresden, Geschaftsbereich Wirtschaft, Umweltamt. (2011). Plan Hochwasservorsorge, Dresden: Betrachtungsgebiet 3-Plauen, Löbtau.

Landehauptstadt Dresden. (n.d.). Stadtentwicklung& Umwelt: Gewasser in Dresden, Gewassernetz und Wasserstande. Date retrieved: 05.06.2014, address: http://www.dresden.de/de/08/03/055/01/gewaessernetz.php.

Landestallsperrenverwaltung des Freistaates Sachsen. (2004). Hochwasserschutzkonzeption linkselbischer Fließgewasser: Gefahrenkarte Vereinigte Weißeritz Dresden.

Lange, B. and Metz, G. (2012). Innovative Bauverfahren beim Bau von Hochwasserrückhaltebecken. Technische Universitat Dresden-Fakultat Bauingenieurwesen, Institut für Wasserbau und Technische Hydromechanik. *35. Dresdner Wasserbaukolloquim 2012: "Staubauwerke-Planen, Bauen, Betrieben".*

Larinier, M. (1992a). Passes à bassins successifs, prébarrages et rivières artificielles. – Bull. Fr. Pêche Piscic. *326/327*, 45-72.

Larinier, M. (1992b).Les passes a ralentisseurs– Bull. Fr. Pêche Piscic. *326/327*, 73-94.

Larinier, M., Travade, F. (1992a). Les techniques de controle des passes a poisons-Bull. Fr. Pêche Piscic. *326/327*, 151-164.

Lauterbach, G. (2000). Wasser- und Stoffhaushalt dreier Wald¨okosysteme des Osterzgebirges. Dissertation an der Georg-August-Universit¨at, Institut fur Geologie und Dynamik der Lithosphare Göttingen.

LAWA. (2003). Definition und Kurzcharakteristiken der Gewassergüteklassen entsprechend LAWA-Bewertungverfahren.

LAWA. (2007). Rahmenkonzeption Monitoring (RaKon Monitoring), Teil B Bewertungsgrundlagen und Methodenbeschreibungen, Arbeitspapier II „Hintergrund- und Orientierungswerte fur physikalisch-chemische Komponenten". Landerarbeitsgemeinschaft Wasser. Ausschuss „Oberirdische Gewasser und Kustengewasser", Status: 07.03.2007.

Legendre, P., Roy, A. R. and Roy, M. L. (2010). The relationship between 'standard' fluvial habitat variables and turbulent flow at multiple scales in morphological units of a gravel-bed river. *River Research and Applications*, *26,* 439-455.

Little, S., Moir, H. J., Rice, S. P., Vericat, D. and Wood, P. J. (2010). The relative contributions of ecology and hydraulics to ecohydraulics. River Research and Applications, *26,* 363-366.

Mannsfeld, K. and Richter H. (1995). Naturräume in Sachsen. Forschungen zur deutschen Landeskunde, Band 238. Zentralausschuss für deutsche Landeskunde, Trier.

Martinez, C. B., Pompeu, P. S. and Santos, H. A. (2007). Swimming performance of the Neotropical fish Leporinus reinhardti (Characiformes: Anastomidae). Neotropical Icthyology, *5*, 139-146.

Matouskova, M., Matschullat, J., Weiß, A. (2010). Ecological Survey of River Habitat Diversity: Trans-boundary Cooperation In The Ore Mountains (Krusne Hory, Erzgebirge). Geografie *115*, No.3, 284-307.

Müller, K. (1968). Die Tages- und Jahresperiodik der Bachforelle (Salmo trutta L.) am Polarkreis- Aquilo, Ser. Zool. *8*, 50-62.

OPAQUE (2006). Role of reference elements in the selection of resources by psychology undergraduates. *Journal of Bibliographic Research*, *5*, 117-123. Date retrieved: 10.07.2014, address: http://brandenburg.geoecology.uni-potsdam.de/projekte/opaque/weissitz.php.

Paul, L. and Peters, U. (2014). Personal communication.

Pavlov, D.S. (1989). Structures assisting the migration of non-salmonid fish: USSR. –FAO Fisheries Techn. Pap. 308, 98 S.

Peake, S. J. and Farrell, A.P. (2006). Fatigue is a behavioural response in respirometer-confined smallmouth bass. *Journal of Fish Biology*, *68*, 1742-1755.

Peckmann, P. and Stahlberg, S. (1986). Bestimmung der kritischen Strömungsgeschwindigkeitenn einheimischer Kleinfischarten. – Wasserwirtschaft.

Perillo, J. (2006). Evaluating the Use of Fairmount Dam Fish Passage Facility by Anadromous Fishes in the Schuylkill River, Philadelphia, Pennsylvania. Philadelphia Water Department.

Population Information Network (POPIN) Gopher of the United Nations Population Division, Department for Economic and Social Information and Policy Analysis contrib. by FAO. (1994). Population and Water Resources. *Impact of Population on Water Supply. (*ch. 3).

Pottgiesser, T., Sommerhauser, M. (2004). Fliesgewassertypologie Deutschlands: Die Gewassertypen und ihre Steckbriefe als Beitrag zur Umsetzung der EU Wasserrahmenrichtlinie. In: Steinberg, C., Calmano, W., Wilken, R. D., Klapper, H. (eds.): Handbuch der Limnologie. 19. Erg. Lfg. 7/04. VIII-2.1, 1–16 + Appendix.

Pöhler, H. A. (2006). Anpassung von WaSiM-ETH und die Erstellung und Berechnung von Landnutzungs und Klimaszenarien für die Niederschlag-Abfluss- Modellierung am Beispiel des Osterzgebirges. *TU Freiberg*, *Der Fakultat für Geowissenschaften, Geotechnik und Bergbau, Dissertation*.

Sachsisches Staatsministerium für Umwelt und Landwirtschaft (SMUL). (n.d.). Wehrdatenbank der sachsischen Fließgewasser: Ausrüstungsstand der Querbauwerke mit Fischaufstieganlage- Vereinigte Weißeritz. Date retrieved:07.08.2014, address: http://www.smul.sachsen.de/Wehre /BerichtQuerAusruestFAA.aspx?id=?ID=635442289796555013_cd9b 62a2-6ab0-4971-b8f5-319cecd7737b.

Sachsisches Staatsministerium für Umwelt und Landwirtschaft (SMUL). (n.d.). Wehrdatenbank der sachsischen Fließgewasser: Ausrüstungsstand der Querbauwerke mit Fischaufstieganlage- Rote Weißeritz. Date retrieved:07.08.2014, address: http://www.smul.sachsen.de /Wehre/BerichtQuerAusruestFAA.aspx?id=?ID=63544229790527894 7_07a35260-43d4-4dc8-9aaf-7af16f097435.

Sachsisches Staatsministerium für Umwelt und Landwirtschaft (SMUL). (n.d.). Wehrdatenbank der sachsischen Fließgewasser: Ausrüstungsstand der Querbauwerke mit Fischaufstieganlage- Wilde Weißeritz. Date retrieved: 07.08.2014, address: http://www.smul.sachsen.de /Wehre/BerichtQuerAusruestFAA.aspx?id=?ID=63544229700872970 6_eeb5b7dc-a5b9-4e6d-8669-55aa15b1d560.

Sachsisches Staatsministerium für Umwelt und Landwirtschaft (SMUL). (n.d.). Wehrdatenbank der sachsischen Fließgewasser: Detailbericht der Querbauwerke- Vereinigte Weißeritz. Date retrieved: 07.08.2014, address:http://www.smul.sachsen.de/Wehre/BerichtQuerDetail.aspx?i d=?ID=635442295852279467_59465cd4-5255-41a5-a453 61eed72a5ce0.

Sachsisches Staatsministerium für Umwelt und Landwirtschaft (SMUL). (n.d.). Wehrdatenbank der sachsischen Fließgewasser: Detailbericht der Querbauwerke mit Fischaufstieganlage- Vereinigte Weißeritz. Date retrieved:07.08.2014, address: http://www.smul.sachsen.de FAA.aspx?id=?ID=635442284687612766_ba194fc9-3ad5-4669- a666-9de76c63f385.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (n.d.). Geologie, Karten und GIS-Daten: Hydrogeologische Karten- Hydrogeologische Übersichtkarte 1:400000. Date retrieved: 15.08.2014, address: http://www.umwelt.sachsen.de /umwelt/geologie/7692.htm.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (2003). Gewassergütebericht mit Gewassergütekarte, Freistaat Sachsen.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (2012). Hydrologisches Handbuch: Gewasserkundliche Hauptwerte, Teil 3.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (2012). Hydrologisches Handbuch: Haupttabelle der mittleren Durchflussextremwerte, Teil 4.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (2012). Hydrologisches Handbuch: Haupttabelle der oberen Durchflussextremwerte, Teil 5.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (2012). Hydrologisches Handbuch: Haupttabelle der unteren Durchflussextremwerte, Teil 6.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (n.d.). Landestallsperrenverwaltung des Freistaates Sachsen: Stauanlagen im Überblick. Date retrieved: 05.06.2014, adress: http://www.smul.sachsen.de/ltv/16984.htm.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (n.d.). SYNERGIS Web Office System. Date retrieved:14.08.2014, adress: http://www.umwelt.sachsen.de/umwelt/infosysteme/weboffice101/synserver?project=wasser-wrrlzustand&language=de.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (2009). Thematische Karten, Freistaat Sachsen.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (2014). Umwelt Sachsen-Upper Elbe River Basin. Date retrieved: 22.09.2014,address:http://www.umwelt.sachsen.de/de/wu/umwelt/lfug/lfug-internet/hwz/Elbe/index.html.

Sachsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfUG). (n.d.). Wasser, Wasserwirtschaft, Zustand der Wasserkörper-Kartenübersicht. Date retrieved:15.07.2014, address: http://www.umwelt.sachsen.de /umwelt/wasser/9117.htm#article9126

Saxony Dam Administration. (2014). Personal communication.

Smith, D. L., Brannon, E. L. and Odeh, M. (2005). Response of juvenile rainbow trout to turbulence produced by prismatoidal shapes. *Transactions of the American Fisheries Society*, *134*, 741-753.

Smith, D. L., Brannon, E. L. and Odeh, M. (2005). Response of juvenile rainbow trout to turbulence produced by prismatoidal shapes. *Transactions of the American Fisheries Society*, *134*, 741-753.

Statistics of Free State of Saxony. (2012). The population and area of interested districts in Federal Republic Germany.

Towler, B., Hoar, A. and Ahlfehld, D. (2012). Ecohydrology and fish-passage engineering: legacy of Denil and the call for a more inclusive paradigm. *Journal of Water Resources Planning and Management*, *138*, 77-79.

Tritico, H. M. (2009). The Effects of Turbulence on Habitat Selection and Swimming Kinematics of Fishes, PhD dissertation, University of Michigan, USA.

Umweltamt Dresden. (2002). Personal communication.

Vowles, A. S. and Kemp, P. S. (2012). Effects of light on the behavior of brown trout (Salmo trutta) encountering acceleration flow: Application to downstream fish passage. Ecological Engineering, *47*, 247-253.

Wagenbreth, O. (1982) Geologische Streifzuge - Landschaft und Erdgeschichte zwischen KapArkona und Fichtelberg. Deutscher Verlag fur Grundstoffindustrie, Leipzig.

Werkstattstadt. (2013). Flood protection in connection with urban renewal: Dresden "Weißeritz urban development concept". Date retrieved: 26.06.2014, adress: http://www.werkstatt-stadt.de/en/projects/246/.

Weis, A., Meier, H., Matschullat, J. (2003). Reservoir Catchment Management in Mountainous Regions (EMTAL). In: Rohling, H.-G., Steinbach, V. (eds.): MAEGS 13, Geosciences and the European Water Framework Directory, 10.–13.09.2003 in Hannover,Schriftenreihe Deutsche Geologische Gesellschaft, *28*, 141–148.

Weißeritz (Vereinigte). (n.d.). In *Wikipedia.* Date retrieved: 07.06.2014, address: http://de.wikipedia.org/wiki/Wei%C3%9Feritz.

Wood, P., Hannah, D. and Sadley, J. (eds) (2008). *Hydroecology and Ecohydrology: Past, Present and Future*, John Wiley&Sons, Ltd, Chichester, UK.

APPENDICES

APPENDIX A: Maps

APPENDIX B: Tables

APPENDIX C: Fish types and fish passages

APPENDIX D: Fish passage plan and longitudinal section (2000)

APPENDIX A

Figure A.1: Hydrogeology map of Free State of Saxony (LfUG, n.d.).

Figure A.2: Water quality of Free State of Saxony watercourses (LfUG, 2003).

APPENDIX B

Table B.1: Minimum flowrate (discharge) measures between 1999-2010 at stream gauge station Cotta (LfUG: Hydrologisches Handbuch Teil 6, 2012).

Year	Nov. (m^3/s)	Dec. (m^3/s)	Jan. (m^3/s)	Feb. (m^3/s)	Mar. (m^3/s)	Apr. (m^3/s)	Ma. (m^3/s)	June (m^3/s)	July (m^3/s)	Aug. (m^3/s)	Sept. (m^3/s)	Oct. (m^3/s)	Win. (m^3/s)	Sum. (m^3/s)	Yr. (m^3/s)
1999			2.77	3.73	3.30	1.11	0.913	0.490	1.19	0.581	0.792	0.449	1.11	0.449	0.449
2000	0.490	0.913	1.26	3.88	6.02	1.26	0.535	0.336	0.371	0.303	0.371	0.371	0.490	0.303	0.303
2001	0.371	0.371	0.371	0.682	0.978	1.88	1.05	0.913	0.851	0.409	0.581	0.630	0.371	0.409	0.371
2002	0.630	2.19	1.78	4.53	2.30	1.34	0.978	0.792	0.490	0.535	1.30	1.30	0.630	0.490	0.490
2003	2.60	1.51	3.48	1.51	1.63	0.853	0.580	0.371	0.371	0.257	0.258	0.344	0.853	0.257	0.257
2004	0.393	0.517	0.370	1.95	1.45	1.16	0.912	1.16	0.604	0.306	0.306	0.440	0.370	0.306	0.306
2005	0.518	0.912	3.78	2.34	4.35	1.45	0.801	0.440	0.518	0.518	0.699	0.912	0.518	0.440	0.440
2006	0.518	0.912	1.45	1.61	1.61	3.51	0.912	0.518	0.440	0.440	0.440	0.440	0.518	0.440	0.440
2007	0.699	0.604	1.16	3.51	2.55	0.699	0.518	0.518	0.440	0.518	1.03	2.14	0.604	0.440	0.440
2008	1.82	2.36	1.59	2.28	2.73	4.21	0.841	0.357	0.349	0.165	0.351	0.433	1.59	0.165	0.165
2009	1.14	1.69	1.77	1.76	8.73	1.44	0.713	0.713	1.56	0.598	0.068	0.140	1.14	0.068	0.068
2010	1.29	1.45	1.53	0.753	5.10	2.19	1.00	0.576	0.244	1.89	1.59	2.25	0.753	0.244	0.244

Table B.2: Mean flowrate (discharge) measures between 1999-2010 at stream gauge station Cotta (LfUG: Hydrologisches Handbuch Teil 4, 2012).

Year	Nov. (m^3/s)	Dec. (m^3/s)	Jan. (m^3/s)	Feb. (m^3/s)	Mar. (m^3/s)	Apr. (m^3/s)	Ma. (m^3/s)	June (m^3/s)	July (m^3/s)	Aug. (m^3/s)	Sept. (m^3/s)	Oct. (m^3/s)	Win. (m^3/s)	Sum. (m^3/s)	Yr. (m^3/s)
1999			3.68	10.6	8.68	2.08	1.32	1.40	2.69	0.925	0.971	0.613	6.19	1.32	3.24
2000	1.06	1.11	2.58	7.11	17.5	5.60	0.902	0.546	0.606	0.457	0.658	0.665	5.85	0.639	3.23
2001	0.720	0.604	0.629	7.17	5.91	2.80	2.87	1.25	1.09	0.776	1.78	1.31	1.99	1.51	1.75
2002	2.09	4.60	7.41	7.30	5.06	1.98	1.14	1.29	0.911	23.9	2.26	1.97	4.73	5.28	5.00
2003	10.7	6.22	11.3	3.54	4.14	1.73	1.00	0.579	0.531	0.352	0.324	0.492	6.31	0.548	3.41
2004	0.482	0.601	0.971	5.23	3.11	1.76	3.45	1.57	1.37	0.483	0.567	0.817	2.00	1.38	1.69
2005	4.70	2.33	6.62	9.30	11.1	3.72	1.41	0.864	1.27	1.31	1.21	1.26	6.26	1.22	3.72
2006	0.881	3.89	3.48	4.12	8.51	11.5	1.84	1.16	0.581	1.14	0.638	0.875	5.40	1.04	3.20
2007	2.26	0.938	2.26	7.80	5.79	1.21	1.28	1.10	0.862	1.33	2.91	3.28	3.32	1.79	2.55
2008	9.22	6.63	5.85	4.82	5.54	11.2	1.88	0.686	0.624	0.702	0.968	0.899	7.20	0.962	4.06
2009	1.58	3.99	2.48	3.57	12.2	5.14	1.23	3.31	4.38	2.01	0.393	4.96	4.86	2.72	3.78
2010	6.93	4.16	3.72	3.30	9.64	4.58	1.97	5.99	1.82	8.77	10.9	7.78	5.42	6.18	5.80

Table B.3: Maximum flowrate (discharge) measures between 1999-2010 at stream gauge station Cotta (LfUG: Hydrologisches Handbuch Teil 5, 2012).

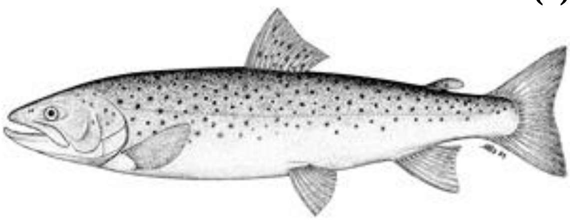
Year	Nov. (m^3/s)	Dec. (m^3/s)	Jan. (m^3/s)	Feb. (m^3/s)	Mar. (m^3/s)	Apr. (m^3/s)	Ma. (m^3/s)	June (m^3/s)	July (m^3/s)	Aug. (m^3/s)	Sept. (m^3/s)	Oct. (m^3/s)	Win. (m^3/s)	Sum. (m^3/s)	Yr. (m^3/s)
1999			6.22	22.2	28.1	4.53	3.03	6.22	16.1	5.62	6.64	1.19	28.1	16.1	28.1
2000	2.65	1.69	14.3	17.7	42.7	24.3	4.04	1.98	9.29	2.90	2.08	1.69	42.7	9.29	42.7
2001	1.78	1.60	1.78	3.30	14.0	5.62	8.01	15.1	6.02	3.73	3.58	2.77	14.0	15.1	15.1
2002	5.62	13.2	25.0	19.3	21.0	3.16	1.88	3.44	4.37	300	11.3	3.29	25.0	300	300
2003	36.0	24.5	37.3	11.3	11.3	3.48	18.4	1.63	4.07	0.611	0.873	1.27	37.3	18.4	37.3
2004	1.06	1.03	1.95	10.9	6.0	3.51	10.2	6.37	18.3	2.14	7.15	4.06	10.9	18.3	18.3
2005	20.1	4.97	9.88	25.7	32.0	15.4	3.51	3.78	6.37	11.3	5.30	3.01	32.0	11.3	32.0
2006	1.77	14.6	8.27	19.2	36.5	34.7	4.35	12.7	4.35	8.90	2.14	8.58	36.5	12.7	36.5
2007	32.0	1.30	7.15	13.8	9.88	4.65	37.6	17.0	9.88	14.2	8.27	9.22	32.0	37.6	37.6
2008	24.4	15.7	18.4	15.1	9.11	22.4	6.43	11.5	3.22	18.7	11.7	7.62	24.4	18.7	24.4
2009	3.61	28.4	4.22	21.5	20.2	12.0	4.86	19.9	32.2	15.4	9.11	12.0	28.4	32.2	32.2
2010	15.7	12.6	10.1	17.8	16.3	10.8	11.4	27.2	24.4	29.3	47.0	37.2	17.8	37.2	37.2

Table B.4: Water depth measures between 2001-2010 at stream gauge station Cotta (LfUG: Hydrologisches Handbuch Teil 3, 2012).

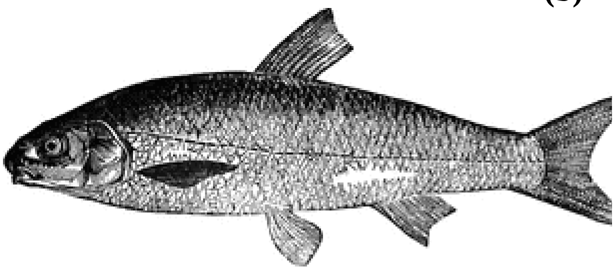
Year	Nov. (cm)	Dec. (cm)	Jan. (cm)	Feb. (cm)	Mar. (cm)	Apr. (cm)	Ma. (cm)	June (cm)	July (cm)	Aug. (cm)	Sept. (cm)	Oct. (cm)	Win. (cm)	Sum. (cm)	Yr. (cm)
	2003+	2003	2004	2010	2004	2007	2007	2005+	2006+	2004+	2004	2004+	2004	2004+	2004+
LWL	16	16	15	23	24	18	16	15	15	13	13	15	15	13	13
MLWL	25	28	31	34	39	33	26	23	22	21	22	23	23	19	19
MWL	40	39	45	46	56	45	32	31	28	35	31	32	45	31	38
MHWL	74	71	74	85	89	69	65	73	70	104	64	59	110	136	151
HWL	132	123	151	135	140	108	113	128	134	430	174	148	151	430	430
	2002	2008	2002	2002	2002	2006	2007	2010	2009	2002	2010	2010	2002	2002	2002

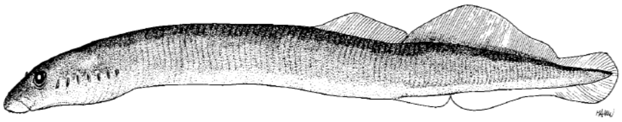
APPENDIX C

(a)



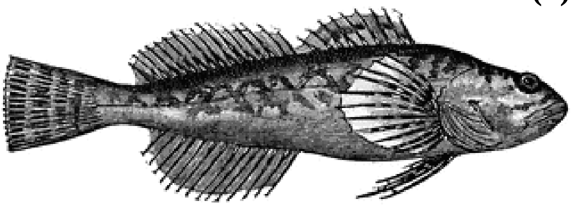
(b)



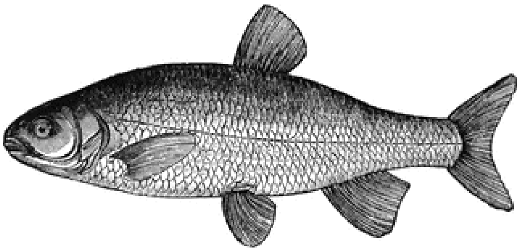


(c)

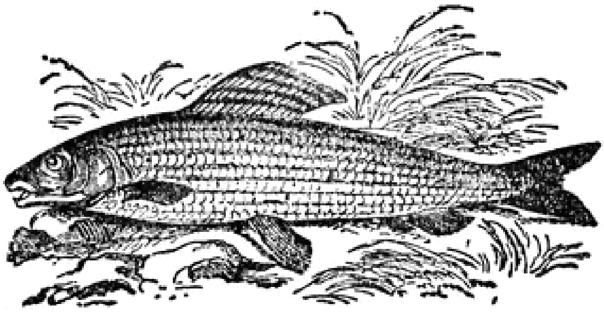
(d)



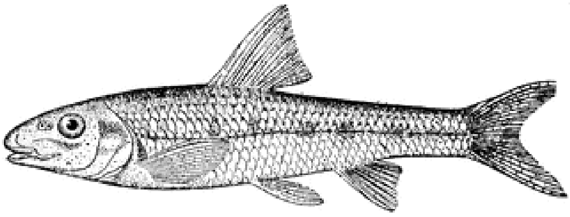
(e)



(f)



(g)



(h)

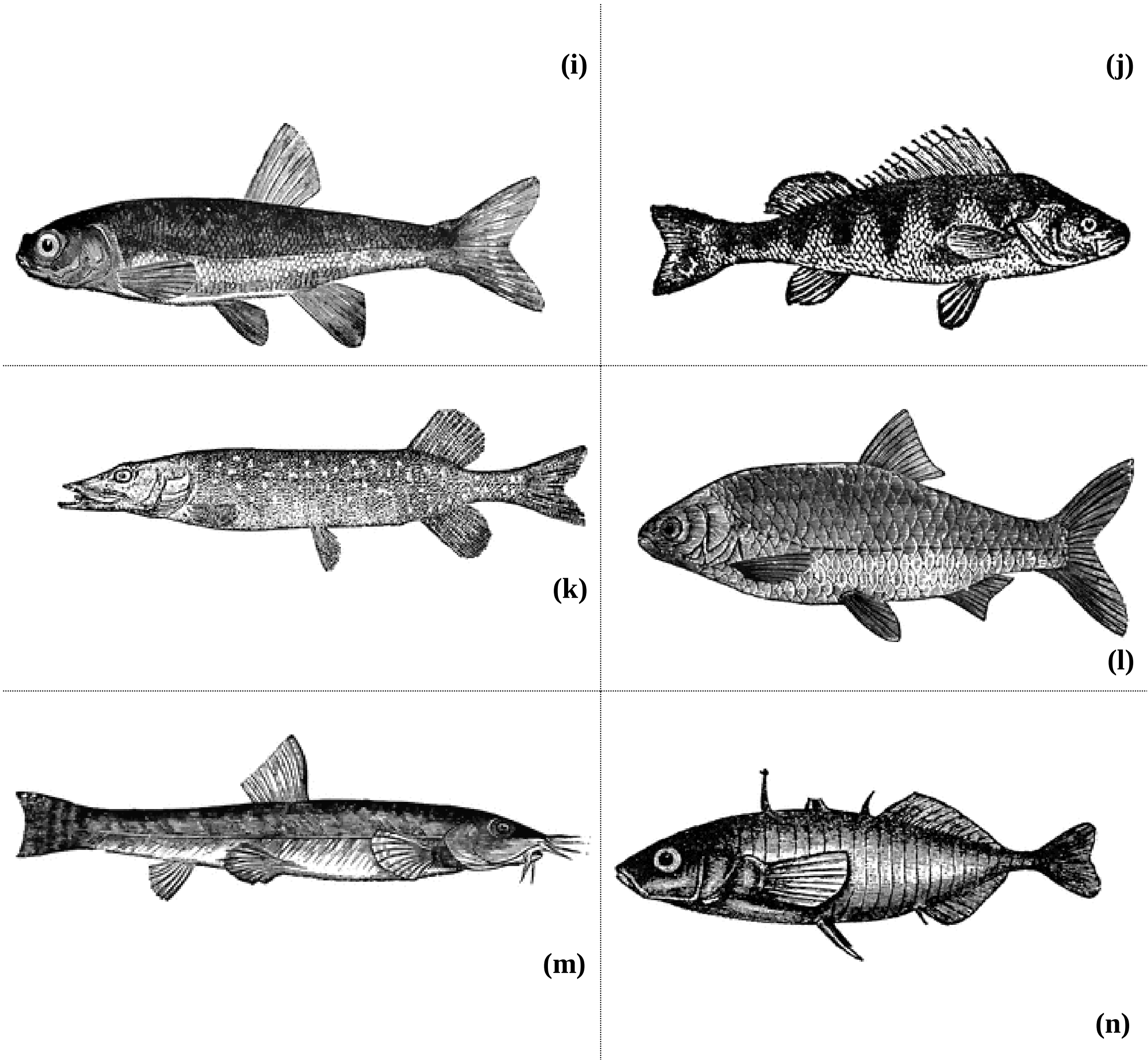


Figure C.1: Representations of fish species along the Vereinigte Weißeritz River (Educational Technology Clearinghouse, 2014) (a) Brown/Sea trout (Salmo trutta fario) (b) Dace (Leuciscus leuciscus) (c) European brook lamprey (Lampetra planeri), (d) European bullhead (Cottus gobio), (e) European chub (Squalius cephalus), (f) European river lamprey (Lampetra fluviatilis), (g) European grayling (Thymallus thymallus), (h) Gudgeon (Gobio gobio), (i) Minnow (Phoxinus phoxinus), (j) Perch (Perca fluviatilis), (k) Pike (Esox lucius), (l) Roach (Rutilus rutilus), (m) Stone loach (Barbatula barbatula), (n)Three-spined stickleback (Gasterosteus aculeatus).


(a)


(b)


(c)


(d)


(e)


(f)

Figure C.2: Fish passage types along the Vereinigte Weißeritz River (SMUL, n.d.) (a) Bottom ramp and slope type fish passage at headwater (b) Fish ramp type fish passage at headwater (c) Fish ramp type fish passage combined with technical fish passage (d) Bottom ramp and slope fish passage (e) Bottom ramp and slope type fish passage (f) Vertical slot fish passage at headwater.

APPENDIX D

Figure D.5: Fish passage (2000) plan.

Figure D.6: Fish passage (2000) section.

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