Pilot Study: Hydromorphological Survey and Mapping of the Drava and Mura Rivers

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For:
International Association for Danube Research (IAD)
General Secretariat, Vienna, Austria

Vienna, May 2007

Schwarz, U. (2007). Pilot Study: hydromorphological survey and mapping of the Drava and Mura Rivers. IAD Report prepared by FLUVIUS, Floodplain Ecology and River Basin Management, Vienna pp. 140.

Cover photo by Ulrich Schwarz: Drava near Novacka, rkm 217

Preface

The objective of this study is to provide firstly a review of methodological approaches to survey and assess the hydro-morphological conditions along large rivers, secondly to develop an adapted method for assessing large rivers, based on the European CEN Guidance Standard in respect to already existing inventories in the Danube River Basin (e.g. UNDP/ICPDR), and thirdly to survey the lower Drava and Mura Rivers and to compare as far as possible the results with already existing inventories for upper river reaches in Austria.
The product of this inventory is a detailed map of the lower Drava and Mura rivers showing the main hydromorphological features and alterations and an evaluation of the situation regarding a five-class quality assessment system based on hydromorphological reference conditions, which fits to the evaluation system of the EU Water Framework Directive. These results can thus also be used for WFD “Programmes of Measures” in that field. Finally a comprehensive overview map of the Drava was compiled to allow a first comparison of the situation in the upper and lower river basin.

In addition to the opportunity to compare, for a first time, quantitative hydromorphological data for a large transboundary river in the Danube Basin, this study should also serve as a source for methodological approaches and as an example for the feasibility of such a study for the Danube (module-based IAD proposal to develop a hydromorphological inventory of the Danube). Important aspects of sediment transport and flood mitigation, when assessing retention areas in floodplains as well as river restoration projects, are closely connected with the hydromorphology. The study results should finally support and critically review the ongoing WFD activities in the field of (hydromorphological) reference conditions, typology, water body assessment, monitoring (which are mostly based on Biological Quality Elements) towards the River Basin Management Planning 2009. One challenge and symbol should be the restoration of the entire river continuum to again allow Sturgeon migration from the Black Sea up to the Austrian and possibly the German Danube section.

Acknowledgements

Financial support:

Eawag: Swiss Federal Institute of Aquatic Science and Technology

External data support:

Various GIS and map data (topographical maps, aerial pictures, multi-temporal and multi-sensorial satellite data such as CORONA images, KFA and Landsat as well as historical maps for selected parts) were provided by:

EURONATUR, Radolfzell, Germany (www.euronatur.org)

WWF Austria (Office for Central-Eastern Europe, www.wwf.at)

FLUVIUS, Vienna (www.fluvius.com)

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Comments:

Valuable comments were kindly provided by Jürg Bloesch (Eawag), Ivana Theodorovic (University of Novi Sad, President of the IAD), Laszlo Rakoczi (VITUKI Budapest). The study was proof-read by Alexander Zinke (Zinke Environment Consulting for CEE, Vienna).

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List of Abbreviations and Acronyms

BQE	Biological quality elements (under the WFD)
BfG	German Federal Institute of Hydrology
CEN	European Committee for Standardization
CORINE	European-wide landuse database
DRBD	Danube River Basin District
DPRP	Danube Pollution Reduction Programme
EC	European Commission
EU	European Union
FFH	EC Flora-Fauna-Habitat Directive
GES	Good Ecological Status (under the WFD)
GEF	Global Environmental Facility
GIS	Geographical Information Systems
HMWB	Heavily modified water body (under the WFD)
ICPDR	International Commission for the Protection of the Danube River
ISO Country codes	AT: Austria, BG: Bulgaria, CZ: Czech Republic, DE: Germany, HR: Croatia, HU: Hungary, PL: Poland, RO: Romania, RS: Serbia, SI Slovenia, SK: Slovakia, UK: United Kingdom
JDS	Joint Danube Survey (ICPDR)
LWD	Large woody debris
PoM	Programme of Measures (under the WFD)
RHS	River habitat survey
UNDP	United Nations Development Programme
WFD	EU Water Framework Directive

Glossary of selected terms

Bed load	Transported coarse river bed material (mostly gravel) along the bottom (coasting, sliding or jumping), or sand in lowland rivers.
Channel incision	River bed erosion due to reduced or missing sediment supply, often in combination with river straightening and increased shear stress at the bottom.
Discharge	Volume of water flowing through a cross section of a river within a certain time period.
Hydromorphology	Science of the physical characterisation of riverine habitats based on hydrologic-hydraulic and morphologic-sedimentological parameters, including the channels, the banks and the floodplain.
Active and morphological floodplain	The active floodplain is still regularly flooded in between the flood protection dikes; the morphological floodplain describes the former, temporary inundated area in between the lower terraces created during the Holocene.
Risk Assessment	Investigation addressing the risk of failure to achieve the environmental objectives (Good Ecological Status) under the WFD.
River engineering	Complex types of measures applied to modify rivers for different purposes (flood protection, waterway transport, hydropower, urbanization, agriculture) by different technical works (e.g. dredging) and artificial structures such as dams, weirs, bank protection (rip-rap), groins, reflectors, ground sills and others.
rkm	River kilometer.

Executive Summary

In recent years, scientific research about the interrelation between hydromorphology, floodplains and the role of habitat variability for biodiversity, i.e. the functioning of dynamic aquatic ecosystems, has gained much attention.
Hydromorphological data of water bodies, especially of rivers, became more relevant, since the European Water Framework Directive (WFD) includes hydromorphology as an additional parameter to evaluate the quality of surface water bodies (rivers, lakes, coastal and transitional waters) and to provide development targets ("Good ecological status" and, for heavily modified water bodies, "Good ecological potential"). For the reference conditions, for the water body delineation as well as for the typology of surface water bodies, selected hydromorphological data are already used. In addition, the designation of "Heavily Modified Water Bodies (HMWB)" as described in the WFD is depending on hydromorphological conditions. The assessment should be based on harmonised hydromorphological parameters (where available extracted from existing or ongoing inventories). Although the WFD requires only the morphological characterisation of water bodies, hydrological and sedimentological changes in river systems are also induced, e.g. by dams and water abstractions, and must also be part of hydromorphological inventories for risk assessments (risk of failure to achieve the environmental objectives, as required by the WFD) and the further management planning. First risk assessments in Europe indicate the importance of hydromorphological alterations. E.g. for Austria the first "characterisation and analysis report" for the WFD in 2005 indicated about 85% of all water bodies as "possibly at risk", including over 30% of HMWB's (Lebensministerium 2005). As regards the biological and chemical water quality deterioration, pollution and hydromorphological impacts are the most significant.
Research projects such as the European STAR (Standardisation of River Assessment Methods, www.eu-star.at) project show that the relation between biological and chemical quality elements and hydromorphological parameters have to be evaluated more precisely.

In the 1990s, hydromorphological inventories in the German-speaking region of the Upper Danube River Basin used an evaluation chart of 7 deterioration classes, from "not affected" to "completely modified", similar to the 7 classes approach for the saprobiology ("not polluted" to "heavily polluted"). During the last years, efforts were made to reduce these seven classes to five classes for both systems to ensure comparability between the assessments and to meet WFD requirements. These methods must now be harmonized for both systems (CEN standardisation, harmonizing approaches developed in the United Kingdom, France, Germany and Austria). The CEN standard CEN/TC 230 N 0463 offers a basic survey and assessment tool, based mostly on systems developed in the UK, Germany and Austria. To modify and adapt the CEN standard for large rivers such as the Danube it is important to analyse existing methods for medium and large rivers, mostly developed in Germany.

For the Danube River Basin only data for Germany and Austria are available but surveyed with slightly different approaches, while in most other Danubian countries, no data can be used. As the hydromorphological characterisation is part of the water body definition and description for the WFD, all new EU countries (CZ, SK, HU, SI, PL, BG, RO) and accession countries (HR) have to prepare similar inventories over the next years. Potential candidates (RS, BiH, Montenegro) are coordinated in the framework of ICPDR. This underlines the importance of a pilot study for the Drava Basin, which can help to understand and apply the CEN standard within the Danube Basin and provide guidance to these countries.

Based on the international review, the method developed by Kern and Fleischhacker, adopted by the BfG (German Federal Institute for Hydrology 2002), was taken as a basis for the further development in this pilot study. Several modifications and additions were made to fit the method better into the CEN standard and to allow a flexible usage for WFD purposes. Subsequently the method allows the full five-class assessment and offers first approaches to develop measures to reach the Good Ecological Status (GES) under the Water Framework Directive (WFD). To assess large rivers a long-term preparation and data analysis of existing data must be expected in comparison to small rivers.

The Drava and Mura rivers were chosen for this pilot study due to the excellent base data available and the long experience (over eight years) and earlier hydromorphological surveys by the consultant. Further, the Drava and Mura rivers offer great variability of hydromorphological types, from their alpine headwaters and upper catchments (up to 3,600 m a.s.l.) down to the Illyric and Pannonian lowlands when entering the Danube at the famous Kopački Rit wetland (80 m a.s.l.). Beside the landscape-ecological and eco-regional subdivision, the current use of the rivers are typical for many rivers coming from mountains: Intensive use of hydropower and related alterations of the hydrological regime, retention and excavation of about 1/3 of the bed load sediments within the impounded sections, a chain of weirs and dams, sediment dredging for commercial and water management purposes in the middle river courses and finally waterway transport on the last 100 km of the lower Drava.

For this assessment, the lower Drava and Mura rivers were surveyed by boat and, for several stretches, over land during the summer of 2005. Later in 2005 long stretches of the middle and upper section of the Drava were visited to gain local samples for calibrating the already existing information from Austria.

A GIS database was then developed to allow an easy and fast analysis of about 500 datasets (left and right "bank" stretches), which are available for each 50 different parameters with different values. As the survey for large rivers requires a lot of base data from different sources (such as hydrological data, navigation data, water management data, dredging activities) a long time was spent in early 2005 to collect and analyze these data. In parallel the development of the hydromorphological reference conditions was carried out by analyzing additional historical maps and data. This serves as the base for assessing today's hydromorphological status, which has to be calibrated with the surveyed features after the field work.

The results of the study highlight the importance to systematically survey hydromorphological features also for large rivers, and to develop a concise database to allow and discuss all further assessments and evaluations under the WFD. The results are subdivided into three main parameter groups (channel, banks/riparian zone, floodplain) according to the CEN standard and finally summarised and assessed in the five class system, as required by the WFD:

Channel: Only a very few stretches of the entire Drava and Mura (together about 90 km out of 1,100 km but very scattered) could be attributed to the best quality class. They are mostly located along the lower courses, showing all features of a near-natural channel in comparison to the reference condition. Over 25% of all channel sections are completely modified (impounded). After all, about 30 % belong to the quality class 2, indicating a still high ecological potential of the rivers. The two most significant pressures are flood protection and hydropower generation. But for the lower Drava, in particular the non-existing but maintained navigation (mean and low water regulation) and the commercial gravel and sand extraction are significant pressures.

Banks/Riparian zone: Only about 20% of the surveyed steep banks (indicating lateral erosion and channel shifting) reflect natural conditions, the other 80% are reinforced by rip-rap (different age and type of bank stabilisation). Compared to reference conditions the potential total length of erodable steep banks must be estimated 2-3 times higher compared to the current situation. Summarizing, only about 5-10% of the originally available steep banks still exist (only at the lower Drava and Mura, about 310 rkm).

Floodplain: Today, more than 75% of the morphological floodplain (2,450 km²) is cut off or lost from the regularly flooded area. The remaining area still hosts most of the typical soft and hardwood habitats in particular along the lower Mura and Drava.

The results for the lower Drava indicate that about half of the river is affected by the hydropeaking of the last Croatian hydropower plant Dubrava, which lowers the overall assessment for several upper stretches with still very good hydromorphological conditions. This is remarkable for the high differentiation and detailed interpretation of the hydromorphological data, allowing on the one hand a clear pressure-oriented approach and on the other hand giving a clear picture about the potential for development and (self-) restoration.

For the upper river courses, the Austrian data can be used directly for the overview and comparison purposes. For several Drava and Mura sections the existing very detailed hydromorphological data and reference analyses indicate a high compatibility with the results gained at the lower Mura and Drava rivers. Concerning the WFD relevant risk estimation and thresholds, the variability of the results does not exceed the expectations, however, for several longer sections of the lower Mura in Austria the assessment seems to be too positive in direct comparison to the lower Mura in Croatia/Hungary which should serve as a reference for the Austrian sections (with type-specific morphological differences, of course).

The pilot study underlines the importance of a detailed knowledge of the hydromorphological features of large rivers in the Danube Basin, which is not continuously secured, not even in Germany and Austria. The results allow a precise estimation and assessment of all required parts under the WFD - from the reference conditions over the status assessment towards the measures – in order to preserve or enhance the good ecological status. Hydromorphology serves thus not only as an additional “parameter” to support biological parameters, but much more as a comprehensive assessment of the overall river and floodplain status, allowing to define measures for the future river- and floodplain management. As the used method fits into the CEN Guidance standard the basic comparability and assessment will be guaranteed. However the response of the Biological Quality Elements (BQE) should be analysed more in detail, in particular for large rivers.

1 Introduction: Hydromorphological Inventories

Historically, many countries in Europe have assessed river ‘quality’ simply in terms of the chemical or pollution status of their waters. Today, a more comprehensive view of river habitats is required to respond to the pressing ecological questions, such as those arising from the EU Water Framework Directive (WFD) and the EU Habitats Directive, to address the International Convention on Biodiversity, or to assess proposed river engineering schemes and other catchment developments. In most European countries, there is now pressure from statutory and non-governmental environment and conservation bodies to return rivers to more natural and dynamic conditions. This implies a need to evaluate riverine areas, which require protection and restoration, and to encourage better management of river systems throughout Europe.

In the past, the hydromorphological structure of streams and rivers was only investigated in selected sample sections where limnologists focused on specific habitat conditions for riverine species. In other cases, river engineers have analyzed and modified river reaches, their slope, planform and bank character in order to protect settlements from floods, to improve navigation conditions or to build power plants. The third interest group, fluvial geomorphologists, started half a century earlier with the description of morphological river types and prepared first inventories of floodplains and riverine landscapes.
In the 1970s and early 1980s, the progressing degradation of surface waters and the growing ecological knowledge of the dependency of aquatic and semi-aquatic species on riverine ecotopes strengthened the interdisciplinary approach to investigate and, in a second step, to assess hydromorphological features of rivers. First comprehensive surveys and evaluation schemes were developed after 1980 in Austria, the United Kingdom, Germany and France.

Detailed quantitative pre-evaluations such as the counting of defined structural elements along given river stretches and the statistical evaluation to define morphological type groups were described e.g. by Sommerhäuser & Klausmeier 1999 for German lowland rivers, or by Mader et al. 1999 for Austrian rivers.

Based on the ecomorphological survey, the benchmark for evaluation is the natural functionality or near-naturalness of a river stretch, or in other words, its potential natural state or reference condition. Such a river stretch may be termed natural or near-natural, respectively, when a free lateral movement of the river course is possible. This implies longitudinal continuity, lateral connectivity as well as vertical groundwater relations (compare Ward 1989) of the riverbed (riverbed dynamics), the mobility of the bank (bank dynamics), and the natural flooding and lateral movement of the river channel within the floodplain (floodplain dynamics, compare Dister 1991). The result using scoring points for parameter groups is a 5, 6 or 7 class evaluation scheme, ranging from “not affected (1)” to “completely modified” class 5 under the WFD, class 6 according to RHS in the UK, or class 7 according to Werth 1992, LAWA 2000 in DE/AT), compare also Figure 1. Apart from initial inventories urgently needed for many Danubian countries, a re-assessment of hydromorphological features should be done if changes can be documented (the WFD recommends a general monitoring cycle of six years). Those results in the field of hydromorphology depend on restoration projects, which have to be started within the next years, on big flood events and their hydromorpho-dynamic processes and on the way how maintenance work will be done in the future, in particular related to waterway transport and flood protection on the Danube and major tributaries. More land (more space) for a river needs less maintenance regarding a sustainable development, reduces the flood damages and is a precondition for improving the hydromorphological features.

To fulfill the urgent needs of the WFD, the trend in recent years goes much more towards fast screening methods, allowing a five class evaluation, based on a few parameter groups without specific reference conditions (Austrian screening for small rivers, BAW, 2005) and focusing on the WFD impact and pressure analysis. One major issue for the method development is therefore the combination or at least compatibility and flexibility between a quantitative hydromorphological inventory and the urgent WFD requirements to estimate the general risk of failure to achieve the good ecological status and to approve the designation of heavily modified water bodies.

In the future, hydromorphological inventories have to be expanded also to standing waters; especially for lakes more systematic approaches and harmonization are needed. A new “Lake Habitat Survey“ (LHS) for the United Kingdom was developed by Rowan et al. (2006).

Finally the recent flood events and EU Directives on Floods and Sediments (proposed) as well as the need for more river restoration underline the importance of concise hydromorphological inventories for many future tasks.

2 Existing Methods, Standards and Applications

This chapter gives a thematic introduction and comparison of different methods and survey approaches highlighting the European CEN standard. Due to the numerous different approaches, parameters and evaluation schemes, only the German and British methodologies are explained (the UK RHS is described in chapter 2.2 under “Other European inventories and comparisons”). In addition to the focus on WFD relevant features and assessments the picture has to be completed through a broader scope related to river engineering, morphological reference conditions, floodplain inventories, restoration projects and measure tools.

2.1 German and Austrian inventories

Since the early 1990s, different approaches to evaluate the hydromorphology (the term eco-morphology was first used in German speaking countries) were developed in Austria, Germany, the UK and France. First comprehensive inventories were published at the beginning of the 1990s, and since 1995, systematic national inventories are under preparation or even completed.

In Germany, the LAWA (Länder Arbeitsgemeinschaft Wasser) developed over a timeframe of nearly 10 years a common standard methodology for small and medium rivers (LAWA 2000). The German Bundesländer (federal provinces) usually based their investigations and evaluation on this methodology. The following example from the German Hydrological Atlas shows a generalized overview approach based on the *on-site approach* mentioned above and an *overview approach* which is described in chapter 2.4.

Table 1
Parameters for the On-site methodology to assess German rivers (HAD, 2003).

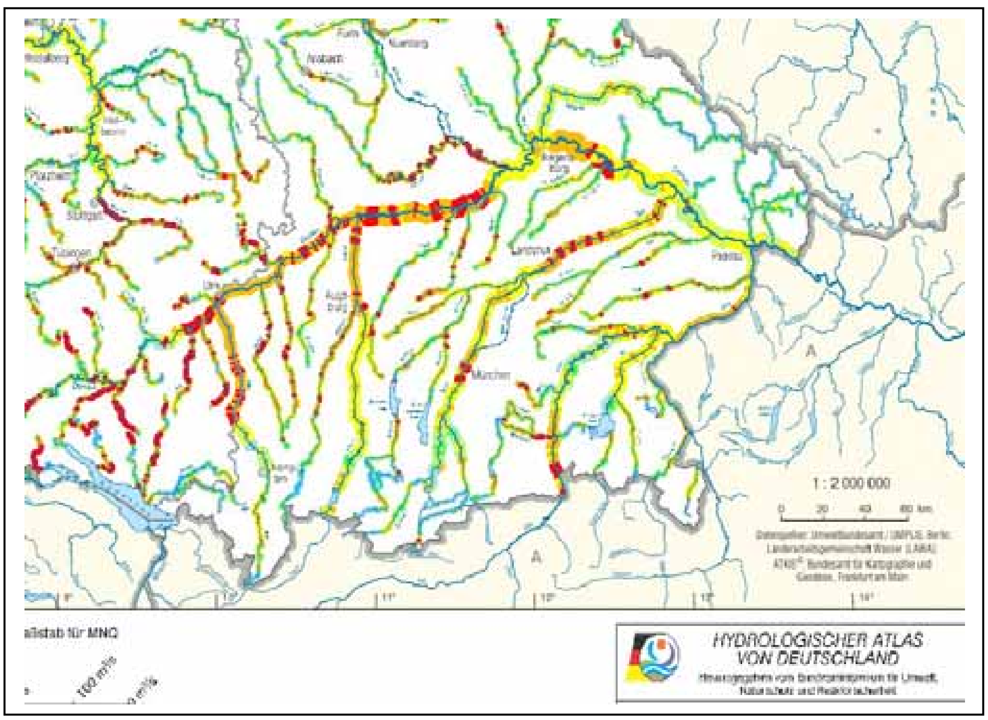
individual parameters	functional unit	main parameters	area	
sinuosity, longitudinal bars, special structures of the course	curves	planform	channel	total assessment
curve-based erosion, profile depth, bank impairments	mobility			
transverse bars, current diversity, depth variation	natural long section elements	long section		
weirs, piping, traffic crossings, backwaters	artificial wandering barriers			
substrate types, substrate diversity, special bed structures	type and distribution of substrates	bed substrates		
bed impairments	bed impairments			
profile depth	profile depth	cross-sectional profile	river banks/ riparian zone	
width erosion, width variation	width development			
profile form	profile form			
special bank features	form typical for the river type	bank substrates		
riparian vegetation	natural vegetation			
bank impairments	bank impairments			
river corridor	river corridor	lateral connectivity	flood-plain	
land use, other local structures	floodplain corridor			

Figure 1
Classes of hydromorphological features and total percentage of each class for German rivers in 2001 (HAD, 2003).

class	classification of hydromorphological features*	short description	year 2001
1	not affected	The hydromorphological features are comparable to the potentially natural state.	2%
2	slightly affected	The hydromorphological features are slightly affected by singular, local influences.	8%
3	moderately affected	The hydromorphological features are moderately affected by several local influences.	11%
4	significantly affected	The hydromorphological features are significantly affected by several impacts, e.g. in bed, banks, by impoundments and/or uses in the floodplain.	19%
5	strongly modified	The hydromorphological features are modified by a combination of impacts, e.g. in course, by bank impairments, transverse bars, impoundments, flood protection measures and/or uses in the floodplain.	27%
6	severely modified	The hydromorphological features are severely changed by a combination of impacts e.g. in the course, bank impairments, transverse structures, impoundments, flood protection measures, and/or uses in the floodplain.	23%
7	completely modified	The hydromorphological features are completely modified by impacts on course, by bank impairments, transverse structures, impoundments, flood protection measures and/or uses in the floodplain.	10%

*At certain stretches, the hydromorphological features cannot be changed substantially because of the degree of utilisation for shipping, settlements, hydropower or flood prevention measures.

Figure 2
Map extract showing the German part of the Danube Basin (HAD, 2003).



In Austria, Werth (1992) developed very early one of the first survey systems. Most of the Austrian Bundesländer use his methodology and, today, nearly 80 % of the entire country is covered by comparable inventories, at least for the larger rivers with catchments of approx. > 100 km². The change from the 7-class to the 5-class evaluation system, which is in line with the WFD requirements, can be described for Austria (in Germany a slightly different adaptation was applied, see table 2). This class reduction is an integral part of the national strategy to prepare national reports for the WFD by the Ministry for Environment (Lebensministerium) and the Austrian Federal Environmental Agency (UBA). Concerning the final WFD risk assessment and the HMWB designation, the 5-class system of the hydromorphological assessment was further reduced into three categories: not at risk (class 1-2), possibly at risk (class 3), at risk (class 4-5). The threshold is between the classes two and three depending on the water body and the specific characterisation (e.g. migration obstacles, residual water, hydropeaking).

Table 2
Adaptation of national inventories from the 7 class to the 5 class system in Austria (in Germany the first two and the last two classes were merged)

old 7 class system	new 5 class system (WFD)
1	1
1-2	
2	2
2-3	
3	3
3-4	4
4	5

Based on the results of Muhar since 1999 (e.g. Muhar et al. 2004), the Austrian rivers with catchments over 500 km² were assessed using parameter groups (morphology, fish and floodplain vegetation), and a large project on riverine landscapes was carried out. Especially in the light of the morphological typology and overall evaluation of Austrian rivers the results are very impressive.
Recent approaches in Austria analyze the potential of the usage of aerial images for detailed surveys (Oberösterreichische Landesregierung 2005). In order to close the gaps concerning the WFD the Austrian Institute for Water Quality developed in 2005 a so-called "Screening method for small rivers with a catchment below 100 km² (BAW 2005).

2.2 Other European inventories and comparisons

Prior to presenting the CEN standard in more detail in chapter 2.3, reference should be made to another document prepared in 2002 (at the beginning of the CEN procedure) within the European STAR Project (Standardization of River Classifications, formerly AQUEM project, www.eu-star.at), entitled "Guidance for the Assessment of Hydromorphological Features of Rivers within the STAR Project". This guidance is based on the UK standard RHS (River Habitat Survey), giving more attention to the direct link and providing quantitative data on hydromorphology in relation to aquatic organisms (organism-response relationships). This river-habitat assessment method is not planned as a standard parallel to the new CEN standard (in fact, most parts overlap with the CEN Standard). Advantages of this method for questions related to the STAR project are given by the consideration of transect surveys of flow types (useful to link an invertebrate community and sampling stretches with the habitat structure). Another specification of this method is to work with 500 m long river sections, which are divided into 50 m stretches (allowing a statistical analysis). This evaluation system has only six classes. RHS in its current form is unsuitable for over 100 m wide rivers or braided rivers but offers a comprehensive, easy-to-use application and, of course, its English terminology. STAR tries to harmonize river in-stream habitat surveys with the biological components and linkage with standardized indicator groups and proposes positions for the sampling sites of macroinvertebrates, phytobenthos, macrophytes and fish where applicable. The distinction in the AQUEM sampling methodology in riffle (lotic sites/erosional) and pool (lentic sites/depositional) areas can be considered within the RHS method: The specific flow velocity indication over a transect allows detailed information of a specific habitat in combination with different substrate types (in this regard also the eco-hydraulic modeling should be mentioned, e.g. Jorde et al. 2000). But it should be considered that these inventories were tested only on the smaller pilot streams of the AQUEM project and raised new questions, especially in cases where the hydromorphological conditions are more homogenous (plains or uplands). The extension of the RHS system for the use in South European rivers shows the necessity to consider two specific features for specific river and substrate types: Firstly the presence of secondary wetted channels, and, secondly, the relative width of the wetted channels versus the total channel width.

Raven at. al. (2002) tested the three hydromorphological and river habitat assessment methods, developed in Germany, France and the UK, for qualitative cross-comparison in 2001. Each was tested on river stretches in North-east France and in the French Pyrenees. The type of features recorded by all three methods was broadly similar, but differences in survey strategy, data collection, and analysis resulted in variations in quality assessment. Different interpretation of what constitutes 'undisturbed conditions' has a major impact on outputs. There are also scale-related problems when comparing the different methods. Despite these differences, there is sufficient common ground to allow refinement of the methods to achieve better harmonization. The CEN standard will be one step in the right direction. The upcoming "Assessment quality and calibration" Standard should secure and strengthen the harmonization and comparability of the practical work and results.

……………………
Table 3
Synopsis of the English (RHS), French (SEQ physique) and German (LAWA) hydromorphological methods.

	RHS	SEQ	LAWA
Survey type	Site oriented	continuous	continuous
River size	< 100 m, no braided rivers	< 100 m	<50 m or any kind of large rivers
No of parameters	200	50	25-50
CEN conform	yes	mostly	yes

In the meantime two extensions to the RHS were developed, the so-called GeoRHS (Geomorphological River Habitat Survey, Defra 2005) offering the detailed characterisation of channel and floodplain geomorphology over 500 m reaches and the RCS (River Corridor Survey), which produce vegetation structure maps. The SERCON evaluation process (System for Evaluating Rivers for Conservations) is a synthesis of RHS, RCS and the biological water quality, assessing the conservation value based on naturalness, physical habitat diversity and species richness.
Finally, the so-called LHS (LakeHabitat Survey, Rovan et al. 2006) opens a new perspective for the hydromorphological assessment of lakes and standing water bodies.

2.3 CEN Guidance Standard 2004

Recently a couple of new CEN standards related to fresh water quality are under finalization, e.g. for macroinvertebrates, zooplankton, phytobenthos, phytoplankton, macrophytes, fish and hydromorphology. All these CEN-standards should support the harmonization within the WFD implementation. The CEN Standard was prepared based on the long experience of British experts with the RHS and the European STAR project over the past years. Therefore this Standard is mostly based on a biological and limnological perspective, which need a high spatial resolution of surveyed data. The following text is mostly extracted from the CEN Standard CEN/TC 230 N 0463 (CEN 2004):

The European Standard provides guidance on the features to be recorded when characterizing and assessing the hydromorphology of rivers. It is based on methods developed, tested, and compared in Europe. Its main aim is to improve the comparability of hydromorphological survey methods, data processing, interpretation and presentation of results. Whilst it has particular importance in relation to the reporting requirements of the WFD, it also has a considerably wider scope for other applications. Although hydromorphology is dependent on hydrology and the underlying geology, this standard is focused on the structural features of rivers and on river continuity. In addition, whilst recognizing the important influence of hydromorphology on plant and animal ecology and, conversely, the influence of plants and animals on hydromorphology, no attempt is made to provide guidance in this area.

2.3.1 Principle, survey requirements

A standard assessment protocol is described for recording the physical features of river channels, banks, riparian zones and floodplains. The range of features surveyed, and the methods used for survey, may vary according to river character and the objectives of the study but this standard provides a common framework for these different methods. Guidance is given on the hydromorphological features that should be used for characterizing river types and for further assessing the morphological integrity through comparisons with reference conditions. The selection of features for survey will depend upon geographical scale and on the purpose of the exercise, with some features suitable for characterizing river types, some for assessment, and some for both. River types and the division into river reaches have to be defined according to system A or B used in the WFD for river types, and the division has to follow the specific survey requirements (system A is based on simple overall parameters, the altitude and catchment in size classes and the principle geology, whereas system B allows in addition optional parameters such as discharge, width and depth, valley shape or substrates).

2.3.2 Features for survey and assessment

The following list provides a standard check list of hydromorphological features for survey and assessment. These are grouped in 10 categories and cover the three broad zones of river environments:

a) Channel: geometry, substrates, vegetation and organic debris, erosion deposition character, flow, longitudinal continuity as affected by artificial structures
b) River banks / riparian zone: bank structure and modifications, vegetation type / structure on banks and adjacent land
c) Floodplain: adjacent land use and associated features, degree of lateral connectivity of river and floodplain and lateral movement of the river channel

1. Dividing rivers into reaches based on changing geology, valley form, slope, planform, discharge, land use and sediment transport
2. Survey strategy (entire stretch or sampling within a reach)
3. Scale of survey and evaluations
4. Timing and frequency of field survey
5. Reference conditions
6. Bed and bank character
7. Planform and river profile
8. Lateral connectivity and freedom of lateral movement
9. Free flow of water and sediment in the channel
10. Vegetation in the riparian zone

The field survey procedure: Depending on the purpose of the assessment, field survey should be preceded or followed by exhaustive use and interpretation of all available data, such as historical or recent maps or remote sensing. Field survey should be carried out by walking along the riverbank (left or right). Where floodplain features on the opposite side of the river cannot be seen clearly, a check of that side of the river is strongly recommended. Using a boat can help in checking channel and bank features in places not easily accessible from the banks. Under certain conditions, it may be impossible to gain access to the channel to record features such as river substrates. These may sometimes be obvious from the bank, but entering the channel to check is recommended wherever possible.
Field recorders require a good understanding of the survey method and familiarity with the features recorded. Surveys should characterize the river by recording the presence and relative abundance of hydromorphological features and attributes, whether natural or artificial, rather than producing detailed descriptions. Completed survey forms should be complemented by photographs of the site with details of the recorded location; these are important for reporting purposes as well as for future comparisons. Locations of sites (e.g. upstream and downstream limits, positions of photographs) should be accurately determined using GPS equipment and always checking the site locations against a map.

2.3.3 Classification and reporting

The procedure for assessing hydromorphological survey data varies according to the purpose of the assessment (e.g. assisting local river management, guiding the rehabilitation of degraded river stretches, or identifying sites or reaches for the reference condition under the WFD). This European standard takes account of the present level of sophistication of national hydromorphological assessment methods and provides guidance to enable a basic assessment of the extent of deviation from reference conditions. It is intended that further development of national methods and inter-comparison of the results will lead to harmonized assessments, based on type-specific predictions of the occurring physical features in a river. The extent of deviation from a reference condition is used to place a site or reach in one of five classes according to its degree of modification. This is achieved by assessing data from field survey and other sources (e.g. maps, remote sensing).
The presentation of the assessment in maps should be made in a five-class chart, with 1 (blue, reference conditions), 2 (green), 3 (yellow), 4 (orange) and 5 (red).

2.4 Inventories and applications for large rivers

Basically, the first methodological approaches were developed for small to medium-sized rivers, but recently, most of the methodologies proved to be insufficient to evaluate the floodplain and backwaters of large rivers. The application and observation of all relevant parameters on a large river is much more difficult (visibility of the bed and substrates, slope, river type, segmentation and river reach definition for the evaluation). An often applied approach is to reduce bed parameters in large rivers and to scale up the minimum investigation stretch, e.g. from 100 to 400 m but the application of methods for small rivers on large rivers leads to accuracy problems. The LAWA in Germany developed an overview methodology mostly based on aerial pictures and on an evaluation of existing data without extensive field investigations. The parameters of the riverbed and the banks are summarized here as “riverbed dynamics”, the minimum investigation stretch is larger than 1 km. This method is only applicable for rivers, which are very well visible by aerial pictures and for which detailed local information already exists. In particular the second summarized parameter, the “floodplain dynamics” can only be determined if extended local data are available which can explain the floodplain retention and lateral connectivity.

Under the guidance of LAWA and DVWK (1997), several pilot studies in large rivers in Germany were carried out. These inventories offer more accuracy especially in lateral direction and for bank- and bed-building processes. The disadvantage is the large amount of data to be surveyed and processed. Kern, Fleischhacker and Rast (1999) developed a methodology for medium-sized rivers tested and evaluated in detail along the eastern German river Mulde (Elbe tributary). On the same river Pauschert & Buschmann (1999) tested their methodology on the evaluation of ecomorphology of floodplains (“Strukturgüte von Flußauen”). Kern proposed for large rivers (80-220 m width) minimum survey stretches of 2.5 km and for very large rivers (Danube) over 220 m wide a minimum stretch of 5 km. Due to the missing experience for large rivers and the existence of many small deteriorations such as regulation works (e.g. new rip-rap or reflectors over several rkm) or concrete banks in front of dams it seems to be necessary to consider also stretches with about 1-2 km minimum size. This matches also with the official recommendations of LAWA (rivers < 10 m: 100 m stretches, rivers > 100 m: 1,000 m stretches). In this matter the question of the cartographic visualization should be mentioned: The smallest visible stretch in a Drava catchment map of a scale of 1: 1,350,000 is about 5 km (2 mm on the map). Lessons learned from the generalization for the German hydrological atlas (HAD, compare figure 2) at the scale of 1: 2,000,000 should be used.

Another inventory was applied along the Austrian Danube within the Danube national park (WSD 1999). The investigation was focused on the riverbanks of the Danube main stream and in the adjacent floodplain behind the embankment (so-called Treppelweg) of the waterway. For the riverbanks, the morphology and the vegetation were recorded but no assessment was applied. The floodplain was described using parameters such as the lateral connectivity, the topography and again the vegetation.

Schwarz & Mohl (1998) applied for a 40 km long Drava stretch a specific inventory method, including all floodplain waters such as side channels, oxbows and small floodplain waters (pools, small channels). A lot of detailed data for steep banks and pioneer stands were collected. Later in 2002 the stretch was evaluated according to the five-class system based on the Austrian methodology. Schwarz & Jensen (2002) also proposed a remote sensing-based floodplain inventory of the Danube.

All these extended inventories allow a more detailed evaluation of the floodplain and the reference status of river and floodplain. For the definition of the reference status additional parameters such as side channels and floodplain sediments are added to basic parameters such as hydrological regime, planform or valley form, which are included in the CEN standard. In floodplain inventories additional parameters such as the discharge through the floodplain, the floodplain relief, the biotopes and the structure of use of the floodplain have to be considered. Koenzen 2005 developed a floodplain typology and reference conditions for larger rivers in Germany.

Finally, this detailed approach matches much better the conditions of large rivers but the survey is much more extensive than the CEN standard and most of the national inventories. In the best case the CEN standard framework could be applied for large rivers, while keeping as many standard parameters as possible but adding new parameters for the lateral connectivity and the floodplain.

2.4.1 German method for large rivers and waterways

The BfG method (BfG 2002) for large rivers was developed by Kern and Fleischhacker since 2000 (Kern et al. 2002) offering the possibility to survey large rivers and, in particular, waterways. The field survey should be minimized as much as possible. Otherwise this means the intensive use of already existing data on hydrology, navigation and floodplain features derived from maps as well as from aerial pictures. The method was tested along the Rhine and particularly along the Elbe River in Germany and the Czech Republic (figure 3; BfG 2001).

As mentioned above the most important difference to methods for small rivers is the extended evaluation of river draining features such as groynes mostly for the waterway transport and the floodplain evaluation.

An other method based on the LAWA approaches and the inventory in Nordrhein-Westfalen (so called LAWA method for medium to large rivers) were used for the Rhine inventory by the IKSR (International Commission for the Protection of the River Rhine) (IKSR 2003). The sample map (compare figure 4) shows the similar colour ribbon map as used for the Elbe.

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Figure 3: Example for the BfG pilot mapping along the Czech and German Elbe, showing a coloured ribbon map with the former seven class evaluation scheme (BfG 2001).

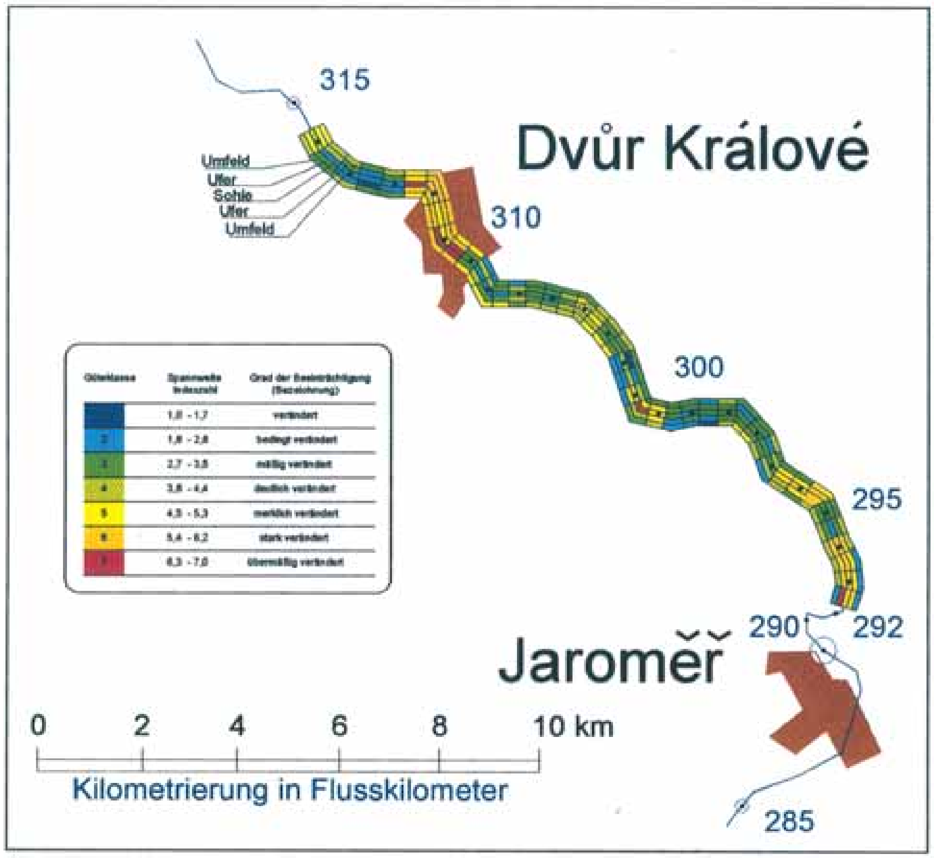

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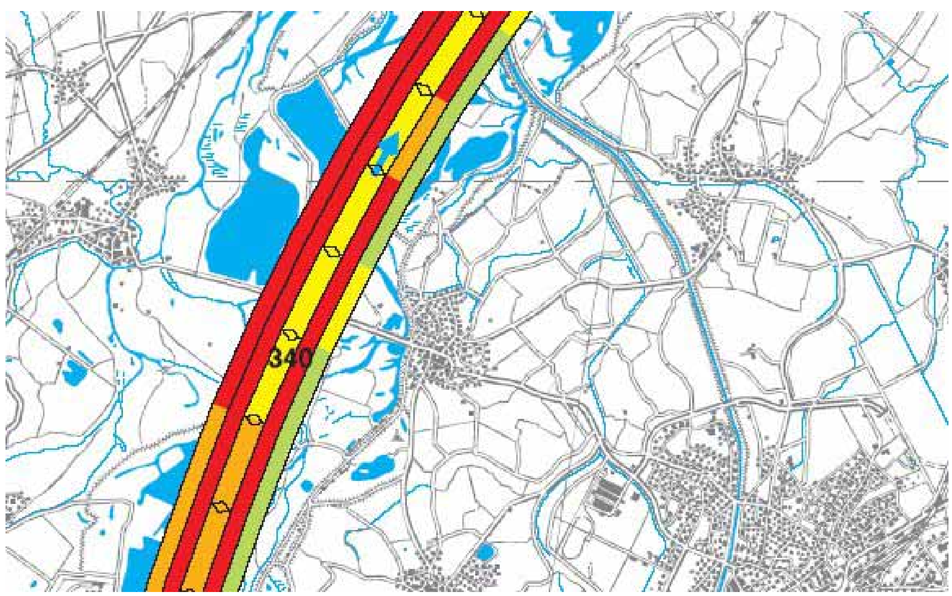
Figure 4:
The recent inventory of the IKSR 2003 is already shown in the five class scheme. The extract shows the Rhine near Rastatt with a channel evaluation in the classes 3 and 4, strongly modified banks (class 5 in red) and only good (2) values for the floodplain along the right bank.



2.4.2 Development of reference conditions

In recent years the importance of the development of reference conditions and “Leitbilder” for large rivers was recognized, but only for a few river stretches such an analysis was prepared (e.g. Austrian Machland by Hohensinner et al. 2005, Möll by Muhar et. al. 2003). For the lower Rhine in Germany LUA 2003 proposed a differentiated development for river section specific reference conditions for a large river. Also for the Elbe River continued evaluations were performed (Rommel 2000). Koenzen (2005) published a floodplain and large river typology including reference conditions for large and medium German rivers.
For the Drava and Mura rivers in this study only the lower river sections where characterized in this detail, for the upper catchment in Austria Muhar et al. (2003 and 2004) offer a detailed analysis.

2.4.3 River engineering, flood and sediment management

Beside the developments of eco- and hydromorphological inventories by biologists, geographers and water engineers, a lot of relevant hydraulic and sedimentological experience was achieved by engineers working mostly with river regulations. Especially the discussion of the channel incision (by river straightening and bed load deficits due to dams) which causes many ecological and partly economic problems such as the groundwater level decrease and instability of structures with adverse effects on the vegetation or the morphological alterations (massive reduction of lateral connectivity and inundation dynamics) was discussed controversially. On the one hand it is estimated that in Europe about 1/3 of the overall sediment load of rivers is trapped in dams and dredged regularly (SEDNET 2004). On the other hand the water management accepted to feed gravel again while at the same time a large amount of bed material has to be dredged for navigation and flood protection purposes. Parallel to the bed incision the fast floodplain aggravation with fine sediments can be observed as a further effect of wide-spread river regulation works. The understanding of these processes is crucial for the hydromorphological survey of rivers.
Most of the hydromorphological impacts are caused by river regulation works over the past 300 years and in particular the last 150 years. Related activities include:

<u>High-water regulation:</u> Flood protection, floodplain cut-off, first channel regulations.
<u>Mean water regulation:</u> Straightening of the main channel and cut off of side arms and meanders, enforcing waterway transport and the flood capacity during flood events.
<u>Low water regulation:</u> Mainly used to enhance the navigability during low water by groynes and guiding structures in the channel.

The flood management (upcoming EU Flood Directive) gives another important aspect for hydromorphological inventories. Especially along the lowland reaches of rivers the discharge capacity is very important. It has to be based on a cross-sectional widening in form of parallel and secondary channels as well as on extended floodplain cross sections.
Finally the sediment household is a very crucial aspect for the hydromorphological conditions. Recent comparisons show the high importance of artificial dredging of sediments for commercial purposes or for waterway maintenance. The amount of dredged material in the middle and lower courses of rivers exceeds by far the material retained behind dams in the headwaters and upper reaches.

2.5 WFD relevance and usage of hydromorphological data

For the overall planning process of the WFD, hydromorphological data and assessments are getting more and more important, in particular for the programmes of measures (PoM) and for the application of other EU Directives such as for Habitats and the upcoming Floods Directives. Based on the results of the "characterisation and analysis reports" in 2005 (e.g. Austrian report, Lebensministerium 2005) more than 70% of the water bodies at risk across Europe can be seen as hydromorphologically altered or even heavily modified (some 30%). For the following main tasks within the WFD planning process hydromorphological data are needed in relation to the biological quality elements (BQE), in particular related to fish, macrozoobentos, algae and macrophytes:

Status quo and target (regarding hydromorphological conditions and alterations):

- Reference conditions and typology (river type specific)
- Current status and relation to the good ecological status
- Base line scenario for 2015

The following points consider socio-economic parameters (regarding hydromorphological alterations):

- Pressures and impact analysis
- HMWB, AWB (artificial water bodies) designation
- Status or good ecological potential (less stringent measures)
- Monitoring (six years interval)

Restoration measures to reach the target (regarding hydromorphological alterations):

- Gap analysis and programme of measures (PoM)
- Implementation of the PoM
- Evaluation of the PoM

Since 2006 the EC is preparing a policy paper on hydromorphology and a "best practise paper" for measures in the field of hydromorphology within the CIS (EC Common Implementation Strategy) Guidance library.

3 Review of the Situation in the Danube River Basin

The following chapter analyzes the situation in the Danube Basin and tries to indicate the most important data gaps and the lack of methodological harmonization.

3.1 Existing national hydromorphological inventories

Germany and Austria already investigated most of their larger rivers over the last ten years, as described in chapter 2.1. In Austria not all of the larger rivers are already continuously evaluated, including the Drava and Mura Rivers but many studies and detailed analysis for selected stretches are available.
The access to hydromorphological background data (data for single parameters) is still deficient in Austria, often only overview maps and charts are available. For all other Danube countries so far only mostly unpublished pilot projects are available or were conducted by foreign research teams (RHS in Slovenia, Aquaterra in Hungary). In Slovenia a seven class evaluation scheme was applied at an overview scale, and in Romania a similar system, so-called IMPAHID (both cited in DRP 2003), tries to assess the impacts on the hydromorphological conditions. An advanced national method was developed in Slovakia based on the BfG approach for large rivers (SHMI 2004). Similar to Slovakia, a Bulgarian EC Twinning Project developed first approaches for a rapid and simple assessment of the hydromorphological conditions based on the sinuosity (channel length / valley length).
The Slovakian method - as one of the most developed methods but still undergoing revisions - is based on a two-step approach: First, rivers were evaluated with a site-related method using transects over a given 1,000 m stretch (depending on the river size), based on CEN and the British RHS but combined with the scoring and assessment of the German BfG method. In the second step the river sections in between were evaluated only for absolutely necessary WFD requirements (reduced parameter sets for the impact and pressure analysis and the risk assessment to fail the GES). The method was developed by hydrologists and sedimentologists and is now under review.

3.2 Existing basin-wide inventories and approaches (ICPDR)

The International Commission for the Protection of the Danube River (ICPDR) has a key facilitating function for implementing the WFD and for all basic environmental objectives related to surface and groundwater in the Danube River Basin. In 2004, the ICPDR prepared a first comprehensive Roof Report (WFD), covering most of the relevant water-related characteristics. Apart from the extensive description of the river basin and its surface and groundwater bodies, in particular the elaboration of risk and pressure inventories gives a completely new picture of the situation in the basin. Related to the hydromorphology at least three inventories and maps should be taken into consideration:

1. The first database and map titled “Major Hydraulic Structures” provides partly detailed data on migration obstacles (such as major dams and weirs), on the existing navigable river sections and harbours along the Danube and its main tributaries as well as a categorisation of rivers in three classes (free-flowing river, strongly regulated river and impounded river sections). Especially the latter inventory can considerably help to define major river sections having similar hydromorphological conditions. For some countries, the database contains very detailed information down to single river kilometres. This inventory which is based on an earlier study prepared in 1999 by the UNDP/GEF Danube Pollution Reduction Programme, lacks still precise definitions for the three river section categories, therefore the inventory can offer only a first basic overview (ICPDR 2005).
2. The second very important inventory shows hydromorphological alterations of surface water bodies with respect to the risk of failure to reach the environmental objectives (Good Ecological Status). As expected these data, in direct comparison to the risk for organic and nutrient pollution (“water quality”), show that the risk by hydromorphological alterations is by far the highest for the Western Danubian countries whereas the hydromorphological risk for the Eastern Danubian countries is lower but high for water quality parameters (ICPDR 2005).
3. The map “Ecological potential of the Danube floodplains”, formerly produced for the UNDP/GEF DPRP wetlands study in 1999 (DPRP 1999) and showing the location and ecological potential of floodplains in the DRBD, presents the remaining, ecologically valuable floodplain areas along the Danube and its main tributaries at an overview scale. In most cases intact floodplains coincidence with intact hydromorphological conditions.

Other inventories, such as of basin-wide important “Heavily Modified Water Bodies” (HMWB), or protected areas complement the overview picture (ICPDR 2005). All inventories could be seen as preliminary for some regions due to methodological discrepancies but, in general, similar inventories are available for the first time for the Danube River Basin. The ongoing preparation of an ICPDR Action Plan for sustainable flood protection and a proposed necessary wetland management strategy has to be highlighted, because both initiatives could profit considerably from a systematic hydromorphological inventory.

Under the UNDP/GEF Danube Regional Project (DRP) a method review and first harmonisation were carried out in relation to the impact and pressure analysis, addressing in particular hydromorphological alterations (DRP 2003). The results will be discussed in the method chapter 4.2.

Finally, single actions such as the Joint Danube Surveys (JDS) in 2001 (ICPDR 2002) and 2007 could help to compare and calibrate both abiotic and biotic data. Unfortunately, the bank structure and morphological structures were yet not sufficiently documented (at least not with continuous photo series or onboard video and a basic description). But for the JDS II in 2007 it is planned to also survey hydromorphological features at the about 100 sampling sites along the Danube in detail and for selected overview parameters along the entire reach. This activity will be used to encourage countries to start their own inventories and to harmonise existing approaches.

3.3 Other inventories and related projects

Over the last five years, several different research projects were related to hydromorphological inventories concerning the WFD and CEN standards. The following two examples highlight only basin-wide projects and data sources.

3.3.1 MIDCC, Danube Corridor

The abbreviation of MIDCC stands for „Multifunctional Integrated Study Danube Corridor and Catchment“; it focuses on a detailed investigation and survey of macrophytes in all types of river and floodplain waters (running and still waters). The project is financed by the Austrian Federal Ministry for Education, Science and Culture and conducted by the University of Vienna, department of Hydrobotany (Janauer et al. 2003).
Concerning abiotic parameters, the survey covers basic information about:

- the bank structure (from artificial rocks over gravel, sand to fine organic material; in total 8 classes),
- the sediment type (from solid over sand to detritus; in total 6 classes),
- the connectivity type (side channels, oxbows, floodplain lakes, main channel; in total 14 classes),
- the land use type according to CORINE; in total 19 classes,
- the flow class (from stagnant water over low flow velocity to high flow velocity > 70 cm/s; in total 5 classes) and
- the Secchi depth transparency (5 cm accuracy).

The survey was conducted by local partners in all Danubian countries and offers a high spatial resolution up to a scale of 1: 25,000 covering most of the entire Danube. In particular the surveyed abiotic parameters could help to prepare a hydromorphological inventory, whereas the data lack longitudinal continuity (continuously covering the entire river bed, fluvial features, bank, berm and the adjacent riparian zone). First results indicate e.g. about 40 % of rip-rap protected banks after a total survey of 5,000 km (right and left banks of the Danube including side channels and oxbows).

In any way such data should be made available for comparison, and especially the network of local researchers could be used for further Danube inventories.

The last strategy is prepared since 2006 in an "Issue paper on hydromorphology" (ICPDR 2006, to be finalized in 2007), following the impact and pressure analysis and HMWB designation but also highlighting the necessary improvement of national methods, approaches and inventories.

3.3.2 Danube Navigation Commission

The Danube Commission (worldwide one of the first international commissions under UN law, founded in 1948) has its headquarter in Budapest and is responsible for all issues concerning inland waterway transport and navigation on the Danube. In this function, the Commission published detailed topographic Danube maps of a scale ranging from 1: 5,000 to 1: 25,000 and covering the entire Danube for the period 1985 to 1995.

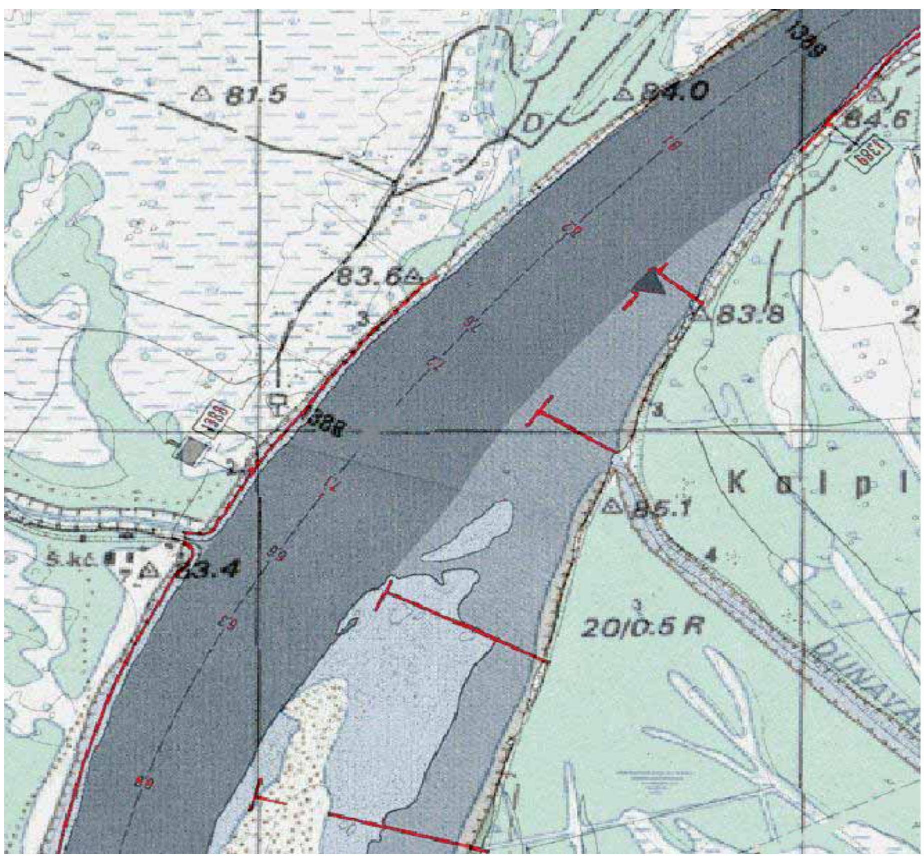


Figure 5 Overlay of the Danube navigation map (Donaukommission 1987) with the topographical map 1: 50,000 (red features show river engineering works such as groynes (right bank) and rip-rap (left bank)).

company viaDonau in Vienna (Germany and Austria are already completely covered as well as parts of Slovakia and Hungary). Next to the detailed navigation information, the map is showing the basic river bed structure at low navigation water level, in particular the exact position of embankments, reflectors, groynes and other stabilisation works which are of great importance for the evaluation of hydromorphological conditions.

In the meantime many of these structures are eroded or silted over, especially in former Yugoslavia, but due to the decrease of transport after 1990 the maintenance of regulation works was considerably reduced also in many other Danubian countries. Since a few years, the transport increases slowly again and the EU declares the Danube transport corridor as one of the most important links between Western and Eastern Europe (TEN-T projects (http://ec.europa.eu/ten/index_en.html), compare also WWF 2002). In consequence, the permanent survey and update of the detailed navigation conditions will become more and more important, the removal of shallows and so-called bottlenecks will be one of the most important targets, but also the hydro-technical improvement of the entire main channel, including the reconstruction of groynes, reflectors and closures of side channels at low water, could become the task of the Danube Commission. It seems to be necessary and helpful to involve this Commission into a hydromorphological survey of the Danube to prevent conflicts and to guarantee the consistent application of EU standards related to the WFD (deterioration prescription concerning the ecological quality, in this specific case including all hydromorphological alterations) and FFH.
The national authorities (e.g. the ViaDonau - Austrian waterway authority) and institutions are doing regular surveys of the river bed (mostly by sonar). Those data as well as the long-term hydrological analysis of discharge and sediment data (e.g. rating curves, the ratio between water discharges and levels) highly support the hydromorphological evaluation of large rivers.

3.3.3 River management concept Vienna-Bratislava

As an example for a possible sustainable solution between waterway transport and enhancements in the hydromorphological environment the river engineering concept for the Danube between Vienna and Bratislava must be mentioned (e.g. Schabuss et al. 2006, www.donau.bmvit.gv.at). The main topics are the reduction of river bed incision by adding a surface layer of large gravel (30-40 mm grain size), the removal of bank reinforcements (including groynes) and the re-opening of side arms. The third and maybe most important and controversial objective of this project is the improvement of the waterway (new low water regulation). The effect of the complete removal of fords over 40 rkm and the situation during very low discharge (400-500 m³/s) in relation to the groundwater situation in the floodplain is rather unclear. The inner colmation between the artificial large grain sized armoured bed layer and the consequences on the groundwater infiltration are not described sufficiently. Due to the higher flow velocity (plus 10%) the navigability upstream has to be more critically analyzed. Until 2008 an environmental impact assessment (EIA) study will examine the project.

First results of the removing embankments vis-à-vis to Hainburg along about 3 km are very promising and also the proposal to reduce the bed incision to a minimum improves the current situation.

Large rivers with sufficient discharge volumes allow a more ecological maintenance of waterways which is not so easy for many upper and some middle reaches (e.g. the Danube at Straubing-Vilshofen in Bavaria).

4 Hydromorphology of the Drava and Mura Rivers

4.1 The Drava Basin

The lower Drava and Mura Rivers along the border between Croatia, Slovenia and Hungary represent one of the last remaining continuous riverine landscapes in Central Europe, with all typical natural river elements, such as large natural islands, gravel and sand banks, side channels, meanders, loam cliffs, oxbows and soft woods. Together with its main tributary, the Mura River, the Drava represents an unique "river corridor" of about 380 km without dams.

The Drava with a river length of about 750 km crosses a broad range of eco-regions such as the high Alpine mountain reach (the Grossglockner with 3,797 m above sea level is the highest peak in the catchment), the Alpine basin reach, the foothill reach and the Pannonian-Illyrian plain (the confluence is at about 80 m above sea level). The mouth of the Drava into the Danube is a huge wetland triangle with the internationally important nature reserve "Kopački Rit".

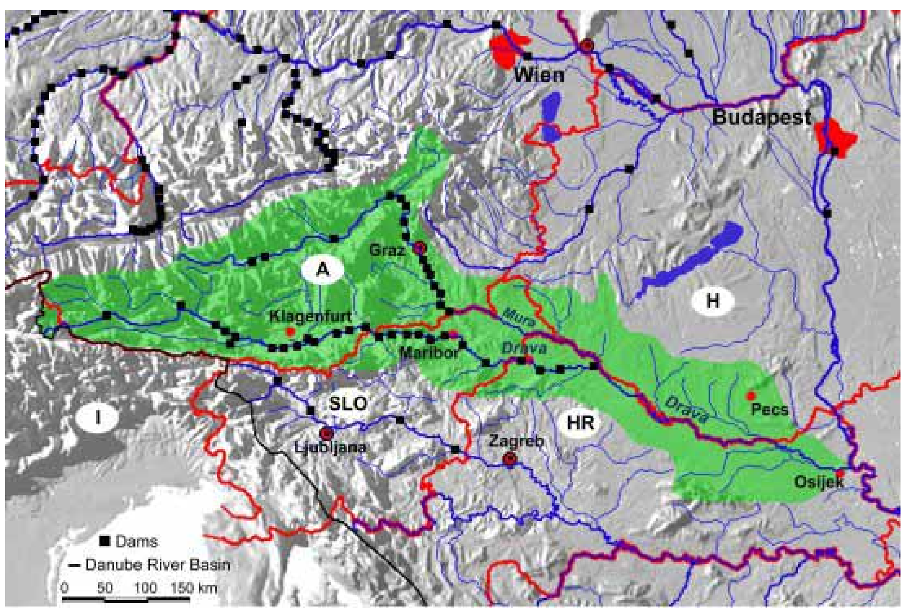


Figure 6: The Drava River Basin is shared by Italy, Austria, Slovenia, Hungary and Croatia.

All typical fluvio-morphological river types from straight over braided up to meandering channel characteristics are present in a broad range. After the confluence of the Mura, the Drava River builds a transition type of a braided to a meandering system with anabranching. This leads to a very rich morphological characterisation of this part of the river corridor. The Drava-Mura river system with a river basin of 40,150 km² and an average discharge of 578 m³/s is the third largest in the Danube Basin: The relief of the Lower Drava consists mostly of lowlands with quaternary sediments and terrace systems. The course follows partly geological basin fracture lines (e.g. high banks in Hungary). The climate is mild-continental and partly humid (illyric) with an average annual temperature of 10.9° and an average rainfall of 600-750 mm/year, very suitable for the famous Slavonian oak forests.

The hydro regime is determined by the alpine region (see fig. 7), the highest discharge occurs between May and July. The Upper Drava has still a glacial regime (climatic change with fast melting glaciers) whilst the Mura, its most important tributary, has a nival regime (peak already in May). The high discharge in autumn is due to the more Mediterranean precipitation characteristics in the middle-south (including parts of the Southern Alps) and lower course of the river. The natural water level fluctuation is between 5-6 meters near Botovo, the mean long-term annual average of discharge ranges between 237 m^3/s (low water - the absolute minimum discharge is around 70 m^3/s), 526 m^3/s (mean water) and 850 m^3/s (high water); the 10 years flood is at about 2,100 m^3/s, the 100 years flood at about 3,200 m^3/s.

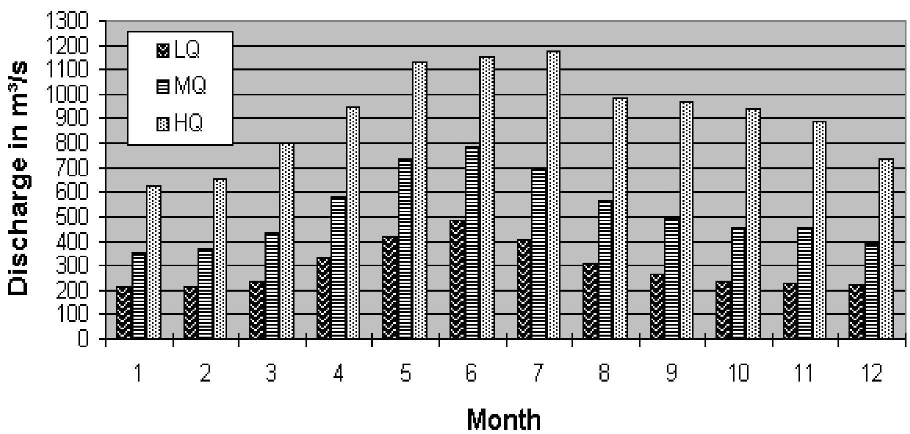


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Figure 7: Average monthly discharge at the gauge station Botovo (1961-1990), 15 km downstream of the Mura confluence, the most important tributary of the Drava.
LQ = low discharge
MQ = mean discharge
HQ = high discharge

Downstream of the last Croatian hydropower plant at Dubrava the hydropeaking is the most important pressure. Several times a day the water level drops and rises about 1-1.5 m (see fig. 8). As the still existing morphological conditions (lateral connectivity) allow the water to enter side channels and the lowest part of the floodplain, the peaks are buffered to a certain degree (retention in side channels). During "low" water periods the water flows back into the main channel.

The lowland rivers Drava and Mura remained quite untouched due to their long-term function as strict border line, recently as the "Iron Curtain" between Hungary and the former Yugoslavia until 1990 (today HU-HR and HU-SI). Today, this border river is subject to contradictory hydro dam and nature conservation plans. In Hungary the lower Drava is part of the Danube-

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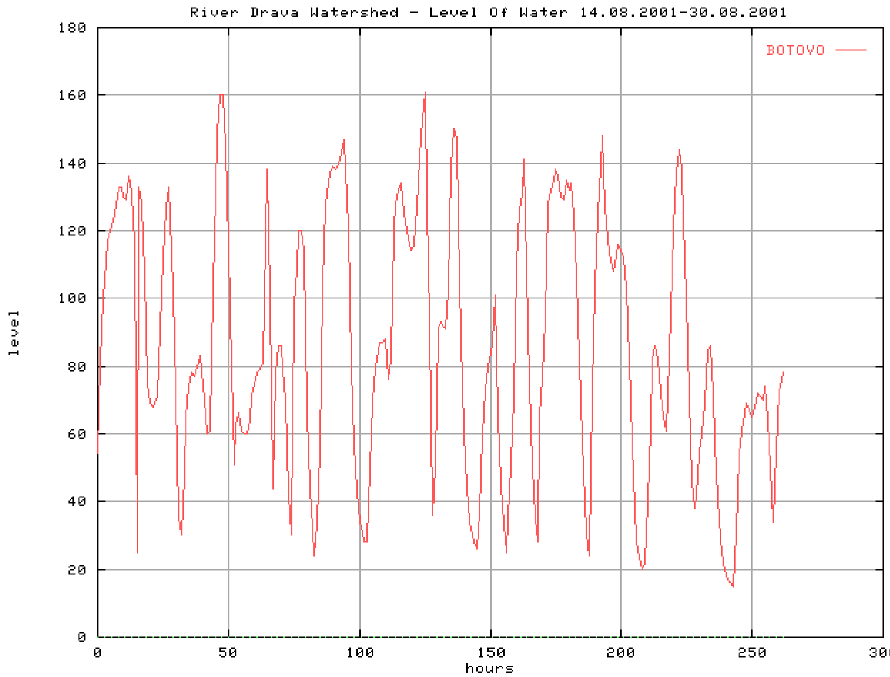
Figure 8: Daily water level fluctuations in the Drava below the Durbrava hydrodam and the Mura confluence.



Drava national park and large areas in Slovenia, Hungary and Croatia are proposed as protected areas (Natura 2000 system). A proposal to establish a multilateral Biosphere reserve along this corridor is under preparation.

More than 3.4 million people live in the Drava Basin. Concerning water pollution the evaluation of the ICPDR (ICPDR 2005) lists along the lower Mura and Drava about 11 high priority municipal hot spots and three high priority industrial hot spots. Several projects address water quality and aim at reducing the pollution from point and diffuse sources.

4.2. Methodology for the hydromorphological inventory

Based on the experience of large river investigations in Germany (Elbe, Rhine and other waterways) the overall methodology can be structured in three main parts:

1. Substantial preparation and data collection and analysis of already existing data, including inventories, base and detail maps, historical maps, aerial pictures and satellite images where applicable, literature review, database development. The experience shows that this first level covers almost 40-50% of the whole work for the inventory along large rivers.
2. Field survey, preparation of field forms and maps, data entry during boat and surface survey, sectioning of

homogenous river reaches for the left and right bank or pre-defined fixed measurement units, photo/video documentation with GPS management.

3. Database and GIS integration (partly covered in the first phase), evaluation and post calibration and comparison of parameter groups, final analysis and mapping.

Depending on the basic river characterisation (river already completely modified by hydropower or canalised for waterway transport, or alternatively near-natural stretches with minor alterations), it is possible to reduce both the desk preparation work and the field work. The whole methodology assumes an advanced technical level of hard- and soft ware requirements and usage, and for the field survey an experienced surveyor. The latter is in particular important for the recognition of parameter groups and the specific structure and patterns of hydromorphological features and indicators. In addition it is not possible to make very detailed measurements during the survey such as cross-section, depth and velocity measurements, advanced sediment analysis or specific botanical surveys.

4.3 Hydromorphological reference conditions

Hydromorphological reference conditions considerably amend the general reference conditions relevant for the river typology and assessment of ecological status according to European standards and directives. The development of detailed reference conditions indicates the methodological as well as data gaps concerning systematic hydromorphological background and reference data, in particular considering the results of the risk assessment showing the strong hydromorphological alterations all over Europe. Therefore the detailed analysis of the hydromorphological reference conditions of the river system can provide valuable inputs. Also for future programmes of measures under the WFD and floodplain restoration projects the reference conditions are of great importance. Generally the preparation of those conditions is faced with the following problems:

- Often recent and suitable river stretches do not exist as basis and for comparison (in particular for large rivers).
- Many catchment parameters such as flow pattern, landuse, sediment delivery and so on have changed since the times of historic reference systems.
- Climatic changes since the Holocene and nowadays often not allow to compare in detail the hydrological and sedimentological conditions.
- Alien species often influence the situation due to increased human disturbance and decreased geomorphological dynamics.
- The riparian landscape influences the single location very much such as the plant succession by the disturbance in many

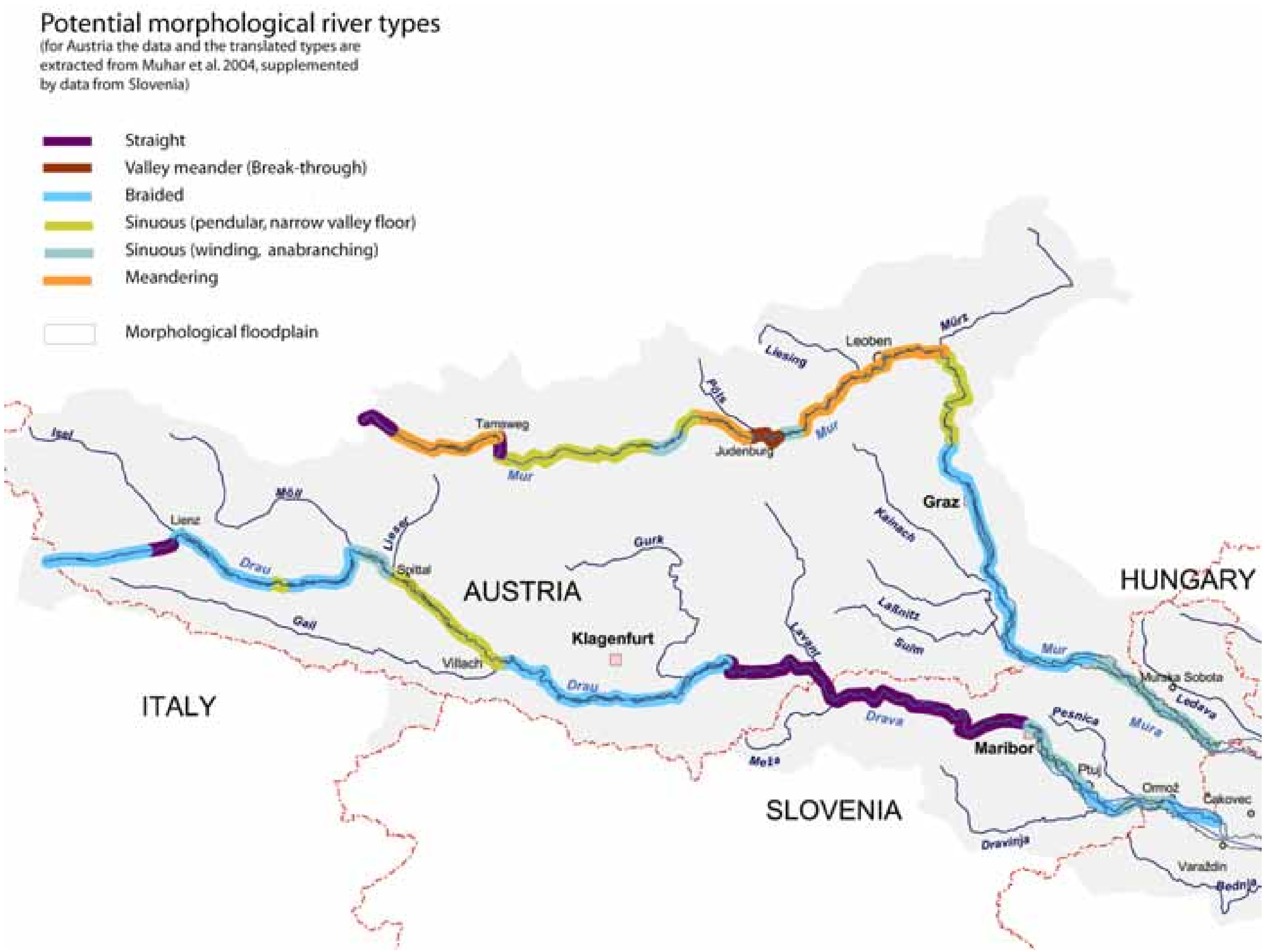
scales and the created habitat mosaic. Therefore, at any point in space and time, species assemblages are probably unique in terms of precise combinations of species type, numbers, and age structure.

The hydrological reference conditions are intensively discussed by hydrologists (e.g. by Mader et al. 1996 for Austria) and climatologists. The pristine hydrological regime is depending on the climatic changes within the Holocene (since 10,000 years). Comparable measurements of water stages or discharges are in the best case available for the last 100-150 years. Therefore the long-lasting statistical modelling for the precipitation in the catchment and runoff calculations can provide important details. Also the recent climate change research must be mentioned not only in the light of the huge floods in 2006. Much easier is the measurement of the impact of the water management on the hydrological and sediment regime during the last century. Thus the evaluation chapter will discuss in particular the impacts of the hydropower stations with large storage volumes and hydropeaking as the most important alterations to the reference conditions and on the hydrological and sediment regimes.

After the overview of the upper river stretches in Austria the following main analysis is geographically limited to the lower Mura and Drava rivers. A lot of historical maps were evaluated concerning fluvio-morphological parameters. The availability, comparability and the analysis technique of historical data and in particular maps cannot be discussed in detail. References are given in LUA 2003 (Rhine), Hohensinner 2005 (upper Danube), Rommel 2000 (Elbe) and Schwarz et al. 1998/2005 (Drava/Danube). The basic historical high resolution map in the scale of 1:25,000 and in colour is the 3rd Austrian "Landesaufnahme" from 1875-1885 for the entire stretches, but different maps were available (and necessary for meander cut-offs) since the early 18th century. Older maps are topologically problematic and cannot be used in the GIS but for the general interpretation (e.g. to document meander cut-offs since the beginning of the 17th century). The main parameter groups which were assessed are the channel form/types, the longitudinal profile, the river bed structure, the cross section, the bank structure and the floodplain. The continuous comparison of the parameters allows a subdivision of the rivers into main "River-section-types" and sub-types for the morphological reference conditions. This qualitative approach is confirmed by several quantitative values and could be described much more in detail with statistical analysis.
Beginning with the upper river courses in Austria a short introduction should be given based on the results of Muhar et. al. 2004, which are related to the overall river typology and riverine landscapes. The Austrian team evaluated major rivers in Austria based on morphological parameters as well as fish and floodplain vegetation. The aim of the study was a riverine landscape typology for Austrian rivers. The typology was developed based on the biogeographical ecoregions,

the river dimension, the altitude and valley slope, the morphological river type and the floodplain width as well as natural fish regions and floodplain vegetation. At this stage only the morphological results will be shortly presented. The morphological river types and the morphological floodplain width (which was continuously recorded in this report) are of importance for the hydromorphological reference conditions in particular. Figure 9 shows the morphological river types according Muhar (translated and extracted from Muhar et al. 2004) supplemented by the information for the Slovenian stretches.

Figure 9: Main river types for the Austrian Mura and Drava according to Muhar et al. 2004 and estimation for Slovenia by using historical maps.



As indicated there are big differences between the Drava and Mura: After a straight glacier headwater reach the Mura starts immediately to meander in a high valley as a small river. After two smaller break-throughs the river meanders or flows pendular within the relatively broad upper valley. After another break-through upstream of Graz the river starts the typical sequence of larger rivers leaving the Alps with a braided reach followed by a sinuous winding reach and finally in the lowest reaches (not indicated in the map) as a meandering river. The Drava never meanders in the upper course and is mainly characterized by braided and sinuous types. After the long break-through upstream of Maribor, the river starts also the typical sequence from braided towards sinuous winding and anabranching stages to finally meandering.

The subsequent lower river reaches were characterised more in detail based on the following parameters: Channel width, valley form, slope, channel morphology (development and sinuosity), channel type, lateral erosion / shifting behaviour, stream characteristics and depth variance, channel structure, channel substrate, cross sections (width variance, incision and profile depth), bank structure and floodplain.

The whole surveyed stretch can be divided into 5 divisions according to table 3 (three for the lower Drava with additional sub-units and two for the lower Mura rivers):

Table 3: The most important river-section-types of the lower Mura and Drava rivers (compare fig. 10)

River-section-type	Stretch location	Main characteristics
River-section-type Mura M-I	rkm 85 (Mura near Ljutomer) – rkm 45 (near Letenye)	Transition type from a braided towards a sinuous and meandering river type, moderate anabranching with small side channels, medium-large lowland river with gravel
River-section-type Mura M-II	rkm 45 (near Letenye) – rkm 0 (Drava confluence, Örtilos)	Meandering single-channel river system, few small side channels, medium-large lowland river with gravel
River-section-type Drava D-I	rkm 310 (Ormoz) – rkm 235 (Mura confluence, Örtilos/Legrad)	Predominantly braided river system, anabranching with a lot of small side channels, with less slope increasing sinuosity and less side channels, large lowland river with gravel
River-section-type Drava D-II	rkm 235 (Mura confluence, Örtilos/Legrad) – rkm 185 (near Babocsa)	Transition type from D-I towards a sinuous and meandering river type, only partial anabranching, large lowland river with gravel and coarse sand
River-section-type Drava D-III	rkm 185 (near Babocsa) – rkm 0 (Danube confluence, Aljmas)	Meandering single-channel river system, several small side channels and typical floodplain waters, large lowland river with sand

Figure 10 illustrates the position of the river section types and sub-types. Tables 4 and 5 describe each type, followed by characteristic river type and floodplain profiles (figure 11, tables 6 and 7).

Mura:

The lower Mura can be characterised as a dynamic medium-large gravel lowland river having mostly anabranching channels in the upper and meandering reaches in the lower course. Mentionable is the occurrence of gravel down to the meander stretch to the confluence into the Drava. As a consequence the Mura delivers a part of the Drava bedload which is drastically reduced due to the hydropower plants upstream along the Drava (the last hydropower plant along the Mura is 150 km from the confluence in Austria). The Mura contributes about 40% of the whole discharge of the lower Drava, therefore the large confluence triangle between the two rivers hosts a very rich riverine landscape inventory.

Drava:

The middle and lower Drava can be subdivided at least into three main parts. The first one, the upper reach is part of the Middle Drava, leaving the Alpine foothills and accumulating a lot of gravel in the plain. The river is characterised by a braided multi-channel system with many meandering side channels and a high diversity of dynamic habitats such as pioneer islands and shifting channels. After the confluence with the Mura the lower river reach starts with a transition type from a sinuous to a finally meandering large lowland river. The river has a large to very large floodplain up to 15 km which is limited by different terrace systems. On some reaches the river directly touches the terrace building impressive steep banks of up to 35 m width (subtype IIb). The second type can be seen as transition type losing slop degree and the grade of anabranching towards a more and more meandering river hosting the highest diversity of riverine landscape features from pioneer stands on gravel and sand bars up to large oxbows and hardwood stands on fine sediments.

The third and longest river reach belongs to the meandering and strongly meandering large sandy lowland rivers. The typical sequence of point bars with steep banks and shallows in the transition reach between the meander belts can be observed. A large number of oxbows and typical lowland floodplain waters occurs, the whole area was regularly submerged by long-lasting floods in particular with decreasing distance to the Danube confluence, building one of the largest wetland and floodplain complex along the entire Danube, the Kopački Rit.

Figure 10: Morphological River section types of the lower Mura and Drava rivers

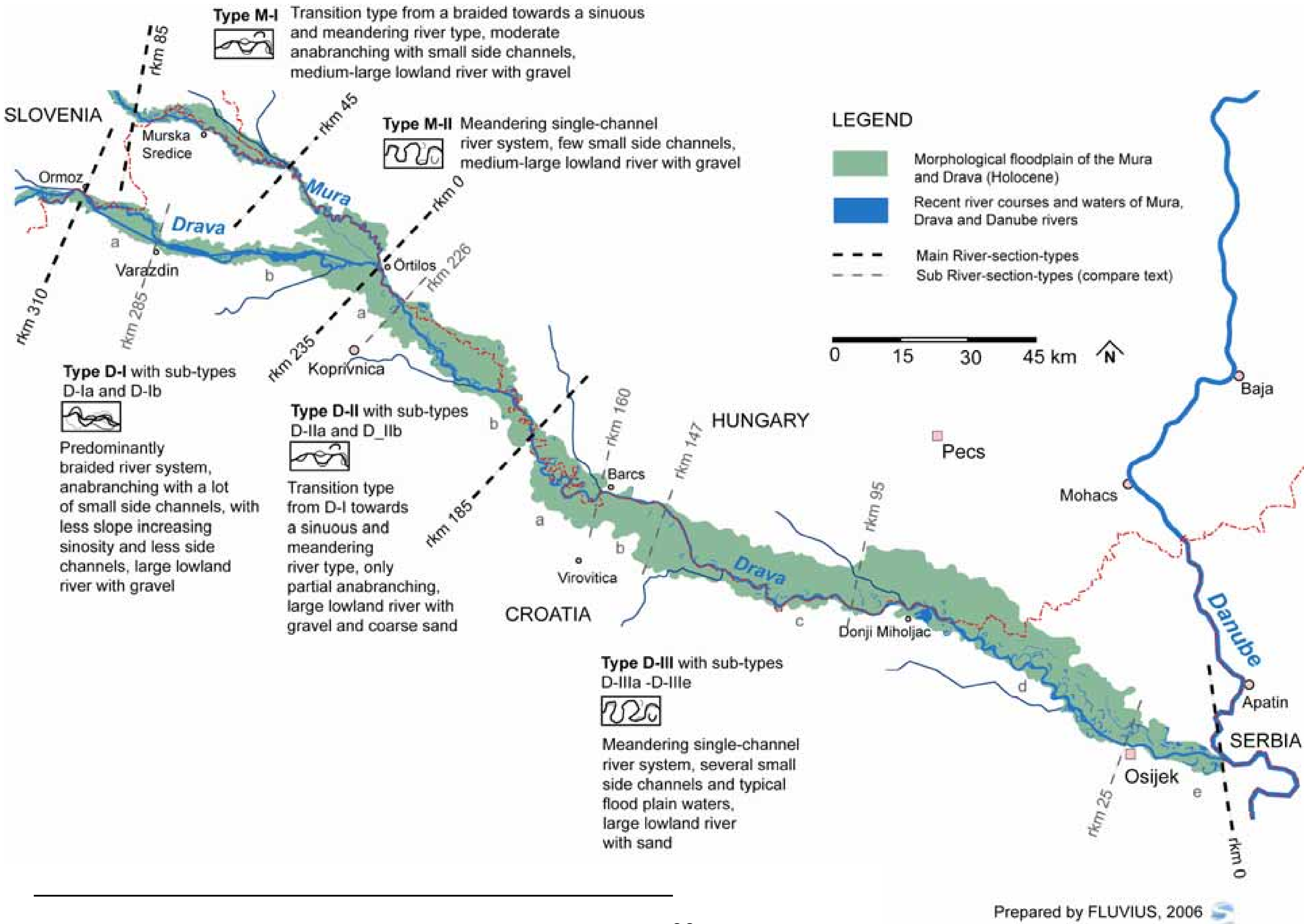


Table 4: Morphological characterisation of river-section-types I and II of the lower Mura River

River-section-type	River-section-type M-I	River-section-type M-II
River type	Medium-large lowland river with gravel (after preliminary ICPDR-Classification: HR_type_3, SI-Type H2)	Medium-large lowland river with gravel (after preliminary ICPDR-Classification: HR_type_3, SI-Type H2, HU-Type 14)
Hydrological type	Permanent, balanced and high average discharge	Permanent, balanced and high average discharge
PARAMETER		
Position of the stretch	rkm 85 (Mura near Ljutomer) – rkm 45 (near Letenye)	rkm 45 (near Letenye) – rkm 0 (Drava confluence, Örtilos)
Channel width	approx. 80-250 m	approx. 80-150 m
Distance from source	approx. 360-400 km	approx. 400-445 km
Valley and valley floor form	Lowland with broad valley floor in the north, terrace in the south • Valley floor (min/max): 5 km- app. 10 km • Channel width/ valley floor width: average1:22; min/max: 1:16 / 1:25 The morphological floodplain is defined by a distinctive narrow terrace along the southern bank with a thickness of 15-20 m containing mostly Pleistocene loess. The northern margin follows a not very well developed lower terrace based on former river sediments of the Vistula ice age	Lowland with broad valley floor in the north, terrace in the south • Valley floor (min/max): 7 km- app. 15 km • Channel width/ valley floor width: average1:11; min/max: 1:11 / 1:14 The morphological floodplain is in a short upper part defined by a terrace along the northern bank with a thickness of 10 m containing mostly Pleistocene loess followed by the confluence flatland with the Drava. The northern margin follows the Zakany hills (up to 100 m above the floodplain level), which come closer towards the confluence
Valley floor slope	Average 0.93 ‰	Average 0.51 ‰
Vally floor characteristics	Slight shaped and sloped valley floor with a loamy and silty coverage over gravel sediments with sand intrusions, single high flood depressions and former meanders, large and shallow flooded area	Slight shaped and sloped valley floor with a partly immobile loamy and silty coverage over gravel sediments with sand and silt intrusions, single high flood depressions and former meanders, large and mostly shallow flooded area
CHANNEL (PLAN-) FORM		
River-section-type	Transition type from a braided towards a sinuous and meandering river type, moderate anabranching with small side channels, medium-large lowland river with gravel	Meandering single-channel river system, few small side channels, medium-large lowland river with gravel
River course development, meandering degree	Sinuous (winding) to meandering approx. 1.5	Meandering to strongly meandering approx. 2.1

River-section-type	River-section-type M-I	River-section-type M-II
River course type	Mostly mono-channel with a typical sequence of steep banks and point bars, island development along shallows and riffles, often anabranching, with frequent anastomosing side channels	Mono-channel with a typical sequence of steep banks and point bars, island development along shallows and riffles, seldom anabranching
Lateral erosion, channel shifting	The river takes large areas of the floodplain with unsteady shifts of the active channel belt crossing former structures, strong channel width variations (point bars and islands, narrow deep reaches along the terrace), anabranching possible through regular bank and island development, relocation of the main stream	The river takes large areas of the floodplain with unsteady shifts of the active meander belt crossing former structures, medium channel width variations (point bars, steep banks, small islands)
Channel patterns	Large woody debris (LWD) is very important for morphological changes, side channels are already connected during small flood events Tributary confluences are retarded and often relocated by the main stream: • Migration and channel cut-off (neck and mostly chute cut-offs) • Bank erosion und island development • Lateral and downstream shifting of the main channel (migration celerity): approx. 10-40 m/a depending on erodable substrate During extreme flood events chute cut-offs can considerably shorten the channel Many floodplain waters are temporary connected with the main channel • The lateral shift of the channels is considerable, eroding former channel fills and alluvial substrates, limited by the terrace margin and building of steep banks • Distinctive floodplain relief with many oxbows	Large woody debris (LWD) is still important for morphological changes, side channels are already connected during small flood events, remote channels in the floodplains are connected each year Tributary confluences are retarded and parallel to the main stream and strongly meandering: • Migration and cut-off (neck and chute cut-offs) • Bank erosion und point bar development • Lateral and downstream shifting of the main channel (migration celerity): approx. 5-20 m/a depending on erodable substrate (the Drava and Mura gravel is relatively immobile) During extreme flood events chute cut-offs can considerably shorten the channel leading temporarily to a less sinuous reaches. Many floodplain waters are periodically connected with the main channel • The lateral shift of the channel is slow, limited by coarse sediment fills of former channels • Distinctive floodplain relief with riffle and swale structure and many oxbows
Specifics		The confluence with the Drava influences the lower Mura course, which is partly strongly meandering in the gravel sediments of the Drava, the confluence is regularly relocated, the backwater of the Drava influences only a few kilometres

River-section-type	River-section-type M-I	River-section-type M-II
LONGITUDINAL PROFILE		
Slope	0.4 ‰	0.25 ‰
Slope structure / crossing banks	Sequence of shallows and pools, altering slope structures depending on the sinuosity, large point bars and banks along islands, partly sediment accumulation and abrupt shift of the thalweg, during high flood events bank overtopping and development of chutes initiating chute cut-offs, low natural bed incision	Shallows and pools alternate just below the crest of the meander and a little downstream from the transition reach between the meanders depending on the sinuosity, point bars, seldom sediment accumulation and abrupt shift of the thalweg, during high flood events bank overtopping and development of chutes initiating chute cut-offs, very low natural bed incision also due to the Drava confluence
Flow characteristics	• Predominantly slow to medium • In sections faster • Turning drift • In side channels different stream patterns • Only oxbows close to the river are periodically connected, partly strong accumulation of the connection	• Predominantly slow • In sections stagnant • Turning drift • Oxbows with a very slow flow through, heterogeneous suspended load and trophic conditions
Flow diversity / depth variance	High, along the banks with woody debris and steep banks heterogeneous flow mosaic, variable within accumulation and erosion stretches (LWD in the main channel), in side channels and around islands	Medium to high, along the banks with woody debris and steep banks heterogeneous flow mosaic, variable within the transition reaches between the meanders with shallows and pools
Abundance and spatial distribution (explanations listed in descending abundance)	Fast (> 0.3 m/s) and deep (> 0.5 m) *Predominant* In the main channel Fast (> 0.3 m/s) and shallow (< 0.5 m) *Subsidiary* Along point pars and shallow banks, partially in side channels Slow (< 0.3 m/s) and deep (> 0.5 m) *Frequent* In the main channel and side channels, pools and in the flow shadow of island and banks, in oxbows during the flood Slow (< 0.3 m/s) and shallow (< 0.5 m) *Subsidiary* In point bar reaches, along banks in side channels, in shallow flooded areas and broad chutes	Slow (< 0.3 m/s) and deep (> 0.5 m) *Predominant* In the main channel and side channels, pools and in the flow shadow of island and banks, in oxbows during the flood Slow (< 0.3 m/s) and shallow (< 0.5 m) *Frequent* In point bar reaches, along banks In the main and side channels, in shallow flooded areas and broad chutes Fast (> 0.3 m/s) and deep (> 0.5 m) *Subsidiary* Meander apex reaches, pools, short straight reaches Fast (> 0.3 m/s) and shallow (< 0.5 m) *Subsidiary* Shallow reaches (in straight reaches), side channels

River-section-type	River-section-type M-I	River-section-type M-II
RIVER BED STRUCTURE		
Structure	• The lower Mura flows mostly in its own alluvial sediments (gravel and sand-silty valley fills) • The grain size contributes to mostly gravel and sand fractions with additional silt-clay intrusions or layers • In addition to the typical pool-riffle sequence high dynamic bank and LWD structures increase the river bed diversity • An up to one meter thick floodplain loam layer stabilizes partly the channel, but the river mostly erodes and excavates gravel and sandy substrates below the layer and shifts laterally	• The lower Mura flows mostly in its own and in the Drava alluvial sediments (gravel and sand-silty valley fills) • The grain size contributes to mostly gravel with high silt and sand fractions as well as clay intrusions or layers on top • In addition to the typical pool-riffle sequence the bank and LWD structures increase the river bed diversity • An up to one meter thick floodplain loam layer stabilizes partly the channel, but the river mostly erodes and excavates gravel and sandy substrates below the layer and shifts laterally
Substrat	Predominantly mean gravel fractions at the river bottom: 15 mm (limits of variation 5-25 mm)	Predominantly fine gravel fractions at the river bottom: 5-10 mm (limits of variation 5-20 mm)
Substrate types in descending abundance	• Gravel • Sand • Silt • Woody and organic debris	• Fine gravel • Sand • Silt • Clay • Organic substrates • Woody and organic debris
Specifics	The gravel substrate accumulates suddenly behind stream obstacles such as low slope reaches, LWD or islands	The mostly fine gravel substrate has a higher mobility and is transported during floods over longer distances, partly the river incises the gravel sediments of the Drava in the confluence reach
Substrate diversity and -distribution	High substrate variablity	Medium to low substrate variability
Bed structure	Gravel dominated, development of bars and partly huge islands, crossing banks as initial parts for anabranching	Fine gravel dominated, development of typical point bars and partly deep pools in the meander bends

River-section-type	River-section-type M-I	River-section-type M-II
Specific bed structures	LWD structures (whole black poplars or large white willows) can lead to changes in channel shift and development, gravel bars in the flow shadow of islands and side channel confluences • Development of highly structured accumulations with typical riffle-pool-sequence • Partly stabilisation of the bottom with larger gravel, erosion only during high flood events • Fine sediments will be only accumulated in the flow shadows	Accumulation only along point bars and between the meander bends (shallows) • Development of highly structured accumulations with typical riffle-pool-sequence based on the highly mobile of finer gravel • Point bars with island development, often submerged downstream • Pools, distinctive thalweg, shifting and wandering bottom bars
CROSS SECTION		
Cross section	Natural profile, diverse partly asymmetric in the curves, well developed shallows, no distinctive thalweg, heterogeneous bank structures with many side connections to the floodplain	Natural profile, asymmetric in the meander bends, shallows not well developed, but variable because of the wandering bars in the transition reaches between the meander bends, distinctive thalweg, slight bank wall development
Width variance	approx. 1:10	approx. 1:3
Incision depth (natural)	approx. 100-150 cm	approx. 100-200 cm
Profile depth	Broad and not very deep, profile depth varies between 1 and about 6 m, average depth is about 2 m	Broad and deep, profile depth varies between 2 and about 10 m, average depth is about 3 m
BANK STRUCTURE		
Bank structure	Natural banks, changing and unsteady bank shape, steep banks along the lower terrace at the South of up to 20 m (loess), shallow and flattened point bars with chutes, bank walls with partly interruptions and lowering, LWD, bank shape depending on erodable substrates can be very heterogeneous	Natural banks, changing and unsteady bank shape, steep banks along the lower terrace at the South of up to 20 m (loess), shallow and flattened point bars with chutes, bank walls with partly interruptions and lowering, LWD, bank shape depending on erodable substrates can be very heterogeneous
FLOODPLAIN		
Flood characteristics	Medium-large floodplain of up to 3 km width, periodically flooded beginning with the inner floodplain along side channels and oxbows close to the river, slowly floating conditions in the remote areas	Large floodplain of up to 5 km (near the confluence with the Drava up to 10 km), regularly flooded by relatively long-lasting and partly stagnant floods (only at the confluence), flooding of high flood chutes in the lower terrace, during flood reconnection of former channels far from the main channel

River-section-type	River-section-type M-I	River-section-type M-II
Riparian landscapes	The relatively broad valley floor hosts a lot of different riparian landscapes including large forms such as oxbows or already silted up former channels with vegetation succession, small floodplain terraces and a rich mosaic of parallel structures with different succession status	The broad valley floor hosts a lot of different riparian landscapes including the typical riffle and swale floodplain relief, large forms such as oxbows or already silted up former channels with vegetation succession, distinct former bank walls, small floodplain terraces and a rich mosaic of parallel structures with different succession status
Substrate diversity and distribution in the floodplain	Near the main channel predominantly gravel and sand accumulations (coarsest sediments in the bank walls) followed by mostly sandy and silty substrates and far from the river mostly loamy accumulations, all different soil types from very fast maturing fluvial soil types up to clay soils in depressions (all soils are strongly determinated by the contact to the groundwater in the deeper gravel layer and the flood dynamics, along the remote depressions of the valley partly wet meadow development, floodplain loam coverage partly up to 1 meters and transition to loess soils along the terrace margins, high accumulation and erosion of fine particulate matter during floods (fine sand and silt) Below the fine sediments of the valley floor mostly gravel sediments can be found: • Predominantly floodplain gravel and sand (gravel, sand, silt with different groundwater conditions) • Additional floodplain loam (silt, fine sand, very little calcareous, partly with layers and horizons of sand and gravel)	Near the main channel predominantly coarse sand and fine gravel accumulations (coarsest sediments in the bank walls) followed by mostly silty and loamy substrates and far from the river mostly clay accumulations, partly high organic constituents, all different soil types from very fast maturing fluvial soil types up to very dense and stagnant clay soils in depressions (all soils are strongly determinated by the flood dynamics (frequency and duration or permanent hydration) and the groundwater connection, along the remote depressions of the valley partly fen and swamp development, floodplain loam coverage partly up to 2 meters and transition to loess soils along the terrace margins, high accumulation and erosion of fine particulate matter during floods Below the fine sediments of the valley floor mostly gravel sediments can be found: • Predominantly floodplain gravel and sand (gravel, sand, silt) • Additional floodplain loam (silt, fine sand, very little calcareous, partly with layers and horizons of sand and gravel) • Extensive bank wall development with fine to coarse sands, with silt)

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Table 5: Morphological characterisation of the River-section-types I and II of the lower Drava River

River-section-type	**River-section-type D-I with sub-types D-Ia and D-Ib**	**River-section-type D-II with sub-types D-IIa and D-IIb**	**River-section-type D-III with sub-types D-IIIa, D-IIIb, D-IIIc, D-IIId, D-IIIe**
River type	Large lowland river with gravel (after preliminary ICPDR-Classification: HR_type_2)	Large lowland river with gravel and coarse sand (after preliminary ICPDR- Classification: HR_type_2, HU-Type 15)	Large lowland river with sand (after preliminary ICPDR-Classification: HR_type_1, HU-Type 15)
Hydrological type	Permanent, balanced and high average discharge	Permanent, balanced and high average discharge	Permanent, balanced and high average discharge
PARAMETER			
Position of the stretch	rkm 310 (Ormoz) – rkm 235 (Mura confluence, Örtilos/Legrad)	rkm 235 (Mura confluence, Örtilos/Legrad) –rkm 185 (near Babocsa)	rkm 185 (near Babocsa) – rkm 0 (Danube confluence, Aljmas)
Channel width	approx. 100-850 m	approx. 150-1500 m	approx. 200-400 m
Distance from source	approx. 440-515 km	approx. 515-565 km	approx. 565-750 km
Valley and valley floor form	Lowland with broad valley floor (leaving the last alpine foothills) • Valley floor (min/max): 5 km-approx. 10 km • Channel width/ valley floor width: average 1:16; min/max: 1:50 / 1:12 The morphological floodplain is defined by a lower terrace of Holocene gravel transported by the Drava during the Pleistocene. The river accumulates a lot of sediments leaving the Alpine foothills building a huge sediment fan	Lowland with broad valley floor in the north, terrace in the south • Valley floor (min/max): 5 km-approx. 10 km • Channel width/ valley floor width: average 1:9; min/max: 1:33 / 1:7 The morphological floodplain is defined in the north by the Zakany hills (sub-type a), further downstream by the distinctive narrow terrace with a thickness of 20-35 m containing mostly Pleistocene loess. The southern margin follows a not very well de-developed lower terrace from the ice age. Down from the Zakany hills a huge bifurcation splits the river into two branches and builds a broad island about 25 km long (sub-type b)	Lowland with broad valley floor in the north, terrace in the south (subtype d) • Valley floor (min/max): 8 km-approx. 15 km • Channel width/ valley floor width: average1:50; min/max: 1:40 / 1:37 The morphological floodplain is defined in the northern part mostly by a not very well developed lower terrace based on former river sediments of the Vistula ice age (sub-types a, c, d, e, only near Barcs (b) the lateral development is limited by sand and loess accumulations) and a distinctive narrow terrace along the southern bank with a thickness of 20-30 m containing mostly Pleistocene loess (sub-types d and e)

River-section-type	River-section-type D-I with sub-types D-Ia and D-Ib	River-section-type D-II with sub-types D-IIa and D-IIb	River-section-type D-III with sub-types D-IIIa, D-IIIb, D-IIIc, D-IIId, D-IIIe
Valley floor slope	Average 0.88 ‰	Average 0.47 ‰	Average 0.17 ‰
Vally floor characteristics	Slightly shaped and sloped valley floor with a loamy and silty coverage over gravel sediments with sand intrusions, single high flood depressions and former channels	Slightly shaped and sloped valley floor with a loamy and silty coverage over fine gravel sediments with sand intrusions, single high flood depressions and former meanders, large and shallow flooded area	Slightly shaped and sloped valley floor with relative immobile floodplain loam coverage over salty sediments with sandy intrusions, single high flood depressions and former meanders, large and deeply flooded area
CHANNEL (PLAN-) FORM			
River-section-type	Predominantly braided river system, anabranching with a lot of small side channels, with less slope increasing sinuosity and less side channels, large lowland river with gravel	Transition type from D-I towards a sinuous and meandering river type, only partial anabranching, large lowland river with gravel and coarse sand	Meandering single-channel river system, several small side channels and typical floodplain waters, large lowland river with sand
River course development, meandering degree	Sinuous (winding) approx. 1.3	Sinuous to meandering (in particular sub-type b) approx. 1.5	Strongly meandering approx. 2.2
River course type	Mostly braided (multi-channel) in the lower part towards mono-channel with typical shifting gravel bars and islands, many shallows and riffles, often anabranching, with frequent anastomosing side channels	Mostly mono-channel with a typical sequence of steep banks and point bars, island development along shallows and riffles, often anabranching, with frequent anastomosing side channels	Mostly mono-channel with a typical sequence of steep banks and point bars, island development along shallows and riffles, seldom anabranching, with a few anastomosing side channels
Lateral erosion, channel shifting	The river takes large areas of the floodplain with unsteady shifts of the active channel belt crossing former structures, strong channel width variations, anabranching frequent through bank and island development, relocation of the main stream	The river takes large areas of the floodplain with unsteady shifts of the active channel and meander belt crossing former structures, strong channel width variations (large point bars and islands), anabranching is possible through regular bank and island development, relocation of the main stream	The river takes large areas of the floodplain with unsteady shifts of the active meander belt crossing former structures, medium to partly strong channel width variations (huge point bars, narrow deep reaches along the terrace)

River-section-type	**River-section-type D-I with sub-types D-Ia and D-Ib**	**River-section-type D-II with sub-types D-IIa and D-IIb**	**River-section-type D-III with sub-types D-IIIa, D-IIIb, D-IIIc, D-IIId, D-IIIe**
Channel patterns	Large woody debris (LWD) is very important for morphological changes, large side channels are connected during the whole year Tributary confluences are retarded and often relocated by the main stream: • Permanent channel shift (mostly relocation of channels and chute cut-offs on islands) • Bank erosion und island development • Lateral and downstream shifting of the main channel (migration celerity): from several meters to completely relocated channels During extreme flood events remote channels can form a huge network of backwaters and have a high potential for anabranching Many floodplain waters outside the channel system are temporarily or only intermittently connected • The lateral shift of the channels is considerably within the active channel belt, eroding former channel fills and alluvial substrates • Distinctive floodplain relief with many former channels	Large woody debris (LWD) is still important for morphological changes, side channels are already connected during small flood events Tributary confluences are retarded and strongly meandering: • Migration and channel cut-off (neck and mostly chute cut-offs) • Bank erosion und island development • Lateral and downstream shifting of the main channel (migration celerity): approx. 10-40 m/a depending on erodable substrate During extreme flood events chute cut-offs can considerably shorten the channel Many floodplain waters are temporarily connected with the main channel • The lateral shift of the channels is considerable, eroding former channel fills and alluvial substrates, limited by the terrace margin and building of steep banks • Distinctive floodplain relief with many oxbows	Large woody debris (LWD) with a local importance for morphological changes, side channels are already connected during small flood events, remote channels in the floodplains connected each year Tributary confluences are retarded and parallel to the main stream and strongly meandering: • Migration and cut-off (neck and chute cut-offs) • Bank erosion und point bar development • Lateral and downstream shifting of the main channel (migration celerity): approx. 10-30 m/a depending on erodable substrate During extreme flood events chute cut-offs can considerably shorten the channel leading temporarily to a less sinuous reach Many floodplain waters are periodic-ally connected with the main channel • The lateral shift of the channel is considerable, eroding former channel fills and alluvial substrates, limited by the terrace margin and building of steep banks • Distinctive floodplain relief with riffle and swale structure and many oxbows

River-section-type	River-section-type D-I with sub-types D-Ia and D-Ib	River-section-type D-II with sub-types D-IIa and D-IIb	River-section-type D-III with sub-types D-IIIa, D-IIIb, D-IIIc, D-IIId, D-IIIe
Specifics	Just after leaving the foothill reach near Ormoz the river poured a huge sediment fan (sub-type b)	After the Mura confluence and down from the Zakany hills in Hungary the river tends to bifurcate, which is similar to the Szigetköz at the Danube downstream of Bratislava (sub-type b)	The backwater of the Danube and the huge floodplain and wetlands of the confluence area lead to long lasting floods along the lower Drava covering large areas (sub-type e)
LONGITUDINAL PROFIL			
Slope	0.61 ‰	0.31 ‰	0.08 ‰
Slope structure / crossing banks	Sequence of shallows and pools, altering slope structures through channel relocation and stream interruptions, many crossing banks, bars along islands, partly sediment accumulation and abrupt shift of the channel, during high flood events bank overtopping and development of chutes initiating chute cut-offs, low natural bed incision (accumulation reach)	Sequence of shallows and pools, altering slope structures depending on the sinuosity, large point bars and banks along islands, partly sediment accumulation and abrupt shift of the thalweg, during high flood events bank overtopping and development of chutes initiating chute cut-offs, low natural bed incision	Shallows and pools alternate just below the crest of the meander and a little downstream of the transition reach between the meanders depending on the sinuosity, large typical point bars, seldom sediment accumulation and abrupt shift of the thalweg, during high flood events bank overtopping and development of chutes initiating chute cut-offs, very low natural bed incision
Flow characteristics	• Predominantly fast to medium • In sections faster • Turning drift, eddy flows • In all channels various stream patterns • partly strong accumulation of side channels and heterogeneous flow pattern at the begin and confluence of side channels	• Predom. medium velocity • In sections faster • Turning drift • In side channels different stream patterns • Only oxbows close to the river are periodically connected, partly strong accumulation of the connection	• Predominantly slow • In sections stagnant • Turning drift • In side channels different stream patterns, mostly calm • Oxbows with a very slow flow through, heterogeneous suspended load and trophic conditions
Flow diversity / depth variance	Heterogeneous flow mosaic, high depth variance, variable within accumulation and erosion stretches (LWD in the main channel), in side channels and around islands	High flow and depth variance, along the banks with woody debris and steep banks flow mosaic, variable within accumulation and erosion stretches	Medium to high, along the banks with woody debris and steep banks heterogeneous flow mosaic, variable within the transition reaches between the meanders with shallows and pools

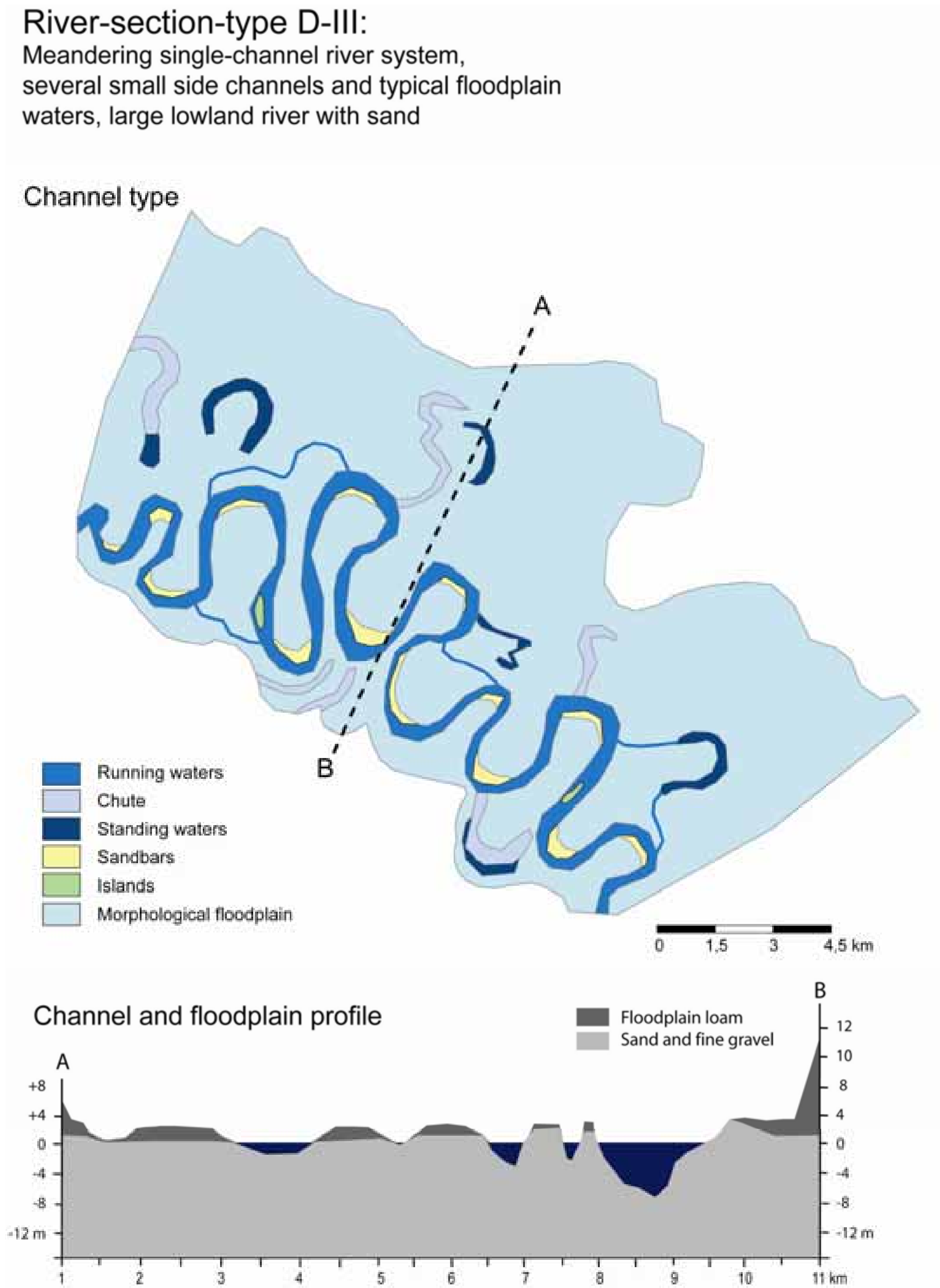
River-section-type	River-section-type D-I with sub-types D-Ia and D-Ib	River-section-type D-II with sub-types D-IIa and D-IIb	River-section-type D-III with sub-types D-IIIa, D-IIIb, D-IIIc, D-IIId, D-IIIe
Abundance and spatial distribution (explanations listed in descending abundance)	Fast (> 0.3 m/s) and deep (> 0.5 m) *Predominant* In the main channel Fast (> 0.3 m/s) and shallow (< 0.5 m) *Frequent* Along point pars and shallow banks, in side channels Slow (< 0.3 m/s) and deep (> 0.5 m) *Subsidiary* In pools of the main channel and side channels, pools and in the flow shadow of island and banks, in oxbows during the flood Slow (< 0.3 m/s) and shallow (< 0.5 m) *Subsidiary* In the flow shadow of islands and bars	Fast (> 0.3 m/s) and deep (> 0.5 m) *Predominant* In the main channel Fast (> 0.3 m/s) and shallow (< 0.5 m) *Subsidiary* Along point pars and shallow banks, partial in side channels Slow (< 0.3 m/s) and deep (> 0.5 m) *Frequent* In the main channel and side channels, pools and in the flow shadow of island and banks, in oxbows during the flood Slow (< 0.3 m/s) and shallow (< 0.5 m) *Subsidiary* In point bar reaches, along banks in side channels, in shallow flooded areas and broad chutes	Slow (< 0.3 m/s) and deep (> 0.5 m) *Predominant* In the main channel and in the flow shadow of island and banks, in oxbows during the flood Slow (< 0.3 m/s) and shallow (< 0.5 m) *Frequent* Along point bar reaches, in shallow flooded areas and broad chutes Fast (> 0.3 m/s) and deep (> 0.5 m) *Subsidiary* Meander apex reaches, pools, short straight reaches Fast (> 0.3 m/s) and shallow (< 0.5 m) *Subsidiary* Shallow reaches (in straight reaches), side channels
RIVER BED STRUCTURE			
Structure	• The Drava flows mostly in its own alluvial sediments (gravel valley fills) • The grain size contributes to mostly gravel and sand fractions • In addition to the typical pool-riffle sequence LWD increases the high dynamic structures • The river mostly erodes and excavates gravel and sand	• The Drava flows mostly in its own alluvial sediments (gravel and sand-silty fills) • The grain size contributes to mostly gravel and sand fractions with additional silt-clay intrusions or layers • In addition to the typical pool-riffle sequence high dynamic bank and LWD structures increase the diversity • An up to one meter thick floodplain loam layer stabilizes partly the channel, but the river mostly erodes and excavates gravel and sandy substrates below the layer	• The lower Drava flows mostly in its own alluvial sediments (silty and sandy valley fills) • The grain size contributes to mostly silt and sand fractions with clay intrusions or layers • In addition to the typical point-riffle sequence the bank and LWD structures increase the river bed diversity • An up to two meters thick floodplain loam layer stabilizes partly the channel, but the river mostly erodes and excavates sandy substrates below the layer and shifts laterally

River-section-type	River-section-type D-I with sub-types D-Ia and D-Ib	River-section-type D-II with sub-types D-IIa and D-IIb	River-section-type D-III with sub-types D-IIIa, D-IIIb, D-IIIc, D-IIId, D-IIIe
Substrat	Predominantly mean gravel fractions at the river bottom with partly coarser fractions: 20 mm (limits of variation 10-40 mm)	Predominantly mean gravel fractions at the river bottom: 10-15 mm (limits of variation 5-25 mm), at the end of the sub-type b abrupt change to coarse sand	Predominantly mean sand fractions at the river bottom: 1 mm (limits of variation 0.1-2 mm)
Substrate types in descending abundance	• Gravel • Sand • Silt • Woody and organic debris	• Gravel • Sand • Silt • Woody and organic debris • Clay	• Sand • Silt • Fine gravel • Clay • Organic substrates • Woody and organic debris
Specifics	The gravel substrate accumulates suddenly behind stream obstacles such as low slope reaches, LWD or islands	Very high diversity of sediment fractions on islands as bars from medium gravel over sandy bars and dunes to fine silty accumulations	The mostly sandy substrate has a high mobility and builds large sand fields at the bottom and bars along islands and point bars
Substrate diversity and -distribution	High substrate variablity	Very high substrate variablity	Low substrate variablity
Bed structure	Gravel dominated, development of bars and partly huge islands, crossing banks as initial parts for anabranching	(Fine) gravel dominated, development of typical point bars and partly deep pools in the meander bends but still extensive bar and island development	Sand dominated, development of bars and partly islands not only in the meander bend
Specific bed structures	LWD structures (whole black poplars or large white willows) can lead to changes in channel shift and development • Development of highly structured accumulations with typical riffle-pool-sequence • Partly stabilisation of the bottom with larger gravel, erosion only during high flood events • Fine sediments will be only accumulated in the flow shadows	LWD still of great importance, accumulation mostly along point bars and islands • Development of highly structured accumulations based on the high mobility of finer gravel and sand • Point bars with island development, often submerged downstream • Pools, distinctive thalweg, shifting and wandering bottom bars	LWD structures less important for channel development (relevant down to 2 m depth), large sand bars in the flow shadow of islands and tributary confluences, skid development • Structured accumulations based on the highly mobile sands (bottom bars) • Point bars with island development, often submerged downstream • Pools, distinctive thalweg, shifting and wandering

River-section-type	River-section-type D-I with sub-types D-Ia and D-Ib	River-section-type D-II with sub-types D-IIa and D-IIb	River-section-type D-III with sub-types D-IIIa, D-IIIb, D-IIIc, D-IIId, D-IIIe
CROSS SECTION			
Cross section	Natural profile, diverse with several parallel channels, partly asymmetric in the curves, well developed shallows, no distinctive thalweg, heterogeneous bank structures with many side arms	Natural profile, diverse and partly asymmetric in the curves, well developed shallows, slightly developed thalweg, heterogeneous bank structures with many side connections to the floodplain	Natural profile, asymmetric in the meander bends, not very strongly developed shallows, but very variable because of the wandering sand bars, distinctive thalweg, strong bank walls development
Width variance	approx. 1:15	approx. 1:8	approx. 1:5
Incision depth (natural)	approx. 100-150 cm	approx. 100-200 cm	approx. 150-250 cm
Profile depth	Broad and shallow, profile depth varies between 1 and about 10 m, average depth is about 1,5 m	Broad and partly deep, profile depth varies between 1 and about 10 m, average depth is about 3,5 m	Broad and deep, profile depth varies between 2 and about 15 m, average depth is about 5 m
BANK STRUCTURE			
Bank structure	Natural banks and diamond formed islands of different size, changing and unsteady bank shape, shallow and flatten point bars with chutes, shallow highly structured banks, LWD	Natural banks, changing and unsteady bank shape, steep banks along the loess terrace at the north of up to 30 m, shallow and flattened point bars with chutes, bank walls with partial interruptions and lowering, LWD, bank shape depending on erodable substrates can be very heterogeneous	Natural banks, changing and unsteady bank shape, steep banks along the lower terrace at the South of up to 20 m (loess), shallow and flattened point bars with chutes, bank walls with partial interruptions and lowering, LWD, bank shape depending on erodable substrates
FLOODPLAIN			
Flood characteristics	Large floodplain of up to 6 km width, periodically to sporadically flooded, beginning with the inner floodplain along the side channels of different degree of connection, floating conditions in the remote areas	Large to very large floodplain of up to 10 km width, periodically flooded beginning with the inner floodplain along side channels and oxbows close to the river, slowly floating conditions in the remote areas including a large groundwater influenced area in the adjacent lowlands	Mostly very large floodplain of up to 12 km (mostly in the North), regularly flooded by long-lasting and partly stagnant floods, due to the Danube flood backwater influences up to 20 km upstream of the confluence, flooding may cause high flood chutes in the lower terrace, during flood reconnection of former channels far from the main channel

River-section-type	River-section-type D-I with sub-types D-Ia and D-Ib	River-section-type D-II with sub-types D-IIa and D-IIb	River-section-type D-III with sub-types D-IIIa, D-IIIb, D-IIIc, D-IIId, D-IIIe
Riparian landscapes	The relatively broad valley floor hosts a lot of different riparian landscapes including large forms such as already silted up former channels with vegetation succession, small floodplain terraces and a rich mosaic of structures with different succession status (very high habitat turnover)	The relatively broad valley floor hosts a lot of different riparian landscapes including large forms such as oxbows or already silted up former channels with vegetation succession, small floodplain terraces and a rich mosaic of structures with different succession status (high habitat turnover)	The broad valley floor hosts a lot of different riparian landscapes including the typical riffle and swale floodplain relief, large forms such as oxbows or already silted up former channels with vegetation succession, distinctive former bank walls and levees, small floodplain terraces, and a lot of parallel forms of different development stages (moderate habitat turnover)
Substrate diversity and distribution in the floodplain	Predominantly gravel and sand accumulations in the channel reach followed by mostly sandy and silty substrates and far from the river mostly loamy accumulations, typical pioneer soil types of different maturity, very dry soils on gravel and small parts of permanently hydro-morphed depressions (all soils are strongly determinated by the contact to the groundwater in the deeper gravel layer and the flood dynamics, along the remote depressions of the valley partly wet meadow development, increasing floodplain loam coverage and transition to loess soils along the terrace margins, high accumulation and erosion of medium to fine particulate matter during floods (sand and silt) Below the partly thin fine sediment coverage of the valley floor mostly gravel sediments can be found: • Predominantly floodplain gravel and sand (gravel, sand, silt with different groundwater conditions) • Additional floodplain loam (silt, fine sand, calcareous, often with layers and horizons of sand and gravel)	Near the main channel predominantly coarse sand and fine gravel accumulations (coarsest sediments closed to the main channels) followed by mostly sand-silty and silty substrates and far from the river mostly loam accumulations, all different soil types from very fast maturing fluvial pioneer soil types up to very dense and stagnant clay soils in depressions (all soils are strongly determinated by the groundwater connection (gravel) and the flood dynamics, along the remote depressions of the valley partly fen and swamp development, floodplain loam coverage partly up to 2 meters and transition to loess soils and sandy dunes along the terrace margins, high accumulation and erosion of particulate matter during floods. Below the fine sediments of the valley floor mostly gravel sediments can be found: • Predominantly floodplain gravel and sand (gravel, sand, silt) • Additional floodplain loam (silt, fine sand, calcareous, partly with horizons of sand/ gravel) • Extensive bank wall development with fine to coarse sands, with silt	Near the main channel predominantly sandy and silty accumulations (coarsest sediments in the bank walls) followed by mostly silty and loamy substrates and far from the river mostly clay accumulations, partly high organic constituents, all different soil types from young fluvial soil types up to very dense and stagnant clay soils in depressions (all soils are strongly determinated by the flood dynamics (frequency and duration or permanent hydration), along the remote depressions of the valley partly fen and swamp development, floodplain loam coverage partly up to 2-3 meters and transition to loess soils along the terrace margins, high accumulation and erosion of fine particulate matter during floods. Below the fine sediments of the valley floor mostly sandy and partly fine gravel sediments be found: • Predominantly floodplain loam (silt and clay, fine sand, a little calcareous, partly with horizons of fine sand) • Additional floodplain sand (fine sand, silt, a little calcareous, often below silty accumulations) • Extensive bank wall development with fine to coarse sands / silt

Figure 11: Example: Morphological characterisation of the river-section-type VI (compare tab. 5)



Based on the morphological characterisation of the reference conditions (compare tables 4, 5 and fig. 11) a comparison with the recent situation can indicate first changes and assessments of the whole riverine landscape:

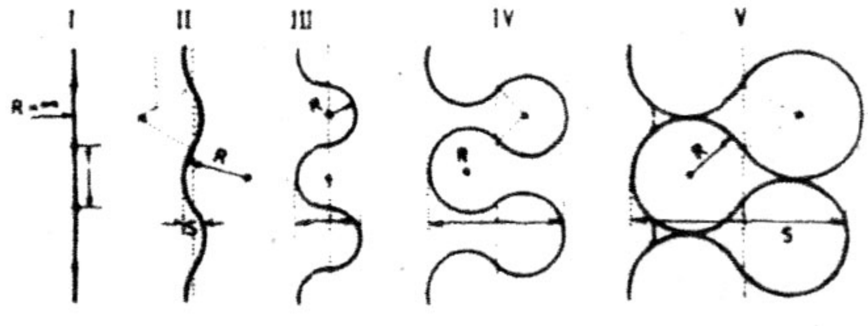
Table 6: Important fluvio-morphological parameters in comparison with the reference conditions for the lower Mura River

Parameter	Mura M-I (reference / current situation)	Mura M-II (reference / current situation)
Reach length in km	47 / 40	54 / 45
Channel width in m	80-250 / 50-180	80-150 / 40-100
Meander wave length in km	3.2 / 5.7	1.5 / 2.2
Meander amplitude	2 / 0.9	3.2 / 2.3
Sinuosity	1.5 / 1.3	2.1 / 1.9
Number of islands	approx. 80 / 10	7 / 4
5 meander development stages (in percent of the reach length, compare fig. 12)	II (40%) / (50%) III (45%) / (50%) IV (10%) / (0%)	II (20%) / (49%) III (40%) / (50%) IV (30%) / (1%) V (10%) / (0%)

Table 7: Important fluvio-morphological parameters in comparison with the reference conditions for the lower Drava River

Parameter	Drava D-I (ref./current)	Drava D-II (ref. / current)	Drava D-III (ref. / current)
Reach length in km	95 / 75	68 / 50	295 / 185
Channel width in m	100-850 / 40-150	100-1500 / 80-450	200-400 / 120-300
Meander wave length in km	-	4 / 6.2	3.8 / 5.3
Meander amplitude	-	3.1 / 1.1	4.5 / 2.2
Sinuosity	1.3 / 1.1	1.5 / 1.2	2.2 / 1.5
Number of islands	approx. 500 / 30 (former Drava)	90 / 15	45 / 6
5 Meander development stages (in percent of the reach length, compare fig. 12)	- (braided)	II (20%) / (70%) III (60%) / (30%) IV (20%) / (0%)	II (15%) / (50%) III (45%) / (50%) IV (35%) / (0%) V (5%) / (0%)

Figure 12: Five development phases of meanders; after Laszloffy (in: Bogner, 1990)



The overall loss of the river length is for the Mura moderate with only 15% in comparison with the reference length. However, the reduction of the lower meandering Drava is considerable and reaches nearly 40%. The average channel width of the Mura was lowered by about 30-40%. The upper Drava reach D-I lost about 40-80% of its former average channel width and most of its width variability. But also the anabranching D-II section lost about 35% and the lower meandering reach about 30%. In the regulated sections, the lower Drava lost more than 50%.

The sinuosity and meander parameters including the 5 stages of meander development (fig. 12) clearly indicate the considerable reduction of meander activity for all sections. Only selected sub-sections such as D-IIIa and D-IIId still host typical meander sequences. Whereas the meanders of the lower Mura and the section D-IIa are mostly fixed by riprap and river engineering the section D-IIId still provides the conditions for a free meander development. Very interesting is the detailed evaluation of the distribution of the meander development stages for that section as it currently comprises mostly initial stadiums of meanders and not many reaches of the fifth class (with cut-offs). The main reason is the relatively short period of 150 years since the river was completely straightened for navigation (compare also Bognar 1990).

4.4 Drava survey 2005

As already indicated and visualized in chapters 4.2. and 4.3 the initial preparation work to elaborate the morphological reference conditions spreaded over several months. This included also the method development, which is described more in detail in the following chapter giving the precondition for the technical implementation of the survey.

4.4.1 Method development

An adapted method and field protocol was developed based on the method suggested by Kern & Fleischhacker (BfG 2002). It considers the specific implications of the River Habitat Survey (RHS), the CEN standard and the already undertaken work for the Danube (DRP 2003). Table 8 shows a collection of the main parameters in the three main groups “channel”, “banks/riparian zone” and “floodplain”.

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Table 8: Main hydromorphological parameter groups based on existing Methods (BfG 2002 and DRP 2003)

Main parameter groups	Main parameter	Sub-parameters	Technical comments	Data* obtained from
Channel	Planform and cross-section (width and depth)	a) bankfull width b) entrenchment depth (to bankfull) c) average stream width c) mean depth of water body d) maximum depth of waterbody	(stream depth at the main sampled habitat)	Data/ other information, Field survey
	Average velocity (littoral, channel)	Flow classes: no flow (stagnant), low flow (just visible-approx. 0.3 m/s), medium flow 0.35-0.65, high flow > 0.7 m	Velocity at the main sampled habitat	Field survey
	Channel type	Single thread, parallel channels, braided / meandering, braided, sinuate, constrained (nat./artificial)		Map, field survey

Main parameter groups	Main parameter	Sub-parameters	Technical comments	Data* obtained from
	Navigation channel	5 classes (no navigation channel, <1/3 of the bottom area, 1/3-2/3, 2/3-3/3 regarding width and depth, 2/3-3/3 with strong impact (waves, ship propellers)	Compare IMPRESS DRP outcome 2003 (DRP 2003)	Map, field survey
	Riverbed features	Bars, islands, riffles; accretion between groynes; large woody debris		Field survey
	Flow diversity/ variation in depth	(sum parameter of riverbed and bank features as well as the navigation channel)		Data (sum parameters), field survey
	Channel substrates	Undisturbed, dredging, groynes / rip rap, bed reinforcement, navigation	To be harmonized with “Navigation channel”	Field survey
	Grain size of sediment (littoral, channel)	Inorganic: Bedrock, boulder, cobble, gravel, sand, silt, clay, concrete and other artificial material; Organic: a) detritus: sticks, wood, coarse plant materials (CPOM), b) Muck-Mud: black, very fine organic matter (FPOM), c) Marl: grey, shell fragments	%composition in sampling reach/site; black colour indicating an-oxic conditi-ons/ odours; considering vertical connectivity (clogging) for the littoral	Field survey
	Composition of channel substrates	5 classes (no artificial changes, no changes in >70% of the evaluated section, reduction of grain size due to back waters, backwaters with mostly changed flow velocity and grain size, totally impounded sections	Compare IMPRESS DRP outcome 2003 (DRP 2003)	Data, field survey
	Channel stabilisation		To be harmo-nized with “navigation channel”	Data, field survey

Main parameter groups	Main parameter	Sub-parameters	Technical comments	Data* obtained from
	Active incision	In cm/y		Other information
	Migration barriers longitudinal (type)			Field survey, other information
	Longitudinal continuity	5 classes for: a) height of structures b) channel substrates c) migration barriers (for the migration capacity)	Compare IMPRESS DRP outcome 2003 (DRP 2003)	Field survey, other information
	Migration barriers lateral (type)			Field survey
	Lateral connectivity	5 classes (whole floodplain area is connected, >50% of the floodplains are connected, 50-75% disrupted, 75-90% disrupted, < 10% are connected	Compare IMPRESS DRP outcome 2003 (DRP 2003)	Field survey
	Water abstraction	5 classes (to be defined for large rivers)	Compare IMPRESS DRP outcome 2003 (DRP 2003)	Field survey, other information
	Hydropeaking	5 classes (to be defined for large rivers, it seems to be important to record daily changes above 15 cm)	Compare IMPRESS DRP outcome 2003 (DRP 2003)	Field survey, other information
	Macrophytes	None, few, patches, completely covered (rooted emergent, rooted submergent, rooted floating, free floating, floating algae, attached algae)		Field survey
Banks/ Riparian Zone	Bank profile	Type, extent natural, remaining, bank structure: fine substrate/ flat (to medium) slope, vs. (very) steep slope		Field survey
	Extent of natural vegetation			Field survey
	Bank stabilization			Field survey

Main parameter groups	Main parameter	Sub-parameters	Technical comments	Data* obtained from
	River engineering-banks	5 classes (natural >75%, 50-75%, 20-50%, <20%, 0%	Compare IMPRESS DRP outcome 2003 (DRP 2003)	Field survey
	Modification in width		(to be harmonized with river engineering)	Field survey, other information
	Lateral erosion		(to be harmonized with river engineering)	Field survey
	Impoundment			Field survey
	Mean water level dynamics			Other information
Floodplain	Width			Map
	Landuse	Artificial, agricultural, forest/ semi natural areas, wetlands, water bodies		Map, other information
	Oxbows/ side channels, tributaries	Connection type: main channel, tributary, small side arm, open end oxbow (lower end open), oxbow, semi-separated (no permanent plant growth on the connecting zone, gravel), big secondary channel, floodplain lake, reservoir		Map, other information
	Riparian corridor			Map, other information
	Relative size of inundation flow	(guiding dikes/ embankments		Map, other information
	Capacity of regulated channel			Map, other information
	Flood level dynamics	(frequency, modification)		Other information
	Potential lateral connectivity for restoration			Other information

*data includes in particular remote sensing data as well as historical and recent maps

According to the recent pressure and impact analysis and discussion under the WFD in the Danube Basin the following assessment groups were provided by the UNDP/GEF (DRP 2003) output:

1. Lateral connectivity
2. Navigation channel
3. Longitudinal interruptions: a) height of structure, b) composition of channel substrate, c) migration barrier
4. River engineering banks
5. Effects of water abstraction (residual water)
6. Hydropeaking

All groups are defined by a 5 class assessment and the discussion of thresholds to define the risk assessment for the water bodies under the WFD. In particular the detailed values for the water abstraction (residual water in the former river bed) and the assessment classes for the hydropeaking were controversially discussed. In the recent study both parameters are recorded. The information for the residual water is provided by the hydropower companies and responsible authorities and the hydropeaking can be analysed by different gauging stations and the visual interpretation in the field. Therefore for the Drava project only the absolute values instead of percentages to the specific discharge were given with a simplified evaluation. For the investigated Drava and Mura stretches only the hydropeaking is relevant.

The following adaptations and additions were made based on the method of Kern & Fleischhacker (BfG 2002):

The parameters are grouped and have scores from 1-5 or bonus/ malus scores following the BfG method. Finally the overall score for each parameter group or even the whole assessment is based on average values. The existing manual (BfG 2002) includes a detailed description of each parameter and the assessment with the scores. Several important changes were made as described in the following:

1. System of the inventory: Instead of continuous equidistant evaluation stretches (e.g. 1 km), an inventory of the right and left channel/banks/floodplain with an independent length for each evaluation section was chosen. The minimum size for each section is 150 m. This value is related to the Drava but can be also valid for comparable rivers (for the Danube it could be 500 m, but the smallest recordable draining structures or the closure of large side channels by groynes is often less than 500 m). The pros and cons of this more precise but also more time consuming procedure is discussed below. As the real counts (e.g. for islands, bars or woody debris) refer to 1 km stretches in the used BfG method, those values have to be related if the stretches are shorter or longer. Only a few parameters (LWD, groynes) are assessed individually for the left and right part of the channel.

Therefore the overall evaluation cannot change for more than 0.5-1 classes.

2. The most important criteria for the local stretch length definition (homogenous instead of equidistant reaches) are differences of the channel, banks and floodplain: If one of these three parameter groups changes significantly a new segment has to be delineated. Practically this means that the term “significantly” indicates a change from one quality class to another. Typical criteria are changing planform of the channel, change from rip-rap to natural bank/ bank with natural vegetation or tree galleries or banks without vegetation, floodplain width in comparison with the morphological width, significant landuse changes (floodplain forest to agricultural land). The focus has to be on the parameter groups for the channel and the banks instead of differentiated landuse pattern.
3. Extension of the floodplain survey (where information is available) mostly based on secondary data (flood dynamics, habitat inventories) for the parameter “potential lateral connectivity for restoration” (this parameter is not included in the scoring scheme)
4. Improvement of the colour ribbon map highlighting the two main groups channel and banks/riparian zone and showing the floodplain in a transparent colour filling the real active floodplain segments. As background a coloured satellite image (or aerial images) overlaid by the recent topographic information (transparent layer of the topographical maps) is used.
5. Validation and proposal how to change selected scores (e.g. the numbers of bars/islands related to the river type) used for the BfG 2002 method based on the gained experience after the analysis, but not touching the basic assessment which should be directly comparable to the BfG method.

The usage of variable versus equidistant assessment units should be discussed in brief: The advantage of variable units is a better description of different contents or topics such as the homogeneity of parameter groups related to the channel, bank and floodplain. Variable units allow a fast and very precise characterisation of the river. Often it is possible to summarize longer stretches and to reduce the total number of evaluation units.
Equidistant units on the other side allow a very good calculation and data comparability as well as reliability and simplification related to future monitoring and changes (simple update of fixed GIS units).

The analysis and overlay of multi-parameter sets is depending on the mapping quality, independently of the method (variable versus equidistant units). The same is valid for the definition of variable units which is not a kind of expert judgment but defined by clear rules (change of one of the three main parameter groups for one full quality class causes a new evaluation stretch).

4.4.2 Database and GIS application

Based on the developed method an Access data base was compiled offering a related database with graphical interface which was further developed for the production of field protocols. For feasibility reasons the forms should be as simple and as short as possible (the option is to reproduce the field protocol on one A4 duplex sheet, compare figure 13). As mentioned earlier a lot of data and information must be gathered before from external sources. Therefore it is recommended to keep all external information in a separated form which is directly associated with each field protocol.

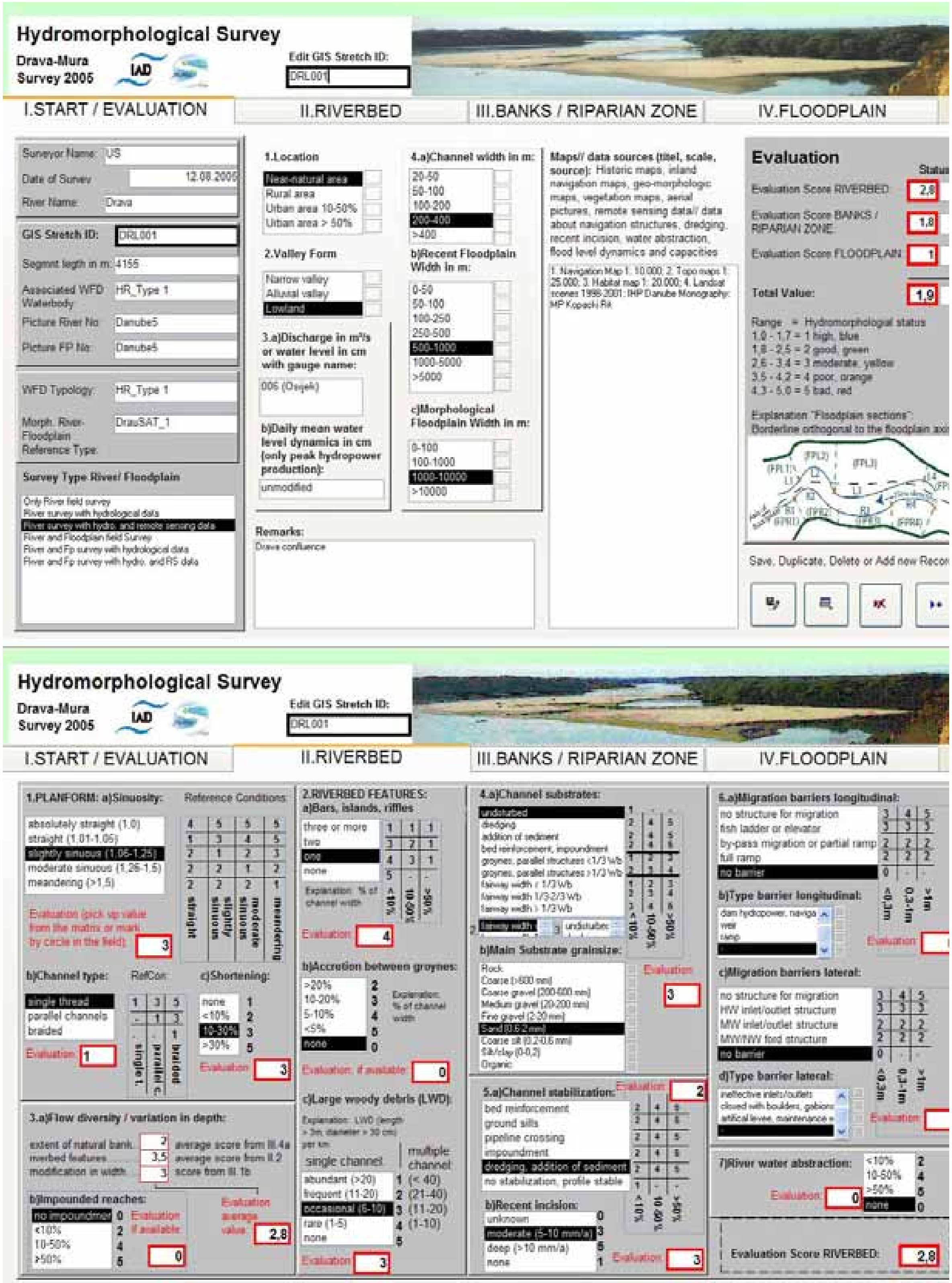
The prototype method was successfully tested along the Danube (Schwarz 2005).

In addition to the database development a separated GIS project was setup based on recent Landsat data and topographical maps (from the 1990s) in the scale of 1: 25,000. Two independent mapping approaches were developed: Firstly a high precision survey for the lower Drava and Mura rivers with a scale of 1: 25,000 (printed in this study in a scale of about 1: 50,000) showing a colored-ribbon map (as polygons) separated in left and right channel, banks/riparian zone and floodplain.

Secondly an overview for the entire Drava Basin in the scale of 1: 1,350,000 was developed showing only one generalised assessment band (summarizing the three main parameter groups).

As the Access database can be directly linked with the GIS (or easily exported via Dbase or Excel files) it is possible to explore the data in many ways, visualising and analyzing single parameters, comparing parameters or set specific parameter combinations/groups as well as any quantitative analysis and statistics.

Figure 13: Database form - extract (register cards I. Start/Evaluation and II. Riverbed)



4.4.3 Technical implementation

The preparations of the whole project and in particular the field surveys during summer and autumn 2005 started with the systematic data acquisition and collection, necessary for the required background information (e.g. hydrological data, navigation information, historical maps and recent satellite images) for the database and the development of the reference conditions.

Table 9 gives a first overview of the available data and the performed field survey.

………………

Table 9: Available data and methods for the Drava and Mura rivers survey in 2005

	AT	SI	HU	HR
Hydro-morph. Invent-tories	Continuous data for most of the Drava and Mura, mostly based on the method of Werth (1992)	No data and methods, SI was a partner country in the STAR/AQUEM, test inventories with the RHS	No data and methods (Aquaterra based on RHS), methods are under preparation	No data and methods
Others data	Hydrological and hydraulic data, sediment data, fish data and regions	Hydrological data, sediment data	Hydrological and hydraulic data , sediment data	Hydrological and hydraulic data , sediment data
Field survey Drava/ Mura 2005	Only sample stretches and basic parameters for the Drava (by surface), all other information including the upper Mura derived from existing inventories)	Only sample stretches and basic parameters (by surface)	Entire Mura and Drava border rivers (by boat/surface)	Drava down from Mura confluence (by boat/surface), hydropower plant-reach only by surface

The profound knowledge and extensive data collections of the author since 1995 facilitated the preparation.

For the field survey a kayak for two surveyors with space for food/materials to cover a two week long journey was charted with the logistic help of Mr. Arno Mohl (WWF) and Borut Stumberger from Slovenia. Parallel to the hydromorphological survey Dr. Stumberger collected ornithological data about river specific species such as terns, ring plovers and sand martins, nesting in steep banks and on sediment bars. Very important is the continuous photo documentation of both banks and riverbed features. At this place it must be mentioned that a lot of photo series and videos were gained since the year 1998 for several stretches, which allows a detailed development analysis for many stretches.

In the field maps (coloured, with the topographical map 1: 25,000 overlaid by Landsat images with interpolated 15 m ground resolution and water proofed foil) each channel/bank/floodplain stretch was marked in different (water proofed) colours. As described earlier the channel and bank structures have priority and they are fully visible from the boat.

The length of each evaluation stretch is dependent of considerable change of the main parameter groups channel, bank/riparian zone and floodplain.
On the Landsat image the flood protection dike and therefore the current floodplain can be easily extracted. The margins of the channel and bank structures stretches are interpolated for the floodplain behind by a similar approach than for the BfG method (in narrow meander bends the system is problematic and it is difficult to associate a floodplain portion; compare results in Mura and Drava detail maps 1-6, 1-20 and Drava Basin overview map in chapter 5). The floodplain was separately evaluated based on the satellite images, aerial pictures and existing habitat maps.

5 Results and Analysis

The chapter presents the results for the Drava and Mura Rivers according to the three main parameter groups (channel, banks/riparian zone, floodplain), followed by the overall assessment and accompanied by a photo documentation showing the most important sections. In total about 300 rkm were assessed in detail subdivided into 492 river reaches (right and left bank) with an average length of about 1.2 km (minimum 150 m maximum 5.5 km). Over 2,100 documentation photographs were taken (archive U. Schwarz).

At the beginning the river stretches of the whole upper catchment of the Drava and Mura Rivers which were not investigated in detail will be described according to existing data (archive U. Schwarz). Moreover, the results of the WFD assessment in the year 2004 for Austria and the other countries (ICPDR) must be mentioned here:

Austria assessed the whole Drava downstream of the Möll confluence (near Spittal) to the Slovenian border as "at risk" to reach the environmental objectives under WFD. Main reason is the overall hydromorphological situation in the reaches affected by hydropower schemes which leads to the assessment as HMWB. The half of the remaining reach to the Italian border falls into the class "possibly at risk" (which means basically that not enough data is available for the assessment) and the other part in the class "not at risk". About one third of the Mura falls into the categories "at risk" and "possibly at risk". This scattered stretches are located along the lower Austrian Mura (upstream and downstream of Graz) and are also designated as HMWB. The detailed map available for Austria showing the hydrological alterations (residual water in former channels, hydropeaking) indicates a huge number of scattered stretches with significant impacts of both pressures not only for the Drava and Mura, but also for many tributaries and its headwaters (alpine reservoirs and abstraction systems).
Concerning the risk assessment to reach the environmental objectives in the other countries only data for Slovenia and Hungary are available. Slovenia designated the whole Mura and Drava stretches as "possibly at risk". Hungary evaluated the border reach of the Mura with Croatia as "not at risk" and the Drava reach along the border as "possibly at risk". Slovenia provisionally designated the Drava reach from the Austrian border to Maribor as HMWB. But keeping in mind that Croatia nominated the whole Drava stretch from the Slovenian border to the Mura confluence as provisional HMWB, also the Slovenian stretch between Maribor and the Croatian border should be identified as HMWB due to the similar hydropower scheme. The overall picture for the lower reaches of the two rivers indicates the still existing data gaps (many "possibly at risk" designations).

5.1 The Drava and Mura in Italy, Austria, Slovenia and Croatia (without detailed field survey data)

Drava

The Drava source is situated at the foot of the up to 2,400 m high lime mountain ridges at the margin of the Dolomites in the “Toblacher field” which is on 1,200 m a.s.l. and builds a very flat valley floor and watershed division into the Mediterranean Sea (Adige) and the Black Sea (Drava/Danube). From the beginning the small creek is regulated in the intensively used meadows and the course is marked by regularly cut grey alder and willow bushes before the river enters the small town of Innichen. Here the Sextener Bach joins the Drava, which is more than 10 times larger and already influenced by small hydropower plants in the headwaters. The Italian reach of once about 17 km is mostly characterised by a sub-mountain meandering creek which was shortened in the past to about 10 km. Nearly half of the river is regulated with rip-rap (compare figure 14) and additionally by concrete in the settlements. Gravel of 2 – 6.3 cm is dominating this stretch. Only one fourth of the whole stretch remains at least without continuous bank protection (gallery wood), but reaching only some times the second evaluation class. Most of the river belongs to class three.

Figure 14:
Regulated Drava on its first kilometres after the confluence of the Sextener Bach in Innichen, Italy.
Hydropeaking and hydropower influence the Austrian Drava from the source.

For the Austrian Drava hydromorphological data from 1994 (Amt der Kärntner Landesregierung 1994) exist at least for the channel and banks (the update of the data is under preparation including the floodplain). The data are only available in aggregated form and characterised the upper Carinthian Drava mostly in the classes 1-2 (20%) and 2 (70%) of the former 7 class system with small exceptions belonging to class 2-3 and 3. Nearly 80% of the total river length in Carinthia were not evaluated (impounded reaches, hydropower use).
For the upper reach which partly belongs to Tyrol a lot of data is available prepared by an EU-Life project for the restoration of the upper reach. Whereas parts of the Drava upstream of the Möll confluence belong clearly to the second class, the Drava near Lienz is strongly regulated (class 3-4) and further upstream influenced by

residual water and hydropeaking (compare again figure 14). Just upstream of Spittal the last remaining large grey alder floodplain forest, the “Baldramsdorfer Aue” and ongoing restoration activities raise the hydromorphological conditions (class two). Further downstream the Austrian Drava is HMWB. Figure 15 illustrates the situation of the fully regulated channel with continuous embankments and impoundments near the power plants.

Figure 15: Typical view of the Drava river in Carinthia: Canalised river reaches with power plants. (Photo credit: Draukraft-werke AG)

Downstream of Villach the power plant type changes into a large barrage system as visible in figure 16 near Völkermarkt.

Basically the river in Austria can be subdivided into three main reaches (compare figure 9 morphological river types for the Austrian reach):

1. From the source downstream to Spittal the Drava is affected only by scattered small weirs and selected stretches are influenced by hydropeaking. Several restored river stretches such as Kleblach-Lind and the still existing floodplain (typical grey alder woods) of Baldramsdorf raise locally the hydromorphological values.
2. From Spittal to Villach the Drava flows in a broad valley and has pendular characteristics. The whole stretch is used for hydropower generation in the river-run mode (without diversion canals or regular hydropeaking). This section is heavily modified.
3. From Villach to the Slovenian state border the river is drowned into a chain of hydropower lakes and lost its natural characteristics completely. Only a view former meanders are proposed for restoration. This section is heavily modified.

....
Figure 16: The lower Drava section in Carinthia is mostly characterised by larger river dam lakes. (Photo credit: GoogleEarth)

Muhar characterised the Austrian Drava from the Slovenian border in different groups such as: Impounded potamon river in agricultural land, the same in woodland, impounded rhithron river (with the same two sub-types), straightened rhithron river in wood and agricultural land and straight alpine rhithron river in alpine woodlands.

In Slovenia the Drava flows over 40 km in a narrow breakthrough valley with very high Pleistocene terraces. This reach is completely used for power generation and partly impounded. The subsequent formerly braided downstream reach is characterized by long diversion canals for the hydropower generation with increasing reservoirs (Ptuj 4 km², Ormoz 3 km², Varazdin 11 km² and Dubrava 16 km², mostly built in the 1980s, compare figure 17). This second reach downstream of Maribor and further downstream in Croatia hosts still some former Drava channels with low residual water discharge which are only used in case of catastrophic floods. Here is a potential to increase ecological quality of the former channels by providing more residual water.

....
Figure 17: The upper Drava River section in Croatia: Large accumulation lakes of up to 16 km² and bypass canals as well as the former river bed. (Photo credit: GoogleEarth)

Mura

The Austrian Mura was surveyed since the early 1990s.
The Mura in Austria can be subdivided into several main reaches (compare figure 9 morphological river types for the Austrian reach):

1. The catchment of the headwaters of the Mura (>1,500 m a.s.l.) are used partly for hydropower-abstraction (Salzburg county).
2. The upper reach from Tamsweg to Judenburg passes several breakthroughs and is partly used for hydropower production.
3. Between Judenburg and Leoben the river still meanders in its broad valley of about 1-1.5 km width. This section is mostly free flowing.
4. From Leoben to Graz the river crosses again a narrow valley which is totally impacted by hydropower plants (mostly with short diversion canals) which is designated as heavily modified reach.
5. From Graz to Spielfeld the Mura enters a large plain in the alpine foothills which is mostly used for hydropower (run of the river mode or diversion canals).
6. Down from Spielfeld along the Slovenian border the Mura is strongly regulated but free-flowing and still hosts important floodplain forests of national importance.

Figure 18: Residual water in a diversion stretch of the upper Mura.

The official evaluation (data of 2000) of the Styrian water management authority, modified according the approach to reduce the seven into the five class system, shows the following characteristics:

Table 10: The re-arranged hydromorphological data for the Austrian Mura shows the difficulty to directly compare different methods.

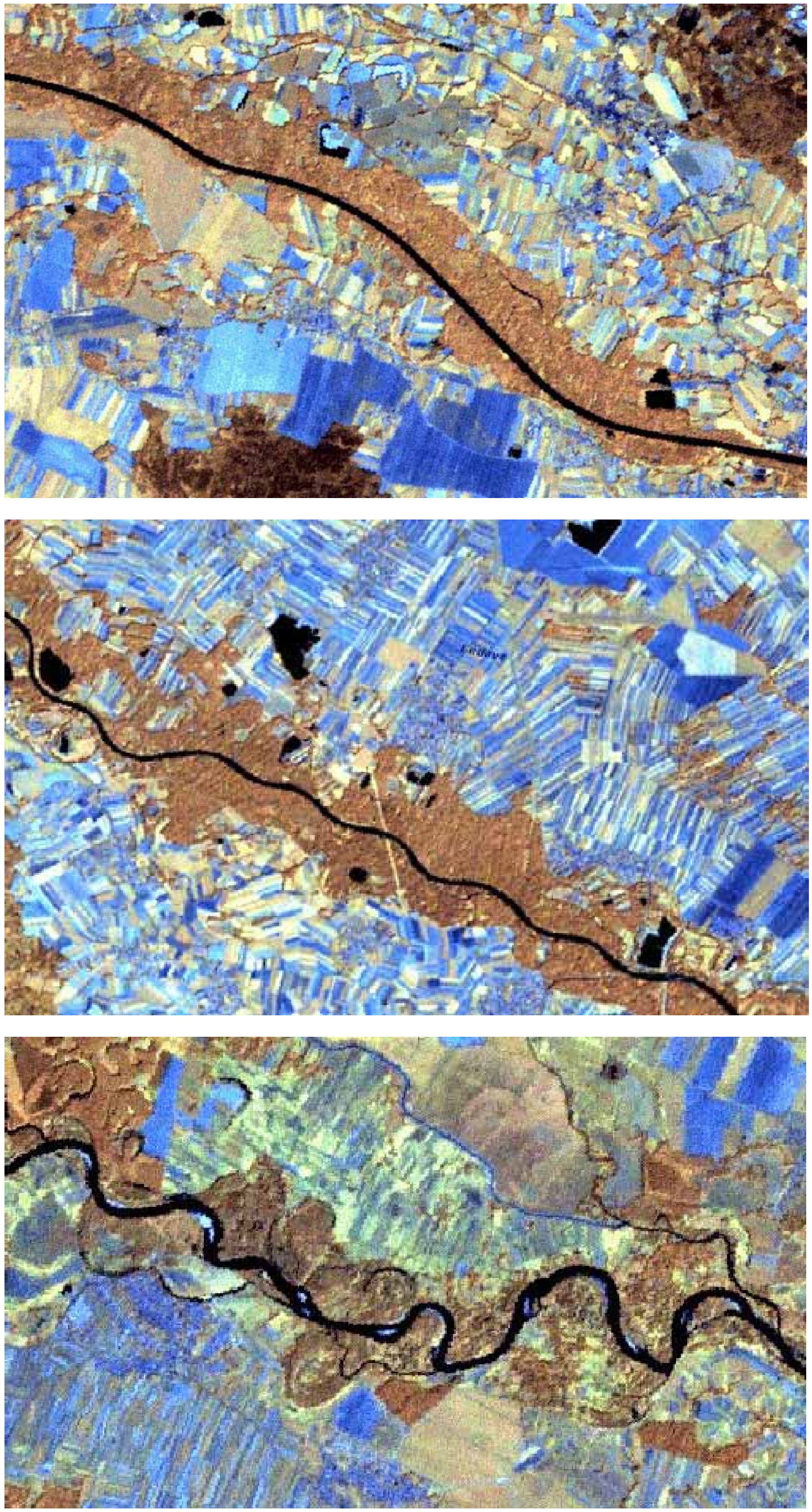
Class	Channel	Banks	Floodplain (adjacent vegetation)	Total value (including additional parameters)
1 (high)	33%	10%	23%	11%
2 (good)	29%	49%	49%	62%
3 (moderate)	12%	14%	2%	1%
4 (poor)	0%	1%	0%	0%
5 (bad)	26% (impoundment)	26% (impoundment)	26% (impoundment)	26% (impoundment)

The overall picture seems to be very positive and shows the difficulty to directly compare the methods. The parameter group channel (figures 19-21 represent the detailed background data not visible in table 10) includes the "river course development/ flow characteristics" which has only 13% in the first class but 24% in the third class whereas the substrate of the channel got very high values of over 50% in the first class. In line with many other evaluations the basic result points towards the right direction. The 26% of impounded rivers were allocated to the worst class 5, possibly parts of these stretches could also be allocated to class four. Finally the official results show about 1/3 of the river is under poor hydromorphological conditions and nearly 2/3 of the river should be in the 1-2 class. Taking into account that more than half of the second class belongs to the critical transition class 2-3 (in the former seven class system), the overall picture should be shifted into 1/3 HMWB, 1/3 moderate (class 3), nearly 1/3 good (class 2) and the rest belongs to class 1. Considering that hydropeaking and a real floodplain assessment was not included in the evaluation the results become more and more realistic and directly comparable with the results gathered in this study.

Several river stretches along the upper, middle and lower Mura (Border Mura with Slovenia) in Austria were surveyed in detail (Büro Freiland 1995). The results clearly indicate the deficits concerning the river course development and the in-channel features such as different sediment bars or large wood debris. Only a few stretches of some kilometres reach the reference quality after Werth 1992. After Muhar 2004 the river can subdivided from down- to upstream into straightened potamal river in woodlands and agricultural land, impounded potamal river in woodland, straightened rhithron river in agriculture, meandering, winding rhithron river in agriculture, and straight rhithron river in agricultural and braided rhithron river in agricultural land.

The Slovenian Mura is still free flowing and with larger distance to the Austrian border the river still has good to very good hydromorphological conditions (compare figure 18).

....
Figure 18: Comparison of three Mura stretches with partly similar hydromorphological characteristics (partly braided to sinuous, anabranching to a meandering river system). The upper image shows the border Mura between Austria and Slovenia (evaluated with 2-3 / class 2 WFD), the middle image shows the stretch just below, and the third one is directly attached further downstream (which got mostly the class 1). The scale of the Landsat images is 1: 50,000. According to the evaluation system used in this study the first river reach belongs clearly to class 3 (moderate), only the floodplain belongs to 2 and not to class 3 (without substantial restoration activities which are under planning). Also the second reach needs further restoration measures to belong clearly to the second class, in particular the reconnection of side channels. (credit: WWF-AT)



5.2 Mura River from upstream Murska Sredice to the mouth into the Drava (rkm 85 – 0)

The Mura River forms in the lower reach first the border between Slovenia and Croatia and for the last 40 km the border between Croatia and Hungary. The river was subdivided into about 80 river segments each independently for the right and left bank and with a different length (range from 150 m to 3 km).

5.2.1 Evaluation of parameter groups

5.2.1.1 Channel

As it could be expected (compare the description of the upper catchments and figure 18) the channel can be assessed as of good hydromorphological conditions with several reaches of a very good assessment according to the reference conditions described in chapter 4.3. More than one fourth belongs to the first class. Only 11% can be characterized as moderately and poor. A lot of reaches of the second class are influenced by meander cut offs or a reduced channel shift, which are under the slow process of regeneration. Therefore the potential for the reconnection of side-channels and the reduction of the moderate recent incision can be estimated as very high. So far the river is not impacted by hydropeaking.

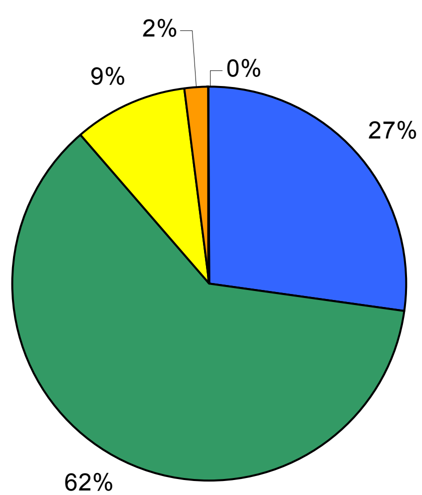


Figure 19: Channel evaluation for the Mura

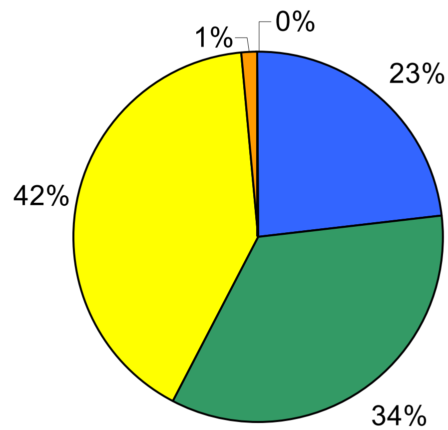
Legend:
Blue: high (1)
Green: good (2)
Yellow: moderate (3)
Orange: poor (4)
[Red: bad (5)]

5.2.1.2 Banks/riparian zone

The picture for the banks/riparian zone looks slightly different in comparison with the channel. More than 40% of the banks belong to the class three indicating the bank protection of at least 50% of the evaluation reaches. This reflects reduced lateral erosion potential and river course development as well as a considerable loss of natural steep banks and adjacent sediment bars. In particular the lower meandering reach of the Mura is affected, where each steep bank is protected by rip-rap. The channel form and sinuosity contribute, as recorded for the channel, mostly to class two (compare 5.2.1.1). But the lateral shift is restrained by the protected banks. Only very view reaches are strongly protected by rip-rap (infrastructure only).

Figure 20:
Banks/riparian zone evaluation for the Mura

Legend:
Blue: high (1)
Green: good (2)
Yellow: moderate (3)
Orange: poor (4)
[Red: bad (5)]

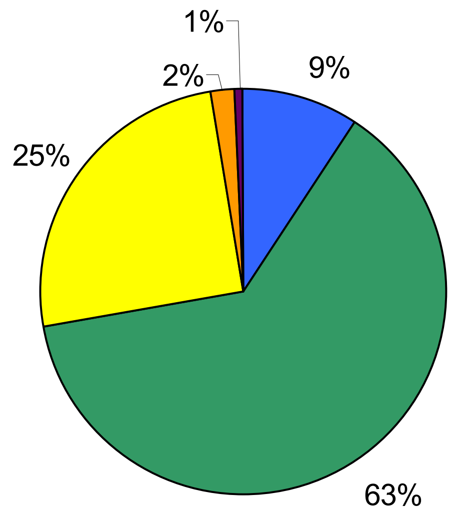


5.2.1.3 Floodplain

The Mura floodplain still covers a nearly complete river-floodplain corridor. Along the southern terrace the river has still its full floodplain extent. Along the lower meandering reach the flood protection dike is partly very narrow along the steep banks (one reason for the bank fixation). In the meantime several floodplain segments are influenced by filled gravel pits which destroy step by step larger natural areas. This can be observed in particular within the meander belts and the point bars. On some reaches the gravel pits expand very close to the current channel. As smaller formerly filled gravel pits are different for the evaluation (bonus as altered “floodplain”, malus as “excavation/deposition”) this parameter has to be assessed in the post analysis of the method.

....
Figure 21:
Floodplain evaluation for the Mura

Legend:
Blue: high (1)
Green: good (2)
Yellow: moderate (3)
Orange: poor (4)
Red: bad (5)



5.2.2 Overall assessment

About one fourth of the whole lower Mura can be assessed as under very good hydromorphological conditions. This is still a very high value in comparison with similar rivers in central Europe and of course the upper catchment. With another part of nearly 50% the reaches under good conditions indicate the high overall status and potential for this river. The second and first classes further belong to the group “not at risk” to reach the environmental objectives under the WFD. Only one fourth can be assessed as moderately or strongly altered mostly resulting from river bed corrections, meander cut offs and bank protection. The latter is important in particular for the lower fixed meander reach. The removal of bank protection would raise the evaluation considerably. The still increasing use of the floodplain, especially the numerous commercial gravel pits must be rated as critical impact.

5.2.3 Photo documentation

At the beginning of this chapter selected aerial images will highlight stretches with possible reference character for the lower Mura. Concerning the unlimited floodplain availability (natural terrace margins) only very few sections still exist mostly along the border that formed the iron curtain. Further the hydrological and sedimentological changes and deficits must be taken into consideration even if the next hydropower dam is about 150 km upstream.

....
Figure 22: Transition type from a sinuous to a meandering river course still with a high potential of anabranching, sediment bar development and shifting processes (Type M1 to Type M2) (Photo: Arno Mohl).

....
Figure 23: Typical meander belt of the lower Mura, with protected steep bank (due to the narrow flood protection dike in the background) and the mostly intact point bar reach (Type M2) (Photo: Arno Mohl).

Sample stretch 1 (from rkm 80 to rkm 85):

This Mura stretch belongs to the moderate and strongly modified Mura reaches in Slovenia and along the Austrian border. The banks are mostly protected, only few side channels are still connected, but due to the higher flow velocity in the main channel the ongoing bed incision reduced the frequency of the connection and the floodplain inundation.

Figure 24: Both banks are mostly protected by rip-rap. The vegetation often covers the bank protection. The occurrence and variability of in channel features is low (Photo: U. Schwarz).

Figure 25: In addition to the bank protection, a few groynes are placed sporadically along the remaining convex banks. The construction material contains boulders and wood piles (Photo: U. Schwarz).

Sample stretch 2 (from rkm 40 to rkm 65):

In this reach the fluvial dynamics still provides the full set of in-stream structures such as different sediment bars, islands, large wood debris, steep banks and point bars and a differentiated floodplain relief with regularly connected floodplain waters.

....
Figure 26: Islands with different size and vegetation cover are well developed. Typical sequences of steep banks and well developed gravel bars further downstream can be observed (Photo: U. Schwarz).

....
Figure 27: Often the young softwoods (15-20 years) developed on former islands will be eroded and deliver a permanent LWD (large woody debris) which forms again new sediment bars and provides many habitats for aquatic and semi-aquatic species (Photo: U. Schwarz).

Sample stretch 3 (from rkm 5 to rkm 30):

The typical situation along the lower meandering Mura: The bank protection in the steep banks prevents further lateral sediment erosion and sediment bars subsequently accumulated in the shallows between the meander belts are rare.

Figure 28: Along the steep banks the floodplain corridor is often reduced to some 50 m (vegetation galleries only). Nearly each of the steep banks is enforced by rip-rap (Photo: U. Schwarz).

Figure 29: Due to the usually low flow velocity in the long meander bends and the missing erosion material from the steep banks, the point bars are not very well developed in this reach. Only a few typical point bars and islands can be recorded. The variance of the flow pattern is also reduced in comparison with the natural reaches, which contributes also to different habitat conditions for fish and macrozoobenthos (Photo: U. Schwarz).

5.3 Drava River from the Mura confluence to the mouth into the Danube (rkm 218 – 0)

The Drava River constitutes for about 15 km the border between Croatia and Hungary after the confluence with the Mura River. The next about 30 km of the Drava flows in Croatia only. The subsequent stretch down to Donij Miholjac constitutes again the Hungarian-Croatian border before the river finally crosses Eastern Slavonia in Croatia and joins the Danube at Ajmas.
The river was subdivided into about 160 river segments each independently for the right and left bank (in total 324) and with different length varying between 200 m and 5.5 km.

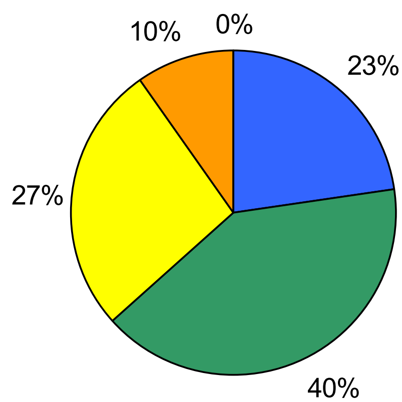
5.3.1 Evaluation of parameter groups

5.3.1.1 Channel

According to the reference conditions two main River-Section-Types with several sub-types can be distinguished. Still over 20 % of the channel sections belong to the first class (absolute scores are often between 1.5-1.7 which clearly indicates the trend of many reaches to shift from the first towards the second class). Those stretches are distributed along the whole river corridor with spotlights just downstream of the Mura confluence, close to the Repas forest with the subsequent high steep bank in Hungary as well as several meander bends upstream of Barcs and Belisce. As different to the Mura the Drava has some more stretches in the poor class four, in particular where the river crosses larger towns (Barcs, Belicse, and Osijek).

....
Figure 30: Channel evaluation for the Drava

Legend:
Blue: high (1)
Green: good (2)
Yellow: moderate (3)
Orange: poor (4)
[Red: bad (5)]

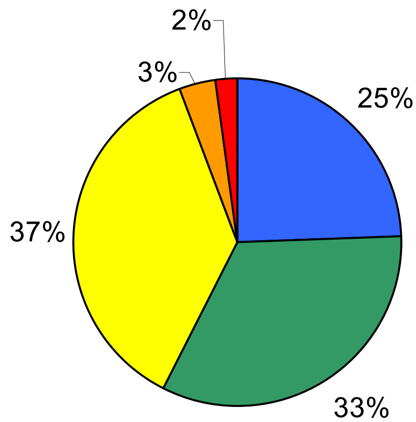


5.3.1.2 Banks/riparian zone

Large stretches of the river are controlled by bank protections mostly in form of rip-rap and selected groynes. The absolute values of modified banks also include very small but highly efficient river engineering works, such as the closure of side channels (not only the quantitative aspect but also the qualitative aspect should be considered). The second class includes some banks with former collapsed bank protection. In summary over 50% of the banks belong to the first two classes.

Figure 31: Banks/ riparian zone evaluation for the Drava

Legend:
Blue: high (1)
Green: good (2)
Yellow: moderate (3)
Orange: poor (4)
Red: bad (5)



The most serious impact for the semi-aquatic habitats along the river banks is caused by hydropeaking, which affects more than half of the entire 218 km long river stretch. The river buffers the extraordinary daily peak of up to 1.8 m downstream of the Mura confluence and through the flowing retention in side-channels. As indicated by Tockner et al. 2004 the impact of hydropeaking is considerable even if the morphological conditions with shallow banks and rich structured channels still partly exists. The analysed beatle (Carabidae and Staphylinidae) and spider communities living in the semi-aquatic bank habitats or on sediment bars have significantly reduced abundance in river stretches with hydropeaking. In addition the alteration of natural banks and removal of sediment bars lead to a reduction of species and abundance.

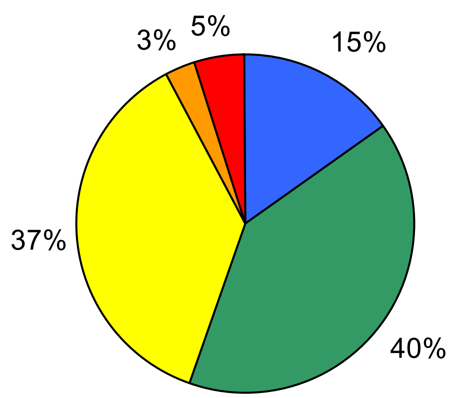
Beside the effect of daily water oscillations with submerged and dry conditions and the temporary lateral disconnection, the accumulation of fine material transported by the Mura River or periodically released by sediment spills of the last Croatian hydropower plant leads to colmation effects and influences the vertical connectivity (hyporheic interstitial, compare figure 42).

5.3.1.3 Floodplain

Due to the considerable channel deepening of up to 2.5 m within the last 30 years several parts of the floodplain are disconnected from the flooding regime. Considering this lowering of the groundwater table it is remarkable to find still 55% of the floodplains in the good and very good classes, but keeping in mind the retardation of the floodplain development since the completion of the hydropower chain in 1990 the development is clearly negative (further disconnection of floodplains). Impressive is the still nearly closed floodplain corridor along the entire reach. Only downstream of Barcs the corridor is very limited on both sides. The left bank (mostly Hungarian national park) has significantly more pristine floodplain areas (total length of nearly 38 km) than the right bank (17 km).

Figure 32: Floodplain evaluation for the Drava

Legend:
Blue: high (1)
Green: good (2)
Yellow: moderate (3)
Orange: poor (4)
Red: bad (5)



5.3.2 Overall assessment

The Drava still hosts a plenty of different habitat types and morphological sub-types and builds together with the Mura an over 380 km long free flowing river system. The river was modified over the past 300 years in particular to improve navigation and flood protection. Today the waterway transport is de facto absent upstream of Osijek but the channel is maintained up to rkm 189. Therefore hydropeaking along the upper reach and maintenance and meander cut offs along the lower reach are the main impacts together with sediment extraction. Any reduction of one of these pressures will improve the situation.

5.3.3 Photo documentation

Selected aerial images will again highlight stretches with possible reference character for the lower Drava. As discussed for Mura only few sections have “reference character” in respect to the hydrological and sedimentological regime. In particular, this reflects hydropeaking, the reduction of small annual floods by the upstream reservoirs and the sediment deficit due to the dams in the upper gravel sections and the partly excessive gravel and sand extraction.

Figure 33: Just 10 km downstream of the Mura confluence the river intensively works in its own alluvial deposits (medium to fine gravel) and builds partly braided structures and diamond bars (Photo: Arno Mohl).

Figure 34: 30 km downstream the river accumulates still a lot of gravel. The picture shows the recently reinforced bank (groynes on the right image side) to prevent a further channel shift (Photo: Arno Mohl).

....
Figure 35: One of the most spectacular meanders in sandy substrate can be found 10 km upstream of Barcs. The sequence of ridges and swales and the typical pioneer vegetation beginning from the sand bar and followed by willow and natural poplar softwoods is very seldom, as most of the meanders are fixed by rip-rap. In the background one of the largest and still connected oxbows is visible (Photo credit: Arno Mohl).

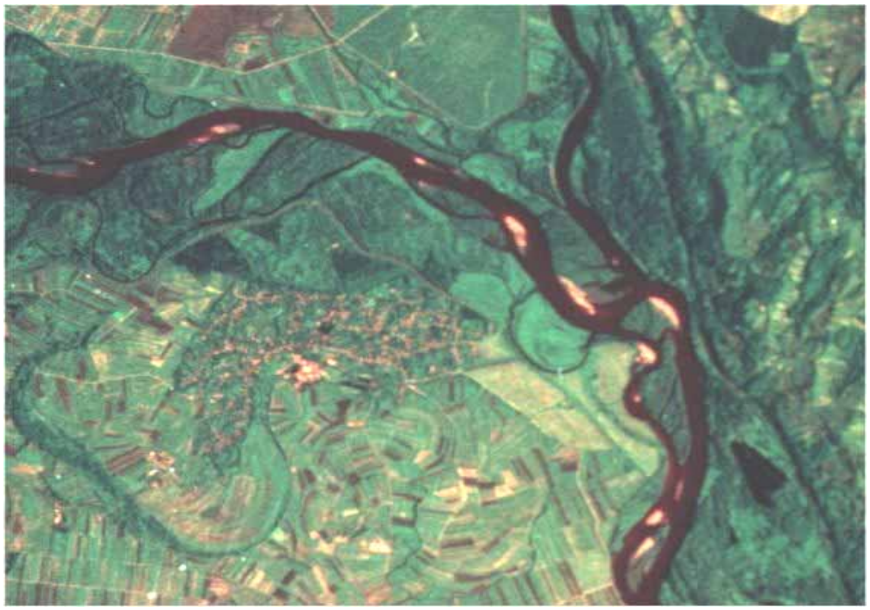
....
Figure 36: The steep bank on the erosive side of the meander, right part of figure 35, is about 5 km long and up to 15 m high. The river erodes grass and brush lands which is part of the Hungarian Danube-Drava national park (Photo: U. Schwarz).

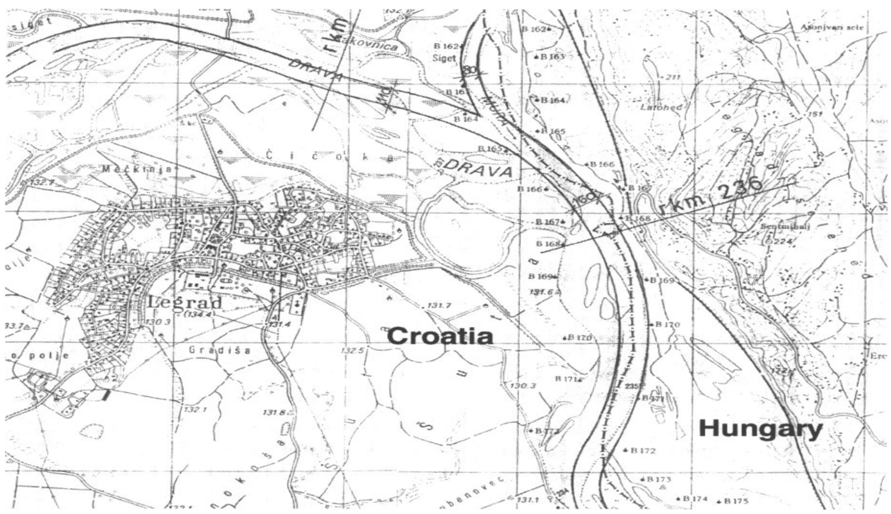
....
Figure 37: In addition to the current meander reaches of the Drava several large oxbows raise the floodplain evaluation. Most of these meanders were cut during the last 100 years (Photo credit: Arno Mohl).

Sample stretch 1 (from rkm 196 to rkm 218):

This Drava stretch just downstream of the Mura confluence is characterised by highly dynamic fluvial habitat patterns along the Örtilos hills (Hungarian border). The German *tamaracks*, a typical Alpine riverine plant, reaches its eastern limit of distribution in this stretch of the Drava and Mura.

....
Figure 38: Typical dynamic pioneer habitats for *Tamarix germanica*, endangered on European level, just below the Mura confluence (Photos: U. Schwarz).





....
Figure 39: Comparison of the Mura confluence in 1991 and the still not abandoned long-term regulation scheme of the water authorities (after Schneider-Jacoby, 2005). In the meantime the right river bank along the Drava was reinforced for a stretch of approximately 1 km and a side channel was closed just before the confluence, to stabilize the confluence area (see photo below, bank in front of the meadow in the foreground and left meander) (Photo credits: above: Euronature, below Arno Mohl).

....
Figure 40: High supply of sediments and LWD on the remaining steep banks (Photo: U. Schwarz).

....
Figure 41: Frequent development of large islands and partially braided channels (Photo: U. Schwarz).

Sample stretch 3 (from rkm 180 to rkm 170):

This reach is characterised by the cut-of meander (in 1980) near Belavar and reaches the steep bank along the loess terrace on the Hungarian side. The reach still hosts habitats for the Little Tern *(Sterna albifrons)* but it shows also the adverse effects of the channel shortening (drying up of the Belavar branch) and the daily hydropeaking.

Figure 42: Belavar side channel during "low water peak" and clogging of the gravel by fine sediments due to the daily water oscillation of more than one meter (Photos: U. Schwarz).

Figure 43: Islands and side bars provide in this stretch the habitat for the Little Tern, endangered at European level, in particular far from sea coasts. Only along the Loire/Allier (France) and Wistula (Poland) rivers this bird occurs regularly (Photo: U. Schwarz).

....
Figure 44: The steep bank between Belavar and Heresznye on the Hungarian side is the highest along the middle and lower Drava with up to 35 m and nearly one km length (Photo: U. Schwarz).

Sample stretch 4 (from rkm 100 to rkm 105):

This stretch is characterised by several huge meander cut offs and a nearly straight river course. Official planning documents declare the Drava as a navigable river upstream to rkm 189 as ECW class III waterway and from Osijek down to the Danube confluence as class IV (Danube has class VI). This includes the regular dredging to maintain the navigation corridor and the compliance of a minimum radius (last meander cut-offs and straightening date from the 1980s). A lot of adverse effects such as the further bed degradation and incision can be observed.

....
Figure 45: Monotonous straightened river stretches with scattered gallery woods are typical for this river reach (Photo: U. Schwarz).

....
Figure 46: Scattered adjacent forests are predominantly made by hybrid poplar plantations. The navigation buoy makes the constant stream velocity visible (Photo: U. Schwarz).

Sample stretch 5 (from rkm 60 to rkm 75):

This stretch should show the band-width from modified reaches close to the small town Belicse down to the pristine meanders just 15 km upstream of Osijek.

....
Figure 47: Belicse: The small town of Belicse (about 15,000 inhabitants) is the biggest settlement between Dolnji Miholjac and Osijek and the site of a paper and pulp factory (point source of pollution) with railway connection and small harbour (very little waterway traffic). The right bank is strongly enforced (Photo: U. Schwarz).

....
Figure 48: Just downstream of Belicse the river is regulated with groynes and riprap (Photo: U. Schwarz).

....
Figure 49: The stretch downstream of Belicse is partly regulated, mostly along the steep banks, by old onset riprap. All other bank stretches are more or less undifferentiated, hosting mostly a near natural vegetation in form of white willow galleries in front of poplar forests (mostly hybrid poplar plantations) (Photo: U. Schwarz).

....
Figure 50: On several places the bank stabilisation disappears due to undercut or missing protection. Additionally this happens much more in the “lower energy” stretches between meanders or at the beginning of steep banks. Depending on the accessibility and use of the adjacent floodplain a rich vegetation composition can be found on more elevated stands which link to the hardwood (Photo: U. Schwarz).

....
Figure 51: Only a few parts of the right bank are used for small fishermen settlements or weekend houses, mostly “protected” by simple groynes and scarce rip-rap (Photo: U. Schwarz).

....
Figure 52: Behind groynes small sand bares are frequent. Due to the protection of most of the steep banks these features slightly enrich the bank structures (Photo: U. Schwarz).

....
Figure 53: About 12 rkm downstream of Belicse a more natural river stretch can be observed: Some large islands and point bars (in the used satellite image from 2001 clear from pioneer and willow vegetation) spread along a five km section (Photo: U. Schwarz).

....
Figure 54: The aerial view reveals the full set of meander features with steep banks and a large (partly flooded) point bar in the foreground. This area must be seen as a “reference” meander for the lower Drava, showing the still highly dynamic sandy lowland river system. In the background oak forests are visible. (photo credit: Mario Romulic)

....
Figure 55: The same meander as in fig. 54 from the boat's view: at lower water level an extensive point bar hosting a wide and varying habitat mosaic of sand bars, small ponds, pioneer and young willow stands appears (Photo: U. Schwarz).

....
Figure 56: The steep bank cutting about 5-10 m into the loess terrace over a length of nearly 4 km. The relatively wet terrace (partly plunged with fine loamy lenses) still hosts the famous Slavonian oak forest (*Quercus robur*). The steep bank as well as the point bar are not easily accessible due to the omnipresent mine fields along the banks (warning signs every 500 m mostly on both banks) (Photo: U. Schwarz).

....
Figure 57: Downstream of the "model meander" the next near-natural part follows. The picture gives an impression how much the large woody debris can prevent fast lateral erosion. In spite of the quite high flow velocity of 0.5 m/s (compared with other stretches in this Drava part), the lateral erosion is limited due to parallel "adjusted" trunks which collect finer debris and eroded material from the banks. During high water levels and floods this "protection" is of course not very stable (Photo: U. Schwarz).

5.4 Maps

5.4.1 Maps 1: 25,000 for the lower Mura and Drava

As already described in the method chapter an adapted colour-ribbon map was prepared showing all segments of each river reach independently for the right and left river channel/bank/floodplain. These high-resolution maps can be used only on a scale of 1: 25-50,000 depending on the width of the river and the paper format (A3, A4). To improve the visualisation for very narrow channels a part of the floodplain should be used for the overlay of the channel and banks. In particular the independent evaluation and stretch length allow a very precise visualisation of the real situation concerning highly effective bank protection/side-arm closure or still existing continuous backwater and oxbow systems in the floodplain. Basically the floodplain delineation is easy for a rather straight channel part by using right angle segments based on the main river axis. In meandering reaches this is much more complicated in particular as the combined parameters for the channel and the banks are more important than the floodplain evaluation.

In addition to the evaluation the layer of flood protection dikes and the morphological floodplain was added to facilitate the understanding of the individual position and situation. This is of particular interest where the river is very close to the dike or infrastructure. The latter as well as the settlements are visible with a transparent layer of the topographical maps on the scale 1: 25,000. The flood protection dikes do not include small lateral dikes for local routes or other purposes. Also secondary dikes behind the main protection line are not considered. The morphological floodplain margin is based on the geological and morphological situation. Often the margin is not very clear where lower terraces are missing. In this case the margin is oriented on visible former meander belts of the two main rivers.

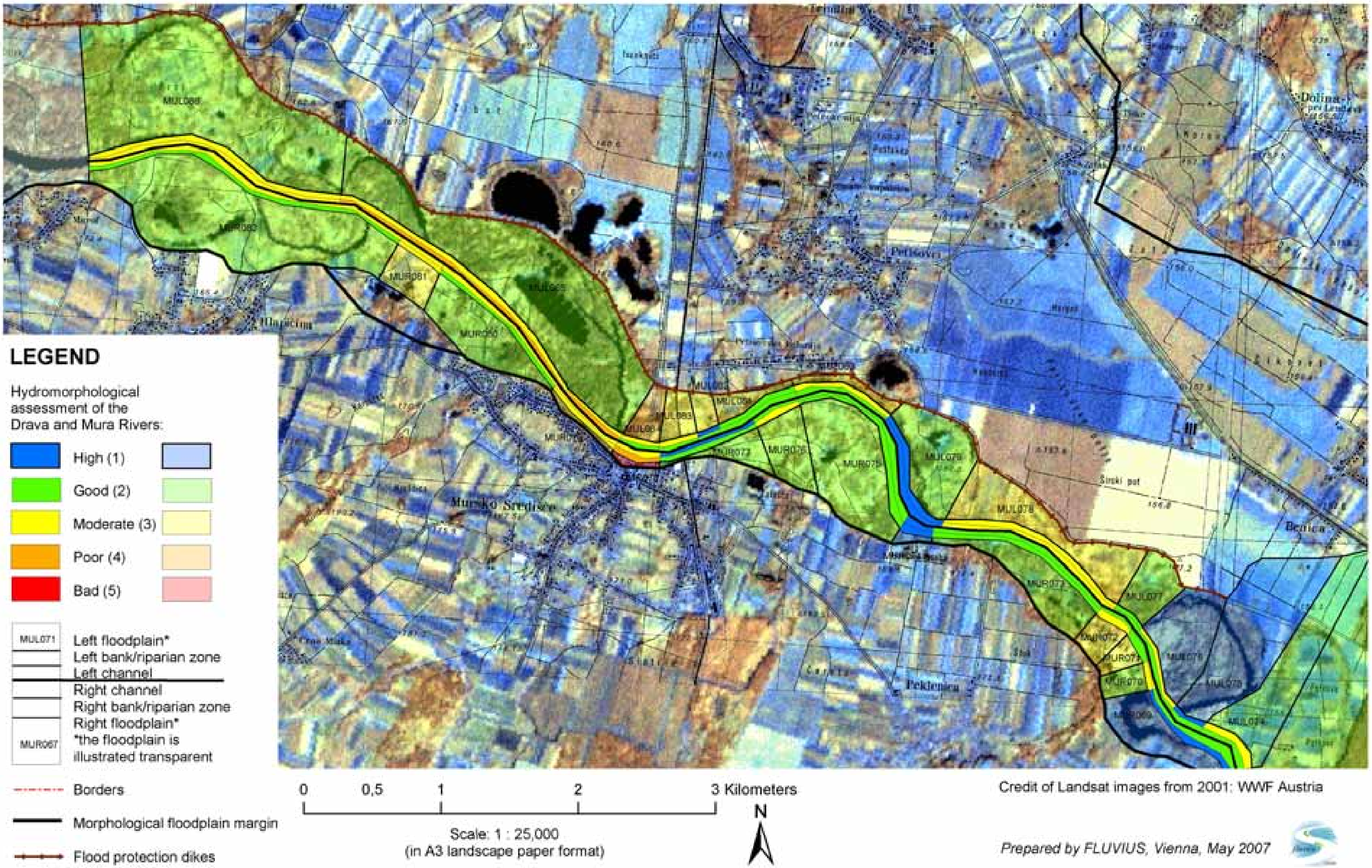
The maps are ordered from the most upper part of the Mura (Mura 1) to the confluence into the Drava (Mura 8) and then again beginning with Drava 1 to Drava 24.

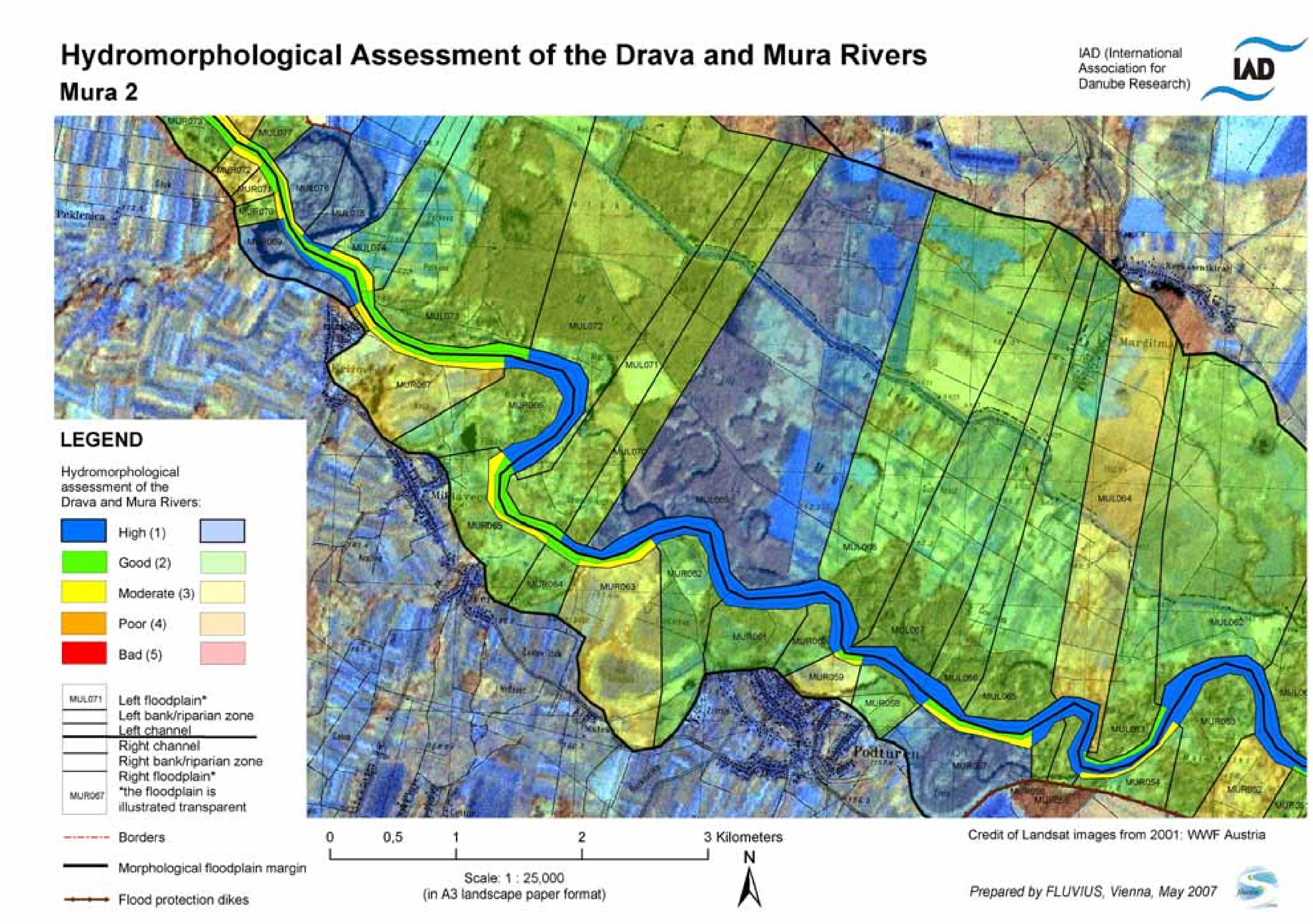
Two additional remarks:
On the map “Mura 6” the morphological floodplain margin “cuts” the upper Drava. This has only technical reasons (polygon GIS calculations) as the upper Drava reach was not further evaluated.
At the Drava confluence into the Danube the margin of the morphological floodplain northwards into the Kopački Rit was simply set to about 1 km to allow and estimate polygon calculations for the floodplain size and to set limits for the illustration in the map. The Danube and Drava share the floodplain for more than 20,000 ha.

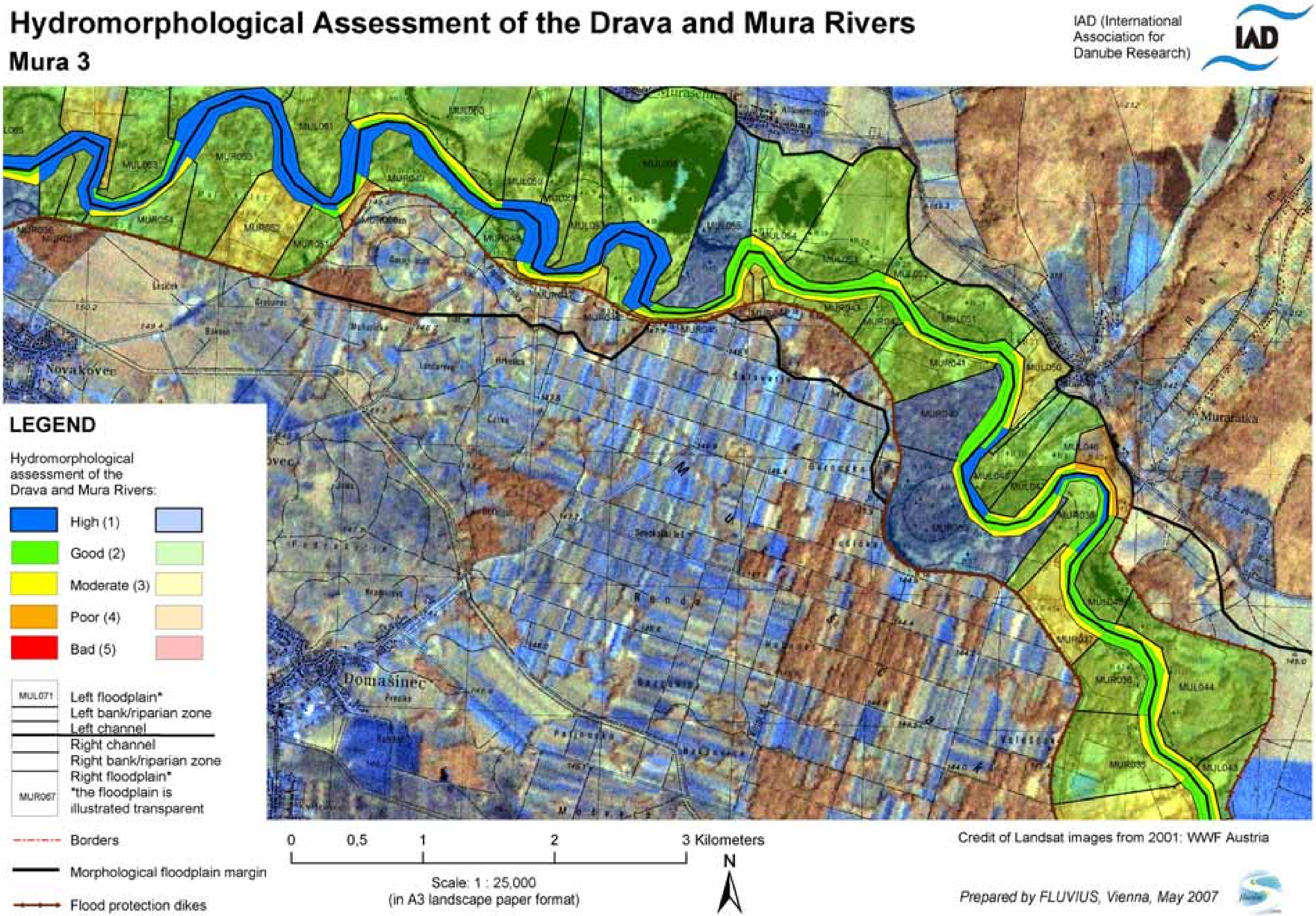
Hydromorphological Assessment of the Drava and Mura Rivers

Mura 1

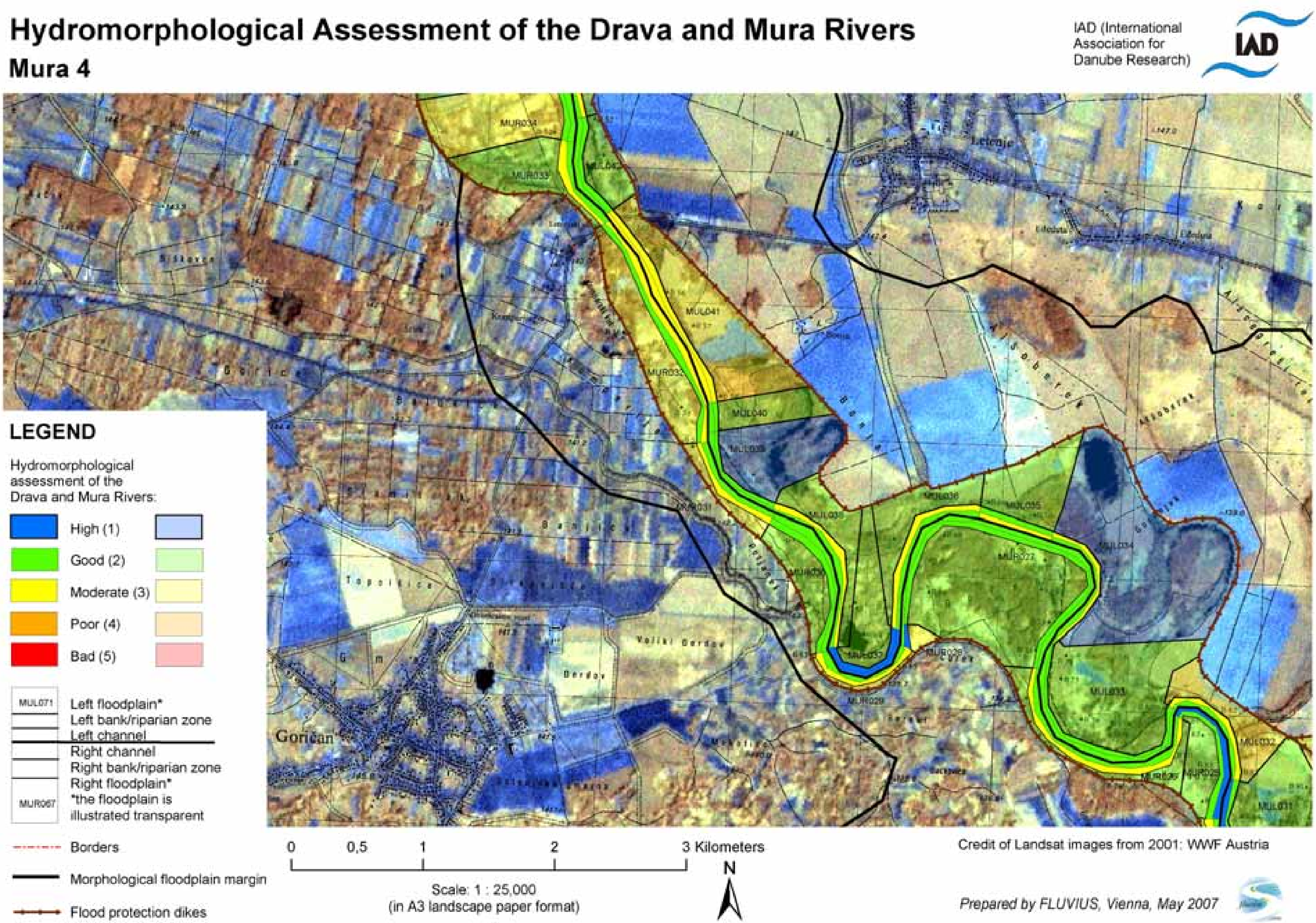
IAD (International Association for Danube Research)




Hydromorphological Assessment of the Drava and Mura Rivers
Mura 2
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
MUL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
MUR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007



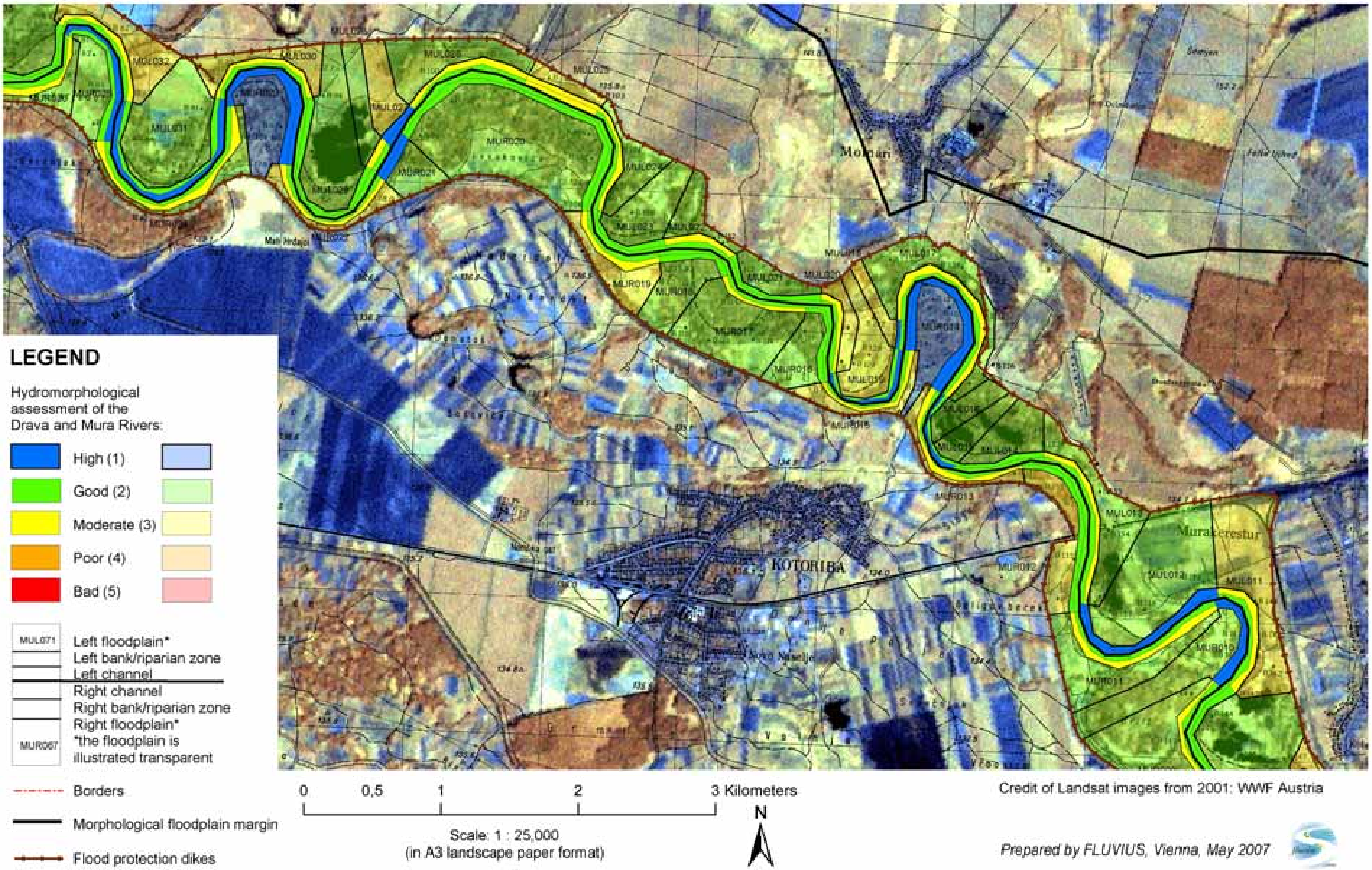
Hydromorphological Assessment of the Drava and Mura Rivers
Mura 3
IAD (International Association for Danube Research)
IAD
Novakovec
Domašinec
Muraratka
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
MUL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
MUR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007

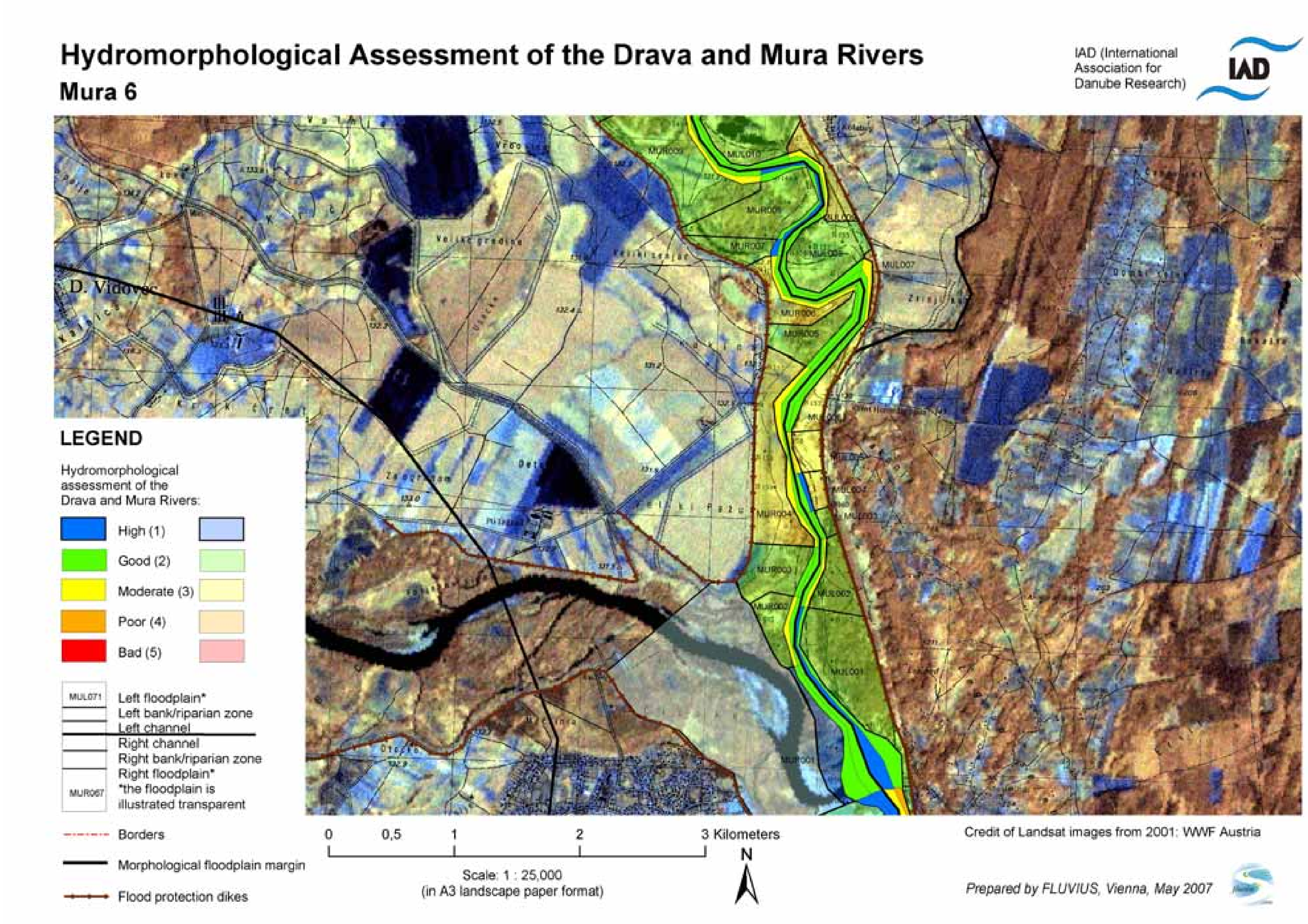

Hydromorphological Assessment of the Drava and Mura Rivers
Mura 4
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
MUL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
MUR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007
Goričan
MUR034
MUR033
MUL041
MUR032
MUL040
MUL036
MUL035
MUR031
MUR027
MUL034
MUR029
MUL032
MUL031

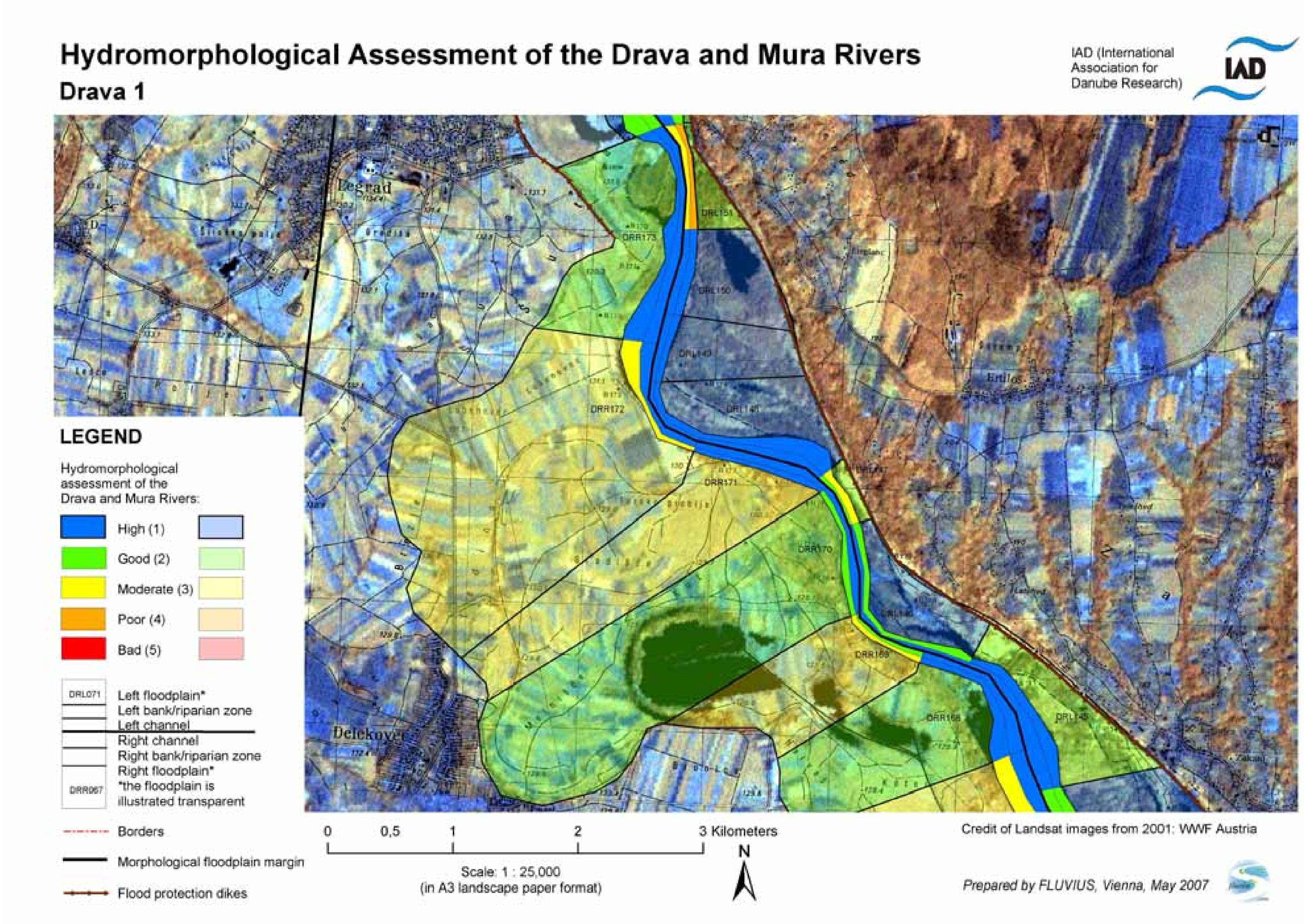
Hydromorphological Assessment of the Drava and Mura Rivers

Mura 5

IAD (International Association for Danube Research)



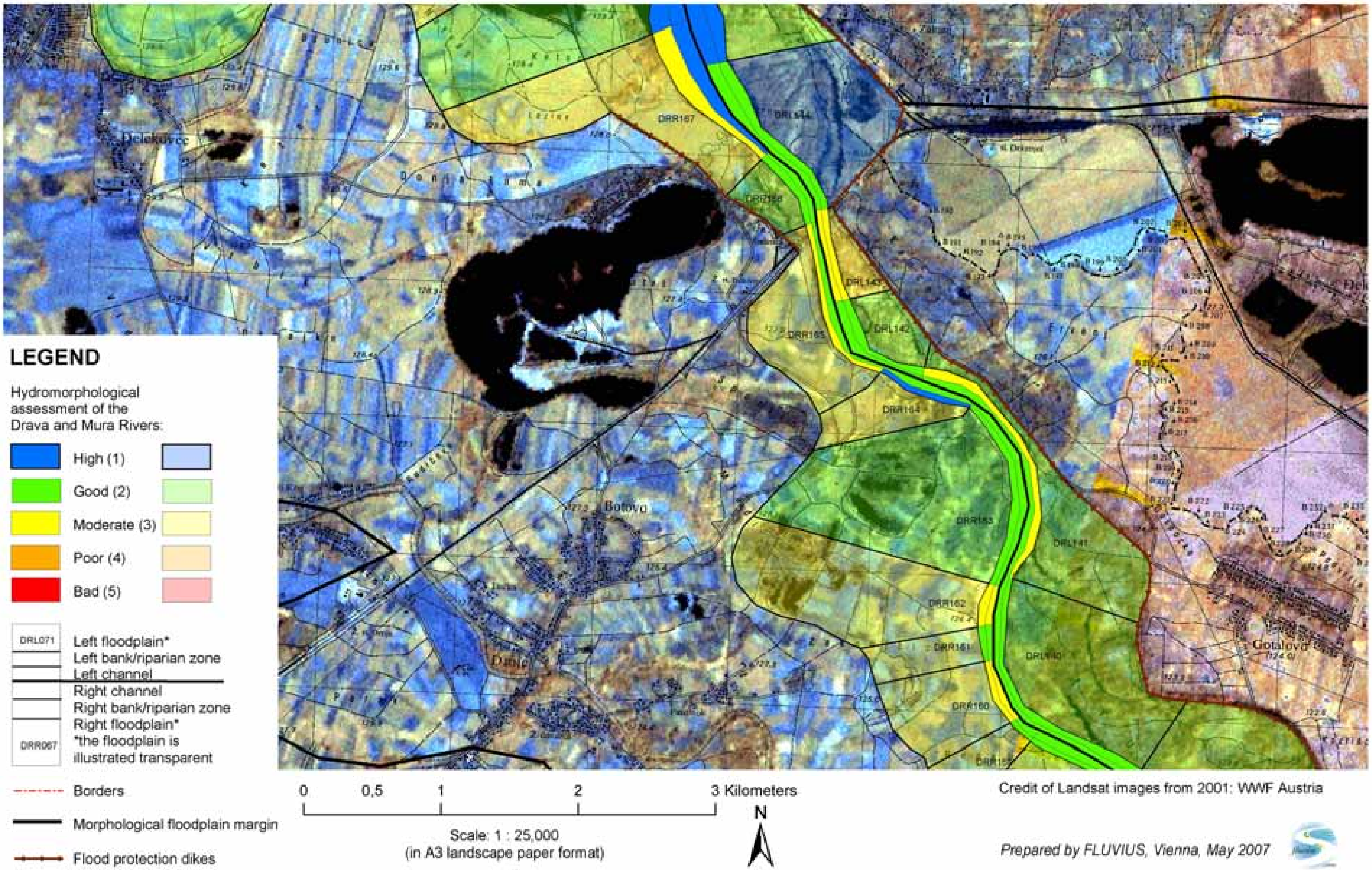

Hydromorphological Assessment of the Drava and Mura Rivers
Mura 6
IAD (International Association for Danube Research)
IAD
D. Vidovec
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
MUL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
MUR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007

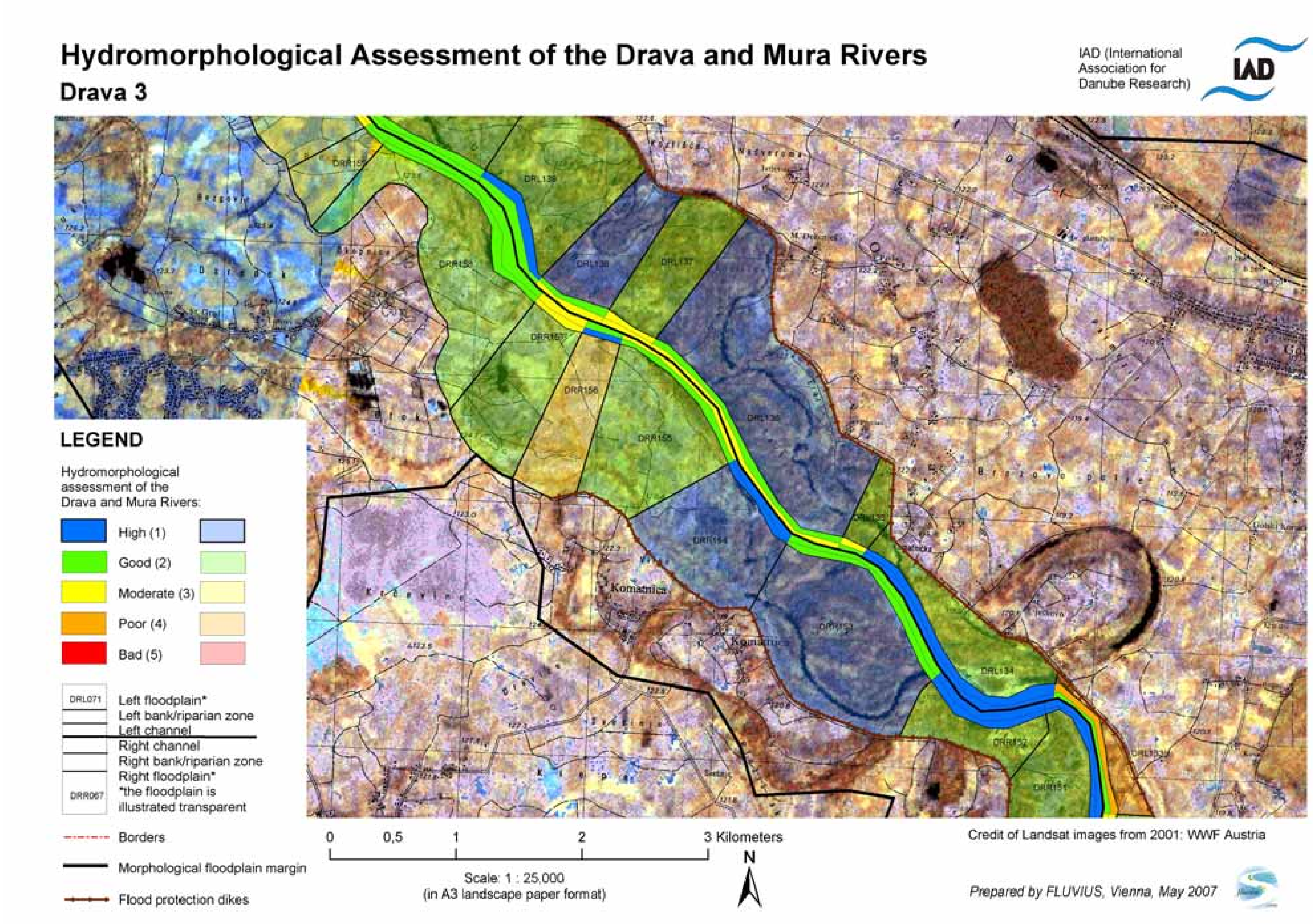

Hydromorphological Assessment of the Drava and Mura Rivers
Drava 1
IAD (International Association for Danube Research)
IAD
Legrad
Delekovec
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071 Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
DRR067 Right floodplain*
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0 0,5 1 2 3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007

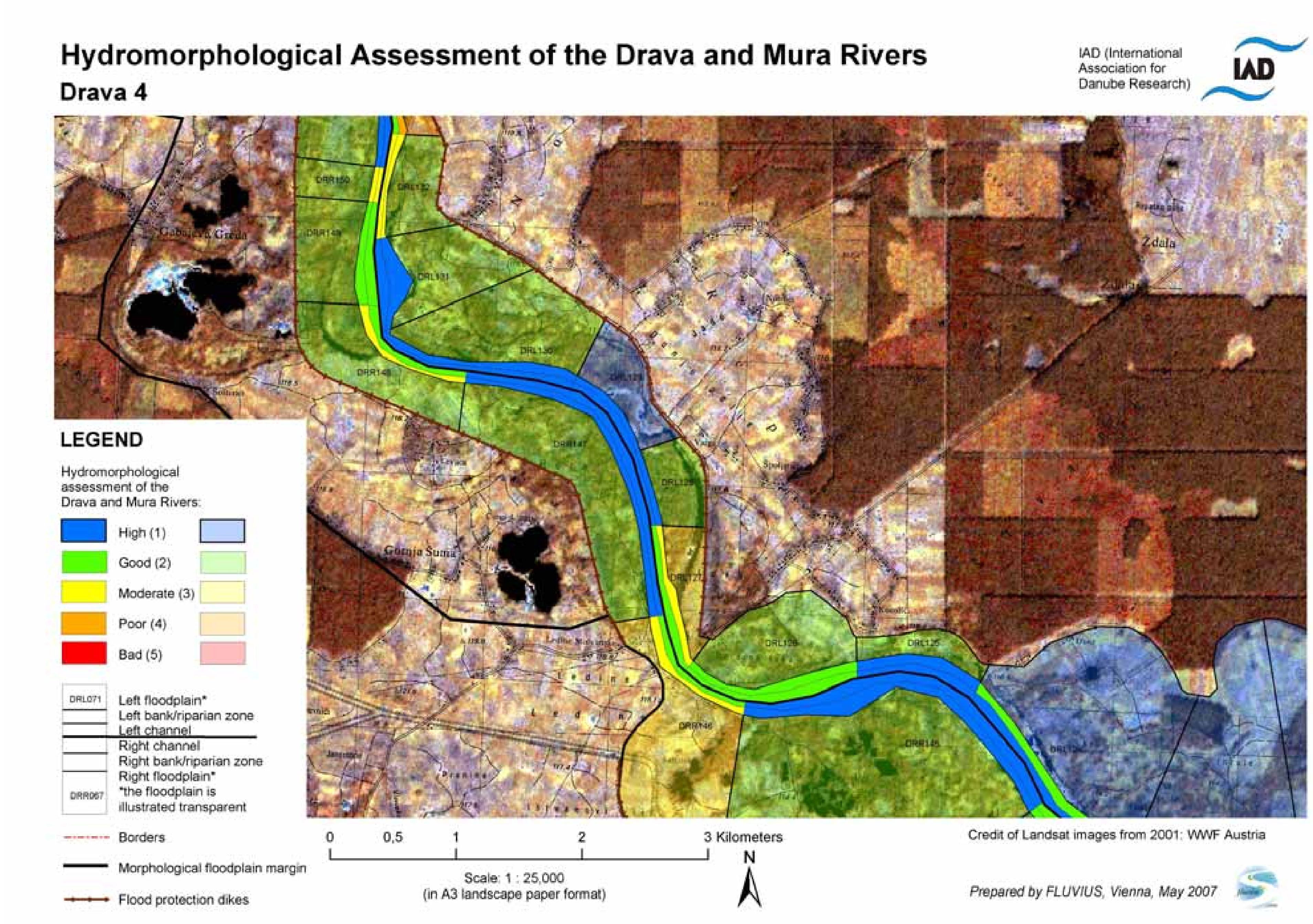
Hydromorphological Assessment of the Drava and Mura Rivers

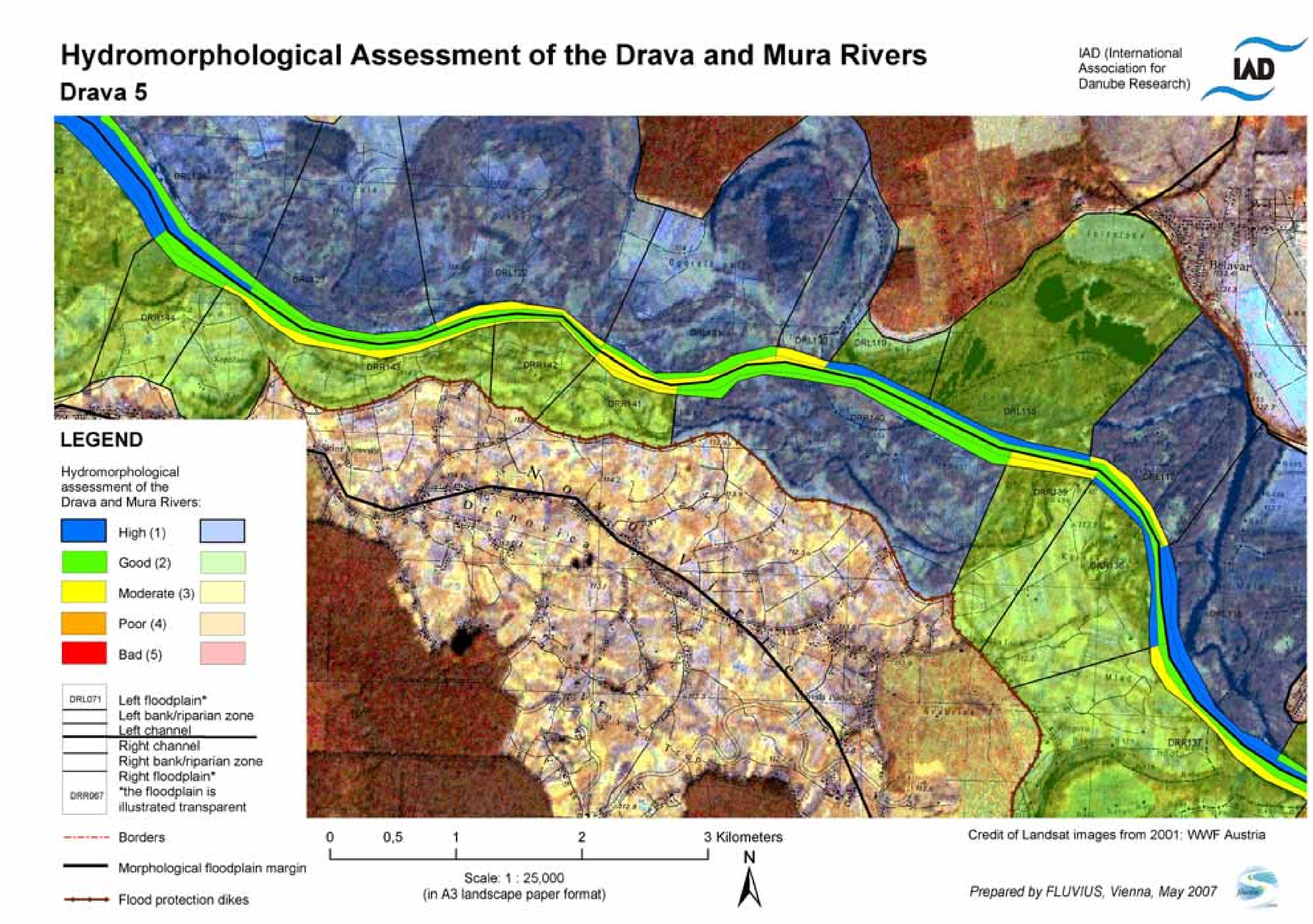
Drava 2

IAD (International Association for Danube Research)




Hydromorphological Assessment of the Drava and Mura Rivers
Drava 3
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007
Komatnica

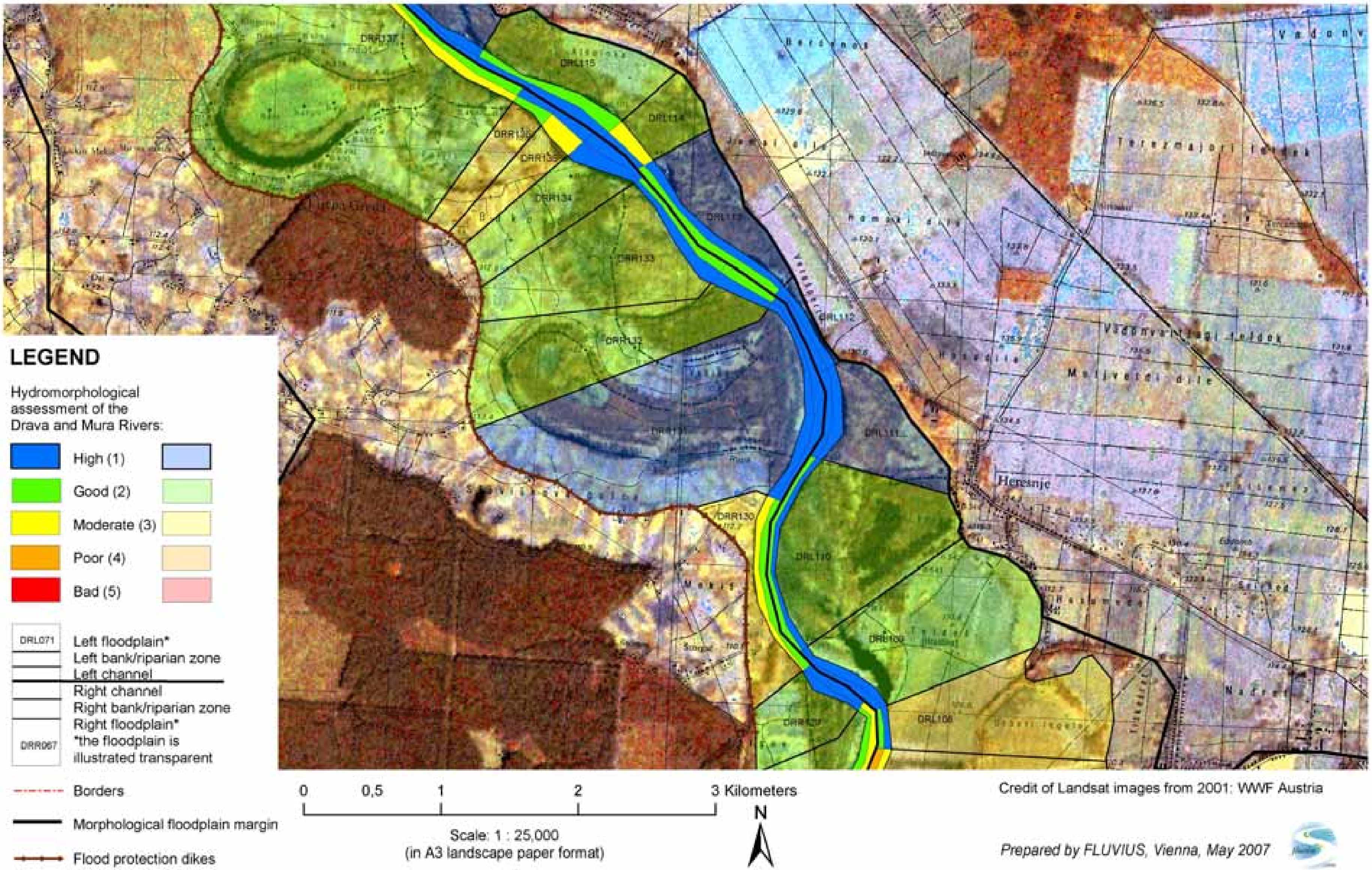

Hydromorphological Assessment of the Drava and Mura Rivers
Drava 4
IAD (International Association for Danube Research)
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007


Hydromorphological Assessment of the Drava and Mura Rivers
Drava 5
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007

Hydromorphological Assessment of the Drava and Mura Rivers

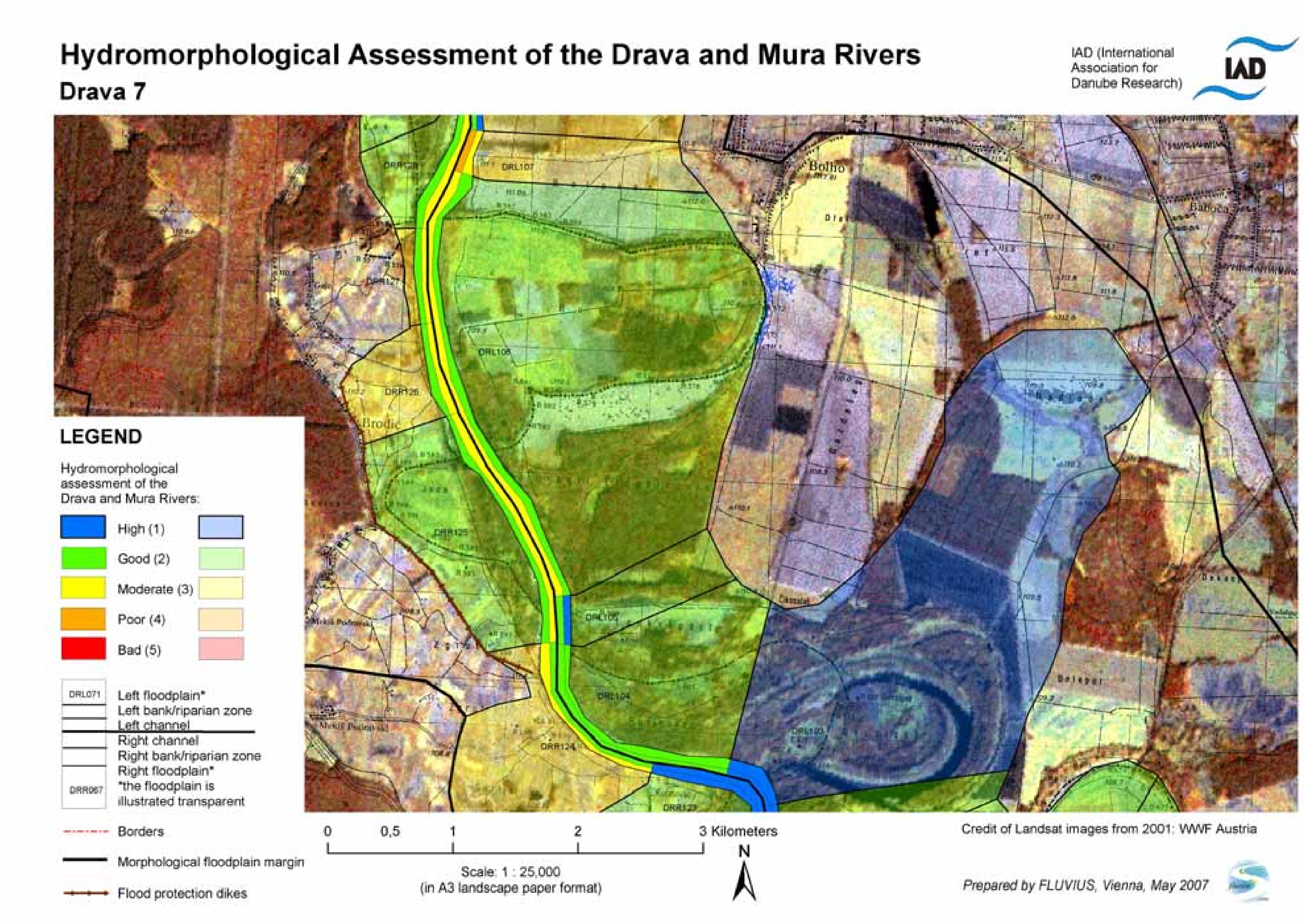
Drava 6

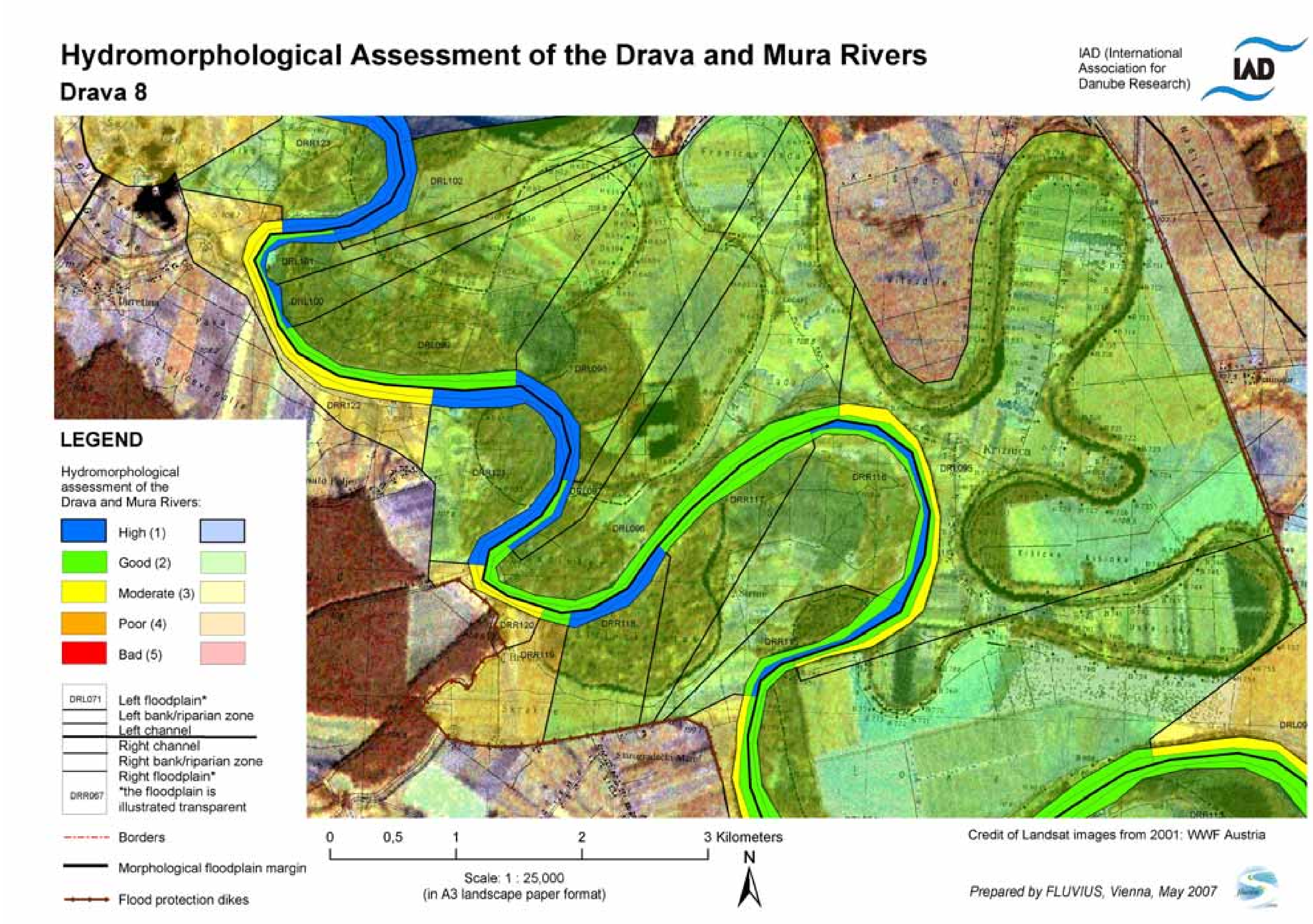
IAD (International Association for Danube Research)

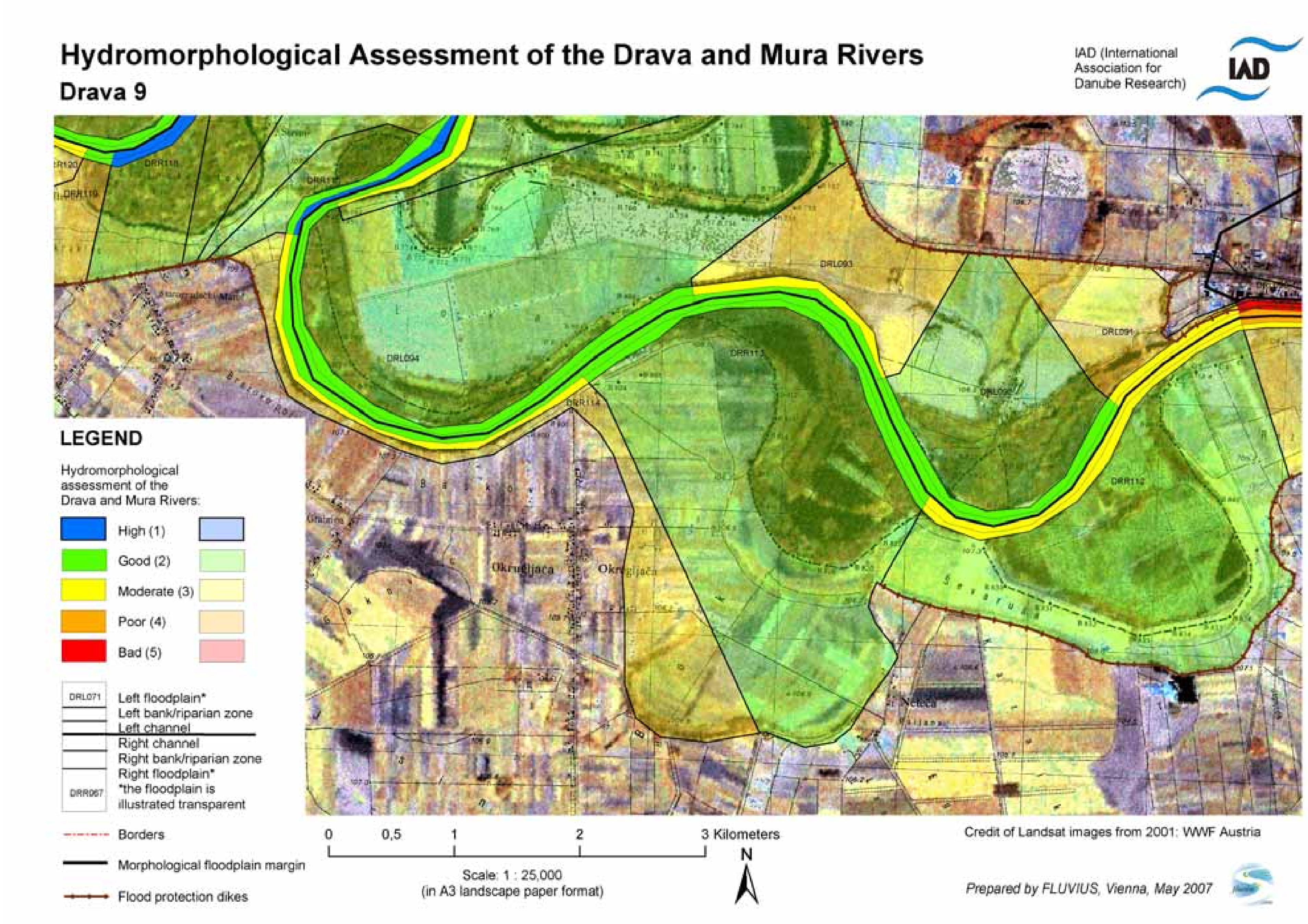


Credit of Landsat images from 2001: WWF Austria

Prepared by FLUVIUS, Vienna, May 2007


Hydromorphological Assessment of the Drava and Mura Rivers
Drava 7
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007
DRL107
DRR128
DRR127
DRL106
DRR126
DRR125
DRL105
DRL104
DRR124
DRL103
DRR123
Bolho
Brodić

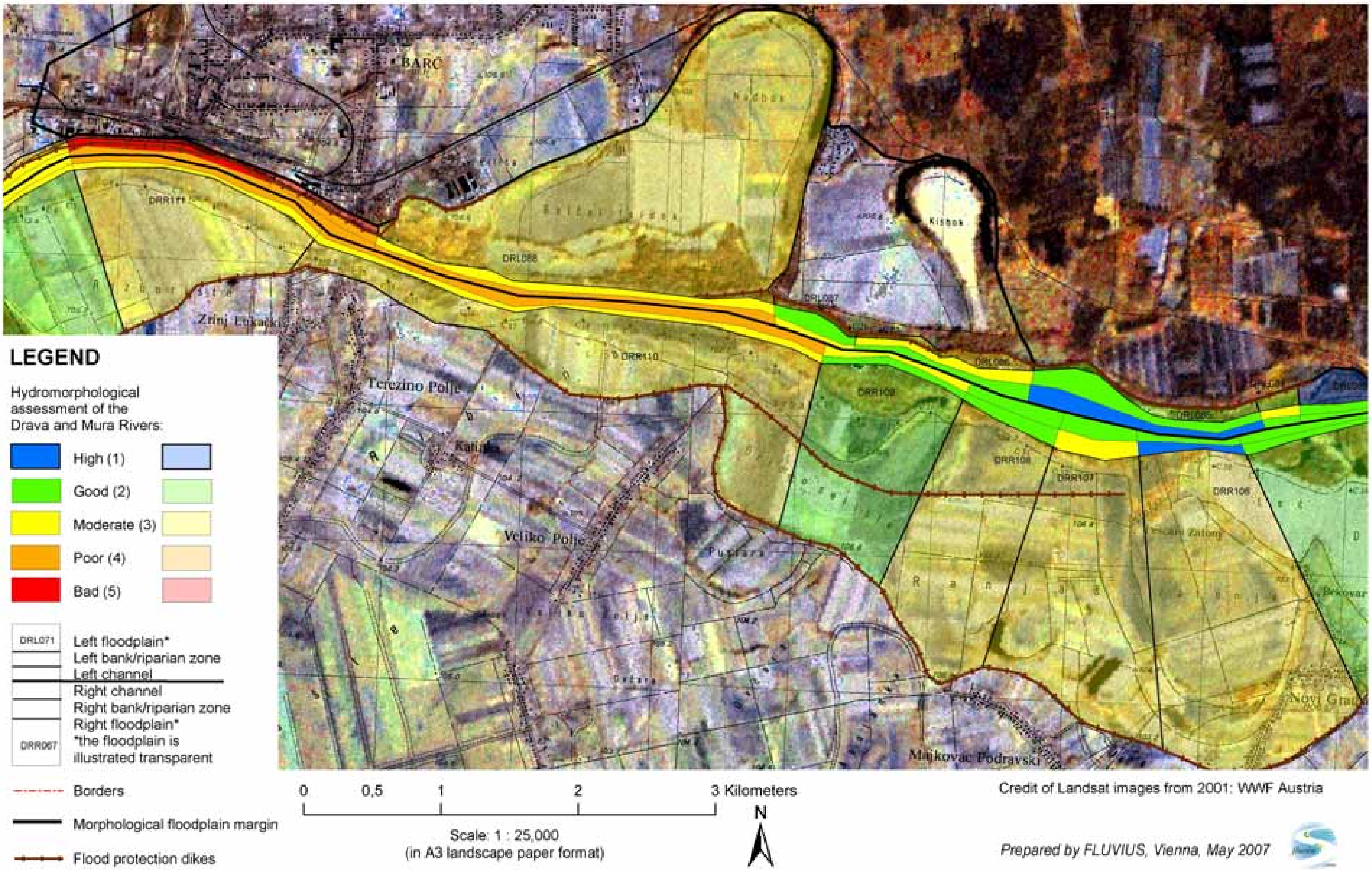

Hydromorphological Assessment of the Drava and Mura Rivers
Drava 8
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007


Hydromorphological Assessment of the Drava and Mura Rivers
Drava 9
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007

Hydromorphological Assessment of the Drava and Mura Rivers

Drava 10

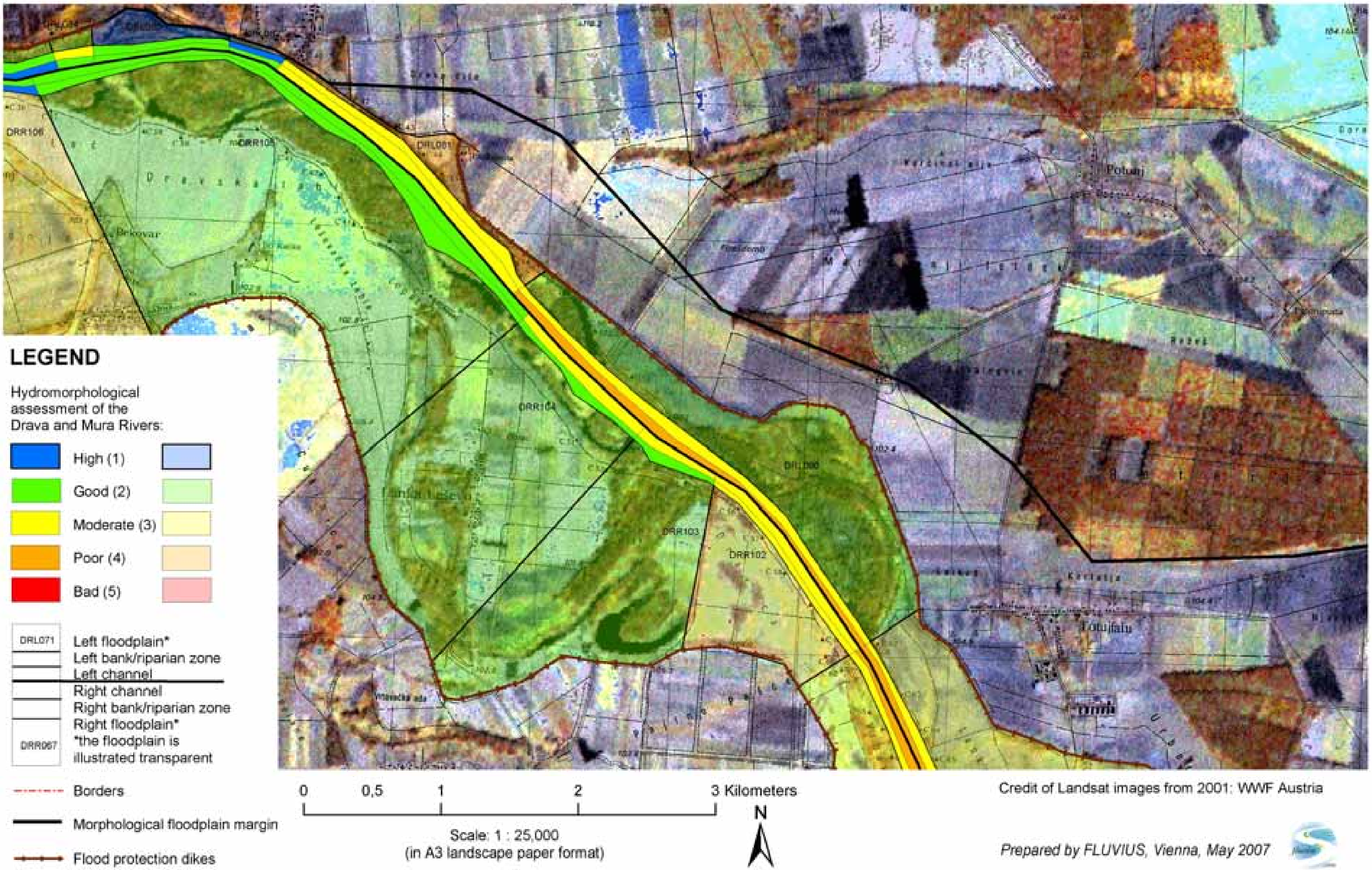
IAD (International Association for Danube Research)



Hydromorphological Assessment of the Drava and Mura Rivers

Drava 11

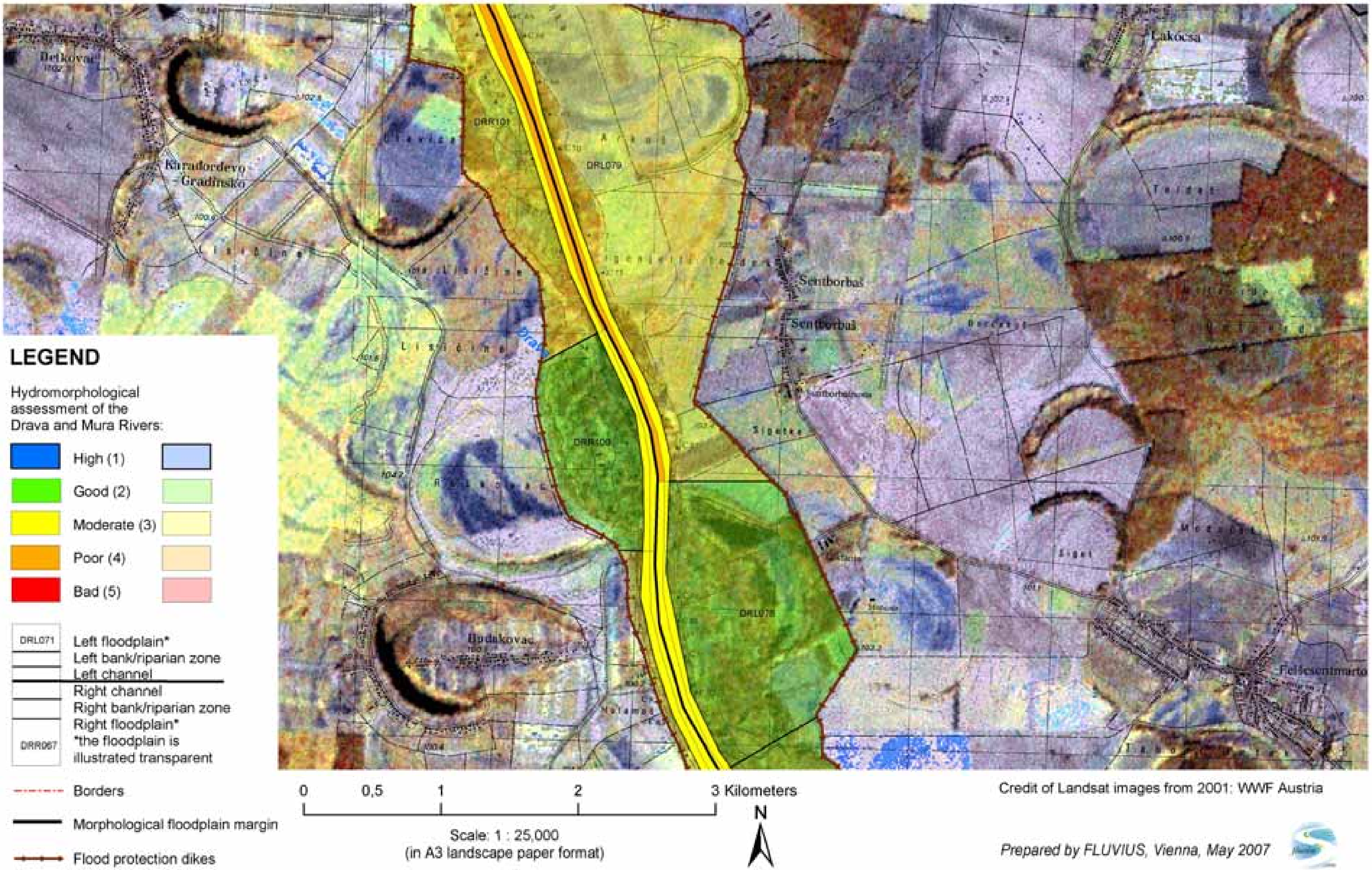
IAD (International Association for Danube Research)



Hydromorphological Assessment of the Drava and Mura Rivers

Drava 12

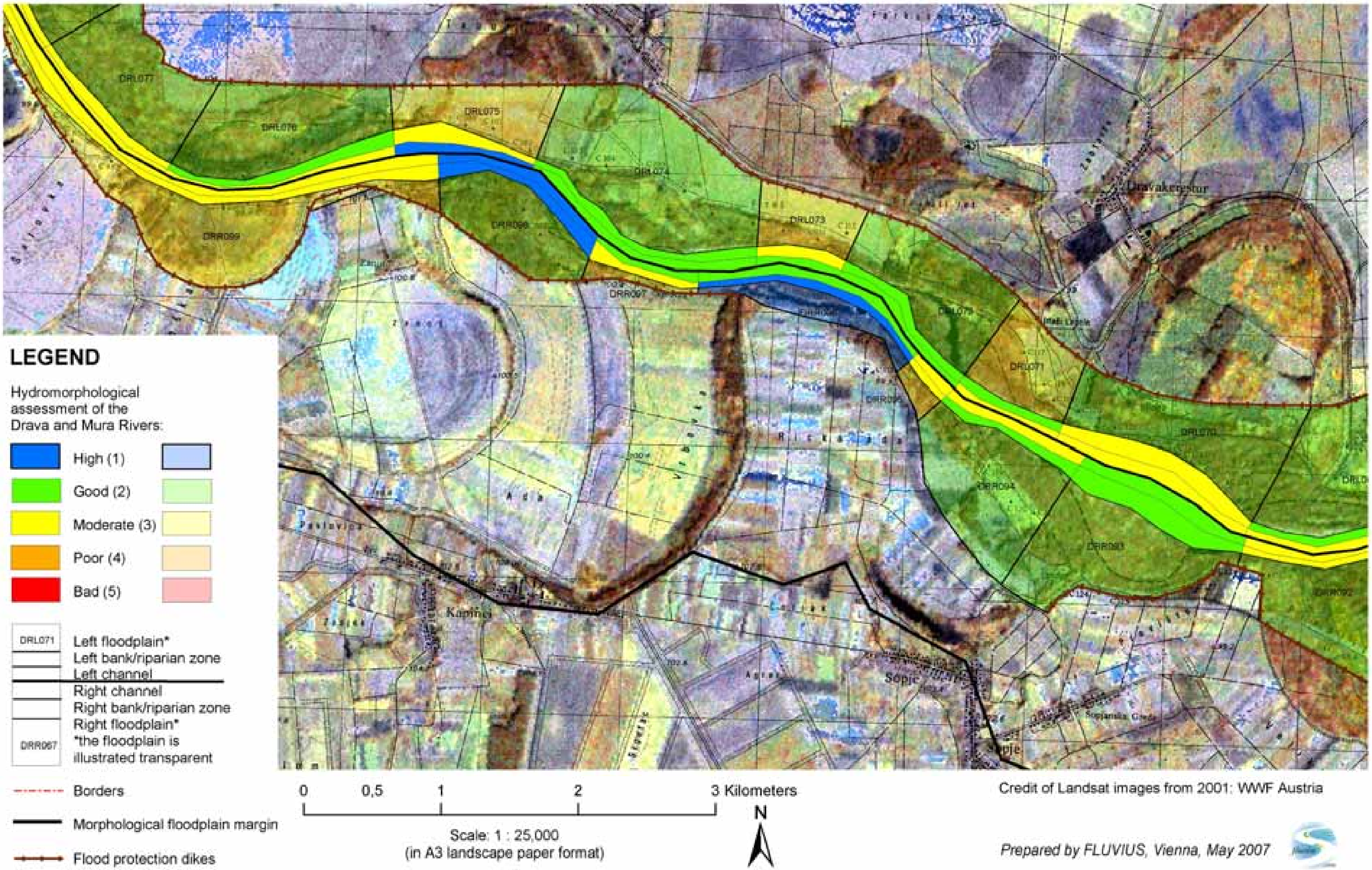
IAD (International Association for Danube Research)

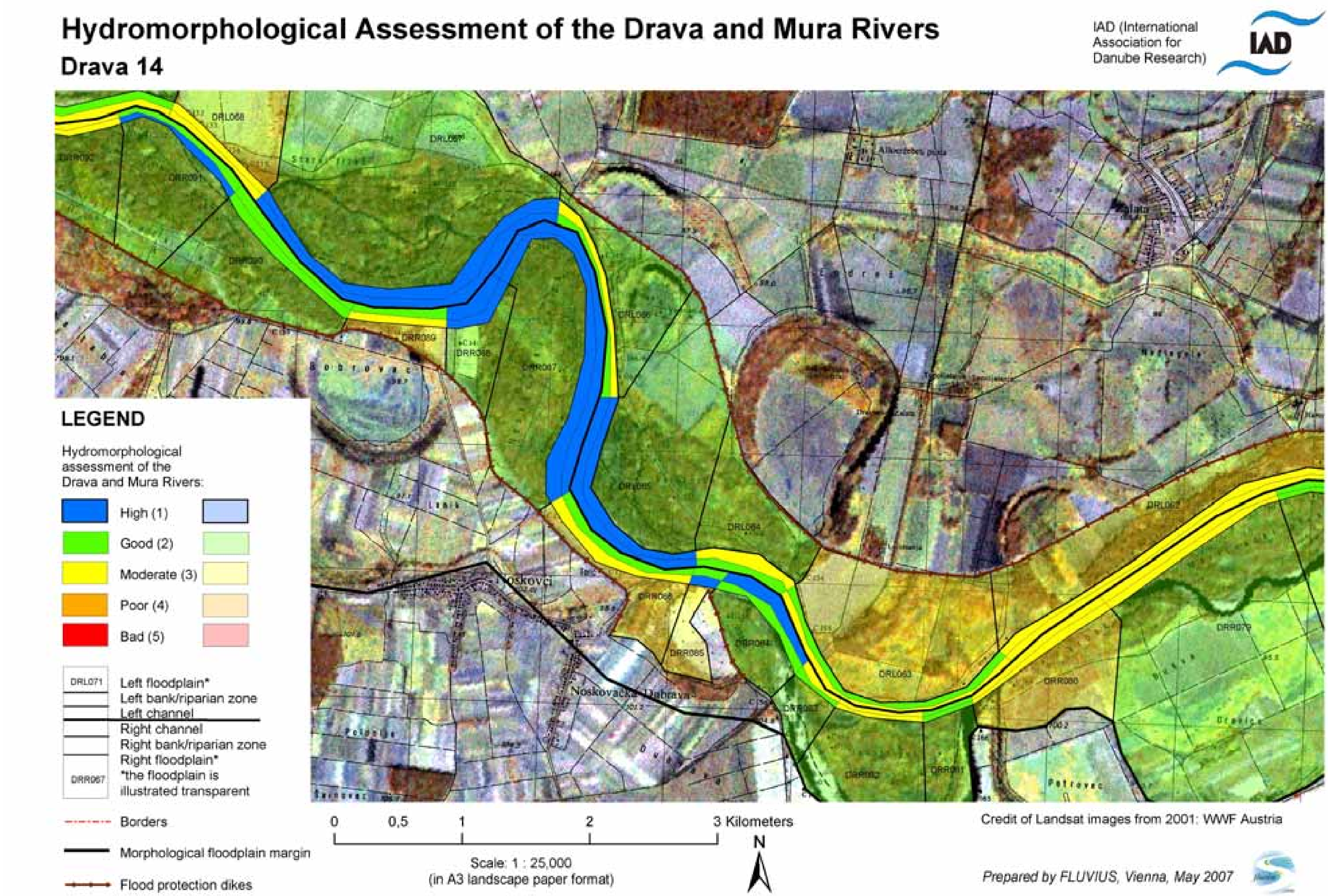


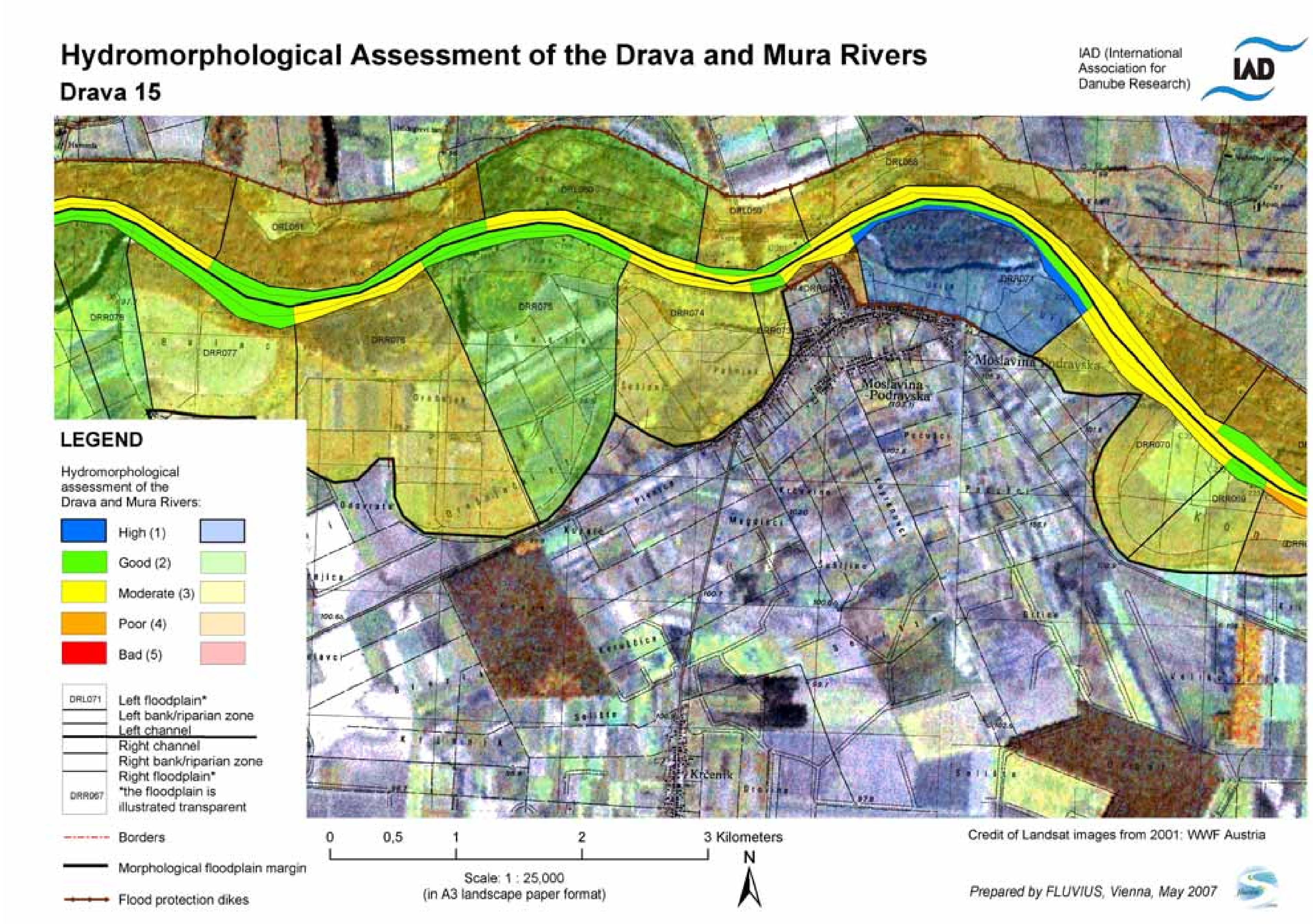
Hydromorphological Assessment of the Drava and Mura Rivers

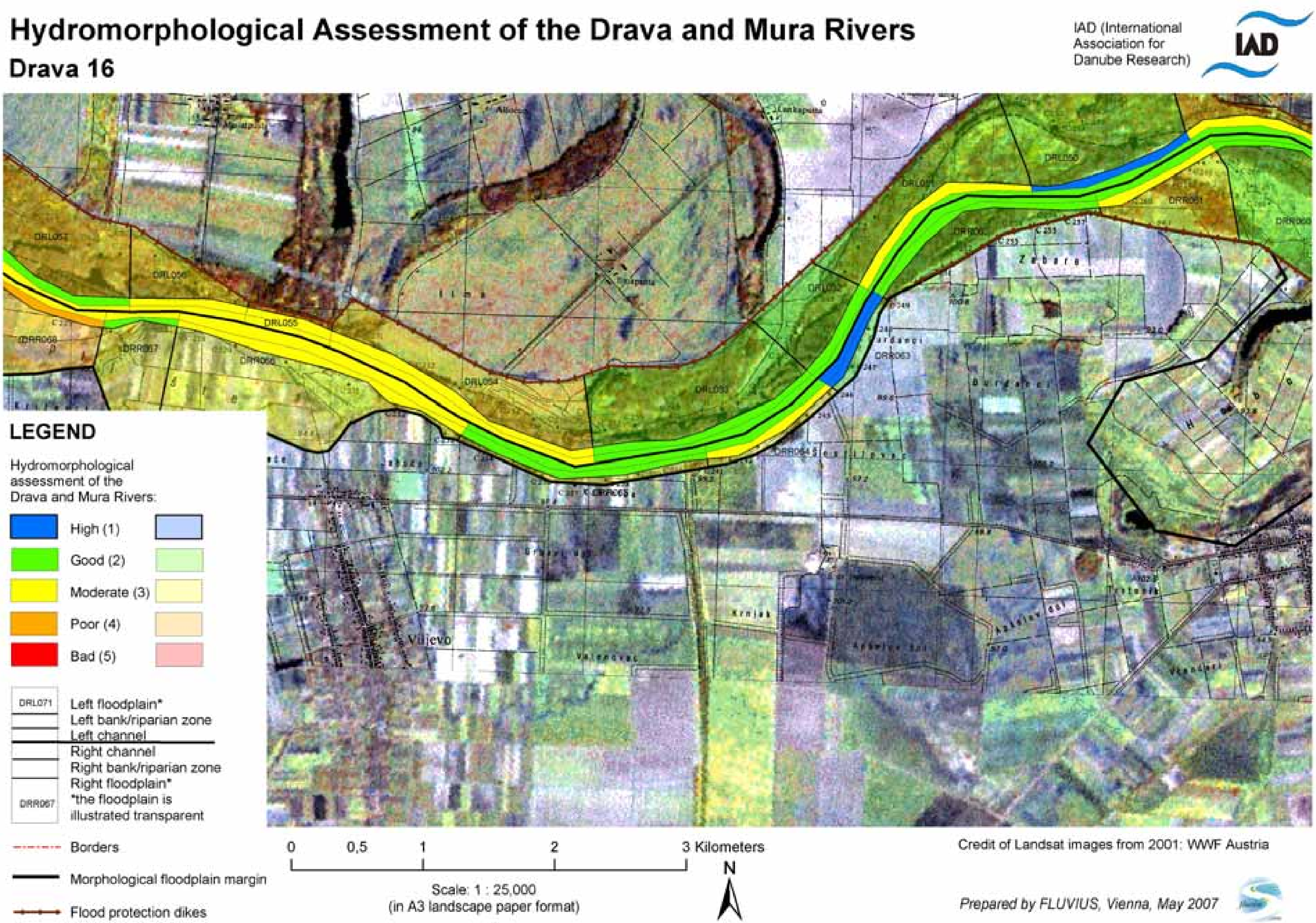
Drava 13

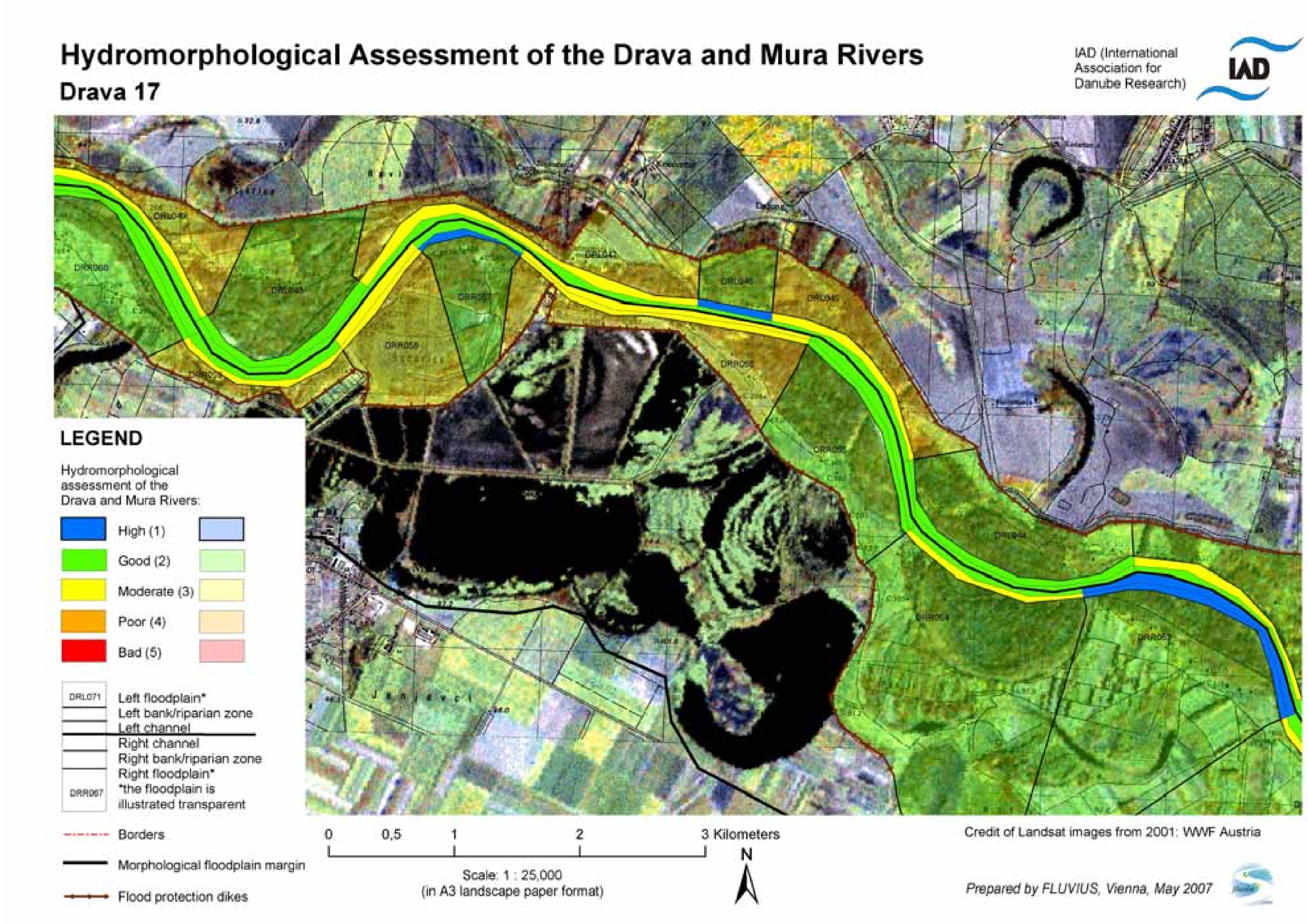
IAD (International Association for Danube Research)




Hydromorphological Assessment of the Drava and Mura Rivers
Drava 14
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007
Noskovci
Noskovačka Dubrava


Hydromorphological Assessment of the Drava and Mura Rivers
Drava 15
IAD (International Association for Danube Research)
IAD
Moslavina Podravska
Krčenik
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0 0,5 1 2 3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007

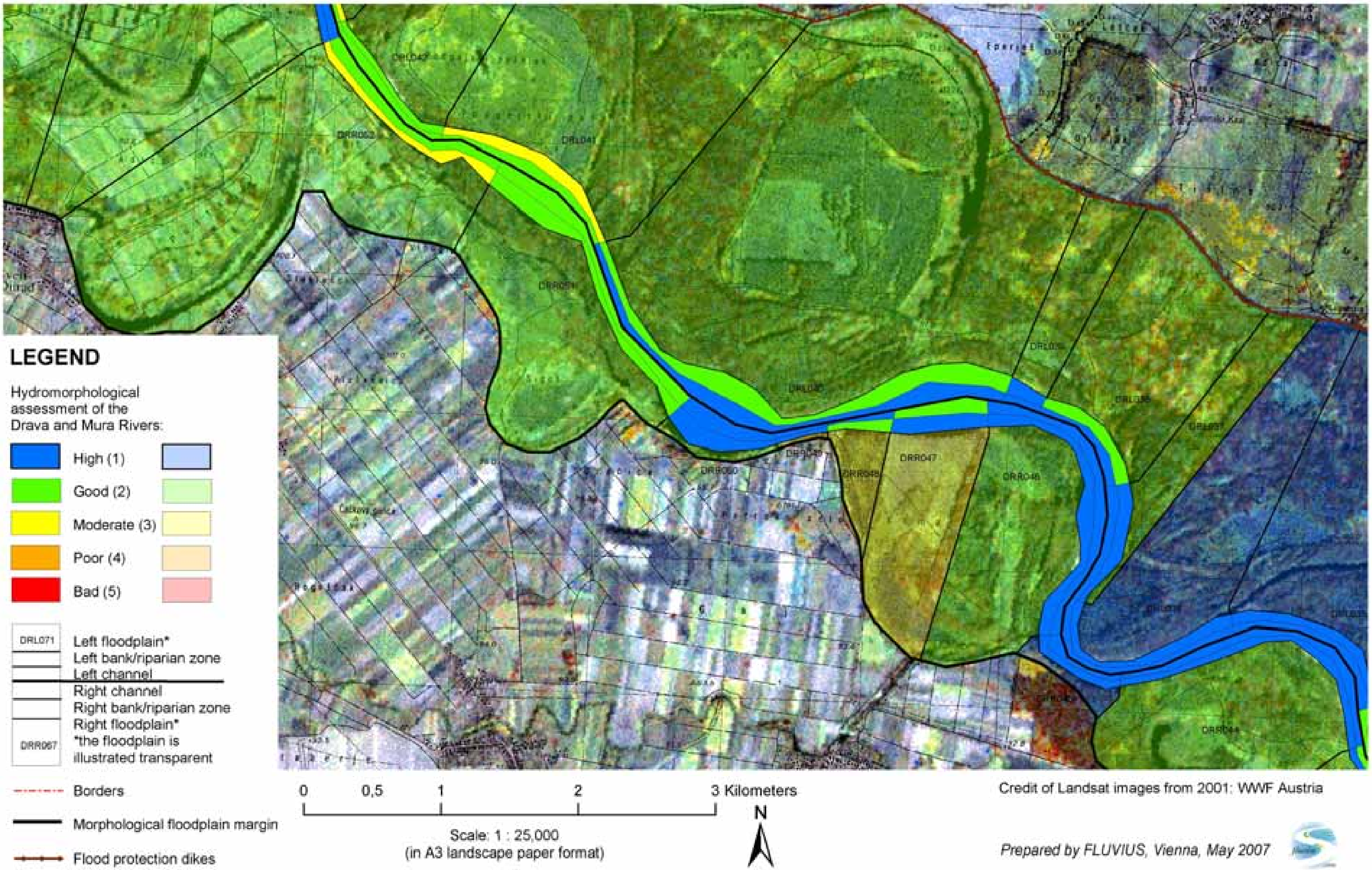

Hydromorphological Assessment of the Drava and Mura Rivers
Drava 16
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
N
Scale: 1 : 25,000
(in A3 landscape paper format)
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007
Viljevo

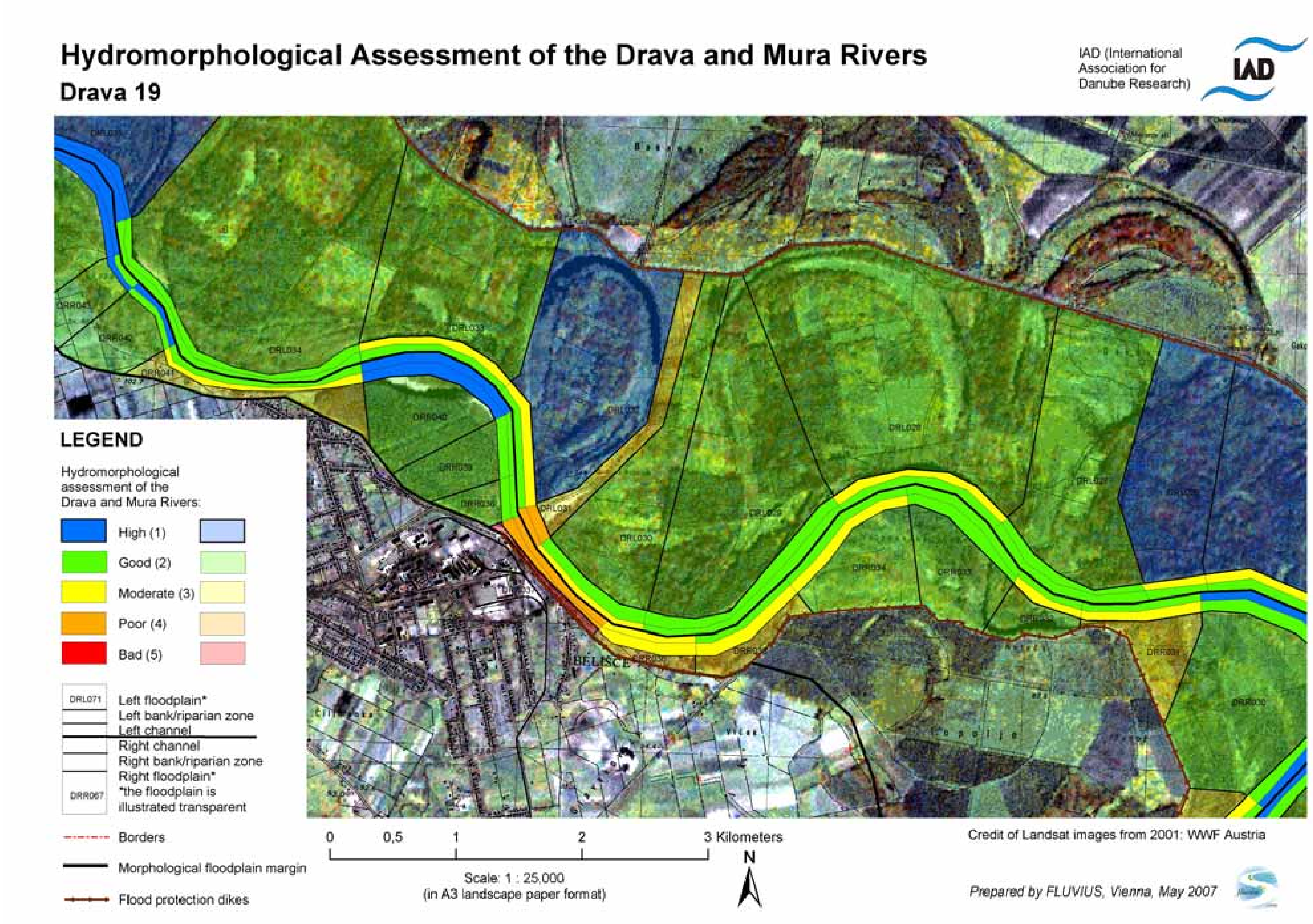

Hydromorphological Assessment of the Drava and Mura Rivers
Drava 17
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007

Hydromorphological Assessment of the Drava and Mura Rivers

Drava 18

IAD (International Association for Danube Research)

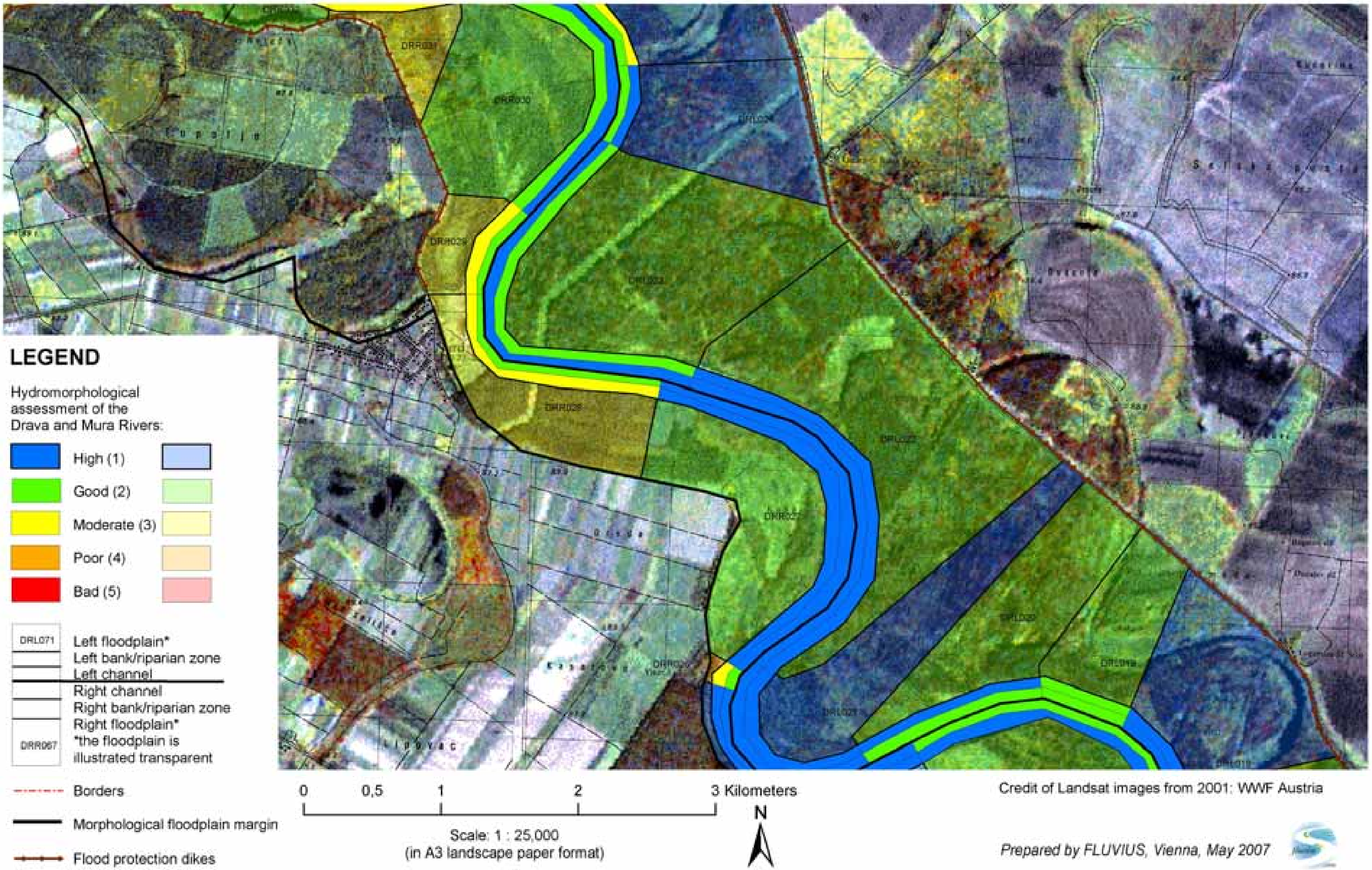



Hydromorphological Assessment of the Drava and Mura Rivers
Drava 19
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0 0,5 1 2 3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007

Hydromorphological Assessment of the Drava and Mura Rivers

Drava 20

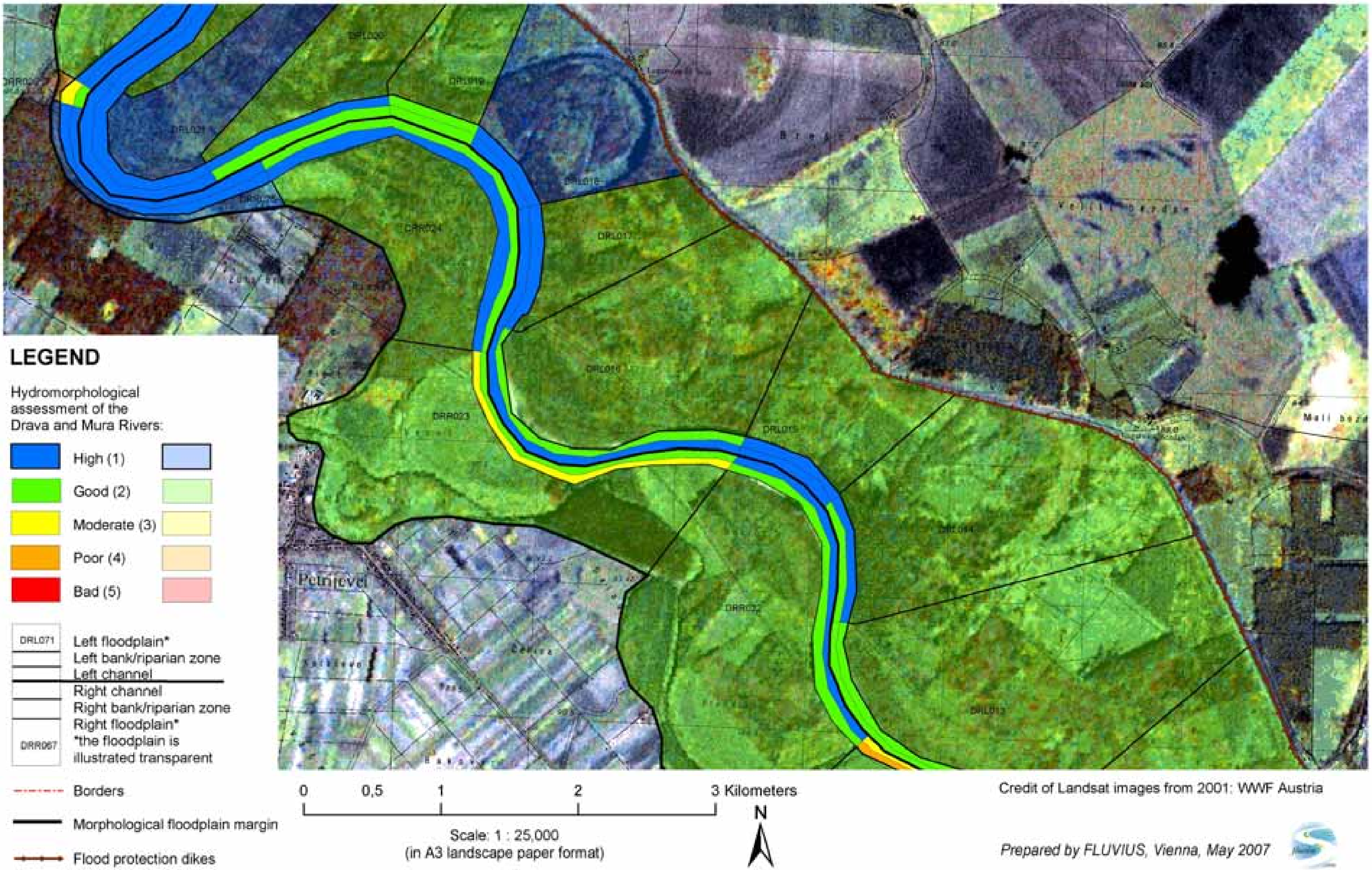
IAD (International Association for Danube Research)

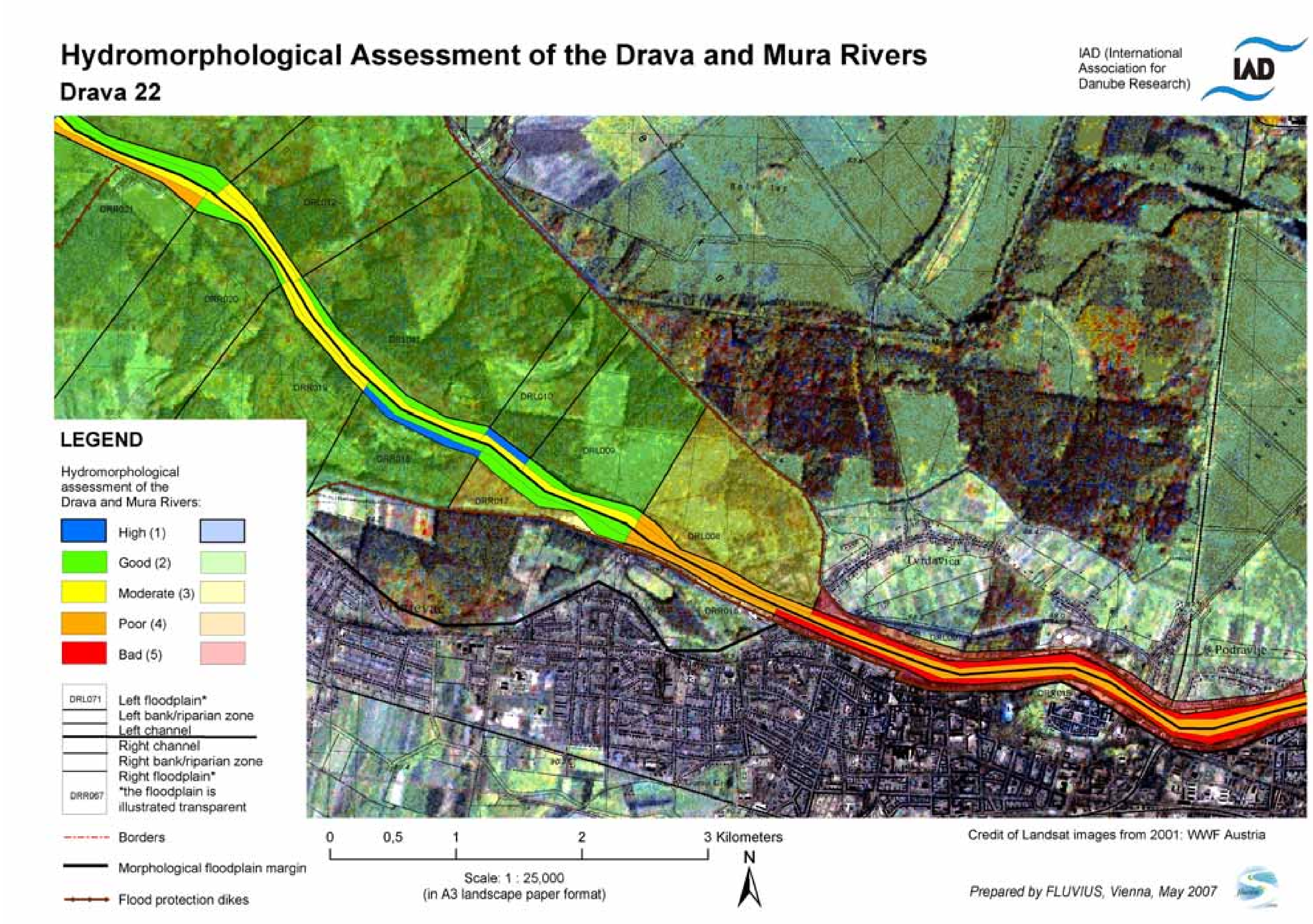


Hydromorphological Assessment of the Drava and Mura Rivers

Drava 21

IAD (International Association for Danube Research)

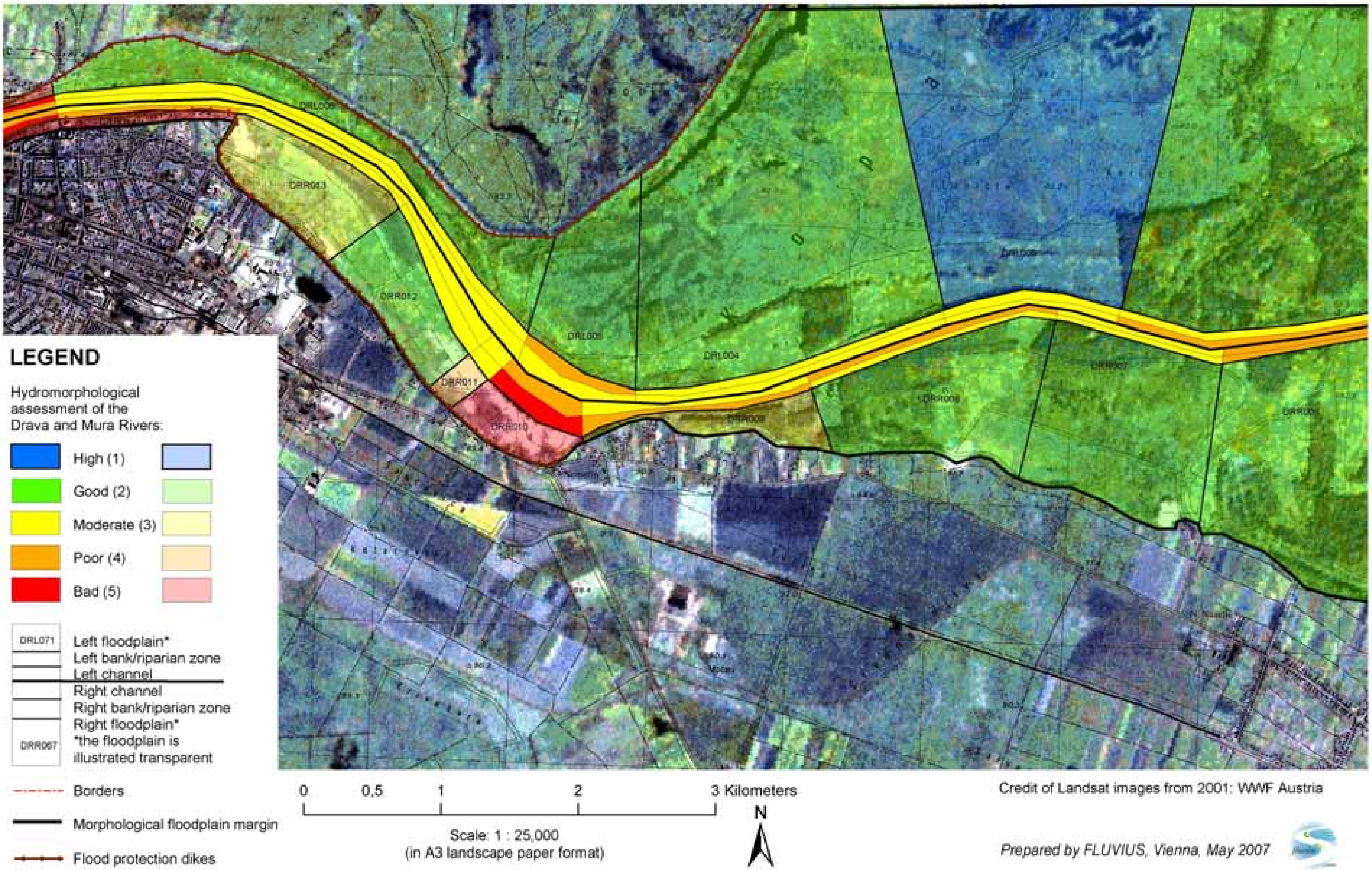



Hydromorphological Assessment of the Drava and Mura Rivers
Drava 22
IAD (International Association for Danube Research)
IAD
LEGEND
Hydromorphological assessment of the Drava and Mura Rivers:
High (1)
Good (2)
Moderate (3)
Poor (4)
Bad (5)
DRL071
Left floodplain*
Left bank/riparian zone
Left channel
Right channel
Right bank/riparian zone
Right floodplain*
DRR067
*the floodplain is illustrated transparent
Borders
Morphological floodplain margin
Flood protection dikes
0
0,5
1
2
3 Kilometers
Scale: 1 : 25,000
(in A3 landscape paper format)
N
Credit of Landsat images from 2001: WWF Austria
Prepared by FLUVIUS, Vienna, May 2007
Podravlje

Hydromorphological Assessment of the Drava and Mura Rivers

Drava 23

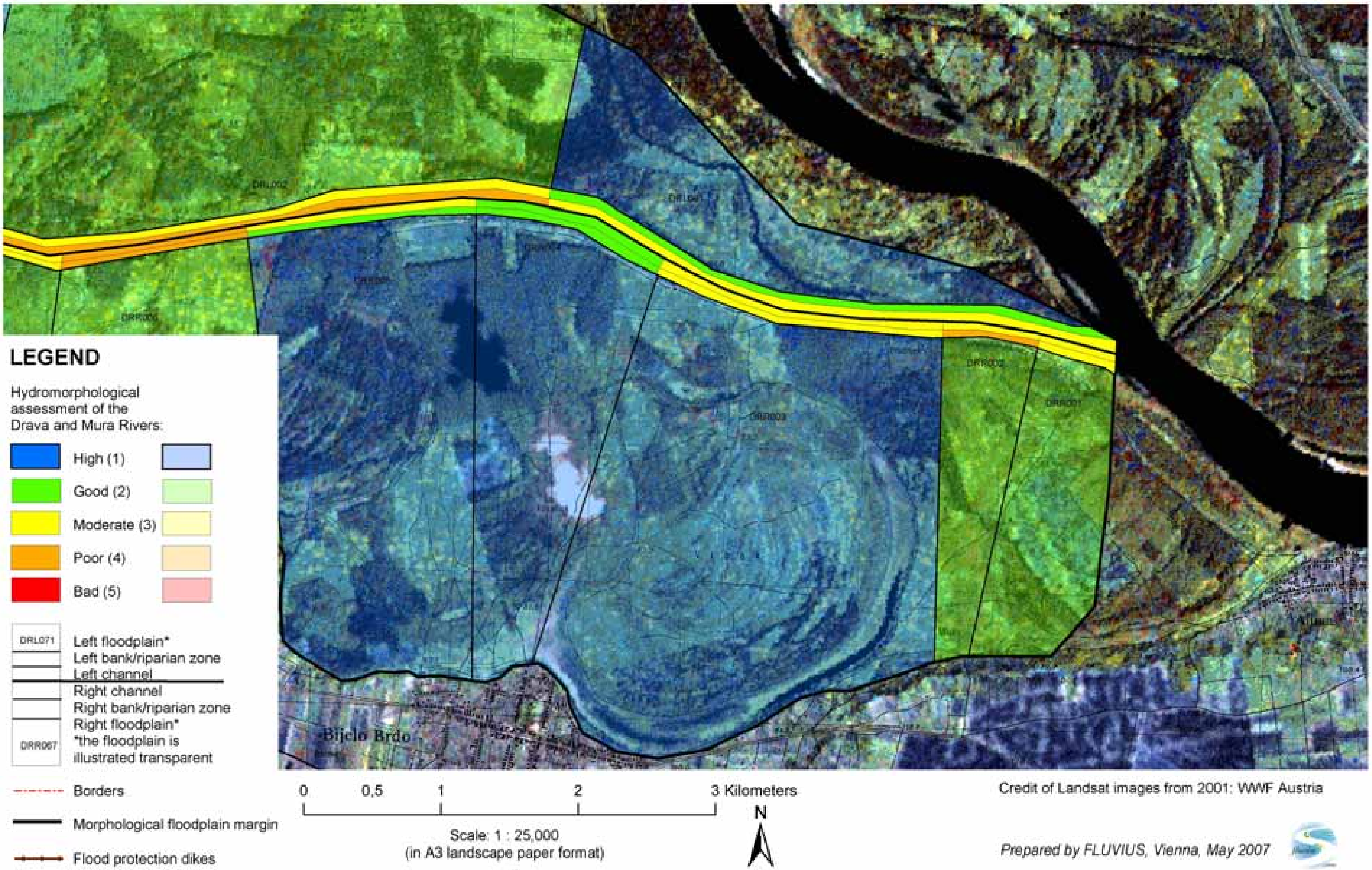
IAD (International Association for Danube Research)



Hydromorphological Assessment of the Drava and Mura Rivers

Drava 24

IAD (International Association for Danube Research)



5.4.2 Overview map of the Drava Basin

The overall assessment integrates the left and right banks of the rivers (also the channel and floodplain) and generalise the minimum stretch size to about 3 km (visibility in the overview map in the scale of 1: 1,350,000 which corresponds with the A3 landscape paper format). The generalisation for the detailed assessed stretch follows an expert judgement according to the most important homogenous river reaches (compare the previous chapters and overall evaluation results). As indicated on the map the content is based on the continuous survey in the year 2005 for a 300 km long stretch of this still relatively intact lower river sections of the Mura and Drava without dams (compare map) and the upper river reaches based on secondary information and the test surveys.

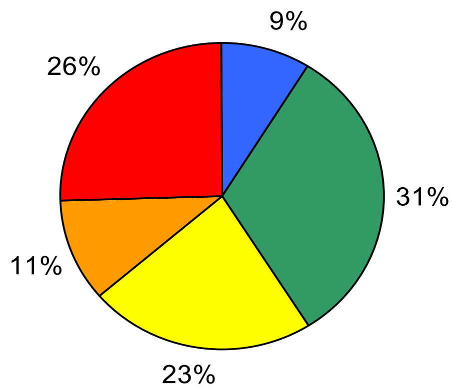
Table 11, figure 58 and the corresponding general map show the overall evaluation result (1,232 km assessed river stretches (Drava 750 km, Mura 482)):

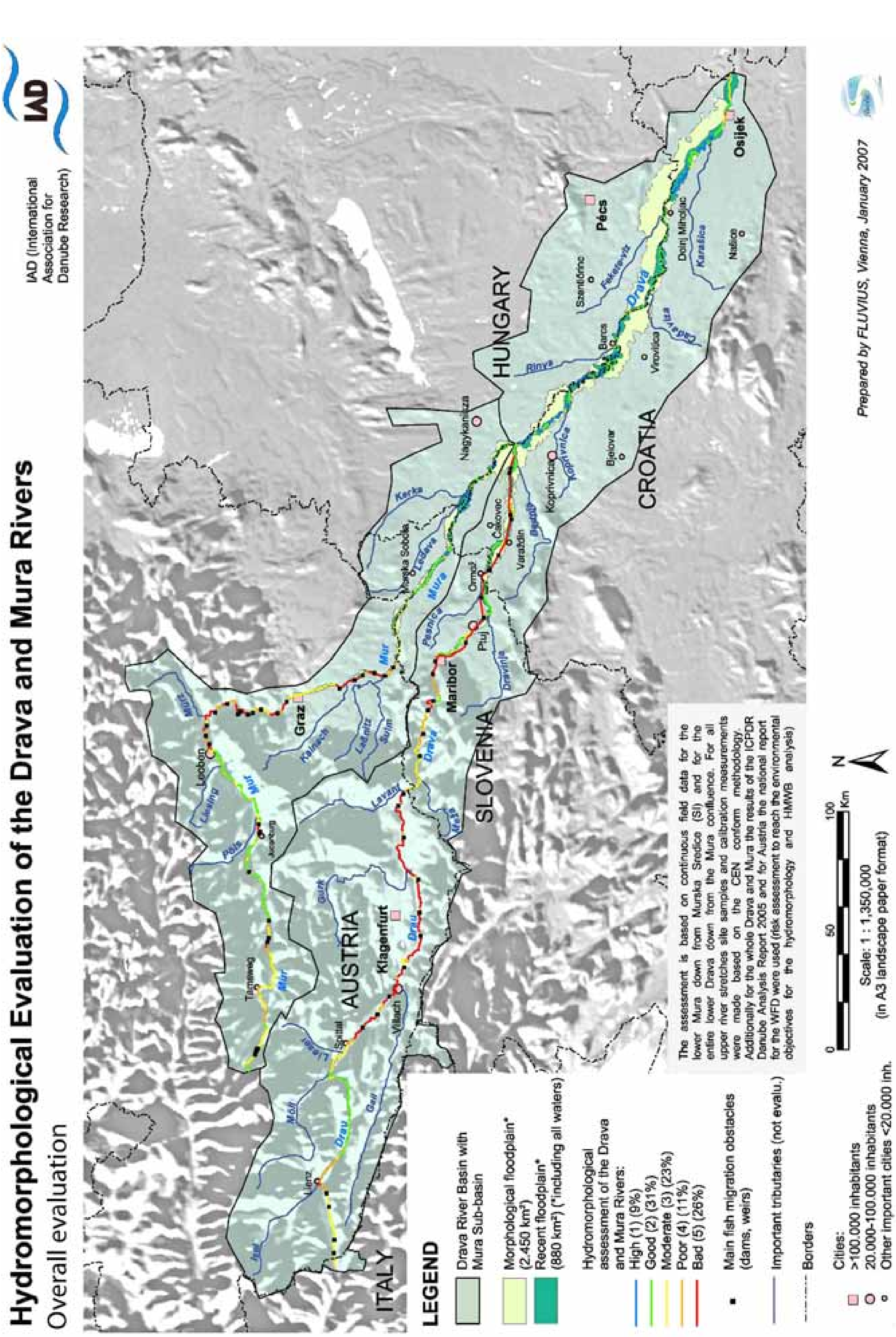
……………………..
Table 11: Overall evaluation of the Mura and Drava

Class (after WFD)	Stretches length	Portion of total length
1) High (blue)	108 km	9 %
2) Good (green)	400 km	31 %
3) Moderate (yellow)	278 km	23 %
4) Poor (orange)	132 km	11 %
5) Bad (red)	315 km	26 %

....
Figure 58: Overall evaluation of the Mura and Drava

Legend:
Blue: high (1)
Green: good (2)
Yellow: moderate (3)
Orange: poor (4)
Red: bad (5)




Hydromorphological Evaluation of the Drava and Mura Rivers
Overall evaluation
IAD (International Association for Danube Research)
LEGEND
Drava River Basin with Mura Sub-basin
Morphological floodplain* (2.450 km²)
Recent floodplain* (880 km²) (*including all waters)
Hydromorphological assessment of the Drava and Mura Rivers:
High (1) (9%)
Good (2) (31%)
Moderate (3) (23%)
Poor (4) (11%)
Bad (5) (26%)
Main fish migration obstacles (dams, weirs)
Important tributaries (not evalu.)
Borders
Cities:
>100.000 inhabitants
20.000-100.000 inhabitants
Other important cities <20.000 inh.
The assessment is based on continuous field data for the lower Mura down from Murska Sredice (SI) and for the entire lower Drava down from the Mura confluence. For all upper river stretches site samples and calibration measurements were made based on the CEN conform methodology. Additionally for the whole Drava and Mura the results of the ICPDR Danube Analysis Report 2005 and for Austria the national report for the WFD were used (risk assessment to reach the environmental objectives for the hydromorphology and HMWB analysis)
Scale: 1 : 1,350,000
(in A3 landscape paper format)
Prepared by FLUVIUS, Vienna, January 2007
ITALY
AUSTRIA
SLOVENIA
HUNGARY
CROATIA
Graz
Klagenfurt
Maribor
Pécs
Osijek
Drava
Mura
Mur
Drau

About 40% of the river sections contribute to the classes 1 and 2 indicating a still intact state of the Drava and Mura Rivers, in particular along the lower rivers. The detailed analysis divided into channel, banks and floodplains gave a more precise picture as well as the comparison of the upper, middle and lower river courses classified for the catchment countries. Compared with the former seven class system (Werth 2002, LAWA 2000) a large number of stretches could be counted with transitional values between class 2 and 3 with a tendency to 2. In other words it could be possible that still good bank and floodplain structures raise the only moderate evaluation for the channel (e.g. straightening, gravel extraction).

Still impressing is the lower river corridor of the Drava and Mura rivers: It is evident that the rivers are able to start self-revitalisation processes of lateral erosion and shift even though they are impacted by hydrological and sedimentological deficits in the upper courses (concerning those deficits the Drava and Mura must be classified as strongly impacted). This could be approved with comparisons of selected reference sites with the historical situation which shows the existence of all typical morphological features but in considerably less quantity, also in comparison to the Danube (Schwarz 2005). It must be clearly pointed out that already small interventions such as the embankment with rap-rap of bank sections with a length of several 100 meters (especially the closure of side channels), cause a considerable deterioration of the general situation. This is a result of the ongoing monitoring of selected river stretches since 1997 (several stretches degrease from the virtual classification 1 or 1-2 to 2-3).

Further analysis shows the mentioned hydrological alterations which are mostly visible for the hydropeaking (daily water oscillation, e.g. downstream of the last Croatian plant Dubrava about 1.8 m, which is reduced mostly by the good hydromorphological conditions and flow retention in side channels on the stretch downwards to Barcs (120 km) to about 30 cm; but this is causing colmation and a lot of problems for bank and gravel species). In the upper parts of the rivers diversion stretches for hydropower generation (allocation of water) are indicated. About 26% of the rivers are already completely altered into dam lakes with mostly stagnant water conditions. Another 35 % have poor or moderate conditions.

Floodplain area

The overall morphological floodplain size (including all riparian water bodies) could be estimated to about 2,450 km². This is about 6% of the total catchment area. The size was calculated according to other studies (DPRP 1999, Hohensinner et al. 2005) by exploring historical, geological, geomorphological and pedological maps of the region. The results could be defined as overview estimations. The definition of the annuality of high floods is rather difficult especially for the large floodplains in the lower courses reaching values of up to 20 km in width. Due to the different raw data for gauges along the river and the bed incision (in some reaches up to 4 m over the past 100 years) it is not possible to reconstruct the flood situation without detailed hydrological and topographical data (Hohensinner et al. 2005). From the morphological point of view the existence of large oxbows far from the river allow the assumption of a 100-200 years annuality. The age and connectivity of oxbows and backwaters is also significant for the estimation of the morphological floodplain.

The active floodplain extent for the Drava and Mura including also all natural as well as artificial water bodies in the main stream (especially the large barrages in Carinthia and Croatia) could be quoted with 880 km². The active floodplain was extracted mostly by up-to-date topographical maps showing all flood protection dikes and impounded stretches of the rivers. After the subtraction of the impounded reaches and lakes in the main stream with mostly untypical standing water (e.g. HEE Dubrava with 16 km², Völkermarkter Stausee 10.5 km²) the remaining area is about 780 km². The still existing floodplains of the Austrian Mura downstream of Graz are strongly modified through a chain of hydropower plants and a monotonous main channel without lateral connections. Other negative and limited situations can be given for parts of the middle course of the Drava in Slovenia and Croatia where the former river beds receive only about 5-10% of the discharge resulting in a permanent decrease of near-natural floodplain in those stretches. All together these strongly or heavily modified floodplains can be estimated to about 200 km² (remaining 560 km²).
For the entire Drava and Mura Rivers the overall floodplain loss amounts to about 75%. From the remaining 25% nearly 80% of floodplains suffer from considerable bed incision rates (up to 4 m), hydrographical alterations (flood retention of 1-5 year floods in the existing storage lakes and also in the mountainous headwater reaches, unification of the natural flood dynamics or hydropeaking) and forest cultivation (large hybrid poplar forests along the lower Drava).
Finally it must be stated that only very few larger floodplain areas remain under near natural ecological conditions along the Drava and Mura (estimation of 10-15% of the active floodplain, mostly high dynamic pioneer stands and wet softwood areas).
Despite of the overall loss, the local distribution and ecological potential of floodplains is very different. Especially the lower Drava hosts still large potentially flooded forests (mostly hybrid poplar plantations).

In addition to the quantitative aspects it is important to propose for the future an overview assessment concerning the groundwater situation (average level, temporal dynamic) in the floodplain and a more precise characterisation of the flood magnitude and frequency. The latter is already included in the Drava assessment but is based mostly on assumptions in respect to the available hydrological data since about 1970. Concerning the assessment of pressures it would be necessary to carefully analyse hydraulic and hydrological parameters impacted by human usages such as hydropower dams in barrages and reservoir lakes and to discuss the flood situation in dam backwater reaches and former channels (residual water versus extreme flooding). Further fluvial landforms their occurrence and characteristics (time cycles and succession, e.g. the development from oxbows to terrestrial habitats) must be part of a more enhanced floodplain evaluation (compare also Koenzen 2005). The morpho-dynamics and assessment of still existing fluvial landforms in the active and morphological floodplain as well as the survey and assessment of impacts such as removal of those floodplain typical landforms, or their intensive usage could be used for such an evaluation. As the river and its floodplain have built a unit and continuum in the longitudinal, lateral and vertical (groundwater) direction it is necessary to calibrate and assess all those floodplain parameters using reference conditions at least as described in this study for the pilot reaches. For the ecological assessment the vegetation is the most significant aspect of floodplain inventories and assessment methods. Therefore the habitat structure and suitability for various indicator species must support those inventories from the beginning.

6 Outlook and implications for hydromorphological inventories in the Danube Basin

6.1 Validation and improvements

With the upcoming CEN standard for the validation of hydromorphological inventories based on the general CEN standard a new tool will be available allowing the calibration and comparison of results. This could be an important step to gain more harmonized information. The study clearly indicates how important it is to collect quantitative hydromorphological data in a first step, to carefully define morphological reference conditions in a second step, and to finally assess all field data according to a common five-class evaluation scheme. Based on the experience of the pilot study, several suggestions can be made to improve the method of BfG 2002 to meet the WFD requirements and the CEN Standard.

Still unsatisfying is the survey of floodplains: As an example, the parameter of width (today's areas compared to morphological floodplains) has the same value as the corridor (narrow floodplains/galleries very close to the river). This can even raise the overall value for the lower Drava on many places where nearly 90% of the potential floodplain are lost. Under the perspective of flood protection, restoration and nutrient retention, the loss of floodplains is much more important and should deteriorate the evaluation. Further improvements should be prepared for the type-specific assessment (hydromorphological and biological reference conditions or maximum ecological potential for many large rivers which are HMWB).

The discussion of hydromorphological indices in relation to the BQE should be deepened according to Hering et al. 2006 or Feld et al. 2005: Scaling aspects (whole catchment (landuse), longer reaches, sites, upstream and downstream influences) and a more type-specific evaluation should be introduced. Fish indices such as the European Fish Index project (EU project EFI+ http://efi-plus.boku.ac.at) or the German Perlodes System (www.fliessgewaesserbewertung.de) for macrozoobenthos give more precise subselections of hydromorphological parameters. To combine those indices with used or planned hydromorphological inventories or surveys is the most important task.

Several river type-specific statistical analysis in relation to river degradation parameters (metrics) on periphytic diatoms, macrophytes, benthic macroinvertebrates and fish across Europe were prepared over the last years (e.g. within the STAR project, Hering et al. 2006) including also many hydromorphological and landuse parameters. The results underline the significance of those parameters for fish and benthic macroinvertebrates as well as partially macrophytes depending on the river type (mountain and lowland rivers, fish and macrophytes e.g. show a less strong response to degradation indices in mountainous reaches but a than for lowland rivers).

6.2 Implications for the Danube Basin

Based on this case study and the development of different hydromorphological methods in Danubian countries, such as in the Slovak Republic, Hungary or Romania, it would be necessary to establish comparable data on hydromorphology for the entire Danube. A first important opportunity to strengthen the methodological aspect and to prepare at least overview data will be the ICPDR JDS 2 (Joint Danube Survey) in late summer 2007 surveying the lower 2,500 km of the river. The IAD together with the consultant offers a module-based approach to reach the target within a certain timeframe (compare figure 59). In a first step in 2007 about 100 sampling sites along the Danube as well as basic continuous information collected by videography for the whole navigable section of the Danube are proposed for the JDS survey.

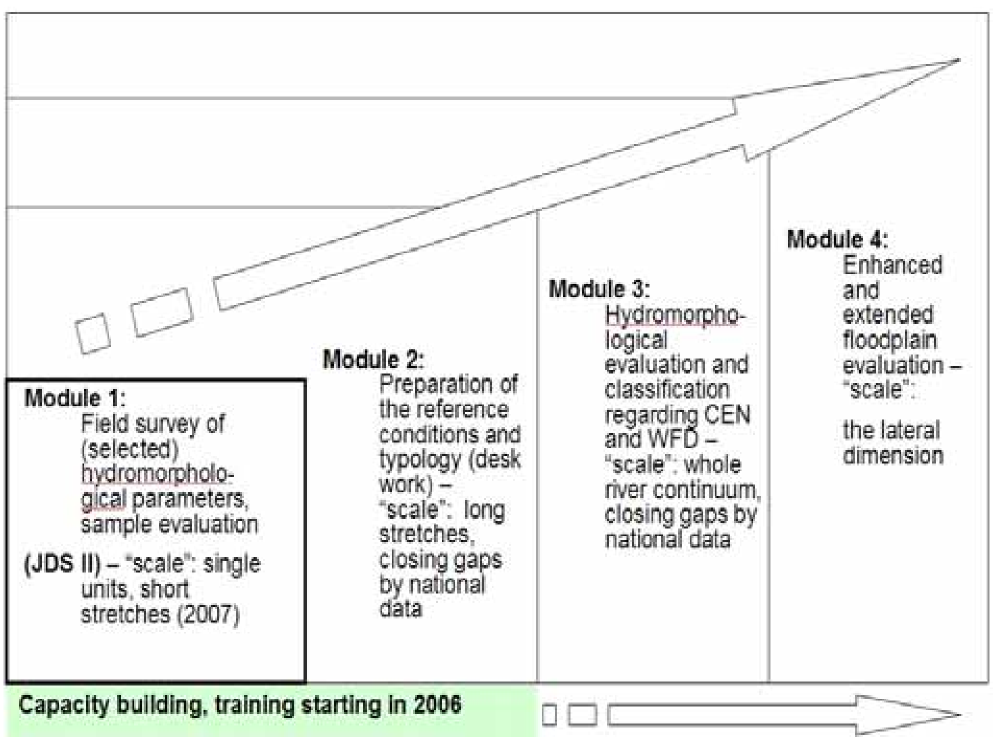


Figure 59: IAD proposal for a module-based hydromorphological inventory of the Danube

By all means, the national methods must be, as much as possible, compatible with the CEN standard and therefore a future overall data collection with quantitative hydromorphological data from each country will allow a much better understanding of the hydromorphological situation along the Danube. The scale of the inventories has to be chosen carefully. For the urgent WFD needs in respect to the preliminary risk assessment simple water body evaluations are sufficient to assess only some important parameter groups (screening methods). But for the definition of the river basin management plans in 2009 and for the further integrated river and floodplain management it is necessary to survey the full parameter sets of the CEN Standard.

Detailed hydromorphological reference conditions as well as a systematic floodplain typology could support the objectives of WFD and other European Directives (FFH, Birds Directive, and upcoming Floods Directive).

Possible programmes of measures (PoM) should be oriented on different scale levels, such as the Danube DRBD, the Drava catchment and other large Danube tributaries level, the national level and the water body level. Basically, the interrelation between abiotic conditions and biota must be strengthened. In particular this concerns for large rivers the importance of navigation and hydropeaking as well as hydropower in generally. Highly sensible will be the discussion how to reduce the hydropeaking impacts (in the case of the Drava) and the direct deteriorations by navigation (wave, turbidity, propeller noise, mean and low water regulation according to ongoing and proposed river engineering works and dredging for the Trans-European Transport Network (TEN-T), where the Danube is one of the most important transport corridors).
In this respect the long-term stability of the hydrological and sediment balance must be highlighted. For sediments this would mean:

- Stop of sediment extraction including intensive dredging to remove bottlenecks for waterway transport
- Remobilisation of lateral sediments by erosion
- Longitudinal continuity for the sediment transport in particular in the upper catchments by changed operation of dams (instead of flushing or clearance allowing a permanent sediment transport, transferring sediments from reservoirs)
- Addition of sediment (artificially)

In addition, the channel and bank structures should be enhanced by more self-driven dynamics (stop of maintenance works) and, where necessary and possible, the removal of bank protection and rip-rap.

For the pilot rivers Drava (and mostly the Mura) the following representative list of measures can be summarised:

1. No further deterioration of the still intact reaches
2. Reduction of the dangerous bed incision in the lower Drava and stop of any sediment extraction from the river bed for commercial (Rakoczi 2004) or navigation purposes
3. Reduction of hydropeaking which is influencing the entire lower Drava
4. Improvement of lateral connectivity (removal of closures of side-channels and backwaters
5. Bed widening through self-eroding processes
6. Revitalisation of the former river courses within the hydropower plant reach instead of rectification, stabilization with sills and massive gravel extraction
7. Restoration of the longitudinal continuity, using the former Drava river courses in Croatia and Slovenia (sufficient residual water) as well as the main channel along the Austrian Mura.

Besides the scaling of measures, the following issues are relevant:
• to respect the detailed natural circumstances (deterioration)
• to evaluate the necessity for each measure at a certain stretch (probably it makes more sense to improve the situation from class 3 to 2 outside the strongly modified stretches near settlements, and to plan measures as ecological network along river corridors, instead of focusing only on some sections)
• to prioritize the ranking and realisation costs
• to perform a cost/benefit analysis.

Finally the communication of restoration experiences and the permanent improvement of single measures must have high priority in the ongoing planning.

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