Supplementary Material

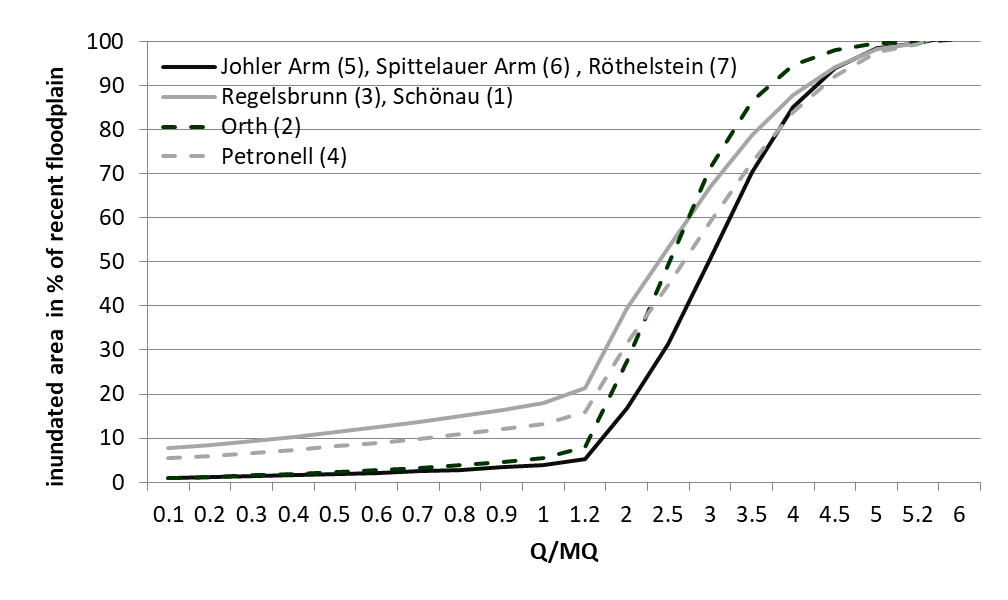
# Overview of hydro-morphological and water quality characteristics of the side arms in the Danube Floodplain National Park (DFNP)

The investigated side arms show distinct hydro-morphological differences. Johler Arm experiences the most frequent surface water connection, followed by Orth and Regelsbrunn. Whereas the most recently reconnected Johler Arm is open to the Danube River at its full width, the narrow culvert into the side arm system Regelsbrunn was constructed in a very technical manner (Supplementary Figure 1). Orth has rather natural inlets, but they do not extend over the whole channel width. Regelsbrunn has gentle bars and the inundated area is increasing steadily with increasing discharge; Orth is dominated by steep erosion banks and its inundated area increases rapidly after the water level reaches bankfull (compare with Supplementary Figure 2). Johler Arm has less pronounced erosion banks than Orth, but steeper banks than Regelsbrunn. The inlets and outlets of Röthelstein and Spittelauer Arm are completely blocked, meaning that with average discharge the oxbows are groundwater fed until the Danube discharge exceeds an annual flood. The restored inflow in Schönau was completed in 2004, and consists of a bed sill, which allows inundation slightly above MQ (Supplementary Figure 1).

Furthermore, these hydro-morphological differences are reflected in differing TP retention capacities in times of surface water connection. Johler Arm, completely reconnected at full width, shows the highest TP retention in response to incoming TP load, despite experiencing the highest hydraulic load of all side arms. TP retention in Johler Arm is followed by Orth and Regelsbrunn, which shows no response (Supplementary Table 1). The difference in surface water connectivity (d a-1), morphology and TP retention capacity of the respective side arms led to their assignment to three connectivity classes (Supplementary Table 2). This classification scheme was used by the statistical model to estimate nutrient retention in the remaining side arms to be reconnected without water quality measurements.

In the reconnection scenario (ALL), all side arms are reconnected at a Danube discharge below 1000 m³s-1 for 365 to 287 days in a wet (2002) and dry (2003) year, respectively. Johler Arm is already connected at lower water levels and therefore shows slightly increased connectivity (Supplementary Table 3)



Figure 2: Share of inundated floodplain of the recent floodplain (100% inundation at HQ30 event). The ratio of Q (discharge) and MQ (average discharge) of the Danube is considered.

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| Supplementary Table 1. Results of single linear regression analyses between TPdc (mg m-3 m-1) and incoming TP concentration (mg m-3) and discharge (m3 s-1) in three differently connected side arms. | | | | | |
| **System** | **Variables** | **Intercept** | **a** | **R²** | **p** |
| Johler Arm | TP | -0.039 | 0.00097 | 0.81 | <0.001 |
| Orth | TP | -0.029 | 0.00032 | 0.75 | <0.001 |
| Regelsbrunn | TP | 0 | 0 | 0 | n.s. |
| Johler Arm | Q side arm | -0.004 | 0.00160 | 0.50 | 0.007 |
| Orth | Q side arm | -0.203 | 0.00092 | 0.36 | 0.017 |
| Regelsbrunn | Q side arm | 0 | 0 | 0 | n.s. |

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| **Supplementary Table 2.** Assignment of connectivity classes by hydro-morphological characteristics including the ratio of the width of the inlet structure to the mean channel width at the beginning of surface water connection (Winlet/Wside arm) and days of connection in an average hydrological year (2015). These characteristics in other side arms were applied to estimate TP retention after complete reconnection using the multivariate adaptive regression spline model (earth) (Milborrow, 2015). | | | | |
| **Winlet/Wside arm** | **Connection** [days in 2015] | **Connectivity class** | **Description** | **R² (earth)** |
| 0.7-1 | >300 | high | Width of inlet at connection approximately equal to water body, frequent connection (Johler Arm: ~1) | R² = 0.79 |
| 0.3-0.7 | 90-300 | medium | Width of inlet at connection half of water body, intermediate connection (Orth: 0.54) | R² = 0.98 |
| 0-0.3 | <90 | low | Width of inlet at connection much narrower than water body, rather poorly connected (Regelsbrunn: 0.17) | Intercept-model TP dc m-1 = 0.00035 mg m-3 m-1 (R² = 0) |

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| **Supplementary Table 3.** Start of connection of side arm systems with the Danube for the scenarios and the number of days connected for the current state (CUR) and after reconnection (ALL) in a wet and dry hydrological year. | | | | |
| **Side arm system**  (ID number) | **Start of connection**  [m³ s-1 of Danube discharge] | | **Days of connection for the years WET / DRY**  [d a-1] | |
|  | **CUR** | **ALL** | **CUR** | **ALL** |
| **Schönau (1)** | 1994 | 980 | 235 / 72 | 365 / 287 |
| **Orth (2)** | 1758 | 980 | 289 / 125 | 365 / 287 |
| **Regelsbrunn (3)** | 2100 | 980 | 208 / 52 | 365 / 287 |
| **Petronell (4)** | 2689 | 980 | 98 / 16 | 365 / 287 |
| **Johler Arm (5)** | 916.6 | 916.6 | 365 / 311 | 365 / 311 |
| **Spittelauer Arm (6)** | 3618 | 980 | 33 / 7 | 365 / 287 |
| **Röthelstein (7)** | 3518 | 980 | 41 / 8 | 365 / 287 |

# Calculation of transported nutrient loads into the floodplains

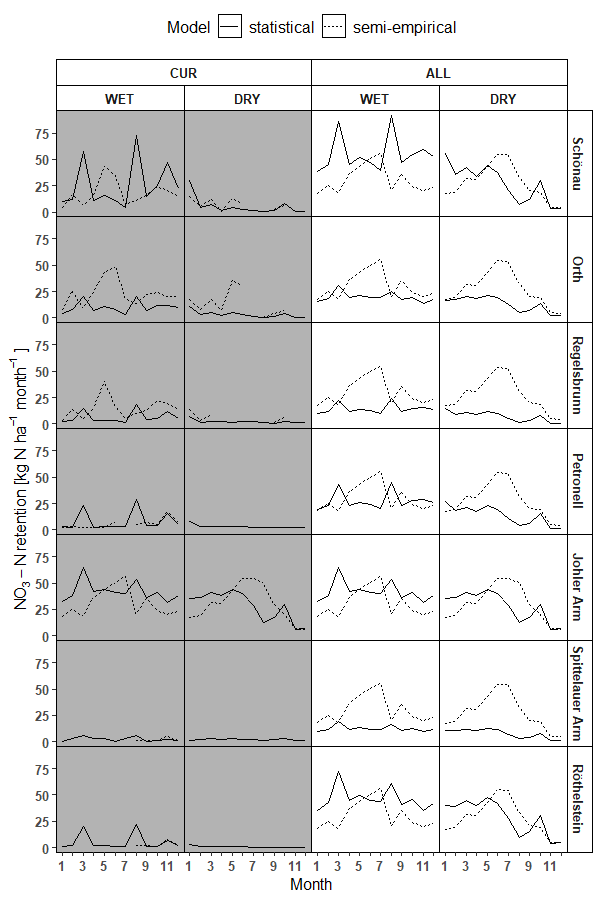
For the semi-empirical model, nutrient concentration proxies were used to calculate daily incoming nutrient loads into the floodplain. For TP, seasonal and discharge-related proxies were used. This is the median, based on monthly concentration measurements in FW31000187 Wildungsmauer for the period 2001-2017 (<https://wasser.umweltbundesamt.at/h2odb/>). For NO3-N, monthly concentrations were calculated as the median of NO3-N concentration measurements in FW31000187 Wildungsmauer for the period 2000-2017.

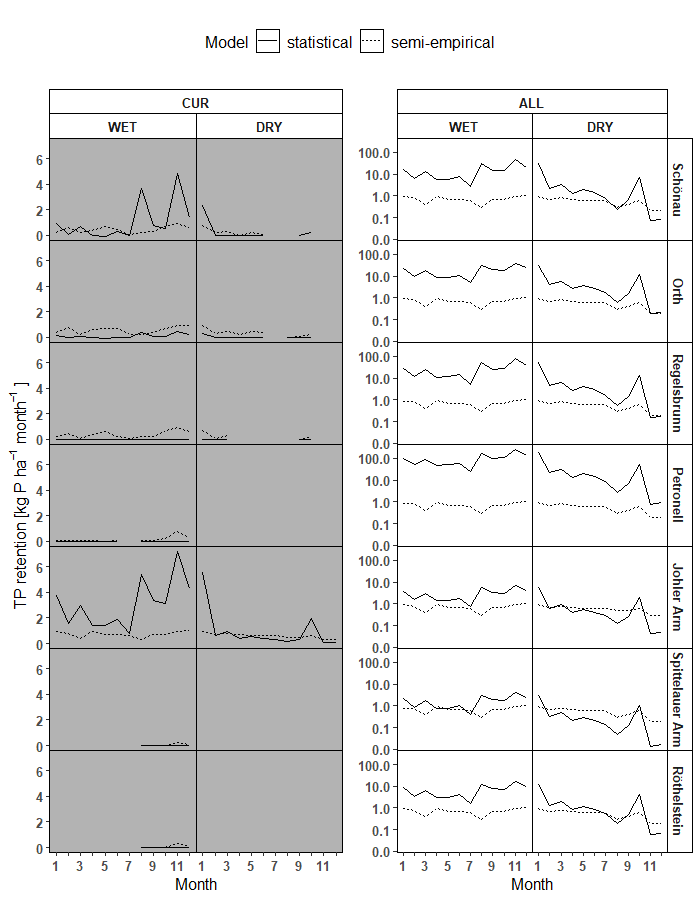
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| |  |  | | --- | --- | | **Supplementary Table 4.** Seasonal concentration proxies dependent on discharge for the calculation of daily TP loads entering the floodplain. | | | **Season/Hydrology** | **TP [mg l-1]** | | Winter>MQ | 0.072 | | Summer>MQ | 0.052 | | Summer>MQ | 0.047 | | Winter<MQ | 0.058 | | |  |  | | --- | --- | | **Supplementary Table 5.** Monthly concentration proxies for the calculation of daily NO3-N loads entering the floodplain | | | **Month** | **NO3-N [mg l-1]** | | January | 2.86 | | February | 2.93 | | March | 2.62 | | April | 2.18 | | May | 1.25 | | June | 1.46 | | July | 1.33 | | August | 1.39 | | September | 1.53 | | October | 1.79 | | November | 2.05 | | December | 2.52 | |

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# Monthly nutrient retention values

In the following section, detailed monthly retention values for the seven investigated side arm systems in the respective implementation scenarios and model years are presented (Supplementary Figures 3 and 4). It is clearly visible that the statistical model follows discharge patterns, whereas the semi-empirical model follows primarily the hydraulic load. The greatest discrepancy is generally in larger systems in times of elevated discharges in the ALL scenario for TP.

**Supplementary Figure 3.** Model comparison for monthly areal NO3-N retention rates in the respective side arms and implementation scenarios.

**Supplementary Figure 4.** Model comparison for monthly areal total phosphorus retention rates in the respective side arms. For visualization purposes, a comparison of the models for TP in the ALL scenario is displayed separately on a log scale.

# Literature study of nitrogen and phosphorus retention rates and efficiency in temperate floodplains

Literature values for phosphorus (20 publications) and nitrogen retention (17 publications) in floodplains located in the temperate climate zone are compiled in Supplementary Tables 6 and 7. Absolute rates (kg ha-1a-1) and retention efficiencies (%) vary considerably, probably due to different quantification methods, hydrology, nutrient loads, scales and climatic factors. Phosphorus retention ranges between -5 and 260 kg P ha-1a-1 and nitrogen retention ranges between 2.7 and 680 kg N ha-1a-1. In the case of phosphorus, release is also reported by Hoffmann *et al.* (2011, 2012).

**Supplementary Table 6.** Selected literature values for phosphorus retention of floodplains in the temperate climatic zone. Method states the quantification of different P-retention mechanisms: sedimentation (S), plant uptake (P), mass balances (M) and meso-scale models (Mo) or not stated (n.s.).

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| --- | --- | --- | --- | --- | --- | --- |
| **Author(s)** | **System, River** | **Region** | **Method** | **P-fraction** | **P-retention**  (kg P ha-1a-1) | **P**  (%) |
| Hoffmann *et al.* (2009) | Nagbøl Å restored floodplain | DK | M | TP | 0.9 | 11 |
| Hoffmann *et al.* (2009) | Hjarup Bæk restored floodplain | DK | M | TP | 12 | 42 |
| Hoffmann *et al.* (2011) | Brede floodplain restored | DK | M | TP | -5 |  |
| Hoffmann *et al.* (2012) | Egescov floodplain | DK | M | TP | -0.15-0.08 | -25-6 |
| Hoffmann *et al.* (2012) | Stor Å floodplain | DK | M | TP | -0.9 - -0.33 | -127- -22 |
| Jordan *et al.* (2003) | Restored wetland receiving agricultural runoff | USA | M | TP | 7.6 | 27 |
| Klimo (1985) in Penka *et al.* (1985) | Floodplain forest | CZ | P | TP | 18 |  |
| Kronvang *et al.* (1999) | Gjern river streambed | DK | M | TP | 37–83 |  |
| Kronvang *et al.* (2002) | Gjern floodplain (single floods) | DK | S, M | TP | 11.8-65 | 2.7-5.4 |
| Kronvang *et al.* (2007) | Gjern floodplain | DK | S, M | TP | 73 | 4.1 |
| Kronvang *et al.* (2007) | Skjern floodplain (restored - single floods) | DK | S, M | TP | 12 | 4 |
| Kronvang *et al.* (2007) | Odense floodplain (restored - single floods) | DK | S, M | TP | 24 | 5.1 |
| Kronvang *et al.* (2007) | Brede floodplain (restored - single floods) | DK | S, M | TP | 36 | 7 |
| Lowrance *et al.* (1984) | Riparian buffer Little River | USA | M, P | TP | 1.7 | 30 |
| Scholz *et al.* (2012) | Floodplains of large rivers | DE | Mo | TP |  | 11-48 |
| Mitsch *et al.* (2000) | Selected wetlands | USA, AUS, NZ | M | TP | 4-75 |  |
| Mitsch *et al.* (2008) | Diversion Wetland steady flow | USA | M | TP | 29 |  |
| Mitsch *et al.* (2008) | Diversion Wetland, pulse flow | USA | M | TP | 45 |  |
| Natho (2013) | Floodplains Rhein, Main, Elbe | DE | Mo | TP | <1-28 |  |
| Noe and Hupp (2005) | Decoupled coastal floodplains | USA | S | TP | 2.2-3.5 | 8 |
| Noe and Hupp (2005) | Connected coastal floodplains | USA | S | TP | 4.4-41.3 | 10 |
| Olde Venterink *et al.* (2003) | Ijsel | NL | M | TP |  | 20-45 |
| Olde Venterink *et al.* (2006) | Floodplain forest Waal und Ijsel | NL | S, P | TP | 34 |  |
| Olde Venterink *et al.* (2006) | Floodplain pond Waal und Ijsel | NL | S, P | TP | 260 |  |
| Olde Venterink *et al.* (2006) | Reed belt Waal und Ijsel | NL | S, P | TP | 95 |  |
| Peterjohn and Correll (1984) | Floodplain forest Rhode river | USA | M | TP | 2.9 | 80 |
| Richardson (1990) | Floodplain forest | USA | n.s. | TP | 1.5 |  |
| Van Oorschot (1996) | Flooded meadow | UK | M | TP | 17.4 |  |
| Yates and Sheridan (1983) | Floodplain forest Little river | USA | M | SRP | 0.09 | 37 |

**Supplementary Table 7.** Selected literature values for nitrogen retention of floodplains in the temperate climatic zone. Method states the quantification of different N-retention mechanisms: sedimentation (S), denitrification (D), plant uptake (P), mass balances (M) and meso-scale models (Mo) or not stated (n.s.).

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| --- | --- | --- | --- | --- | --- | --- |
| **Author(s)** | **System, River** | **Region** | **Method** | **N-fraction** | **N-Retention**  (kg N ha-1 a-1) | **N**  (%) |
| Andreasson-Gren and Groth (1995) | Danube floodplains | EUR | M | n.s. | 100 |  |
| Hoffmann *et al.* (2011) | Brede floodplain restored 1995 | DK | M | NO3-N | 92 | 71 |
| Hoffmann *et al.* (2011) | Brede floodplain restored 1999-2000 | DK | M | NO3-N | 141 | 95 |
| Hoffmann *et al.* (2012) | Egescov floodplain | DK | M | NO3-N | 23-104 | 41-90 |
| Hoffmann *et al.* (2012) | Stor Å floodplain | DK | M | NO3-N | 150-219 | 26-32 |
| Jansson *et al.* (1994) | Flooded meadow | SW | D | NO3-N | 250-680 |  |
| Jordan *et al.* (2003) | Restored wetland receiving agricultural runoff | USA | M | NO3-N | 12 | 52 |
| Klimo (1985) in Penka *et al.* (1985) | Floodplain forest | CZ | P | TN | 224 |  |
| Kronvang *et al.* (1999) | Gjern river streambed | DK | M | Organic N | 72–161 |  |
| Lowrance *et al.* (1984) | Little river floodplain | USA | M | TN | 51.8 | 68 |
| Scholz *et al.* (2012) | Floodplains of large rivers | DE | Mo | TN |  | 7-9 |
| Mitsch *et al.* (2000) | Selected wetlands | USA, AUS, NZ | M | NO3-N | 30-670 |  |
| Mitsch *et al.* (2005) | Diversion Wetland, Mississippi | USA | M | NO3-N | 460 | 39-92 |
| Mitsch *et al.* (2005) | Diversion Wetland, Olentangy | USA | M | NO3-N | 390 | 35 |
| Mitsch *et al.* (2008) | Diversion Wetland, pulse flow | USA | M | NO3-N | 150 | 47 |
| Mitsch *et al.* (2008) | Diversion Wetland, steady flow | USA | M | NO3-N | 80 | 64 |
| Natho (2013) | Floodplains Rhein, Main, Elbe | DE | Mo | NO3-N | 100-400 |  |
| Noe and Hupp (2005) | Decoupled coastal floodplains | USA | S | TN | 35-48 | 8 |
| Noe and Hupp (2005) | Connected coastal floodplains | USA | S | TN | 42-134 | 9 |
| Olde Venterink *et al.* (2006) | Floodplain forest Waal und Ijsel | NL | D, P, S | TN | 90 |  |
| Olde Venterink *et al.* (2006) | Reed belt Waal und Ijsel | NL | D, P, S | TN | 236 |  |
| Olde Venterink *et al.* (2006) | Floodplain pond Waal und Ijsel | NL | D, P, S | TN | 570 |  |
| Peterjohn and Correll (1984) | Rhode river floodplain | USA | M | NO3-N | 2.7 |  |
| Richardson (1990) | Floodplain forest | USA | n.s. | TN | 38-52 |  |

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