

2.3 Impact of value-driven scenarios on the geomorphology and ecology of lower Rhine floodplains under a changing climate

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i. Problem

In the future, the bio-geomorphological functioning of lowland floodplains is likely to be altered at an increasing pace. Together with increasing socio-economic demands, climatic changes are expected to increase the pressures on lowland rivers in developed countries. To cope with these pressures, integrated management plans have been developed for riverine areas across Australia, North America, and Europe (Brierley and Freyirs, 2008; Klijn et al., 2008). The choice and design of the measures proposed in these plans depends on the choices made in the decision making process, which in turn is strongly influenced by the value systems of the stakeholders. Planning of landscaping measures requires a long time horizon - decades to centuries - as the implementation is time-consuming and costly. Planning, therefore, involves scenario analysis to determine the feasibility and effects of potential landscaping measures.

ii. Aim

Our main objective was to explore the potential changes in future bio-morphological functioning of lowland rivers. In this project we adopted Spiral Dynamics (SD; Beck and Cowan, 1996; Graves, 2006) as a basis for scenario development. The advantage of this concept when compared to traditional methods is that it makes the role of human values explicit (Grumbine, 1997), and gives a framework of value systems that is hierarchic in nature, thereby limiting transitions to steps up or down the hierarchy. This makes that SD has an excellent potential for application in scenario development. We combined SD-based scenario development for river management with a quantification of the effects of the scenarios on floodplain bio-geomorphology. We firstly developed scenarios for 2050 based on shifts in the dominant value system in river management. For each scenario, we quantified the spatially distributed effects on the bio-geomorphology using existing spatially distributed simulation models. We exemplified these objectives for the lower Rhine River floodplain in The Netherlands.

iii. Results

Spiral Dynamics and Scenario Development

Spiral Dynamics (SD) structures the evolution of human value systems in a color-coded double helix (Graves, 2006; Fig. A-2.9). Each stage of development on the spiral represents a value system, which is a container for methods, beliefs and opinions. The hierarchy in value systems represents increasing inclusiveness and complexity. The spiral dynamics describe transitions up or down along the spiral. The current dominant value system in the Netherlands, with its consensual attitude and attention for ecology and landscape diversity, can be considered 'green' (Straatsma and De Nooij, 2010). Hence, starting from the green value system, we established three different scenarios that are plausible given the possible dynamics in value systems in

relation to the time horizon of 2050 (Tab. A-2.1). This means that shifts from green to e.g. blue or turquoise are not considered realistic based on SD.

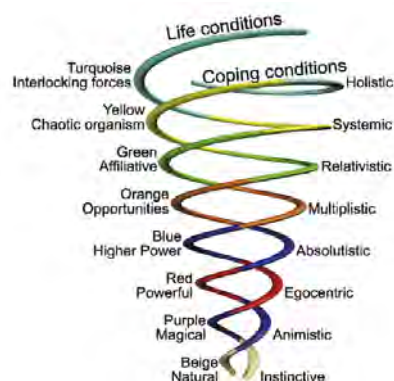


Fig. A-2.9: The color-coded spiralling double helix of the biopsychosocial human development in Spiral Dynamics. One spiral represents the life conditions, the other the mind/coping capacities required for dealing with these life conditions. See Table A-2.1 for details.

Tab. A-2.1: Overview of the scenarios based on green, orange and yellow river management

Value system	River management	Implementation
GREEN		
<ul style="list-style-type: none"> • Living with the human element • Getting along with others • Consensual 	<ul style="list-style-type: none"> • Consensus mentality, local communities have a say • Focus on ecology • Dike raising is no option 	<ul style="list-style-type: none"> • Space for the river combined with ecological restoration • Solutions for individual floodplain sections • Groyne lowering • Cyclic floodplain rejuvenation
ORANGE		
<ul style="list-style-type: none"> • Conquering the physical universe as to overcome needs • Oriented at technology and competition • Pragmatic 	<ul style="list-style-type: none"> • Centralized authority • Cost-benefit analyses • Dike raising is a cheap option 	<ul style="list-style-type: none"> • Dike raising • Groyne lowering • Removal of hydraulic bottlenecks • Removal of vegetation that obstructs flow • Removal of minor embankments • Retention areas
YELLOW		
<ul style="list-style-type: none"> • Restoring vision in a disordered world • Integrative 	<ul style="list-style-type: none"> • Spatially coherent plan for the whole river section • Interactive • Local communities participate from the design phase • Water as the guiding principle • Dike raising is an option when needed 	<ul style="list-style-type: none"> • Side channels follow the historic swale channels • Cyclic floodplain rejuvenation • Local initiatives in line with the overall direction • Multi-purpose groyne lowering

Using the SD value systems framework, we established three fundamentally different color-coded sets of landscaping measures (Fig. A-2.10):

The green relativistic scenario incorporated measures in three regions where consensus was found. Measures comprised side channels with naturally vegetated banks, 32 floodplain lowering projects, three dike section relocations, minor embankment removal, and natural management of ecotopes.

The orange multiplistic scenario was characterized by a productive-efficient layout applied to the entire study area. Measures comprised deep side channels with unvegetated banks, 51 floodplain lowering projects, minor embankment removal, and emphasized agricultural production.

The yellow systemic scenario showed a diverse pattern of city expansion, nature development, agricultural production and innovative groyne lowering. It comprised 52 floodplain height change projects, minor embankment removal outside the production regions, and seven dike repositioning projects.

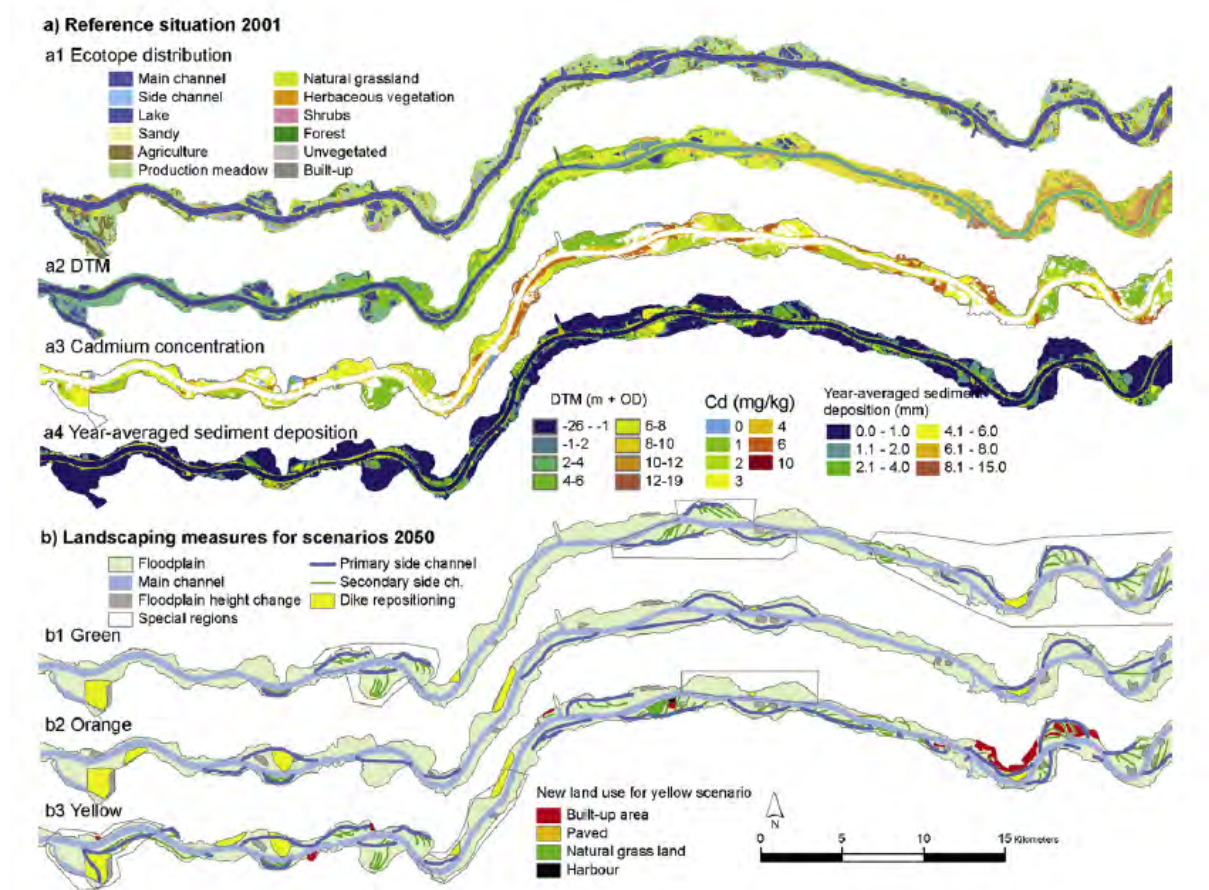


Fig. A-2.10: a) Reference situation of the study area: ecotope distribution, terrain heights, soil cadmium concentrations, and year-averaged deposition of suspended sediment. b) Landscaping measures (floodplain height change, dike repositioning and side channels) for the scenarios: green, orange and yellow.

Climate and river discharge scenarios

To determine the river discharge regime for 2050, we selected the KNMI-W scenario (Van den Hurk et al., 2006). This scenario assumes a 2°C increase in temperature and a change in precipitation of +6 % in winter and -5 % in summer, and an 8 % increase in summer evaporation from 1990 to 2050. Hydrological simulations based on climate change scenarios indicate an increase in flooding probability for the Rhine as its regime will shift from a combined rain-fed/meltwater river into a mainly rain-fed river (Shabalova et al, 2003). Accordingly, for our scenario study, we adopted an increase design discharge for flood protection structures from 15,000 m³.s⁻¹ to 17,000 m³.s⁻¹ at Lobith for 2050. To facilitate comparison, we assumed equal input of heavy metals and suspended sediment between the three scenarios.

Floodplain biogeomorphology models

To quantify the effects of the three scenarios on the bio-geomorphology of the River Rhine floodplains and to compare these to the reference situation, we used a suite of spatially explicit simulation models, which were all calibrated and validated in earlier studies. We broke down the assessment into the following stepwise approach:

- Computation of the hydrodynamics using the 2D WAQUA model (RWS, 2007).
- Computation of the year-average deposition of sediment and metals using the SEDIFLUX model (Middelkoop and Van der Perk, 1998).
- Assessment of the potential ecotoxicological risk of heavy metal contamination (Cd) using a simplified version of the SpaCE model (Schipper et al., 2008a).
- Evaluation of the potential values for protected and endangered flora and fauna species using BIO-SAFE (De Nooij et al., 2004; Lenders et al., 2001).

We evaluated the impacts by comparing results for the reference situation with the current discharge regime (REF2001), the reference situation with the KNMI-W discharge regime for 2050 (REF2050), and the value-based scenarios with the KNMI-W discharge regime for 2050 (Tab. A-2.2).

Ecotope distribution and biodiversity

The ecotope distributions resulting over time from the landscaping measures for the scenarios are shown in Figure A-2.3a. Considerable differences in land use show up between the scenarios. Potential biodiversity values of the river landscape increase for the yellow and green river management strategies in comparison with the reference situation (Fig. A-2.12). This is due to the increasing areas of side channels, natural grassland and herbaceous vegetation at the expense of production meadows and agriculture. The orange strategy reduces potential biodiversity, due to a decrease in surface area of natural grassland, herbaceous vegetation, shrubs and forest and strong expansion of production grassland. Thus, based on potential values of the riverine landscape for protected and endangered species, the ranks of the management strategies show the following order: yellow > green > orange (Tab. A-2.2, Fig. A-2.11, A-2.12).

Tab. A-2.2: Summary of modeling results

	REF2001	REF2050	Green	Orange	Yellow
Average lowering of peak water level at 17000 m ³ .s ⁻¹ (m)	NA	NA	0.11	0.65	0.37
River length requiring additional lowering of water level or dike raising (km)	85	85	85	41	84
High water free surface area (km ²)	12.4	8.7	8.2	9.8	9.7
Sediment deposition in groyne area (mm)	3.61	5.06	3.56	4.33	3.68
Year-averaged sedimentation on floodplain (mm)	1.15	1.81 (+58 %)	2.44 (+112 %)	2.85 (+148 %)	2.80 (+ 143%)
Total deposition of sediment (10 ⁶ kg/y)	199	306	358	422	406
Total deposition of Cd (kg.y ⁻¹)	655	989	1157	1372	1329
Sediment trapping during floodplain inundation (%)	26	27	31	37	35
Average cadmium concentration in floodplain soil (mg.kg ⁻¹)	2.74	2.74	2.95	3.01	3.04
No. of species for which PEC _{Cd} > PNEC _{Cd} (cumulative affected fraction of habitat)	5 (39 %)	5 (39 %)	4 (37 %)	5 (40 %)	4 (37 %)
Relative BIO-SAFE scores	1	1	1.23	0.96	1.39

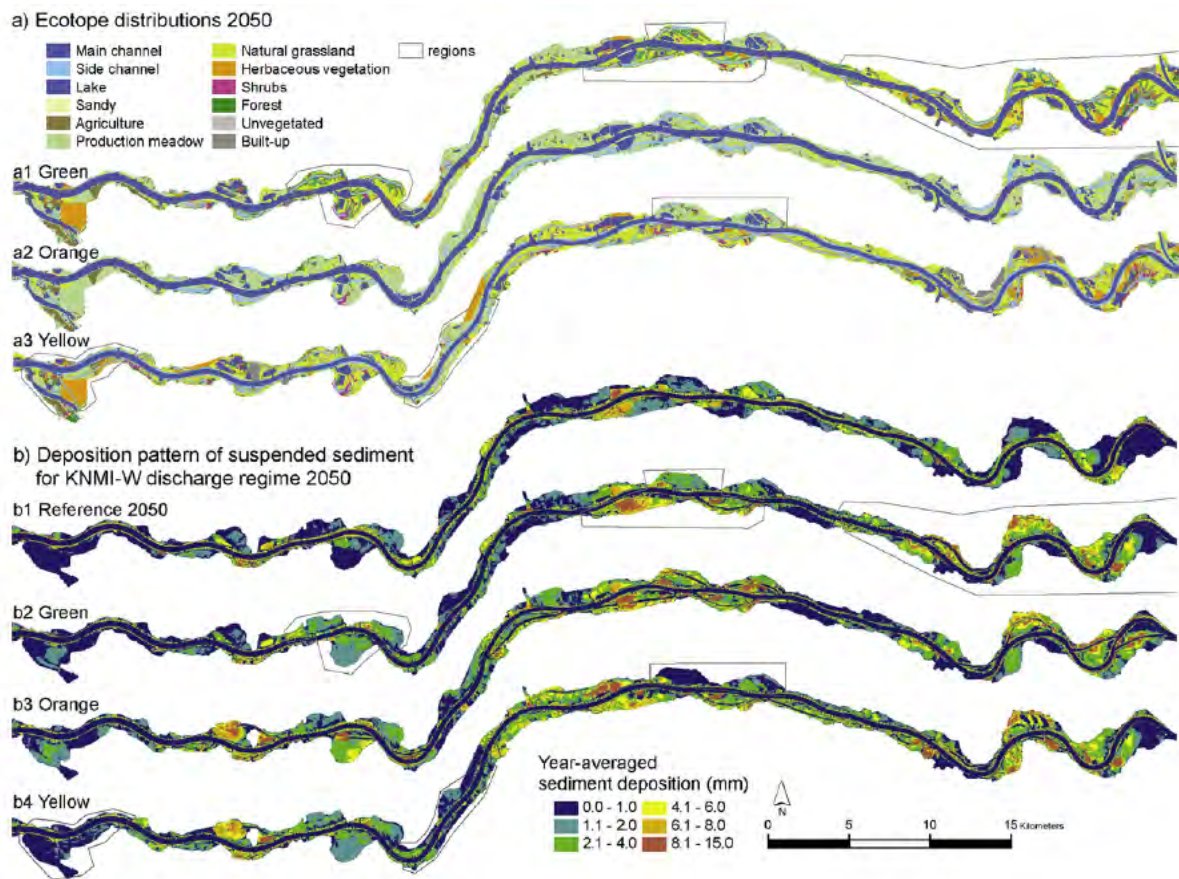


Fig. A-2.11: a) Ecotope distribution for the scenarios, b) pattern of suspended sediment deposition in the Waal for the KNMI-W discharge regime.

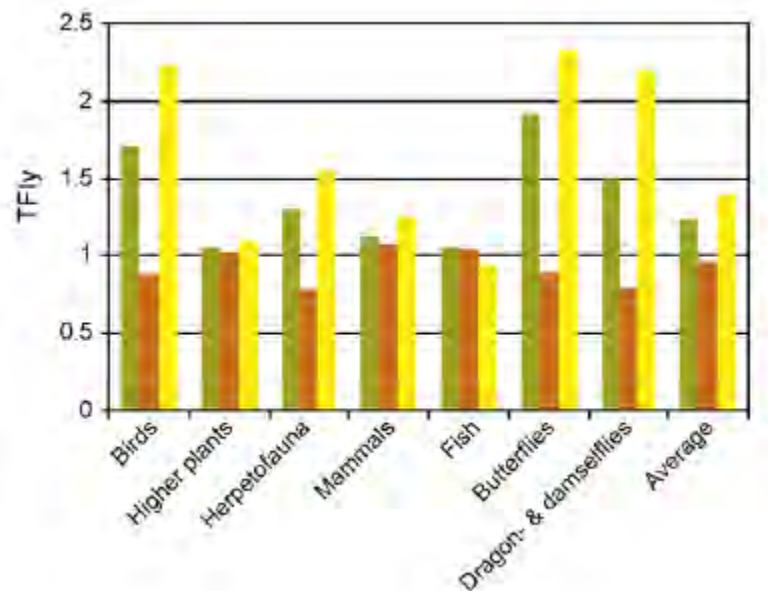


Fig. A-2.12: Taxonomic group Floodplain Importance (TFI) scores for various taxonomic groups. Values are relative to the scores in the reference situation, hence all TFI scores for the reference situation would be one. Colors refer to scenarios.

Hydrodynamics

The landscaping measures strongly affect the flow patterns and peak water levels. The average water level reductions along the river axis at a $17,000 \text{ m}^3\text{s}^{-1}$ discharge are 0.11 m in the green, 0.37 m in the yellow, and 0.65 m in the orange scenario. Still, the strategies do not compensate for the expected increase in water level, due to the introduction of hydraulically rough ecotopes, such as floodplain forest.

Sediment and heavy metal deposition

Climate change leads to more frequent inundation of the floodplains, increasing average sediment deposition over the floodplain area from 1.15 to 1.81 mm.y^{-1} (+58 %), with considerable spatial variation. However, landscaping measures more than double the floodplain sedimentation (+112 % to +148 %). Spatial differentiation between the scenarios is large, depending on the design of side channels (Fig. A-10b). Changes in deposition pattern of Cd largely follow the pattern in sediment deposition. The reference situation has the lowest Cd deposition rate (655 kg.y^{-1}), the orange scenario the highest (1372 kg.y^{-1} ; Tab. A-2.2). Little difference (<10 %) was present for the resulting Cd concentrations.

The filter function of the river Waal within the coastal zone is expressed as the total trapping efficiency of the river for suspended sediment, calculated for Rhine discharges $>3500 \text{ m}^3\text{s}^{-1}$ that cause floodplain inundation. The reference situation with the current discharge regime shows a 26 % trapping efficiency and a total annual deposition of 0.2 Mton.y^{-1} . The reference situation in 2050 has a similar trapping efficiency of 27 %, with 0.3 Mton.y^{-1} deposition. The orange scenario shows the highest trapping efficiency of 37 % (Tab. A-2.2).

Ecotoxicological risks

Predicted exposure concentrations (PECs) of cadmium for 10 terrestrial vertebrate species show no substantial differences between the scenarios (Tab. A-2.2). Irrespective of scenario, for four species (i.e. common shrew, European mole, badger and little owl) the largest part of the habitat area remains characterized by PECs that are higher than the corresponding toxicity reference values (predicted no-effect concentrations (PNECs); Tab. A-2.2). For the weasel, the PNEC is exceeded in a small fraction (< 1 %) of the habitat area for three out of five scenarios. For the remaining five species, the entire habitat area is characterized by exposure concentrations lower than the corresponding PNECs.

iv. Conclusions

The present study illustrates the great potential for the application of SD in the design of floodplain management scenarios, as the shifts in value systems provide a guide for selecting and positioning specific landscaping measures. In addition, the value systems analysis promotes the internal coherence of the scenarios, as measures are chosen within a storyline rather than individually. This first attempt to develop scenarios for floodplain management based on Spiral Dynamics (SD) demonstrates that the value systems analysis provides a broad interpretive framework for development of scenarios that are internally coherent and plausible.

The river floodplain bio-geomorphology is influenced by the combined effects of a climate-induced change in discharge regime and local landscaping measures. Climate-induced changes in

river discharge regime may increase the year-average floodplain sedimentation by the order of 50 % but this is overshadowed by the increase of more than 100 % due to human landscaping measures. Thus, the filter function of this lowland river is more sensitive to local measures than changes in discharge regime. The trapping efficiency is positively correlated to floodplain discharge capacity. The orange scenario provided the extreme case of high discharge and high deposition.

Natural vegetation should be compensated for by sufficiently large side channels to increase discharge capacity and prevent driving up the water levels. The ecotoxicological risks of cadmium contamination remain similar as to date. The scenarios also point to the human influence on future potential biodiversity values ranging from -4 % to +39 %. None of the scenarios shows the ideal combination of a high flood peak reduction, low sedimentation, low ecotoxicological risks, and high biodiversity potential.

References

- Arthington, A.H., Naiman, R.J., McClain, M.E., Nilsson, C. (2010). Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. *Freshwater Biology* 55:1-16.
- Baptist, M.J., Babovich, V., Rodríguez Uthurburu, J., Keijzer, M., Uittenbogaard, R.E., Mynett, A., Verwey, A. (2007). On inducing equations for vegetation resistance. *Journal of Hydraulic Research* 45:435-450.
- Beck, E.D. and Cowan, C.C., (1996). Spiral dynamics, waarden, leiderschap en verandering in een dynamisch model (in dutch). Altamira-Becht, Haarlem, The Netherlands.
- Brierley, G.J. and Fryirs, K.A. (2008). River futures: an integrative approach to river repair. Island Press, Washington D.C., USA.
- Buijse, A.D., Coops, H., Staras, M., Jans, L.H., Van Geest, G.J., Griffiths, R.E., Ibelings, B.W., Oosterberg, W. and Roozen, F.C.J.M. (2002). Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biology* 47:889-907.
- Cobby, D.M., Mason, D.C., Davenport, I.J. (2001). Image processing of airborne scanning laser altimetry data for improved river flood modeling. *ISPRS Journal of Photogrammetry and Remote Sensing* 56:121-138.
- Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., Van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.
- De Nooij, R.J.W., Lenders, H.J.R., Leuven, R.S.E.W., De Blust, G., Geilen, N., Goldschmidt, B., Muller, S., Poudevigne, I. and Nienhuis, P.H. (2004). BIO-SAFE: assessing the impacts of physical reconstruction on protected and endangered species. *River Research and Applications* 20:299-313.
- Dudley, S.J., Bonham, C.D., Abt, S.R., Fischenich, J.C. (1998). Comparison of methods for measuring woody riparian vegetation density. *Journal of Arid Environments* 38:77-86.
- Graves, C. (2006). The never ending quest: Clare W. Graves explores human nature. ECLET publishing, Santa Barbara, CA.
- Grumbine, R.E. (1997). Reflexions on "What is ecosystem management?". *Conservation Biology* 11:41-47.

- Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M., Baret, F. (2004). Review of methods for in situ leaf area index determination: Part I. Theories, sensors and hemispherical photography. *Agricultural and Forest Meteorology* 121:19-35.
- Klijn, F., Samuels, P. and Van Os, A. (2008). Towards flood risk management in the EU: State of affairs with examples from various European countries. *International Journal of River Basin Management* 6:307-321.
- Kouwen, N., Li, R.M. (1980). Biomechanics of vegetated channel linings. *Journal of Hydraulics Divisions* 106:1085-1103.
- Lake, P.S., Bond, N., Reich, P. (2007). Linking ecological theory with stream restoration. *Freshwater Biology* 52:597-615.
- Lenders, H.J.R. (2003). Environmental rehabilitation of the river landscape in the Netherlands: a blend of five dimensions. PhD thesis, Radboud University Nijmegen, Nijmegen.
- Lenders, H.J.R., Leuven, R.S.E.W., Nienhuis, P.H., De Nooij, R.J.W. and Rooij, V. (2001). BIO-SAFE: a method for evaluation of biodiversity values on the basis of political and legal criteria. *Landscape and urban planning* 55:121-137.
- Lim, K., Treitz, P., Wulder, M., St-Onge, B., Flood, M. (2003). Lidar remote sensing of forest structure. *Progress in Physical Geography* 27:88-106.
- Marks, K., Bates, P. (2000). Integration of high-resolution topographic data with floodplain flow models. *Hydrological Processes* 14:2109-2122.
- Middelkoop, H. (2000). Heavy-metal pollution of the river Rhine and Meuse floodplains in the Netherlands. *Netherlands Journal of Geosciences* 79:411-428.
- Middelkoop, H. and Van der Perk, M. (1998). Modelling spatial patterns of overbank sedimentation on embanked floodplains. *Geografiska Annaler* 80 A:95-109.
- Nienhuis, P.H., Buijse, A.D., Leuven, R., Smits, A.J.M., de Nooij, R.J.W., Samborska E.M. (2002). Ecological rehabilitation of the lowland basin of the river Rhine (NW Europe). *Hydrobiologia* 478:53-72.
- Nienhuis P.H., Leuven R. (2001). River restoration and flood protection: controversy or synergism? *Hydrobiologia* 444:85-99.
- RWS (2007). Users guide WAQUA: Technical Report SIMONA 92-10. National Institute for Coastal and Marine Management, The Hague, Online documentation, <http://www.waqua.nl/systeem/documentatie/usedoc/slib3d/ug-slib3d.pdf>, visited 13-02-2008.
- Schipper, A.M., Loos, M., Ragas, A.M.J., Lopes, J.P.C., Nolte, B., Wijnhoven, S., Leuven, R.S.E.W. (2008a). Modeling the influence of environmental heterogeneity on heavy metal exposure concentrations for terrestrial vertebrates in river floodplains. *Environmental Toxicology and Chemistry* 27:919-932; 2627-2628.
- Schipper, A.M., Wijnhoven, S., Leuven, R.S.E.W., Ragas, A.M.J., Hendriks, A.J. (2008b). Spatial distribution and internal metal concentrations of terrestrial arthropods in a moderately contaminated lowland floodplain along the Rhine River. *Environmental Pollution* 151:17-26.
- Schipper, A.M., Koffijberg, K., Van Weperen, M., Atsma, G., Ragas, A.M.J., Leuven, R.S.E.W. (2010a). The distribution of a threatened migratory bird species in a patchy landscape: a multi-scale analysis. *Landscape Ecology*: submitted.
- Schipper, A.M., Lotterman, K., Geertsma, M., Leuven R.S.E.W., Hendriks, A.J. (2010b). Using datasets of different taxonomic detail to assess the influence of floodplain characteristics on terrestrial arthropod assemblages. *Biodiversity and Conservation* 19:2087-2110.

- Schipper, A.M., Lotterman, K., Leuven, R.S.E.W., Ragas, A.M.J., De Kroon, H., Hendriks, A.J. (2010c). Plant communities in relation to flooding and soil contamination in a lowland Rhine River floodplain. *Environmental Pollution*: accepted.
- Schröder, T. (2005). Solid-solution partitioning of heavy metals in floodplain soils of the rivers Rhine and Meuse: Field sampling and geochemical modelling. PhD thesis, Wageningen University, Wageningen, The Netherlands.
- Shabalova, M.V., Van Deursen, W.P.A. and Buishand, T.A. (2003). Assessing future discharge of the river Rhine using regional climate model integrations and a hydrological model. *Climate Research* 23:233-246.
- Sparks, R.E. (1995). Need for ecosystem management of large rivers and their floodplains. *BioScience* 45:168-182.
- Stanford, J.A., Ward, J.V., Liss, W.J., Frissell, C.A., Williams, R.N., Lichatowich, J.A., Coutant, C.C. (1996). A general protocol for restoration of regulated rivers. *Regulated Rivers: Research & Management* 12:391-413.
- Stoesser, T., Wilson, C.A.M.E., Bates, P., Dittrich, A. (2003). Application of a 3D numerical model to a river with vegetated floodplains. *Journal of Hydroinformatics* 5:99-112.
- Straatsma, M.W. (2007). Hydrodynamic roughness of floodplain vegetation: airborne parameterization and field validation. Faculty of Geosciences. PhD thesis, Universiteit Utrecht, Utrecht, p. 176, The Netherlands.
- Straatsma, M.W., Schipper, A.M., Van der Perk, M., Van den Brink, C.G., Leuven, R.S.E.W., Middelkoop H. (2009). Impact of value-driven scenarios on the geomorphology and ecology of lower Rhine floodplains under a changing climate. *Landscape and Urban Planning* 92:160-174.
- Straatsma, M.W., (2008). Quantitative mapping of hydrodynamic vegetation density of floodplain forests using airborne laser scanning. *Photogrammetric Engineering and Remote Sensing* 47:987-998.
- Straatsma, M.W. (2009). 3D float tracking: in situ floodplain roughness estimation. *Hydrological Processes* 23:201-212.
- Straatsma, M.W., Baptist, M.J. (2008). Floodplain roughness parameterization using airborne laser scanning and spectral remote sensing. *Remote Sensing of Environment* 112:1062-1080.
- Straatsma, M.W., De Nooij, R.J.W., (2010). Evolution of river management: up to integrated and beyond? *Nature and Culture* 5:99-115.
- Straatsma, M.W., Middelkoop, H. (2007). Extracting structural characteristics of herbaceous floodplain vegetation for hydrodynamic modeling using airborne laser scanner data. *International Journal of Remote Sensing* 28:2447-2467.
- Straatsma, M.W., Warmink, J.J., Middelkoop, H. (2008). Two novel methods for field measurements of hydrodynamic density of floodplain vegetation using terrestrial laser scanning and digital parallel photography. *International Journal of Remote Sensing* 29:1595-1617.
- Thonon, I. (2006). Deposition of sediment and associated heavy metals on floodplains. PhD thesis, Utrecht University, Utrecht, The Netherlands.
- Tockner, K., Stanford, J.A. 2002. Riverine flood plains: present state and future trends. *Environmental Conservation* 29:308-330.
- Tockner, K. and Stanford, J.A. (2002). Riverine flood plains: present state and future trends. *Environmental Conservation* 29:308-330.
- Torres, K.C. and Johnson, M.L. (2001). Bioaccumulation of metals in plants, arthropods, and mice at a seasonal wetland. *Environmental Toxicology and Chemistry* 20:2617-2626.

- Traas, T.P., Luttik, R., Jongbloed, R.H. (1996). A probabilistic model for deriving soil quality criteria based on secondary poisoning of top predators. I. Model description and uncertainty analysis. *Ecotoxicology and Environmental Safety* 34:264-278.
- Van den Hurk, B.J.J.M., Klein Tank, A.M.G., Lenderink, G., van Ulden, A.P., van Oldenborgh, G.J., Katsman, C.A., van den Brink, H.W., Keller, F., Bessembinder, J.J.F., Burgers, G., Komen, G.J., Hazeleger, W. and Drijfhout, S.S. (2006). KNMI climate change scenarios 2006 for the Netherlands, KNMI, de Bilt, The Netherlands.
- Van Stokkom, H.T.C., Smits, A.J.M., Leuven, R.S.E.W. (2005). Flood defense in the Netherlands: a new era, a new approach. *Water International* 30:76-87.
- Walling, D.E. and Owens, P.N. (2003). The role of overbank floodplain sedimentation in catchment contaminant budgets. *Hydrobiologia* 494: 83-91.
- Ward, J.V., Tockner, K., Arscott, D.B., Claret, C. (2002). Riverine landscape diversity. *Freshwater Biology* 47:517-539.
- Ward, J.V. (1998). Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation* 83:269-278.
- Wassen, M.J., Peeters, W.H.M., Olde Venterink, H. (2002). Patterns in vegetation, hydrology, and nutrient availability in an undisturbed river floodplain in Poland. *Plant Ecology* 165:27-43.
- Zehm, A., Nobis, M., Schwabe, A. (2003). Multiparameter analysis of vertical vegetation structure based on digital image processing. *Flora* 198: 142-160.