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		
• Living with the human element • Getting along with others • Consensual	• Consensus mentality, local communities have a say • Focus on ecology • Dike raising is no option	• Space for the river combined with ecological restoration • Solutions for individual floodplain sections • Groyne lowering • Cyclic floodplain rejuvenation
ORANGE		
• Conquering the physical universe as to overcome needs • Oriented at technology and competition • Pragmatic	• Centralized authority • Cost-benefit analyses • Dike raising is a cheap option	• Dike raising • Groyne lowering • Removal of hydraulic bottlenecks • Removal of vegetation that obstructs flow • Removal of minor embankments • Retention areas
YELLOW		
• Restoring vision in a disordered world • Integrative	• 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	• 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.

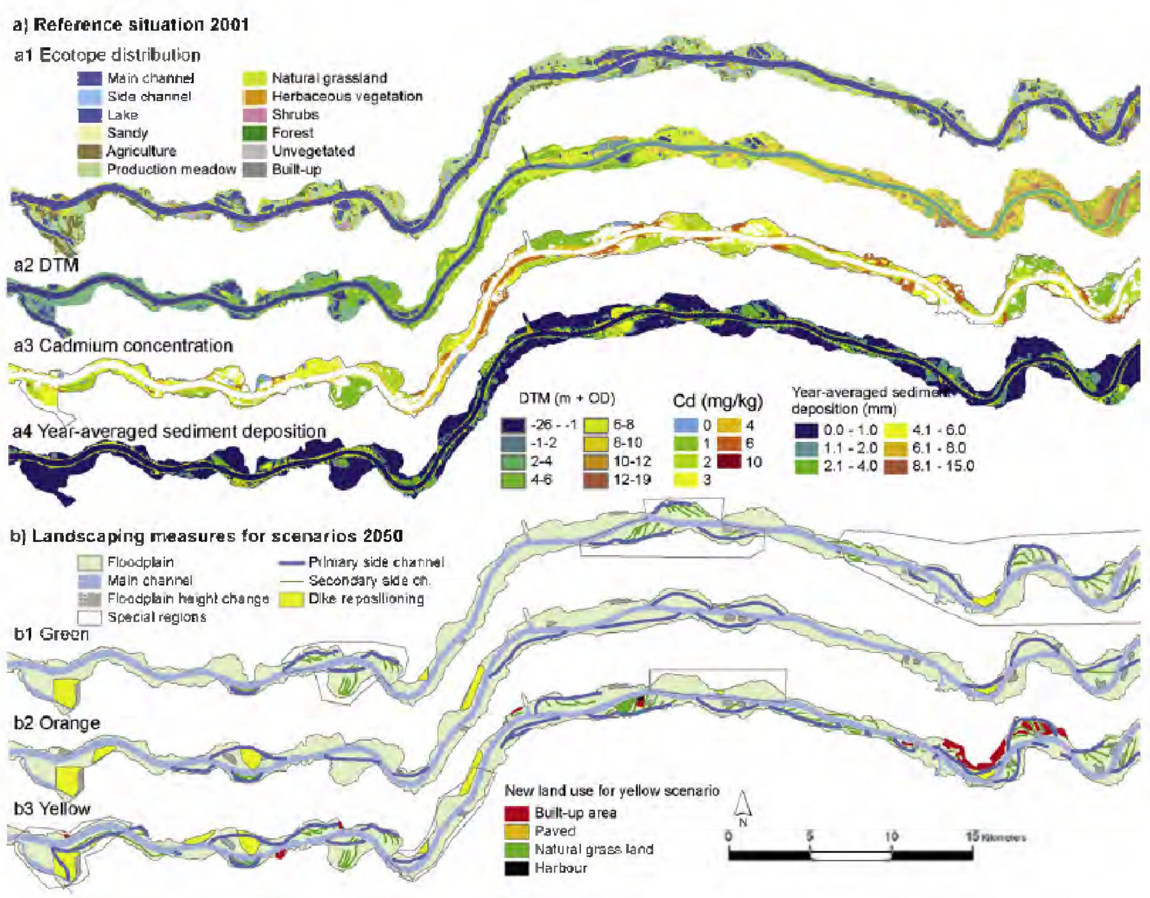

Fig. A-2.10: a) Reference situation of the study area: ecotope distribution, terrain heights, soil cadmium concentrations, and year-averaged deposition of suspended sediment. b) Landscaping measures (floodplain height change, dike repositioning and side channels) for the scenarios: green, orange and 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 2ºC 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 $m^3.s^{-1}$ to 17,000 $m^3.s^{-1}$ 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 (10^6kg/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

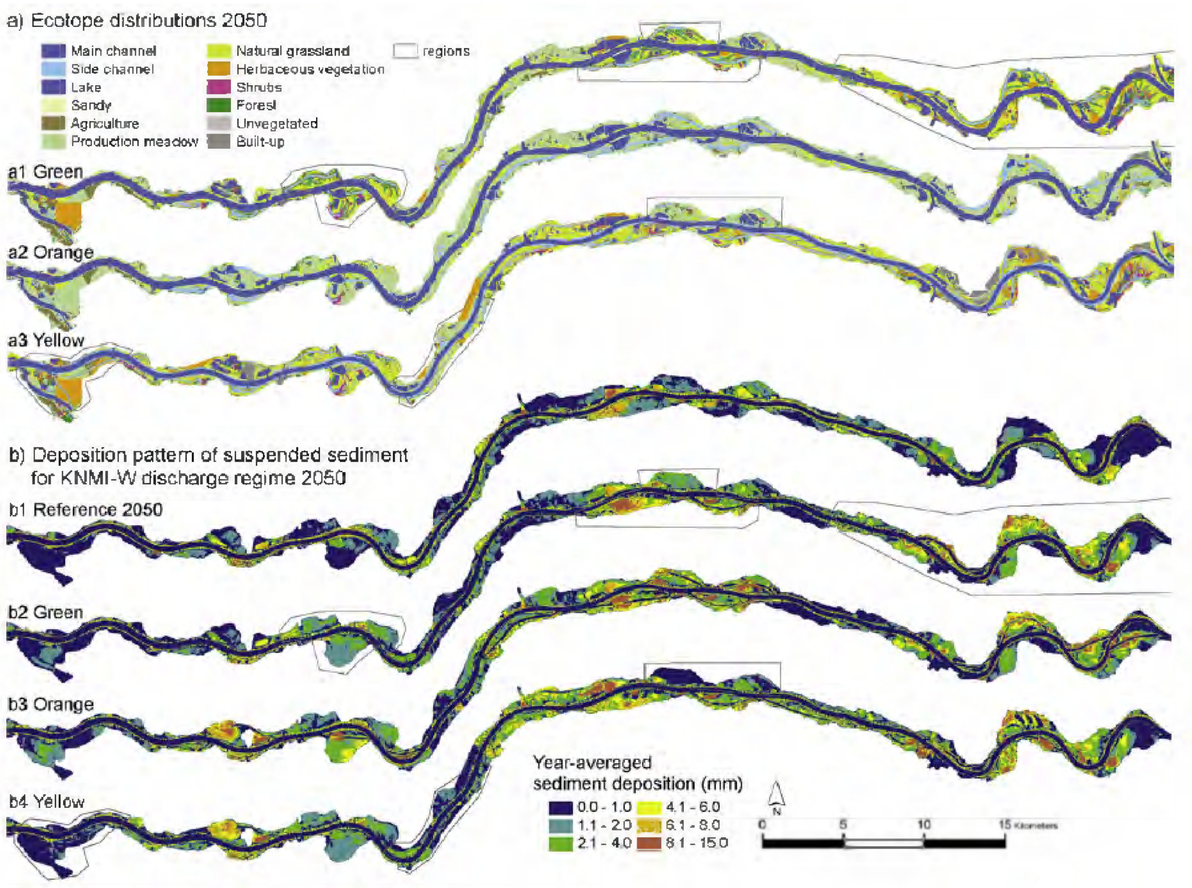

Fig. A-2.11: *a) Ecotope distribution for the scenarios, b) pattern of suspended sediment deposition in the Waal for the KNMI-W discharge regime.*

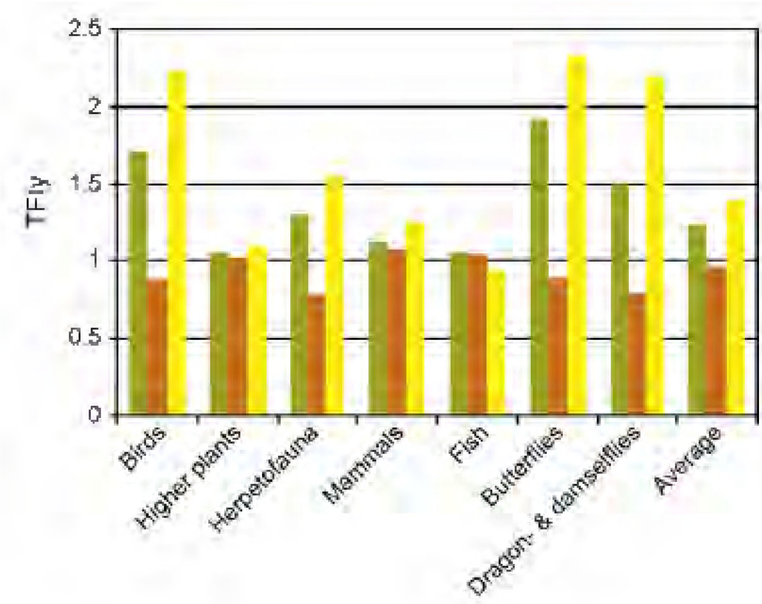

Fig. A-2.12: *Taxonomic group Floodplain Importance (TFI) scores for various taxonomic groups. Values are relative to the scores in the reference situation, hence all TFI scores for the reference situation would be one. Colors refer to scenarios.*

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 $m^3.s^{-1}$ 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 $m^3.s^{-1}$ 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.

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