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The Smart Rivers approach: Spatial quality in flood protection and floodplain restoration projects based on river DNA

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Abstract
Many river rehabilitation projects have been implemented in the past 30 years, strengthening the natural dynamics and ecology of river systems, while reconciling the functions of flood protection, navigation, sediment extraction, and cultural identity. Still, the planning and design of floodplain projects is subject to debate on how to best follow the "natural" characteristics of specific river stretches, the "DNA of the river." Unlike many other approaches of integrated river management, this approach entails a design strategy for spatial quality in river floodplain development projects at local and regional level, where the current discharge characteristics of the upstream river basin are taken as given. Starting point is the landscape ecological basis of the river, defining the characteristic (hydro-morphological) processes and geomorphological/geological structures in each stretch of the river and floodplain area. An in-depth characterization of these structures and processes helps design floodplains that can accommodate the various river management and development objectives. Often economically strong functions, like flood protection, can be partnered with weaker ones, such as ecosystem restoration. To safeguard spatial quality and sustainability in these integrated projects, the governance aspect is essential. Therefore the Smart Rivers approach addresses both substantial aspects (the "DNA of the River") as well as procedural and governance elements (called the "Quality Relay"). The principles of the approach are applicable to project design along regulated rivers in densely populated areas all over the world.

This article is categorized under:
Water and Life > Conservation, Management, and Awareness

KEYWORDS
floodplain design, flood protection, river management, river restoration, spatial quality

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1 | INTRODUCTION

1.1 | River rehabilitation along regulated rivers

A wealth of scientific approaches is available for integrated river management and comparable challenges, for example, in metropolitan areas (Gupta et al., 2016; van den Brandeler, Gupta, & Hordijk, 2019), in entire catchments ("integrated river basin management" (da Silva et al., 2020)), in relation to governance and participation (Garcia, Benages-Albert, Buchecker, & Vall-Casas, 2019; Giakoumis & Voulvoulis, 2018), or in relation to ecosystem services and nature-based solutions (Albert et al., 2019). This paper takes a narrower view, focusing on the spatial quality of rehabilitation opportunities of floodplain systems along regulated rivers, starting from the potential of the river ecosystem characteristics as they can be observed today (Schindler et al., 2016). Spatial quality in this context is an indicator of the characteristic coherence of patterns and processes in the landscape (see Section 1.2). This is relevant especially in areas with a large accumulation of investments into housing, industry, and infrastructure in flood prone areas such as the floodplains of the German Rhine (Schultze, Gellert, Koenzen, Riecker, & Rittner, 2019; Zingraff-Hamed, Greulich, Wantzen, & Pauleit, 2017), the Danube in Austria (Hein et al., 2016), and the Rhine and Meuse rivers in the Netherlands (Busscher, van den Brink, & Verweij, 2019), as well as of other big rivers such as the Yangtze in China (Halbe, Knüppe, Knieper, & Pahl-Wostl, 2018). The transformation of the floodplains along the Rhine and Meuse in the Netherlands is often considered a showcase of river rehabilitation in the international context of substantially changed river landscapes of strongly regulated rivers and cultivated floodplains (Straatsma, Bloecker, Lenders, Leuven, & Kleinhans, 2017; Verweij, 2017). Many projects have been realized in the past 30 years, strengthening the natural dynamics and ecology of the river system, while reconciling the functions of flood protection, navigation, agriculture, and cultural identity (Sijmons, Feddes, Luiten, & Bosch, 2017). Meanwhile, more than 12,000 ha of (more) natural habitats have been developed (of the total surface of ca 120,000 ha of submergible floodplains in the Netherlands), by redeveloping agricultural lands and restructuring clay, sand, or gravel extraction projects (Figure 1). In many cases floodplain projects have been realized to benefit flood protection, enhancing the river's discharge capacity. Secondary channels were created, and in some places natural point bars and riverbanks were allowed to develop through (re)widening of the river bed. As Figure 1 shows, this has led to substantial improvements of the ecology of the Dutch river systems (Peters & Kurstjens, 2012; Straatsma et al., 2017). Otter, beaver, spoonbill, osprey, salmon, and sturgeon are back, and species-rich river grasslands and floodplain forests are developing again.

This floodplain transformation is the result of a multidimensional activity in which project managers, engineers, (landscape) ecologists and architects, contractors, and many others collaborate to address a wide range of challenges and meet multiple objectives and boundary conditions. This requires a consistent and normative format to define the spatial quality goals, objectives and—ultimately—targets.

1.2 | Spatial quality

Although "spatial quality" as a concept lacks a clear and internationally accepted definition, it is a very useful concept to describe the inherent character and associated values of an area, in its typical patterns and processes. Introduced as a design concept in urban planning (Goethals (2007); Khan, Moulaert, Schreurs, and Miciukiewicz (2014)), it can be recognized in many river rehabilitation approaches described in the literature. Khan et al. (2014), for example, emphasize the good sense to combine the traditional control paradigm with an ecosystem-based paradigm combined with strong stakeholder involvement. As another example, the "biomic river restoration" approach has recently been introduced to overcome undue emphasis on engineering of hydro-morphological processes and instead incorporate the river ecosystem as a whole (Johnson et al., 2020). Such approaches go beyond the river basin management approach, as adopted also in the EU's Water Framework Directive (Giakoumis & Voulvoulis, 2018).

In the Dutch project environment (e.g., by review teams or experts) spatial quality is traditionally defined as the sum of three criteria/values: (a) functionality, (b) aesthetic value, and (c) durability/future value (Klijn, de Bruin, de Hoog, Jansen, & Sijmons, 2013). For complex systems such as floodplains this is insufficient, as local projects have deep impact on the (eco)system as a whole—and are even meant to do so. We therefore use (d) systemic value as a fourth, separate touchstone for spatial quality. Systemic value includes systemwide water management, naturalness of morphological and hydrological processes, landscape ecological integrity, and ecosystems effects beyond the project location. Moreover, we require the objectives in all four categories to be consolidated consistently and coherently to be regarded as a valid definition of integrated spatial quality in any given case. This requires a governance approach that transcends

FIGURE 1 Along the branches of Rhine and Meuse, almost 150 river restoration projects were realized since 1990, often as a coalition of flood protection and nature development. This approach has led to strong ecological recovery and increased spatial quality of the Dutch riverscape

sectoral and strictly local interests. It will only come about with balanced cross-sectoral partnerships and stakeholder collaboration (governmental and non-governmental organisations, and commercial parties alike) at all levels, as is also suggested by Fulgenzi, Brouwer, Baker, and Frijns (2020).

This paper gives an overview of pathways to spatial quality to be followed in a solution-oriented approach to floodplain restoration and flood protection, presented as the "Smart Rivers" approach. It can be understood as a dedicated elaboration of *Nature-based Solutions* for river rehabilitation (Albert et al., 2019).

2 | THE SMART RIVERS APPROACH

The Smart Rivers approach is based both on substantive content and on a sound procedure:

1. Substantive content requires (A) a thorough inventory and analysis to define the "DNA" of the specific stretch of the river including floodplains, translating it into area- or project-specific design concepts, as well as (B) a structured design method for designing "DNA-proof" projects, measures, or developments.
2. Sound procedure. To achieve a design realizing the project goals balanced with a high spatial quality, a sound procedure should be followed, from the first concept surveys and planning to realization and beyond (the "Quality Relay").

2.1 | Identifying the DNA of the river: Reading the river landscape

Recognizing and describing the DNA on a specific (stretch of the) river is a fundamental starting point for the Smart Rivers approach. This River DNA expresses itself in the underlying layer of the natural landscape, representing the abiotic characteristics, the geomorphology and the "natural processes" of a riverscape. Although not the only relevant layer of spatial quality, it is considered the most fundamental and important one for further design. If interventions misinterpret this layer, results are often definitive and irreversible. For example, excavating deep gravel or sand pits in a floodplain is in many cases not only detrimental for the natural and (eco)systemic qualities of the area, but also limits use and economic value for future generations.

The River DNA can be identified by reading and interpreting the landscape, especially the underlying geomorphological and historic-morphological features, as well as hydro-morphological and other natural processes, thus emphasizing a modern concept of Design-with-Nature (Bryant & Turner, 2019). For this, historical and recent topographical maps, elevation data and (field) data on critical aspects like river discharge characteristics, soil quality, groundwater, and morphological dynamics, may reveal the "true nature" of today's river. Essential in establishing the River DNA is also the analysis of which landscape ecological processes (erosion, sedimentation, flooding, groundwater flows) are still present or can be revitalized. This exercise is not so much about going back in time and recreating "a river as it may have existed long ago," but rather about properly understanding the actual river system, recognizing which processes and features can still be restored to fit the current river system. Often (ideally) this will lead to design concepts that are close to historical structures and process restoration, but in some cases river stretches have been altered so strongly that they gained (partly) a new DNA, no longer corresponding to the historical maps or narratives. This is for example the case in impounded river sections, where the dynamics of flowing water and fluctuating water levels have been replaced by those of a more muted wetland. We can find examples of such altered characteristics not only along the Dutch Lower Meuse and Rhine, but also along the Hungarian Middle Tisza (Lake Tisza), parts of the river Danube, the British river Thames, and the German Upper Rhine (Gibbard, 2020; Halbe et al., 2018; Lóczy, Dezső, & Ronczyk, 2016). By sometimes accepting irreversible systemic changes as part of the new DNA of a river system, the Smart Rivers approach touches on the idea of "novel ecosystems" (and hybrid ones), that gained traction in the last 15 years (Hobbs et al., 2014; Teixeira & Fernandes, 2020; Tockner, Pusch, Gessner, & Wolter, 2011).

The DNA of individual rivers and river stretches may be completely different, thus reflecting the landscape ecological differentiation that is connected to the "*Genius of the Place*" (in accordance with Alexander Pope's "translation" of the classical Roman *Genius Loci* to put forward the general objective of landscape planning and landscape architecture (Helmer, Litjens, and Overmars (1995); Overmars (2020)). To prevent detrimental effects as mentioned above, this notion of local and regional differentiation of (natural) processes and characteristics is crucial for actual site-specific design and the realization of successful river restoration projects. Two examples along different river stretches in the Netherlands illustrate this.

2.1.1 | Example Waal

The river Waal, the most important Rhine branch in the Netherlands, is a large, sandy lowland river. Although nowadays it is fully regulated and narrowed by dikes (embankments up to 8 m high), its underlying character is one of large, free flowing channels, sandy (point) bars, and natural sandy levees. The structure of old side channels, displacing through time is still recognizable in the underground and the current (geo)morphology. This typical characteristic is being used in ecological restoration as well as flood protection projects: by "peeling away" the old layer (hundreds of years) of accumulated silt and clay, following the boundary of underlying sand deposits, the natural, sandy landscape and braided channel structures can be revealed and revitalized (Figure 2). Side channels can connect to the main river and add new habitat for fish and other (semi-)aquatic life, away from the busy navigation channel. A more deliberate extraction of clay and in some case gravel and sand in this way has enabled many Dutch river restoration projects.

The floodplain near Gameren is one of the sites along the Rhine in the Netherlands where side channels were rehabilitated. It led to a strong ecological recovery, at the same time reactivating critical processes of sand sedimentation, flowing water, and the spontaneous establishment of riparian forests in the floodplain. By extracting the clay in the form of new side channels, discharge capacity grew, lowering peak flood levels with around 9 cm, thus substantially improving flood safety for several 100 thousands of inhabitants behind the dike. Moreover, for the local community and economy, "Gameren" has become a valuable recreational area and nature reserve.

Obviously there are limits to depth and width of these channels and to floodplain lowering in general. By using the "DNA of the river" as a quality criterium, one can prevent overdimensioning of interventions and give direction to extraction concessions complying with the landscape-ecological and spatial quality of a project.

2.1.2 | Example Meuse

About 25 km to the south of the Waal, the Meuse river reflects a completely different DNA. Here we find a narrow, singular channel bed that, through tectonic elevation of the surrounding land, continuously deepened and incised itself. As a result, the river formed a geological landscape of staged river terraces (the "Terrace Meuse"). Old side channels and swales are still recognizable, but are positioned (far) above current mean water levels of the river, thus devoid from river water during a regular discharge situation. Instead, these fossil flow channels drain groundwater from even higher positioned terraces. Supported by this clear seepage water, they host potentially rich ecological communities, that vastly differ from those in the side channels of the river Waal described above. Following the Smart Rivers approach, the design concept for floodplain interventions differs from the one along the Waal as well.

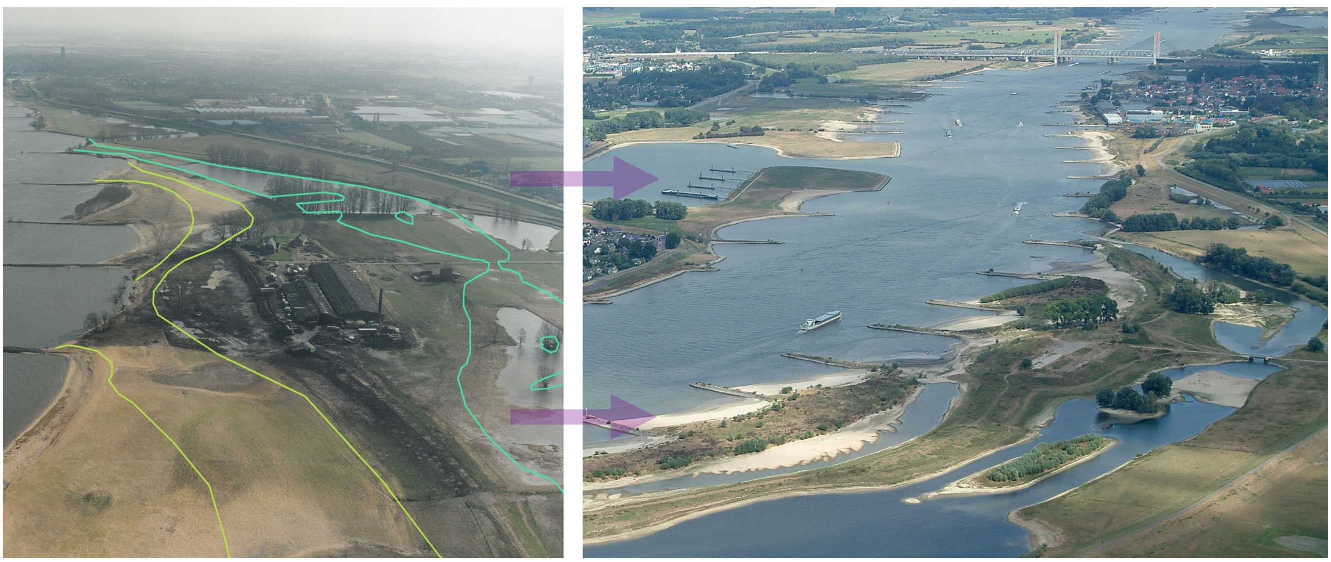

FIGURE 2 The design of several side channels in the floodplain of Gameren (location see Figure 1), along the navigation channel of the Waal branch of the river Rhine in the Netherlands. On the left the original situation, with an old brick factory, agricultural use, and several old clay mining pits in 1994. On the right the situation in 2003, 4 years after the reconstruction in 1999. Old excavations have been made part of the new side channel (Photo's: Rijkswaterstaat Oost-Nederland & RWS-Beeldbank/Joop van Houdt)

Therefore, in the "Ooijen-Wanssum project" (location see Figure 1) in this section of the Meuse a more dual approach was defined. Here, much smaller channels were excavated, following the old geology of shallows, swales, and terrace edges. Instead of large river-water-dominated channels, the project realized shallow groundwater-fed habitats that fit the local river system and geomorphology. But although these more DNA-proof interventions contributed substantially to flood level lowering (35 cm), this was not enough to meet the national flood safety standards in the Netherlands. To achieve these just by floodplain widening, one would have to lower complete terraces, thus destroying this valuable landscape and its unique character. Consequently, river widening (by clay and loam extraction) was combined with the construction of new and better local dikes that had to be upgraded anyway. The clay and loam from the excavations provided material to build innovative "terrace edge dikes," which more or less form a natural terrace. These new dikes deliver additional flood safety, but also fit the geomorphological DNA of the area better than the classical river dikes of lowland Holland (Figure 3).

So, rather than maximizing water level effects through floodplain widening far beyond the river's DNA, reaching adequate flood protection through the construction of smart new dikes turned out to be a more elegant and sustainable solution for this river stretch.

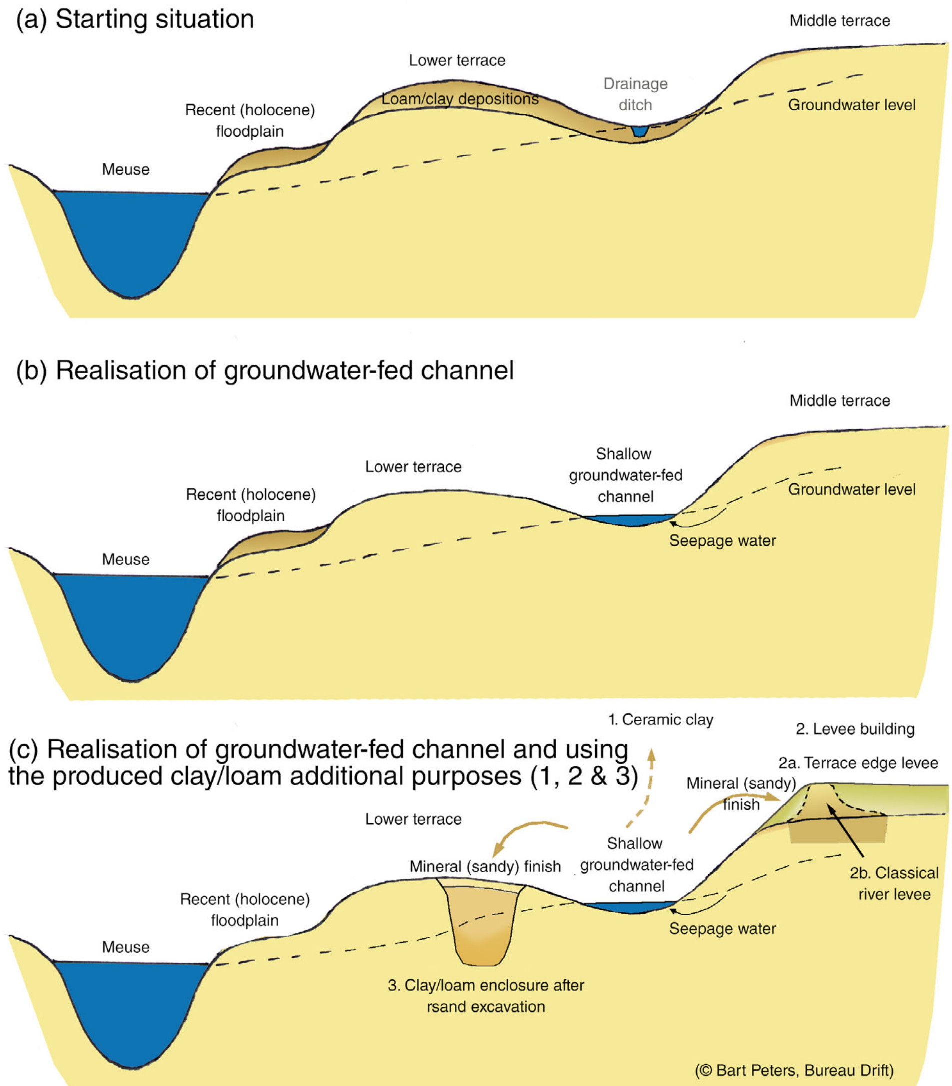

FIGURE 3 The design concept for DNA-proof groundwater-fed channels along the Terrace Meuse. Because of the positioning and dimensions these small side channels only contribute very limited to a higher discharge capacity on the river. But dug up material (clay and loam) can be used to build new ring dikes around local villages as well as more innovative "terrace edge dikes," thus contributing to flood safety as well as nature development (Peters, 2019)

2.2 | Design method

The Smart Rivers approach also represents a design method, built upon landscape and system characteristics of a river floodplain. Figure 4 shows a layered design concept for (river) projects, starting with the definition of the appropriate landscape(−ecological) fundaments. This includes a thorough landscape-ecological analysis on the basis of elevation maps, historical maps, flood frequencies and flood level data, groundwater and soil data (e.g., sand layer depths), and many more terrain aspects that determine the local DNA of an area or river stretch (Van der Molen, Baaijens, Grootjans, and Jansen (2011)). Subsequently a design is further detailed on (landscape) ecological key factors, species requirements, and spatial quality. Building up a design like this, as a non-negotiable sequence of steps from a high abstraction level (landscape scale) toward a very detailed level (local values) (Figure 4), is essential to safeguard spatial quality as discussed in the next section.

One of the pitfalls in many restoration projects is starting high up in the "design triangle," for example, if project goals are solely built around "species goals" derived from the European Commission's Water Framework or Habitat Directives or ecological mitigation measures in large spatial projects. The Dutch floodplains are littered with examples, where an initiator (with good intentions) wanted to improve conditions for individual species, like beaver, crested newt, or specific river fish, but without a system-based design underlayer. In many cases this led to illogical or even damaging excavation initiatives (specifically on a landscape scale), introducing alien waterbodies or removing valuable geomorphological structures. In other cases the end result was disappointing because the processes needed for specific habitat development (e.g., flowing water for rheophilic fish, or dynamic sandy soils for a specific flora) where simply not/no longer at hand or restorable (Stoffers et al., 2020).

In practice the spatial quality of floodplain designs is always influenced by pragmatic limitations (available budgets, land property rights, planning policy, navigation requirements, etc.). The Smart Rivers approach also helps to decide on second best options, thus improving the quality of the overall planning and design process. It helps to decide were quality concessions, like deeper channel excavation or more floodplain lowering, are least damaging or how they can be minimized (e.g., in terms of affected area, hydrological effects or expected vegetation development). In some cases a designer can compensate quality concessions through added value, for example if a limited expansion of the excavation depth leads to an opportunity to access (ecologically favorable) mineral and sandy soils, instead of clay layers.

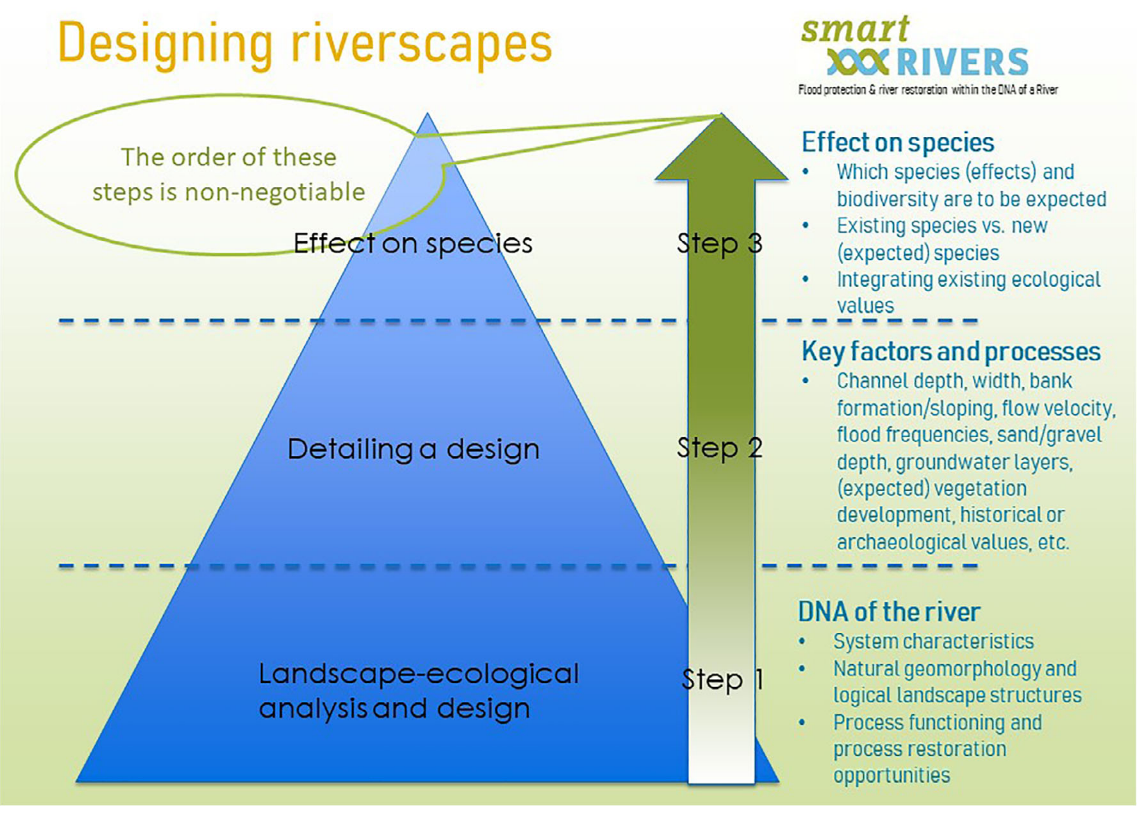

FIGURE 4 The triangle of spatial quality in designing riverscapes: Schematic picture of a design process in river restoration projects, starting at the base with landscape-ecological analysis and design, and working toward an increasing level of (local) detail

2.3 | Safeguarding spatial quality in river projects: The quality relay

While realizing river rehabilitation programs, the implementation projects generally start out with high ambitions and a sound design concept integrating the various interests and objectives. However, when these expectations are not managed in a transparent way during the entire planning process (and translated into budgets and mandate early on), projects can still leave an unsatisfying end result (Angelopoulos, Cowx, & Buijse, 2017; van den Brandeler et al., 2019). Therefore the Smart Rivers approach is not just based on fundamental physical knowledge and insights, but also includes a strict quality management procedure, which we call the "Quality Relay" (Van den Herik, 2015).

The Quality Relay addresses the problem that floodplain projects are characterized by long duration (up to 20 years between concept and transfer to long term management and maintenance) and frequent shifts in staff functions and roles. Traditional project management tools are too phase specific and output oriented to sufficiently safeguard the required spatial quality. "The Top 7 Properties of Successful Projects" (Figure 5) have been defined as part of the Smart Rivers approach to secure spatial quality objectives. They require a fully realized definition of spatial quality as described in Section 1.2, and rely on proper organization of staff roles, decision-making, and business rules. These seven properties provide a systematic approach for long-term quality control in integrated and multistakeholder floodplain projects, challenging decision makers, designers, planners, and project managers to integrate and coordinate across organizational, sectoral, and disciplinary boundaries (Beechler, Søndergaard, Miller, & Bird, 2004; Van den Herik, 2015).

3 | CONCLUSION: TOWARDS AN INTEGRATED DESIGN APPROACH

The Smart Rivers approach was developed from the rich and successful Dutch practice on river restoration and floodplain development (De Bruin et al., 1987; Peters, Overmars, Kurstjens, & Rademakers, 2014; Sijmons et al., 2017). Rather than focusing on entire river basins, the idea of establishing the local "DNA of the river" as a starting point for

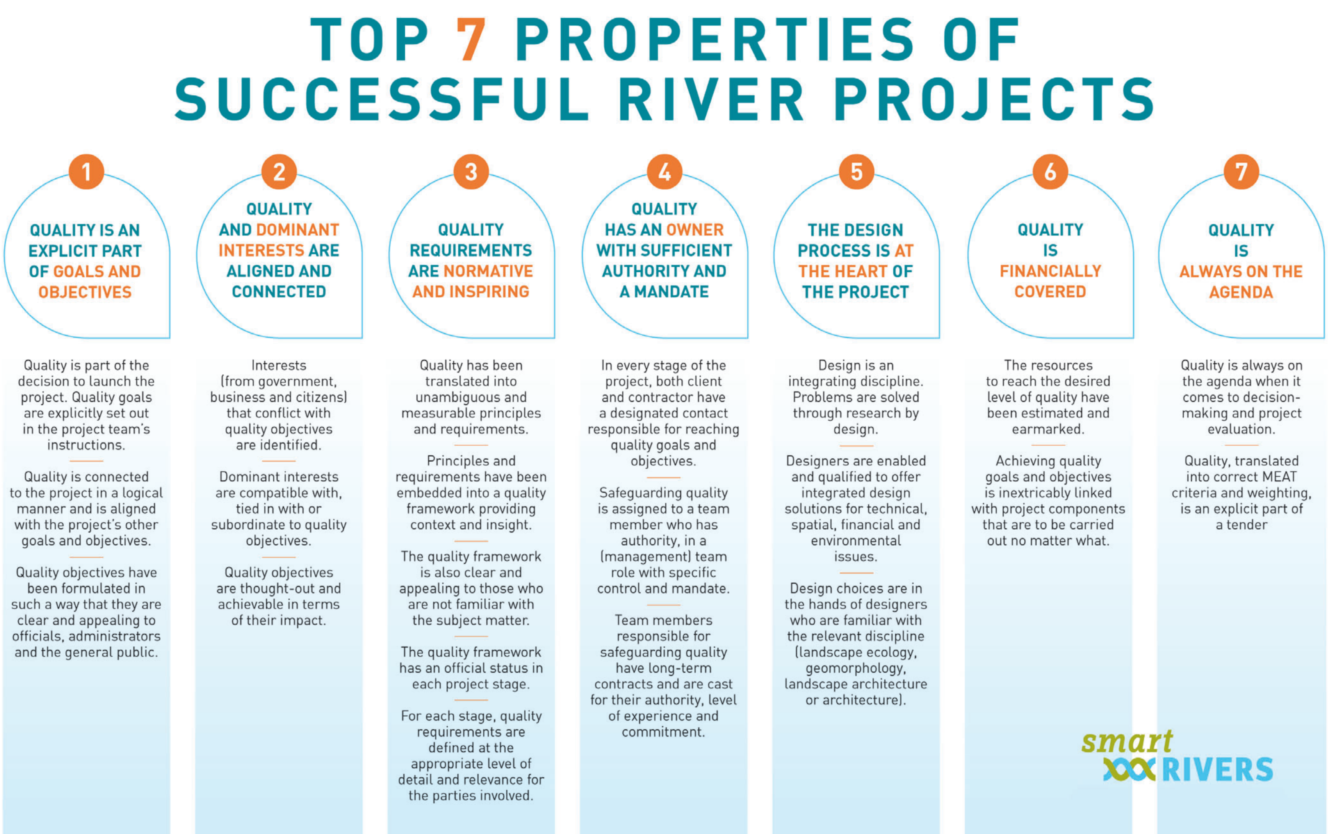

FIGURE 5 The Quality Relay: seven properties for successful river rehabilitation projects (Van den Herik, 2015)

integrated planning, design, and management proved to be fundamental to add more value to regulated rivers, and as such is complementary to the Integrated River Basin Management approach (Rijke, van Herk, Zevenbergen, and Ashley (2012)). Detailed ecological and morphological approaches can provide essential inputs, such as Ecosystem Services Assessment (Albert et al., 2016; Halbe et al., 2018) and dedicated morphological studies (Schultze et al., 2019), besides proper participatory methodology (Garcia et al., 2019). An array of “tools” and close cooperation between many experts and shareholders thus should add to fruitful results. The combination of understanding the physical landscape and processes (River DNA, that is, river flow, morphological processes, species development, etc.) *and* procedural aspects in the “Quality Relay” are fundamental cornerstones of the Smart Rivers approach.

Though best practices in the field underpin the Smart Rivers approach (Figure 1), further research is necessary to build a flexible but reliable set of tools and procedures. Adaptation and transmission to other (bio)geographical regions and other planning and management cultures require thorough and systematic methods. In several river management programs and projects, further applications of the Smart Rivers approach are currently being realized, adding up to the development of innovative methods and applications. Provided there is a sound political and societal ambition to improve spatial quality, the Smart Rivers approach, thanks to its clear principles—the DNA of the River, the layered design approach, and the Quality Relay—, is applicable to regulated rivers in numerous countries.

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AUTHOR CONTRIBUTIONS

Bart Peters: Conceptualization; formal analysis; funding acquisition; methodology; visualization; writing-original draft; writing-review and editing. **Michaël van Buuren:** Conceptualization; methodology; visualization; writing-original draft; writing-review and editing. **Keesjan van der Herik:** Conceptualization; methodology; visualization; writing-original draft. **Martijn Daalder:** Conceptualization; methodology; writing-original draft. **Barbara Tempels:** Conceptualization; methodology; writing-original draft. **Jeroen Rijke:** Conceptualization; methodology; writing-original draft. **Bas Pedroli:** Conceptualization; investigation; methodology; writing-original draft; writing-review and editing.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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