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Societal drivers for the integration of hydrogeomorphology and human benefits in river restoration projects

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Abstract

Integrating hydrogeomorphological (HGM) principles into the restoration of degraded rivers can achieve sustainable results and provide various human benefits. HGM principles mainly involve understanding the context and processes that shape a fluvial system before any intervention, in order to support its dynamism and to align with its potential functioning and uses. Despite recent management approaches inspired by HGM principles, most restoration projects carried out in Quebec (Canada) are not process-based and target specific one-dimensional objectives. Although there is an overall lack of post-project monitoring, several projects appear to have failed or had mixed success. This research aims to shed light on the diversity of societal drivers behind river restoration projects and to examine how they influence the integration of HGM principles and human benefits. Four restoration projects were characterized through participant observation and interviews with the organizations running them. Representatives of two ministries involved in river restoration and management were also interviewed. The results show that projects were mainly shaped by public acceptance disregarding HGM principles, which can lead to poorly-informed action. Project funding and stakeholders' expertise have also challenged project implementation and played a key role in defining their objectives. The addition of these components improve the current analytical frameworks for identifying river restoration objectives. Depending on specific sociocultural, political and legislative contexts, funding programs and stakeholders' expertise may either facilitate or restrict the integration of HGM principles and human benefits in the projects. Recognizing these key drivers reframes river restoration as a fundamentally social activity and enlightens how they could impel innovative approaches towards more sustainable results.

KEYWORDS
decision-making, human benefits, hydrogeomorphology, management, project planning, river restoration, sociogeomorphology

1 | INTRODUCTION

In the wake of the significant degradation observed in fluvial systems, river restoration has emerged and evolved since the 1970s to become a scientific discipline as well as an "essentially contested concept" (Cottet et al., 2022; Friberg et al., 2016; Wohl et al., 2015). Since it is largely accepted that returning to previous conditions based on a historic reference is both unrealistic nor desirable (Dufour & Piégay, 2009), restoration now embraces any human intervention on rivers aimed at "recovering a quality considered degraded or lost" (Cottet et al., 2022, p. 6). This may involve improving hydrogeomorphological (HGM) dynamics, biodiversity, water quality, aesthetics, heritage enhancement, etc. as well as rehabilitating ecosystem functions and several human activities that depend on this ecosystem (water resources, transport, recreation and tourism, etc.) (Auerbach et al., 2014; Cottet et al., 2022; Friberg et al., 2016; Gilvear et al., 2013; Larocque & Biron, 2022; Wohl et al., 2015). Following the view of Ashmore (2015) on sociogeomorphology, river restoration thus represents a social activity interacting with biophysical processes in the coproduction and the coevolution of river systems. Those systems are therefore considered "socio-natures" (Swyngedouw, 1999) or "hybrid" rivers (Ashmore, 2015; Lespez & Dufour, 2021).

Evidence-based approaches in river restoration are recognized to enhance the sustainability of project outcomes (Friberg et al., 2016). In particular, integrating HGM principles, that is acknowledging the fundamentally dynamic behaviour of rivers instead of focusing on static historic references, can achieve sustainable results and provide various human benefits (Beechie et al., 2010; Brierley & Fryirs, 2022; García et al., 2021; Piégay et al., 2023). Firstly, hydrogeomorphology allows a better preliminary understanding of a river system, its trajectory and its degradation (Brierley & Fryirs, 2016; Fryirs, 2015; Fryirs & Brierley, 2016; Grabowski et al., 2014; Mould & Fryirs, 2018). Secondly, that understanding guides an evaluation of the river's restoration potential, to frame which uses and human benefits are reasonable to expect in the system, and which are not (Auerbach et al., 2014; Gilvear et al., 2013; Serra-Llobet et al., 2022). Finally, it is crucial for monitoring the results and repercussions of a project (Fryirs et al., 2018).

Dufour and Piégay (2009) conceptualized river restoration inputs combining society's wishes with potential functioning boundaries (Figure 1). Society's wishes depicts what a community prioritizes in terms of human benefits, identified in relation to motivations. As the expectations of heterogeneous stakeholders and other members of the community are based on various rationales, this process must be supported by sustained social participation (Dufour & Piégay, 2009). It also implies potentially conflicting dynamics of deliberation, negotiation and reframing between stakeholders, shaping their values, interests and priorities towards a consensus (Anquetil et al., 2018; Emery et al., 2013; Failing et al., 2013). Potential functioning boundaries represent the range of conditions that are physically possible to reach in the river system in terms of processes and anticipated evolution, based on its historical trajectory and functional reference sites (Dufour & Piégay, 2009). Framing society's wishes into potential

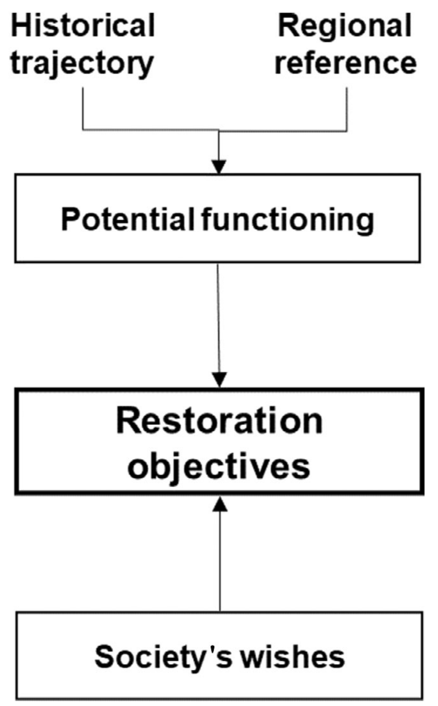

FIGURE 1 Framework to define objectives for river restoration projects (adapted from Dufour & Piégay, 2009).

HGM functioning would lead to more complex river systems providing more diverse human benefits that are coherent with their sociogeomorphological context. Several management approaches inspired by these principles have recently appeared, namely freedom space for rivers (Biron et al., 2014; Buffin-Bélanger et al., 2015), process-based restoration (Beechie et al., 2010; Brierley & Fryirs, 2022, 2009; Kondolf et al., 2006), social-ecological restoration (Dufour & Piégay, 2009; Fernández-Manjarrés et al., 2018; Maniraho et al., 2023), human-river relational restoration (Brierley, 2020; Hikuroa et al., 2022; Mould et al., 2018; Wantzen, 2024), etc.

In the province of Quebec (Canada), approaches inspired by hydrogeomorphology and human benefits have yet to be adequately considered in river management directions and practices (Biron et al., 2018; Paradis & Biron, 2017), despite their global recognition. The province's river management regulation is based since 2017 on market-based approaches, offsetting degradation to reach zero net loss at the territorial scale (Jacob, 2022). This approach is similar to that of river management in the United States, but quite different from the European approach. Indeed, there is no obligation in Quebec to improve the ecological status and quality of aquatic systems, as is the case in Europe (Bouleau & Pont, 2015; Drapier et al., 2018; Jacob, 2022). Compared to these two other contexts, little attention is paid in Quebec to hydrological, sedimentary or ecological continuity, and even less to the removal of human infrastructures (Biron et al., 2018; Drapier et al., 2018). Rather than focusing on multiple benefits, most of the projects carried out in the province target specific one-dimensional objectives that are often associated with the habitat of a few high-valued fish species, stable channels and river aesthetics (Biron et al., 2018). Many of them explicitly exclude HGM principles and involve controlling river processes and morphology with "stream cleaning" and engineering works (Biron et al., 2018), generally leading to further artificialization and degradation. Because of the inconsistency between river dynamics and created or stabilized morphology, many of these restoration structures are also quickly eroded or dismantled (Baril et al., 2019; Gariépy-Girouard et al., 2023).

The above observations suggest that a wider variety of drivers lead to the implementation of projects aiming at "restoring" rivers. In other words, drivers other than society's wishes or potential HGM functioning, the two key components identified by Dufour and Piégay (2009), may influence the ways stakeholders deal with decisions, and thus shape river restoration practice in Quebec. However, current frameworks focus on decision-making components as tools to achieve project goals instead of drivers shaping them (e.g. Angelopoulos et al., 2017; Dufour & Piégay, 2009; Failing et al., 2013; Harman et al., 2012; Hawley, 2018; McDonald et al., 2004). Most of the frameworks also identify intrinsic and extrinsic social components directing restoration problems and strategies, without clearly conceptualizing how they contribute to decision-making processes. This research aims to shed light on the diversity of drivers behind river restoration projects and to examine how they influence the integration of HGM principles and human benefits. These are addressed through the analysis of four projects, with the aim to (1) characterize their structure and decision-making processes, (2) evaluate their level of integration of HGM principles and diverse human benefits, and (3) identify challenges experienced by the organizations leading them. Based on this analysis, we suggest adjustments and improvements to existing analytical frameworks to promote comprehensive decision-making in river restoration.

2 | METHODOLOGY

2.1 | Studied sites, projects, and participants

Four river restoration projects (Figure 2) were selected according to criteria of diversity, information accessibility (since there is no national database for river restoration projects), and stakeholders' interest to take part in the research. All sites except Canal Saint-Georges (CSG) are located in hydrographic regions that are overseen by *Watershed Agencies* (OBV), which carry out many river restoration projects in the province. The site selection was based primarily on a case study approach, aimed at identifying specific elements that are missing from current frameworks for defining river restoration objectives and opening up an exploratory discussion on the subject, rather than generalizing the findings (Yin, 2017). The projects were initially monitored as part of a qualitative research process through participant observation. In two cases (CSG and Rivière Centrale (RC)), authors of this paper were directly involved in the projects as specialists in hydrogeomorphology. A hydrogeomorphogy research team who did not contribute to this paper also supported the two other projects. The authors' involvement in the projects was central to the data collection process, giving them a privileged position from which to observe the dynamics of project management and their outcomes.

The sites are located in contrasted geographical contexts (Table 1). Three are in urban and suburban environments, with only RC in agricultural surroundings. This may represent a bias, as river restoration projects carried out in Quebec are mostly located in agricultural areas. RC is also the only one to be considered a small stream (watershed area ≤50 km^2, Strahler order ≤3). However, CSG is also fairly small whereas Rivière à Mars (RAM) and Rivière Les Escoumins (RLE) are medium-sized (Strahler order between 4 and 6). The selected projects originate mainly from observed or documented issues related to anthropogenic infrastructures' degradation, farmland erosion, fish population decrease, and sedimentary disconnection caused by emergency bank stabilization. Their objectives are systematically ecological, with a few side objectives (e.g. public safety, water quality, HGM processes, and recreational uses). The resulting interventions vary and may consist in habitats and riparian buffers development, farming practices adaptation and different approaches to anthropogenic infrastructures management, from their restoration to their removal. The RAM project was entirely based on the development of a *Living Lab* approach, with the aim of determining public acceptance of the objectives and actions planned. As the projects are at different levels of advancement, some do not have budgets yet. This may be a potential bias for this study, as stakeholders at the planning stage may not have faced challenges that stakeholders in completed projects have.

The stakeholders have different backgrounds and scopes, but they are all territorial and environmental management organizations. First, OBV and *Coastal Zones Agencies* (ZIP) are both non-profit organizations. Their mandates mainly involve promoting concerted action between the main users of the environment to resolve local and regional ecosystem problems, in delegated watersheds in the case of the former, and around specific areas of the St-Lawrence River in the case of the latter. Second, the *Regional County Municipalities* (MRC) are supra-local territorial administrative organizations that assume, among other things, legal responsibility for the management and maintenance of streams, excluding, however, their restoration. Third, *Contact Nature Rivière-à-Mars* (CN) is a non-profit organization responsible for managing a *Controlled Exploitation Zone* (ZEC), including hunting, fishing and wildlife management, fauna conservation, and facilitating access to outdoor activities on public land for users. Finally, an important similarity between the stakeholders is that all had at least the intention of integrating hydrogeomorphology into their project teams (mainly with ecology and engineering), by working with university research teams in this discipline. This could create a bias in this study by overestimating the overall level of integration of HGM principles in river restoration projects in Quebec. However, the main objective of this paper is not to paint a picture of the overall situation in the province. It focuses on the diversity of drivers behind the identification of river restoration objectives. Once again, the limited number and heterogeneity of the projects and participants studied gives the research a rather exploratory character, whose conclusions must be treated with caution.

FIGURE 2 (a) Water management areas overseen by OBVs in Quebec (dark gray areas delineated with white lines), location of the projects studied (black triangles) and pictures of the sites (b) RAM: Rivière à Mars; (c) RLE: Rivière Les Escoumins; (d) RC: Rivière Centrale; (e) CSG: Canal Saint-Georges. [Color figure can be viewed at wileyonlinelibrary.com]

2.2 | Interviews and analysis

Interviews were carried out with each project stakeholder(s), because of their central role in the management and direction of documented projects (ethics approval CER-119-936 from *Université du Québec à Rimouski*). Although decision-making involves many other participants, the stakeholders' position has above all enabled them to observe and steer the mechanisms underlying these processes, and to fully experience the challenges that this research aims to uncover. The first author moderated all the interviews based on an open-ended interview guide (see supporting information) and were carried out by videoconference during winter 2022. Since each organization had different numbers of participants and their projects had diverse levels of advancement, interview duration varied between one and 2 h. The main topics addressed during the interviews were (1) the project operational structures and decision-making processes for the formulation of their restoration objectives, (2) their level of integration of HGM principles and diverse human benefits and the mechanisms for integrating them, and (3) the challenges experienced by the organizations during the project implementation. In addition, two ministries' representatives involved in river restoration and management (*Environment, Fight Against Climate Change, Fauna, and Parks*, MELCCFP, and *Transportation and Sustainable Mobility*, MTQ) were interviewed to connect governmental directions with stakeholders' views and experiences, but results were not analyzed according to the affiliation of the participants. All seven interviews (with 10 participants) were transcribed, and their content was analysed using *NVivo* software and an open-ended analysis grid accounting for the frequency of mention of each code by each project stakeholder(s). The analysis grid was consistent with

TABLE 1 General settings of the four study sites and information about the restoration projects carried out on each site.

	Canal Saint-Georges (CSG)	Rivière Centrale (RC)	Rivière les Escoumins (RLE)	Rivière à Mars (RAM)
Location	Port-Menier, Anticosti Island	Saint-Simon-de-Rimouski	Les Escoumins	La Baie, Saguenay
Context and origins	• Suburban • Anthropogenic waterway • Infrastructures' degradation	• Agricultural • Regressive erosion • Farming equipment crossing	• Suburban • Emergency infrastructure removal (2013) • Fish population decrease	• Urban • Emergency bank stabilization (1996) • Sedimentary disconnection
Watershed area (km^2)	64	44	798	664
Strahler number	3	2	5	6
Level of advancement	• Completed • 2019–2022	• In progress • 2013 - […]	• Planning • 2020 - […]	• Planning • 2018 - […]
Budget ~ (CAD)	$600,000	$500,000	-	-
Objectives	• Ecological habitats • Public safety	• Water quality • Ecological habitats • Public safety	• Ecological habitats • HGM processes • Recreational uses	• Ecological habitats • HGM processes
Interventions	• Weir restoration • Habitats development	• Farming practices • Riparian buffer and vegetalization • Crossing structures development	• HGM processes restoration • Bank stabilization removal • Meander reconnexion	• HGM processes restoration • Bank stabilization removal • *Living Lab* development
Interviewed stakeholders (number of participants)	• ZIPCNG – Comité ZIP Côte-Nord-du-Golfe (2)	• MRCB – MRC des Basques (2) • OBVNEBSL – OBV du Nord-Est-du-Bas-St-Laurent (2)	• OBVHCN – OBV de la Haute-Côte-Nord (1)	• CN – Contact Nature Rivière-à-Mars (1)

the interview guide (see supporting information), and their themes and codes are shown in Tables 2 and 3.

To facilitate the discussion around the second topic, a conceptual diagram (see Figure 4a) was used to illustrate the level of integration of the different components (HGM principles, human benefits, stakeholders' expertise, and project funding) of each project according to the participants. Stakeholders could thus represent the structure and the level of integration of the three components into their projects by adapting the diagram themselves, the size and the relative position of each circle representing the importance of the corresponding component, and their layout representing their level of integration. Finally, *Gephi* software was used to achieve a social network analysis (Bastian et al., 2009; Chignell, 2023), visualize the structure of the projects, and characterize the various relation types between all the organizations involved (collaboration, funding, mandate, recommendation, information, planning). Relational data used to build the sociogram come directly from the interviews, as the participants openly stated relationships between organizations and detailed their nature. The *ForceAtlas2* spatialization algorithm was used to group the natural communities present in the data, based on the betweenness centrality of the nodes (frequency of a node cutting shortest paths between nodes in the network) and the density of the relationships (number of links out of the total potential number) (Jacomy et al., 2014).

3 | RESULTS

3.1 | Project structure

The social network analysis (Figure 3) shows the individual entity of the four projects, as well as their interconnection. Most of the organizations are indeed involved in just one of the projects, particularly the territorial management bodies, which are rooted in local contexts, and, surprisingly given the geographical proximity of the case studied, consulting firms. The latter consist of many small local agencies, with the exception of two larger ones (AECOM and BPR, which is no longer active). This reveals close, almost personal relationships between them and stakeholders, who often call on consultants and specialists with whom they are used to working:

> "We already worked together many times, that makes our collaboration easier!"
>
> (translated from P08).

Some funding agencies and academic research teams seem to be involved at a more global level. The latter is probably explained by the scarcity of their expertise:

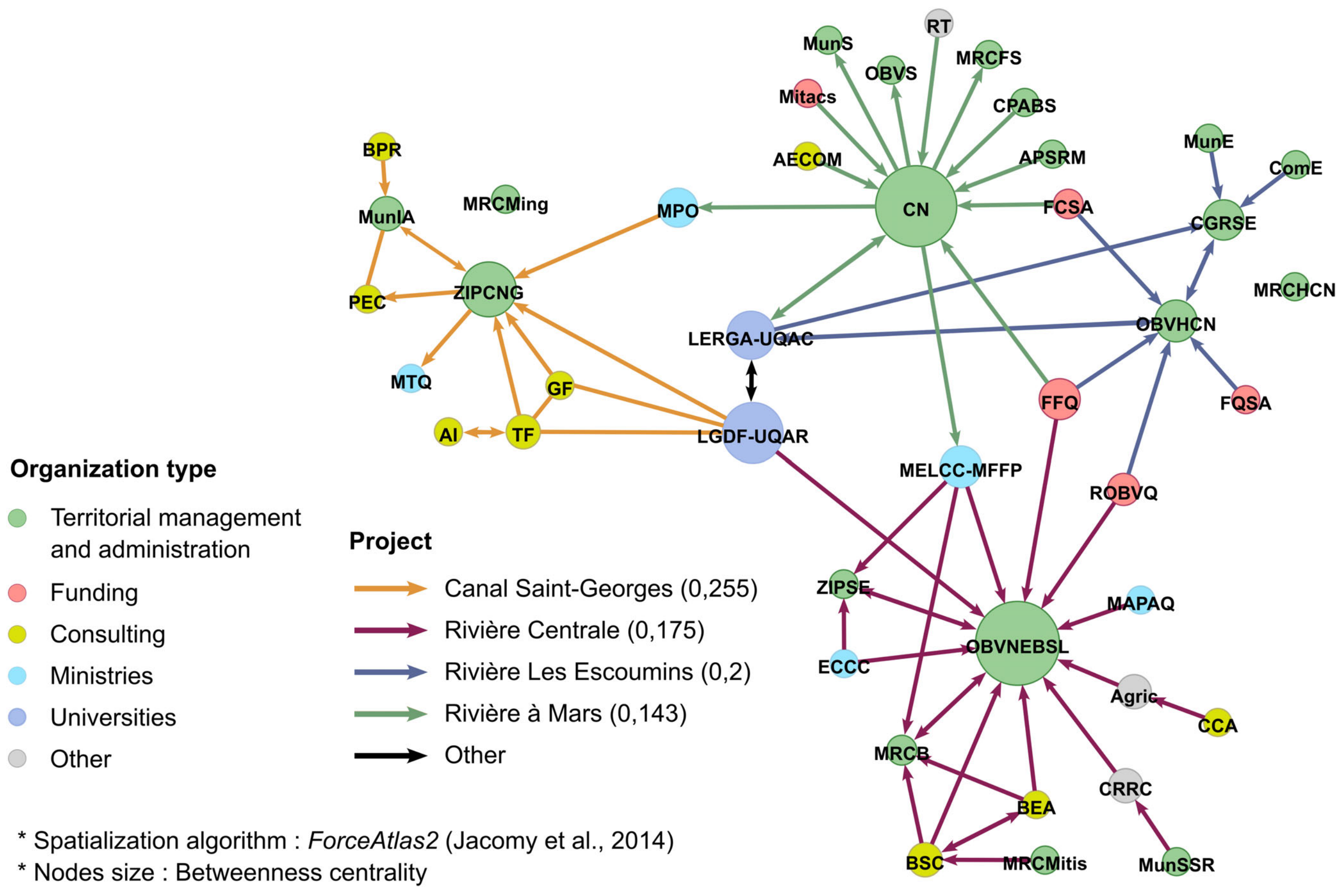

FIGURE 3 Sociogram of the organizations involved in the four studied projects, spatialized with *ForceAtlas2* algorithm (Jacomy et al., 2014). Numbers in brackets are the relationships density for each project and nodes size are function of their betweenness centrality. Direction of links depends on relation type (bilateral: collaboration; unilateral: funding, mandate, recommendation, information, and planning). Definition of the acronyms is in Appendix A. [Color figure can be viewed at wileyonlinelibrary.com]

> "If we were in a more isolated region, where there's no university with a geomorphology department, we'd have had serious problems understanding the problem."
>
> (translated from P03).

The ministries, which should be involved in most projects, seem to have very specific roles instead. For instance, *Fisheries and Oceans Canada* (MPO) only contributed financially to the CSG project, as did *Environment and Climate Change Canada* (ECCC) and the provincial ministries of the *Environment* (MELCCFP) and of *Agriculture, Fisheries and Food* (MAPAQ) for the RC project. MPO and MELCCFP also have information links (meaning the relationships between the latter and the central stakeholders are unilateral and have a low level of participation) with the RAM project, as MTQ does with the CSG project. It should also be mentioned that MRCs are involved in only two projects in their respective area, including one (RAM) in which it only has an information link with the central stakeholder.

At the project level, internal structure is highly variable, but it is systematically centred around a major stakeholder assuming the project coordination (high betweenness centrality). For instance, CSG and even more importantly RC show multiple links between the peripheral organizations (higher density), allowing information to flow without necessarily going through the central stakeholder. In contrast, the RLE and RAM projects are structured with multiple independent links between the central stakeholder and the other organizations (lower density), the latter having a greater number of relationships that are all disconnected from each other. The level of advancement of these projects could explain the lower density of relationships observed, given that the networking stage took place mainly between the coordinating stakeholder and the peripheral organizations rather than between the latter. The first case scenario (CSG and RC, higher density) enables comprehensive decision-making based on direct exchanges between all the nodes in the network. However, it may lack unity and coherence because the central stakeholder is not necessarily behind every decision or misses important parts of the process:

> "The idea was to have constant and concerted discussions, simultaneously to decision-making. […] We could do this to a certain extent when we were all together, but pursuing remote and parallel concertation is difficult."
>
> (translated from P05).

The second case scenario (RLE and RAM, lower density) concentrates all the decisions in the hands of the central stakeholders, who really determine the orientation of the projects. However, it may hinder the contribution of other participants, but it allows for faster and more flexible decision-making:

> "I think our prominent leadership role makes collaborative work easier."
>
> (translated from P07).

3.2 | Integration of HGM principles and human benefits

Figure 4 shows each stakeholder's representation of its own project based on the conceptual diagram around which the second part of the interviews were conducted. Systematically, project funding and the expertise of the organizations are said to have given greater direction to the objectives of the projects. In all cases, except for the RAM project, this component overlaps with the human benefits component, which also has an important relative contribution in the process of framing objectives. In the case of the RAM project, combining the removal of bank stabilization structures with the wishes of the community appeared challenging, particularly as they are still imbued with vivid memories of a particularly devastating flood in 1996. In contrast, RAM is also the only project that seemingly places a major emphasis on HGM principles (Figure 4f), suggesting a disparity between objectives arising from that component and society's wishes. The development of a *Living Lab* was initiated as a tool to show how the planned interventions would benefit the local community, and to adjust the details of the project in line with their wishes. The other projects all attach little to no importance to HGM principles, although the stakeholders seem to be aware that failure to integrate them often leads to project deficiency:

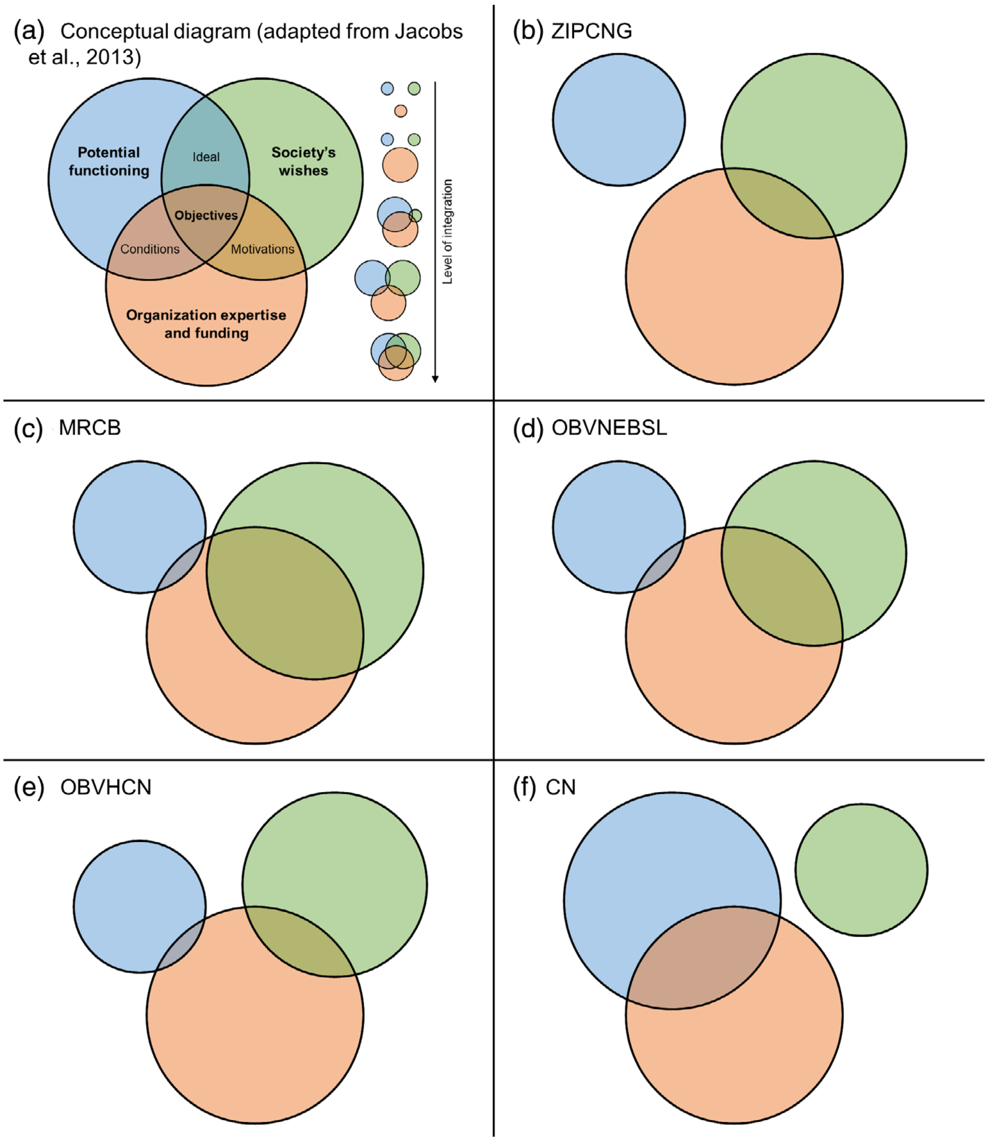

FIGURE 4 (a) The conceptual diagram (Jacobs et al., 2013) that was used to conduct the second part of the interviews, and diagrams produced by each stakeholder to represent their own project's level of integration of HGM principles (blue), human benefits (green), and expertise and funding (orange): (b) Canal Saint-Georges (CSG); (c and d) Rivière Centrale (RC); (e) Rivière Les Escoumins (RLE); (f) Rivière à Mars (RAM). [Color figure can be viewed at wileyonlinelibrary.com]

> "It's the smallest, it's the one that's perhaps furthest behind, but it's the considerations that must be brought back by force, because we know that ultimately, it's this component that can bring everything down, because natural processes will always end up getting the upper hand."
>
> (translated from P05)

Based on a qualitative assessment proposed by Jacobs et al. (2013), the projects analyzed therefore show a low level of integration (overlap) of the three spheres, particularly for HGM principles, which have a very low capacity (size of the sphere) except in the RAM project. Human benefits generally have higher capacity, especially in the RC project and except in the RAM project, but are still poorly integrated in contrast to expertise and funding.

Table 2 shows the frequency of mention of the codes related to the second part of the interviews. Each component of the conceptual diagram (thematic) is divided into a conditional effect and a motivational effect (code) to take account of the divergent considerations regarding their integration into the identification of restoration objectives. Firstly, the stakeholders rarely mention HGM principles. When it is the case, HGM principles are most often seen as means rather than functional limits within which restoration objectives can be achieved. In contrast, human benefits are considered as the basis of every river restoration project, but they largely represent conditions (acceptance) to the project rather than motivations (wishes). This leads either to identify the environmental payoffs that will eventually provide human benefits:

> "What are the priority issues for the people who live with it? Then we're going to bring hydrogeomorphology to bear on these more specific issues."
>
> (translated from P04)

or, conversely, to focus on specific river functions in order to optimize the related human benefits:

> "We'll direct it according to wishes, needs and intentions. But it's still a little bit to the detriment of everything the stream has to offer."
>
> (translated from P05)

However, human benefits seem to play an important role in raising community awareness and direct participation in projects. All participants see these two considerations as major positive results of the projects.

Secondly, the expertise of the stakeholders, mainly centred on biology and ecology, sometimes motivates their objectives:

> "We don't have that kind of expertise [hydrogeomorphology], apart from picking up little training courses left and right. I'm a biologist, so water quality and biodiversity speak to me. We've certainly invested a lot in that."
>
> (translated from P01)

But above all, their expertise seems to limit their abilities. Even though everything revolves around them, they often feel insufficiently qualified to integrate all the components required by the projects on their own. Once they identify objectives, they therefore prefer to bring regular collaborators and consultants together in interdisciplinary teams in which they play the role of coordinators:

> "It's all about us, but we don't have the technical expertise. Our role was not to be an expert in every field, but to bring the necessary experts to the table."
>
> (translated from P05)

Finally, project funding seems almost systematically to direct restoration objectives, rather than financially restrict what can be

TABLE 2 Matrix summarizing the frequency with which the codes were mentioned by the stakeholders involved in each project for the second part of the interviews. The last column shows how many organizations (out of five) are mentioned in each code.

		CSG	RC		RLE	RAM		
Thematic	Code	ZIPCNG	MRCB	OBVNEBSL	OBVHCN	CN	Total	N organizations
HGM principles	Condition (potential functioning)	5	1			2	8	3
	Motivation (means)	1	3	3	3	2	12	5
Human benefits	Condition (public acceptance)	4	6	12	2	3	27	5
	Motivation (society's wishes and needs)	2	11	6		1	20	4
	Other (sensibilization and participation)	5	6	20	4	8	43	5
Organization's expertise	Condition (abilities)	10	12	5	1		28	4
	Motivation (interests)	3	1	5		2	11	4
Project funding	Condition (capacities)	10	13	5		2	30	4
	Motivation (imperatives)	22	8	12	9	1	52	5

targeted. Instead of applying for funding in line with pre-defined objectives, stakeholders first seek funding by stating objectives that correspond to the requirements of the programs – in order to ensure the sustainability of their organization – even if the basic motivations for the project were different:

> "Since the beginning of the project, we've been opportunistic. In other words, if there's an envelope […]" (translated from P03) "[…] we think 'okay, there's this possibility of doing this type of project […]', so we dictate our objectives in relation to the funding envelope."
>
> (translated from P01)

By combining the results in Figure 4 and Table 2, the configuration presented in Figure 4b–e (CSG, RC and RLE) implies that extrinsic factors such as funding and expertise initially corresponded to the desired state of the streams, therefore ensuring the project objectives. Stakeholders could then select and mobilize the HGM principles and tools that directly meet their needs. This is an opportunistic strategy in which available funding in particular is mobilized primarily to shape and implement projects. Conversely, Figure 4f shows a configuration in which HGM considerations drive objectives, mainly because stakeholders were already aware of their importance and because they sought specific funding in line with their objectives. This objective-driven strategy only seeks resources once the objectives have been determined to ensure their consistency. Its disadvantage is the potential distance between the initially stated objectives and the wishes of the community, which could limit public acceptance and probably justified the adoption of a *Living Lab* approach to fill this gap in the case of RAM.

3.3 | Challenges encountered

The third theme of the interviews was to identify the drivers that have contributed to levels of integration described above, on the basis that they are closely linked to the challenges faced by the stakeholders during their projects. Except for highly contextual challenges such as the COVID-19 pandemic, the main challenges related primarily to the level and structure of funding (Table 3). As most programs do not fund complete projects, organizations must combine funding from different sources, and the multiple resulting requirements end up directing their objectives. It also represents "repeated work to always sustain, resubmit, re-justify, etc." (translated from P01). This seems to require stakeholders to spend more time working on funding requests than on their actual projects. Program timescales also vary between one and 3 years, excluding in most cases preliminary studies which are "a project itself" (translated from P03) and which are crucial to science-based decision-making process. This precipitates interdisciplinary collaboration, leads to ill-informed actions, and avoids post-project monitoring:

> "Funding programs' structure ultimately led to absurd decisions."
>
> (translated from P05).

Stakeholders have also encountered difficulties related to the lack of expertise, human resources, and interdisciplinary work (Table 3). The difficulty of getting different skills and sectors to talk to each other and understand each other seemed to be a particular barrier to collaboration. Despite their intentions and the recent regulatory measures promoting hydrogeomorphology for river restoration, the availability of specialists from this discipline is still low, which often redirects "interdisciplinary" teams towards more established expertise, especially engineers:

> "The program requires an opinion from a hydrogeomorphologist. These are quite specialized skills, and they don't come along very often […]. When you don't have this specialty, you turn to engineers who

TABLE 3 Matrix summarizing the frequency with which the codes were mentioned by the stakeholders involved in each project for the third part of the interviews. The last column shows how many organizations (out of five) are mentioned in each code.

		CSG	RC		RLE	RAM		
Thematic	Code	ZIPCNG	MRCB	OBVNEBSL	OBVHCN	CN	Total	N organizations
COVID-19		1				1	2	2
Lack of expertise		5	19	5	5		34	4
Project funding	Quantity	18	6	3	6	1	34	5
	Structure and duration	2	12	7	3	1	25	5
Interdisciplinarity and intersectoriality		18	4	2		2	26	4
Legislation and regulation		2	9		12	7	30	4
Land use			2	17			19	2
Social representations			4	6		1	11	3
Human resources		2	7	1		1	11	4

> don't necessarily have the understanding of a geomorphologist."
>
> (translated from P03)

The challenges of integrating HGM approaches is also exacerbated by the regulations governing the restoration and management of rivers, which require specific expertise, namely engineering, before projects can be approved and implemented:

> "Even if, in theory, we believe that every opinion has equal value, this is not so true in terms of the law. The engineer has the final say, based on other considerations."
>
> (translated from P05)

In addition, regulations seem to inhibit, at least partially, the restoration actions that are regularly promoted by hydrogeomorphology, including the legal obligation for MRCs to ensure adequate drainage of water. This is particularly true for the RLE et RAM projects (Table 3), which were in the planning phase and for which stakeholders were in the process of assessing which interventions might be acceptable in terms of laws and regulations:

> "Currently, the law doesn't allow you to remove dams, because there's a reservoir [...] and if you remove it, the water level goes down, you reduce fish habitat, and then you're breaking the law."
>
> (translated from P08)

Finally, land use and social representations were the major challenges according to the two RC project stakeholders (Table 3). The highly agricultural context that characterizes this site alone would have imposed particular challenges on the project if it had proposed interventions more imbued with HGM principles. This probably explains the direction RC project stakeholders took towards farming practices:

> "There's going to be a loss of acreage [...]. Farmers aren't really going to accept losing farmland."
>
> (translated from P02)

As many river restoration projects are carried out in agricultural contexts, particularly in southern Quebec, these challenges may be underestimated here and represent a major obstacle (Paradis & Biron, 2017). Therefore, public acceptance seems to play a particular role in this context. Despite the recent focus on maintaining river mobility, rivers are still largely considered as static rather than dynamic entities, and negative discourses on bank erosion are still very common, even in the restoration sectors. Social representations of both rivers and their restoration then seem to challenge stakeholders wanting to integrate more HGM principles in their projects:

> "We're also afraid of public perception, we're told everywhere that erosion is bad."
>
> (translated from P08)

4 | DISCUSSION

4.1 | Conceptualization of the process for identifying river restoration objectives

Our results allow us to suggest improvements to Dufour and Piégay (2009) framework for identifying the objectives of river restoration projects (Figure 5), mainly by adding extrinsic inputs to the intrinsic drivers already included in the diagram. Indeed, although expertise and funding are extrinsic to the sites being restored, this study suggests that they are key drivers framing river restoration objectives. Their weight in project planning is probably even greater than that of intrinsic inputs, which suggests that stakeholders have less power than expected in these decision-making processes, and that their projects are shaped according to local and pragmatic or organizational and strategic considerations. Sher et al. (2020) estimated that 60% of the variability in the success of vegetation restoration could be explained by stakeholders' characteristics, but regulation, funding mechanisms and governance frameworks may be even more significant (Carré et al., 2022; Carter et al., 2022; Jacob, 2022; Linton, 2022). The "human variables" of projects, such as the number of collaborators, the number of sources of information used, the number of roles occupied by stakeholders, the level of education, etc. appear to be determined by wider societal drivers, such as the requirements of funding programs and the expertise put forward in river management in a specific political context (Lave, 2016; Skinner et al., 2023).

These two key drivers may frame projects as conditions and motivations simultaneously (Figure 5). Indeed, expertise could both restrict stakeholders' abilities and direct objectives according to particular interests. In Quebec, environmental management has historically been related to biologists and engineers, which may still hamper the integration of emerging disciplines and innovative approaches (Biron et al., 2018). Tensions and power relations arising from different expertise or sectors, for instance academic researchers vs. practitioners, are indeed much discussed in river restoration science (Germaine et al., 2022; Gillilan et al., 2005; Jacob, 2022; Lave, 2009, 2012, 2016; Linton, 2022; McDonald et al., 2004; Sneddon et al., 2017). In the same vein, funding could both limit financial capacity and determine the content of projects. Lack of funding is regularly cited as limiting innovative environmental management practices (Clark et al., 2019; Sauvé et al., 2020; Skinner et al., 2023), but we suggest that the major influence of funding has more to do with the outdated and overly specific requirements of funding programs. Some explicitly expect specific objectives to be addressed and actions to be taken, sometimes concealing non-restorative actions and to the detriment of the initial motivations and objectives:

> "We were only supposed to remove the anthropogenic obstacle, restore the natural state. The 'habitat' component came with the funding opportunity. [...] We're going to say that it's a fish habitat project so we'll be able to solve the other issues along the way."
>
> (translated from P05)

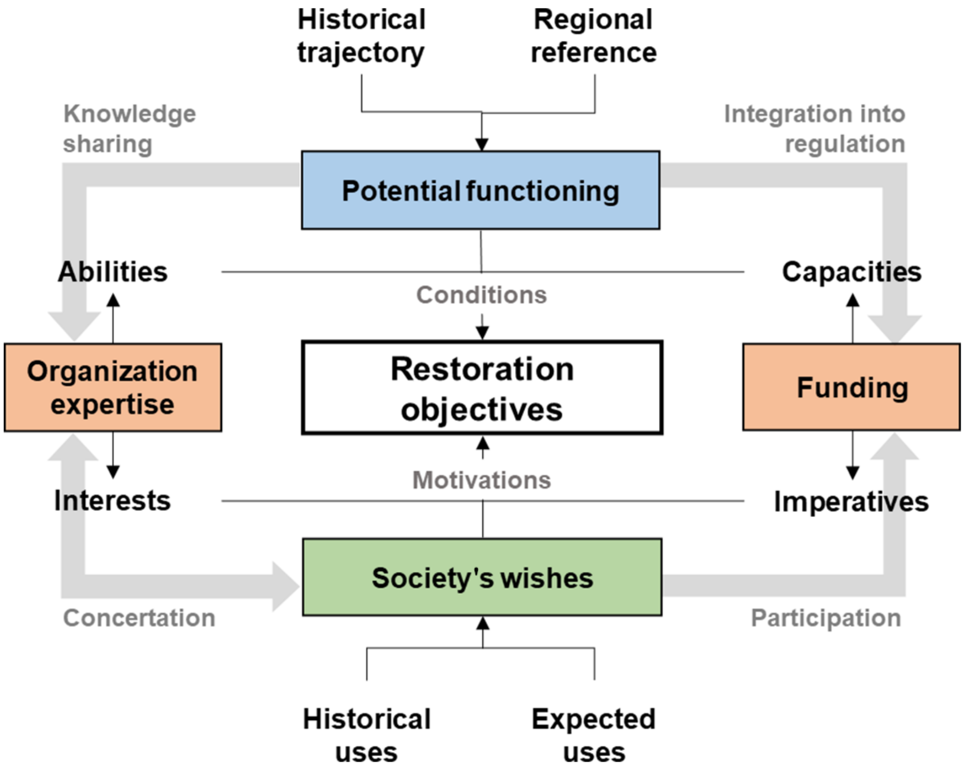

FIGURE 5 Adjusted framework to define objectives for river restoration projects (adapted from Dufour & Piégay, 2009), synthesizing drivers that are intrinsic (blue and green) and extrinsic (orange) to the sites that are being restored, the ways they drive the objectives, and the interactions among these drivers. Grey arrows represent potential opportunities to overcome the challenges they impose. [Color figure can be viewed at wileyonlinelibrary.com]

Indeed, market-based approaches and traditional river restoration practices within neoliberalism are known to shape both the structure of projects (Jacob, 2022; Lave et al., 2010; Palmer et al., 2014; Palmer & Filoso, 2009) and their outcomes (Doyle et al., 2015; Lave & Doyle, 2021). The same is true of certain governmental guidelines which target very specific objectives (mainly ecological habitats), and which are poorly based on scientific data (Biron et al., 2018; Skinner et al., 2023). Moreover, the positive environmental representation of "restoration" itself and the availability of funding for it can sometimes encourage stakeholders to use it opportunistically to justify interventions, which nevertheless leads to more artificialization, particularly if we consider that the success of river restoration is largely based on perception (Jähnig et al., 2011; Skinner et al., 2023). We would add that these discrepancies between the funding orientations and the fundamental motivations of a project (society's wishes) can lead to unsustainable interventions and unsatisfactory human benefits.

The drivers inside Dufour and Piégay (2009) framework are also called into question by our findings. In theory, the society's wishes should drive restoration objectives in a bottom-up process, but within a top-down framework related to potential functioning boundaries (Dufour & Piégay, 2009). Instead, this study suggests that decision-making is based on an entirely bottom-up approach dominated by public acceptance and a wider societal context, consequently excluding HGM principles. On the contrary, HGM tools are involved as a mean to achieve objectives that have already been identified. This quote from an interviewed stakeholder illustrates how public acceptance and wishes are a lever for any river restoration project, funding, objective, and action:

> "If the wider community agrees, we'll have the political support to guarantee funding, and if the funding is there, we can go and get the expertise [hydrogeomorphology]."
>
> (translated from P04)

As mentioned, this study may overestimate the level of integration of HGM principles in river restoration projects in Quebec. As the projects studied did little to incorporate them, the overall picture is probably worse, even excluding hydrogeomorphology completely from the projects, both as boundary conditions and as tools.

Ultimately, it all comes down to the general sociocultural, political and legislative context that underpins the framework, which simultaneously integrates and shapes its components, and which is rooted in a historical trajectory of territorial management (Castonguay & Fougères, 2013). Indeed, the framework as a whole could evolve in space and time according to interdependent societal and cultural values (Ashmore, 2015; Carré et al., 2022; Carter et al., 2022; Failing et al., 2013; Linton, 2022; Zingraff-Hamed et al., 2017, 2022) such as the human-river relationship and the representation of rivers, their quality, benefits, degradation, and restoration (Anquetil et al., 2018; Castonguay, 2015; Jähnig et al., 2011; Jørgensen, 2017; Nassauer, 1995). As a result, each varying component of the framework can shape river restoration activities and decision-making processes, either facilitating or constraining the integration of HGM principles to achieve a range of objectives, human benefits, and sustainable outcomes. For example, the introduction of the *Water Framework Directive* (WFD) in Europe, with its objective of improving the ecological status of aquatic systems, has led to the development of various types of expertise, including hydrogeomorphology, into organizations, the integration of this requirement into funding programs and the implementation of coherent projects (Bouleau & Pont, 2015). However, even in this context characterized by powerful macro-scale legislation, national policy, sociocultural contexts (Zingraff-Hamed et al., 2017) and stakeholders' roles and course of action (Drapier et al., 2018) still determine the characteristics of river restoration projects. Therefore, and despite the limited number of projects studied, we believe that the relevance of the proposed framework (Figure 5) lies in its potential transferability to a variety of sociocultural contexts, which always form its backdrop. It is meant as a comprehensive analysis tool that provides a better understanding of the diversity of drivers likely to shape projects, which are in all cases at least funded and associated with more or less specific expertise. It conceptualizes how contexts can influence the approaches, logistics and outcomes of river restoration in different ways to produce "hybrid" fluvial systems (Ashmore, 2015; Lespez & Dufour, 2021).

4.2 | Integrating HGM principles and human benefits into stream restoration projects

Expertise and funding could eventually make it easier to incorporate HGM principles into river restoration projects, with a view to achieving more diverse human benefits. Indeed, the framework we propose is intended as a tool for comprehensive and objective-driven strategies in project planning, to move away from opportunistic attitudes (Piégay et al., 2023). Based on an "interdependency" perspective (Carter et al., 2022), Figure 5 also presents potential opportunities for overcoming the challenges imposed by these drivers. Firstly, effective sharing of knowledge between river scientists and practitioners should be encouraged. Clark et al. (2019) highlight, as drivers for effective communication, the need for boundary organizations (organizations that bridge science and management) to be consensual and central stakeholders, which was true for all projects studied, and river-wide collaboration, which is absent from most projects that are very local and specific. However, the lack of funding for longer-term, more elaborate projects was perceived as a brake on the effective exchange of knowledge and the integration of scientists' recommendations. Bringing a wider range of experience and expertise into the teams of environmental organizations could also make it easier to implement sustainable projects. Mould et al. (2018, 2020) stress the importance of establishing relationships and dialogue in river research and management to fully put sociogeomorphology into practice. Timeframe constraints are crucial to build a common understanding of rivers, particularly in advance of projects. Furthermore, the involvement of different people and organizations in these timeframes should be structured chronologically according to their role, mandate, and interests. For example, the role of academic researchers, which is to gain an understanding of river dynamics, is temporally incompatible with the technical planning and design of engineers, or with the monitoring of flora and fauna by ecological organizations (Skinner et al., 2023). The duration and timeframe of funding programs must therefore be adapted to this reality on the ground.

Secondly, the integration of HGM principles into the regulations is more than necessary. Indeed, as the WFD has shown, the development of national expertise and its integration into funding programs are based on regulation (Bouleau & Pont, 2015):

> "If there's no requirement, there'll never be anyone to do it. If it is required, expertise will build."
>
> (translated from P10)

In Quebec, new regulations on river mobility are slowly being introduced, as recent floods have revealed the need to better integrate this process into land-use planning and infrastructure design. As a result, government bodies are gradually demanding that the mobility space of a river corridor be defined before any action is taken in or around it, and are looking for professionals to take on this task. The government-funded *Program to restore and create wetlands and rivers* (PRCMHH) also encourages, on a provisional basis, the integration of HGM principles and various human benefits in the projects it funds. However, expertise is scarce and there is still much to discuss before HGM principles are integrated into wider and more powerful regulation, even more so into funding programs for river restoration.

Finally, continuous collaboration and the direct participation of local communities from the very beginning of the projects are essential to the effectiveness of river restoration (Buletti et al., 2022; Germaine et al., 2022; Maniraho et al., 2023; Mould et al., 2020; Reed et al., 2018), and to guarantee the effects of projects on sociocultural relationships with rivers (Hikuroa et al., 2022; Wantzen, 2024). In addition to the duration of projects and funding programs, approaches and tools are still needed to formally integrate and conciliate the heterogeneous wishes of communities and local knowledge into projects, including at the pre-planning, design, implementation and monitoring stages. *Living Labs* are recognized as innovative approaches to environmental management, particularly for collaborative planning and design (Lupp et al., 2021). However, the risk of such an approach, as we saw in the RAM project, is that it is used to justify planned interventions rather than starting from the wishes of the communities (Buletti et al., 2022):

> "Once you've done your job you leave, but they [community members] stay. How can they take ownership of your action, make it their own and not be subjected to it?"
>
> (translated from P05)

As mentioned, decision-making on river restoration in Quebec appears to be based solely on a bottom-up approach dominated by public acceptance and the wider societal context. We do not advocate a top-down approach that is entirely driven by HGM principles to the detriment of local communities, which can lead to sociotechnical controversies, public contestation, and project failure (Carré et al., 2022; Flaminio, 2021; Fox et al., 2016; Germaine & Lespez, 2017; Magilligan et al., 2017). Following the view of Dufour and Piégay (2009), in addition to acknowledging the major influence of funding and expertise, we propose a mixed framework rooted in society's wishes and underpinned by HGM principles, which inform on potential river functions, capacities, human benefits, and unrealistic options, to prevent intervention failure and improve projects sustainability. It also crystallizes all the complexity of the processes underlying the identification of river restoration objectives. Each box representing the components of the framework could be unfolded and would certainly lead to other questions and interests that could be explored in greater depth.

5 | CONCLUSION

In this study, we propose adjustments to improve the frameworks for identifying river restoration objectives (Figure 5), based on an analysis of the decision-making processes of four river restoration projects in Quebec, their level of integration of the main components of river restoration and the challenges faced by the stakeholders. We suggest that expertise and funding are key drivers behind the objectives of river restoration projects, supporting the idea that river restoration is a fundamentally social phenomenon. These drivers may either promote or restrict the integration of HGM principles and human benefits. The examples from the province of Quebec on which this paper is based illustrate the latter case. Depending on different sociocultural, political and legislative contexts, the content of the framework may evolve in space and time, leading to different approaches to river restoration, project objectives and structures, and producing “hybrid” rivers. The adjusted framework (Figure 5) is designed as an analytical tool to better understand the diversity of drivers that can shape projects and to move from opportunistic to strategic objective-driven project planning in river restoration (Piégay et al., 2023).

Indeed, the framework we propose is rooted in an historical trajectory of territorial management and can shed light on its future by promoting comprehensive decision-making in river restoration. As a result, this paper argues firstly for regulation that is better informed by scientific knowledge of HGM river dynamics and related sociocultural dynamics, for funding programs that are better adapted to the reality of project implementation, particularly in terms of timeframes, and for the sharing of knowledge between academic research and stakeholders, including the integration of a greater diversity of expertise. Secondly, it fosters in-depth and continuous collaboration between stakeholders and communities, in addition to their direct participation in projects. Finally, it stresses the importance of framing restoration objectives according to the desired state of rivers, within their potential functioning boundaries. These insights can lead to innovative approaches to river restoration, for more sustainable results.

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CONFLICT OF INTEREST STATEMENT

Two of the authors of this article (Étienne Gariépy-Girouard and Thomas Buffin-Bélanger) were partners, as specialists in hydrogeomorphology, in projects (Canal Saint-Georges and Rivière Centrale) discussed in this article. This involvement led them to inform projects' orientations and allowed a privileged position from which to observe the dynamics of project management and their outcomes.

DATA AVAILABILITY STATEMENT

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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APPENDIX A: DEFINITION OF THE ORGANIZATIONS' ACRONYMS

AECOM	AECOM
Agric	Agriculteurs (farmers)
AI	Aqua Ingenium
APSRM	Association des pêcheurs sportifs de la Rivière à Mars (ZEC)
BEA	Bureau d'écologie appliquée
BPR	BPR
BSC	Bouchard Service-Conseil
CCA	Clubs-conseils agricoles
CGRSE	Corporation de gestion de la rivière à saumon des Escoumins (ZEC)
ComE	Communauté innue Essipit (indigenous community)
CN	Contact-Nature Rivière-à-Mars (ZEC)
CPABS	Centre de plein air Bec-Scie (campground)
CRRC	Comité de restauration de la rivière Centrale (citizen comitee)
ECCC	Environnement et Changements Climatiques Canada (Ministry of the Environment and Climate Change Canada)
FCSA	Fondation pour la conservation du saumon atlantique (Atlantic Salmon Conservation Foundation)
FFQ	Fondation de la Faune du Québec (Quebec Wildlife Foundation)
FQSA	Fédération québécoise pour le saumon atlantique (Quebec Atlantic Salmon Federation)
GF	Gerfaut inc.
LERGA-UQAC	Laboratoire d'expertise et de recherche en géographie appliquée – Université du Québec à Chicoutimi
LGDF-UQAR	Laboratoire de géomorphologie et dynamique fluviale – Université du Québec à Rimouski
MAPAQ	Ministère de l'Agriculture, des Pêches et de l'Alimentation du Québec (Ministry of the Agriculture, Fisheries and Food of Quebec)
MELCC-MFFP	Ministère de l'Environnement, de la Lutte contre les Changements Climatiques, de la Faune et des Parcs du Québec (Ministry of the Environment, Fight Against Climate Change, Fauna, and Parks of Quebec)
Mitacs	Mathematics of Information Technology and Complex Systems
MPO	Pêches et Océans Canada (Ministry of Fisheries and Oceans Canada)
MRCB	MRC des Basques
MRCFS	MRC Le Fjord-du-Saguenay
MRCHCN	MRC de la Haute-Côte-Nord
MRCMing	MRC de la Minganie
MRCMitis	MRC de la Mitis
MTQ	Ministère des Transports et de la Mobilité durable du Québec (Ministry of Transportation and Sustainable Mobility of Quebec)
MunE	Municipalité des Escoumins (municipality)
MunIA	Municipalité de L'Île d'Anticosti (municipality)
MunS	Municipalité de Saguenay (municipality)
MunSSR	Municipalité de Saint-Simon-de-Rimouski (municipality)
OBVHCN	OBV de la Haute-Côte-Nord
OBVNEBSL	OBV du Nord-Est du Bas-Saint-Laurent
OBVS	OBV du Saguenay
PEC	PEC inc.
ROBVQ	Regroupement des OBV du Québec (Association of the OBVs of Quebec)
RT	Rio Tinto
TF	Terra Formex
ZIPCNG	Comité ZIP Côte-Nord du Golfe
ZIPSE	Comité ZIP du Sud-de-l'Estuaire