Rhône River: Restoration Recommendations for the Miribel Canal

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Abstract

The Miribel Canal is in need of restoration due to issues with incision and sediment management. The team aimed to research restoration projects that will aid with these issues by looking at case studies and interviewing experts in the field. We identified five viable restoration techniques: widening the river, steepening the banks, replenishing sediment, plant barriers, and bank armoring. The team analyzed the strengths and weaknesses of each technique to determine how applicable they could be for the Miribel Canal. Small-scale field applications of these techniques are recommended for the Miribel Canal to further analyze their applicability.

Executive Summary

The Problem with the Miribel Canal

The Rhône River is a heavily modified river in Europe that has been channelized for many years. Two of the most integral channels to the city of Lyon, France are the Miribel and Jonage. The utilization of these canals has caused the Miribel to deteriorate. Erosion from suspended sediment pollution has significantly lowered the canal bed. From this, the Lyonnais community members are seeing negative effects on their recreational areas and river ecosystems. Therefore, the problems cannot continue to persist and some restoration must be pursued. To identify some possible solutions the team executed the three following objectives.

Objectives

- Identify core challenges faced by the Miribel canal
- Collect Restoration Techniques and Compile their Strengths and Weaknesses
- Analyze Techniques Applicable to the Miribel Canal

Methods

Partner Communications

The team mainly communicated with the project's 9 partners through our contacts with the Grand Parc: Valérie Marion and Marion Guibert. The team remotely met with Valérie and Marion once per week. Fabienne Miller and Inès Hamidou also attended the meetings and acted as translators. These meetings provided the team with first-hand information regarding the core challenges faced by the Miribel Canal.

Expert Interviews

The team interviewed several experts to gain a better understanding of the challenges. Valérie introduced the team to Frédéric Laval. Laval explained some technical aspects of the canal to the team. Laval referred the team to several other experts: Benoît Terrier(Agence de l'Eau), Rémi Loire(EDF), and Rémi Taisant (CNR). These experts provided various perspectives on the issues faced by the canal and possible restoration techniques for the canal. The team also interviewed several WPI professors: John Bergendahl, Laureen Elgert, and Katherine Foo. These professors provided general information regarding river restorations. Additionally, these experts shared case studies that were similar to the Miribel Canal with the team.

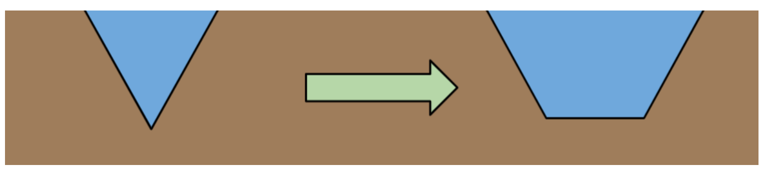
Case Study Analysis

The team also utilized case studies which helped determine in finding different methods of river restoration and how to define them as "successful." The criteria used for selecting case studies included ecological and social problems. These are shown in the table below. Articles supported this selection as they analyzed the weak spots in common urban planning methods and determined if it was truly in the greater interest of the cities or developers.

Ecological Problems		**Social Problems**
Restorations that interfere with **channel incision**	Restored rivers, or canals that have issues with **flooding**	Canals impacting **drinking water supply**
River aggradation	Rivers that have **irregular flow rates**	**Recreational areas** near waterways
Restoration concerning **biodiversity**		

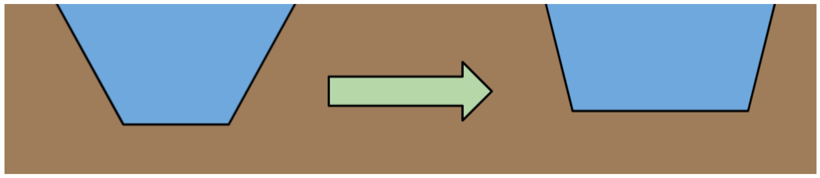
Findings

Widening the Canal



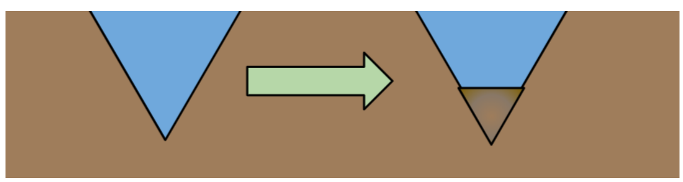
This technique involves widening the cross-section of the river. Wider channels can accommodate more water, and thus reduce the flow velocity and the stream's capacity to transport sediment. The Isar Plan widened the Isar River and flattened its banks. As a result, the river's ecosystem, flood runoff, aesthetics, and recreation opportunities improved (Isar-Plan Munich: A New Lease of Life for the Isar River, 2013). Experts were generally in favor of this technique as it would reduce incision, flow velocity, and flooding. However, the land required to enlarge the river can be hard to acquire in urban areas(R. Taisant, personal communication, June 29, 2021). Additionally, the digging required to physically widen the river could be harmful to the ecosystem and drinking water supply(F. Laval, personal communication, June 14, 2021).

Adjusting Bank Slopes



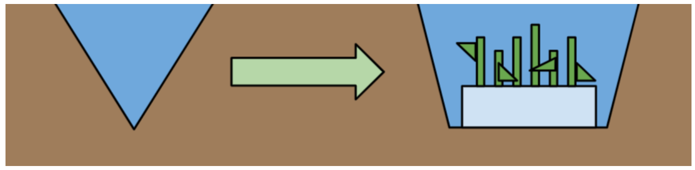
A technique that is similar to widening involves adjusting the slopes of the banks (See *Figure 8*). The methods used for adjusting the slopes are comparable to the methods used for widening. Thus, this technique is often used in conjunction with widening. A restoration project on the Lower Rhine River in Germany utilized this method. The banks of the Rhine were steepened in order to mimic incision. This resulted in decreased incision rates (Arbós et al., 2020). Experts had mixed opinions on this technique when it was mentioned in interviews. Benoît Terrier raised some concerns. The equilibrium of the river requires a specific slope, if the slope is wrong the river can be eroded and stripped of nutrients. It is difficult to find the correct slope due to uncertainty with models (B. Terrier, personal communication, June 21, 2021). Rémi Loire agreed that this technique would lessen the flow rate pressure. However, Loire was concerned that this technique is too artificial, as it just makes the canal bigger rather than restoring its natural shape (R. Loire, personal communication, June 25, 2021). While this technique may be a viable solution, it has many limitations that may make it less effective than some alternatives.

Sediment Replenishment



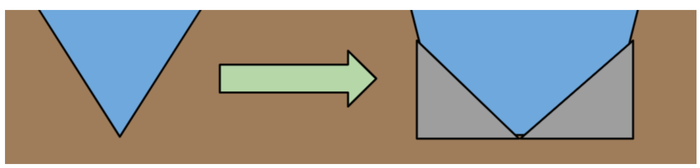
Sediment replenishment is another restoration technique that involves replacing the eroded sediment in the river with other sediments. The replacement sediment can either be retrieved from other areas of the river with excess sediment or added in from another source. There are places in the Rhone with too much sediment such as in the Jonage canal and this can be excavated and placed into areas of the river with sediment depletion that has been caused by incision (F. Laval, personal communication, June 16, 2021). Removing coarse sediment will help decrease the amount of damage and erosion done to the Miribel canal. This method involves adding forms of sediment to a body of water. Concerns of this method involve coarse sediment being able to get stuck downstream where the dams are located (R. Taisant, personal communication, June 29, 2021), the sediment being washed away (B. Terrier, personal communication, June 21, 2021), as well as issues with biodiversity (R. Loire, personal communication, June 25, 2021)

Plant Barriers



Plant barriers are a restoration technique that involves planting semi-aquatic plants in the river in order to slow the flow and collect sediment (Kałuża et al., 2018). Plant barriers would aid the Miribel canal since slowing the flow would prevent incision and the plants would collect the sediment that is being depleted and carried downstream. This technique would also increase the biodiversity in the river since the variation of water flow caused by the plant makes a more suitable environment for more species and the build-up of woody debris would also improve the ecosystem (Kałuża et al., 2018) (B. Terrier, personal communication, June 21, 2021). Some limitations to this technique are that the technique has been primarily used on small lowland rivers so its ability to slow a faster river such as the Miribel Canal is questionable. Another concern is that once the plants die the plant matter will get caught in the dams downstream from the river (R. Taisant, personal communication, June 29, 2021)

Bank Armoring



Another restoration technique that is applicable is one known as riverbank armoring. Riverbank armoring utilizes large, jagged rocks known as riprap. These rocks are placed along the banks of the river, especially in areas where scour is present. These rocks decrease sediment pickup since the rocks act almost as anchors for sediment found at the bottom of the river. With the decreased sediment pickup, riprap also aids in slowing the rate of flow in the river, as water traveling across these rocks is unable to gain or retain the same speeds as without them (J. Bergendahl, personal communication, June 21, 2021). Along with the previous benefits to riverbank armoring, one final benefit is the low cost. Because it is a somewhat simple technique, the majority of any cost is in researching the size and amount of riprap needed to successfully slow river flow, as well as transporting these boulders to the river. Although it is a cheaper method, the effectiveness of this technique is extremely dependent on the initial research, as the location of the rocks along with their size and shape is crucial. Riprap that is too effective can disrupt steady flow rates and destroy habitats, while rocks that aren't effective enough do not address the needs of an incising river (J. Bergendahl, personal communication, June 21, 2021). With this in consideration, riverbank armoring is a viable technique that solves many problems, especially when paired with other techniques.

Problem ---------------- Restoration Technique	Urban Proximity	Incision	Biodiversity	Sediment Management	Flooding	Flow Rate	Drinking Water
Widening the River							
Adjusting Bank Slopes							
Sediment Replenishment							
Plant Barriers							
Bank Armoring							

Recommendations

From the weekly meetings with our partners and interviews with other river experts in Lyon, the main problems facing the river have been identified as; incision, sediment management, drinking water, and biodiversity. While the team did not find any restoration techniques that specifically looked at improving biodiversity or the drinking water supply, all of the restoration techniques that were researched may have positive or negative consequences to these issues. For this reason, the team believes that when considering any restoration technique the impact on biodiversity and the drinking water supply should be heavily considered. The team also believes that implementing a restoration technique on a smaller scale first may be a beneficial way to determine how the technique will work on the Miribel Canal.

Conclusion

The team researched 5 restoration techniques involving widening the canal, adjusting the bank slopes, sediment replenishment, using plant barriers, and bank armoring in order to develop recommendations for the management of the Miribel Canal. The restoration methods were retrieved and analyzed using case studies as well as through expert interviews. After analyzing the case studies, the team concluded that certain parts of the river restoration projects could be applicable but not be a complete fit to mirror the issues of the Miribel Canal. Considering the effects and concerns of these restoration techniques, cost, and long-term effects should also be considered. Overall, the team recommends that every technique should be further analyzed and that the potential technique used for restoration should also consider biodiversity and the drinking water supply of Lyon.

Introduction

Only 2.5% of water on earth is fresh, and only 1.2% of that freshwater is found on the surface (Shiklomanov, n.d.). Despite its scarcity, freshwater supports over 100,000 species (WWF, n.d.). Water is necessary for all life on earth, including humans. Generations of humans have forced the environment to adapt to human needs, rather than adapt themselves. This phenomenon is particularly obvious when it comes to rivers. Humans have been altering rivers for thousands of years and these alterations come with severe consequences. The Rhône River is a heavily modified river, as it has been channelized for many years. As a consequence of this modification, the Miribel Canal is facing a plethora of issues. Most of these issues involve sediment transport and flow rate. Due to the rapid flow rate the coarse sediment in the river gets picked up and brought down the river. This has caused issues with lowering the water level, affecting the drinking water supply, and flooding.

Floodplain restorations have been attempted to correct problems like flow rate, but have not yet been successfully completed. Examples of previous restoration projects include Plan Rhône and Mission Rhône which were both unsuccessful (Souchon, n.d.)(Guerrin, 2015). The main reasons for the lack of success was due to problems with leadership and support. Now a group of nine partners have joined together to restore the Miribel Canal.

For a large-scale restoration project like this there are many important factors to consider. Restoration teams must consider various laws, budgets, and species when designing their projects. All these obstacles make it difficult for restoration projects to get started. Furthermore the issues on the canal are complex and will need creativity to help with finding solutions. Our team was able to aid with this by having an outsiders view of the problem which we used to find restoration techniques to help with the issue.

The team identified five restoration techniques including, widening the river, adjusting the slope of the banks, sediment replenishment, plant barriers, and bank armoring. After thoroughly researching these techniques, strengths and weaknesses of each method were found and presented to the partners of this project.

Background

The Rhône River has a long and important history in Lyon and continues to play a role in the community to this day. The people of Lyon have had a strong connection with the river for centuries, whether through transportation, for power, as a park, or as a habitat for the many species that reside in it. The Rhône travels straight through the city of Lyon making it an important natural and cultural resource for the city. Currently, the Miribel Canal, which is attached to the Rhone, is sinking as a result of incision which is causing many issues to the community including safety concerns, flooding, and contamination of drinking water (F. Laval, Personal communication, June 14, 2021). For these reasons, it has become increasingly important to find methods of restoring the canal to alleviate these problems. In order to find methods of restoring the canal it is important to understand the complexity of the Rhône River and the history of other restoration attempts.

The Rhône

The Rhône is a relatively short river that is 505 miles (813 km) long. It originates from Lake Geneva in Switzerland, then eventually passes through the Southeast corner of France. As it passes through France, it travels straight through the city of Lyon. Before the adoption of railroads and highways, the Rhône was commonly used for inland transport, for people and goods. Traveling down the Rhône would take approximately three weeks by sail, and only three days by motorized vessel. Once more modern forms of transportation became more viable, the Rhône was no longer needed for shipping and travel. Trains and cars could travel much more efficiently to their destination, as they were not required to follow the meandering path of the river. These new forms of transport were more direct and thus took less time. Originally, all of the Rhône was accessible to ships, mostly small, but as of 2017, the section between Lyon and Sault-Brénaz is closed for navigation (Charles**,** 2008). Aside from navigation the Rhône provides for the surrounding communities in many other ways too.

The Rhône has been a resource to those living along it as long as the river has existed. Irrigation and other agricultural practices during the Middle Ages would rely on the flood patterns of the river. Therefore, the livelihood and water source for the people of Lyon and other French communities was the Rhône. They still use the river as a resource, but also for modern purposes, like energy and tourism (Sapiega, 2014). As a result, dams and reservoirs were constructed to harness hydropower and manage flood levels.

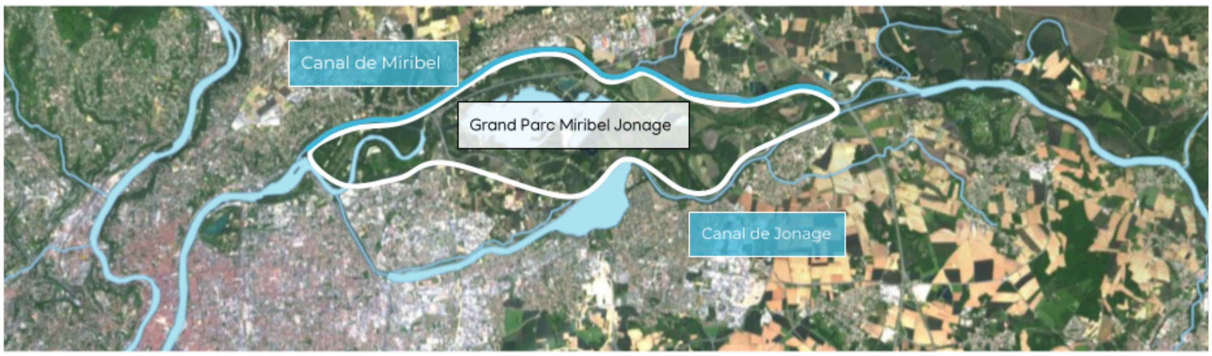
Examples of such projects can be found in regions outside and inside of Lyon. The Serre-Ponçon Dam is the largest dam in Europe and is located on a tributary on the Rhône This dam is an EDF hydroelectric power station that is used to harness energy as well as provide a reliable water source (*The Serre-Ponçon and Durance Dam History*, n.d.). Dams like this are found throughout the Rhône and should be considered when restoring a river since modifications to one area can have an effect downstream of the river. The Rhône is not only harnessed for hydroelectric power but nuclear power as well. There are roughly 20 nuclear reactors along the Rhone and other waterways in France, compensating for 70% of the country's electricity(*Nuclear Power in France | French Nuclear Energy - World Nuclear Association*, n.d.). Another example of a dam on the Rhône is the Jons dam, located on the Jonage Canal in Lyon. The construction of the Jons dam created a need for the construction of the Miribel Canal.

Figure 1: The Rhône divided into 3 sections: Haut-Rhône(Upper), Rhône(Middle), Petit Rhône(Lower).

Construction of the Miribel Canal

The Miribel canal was first created in 1848-1857 to improve transportation (See *Figure 2)*. In 1899, part of the flow was diverted to the Jonage canal. The Jonage canal led to a hydroelectric station that provided power for riverside communities (Petit et al., 1996). Because of the Jonage canal's hydroelectric purpose, it requires a constant and steady flow of water. The constant diversion of flow resulted in erratic conditions for the Miribel. In 1937, the Jons dam was constructed to better distribute flow between the Miribel and Jonage canals. Starting in the late 1950s, riverbed sediment was extracted for industrial purposes, like being used for gravel to make roads. However, the Miribel canal was not harvested until 1979. Gravel extraction lowered the riverbed, which exacerbated the problems that originated with the construction of the canal. Industrial gravel extraction had negative effects on both the river ecosystem and water supply, yet it continued until 1991 (Petit et al., 1996).

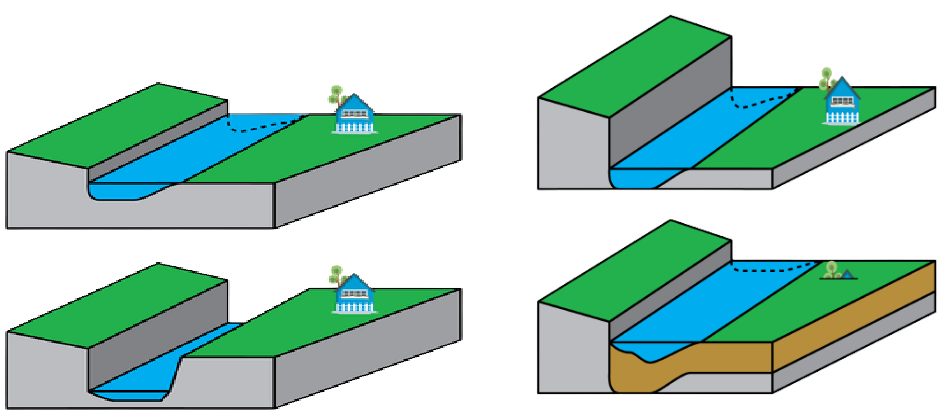
Figure 2: Map of Miribel and Jonage Canals



Current Issues with the Miribel Canal

The same type of erosion is still taking place today causing the Miribel to sink by 4 yards over the course of 50 years (V. Marion, Personal Communication, April 29, 2021). Incision causes the riverbed in the area to sink as seen in the left image below. While aggradation is pictured on the right as the bed raises (See *Figure 3*). The combination of incision and aggradation along the Miribel is what is causing most other problems along the canal. Making channel incision the project's biggest concern (V. Marion, Personal Communication, June 23, 2021).

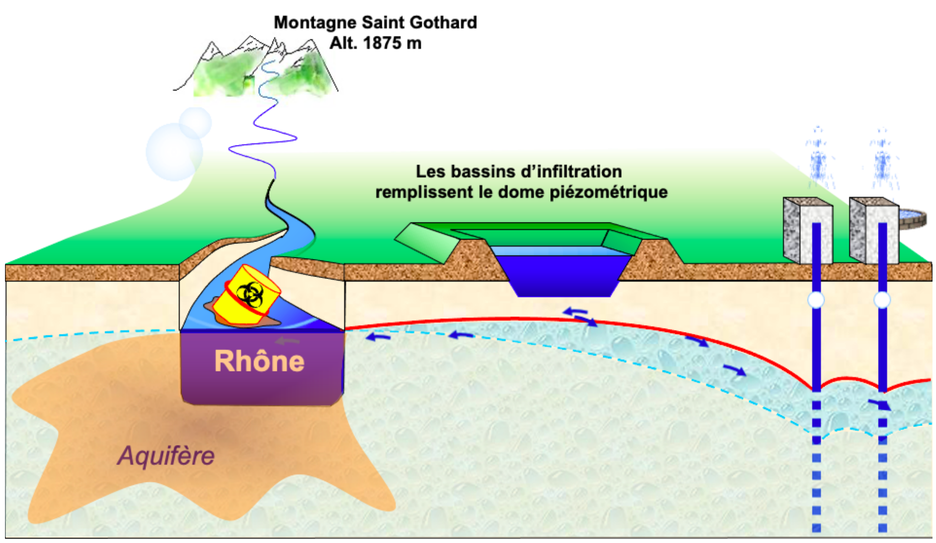
Figure 3: River Incision and Aggradation



The next issue is sediment management. During a flood, the canal water flows at extremely fast speeds which causes the riverbed sediment to be suspended and deposited further downstream. This lowers the riverbed in some areas and raises it in others. The sediment ranges in diameter, fine is less than 2mm, and coarse greater than 15mm (R. Taisant, Personal Communication, June 29, 2021). In the instance of incision, both sediments are carried downstream and cause their own issues. Suspended sediment pollution threatens river ecosystems because it prevents organisms from seeing their foods due to the murky environment and disrupts the growth of natural vegetation (EPA). Because of this usage, there have been influences of suspended particulate matter (SPM) dynamics such as resuspension and fluxes as well as the quality of the river having to do with the physicochemical characteristics and contamination (LePage et al., 2020).

Currently, sediment is being deposited near Crépieux Charmy, which provides drinking water for the city of Lyon. The increase in sediment here has a negative impact on Crépieux Charmy (F. Laval, Personal Communication, June 14, 2021) Therefore, the third most important issue to consider is the cleanliness of the water. According to an interview conducted with Frederic Laval, there are major water basins on the island of the Grand Parc, which help keep the drinking water free of pollution by creating a mound-like structure in the aquifer (See *Figure 4*). Additionally, the accelerated incision results in steep riverbanks. These steep banks have caused trees to fall and pose a threat to nearby communities. Lyon needs to be aware that this is an active large body of water that has a proxy to one of the largest parks in France, nearly 50 acres larger than Central Park in NYC. Any restoration undertaken should be effective in managing water without harming any Lyonnais communities or native ecosystems (V. Marion, Personal Communication, April 29, 2021).

Figure 4: The hydraulic barrier formed by the canal and basins.



The Rhone, at least in this area of France, is very familiar with flooding and has been attempted to be managed by diverting the flow to the Miribel (V. Marion, Personal Communication, April 29, 2021). This has caused canal walls to become damaged. One problem builds off the rest, as irregular flow of the water is a result of incision, flooding and past restorations. The current issues facing the Rhôneare summarized in *Table 1*. However, in order to determine ways to alleviate these issues an understanding of previous restoration projects should first be obtained.

Table 1: Ecological and Social Problems of the Miribel Canal

Ecological Problems		Social Problems
Channel incision	Flooding	Drinking-Water Contamination
Sediment Management	Irregular Flow Rate	Urban Proximity
Biodiversity		

Previous Rhône Restoration Projects

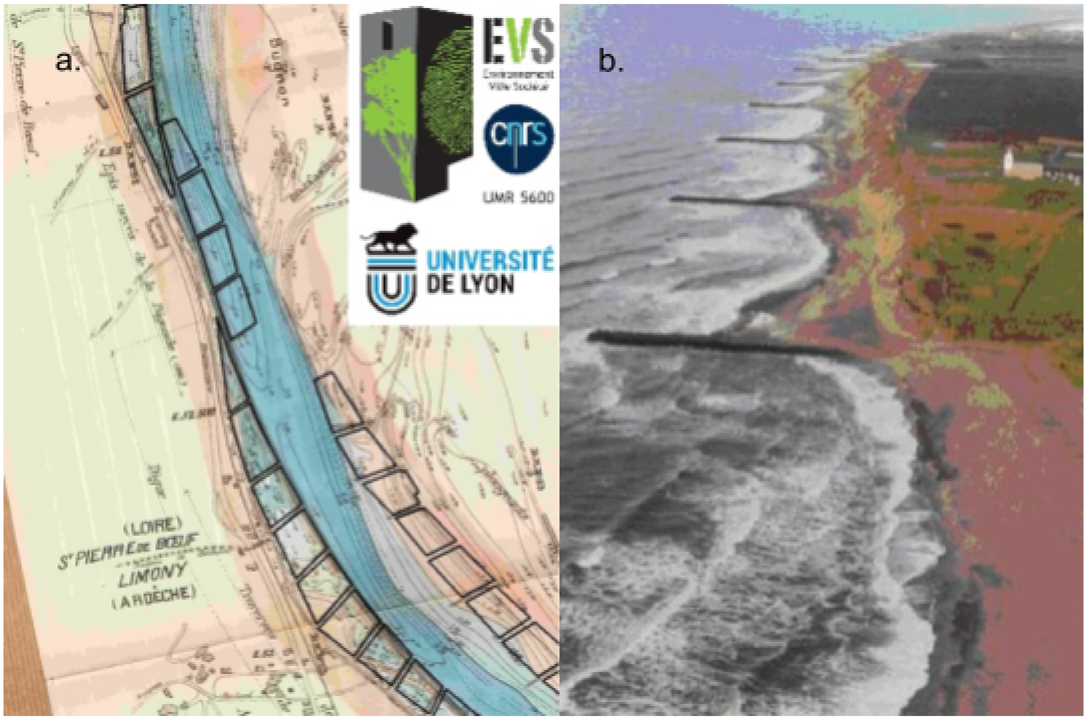
In 2002 and 2003, the Rhône experienced major flooding. As a result, Plan Rhône was created. This project lasted for seven years before it was abandoned. Plan Rhône was a floodplain restoration project that aimed to prevent future major floods (Souchon, n.d.). In addition to flood management, the plan was also concerned with tourism, culture, energy, water quality, and transport policies. The plan had to consider the multifunctional ways the Lyonnais people utilized the park. Ecosystem services is the concept of nature as an important resource for people that can provide them with recreation and agriculture. Ecosystem services in restoration work consider the relationship between people and nature and as a result, the use of the ecosystem can be managed in a sustainable way (Martin-Ortega et al., 2015). Incorporating ecosystem services is key to making urban green spaces successful.

Another restoration protest was Mission Rhône, a team within Plan Rhône that focused on the flood management aspect of the project. Mission Rhône split the river into three sections (See *Figure 1*). Local strategies for restoration were created for each section. For the lower Rhône, one strategy aimed to reduce dike failure by redistributing flood risk for towns along the river. Some towns were often flooded and others were shielded by National Rhône Company protective structures, also known as dikes. Economically valuable towns specifically were considered too vulnerable to floods (Guerrin, 2015).

Many factors contributed to the failure of Plan Rhône. One institutional factor was Plan Rhône's lack of power and legitimacy. Because the Plan was so new, local authorities had no reason to trust its proposed interventions. In addition to this, the Plan lacked sufficient leadership and funding. The Plan was supposed to be backed by several partners, including the French State, the EU, and the National Rhône Company (CNR). However, the Plan received no significant support from any of these organizations. The lack of leadership, funding, and power caused the Plan to neglect the sociopolitical aspects of river restoration and created a disconnect between local communities and the project (Guerrin, 2015).

More recent restoration projects seem to have considered the failures of these previous attempts. For example, one effort investigated the socio-environmental implications of Casiers Girardon structure removal. Casiers Girardon are similar to groyne fields and were built at the end of the 19th century (See *Figure 5*). Since then the structures have greatly deteriorated, 90% of the caisers have been fully terrestialized. The Human-Environment Rhône Valley Observatory (OHM VR) researched the consequences of removing the structures for 3 years. This research phase consisted of 12 interdisciplinary seminars between 2013 and 2015. The OHM VR utilized this research to model the effects of dismantling the structures. The model suggests that most terrestrialized Casiers Girardon should be dismantled, however, the remaining aquatic Casiers Girardon still contribute to the functionality of the river (Thorel et al., 2018). In Limony and Salaise-sur-Sanne (*See Figure 6*), the removal of the Casiers Girardon resulted in an increase in biodiversity, semi-aquatic vegetation, and riverbed size (Grand Parc, 2020). Currently, a new restoration for the Miribel Canal is in the works. This project involves several organizations.

Figure 5: Casiers Girardon and Groyne Fields



a. Map of Casiers Girardon in the Rhône

b. Example of Groyne Fields at the Danish North Sea Coast

Figure 6: Map of the platière in Limony and Salaise-sur-Sanne

Partners

The Grand Parc Miribel Jonage is the primary partner working on this project. Symalim is the parent company that owns the Grand Parc. They are in charge of defining guidelines for the park's development. SPL Segapal works under Symalim. They are responsible for the overall management of the park. The specific interests and areas of expertise of SPL Segapal include environmental education, management of natural and agricultural areas, events, public relations, water, works and improvements, and general management (SPL Segapal, n.d.). The Grand Parc partnered with 8 other organizations for the restoration project: Ain le Département, Agence de L'eau Rhône Méditerranée Corse, Centrale de Cas et de Médias Pédagogiques (CCMP), Communauté de Communes de la Côtière à Montluel (3CM), Électricité de France (EDF), Grand Lyon Métropole, Préfet Coordonnateur de Bassin Rhône-Méditerranée, and Voies Navigables de France (VNF). Some essential partners involved in the project include: Agence de l'Eau, which is one of the founding partners of the restoration project, and EDF, who manages the electricity for France.

As the primary partner, the Grand Parc liaisons communications between the research team and the partners. The main contacts within the Parc are Valérie Marion and Marion Guibert. They provide the majority of first-hand information received by the team. Although much of this information is used, there are other areas in which information must be analyzed. For example, the team relied heavily on analyzing the strength and weaknesses of case studies describing other restorations in order to better understand the issues with the Miribel Canal and potential techniques to restore it.

Examples of an Analysis of Restoration Case Studies

River ecosystems are very important to the environment and their communities, which can make decisions on how to restore them difficult. To determine if a restoration project is successful a holistic approach needs to be taken to account for many different issues regarding the project. Factors involved in restoring a river can include; morphological changes, changes in biodiversity, fluvial dynamics, and sediment management. When restoring a river different methods of restoration techniques may improve some factors more than others. By analyzing case studies, the team can obtain a better understanding of how different techniques affect different elements.

An example of a restoration method that could help with both the flow of the river and the sedimentation would be to widen the canal. Due to a prediction of increased discharges into rivers in other parts of Europe, widening rivers has been a proposed restoration method for canals such as the Rhine and Meuse rivers (Meulen et al., 2006). In this case, the river would be widened by removing sediment from the river and the nearby banks. This removal of sediment would allow for the water in the river to have more room to flow. In the case of the Meuse River, the increased area for the water could prevent flooding. While this method appears to be sound, there are limited examples of rivers where this restoration has actually been applied (Meulen et al., 2006). Furthermore, the removal of sediment would be a large and costly process especially if the sediment is polluted (Meulen et al., 2006). For these reasons taking on a large restoration project like this may be risky. This restoration method focused heavily on the morphology of the river as opposed to other aspects such as biodiversity.

Another type of restoration would involve using plant barriers. Plant basket hydraulic structures (PBHS) are a form of restoration that involves using plant barriers as a tool to catch sediment and prevent it from flowing down the river (Kałuża et al., 2018). The addition of PBHS also influences the fluvial process of the river (Kałuża et al., 2018). A case study looking at the Flinta River in Poland showed that the addition of PBHSs increased the diversity of flow rates throughout the river which resulted in increased biodiversity in the river (Kałuża et al., 2018). This restoration technique would apply to the Mirabel Canal since sediment movement and hydromorphology are issues facing both rivers. PBHS would provide a way of remedying these problems while also benefiting the biodiversity of the river.

The problems found on the Rhône are complex, requiring extensive scientific knowledge of the issues at hand as well as the means by which they can be remedied. Some of the conditions that can be found on the Rhône are also analyzed in a case study that models fluvial incision and transient landscape evolution. In doing this, the study uses scientific equations to model these relationships. These equations are directly modeled after the Yarlung Tsangpo and the Rio Torto Rivers which were observed. The case study determined that with dynamic channel width adjustment, both aggradation and incision can be decreased upstream of these rivers (Tucker et al., 2008).

In conclusion, the Rhône is a very complex and important part of Lyon. The citizens both on and around the river deserve a clean and beautiful Rhône. Thus, maintaining the river and its surroundings is extremely important, as the Rhône is important to citizens in the area, nearby industry, and species living there. Due to climate change, pollution, and damming, the Rhône and the Grand-Parc are now in dire need of revitalization. If no action is taken now, the river may undergo irreversible changes, as well as the city surrounding it therefore the team conducted several interviews as well as reviewed case studies to recommend a solution to this problem.

Methodology

The goal of our project was to make a set of recommendations for restoring the Miribel canal. The team wanted to be able to find applicable restoration techniques for the problems that the Miribel canal faces and analyze them in relation to the restraints of the canal. In order to do this the team aimed to answer three research questions.

1. What are the core challenges faced by the Miribel canal?
2. How have previous river restoration techniques succeeded or failed?
3. How are these techniques applicable to the Miribel canal?

The methods we used to answer these questions and collect data were case study research and expert interviews. They are detailed below. By researching a variety of restoration methods and analyzing their usefulness, the team is completing work that will help our partners begin their research on different methods that could be implemented. Furthermore, it will show that similar restorations have been successful which will be beneficial to motivate other stakeholders in the project. It is vital that the Miribel Canal gets restored and the data obtained in this project can be a starting point for that work. The first step in this process involved identifying the challenges that the Mirible Canal is currently facing

Identify Core Challenges Faced by the Miribel Canal

<u>Partner Communications and Expert Interviews</u>

The team mainly communicated with the project's 9 partners through our contacts with the Grand Parc: Valérie Marion and Marion Guibert. The team remotely met with Valérie and Marion once per week. Fabienne Miller and Inès Hamidou also attended the meetings and acted as translators. These meetings provided the team with first-hand information regarding the core challenges faced by the Miribel Canal.

Valérie introduced the team to Frédéric Laval. Laval manages sediment for the Rhone and thus could explain some technical aspects of the Canal. Laval also shared cases that were similar to the Miribel Canal with the team. The cases Laval shared were: Isar River (Munich), Meuse River (Belgium), and Drac River (Grenoble). The team arranged an interview with Laval (See *Interview Questions: Partner*). After the interview, Laval shared several documents and contacts with the team. The contacts he provided were: Benoît Terrier(Agence de l'Eau), Rémi Loire(EDF), and Rémi Taisant (CNR). Interviews were arranged with each of them.

Expert interviews were semi-structured. Semi-structured interviews are essentially guided conversations between interviewer and interviewee. The interviewer used a guide/set of questions to facilitate the interview, but they did not strictly adhere to it. This allowed the interviewer to ask on-the-spot questions for additional information. Semi-structured interviews provided a relaxed yet objective-driven environment.

Interviews were mainly conducted through Zoom. Other services, such as Microsoft Team, were employed if the interviewee could not use Zoom. The interviewer took notes during the interview and recorded the interview(with the consent of the interviewee). Many interviews required a translator to facilitate communications. These interviews helped aid the team in finding applicable case studies that utilized restoration techniques that may benefit the issues on the Miribel Canal

Determine how Previous River Restoration Techniques Succeeded or Failed

<u>Case Studies</u>

Case studies helped the team determine different methods of restoring rivers and define a “successful” restoration. Using databases, the team found and reviewed 25 case studies. These were collected through team research and expert referrals from interviews. The WPI library databases, like Greenfile, were heavily utilized as well as recommendations of past water restoration IQP’s from the advisors.

The criteria used for selecting case studies included ecological and social problems. By evaluating a large scope of factors involved in river restorations, a holistic approach for determining a successful restoration was followed. Because river restorations are becoming a more prevalent issue, many researchers have decided to examine previous restoration projects to evaluate what people consider to be a success (Jähnig et al., 2011). Furthermore, researchers have evaluated case studies in order to determine metrics for deciding the benefits and disadvantages of certain restoration methods in order to aid in the decision of which restoration may be most useful for a certain problem (Muhar et al., 2016). Due to the complex nature of restoration, the use of case studies helped the team develop a thorough understanding of factors to consider when proposing suggestions for restoration methods.

Articles, like “Planning for the North-European Waterfront Cities”, found through the Engineering Village Database provided insight on planning methods and “guides to good practice” when it comes to restoring waterfronts in Europe (Lorens, 2019). This supported the objective as the article analyzed the weak spots in common urban planning methods and if it was truly in the greater interest of the cities or developers. Therefore, case studies were chosen through the below criteria. The keywords for the searches of the team are bolded and were often searched in conjunction with rivers, restoration, or canals (See *Table 2*). After applicable case studies were identified, the team consulted experts in the field to help determine the usefulness of these techniques on the Miribel Canal.

Table 2: Criteria for selecting case studies

Ecological Problems		**Social Problems**
Restorations that interfere with **channel incision**	Restored rivers, or canals that have issues with **flooding**	Canals impacting **drinking water supply**
River aggradation	Rivers that have **irregular flow rates**	**Recreational areas** near waterways
Restoration concerning **biodiversity**		

Analyze Techniques Applicable to the Miribel Canal

<u>Expert Interviews</u>

The team interviewed several French restoration experts, including: Frédéric Laval (See *Interview Questions 1*), Benoît Terrier (See *Interview Questions 2*), Rémi Loire (See *Interview Questions 3*), and Rémi Taisant (See *Interview Questions 4*). We conducted semi-structured expert interviews that addressed our second research question regarding the successes and failures of the restoration techniques.

The team also interviewed several professors from WPI, including: John Bergendal (See *Interview Questions 5*), Laureen Elgert (See *Interview Questions 6*), and Katherine Foo (See *Interview Questions 7*). We conducted semi-structured expert interviews to gain insight regarding general river restorations.

We mainly conducted interviews through Zoom. However, we employed other services, such as Microsoft Teams, for interviewees who could not use Zoom. One of the expert interviews was conducted with John A. Bergendahl who is a professor at WPI that specializes in Civil Environmental engineering. In these interviews, the interviewer took notes during the interview and recorded the interview. While these methods provided the team with an abundance of data, the team still faced challenges when collecting information.

Obstacles

This project had many important parts, stakeholders, and played a role in the future of Lyon. Therefore, the team could not overlook any obstacles. Expecting any roadblocks in the future helped us plan ahead and improved the quality of our work.

The first, and largest, obstacle that the team faced was the language barrier. The members of the team have a very limited background in the French language, which made it complicated to communicate with our partners. In order to aid with this communication, we used a translator in our meetings and relied on Google Translate to help with written communication. Using these solutions the team exchanged information as needed with our french partners.

Deliverables

Once the team finished collecting data and analyzing it, a menu of potential restoration methods was compiled. The team organized these potential restoration methods based on how beneficial they would be at managing different aspects of the canal. For example, the team found restorations that would be best for biodiversity or hydromorphology issues. This proposal was provided to the sponsor so that they could see which restoration techniques are more suitable for particular concerns. Using this information our sponsors would be able to continue researching techniques of interest that they believe would be useful for restoring the Miribel Canal.

Another deliverable the team created a table in which all of the case studies were organized. In addition, a one-page summary of each case study was created which would also be provided to our partners in order to help them get a brief summary of the main takeaways of each case study.

Results and Analysis

The Rhone river, specifically the Miribel canal, is a complex water body with a variety of problems. The team compiled a list of issues from communicating with our partners and interviewing experts. Then the team collected information on various river restoration techniques. There are five different techniques identified as potential solutions to these problems. These have been collected through case studies and analyzed through the recommendations of experts on river restoration.

Identify Core Challenges Faced by the Miribel Canal

Marion Guibert and Valérie Marion are the team's main connection with the Miribel Canals's restoration. Thus, the team's connection with them is significant. Over the course of seven weeks, the team met with Guibert and Marion on a weekly basis. In these meetings, our partners provided first-hand insight into the challenges faced by the Miribel Canal.

The canal is facing a variety of issues, the first of which being incision. Incision causes the river to cut into the riverbed. High flow rates cause coarse sediment to become suspended and transported downstream, leading to a sunken riverbed. Deposition, on the other hand, occurs when sediment is deposited downstream, leading to a raised riverbed. One area that is experiencing high deposition rates is Crépieux-Charmy, which is the largest well-field in France. Crépieux-Charmy provides drinking water for the city of Lyon. The buildup of sediment in this area could lead to a contaminated potable water source.

In order to better understand some of the technical aspects of the river, the team interviewed Frédéric Laval, a project manager with Ginger Burgeap. When summarizing the issues that the river faces, Laval focused mainly on the issues involving sediment in the river. Fine sediment causes minimal issues for the river however it can still cause clogs in the flow of the river. On the other hand, coarse sediment has been causing problems for the river since it gets caught in the gravel pits that are along the river. Sandy sediment is in between coarse and fine sediment. These sediment fluxes can cause a biodiversity problem. The first way is through coarse sediment which is important for fish spawning, so a lack of coarse sediment can harm the fish population. Laval noted that this issue was the least worrisome since coarse gravel could be replenished to help aid this issue. The second issue involves security problems such as flooding and damage to dikes and dams, which occur as a result of too much coarse sediment which raises the water bed. The third issue that is occurring due to the sediment fluxes is related to water usage. Coarse sediment has caused issues with the aquifers as it creates an obstruction for getting drinking water. The groundwater system between the Miribel and Jonage has been constructed in a way in which basins in the park help to create a dome that prevents pollution from entering the wells. When sediment fluxes interfere with this system, it can make the drinking water system more fragile. Overall, the fluxes of sediment cause a variety of issues that are all related to each other and have their own challenges when thinking about restoration (F. Laval, personal communication, June 16, 2021).

Most sedimentation issues stem from the canal's irregular flow rates. Part of the Miribel Canal's flow is diverted to the Jonage Canal to generate hydroelectric power. Since the Jonage requires a constant flow rate, any floods or droughts have a harsher impact on flow rates in the Miribel. Additionally, irregular flow rates can be deadly for plant and animal life that call the river home. Certain species can only survive in that particular flow rate of the river. Not only could a flood increase erosion rates, but it could also wipe out plant and animal life alongside the river.

Benoît Terrier, the chief of hydromorphological projects at Agence de L'eau Rhône Méditerranée Corse, noted the importance of improving the ecological standing of the river according to the Water Framework Directive (WFD). The WFD is a European directive that dictates how water bodies must be restored. The directive ensures that during a restoration project, ecological benchmarks are set in order to understand how the environment has been improved through the project. Monsieur Terrier noted that because the Miribel Canal is considered heavily modified it is difficult to establish biological standards for this type of waterway. Because the Agence de l'Eau enforces the Water Framework Directive, improving biodiversity and other ecological factors are very important to this stakeholder (B. Terrier, personal communication, June 21, 2021). To summarize the most important factors that our partners were concerned with included incision, sediment management, biodiversity, and drinking water. Restoration techniques were found in order to help aid these issues.

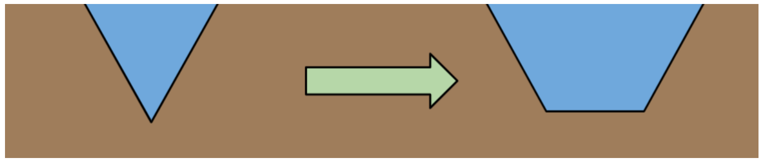
Collect Restoration Techniques and Compile their Strengths and Weaknesses

In order to best address the issues identified by our partners and other experts on the Miribel Canal, various restoration techniques were researched. The team identified five techniques that would address some of the issues faced by the canal and analyzed these techniques to see how they could be applied. The five techniques chosen were; widening the river, adjusting the slope of the banks, replenishing sediment, plant barriers, and bank armoring.

a. Widening the river can help with flow rate, flooding, and incision

One potential restoration technique is enlarging the canal's cross-section (See *Figure 7*). A wider cross-section can better accommodate strong flows, thus reducing channel incision. Additionally, by widening the surrounding floodplains and channel itself, this technique could reduce flooding (Isar-Plan Munich: A New Lease of Life for the Isar River, 2013). Although this technique is very effective, it is difficult to utilize in situations like the one found on the Miribel Canal. This is due to the large amount of the waterway which is surrounded by the city of Lyon. Acquiring land is necessary when attempting to increase the area of the banks. Therefore, in certain areas widening is not possible without displacing people's homes and businesses.

Figure 7: Cartoon depicting widening of river cross-section.



The Isar-Plan was a nature-based restoration of the Isar River in Munich, Germany which was implemented from 2000 to 2011. The Plan aimed to improve flood protection, restore ecological and morphological aspects, and improve recreation opportunities by widening the cross-section of the river. The riverbed was widened by 40m. This technique was combined with riverbank restorations. Banks were flattened, and concrete dikes were replaced with "backward hidden protection". (Isar-Plan Munich: A New Lease of Life for the Isar River, 2013). The Isar has similar concerns as the Rhone, such as urban proximity, incision, and biodiversity.

The Isar case study was recommended by Frédéric Laval. Additionally, Laval referred the team to Benoît Terrier. Terrier explained how techniques can be more beneficial depending on how they are applied. Widening embanked areas of the river would be more beneficial than widening non-embanked areas. Based on conversations with the partners, there is a desire to allow the canal to develop naturally with minimal construction. So the technique of widening could be useful when considering the naturalization of the canal, but the balance between humans and the environment must be met.

More incised channels like the Walla Walla and Tucannon rivers have also experienced flooding issues since the end of the last ice age. This caused the channel to incise, meaning the initial incision naturally evolves to a stable condition in which the river lies in the floodplain between elevated terraces (Beechie et al., 2008). This is a 5 stage process that can take an estimated time based on $\frac{incision\ depth\ (m)}{\Delta d}$.The time frame could take anywhere from 40 to 200 years, depending on river depth (Beechie et al., 2008).

Small, deeply incised channels like the Miribel tend to retain sediment on the river floor because they are too small to export sediment as rapidly (Beechie et al., 2008). Thus, these channels tend to resist widening. Therefore, we may need to assist the environment in this natural process. This technique would not only address incision, flow rate and flooding of the Miribel canal, but when utilized in the correct ways can improve biodiversity. Depending on the scale of the project the effects of widening on the ecology and sediment can easily be maintained.

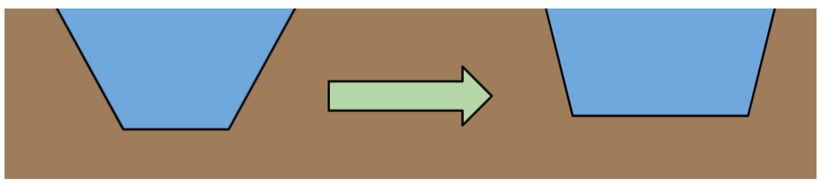
This restoration technique would address many of the essential issues of the Miribel canal and appears to be growing in popularity in Europe. The strengths of this technique include its ability to prevent flooding and icision while also helping the channel take a more natural and river-like morphology. Many experts including; Marion Guibert, Valarie Marion, and Frédéric

Laval believed that this issue would be immensely beneficial to the river. However, while the strengths of this method are great, so are its weaknesses. For example, implementing this technique would involve: acquiring large amounts of land, large scale construction to dig the river, and finding a location for the sediment that is removed from the river. These processes are costly; making it difficult to implement this technique, despite all the benefits it may provide to the canal.

b. Adjusting bank slopes would help with flow rate, flooding, and incision

A technique that is similar to widening involves adjusting the slopes of the banks (See *Figure 8*). The methods used for adjusting the slopes are comparable to the methods used for widening. Thus, this technique is often used in conjunction with widening. A restoration project on the Lower Rhine River in Germany utilized this method. The banks of the Rhine were steepened in order to mimic incision. This resulted in decreased incision rates (Arbós et al., 2020).

Figure 8. Cartoon depicting adjustment of riverbank slopes.



Experts had mixed opinions on this technique when it was mentioned in interviews. Benoît Terrier raised some concerns. The equilibrium of the river requires a specific slope, if the slope is wrong the river can be eroded and stripped of nutrients. It is difficult to find the correct slope due to uncertainty with models (B.Terrier, personal communication, June 21, 2021). Rémi Loire agreed that this technique would lessen the flow rate pressure. However, Loire was concerned that this technique is too artificial, as it just makes the canal bigger rather than restoring its natural shape (R. Loire, personal communication, June 25, 2021).

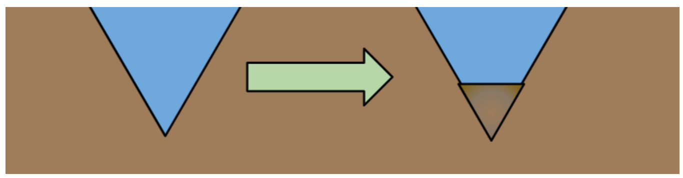
While this technique could help the Miribel Canal with incision, and consequently sediment management, it has many limitations. The largest issue with this technique is disrupting biodiversity. The digging required to adjust the slopes can increase sediment suspension and disturb riparian ecosystems. Additionally, if the construction impedes the river's equilibrium and its nutrients are stripped, the river won't be able to support life. A more nature-based restoration technique may be a safer alternative.

Overall this technique has many of the same benefits as widening the river, however it is much less complete of a technique since it would just further chanalize the river as opposed to helping it return to its natural morphology. For this reason the team believes that widening the river would be a better technique than steepening the river banks. Nevertheless, the team believes that there could be some benefit of combining widening the river with steepening the river banks.

c. Sediment replenishment would help areas where sediment has been depleted

Sediment replenishment is another possible method that can be used to manage the sediment of the Miribel Canal(*See Figure 9*). There are places in the Rhone with too much sediment such as in the Jonage canal and this can be excavated and placed into areas of the river with sediment depletion that has been caused by incision (F. Laval, personal communication, June 16, 2021). Removing coarse sediment will help decrease the amount of damage and erosion done to the Miribel canal. This method involves adding forms of sediment to a body of water.

Figure 9: A cartoon depicting sediment replenishment in a canal



With the Miribel canal specifically, the sediment has been stripped away in some areas due to the incision and rapid flow rate. For this reason, adding sediment into the river could aid with this issue. For example, adding sediment would help raise the water table of the aquifer and thus provide a better drinking supply for the city of Lyon. While this is beneficial it also poses another issue since it can result in the water being held for longer periods of time which can lead to bacterial contamination (F. Laval, personal communication, June 16, 2021).

In one case study gravel replenishment was also used to restore an active channel affected by an incision that is connected to the Saint-Sauveur dam in Quebec, Canada. The goal of the case study was to quantify the morphological changes after the method was implemented in order to measure its success. Sequential high-resolution digital elevation models, bedload tracing using active ultrahigh-frequency radio-frequency identification technology, and complementary field surveys were used to evaluate the efficiency of the restoration (Brousse et al., 2019). As a result, the sediment replenishment operation was not successful in shifting the channel, but the methods used for measuring its success were accurate and useful.The technology used in this case study could be beneficial to the Miribel Canal project since concern that was mentioned in an interview is that coarse sediment can get stuck downstream where the dams are located (R. Taisant, personal communication, June 29, 2021) Given the results of this case study, sediment replenishment may not always be effective as a restoration method therefore this should be considered when finding the best method to restore the Miribel canal.

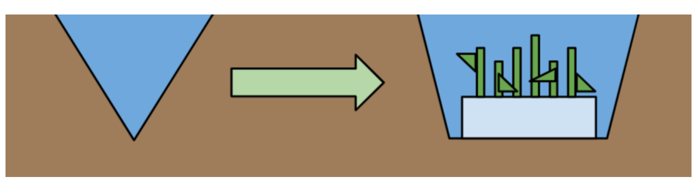
Another case study focused on restoring sandy-bottom lowland streams in the Netherlands that have been affected by channel incision. This consisted of adding sand and woody debris to the stream channel. (Oliveira et al., 2019). The goal of adding these was to see if there could be any improvement within hydrology stream complexity that would increase macro biodiversity. The sand and wood debris addition did end up being a success because the instream conditions were improved therefore being a successful restoration method for incised lowland streams (Oliveira et al., 2019). Frederic Laval also commented that sediment replenishment could be beneficial to biodiversity since fish require a bed of coarse sediment as a location for spawning (F. Laval, personal communication, June 16, 2021). Furthermore, the information provided in this case study could be used for our method of widening the river because if it is widened, the ecosystems will be threatened but with sediment replenishment, this effect can be reduced therefore being an effective solution (V. Marion, Personal Communication, April 29, 2021).

While this technique would not address the cause of the sediment management problems, it would help in the short term with many of these issues. Furthermore there is a readily available supply of coarse sediment from the Jonage Canal and other areas in the Rhône that could be used to replenish the sediment. For this reason the team believes that this would be a feasible restoration technique that would aid in some of the issues the Mirbel Canal is facing in the short term. The team does note that since this technique does not address the root of the issue eventually the sediment would just get washed further down the stream again. For this reason the tema recommends combining these techniques with another restoration method in order to address the cause of the sediment issues.

d. Plant barriers would help the flow of the river and collect sediment

A significant issue that the Miribel Canal is facing is that the river has a rapid flow that picks up sediment and transports it along the river resulting in both incision and aggradation. A potential restoration method that could help combat this is the use of plant basket hydraulic structures(PBHS). PBHS are aquatic plants that act as barriers in the river and collect sediment that is flowing downstream (Kałuża et al., 2018). The PBHS are made from plastic baskets that are filled with sand and gravel as well as willow cuttings which are placed vertically in the baskets (See *Figure 10)* (Kałuża et al., 2018). These structures function similarly to weirs and can affect the hydromorphology of the river.

Figure 10: Cartoon depicting plant barriers in a canal



One strength of plant barriers as a restoration technique is their ability to slow the flow of the river by creating an obstruction. A specific case study that used this restoration method was the case of the Flinta River in Poland. The addition of the PBHS was used to help improve the hydromorphic status of the river by returning it to its natural state. After the PBHS technique was incorporated into the river morphological changes were seen in the river including; an increase in shear stress after the structures, a diversion in the fluvial direction, and increased variability of fluvial velocities (Kałuża et al., 2018). Overall, these changes resulted in a better hydromorphic status of the river, increasing the status from class IV to class III according to the River Habitat Survey method (Kałuża et al., 2018). The effects of plant barriers on the velocity of the river were further supported by a study on the Ślęza River in Poland, which is another lowland river. In this study, Phragmites australis, a common read, was analyzed to determine how clusters of this plant affect the fluvial velocity of a river (Wolski & Tymiński, 2020). The main findings of the study showed that when patches of *Phragmites australis* are found in rivers it can cause the velocity of the river to slow down directly after the cluster and increase around the cluster (Wolski & Tymiński, 2020). The study also found that the effects of the velocity were highly dependent on the density of the plants in the river (Wolski & Tymiński, 2020). Furthermore, Plant barriers can be very beneficial for collecting sediment and preventing it from flowing further downstream. In the case study with the Ślęza River in Poland, it was found that variation of velocity due to the plant structures causes an increase in drag and turbulence in the river which can affect the transport capacity of the river (Wolski & Tymiński, 2020).

Due to the changes in flow velocity and the collection of sediment, plant barriers could benefit the ecological condition of the river by increasing biodiversity. It was found that on the Flinta River biodiversity increased after the plant barriers were added because they increased the diversity of the flow rate along the river (Kałuża et al., 2018). These diverse flow rates made the environment more suitable for more types of species thus increasing biodiversity. In addition, Benoît Terrier noted that the collection of sediment and woody debris that would result from implementing these structures would also help the ecosystem (B. Terrier, personal communication, June 21, 2021).

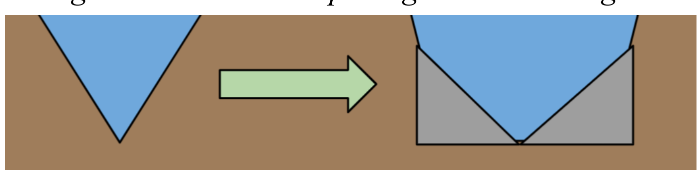
Plant barriers are also appealing from the standpoint that they are very cost-effective and have limited risks to the river. One important potential risk which Terrier mentioned is that the barriers could collect too much sediment, resulting in the river becoming dammed (B.Terrier, personal communication, June 21, 2021). In order to prevent damming, a balance would need to be reached so that there are enough plants to slow the river but not enough to dam it. Other potentially harmful consequences of using plant barriers as a restoration technique include erosion and clogging the dams downstream. In the Flinta River, the increase in shear stress created by the PBHS resulted in erosion however the authors noted that the erosion will not exceed 1.5m (Kałuża et al., 2018). Also, effects of the PBHS are seen locally where the structures were added and do not have a significant effect further downstream from the river. Rémi Taisant, a hydromorphical expert at CNR, also had concerns regarding debris from the plants when they die getting caught in the dams downstream from the Mirbel Canal (R. Taisant, personal communication, June 29, 2021). It is also important to note that both the Flinta and the Ślęza River are lowland rivers that have much slower flow rates than the Miribel Canal which makes the feasibility of implementing this technique questionable. In order to have this method be successful a plant with a strong root system would likely need to be chosen (K. Foo, personal communication, July 1, 2021). While there are many benefits to using plant barriers as a restoration method there are also many limitations to consider as well.

Overall Plant barriers have many benefits including; variating the flow of the river, collecting sediment, and increasing biodiversity. The main drawback of this technique is that it has primarily been done on small lowland rivers. For this reason the feasibility of implementing this technique is questionable since the plants may not be able to withstand the faster flow of the Miribel Canal. However, this technique is relatively inexpensive and has few negative consequences so the team believes that it may be a worthwhile technique to attempt.

e. Riverbank armoring will help prevent incision

As stated before, the Rhône River is experiencing high flow rates as well as incision due to sediment being transported downstream. Another restoration technique that is applicable is one known as riverbank armoring. Riverbank armoring utilizes large, jagged rocks known as riprap. These rocks are placed along the banks of the river, especially in areas where scour is present (See *Figure 11)*. These rocks decrease sediment pickup since the rocks act almost as anchors for sediment found at the bottom of the river. With the decreased sediment pickup, riprap also aids in slowing the rate of flow in the river, as water traveling across these rocks is unable to gain or retain the same speeds as without them (J. Bergendahl, personal communication, June 21, 2021).

Figure 11: Cartoon depicting bank armoring in a canal



This technique, although not beneficial to life-forms inhabiting the river, is not harmful either. In case studies observing the biological effects of riverbank armoring, it was found that biodiversity was neither increased nor decreased in areas where armoring was placed nor downstream (Stein et al., 2013). Although not directly beneficial to life forms on its own, when paired with PBHS, riverbank armoring may in fact aid in the plants' ability to stay rooted in the strong currents of the Miribel Canal. The large rocks, if placed correctly, can act almost as anchors for the roots of the PBHS (Katherine Foo, personal communication, July 1, 2021). According to the CRAM (California Rapid Assessment Method) index test, in areas where armoring was present, there were slightly lower scores in areas with riprap. This is believed to be caused by the lack of riparian vegetation and instream habitat due to armoring. This difference was minimal, and downstream effects were non-existent. In terms of macroinvertebrates, there was no observable change at or after the armoring (Stein et al., 2013).

One case study conducted on 6 rivers in Southern California analyzed the effects of riverbank armoring. Specifically, it reviewed what effects this technique had on both river geomorphology and biology. First, in the areas where armoring was present, it was concluded that the channel had been incised the least, and in areas downstream, the incision was less dramatic than areas upstream unaffected by bank armoring. Additionally, the sediment size in areas with armoring was smaller on average, meaning sediment normally transported in incising rivers was not being carried downstream due to riprap (Stein et al., 2013).

Along with the previous benefits to riverbank armoring, one final benefit is the low cost. Because it is a somewhat simple technique, the majority of any cost is in researching the size and amount of riprap needed to successfully slow river flow, as well as transporting these boulders to the river. Although it is a cheaper method, the effectiveness of this technique is extremely dependent on the initial research, as the location of the rocks along with their size and shape is crucial. Riprap that is too effective can disrupt steady flow rates and destroy habitats, while rocks that aren't effective enough do not address the needs of an incising river (J. Bergendahl, personal communication, June 21, 2021).

River bank armoring is a relatively simple restoration technique that could help the Miribel Canal by slowing the flow and preventing incision. While this would benefit the river the team is concerned that there are limited case studies that utilize these techniques. For this reason the team is hesitant to strongly recommend this technique without further research.

Recommendations

The issues pertaining to the Miribel canal are very complex and intersect with each other in many ways. This creates a challenge when considering a method of restoring the canal. Five potential restoration methods were researched to help fix the seven problems on the canal that were identified (see *Table 3*). In order to determine which restoration techniques would be most suitable, the most important issues with the canal were identified. By talking to our partners, Valarie Marion and Marion Guibert, and several experts, the most important issues were identified. Our partners identified Incision as being the most important issue followed by sediment management and drinking water. Furthermore, many of the experts including Frédéric Laval and Benoît Terrier stressed the importance of biodiversity. For this reason when considering restoration techniques to recommend the team focused on restorations that would be best suited to address these issues.

Table 3: Potential restoration techniques and problems with the Miribel Canal

Restoration Technique	**Problem with the Canal**
Widening the Canal	Urban Proximity
Adjusting Bank Slopes	Incision
Sediment Replenishment	Biodiversity
Plant Barriers	Sediment Management
Bank Armoring	Flooding
	Flow Rate
	Drinking-Water

These techniques have been implemented around the world, however they need to be tested on site to determine their specific applicability to the Miribel Canal. Since the Miribel Canal is in such a unique position, it is difficult to predict the effects of these techniques. The best way to test the applicability of restoration techniques is small-scale experimentation. Restoration specialists should implement a mix of these techniques to small sections of the Miribel Canal. A possible example of this type of experiment, recommended by Professor Foo, could be to widen the river in a shallow area of the river. This could enhance recreation spaces for the park and slow the rate making the flow safer for the community. Downstream effects, biodiversity, and the drinking water should be closely monitored prior, during, and after the techniques are implemented.

Biodiversity and Drinking Water Should Be Considered with any Restoration Technique

Biodiversity and drinking water are aspects that may be unintentionally affected by restoration methods used to fix other problems. For drinking water specifically, it is important to consider how the restoration technique may affect the drinking water supply. For example, sediment replenishment will allow for the water table to rise which would increase the supply of drinking water (F. Laval, personal communication, June 16, 2021). While this may seem like a benefit it is a bit more complicated since too great a supply of drinking water could result in the water sitting which would allow for bacteria to contaminate the water (F. Laval, personal communication, June 16, 2021). On the other hand, widening the river may be harmful to the environment since it would lower the water reserve in the river.

Biodiversity is another important problem that should be considered when restoring the river. While none of the techniques discussed are specifically used to increase biodiversity, many of them can affect biodiversity in positive or negative ways. For example, plant barriers would be used to slow the flow of water and collect sediment, however, the variation of flow rates caused by these structures would likely increase biodiversity (Kałuża et al., 2018). Other more natural forms of restoration such as bank armoring may also be good for biodiversity. There are also methods that could be potentially harmful to biodiversity such as sediment management. While increasing the supply of coarse sediment could help increase the species of fish by providing an area for them to spawn, it could also be very damaging to the aquatic environment if it is not done properly. For example, adding too much sediment or incorporating the sediment in the wrong way could harm the aquatic species in the canal. The construction required to implement these techniques also poses a threat to biodiversity. Nature-based solutions, such as the Isar Plan, plant native flora post construction (Isar-Plan Munich: A New Lease of Life for the Isar River, 2013. The native vegetation acts as a bandaid for the scars left by construction and stimulates the ecosystem from the base of the food chain.

Economic and Political Considerations Need to be Taken into Account in the Future

The next set of recommendations aim to consider the future of this project. Ecological and social factors are not the only concerns when making final decisions on restoration techniques. Economic considerations will be necessary to make a reasonable conclusion within budget. Some methods like sediment replenishment or displacement require expensive transportation (R. Loire, personal communication, June 25, 2021). While others like plant barriers being bought and installed by a partner may be cheaper depending on the decided flora. There are also french regulations to follow which outline the European Water Framework Directive and gravel mining rules (R. Loire, personal communication, June 25, 2021).

Overall we recommend choosing one or a combination of a couple of techniques and trying it on a small scale. Which lowers the stakes and may help motivate the solution to be completed. For example, professor Katherine Foo of WPI proposed a solution where a shallow part of the river could be widened to slow down water flow, prevent incision and create a swimming area or recreational place for the park. Any result should consider not only how restoration can consider the environment, but work with the ecosystem. Creating a multifunctional park and project which benefits the community and stakeholders will be the greatest challenge.

Conclusion

Bank armoring, plant-based hydraulic structures, and sediment replenishment are three techniques that are recommended by the team for sediment management within the Rhone. Bank armoring consists of using angled rocks or formations along the banks of a river or stream. These angled rocks or structures can be used to slow down the flow rate of a moving body of water due to the obstruction that they cause. This can help with sediment management because since the flow rate will be reduced, the rate at which the sediment is being transported will also be reduced. If these are implemented in an effective way, then the coarse sediment within the river can be less destructive. Plant basket hydraulic structures are baskets set at the bottom of a river that is filled with plants. These structures can be used as an obstacle for sediment flowing at the bottom of the river, therefore, collecting the coarse sediment of the river. This helps with sediment management because it decreases the amount of sediment flowing through the river, therefore, decreasing its chances of eroding the Miribel canal. Sediment replenishment is the final method recommended by the team for sediment management and it consists of removing sediment and adding that sediment to different locations of the body of water. Sometimes this method consists of simply adding a type of sediment to an area that needs it that has not been removed from the same body of water. While these methods seem promising for managing sediment, some of the same methods and other methods should be considered to make sure that the drinking water issues are also addressed.

The team researched 5 restoration techniques involving widening the canal, adjusting the bank slopes, sediment replenishment, using plant barriers, and bank armoring in order to develop recommendations for the management of the Miribel Canal. The restoration methods were retrieved and analyzed using case studies as well as through expert interviews. After analyzing the case studies, the team concluded that every technique should be further analyzed and that the potential technique used for restoration should also consider biodiversity and the drinking water supply of Lyon. Overall the main takeaway is that the problems on the Miribel canal are significant and will continue to get worse if nothing is done. For this reason it is important that something is done even though the issues are complex. This restoration project is significant and has many complicating factors, yet the team believes that this project can be successful. Many restoration techniques have been found that can aid with some of the issues the Miribel Canal is facing and with the continued support of all the partners of the project the team hopes one of them could be implemented in the future.

Appendices

Interview Questions

1. Frédéric Laval, Ginger Burgeap
    a. What is your role in working with the Miribel Canal?
    b. How would you summarize the issues with this portion of the Rhône?
    c. Have you worked on past restorations with the Rhone, if so what were they?
    d. Do you know any other key subject matter experts that we could contact?
    e. What were the most significant obstacles that the organization has faced while working on this restoration plan?
    f. How do restoration attempts affect groundwater and drinking water supply?
2. Benoît Terrier; Agence de l'Eau
    a. What is your role in working with the Rhône? Have you ever worked with the Miribel Canal?
    b. How would you summarize the issues with the Rhone? Specifically, how is the drinking water being affected?
    c. What were the most significant obstacles that the Agence has faced while working on this restoration plan?
    d. What are the important goals for a restoration project?
    e. Do you know any other subject area experts that would be beneficial for us to reach out to?
    f. Do you have any thoughts on these restoration techniques?
        i. Widening the river
        ii. Using plant barriers to slow the flow and collect sediment
        iii. Increasing the gradient of the river banks
        iv. Replenishing sediment into the river
3. Remi Loire; EDF
    a. What is your role in working with the Rhône?

    i. Have you ever worked with the Miribel Canal?

b. How would you summarize the issues with the Rhone?

    i. Specifically, what is the effect on hydroelectric power plants?

c. How would you summarize sediment transport along the Rhone?

d. What were the most significant obstacles that the EDF has faced while working on this restoration plan?

e. What are the important goals for a restoration project?

f. Which articles or books of yours will be the most applicable to our research? How might we find them?

g. Do you have any thoughts on these restoration techniques?

    i. Widening the river

    ii. Using plant barriers to slow the flow and collect sediment

    iii. Increasing the gradient of the river banks

    iv. Replenishing sediment into the river

h. Do you know any other subject area experts that would be beneficial for us to reach out to?

4. Remi Taisant; CNR

    a. What is your role in working with the Rhône?

        i. Have you ever worked with the Miribel Canal?

        ii. We understand CnR works in the Pierre-Benite area of Lyon, could you tell us more about this?

    b. How would you summarize the issues with the Rhone?

        i. Specifically, what is the effect on hydroelectric power plants?

    c. How would you summarize sediment transport along the Rhone?

    d. What were the most significant obstacles that the CNR has faced while working on this restoration plan?

    e. What are the important goals for a restoration project?

f. Do you know any other subject area experts that would be beneficial for us to reach out to?
g. Do you have any thoughts on these restoration techniques?
    i. Widening the river
    ii. Increasing the gradient of the river banks
    iii. Replenishing sediment into the river

5. John Bergendahl, WPI
    a. Could you describe some of the work you have done with hydraulics?
    b. Do you know of any restoration techniques that could be used to slow down the flow of a river?
    c. Do you have any thoughts on these restoration techniques?
        i. Widening the river
        ii. Using plant barriers to slow the flow and collect sediment
        iii. Replenishing sediment into the river
6. Laureen Elgert, WPI
    a. Do you have any experience with restoring canals or other waterways?
    b. What can you tell us about landscape evolution models?
    c. One restoration technique we are researching involves widening the river and adjusting the slopes of the river banks.
        i. Do you have any thoughts on this technique?
        ii. How could landscape evolution be beneficial to this module?
    d. How can restoration projects gain political and public support?
    e. When thinking about a restoration project, do you have any insight about how to plan it so that the ecosystem is either unaffected or improved?
        i. Do you have any tips for incorporating an environmental perspective into a remote project?

7. Katherine Foo, WPI

    a. Do you have any experience with waterfront development or restoration?

    b. How can restoration projects consider political and public cooperation?

    c. One restoration technique we are researching involves widening the river and adjusting the slopes of the river banks. Do you have any thoughts on this technique?

    d. When thinking about a restoration project, do you have any insight about how to plan it so that the ecosystem is either unaffected or improved?

    e. Do you have any tips for incorporating an environmental perspective into a remote project?

    f. What are the biggest consequences of not considering biodiversity when restoring rivers?

Timeline

Task	PQP	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Research case studies on global river restoration project								
Interview partners of the Grand-Parc								
Conduct interviews with experts on restoration								
Create Recommendations								

Case Studies Organizational Chart

Title	Date	Overview	Biodiversity	Incision Prevention	Sediment Management	Flooding	Flow rate	Drinking Water	Urban Proximity	Pros	Cons	Relevence (1-3)	Restoration Method
The Impacts of Natural Flood Mana	2016	The technique	☐	☐	☑	☑	☑	☐	☐	These te	These tech	1	N/A
Hydraulic Research for Lateral Pla	2019	plants have be	☐	☐	☑	☐	☑	☐	☐	This expe	The experi	2	Plant Barriers
Modeling fluvial incision and transi	2008	Our results em	☐	☑	☐	☐	☐	☐	☐	We show	Very theor	3	N/A
Nature-Based Solutions (NBSs) Ap	2020	Analsys of Isa	☑	☑	☐	☑	☐	☐	☑	Deals with river wide		3	Widening
Isar Plan	2011	Widening a riv	☑	☑	☐	☑	☐	☐	☑	Deals with river wide		3	Widening
River Response to Anthropogenic	2020	Steepening th	☐	☑	☐	☐	☑	☐	☐	Deals dir	technique	3	Channel Steepening
Channel incision, evolution and po	2019	This consisted	☐	☑	☑	☐	☑	☐	☐	could be	deciding w	3	Sediment Replenishment
Channel response to sediment rep	2020	gravel replenis	☐	☑	☑	☐	☑	☐	☐	methods	the sedime	3	Sediment Replenishment
On the morphological evolution of	2018	This case stud	☐	☑	☐	☑	☐	☐	☐	River is s	Studies the	1	Sediment Replinishment
Channel incision, evolution and po	2007	Analyzing the	☐	☑	☐	☑	☑	☐	☐	The effec	Does not p	2	Widening
Lowland stream restoration by san	2019	adding woody	☐	☑	☑	☐	☐	☐	☐	Prevents	Sand is no	2	Sediment Replenishment
Research on urban canal renewal	2021	Looks into lan	☐	☐	☐	☐	☐	☑	☑	Takes a l	Less abou	1	N/A
Channel response to sediment rep	2020	Adding gravel	☐	☑	☑	☐	☐	☐	☐	The grav	gravel repl	3	Sediment Replenishment
Plant basket hydraulic structures (F	2018	plant barrieres	☐	☐	☑	☐	☑	☐	☐	helped sl	mostly goo	3	Plant barriers
Studies on the threshold density of	2019	understanding	☐	☐	☑	☐	☑	☐	☐	created d	could effec	3	Plant Barriers
Diversion canal to decrease floodir	2020	Discusses dive	☐	☐	☐	☑	☑	☐	☐	Uses dat	Diversion	2	Diversion Canal
The anthropogenic nature of prese	2015	Analyzes the v	☐	☐	☑	☐	☑	☐	☐	Looks at	Low energ	2	N/A
Reach-Scale Geomorphic and Biol	2013	Analyzes biolo	☑	☐	☑	☐	☑	☐	☐	Analyzes	any uninte	3	Riverbank Armoring

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