Additional Case Study Analysis on Sediment Replenishment Appendix Section of-

Rhône River: Restoration Recommendations for the Miribel Canal

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Sediment Replenishment Overview

In some cases bodies of water will be depleted of sediment or have too much of it. Sediment replenishment is a method used for sediment management. This technique involves the addition of bed-load sized sediment into areas that need this type of restoration (Izumi et al., 2021). There are several situations where dams that are used for hydropower contribute to streambank erosion such as in the Miribel canal. Therefore this method has been widely used in Japan and is starting to become more common all around the world because of its efficiency in restoration projects.

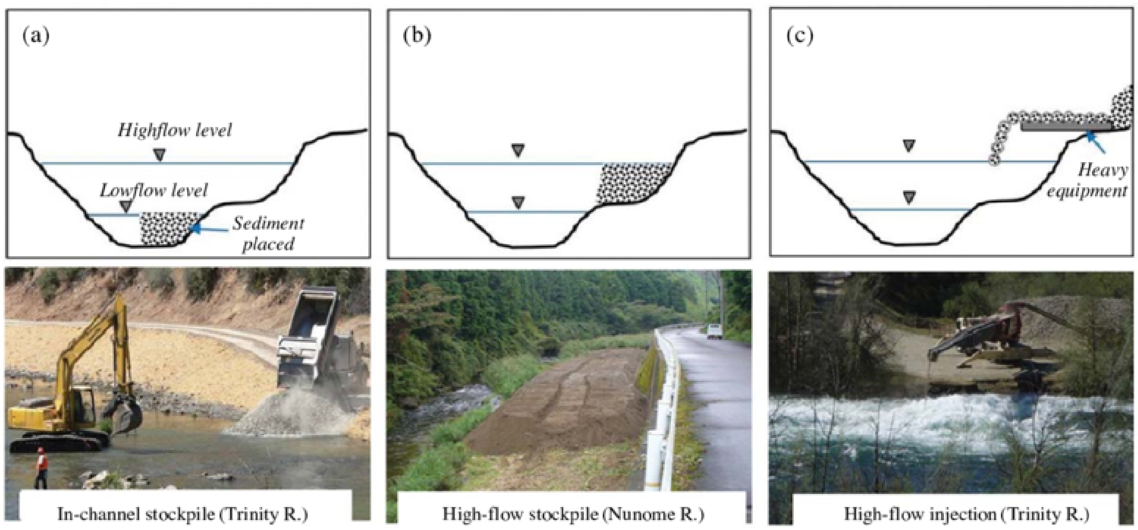

Figure 13: Sediment Replenishment Examples

Importance of Sediment Replenishment

Sediment is a very important aspect within bodies of water because it is important from the ecological perspective. A balance between sediment transport and deposition is necessary in maintaining the ecological equilibrium within a system. However, structures such as dams and reservoirs make an ecological equilibrium a little bit more difficult to maintain because of the disruption of the morphology and hydromorphology of the aquatic system. The distribution of sediment is especially disrupted, causing effects on the biodiversity within the environment as well as disrupting the ecology (Izumi et al., 2021). Because of these effects, sediment management is needed to ensure that the hydromorphology of the aquatic system is as natural as possible.

Sediment replenishment can manage sediment because in deficient areas or areas with more sediment than needed, these locations can be fixed. Removing the excess sediment from areas that are overwhelmed into areas with deficits in sediment can be helpful in making sure that the sediment types are not changed while fixing the problem (Battisacco et al., 2016).

This method also has the ability to help fish species in creating spawning areas because they use different types of sediment. Some fish species prefer either coarse, sandy, and fine sediment as shown in Figure 14. This is important in the Rhône because it has around 30 fish species and improving the ecology of the river is a goal of restoration (F. Laval, personal communication, June 14, 2021). Because fish species and certain organisms rely on sediment, ensuring that there is limited sediment deficiency is necessary for their populations to thrive.

Figure 14: Baby Trout in coarse sediment spawning area.

Sediment Replenishment in the Rhône River and Miribel Canal

When considering sediment replenishment in rivers, the type of sediment used for replenishment should be considered carefully. The morphology of the river should stay fairly natural to sustain the ecology and natural flow. Choosing a proper implementation method for the sediment is also necessary.

Fine sediment and coarse sediment are the two types of sediment that should be considered when thinking about sediment replenishment in rivers and canals (F. Laval, personal communication, June 14, 2021). These types of sediment might be more abundant in different areas of the river. Analyzing which types of sediment are accumulating in specific areas is necessary. If there is naturally occurring coarse sediment in a specific location that has a sediment deficiency, then more coarse sediment should be added to that area. The same method can be applied to fine sediment. If a river has more fine sediment in a specific area that has a deficiency, then more fine sediment should be added there to help the morphology of the river (F. Laval, personal communication, June 14, 2021).

Coarse sediment is very useful when thinking about river ecosystems. In very common cases, this type of sediment is useful for fish spawning. The Rhône has around 30 species of fish therefore adding this type of sediment will be useful in maintaining the biodiversity of the river (F. Laval, personal communication, June 14, 2021). Although using too much coarse sediment can lead to the waterbed being raised causing the flow rate to be more intense which can cause flooding or destruction of water storage infrastructure such as canals, dams, or bridges. Another issue with coarse sediment is the possibility of increasing drinking water supply obstruction (F. Laval, personal communication, June 14, 2021). In this, too much coarse sediment can affect the relationship between the river and the aquifer by decreasing its accessibility. An example of this in the Rhône is the hydraulic barrier being affected by coarse sediment. The purpose of the hydraulic barrier is to guide superficial water in the river away from the aquifer into the surface so that pollution cannot infiltrate it as shown in Figure 4. There is a slope that allows for pollution to be guided in an opposite direction, and if this slope is obstructed then it will become fragile and allow for more pollution entry (F. Laval, personal communication, June 14, 2021). While identifying the proper sediment type that should be used, the implementation methods of the sediment itself should be considered.

In the case of the Miribel canal and Rhône river, coarse sediment is most suited to use in a sediment replenishment restoration project. There are 4 main techniques in injecting the sediment: in-channel bed stockpile, high-flow stockpile, point bar stockpile, and high-flow direct injection (Ock et al., 2013). The in-channel bed stockpile method consists of placing spawning gravels into the channel when there are low flows. High-flow bed stockpile consists of placing the coarse sediment along the margin of the bank and allowing the sediment to be distributed when there are high flows as shown in The point-bar stockpile method introduces sediment in an angular way which allows for the sediment towards the river bed to be transported in high flows. The last method used for coarse sediment implementation is the high-flow direct injection method. In this, the coarse sediment is conveyed into the river using heavy machinery during high flows (Ock et al., 2013). These four methods are shown in Figure 15 .

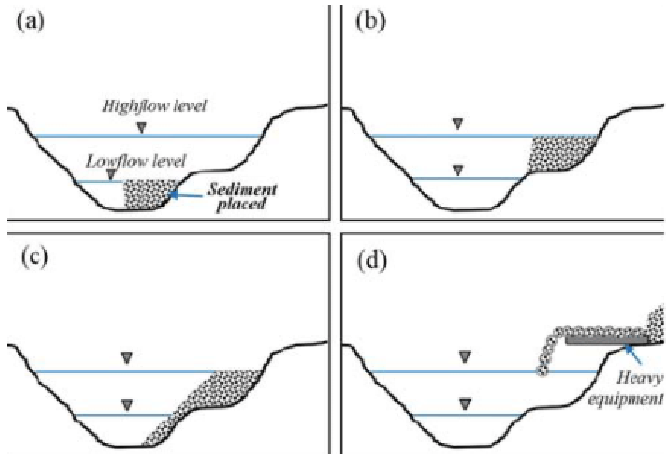

Figure 15: Sediment Replenishment injection methods

Although there are some considerations for sediment replenishment such as using coarse sediment and choosing the correct implementation method, further analysis through case studies can be used to see possible effects.

Additional Case Studies on Sediment Replenishment and Analysis

Laboratory-made alpine gravel-bed stream in Switzerland

Overview

This case study revolves around the effects of dams trapping sediment in upstream areas such as a reservoir. This study was conducted in a laboratory-made alpine gravel-bed stream in Switzerland.

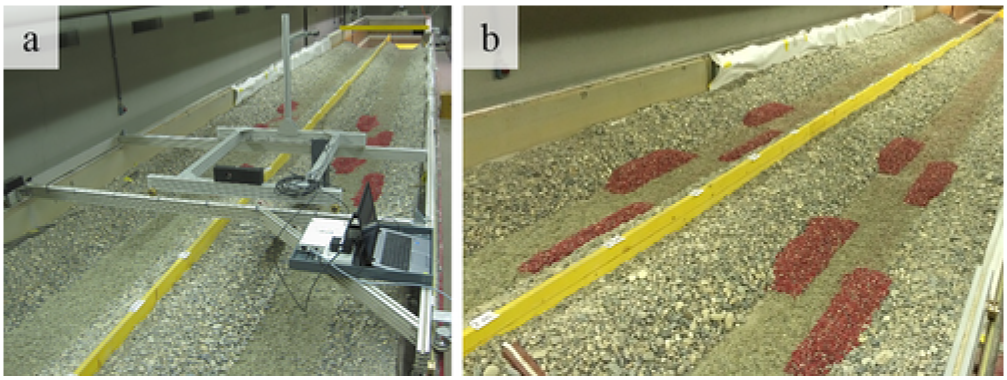

Figure 16: Experimental design of laboratory-made stream

In this study, sediment was added into a flume in four different deposits in order to affect the morphology downstream in a laboratory type setting. The sediment was placed into four different deposits because different methods of sediment replenishment wanted to be tested (Battisacco et al., 2016) and one of these methods is shown in Figure 1 . This experiment was conducted to evaluate different sediment replenishment methods, in order to use in areas that have been damaged by dams that do not have flushing devices. Flushing devices are needed to maintain the natural sediment transport of rivers as well as maintain their morphology and if there are none, sediment will be trapped in certain areas (Battisacco et al., 2016). Sediment entrapment also leads to riverbed incision and streambank erosion.

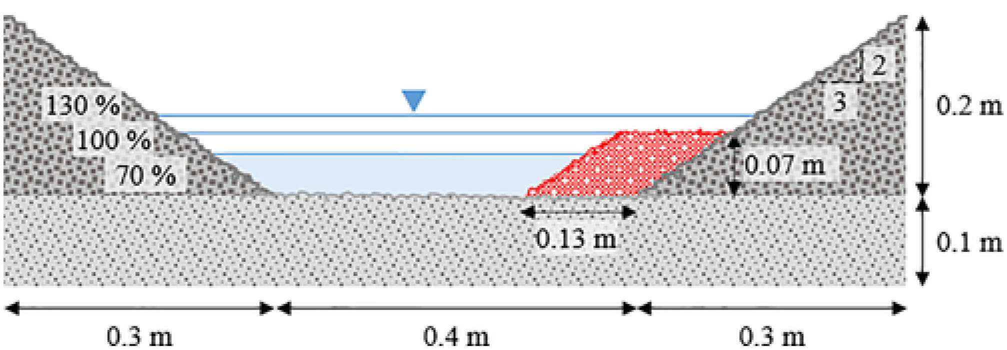

Figure 17 : Sediment Replenishment Model Example

Results

In terms of the results of this case study, the researchers determined that conducting a systematic laboratory experiment can provide key information on the discharge amount, the amount of gravel needed and geometrical configuration needed in order to have a successful sediment replenishment project. In this case these aspects were needed to determine which of 6 geometrical configurations on a flume would be the most successful for sediment replenishment in downstream dams (Battisacco et al., 2016). In the experiments, completely submerged sediments that were used for replenishment and enabled by processes such as artificial floods, were able to successfully provide sediment downstream (Battisacco et al., 2016). Specifically, parallel geometrical configurations of the sediment replenishment method allowed for eroded material to be more spread out but alternating between different ones can allow for more natural bed morphology (Battisacco et al., 2016). Allowing for natural morphology improves the ecological habitat.

Analysis

In the case of the Miribel canal and the Rhône river, there are issues with incision in the upstream area because a lot of suspended sediment has passed through the area. The same issues are dealt with in the case study therefore the goals of it mirror the issues needing to be solved with the canal. The study was also conducted with the goal of being an alpine gravel-bed stream which makes the stream similar to the streams and canals in Southeast France. This case study outlines how six different geometrical conditions and submergence replenishment volumes can be tested therefore using this method to test the effects on the Miribel canal and Rhône river may be useful. Although conducting a laboratory-made experiment mirroring the conditions of the Rhône and Miribel canal would be promising in measuring the effectiveness of the restoration project, the cost and time to set this up would be too much given the goal of having a solid restoration plan by 2024.

Effect of sediment replenishment on downstream reaches of dams: case study of the Futase Dam

Overview

This case study focuses on the results of a sediment replenishment and monitoring survey project around the Futase Dam in Japan from 2003 to 2016. The monitoring survey consisted of obtaining information on the riverbed material, river channel shape, Japanese fluvial sculpin population,and number of benthic invertebrates after the sediment replenishment project around the dam. The Japanese fluvial sculpin are used as an indicator species because they rely on environments with coarse sediment as well as sandy sediment, therefore changes in these conditions would affect them and their population levels (Kato et al., 2017). The sediment replenishment project started in 2003 and as a result a total of 100,000 m^3 of sediment has been replenished since. The project was undertaken because the sediment storage capacity was around 90% filled and because the riverbed elevation below the dam decreased so much that large boulders and rock masses started to appear (Kato et al., 2017). In the project, sediment was excavated from a reservoir upstream on the Kamanakao site and was then dumped into the Arakawa river which is located below the Futase dam. This allows the sediment to be carried downstream when the channel floods.

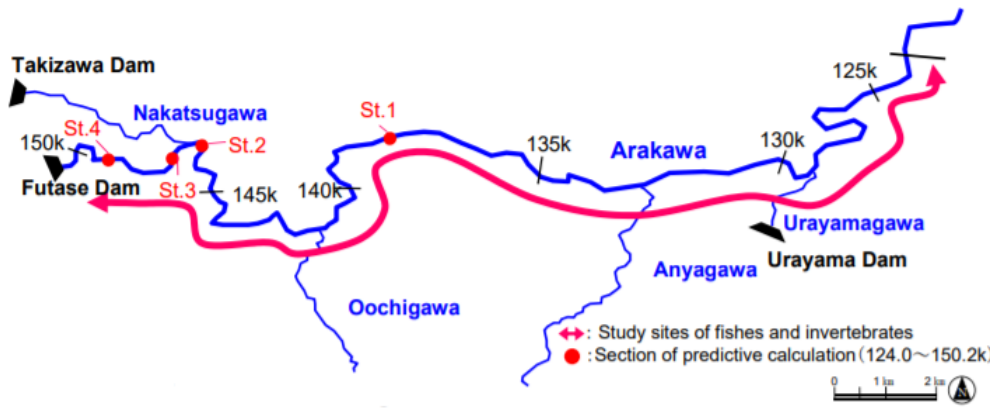

Figure 18: Study sites and forecasted range for monitoring surveys

<u>Results</u>

The Futase dam management office was responsible for conducting sediment replenishment tests from 2003 to 2016 excluding the years 2011 and 2012 (Kato et al., 2017). They did this by collecting sediment from a check dam upstream of the reservoir when water levels dropped. The excavated sediment is then transported into the Arakawa river using dump trucks (Kato et al., 2017). After analyzing data from the sediment replenishment project, there was a conclusion that in the years where there was severe flooding and the sediment replenishment project was halted,the numbers of Japanese fluvial culpin decreased as well as the numbers of benthic invertebrate species as shown in Figure 19. Although when sediment replenishment was continued afterwards, increases in the indicator species and benthic invertebrates increased. Therefore when the sediment replenishment project is continuous, there are beneficial results.

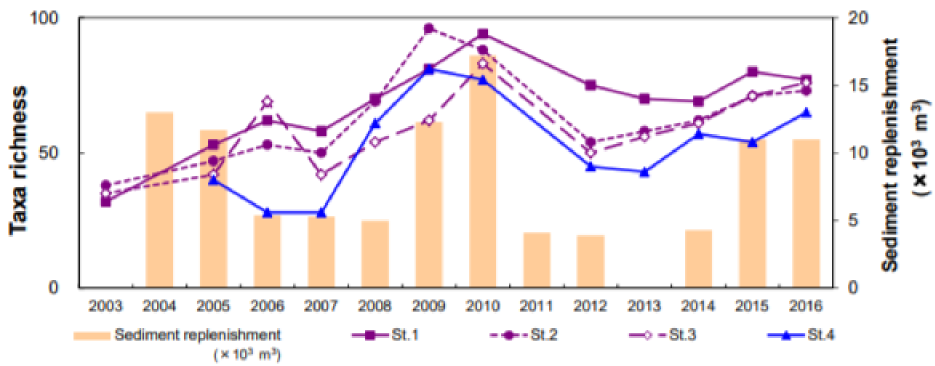

Figure 19: Benthic invertebrate reaction to sediment replenishment

Analysis

______This case study outlines a monitoring system that ensures the success of a sediment replenishment restoration project. Ensuring that the riverbed material is staying the same, the river channel shape is remaining the same, the indicator species and benthic invertebrate levels are increasing or being at their natural levels are all important to monitor. Using this outline can be useful for a restoration plan involving the Rhône river and miribleі canal. Making sure that species and invertebrates in the river are not declining and that the material and morphology of the river are necessary to consider. Therefore addressing these aspects can help with a sediment replenishment restoration project in the Rhône river.

Sediment replenishment downstream reaches below dams: Implementation perspectives.

Overview

This case study entails the effects of different types of sediment replenishment injection methods on the Nunome River of Japan and Trinity river of California. The Nunome river study consisted of adding a maximum of 500 cubic meters of sand and gravel-like sediment into a stream channel using a high-flow stock pile method (Ock et al., 2013). The Trinity river restoration project consisted of adding sediment using the in-channel stockpile, high-flow stockpile, and high-flow direct injection methods. The goal of the study was to compare the effects of these rivers and their injection methods to make recommendations based on flow rate settings (Ock et al., 2013). In the Nunome river restoration project sand and gravel sediment was excavated in a check dam that was located upstream and then used for replenishment downstream. This project was conducted in 2009 and the machines used for excavation were dumpstrucks. In the Trinity River restoration project, coarse sediments over 8 mm were used to aid in salmon fish spawning. The amount of gravel introduced was determined based on 5 water year types that describe the peak flows and sediment augmented in the river as shown in Figure 20.

	(a) Downstream release depending on reservoir inflow				(b) Peak flow and sediment augmented		
Water year type	Reservoir inflow (mcm)	Downstream allocation (mcm)	Ratio inflow to allocation	Probability of occurrence	Peak flow released (cms)	Peak flow duration (days)	Volume of sediment augmented (m^3)
Extremely wet	> 2,467	1,005	35%	0.12	311	5	23,701–51,224
Wet	1,665–2,466	865	44%	0.28	241	5	7,645–13,761
Normal	1,264–1,664	798	58%	0.20	170	5	1,376–1,682
Dry	801–1,263	559	56%	0.28	127	5	115–191
Critically dry	< 801	455	81%	0.12	42	36	0
average		*733*	*43%*				

'mcm' and 'cms' indicate million cubic meters and cubic meters per second, respectively.

Figure 20: Water Year Types

<u>Results</u>

In recommending improvements for the Nunome and Trinity river restoration projects, there is emphasis on considering higher magnitudes of flushing flow and the duration of longer peak flows. The Nunome river restoration project consisted of using the high-flow stockpile method during a typhoon where there was major rainfall (Ock et al., 2013). This was a limited peak duration allowing for a lot of the sediment to be transported but because of the limited time, there was hardly any difference compared to the high-flow direct injection method. Because of this, there was sediment accumulation below the Nunome Dam which was not an intended effect (Ock et al., 2013). The study also outlines the comparisons of the sediment replenishment restoration methods of the two rivers and shown in Figure 21. This table outlines the purposes, implementation methods, and flow levels when the restoration projects were conducted.

Table III. Comparative analyses of sediment replenishment activities between Nunome River and Trinity River

		Nunome River	Trinity River
Year started		2004	1972
Organization		Japan Water Agency	US Bureau of Reclamation
Purposes	Physical objectives	to protect riverbed degradation	to induce natural fluvial process for gravel bar formation
	Ecological objectives	to detach attached algae	to restore salmon habitat structure
Implementation method		High-flow stockpile	In-channel stockpile, High-flow stockpile, High-flow injection
High flow regime	Peak discharge	by peak control by the dam	by the water year type determined based on reservoir inflow within a given year
	Peak magnitude	approx. 80 m^3/s	by the water year type ranging from 42 to 311 m^3/s
	Frequency	once or twice a year in summer	once a year in spring
	Peak duration	2–4 hours	over 5 days
Sediment added	Source of excavated sediment	check dam located at end of reservoir	on the channel derived from mechanical floodplain rehabilitation
	Number of sites	a single site just below dam	four sites along downstream channels
	Sediment volume added per year	by the peak discharge (max 500 m^3)	by the water year type (max 51,224 m^3)
	Grain size	mixed sand and gravel (0.075–19 mm)	mixed gravel and boulder (15–102 mm)

Figure 21: Sediment Replenishment Activities of Nunome and Trinity River Comparative Analysis

Analysis

This case study emphasizes the proper identification of the sediment replenishment injection method as well as the importance of using this method when the flow rate is the most effective. The recommendations used for every type of injection method can be considered when choosing the best method for restoration on the Miribel canal. The Miribel canal floods were often therefore considering this and trying to map when this happens should be considered. Some methods consist of using low flow levels while others consist of using high flow levels. Knowing when water levels are going to be higher in the Rhône river is important because the water level and flow rate will determine how effective the replenished sediment will be distributed. Furthermore, the Trinity river method should be considered because in its restoration project, coarse sediment was also used to aid in fish spawning therefore analyzing the conditions on why the specific injection method was chosen could be useful.

Case study Applications on the Miribel Canal

Using the team's matrix to analyze case studies was also useful in determining if the additional case studies were useful when considering a restoration project in Rhône river and Miribel canal. Although the metrics of biodiversity, incision prevention, sediment management, flooding, flow rate, drinking water, and urban proximity were aspects used to rank potential restoration methods, they could also be used to identify case studies that could be used for a restoration project. The case studies highlighted in blue in Figure # are the additional case studies analyzed in this section and are the most fitting when analyzed using this template.

The case study about the laboratory-made stream in Switzerland has benefits such as including analysis on incision prevention, sediment management, and flow rate. In this project, the stream was made to test for incision and outline prevention methods. With this, sediment management and flow rate were also considered. The Miribel canal has been damaged by incision therefore solutions for sediment management and techniques to deal with the effects of the flow rate should be considered.

The case study on Futase Dam includes aspects such as biodiversity, incision prevention, sediment management, flow rate, and drinking water. This case study focuses on fish species and benthic invertebrates (Kato et al., 2017). Something that has been highlighted by many experts interviewed by the team is ecological restoration. One of the main goals of a potential restoration project is to ensure that the environment within the river is benefitting from it and not being threatened.

Lastly, the case study comparing the Nunome Dam and Trinity River offers insight into biodiversity, incision prevention, flow rate, and drinking water aspects. In this case study there is emphasis on choosing the correct sediment replenishment injection method and pursuing the project when the flow rate is the most fitting. There is also emphasis on the importance of using coarse sediment for fish spawning of salmon (Ock et al., 2013). These two subjects relate directly to the issues of the Miribel canal. A proper injection technique will need to be chosen as well and the proper sediment type would need to be used in order to help the fish species on the Rhône (F. Laval, personal communication, June 14, 2021).

Title	Date	Overview	Biodiversity	Incision Prevention	Sediment Management	Flooding	Flow rate	Drinking Water	Urban Proximity	Pros	Cons	Relevence (1-3)
Channel incision, evolution and po	2019	This consisted	☐	☑	☑	☐	☑	☐	☐	could be	deciding w	3
Channel response to sediment rep	2020	gravel replenis	☐	☑	☑	☐	☑	☐	☐	methods	the sedime	3
On the morphological evolution of	2018	This case stuc	☐	☑	☐	☑	☐	☐	☐	River is s	Studies the	1
Lowland stream restoration by san	2019	adding woody	☐	☑	☑	☐	☐	☐	☐	Prevents	Sand is no	2
Channel response to sediment rep	2020	Adding gravel	☐	☑	☑	☐	☐	☐	☐	The grav	gravel repl	3
Laboratory-made alpine gravel-bec	2016	This case stuc	☐	☑	☑	☐	☑	☐	☐	The study	Is a labora	3
Effect of sediment replenishment o	2017	This case stuc	☑	☑	☑	☐	☑	☑	☐	Focuses	is in a diffe	3
Sediment replenishment downstre	2013	This case stuc	☑	☑	☐	☐	☑	☑	☐	Focuses	Different lo	3

Figure 22: Table used for Case Study Analysis

A case study used for a potential restoration project should have similar goals and issues for the project. In this the team acquired the most pressing issues from interviews with experts on the problem. Acknowledging that every case study may not fit an exact outline of the problem that is trying to be solved is important. Although, using an outline that calculates which case studies can fit many categories can be helpful in moving forward with a project. Furthermore, when considering a potential restoration project, all aspects such as cost, political and social factors, as well as ecological effects should be acknowledged.

Sediment Replenishment Project Considerations for the Miribel Canal

Overall, when considering a sediment replenishment restoration project, cost, political, and ecological effects should be considered (F. Laval, Personal communication, June 14, 2021) (R. Loire, personal communication, June 25, 2021). A restoration project needs to consider these aspects because the environment should be affected in a beneficial way and the community and stakeholders should also agree on these changes because the project has to be in line with the current laws regarding sediment removal and river modification (R. Loire, personal communication, June 25, 2021). Because the Lyon community relies on the river for drinking water, ensuring that the restoration plan does not negatively affect the accessibility of the aquifer is necessary (F. Laval, personal communication, June 14, 2021).

Cost is important to consider when planning a restoration project using sediment replenishment. Knowing what devices will need to be used and how much they will cost is important to consider. The cost for a restoration project must not exceed the budget put in place. Sediment replenishment can be costly and a bit difficult to plan for because the process entails excavating and moving large portions of sediment. Sediment replenishment is a process that must be planned for in the case of the Miribel canal due specific circumstances that are at hand. It is very costly to transport sediment in the Lyon area because the roads are smaller therefore a certain type of truck needs to be used. This smaller truck can only hold 8 cubic meters of sediment at a time which makes the amount of trucks and workers contracted higher (R. Loire, personal communication, June 25, 2021). The restoration project would entail removing around 100,000 cubic meters for now and a total of 3 billion cubic meters, therefore moving sediment in such little amounts is a bigger obstacle (R. Loire, personal communication, June 25, 2021).

The political and social aspects also need to be considered when planning a sediment replenishment restoration project. The community must agree with what is being done because some might feel more attached to the architecture. In terms of authorities and laws, the French authorities say that restoration projects must be finished with a global vision (F. Laval, personal communication, June 14, 2021). Other authoritative organizations such as the Water Framework Directive (WFD) also have the role of ensuring that the restoration project will not have bad effects on the environment therefore a restoration project must comply with their guidelines (B. Terrier, personal communication, June 21, 2021).

Coarse sediment is a natural part of the river ecology of the Rhône therefore it should be used when thinking about a restoration project. A lot of sediment has incised the canal upstream and has accumulated downstream near Crepeaux Charmy where Lyon relies on its drinking water. Using sediment from the drinking water area and depositing it upstream where there is incision can be considered. Not only can coarse sediment be used to fill areas that have sediment deficits, but they can be used in aid for fish spawning (Wheaton et al., 2004). Because there are thirty fish species in the Rhône, having this time of sediment is beneficial. Besides knowing what type of sediment should be introduced, knowing what exact location for it to be introduced and what quantity is also important to consider. Making sure that these factors are both considered is needed to make sure that the ecosystem is healthy (R. Loire, personal communication, June 25, 2021).

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