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Research Article

Chronology of meander abandonment by a large river: a case study based on the São Francisco River, Brazil

Cronologia de abandono de meandro por um grande rio: um estudo de caso baseado no Rio São Francisco, Brasil

Iara Christina de Campos[1], Rodrigo Wagner Paixão[2], Luciana Hiromi Yoshino Kamino[3], Flávio Fonseca do Carmo[4], André Augusto Rodrigues Salgado[5]

1 Pristino Institute, Belo Horizonte/MG, Brazil.iara@institutopristino.org.br
ORCID: https://orcid.org/0009-0000-4064-0182
2 Rio de Janeiro State University, Department of Physical Geography, Rio de Janeiro/RJ, Brazil.rodrigowpp1@gmail.com
ORCID: https://orcid.org/0000-0002-2640-7138
3 Pristino Institute, Belo Horizonte/MG, Brazil.luciana@institutopristino.org.br
ORCID: https://orcid.org/0000-0003-2624-0128
4 Pristino Institute, Belo Horizonte/MG, Brazil.flavio@institutopristino.org.br
ORCID: https: //orcid.org/0000-0002-5423-7957
5 Federal University of Goiás, Institute of Socioenvironmental Studies, Goiânia/GO, Brazil.salgado@ufg.br
ORCID: https://orcid.org/0000-0001-7679-5944

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Abstract: Meandering rivers are characterized by morphodynamics associated with low energy and high sedimentation rates. Their banks are subject to erosive and depositional processes, which can result in channel migration and the eventual abandonment of meanders. Although this dynamic is known, the time required for events that naturally lead to the abandonment of a meander is still unclear. This work aimed to better understand the temporal dynamics of the abandonment of a large meander from a case study in Volta Grande in Lagoa da Prata/MG, where the São Francisco River underwent artificial straightening in 1981 with the excavation of a 300-m-long channel. For this purpose, images from Landsat 5, Landsat 8 and ResourceSat satellites, captured between 1984 and 2015, were analyzed via false-color band compositions. Although accelerated by human intervention, the process of abandoning the meander occurred slowly and gradually and took more than three decades. This study highlights the complexity and slowness inherent to the natural straightening process in meandering rivers, which involves erosion, sedimentation and adjustment to the new river channel.

Keywords: Meandering rivers; River channel; Tropical rivers; Morphodynamics.

Resumo: Rios meandrantes são caracterizados por uma morfodinâmica associada à baixa energia e alta taxa de sedimentação. Suas margens estão sujeitas a processos erosivos e deposicionais, que podem resultar na migração dos canais e no eventual abandono dos meandros. Apesar desta dinâmica ser conhecida, ainda não está claro o tempo necessário para a ocorrência dos eventos que naturalmente levam ao abandono de um meandro. Este trabalho objetivou melhor compreender a dinâmica temporal do abandono de um grande meandro, baseando-se no estudo de caso de Volta Grande, em Lagoa da Prata/MG, onde o Rio São Francisco passou por uma retilinização artificial em 1981, com a escavação de um canal de 300 m de extensão. Para tanto, foram analisadas imagens dos satélites Landsat 5, Landsat 8 e ResourceSat, capturadas entre 1984 e 2015, utilizando-se composições de bandas em falsa cor. Constatou-se que, embora acelerado pela intervenção humana, o processo de abandono do meandro ocorreu de maneira lenta e gradual e consumiu mais de três décadas. O estudo destaca a complexidade e a

lentidão inerentes ao processo de retilinização natural em rios meandrantes, que envolve erosão, sedimentação e ajustamento ao novo canal fluvial.

Palavras-chave: Rios meandrantes; Canal fluvial; Rios tropicais; Morfodinâmica.

1. Introduction

Meandering rivers are common in areas with low tectonic activity with humid or semihumid tropical climates. Notably, they occur in plains and plateaus that are rarely dissected and usually have extensive floodplains around them. They are also characterized by their sinuous channels and typical morphodynamics and sedimentation. They are common in Brazil, and their name derives from the recurring curves they present: the **meanders**. The genesis of the meanders is due to the low energy of the channels that drain plains and flat regions and the high load of suspended sediments—silt and clay—that they carry; therefore, high sinuosity begins to occur as a way to overcome the obstacles associated with relief. Owing to their low energy, they also tend to overflow during high-water seasons, and this phenomenon, together with the high suspended sedimentary load, results in the formation of large alluvial plains in their surroundings due to the deposition of silt and clay present in the waters that overflow. The morphodynamics of a meandering river imply that, over time, the channels become increasingly sinuous until, by the overflow of its waters in a flood or a virtual "strangulation" of a meander, the river course regains a more rectilinear profile. In this case, the old meander will be abandoned, i.e., it will be disconnected from the river network and will become a flood lagoon/marginal lagoon. As such, the abandoned meander tends to be reconnected to the river course only during high floods, and if it is not reincorporated into the river channel owing to a new natural increase in its sinuosity, the tendency over time is for complete siltation and incorporation into the floodplain.

The morphodynamics of meandering rivers described above represent a consensus in the geomorphological literature and are repeatedly oulined in geomorphology books and manuals, including Baker et al. (1988), Bridge (2003), Keith (2004), Knighton (1998), Leopold et al. (1995), Leopold (1997; 2006), Miall, (2007), and Schumm (2003; 2005). However, a poorly understood issue is the time required for these processes to occur, especially the time required for a river channel of reasonable dimensions, i.e., one that is at least a few tens of meters wide, to abandon one of its meanders. In fact, opportunities to observe a river abandoning a meander in favor of a more rectilinear channel are rare because although this process has been common throughout the geological time scale, it is rare at the human time scale. In Brazil, the main observation occurred in 1990 in the Taquari River, a river course located in the Pantanal of Mato Grosso and a tributary of the Paraguay River. After a flood, the Taquari River altered its meandering course so much that it began to empty into the Paraguay River, approximately 30 km upstream from where it flowed before the flood (ASSINE, 2005; 2015; ASSINE et al.). 2005). Nevertheless, on the basis of a single case, it is not possible to state that all meandering rivers will change their course quickly. Additionally, studies of meandering rivers in the Amazon that involve "aggressive" river capture processes have shown that a river course of this type may need decades or centuries to abandon its former channel (STOKES et al., 2018; SALGADO et al., 2021).

Understanding the process and chronology of the abandonment of a channel by a river course in environmental terms is highly valuable. Whether river capture or meandering, the time taken by a river to change its drainage channel directly impacts biodiversity. Abrupt changes imply that there is no time for all freshwater fauna to adapt (SAYER et al., 2025). In turn, the gradual changes allow not only this adaptation but also, in the case of river captures, the wide migration of freshwater samples between the different watersheds. In addition, we live in a period in which anthropic activity is increasingly active, as well as where land use and occupation tend to become more intense. In this context, the speed with which a river changes its channel directly impacts the lives of

the people who live on its banks, as well as the economic activities that are developed there. Furthermore, in areas with high anthropic interference, it is important to recognize whether the process of abandonment of a meander occurs in the same way and at the same speed as it would naturally occur, and this can only be verified using case studies.

In this context, the present study investigates the abandonment process of an extensive meander along the São Francisco River, in the Volta Grande region, in the municipality of Lagoa da Prata/MG. In fact, this constitutes one of the few opportunities to observe the chronology of events that involve the abandonment of a meander by a river. This is possible because a farmer dug a 300-m channel in this region in 1981 with the objective of straightening the São Francisco River and reducing the legal reserve area that it should preserve. Until 1981, the São Francisco River, instead of the current 300 m, traversed a 7.5 km meander, and the straight channel allowed, little by little, the abandonment of this extensive meander. Thus, knowing the moment when the channel was opened, it becomes possible to verify the time required for each morphodynamic process to occur. In parallel, this case study also allows a better understanding of the fluvial dynamics of meandering rivers in the face of anthropic action, as it makes it possible to verify whether the abandonment of a meander when induced by human activity is different from that which occurs naturally.

2. Study Area

The study area (Figure 1) is located in Lagoa da Prata in the center-west of the state of Minas Gerais. In this municipality, in a locality known as Volta Grande, the São Francisco River channel crosses its extensive and thick floodplain (Figure 2) and is deposited on carbonate rocks of the Bambuí Group (CPRM, 2008). The São Francisco River Basin upstream of Volta Grande runs for 225 km (Figure 2) and drains an area of approximately 8,500 km^2. The most upstream part of the watershed is over quartzites of the Canastra Group in the homonymous mountain range. In Serra da Canastra, the São Francisco River drains high-altitude areas and has a high-energy profile because of the terrain (Figure 2). However, these areas have low anthropic activity and even include a national park. When a river enters a carbonate depression, it loses energy, and land use becomes much more intense. However, over the last 40 years, this use has changed significantly due to the growth of agribusiness. Until the 1990s, extensive livestock farming predominated. Over the last few decades, this has given way to intensive livestock farming and high-productivity commercial crops, especially sugarcane, soybeans and corn. This rapid change in land use and occupation likely altered the rates of erosion in the watershed and, consequently, of sediment transport and deposition in the São Francisco River. However, to the best of our knowledge, there are no studies or records that accurately measure this phenomenon for the Volta Grande region.

The regional climate is semihumid tropical, with dry winters and humid summers (Figure 3). The wet season lasts six months and extends from October to April. The drought begins in April and lasts until October. The rainfall indices in the wet season are approximately seven times greater than those in the six dry months but can reach rates up to ten times greater, as was the case in 2002 and 2004 (Figure 3). This rainfall variation leads to several changes in the São Francisco River flow between the dry and wet seasons of the year common. This high seasonality can be explained by the fact that throughout the 20th century, the São Francisco River recorded variations of more than 3,000% between its historical minimum and maximum flow (CPRM, 2001). Obviously, variations that reach this size in flat areas such as Volta Grande (Figure 2) tend to cause the waters of the São Francisco River to overflow into its floodplain with some recurrence.

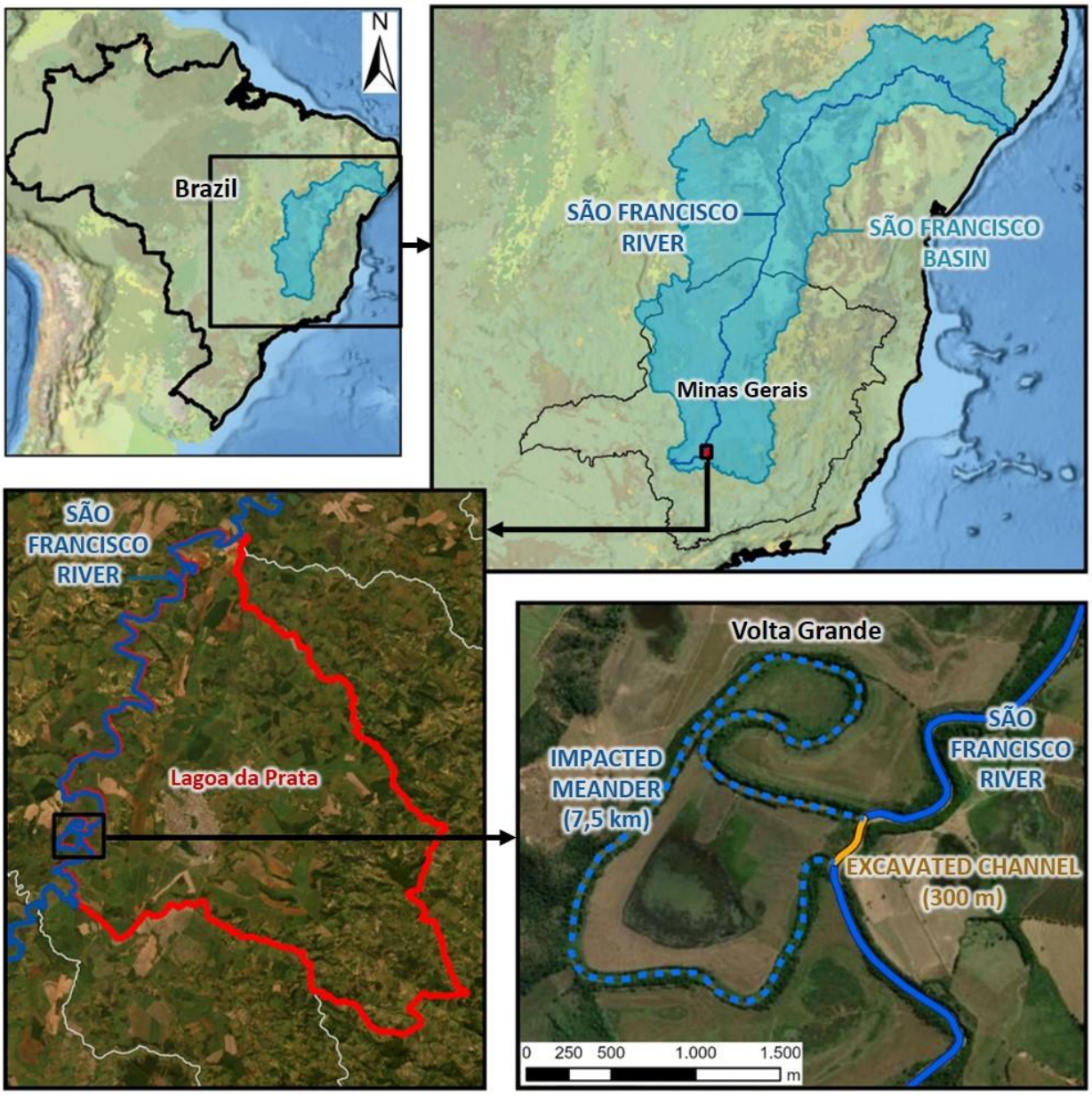

Figure 1. Location of the 300-m channel (orange line) excavated in the course of the São Francisco River (solid blue line) and of the 7.5 km stretch of the impacted meander (blue dotted line) in the region known as Volta Grande, municipality of Lagoa da Prata, Minas Gerais. (ESRI World Imagery Wayback Image – WorldView-03 of June 3, 2021).

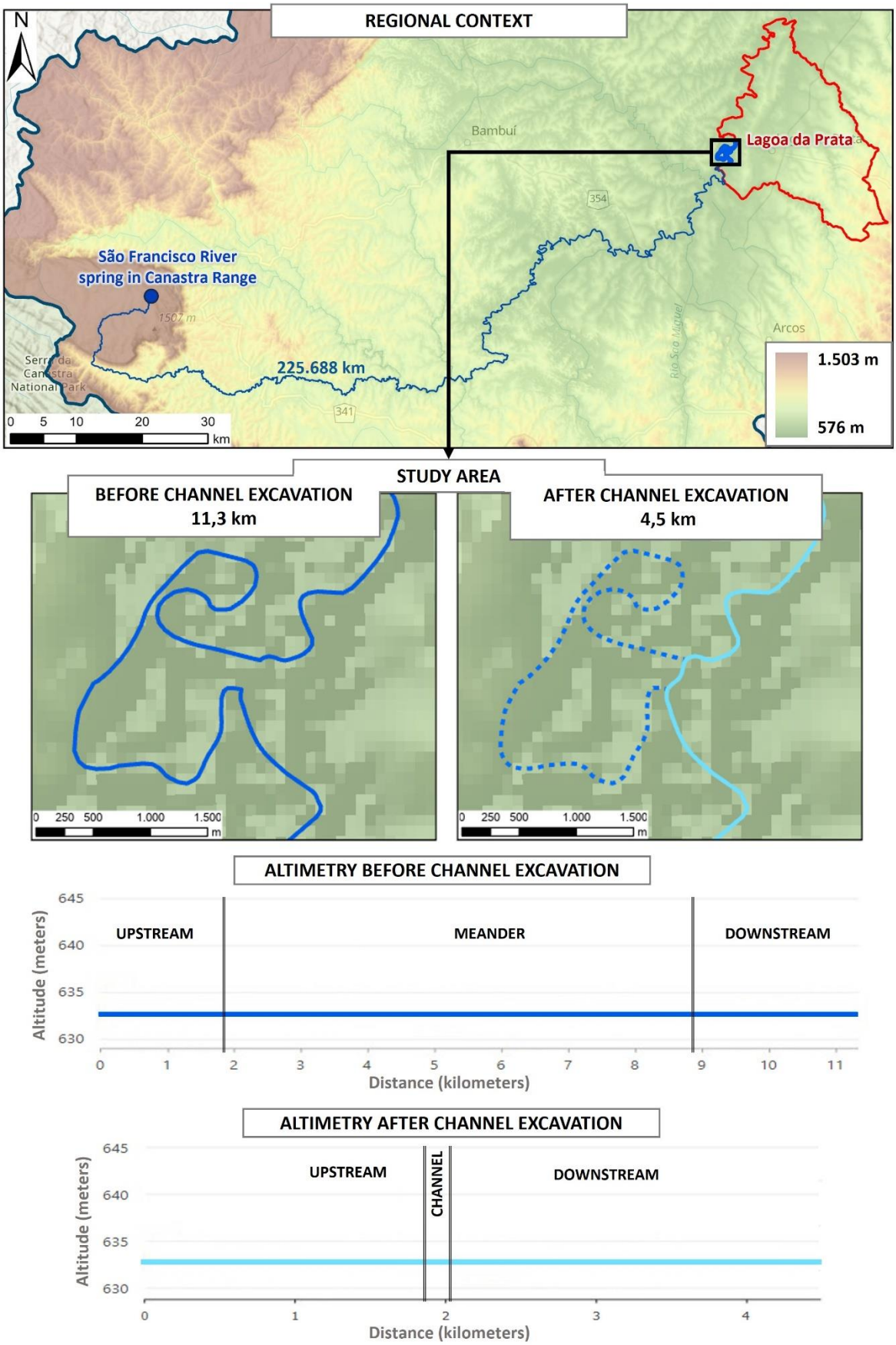

Figure 2. Regional context of the São Francisco River and channel altitude in the study area. SRTM image, source: Miranda (2005).

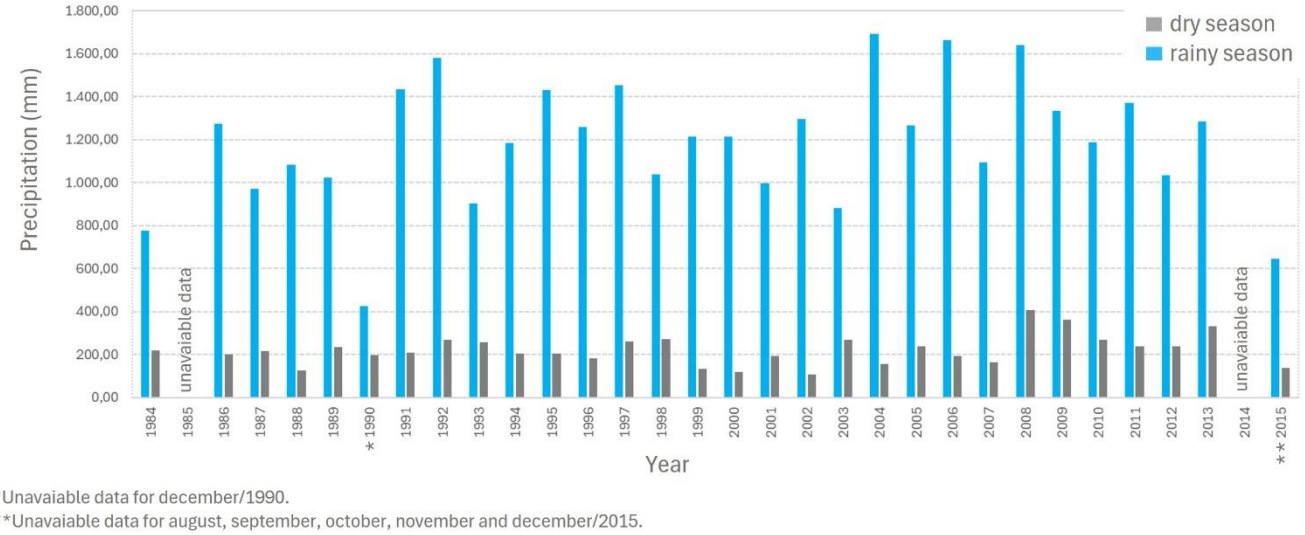

Figure 3. Total rainfall indices of the dry (April to October) and wet seasons (October to April) for the Volta Grande region in Lagoa da Prata/MG.

In Volta Grande, the São Francisco River drains an extremely flat area (Figure 2), which is mostly occupied by its wide floodplain. This flatness also favors the meandering process. Among the naturally formed meanders, there is a large meander approximately 7.5 km in length, which gives name to the region of Volta Grande. It is currently abandoned and is only reconnected to rivers during extreme floods. The abandonment of the meander began in 1981 when the former owner of the area built a 300-m irregular channel straightening the São Francisco River and starting the process of abandoning the 7.5 km meander. Although the construction was clandestine, the 300-m channel was excavated with the aid of explosives and excavators, and it did not reach the depth of the São Francisco River bed.

3. Materials and Methods

To observe the evolution of the São Francisco River channel in the study area after straightening, the Geocatalogue database of the National Institute for Space Research (INPE) was consulted, and 62 images were obtained for the study area between 1984 and 2015. Images with spatial resolutions ranging between 15 and 30 m from Landsat 5, Landsat 8 and ResourceSat-1 satellites were used. In the public databases consulted, no images were found with a spatial resolution equal to or greater than 30 m for the years 1981, 1982, 1983 and 2014, making the analysis in these periods unfeasible.

The images from the Landsat 5 and ResourceSat-1 satellites were recorded via ArcGIS software, with the drainage of the municipality of Lagoa da Prata used as a spatial reference. The registration process was not applied to the Landsat 8 images, which, unlike the other images, are already available as orthorectified by the USGS/NASA (DUARTE et al., 2014).

To create the images used in the study, the composition of bands in false color was chosen with the objective of revealing the bodies of water in the landscape. The spectral signature of liquid water has a maximum absorption of electromagnetic energy above 0.7 μm, making it possible to interpret dark colors in satellite images as indicative of the presence of water (STEFFEN et al. 1996). Thus, two bands comprising values above this spectral range were chosen for each satellite for the composition of the image to enhance the visualization of water bodies in the scenario. After the bands of the satellite images were recorded and composed, the physical elements in the

landscape were identified through visual interpretation according to their spectral behavior and roughness patterns.

We sought to identify visible changes:

- in the bed of the São Francisco River
- in the rectification channel built in the river meander
- in the meander of the river

To support the selection for satellite images that best represent the dynamics of floods and droughts in the river's floodplain, meteorological data in the region were compiled using data from automatic stations of the National Institute of Meteorology (INMET, 2015). Data from the Bambuí and Bom Despacho stations, located approximately 40 km from the study area, were used. No orographic barrier were identified that could directly influence the rainfall patterns in the region between the study area and the stations in question, making it acceptable to use the data measured at the stations to infer the meteorological dynamics in the area of interest.

The meteorological data were compiled between 1981 (the date of construction of the riverbed rectification channel) and 2015. For each year, the driest and the wettest months were identified, directing the search of satellite images for these dates. Thus, we sought to create a panorama of representative images of the dry and rainy seasons of the entire river floodplain over the years. However, it should be noted that due to the high incidence of clouds in the images from the rainy season, it was not always possible to use images from the wettest month of each year. Finally, fieldwork was conducted in the dry season of 2015, aiming to verify and record the situation of the São Francisco River 34 years after the beginning of the abandonment process of the Volta Grande meander.

4. Results

The work was carried out in 1981, and since then, during the rainy season, water has flowed simultaneously through the 300-m canal that was built and through the old meander. However, the first images obtained during the dry period are from 1984 and show that, even three years after the straightening of the river channel, during the dry season, the São Francisco River continued to flow only through the Volta Grande meander, leaving the flat bed flat dry (Figure 4A). This situation changed only at the end of the dry period of 1985, when it was possible to verify evidence of water in the constructed channel (Figure 4B). Since then, the process of gradual abandonment of the meander has continued because, in the dry season of 1994, although most of the flow of the São Francisco River clearly still passes through the Volta Grande meander, there is a good flow of water running through the constructed channel (Figure 4C). In the dry season of 2001, both the meander and the constructed channel continued to flow from the São Francisco River, but the situation was reversed: most of the river water crossed the channel (Figure 4D). During the dry period of 2006, the bed of the meander was almost completely dry and silted, and the river flow was concentrated in the constructed channel (Figure 3E). Thus, in 2006, during the drought, the meander behaved almost as if it were abandoned, similar to a flooded lagoon. This trend worsened in the dry period of 2015 (Figure 4F), showing that 34 years after the beginning of straightening, the meander was abandoned in the dry period but still contained some water in its interior, behaving like a flood lagoon connected to the river only during high floods. This abandonment of the meander during the dry period can be verified by the presence of at least 3 m of sediment deposited in its old trough (Figure 5) and in its complete silting (Figure 6), a fact that shows that the São Francisco River reaches its former bed only in severe floods.

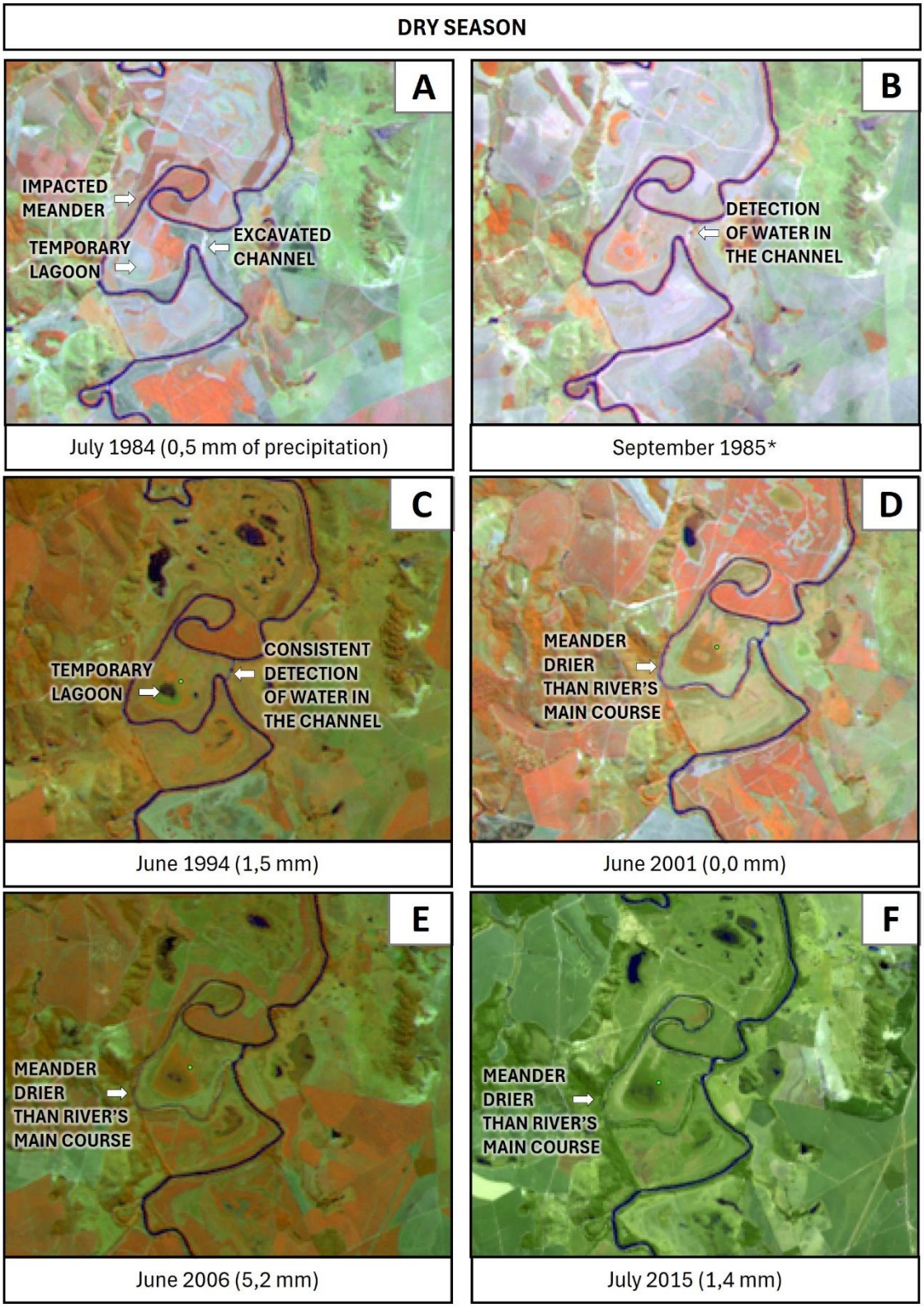

Figure 4. Time series (1984–2015) of the dry season identifying the process of abandonment and silting of 7.5 km of the former natural bed of the São Francisco River. Note that over the years, the color (reflectance pattern) of the meander changed, indicating the presence of less water, i.e., an increase in the amount of sedimentary material causing silting. The rainfall totals for that month are shown in parenthesis next to the information for the month of each image.

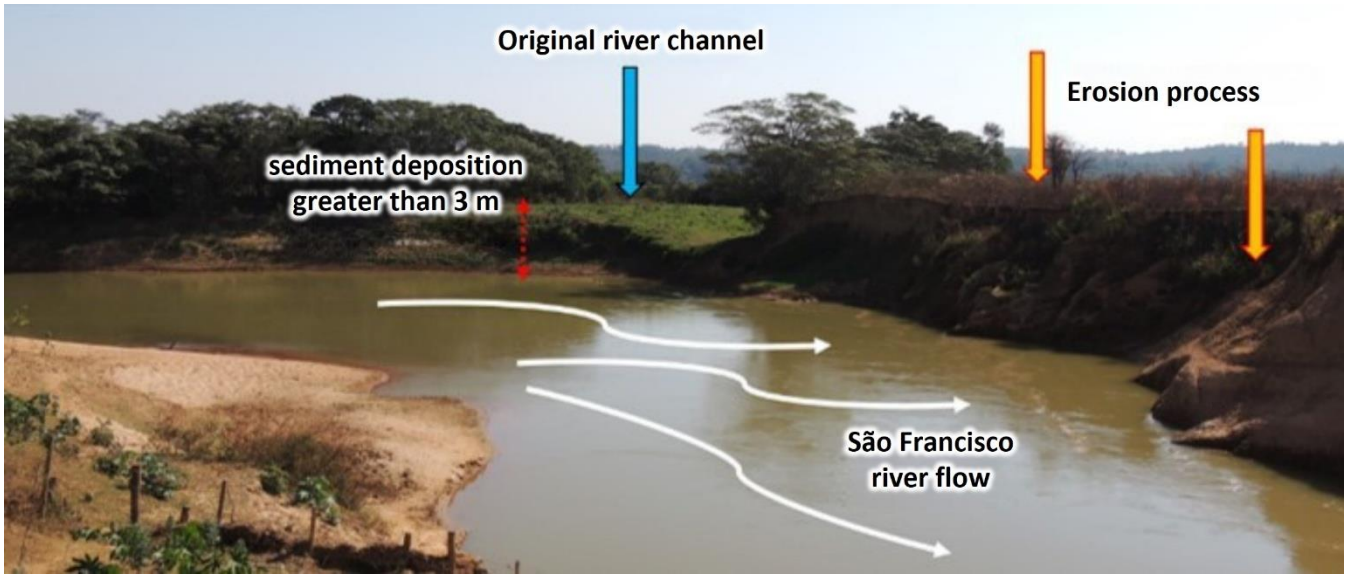

Figure 5. Photo from the dry period of 2015 at the site where the channel excavated in the São Francisco River was built along with the entrance to its former meander. There is an accumulation of sediments and silting of the old meandering trough, as well as an erosive process on the current banks of the rectilinized channel. Photo: authors.

Figure 6. Photo from the dry period of 2015 of the silted former natural bed of the São Francisco River in the Volta Grande meander. Photo: authors.

In relation to the images of the rainy season, a similar behavior can be observed in relation to the dry season. Initially, in 1984, even in a December with almost 350 mm of rainfall, it was almost impossible to observe the presence of water in the artificial channel, and the meander showed a significant amount of flow in its riverbed (Figure 7A). This fact shows that, despite the construction of an artificial channel, little has changed in the flow of the São Francisco River in the study area. It was only in the summer of 1985, four years after the construction of the canal, that it became possible to verify the existence of signs of water in the artificially straightened bed (Figure 7B). In February 1994, despite the low rainfall in that month, water was clearly identified in the straight channel (Figure 7C). However, the water continued to flow in greater amounts through the meander of the river. In the wet season of 2001, both the channel and the meander experienced water flow, but the trend of the flow concentration inverted (Figure 7D). During the rainy season of 2006, the artificial channel was observed to contain water, and the river meander was nearly dry and practically disconnected from the water flow (Figure 7E). The behavior of the São Francisco River water flow during the wet season of 2015 was practically the same as that of 2006 (Figure 7F), emphasizing that the month of the image obtained this year—March—was at the end of the wet season, with a month with more rainfall than in 2006, the year in which the image shows February (Figures 7E and 7F). Thus, in 2015, the meander no longer has a river flow and thus behaves like an abandoned meander that is connected only to the São Francisco River during high floods (Figures 4F, 5F, 6F and 7F).

The excavated channel locally favored an increase in the speed and energy of the river flow, thus accelerating the erosion of the banks and the associated decrease in vegetation. Over the years, this process has deepened. In 2001, the riverbank located opposite the outlet of the channel was still stable (Figure 8A), which verifies that until this moment, that is, up to 20 years after the construction of the channel, the flow of the river that flowed through it was still relatively small and did not have great erosive power. However, between 2001 and 2014, erosion was observed in the concave banks (Figure 8B and Figure 9), causing the suppression of the riparian forest and erosion of the banks. This phenomenon should continue to occur at an accelerated rate until the conditions of fluvial equilibrium are naturally reestablished and a new meandering process begins.

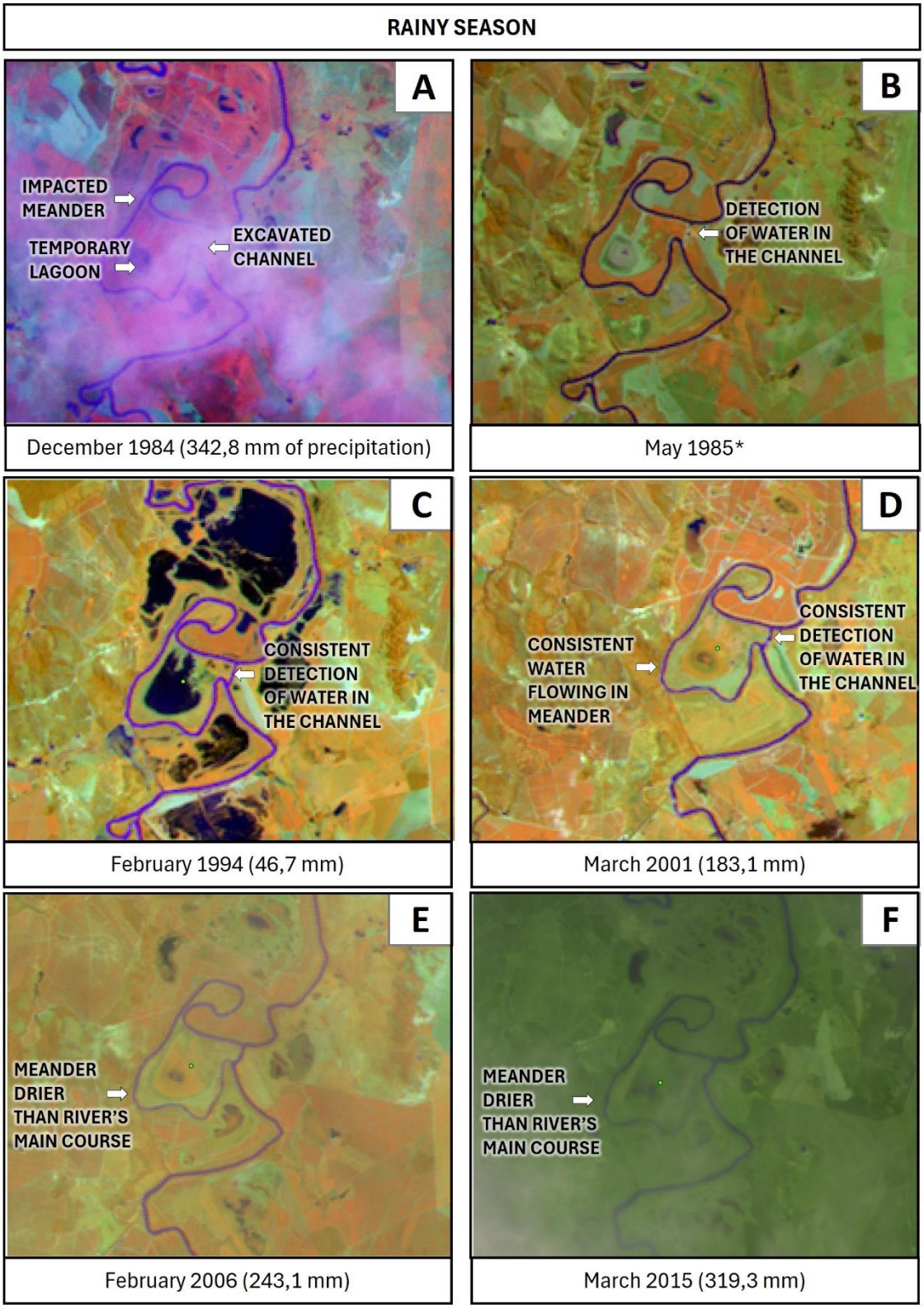

Figure 7. Time series (1985–2015) of the humid season identifying the process of abandonment and silting of 7.5 km of the former natural bed of the São Francisco River. Note that over the years, the color (reflectance pattern) of the meander changed, indicating the presence of less water, i.e., an increase in the amount of sedimentary material causing silting. The rainfall totals for that month are shown in parenthesis next to the information for the month of each image.

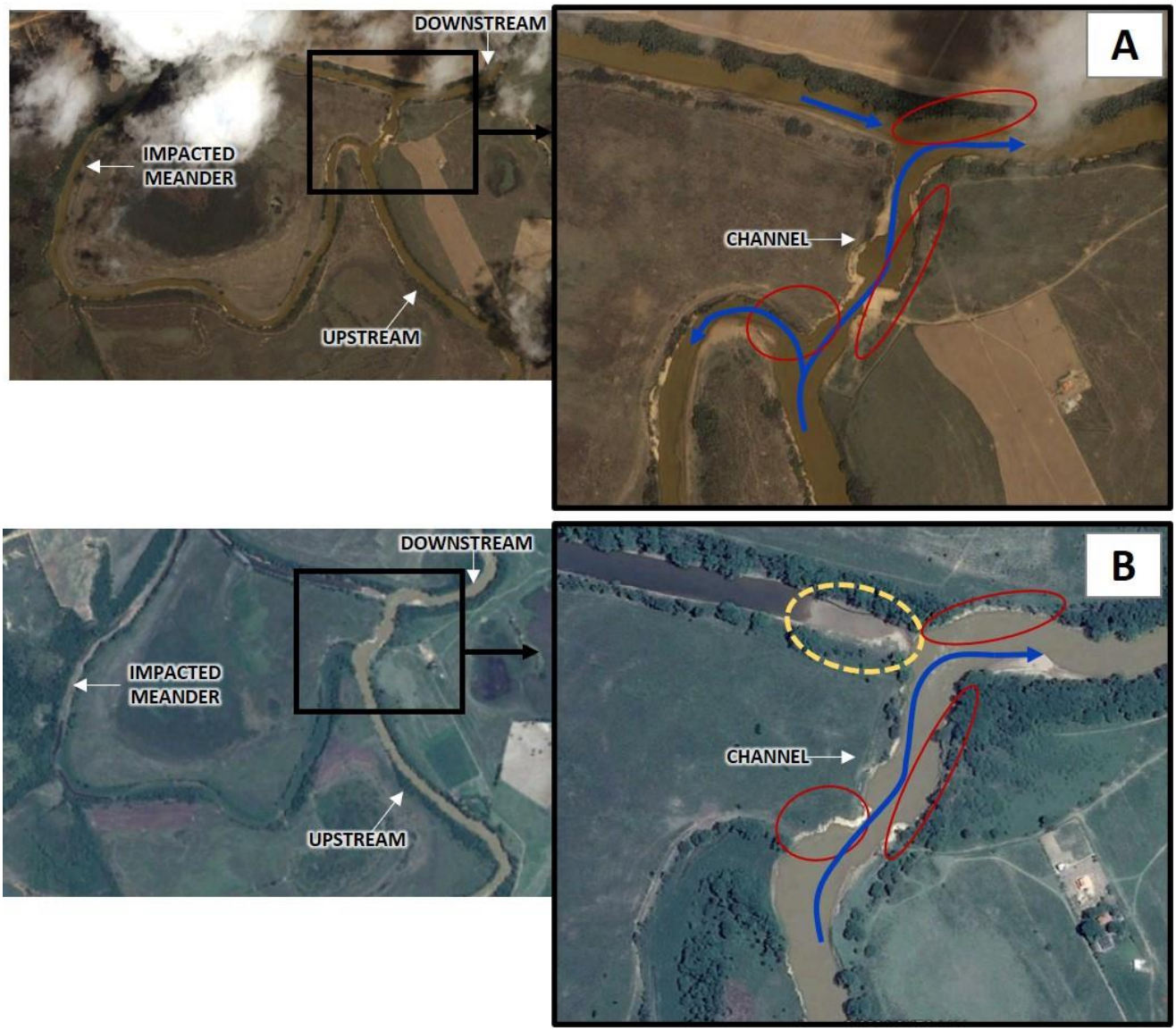

Figure 8. The excavated channel favored a gain in velocity and energy of the São Francisco River flow, accentuating the erosive process in the concave banks, the consequent silting and the suppression of the riparian forest. The red polygons highlight the banks eroded by river flow. Notably, sandbank disappearance occurred with increasing water flow in the excavated channel. Figure 8A: 2001 image; Figure 8B: 2014 image. Adapted from *Google Earth Pro*.

Figure 9. Concave margin immediately downstream of the excavated channel during the dry period of 2015. Figure 9A: Erosive process on the bank that caused natural suppression of Riparian Forest. Figure 9B: Details of the erosive process on banks and impacted trees. Photos: authors.

5. Discussion

Considering that the São Francisco River in Lagoa da Prata exhibits a meandering pattern and that Volta Grande itself is a mega-meander with sub-meanders along its 7.5 km extension (Figure 1), the trend of the dynamics in this region was to naturally cause straightening, the "strangulation" of the São Francisco River and,

consequently, the abandonment of the entire Volta Grande. The construction of the canal most likely only advanced and accelerated a process that would have naturally occurred. In fact, after the channel was excavated, the entire abandonment process of the Volta Grande meander occurred under conditions very similar to those that would occur naturally. It is also possible to note that the Volta Grande meander is like a meander with sub-meanders in its interior and that the one located in the extreme north is practically "strangulated" (Figure 10). Thus, Volta Grande was a meander that would be abandoned, having in its interior sub-meanders that were also in the process of abandonment. It is very likely that the entire process of the abandonment of meanders did not occur all at once but rather in different phases and would tend to demand a certain amount of time until it was completed. Initially, the water flow increases the sinuosity of the river in its more pronounced curves (Figure 10A). Such an increase in sinuosity would lead to the "strangulation" of the meander located in the extreme north of Volta Grande and its abandonment by the main course of the São Francisco River (Figure 10B). The new meander formed by this bottleneck subsequently tends to adjust to the new curvature and be abandoned (Figure 10C). During this process, the entire course of Volta Grande would be slowly "strangled" due to the increase in the sinuosity of the curve of the São Francisco River at its entrance. Finally, the entire Volta Grande meander was completely abandoned (Figure 10D).

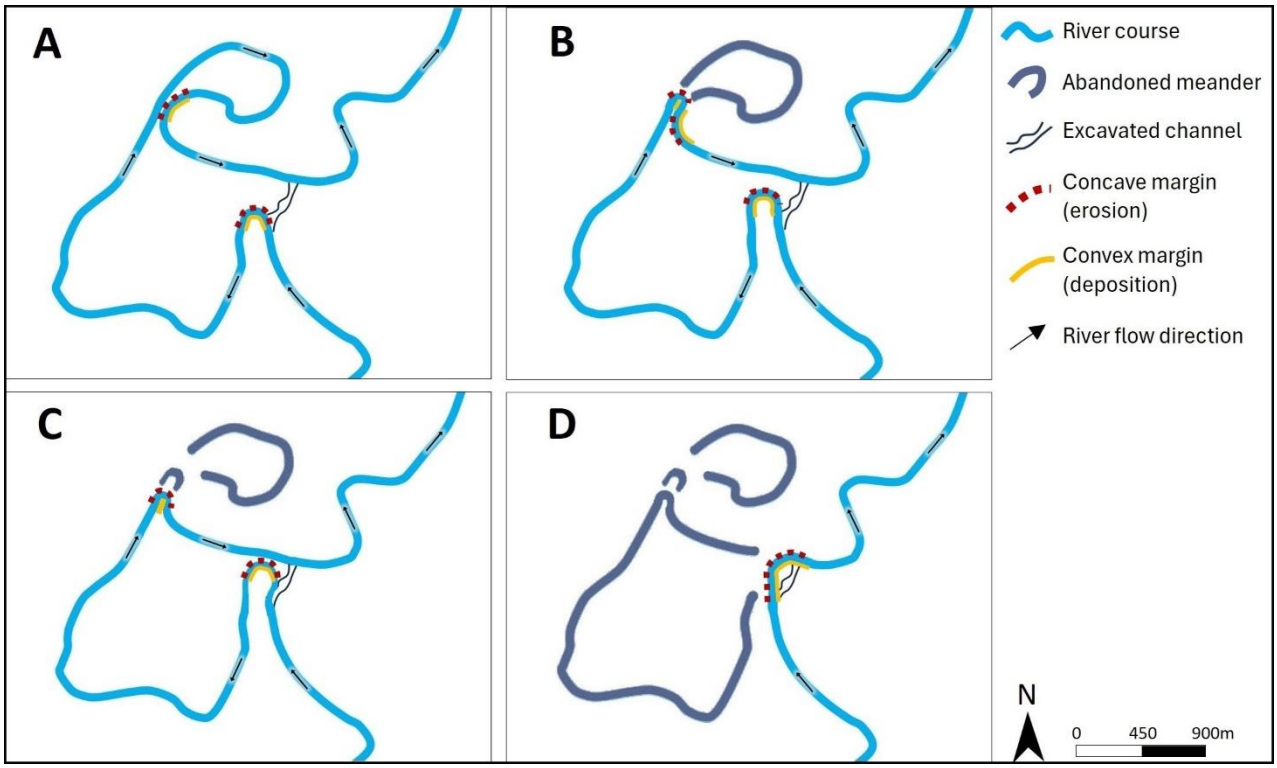

Figure 10. Natural trend of the natural evolution of the São Francisco River channel in the Volta Grande region of Lagoa da Prata/MG. The location of the excavated channel is indicated by parallel black lines.

Thus, excluding the processes that did not occur with the sub-meanders inside the large meander of Volta Grande, it can be affirmed that the events observed between 1981 and 2015 correspond to something similar to what occurs naturally when a large river leaves a great meander. This is due to the high sedimentation rates in the abandoned channels and their long stay in the landscape after the straightening of the river (HOOK, 1995). In this context, the sedimentation rate inside the meander depends greatly on the sedimentary load of the river and on the connectivity maintained between the channel and the abandoned meander (CITTERIO and PIEGAY, 2009;

GREENBERG and GANTI, 2024). However, there are no reliable data for establishing the sediment load transported by the São Francisco River in Volta Grande during the study period. However, in Volta Grande, this connectivity was relatively continuous for at least 20 years, from 1981 to 2001 (Figures 4 and 7). However, during the wet season, it extended for a few more years because, in the summer of 2015, the meander still received some water from the São Francisco River (Figure 7F). In parallel, the São Francisco River in Volta Grande developed other geoforms that would be expected (DIERAS et al., 2013; HOOK, 2023), such as sandy bars at the end of the open channel (Figures 8 and 9A) and erosion of the banks that directly received the water flow of the new channel (Figures 8 and 9B). This bank erosion and sediment deposition in the form of bars at the outlet of the channel, to the same extent that they are signs of abandonment of the old meander of Volta Grande, indicate the occurrence of a new meandering process (Figures 8 and 10). This is a typical dynamic of this type of channel because meandering rivers, in the absence of significant environmental changes, tend to maintain their sinuosity, abandoning meanders in some stretches and creating them in others (HOOK, 2023). This new meander tends to evolve quickly, since in this location, the riparian forest was almost completely removed (Figures 8 and 9), facilitating the development of sinuosity (HOOK, 2023; GREENBERG and GANTI, 2024).

The relationships between annual rainfall and changes in the process of abandonment of the meander do not seem to be direct. For example, 1994 was a year with little rainfall (Figure 3), but it marks the beginning of the period in which during both the dry and wet seasons, water begins to run consistently through the excavated channel (Figures 4C and 7C). Perhaps heavier rains in previous years (Figure 3) even made it difficult to abandon the meander because the increased flow caused more water to naturally flow through it. In addition, in wetter years, the flow of the São Francisco River tended to be more intense, which also hindered the deposition of sediments because silt and clay require less energy to be deposited. Thus, in the case of Volta Grande, the abandonment of the meander seems to be related to a slow process, where little by little, the São Francisco River excavated its new straight channel as it abandoned and silted up the meander that constituted its old bed.

Thus, what was observed in the case of Volta Grande is that the abandonment of a meander under these conditions is a slow process, which tends to take decades to complete. In fact, even during a large flood, a river, by "strangling" one of its meanders and creating a new, more rectilinear channel, will hardly be able to carve this new channel to the same depth as the old one that is still meandering. Thus, the tendency is for the water to flow gradually to deepen the new straight channel. Only when this new channel has a certain depth will this water flow begin to lose strength in the meandering channel, which at the same time will allow sediments to begin to be deposited in greater quantity, silting it up (Figures 5 and 6). This confirms that, as already noted by several authors, the time required for the process to be completed depends on many factors (HOOK, 1995; 2023; GREENBERG and GANTI, 2024). The variations in the flow and energy of the channel, the sediment load that it transports, the geological substrate and the integrity of the banks are noteworthy. In our case study, owing to the lack of baseline data for the period of occurrence of the phenomenon, it was impossible to determine the contributions of flow and sedimentary load to the evolution of the process. However, considering that the study area is very flat (Figure 2), that the banks of the river course are sparsely vegetated (Figures 5, 8 and 9) and that the substrate is the sediments of the São Francisco River (CPRM, 2008)—gravel, sand, silt and clay—deposited on carbonates, it is imagined that the process tends to be even longer in equally flat areas but on more resistant rocks and with better preserved margins.

In this context, it should be noted that the process of abandonment of the Volta Grande meander was slow at its beginning, between 1981 and 2001, and more accelerated at its end, between 2001 and 2015 (Figures 4 and 7). It took 20 years for the straight channel to drain more water than it normally would and only 14 years for the Volta Grande meander to be abandoned after that. Considering this, in a completely natural process, it is possible to

expect several decades to elapse before a channel created by the natural "throttling" of a meander reaches the depth of the channel bed built in 1981. Initially, as an artificially excavated channel, it was only after 20 years that the São Francisco River turned it into its main bed (Figures 4 and 7) and began to have the strength to erode its new concave bank (Figures 8 and 9). Thus, the abandonment process of the Volta Grande meander in the São Francisco River evolved temporally, similar to a geometric progression, where with each passing year, the river course adapted to the new channel more quickly. This observation, although simple, shows the complexity involved in the morphodynamics of meandering rivers, as Hook (1995) observed for a different process in England: rapid changes in the channel between 2 and 3 years after straightening and subsequent loss of velocity in the morphological adjustments. In other words, in terms of the evolution of the rate of occurrence of geomorphological processes, the São Francisco River in Volta Grande exhibited a behavior contrary to that of the river channels investigated by Hook (1995). The geoforms created were similar, and the same processes occurred; however, in England, the main changes occurred soon after straightening, and in Brazil, it took at least 20 years for significant changes to occur (Figures 4 and 7). This fact may be related to the differences in climate, substrate and size between the channels investigated but shows the importance of further studies on the subject.

In parallel, studies of this type are not only important for a better understanding of the processes and speed of river meandering. They are also of paramount importance for biogeographic studies of freshwater fauna and for those investigating the processes of drainage rearrangement, as they show that, contrary to what was previously thought and in accordance with what has been observed in the Amazon (SALGADO et al., 2021; STOKES et al., 2018), medium and large rivers take many years to completely abandon an old bed. Therefore, in the process of river capture, it is expected that there is time for the aquatic fauna of one watershed to invade the other. This verifies that the processes of drainage rearrangement can enable intense migration of fish between neighboring watersheds, such as those that occurred between the large watersheds of South America (ALBERT and REIS, 2011).

6. Conclusions

Although the abandonment of the Volta Grande meander on the São Francisco River was initiated and accelerated by a construction project, it exhibited typical morphodynamics and developed almost exactly as it would in a natural process. In parallel, the results obtained show that the process of abandonment of the studied meander, even if accelerated by work, was not fast, as it required more than thirty years to complete. During the rainy season, for more than three decades, water has flowed through both channels. During the dry season, it took twenty years for more water to flow through the straight channel than through the meander. In addition, it was possible to conclude that, for this specific case, the process of abandoning the meander was initially slow but tended to accelerate over time.

Regarding the impacts that the results of this study may have on the dynamics of freshwater biodiversity, it is concluded that in the processes of the abandonment of channels by rivers that are not headwaters and that drain poorly dissected plains or plateaus, there is likely enough time for the fauna to adapt to changes in drainage. This includes the migration of aquatic samples between different watersheds because, on the basis of this study, when the headwater of a river intersects the channel of a river course belonging to another watershed, several years tend to elapse before the channel of the pirated river is deep enough to completely steal the flow of the pirated river. Therefore, during this period, the wide migration of aquatic samples between the two watersheds was possible. In this sense, all these conclusions reinforce the observations of Stokes et al. (2018) and Salgado et al. (2021), who indicated that voluminous rivers that drain poorly dissected plains usually require decades to abandon old beds. This study revealed that this occurs even when these abandoned beds are meanders of the river itself.

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