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Mapping the Maracanã Aqueduct: Reconstructing the Route of Rio de Janeiro's Second Major Aqueduct[1]

Keywords: Rio de Janeiro, Maracanã, *Aqueduct*, Cadastral Map, ArcGIS

Summary: This paper reconstructs the route of the nineteenth-century aqueduct from the Maracanã River into the city of Rio de Janeiro using historical maps, archival records, and visual imagery. The first cadastral survey of the municipality of Rio, the *Planta da Cidade do Rio de* Janeiro [1870] and an engineering plan of 1845 are studied for the first time in ArcGIS and ArcScene in order to understand how the original channel, and as well as a second, underground piped conduit, came into the city. Georeferencing several segments of the same map, using modern contour data, and comparing historical maps are all techniques used in ArcGIS to establish the most likely route. In addition, historical, visual and textual sources provide further confirmation of the location of the Maracanã Aqueduct.

The supply of fresh and pure water is essential to life in any city, but the history of water infrastructure is not always easily reconstructed. In the case of Rio de Janeiro, the Carioca Aqueduct is well known. Its monumental, double-arched water bridge still stands. A rich collection of visual images heralds its importance through time, thick descriptions written by many who walked its course can be found in nineteenth-century books, and archival sources document its construction, maintenance, and location (Metcalf, Smith, and Kennedy, 2016). As Rio grew in the nineteenth century, the Carioca Aqueduct could not deliver enough water, and a second aqueduct, the Maracanã, was built. Where this aqueduct ran is much less clear, even as it greatly increased the amount of fresh water in the city. The route of the Maracanã Aqueduct is difficult to reconstruct because it did not have a magnificent architectural feature that residents and visitors described, painted, and visited. Although archival sources can be used to understand its construction, its actual location is difficult to place. We set out to reconstruct the route of the Maracanã Aqueduct using the first cadastral map[2] of Rio, the *Planta da Cidade do Rio de Janeiro* [1870], which presents not only highly detailed mapping

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[2] A cadastral map is one that shows "the boundaries of subdivisions of land, often with the bearings and lengths thereof and the areas of individual tracts, for purposes of describing and recording ownership. It may also show culture, drainage, and other features relating to land use and value," Glossary of Cartographic Terms, Perry-Castañeda Library Map Collection, University of Texas Libraries, UT-Austin https://www.lib.utexas.edu/maps/glossary.html.

of the city but extends far enough into the Tijuca Forest to show where the Maracanã Aqueduct began. Although we worked carefully with the *Planta da Cidade,* and even developed new techniques to extract geographic information, a cautionary tale emerges. Single historical maps, even ones that seemingly present reliable documentary evidence, must be studied in tandem with other maps, visual imagery, and archival sources before reliable historical information can be extracted. Nevertheless, our mapping of the Maracanã Aqueduct opens up new ways of understanding nineteenth-century Rio de Janeiro.

Why does it matter exactly where the Maracanã Aqueduct ran? Water infrastructure is essential to the expansion of any city, it is costly, and it affects the most intimate aspects of daily life. Not only must engineers be contracted to study the problem and to draw up plans, but materials must be purchased and laborers acquired. The Carioca Aqueduct was decades in the making, and it was built by forced Native labor and African slaves. Even though the Maracanã Aqueduct was engineered and built much more quickly in the nineteenth-century, and even as it took advantage of modern materials, it too was likely built with slave labor. Moreover, it relied on colonial modes of distributing water. The Maracanã Aqueduct delivered water to public fountains, from which it was carried throughout the city by watercarriers and domestic servants who, in their majority, were slaves (Graham, 1988: 40-41). Later, when the aqueduct was redesigned and reconstructed using cast-iron pipes and a system of individual *penas* or "quills" brought water directly to some buildings, factories, and residences, it was still the case that domestic servants, most certainly enslaved, continued to carry water from public fountains to private homes. These basic facts of how water came into the city and how it was distributed are essential for understanding daily life in Rio, which included one of the largest urban slave populations in the nineteenth-century city Atlantic world.

Quite early major cities, such as London, recognized water infrastructure as key to their future (Halliday, 2004; Melosi, 2000: 23-40). Most early modern European cities lay along rivers, which facilitated trade and provided ample water, even though pollution and contamination posed serious problems before the advent of sanitary sewage disposal. Yet, the patterns of the development of water infrastructure were not necessarily the same for the port cities of the Atlantic World. Although several small rivers and streams emptied into the Guanabara Bay, Rio de Janeiro was not founded on the banks of any of them. The location for the first settlement—on top of the Morro do Castelo—was chosen with defense and evangelism in mind. The role of the fortified settlement was to maintain Portugal's claim over the magnificent Guanabara Bay and to provide a base for the Jesuit missionary enterprise (Karasch, 1985: 124).

Rio developed slowly in response to the rhythms of the Atlantic economy, and water infrastructure followed rather than led the expansion of the city. In the sixteenth and seventeenth centuries, the small settlement (a city only in name) extended along the shoreline of the Guanabara Bay just south of the Ilha das Cobras to the Ponto do Calabouço between the *morros* (hills) of Castelo and São Bento. Much of the land below the hills was marshland, and fresh, good water had to be fetched from streams and rivers at some distance, such as from the Carioca River to the south, and the Comprido River to the west. During the eighteenth century, as the city grew in response to the gold rush in Minas Gerais, the city spread back to the west, still in rectangular fashion hemmed in by a second pair of morros: the Santo Antônio and Conceição hills. The lack of good water was recognized as a serious impediment, and by the first decades of the eighteenth century, water began to flow into the city via the Carioca Aqueduct that channeled water from the base of the Corcovado Peak into the

southwest side of the city, at the Largo da Carioca (fig. 1). The monumental double-arched water bridge became a part of the aqueduct in 1750, and underground pipes carried water to the fountain in the main public square: the Largo do Carmo, later known as the Largo do Paço, and to a few other fountains (Metcalf, 2014). The filling in of a lagoon allowed the city to develop south into the neighborhood of Lapa where a branch of the Carioca aqueduct fed several more public fountains. By the nineteenth century, when coffee became an important commodity for export, the city center had extended back further, still between a set of morros—the Senado and Livramento—and water remained limited.

Figure 1: The Late Colonial City of Rio de Janeiro. The georeferenced map is *Plano da cidade do Rio de Janeiro elevado em 1791* Biblioteca Nacional (Brasil) http://acervo.bndigital.bn.br/sophia/index.asp?codigo_sophia=973.

When the royal court arrived in Rio in 1808, after having fled Lisbon in advance of Napoleon's invading army, it quickly became apparent that the city would grow and that the lack of water had to be addressed. From archival sources we know that some sort of exploratory work on constructing an aqueduct to bring water from the Maracanã River had been drawn up during the first years of the nineteenth century, during the time of the Viceroy, D. Fernando José de Portugal e Castro (1801-1806). With the arrival of the court, in March of 1808, the urgent need to accommodate the growing

city was clearly felt. In August, a request was made by the Intendente Geral da Policia (Intendant of the Police) Paula Fernandes Vianna to the City Council requesting that the plans for a Maracanã aqueduct be made available to him.[3] At the end of August, a map (current location unknown) was delivered to the Viceroy by the City Council. Recognizing the vulnerability of the city's reliance on a single aqueduct (the Carioca) and the abundant waters of the Maracanã River, the City Council viewed the projected new aqueduct as a great benefit to the residents. It "would at once silence the cries of the people," the councilors wrote.[4] Apparently, the work was begun, or resumed, for subsequently, water was flowing into the Campo de Santana, at the back of the city, by 1818.

Nineteenth-century visitors left rich descriptions of the city of Rio, including its waterworks. Johann Baptist von Spix and Karl Friedrich Philipp von Martius, who led a scientific expedition from Bavaria to Brazil and who were in Rio in 1818, note in their subsequent publication *Reise in Brasilien*, that the fountain in the Campo de Santana was fed by a new aqueduct (Spix and Martius, 1823). "New fountains," they write, "continue to be erected in the city, and during our stay, measures were taken to provide the great square of S. Anna with a fountain, and to lead a new aqueduct to the south-west part of the city" (Spix and Martius, 1824, vol. I: 138).

According to Robert Walsh, the chaplain to the British Ambassador Extraordinary, Viscount Strangford, to the court of Brazil, and who was in Rio in 1828 and 1829, the project to channel waters from the Maracanã River took nine years, and the arrival of the waters was celebrated on the 24th of June 1818. In *Notices of Brazil*, Walsh writes that,

when all was ready, the worthy monarch, with all his family, attended to see the completion of his benevolent and useful work. The fountain, as soon as he arrived, was set flowing from twenty-two brazen spouts; and he saw with delight all the people run to drink of it, as a new and extraordinary luxury brought to this distant part of the town (Walsh, 1831: 279).

The painter attached to the Spix and Martius expedition, Thomas Ender, painted a watercolor (fig. 2) that shows the new fountain in the Campo de Santana. One of the first recorded views of the new fountain, Ender shows a white, circular fountain with a roofed structure next to it, which was intended for laundresses.

[3] Officio do Intendente Geral da Policia Paulo Fernandes Vianna dirigido em 6 de agosto de 1808 ao Presidente do Senado da Camara. The report makes reference to a plan to capture the waters of the Maracanã River that was held by the City Council of Rio de Janeiro and that dated to the tenure of the Vice Roy D. Fernando José de Portugal e Castro (1801-1806). Aqueductos chafarizes, fontes, 51.1.2, pp. 14-15, Arquivo Geral da Cidade do Rio de Janeiro.

[4] Senado da Câmara ao Snr. Conde dos Arcos, Vice Rei deste Estado, 27 de agosto de 1806, in Correspondência do vice-rei. Regimento para os governadores do Brasil. Arquivo Nacional, Rio de Janeiro, available online at: http://www.historiacolonial.arquivonacional.gov.br/cgi/cgilua.exe/sys/start.htm?infoid=237&sid=35.

Figure 2: Thomas Ender, “St. Anna Kirche in Cidade nova, campo St. Anna” [1818]. Kupferstichkabinett der Akademie der bildenden Künste Wien

The new source of water and the draining of marshes allowed the city to expand into the area to the north and west of the Campo de Santana, an area that became known as the Cidade Nova (Andreatta, 2008). The Maracanã waters alleviated shortages in the older neighborhoods of the northern *centro*, even as residents continued to receive water in the traditional ways of the colonial city—carried in jugs on the heads of enslaved domestic servants, or from *aguadeiros* or water carriers, often chained gangs of slaves.

On an excursion into the Tijuca Forest, Spix and Martius describe the new aqueduct. They write that they left the city by the road that led from the city center to São Cristóvão and that "[t]o the west of the road, a new aqueduct conveys the water of a stream from the mountains into the city" (Spix and Martius, 1824, vol. I: 215). Where exactly was this river? Some sources suggest that the name Maracanã referred to several rivers to the west of Rio de Janeiro. In particular, there is confusion between the Rio Trincheiros and the Rio Maracanã, which join before flowing into Guanabara Bay. Both the Trincheiros and the Maracanã flow in the same general direction, but the Maracanã lies farther to the west. The name Maracanã derives from the Tupi-Guarani word *maraka*, which most likely refers to the parrot today known as the Blue Winged Macaw (*Propyrrhura maracana*), then

widely distributed throughout Brazil. Today the parrots live in the forest edge, in palm groves, and along rivers in the Northeast Caatinga (Perlo, 2009: 120–121.) The name Rio Maracanã, therefore, is somewhat generic. Walsh, the British Chaplain who was in Rio in the late 1820s, provides an important detail about the origins of the waters that flowed into the Maracanã Aqueduct. Walsh notes that it was in fact the Maracanã River that was the source of the water that arrived in the Campo de Santana in 1818. Walsh describes a visit he made to the Tijuca Forest where he visited two waterfalls. One waterfall, he writes, "forms the river Maracanan, which runs into the bay near S. Cristovão" and "from this beautiful waterfall . . . a second supply of water is brought to the city." Walsh's description of the waterfall reflects its beauty as well as the volume of water:

The whole river, running along the mountain above, arrives at the almost perpendicular face of the rock, over which it shoots like water from the eaves of a house, scarcely touching the face of the fall. Its height is estimated at fifty braças, or 300 feet . . . displays beautiful rainbows. The valley into which it falls is a deep sequestered glen (Walsh, 1831 I:278).

Spix and Martius describe this same waterfall, from memory and field notes, while Thomas Ender, their landscape painter, produced a watercolor. It is likely that Ender accompanied Spix and Martius on their visit to the waterfall and that their description was written on the very day when Ender painted the falls. From Spix and Martius:

Towards daybreak we proceeded towards the quarter from which we heard the sounds of the water, and just as the sun was rising, were at the declivity of a high rock, from which a crystal brook, partly dissolved into mist, fell from a height of nearly a hundred feet into the valley. . . . At the bottom of the valley and near the cascade stands a simple pleasant cottage, where we were welcomed by Mr. Tonay [sic], an estimable French painter who resides with his family in this secluded spot (Spix and Martius, 1824).

Walsh also states that the waterfall was located next to the dwelling of a French artist; while Ender labels writes on his watercolor that the house was Taunay's (Wagner, Bandeira, and Ender, 2000: 305; Walsh, 1831: 278) (fig. 3).

Figure 3: Thomas Ender, “Kleiner Wasserfall von Tijuca bei Hrn. Taunay's Hause” [1818].
Kupferstichkabinett der Akademie der bildenden Künste Wien.

This French artist with a house next to the falls was most certainly Nicolas-Antoine Taunay, a painter who came to Rio de Janeiro as part of the French Artistic Mission in 1816 (Debret, 1834-1839, I: 2). This waterfall can be positively identified as the Cascatinha da Tijuca.

How did the waters arrive from this distant waterfall into the new fountain on the back edge of the city? A map titled *A Capital do Brasil*, dated 1831 (fig. 4), shows the Maracanã Aqueduct flowing around the contours of hills and reaching the edge of the city. As the map gives no indication of how the water flows through the last stretch of the aqueduct into the Campo de Santana, we assume that this last stretch was piped in under the streets. As with the 1791 map (fig. I), the 1831 map (fig. 4) does not reach far enough back into the Tijuca Forest to show the origins of either the Carioca or the Maracanã aqueducts.

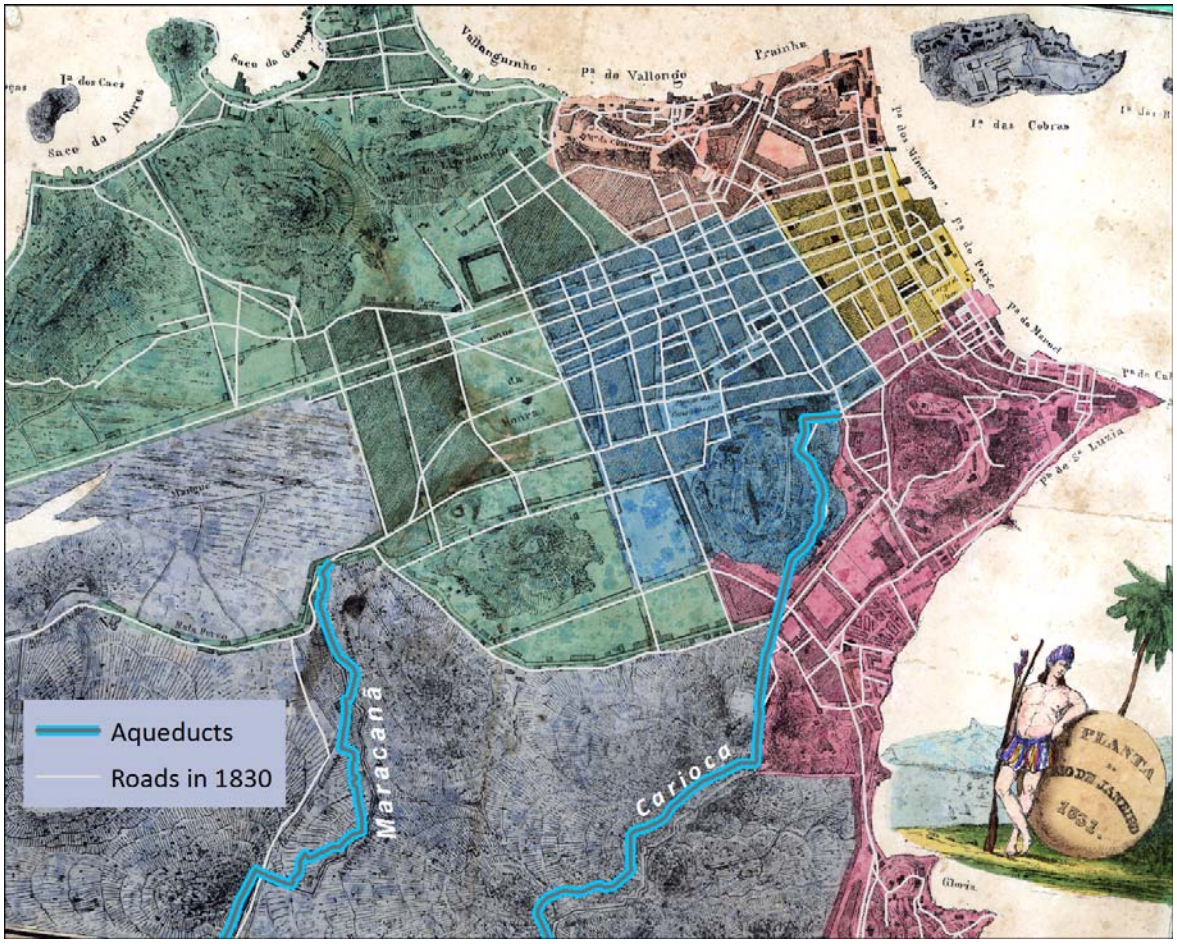

Figure 4: Rio de Janeiro in 1831. The georeferenced map is E. de la Michellerie, *A Capital do Brasil, Planta do Rio de Janeiro, 1831*, Library of Congress, Washington, D.C., http://www.loc.gov/resource/g5404r.ct000633/.

A later and much larger map of the city, the E. & H Laemmert *Nova Planta da Cidade do Rio de Janeiro* (1867)[5] shows more of the Maracanã Aqueduct, suggesting that its significance as a major source of water for the city was well understood. Even this large and complete map of the city does not reach the Maracanã River (fig. 5).

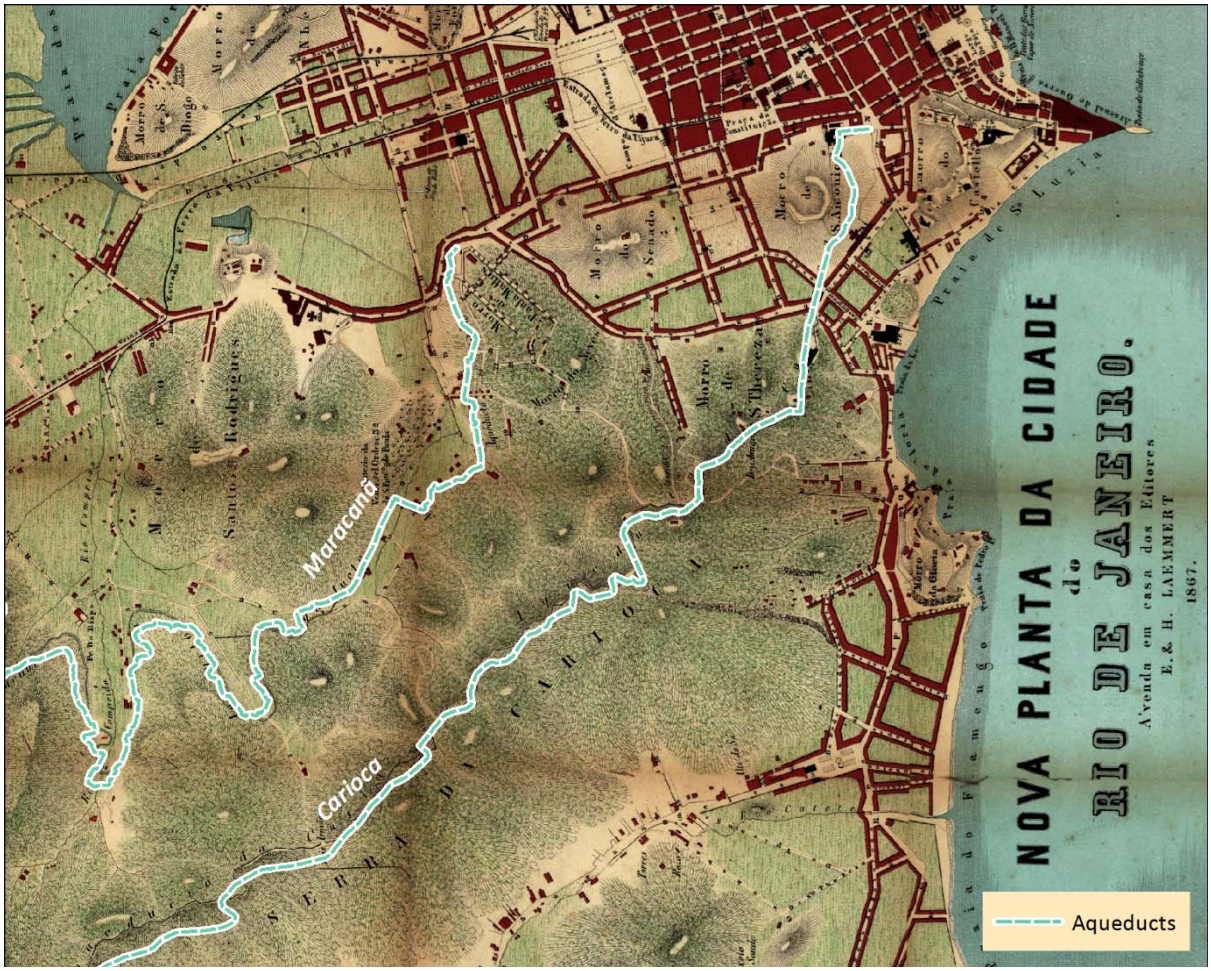

Figure 5: Rio de Janeiro in 1867. The georeferenced map is E. & H. Laemmert, *Nova planta da cidade do Rio de Janeiro, 1867*, Library of Congress, http://hdl.loc.gov/loc.gmd/g5404r.br000055.

The *Planta da Cidade do Rio de Janeiro* [1870],[6] considered to be the first cadastral map of Rio de Janeiro (Czajkowski, 2000), does show the Maracanã River and the origin of the Maracanã Aqueduct deep in the Tijuca Forest. Cadastral maps are part of the tradition of European large-scale mapping, and cadastral surveys exist at least since Napoleonic times (Mastronunzio and Prà 2016), but the 1870 *Planta da Cidade* was the first for Rio. It shows the city in detail, and it was likely used for planning urban improvements, such as those of the Commisão de Melhoramentos (Andreatta, 2008). Although

[5] E. & H. Laemmert, *Nova planta da cidade do Rio de Janeiro, 1867*, Library of Congress, http://hdl.loc.gov/loc.gmd/g5404r.br000055. Originally a folded map, we removed the spaces between the sections before georeferencing it. On georeferencing, see n. 11.
[6] *Planta da Cidade do Rio de Janeiro* [1870] BR AN, RIO 4M.0.MAP.118, Arquivo Nacional (Brasil).

not its intent, the 1870 *Planta da Cidade* provides information on the water infrastructure, especially that provided by the Maracanã Aqueduct, making it an attractive source for historians interested in the history of water.[7]

Mauricio Abreu and others point to 1870 as a turning point for the city of Rio de Janeiro caused by the building of the railroad and tramlines that extended the city beyond the cramped, rectangular historical core (Abreu, 2010; Andreatta, 2006; Sedrez, 2004). How water infrastructure factored into these changes remains unclear. Historians note that after 1870, urban transportation reconfigured the city even before the dramatic urban reforms of Mayor Pereira Passos in the first years of the twentieth century (Boone, 1994). In the closing decades of the nineteenth century, urban workers and the poor began to be pushed out of the central city and into suburban neighborhoods tied to the central city by trams and rails (Boone, 1995). The northern zone became the working class district, whereas the southern became the enclave of the middle and professional classes. Historical maps that survive from the last decades of the nineteenth century (Abreu, 2010; Andreatta, 2006; Sedrez, 2004; *imagineRio*) do not show how water infrastructure encouraged or responded to these changes in the city. Because of its size and detail, the 1870 *Planta da Cidade* is a particularly rich source that does record information on water infrastructure.

The surviving sheets of the 1870 *Planta da Cidade* have been scanned by the Arquivo Nacional in good resolution, which theoretically makes it possible to join the sheets together to create an exciting new source for the spatial history of water in the city. However, this is not so simple. In the first place, the surviving sheets do not necessarily match, nor can they be easily lined up against each other. In an effort to extract geographically useful information from the map, we experimented with a variety of techniques to georeference the map's individual sheets. First, we tried tiling the individual sheets together in Photoshop without resizing them based on the assumption that the digital copies had been created under similar conditions. We quickly discovered that the digital versions of the sheets had been scanned at different resolutions and that they could not easily be reassembled.[8] This issue pushed us to try to georeference[9] sheets individually, relying on our ability to locate them geographically. This technique worked well for sheets that contained multiple fixed geographical points spread throughout them. However, many sheets contained only one or two recognizable points that could be used as control points, and thus they could not be georeferenced well. For instance, sheets covering the *centro* contain numerous roads and other features that allowed them to be

[7] The archival entry indicates that the map was copied by Leopoldo José da Silva, A. Rangel, Afonso Carneiro de Oliveira Soares, C. d'Azambuja, Daniel Muller, J. A. da Cunha, and João Baptista N. It has no scale. The original map consists of 179 sheets, each measuring 75 x 103 cm. On the back of the third sheet is written "Trabalho do engenheiro A. Santana, 5 de abril de 1870 (Carta Geral do Império. Triangulação do Município Neutro) [Work of A. Santana, engineer, April 5, 1970. Map of the Empire. Triangulation of the Municipality of Rio de Janeiro].

[8] This variation between sheets demonstrates that the provenance of the map may be more complicated than Arquivo Nacional source information indicates, see above n. 9. The variations suggest that mapping data may have been compiled over time and that the collection of sheets may come from multiple revisions of the map, rather than a single edition.

[9] Georeferencing transforms an historical map into a vibrant source of geographic information that can be studied in a Geographic Information System (GIS). In ArcMap, a digitized historical map is georeferenced by linking ground control points, which have known x,y coordinates, to locations on the digitized historical map. See "What does georeferenced mean," USGS https://www2.usgs.gov/faq/node/3545 and "Fundamentals of georeferencing a raster dataset," http://desktop.arcgis.com/en/arcmap/10.4/manage-data/raster-and-images/fundamentals-for-georeferencing-a-raster-dataset.htm.

georeferenced as individual sheets, but sheets portraying the city's hilly hinterlands often had only one or two windy roads cutting through them, making them nearly impossible to georeferenced (fig. 6).

Figure 6: Georeferencing the Cadastral Map sheets. The sheets from the *centro* provide many potential control points whereas the sheets from the outlying areas present few.

Continued experimentation with digitally stitching together individual sheets to make larger panels demonstrated that with careful scaling the panels could generally be made to fit together nearly seamlessly. However, small differences in how the sheets were digitized at times led to large divergences in the assembled panels. Moreover, the symbology seemed to vary arbitrarily across the sheets. Symbology is a long-recognized tool that lets the cartographer and map user move from a labeled feature, such as a river, to an unlabeled, but similarly symbolized, feature. However, the symbology used on the Cadastral Map is not always consistent and continuous across its sheets. When the sheets are tiled together, these variations in symbology are readily apparent. Hills, in particular, are represented in a variety of ways, including with sharply shaded contours, light green washes, darkly colored green patches, or not being represented at all. Additionally, some features, including roads and waterways would at times disappear at sheet boundaries (fig. 7).

Figure 7: A section from the *Planta da Cidade* [1870] cadastral map shows that the top row can be joined fairly well, but distortions creep in as additional rows are added. Variations in the symbology are clearly evident with some features, such as hills or rivers, inconsistently represented from sheet to sheet.

Taking these variations into account, and accepting that historical maps always present challenges for historians, we settled on an iterative strategy where relatively small groups of sheets were tiled together based around features of interest. Given our focus on the Maracanã Aqueduct, we created groups that followed the aqueduct's path on the *Planta da Cidade*. This methodology allowed us to trade off the lack of information in individual sheets with the errors introduced in the tiling process.

Beyond simply determining the best way to georeference the map's individual sheets, we also had to work around errors introduced in the mapping process. Especially in mountainous areas, the accuracy of the map (relative to modern maps) is poor. Rapidly changing elevations and few built landmarks made mapping Rio's hinterlands especially difficult in the nineteenth century. Although it is clear that roads on the *Planta da Cidade* follow the twists and turns of modern roads, they are often skewed when compared to modern maps. Similarly, building footprints on the *Planta da Cidade* are often offset as compared to modern data. In order to correct for this, we focused on georeferencing features of interest, such as the Maracanã Aqueduct, based on other nearby features, such as roads, in order to reduce the impact of errors that compound across distance. By georeferencing our groups of sheets containing the aqueduct, as well as those around it, we were able to trace the course of the Maracanã Aqueduct from the *Planta da Cidade*.

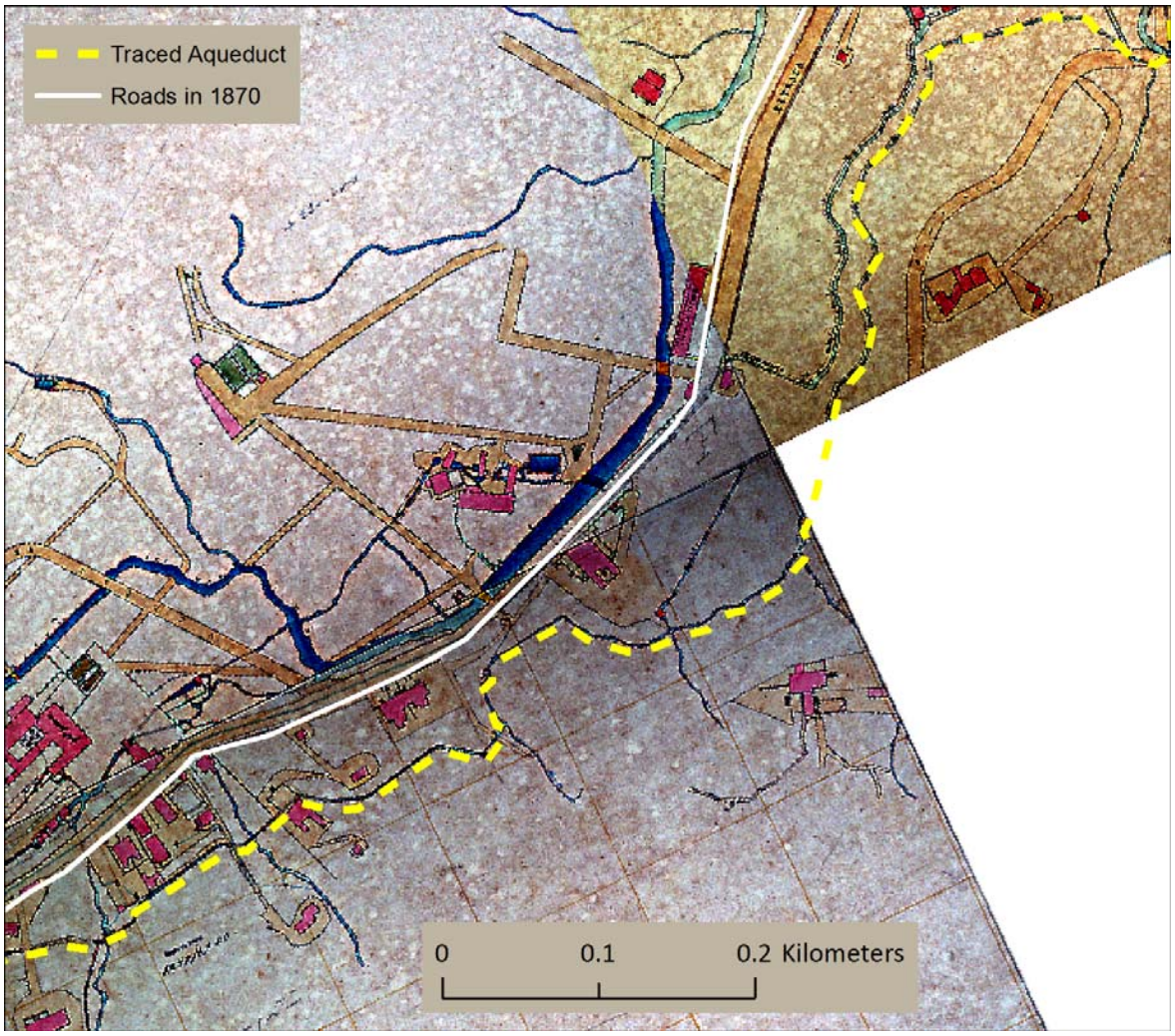

Figure 8: Tracing the Maracanã Aqueduct from the *Planta da Cidade* [1870]. After georeferencing the joined segments of the *Planta da Cidade* 1870 cadastral map, the Maracanã Aqueduct was then traced in ArcMap.

The accuracy of the traced line of the Maracanã Aqueduct can be verified against modern topography data. This technique allowed us to compare the *Planta da Cidade's* representations of the aqueduct to the terrain. Because the aqueduct relied on gravity flow, the engineering required carefully positioning each segment in areas with small changes in pitch. Relying on the aqueduct's gradual but steadily downhill course, we used contour data to refine and reconcile our traced aqueduct line to the topography. First we gathered the elevation of the start and the end of the aqueduct in order to calculate its average slope and to get a sense of how quickly it crossed contours. Then, we drew the aqueduct by tracing contour lines, taking into account both the necessary changes in elevation and the contours' geometric similarities to the mapped aqueduct. This resulted in a probable course for the aqueduct based upon both modern topographical data and historical maps (fig. 9).

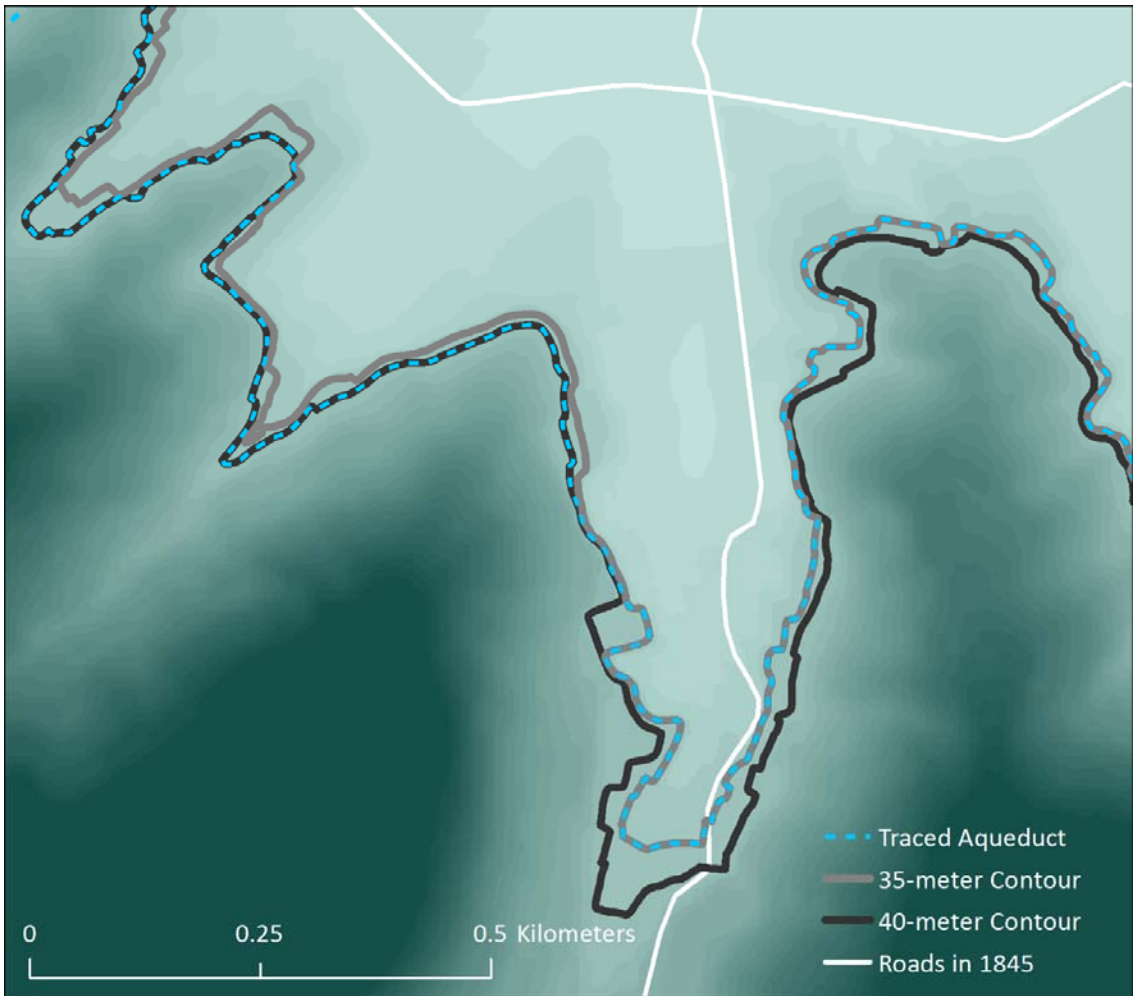

Figure 9: Topography and the Maracanã Aqueduct. As the aqueduct had to maintain a downhill course, modern contour data helps adjust the accuracy of our line traced from the georeferenced segments.

Comparing the *Planta da Cidade* with earlier maps reveals something odd: the *Planta da Cidade* does not show a complete aqueduct running from the Maracanã River into the center of the city. Whereas the Maracanã Aqueduct visible on *A Capital do Brasil* (1831) and on the Laemmert *Nova Planta da Cidade do Rio de Janeiro* (1867) flows around the slopes of hills and right to the edge of the city, this section of the aqueduct does not appear on the *Planta da Cidade* [1870]. Whereas the cadastral map shows the portion of the aqueduct that extended to the Maracanã River (which was not represented on the earlier maps because they were not extensive enough), the Maracanã Aqueduct gets lost as it approaches the city. Because the the symbology used on the *Planta da Cidade* is inconsistent (fig. 7) we assumed that the cadastral map was most reliable for the western-most stretch of the Maracanã Aqueduct, whereas the Laemmert *Nova Planta da Cidade do Rio de Janeiro* (1867) reliably showed the aqueduct course around the hills leading into the city. Where sheets were missing from the *Planta da Cidade* and beyond the range of the earlier maps, we could add the missing segments by tracing a line following the contour lines, assuming that the aqueduct followed a natural downward course.

By combining traced sections from the *Planta da Cidade* [1870] with those of the Laemmert *Nova Planta da Cidade do Rio de Janeiro* (1867) and using the contour data to achieve greater accuracy

and to complete missing segments, we initially believed that we had reconstructed the route of the aqueduct into the city. However, our story is not quite over, for we sought out other historical maps that might shed light on the Maracanã Aqueduct. One historical map, which we initially dismissed as too inaccurate to be helpful, when approached with the techniques we developed to study the *Planta da Cidade*, tells a different story, which caused us to reconsider our understanding of the course of the Maracanã Aqueduct. This map is an engineering plan, dated 1845, and it is titled *Planta d'uma parte da Cidade do Rio de Janeiro com designação em linha azul, das ruas por onde passão os diversos encanamentos d'agua, do Encanamento de Maracanã* (Map of a Part of the City of Rio de Janeiro with blue lines indicating the streets where the various water pipes will go from the Piping of the Maracanã); it is signed by José Pereira de Sá (fig. 10).[10]

Figure 10: The 1845 Plan for the Piping of the Maracanã. José Pereira de Sá, *Planta d'uma parte da Cidade do Rio de Janeiro.* BR_RJANRIO_53_0_MAP_0025, Arquivo Nacional (Brasil).

As the title suggests, this map is a plan for installing cast-iron pipes to carry the water from the Maracanã River through the city. The map is more of a sketch, but it georeferences well for the central city. However, the hilly rural areas behind the city do not, and in particular, the lines for the Maracanã Aqueduct that follow the contours of hillside slopes do not match those from the 1867 Laemmert *Nova Planta da Cidade do Rio de Janeiro*. Noticing that two sections of the map had been

[10] BR_RJANRIO_53_0_MAP_0025_1de2.tif, Arquivo Nacional (Brasil). Sheet one in the two-document set is the map/plan for piping the Maracanã while sheet two shows the iron pipes and how they are to be fitted together.

taped together, we re-georeferenced the hilly back side of the city against our roads layer. There were many fewer possible control points, but nevertheless, the re-georeferenced map allowed us to see that the aqueduct on the 1845 map followed a similar course around the hillsides into the city to that of the 1867 Laemmert *Nova Planta da Cidade do Rio de Janeiro*. Using the 1845 engineering plan, we traced the portion of the aqueduct that flowed around the hills and to the edge of the city. Comparing the line derived from the 1845 *Planta d'uma parte da Cidade* with that of the 1867 Laemmert *Nova Planta da Cidade do Rio de Janeiro* reveals similarities but not very much precision. Using the modern elevation data, as well as the traced lines of the Maracanã Aqueduct derived from both historical maps, we created the likely course of the Maracanã Aqueduct in this region.

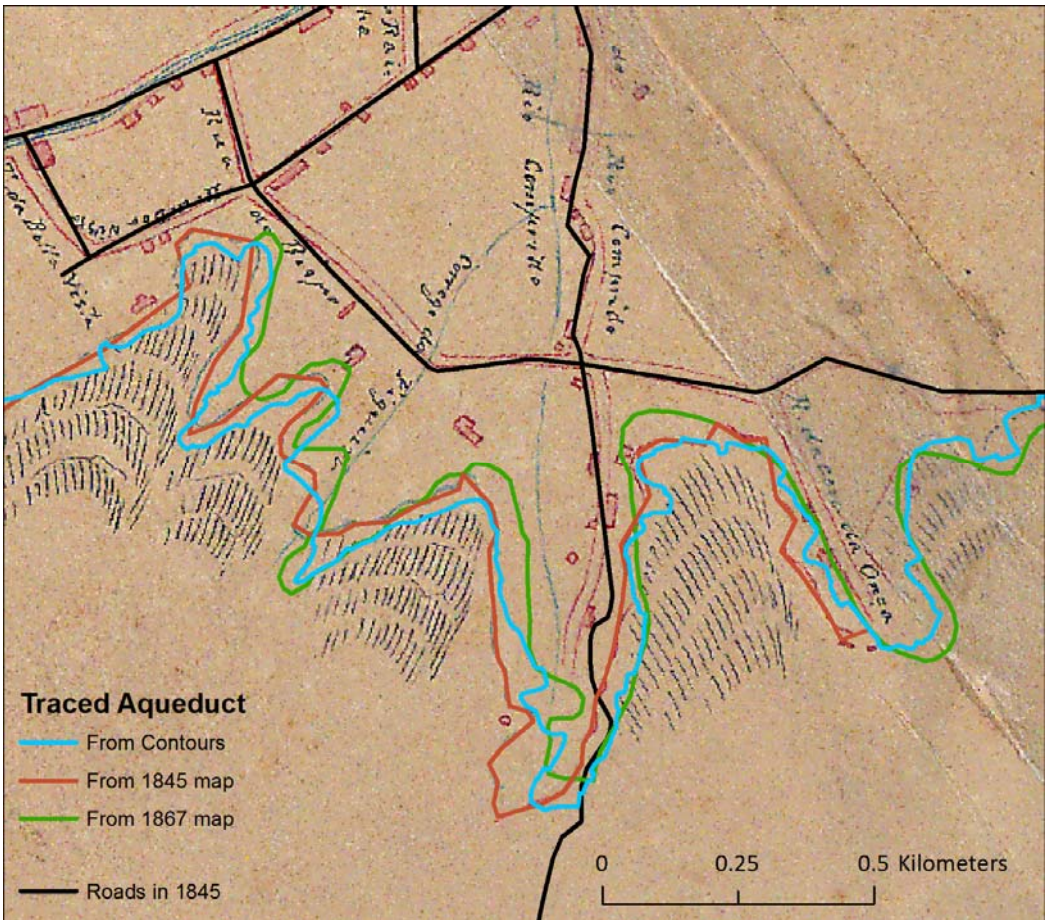

Figure 11: The Maracanã Aqueduct traced from Sá, *Planta d'uma parte da Cidade do Rio de Janeiro, 1845* (in red), Laemmert, *Nova planta da cidade do Rio de Janeiro, 1867* (in green), and from contour data (in blue). Basemap is the georeferenced *Planta d'uma parte da Cidade do Rio de Janeiro, 1845.*

Once again we asked ourselves why the *Planta da Cidade* cadastral map of 1870 does not show this portion of the Maracanã Aqueduct, where the aqueduct follows, in a sinuous, snake-like way, the folds of the hills. Was it deemed not important to the cartographers of the cadastral map? Is the map unfinished? Is the symbology missing? Or what information is represented on two missing sheets in the area? We discovered the likely answer when we traced the line drawn on the 1845 map/plan that

is marked as the route for the cast-iron pipes. This route follows a major road, Caminho Engenho Novo, and we may hypothesize that the pipes were to be laid beneath the roadbed. If in fact the cast-iron pipes were installed after 1845 and successfully carried the waters from the Maracanã Aqueduct into the city, the older section of the aqueduct would have been abandoned. Presumably, by the time the *Planta da Cidade* cadastral map was made in 1870, the cast-iron pipe line was functioning, and the waters no longer followed the course around the hills. Instead, the water ran directly from the Maracanã River in an open aqueduct part of the way, but then went underground and came into the city in the system of buried cast-iron pipes under Caminho Engenho Novo.

Figure 12 is our best estimate of where the aqueducts ran in nineteenth-century Rio. Initially, the Maracanã Aqueduct flowed around the hills and into the city much like the course of the Carioca Aqueduct. Sometime after 1845, the cast-iron pipes brought the water more directly into the city. To capture the differences between the modern city and the nineteenth-century city, we show the roads of the city as reconstructed for 1870. Superimposed on a base map of Rio today, the nineteenth-century city and its dependence on the Tijuca Forest for its water is clearly evident.

Figure 12: The Carioca and Maracanã Aqueducts in Nineteenth-century Rio de Janeiro. The water pipes were laid sometime after 1845, but the exact timing of the transition between the older aqueduct channels and the newer cast-iron piped aqueduct remains unclear. Base map from Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Walsh's description of the Maracanã Aqueduct, as well as other sources, provide details that confirm our reconstruction of the aqueducts in Fig. 12. When Walsh was in Rio in 1829, eleven years had passed since the opening of the aqueduct and fountain in 1818, and the city was nevertheless suffering from a lack of water. Walsh describes that the first waters from the Maracanan flowed through "wooden pipes by the direction of the king" (Walsh, 1831: 278). A document from the city archives dated 1829 reports on work done on the aqueduct by six stonemasons and 6 workers, and the materials used included stone, tile, and lime.[11] Intuitively, it would seem that wooden pipes were not a long-term solution for any waterworks, but elm had been long used in London (Halliday, 2004: 5, 11) and wooden pipes made from alder, cedar, oak, and pine were used in Philadelphia, Boston, and other American cities (Melosi, 2000: 34). In 1832, city records reveal that work began on repairing parts of the Maracanã Aqueduct, which included rebuilding, cleaning, and replacing wooden pipes (Silva, 1910: 34). Where these pipes lay is uncertain, but it is clear that continuous maintenance, as well as new work, was being done on the Maracanã Aqueduct at that time. Moreover, a small reservoir (*açude*) was built in Tijuca, at Boa Vista in 1838 (Silva, 1910: 35). During the drought of 1844, an engineer was charged to pipe two-thirds of the Maracanã, using cast-iron pipes. The next year, three thousand cast-iron pipes were ordered by the government and more small reservoirs built with brick (*caixas de agua*) were begun in the Tijuca Forest. These large holding tanks stored the water that would flow into the city via the cast-iron pipes. When the holding tanks and the newly piped aqueduct began to deliver water to the city, new pipes were laid within the city to deliver the water to new public fountains, faucets, and single quills (*penas*) to private buildings (Santa Ritta, 2009: 85–86; Silva, 1910: 43).

One last riddle remains: the linkage between the Castatinha da Tijuca and the Maracanã Aqueduct. The westernmost sheet of the *Planta da Cidade* cadastral map of 1870 shows the waterfall in the Tijuca Forest, from which Walsh and Spix and Martius claimed the waters of the Maracanã Aqueduct originated. In addition to these nineteenth-century sources, the noted historian of Rio, Francisco Agenor de Noronha Santos, clearly states that the Castatinha da Tijuca was the origin of the Maracanã River (Santos, 1907: 96-97). On the sheet of the cadastral map (fig. 13) the waterfall is clearly visible, and the river flowing over it is labeled Maracanã. Adjacent sheets show extensive waterworks below the waterfall and along the Maracanã as it flows in a northeasterly direction towards the city. Approximately a kilometer and a half (as the crow flies) from the waterfall, the aqueduct begins. Thus, we can conclude that the aqueduct that began to function in 1818 brought waters from the Cascatinha da Tijuca via the Maracanã River and the Maracanã Aqueduct into the city.

[11] Oficio do engenheiro Francisco Cordeiro de Silva Torres, 30 de outubro de 1829, ao Intendente Geral da Policia Luiz Paulo de Araujo Bastos, apresentando o orçamento das obras do Aqueducto do Maracanã, Aqueductos chafarizes, fontes, 51.1.2, pp. 61-62; 63-64, Arquivo Geral da Cidade do Rio de Janeiro.

Figure 13: Waterfall, Maracanã River, and Alto da Boa Vista. Sheets 215, 208, 216, 225 *Planta da Cidade* [1870].

To reconstruct the history and course of the Maracanã Aqueduct, multiple historical maps as well as descriptions of Rio written by visitors, nineteenth-century visual imagery, surviving documents in the archives, and nineteenth and early twentieth-century histories must all be used. Although an impressive (and beautiful) map of Rio, the Laemmert *Nova Planta da Cidade do Rio de Janeiro* of 1867 shows the earlier route of the Maracanã Aqueduct that was no longer functioning in 1867. Why this is so must be due to the fact that the cartographer copied from earlier maps. Nevertheless, even if this representation of the Maracanã Aqueduct is wrong for 1867, the map does preserve information that is important for understanding this portion of the aqueduct in earlier times, before the installation of the cast-iron pipes. The *Planta da Cidade* cadastral map of 1870 provides valuable information on where the aqueduct began, but it obscures where the water went because it does not record the location of the cast-iron pipes laid by1850. Sá's *Planta d'uma parte da Cidade do Rio de Janeiro* (1845) provides the missing link, even if, as a plan, this map is suggestive of what was to be done rather than reflective of what was. Reconstructing the water infrastructure in nineteenth-century Rio de Janeiro, therefore, requires working carefully back and forth with published and archival sources, georeferenced historical maps and plans, and geolocated images.

Figure 14: The Aqueducts flowing into the nineteenth-century city of Rio de Janeiro.

Our traced aqueducts, visualized in ArcScene (fig. 14), illustrate how the nineteenth city received its water. The basic gravity-flow engineering employed for the eighteenth- and nineteenth-century aqueducts is clearly apparent. The city received excellent water from the Tijuca Forest, but it was never enough. The system worked, but it required continual maintenance and left the city vulnerable to droughts and excessive rainfall. The need to maintain the springs, brooks, and rivers that fed the Carioca and Maracanã Aqueducts led to campaigns to reforest the Tijuca Forest. Measures taken in the nineteenth-century to replant the forest had the long-term consequence of allowing significant parts of the forest to survive as woodlands to the present day.[12] Not only were there consequences from the need to protect sources of water in Tijuca Forest in order to enable the inhabitants of the nineteenth-century city to have access to water, but within the city, traditional ways of distributing water—collection and delivery by slaves and domestic servants—continued even past 1870. This too would leave a mark on the social development of the city. The water infrastructure of nineteenth-century Rio holds keys to understanding the social and ecological history of the city, and in that story, the history of the Maracanã Aqueduct is an important piece.

[12] The replanting of the forest is documented in historical sources and maps, although it should be noted that the subsequent woodlands do not replicate the original Atlantic Forest (Cruz, P. et al, 1992).

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