Title

From High Rise to Coast: Revitalizing Riveira da Barcarena

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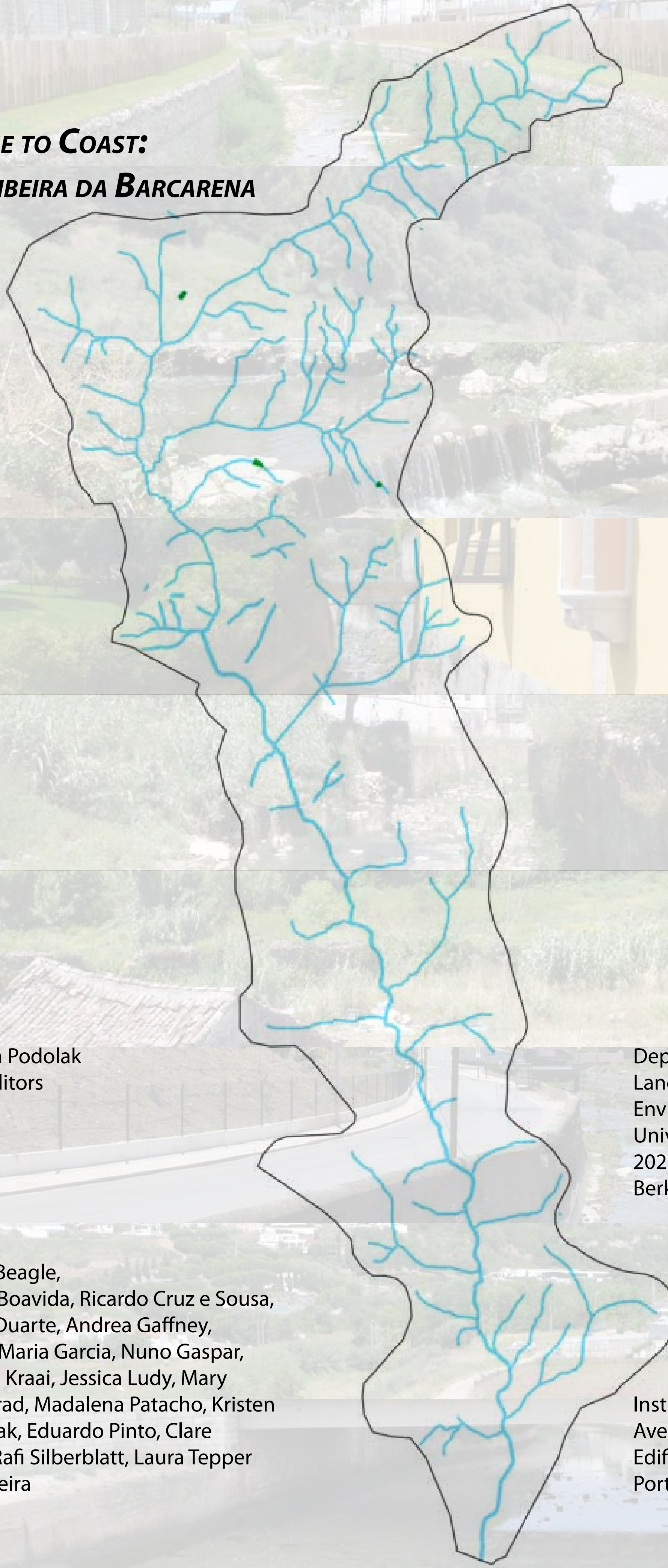

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Abstract

The Lisbon metropolitan region has grown rapidly in population since 1970, due largely to the immigration of people from former Portuguese colonies in Africa and from rural areas of the country in pursuit of higher living standards. Much of this population growth was accommodated clustered high-rise apartment blocks (many unpermitted) in the region west of Lisbon, in the municipalities Oeiras, Cascais, Sintra, and Amadora. These developments were largely unplanned, often did not provide for sewage treatment, and lack adequate mass transit or urban amenities such as parks and other open spaces. Moreover, because the main transport axes run east-west, it is difficult for residents of these apartment blocks to go the relatively short distance southward to the coast (e.g., only 10 km from Cacém to the coast).

This region is drained by a set of subparallel streams (each draining about 20-50 km^2), flowing roughly north-south through deeply incised valleys to debouch into the Atlantic between Lisbon and Cascais. With rapid urbanization peak runoff has increased, resulting from larger impervious surfaces and sewage from illegal housing settlements. Many reaches have been canalized within concrete walls to increase flood capacity, eliminating physical habitat complexity, and reducing amenity and recreational values. However, the urbanization has occurred mostly on uplands, leaving the bottomlands of the incised stream valleys in many reaches surprisingly unaltered. For decades, these drainages were largely neglected, managed mostly to convey floodwaters, although in some reaches there was strong informal use of the stream corridor and floodplains (such as garden plots). The Water Framework Directive (WFD) adopted by the EU Parliament (2000), has motivated extension and improvement of the regional sewer network to improve water quality. The WFD requires that all water bodies in member states achieve 'Good Ecological Status' by 2015, defined in terms of hydromorphological, biological, and physico-chemical quality elements of stream reaches, based on characteristics documented at reference sites.

Located 15 km west of Lisbon, Ribeira da Barcarena-Jardas drains a 35 km^2 catchment, whose uppermost reaches are forested, but otherwise alternates between urbanization and remnant agricultural and open-space uses. With improved sewage treatment and water quality, there is strong potential to preserve and restore ecological functions, consistent with goals of 'good ecological status.' As illustrated by the successful urban stream project in Cacém, there is tremendous potential for the stream corridor to provide parkland for the dense urban settlements. Through GIS analysis of remotely-sensed data, and field surveys of water quality, habitat structure, riparian vegetation, and fish populations, an interdisciplinary workshop of graduate students from Berkeley and Lisbon analyzed potential opportunities to enhance ecological values and human access along the stream. Our analysis indicated that implementation of stormwater management strategies via relatively unobtrusive retrofits of small open bits of urban land and floodplain within the catchment could mitigate many of the negative hydrologic effects of urbanization. By virtue of its linear nature, the stream corridors could provide pedestrian and bicycle connections from population centers (now under-served by parklands) to cultural features and to coastal beaches and trails. A trail could inspire similar efforts on neighboring, parallel basins that have undergone similar urbanization pressures and face similar challenges in providing underserved urban populations with access to recreation and contact with nature.

KW: Stream restoration, Ribeira Barcarena, Ribeira Jardas, Water Framework Directive, Lisbon metropolitan region, linear trail, stream corridor.

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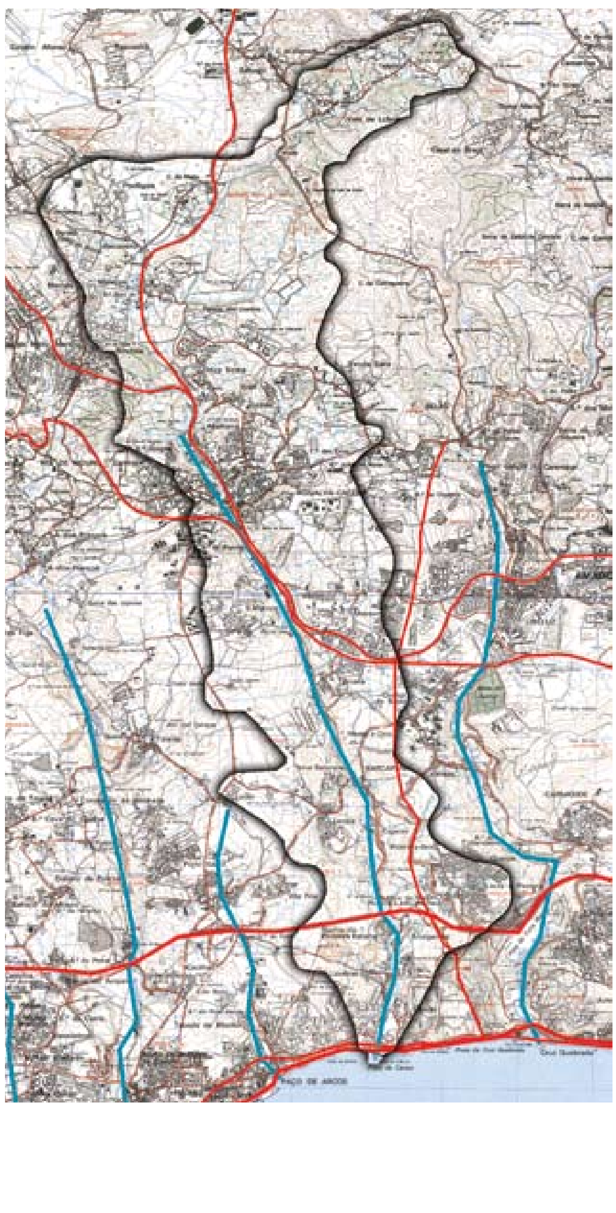
Preface

In Spring 2009, the course 'Mediterranean-Climate Landscapes: Reforming Water Management - Lessons from Europe for California' in the Department of Landscape Architecture and Environmental Planning at the University of California, Berkeley focused on the European Water Framework Directive (WFD), a law adopted by the European Union in 2000 and currently being implemented by its 25 member states. The WFD represents a bold change in river management, emphasizing catchment-scale, public participatory and environmental economics approaches and requiring member states to make substantial progress towards improving water quality and aquatic ecology in their rivers by specific deadlines. River basin plans are now being completed. For students of water resource management in the US, the WFD represents the implementation of many changes recommended for American water management for over a century, but which have generally not occurred because of institutional and political barriers.

In this course, students reviewed the origins of the WFD, its elements, its implementation to date, focusing on the Mediterranean-basin countries, and comparison with water management in California. As a culmination to this class the Berkeley students traveled to Lisbon to do a one-week joint research project with students from the Instituto Superior Técnico. The goal was to plan and design future options for the rehabilitation of Ribeira da Barcarena outside of Lisbon within the context of the WFD.



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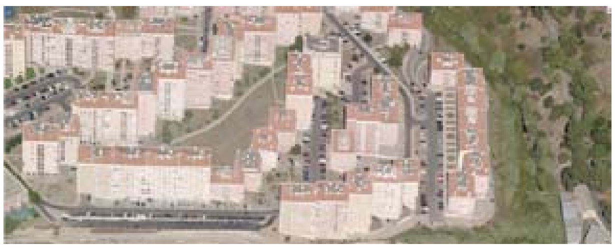
Ribeira da Barcarena

Many major rivers are central to the identity of cities through which they flow. It's hard to imagine Paris without the Seine, London without the Thames, New Orleans without the Mississippi. But many smaller rivers have been neglected or put out of sight, buried in pipes or relegated to concrete culverts, fenced off from human contact, facing the backs of buildings. Poor water quality has historically been a motivation for such treatment, but with improvements in wastewater treatment and improved water quality, we observe an explosion of river and stream restoration efforts, including revitalization of urban waterfronts. Lisbon occupies the banks of the Tagus (Tejo) River estuary, much as San Francisco occupies hills along the margins of San Francisco Bay (the estuary of the Sacramento River). While 'The River' (the estuary) figures importantly in local sense of place, smaller drainages that flow into the estuary have been largely forgotten: put into underground pipes or confined to narrow channels in areas with dense population or infrastructure.

Ribeira da Barcarena within Greater Lisbon



High density housing illustrates typical new construction.

Urbanization in the Barcarena Watershed based on Google Earth imagery from 2007.

The Lisbon metropolitan region has grown rapidly in population since 1970, due largely to the influx of people from former Portuguese colonies in Africa and immigration from rural areas of the country in pursuit of higher living standards. Much of this population growth was accommodated in the region west of Lisbon, where the population of the municipalities Oeiras, Cascais, Sintra, and Amadora grew rapidly from 1971-2001. New developments, mostly clustered high-rise apartment blocks, were rapidly constructed, in many cases without permits. These developments were largely unplanned, did not provide for sewage treatment, and lack adequate mass transit or urban amenities such as parks and other open spaces.

The main transport axes run east-west, connecting these settlements with the centre of Lisbon: the rail line along the Estoril coast to Cascais and another running inland to Sintra, with a fork to Mira-Sintra/Meleças, and major national highways such as the marginal (N6), limited access highways (the A19, A5, A16), and smaller routes. Transport connections running north to south are few. As a result, it is difficult for residents of these apartment blocks to go the relatively short distance from population centers to the coast (e.g., only 10 km from Cacém to the coast, 5 km from Barcarena). The inability to access the nearby coast combined with a lack of nearby parkland results in these urban areas being under served by parks and open-space, and recreational opportunities generally.

Access along riparian corridors could serve as primary north/south pedestrian and wildlife connections.

The region west of Lisbon is drained by a set of subparallel streams draining basins ranging from 20-50 km^2 each, and flowing roughly north-south through deeply incised valleys to debouch into the Tagus estuary and Atlantic Ocean along the Estorial Coast between Lisbon and Cascais. These catchments have experienced rapid urbanization since 1971, with increased peak runoff from impervious surfaces, sewage from illegal housing settlements, canalization of streams within concrete walls to increase flood capacity, eliminating physical habitat complexity, and reducing amenity and recreational values. However, the urbanization has occurred mostly on uplands, leaving the bottomlands of the incised stream valleys in many reaches surprisingly unaltered.

Caçém POLIS park along Ribeira das Jardass

Ribeira dos Ossos near Fábrica da Pólvora

For decades, these drainages were largely neglected, managed mostly to convey floodwaters. While there was strong informal use of the stream corridor and floodplains (such as garden plots cultivated by residents of nearby high rises immigrated from rural areas), water quality was poor due to industrial pollution and untreated sewage from illegal settlements. As a result, beaches along the Estoril Coast were frequently closed because E.coli levels exceeded safe levels under EU bathing standards. The economic impacts of these beach closings, along with adoption in 2000 of the European Water Framework Directive (WFD), has motivated extension and updating of the regional sewer network to improve water quality.

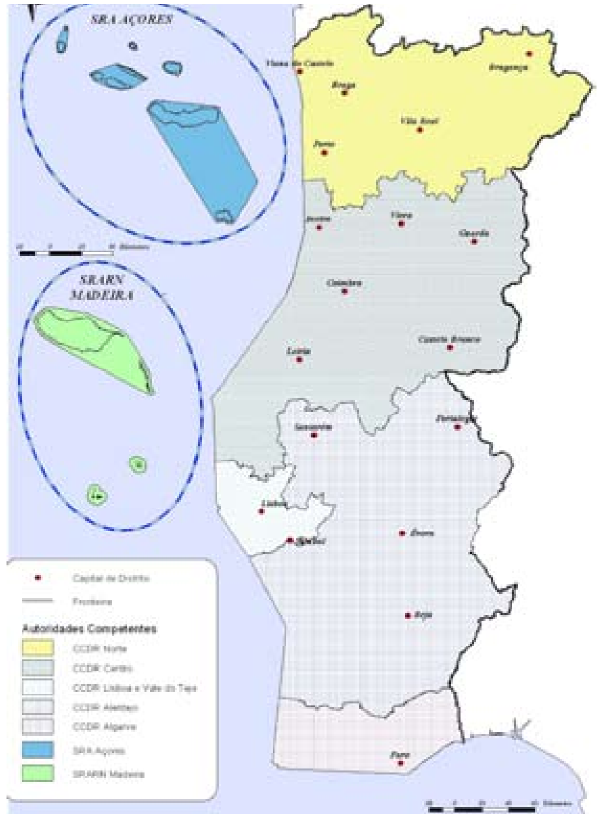
In addition, the WFD requires that all water bodies in member states achieve Good Ecological Status (GES) by 2015. GES is defined in terms of hydromorphological, biological, and physiochemical quality elements of stream reaches, based on characteristics documented at reference sites. As part of the process of transposition to implement the WFD in Portugal, the country's parliament passed the Lei da Água (Water Law, Law Number 58) in 2005 with the long-term goal of improving water and habitat quality.

Ribeira da Barcarena channelized conditions

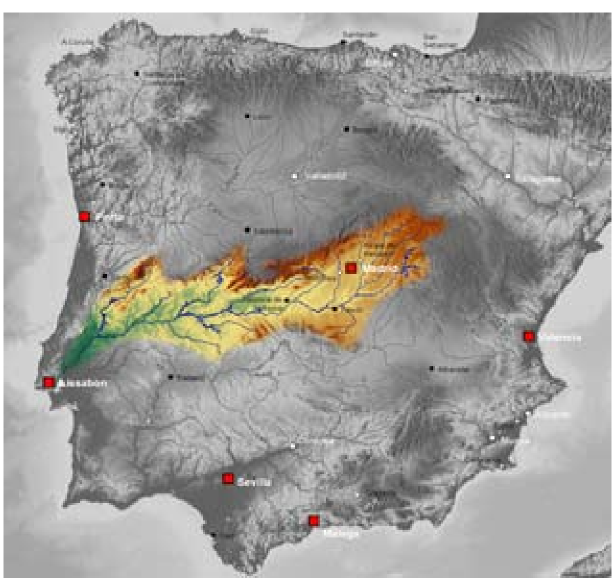
Ribeira da Barcarena with kitchen gardens in floodplain

As sewage treatment capacity expands and water quality continues to improve, the *Ribeira da Barcarena* and its neighboring drainages have the potential to provide parkland for the dense urban settlements nearby. Moreover, by virtue of their linear nature, the stream corridors can potentially provide pedestrian and bicycle connections from population centers to the coastal beaches and trail. Thus, tremendous opportunity exists to revitalize these waterways ecologically and to provide badly needed recreational areas and connections to the coast.

In Portugal, INAG (*Instituto Nacional da Água*) is the central water authority that coordinates at the national level. *Administração da Região Hidrográfica* (ARH) implements the river basin management concept set forth by the WFD. The *ARH do Tejo* is ultimately responsible for the *Ribeira da Barcarena,* as it drains into the Tagus Estuary. To implement the WFD and improve stream health, it is necessary to assess ecological status, determine characteristics of reference sites, and identify opportunities for restoration.

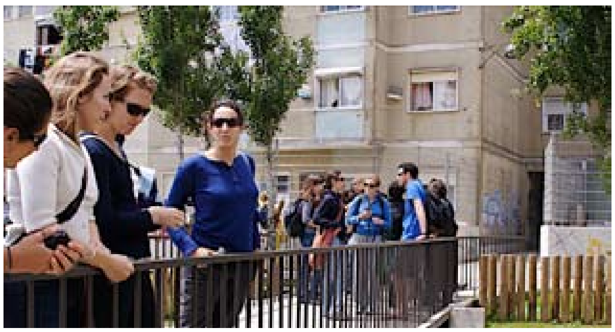


Water Framework Directive Basin Management Districts



The Tagus Basin extends through Spain and Portugal

Water Framework Directive Basins



During a workshop in summer 2009, students from the University of California, Berkeley and the *Instituto Superior Técnico*, Lisbon, participated in a joint research project to plan and design future options for the rehabilitation of the *Ribeira da Barcarena* within the context of the WFD. Our goal was to optimize ecological restoration and improve human access opportunities along the length of the stream. This publication is a synthesis of seven individual studies focused on aquatic ecology, riparian ecology and channel form, the linear park along the *Ribiera das Jardas* in Cacém, opportunities for on-site stormwater management throughout the urbanized catchment, design interventions for *Quinta Real* and the Tagus coast at Caxias, and a trail to connect Cacém, Caxias, and the coast. A trail system along the creek could provide open space opportunities for recreation, habitat restoration, and flood management along the entire mainstream of the river, and connect under-served urban areas directly to the Estoril Coast—a vision for a continuous corridor not previously recognized. A contextual description of the *Barcarena* catchment and the seven studies comprise the contents of this report.

The Ribeira da Barcarena

The *Riberia da Barcarena* has a typical Mediterranean-climate flow regime with mild, wet winters and hot, dry summers. Intense winter rains produce high flows, in strong contrast to the low baseflows of the dry summer season. Precipitation and thus streamflow vary strongly from year to year. As its catchment has urbanized and the extent of impervious surface has increased, less rainfall infiltrates into the soil, and more runs off directly as stormwater, increasing peak flows produced from a given rainfall. The 2-year flow (i.e. the peak flow that occurs on average once every two years) is 78 cubic meters per second (cms), and the 100-year flood is 237 cms (LNEC 2000, ADISA 2001). Due largely to stormwater runoff, the *Barcarena* at times overflows its channel, especially when high flows combine with a high tide. To increase flood conveyance, the lower 1.5 km reach was straightened and channelized with three-meter high concrete walls flanking a 13 m wide bed. Much of the flood prone land was designated a *Reserva Ecológica Nacional* (REN) zone, which prohibits further building.

As the basin was urbanized and paved over, there was less infiltration during the rainy season and likely less recharge into the water table which sustains baseflow. A counteracting trend however, is 'urban slobber', the seepage of water into the stream from over-irrigation of landscape plantings and leaky pipes.

Overall, water quality deteriorated as the catchment urbanized. As described previously, the stream received water from industrial effluent and domestic sewage, point sources that are now being addressed through infrastructure improvements. In addition, runoff from urbanized areas is typically contaminated with automobile-related contaminants, such as grease and oil, copper (from brake linings), hydraulic fluids, and unburned fuel. These non-point-source pollutants will continue to enter the streams unless swales, retention ponds, rain gardens, and other such features designed to induce infiltration instead of instantaneous runoff interrupt the pathways from impermeable surfaces (such as parking lots).

Ribeira das Jardass in Caçém

Ribeira dos Ossos at the culvert of Ribeira das Jardass

Ribeira dos Ossos adjacent to new housing

Ribeira dos Ossos at Fåbrica do Pólvora

A Stream of Many Names

Located 15 km west of Lisbon, *Ribeira da Barcarena* drains a 35 km^2 catchment, whose uppermost reaches are forested, but otherwise alternates between urban areas and remnant agricultural and open-space lands. The headwaters transition from a narrow, forested reach to a flat alluvial valley near the Mira-Sintra/Meleças train station. The alluvial flat is a mostly level surface occupied by farmland, but the hills surrounding the basin are heavily developed (Mira-Sintra and Rinchoa). Immediately downstream from the train station, the stream enters a narrow valley, where the riparian corridor is mostly intact. Downstream, the stream enters the city of Agualva-Cacém, one of the most populous cities in the metropolitan area. The city spreads along the hills on both banks, occupying the whole width of the valley. In this section, the stream was in a trapezoidal concrete channel, until 2008 when an urban renewal project, Cacém Polis Program, transformed the stream into a structural element of a linear urban park.

Just south of Cacém, the stream passes into an underground culvert below the IC19 highway. The highway marks the boundary between the Sintra and Oeiras municipalities, and the change in name from the *Ribeira das Jardass* (upstream in Sintra) to the *Ribeira dos Ossos* (downstream in Oerias until Barcarena). We refer to the entire river system as the *Ribeira da Barcarena*. It emerges from the culvert into a relatively undeveloped valley, flanked by a narrow but continuous riparian corridor, small relict farms, and several historic structures, which transition into high density housing. Continuing downstream we encounter one of these historic ensembles, the Fábrica da Pólvora ("Gunpowder Factory"), which was recently converted into a cultural center. The Ribeira da Barcarena traverses the factory complex, and is surrounded by publicly accessible gardens. A few hundred-meters upstream, a much smaller village known as Barcarena, occupies both banks. From this point downstream, the stream flows through a deeply incised valley with a narrow floodplain (much of which is used for agriculture), flanked by plateau uplands above the level of the valley floor, on which urban settlements (including many high-rise apartment blocks) have been constructed in the past four decades.

The downstream-most 2 km traverse the urban area of Caxias, dominated by low-rise buildings, some of which literally hang over the stream. Here the stream is within concrete walls, with an arterial road along much of the right bank. Along the left bank for 450m is the Jardim da Cascata (Cascade Garden), a Baroque historic garden. The stream then passes under the N6 highway (known as the "Marginal") and the train line to Cascais. It meets the ocean through a pair of breakwaters, next to the Caxias beach and Fort São Bruno. The current course represents a straightening from its original course, whose mouth was to the east of the fort.

Ribeira da Barcarena south of Barcarena

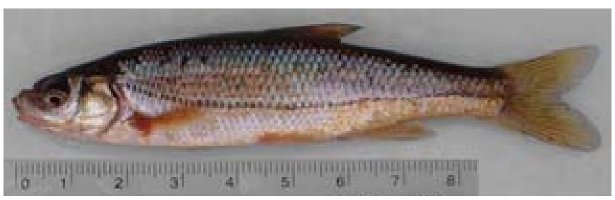
Ribeira da Barcarena at the mouth of the Tagus


CAÇÉM
RIBEIRA DAS JARDAS
RIBEIRA DOS OSSOS
SINTRA
OEIRAS
FÁBRICA DA PÓLVORA
RIBEIRA DOS OSSOS
RIBEIRA DA BARCARENA
BARCARENA
QUINTA DA NOSSA
SENHORA DA CONÇEIÇÃO
A5
CAXIAS
RIO TEJO

Aquatic ecology: establishing reference conditions for fish

Julie Beagle, Joshua Pollak, Clare O'Reilly, Isabel Boavida, Paulo Branco, Nuno Gaspar

Electro-fishing in the Ribeira das Jardass



Portuguese nase

The objective of this analysis was to establish an in-stream habitat reference condition in a less disturbed reach of the *Ribeira das Jardas* for two critically endangered species, the European Eel (*Anguilla anguilla*) and the Portuguese Nase (*Iberochondrostoma lusitanicum*). We examined the WFD policy, performed an analysis using remote sensing and Geographic Information Systems (GIS), sampled species of concern in our study site by electrofishing, and measured physical attributes of our study site. We synthesized this information to characterize our study site, and to look for relationships among mesohabitats and species distribution. Based on geographic analysis of the land use variable, we identified reaches with higher potential for fish habitat restoration and identified data needs for prioritization and design. In this study, we measured some key hydromorphological and biological qualities of a minimally disturbed site on the *Ribeira das Jardas* as a basis for establishing reference conditions for fish habitat.

Species of Concern

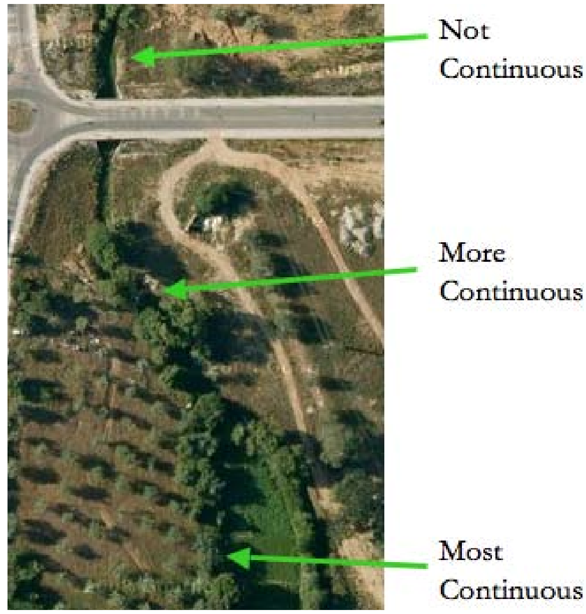
Both the European eel and the Portuguese nase are classified by the International Union of Concerned Scientists as critically endangered, and both have unique habitat requirements. The European eel faces numerous threats, including an unsustainable level of harvest of the species, blocked migration routes, and pollution. The current population is at a historic minimum, and restoration of a stable population could take between 60 to 200 years (Santos & Ferreira 2008). In response to the sharp population decline, the European Council passed Regulation Number 1100 in 2007 to establish measures for the recovery of the European eel, and require all member states that contain eel habitat to establish an eel management plan at a river basin scale (Freyhof & Kottelat 2008).

The Portuguese nase, in contrast to the European eel, is endemic to the western coastal tributaries of the Tagus River. Threats to the nase include water pollution, habitat destruction, the introduction of exotic fish species, and the abstraction of water. The nase lives "in shallow streams of medium flow with vegetation on the banks," which are characteristic of portions of *Ribeira das Jardas* (Crivelli 2006).

In studies to establish reference conditions for development of a river basin management plan, Jose Santos and colleagues at UTL surveyed fish in the *Ribeira das Jardas* about 1.5km upstream of Cacém in 2005, encountering Portuguese nase, European eel and loach. A follow up study found that nase preferred pools shaded by riparian vegetation with fine sediment substrate, and used shallow riffles for spawning (Santos & Ferreira 2008).

European eel

Map of fish ecology reference reach



Aerial indicating riparian habitat continuity

Electrofishing

Habitat Assessment and Study Site Selection

We assessed habitat in a 100-m reach of the *Ribeira das Jardas* near the Mira-Sintra/ Meleças train station, about 700m upstream of the 2005 survey of Santos. Here the stream traverses a mostly undeveloped bottomland, but the surrounding uplands are densely covered by high-rise apartment blocks. The catchment upstream of this site has relatively little urbanization.

The reference site had a diversity of mesohabitats, defined as riffles, pools and runs. Riffles are shallow areas with coarse cobbles and boulders, and higher water velocities than pools, which are deeper. Bed load in pools is often made up of finer material such as silt (Lisle 1979).

Electrofishing

Moving upstream, we used an electrofishing backpack and rod with an electric net emitting a 400-volt shock to collect fish, making single pass sampling surveys. The shock stunned the fish so they were easily netted, but did not kill them. Another field worker followed with a large gathering net, and another with a bucket for collecting the fish. In each pool, riffle or run, we moved from downstream to upstream in a zigzag path and placed the electric net in the stream along this path. After collecting all the fish we could in a single pass through a representative mesohabitat, we counted and measured the length of all specimens before returning them to the mesohabitat from which they were gathered. The fishes had fully recovered from the electroshock before they were returned.

Microhabitat Parameters

We measured the microhabitat parameters of velocity, depth, tree cover, and substrate in each mesohabitat. After sampling the mesohabitats for fish, we surveyed representative cross sections in each one. Starting from the right bank, we moved across the bed of the wetted channel at intervals of 25cm and measured water depth and velocity. We used a digital current meter to measure velocity, holding the meter at approximately half of the water depth above the bed in place for at least ten seconds. We replaced the current meter with a measuring stick to measure water depth, and recorded water depth at 25cm intervals. For each mesohabitat we recorded representative substrate based on visual inspection, and a percent riparian cover based also on visual inspection. Using a statistical analysis program, Statistica (©Statsoft, Inc. 1984-2001), we compared depth and velocity by mesohabitat, and made a histogram of size frequency of fishes by mesohabitat.

Basin scale assessment

Using a land use GIS layer developed by the *Instituto Geográfico Português* (Corine 2000) and satellite imagery from Google Earth (dated 23-06-2007), we examined land use in the basin and categorized riparian connectivity over the stream. We classified four major land uses: open space, agricultural, urban, and industrial. We hypothesized that open space and agricultural land uses would be associated with less modified channel conditions and less polluted runoff, therefore providing suitable conditions for protecting fish habitat. We used designations of riparian vegetation continuity from an eco-status report of the coast of Portugal (ADISA 2001). We overlapped reaches with "more" and "most" riparian vegetation continuity onto reaches flanked by open-space and agricultural land use, to identify reaches with high probability of good fish habitat and thus good candidates for protection.

Longitudinal relation of the sampled mesohabitats

Mesohabitat	Length (m)	Vegetation Coverage Observed	Substrate
Pool 1	0-52	High shade, significant root structure	Silt & boulders
Riffle 1	52-58.8	Medium shade, no roots	Silt, cobbles & boulders (bedrock step)
Pool 2	58.8-90.8	Medium shade, some root structure	Silt & boulders
Riffle 2	90.8-104.3	High shade, no roots	Cobbles & boulders
Run	104.3-119.3	High shade, some roots	Sand & Gravel

Geometries and micro habitat parameters

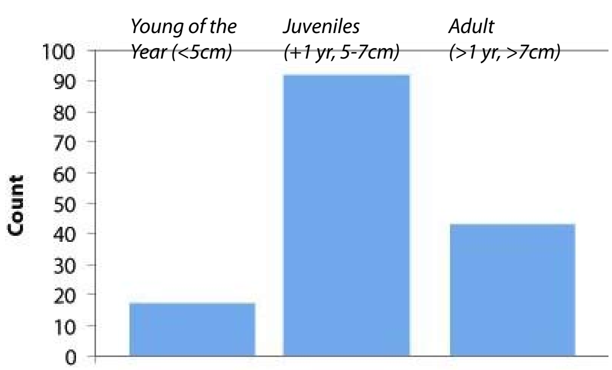
Results

Habitat Assessment

We identified two pools, two riffles and one run in our mesohabitat characterization along a 119.3 m reach. Geometries and microhabitat parameters are shown in the table below. Pool 1 was the longest mesohabitat at 52 m. Substrate varied between pools and riffles, with silt and boulders dominating in pools and cobbles and boulders dominating in riffles. The pools had a higher percentage of shade than the riffles, and also had more significant root structure along the banks.

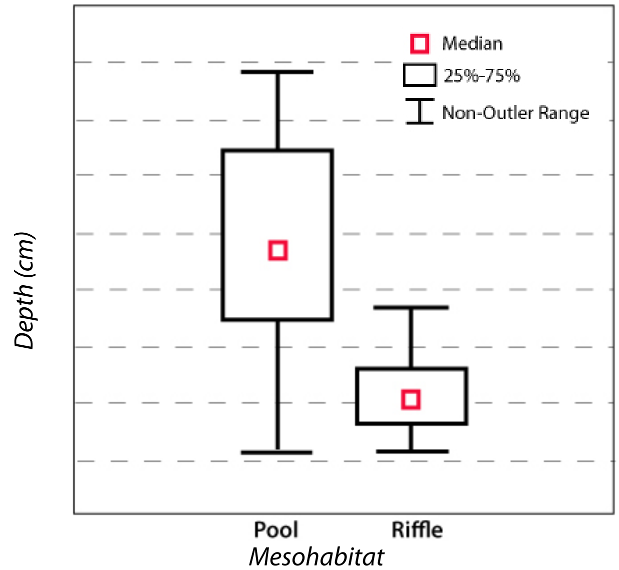
Mesohabitat	Count	Densities (fish/m2)
Pool 1	130 Nase	0.605
Riffle 1	5 Nase	0.195
Pool 2	2 Nase, 1 Eel*	0.021
Riffle 2	10 Nase	0.247
Run	7 Nase, 1 Eel*	0.155
Total	154 Nase, 2 Eels*	

Specimen collection by location

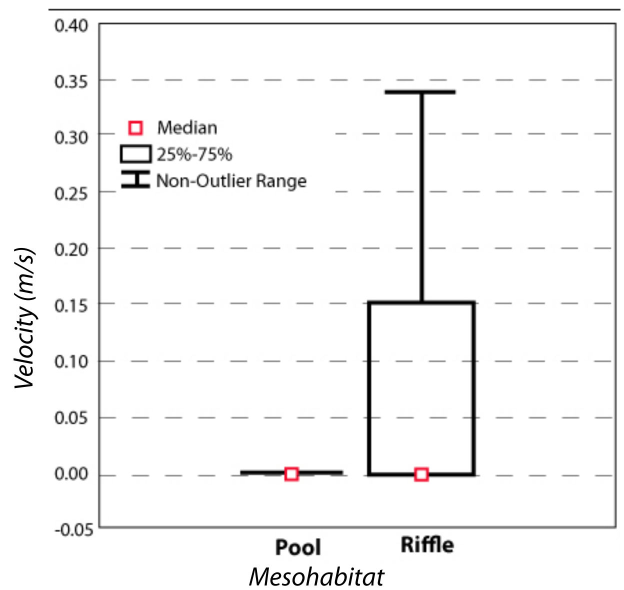


Results of electrofishing survey by age class frequency

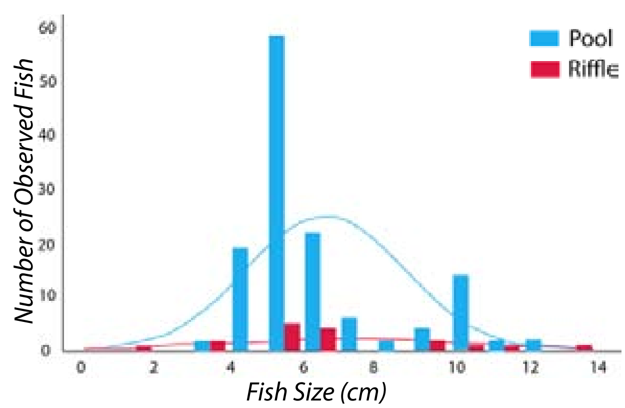
Species and abundance from each mesohabitat are shown in the tables above. We collected a total of 154 Portuguese Nase from the entire study reach, most from Pool 1. We did not conduct a full specimen collection in Pool 2 because we had a full collection from Pool 1. We observed two European Eels, but we were unable to capture them for measurement. The pools had more Nase than did the riffles. We collected mostly juvenile specimens, ranging in size from 5 cm to 7 cm.



Box plot comparison of depth by mesohabitat



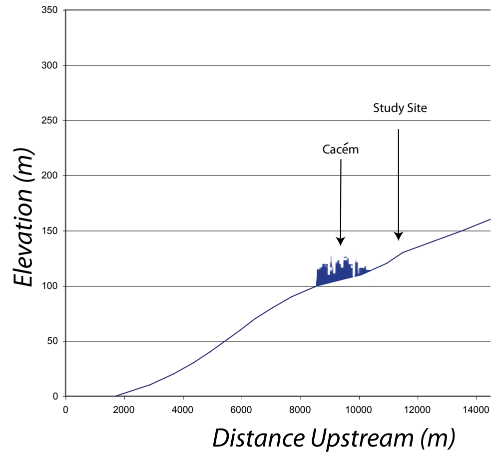
Box plot comparison of velocity by mesohabitat



Histogram of frequency by mesohabitat

Microhabitat parameters

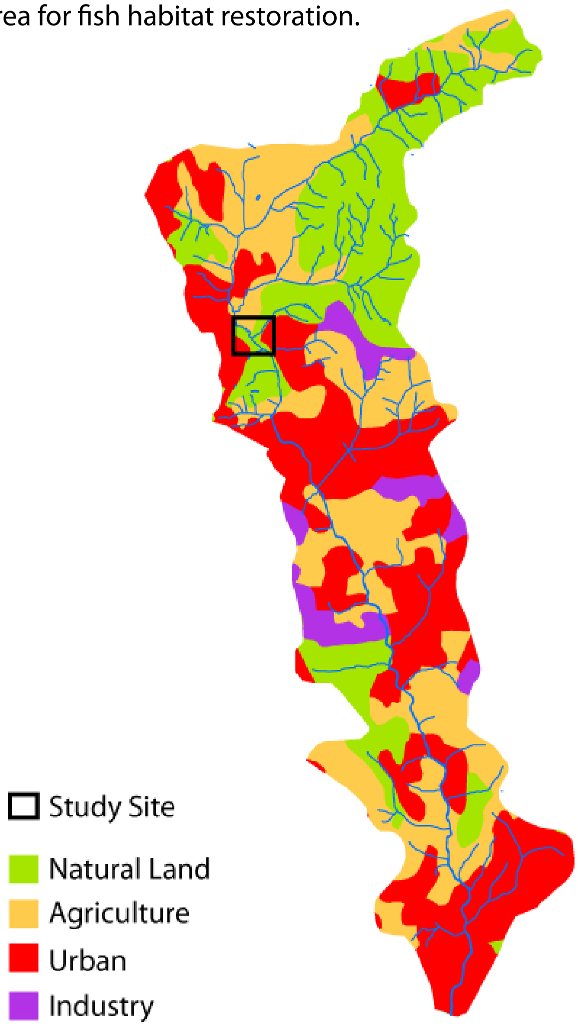
As expected, the pools were deeper and had lower average velocities at the time of our measurement than the riffles. The pools had a greater variety of depths than riffles. At the time of our measurements, median velocities of pools and riffles were similar, but we measured a greater range of velocities in riffles. Pools supported greater numbers of juvenile and adult fishes than riffles.



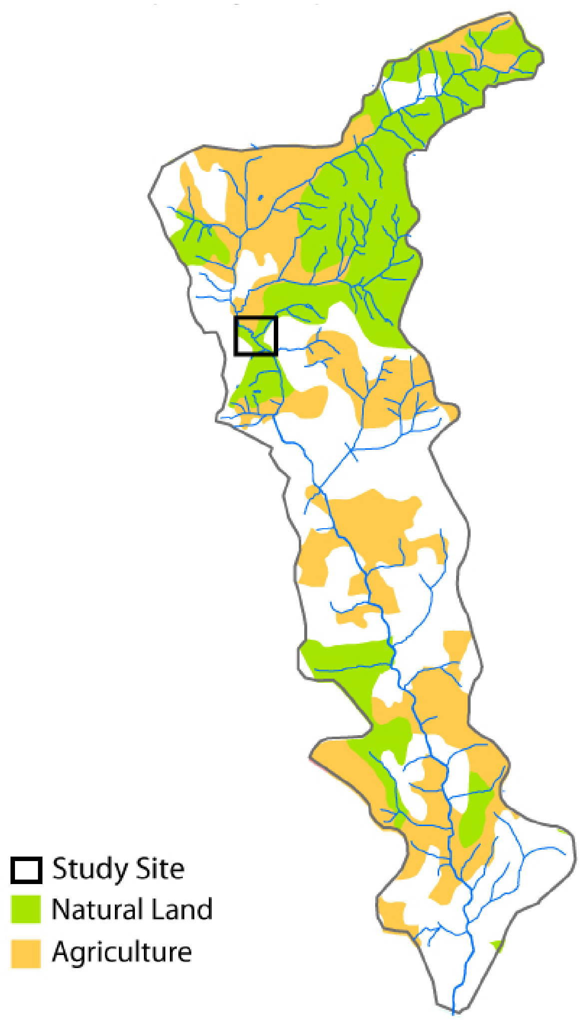
Long profile of Riberia das Jardas

Basin scale assessment

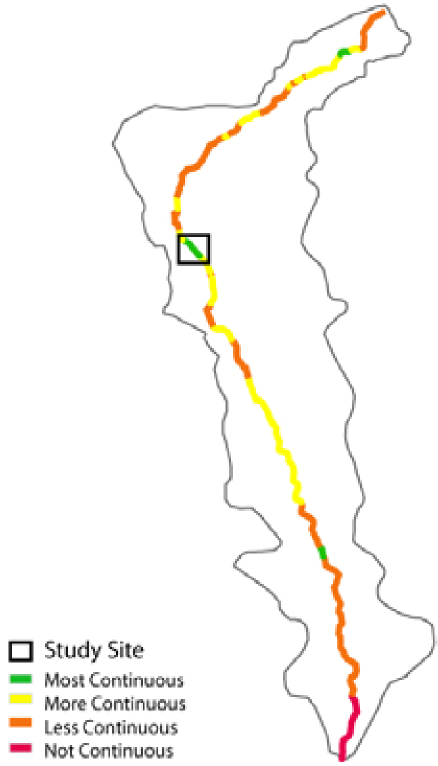
The long profile of the river illustrates where the study site falls along the drainage. The following maps show the layers of land use and riparian connectivity, which we used to determine priority areas for habitat restoration for resident fish populations. Approximately 20% of the main stem is a potential priority area for fish habitat restoration.



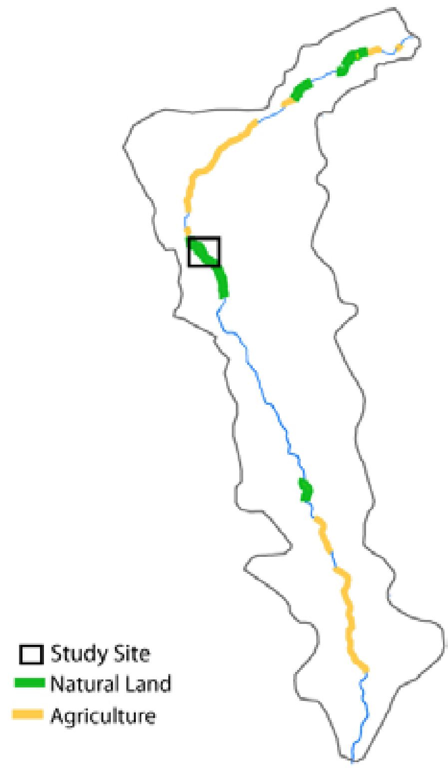
Land use of the Barcarena Basin



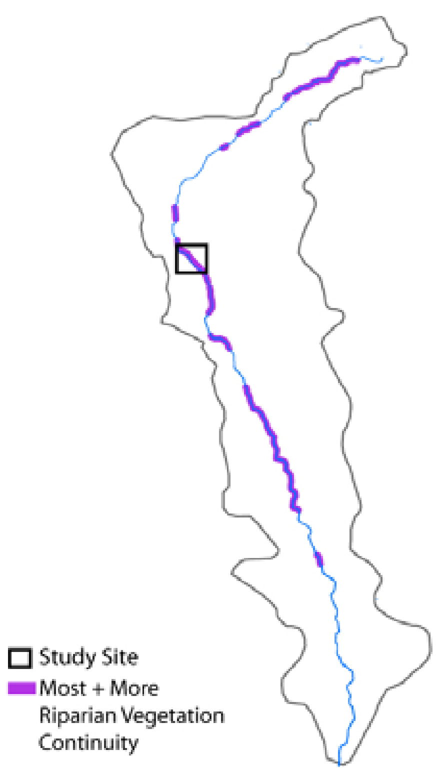
Priority land use for fishes in the Barcarena Basin



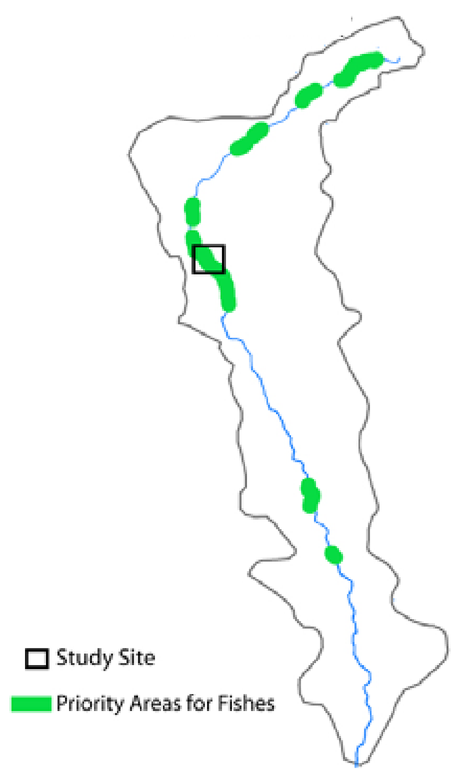
Riparian vegetation continuity



Priority riparian zones for fish



"More" and "Most" riparian vegetation continuity



Overlay of vegetation continuity and land use priority

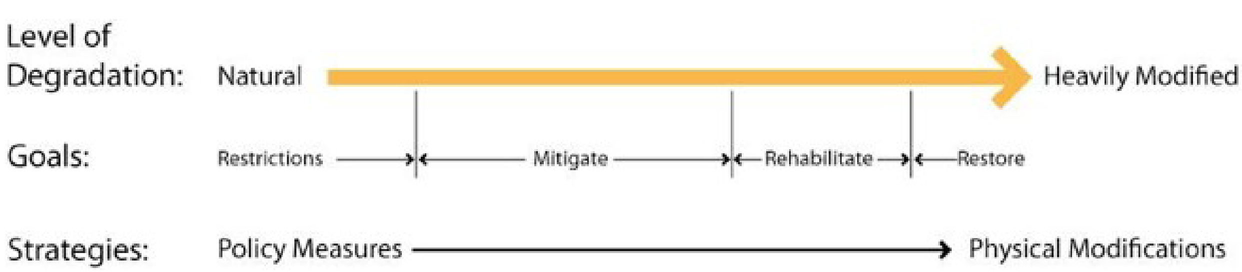
Conclusion & Recommendations

Our results support previous research findings that Portuguese Nase prefers sheltered pools (Santos, unpublished data 2005). We hypothesized that Nase also prefer complex habitats composed of pool-riffle sequences and significant root structure based on the characteristics of our study site and previous research findings (Santos 2008). However, similar studies have yet to be conducted in a larger number of sites reflecting a range in disturbance levels to evaluate this hypothesis.

We propose that river restoration reconnaissance and planning be concentrated initially on the reaches identified as having high potential for conservation from our basin scale analysis of surrounding land use and contiguous riparian vegetation corridors. Additionally, a more detailed ground map of the mesohabitats along the mainstem could improve this prioritization. In these high potential reaches, human activity should be restricted through policy mechanisms, such as protection of the 10m riparian buffer that is regulated by law, to improve fish habitat. In areas that have increasingly modified landscapes, efforts should focus on mitigation and rehabilitation, such as removing concrete walls and reestablishing contiguous riparian vegetation corridors. Placement of instream structures such as boulders and woody debris can help create the riffle-pool sequence necessary for Portuguese Nase in reaches that are heavily modified and simplified. Our results suggest that creating complex habitats, with diverse mesohabitats and vegetation structure could contribute to the survival and thriving of native fish populations in the *Ribeira da Barcarena*.

Once fish populations are re-established, they attract human attention. At the Polis project in Cacém, we observed the sighting of a European Eel attracted significant attention from members of the public. In urban areas, such as Cacém, restoration of the stream corridor should be initiated with fish habitat needs in mind. The Polis project did not explicitly attempt to restore habitat complexity through constructions of instream structures, nor dense planting of riparian vegetation to provide stream cover and shade to buffer instream temperatures for fish. Project planners and designers should bear in mind potential conflicts between riparian vegetation density and human preferences for open park-like landscapes.

Further research should be conducted prior to initiation of restoration projects in the basin so that restoration efforts can be informed by understanding of changes in factors controlling the stream and its ecological function. Instream structures should be implemented on a pilot basis to assess their impacts on fish populations and habitat structure and function. Our basin-scale analysis of restoration potential is only a first step. Land use should also be verified in the field before restoration is initiated in areas we identified. Aerial or ground-based LiDAR should be considered for assessing current mesohabitats. In sum, our analysis just scratches the surface of considerations necessary for restoring and maintaining fish communities in the *Ribeira da Barcarena* catchment, but it can suggest a palette of opportunities for further study.

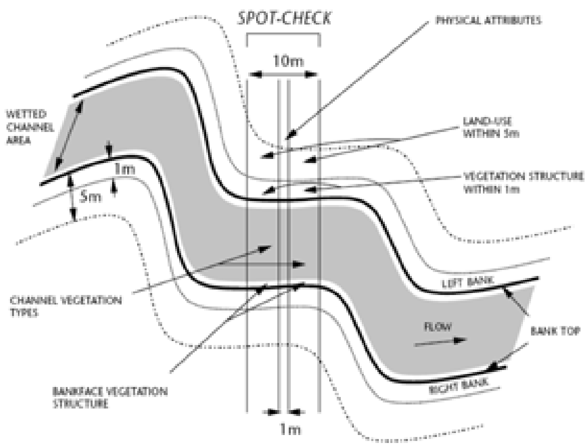


Rural Urban Continuum

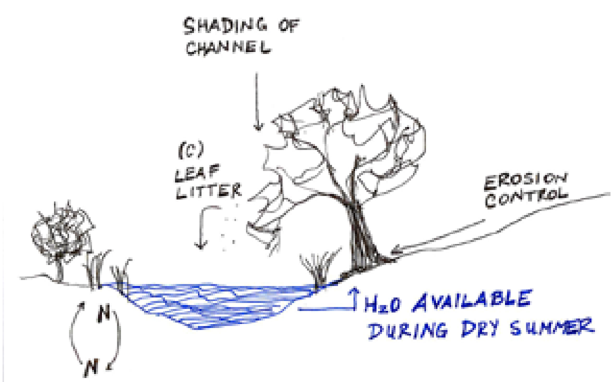
Riparian ecology and channel form

Bojana Anglin, Mary Matella, Leila Duarte and Madalena Patacho

Taking measure at the benchmark site in the upper reach



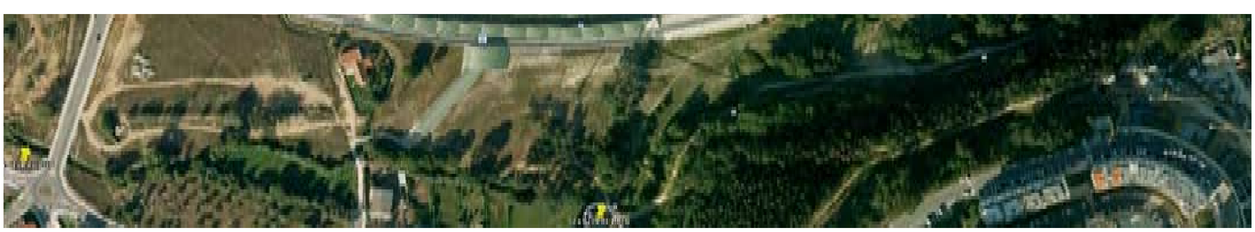
RHS sample collection method diagram



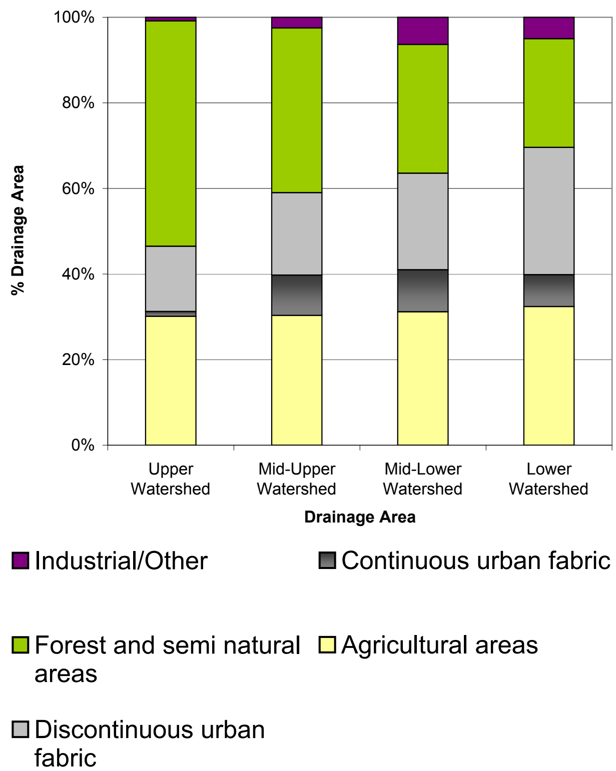
Benchmark site schematic cross-section

To implement the WFD and develop programs of measures to improve stream health, it is necessary to first assess current ecological status and identify opportunities for restoration. Critical stream health variables include the integrity of the riparian corridor and channel morphology. As a standardized approach to data collection and setting baseline conditions, we employed the River Habitat Survey (RHS) to assess structural integrity of channel morphology and vegetation, including the presence of riparian plant indicator species. RHS was developed in the UK in 1994 and adapted by Rui Cortes, Samantha Hughes and the National Water Institute (João Pádua e João Ferreira, with the help of Paul Raven and Nigel Holmes) for application to Mediterranean climates. We used this method on the *Ribeira da Barcarena* to create an index based on level of degradation using the most natural site in the catchment as a benchmark.

We used additional methods (analyzing aerial imagery, land use patterns, and historical floodplain extent maps) to determine the extent of riparian corridor loss and opportunities for restoration to a more natural condition. We used flood inundation maps to identify the potential extent of the natural flood corridor, so we could assess what percent of the remaining corridor was vegetated. We conducted our study along an urbanization gradient to quantify the complexity and degree of disturbance associated with vegetation and channel morphology of the *Ribeira das Jardas*. These metrics can aid in developing appropriate restoration interventions, and the results may have relevance for other catchments in Portugal, which must balance similar development pressure with the WFD goal of good ecological status.



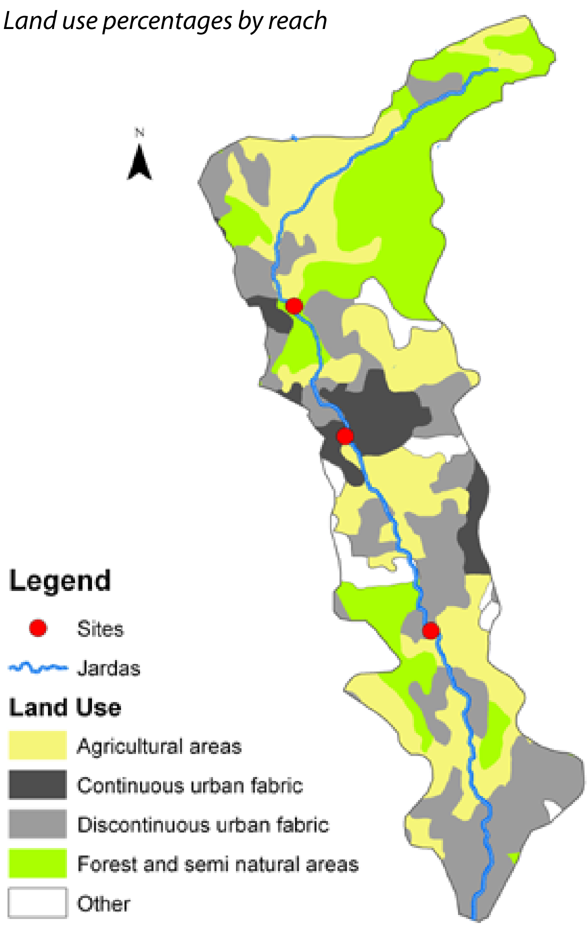
Benchmark site



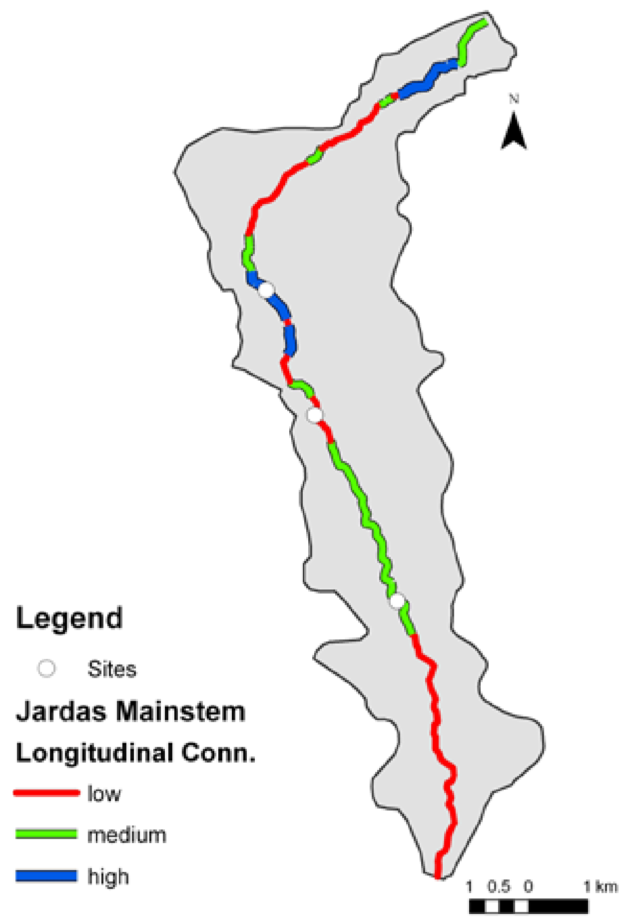
Land use percentages by reach

Basin-scale: land use and longitudinal continuity

We assessed the degree of disturbance of vegetation complexity and channel morphology at three different scales: the basin-, reach- and site-scale. We combined land-use data in ArcMap to assess current land use and change from 1990 to 2000 at the basin-scale. We also used Google Earth aerial imagery to update the SANEST (2001) assessment of longitudinal riparian corridor extent and continuity. This strategy allowed us to reassess longitudinal connectivity of the canopy cover for the mainstem of the Ribeira das Jardas River. We delineated reaches visually to indicate breaks in quality of longitudinal connectivity.



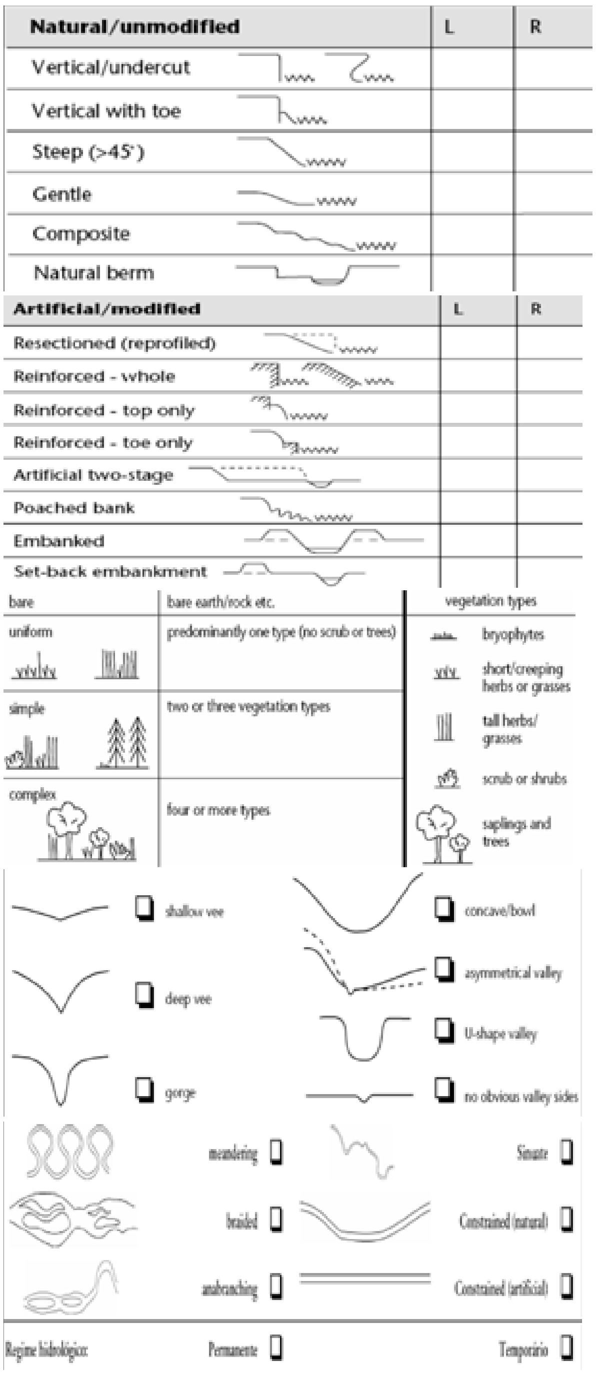
Land use classified for stream characterization



Longitudinal Connectivity Analysis

Reach-scale: lateral connectivity

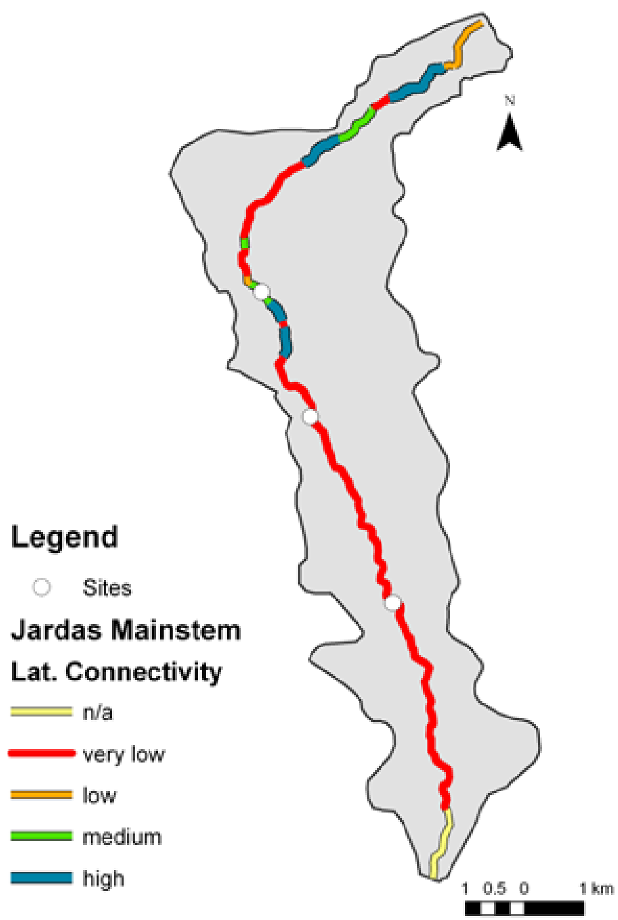
We mapped the extent and continuity of the riparian corridor under current conditions. To estimate historical loss of the riparian corridor, we used flood plain inundation area maps from 1985 Portugal Planning Services documents, assuming that the floodplain delineated in these maps approximated the potential lateral extent of the natural riparian vegetation.



RHS sample collection methods

Site-scale: River Habitat Survey

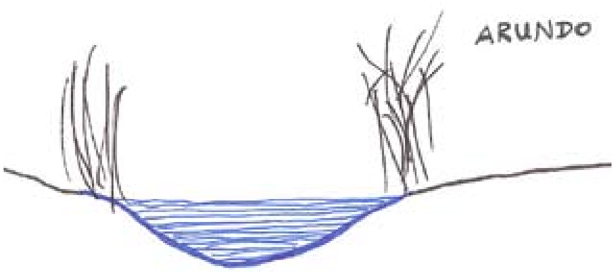
We applied the RHS method at three sites along an urbanization gradient in the *Ribeira da Barcarena* catchment. The RHS surveys approximately 149 different variables. From this standard set, we selected the most critical variables to characterize the morphological habitat quality of the three study sites, based on feedback from project advisors, our own analysis of survey results, and background knowledge of stream habitats. The critical variables that we selected were the following: 1) abundance of riffles and pools; 2) abundance of both vegetated and un-vegetated point and side bars; 3) diversity of channel substrate; 4) complexity of bank-face and bank-top vegetation structure; 5) presence of riparian gallery; 6) presence of indicator riparian tree species; and 7) longitudinal continuity of riparian tree corridor. We scored these variables (Appendix 1) to calibrate an index to our benchmark natural site.



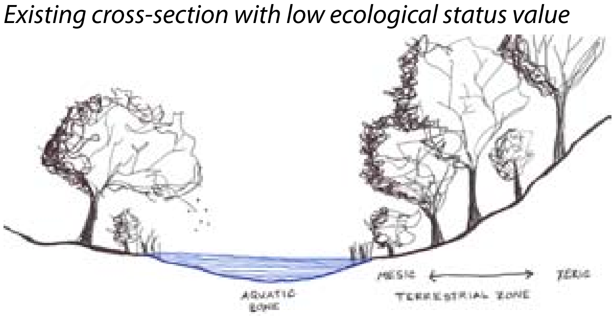
Lateral Connectivity Analysis

Results and Discussion

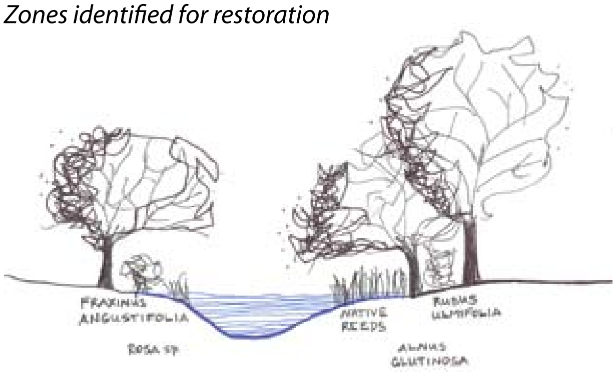
In the context of assessing the reach scale connectivity in the catchment, we analyzed site level data for our three locations representative of an urbanization gradient. We created a RHS derived index based on the presence/ absence of features of recognized biodiversity and habitat quality. A higher score means the stream is more suitable for wildlife (e.g. more ecological niches), the riparian gallery is well developed, and the vegetation continuity between patches is well represented both at longitudinal and lateral scales. The highest score possible in our catchment according to our index is 34. All the scores are the result of the sum of points, presented as a percentage relative to the highest possible score. Appendix 2 lists the scoring system and details more rationale for our metric selection. Results for our customized RHS score are shown for three sites.



Existing cross-section with low ecological status value



Zones identified for restoration

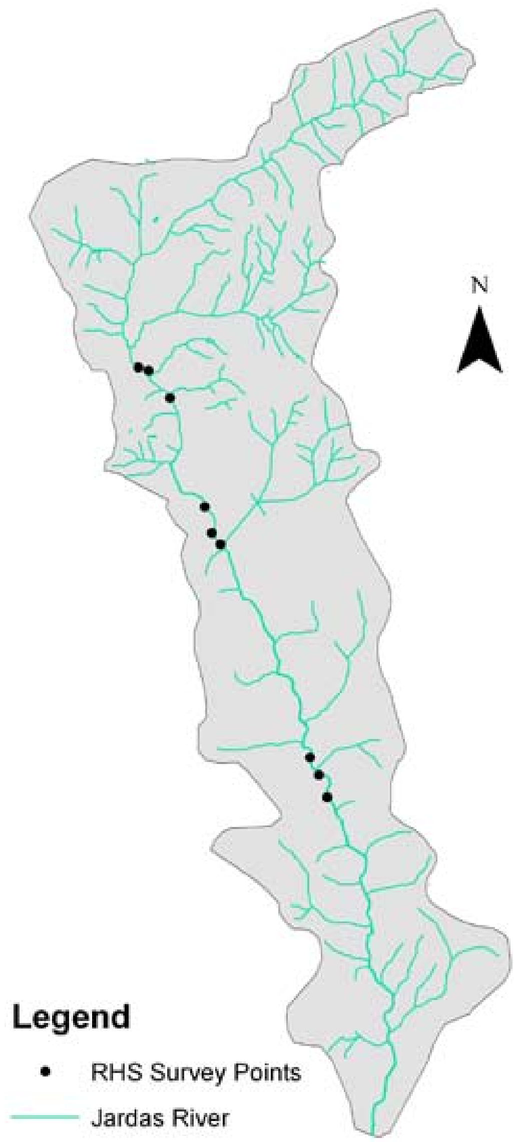


Species identified for restoration

RHS Score for sites on connectivity maps

Site	Name	Points	Percentage
Site 1	Benchmark	25	73,5%
Site 2	Powder Mill	12	35,3%
Site 3	Cacem	2	5,9%

Benchmark Site Conditions



RHS sample collection method diagram


River conditions in the vicinity of the gunpowder factory


Looking upstream in the Cacem Polis project


River conditions at the Gunpowder Factory


The view downstream to the large shade tree and main pedestrian bridge in the Cacem Polis project


River conditions down stream of the gunpowder factory, looking downstream


Walking underneath a roadway bridge at the Cacem Polis project.

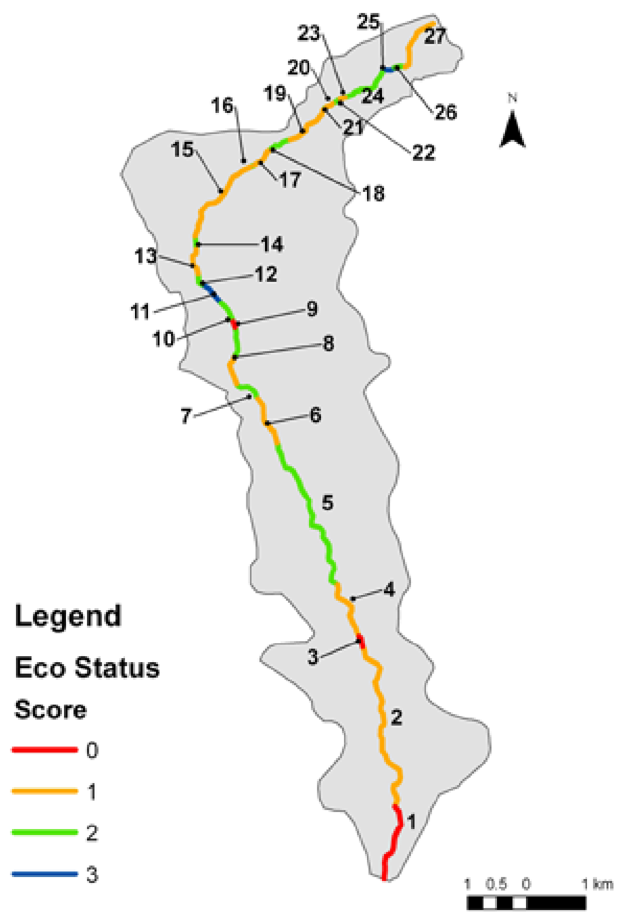
Working at three scales was iterative: findings at the basin-scale scale informed recommendations for specific interventions at the site scale. Using a combination of aerial imagery and flood map analysis to assess restoration opportunities and constraints, we identified two reaches with high potential for restoration.

Meleças (Reach 12)

This reach, located near the Meleças train station, is minimally developed and with few constraints upon its wide floodplain, despite being approximately one-third of the way down the basin and being surrounded by high-rise development on the adjacent uplands. Reach 12 is directly north of our benchmark site (Reach 11) and has a restoration potential rating of 4.0 out of 5.0. Furthermore, there is the potential for enhanced inter-reach longitudinal connectivity due to its adjacency to the benchmark RHS site. Finally, the east side of Reach 12 borders a train station, presenting an opportunity for enhanced public education and outreach with rail commuters. Restoration of reach 12 would require minimal to no re-grading to establish floodplain connectivity. This significantly lowers the cost of restoration, and is an advantage over many other potential restoration sites along the Ribeira da Barcarena. The abundance of the giant reed (Arundo) at this site, however, is perhaps the main restoration challenge. Successful Arundo eradication requires repeated mechanical and chemical control measures over the course of several years; if follow-up eradication measures are not completed, the plant will commonly re-establish and continue to spread. A road delineating the northern edge of Reach 12 represents another potential challenge to future restoration efforts that may wish to extend further northward.

Headwaters (Reach 27)

Reach 27 is located near the headwaters of the Ribeira das Jardas and is the furthest upstream reach assessed for longitudinal connectivity. Our restoration potential index for the site is a 5.0 out of 5.0. While a number of other sites also scored this high on our index, the upstream location of Reach 27 renders it particularly strategic as a restoration site due to the importance of the headwaters for the health of the entire stream. This site also requires minimal to no re-grading to re-establish connectivity to the floodplain. Furthermore, the agricultural land use and lack of development at this site present few physical barriers to restoration. Challenges to restoration here, as at Reach 12 include the presence of Arundo and the delineation of the site's northern edge by a road.



Ecological Status Score and study sites

Conclusion

Combining a catchment level assessment of GIS variables affecting riparian ecology and channel form with detailed field observations can provide understanding with which to assess restoration potential. Using a standardized method for field data collection is important for consistent application of assessment throughout a country and the EU as the WFD is implemented. After using the RHS to collect data, a customized index can be prepared to assist work in any given catchment. Specific objectives related to water quality, stream corridor vegetation habitat, or invasive species control can then be emphasized in a new index assisting prioritization for future work. We recommend making any new index explicit and recommend moving to more standardized methods for a basin-wide riparian corridor aerial imagery assessment of connectivity to compare data across catchments.

Surveying the riparian vegetation along the Ribeira Barcarena

Appendix 1: Survey Reach Notes

Reach id	Long Conn.Notes	Floodplain/Lat Notes	Restoration Opportunity Score	Barriers/Notes
27	50 scattered both, 50 cont. both	20 remains	5.00	no/land use natural, veg, but arrundo
26	100 long cont.	30 remains veg.	5.00	no/land use natural, veg, but arrundo
25	100 long cont.	60 remains veg.	5.00	no/land use natural, veg, but arrundo, arundo less than other reaches
24	80 long cont, 20 one side cont.	left bank 90 fp veg, right bank 55% veg	4.00	suburban devt restrictions on floodpl width
23	0 trees, shrubs only, some bare	one side 0, other side 100%: avg 50%	3.00	suburban devt restrictions, channelization restrictions
22	50 cont	10 perc remains	4.00	arundo, left bank option for restoration (ag on fp extent), road on right bank
21	50 cont	10 perc remains	4.00	arundo, left bank option for restoration (ag on fp extent), road on right bank
20	0 tree, all arundo	50 perc remain	3.50	road on r bank, less option. Left bank full restoration fp potential
19	semi cont long 50%, both banks	20% on right bank. Left bank 30 perc vegetated	3.00	road on left bank where most nat. floodplain exists
18	most arundo/shrubs 20% long connectivey	70%	5.00	road on right bank, but setback, land use natural; image 2007, note wide floodplain here
17	50% long connective	55%	4.50	fp lots of ag use near suburban on one end. Natural land to north/majority;
16	scattered semi cont long 5%	15%	4.00	natural land in fp, much bare, near suburban;
15	sparse trees, long 5%	5%	4.00	most natural land in fp/ag, crosses lots of roads;
14	southern, 100% trees, north, 20% tree continuous	30%	3.50	obvious flood control in place, stream channelized in northern reach;
13	15%	10%	3.00	lots suburban devt to west of stream and ne more encroachment, but stream does have lots of natural land use in immediate buffer; very constrained on north end by development, obvious channel/bank modification
12	85% continuous	20% remains	4.00	no arundo, close to benchmark, natural land; train station on left bank, but set back
11	BENCHMARK. 90% contin.	30% remains	5.00	no arundo, natural land except train tracks on left back set bac;
10	90% contin.	95% remains, but fp narrow	3.00	right bank forest, left bank, train tracks; not high need for restorations. Tracks are constraint. right bank fp naturally constrained
9	scattered 10% long	15	3.00	constrained on left by rail road but room on right and under freeway; arundo appears, channellized
8	scattered 10% long	50%	5.00	mostly natural land, fp not built on; lots arundo on creek
7	5 percent scattered. Mostly shrubs	5%	1.50	very constrained by suburban devt on both banks; fp extensively built on
6	20% contin. Section / right bank	5%	2.00	lots devt on left bank, natural area on right bank; no arundo, channelized, fp built on left bank/ polis project area
5	no contin trees.	0%	1.50	urban site. Lots freeways/train tracks; wide fp almost entirely built on
4	25% continuous, constrained on left bank by road	15%	2.50	some natural, some suburban uses; some channelization, floodplain built on, except some natural area interspersed
3	10/ right bank semi continuous, left bank scattered	10%	2.50	lots natural land use on right bank, more suburban on left bank'; left bank restoration pot. Higher, regrade (4 ranking), constraint is built walls/gabions, not possible to restore left bank
2	0 long conn	5%	1.00	channelized, little veg, fp narrow; lots of channel modification;narrow floodplain to being with? 40-50 meters?
1	scattered 5%	15%	4.00	discontinuous suburban, some natural area, esp on right bank, lots arundo!, left bank channelized; most fp not built on yet though left bank has devt
0	contin 5% then sparse	n/a	3.00	north, higher resto potential, urban mostly on right bank; lots channelization, land will be protected from flooding, so fp restor no possible for historic landmarks

Refer to Reach Key Map on Page 21 for locaions of each study area within the basin.

Appendix 2: Biological Condition Index Description

The index is based on the presence/absence of features of recognized biodiversity and habitat quality importance. A higher score means the stream is more suitable for wildlife (e.g. more ecological niches), the riparian gallery is well developed, and the vegetation continuity between patches is well represented both at longitudinal and lateral scales. The highest score possible in our watershed is 34. All the scores are the result of the sum of points, presented as a percentage relative to the highest possible score. This score was developed using a reference of three sites surveyed with the River Habitat Survey method in the Jardas River in Sintra (Portugal). Thus, the sections and features used for the scoring system were taken from measurements in the field, recorded according to a standardized method, and are listed below with their corresponding score assignments.

Scoring System

Section C – number of riffles and pools:
- score 0 if <10
- score 1 if the total 10≥20
- score 2 if the total >20

– point bars and side bars:
- score 0 if absent
- score 1 if the total <10
- score 2 if the total >10

Section E – channel material:
- score 1 if there are at least 5 or more different (dominant and sub-dominant types)

Section F – vegetation structure:
- score 1 if more than 50% of the structure at bankface is simple or complex
- score 1 if more than 50% of the structure at banktop is simple or complex

Section H – sweep-up land-use:
- score 0 if Broadleaf/mixed woodland is absent
- score 1 if Broadleaf/mixed woodland is present
- score 2 if Broadleaf/mixed woodland is extent

Section I – bank profile:
- score 0 if no natural bank is recorded
- score 1 if natural bank is only present
- score 2 if natural bank is extensive

Section J – riparian gallery:
- score 1 if riparian gallery is present
- score 2 if Alnus glutinosa is present
- score 1 for each other riparian tree species recorded

Section K – extent of trees and associated features:
- score 1 if trees extent is semi-continuous or continuous per bank
- score 1 per feature recorded as present, score 2 if extensive

Section Other – nuissance plants:
- score 1 if absent

This scoring system allows one to rank the overall naturalness of a benchmark site and then compare it to other spots in the same stream. This ranking can be used to prioritize which are the river sections that might be restored to a more natural condition reflecting potential within a given watershed.

Rationale behind our selected metrics:
-The more riffles and pools, the more rich a segment is in micro-habitats
-More channel substrates can correspond to more micro-habitats: also some specific substrates as Bedrock and boulders score for HQA (habitat quality assessment)
-Point bars and side bars are very important for birds, and also score for HQA
-Vegetation structure score for HQA if simple or complex.
-Natural bank was added according to our best professional judgement, as Cacém and Gunpowder Mill had many modifications compared to the benchmark. Also, the modifications detract from vegetation continuity.
-Broadleaf woodland provides a pool of biodiversity for birds, as there are many strata, and niches for nesting. Scrub and shrubs, even though they keep pets away, will not score because *Rubus ulmifolius* is an exotic species.
-The riparian gallery is self-explanatory as an important variable.
-*Alnus glutinosa* scores more tha the other species because they are a good source of food and nesting sites for birds, and their roots are normally exposed and fishes like to hide within them.
-Tree extent scores like this in the HQA index. The aim is continuity so this assessment is appropriate; it can also keep livestock and pets away from the stream.
-Features score 1 if present and 2 if extensive to keep coherence. Also they are very important for wildlife, and a good indicator of habitat quality (it scores highly in the HQA).
-The nuisance plants are mainly refering to *Arundo donax*.

Cacém: Stream as Linear Park in the Heart of the City

Rachel Kraai, Jessica Ludy, Bessma Mourad, Kristen Podolak, Dan Sarna

In 2008, the Polis Programme for the Urban Regeneration and Environmental Enhancement of Cities completed a river restoration project along the *Ribeira da Barcarena* in the city of Agualva-Cacém, Portugal. Polis' primary goals for the four-acre *Ribeira das Jardas* park were to provide flood protection, regenerate aquatic and riparian habitat, enhance scenic and aesthetic qualities, provide space for leisure and recreation, and create connections between the urban community and the river. We conducted a post-project appraisal to evaluate the park. We assessed the human use, user perception, and riparian habitat. The appraisal's objectives were to understand who is using the park, how it is perceived by the community, and how the project has changed the community's relationship to the river. Based on our findings, we make recommendations for future park improvements and greenway planning.

Road infrastructure and public spaces were improved along with the flood control project.

Shaded areas for sitting along the banks of the Jarda

Buildings and walkways adjacent to stream prior to Polis.

Exercise and social space in the park along the water

Ribeira das Jardas prior to Polis project in Cacém

Ribeira das Jardas after the Polis project in Cacém

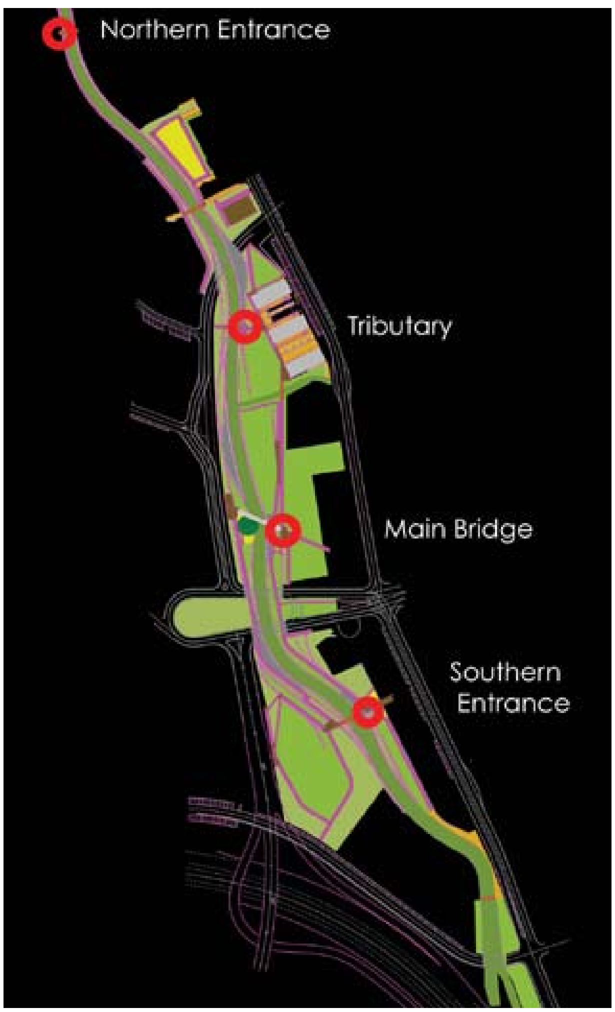
We used four techniques to conduct our assessment: two types of behavior mapping, a survey of park users, and a river habitat survey.

Behavior Mapping

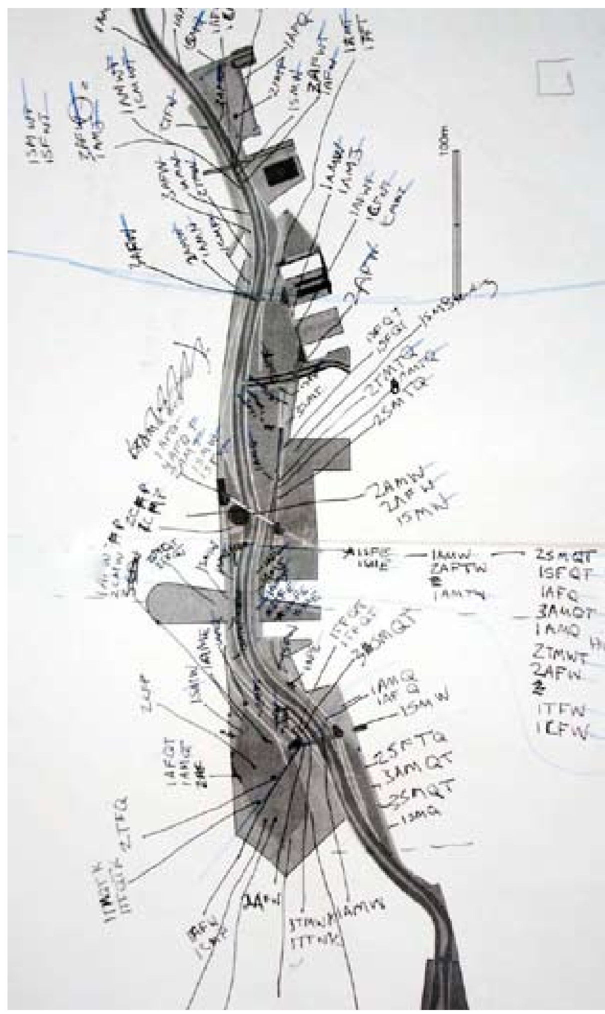
The behavior mapping illustrated user activity throughout the park. We walked transects from the southern to the northern end of the park and recorded age, gender, activity, and location of every user. We walked these transects every two hours, throughout the course of one weekday from 8-20 h, for a total of 7 observation periods. We charted movement and quantified pedestrian flow at four intersections in the park over fifteen minute intervals during the same observation periods as the behavior mapping. We recorded the number of persons passing through each point and the direction in which they were moving.

Park Visitor Perception Survey

We conducted a survey of park visitors. A 35-item survey that included close and open-ended questions was developed as a follow up to a 2003 survey conducted by Fátima Bernardo as part of the URBEM (Urban River Basin Enhancement Methods) project prior to the Polis intervention. In 2003, however, there was no park for people to use so the study reflected nearby resident's perceptions of the river prior to park construction. We compared the 2009 survey results with the 2003 results to assess how community perception and experience of the space have changed since park creation.



Areas along park where surveys were conducted



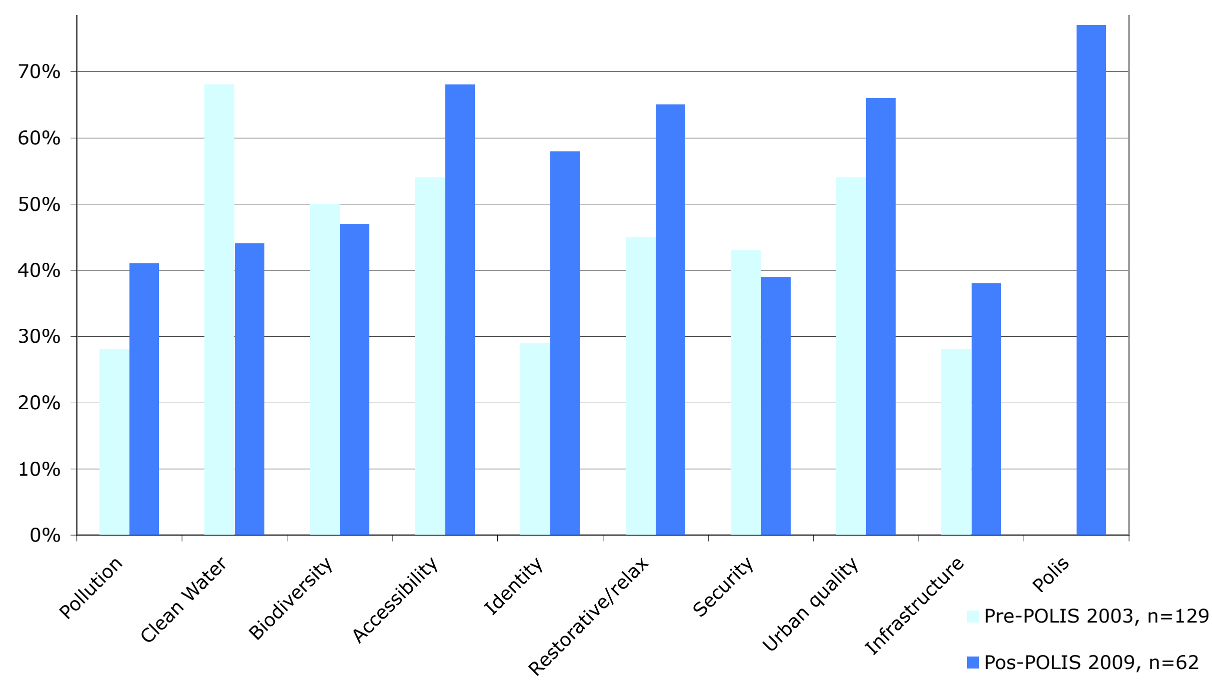
Sample of behavior mapping documentation

The 2009 survey differed from the 2003 survey in two main ways. In 2003 the stream was inaccessible and largely invisible behind floodwalls and fences. In 2009 the stream was very visible, so the respondents' expectations would have been very different in the two years. Surveyors in 2003 administered the questionnaire door-to-door to residents near the stream, whereas in 2009, surveyors approached people in the park, which drew users from more than the immediately adjacent buildings, and in fact was largely dominated by unemployed immigrant workers from Africa. So, the respondent population was potentially very different and self-selected as more likely to use the park.

Despite these differences, we compared the 2003 and 2009 surveys using 10 categories. These categories analyzed positive user perception of the following: overall pollution, water quality, biodiversity, accessibility, identity, restorative/relaxing character, personal security, aesthetic value, infrastructure, and overall intervention (Polis). Interviews were conducted face-to-face with interviewers noting the answers verbatim. To conduct interviews with some of these users, we translated the survey questions into French, Spanish, or English from the original Portuguese text.

River Habitat Survey

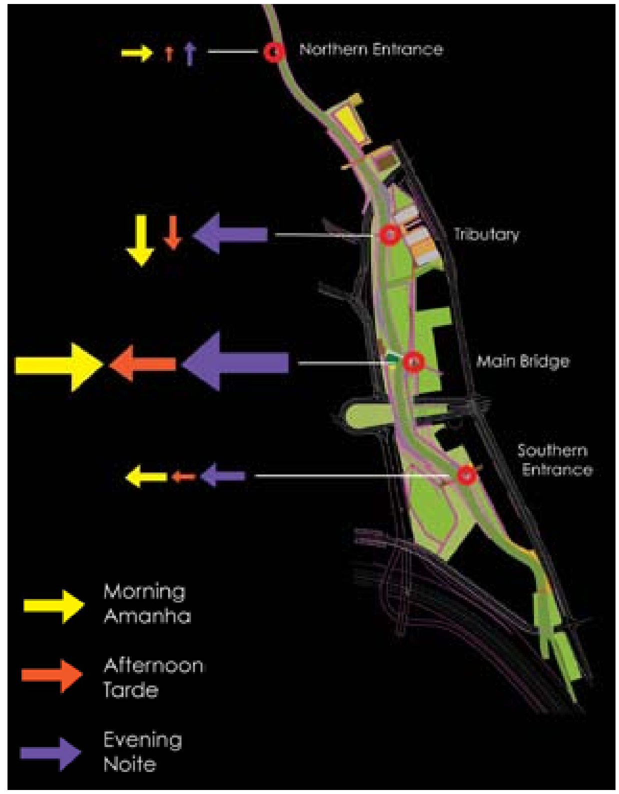
Lastly, we conducted a modified River Habitat Survey (RHS) to assess the ecological health in the Cacém reach of the *Ribeira da Barcarena*. The RHS was developed by the Environmental Agency of the United Kingdom to assess habitat value and assess structural modifications in rivers and is now used throughout Europe. The Riparian Vegetation Group from our workshop analyzed the results of the habitat survey using seven components in the context of additional *Ribeira da Barcarena* sites surveyed during the workshop.



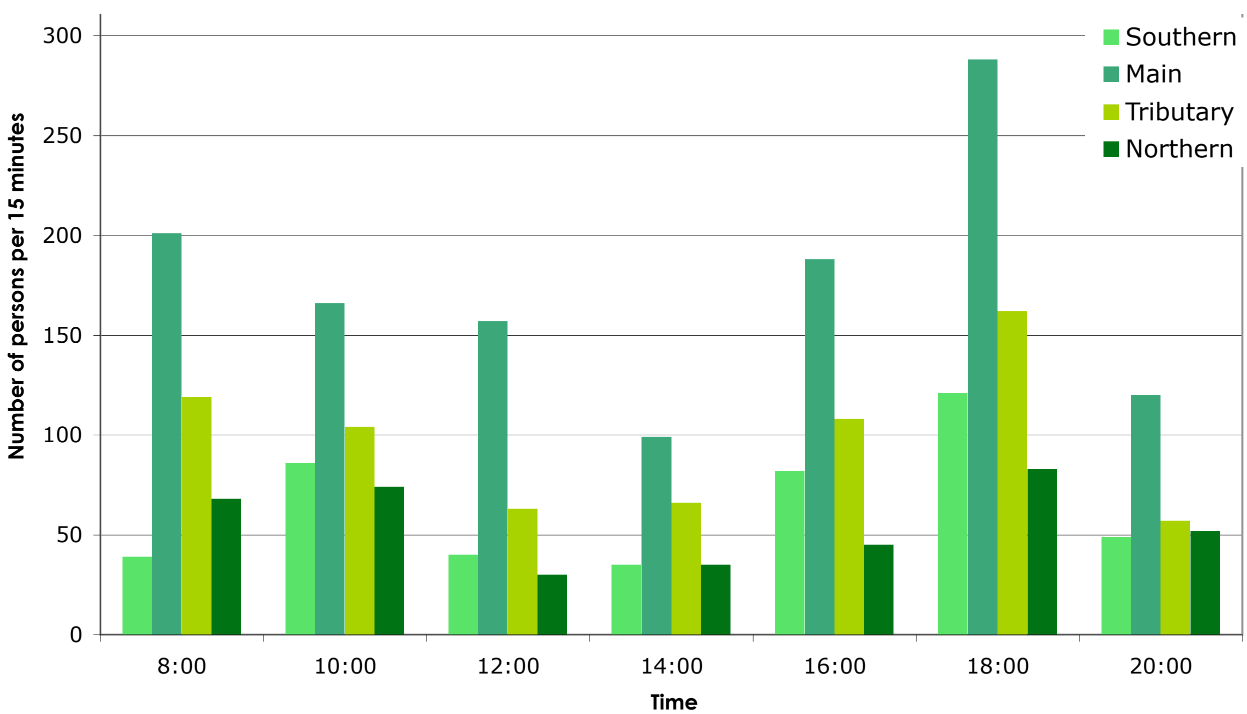
Comparison of perceptions associated with the Ribeira das Jardas between 2003 pre-Polis and 2009 post-Polis

Behavior Mapping

We observed a total of 967 individuals engaged in a variety of activities including walking, sitting, jogging (the three most common), biking, using exercise machines, sitting, kissing, and feeding ducks or otherwise appreciating nature. Park use varied according to age and gender, with more adult men in the park than any other group. 40% of male park users participated in passive activities compared with approximately 20% of female users. Seniors and adults accounted for 75% of users observed throughout the day. Children represented the smallest portion of park users. With the exception of a small increase in the middle of the day, teenagers were largely absent from the park until early evening; this spike of teenagers walking through the park likely corresponds to an end of school or after school activities.

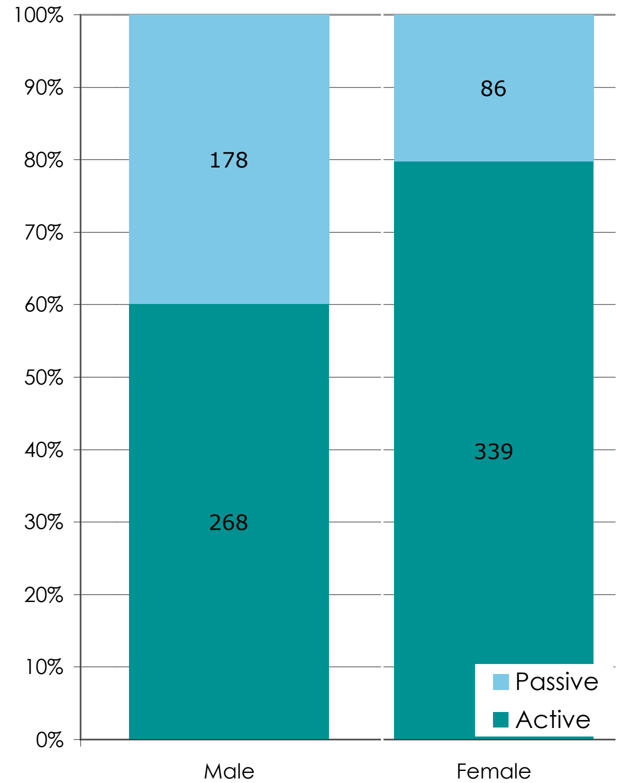


Pedestrian travel direction in a diurnal cycle

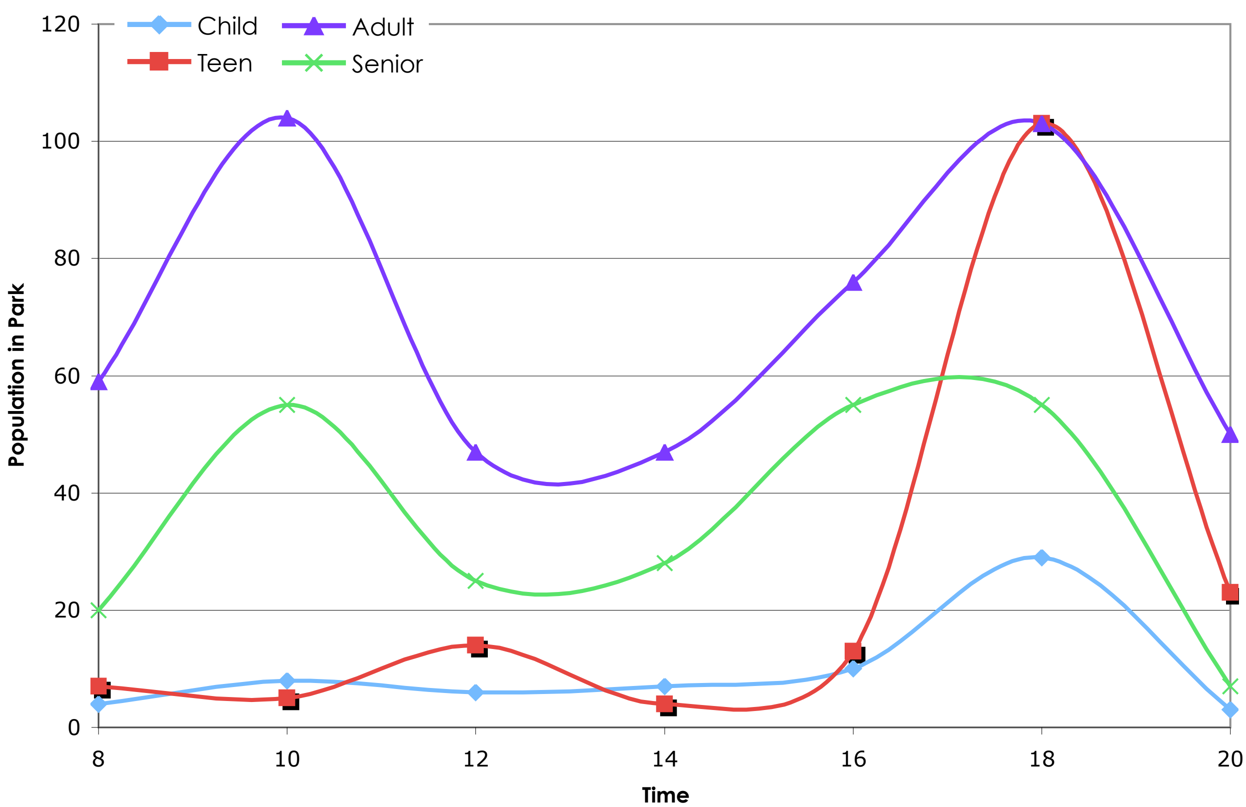


Pedestrian counts throughout the day from four points within the park along the Ribeira das Jardas

Activities varied temporally and spatially throughout the park. Park use was much greater in the mornings and evenings than during the middle of the day. In addition to a daily work and school schedule (9-16 h) one likely reason for this spatial and temporal variation is the intensity of the midday sun and lack of adequate shade throughout the majority of the park. The main source of shade is a large tree on the west side of the main bridge. The shade provided by this large tree is the favored resting place of people during the middle of the day. It encourages sitting, duck watching, chatting, and other activities. Ironically this tree would have been removed according to the original plan for the park, but the plan was modified to preserve the tree after public input.



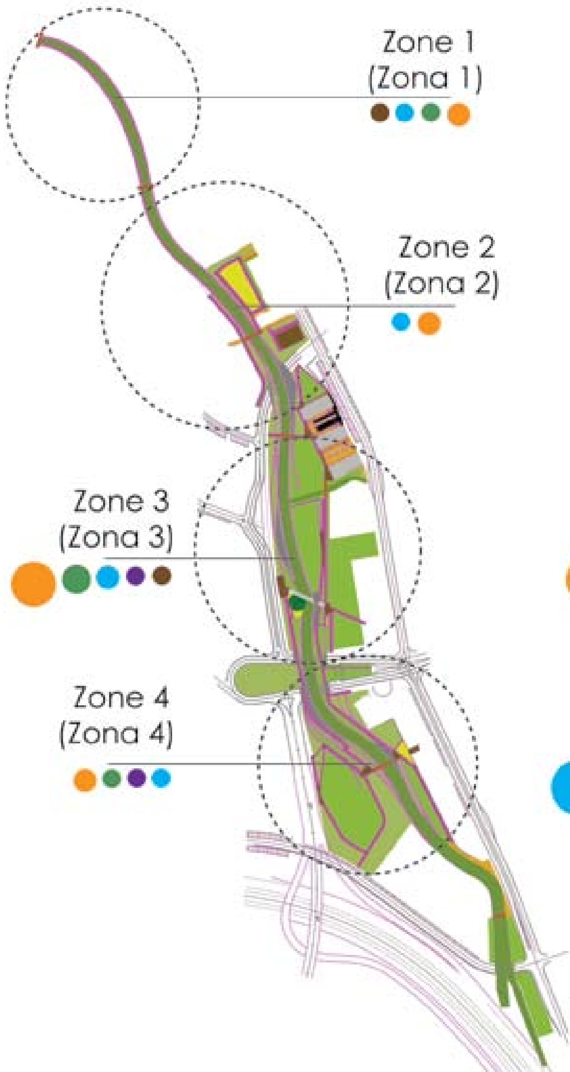
Level of activity by gender

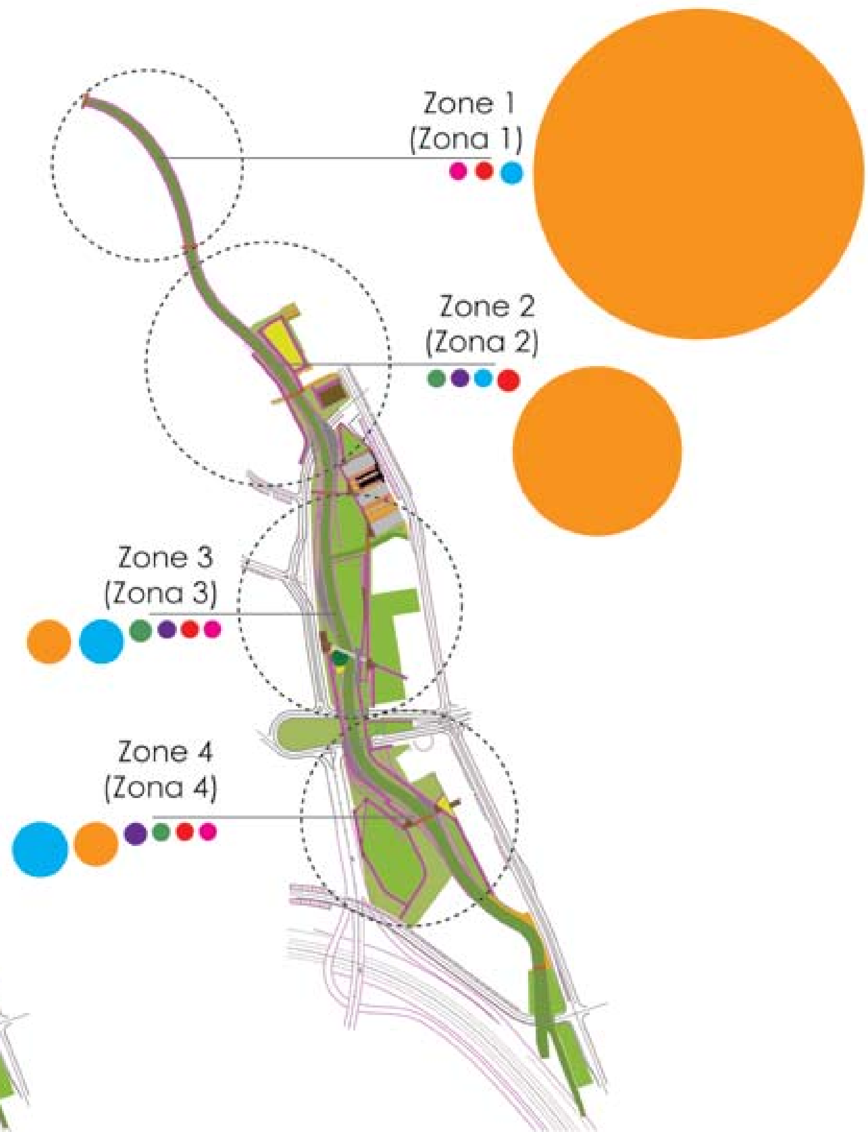


Diurnal population by age group

The busiest time in the park was at 18h in the evening; the busiest observation point was the intersection of the main bridge and the lower trail. This can be attributed to the use of the main bridge as an important circulation route to and from the train station on the east side of the park. The intersections observed at the north and south ends of the park experienced lighter traffic than the middle observation points. In general, there was much more east-west movement (transverse) than north-south movement (longitudinal) through the park.

walking/passear
sitting/sentado
jogging/correr
playing/brincar
biking/bicicleta
nature observation/ observcao de natureza
exercise machines/ maquinas de exercicio





Activities at 12:00

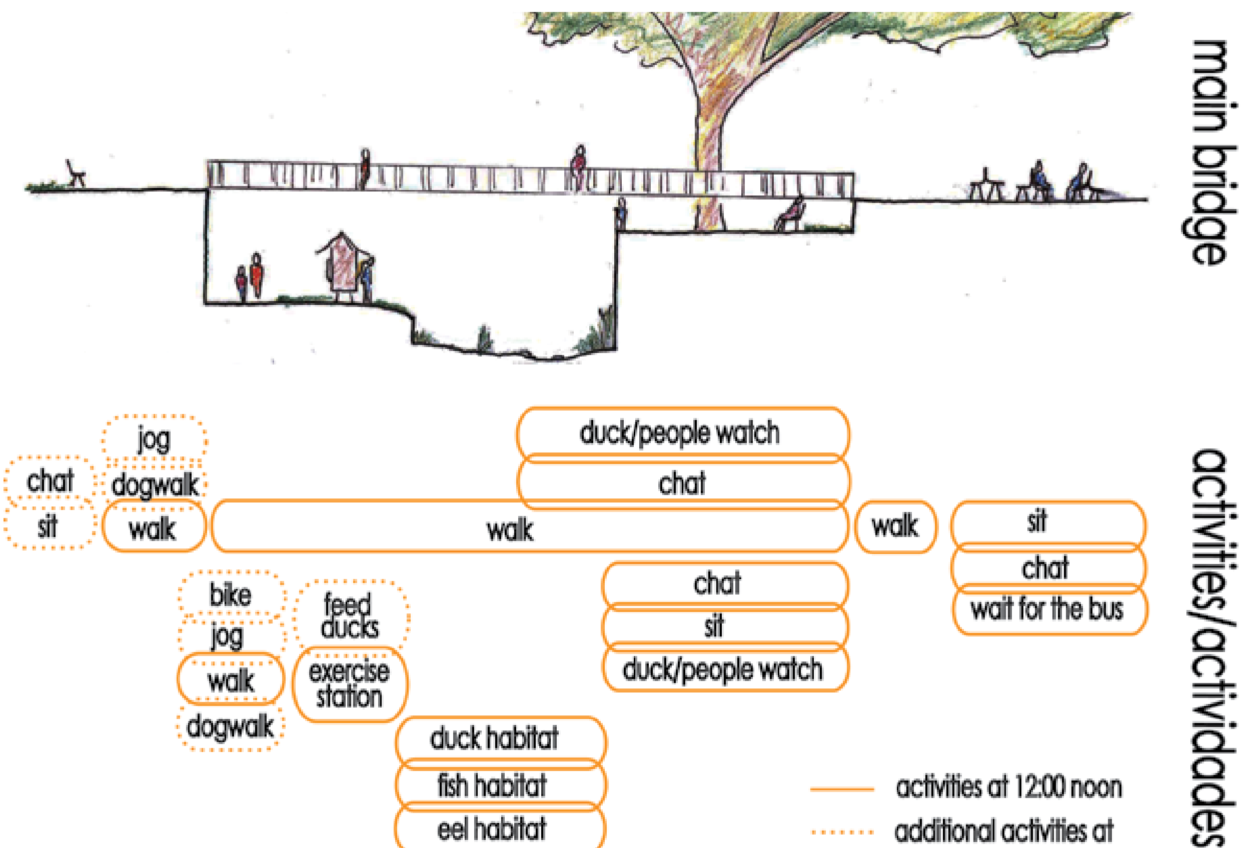
Activities at 18:00

Surveys

Of the 62 surveys conducted over four-days, 36% of respondents were female, 64% male. The survey captured a range of different ages 32% age 45-64, 29% age 25-44, 24% age 64 plus, and 15% age 15-24. The number of respondents was about half of the 2003 pre-project survey (n= 129). Perceptions of park and river were overall more positive in 2009 than 2003. Change was most notable in "identity/attachment" where positive perceptions increased from 29% in 2003 to 58% in 2009, indicating that the community felt more connected to river in 2009. Another improvement is evident in the "restorative/relax" category, indicating that the river park is a source of restoration for users in ways that it was not before the project.

The survey indicated that 77% of people surveyed feel positively about the Polis intervention. Residents consider the intervention to have improved river-accessibility, pollution, and urban aesthetic quality. However, the results were mixed with some indicators of positive perception showing declines. One possible explanation is that site users are now more engaged and invested in the health of the water body and the vitality of the public space. Prior to the park, there was no access to the stream, so residents could not see the water and thus could not judge its quality.

Interestingly, respondents' perceptions of water-quality declined from 2003 to 2009. Several pointed to sewer outfalls as the main source of pollution, noting that they wished to see water quality improvement. Similarly, survey responses and informal comments indicated a general sense that the park is not safe at night. Park visitors mentioned that the north and south ends of the park were less safe than the more populated areas of the middle region.



Diurnal activities at the main bridge along the park

Park Visitor Demands

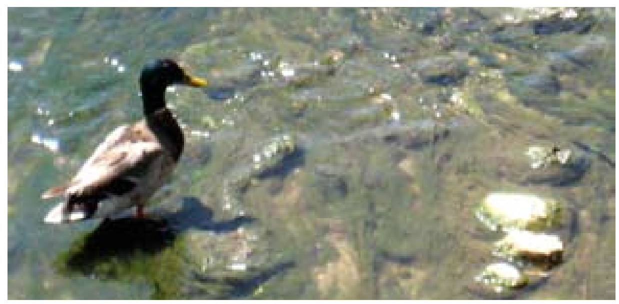
The open-ended question on the survey and discussions with respondents revealed park user needs. Discussion brought attention to the lack of play structures and other facilities for children. Similarly, several respondents requested more shade and additional sports fields. The park serves a large unexpected use for many unemployed immigrants who come to the park when they do not have work. When asked about ways to improve the park, many changed the subject to speak about hardships in Portugal. "What is most important is being legal and finding work." While the park provides an important gathering space for these users, their concerns raise broader issues of inequities at a global scale, which fuel immigrants pressures, and which result in a user population for the Cacém site that is probably very different from what was originally imagined.

Field space for soccer would address park users' needs

Temporary shade structures would benefit certain areas of the park while the trees grow into their shade maturity.

Habitat Survey

The River Habitat Survey generated a score of 5.88 for the reach of the *Ribeira das Jardas* which flows through the Linear Park in Cacém, which was much lower than scores for the more natural *Mira-Sintra* stream and *Fábrica da Pólvora*, a suburban setting (73.5 and 35.3, respectively). However, despite the relatively poor quality habitat, we observed eels (endangered), fish, mallard ducks, and frogs, among the best wildlife sightings of any team along the stream. However, the configuration of the park currently does not provide features to enhance habitat for aquatic and riparian species, such as shade, channel complexity, or food supply.



Ducks are now frequent visitors to the park and stream

An eel seen in the Polis reach of the Jardas

Television as Nase habitat?

Conclusion

Surveys, behavior mapping, and discussion with park users all point to the importance of shade during hotter parts of the day. A single large tree provided most of the shade available in the park. Although many trees were planted as part of the project, it will be years before they provide significant shade. This illustrated the importance of preserving large existing trees in new river projects to jump-start the usability of the new spaces.

The relative lack of children in the park indicated a need for more play areas. Several respondents called for concrete tables for card playing. Park users were also concerned about nighttime safety. Interventions for enhancing park security could include better lighting and police presence. Heavy use during the daytime indicated that the park is not only a success, but also a component of the transportation network, as well as enhancing the recreational space. In a neighborhood with little access to green space, the continuation of a trail network from Linear Park would serve additional users. It would also connect Cacém to the greater *Ribeira das Jardas* Basin.

The lack of vegetation along the stream bank presumably increases the flood conveyance, but can lead to higher water temperatures and limit the potential habitat for aquatic and terrestrial species. Incorporating location-appropriate riparian cover in future project designs can improve habitat for wildlife and people. At the same time, studies show that people prefer open views of the river, less bushy vegetation (Purcell 2002), and grassy banks (Appleton 1975) which suggests that vegetation should be specifically chosen and be maintained for aesthetic and security reasons.

We observed only one pool and two riffles through the reach of the stream in Cacém-Polis site. The lack of in-stream complexity and long riffle lengths create less viable habitat. A potential solution is to add complexity by creating pools along the reach using boulders. Pools should be spaced five to seven times the channel bankful width and constructed with natural materials such as boulders in a way that does not create barriers to eel or fish migration. In addition, bioengineering streambanks through the use of alternative materials (such as willow trees) could provide further in-stream habitat complexity for both aquatic and terrestrial ecosystems.

Survey responses and the habitat survey revealed the need to improve water quality in the stream. Respondents perceived the water to be of poor quality, mentioning the series of outfalls polluting the stream. The RHS confirmed this through observation of the outfalls along the stream. Moreover, the RHS documented a number of aquatic species existing in the *Ribeira da Barcarena* Basin along the urban stretch such as eel, fish, ducks, and frogs. Improving water quality will be conducive to these species' viability in the urban park and may stimulate a deeper connection between the community and the natural ecosystem.

Pedestrian behavior mapping exercise

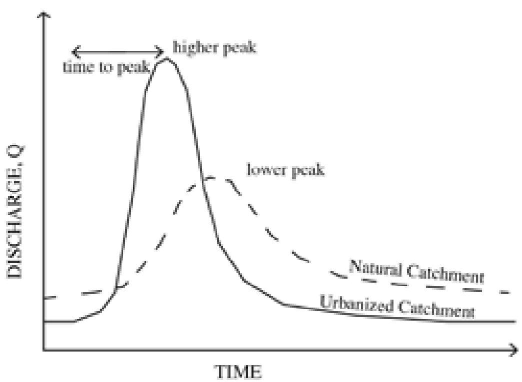
Park user survey

On-site stormwater management toolbox

John Delarroz

To accomplish the goal of the Water Framework Directive for "good ecological status," contaminated stormwater must be contained and treated before it flows into freshwater systems. Stormwater management involves designs that mimic nature by slowing down runoff and increasing infiltration rates. Slowing runoff allows bacteria and vegetation to uptake nutrients and break down pollutants. Increasing infiltration can dampen peak flows and produce a more natural hydrograph in a developed basin. The following section reviews stormwater design solutions and proposes a stormwater management plan for the Barcarena urban area.

Under natural conditions, only a small portion of rainfall becomes surface runoff. The majority of rainfall either evaporates, is absorbed by plant roots and transpired, or infiltrates into the ground. However, urbanization results in the replacement of natural, permeable surfaces with constructed surfaces that do not allow water to flow into the ground. This results in an increase in the portion of water becoming runoff, as well as an increase in sediment potentially impacting aquatic life and organic pollutants lowering biodiversity (BASMAA 1999). Urbanization creates a significant risk to human health and property when faster transport of water flows into the river channel resulting in more frequent, sudden floods.



Peak flow hydrograph of urbanized catchment versus rural/natural catchment

Barcarena village and the Ribeira da Barcarena: note the lack of vegetated surface in the urbanized areas.

Rain Garden
A rain garden is a depression in the landscape designed to catch and treat the water that comes from impervious surfaces. They are created by redirecting the gutters of nearby buildings or runoff from the street into the garden. Rain gardens contain native plants such as shrubs, grasses, and wildflowers that help absorb and filter runoff. These landscaping features help to create beautiful green spaces while absorbing water, reducing runoff, protecting water quality and slowing the transport of water. Rain gardens require flat slopes and therefore may require terracing and greater total expenses. Additionally, the flora in these gardens must be able to tolerate flooded soils and extended dry periods, resulting in a much more limited choice of plants.

Pervious pavement
There are many options available to increase the permeability of roads and parking areas. Specially formulated porous concrete allows water to flow through; however these surfaces are more expensive than traditional options (BASMAA 1999). Surfaces made with permeable pavers contain gaps filled with sand or gravel, which allow passage of water. There are a variety of different styles of pavers available, giving many different choices for different aesthetic needs. This type of pavement can be more expensive than traditional concrete, due to the additional labor costs during installation and maintenance. Both types of alternative pavement allow for replenishment of groundwater, while reducing the amounts of pollutants and sediment in the runoff.

A raingarden in Portland, Oregon accepts runoff from the roof of the adjacent building.

Pervious paving in a parking area in Cascais includes both planted and gravel. Cobblestone paving can also be pervious when the sand is not heavily compacted.

Cisterns

Cisterns are reservoirs capable of collecting part of the rain that falls on the roof of a house or building. Water from roofs is relatively clean, as the water only travels a short distance before being collected and cannot pick up organic pollutants or metals, as usually happens when water flows over roads. Captured water is then available for garden irrigation, use in toilets, or washing outdoor surfaces. This results in lower potable water consumption, and lower costs for both the consumer and the municipality. However, water storage requires substantial amounts of space and the use of an electric pump to increase water pressure to usable levels.

A cistern catches rainwater from the roof which is then used to irrigate the surrounding landscape plantings.

Stormwater Wetlands

Stormwater wetlands are artificial, constructed wetlands designed to treat stormwater while also providing habitat for local wildlife. Native hydrophilic plants in the wetlands foster bacteria which can degrade pollutants. Wetland plants also act as a barrier, helping to slow stormwater and encourage deposition of sediment and adsorbed metals. Metals are then taken up by plants and can be removed from the environment through manual removal of plant biomass. Wetlands can be any size from a square meter to square kilometers. This combination of attributes makes wetlands a versatile yet aesthetically pleasing option for stormwater treatment. Stormwater wetlands have some limitations. The shallow slopes surrounding the edges mean that less water can be detained than in a detention basin of equal area. Stormwater wetlands require sedimentation basins to prevent the wetland from getting overloaded with sediment. Finally, wetlands will eventually require maintenance under normal circumstances, and are a potential breeding ground for mosquitoes unless precautions are taken (EPA 1999).

A constructed stormwater wetland also functions as a park in downtown Portland, Oregon.

METHODS

We selected the left bank of the river in the village of Barcarena as a pilot location to develop a stormwater management plan. We measured the area of impermeable surfaces, such as rooftops, concrete and asphalt-paved areas (e.g., parking lots), and roads, using aerial imagery from Google Earth. To estimate the distribution between public and private ownership of vegetated areas and impervious surfaces, a representative sample of the study area was designated and applied to the entire site area. Wide expanses of land not obviously associated with a building were designated as public, while small gardens and the like are designated as private. The ratio of private to public property was used to determine the feasibility of different management techniques.

We calculated runoff for each type of land cover for the 10-year, 2-hour storm based on the following formula:

$V = CA_{tot}R_d$

Where:

V = design treatment volume (m^3)

R_d = 50 mm – Rainfall for 10 year, 2 hr storm

A_{tot} = total treatment area of site

C = the weighted average runoff coefficient:

$C = (c_i A_i)/A_{tot}$

where:

A_i = i^{th} area

c_i = runoff coefficient for i^{th} area of drainage

c_i = 0.9 for impervious areas

c_i = 0.6 for pervious pavement area

c_i = 0.3 for disturbed pervious areas (compacted)

c_i = 0.15 for undisturbed pervious surfaces

To study the effects of the different stormwater management techniques an array of treatment combinations were analyzed by recalculating the above formula, and altering the "c" value according to the proposed change. Along with this, the size of rain gardens and wetlands were altered, thus changing the volume of water they can treat.

Rain garden opportunity sites in Barcarena (purple) and existing pervious vegetated sites (green).

Results

Vegetated areas covered 43% of the study area, followed by roofs at 29%, roads at 19%, and concrete at 10%. 76% of the vegetated areas, and 66% of the impermeable surfaces were public lands, which suggests that stormwater management could be done exclusively within public lands. Total runoff for the 10-year, 2 hour storm was 4.6 million liters. Despite having the largest amount of area within the study region, vegetated areas contributed the smallest amount to runoff, only 10% of the total, thus reflecting their low runoff coefficient. Roofs were the largest contributor, followed by roads and impervious surfaces.

In evaluating different stormwater options, there was a 3% decrease in total runoff from a change to pervious concrete and a 10% decrease due to pervious roads. One-meter high cisterns resulted in a 15% decrease in stormwater volumes. Rain gardens on one-third of the public vegetated areas resulted in nearly complete treatment of stormwater. Likewise, treatment wetlands with a depth of 0.75 meters resulted in 99% treatment of stormwater.

Although the percentage decrease in stormwater volumes for some of the treatment options are small, they still represent a substantial amount of water. For example, replacement of impervious concrete with pervious paving represented the smallest effect of all the treatment methods, but still reduced stormwater by 155,000 liters. In terms of parking demands, spots made with permeable pavers perform just as well as parking spots with asphalt, and pervious roads feel just the same to travel over, meaning that the public doesn't have to adapt to their use, and there are less obstacles to their acceptance. On the other hand, their reduced visibility means less opportunity for education and outreach to the community about the stormwater issues.

Much of the tributary catchment draining the village of Barcarena is undeveloped, and used for grazing only. As a result, this catchment should produce much less stormwater runoff than more densely urbanized areas. For this study area, the most promising method of stormwater management appears to be rain gardens and treatment wetlands, and in fact implementation of these methods would be required to achieve 100% stormwater treatment. Good sites for rain gardens and treatment wetlands exist, and should be protected from development, lest opportunities for these most cost-effective methods for stormwater treatment be lost. By taking control of the situation immediately, communities can ensure that their best areas for stormwater treatment are not developed. Alternatively, if new development is occurring, the municipality could ensure that the developers implement steps to reduce and mitigate their stormwater impact.

The optimal arrangement may be a combination of various treatment options. The rain gardens suggested in this study are generally large structures, so that 100% of the stormwater can be treated by this one method alone. If rain gardens were combined with other treatment options, these could instead be smaller scale structures, at around the size of a planter located on a sidewalk, or a vegetated divider next to a parking lot. Rain gardens or treatment wetlands could be created in conjunction with a small neighborhood park, thus providing stormwater treatment and a place for children and adults to congregate. Rebate programs for cisterns would allow only willing private participants to reduce stormwater flows and water usage, resulting in better maintenance of cisterns, and better usage of the captured water. Pervious pavers could be used in parking areas, thus adding an aesthetic feature to an otherwise dull area.

Conclusion

Experience elsewhere demonstrates that localized, site specific management of stormwater can decrease the severity of flooding and mitigate some of the adverse effects of urbanization on water quality, thereby supporting efforts to achieve good ecological status. This study shows that it is possible for the town of Barcarena to slow and treat 100% of its stormwater through a relatively modest set of rain gardens and treatment wetlands. The amount of water infiltrated with stormwater designs represents only a small fraction of the total volume and pollutant load for the larger *Ribeira de Jardas* basin. Consequently, some might question whether it is worthwhile to attempt stormwater management in such an environment. Here, however, there is an analogy to the problem of global warming. The decision of a single individual to stop buying imported foods or to reduce their gasoline usage has little effect on the total problem; however, if many people followed the same strategy there could be a substantial reduction in greenhouse gases. Likewise, with increasing participation in stormwater management from other communities in the catchment, means significant gains in both flood management and water quality could be achieved along the Barcarena and in the Tagus.

Opportunity sites for constructed stormwater treatment wetlands (blue) in Barcarena

Caxias: Design Interventions for Quinta Real and the Tagus Coast

Rafi Silberblatt, Laura Tepper, Hugo Vieira, Daniel Silva, Eduardo Pinto, Ana Maria & Pedro R. Garcia

The most downstream section of the *Ribeira de Barcarena* flows through a largely urbanized area of Oeiras, buffered by a greater mixture of land uses and ownership than many other parts of the river.

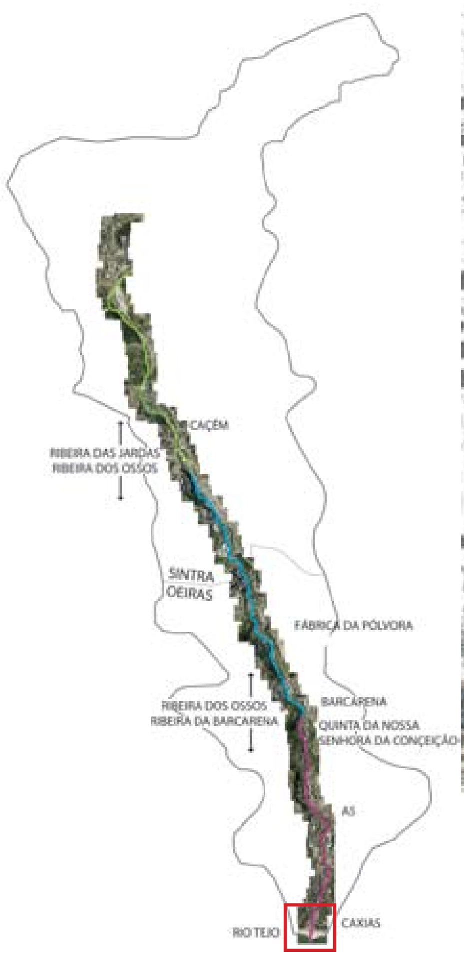
A series of historic cultural landmarks occupy the east side of the river, including a convent (Hospital Prisional de São João de Deus), which is no longer in use and the eighteenth century *Jardim da Cascata* (Cascade Gardens) located in the *Quinta Real de Caxias* (Royal Palace of Caxias).

Historically, the gardens at *Quinta Real* established an axial connection between the palace and the São Bruno fort, which juts out onto the beach. The subsequent addition of the Municipal Garden of Caxias just to the south of *Quinta Real* might have preserved this connection, if not for the train station and highway that sever the physical and visual links to the ocean that once characterized this site.

The residential area and small commercial strip centered around a plaza on the west side of the river are separated from the garden by the river, and the river by a road, railing and obstructive hedge.

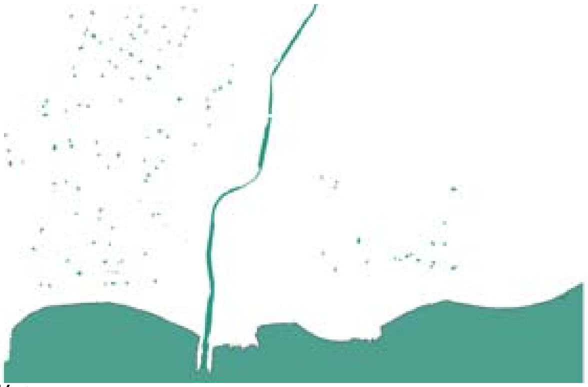
After an initial site visit we conducted a basic analysis of the site's topography, circulation, the presence of water (including private pools in adjacent houses), built structures (including historic landmarks) and ownership (particularly distinguishing public versus private property).

Historical maps of the garden, river channel and waterfront further informed design development.

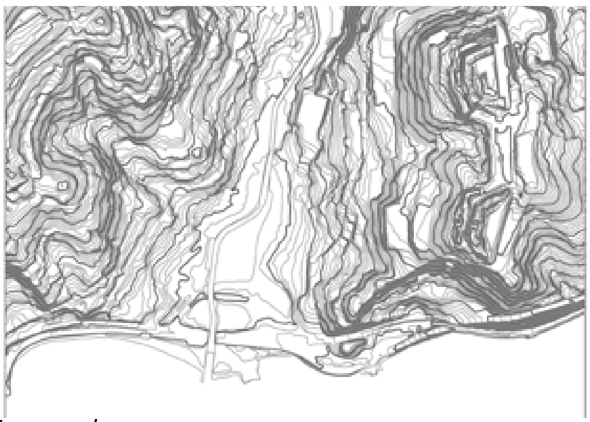


Study site location in the basin

Illustrative plan of study site

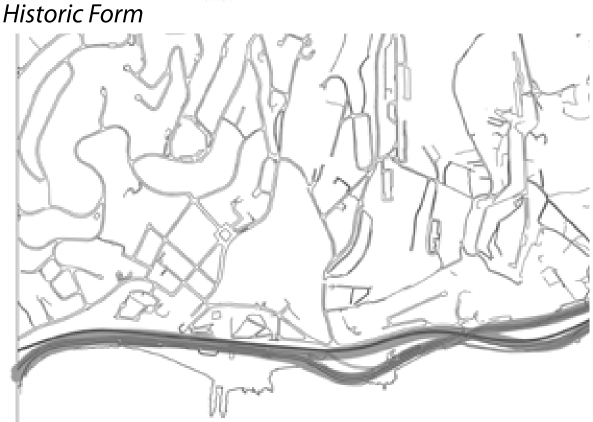

Water


Flood Zone

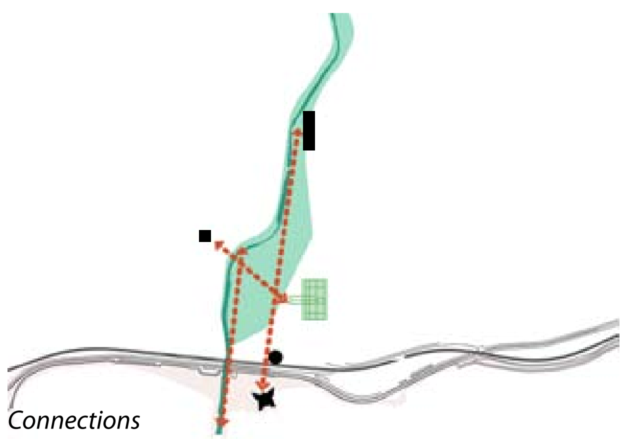

Topography

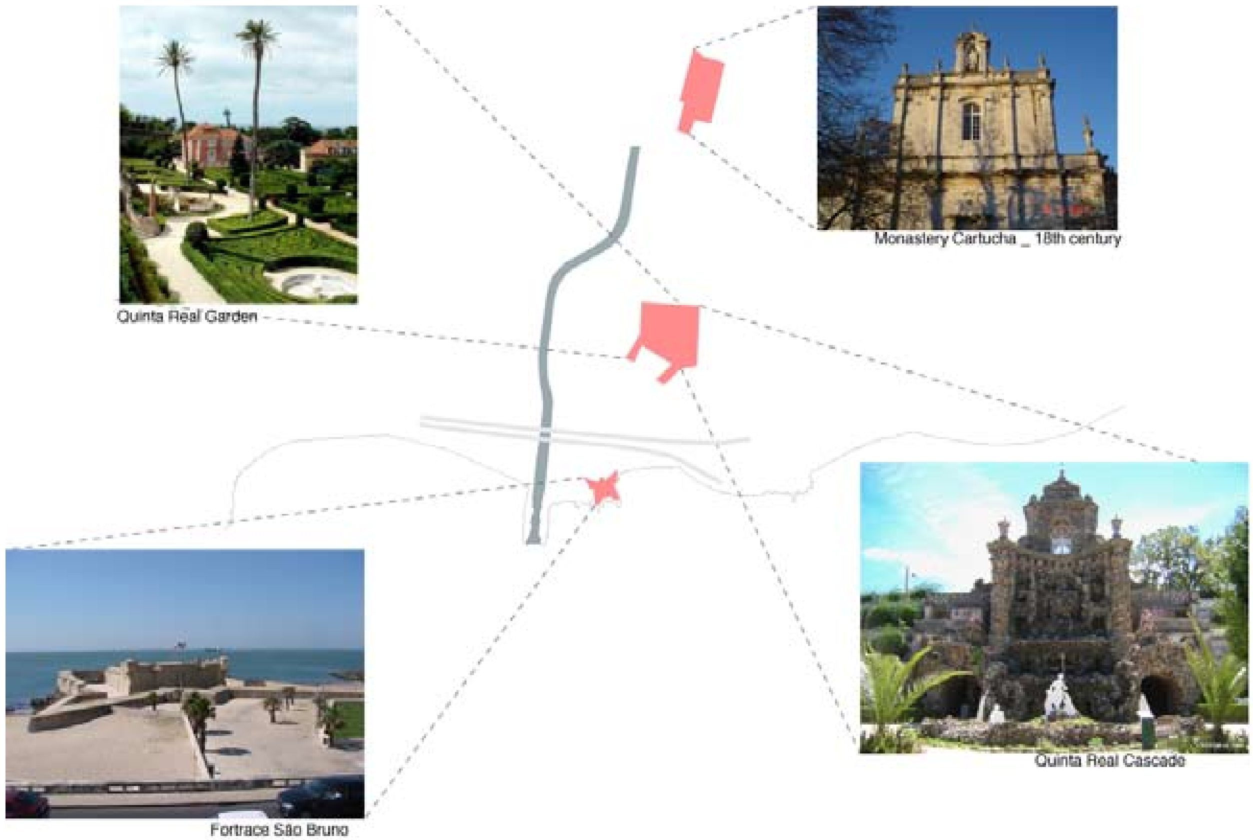

Historic Form


Building Footprints

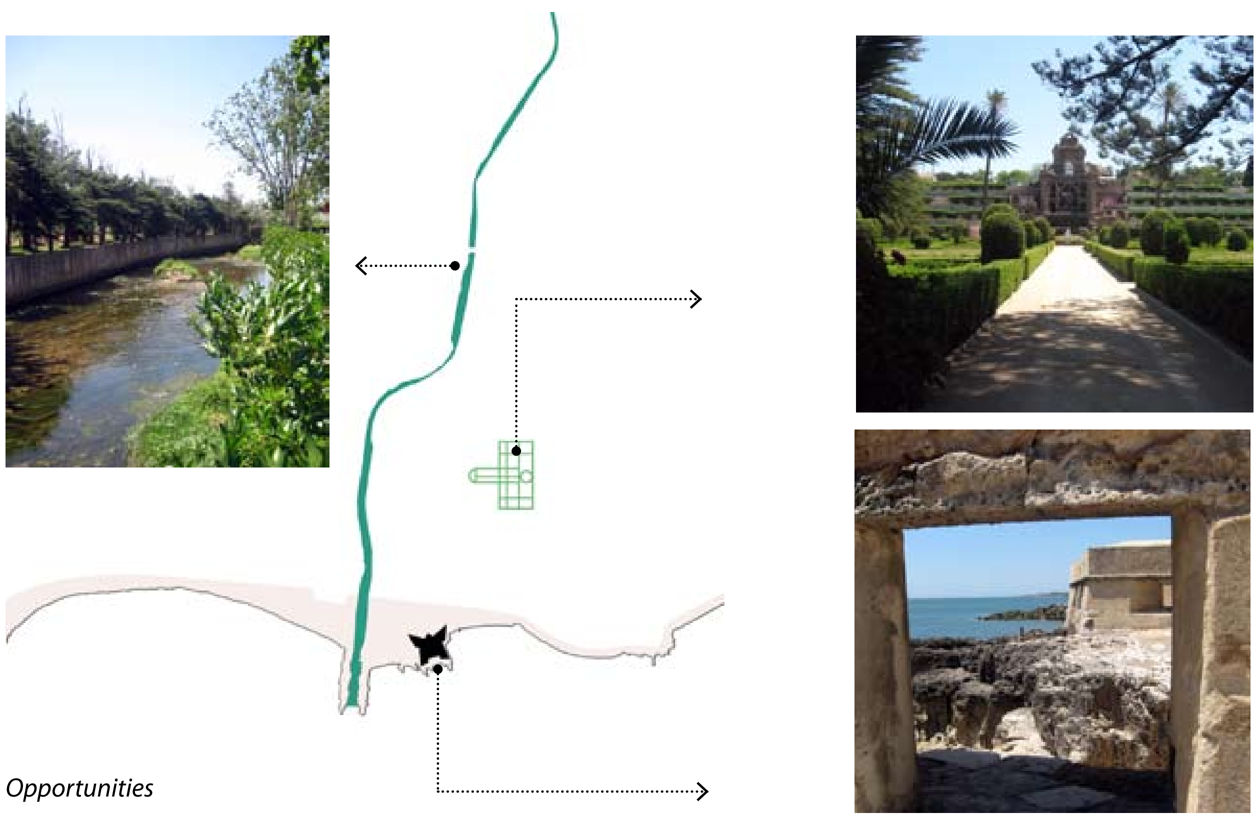

Roads


Vegetation


Connections



Landmarks



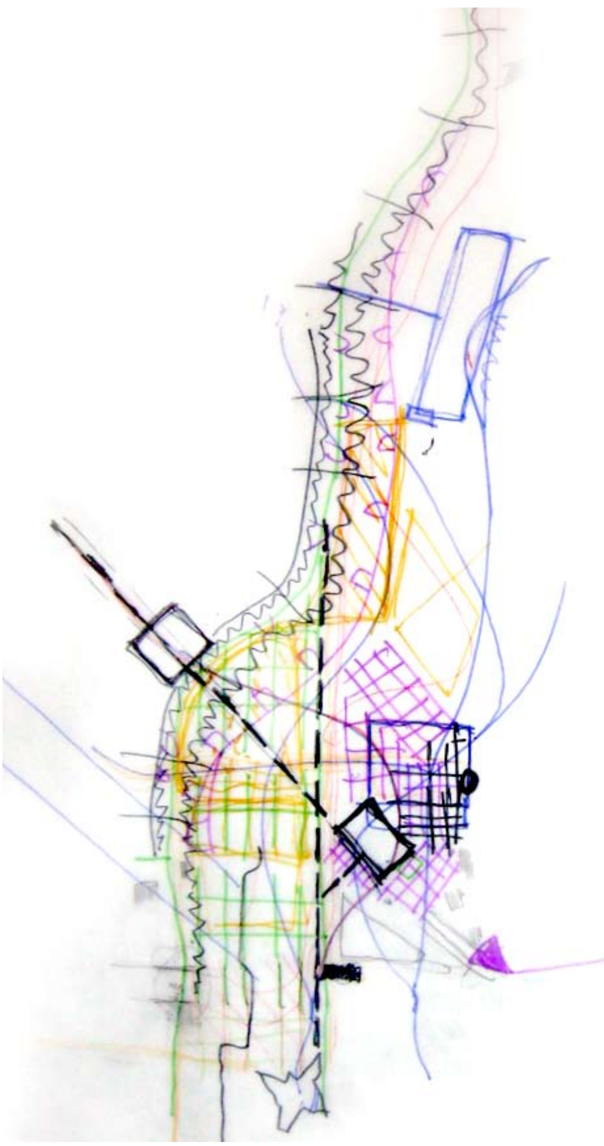
Opportunities

The design process reflected a tenuous and hard-earned balance between individual visions and group consensus.

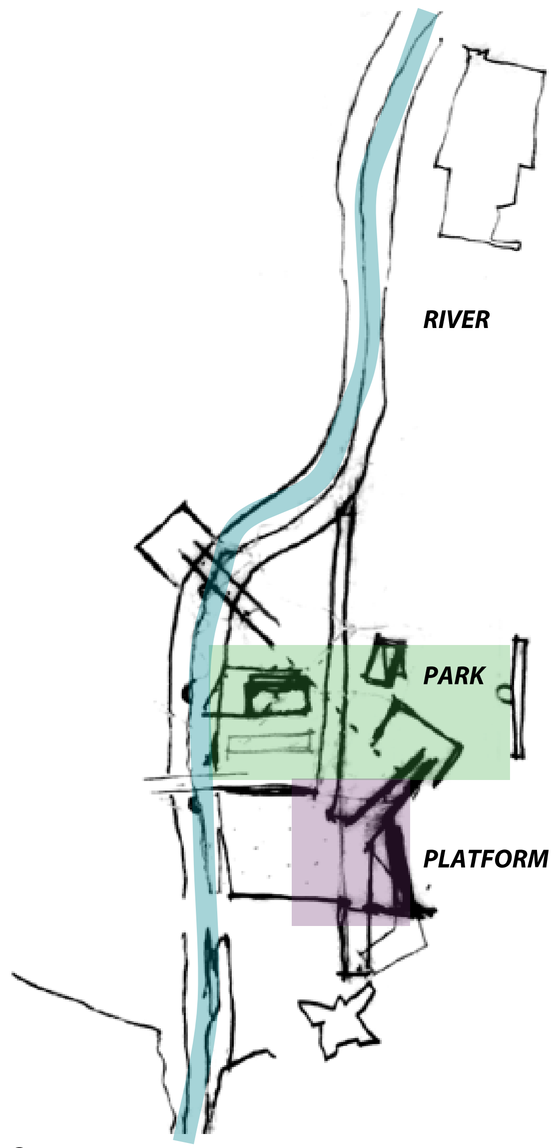
During a second, more extensive site visit we shared our respective design concepts through diagrams and tested their merit against the site. By overlaying each of our individual designs in different colors we were able to generate a composite sketch.

The common themes that emerged through this exercise, including restoring connections and improving access, provided a framework for the next series of individual efforts, which reflected disparate interests manifested in plan, section, and models.

A second overlay compiled from this series of design proposals distinguished commonly agreed upon elements from those that required further discussion. The result of this process is a proposal that addresses common concerns through three distinct design features.

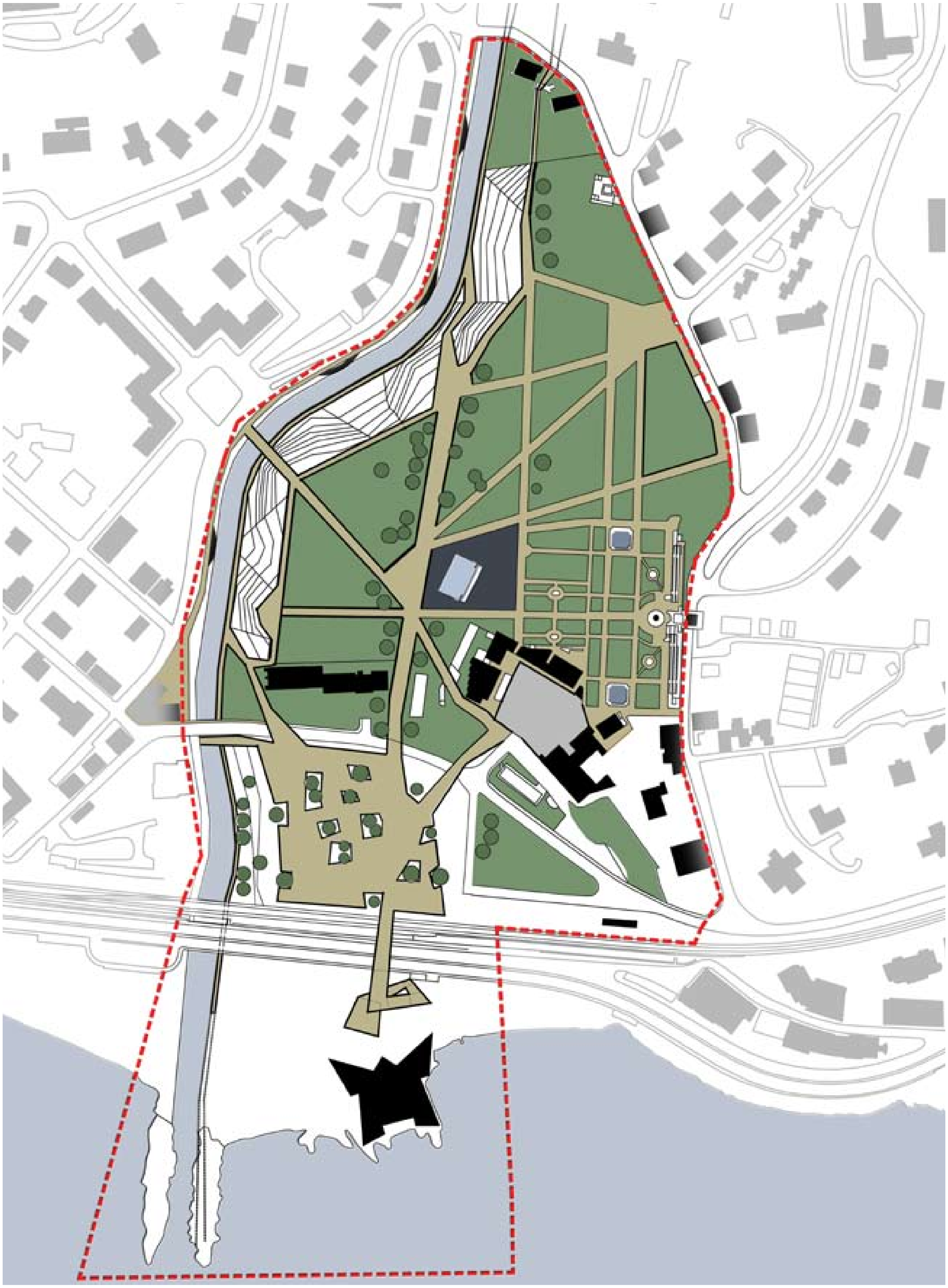


Overlaid Individual Visions



Consensus

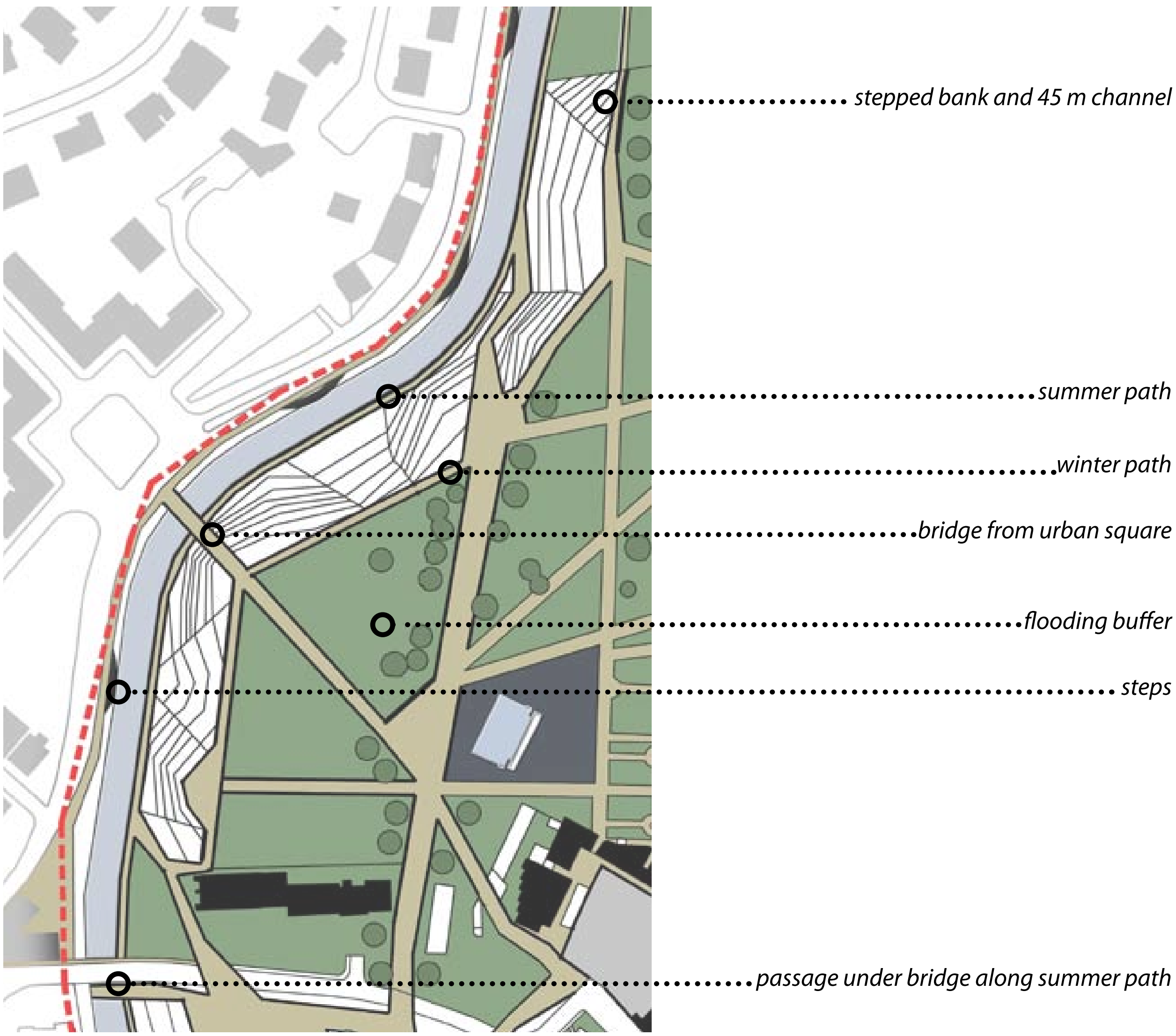
Proposal



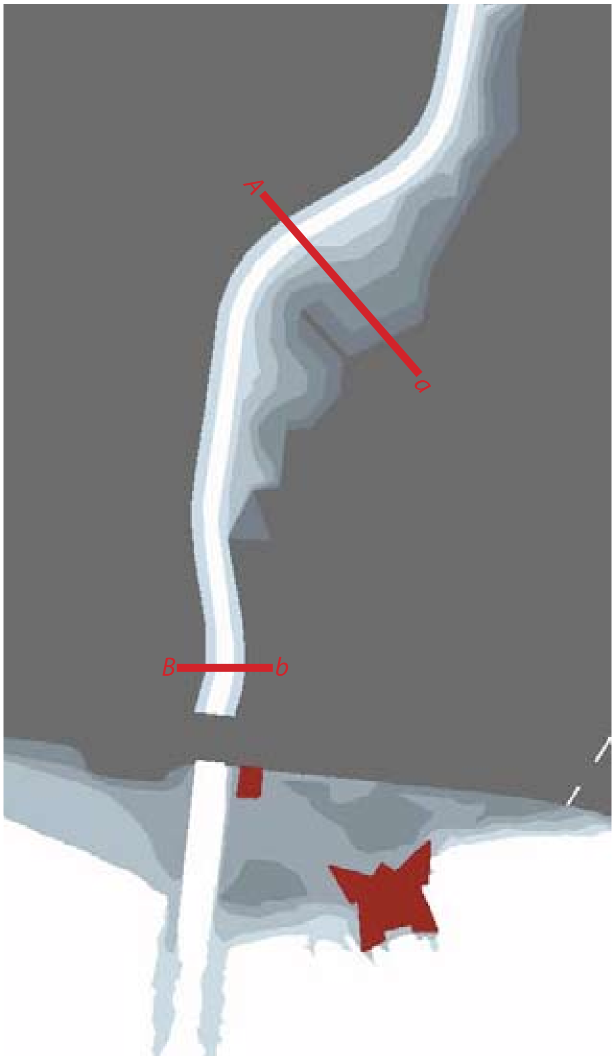
Overall Design Proposal Plan

River

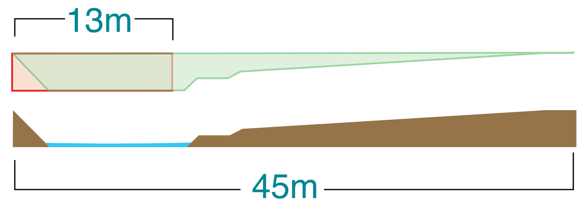
To improve habitat conditions and access to the river, we propose removing the walls on both sides of the river and making use of the REN designation to create a path system through a widened channel. By moving the two-year flood channel so that it is centered three meters to the east it is possible to create sloping banks on both sides of the river that can sustain riparian vegetation. On the west side of the river, steps built into the three meter by three meter bank descend into the channel from several points along the street. On the east side of the river a gently sloping 31-meter bank includes a lower summer path (at the height of Q2.5) and a higher winter path (at the height of Q100). Ramps and a series of shallow terraces connect these paths at several points. The curved geometry of the steps on the west side and the terraces on the east side lend the river a sinuous quality. From bank to bank the new river spans 45 meters, which does not include undeveloped land in the REN zone to the east of the winter path that provides further buffering against flooding. Two bridges (one of which includes the highway and railroad) necessitate a slight design change where the river nears the ocean. We propose widening the channel at this point from 14 meters to 20 meters, which would still provide sufficient space for sloped banks, riparian vegetation, and the continuation of the summer path all the way to the beach, while still accommodating Q100 flows.



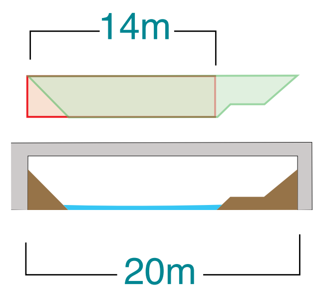
River flood control design strategy



Proposed Flood Zones



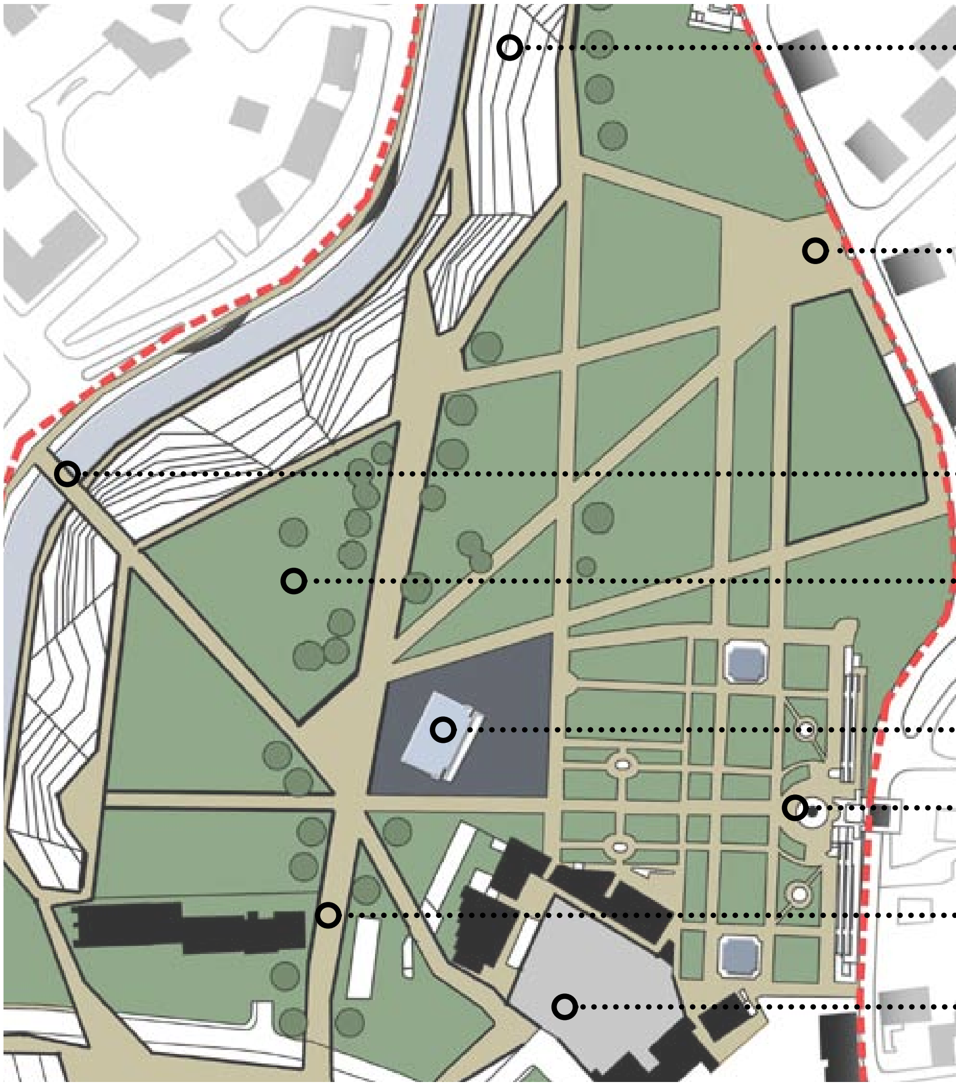
Section A-a Existing cross section (above), proposed cross section (below)



Section B-b Existing cross section (above), proposed cross section (below)

View north along river

View south along river



Park and Pathways
A new bridge will improve access for local residents by connecting an existing plaza on the west side of the river to a new reflecting pool (inspired by the remains of a historic reservoir/ reflecting pool) and two new plazas on the east side. The path over the bridge follows an axis that ends at the eastern entrance to our site, the arrival point for cars coming from Lisbon. This is one of several new axes that make use of the garden's previously extensive grid system as illustrated by historical maps of the site.


Agricultural Gardens

Platform

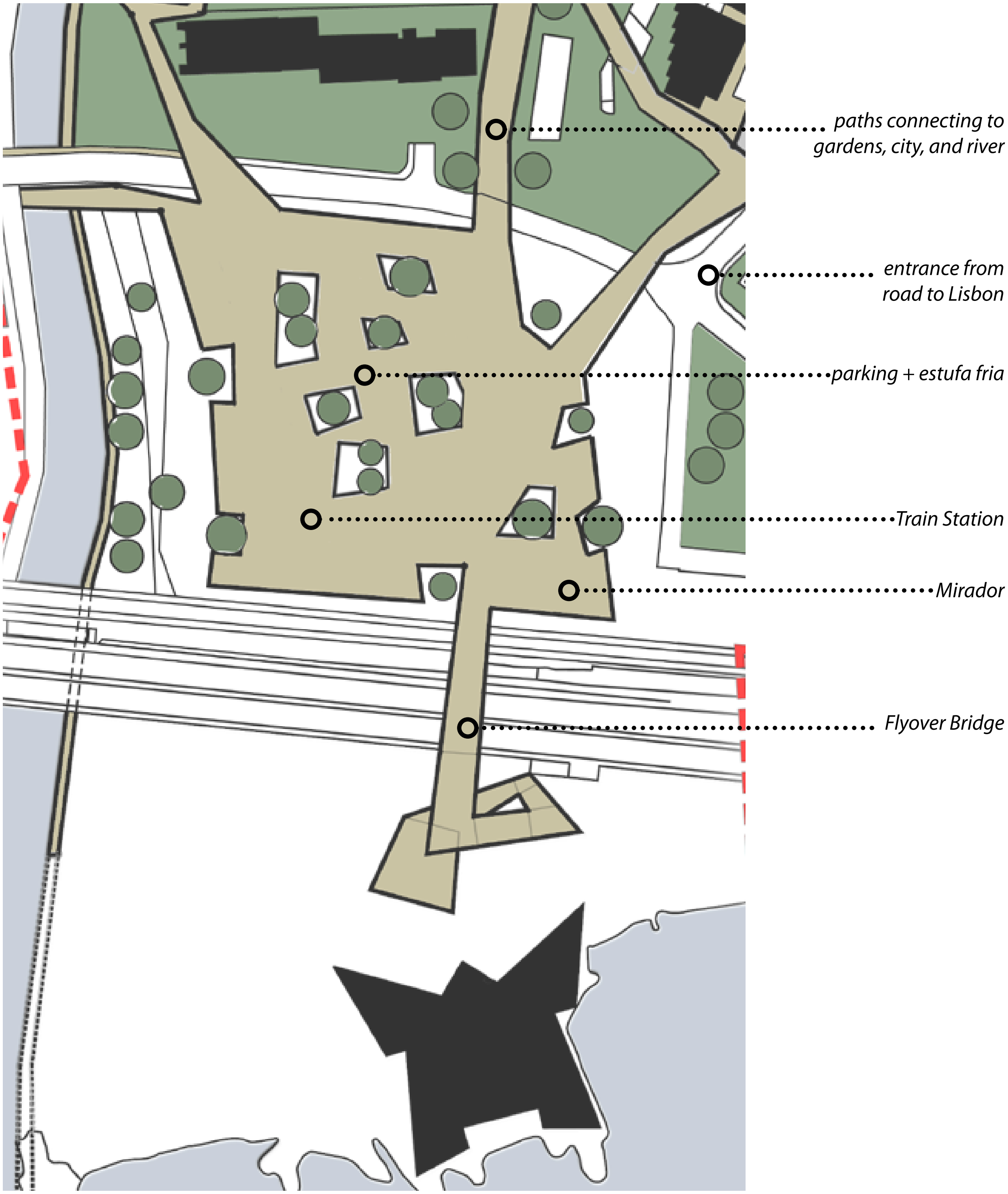
Another proposed axis, based on a historical pathway, would connect the convent to the fort. This connection makes use of the existing topography that was manipulated for the railroad station in order to create a raised platform that slopes up from the current site of the Municipal Garden, to cover a new parking lot, and cantilever over a new railroad station. On the eastern side of this platform a raised walkway crosses the railroad and highway creating a direct path from the fort and beach through the garden and ultimately to the convent. The western side of the platform will provide a scenic overlook providing visual access to the fort and waterfront. Cutouts in the platform allow for those existing trees that do not hinder the view to emerge from below and create an elevated green space.

Platform design strategy

Entrance to parking below platform

Fly-over walkway with view of Tagus and Fort

Parking under platform



Platform Design Strategy

Conclusion

These design strategies successfully address the priority framework we developed. Our plan would improve connections between the important features of our site, allow for increased access to the river and garden for the greater community, and improve the ecological conditions of the river. However, the overall design concept, rooted in analysis and dialogue, is still very much a work in progress. As such, our assumptions and their associated gaps in data merit mentioning:

1. The map showing REN designated land is less specific than is desirable. Since this is the only map or data available to us indicating flood prone areas, our buffer zones are generalized. Furthermore the REN designation remains unclear to us and seems to be based on factors beyond ecological conditions. For example, the area between the two bridges is not REN designated, while large swaths of land immediately upstream are REN designated.

2. We assumed that the current channel was built to accommodate Q100 flows, and based our calculations for the new channel on this assumption. While we have erred on the conservative side, these numbers may require adjusting.

3. Riparian vegetation could have a greater impact on roughness than we have anticipated, this in turn might require a larger channel than we have designed.

4. We have assumed that by building structural supports into the western bank of the river we can prevent the bank from being blown out but have not done calculations to verify this.

5. By widening the channel downstream we may need to further engineer the channel with buttresses upstream to prevent the river from jumping.

6. We do not have adequate data regarding the impact of tidal forces on the river to fully design/plan for their effect.

7. The park design calls for the removal of sections of certain walls from the royal garden to establish axial connections, which may not be permissible given the garden's historic status.

8. We have assumed that some of the greatest costs in our plan, such as expanding bridge spans over the river, can be packaged as part of unavoidable infrastructure repairs. Even so, the creation of the large raised platform may be prohibitively expensive.

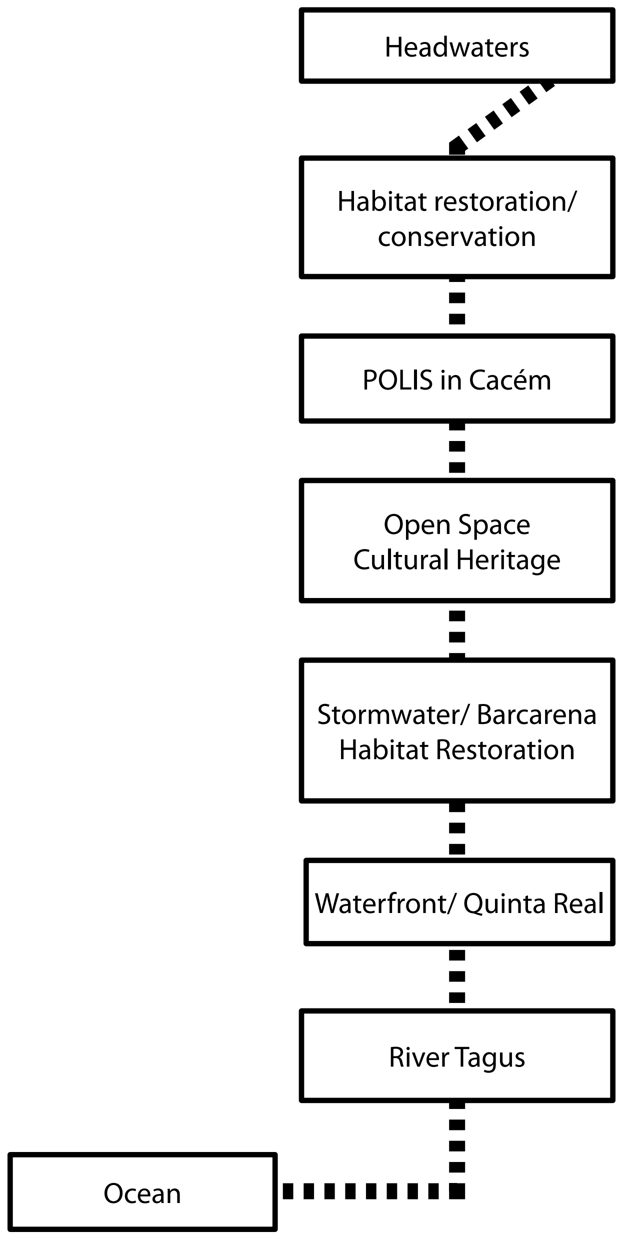
View along river looking towards platform

Connecting Cacém, Caxias, and the Coast: the Ossos Trail

Ricardo Cruz e Sousa, Andrea Gaffney, Stacie Jagger, Pedro Ribeiro

The objectives of the POLIS project were to create open space along the *Ribeira das Jardas* in Cacém and to reduce flooding by increasing channel capacity. However, the park is isolated and trails only extend short distances along the river. A more comprehensive trail could link people living in the headwaters to the beaches of the Tagus and establish a north-south connection for locals and visitors. Our vision is to create a trail network along the stream linking the cultural landscape and connecting people to the river through a multi-functional trail.

Trail connecting to the River Tagus: 10.4 km
Strolling: 2.5 hours
Walking: 1.5 hour
Running: 1 hour
Biking: 30 minutes



Methods

Our three-part analysis for a trail included map and aerial analysis, municipal planning document review, and site visit observation and notation. Using topographic maps, GIS information and aerials from Google Earth, we mapped various conditions in the catchment. We updated GIS land coverage data from 2000 with more current Google Earth aerials from 2006 to create a land use intensity map. The identified urbanized areas represent significant building density in a general location; it is not as precise as the GIS data, but it is representative.

We analyzed the urbanization information with respect to open space demands and increased run-off from impervious surfaces. For increased run-off, we compared the impervious surface area between the 2000 and 2006 aerials, as well, field verification of creeks indicated degradation due to increased peak flow runoff.

From our visit to the municipality of Oeiras, we acquired cultural heritage maps and information regarding the planned trail design and destinations in Caxias, from the Tagus estuary north to the A5 autoroute. During our site visit, we observed and documented the character of the river, slope conditions, and adjacent land uses.

Following the stream north from the A5 to Cacém, we studied the feasibility of connections between selected sites along the river. We identified potential sites and user groups through site visits, interviews with municipality officials and from other research groups conducting behavior mapping and ecological health assessments. With this research, we characterized the types of activities taking place along the stream and the relationship of the users to the water.

Our analysis resulted in identifying a series of nodes such as cultural sites and mapped a continuous route for trail connectivity from Cacém to Caxias.

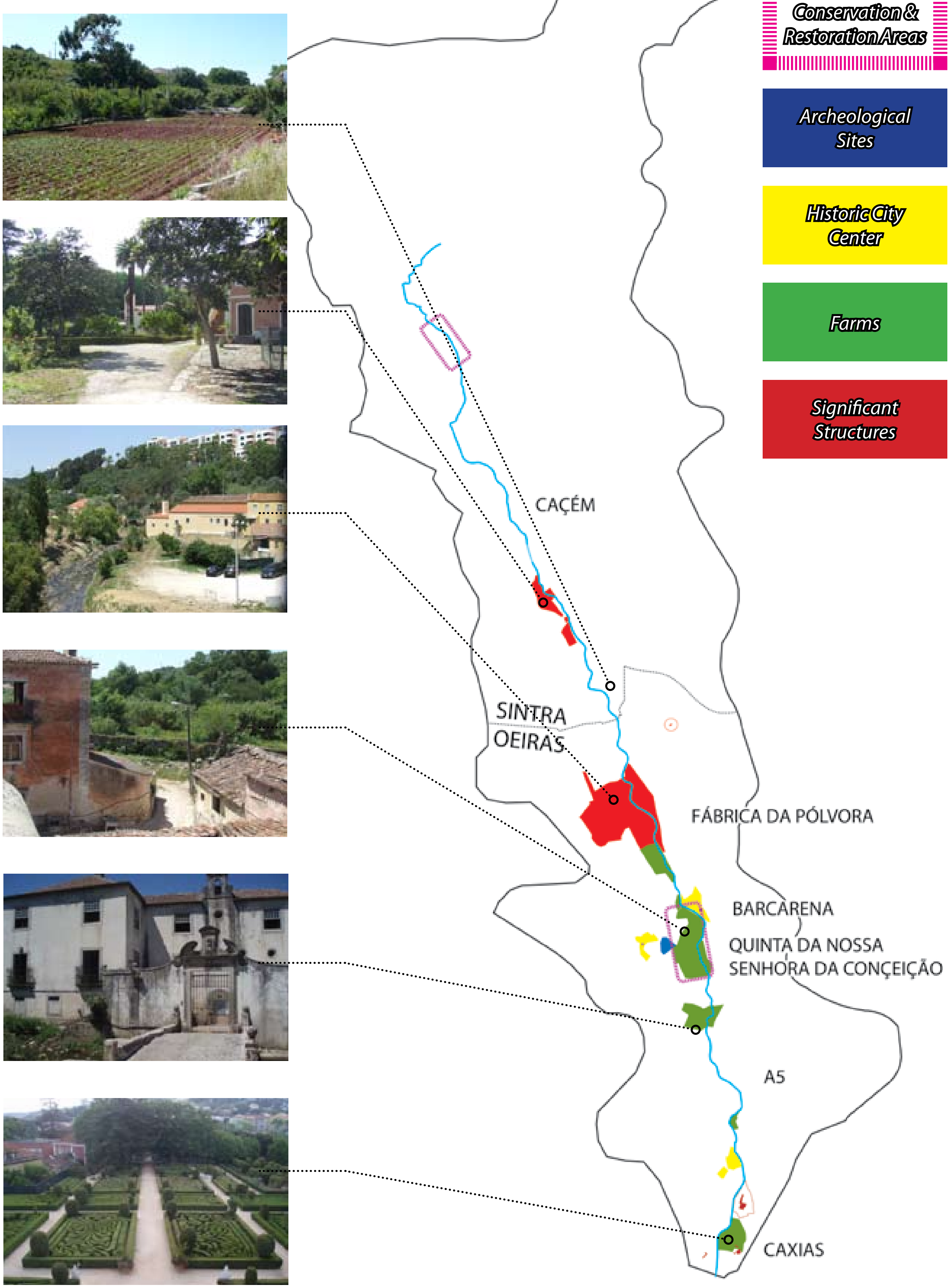
The analysis can be divided into three specific components: a map of the cultural landscape, a gap analysis for trail connectivity, and design typologies for the trail. The cultural landscape map identifies towns, cultural heritage locations, areas prone to flooding, and potential habitat restoration and conservation sites. The gap analysis identifies the built, planned, and informal trails along the drainage.

The design typologies illustrate the different relationships between the water, the trail and the adjacent land uses along the length of the drainage. By overlaying the cultural landscape map and the gap analysis, the areas of focus for the trail connections become apparent.

New urban development

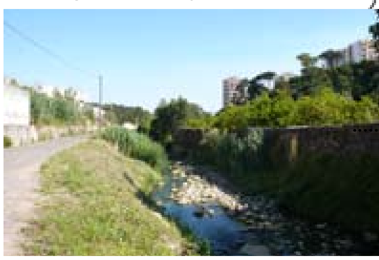
Lack of Programed Open Space

Cultural Landscape Mapping



Trail Condition Gap Analysis

Existing POLIS Project

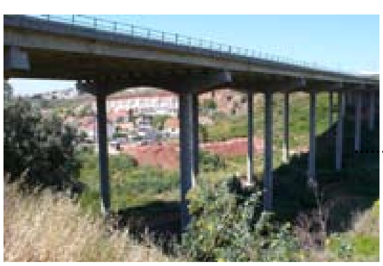


Existing Abandoned Road

Warehouse and Car Storage

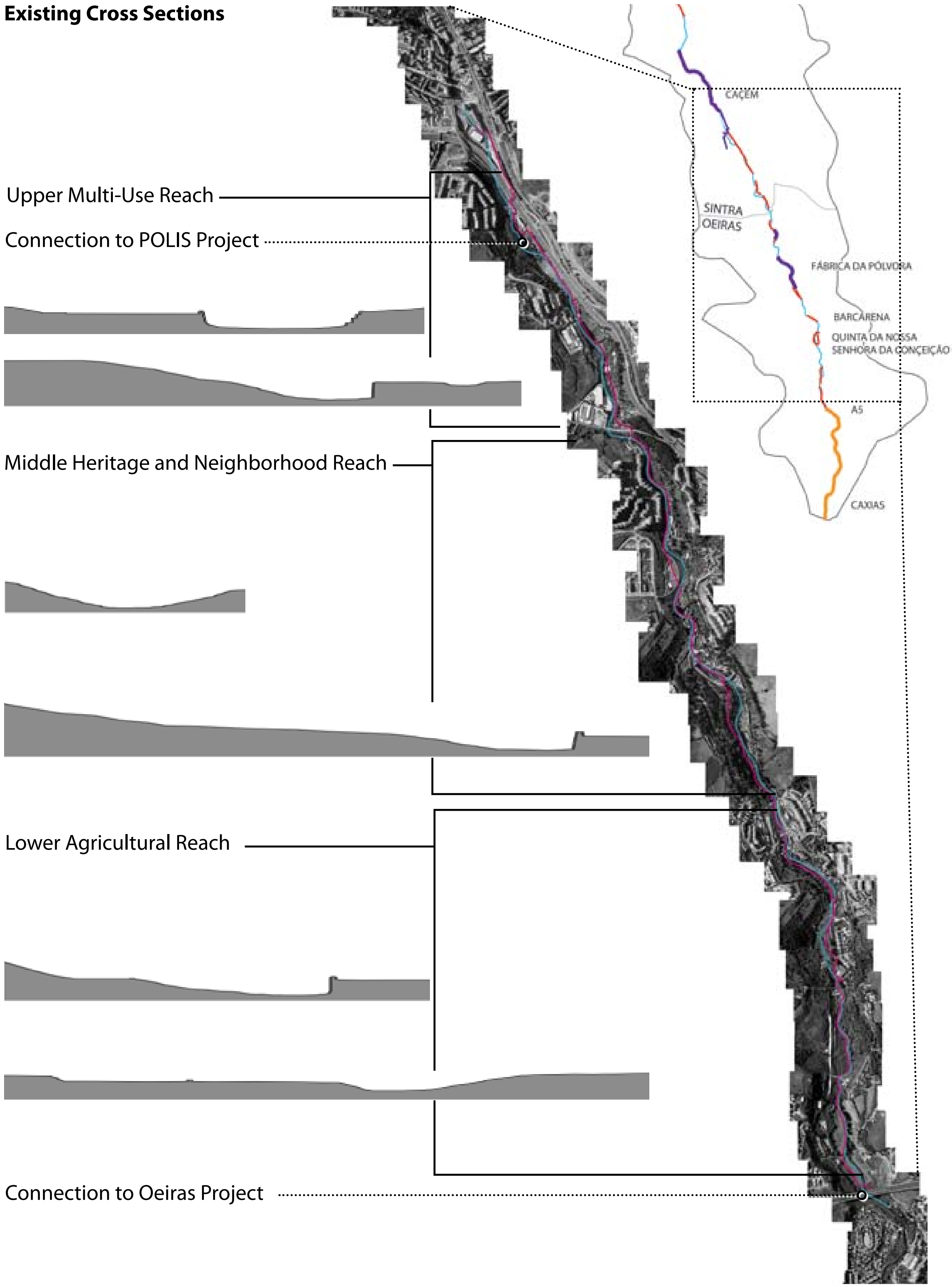
Existing Park

Agriculture

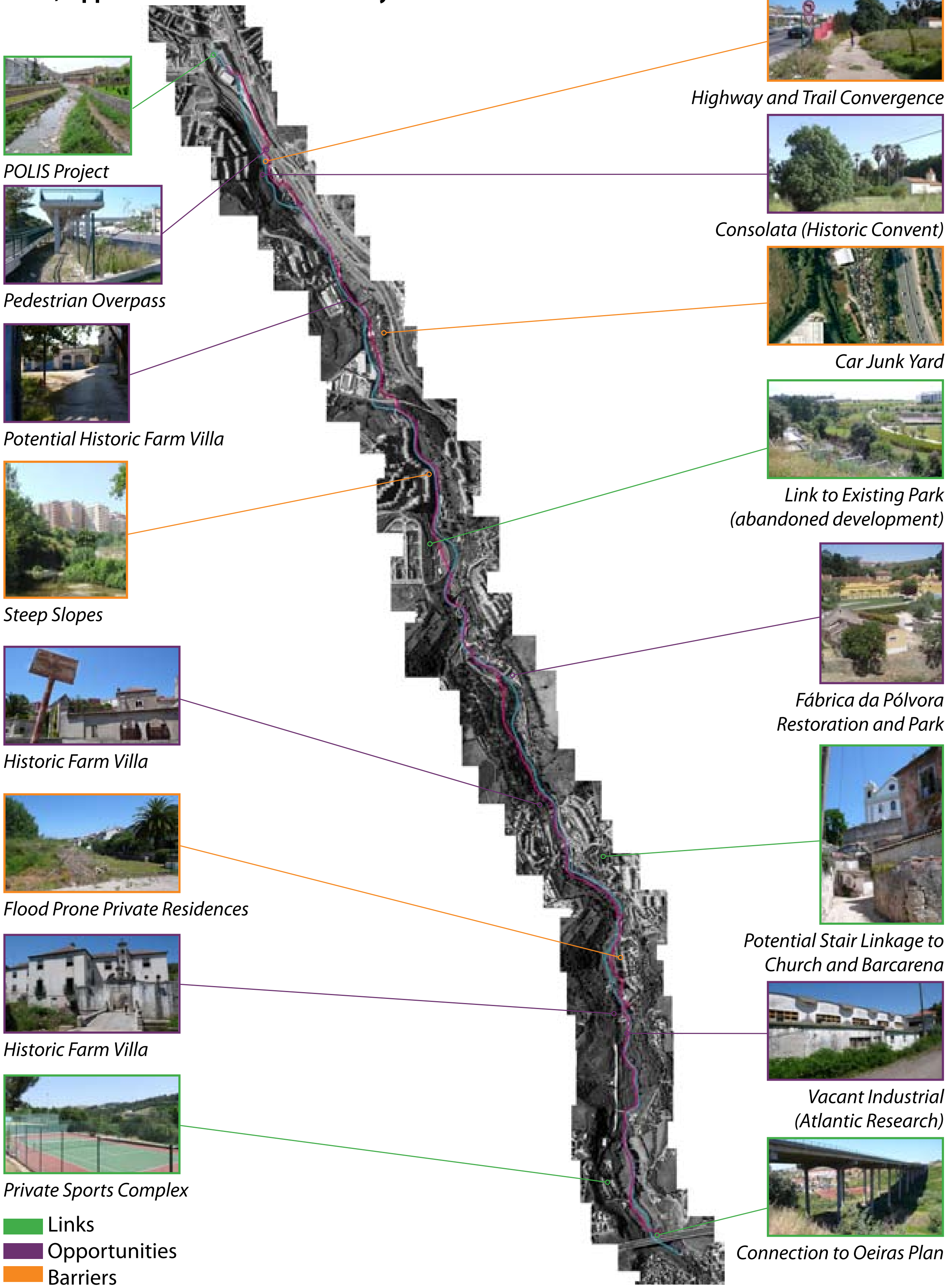


A-5 Highway

Existing Cross Sections



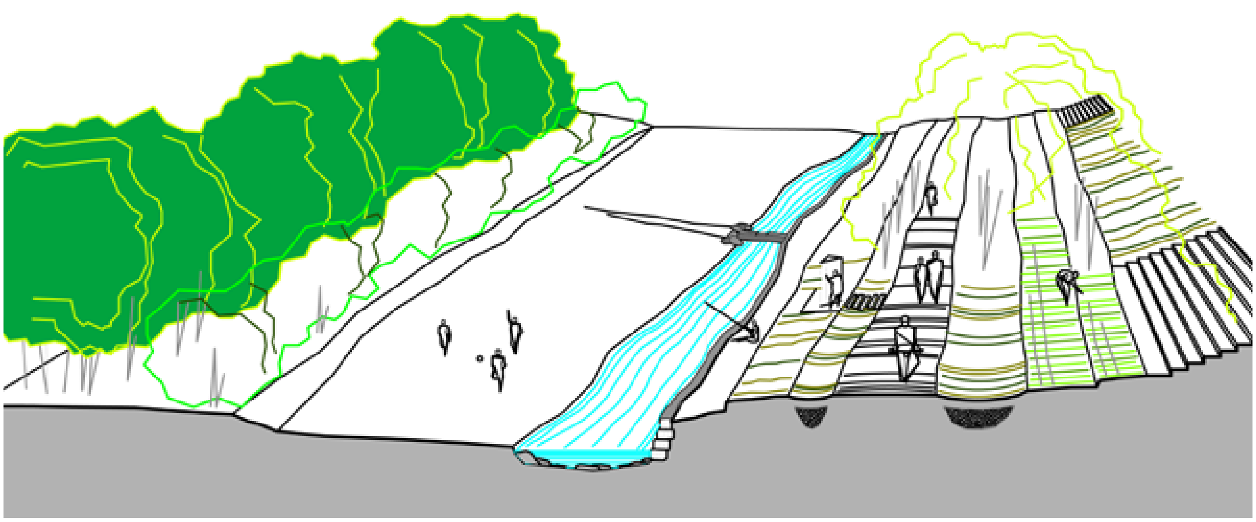
Links, Opportunities and Barriers Analysis



Results

From our analysis, we identified the connection between the planned projects in Caxias with the completed Polis project in Cacém as the section of the drainage with the greatest opportunity for a trail. This section of the creek is also known as *Ribeira dos Ossos*, so we will refer to the trail as the Ossos trail. This reach has large areas of public land adjacent to the stream and an existing informal trail network By filling in the gaps between Cacém and Caxias, a linear open space 10.4 kilometers long could be created along the *Ribeira da Barcarena* stream, connecting most of the population of the drainage with the Tagus River waterfront and the coastal trail that is currently being extended along its length.

Based on existing conditions, we identified three cross-section typologies for the Ossos trail in which to experience the river, classified by perceptual experience – physical, visual and audible. The proposed trail's relationship to the river would change because of the varying slope and edge conditions, ranging from vertical walls to steep slopes and flat floodplains. This variation also explains the different way users would experience the river. In walled or steep slope settings, the physical design translates to visible and audible experiences. In gradually sloped conditions, users will see and hear the river, and may access it physically at locations with specific trail design interventions. In the floodplains, users interact completely with the river through hearing, seeing, and physically accessing the water.



Idealized cross section of activities along stream trail

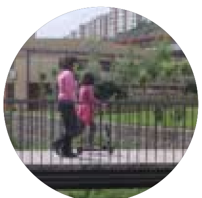
Proposal

The trail's design elements can be assembled together based on specific location conditions. The elements include existing and future cultural landscape elements, types of mobility—bicycle and pedestrian paths, and types of hydraulic conditions along the stream. The cultural landscape elements determine the character of the trail and allow for incorporation of additional programs along the trail. The types of mobility establish the trail width, material, and function.

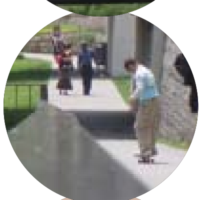
The hydraulic conditions incorporate stormwater management, river restoration, and channel alteration, as well as determine the location of the path in relation to the water and water quality. The combination of these design elements with the specific conditions create the trail cross sections with specific perceptual experiences.

Mobility

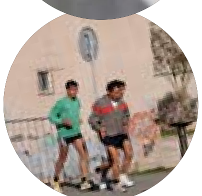
strolling



skateboard



running



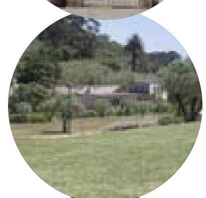
walking

group movement

Cultural Landscape

heritage

open space



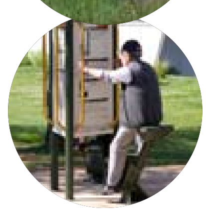
homes

sitting

kitchen gardens

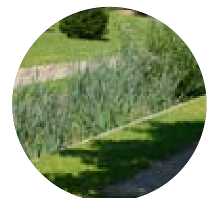
park

parcourse

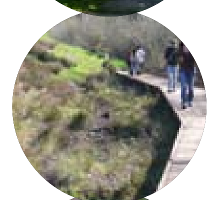


Stormwater Infrastructure

swale

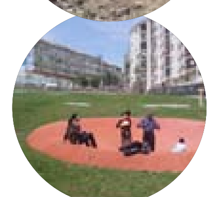


rain garden

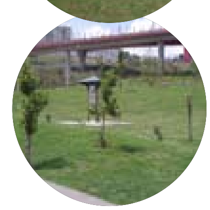


weirs

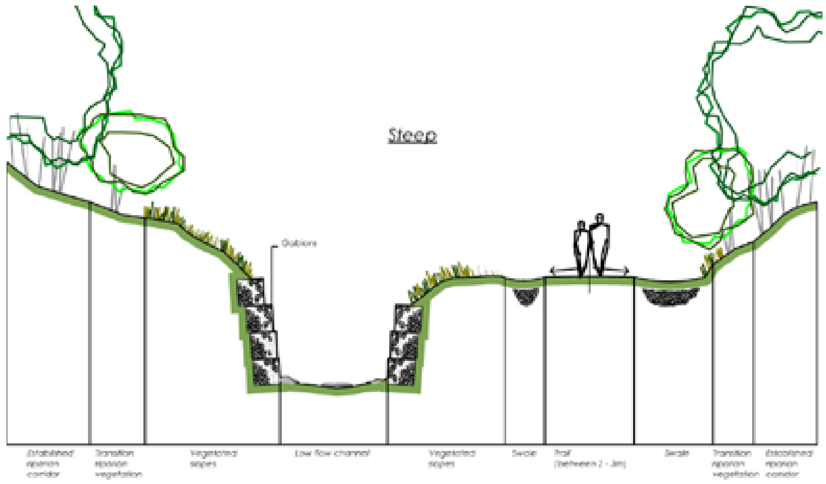
flood storage



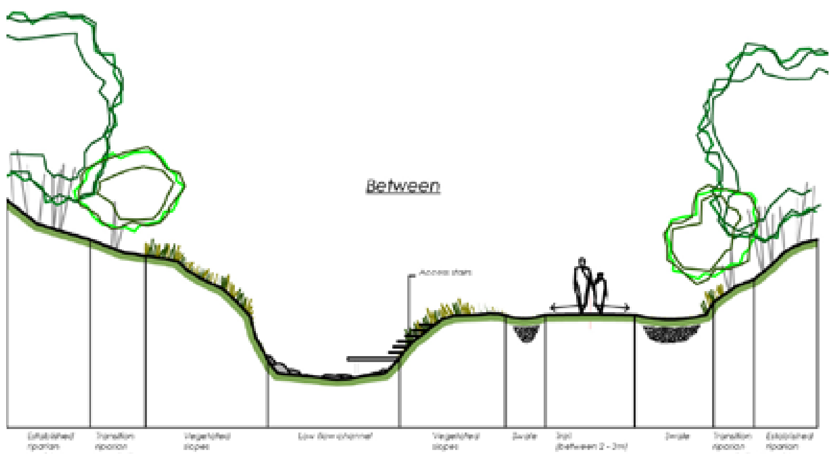
flood storage



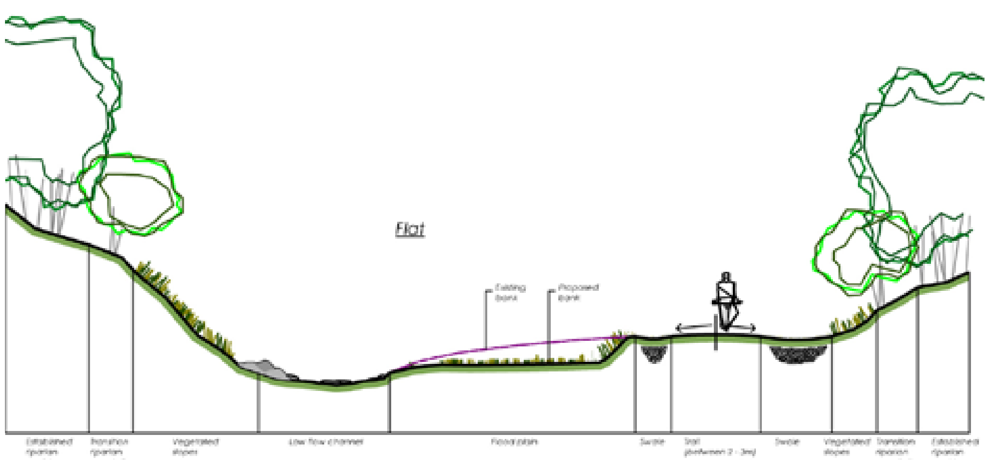
Proposed cross section typologies based on different relationships with the water



Cross Section 1 - steep: Visual, Audible

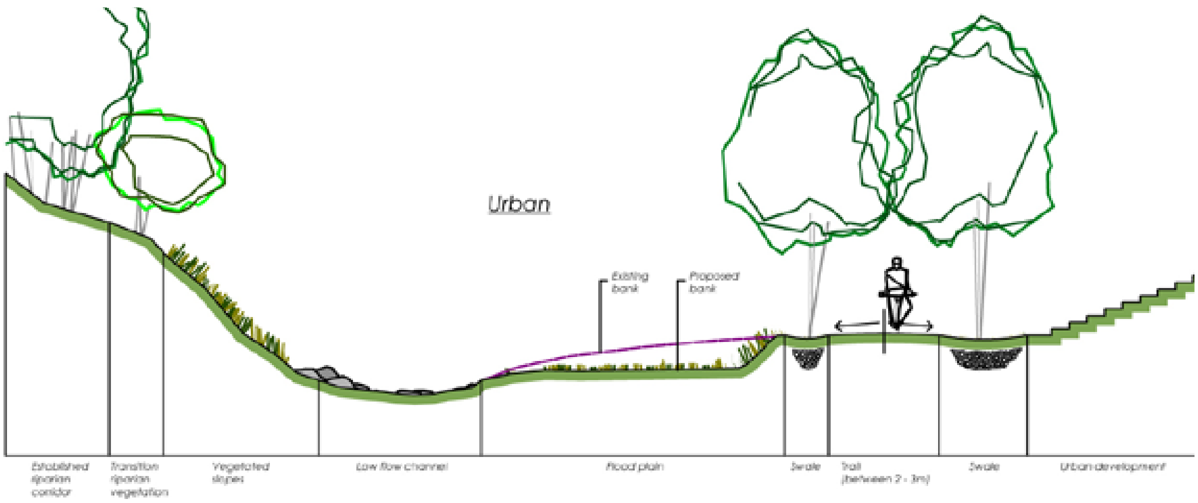


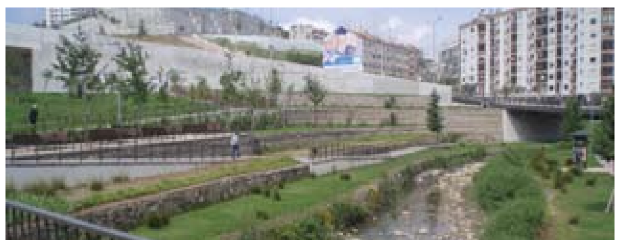
Cross Section 2 - mid: Visual, Audible, Physical



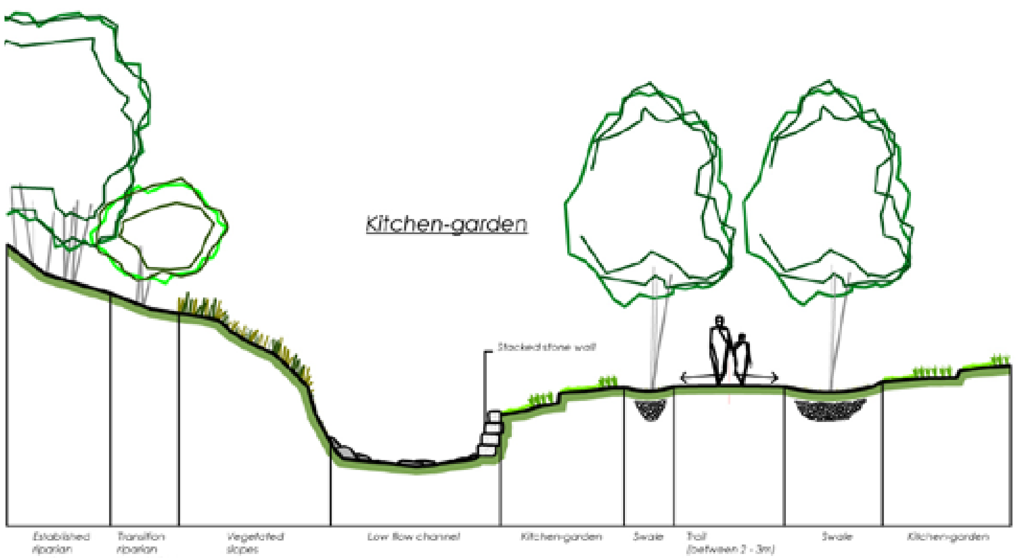
Cross Section 3 - flat: Visual, Physical

Proposed cross section typologies based on adjacent uses





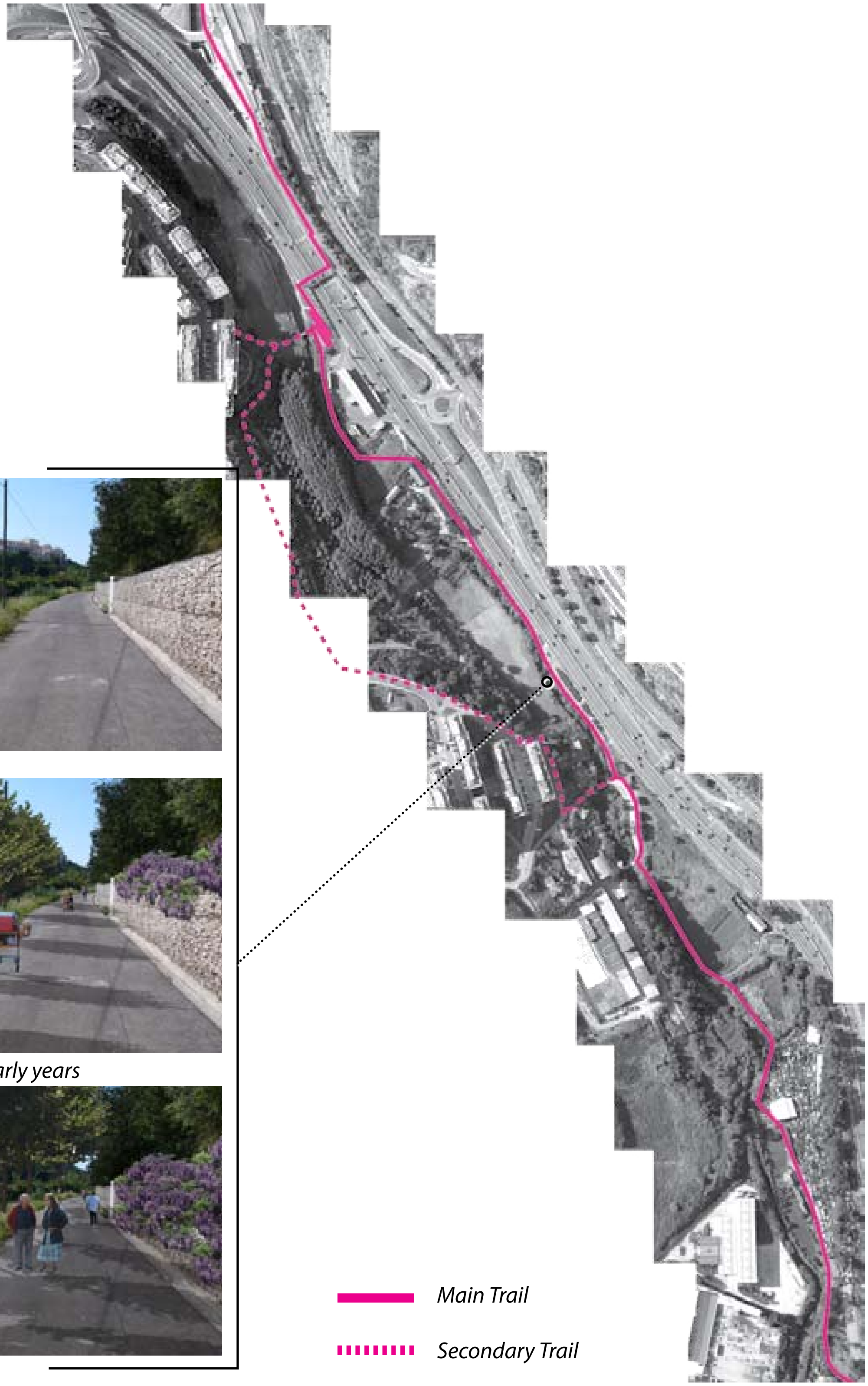
Urban Edge



Agricultural Edge

South of Caçém

DISTANCE: 1.9 km
Strolling: 37 min
Walking: 24 min
Running: 12 min
Biking: 8 min



Existing Condition

Envisioned Condition early years

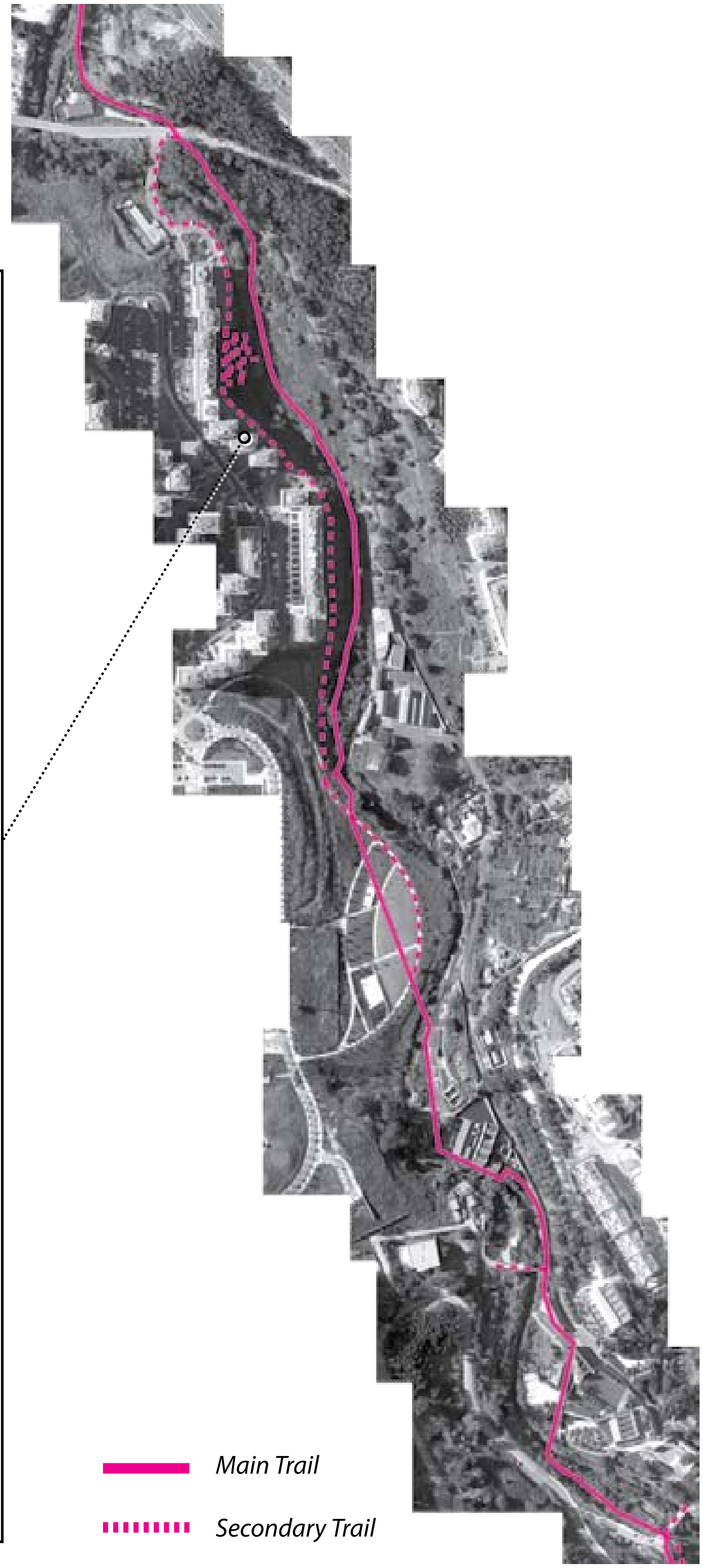
Envisioned Condition

North of the Fábrica da Pólvora

DISTANCE: 1.6 km
Strolling: 29 min
Walking: 20 min
Running: 10 min
Biking: 7 min

Existing Condition

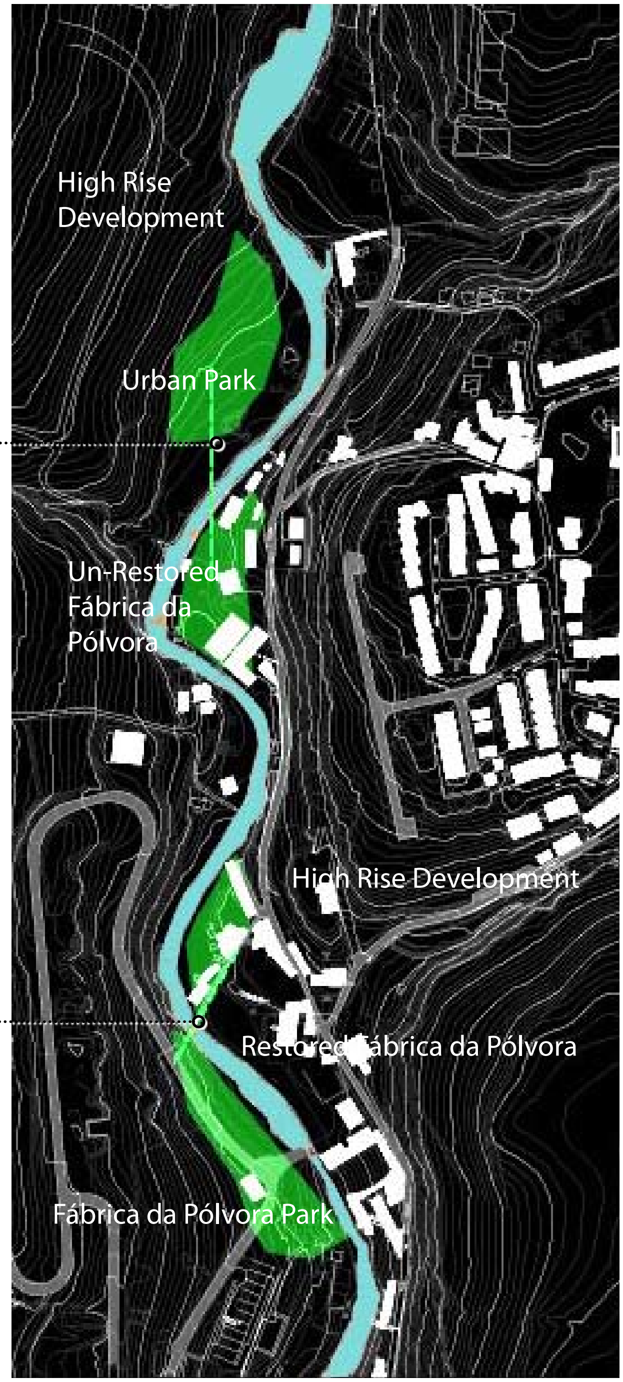
Envisioned Condition



West of Fábrica da Pólvora

Envisioned Urban ResidencesPark

Envisioned Fábrica da Pólvora Park



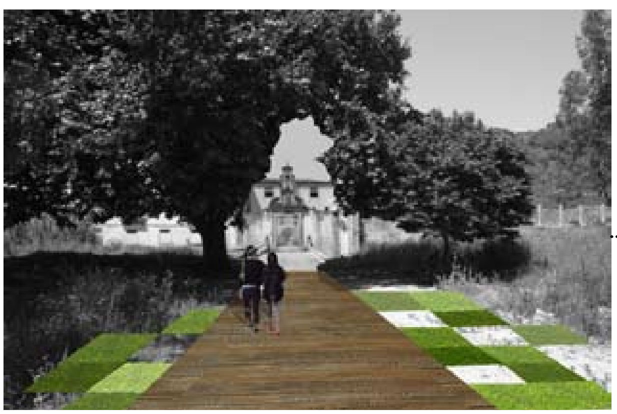
North of Barcarena

<u>DISTANCE: 1.9 km</u>
Strolling: 35 min
Walking: 23 min
Running: 12 min
Biking: 8 min

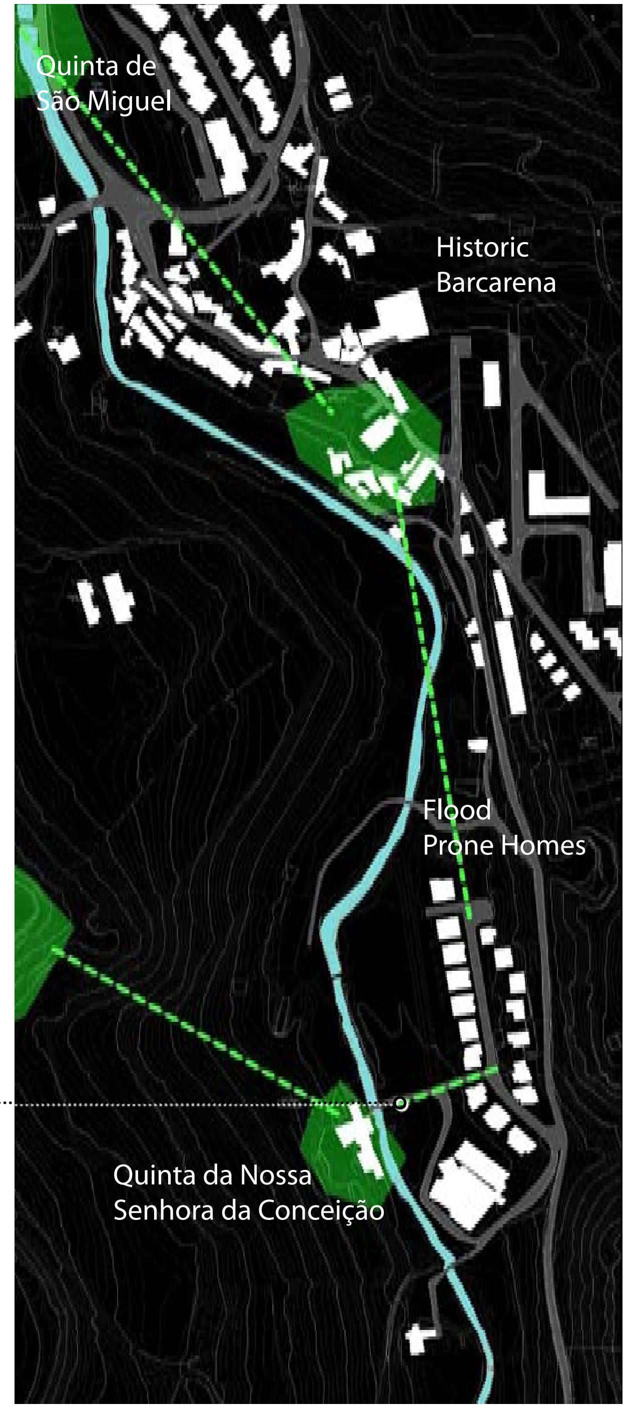
Existing & Envisioned Condition with some maintenance

Southwest of Barcarena

Existing Condition

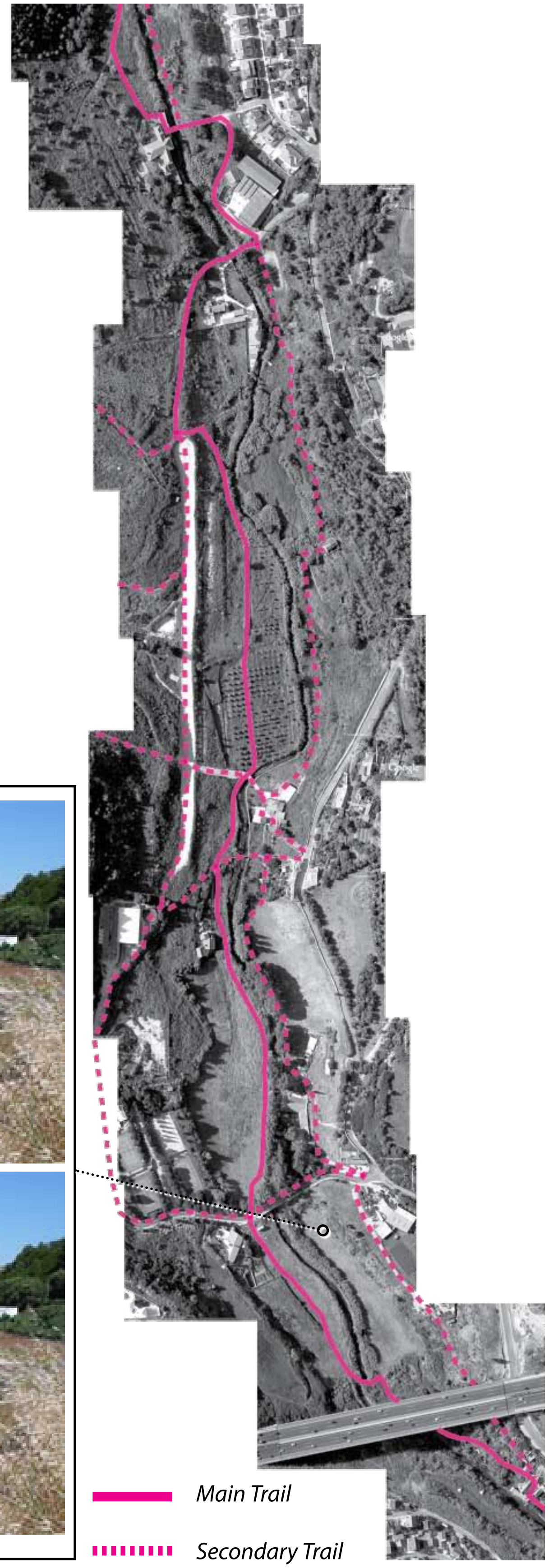


Envisioned Condition



North of A5

<u>DISTANCE: 1.4 km</u>
Strolling: 26 min
Walking: 17 min
Running: 9 min
Biking: 6 min



Existing Condition

Envisioned Condition

Conclusion

Although there is a 10 m public right-of-way from each side of the centerline of the stream, the best location for the trail is not always within this zone. The preferred alignments take advantage of existing opportunities. Points of interest include the *Quinta da Nossa Senhora da Conceição* south of Barcarena, and the northern end of the *Fábrica da Polvóra* including the housing and park. We analyzed these two areas in greater detail and proposed trail connections and alignment issues. The trail connects to the cultural landscape by taking advantage of the publicly owned heritage sites, and the use of an existing informal trail network. Linking these sites increases access to the water and creates a continuous connection from the heart of Cacém to the Tagus Riverfront. Like the fish in the stream, people using the trail prefer a specific microclimate of shade in the warm months and sun in the cool months. Therefore, the placement of trees can be mutually beneficial for aquatic and terrestrial populations.

Any catchment-based trail system through multiple municipalities will require complex coordination. Most of the information for the Ossos trail comes from the Oeiras municipality, but the methods and design can easily be replicated in Sintra to complete the trail along the full 14 km length.

Envisioned condition as vegetation fills in and provides a comfortable micro-climate and habitat.

A Revitalized Ribeira da Barcarena and Beyond

With improved sewage treatment and water quality in the *Ribeira da Barcarena* and neighboring streams, there is strong potential to preserve and restore ecological functions, consistent with goals of 'good ecological condition' required under the WFD. We established reference conditions for two endangered fish species by electrofishing in the headwaters. We suggest potential river restoration priority areas based on mapping of riparian vegetation connectivity, changes in riparian vegetation and land use from 1990 to 2000, and River Habitat Surveys at three locations along the river.

The tremendous success of the Cacém Polis project demonstrates the potential for the stream corridor to provide parkland for the dense urban settlements. Implementation of stormwater management strategies within the catchment can mitigate many of the negative effects of urbanization and increased impermeable surface, and our analysis of one tributary catchment shows that most of the stormwater could be controlled with relatively unobtrusive retrofits of small open bits of urban land and floodplain. There is a wealth of historical and cultural resources along the *Ribeira da Barcarena*, which can function as nodes of attraction along the linear stream course. Some features, like the *Jardim da Cascata*, have tremendous inherent potential for revitalization in themselves. Linked with other such features by a popular trail, they could play a more prominent role in the cultural and recreational lives of residents of the region.

By virtue of its linear nature, the stream corridor can provide pedestrian and bicycle connections from population centers (now underserved by parklands) to cultural features and to coastal beaches and trails. Our results show that a trail from Cacém to the Tagus estuary is feasible with relatively minor infrastructural changes. Unlike the neighboring *Ribeira Jamor*, along which a continuous trail would require an expensive tunnel through the earthen fill supporting a major highway crossing, the technical challenges to a continuous trail along the Barcarena from Cacém to the Estoril coast are relatively minor. Another advantage of the *Ribeira da Barcarena* is that much of the floodplain adjacent to the channel is still undeveloped and can be easily adapted to parkland and trail use.

The potential benefits are enormous. A continuous trail would not only connect people and points of the cultural landscape, it could establish a precedent for other natural corridors in the region. The example of a continuous trail along the *Ribeira da Barcarena* could inspire similar efforts on neighboring, parallel basins that have undergone similar urbanization pressures and face similar challenges in providing under-served urban populations with access to recreation and contact with nature.

Cacém Polis park

Acknowledgements

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