

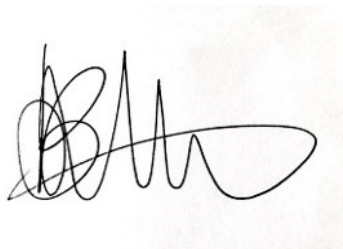
Yumana

Strategic Plan for Regeneration of Biodiversity and Soil

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2 February 2026

YUMANA

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SUMMARY

6 The Yumana site in northern Tijuana is a high plain that rises significantly above its surroundings and has steep slopes on the southern and western sides. For many years, the area remained essentially unchanged. The objective for this location is to redevelop it as a healthy and sustainable urban neighbourhood. In any change from barren land to a developed urban environment, the natural conditions come under pressure. The Strategic Plan for Regeneration of Biodiversity and Soil presents how the area could improve its natural qualities, making it resilient and a regenerative urban place over the long term, in which nature will be more abundant than it is now. In the plan, the two significant parts of this landscape, comprised by the relatively flat meseta and the steep slopes surrounding the tableland, are intrinsically connected, though treated very differently. The hydrological system is the network that connects the two; moreover, the risks of water availability, flooding, and slope landslides depend on the management of water on the meseta. The meseta is, as mentioned, relatively flat, although it is characterized by significant roughness that forms smaller hills, vertices, slopes, ridges, and trenches. The elevation model of the site is simulated using the Topographical Wetness Index (TWI), which indicates likely locations where wet conditions are expected. These

wetlands, primarily small creeks and streams, are considered the basis of the Strategic Plan because water concentrates there, enabling management of the water system. The purpose of the plan is to minimise water discharge from the meseta, thereby mitigating risks on the slopes. For this, it is necessary to select the best possible locations on the meseta to control water. The analysis starts at the very beginning of each stream, where so-called air wells are projected, which concentrate humid air and drop moisture, feeding water to each stream. The distribution of air wells connects them over the ridges of the site, forming a green network. Wherever streams join a water-retention infrastructure (e.g., rock ponds) is projected to control runoff on the meseta. This principle of slowing surface water is supported by expanding streams and junctions to create a robust riparian zone, in which water accommodates and biodiversity proliferates. The whole system aims to reduce water discharge toward the slopes. The slopes need to be adjusted to manage the remaining water, especially during periods of high and extreme precipitation. The strategy here is to redesign the slopes using the Keyline method. This technique is a passive method for diverting surface water to the sides rather than allowing it to flow directly downslope. Additionally, key-

lines can be designed to direct water away from vulnerable and unstable slope sections. Keyline design is integrated with the existing tracks, as proposed in the Master Plan, thereby extending the network of pathways and preventing erosion. Keylines and pathways guide reforestation through dense planting to further stabilize the soil and improve biodiversity on the slopes. The integration of strategies on the mese-

ta and the slopes provides a spatial plan for managing water and reducing the number of vulnerable areas, while enhancing biodiversity by introducing a green network and reforestation for the forthcoming urban development. In the next phase of design and planning, a detailed proposal should be elaborated on these regenerative qualities in Yumana.



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January 2026

CHAPTER 1

INTRODUCTION

8 In 2025, Earth faces numerous challenges. Apart from geopolitical tensions, climate impacts, biodiversity loss, and the vulnerability of urban populations are the most notable elements in nature that influence our life on Earth (UN Habitat, 2024). Cities are not only the cause of deteriorating conditions but also the places where quality of life is reproduced. To achieve this, a fundamentally different way of living in cities is needed. In the past, urban planners designed the city's neighborhoods first and integrated hydrological and ecological systems afterwards. This 'clean sheet' approach to clear field has led to numerous problems in the landscape. Often, geological and soil conditions have been forgotten, leading to soil erosion and, most severely to land-mass wasting. Landslides and other underground alterations impact the built infrastructure and public spaces in cities. The urban water system has been treated as a technical feature that can be manipulated to accommodate urban desires, often leading to unexpected flood-

ing in residential areas. This accommodation results in the design of green spaces with limited and disconnected spatial organization, which induces degradation of the urban ecosystem. It is expected that the top four risks in the next 10 years will only increase the pressure to respond to natural phenomena in cities. Extreme weather events change Earth systems, biodiversity loss, ecological collapse, and natural resource shortage are seen as the top four risks (WEF, 2024). These risks exacerbate the vulnerability of inhabitants in urban neighborhoods and of urban service systems. With accelerating climate impacts (IPCC, 2023), the adverse effects of unprecedented climate disruptions on cities could become disastrous. Recent events had happened in Makkah (extreme heat during the Hadj, with over 1300 deaths), Athens (wildfires, eventually closing the acropolis), Valencia (major flooding, destroying housing and infrastructure), Rio Grande do Sul, Brazil (Extensive flooding), the Los Angeles greater area (wildfires destroying large parts of

cities and the landscape) and many more globally. For each urban (re)development, this situation is crucial in providing a long-term provision on housing and living in a safe, pleasant, and healthy environment. Neglecting these natural phenomena may increase the site's vulnerability and that of its inhabitants. The Yumana site in northern Tijuana, Baja Cal-

ifornia, is such an urban development that can innovate with applied design for regeneration. The nature of the site, with dry conditions and rocky surfaces, exposure to heat and sun, and vulnerability to sudden rainfall, makes it a necessity to think about a regenerative plan for biodiversity and soil.



CHAPTER 2

AMBITION

10 The redevelopment of the Yumana area in Tijuana is an ambitious and exciting development. Located near the US-Mexico border in an arid landscape atop a distinct hill, the development presents several challenges. The Master Plan for the site (Sasaki, 2024) aims to develop an urban area with careful consideration of the natural environment, connecting ecological networks throughout the developmental area and the rest of the city to enhance overall biodiversity. The regeneration of nature in this context requires a good sense of how water can be stored and how soil can be restored, especially but not limited to, on sometimes very steep slopes. It therefore requires an in-depth strategic vision and plan that gradually considers potential future developments, is prepared for changes, and supports natural growth, which takes time to come to fruition. Applying these considerations to the development of green spaces and natural

corridors is essential for improving the quality of life for future residents and enabling them to maintain continuous contact with nature. Natural conditions are determined by the landscape, its geology and soil, water and ecological systems, and relief. Therefore, in the strategic vision and plan, an important element is the way soil and water systems coexist and interact across the site. Whilst urban intensity will increase, ecological quality, water management, and soil stability will become increasingly important. The site is part of the Rio Tijuana watershed (Figure 1), and as such, is an important contributor to drought, flooding, and water availability across the entire river system. In many urban developments, the ratio of paved and impermeable surfaces increases, leading to a growing risk of urban flooding and difficulties in discharging surplus water and eroding fertile soil.

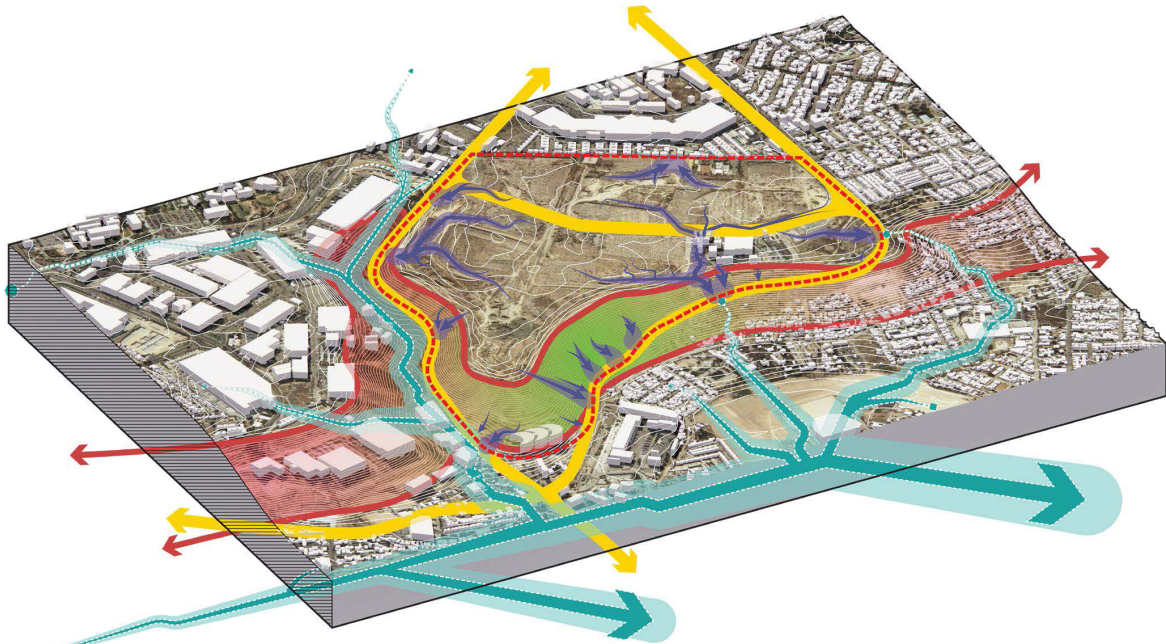
Figure 1. The Rio Tijuana watershed and location for Yumana (Source: Sasaki, 2024).



In the Yumana area, soil instability poses a potential risk. More water could destabilize the soil and slopes, potentially leading to landslides. This illustrates the importance of the substantial role in the extent, connectivity, and distribution of green and water spaces on the site. In the biodiversity and soil regeneration plan, the ambition

is to apply hydrological and ecological principles and to provide space to nature and water. The main objective is to slow the discharge and infiltrate the water when on the meseta, at its highest level. The current streams and flow directions (Figure 2) should be transformed to accommodate water retention and infiltration.

Figure 2. Directions of the current water discharge from Yumana in relation to the direct urban environment and mobility (Source: Sasaki, 2024).



CHAPTER 3

THE SASAKI

MASTER PLAN

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The Master Plan for Yumana (Figure 3) formulates four ambitions:

- Establish a distinctive, transboundary identity for the district: Named after the Yumana tribe, an indigenous people who inhabited the region before the creation of today's established national borders. Yumana will create a one-of-a-kind transborder ecosystem. Yumana thrives from the unique cultural, social, and economic relations between Mexico and the United States. It is inspired by a sense of connection, collaboration, and deep commitment to the natural systems of Baja California.
- Promote a people-oriented wellness community: Yumana will foster a strong

sense of wellness and healthy living, with an approach to urbanism that is centred on quality of life. Yumana will shape new models for urban life that transcend the national borders of Mexico and the United States.

- Add value to the environment with a living landscape approach: Unlike typical developments in Tijuana, Yumana leverages the unique scale, location, and landform design with open spaces that function as working landscapes and provides ecological services. Yumana's robust ecological framework benefits both people and the environment. Ecological restoration of the hillside landscape, stormwater management, and regeneration of Baja California's endemic

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Figure 3. Images of the Master plan designed by Sasaki (Source: Sasaki, 2024)



habitat are key components of the Yumana vision. d. Create a dynamic binational hub for innovation and economic development: The Tijuana-Rosarito-Tecate metropolitan area is growing by 80,000 new residents every year and is projected to become Mexico's second largest city by 2030. Growing relations with the US and investment in next-gen manufacturing, are attracting a larger pool of talent and expanding Tijuana's service sector. Given its proximity to the border and its emphasis on quality of life, Yumana offers an ideal location for economic investment in both workplace and residential development. Yumana is set to be a primary contributor to the economic transformation of the Tijuana- San Diego conurbation. The district's proximity to top-tier universities in both San Diego and Tijuana allows it to tap into the remarkable potential of multiple sectors, such as healthcare, technology, research & development, among others.

[source: Sasaki, 2024]

These are great, but the general objectives can be critiqued for insufficient specificity for the Yumana site. In the Master Plan approach, the language is verbose regarding the living landscape. The structure of the information increases the need to improve the discussion of green and wet spaces. In essence, the current proposi-

tion increases local impermeability without adequate measures to capture and infiltrate water on site, nor to develop soil fertility. The mastery of ideas lacks commenting on mitigation techniques to retain soil and reduce erosion on the site, primarily through slope analysis. The infrastructure placed on the hazardous slopes requires further detail in the vaunted plan. Additionally, the pathways across the inclined sides of the meseta can be tailored to be more natural and pleasant for habitation. Circulation is impeded by closing most blocks, preventing the connection of green spaces and the movement of wildlife. Finally, the road system is over dimensioned both in the number of unnecessary roads and their widths. The proposed Master Plan is a well-thought-through proposition that continues the contemporary tradition of urban design and development. There is significant attention to the housing program, the importance of the car, and economic viability. Still, it lacks convincing proposals that make the area safe for dry spells and droughts, and the consequences of (heavy) rainfall. This affects both the meseta itself, where many more places for retention and ecological connections should be included, as well as the surrounding slopes, where soil stabilization should be a priority and construction on unstable ground should be avoided.

CHAPTER 4

CURRENT

QUALITIES

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The Yumana site appears as a flat, barren, elevated landscape, surrounded by logistics, mixed-use, and industrial urbanisation spanning multiple periods. However, upon closer examination, a wide variety of sub-landscapes emerge. Features of the landscape such as the contours, the aspects, and the steepness of slopes determine the local conditions leading to the natural qualities in the terrain (Figure 4). There are a range of gorges, depressions, and trenches of different scales on site. These places are characterised by steep edges and slopes and therefore exhibit pronounced gradients in ecological diversity. Most of these geomorphological features are man-made and therefore not of significant value from a landscape-his-

torical perspective. The value of these elements lies in their reuse in a new context, such as the trench that surrounds the entire site, which could be transformed into a long walkway. Another opportunity for the reuse of a man-made terraform is in the northern part of the site, where a square piece of land has been excavated. This allows the creation of a nursery that benefits from slightly more humid conditions and can easily cover this space for shade. Wet areas and retention spaces are found throughout the site. These places are natural retention areas. Often, they are accompanied by plants adapted to humid conditions and by other species that form a valuable small-scale ecosystem. These places are vulnerable, and

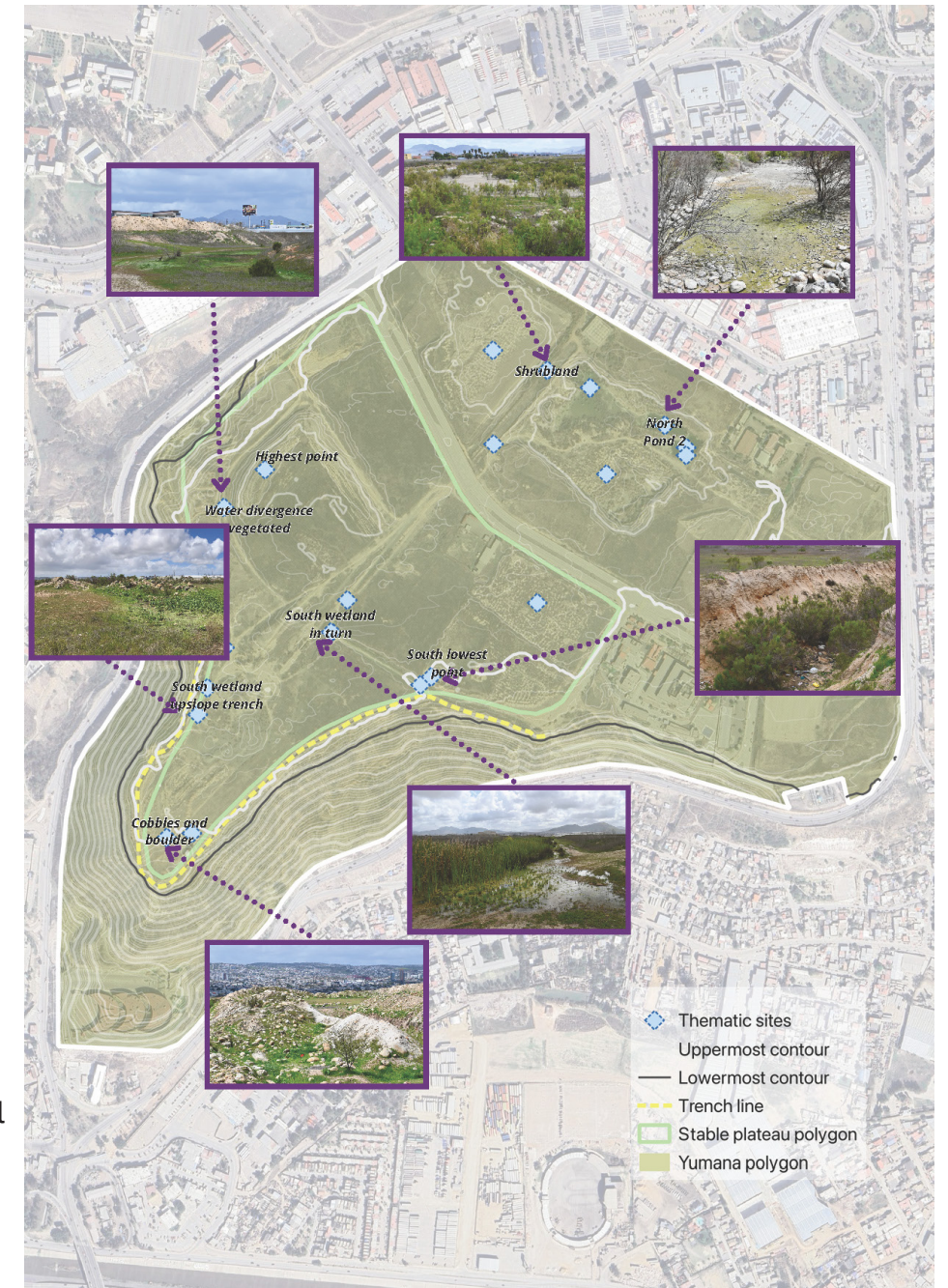
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Figure 4-1. Identified landscape elements with natural values, located in specific thematic sites [source: by the authors, photos by Rob Roggema].



strengthening their resilience would be achieved by connecting them to other similar areas on the site. Whenever new infrastructure is implemented, these valuable spaces should be preserved to ensure high ecological quality from the beginning of the plan (and there is less urgency to create ecological hubs from scratch). The rocks and landscape elements on site are abundant. In particular, the rocks are concentrated irregularly and scattered randomly across the site. Some groups of stones have naturally started to work as an air well. An air well is a structure or device that collects water by promoting the condensation of moisture from air (Anonymous, 1933). Designs for air wells are numerous and varied, dating back to ancient civilizations, but the simplest consist of rocks piled up with spacing between them. This arrangement operates passively, requiring no external energy source or movable parts. More elaborate aesthetic designs of buildings may achieve similar functions by capturing environmental moisture while promoting spaces for relaxation or inspiration. Yumana could use the abundance of rocks to create these air wells throughout the site, particularly by distributing them on the highest (and driest) parts of the landscape, where they create humid and wet conditions, such as by water harvesting on site. In addition to the three categories of on-site landscape elements, Yumana comprises sensitive slopes, some of which pose an imminent geological risk.

Figure 4-2. Identified landscape elements with natural values, located in specific thematic sites [source: by the authors, photos by Rob Roggema].



CHAPTER 5

STRATEGIC PLAN: LANDSCAPE FIRST

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Based on the landscape analysis and the explicit ambition to create a regenerative urban area, the strategic plan for Yumana is conceived using a step-by-step approach of layered maps and interventions within the hydrological system. The overall methodology aims to design a biodiversity and soil spatial strategy that can be compared with the current Master Plan, leading to a regenerative Master Plan (Figure 5). To conceive the regenerative biodiversity and soil strategic plan, the analytical and design process begins with the landscape as the primary approach. This means that, before ur-

ban plans and uses are designated, the natural conditions of the site are the primary elements driving the creation of the plan for the landscape. These elements are elevation, contours, soil, hydrology, and ecology, which play a decisive role (Roggema, 2021; Roggema and Monti, 2021; Roggema et al., 2021a; 2021b; 2021c; Nijhuis 2022; Nijhuis et al., 2022). Once this step of the method is completed, urban uses can be allocated. Applying this procedure to Yumana enables comparison of the biodiversity strategic plan with the existing Master Plan, resulting in a revised Regenerative Master Plan (Figure 5).

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Figure 5. Method of landscape first applied to the meseta of the Yumana site [source: by the authors].



In Yumana, the meseta is relatively flat, with some gorges and trenches, while the slopes flanking the landform are steep to very steep (Figure 6-1). Public data from INEGI were used to construct a digital elevation model. Elevation primarily determines humidity across the site. To this end, the Topographic Wetness Index (TWI) can simulate expected wet conditions in the landscape. With this mapping tool, the terrain can be interpreted to identify waterways and potential streams that will emerge when the ground becomes humid or when surface water flows (Figure 6-2).

Figure 6-1. Elevation contours [source: by the authors].

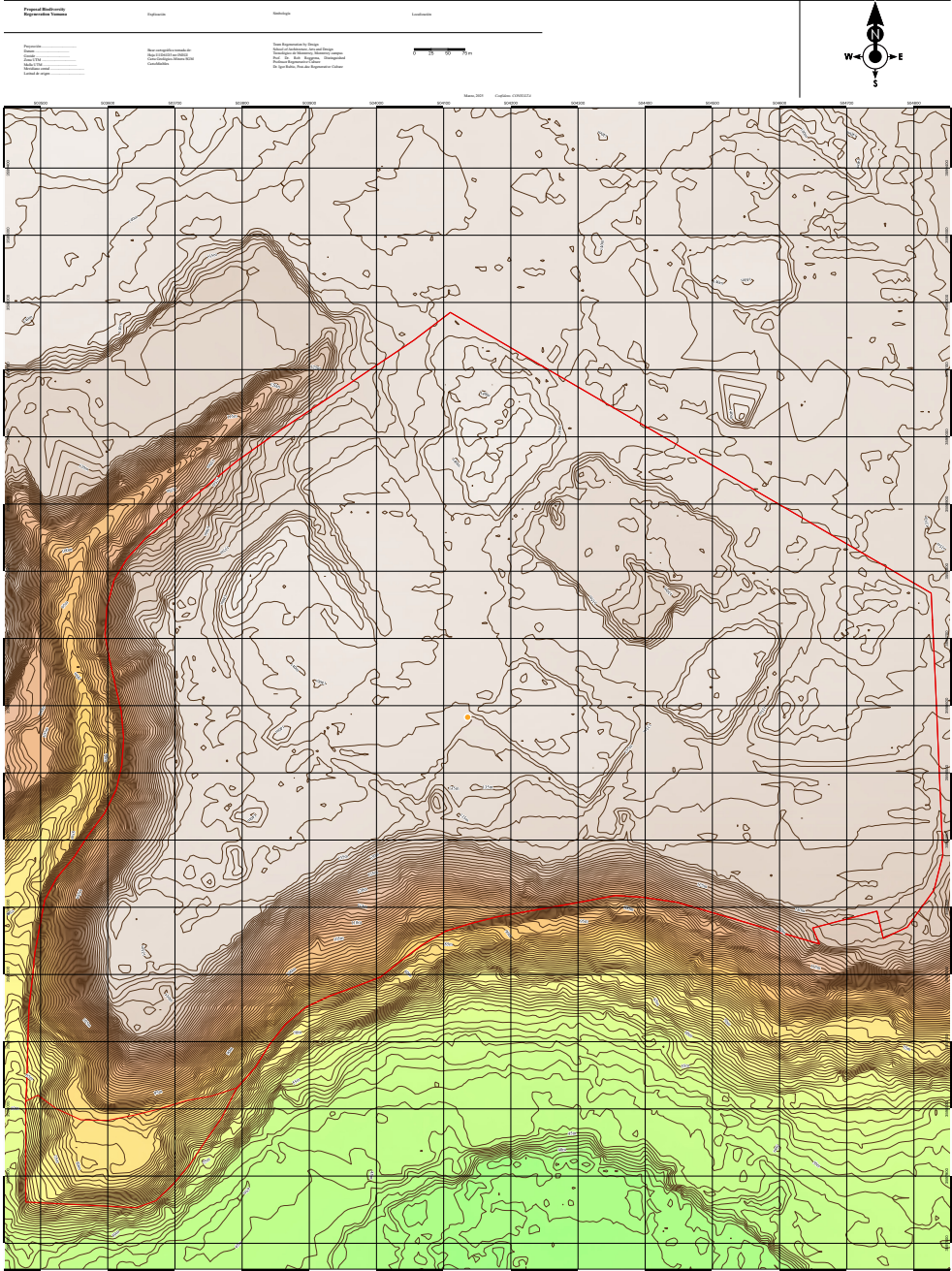
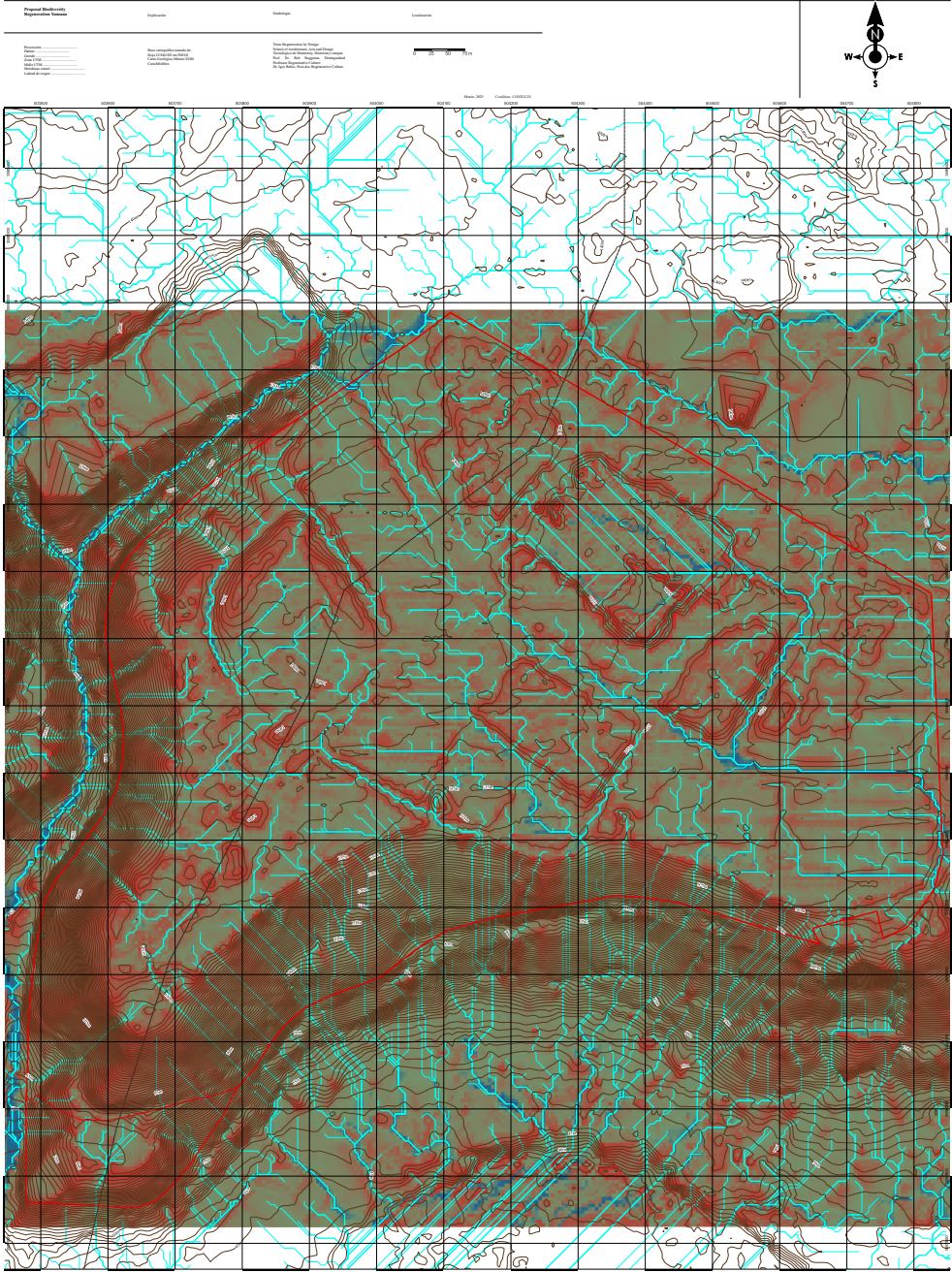


Figure 6-2. The topo-
graphic wetness index
[source: by the authors].



The TWI serves as the basis for developing the Biodiversity Regeneration Strategic Plan. To regenerate biodiversity, it is essential to identify wet conditions and work with them to sustain life throughout the urban design. This will provide a point of departure from which high ecological quality can emerge in a greener urban plan. The connective nature of the TWI can be interpreted to illustrate the interdependencies throughout the site. Figure 7 shows the potential streams used as the underlying basis for the plan.

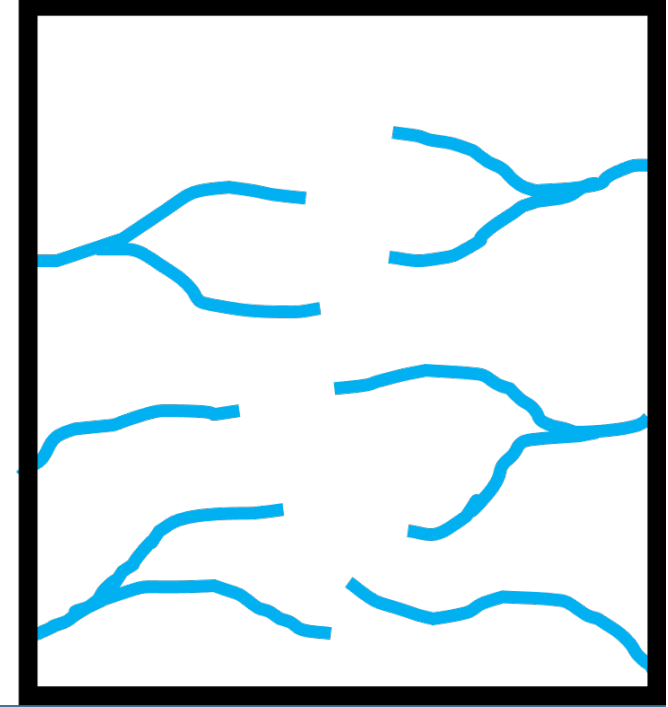
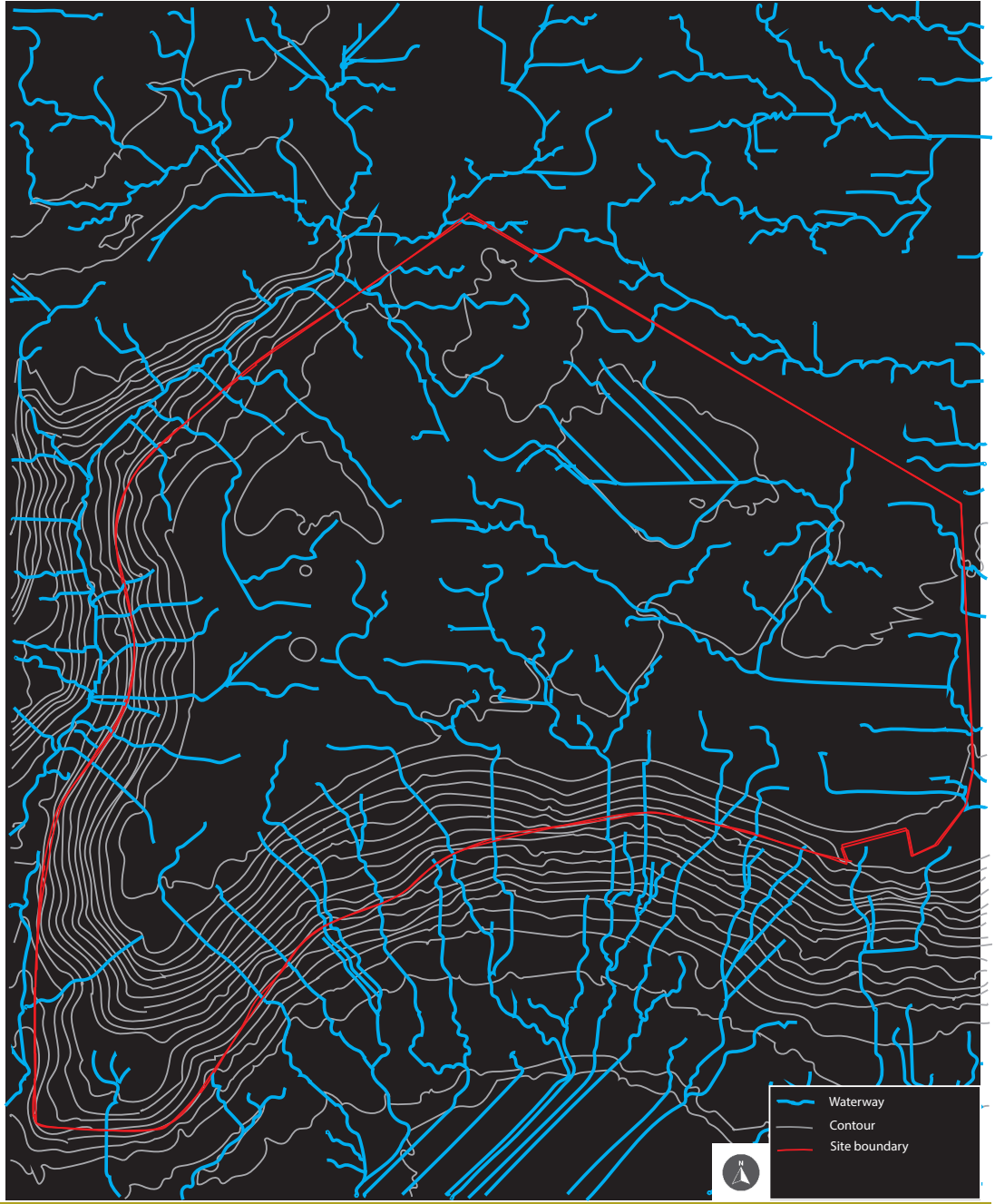


Figure 7. Step 1: Existing humid streambeds and streams [Source: by the authors].



The interpretation of the TWI helps locate the approximate origin of each stream and track its downstream flow (Figure 8). These points of origin at high elevations are fundamental to water management, particularly for harvesting water during dry seasons and for controlling runoff velocity during rainfall. These high points are candidates for implementing methods to capture atmospheric humidity to maintain the water supply for Yumana, since no other high point delivers water to the meseta. The air well principle is an effective passive method for harvesting water (Figure 9). The piles of rocks create a microclimate in which humid air circulates within the spaces between stones. Because the interior is cooler, water condenses, forming droplets that accumulate at the base of the piles until a spring starts flowing into a small stream.

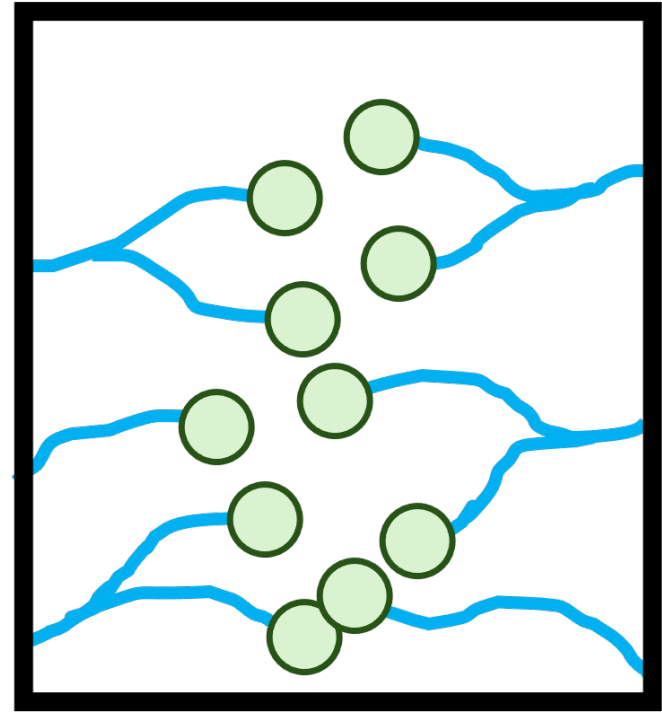


Figure 8. Step 2: Locations for potential water capture (on the highest places) [Source: by the authors].

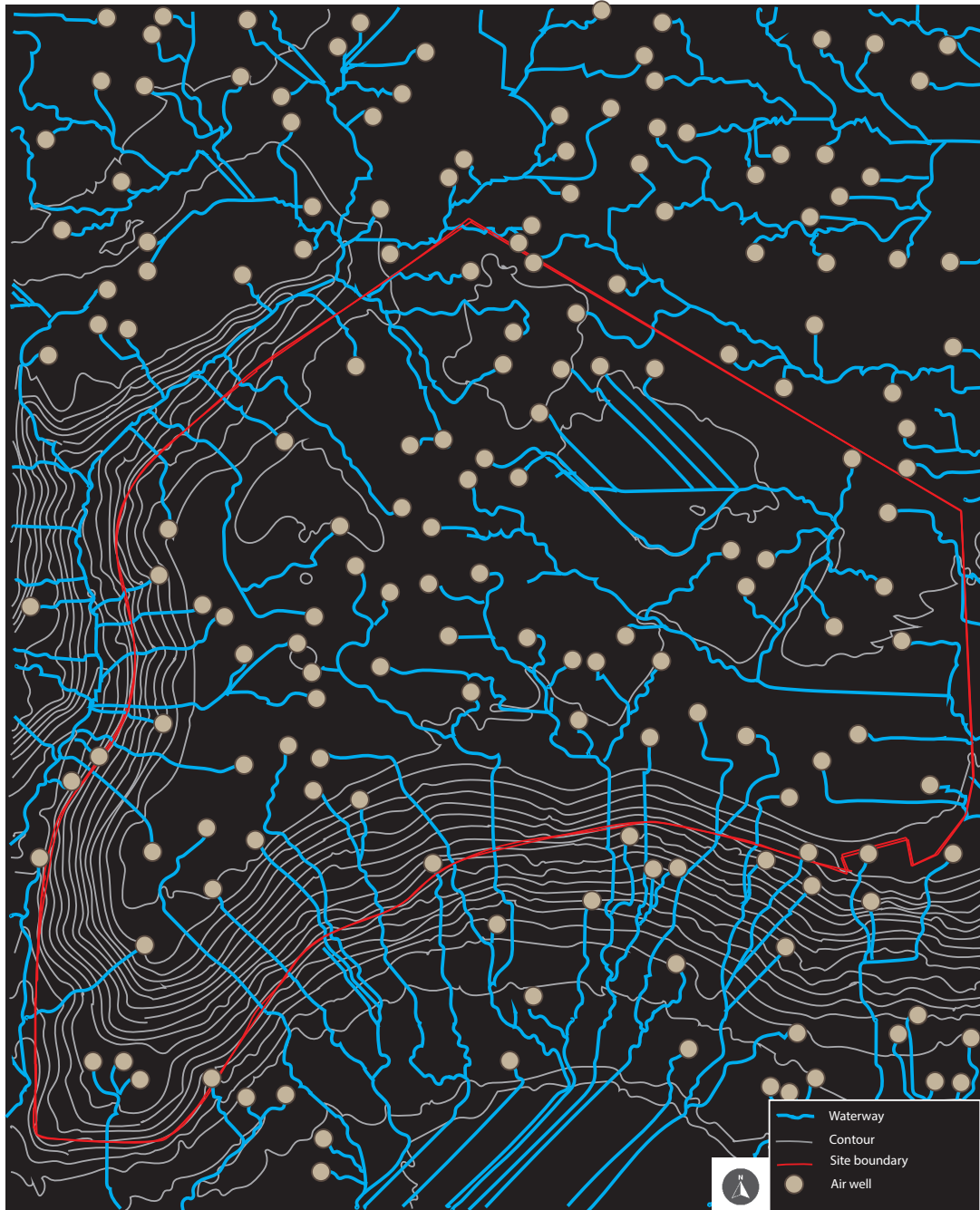


Figure 9. Example of an existing air well on the Yumana site [Picture: Rob Roggema]



Once these air well locations are determined, the next step is to connect them to form an ecological green space. The unification of the higher parts on the site into a common main ridge for the mesa connects with smaller ridges in between the stream valleys (Figure 10). This proposal is based on the principle that ecosystem connectivity is essential to regeneration. Connected ecosystems are exponentially more diverse than isolated ones.

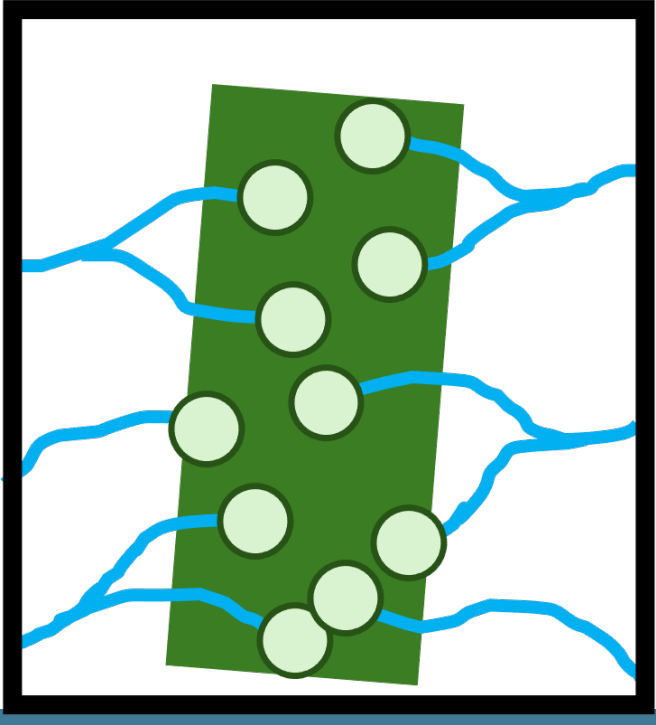
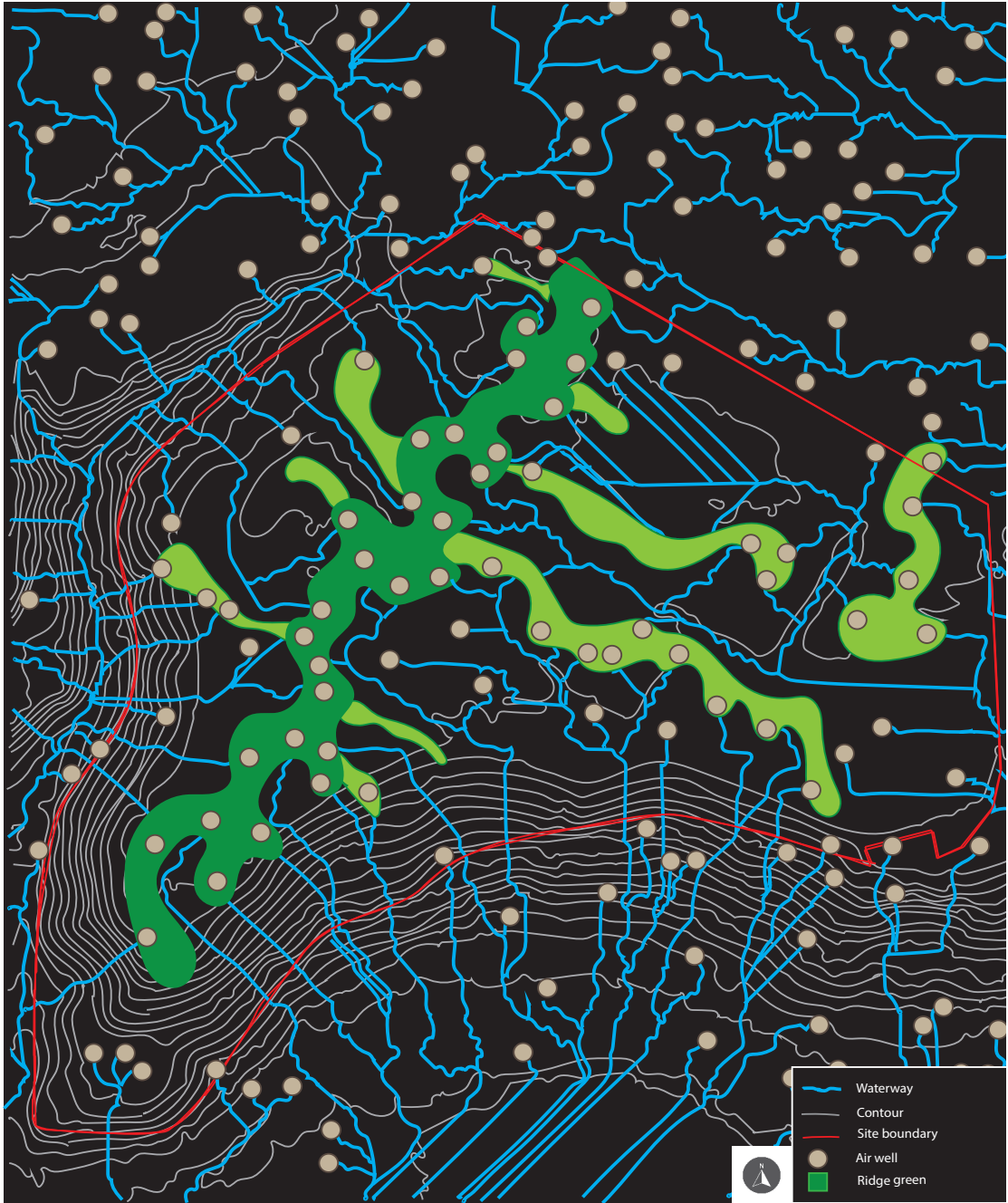
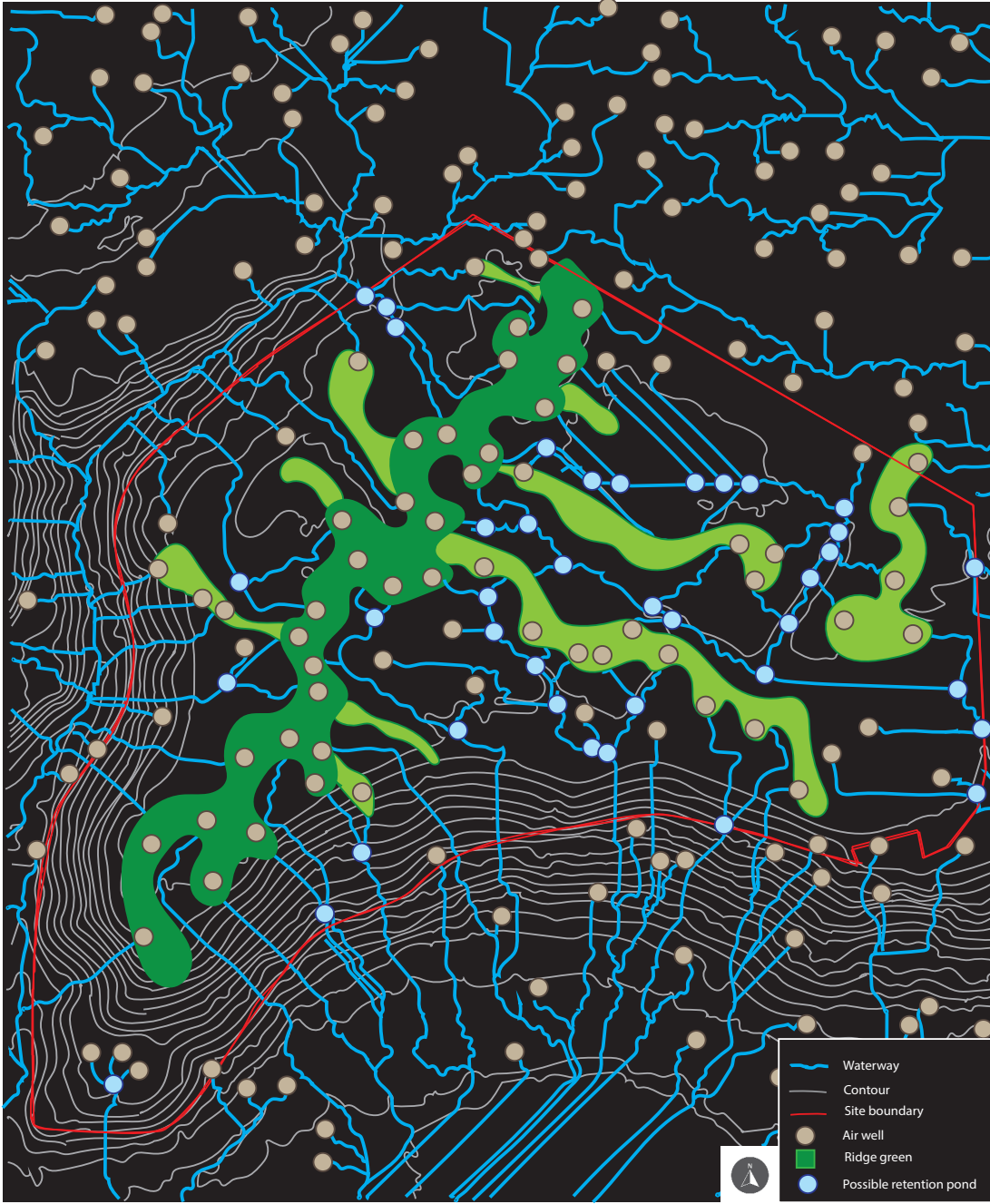
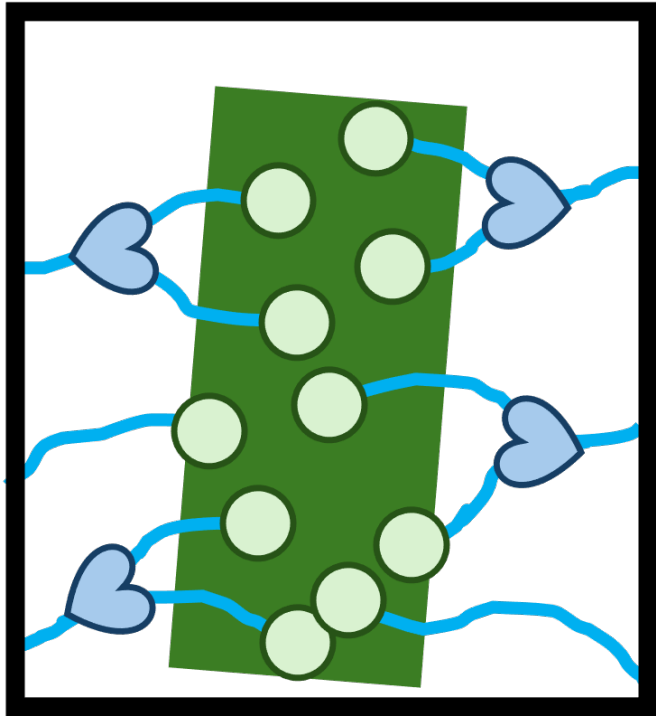


Figure 10. Step 3: Connect the dots in the systemic ecosystem: the highest water sources are located on the central ridge [Source: by the authors].



After establishing the major green framework, the next objective of the Biodiversity Regeneration Strategic Plan is to control water on site as much as possible, thereby preventing downstream discharge and slope erosion. The most effective places for controlling water are at stream junctions (Figure 11). These places are candidates for implementing techniques for water control, either to slow it, accumulate it, or regulate flooding (Figure 12 and 13). The distribution of these techniques can reduce water discharge from the meseta to zero. This is an alternative approach to reducing slope vulnerability to geological hazards and mitigating the risk.

Figure 11. Step 4: Potential water retention (in stream junctions) [Source: by the authors].



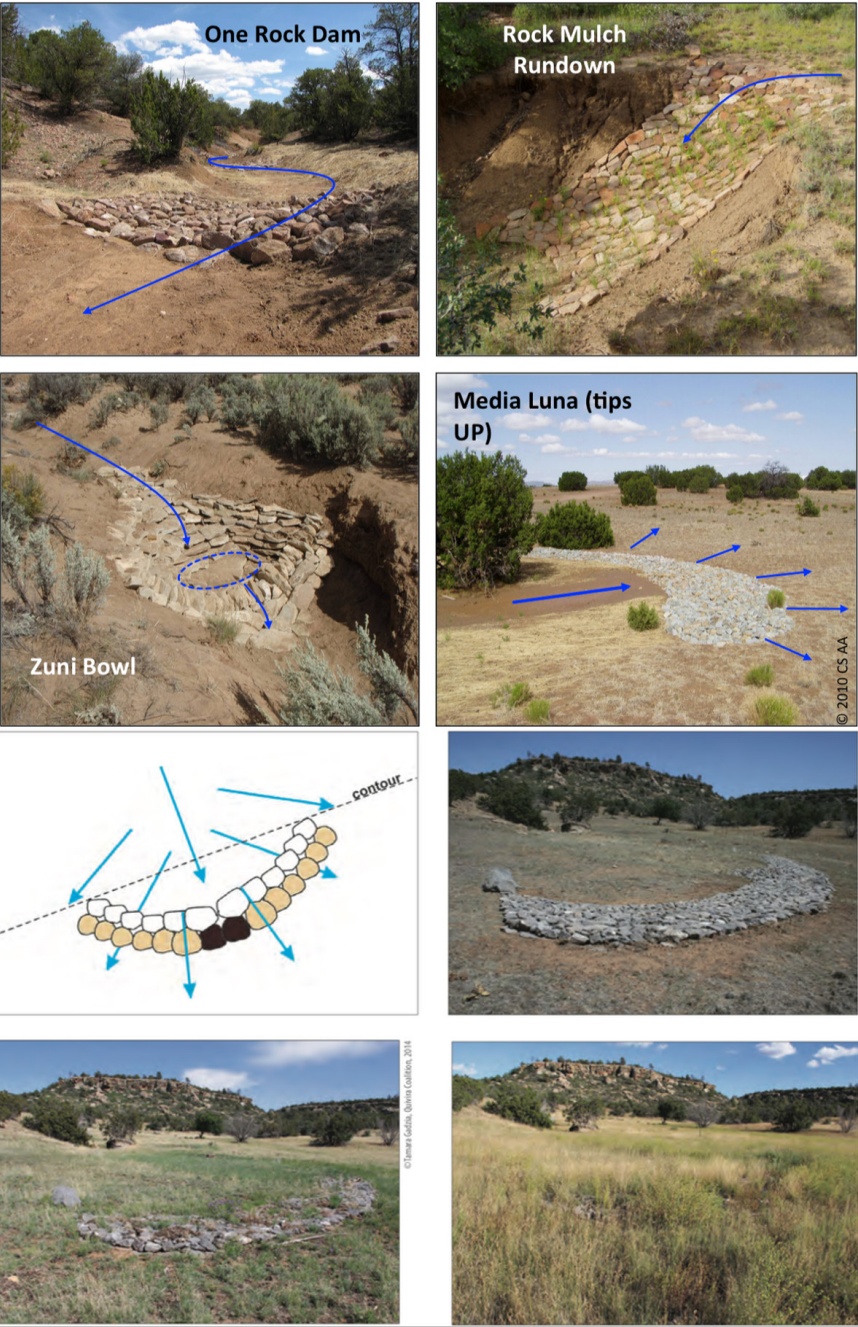


Figure 12. Examples of water retention measures. The last four pictures at the bottom correspond to a Media Luna, showing, in the two lowest pictures-, before construction and after-vegetated conditions (retrieved from Quivira Coalition: William (Bill) D. Zeedyk, Craig Sponholtz & Avery C. Anderson).



Figure 13-1. A natural water retention space in Yumana [photo by Rob Roggema]

Figure 13-2. The water retention boulevard in Luxembourg [Photo courtesy of ELYPS Landscape + Urban Design]

Figure 13-3. Water retention (full and empty) in an urban context, example Piekenhoef, Berghem (NBr), The Netherlands [photo by Royal Haskoning, CC-BY].

Finally, some streams are selected for turning their margins into ecological corridors (Figure 14). These sections of the streams run through the side valleys formed from the central green ridge, and some terminate in the trenches at the edge of the meseta. The lateral expansion of stream margins accommodates water, supports retention capacity, and increases biodiversity. Corridors at the topographic vertices and along the central ridge connect ecological services in Yumana.

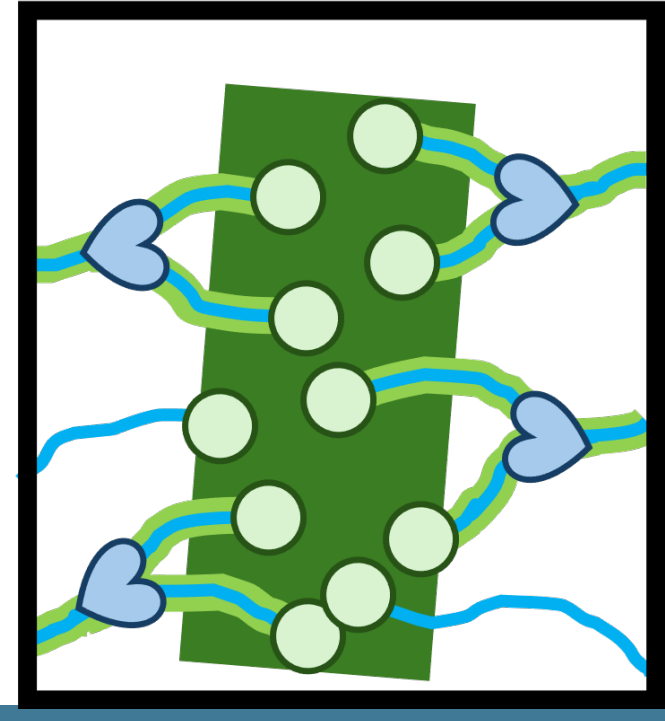
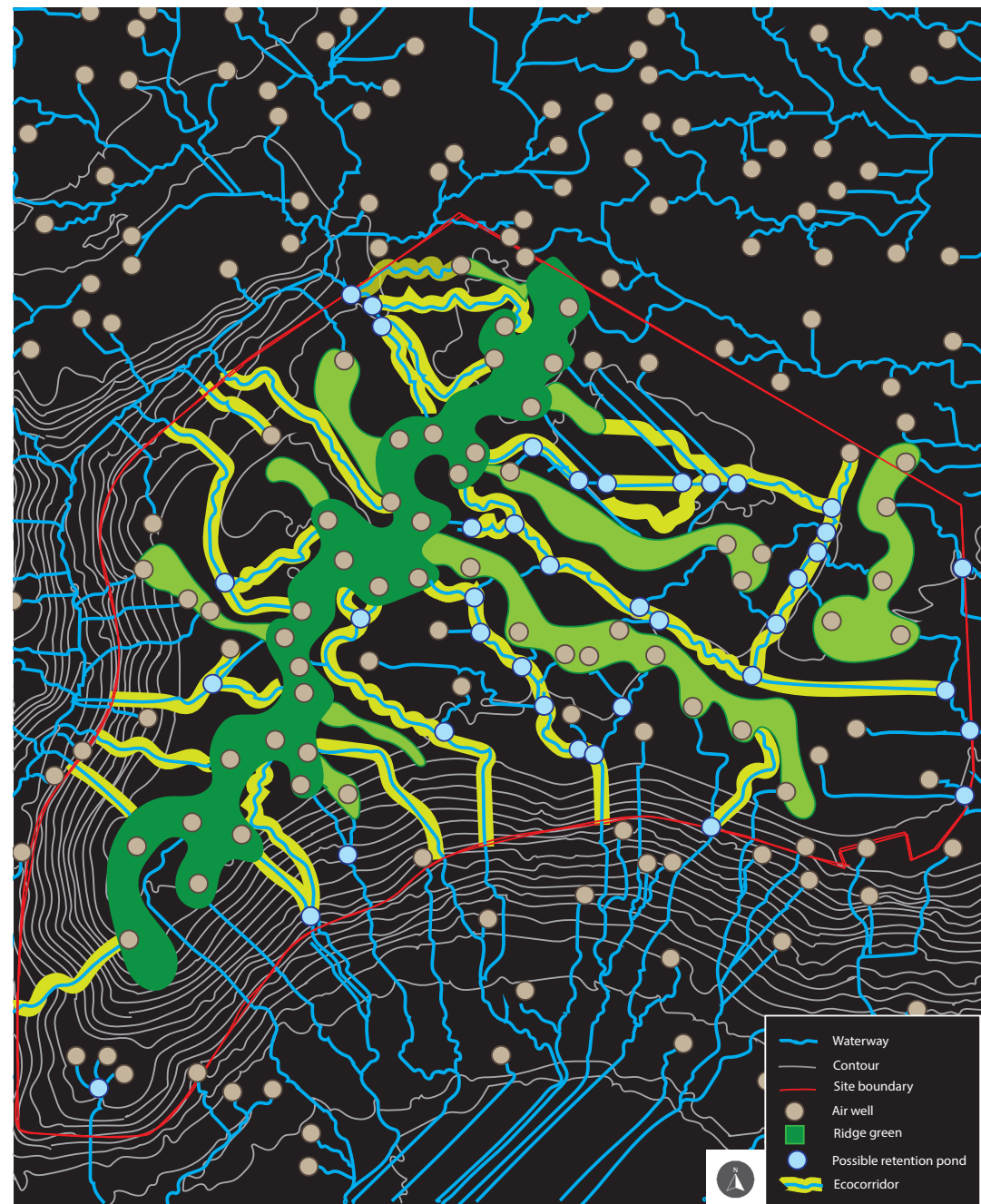
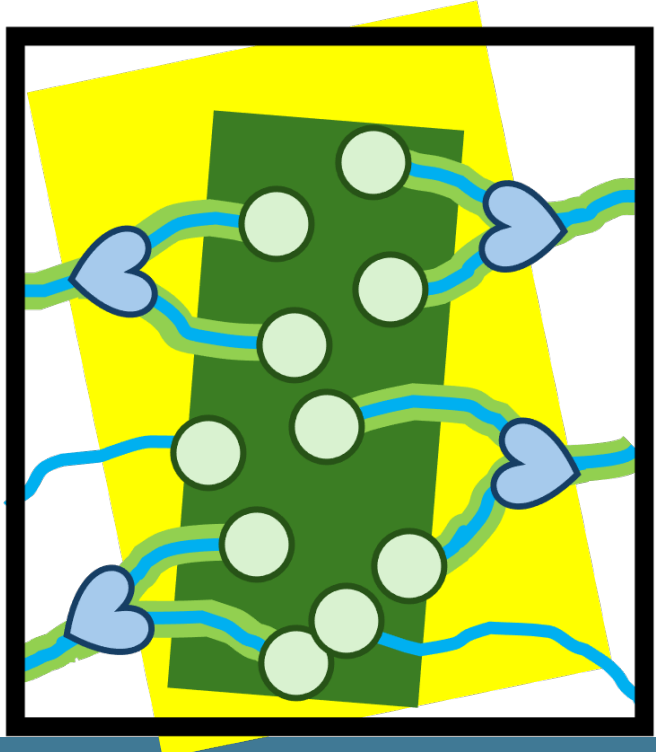


Figure 14. Step 5: Connect the dots of the re-generated ecosystem: connect the central ridge with junctions and slopes [Source: by the authors].



The overarching framework of Biodiversity Regeneration in Yumana consists of air wells at the highest points connected to a master green ridge, water retention works at stream junctions, and eco-corridors along stream margins at the topographic vertices. When urban development is planned, this strategic framework can serve as the underlying basis for embedding new urban uses that are habitable and ecologically productive. In the case of Yumana, the next step would be to overlay the Master Plan with the Biodiversity Regeneration Strategic Plan (Figure 15) or with any parts of future urban design proposals (Chapter 6).

Figure 15. Step 6: The Biodiversity Regeneration Strategic Plan overlaid on the Master Plan to identify discrepancies [Source: by the authors].



CHAPTER 6

Preliminary comparison with stage one of the Gensler plans

44 The Biodiversity Regeneration Strategic Plan identifies the key green and blue spaces and qualities essential to the regeneration of soil and water in Yumana. Any urban development plan and urban design at any scale can be evaluated with this strategy. For the first stage of urban planning, the architectural office Gensler proposed an urban design. This proposal is subject to comparison with the Biodiversity Regeneration Strategic Plan. It turns out that most of the proposed urban uses can be implemented without any problem (Figure 16, left). However, some aspects require attention after the Biodiversity Regeneration Strategic Plan is overlaid on the Master Plan, including the main connective green space on top of the ridge, the location of the retention waterworks and vegetated stream corridors (Figure 16, right). The main concerns are the undisturbed connections of green spaces and ecological corridors, and the overall capacity to manage water on the meseta. The integration of ideas between the plan and

strategy leads to the rearrangement of buildings and infrastructure, as well as to adjustments in the extent of construction or by level (e.g., by making underpasses or overpasses feasible). At first glance, the overlap of viewpoints is the constructions with the large green space connecting the airwells atop the main ridge of the meseta. This contrasting distribution of the buildings can be addressed by 'splitting' the ample green space and providing its continuity around the proposed buildings. The benefit of this is that every building faces a green space on four sides, allowing building occupants to interact more closely with biodiversity, birdwatching, water, air, soil, silence, and potentially to immerse themselves directly in the elements of nature, such as urban 'wilderness'. Some parts of the building require an overpass (dotted lines in figure 16, right), or green spaces need to be added on the roofs. The second element concerns the planned infrastructure, which partially encroaches the green spaces. Since it is for secondary green space,

it can be moved slightly to avoid interfering with the infrastructure (see Figure 16, right). A third aspect is the crossing of green spaces with buildings and infrastructure. Generally, this can be addressed by constructing an underpass or an overpass, or by installing a reverse bump when water crosses a road. Where air wells or water retention are projected, they should be aligned with proposed buildings and infrastructure, in the form of an air well, raingarden, or swale. At some places, the width of the roads can (or must) be reduced, which also operates as a traffic control and safety measure, reducing the speed of crossing vehicles (i.e., Paseo de las

Culturas with its crossing lanes heading north). Finally, the proposed road system is, in many cases, 'double'. This means that, with fewer roads, the same level of accessibility can be achieved. A smaller road surface area improves permeability, mitigates the Urban Heat Island effect, and encourages walking and cycling. In general, it is recommended to integrate the qualities of the Biodiversity Regeneration Strategic Plan into the urban design process, such that an interactive design process would improve both natural and urban qualities by designing them in parallel. Therefore, it is needed to jointly co-design propositions.

Figure 16. Comparison of the Biodiversity Regeneration Strategic Plan with urban design proposals. Comparison and potential conflict (left) and the integration and potential solutions (right).



CHAPTER 7

PLANNING FOR

THE SLOPES

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The slopes of the Yumana site (Figure 17) are a distinct feature, unlike those of the meseta. Where the meseta is relatively flat, with some smaller gorges and trenches, the slopes (figure 18) are generally steep, consist of some instable materials, and form a risk for flooding and landslides.

Figure 17. The southern slopes from East (Top) to West (Bottom) of the road to the airport, Camino al Aeropuerto [photo by Rob Roggema].



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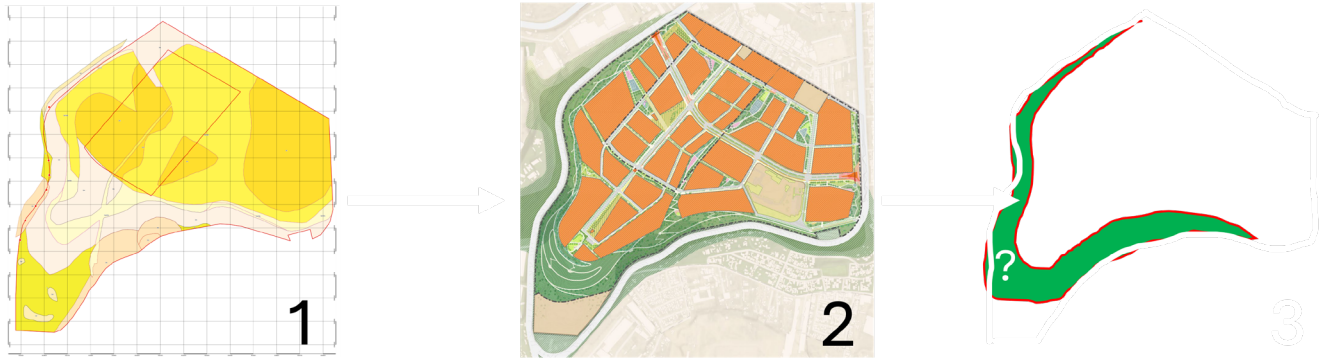


Figure 18. Distinction between the flat landscape of the meseta (green) and the steep slopes (red) [source: Sasaki, 2024].

The strategy of this plan employs the keyline method (Yeomans, 1954; 1971; Cortés Torres & Ramírez Luna, 2013) to stabilize soil around the meseta and reduce slope instability along the vulnerable roads to the airport, Camino al aeropuerto, and Boulevard Lázaro Cárdenas. The Keyline method uses lines on the surface at a gentler angle than the rough topography of the site to conduct runoff and sink rainwater across the landscape, preventing soil erosion and spreading water from wet to drier areas. For the appropriate use of the keyline method, the first step is decodify the contours of the terrain, its geology, and landslide erosion in slopes. The plan for the keylines is to passively divert

water, infiltrate it, and slowly discharge it at the surface and seep underground. Water flows from the wet vertices to the drier ridges on the slopes, improving soil fertility on hilltops. The lines stabilize soil. On slopes, keylines can be drawn by an animal or a compact tractor. The lines to plough can be enhanced through planting of seeds and reforestation, guided by the orientation of the keylines. Pathways on slopes, as provided by the existing Master Plan and the reforestation plan, may follow keylines as well, or interdigitate. The integration of pathways into the reforestation plan by keyline design results in a Soil Regeneration Strategic Plan for the slopes (Figure 19).

Figure 19. Method of approach for the Soil Regeneration Strategic Plan. 1- Geological basis and landslide risks. 2- Current Master Plan for the slopes. 3- Integrate soil stabilization, preventing



This strategy considers the geology of the rock units outcropping on Yumana to determine their locations and boundaries. A legacy map on the geology of Yuama, supported the analysis of surface erosion atop the meseta and landslides on the surrounding slopes (Figure 20). Several concave structures are interpreted on the map for the southern slopes, and another is on the western slopes, delimiting areas with slope instability. Furthermore, some locations vulnerable to landslides (red dots) are also identified. The distribution of these landmarks requires attention for risk mitigation, and the level of derisking may be achieved through passive methods or geotechnical solutions; all these treatments aim to achieve slope stabilization. The legacy geological map (Figure 20) aided understanding of the test drilling described in the geotechnical report. Although no geological structural data are available to recognize the orientation and position of the strata, field observations suggest that rock units dip gently to the west over Boulevard Lázaro Cárdenas. The types of soil found at the site—such as undocumented fill (Qudf), topsoil (Qts), weathered clayey terrace deposits (Qtc), and other highly weathered soil (w)—are not, in their current condition, suitable to directly support

buildings, roads, or other structures. Using these materials without improvement could lead to ground movement and poor structural performance. Some clay soil at the site, identified as very stiff to hard clay terrace deposits (Qtc), compresses only slightly and is generally stable. However, because they exhibit high plasticity and relatively low supporting capacity, they are suitable only for compacted structural embankments. They are not recommended for direct foundation support unless a cushioning soil layer is added to reduce the effects of potential ground expansion. In contrast, the dense to very dense sandstone and conglomerate (Ar-cg / Cg-ar) found at the site are strong and stable materials. They experience very little compression and are well suited to support foundations, fills, and pavement structures. These dense units occur to a depth of approximately 5 m below the surface. A practical consideration is that large rock fragments within these materials may complicate excavation, particularly for underground works such as utility trenches. The existing soil and rock units differ from the types of rock piled on the surface, possibly representing banks left after quarry operations to crush and sieve. Therefore, rock piles are a limited resource for air well construction.

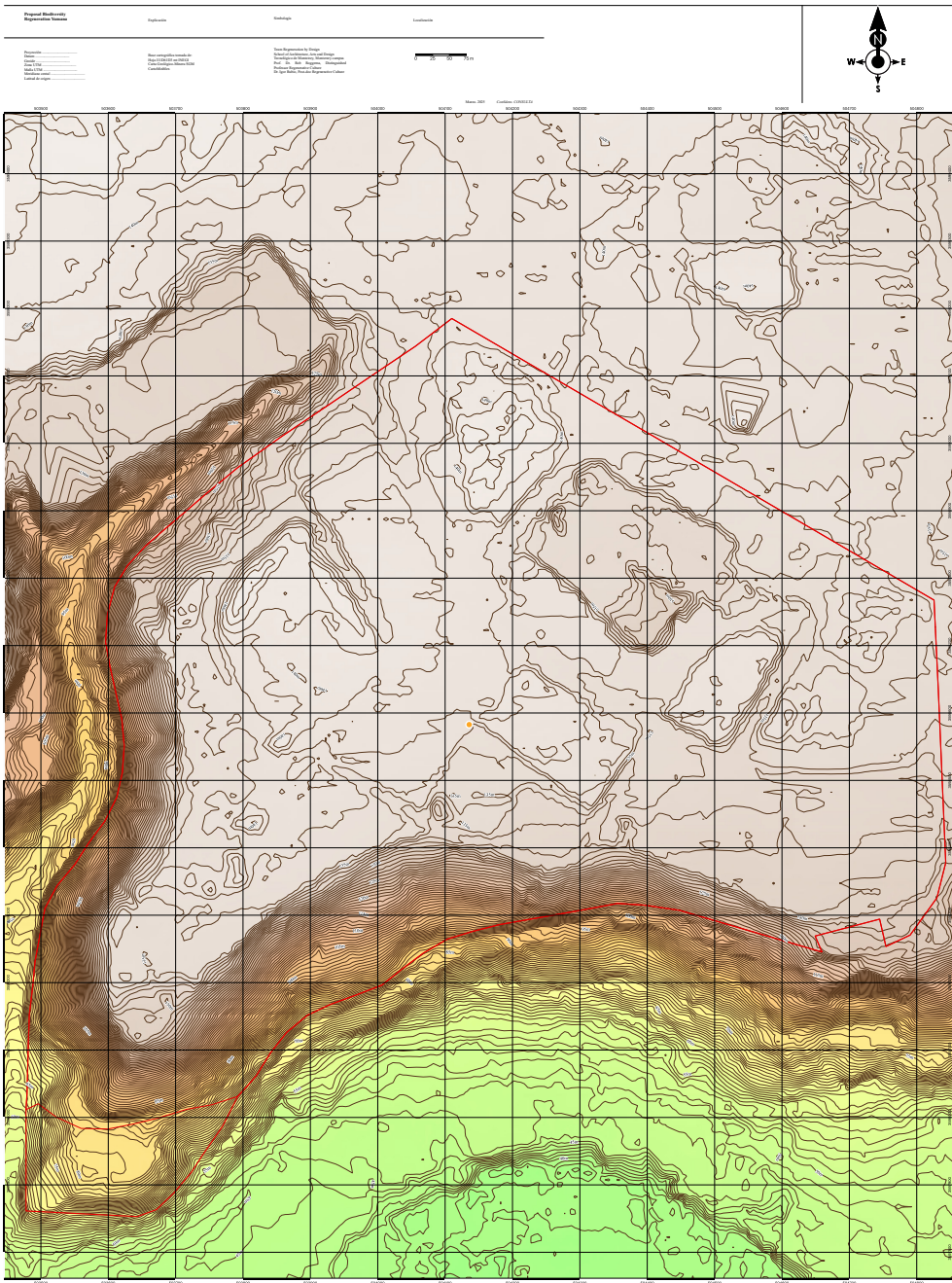


Figure 20. Geology of the Yumana site [retrieved from legacy Figure A21, Geologic map from GEOCON, March 1991: modified by the authors].

The analysis for keyline delineation was improved by georeferencing the geological map and other landscape elements, such as contours, ridges, and vertices. The objective of using keylines is to divert water scouring down from the primary vertices to the hilltops, thereby reducing erosion and surface instability in places where water usually flows straight downhill (schematic explanations in Figure 21; Figure 22; Figure 23; Figure 24; Figure 25).

Figure 21. Example of keylines visible in the landscape [Premio nacional Portugal; Montemor o Novo Apresentacao]

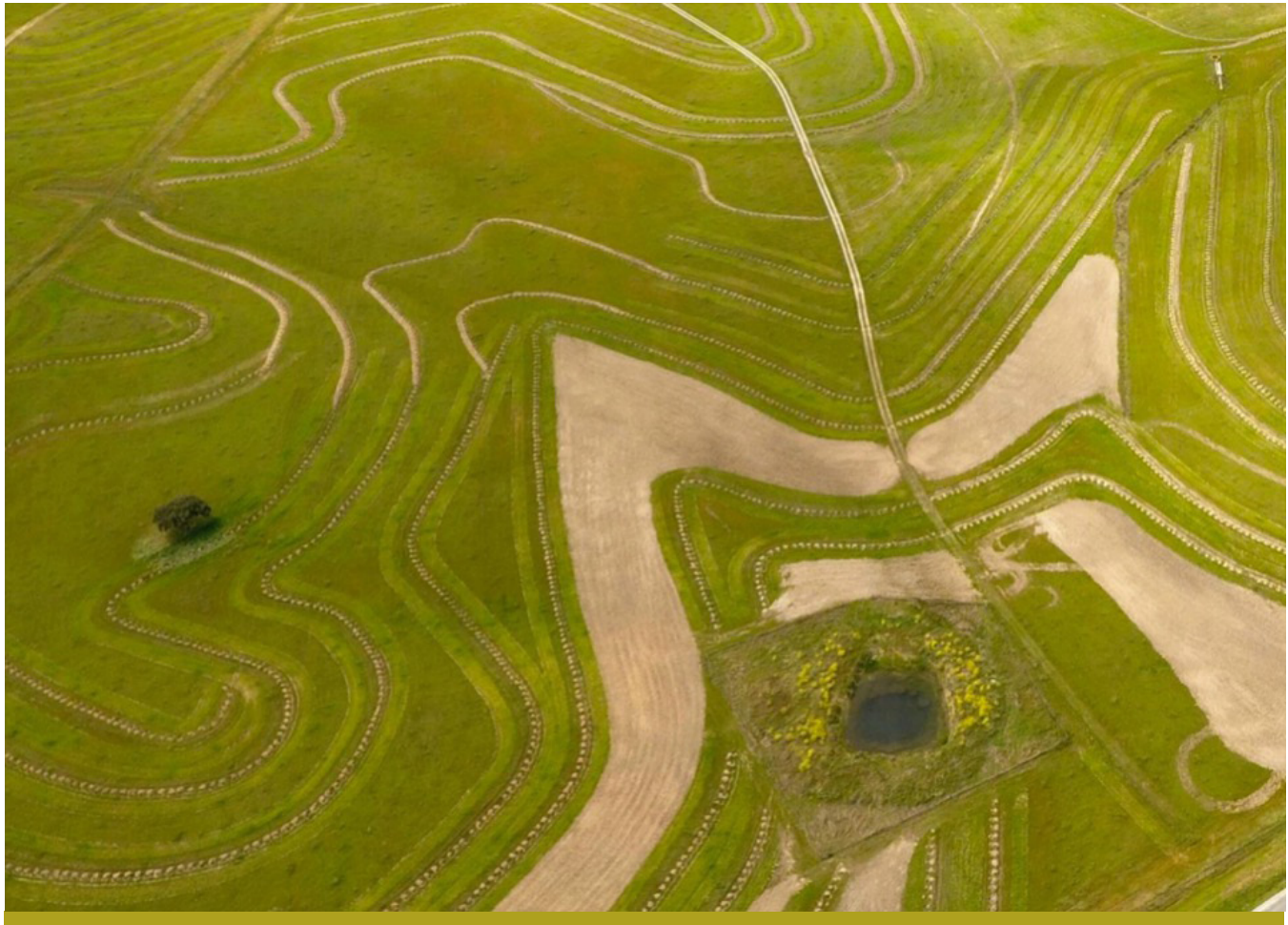


Figure 22. Diagram for the primary valley keypoint. The point of inflection is where the direction of a curve changes. The keypoint of a valley in a vertex is where the valley starts to flatten [Source: Doherty, Jeeves & Pavlov, 2015].

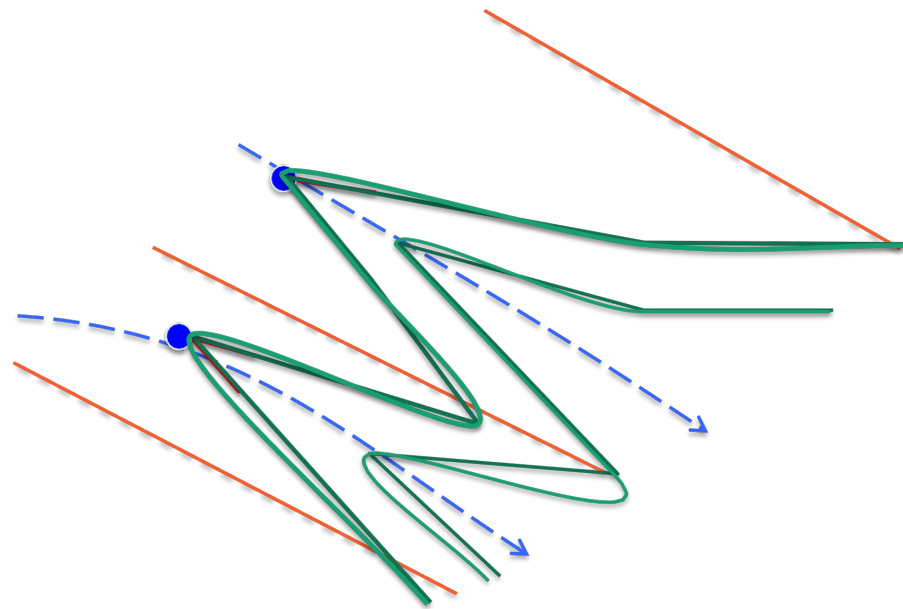
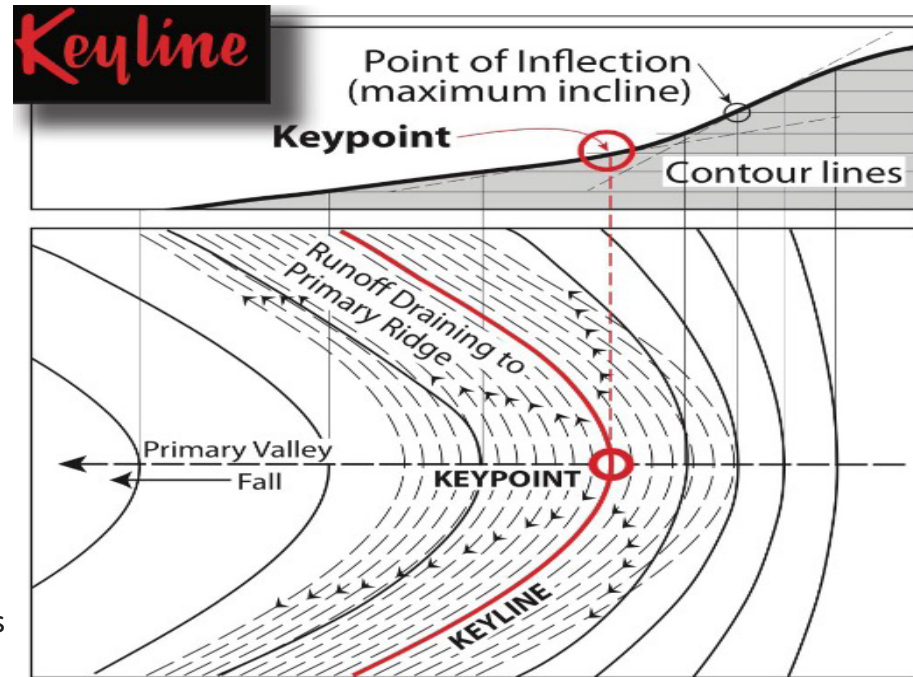


Figure 23. Understanding the Application of Keyline Geometry with a schematic representation for keylines with angular or crooked terminations. [Source: Pavlov, 2015].

Figure 24. Basemap redrawn from P.A. Yeomans, showing a typical procedure to delineate equidistant keylines in a foothills landscape composed of a Main Ridge, Primary Ridges, and Primary Valleys, with a creek below and keypoints (circle), and Keylines marked in thicker black lines. Contour intervals are marked. Marks in the land elements for the lowest primary ridge contours (green), lines at the end of the primary valley and start of the Primary Ridge (dashed pink). Join of the keylines to form one continuous line (black dashed) [Source: Doherty, Jeeves & Pavlov, 2015].

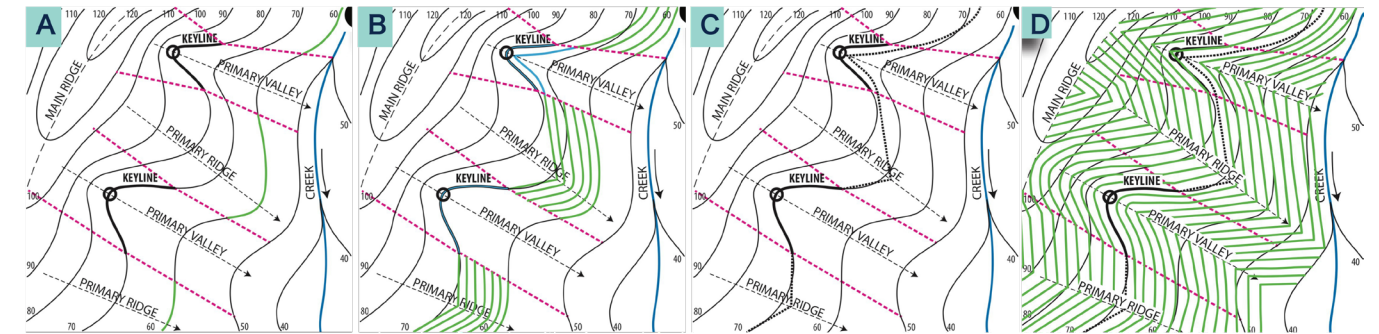
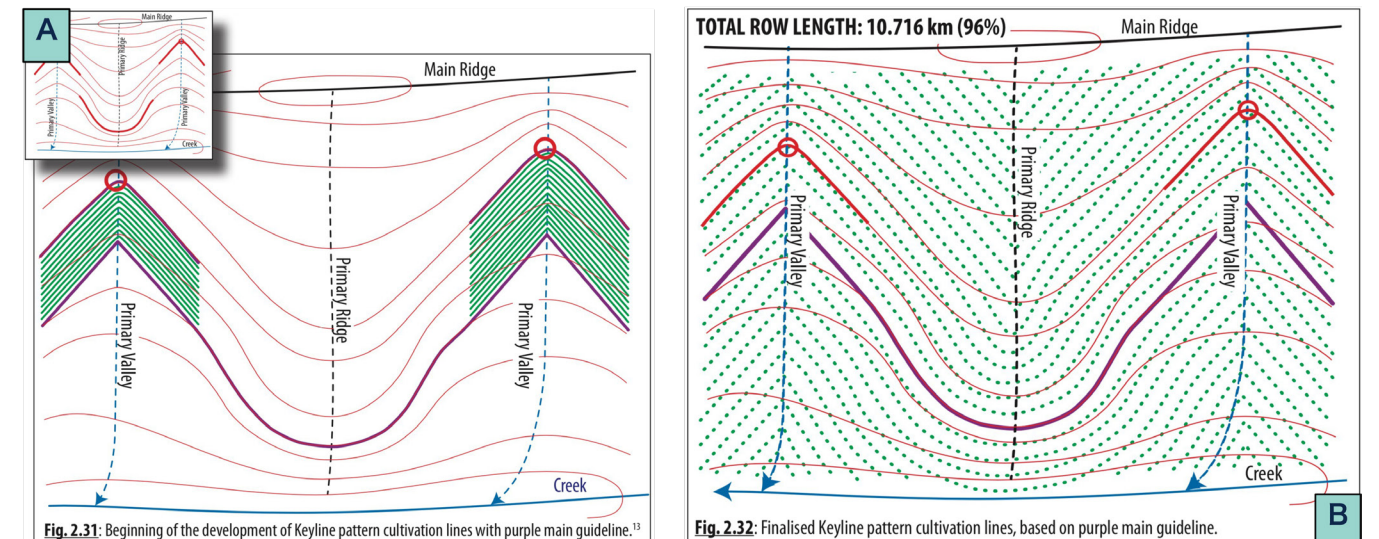


Figure 25. A- Beginning of the development of Keyline pattern cultivation lines with purple main guideline. B- Finalized pattern cultivation lines, based on purple main guideline [Source: Doherty, Jeeves & Pavlov, 2015].



The control of erosion on the slopes requires integration with water retention, ultimately within the trench that surrounds the meseta. These methods for controlling water keep most of the humidity over the meseta and prevent it from scouring the downslopes. To distribute water across the meseta, additional water-retention areas may be required under the urban plans, with at least some more than in the current Master Plan (explanation for Figure 10). However, it is easy to modify and co-design the most optimal variant of detailed urban designs. The slopes will be remodelled to achieve smoother surfaces and reforested using the keyline method (examples in Figure 26; Figure 27). Consequently, this adaptation of methods and techniques will be enhanced by new walkways connected to the original pathway proposed in the Master Plan. This combination of keylines, forestation, and pathway system diverts the humidity with soil retention, hence reducing landslides risks.

Figure 26. Examples of slope stabilization projects: A- El Ratón Nuevo México; B & C: Robbin Sotir & Associates [Gray & Sotir, 1996].



Figure 27. Slope stabilization and plantation using keylines.



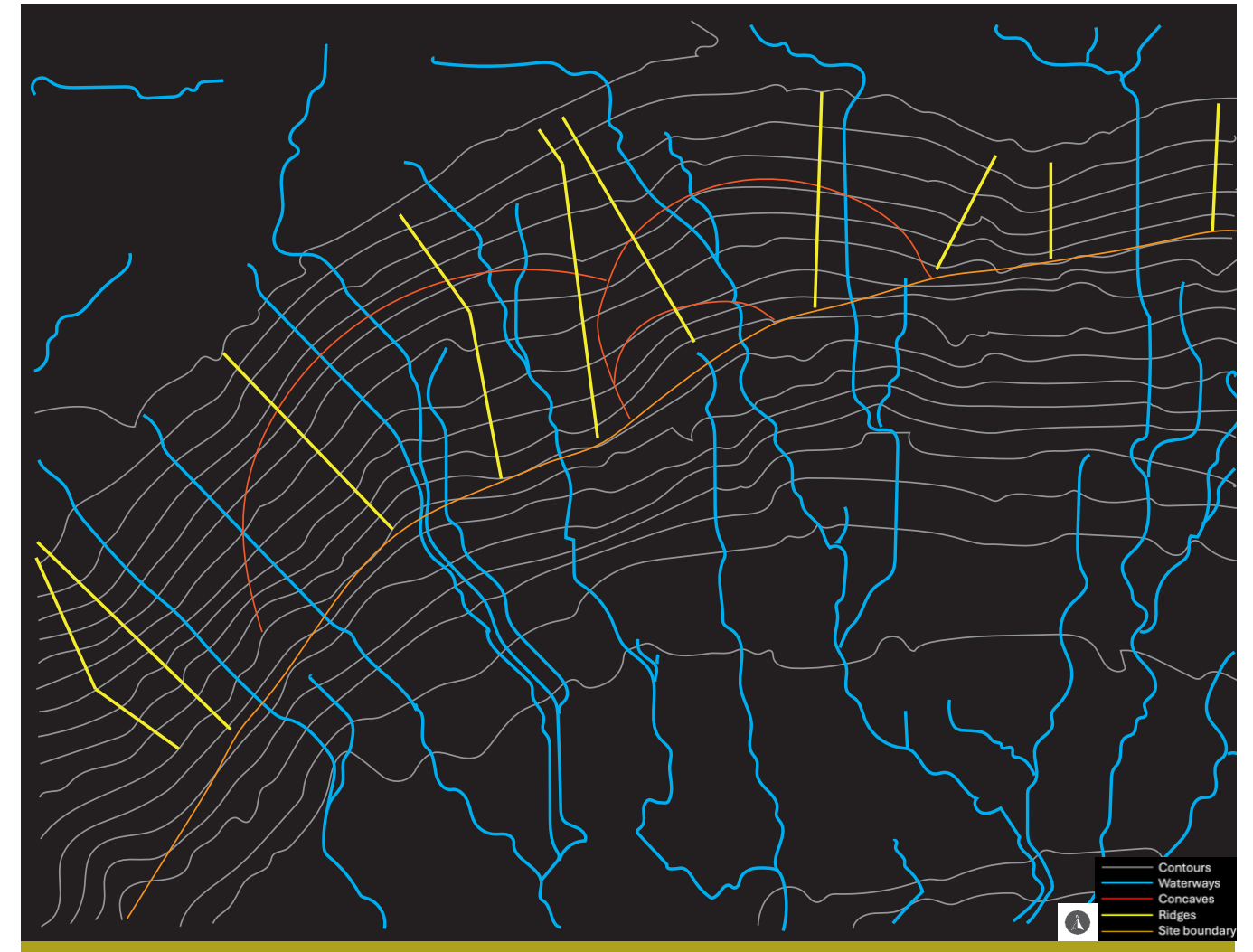
CHAPTER 8

SOUTHERN SLOPES

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The design of the southern slopes aimed at reducing waterflows that run down the slope through reforestation and soil stabilization begins with the location of keylines, which are in relation to the contour lines in the topography, the vertices in valleys, the ridges, and the geological hazards in concave areas. Figure 28 shows these basic features on the southern slopes of the landscape.

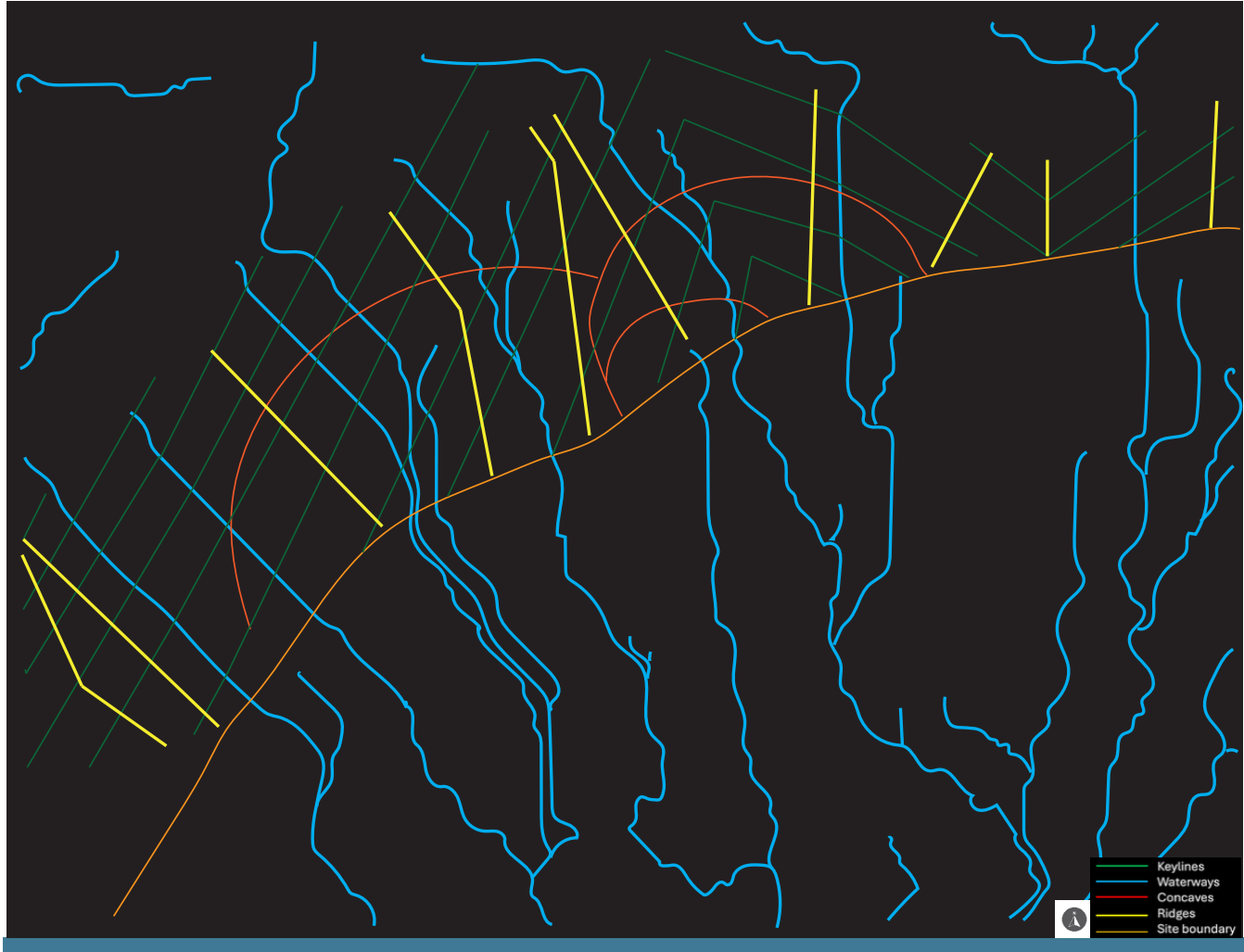
Figure 28. Southern slope next to the road to the airport, Camino al Aeropuerto, showing contours, waterways in valleys, ridges and areas with potential landslides (red concaves) [Source: by the authors].



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The keylines are specifically drawn to be most effective in redirecting available water, thereby reducing surpluses and mitigating risks (Figure 29).

Figure 29. Southern slope next to the road to the airport, Camino al Aeropuerto, with keylines carefully delineated in relation to the ridges, valleys (waterways), and concaves [Source: by the authors].



Given the keylines and the proposed pathways in the Master Plan (Figure 30) a novel and extended pathways system can be proposed (Figure 31). These paths not only serve for recreational walking, running, or biking but also function as waterways with a slight gradient to slow the flow of water.

Figure 30. Keylines in combination with the current pathways on the southern slope next to the road to the airport, Camino al Aeropuerto [source: by the authors].



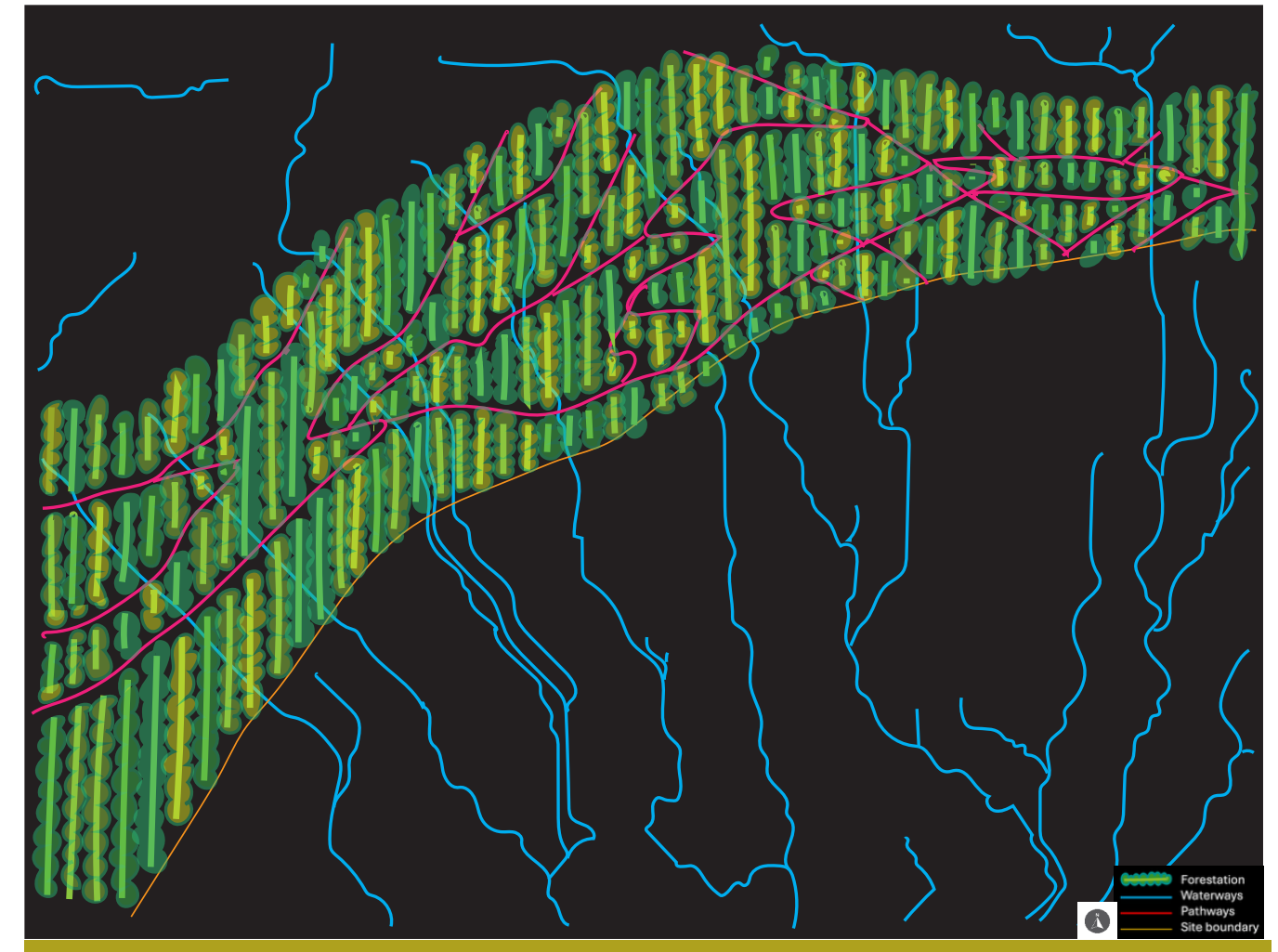
Figure 31. Proposal of a new pathway system as a combination of keyline that includes a selection of those preconceived in the Master Plan for the southern slope next to the road to the airport, Camino al Aeropuerto [Source: by the authors].



The pathways then determine the redundant spaces on the slopes that can be planted and reforested (Figure 32). The slopes are suitable for intensive planting, enabling rapid growth of plants and trees and facilitating favourable

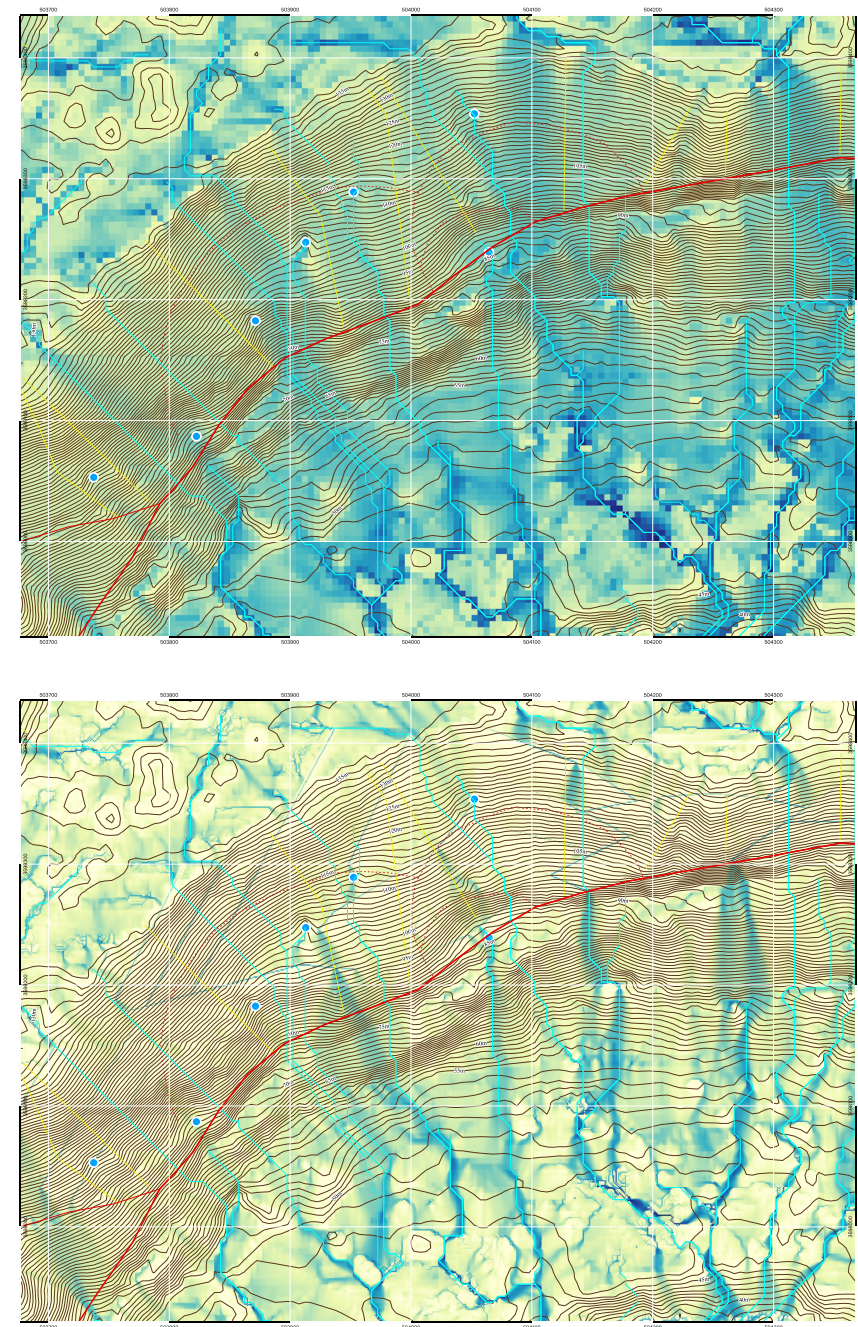
transformation and stabilization of the slope terrain. The Miyawaki forest typology (Miyawaki, 1988; 1999; Rots, 2015; Nargi, 2019) can serve as an inspiring approach to achieving these results.

Figure 32. Illustrative image of the possible reforestation of the southern slopes [Source: by the authors].



The results of the keyline design and forest intervention can be made visible by modelling TWI before and after the proposed intervention (Figure 33). The maps show a clear improvement resulting from the interventions, redistributing moisture to typically dry areas, such as ridges, while reducing water concentration at the vertices. The TWI simulation indicates that passive methods are successful and significantly reduce the risk of flooding and landslides.

Figure 33. Topographical Wetness Index of the Southern Slopes, before (left) and after (right) the interventions with keyline and pathways [Source: by the authors].



CHAPTER 9

WESTERN SLOPES

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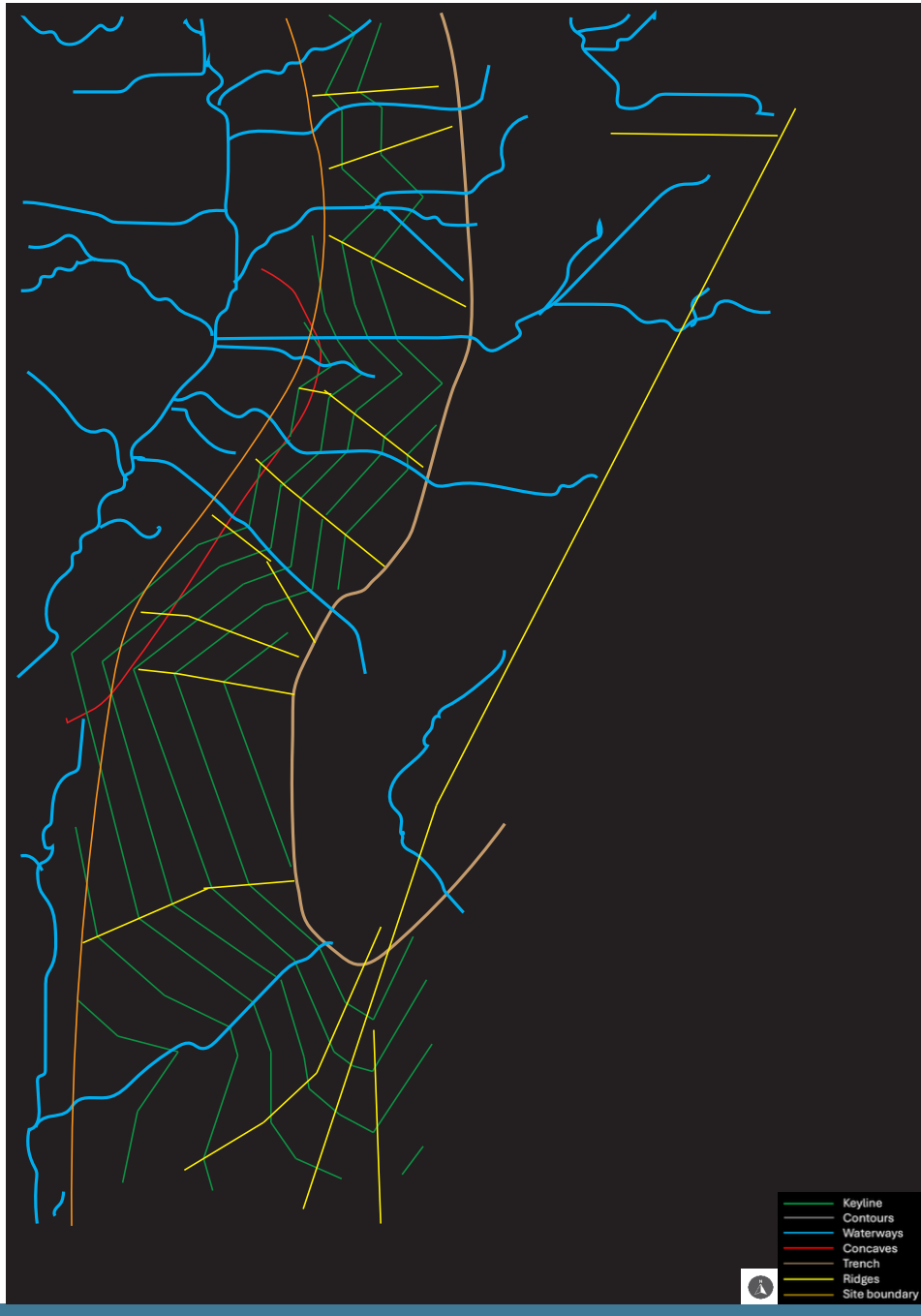
The findings of the southern slopes have also been applied to the western slopes. The inventory of contours, waterways, ridges, and vulnerable soil areas (Figure 34) is used to design the keylines (Figure 35).

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Figure 34. Western slope next to the boulevard Lazaro Cardenas, showing contours, waterways in valleys, ridges, and concave areas with potential landslides in red [Source: by the authors].

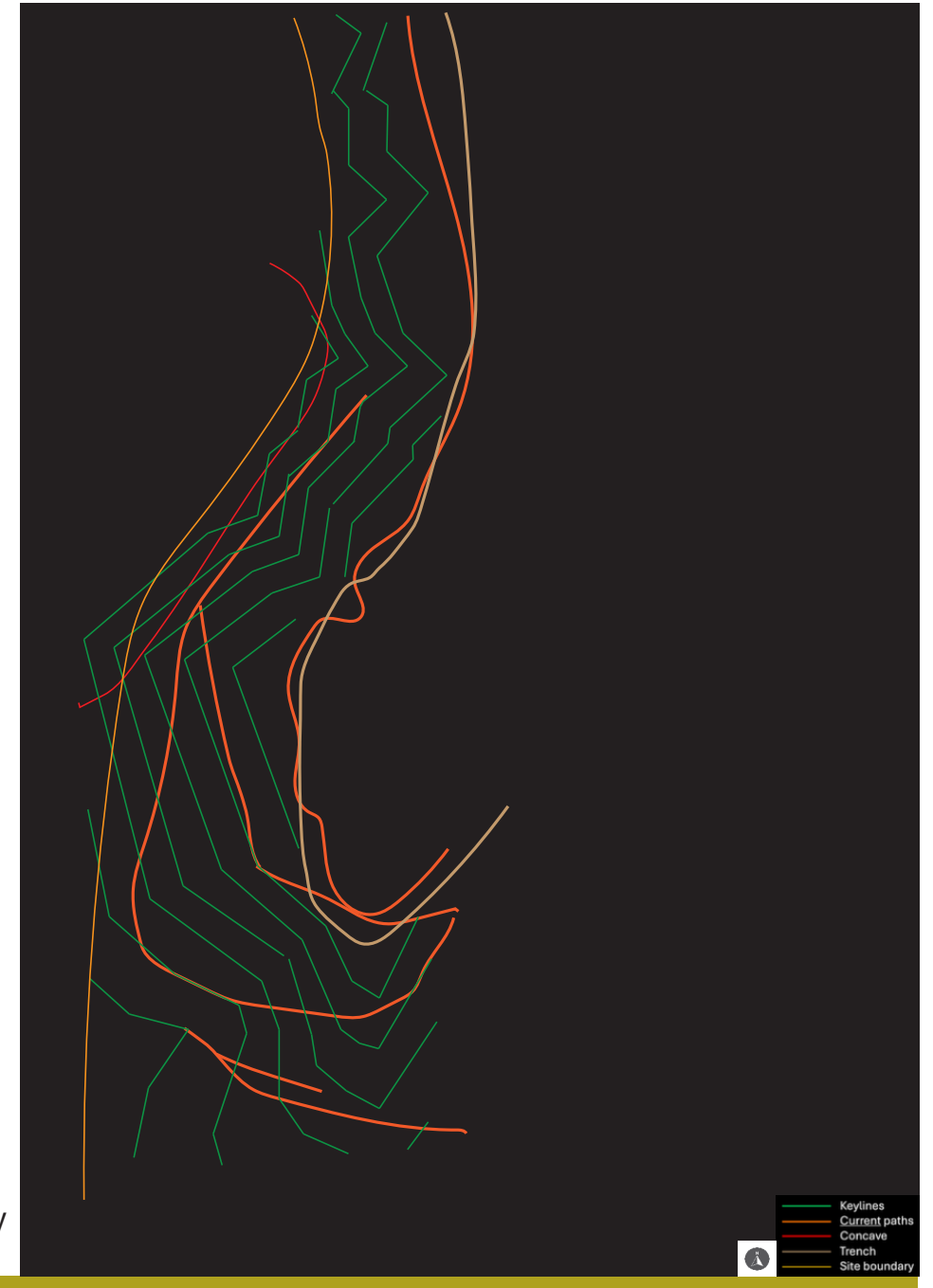


Figure 35. Western slope next to the boulevard Lazaro Cardenas, showing the design of the keylines. [Source: by the authors].



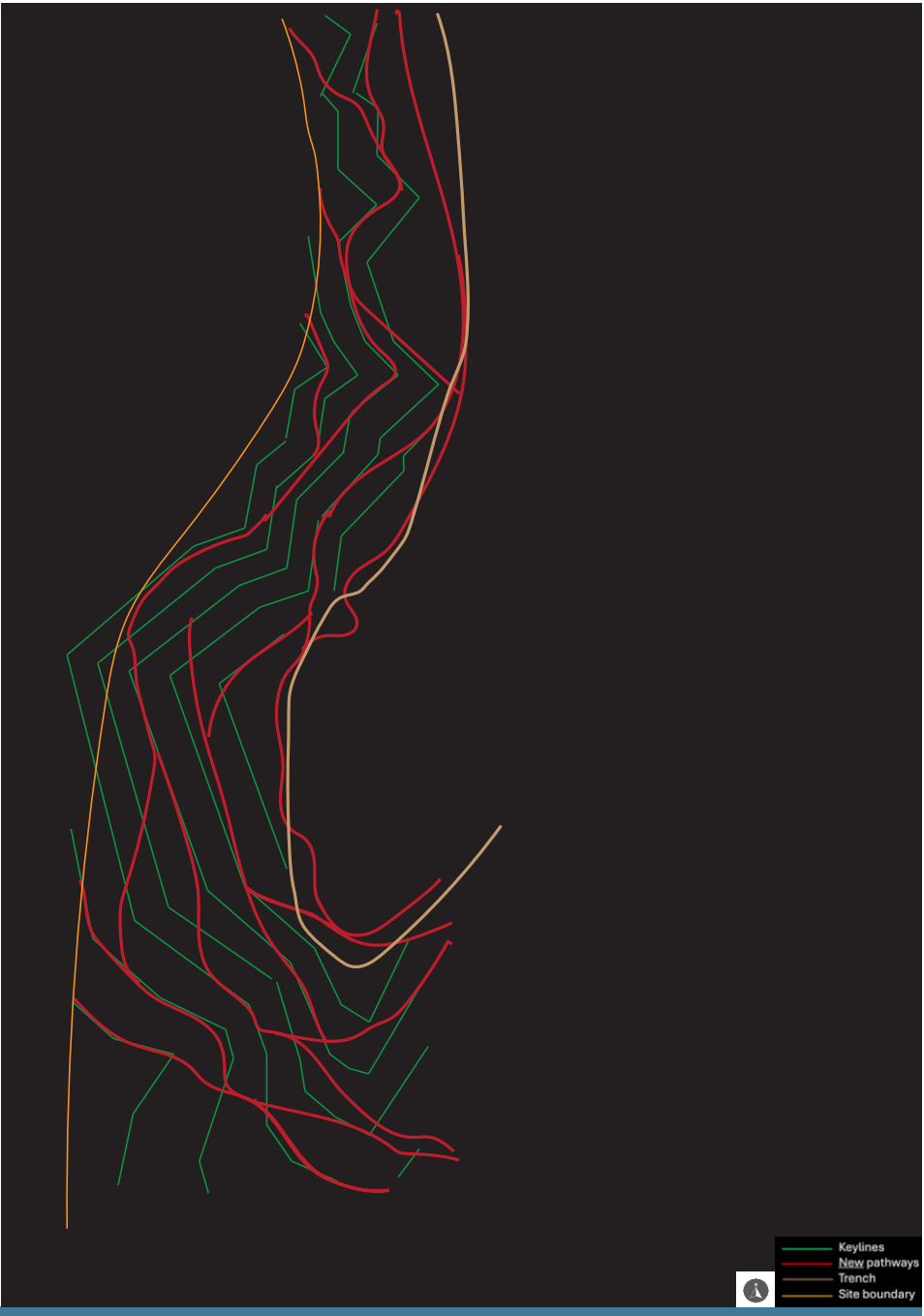
Once the keyline system is understood, it can be compared with the existing proposed pathways in the Master Plan (Figure 36).

Figure 36. Keylines in combination with the current pathways on the western slope next to the boulevard Lazaro Cardenas [Source: by the authors]



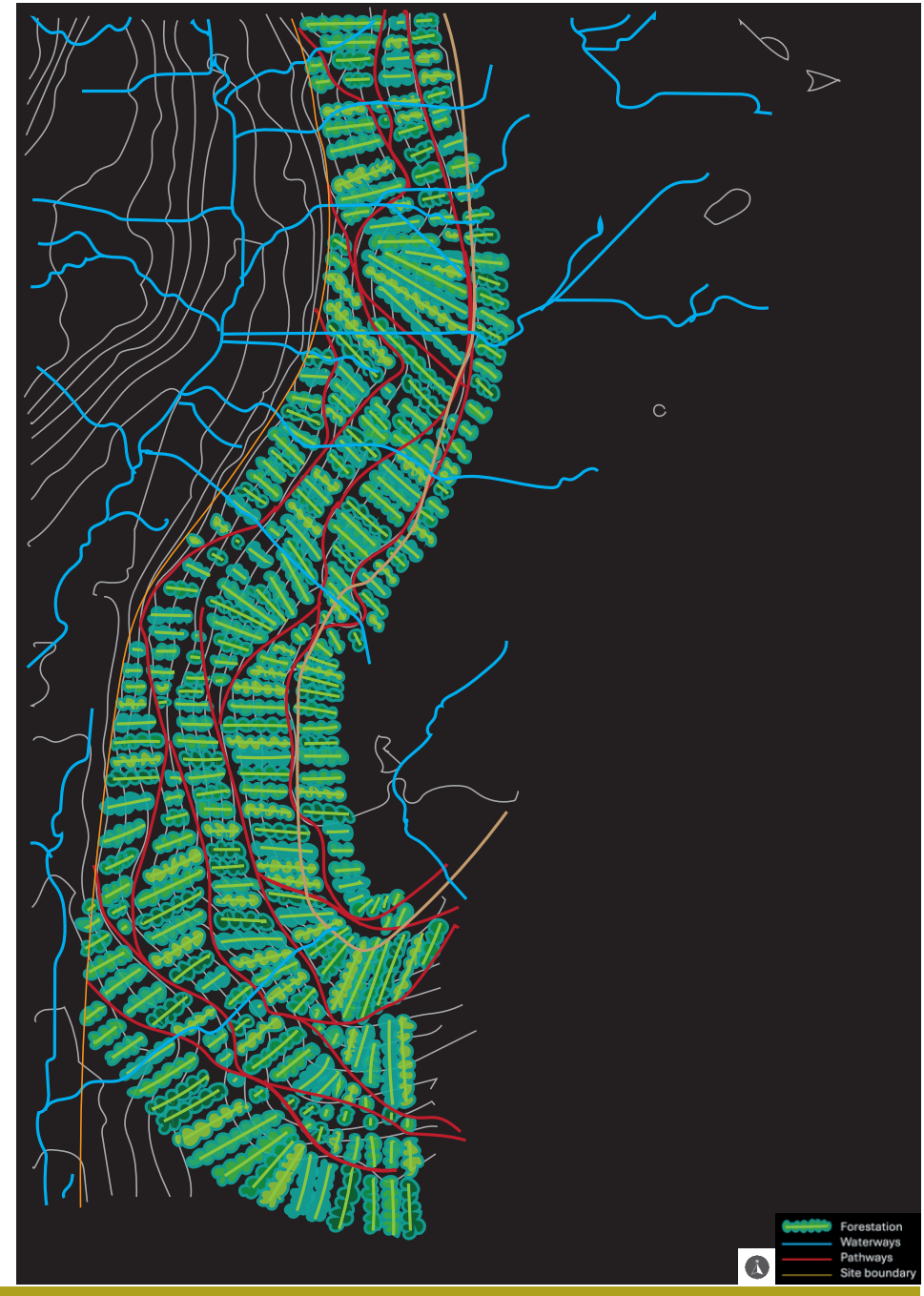
The planned pathway system can then be expanded using the topographical conditions, as illustrated by the keylines (Figure 37).

Figure 37. proposal of a new pathway system as a combination of keylines [Source: by the authors].



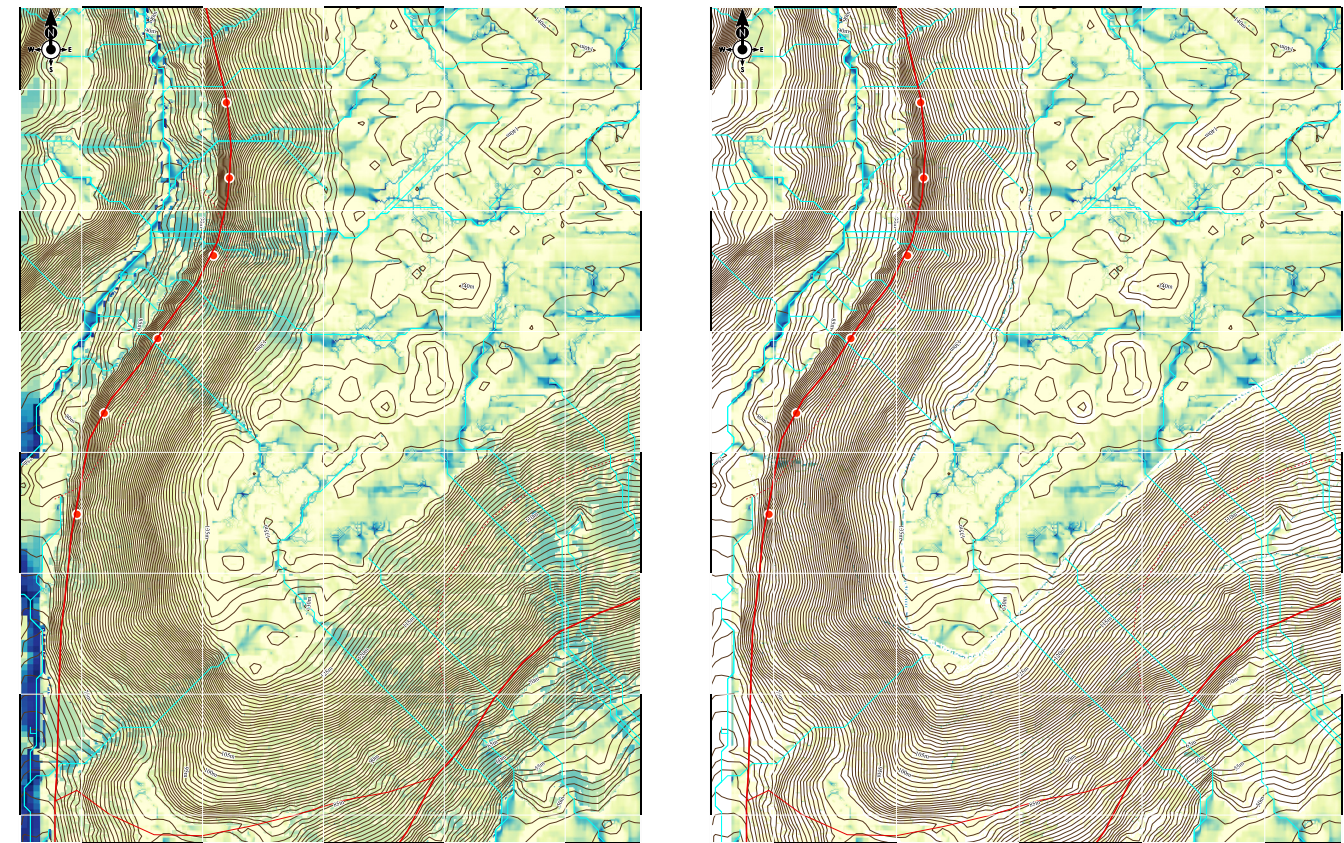
This extended pathway system and the keylines then form the basis for the reforestation proposal (Figure 38). It is recommended to use a dense plantation scheme (4-7 plants/m2), to ensure a successive forest development, forming a well-grown forest that can sustain itself autonomously after two years.

Figure 38. Illustrative image of the reforestation proposal for the western slopes. [Source: by the authors].



This proposal has also been modelled to simulate the differences in the Topographical Wetness Index before and after the intervention (Figure 39). A significant reduction in wetness is achieved, implying improved soil retention, water redistribution, and a consequent decrease in the risk of flooding and landslides.

Figure 39. Topographical Wetness Index of the Western Slopes before (left) and after (right) the interventions with keyline and pathways. Note that the blue color, representing surface wetness, decreases after the interventions. North points to the page header [Source: by the authors].



CHAPTER 10

OVERALL STRATEGIC PLAN

The results of both the regeneration of biodiversity plan for the meseta and the design proposals for stabilizing the soil via reforestation on the southern and western slopes (Figures 40 and 41) show that an increase in ecological quality with a reduction in the risks of flooding and landslides can go hand in hand with urban development. The strategic plan focuses on both biodiversity regeneration and soil regeneration. The two strategies are intrinsically connected, as a rich soil provides the basis for habitat conditions for species in nature. Moreover, measures to increase life on the meseta, such as controlling water, are needed to prevent soil

erosion, particularly on the slopes. In their turn, the slopes, when reforested, will contribute to the regeneration of biodiversity on the meseta. It is essential that the connections as proposed in the strategic plan are not limited nor missed. This will lead to the rapid degradation of natural qualities and biodiversity as such. The large green central space on top of the core ridge, its side ridges and the eco-corridors not only connect the sequence of air wells and stream junctions, but it also connect with the western and southern slope forests. Overall, the interlinkages strengthen the proposal and increase biodiversity relative to current levels.

Figure 40. Overview of a topographic map with a elevation model on the background and contours. Digital cartography of the Biodiversity Regeneration Strategic Plan in the site, including the central green ridge, waterways with stream corridors, junctions with water control structures, keylines (in light green), keypoints (in blue), ridges (in yellow dotted lines), and reforestation in green dots [Source: by the authors]

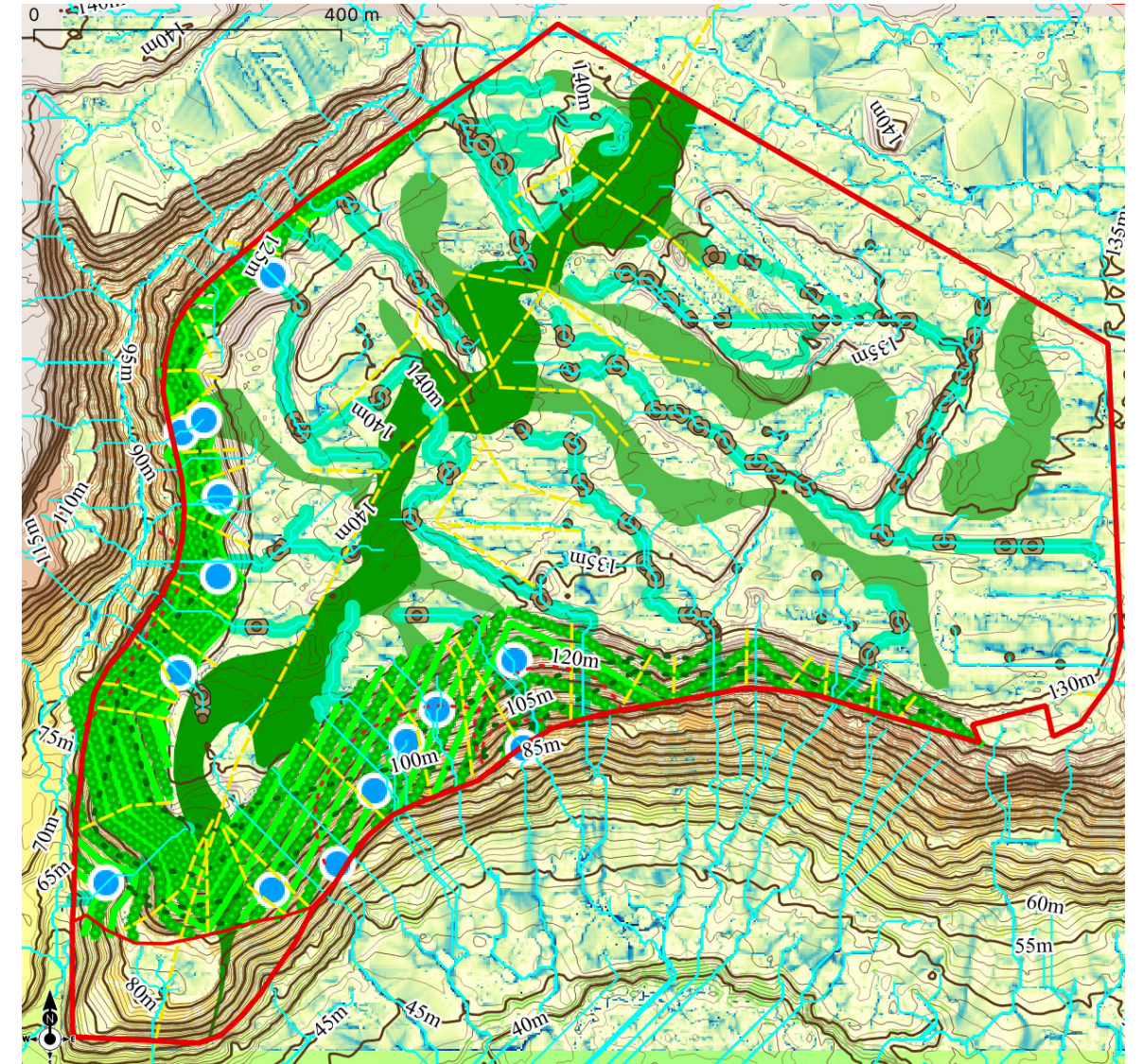
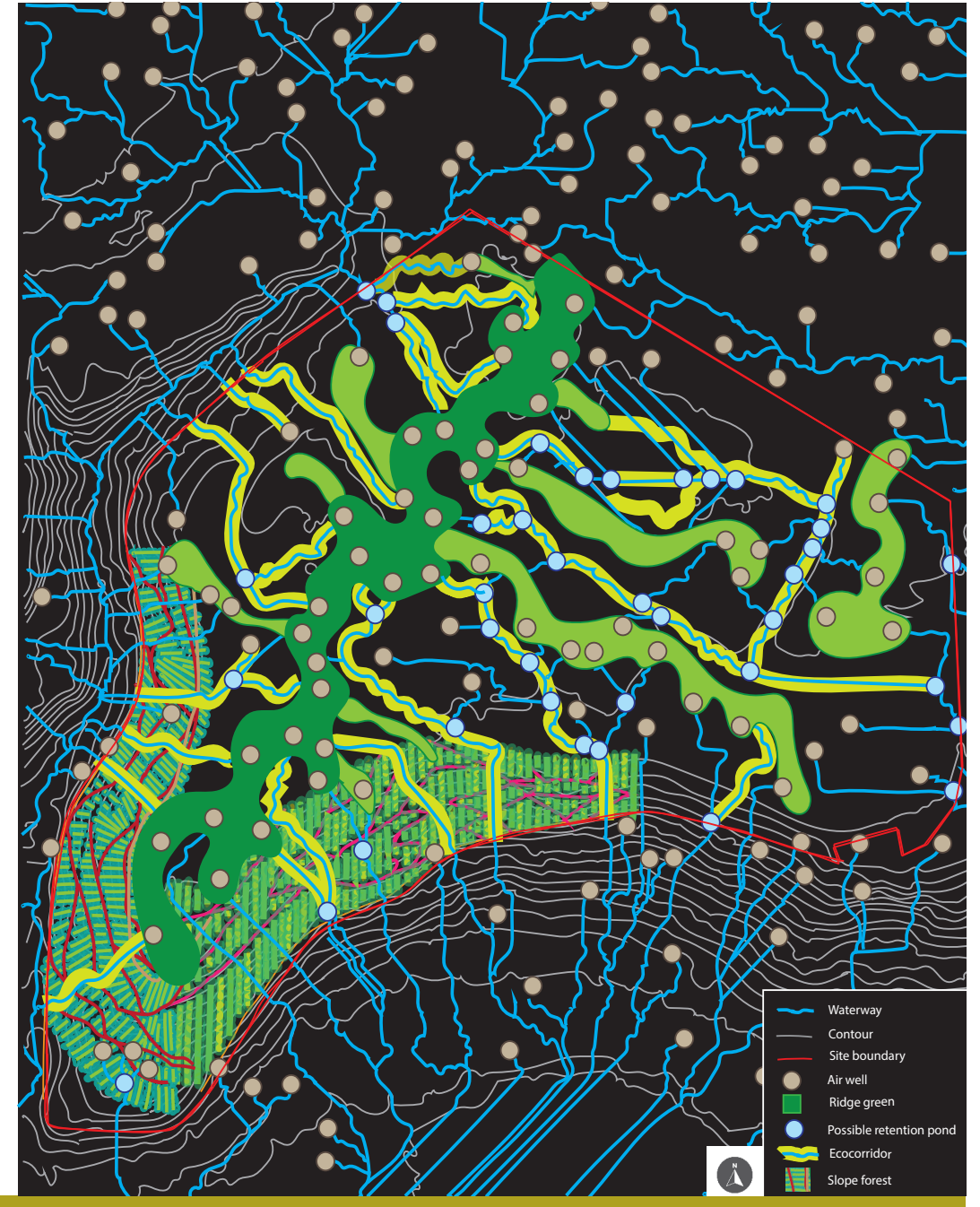


Figure 41. Map showing the greening after applying the Biodiversity Regeneration Strategic Plan for soil regeneration by keyline designs on the slopes [Source: by the authors]



CHAPTER 11

CONCLUSIONS & RECOMMENDATIONS

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The work on designing a strategic plan for biodiversity and soil regeneration in Yumana is vital because it offers a viewpoint on urban development that is embedded in nature and prioritizes the landscape in the planning process. In this sense, it opens its arms to urban design propositions at large and to detailed urban designs, connecting with the strategic features and elements in the regeneration plan: the central ridge green space, the air wells, stream junctions, the eco-corridors, and the slope forests. Urban living conditions are expected to improve for residents of Yumana, owing to the healthy environment provided by regenerated biodiversity and on-site soil.

It is critical to continually use the elements

in this plan as the initial basis for subsequent urban design. The Biodiversity Regeneration Strategic Plan suggests following the recommendations in the legacy geotechnical report regarding the characteristics and uses of rocks and soils. This is important because when urban design is undertaken without accounting for these elements, green spaces in the urban context will become only limited remnants of goodwill, no longer providing healthy and safe conditions for the urban dwellers. Moreover, the remaining, reduced, and disconnected areas for hydrology and ecology are unlikely to provide habitat for the site's many potential non-human inhabitants.

The best way to integrate urban design into this

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strategic plan is to collaboratively co-design urban plans. The geologists, ecologists, and landscape architects who developed this strategic plan, and the urban designers who will design the urban environments, can work together to create proposals in which both ecological and urban qualities are maximized.

This report demonstrates that a strong basis is provided for regenerating biodiversity and soil in Yumana. It could bring more life to the site than is found upon arrival. Therefore, it is recommended to follow-up on this report by experimenting with a couple of initiatives:

- Design and realization of the nursery in the northern part of the site
- Design and implementation of a slope

reforestation project. This part can be large or small and can be chosen anywhere alongside the slopes. A preferred location could be the tip of the slopes at the southern end, as it is the most iconic and significant space. An alternative could be the slope where the risk of landslides and instable soils is largest, between the tip of the southern ridge and the American Consulate location to the east.

- (co)Design and realize a specific urban site in which an air well and/or a water retention area can be integrated into the urban design and development.
- These three suggested experiments can be discussed at the start of the next phase of the urban development process, or as soon as desired.

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