REFILLING PUNJAB'S AQUIFER: Preventing Desertification of the Bread Basket of India

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Well now, before I pack away my maps and notebooks, let me sit a moment and give thanks to the fine folk who helped me on this long and curious journey.

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And as I lay down my pen and tuck these pages into the book of my time, I must whisper, quite honestly:
This practicum is my precious.

1. Snoop Dogg, "Snoop Dogg's Star Ceremony on the Hollywood Walk of Fame," Hollywood Walk of Fame, November 19, 2018, YouTube video, 3:20, https://www.youtube.com/watch?v=oPCcZfM3eUA.

ABSTRACT

Punjab, known as the bread basket of India, is facing an ground water crisis. The over extraction of groundwater for water intensive crops s such as Rice, a legacy of the Green Revolution, has pushed the aquifers of the state towards critical depletion. As a result, Punjab is expected to face desertification by 2050, threatening the food security of the country.

This practicum is both a design inquiry and a personal exploration, as an effort to reconnect to the landscape my grandmother once knew and told me stories about. Farming as not only an essential chore but an activity the community worked on together.

This project explores design to harvest water and refill the aquifer while maintaining agricultural productivity in the state of Punjab, at the Bist Doab region scale, and finally an inter-village scale. The aim is to design a landscape structure that slows, stores and recharges water through different strategies, while offering spaces for cultural and community life.

"When the balance is broken, the land suffers."[2]

Avatar Aang, Avatar: The Last Airbender, Season 3, Episode 1, "The Awakening" (2007)

2. Avatar: The Last Airbender, Season 3, Episode 1, 2007

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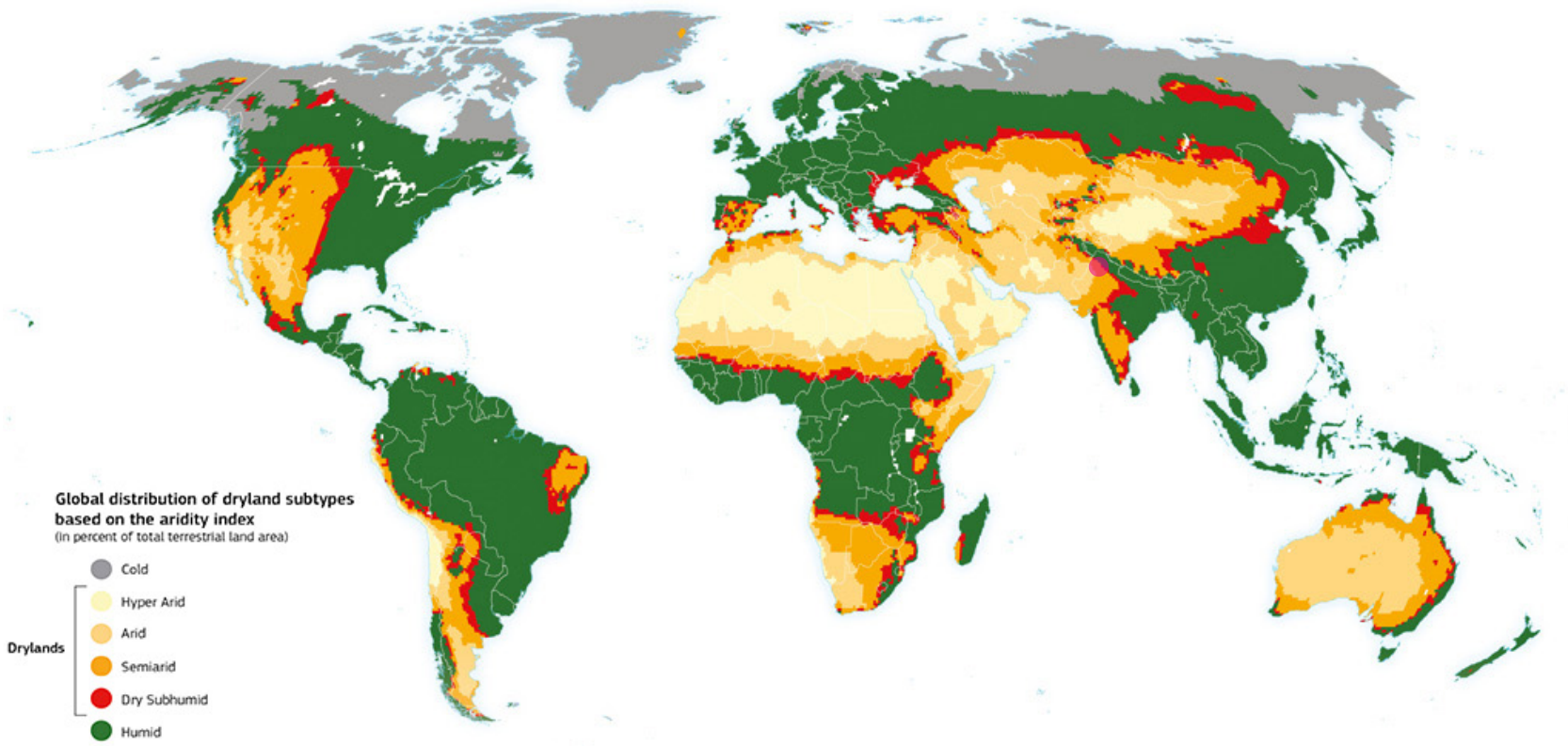


Figure 1: Global distribution of dryland subtypes based on aridity index - Punjab is under the category of humid to sub-arid

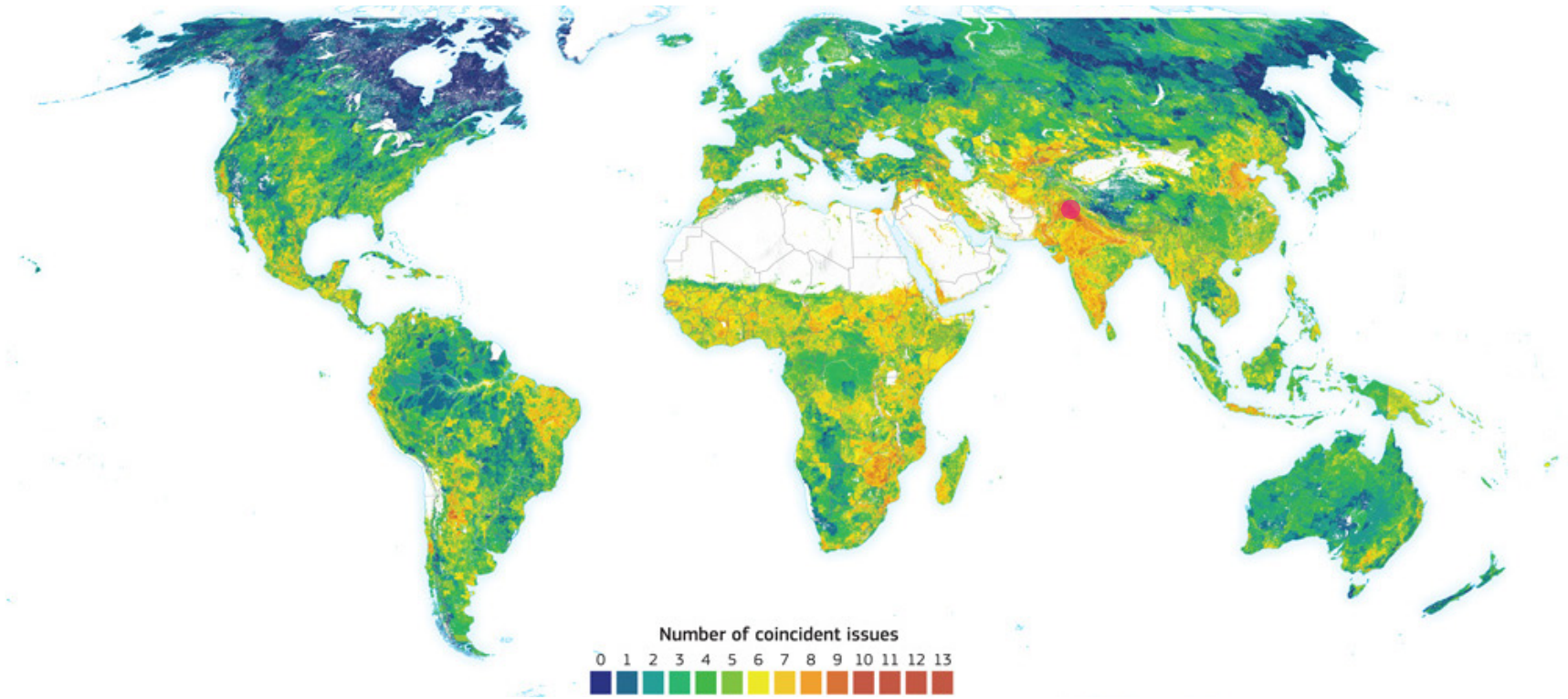


Figure 2: Convergence of land degradation risks based on the third edition of the World Atlas of Desertification.
The map shows areas where multiple land degradation risks occur simultaneously. Color shading represents the number of overlapping risks.

01 GLOBAL DESERTIFICATION

Desertification is usually seen as a problem in dry regions, but it is now happening in places that were once rich, wet and fertile. One such area is Punjab, India, where groundwater is running low now. This chapter looks at global desertification while also showing how Punjab is starting to face similar problems.

"Land degradation or desertification means reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns such as: soil erosion caused by wind and/or water; deterioration of the physical, chemical and biological or economic properties of soil; and long-term loss of natural vegetation." [1]

Ecosystems and people around the world are impacted. Although there are numerous causes of land degradation, the investigation of desertification will be the main emphasis of this practicum.

While the word brings up the windswept sand dunes of Thar in northwestern India, it is an issue that affects far beyond, to those living in and around the world's arid, semi-arid landscapes, threatening the food security and livelihoods of more than 2 billion people.[2]

The impact of climate change, mismanagement of land and unsustainable freshwater use is resulting in degradation of world's various regions.[3] Therefore, degradation is basically a catch all term for land degradation including temporary or permanent decline of soil, vegetation, water resources or wildlife. This in turn causes economic deterioration of the productivity of the land.[4] Arid, semi-arid and sub-humid areas cover 2.7 billion people, 90% of which are in developing countries.[5] (Figure 1)

"Sadly, it's much easier to create a desert than a forest"[6]

The main causes for desertification includes

1. deforestation,
2. overgrazing of livestock,
3. crop over-cultivation and inappropriate irrigation (including over use of groundwater) and secondarily,
4. natural fluctuations such as climate and global warming due to human activities. [7]

Desertification is a long process that is hard to recognize from the beginning as it takes decades to show signs that a landscape is changing. By the time it is identified, it may be too difficult to stop or reverse the damage caused. Moreover, the extents and severity is difficult to confirm due to unreliable information. The cause of desertification is not singular, hence, the world atlas of desertification uses 14 variables associated with land degradation, such as aridity, livestock density, land productivity, etc. (Figure 3), and concludes the degraded areas where the variables coincide. [8] (Figure 2)

While desertification is typically associated with increasing aridity in dry lands, this is not universally true. Some regions, including parts of India, are expected to become wetter by 2100 due to a decline in Potential Evapo-transpiration. [9] (Figure 4)

Land and its water bodies provides for human livelihoods and well-being, supporting primary productivity, food supply, freshwater resources, and numerous ecosystem services. Humans use roughly one-quarter to one-third of global terrestrial potential net primary production. Since 1961, global per capita food calorie supply has risen by about one-third, with vegetable oil and meat consumption more than doubling. Croplands now account for 12–14% of the planet's ice-free surface. Meanwhile, the use of inorganic nitrogen fertilizers has surged nearly nine times, and irrigation water usage has approximately doubled. Human activity impacts 60–85% of forests and 70–90% of other natural ecosystems, including savannahs and grasslands. This extensive land use has led to an estimated 11–14% global decline in biodiversity. [10]

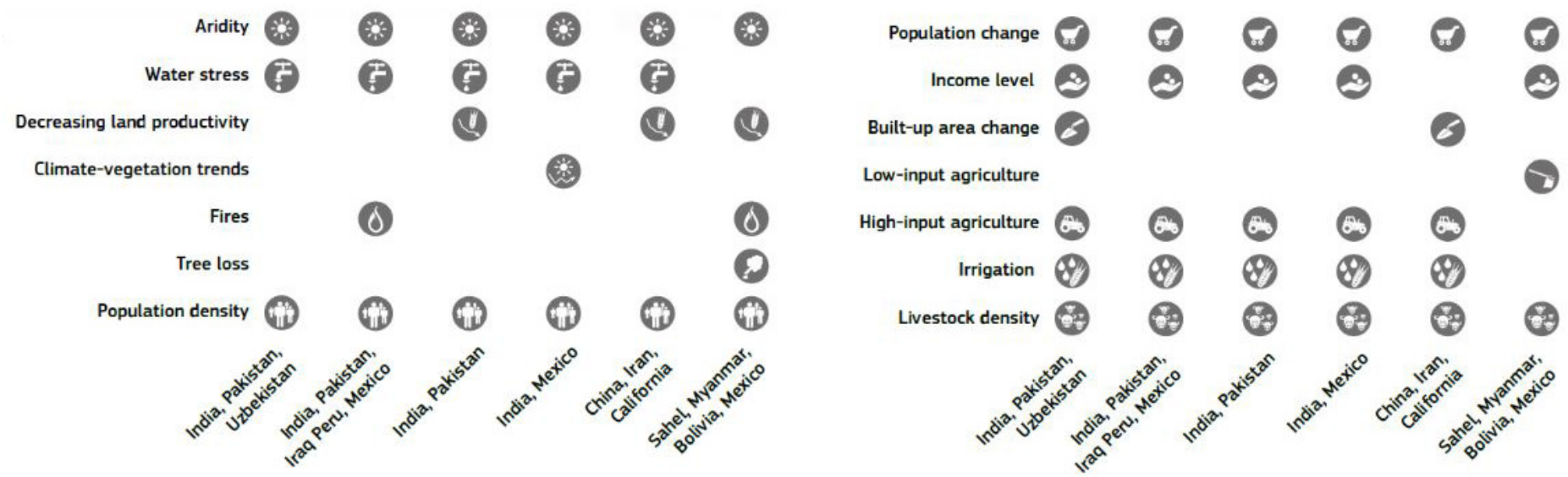


Figure 3: The table shows the six most common combinations of nine overlapping Global Change Issues (GCIs). In total, there are 13,327 different combinations of the 14 GCIs represented in Figure 2.

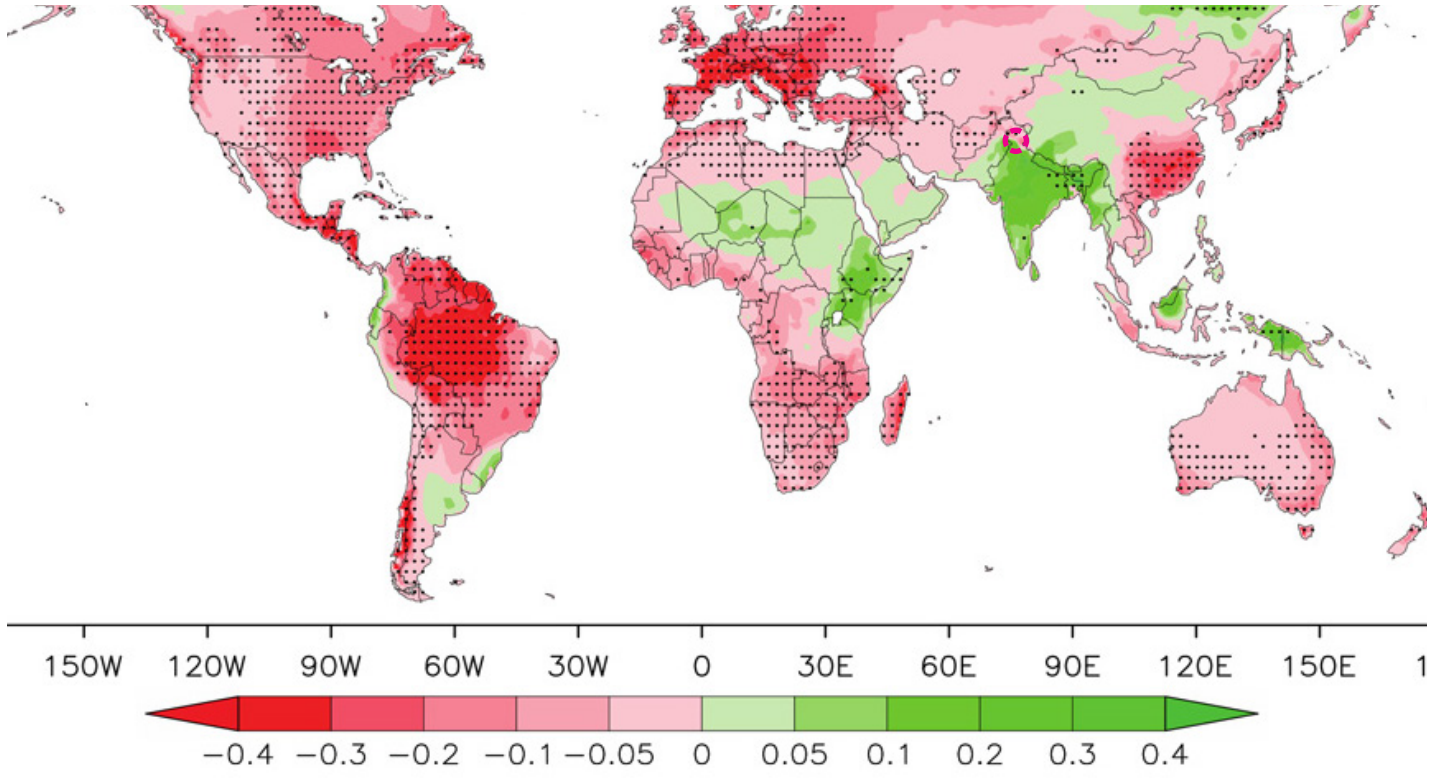


Figure 4: Projected changes in aridity index (the ratio of rainfall to PET). For the area of Punjab, the values range from –0.1 to 0.2, showing that some areas have a small water surplus (rainfall is slightly more than evaporation) while others have a mild water deficit. This means the landscape is generally balanced but can become dry in years with less rainfall.

Desertification has significantly impacted several regions including South and East Asia, the circum-Sahara area, North Africa, the Middle East, and the Arabian Peninsula. Agricultural productivity and incomes have already declined, and biodiversity loss is apparent in some areas. Invasive plant species have further diminished ecosystem services, and groundwater depletion has accelerated due to over-extraction, especially in South Asian countries. Unsustainable land management practices, combined with drought, have intensified dust storms, harming human well-being both within drylands and beyond.[11]
In Asian continent, desertification is currently affecting 38 out of the 48 countries directly. Major river basins, including the Indo-Gangetic Basin in India, Indus Basin in Pakistan, Yellow River in China, Yinchuan Plain in China, Aral Sea Basin of Central Asia are undergoing salinization. [12] Parts of South Asian have been experiencing drying over the last three decades including overgrazing and deforestation in Afghanistan, and Pakistan. 81.4 Mha of land was subjected to various processes of desertification in India in 2005. [13]
Socially speaking, growing human pressures on land, coupled with climate change, will weaken the resilience of dryland populations and limit their ability to adapt. These combined challenges including climate variability, human-induced climate change, and desertification are likely to worsen poverty, food insecurity, and health problems, with the potential to spark conflicts. While the link between climate change and migration in drylands remains contested, desertification under shifting climatic conditions may, in some cases, encourage migration. Women, particularly in regions heavily reliant on agriculture, are expected to face greater impacts from environmental degradation compared to men. [14]
The reduced water retention capacity of degraded soils exacerbates water scarcity by amplifying flood risks, promoting soil erosion, and limiting the replenishment of aquifers, which worsens existing water shortages. [15]
As for India, one of the major causes of desertification is the ground water pumping for agricultural irrigation and water consumption in settlements. The Green Revolution in India addressed food security challenges but brought up a bigger problem, such as introduction of commercial agriculture and over-exploitation of groundwater resources. It has unintentionally aggravated water scarcity and heightened expectations for irrigation water, worsening the issue. According to the UN Convention to Combat Desertification (UNCCD), India lost 30.51 million hectares of healthy land to degradation between 2015 and 2019, representing 9.45% of its landmass. This degradation, affecting 251.71 million people (18.39% of India's population), has compounded challenges like drought, which affected 854.4 million people between 2015 and 2018. To mitigate these issues, the UNCCD emphasizes the importance of working with India to restore one billion hectares of healthy land by 2030, underscoring the critical need for collaborative efforts to address land desertification and its broader socio-economic impacts. [16]



Figure 5: Map of India, indicating Punjab's location.

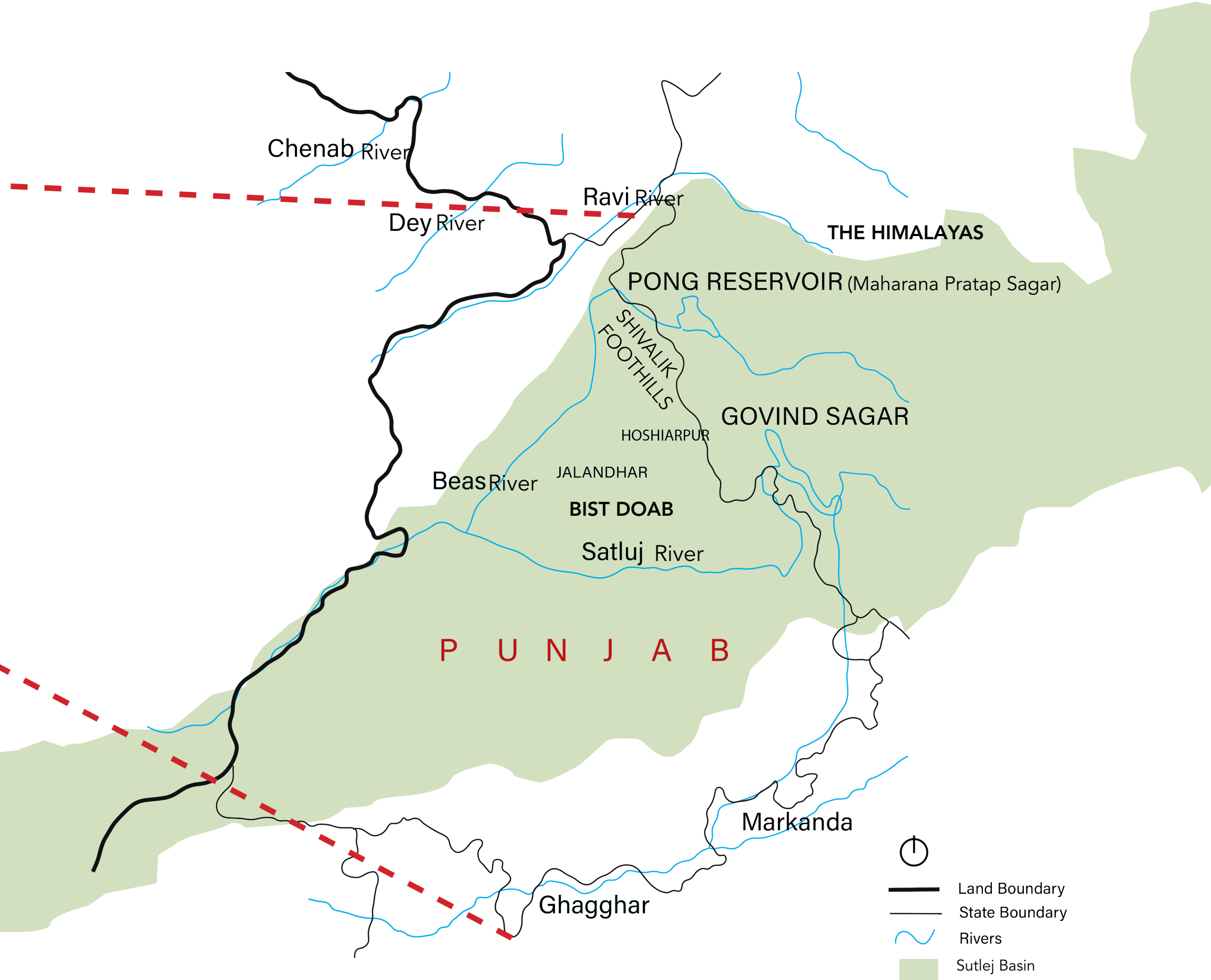


Figure 6: Punjab and its major Rivers



Figure 7: Transplantation of Rice crop in Punjab.

Within the context of India, Punjab (figure 5 & 6) is a region that needs immediate attention in terms of desertification. Punjab is famous for its agricultural productivity, but it is not completely a dry area. The southwest part of Punjab is semi-arid and gradually becomes part of the Thar Desert. However, most of the state is a fertile alluvial plain with a well-developed irrigation system. Punjab's climate is continental, ranging from semi-arid to sub-humid, with hot summers and mostly dry winters.

Between 2000 and 2010, groundwater assessments showed a rise in the number of overexploited blocks (a sub-division of a distrcit), where groundwater extraction exceeds annual recharge.

About 86.7% of the groundwater that is naturally replenished each year is already being used in the state. This means that out of the 18.22 billion cubic meters (BCM) of groundwater renewed every year, most of it is extracted, showing that groundwater resources are heavily used and at risk.[17]

Increased groundwater over-exploitation has been observed primarily in the northern and central parts of the Sutlej basin. Conversely, water-logging, salinity issues, and problems with high fluoride, selenium, and arsenic levels have been reported in the southwestern region and lower Sutlej basin.[18] Overall, these findings indicate a troubling imbalance between groundwater withdrawal and recharge, with most of the basin experiencing negative groundwater storage balances. The compounded effects of these ground water-related challenges including reduced soil quality, declining groundwater levels, and rising salinity are accelerating desertification in Punjab, which threatens not only the landscape but also the livelihoods of millions dependent on agriculture. This situation underscores the urgent need for sustainable water management practices to restore the balance between groundwater extraction and recharge, improve soil health, and prevent further land degradation in Punjab.

Therefore, focusing a project on Punjab is necessary , not only to address the region's pressing challenges but also to develop a framework for strategies that can be adapted nationally. By examining the complex interplay between agriculture, water management, and land use in Punjab, the project aims to generate valuable insights applicable to other regions experiencing comparable pressures. This approach enables the development of scalable and context-specific solutions to mitigate desertification, contributing to broader efforts in sustainable land and resource management on a global scale.

Additionally, growing up, I often heard my grandmother's stories about rural Punjab, that how the land was fertile, ponds were full, and people gathered under trees to rest. Her memories reflect a vibrant landscape closely connected to nature, which now contrasts sharply with the environmental challenges the region faces today.

1.1 Design Framework

This research framework outlines the key questions, methods, and approaches used to understand landscape changes in Punjab and explore resilient strategies for groundwater recharge.

1.1.1 Research Question

To guide this exploration, the main research question is 1. how can I redesign the agricultural landscape of Punjab in a way that the soil is regenerated, the water is collected, purified and stored in the aquifers to create a water balance and;
2. the landscape has enough green areas where people can have pleasant spatial experiences, much like how my grandmother used to experience and appreciate the natural surroundings in her youth.

1.1.2 Design Objectives

The agricultural landscape of Punjab is expansive and deeply intertwined with the natural systems and cultural practices. The agricultural landscape of Punjab is spread over a very diverse region, which requires multi layered, multi scalar approach to address the research questions as well as design objectives. The design objectives are as follows:

1. Harvest rainfall water and Recharge the Aquifer.

2. Optimize water use through resilient farming practices.

3. Prevent wind and soil erosion.

4. Integrate cultural elements and create multi-functional community spaces rooted in agriculture.

5. To maintain crop production levels and ensure farmer income remains stable.

A design response to this region must address these aspects at three scales -

i. at the state level of Punjab through strategic planning;

ii. at the regional scale of the Doab region;
iii. the inter-village scale, where more detailed and testable design interventions are developed.

State and Regional (Bist Doab) System

- Create an ecologically resilient agricultural practices including cropping patterns that adapts to the groundwater depletion and shifts towards water conservation practices.
- Restore and enhance traditional water management systems and restore wetlands to slow, store, reuse surface water and infiltrate or recharge the aquifer.
- Re-establish native vegetation and establish agro-forestry to recharge aquifers, and improve biodiversity.
- The strategies at these scales are largely informed by existing policies and frameworks.

Inter-village System

The design at this scale for refilling the aquifer, must be envisioned as a model framework that could be adapted to similar water stressed, intensively farmed areas. Therefore, this practicum also outlines design objectives that guide the development of smaller, localized projects to directly respond to the unique characteristics and needs of inter village site. Inter village scale interventions demonstrates how cultural heritage, water conservation and food security can co-exist and support each other.

- Design water harvesting systems for farmlands to reduce dependency on tube well irrigation and support farmers.
- Integrate social and cultural spaces, into the farming systems to maintain social ties and cultural continuity.

1.1.3 Theoretical Framework

1. **Personal experiences**
This practicum draws on cultural experience and memory-based approaches to understand and respond to the transformation of Punjab's agrarian landscape. Rather than relying solely on architectural theory, it takes inspiration from lived experiences and local knowledge systems, especially as shared through stories told by my grandmother. Her memories of a diverse, self-sustaining landscape of communities coming together, water systems, and diverse crops offer more than nostalgia, they act as a lens through which to read the land and interpret its changes over time.

2. Regenerative Agriculture (RA) and Water Management
In literature, Regenerative Agriculture emphasizes on five objectives
i. Ensuring Optimal crop evapo-transpiration to manage the water use over time to sustain rain-fed crop growth and yields, alongside proper soil, seed and nutrient management.
ii. Reducing surface runoff and improved infiltration while encouraging water seepage into the soil, which can improve water quality.
iii. Coordinating the use of rainwater and irrigation at both field and farm levels for more efficient water use.
iv. Managing water withdrawals and allocation more efficiently at the catchment level through resource planning.
v. Enhancing soil organic matter and increasing carbon storage in the soil for long term ecological goals.[19]

The RA theory in this practicum works as both a design strategy as well as a guide to address groundwater depletion and land degradation for the Punjabi landscape. This approach helps propose solutions that restore natural water cycles, improve soil health, harvest water in accordance to the natural resources present, and in turn reduce reliance on tube wells.

3. Landscape as Palimpsest
A landscape is one where the area is made up of landforms of different ages, some actively shaped by present day conditions, and some formed by past environments or processes no longer at work. Each new change creates a new layer, like snowfall, partially covering but never fully erasing the traces beneath[20], or as in this practicum, pre-green revolution farming, colonial canal systems, etc,.
In the essay, The Agency of Mapping by James Corner, it revolves around mapping used as a tool to uncover these hidden layers, revealing the multiple temporal and spatial narratives of a place or region.[21] Through mapping, the landscape is not seen as fixed, but an evolving and overlapping record of natural and cultural factors, which is basically the essence of a palimpsest. In this practicum, the layered history of the region was explored through historical maps to present day to recognize the active and remnant systems, guiding in creating strategies honoring these layers.

4. Regional Landscape Architecture Theory
This theory focuses on designing landscapes that respond to the unique ecological, cultural, and social aspects of a region. It focuses on the integration of local natural systems, agricultural practices, as well as community needs. Literature such as Ian McHarg's *Design with nature* talks about ecological planning.[22] Additionally, Sprin's *The language of Landscape* discusses how landscapes communicate with cultural and ecological stories.[23] They both focus on integrating ecological, cultural, and social factors into landscape spatial design to create context sensitive solutions abiding by the theory. This theory guides this project to address specific ecological and cultural needs of the region.

5. Managed Aquifer Recharge (MAR)
MAR Refers to the intentional process of storing and treating water in Aquifers. It is a controlled method of that differs from incidental recharge, which occurs due to activities like land clearing, irrigation, etc,. It is also known as enhance recharge, water banking, or sustainable underground storage and focuses on water management by deliberately increasing aquifer recharge using different methods. This is focused on long term availability and quality by storing any excess water in underground aquifers. It uses different types of systems including Dune filtration, infiltration ponds, percolation tanks, rainwater harvesting, soil aquifer treatments, underground dams, sand dams, recharge releases.[24]
The practicum applies a lot of methods from this theory to strategically fill aquifers such as injection wells and harvesting water for irrigation for long term availability for agriculture, eventually helping in mitigating the risk of desertification and to support resilient farming practices.

1.2 Methodology

Principles of landscape architecture are guiding the overall design, starting with the layer approach for site analysis and regional planning to understand the physical and cultural characteristics of the landscape. The analysis is performed on the natural, cultural and urban layer, understanding the current functional and spatial qualities of the landscape as a result from processes over the past till now.
These layers are evaluated to understand current functional and spatial qualities. This way of understanding the current agricultural practices, land use patterns, and water systems in the region, gives direction to how these can be transformed into more sustainable and adaptive landscapes for future (climate) conditions. This is explored through the following questions:
i. What did the landscape of Punjab look like, how was it organized in the years prior to the green revolution?
ii. What were the consequences of the green revolution?
iii. What is the influence of climate change on the current landscape?
iv. What are effective strategies for recharging aquifers/ groundwater?

Spatial needs of the areas are identified such as:
1. Areas suitable for aquifer recharge
2. Spaces for new plantations
3. Suitability of alternate cropping options
4. Locations for community gathering spots

The data is collected through desk study and field visits.

Desk study consists of:
-literature study; research papers on geomorphology, precipitation, soil, waterways and historical data such as the original farming practice, surface water management, ecological preservation,

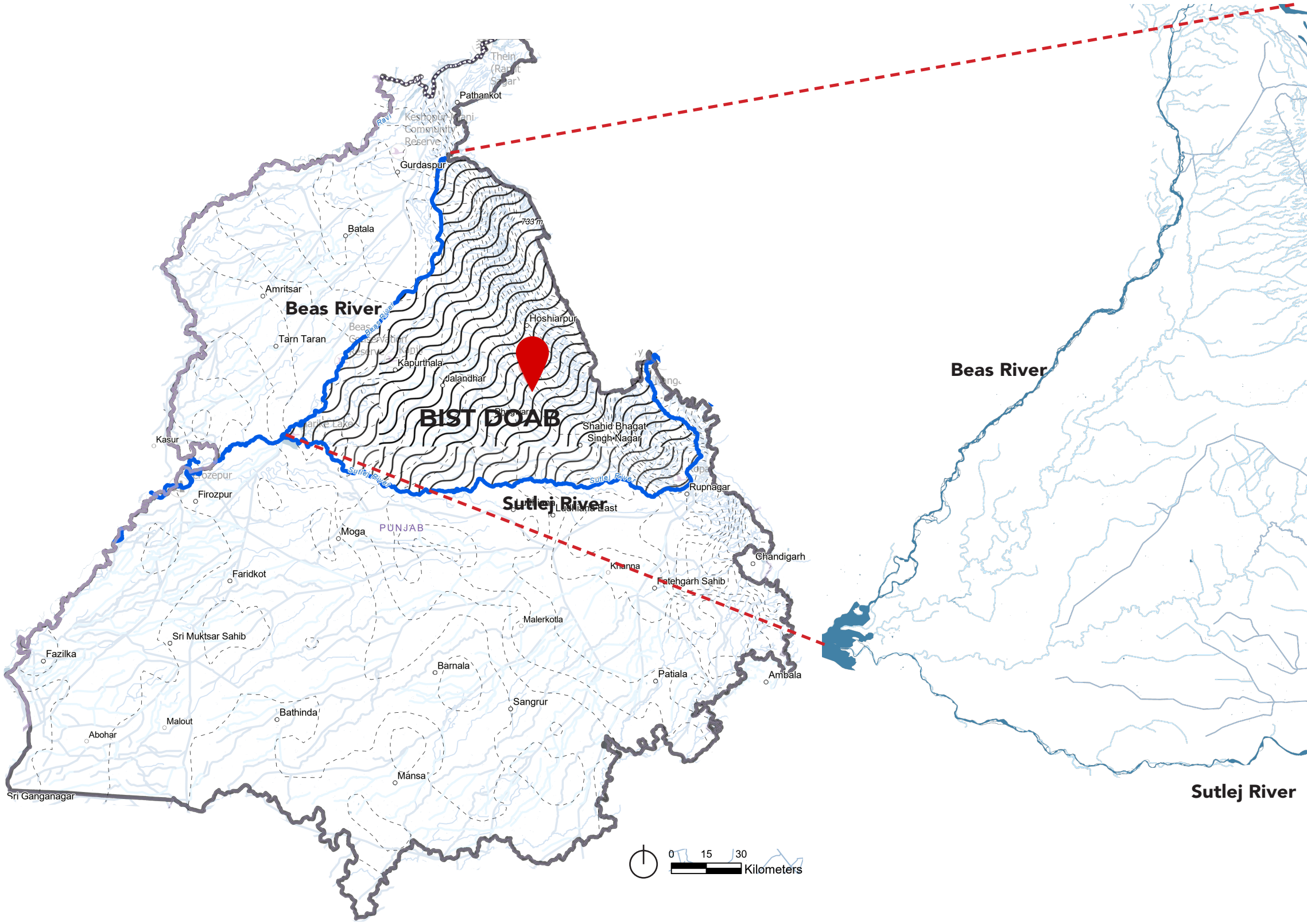
-mapping with the most important databases being government websites such as the Forest Survey of India, Indian Meteorological department, GIS databases, open data platforms.

Design and Representation is done through different types of drawings, plan, perspective, sections, and sectional elevations.

The analysis and design are explored across three spatial scales as mentioned under design objectives.
The design exploration starts from the strategies for aquifer recharge and water management at the State scale after thoroughly analyzing the state. Later on, it zooms in to the Bist Doab Region, a regional scale to develop more localized strategies for more similar landscape characteristics.
Finally, the design zooms in on the inter-village scale, refining these strategies into the detailed interventions for ecological and cultural needs. This is achieved through various iterations of water management systems at an inter-village scale in the district of Hoshiarpur, and in block of Garhshankar.

Initial sketches imagine landscapes characteristics or factors capable of recharging groundwater. These evolve into iterations that not only recharges water but also support harvesting water for agriculture and maintained productivity in alternate cropping patterns, eventually avoiding the risk of desertification.
In addition, it starts to focus on cultural gathering spaces to provide a landscape that fosters communities.

Over time, the focus expands towards designing systems at inter-village scale that are both locally responsive and scalable across different areas within the Doab region.



STATE LEVEL SCALE

REGIONAL SCALE

Figure 8: Three different scales

Original size 1:1,250,000 on 12X12”





- BIST DOAB REGION

INTER VILLAGE SCALE

Original size 1:550,000 on 12X12”

Original size 1:20,000 on 12X12”

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20



Figure 9: Typical present day agricultural landscape of Punjab.



Figure 10: Illustration of story

02 PHYSICAL CONTEXT

2.1 Personal Connection

Today, following the Green Revolution, Punjab's landscape has been transformed into an intensive agricultural region, causing several challenges to the people such as groundwater depletion, soil degradation, and loss of biodiversity. This differs significantly from the landscape of the past, which my grandmother often talks about as mentioned in Chapter 1. I recall her telling me stories about how different the landscape was when she was young. She would describe the vast fields bordered by thick canopies of trees, where they offered cool shade on the hottest days. My grandmother spent most of her life in Hoshiarpur and Jalandhar. Chagran and Mahilpur are villages and small towns in Hoshiarpur, where she spent her younger years. The land has diverse uses, and the communities have a profound bond with it. My father also spoke of his childhood adventures, walking through the trees and alongside 'choes', natural drainage channels during monsoons; these choes would brim with water, safeguarding the fields and villages from flooding. However, these once-thriving landscapes have changed drastically. The loss of native vegetation, depletion of groundwater, and increasing soil degradation have contributed to a shift towards future desertification in Punjab.[1]

2.2 Physiography

Punjab,an agrarian state deeply rooted in farming traditions, highlighted through its festivals such as Baisakhi marking the harvest of winter crops, is located in the northwestern region of India, covers an area of 50,362 square kilometers. It is bounded to the west by Pakistan, to the north by the state of Jammu and Kashmir, to the northeast by Himachal Pradesh, and to the south by Haryana and Rajasthan (figure 6).
The name "Punjab", which translates to "Land of Five Rivers", reflects its historical geography prior to the partition of Hindustan into present day Pakistan and India. [2] These five rivers are the Sutlej, Beas, Ravi, Chenab, and Jhelum; today, only the Sutlej, Ravi, and Beas flow through the Indian state, while the Chenab and Jhelum traverse the Punjab province of Pakistan. The state consists of the following districts, namely, Amritsar, Gurdaspur, Hoshiarpur, Kapurthala, Jalandhar, Ludhiana, Ferozpur, Faridkot, Bhatinda, Sangrur, Patiala and Rupnagar. [3] As of 2024, Punjab has a population of 32.678 million. [4] (Punjab occupies a unique geographical position within the Indo-Gangetic plains of India, situated along the water divide between two major river systems namely, the Indus water system, which drains into the Arabian Sea, and the Ganga system, which flows into the Bay of Bengal, making the region very fertile. The drainage network of the plains is characterized by diverging ephemeral streams, emphasizing the complex hydrological dynamics of the area.[5] Punjab can be categorized into three zones, each defined by unique climatic and hydrological characteristics.
The foothill region, situated along the Shivalik Hills and this region receives an average annual rainfall of 950-1000 mm.[6] The terrain in this region is sloping and prone to water erosion, while groundwater reserves, though deep, are of high quality and supports agricultural productivity.
The central region, also known as the granary of India, where the design site is, contributes about 50% of Punjab's total area. This region has fertile alluvial floodplains with an average annual rainfall of 600-650 mm. [7] The groundwater here is both fresh and deep, which makes it highly suitable for intensive agriculture. As a result, two-thirds of the state's wheat and rice production occurs in this zone, and the two-thirds of Punjab's tubewells are concentrated here,

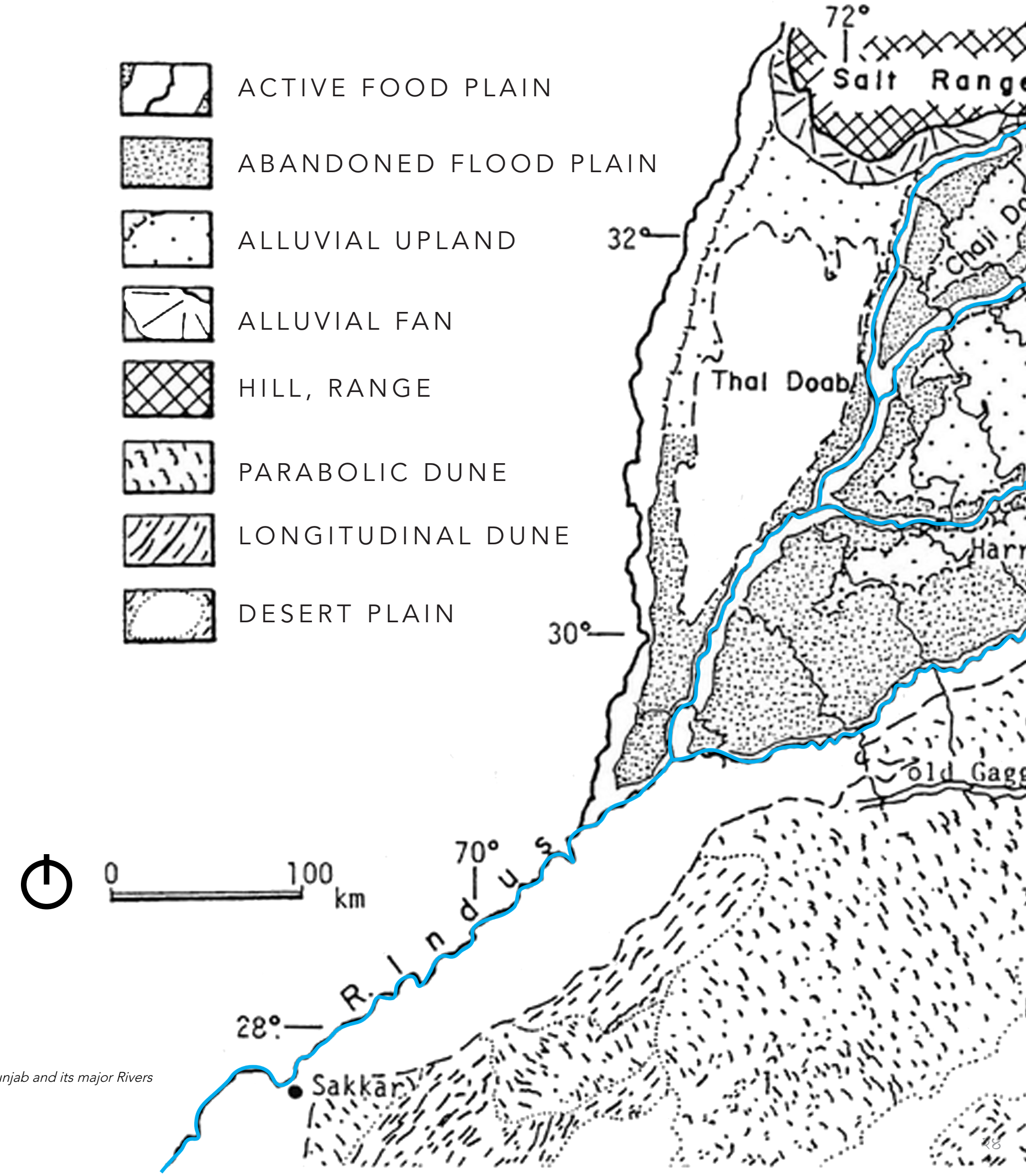
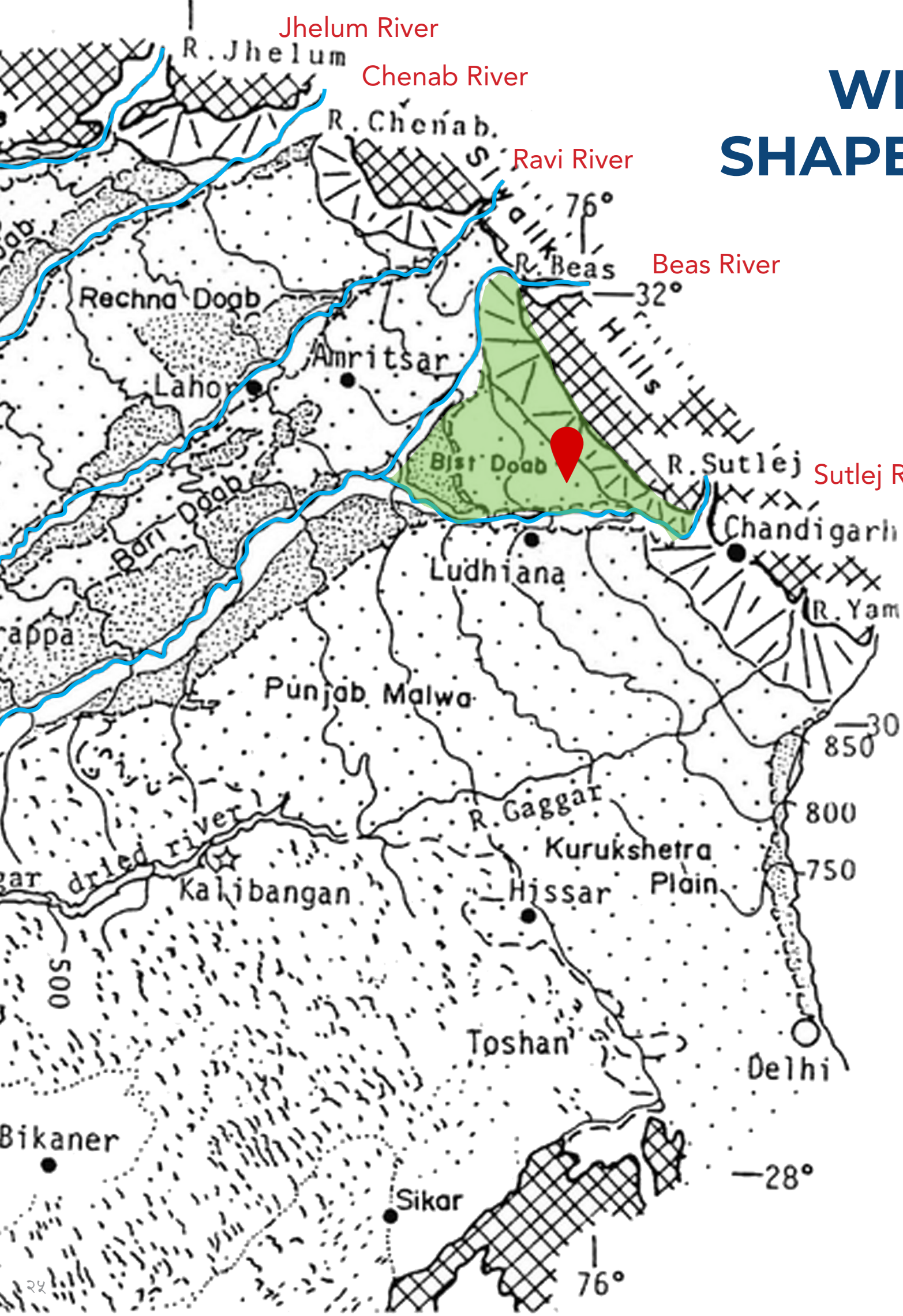


Figure 11: Historic Punjab and its major Rivers

WHERE RIVERS SHAPED THE LAND



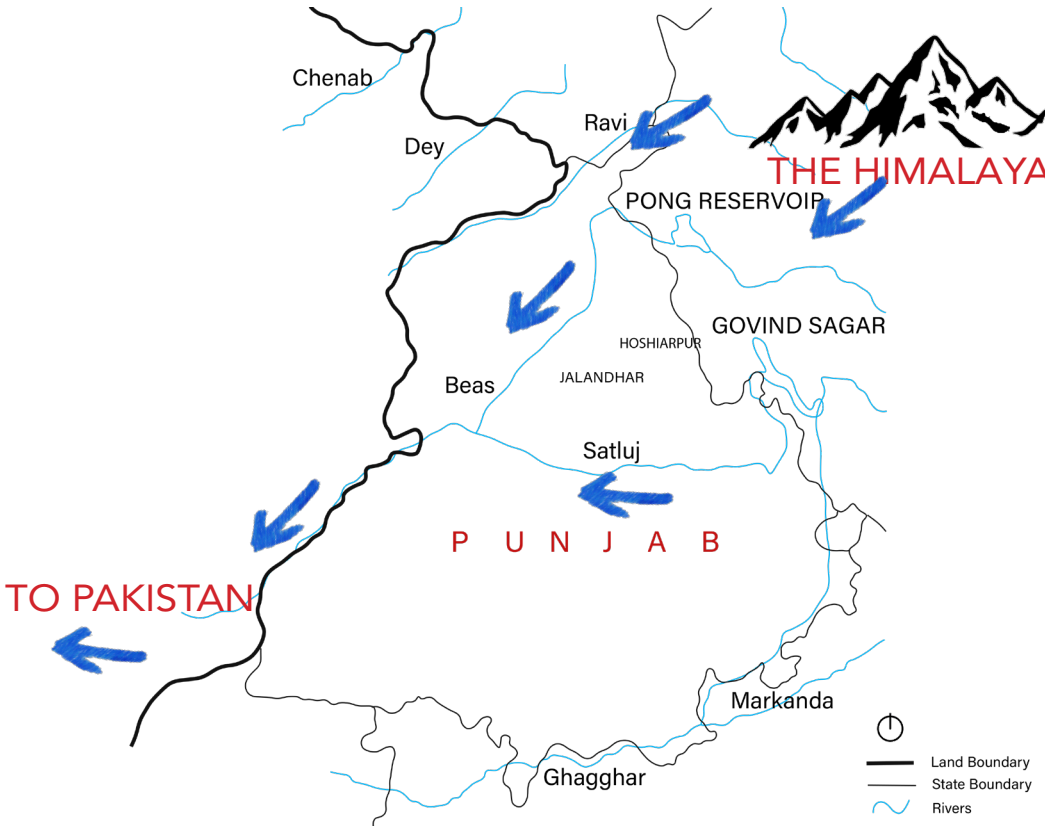


Figure 12: Punjab's Water flow direction

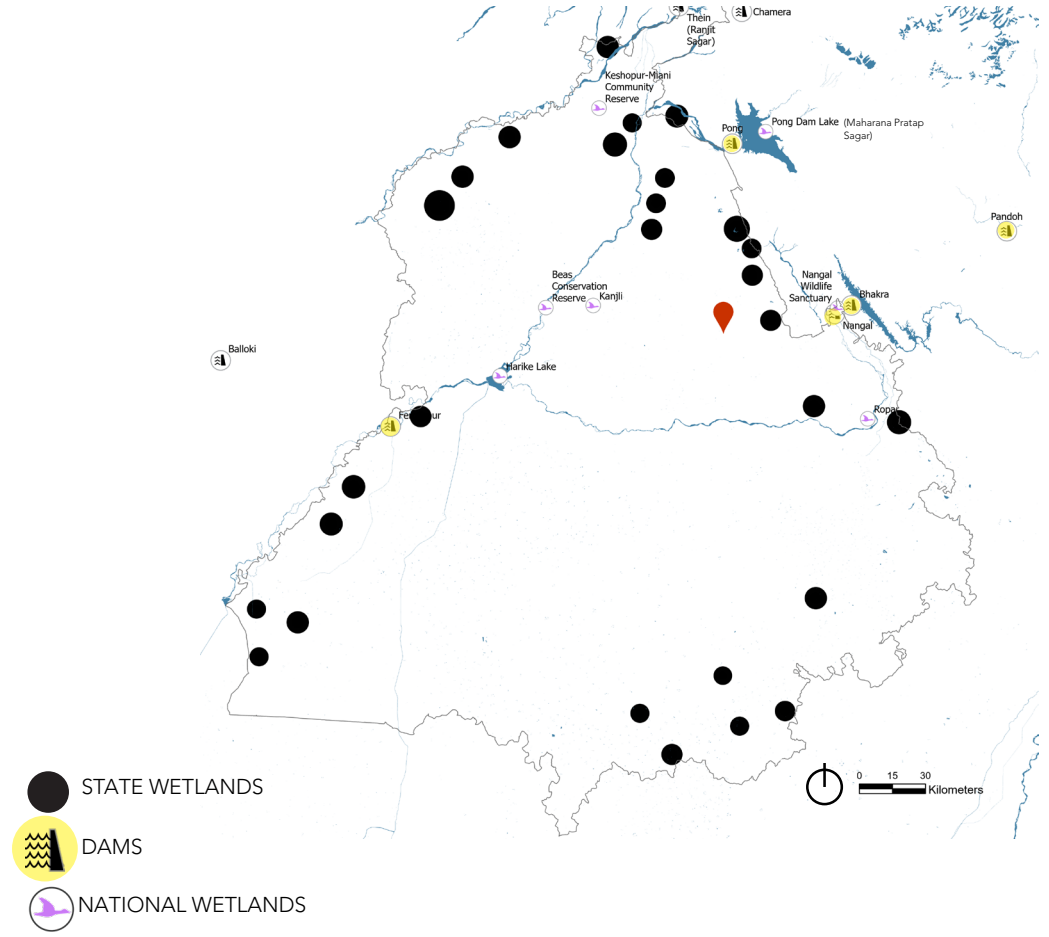


Figure 13: Dams and Wetlands of Punjab

highlighting its significance in the agrarian economy. The southwestern region, which accounts for nearly 37% of the state's land area, experiences the lowest annual rainfall, averaging 400 mm.[8] Groundwater in this region is saline, therefore, making canal irrigation essential for the continuation of agricultural activities. This region faces problems such as water-logging and soil salinity, which threatens long-term agricultural productivity as well as the environment. [9]

2.3 River System

The three main rivers of Punjab, Beas, Sutlej, and Ravi originate in the Himalayas, flowing through valleys (figure 11). As the rivers descend, they expand into wide valleys with meandering paths. During the winter, the streams are small, but with the melting of snow in the hot season, water levels rise and in return they flood the adjacent lands. After the rainy season, the waters recede, making the soils fertile by sedimentation of sand, silt and clay. The major irrigation canals in Punjab include Bhakra, Sirhind, Upper Bari Doab, and Bikaner. [10] The area between the Beas and Sutlej is called Bist Doab, which is the area of study for the second scale - regional.

The Sutlej, historically, was a part of Ghaggar River system, which used to flow independently through Jaisalmer and discharged into Rann of Kachchh. Over time, however, the river gradually shifted westward and became integrated into the Indus River system, leaving behind it remnants of its original course.[11]
Additionally, many sites along the Sutlej River have long been perceived as vulnerable to flooding, which poses risks to nearby settlements and infrastructure. Seasonal floods in the region often result in significant losses, including damage to crops, property, and human lives, by washing away topsoil and reducing vegetation cover, they contribute to land degradation and accelerate the process of desertification.[12]
Moreover, as the rivers of Punjab originate from snow and glacier fed sources in the Himalayas, there has been a change noticed that is the decline in snowfall and retreat of Himalayan glaciers. A study revealed a reduction in snow cover across the Indian-Western Himalayas from 173,776km^2 2008-09, to 169,496km^2 in 2014-15. This decline is expected to directly affect the discharge levels of Punjab's snow fed rivers. A 40 year mass balance analysis of different glacier types indicated an average change of -0.3 ±0.13 meters of water equivalent per year, confirming the ongoing retreat of the glaciers and its effects on freshwater availability of the rivers.[13] Therefore, it is crucial to prioritize rainwater harvesting.

2.3.1 Wetlands

The natural wetlands of Punjab, which once covered an area of 9300 hectares, have now been significantly reduced, particularly since the Green revolution in the 1960s. Thirty two wetlands that used to exist in the 1940s are extinct due to human reclamations they were drained and leveled for agricultural purposes.[14]
Ancient Punjab had a vast collection of wetlands, but in the present day only 0.46% of Punjab is covered with wetlands. 15,000 hectares of area is covered with wetlands larger than 10 hectares. Man-made wetlands cover about 8000ha which has increased from 6500 ha in the 1960s. While there are 30 wetlands of natural origin existing, many of them have lost the characteristics of being a wetland. Punjab hosts wetlands of national importance including Harike wetland (3713.76 ha) which is man-made, and situated at the intersection of Sutlej and Beas River (figure 13). However, the wetland faces several threats, including weed growth, siltation, pollution from industries, urban areas and significantly from agriculture, fishing and poaching, and overgrazing, encroachments for unauthorized agriculture which has taken 792 ha of the wetland. Other wetlands of national importance including Kanjli wetland, Ropar wetland, Nangal wetland, faces similar problems.[15] This is a huge issue as wetlands are ecologically essential as they provide habitat for flora and fauna, in addition to water management, such as regulating water flow, recharging groundwater, and maintaining water quality. The loss of wetlands reduces natural water storage and infiltration, which lowers groundwater recharge and contributes to groundwater decline, making it an important issue for this project.

2.3.2 Dams

Dams on the rivers of Punjab have been constructed such as Bhakra Dam on Sutlej River, Thein Dam on

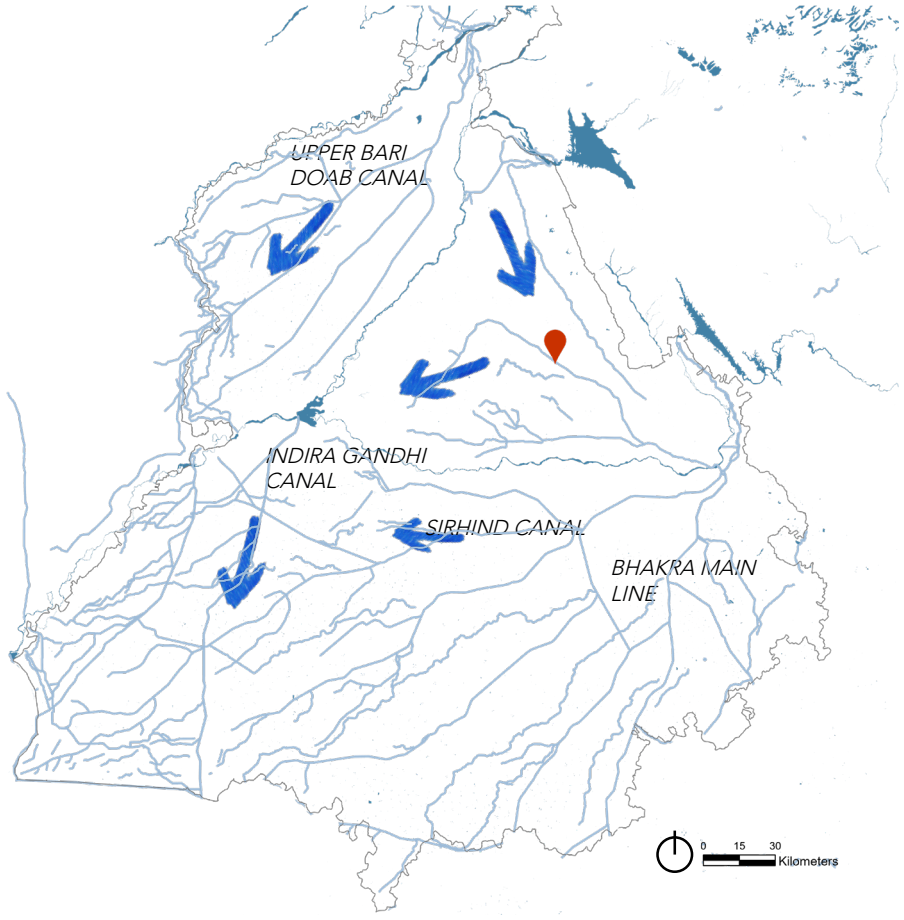


Figure 14: Canal System

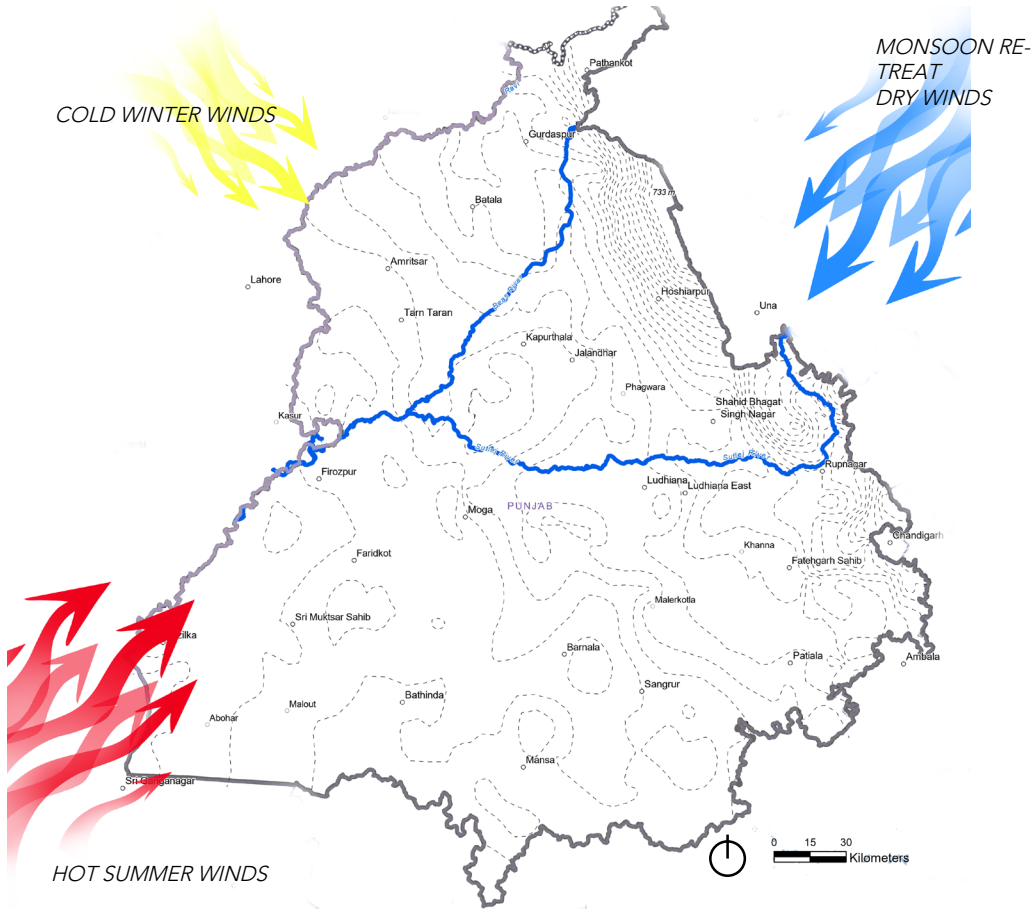


Figure 15: Punjab's Wind direction

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Ravi River, Pandoh and Pong Dam on Beas River for the purpose of generating clean hydro energy. As the population continues to grow, the demand for electricity rises, making this source very important, unless other sources are explored such as solar powered.[16] (figure 13)
The Sutlej and Beas River's flow has been disrupted due to the development of the Bhakra Nangal Dam and Pong Dam, respectively. The change in natural flow of the rivers affects the downstream water availability as well as the groundwater recharge, affecting biodiversity as well as agricultural.

2.4 Climate

According to the Koppen's classification, Punjab's climate is categorised into steppe, semi-arid, hot and subtropical monsoon patterns. There are four main seasons in the state, the winter season from November to March, hot season from April to June, southwest monsoon from early July to early September and post monsoon season also called, the transitions season from September till the early November. The summer months are extremely dry and hot, while the air becomes humid from July to September. [17]
The extreme weather events, such as unseasonal rainfall and droughts, also disrupt the water cycle.

2.4.1 Winds

The atmospheric pressure over Punjab region varies systematically throughout a year, rising higher in winter (January) and then reaching to its lowest during the southwest monsoon season in July. The pressure is higher in the north in January, while it is highest in the west in April and decreases eastward. Winds are variable in January, becomes westerly to northwesterly. As summer commences, a low pressure is developing over the region. The pressure decreases mainly from South to North in the month of July, therefore, the winds become south-westerly. October also known as the transition month has the weakest pressure gradient. The winter type winds start from October. [18]

Winds also affect the region's climate, water evaporation rates, and air quality, which are vital for both farming and overall environmental health. These prevailing winds also contribute towards soil erosion as the lands are mostly flat and unprotected due to lack of tree or vegetation breaks. Understanding these patterns helps in making informed decisions for design interventions.

2.4.1 Rainfall

The monsoon season has the 80% annual rainfall of 648.8mm, with a variation ranging from 260mm to 720 mm in the extreme north parts and northern region respectively. A few locations in the Shiwaliks have an average range of 950-1000mm of rainfall. June to September are the monsoon months with July being the peak month of rainfall. [19] The secondary period of rainfall occurs in winter, from December to March, contributing about 20% of the total rainfall, most of which is absorbed into the soil. Between 2001 and 2020, Punjab recorded deficient monsoon rainfall in 17 of those years, despite the monsoon season extending beyond the typical 77 days. This trend reflects broader climate change impacts, where the duration of monsoon currents has increased, but the average daily rainfall remains below the expected 6 mm while rainfall events have become more frequent - in 2024, the region recorded a 28% deficit from the average, while the preceding four years experienced normal rainfall[20] - this has led to flash flooding and increased surface runoff rather than beneficial groundwater recharge.[21] The excess water quickly flows over the surface, failing to adequately replenish underground aquifers, which reduces the effectiveness of water for agriculture. [22]

2.5 Flora and Fauna of Punjab

Some rivers of Punjab's rivers have crocodiles, including reintroduced gharials in the Beas River.[23] In the Harike wetland, there are Indus river dolphins present.[23] Punjab has a flourishing silk and bee honey production industry, and buffaloes grazing along riverbanks and some camels in the southern desert plains. The wetlands hosts Siberian cranes, falcons, sparrow hawks, bar-headed geese, flamingos, waterfowls and many more. The northeast part of Punjab has horses, while wildlife sanctuaries hosts species such as otters, wild boars, wildcats, fruit bats, hog deer, flying foxes, squirrels and mongooses.[24]
Punjab's State bird is Northern Goshawk (Baaz) (*Accipiter gentilis*), the state animal is a blackbuck (*Antilope cervicapra*), which is under threat of extirpation. The state aquatic animal is Indus River Dolphin (*Plastanista minor*), and the state tree is shisham (*Dalbergia sissoo*).
Species such as the gharials, dolphins and Goshawk have reduced numbers due to the loss of wetlands and flow in the natural rivers. The loss in water is leading to a loss of the wildlife of the state.

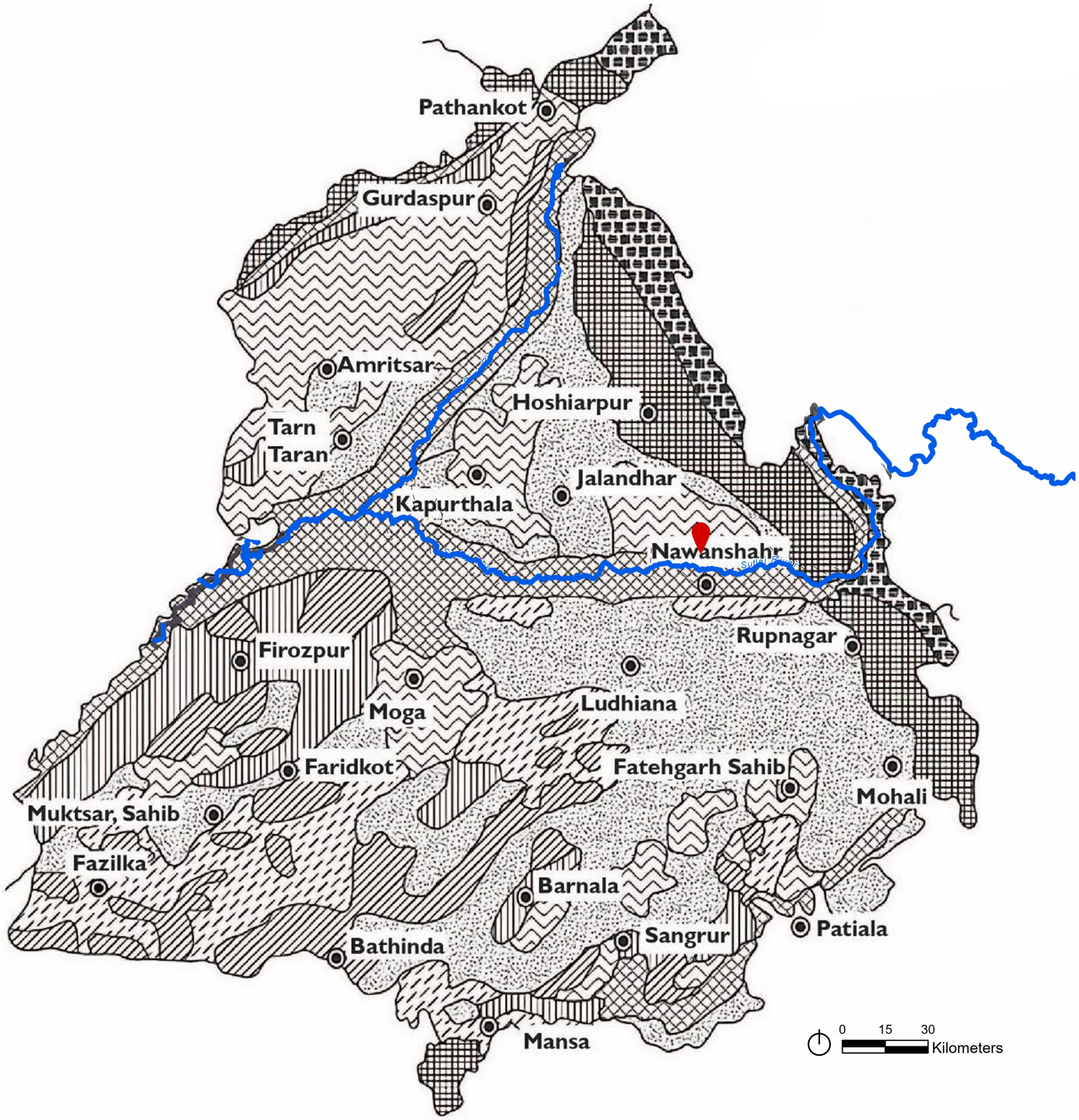

Figure 16: Soils of Punjab

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2.6 Soil

Major soils in Punjab are loamy (Ustochrepts of Ustic), Kandi, Podzolic and forest soils, sierozems, flood plain(bet) soils, sodic and saline soils, sandy and desert soils.[25]
70% of the area of Punjab is covered by Loamy, Kandi and Sierozem soils, which are great moderately suitable for infiltration of water into the ground table. Loamy soils are known to be fertile and good for farming, while Kandi soils, located at Shiwalik hills are badly eroded and less productive and can support dry farming. Sierozems, also known as grey soils, are highly productive when irrigated. Podzolic andforest soils are found in steep sloped areas and rugged topography, and are prone to water erosion. The texture of these souls is gravelly, stony and sandy.[26]

In summary, the diverse soils of Punjab, including loamy, Kandi, sierozem, podzolic, and forest soils, each present unique challenges and opportunities for agriculture. While loamy and sierozem soils support productive farming, Kandi soils struggle with erosion and require dry farming methods. The podzolic and forest soils in hilly areas are prone to water erosion.

2.7 Farming Landscape of Punjab

Farming practices were deeply connected to the local environment and culture. Before the Green Revolution (before 1960s), when chemical fertilizers, high yielding varieties, improved machinery were not introduced yet, farmers of Punjab cultivated a diverse array of native fruits, grains and vegetables.[27]
Farmers cultivated these crops and adapted to natural conditions rather than controlling them. The landscape was managed through careful resource recycling, where organic matter was reused to maintain soil fertility and to reduce waste.
Social systems, such as the caste system, also shaped the landscape of Punjab as different groups focused on specific resources within smaller areas, ensuring there was no over use of resources and populations were self sufficient.[28] Moreover, the traditional landscape was dynamic but was able to change over time in terms of adoption of need seeds and systems such as canal irrigation.[29]

Additionally, traditionally water came from four main sources, rivers via canals, rainfall, wells and ponds. The best farmlands in rural areas used to be near village centres and had access to both the Bhakra Canal minors as well as the wells and ponds. Average quality farmland, located farther from the village relied on irrigation from the wells (groundwater) and the poor quality land depended on rainfall.[30] These water bodies would also have traditional trees (Peepal - *Ficus religiosa*, mango - *Mangifera indica* , dek - *Melia azedarach*, and Banyan - *Ficus benghalensis*) planted by them and would be used as gathering spaces as my grandmother talked about them. Temporary hay structures also used to exist as a resting place for farmers to take breaks and they would spend hours and hours working in the farms prior to mechanized farming. Other trees would include ber (*Ziziphus jujube*), shehtoot (*Morus alba*), Sheesham (*Dalbergia sissoo*), Fulmohar (*Delonix regia*), bottlebrushes (*Callistemon sp.*), Neem (*Azadirachta indica*) and more.
Traditionally, farms were protected by windbreaks as well as tree cover. Tree covers protected soils from excessive heat and also provided shelter.[31]
Farmers used methods of organic husbandry, which required lower amount of water. The demands of the land were low as farmers practiced crop rotation and left the farms fallow to heal for certain periods of time.

Overall, before the Green Revolution, Punjab's landscape was a balanced system of mixed crops, scattered trees, water bodies, and shared gathering spaces. Farmers grew a variety of crops such as wheat, millet, pulses, and vegetables, which supported soil health and reduced pressure on water resources. Trees were commonly found along field boundaries, offering shade, food, and shelter for both people and animals. Water was managed through traditional systems like ponds (tobas), wells, and seasonal streams, which helped recharge groundwater naturally. My grandmother often recalled, "(In those days, people worked with the land… they respected water". These practices supported a healthy groundwater system and a self-sustaining landscape that met both ecological and community needs.
The irrigation water requirements of the region are supported by the Canal water and ground water pumping. Punjab has been an agricultural region since ancient time, therefore had various methods of irrigation developed as early as the Indus valley civilisation, from canals to ponds. Later on, under the British colonial rule, the irrigation systems consisting of many more canals were further developed.



Figure 17: Ficus benghalensis - Peepal tree in a gathering area (Sathh) (above)
Figure 18: Community irrigation pond (below)
Although taken in the present, both images reflect traditional practices of community-based resource management that were once common.





Fruit tree crops such as mango (*Mangifera indica*), beri (*Ziziphus mauritiana*), kinnow (*Citrus nobilis × Citrus deliciosa*), guava (*Psidium guajava*), jamun (*Syzygium cumini*), papaya (*Carica papaya*), mulberry (*Morus alba*) and many more.

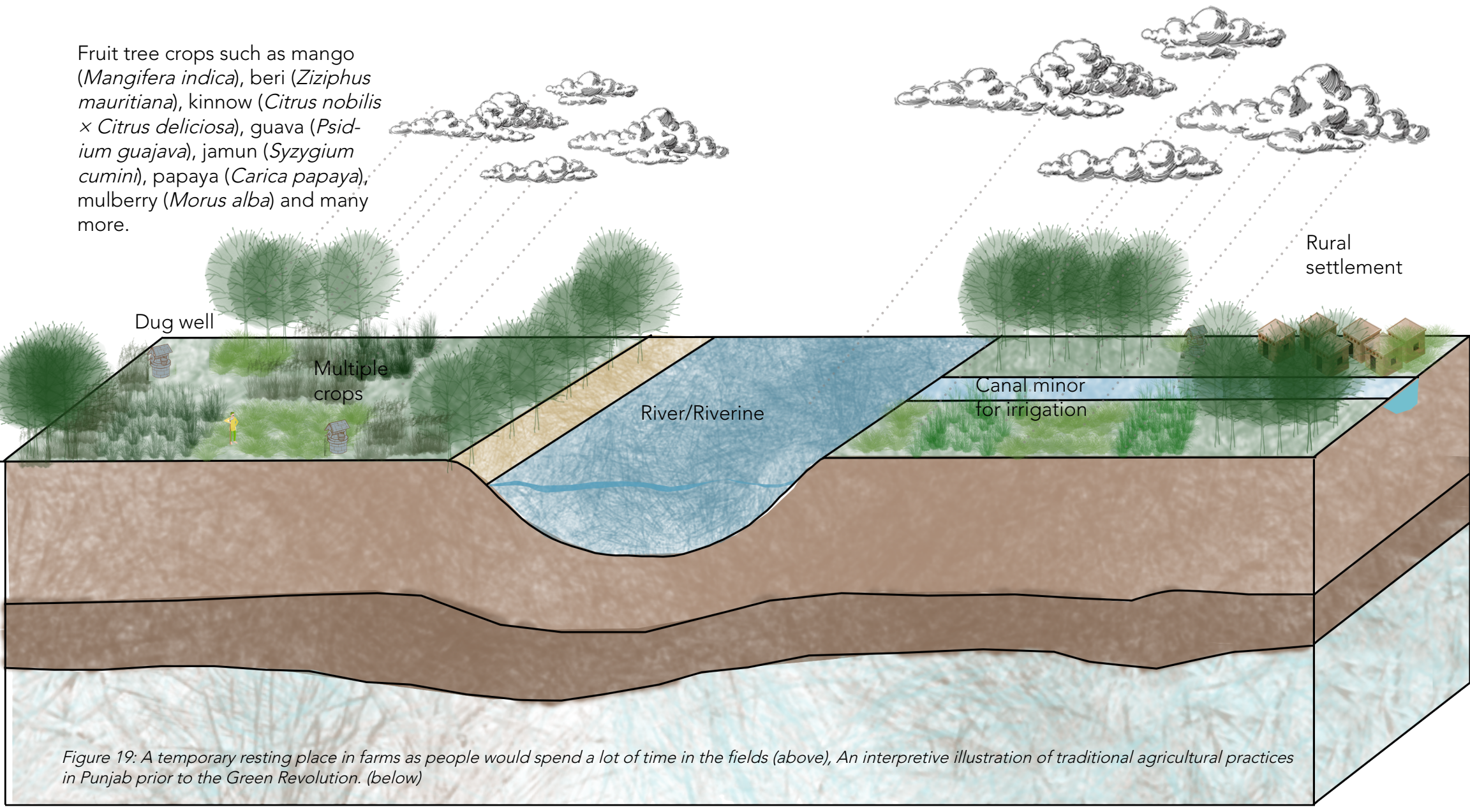


Figure 19: A temporary resting place in farms as people would spend a lot of time in the fields (above), An interpretive illustration of traditional agricultural practices in Punjab prior to the Green Revolution. (below)

33


Pump house
Tree by the water source representing traditional cultural aspect - *Schefflera actinophylla (Umbrella tree)*
Rice crop
Tube well
Water channel to the farms

The independent Indian state saw Punjab as a region that could help solve the serious food deficit problem that the country faced from the mid-1960s onwards […] Punjab was able to capitalise on these initiatives.[32]

2.8 The green revolution and its impact on traditional agricultural practices and the depletion of ground water

Punjab was home to the Indus valley civilisation, renowned for its advanced urban planning and agricultural techniques. After the Independence of India in 1947, like many other countries, in the aftermath of WW2, the country was experiencing severe food shortages, resulting in many deaths, and the agrarian state of Punjab was divided and a large area of Punjab went to Pakistan, country's food supply was disrupted again. Due to this, India relied on import of food from the USA. India faced other natural calamities such as drought and that eventually led to further food shortages in the country. Although Punjab emerged as one of the wealthiest states of the nation, with strong resources such as the surface water resources, developed irrigation systems, electric power resources, a stronger foundation of agricultural research and extension and cooperative credit structure for the residents of the state. Meanwhile, the nation was still struggling to fulfill the food needs for the population. Therefore, there was a need for agricultural transformation to enhance food security for the country. As Punjab already had great resources, it was chosen to be the torch bearer of this revolution.[33]

Hence, in the year 1969, Green Revolution *defined as the adoption of technology, such as the use of high yielding variety (HYV) seeds, mechanized farm tools, irrigation facilities, pesticides, and fertilizers,*[34] took place in India, and since agriculture in the state has intensified through its use of fertiliser and pesticide use, heavy machinery, and irrigation methods. Because of its consistent water supply, the existence of the Indus plains, which make it one of the world's most fertile plains, and its track record of agricultural success, the Indian government chose the state of Punjab to be the first location to test the new crops.[35] Punjab, still, is primarily an agrarian state, has 70% of its population involved in agricultural activities.

As the area's established canals (Figure 15) and dams started maxing out, the shift of irrigation from rainwater and flowing surface water irrigation was moved to groundwater pumping with subsidized energy at zero cost for all farmers. As a result, Punjab hosted year round crops, leading to increase in agricultural productivity, enabling India to become self sufficient in food grains. By 2000, agricultural land under cultivation had expanded over to 83% of the total geographical area of Punjab. Eventually, the cropping intensity rose to 189%, indicating more frequent cropping cycles per year, higher profits, and 98% of cultivable land benefited from assure groundwater irrigation. [36]

The cultivation of the water intensive crop, rice, was one of the major reason to use underground water for irrigation.

Figure 20: A contemporary photograph of a Punjabi farm utilizing tubewell irrigation.

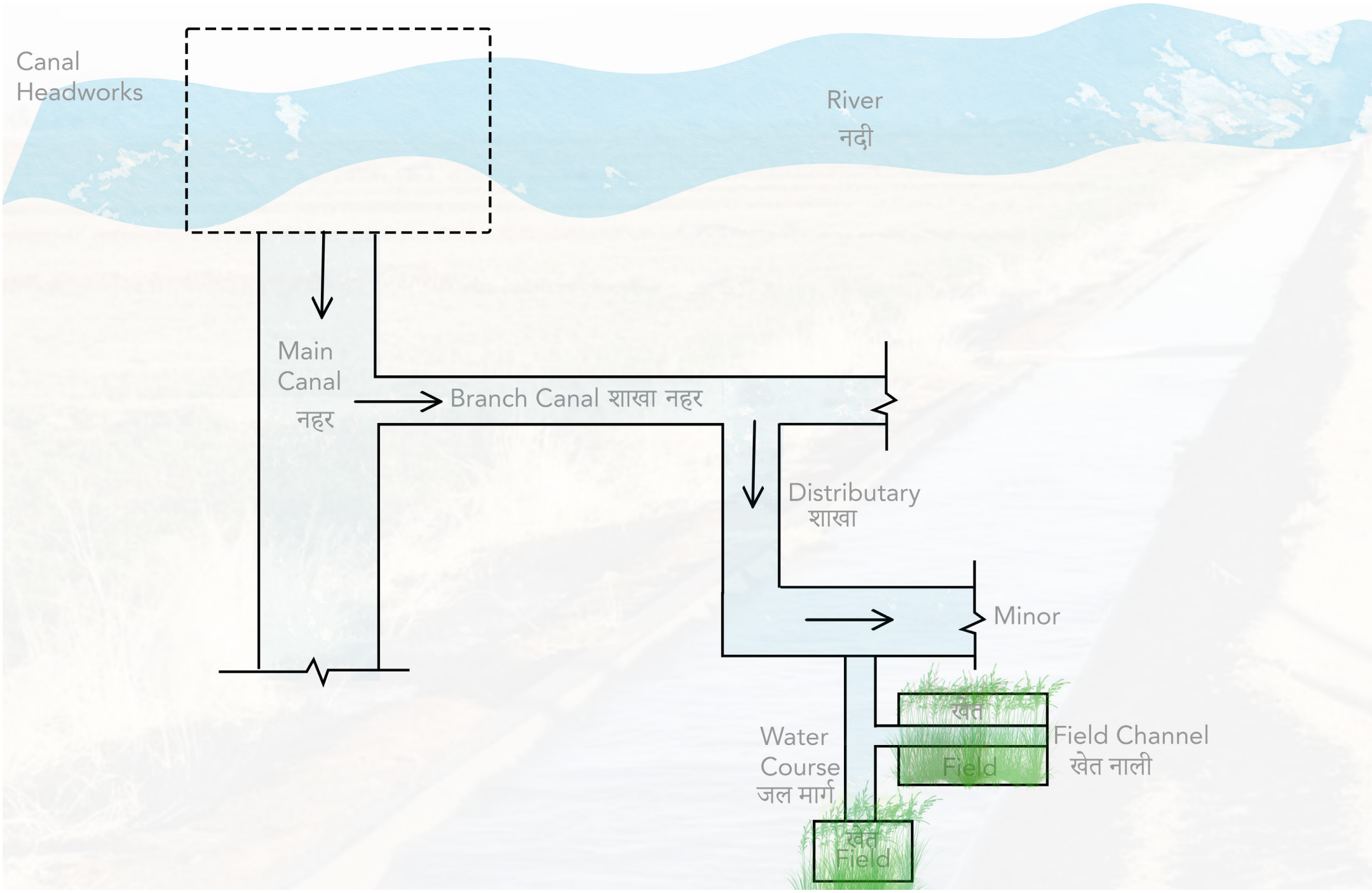


Figure 21: Surface Water Irrigation through canal

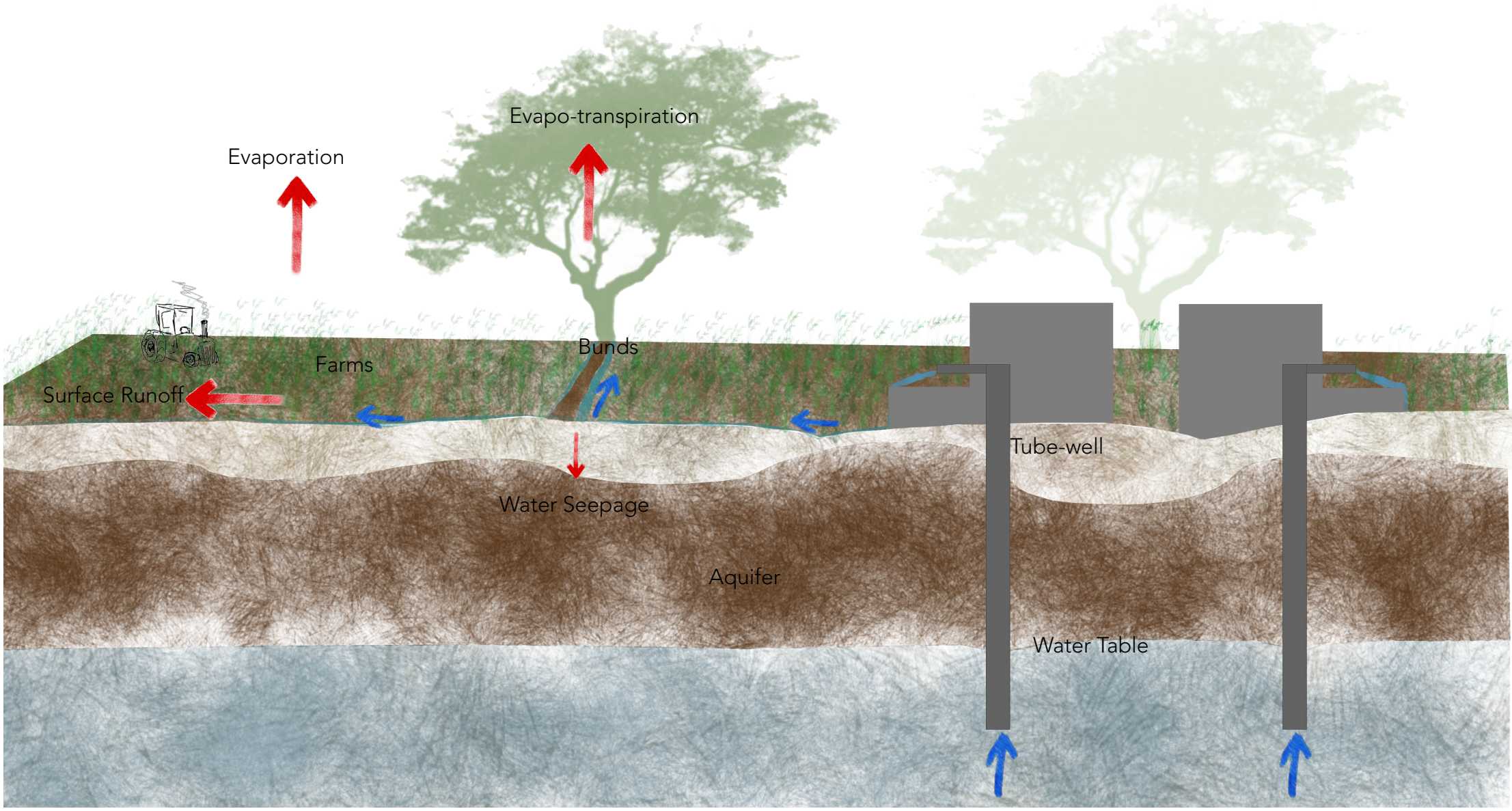


Figure 22: Ground water irrigation

2.12 Impact of the Green revolution on aquifers of Punjab

Understanding the condition of aquifers in Punjab is essential to this practicum, which focuses on restoring balance between water use and natural recharge in an agricultural landscape. Aquifers are an important source of irrigation and drinking water in the region. However, decades of intensive farming practices introduced during the Green Revolution have placed increasing pressure on these systems. This section highlights the key features of Punjab's aquifer systems, explains how they function, and explores how this knowledge can be used to identify suitable areas for groundwater recharge interventions.

"Alluvial aquifers are aquifers that comprises of unconsolidated materials deposited by water, typically occurring adjacent to rivers and in buried paelo-channels." [37]

Majority area of Punjab has alluvium aquifer type, apart from the Shivaliks, where it is sandstone type of aquifer. Alluvial aquifers are known to have good water storage capacities and can transmit groundwater and therefore they are used as a source of water. They are normally shallow and susceptible to contamination. The unconsolidated shallow nature of these aquifers also makes them vulnerable to fluctuations in water levels and to contamination from surface activities such as agricultural chemical applications. In the context of Punjab, it means that the aquifer system has the potential to store large volumes of water, that can support agriculture, but sensitive to extraction and pollution. Therefore the aquifers needs to be managed better to keep have water at an appropriate ground water table.

As for the groundwater depth, it refers to how far below the groundwater is stored. Shallow or very thick aquifers are easy to access but are extremely vulnerable to seasonal fluctuations and pollution, whereas, thick aquifers are more resilient to pollution but are at a risk of overuse in cases, where recharge is slower. Intermediate depth have more stable water quantity as well as quality, but recharge in these zones takes longer. Finally, deep or thick aquifer are older, more protected water, which are hard to extract and even harder to recharge.

In Punjab's alluvial aquifers, the thickness is the vertical extent of the water bearing layer. Thin aquifers store limited water and can be depleted very quickly with overuse. Meanwhile, moderately thick layers offers relatively more storage, and thick aquifers have more storage but the depletion risk is higher as well. Very thick aquifers, hold large reserves, but their slow recharge means unsustainable extraction leads to long term decline. [38]

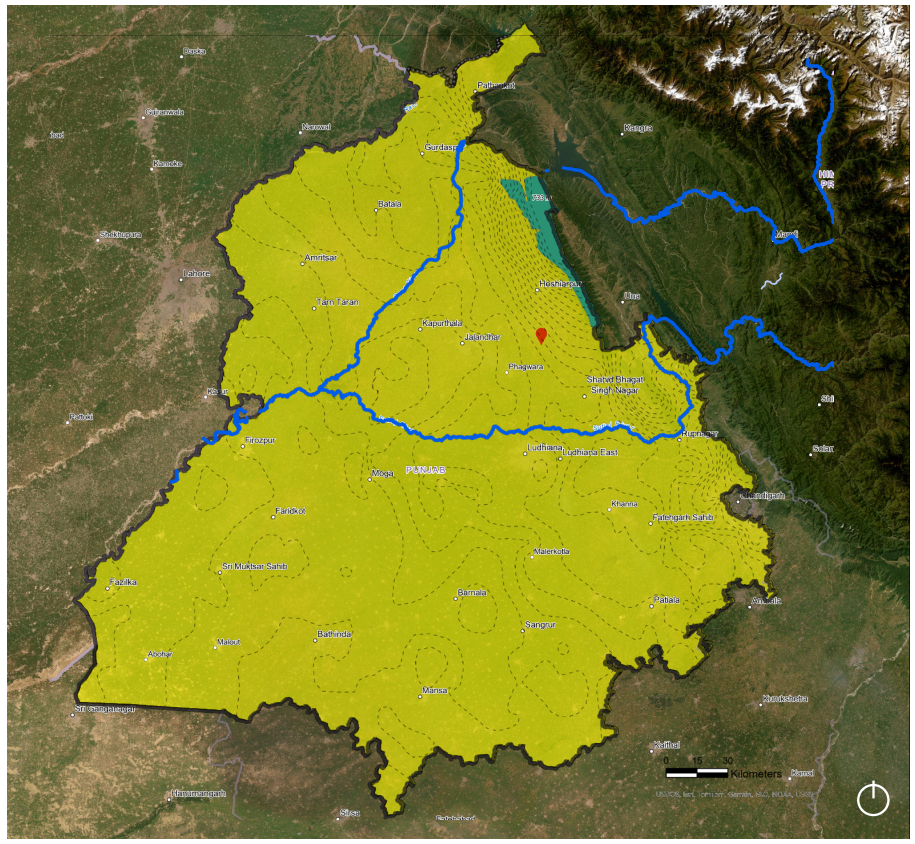


Figure 23: Aquifer Properties

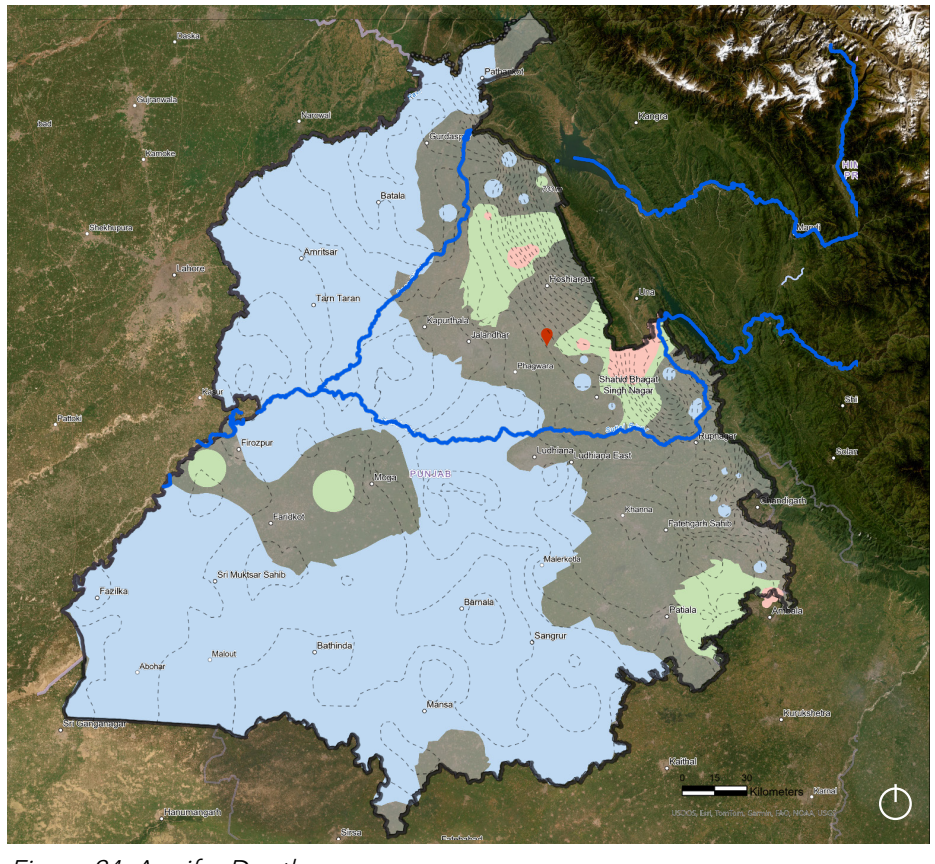


Figure 24: Aquifer Depth

Aquifer Properties

Aquifer Type

Aquifer Material

Alluvium

Sandstone

Aquifer Material – Unconsolidated sediments (sand, gravel, silt, lithomargic clay)

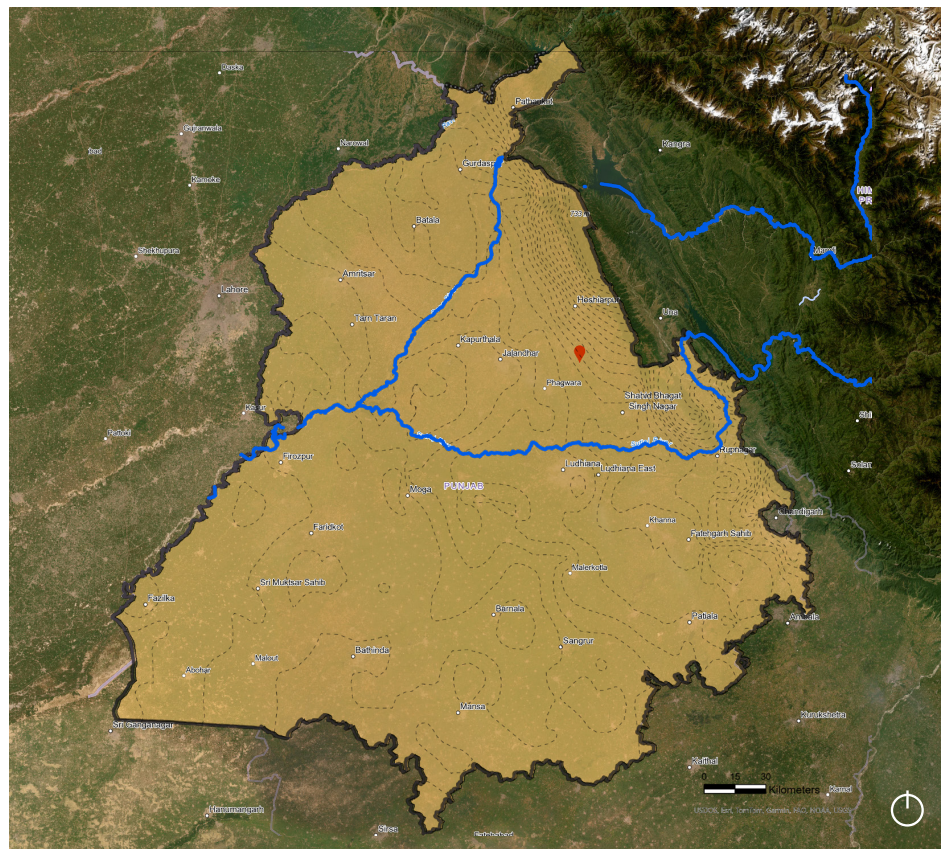


Figure 25: Aquifer Material

Aquifer Depth

Less than 25m (very thin)

25-60m (thin)

60-90m (Intermediate)

More than 90m (thick)

Aquifer Thickness

Less than 50m (thin)

50-100m (moderate)

100-150m (thick)

More than 150m (very thick)

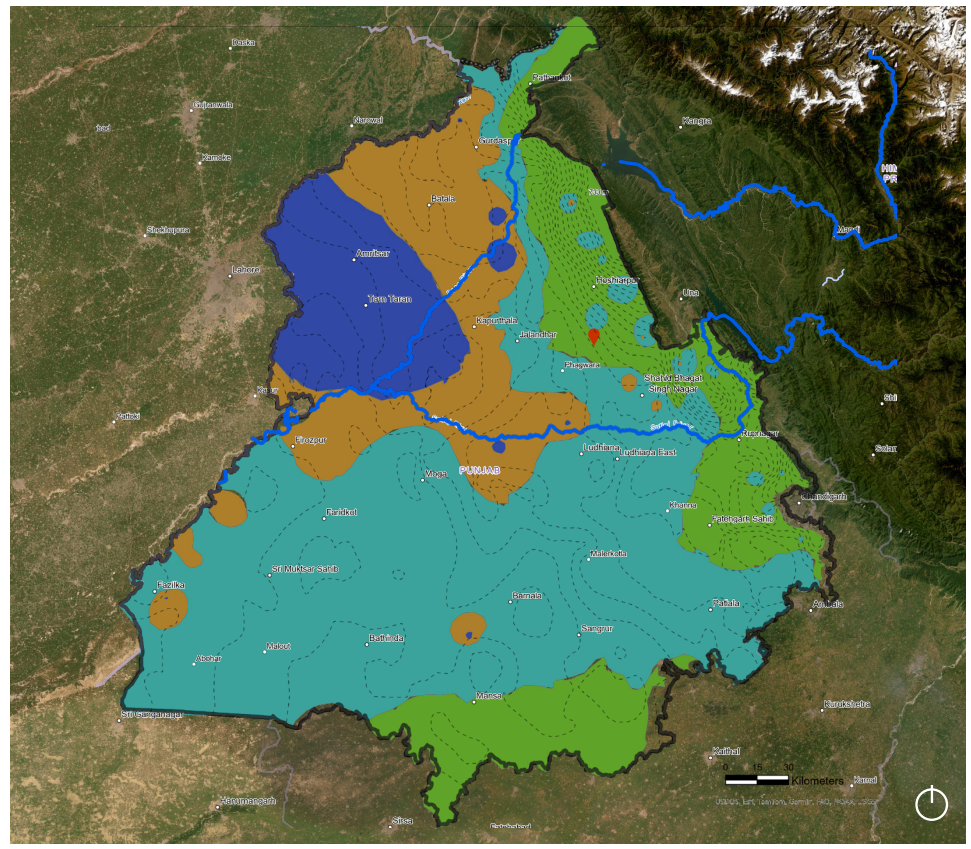


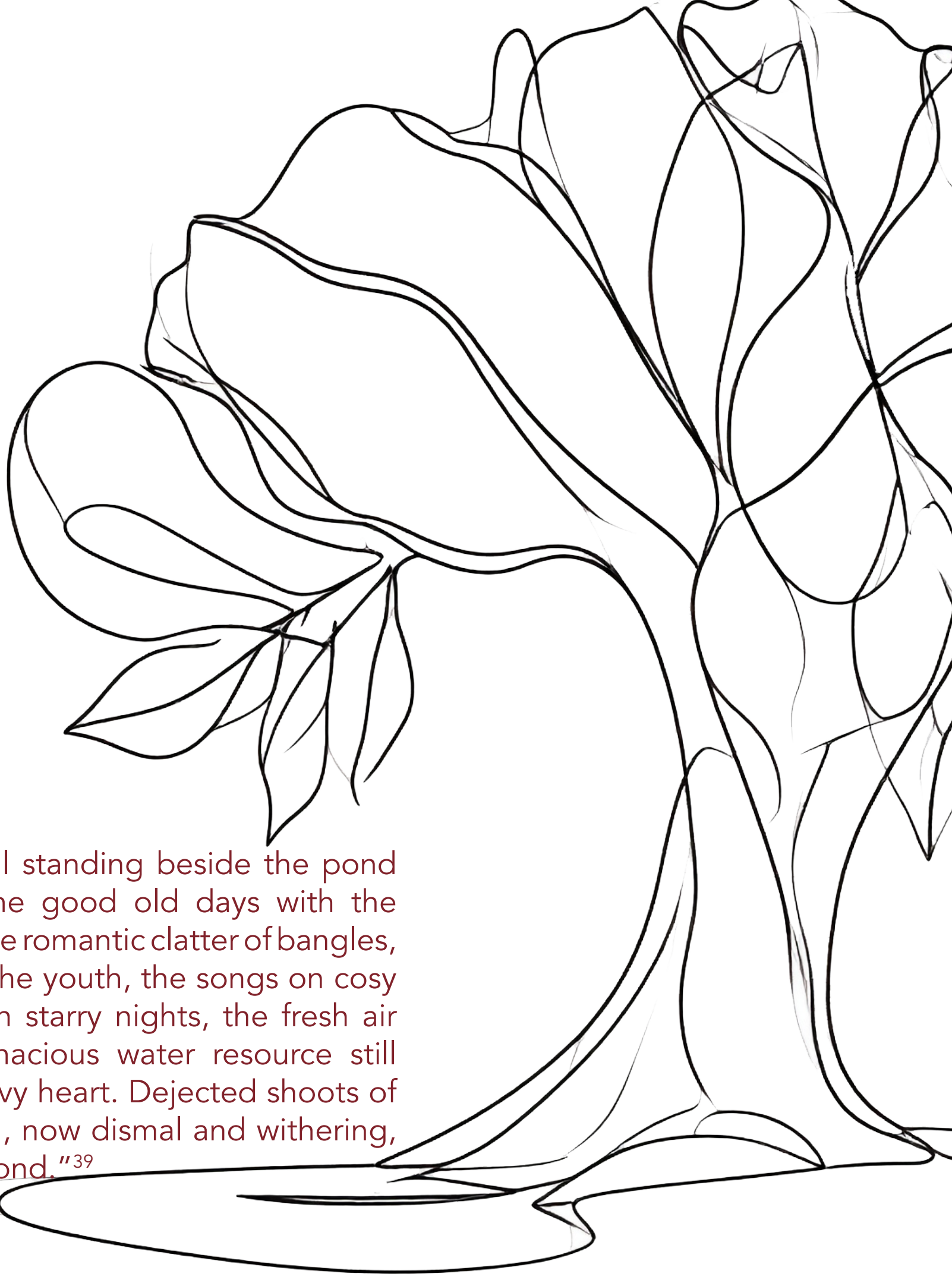
Figure 26: Aquifer thickness

While Punjab's alluvial aquifers offer high storage potential, they are highly sensitive to over extraction and contamination. The varying thickness and depth of these aquifers influence their recharge rates, and ability to retain that moisture in the soil; thinner aquifers are quick to deplete, while thicker ones offer more storage but recharge slowly. The site, with its intermediate to thin aquifer thickness, has a moderate storage potential but a relatively faster recharge rate when compared to thicker aquifers.

In conclusion, before the Green Revolution, Punjab's landscape was shaped by diverse crops, native trees, and a reliance on rainwater and surface water stored in traditional ponds and tanks. Farming practices considered seasonal changes and community-based water management.

In contrast, the post-Green Revolution landscape is dominated by water-intensive farming practices, particularly rice crop, supported by use of electrical tube wells. This shift has put high pressure on the region's alluvial aquifers, leading to over-extraction, reduced surface water use, and groundwater pollution and depletion.

Combined with increasing erratic rainfall and outdated canal infrastructure, these practices are accelerating groundwater decline and going towards a growing threat of desertification of Punjab.



"The old banyan tree still standing beside the pond seems to be recalling the good old days with the giggles of young spirits, the romantic clatter of bangles, the pleasing laughter of the youth, the songs on cosy afternoons, the stories on starry nights, the fresh air and pure water. The tenacious water resource still seems alluring to the heavy heart. Dejected shoots of great grandfather banyan, now dismal and withering, lay beside the dry dirty pond."[39]

END NOTES

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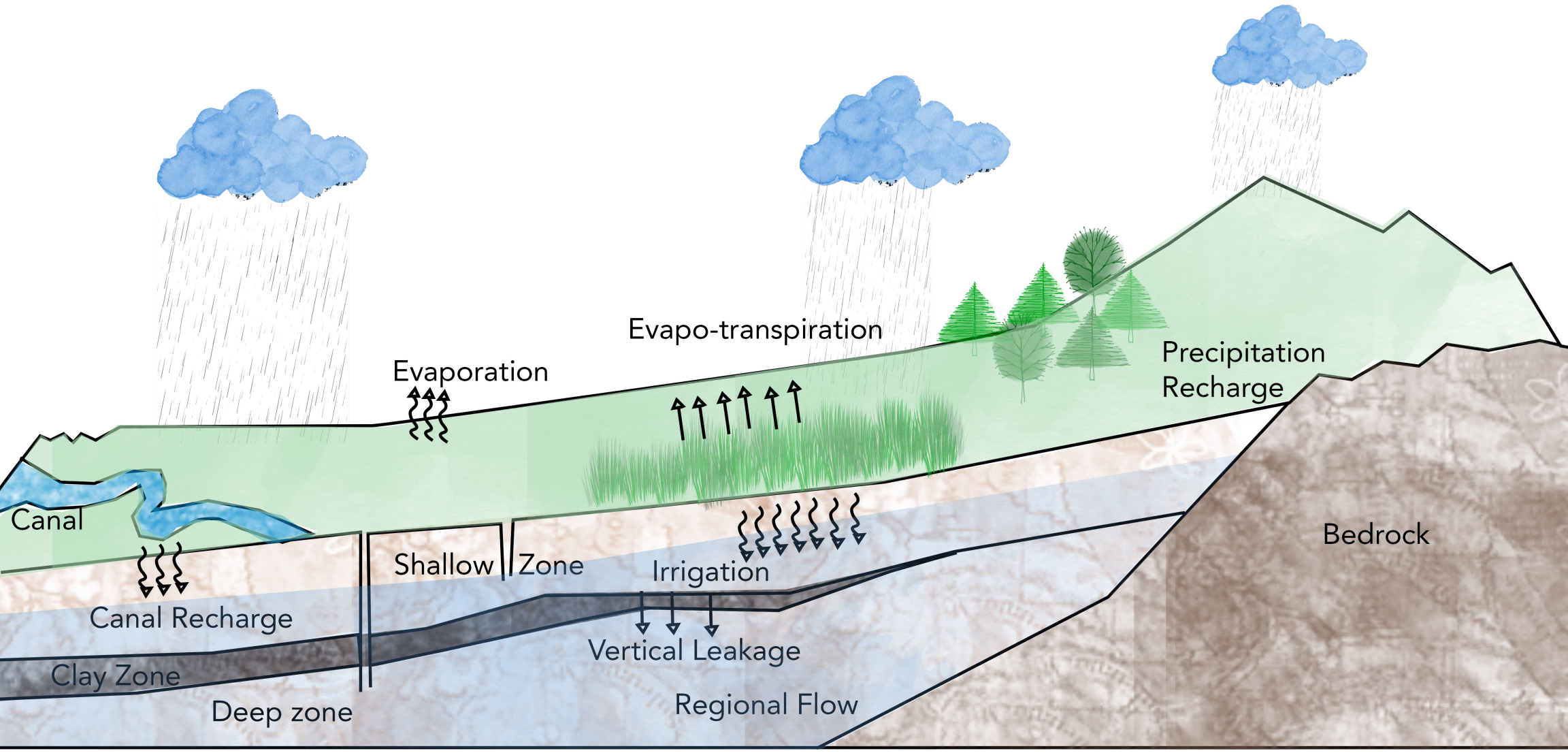


Figure 27: Water Cycle - groundwater and surface

03 THE PROBLEM GROUNDWATER DEPLETION

3.1 Ground Water Use

Groundwater in Punjab is used for both domestic purposes in settlements and for agricultural irrigation. Its immediate availability and reliability have made it an essential resource, especially as the surface water's availability is seasonal and limited.

The practice of irrigation through tube wells and using groundwater in Punjab is recent and unlike canal irrigation, which was developed over the years by either the rulers or government as mentioned in Chapter 2, groundwater irrigation took place as a result of initiative and undertaking of individual farmers. About one-third of the irrigation was being executed using open wells and tube wells before the 1960s, which was the beginning of the green revolution introduced to India by Dr. M.S. Swaminathan.[1] The state of Punjab intensified its agriculture through the use of fertilizers, pesticides, mechanized farming techniques and tools, high yielding varieties of crops, and finally the use of tube wells to pump out groundwater for all year round farming. In addition, the government provided subsidies on electricity for the use of tube wells for all farmers. This brought food and income stability for the country and the farmers and Punjab was designated as the 'bread basket of India'.[2]

In the present day, groundwater irrigation is done mainly through shallow and deep tube wells. Shallow tubewells are usually 50-100m deep, and are owned by individual farmers, while the deep tube well owned by the government are around 300m deep and are used for direct irrigation and drinking purposes in the settlements.[3]

FARMERS ARE DIGGING DEEPER TO EXTRACT...

Some districts to name, **Hoshiarpur (82% - the research area district)**, Gurdaspur, Amristar, Kapurthala, Jalandhar, Patiala, Fatehgarh Sahib, Luydhiana, Ferozpur, Nawanshahr, Ropar, and Sangrur use tube wells for more than 50% of their cultivated land.[4]

Overall, the shift from surface water reliance to widespread groundwater extraction has shaped present day agriculture in Punjab. However, this over extraction s has led to current day situation where the state is at risk of turning into a desert.

3.2 Cropping System

72% of the total land area of Punjab is under rice cultivation, and about 80% of that is irrigated by groundwater irrigation methods. Annually, a mean rate of 4.0 ± 1.0 cm groundwater is depleted.[5]

When assessing crop water requirements across two cropping seasons, the water demand for wheat is comparable to that of other Rabi (Winter) crops, while in contrast, rice, including Basmati rice varieties, is the most water intensive crop cultivated during Kharif(Autumn) season. Approximately 68% of Punjab's net sown area grows rice, and relies on a combination of surface water irrigation as well as groundwater. The majority of rice farmers uses conventional methods of rice cultivation including flooding as well as puddling, to meet the crops water needs[6] , as 1kg of Rice production requires 5000 litres of water as evapo-transpiration is higher.[7]

Reduction in water flow

Addition in water flow

No change in water flow

While major concerns are always in regards to intensive rice, maize is a crop that emerges as both a potential solution and a growing concern, depending on the season in which it is sown. Maize can be cultivated in two seasons, in Rabi (winter) season as well as in Kharif (autumn) season, which would be the same as the rice season. While Kharif maize is rain supported and relatively water efficient, Rabi (Winter) maize requires a large numbers of irrigation cycles, which puts it right under paddy in terms of water demand, especially during hottest months of Punjab's climate. The area under maize has expanded quite extensively as farmer grow it for its higher production. Additionally, farmers often follow Rabi maize with water intensive rice , causing even bigger burden on the land and forcing the water table to drop as the irrigation is fully dependent on groundwater.

Contrastingly, Kharif maize offers more sustainable alternative as it requires less number of irrigation cycles, reducing reliance on groundwater, but as the production is lower in comparison to rice, it is not preferred. Changing this would require refined policy work, otherwise, the state will continue to exhaust its groundwater resources in the next two decades, which this project will explore.[8]

3.3 Drying of the Rivers

Sutlej River is the longest river of Punjab, India and serves as a major source of water for irrigation, drinking, washing, and bathing in the state. The river in present day has shrunk to a rivulet size due to the Bhakra Dam construction near Nangal, disrupting the ecosystem of the water body as much of its water is stored in the Gobind Sagar reservoir for hydroelectric power and irrigation. This diversion has left many areas of Sutlej river with such low water levels that the rivers looks like a drain rather than a mighty river.[9]

The pollution from Industrial waste, and agriculture is affecting the river as well. This is due to untreated sewage being released to Nallas (drains) which eventually joins the rivers turning the river into an unhealthy water body. While the Gobind sagar helps with the aquifer refilling in the Himalayan zone, the over-extraction of groundwater in Punjab is directly linked to the reduced flow of the river water caused by the dams and water diversion to areas outside the Sutlej River basin. This has eventually led to the falling groundwater levels, especially during the dry seasons. The Sutlej with a steady flow would have helped recharge the groundwater by allowing water to slowly seep into the aquifers. However, as the flow of the river has become irregular and low, this natural process has been disrupted. This eventually causes the groundwater levels in the surrounding areas ti fall. When the river runs dry or with less water, it reduces the availability of surface water for farming and daily use but also increases the pressure on groundwater sources, so to meet water needs of the demographic. Moreover, during dry periods, the river's natural role reverses, and instead of adding water to the ground, the river starts pulling water from the groundwater table to maintain its flow, again adding to the groundwater level drop.

In addition to that, deforestation and land use changes have further weakened the river's hydrology, increasing soil erosion, sedimentation and flood risks, while lowering the river's capacity to carry water. Moreover, climate change presents an even greater threat to the Sutlej basin, as the rising temperatures, shifting rainfall patterns, and melting glaciers are changing the basin's water cycle. Due to this process, the basin's glaciers are expected to disappear by 2050.[10]

3.4 Groundwater for Settlements

Urbanization and industrialization, in addition to irrigation, have significantly contributed towards the decline in groundwater levels in Punjab. Between 2001 and 2011, urbanization increased from 10% to 20% and there was a substantial rise in the number of factories as well. At the same time, the net annual groundwater availability dropped by 4% in 2004-05, and 2018-19, even though rainfall was comparatively steady. The core issue, is the inadequate groundwater recharge in settlement areas. It is recommended to restore wetlands in urban areas to help groundwater replenish.[11] Many households in the villages and cities including my own, have their own groundwater pumps to extract water during unavailability of municipal water, or in some cases, due to lack of proper treatment of municipal water.

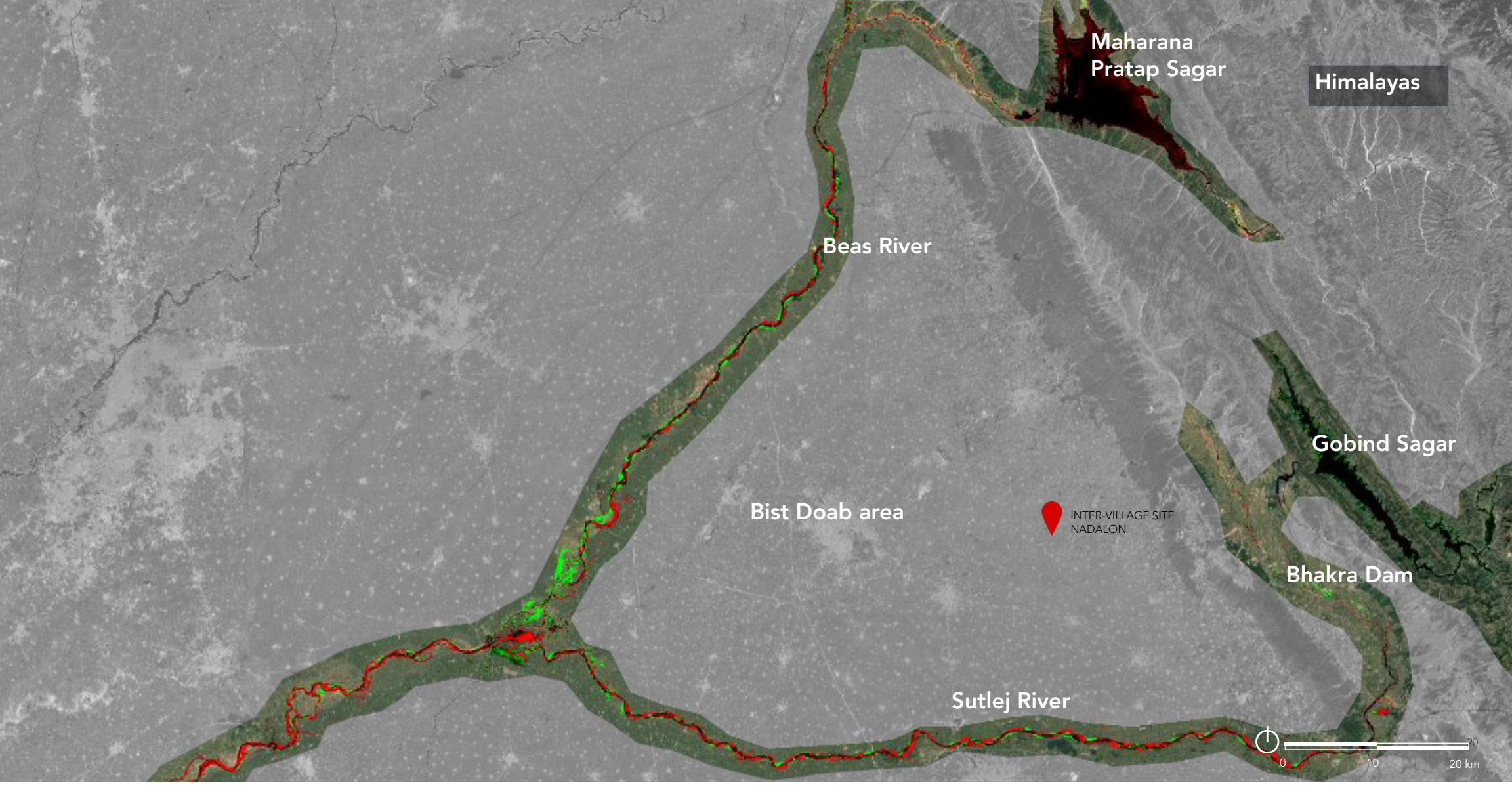


Figure 28: Loss of Sutlej River water

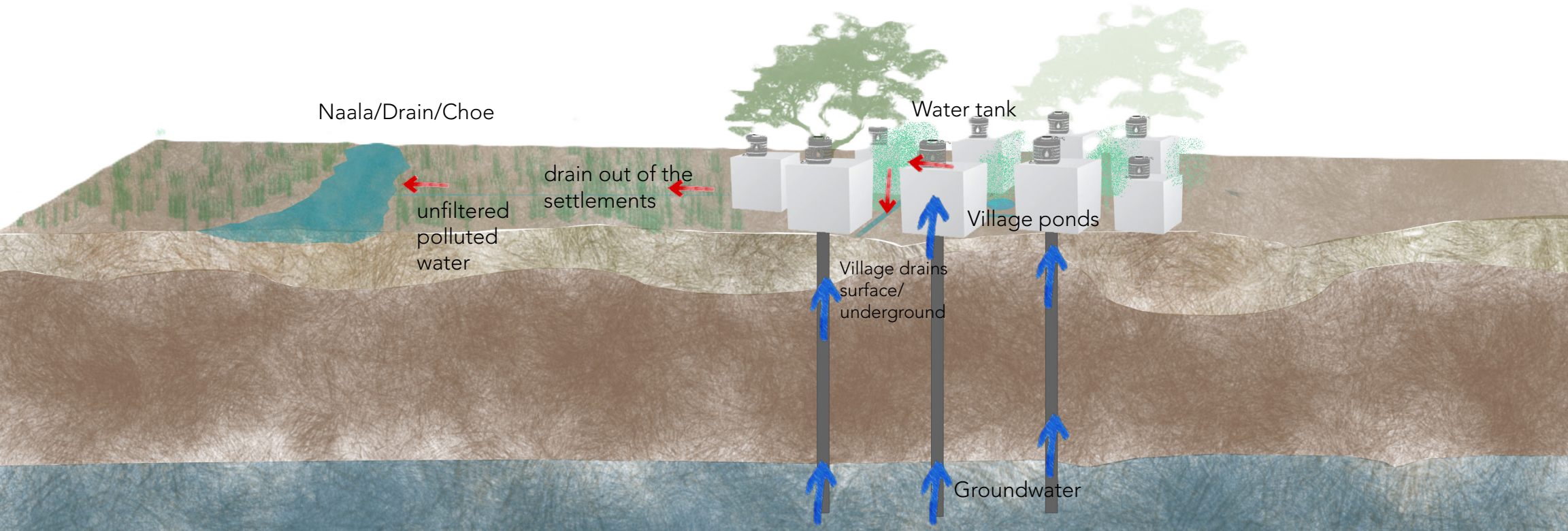


Figure 29: Settlements (rural) groundwater use

1985

2017

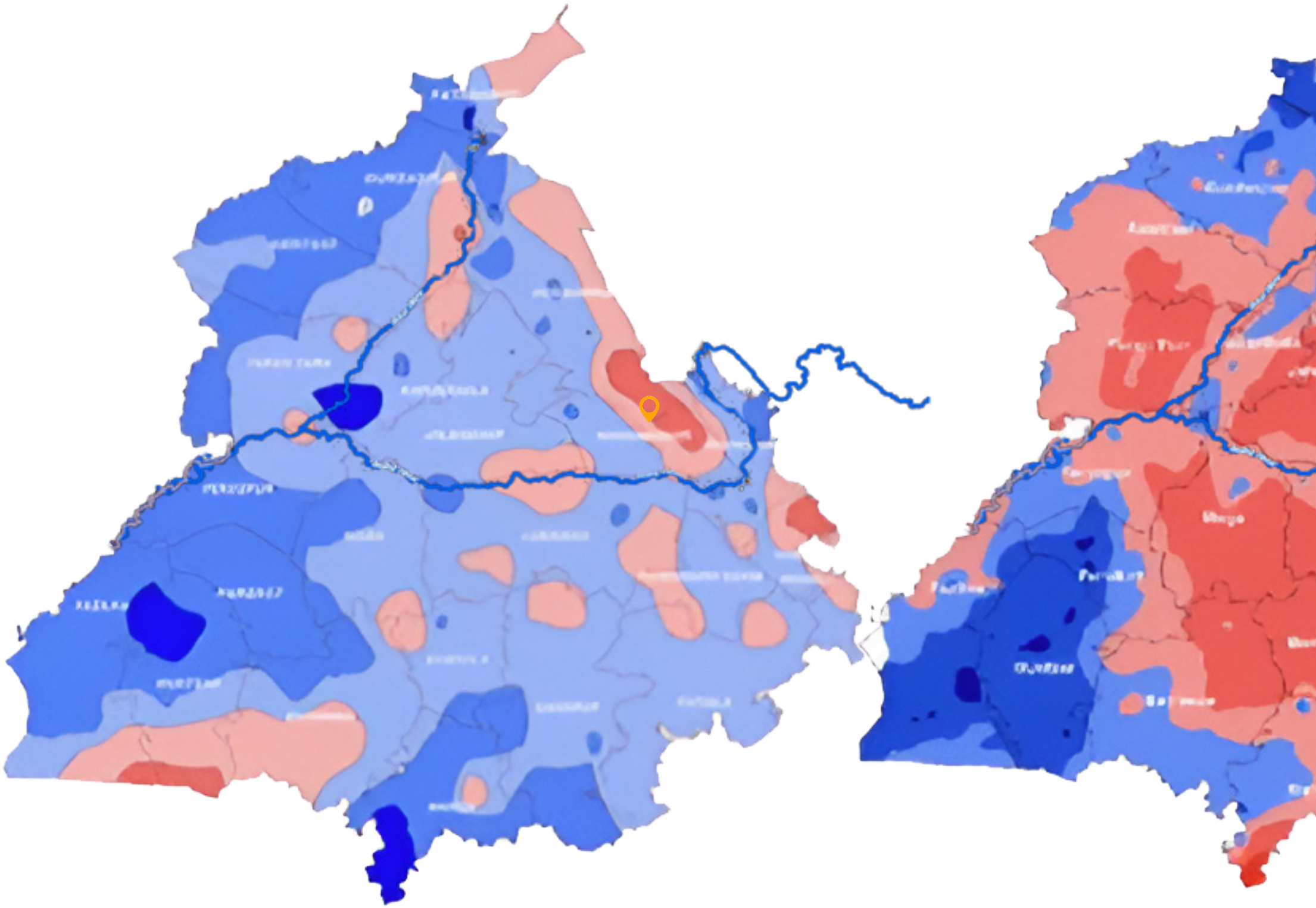
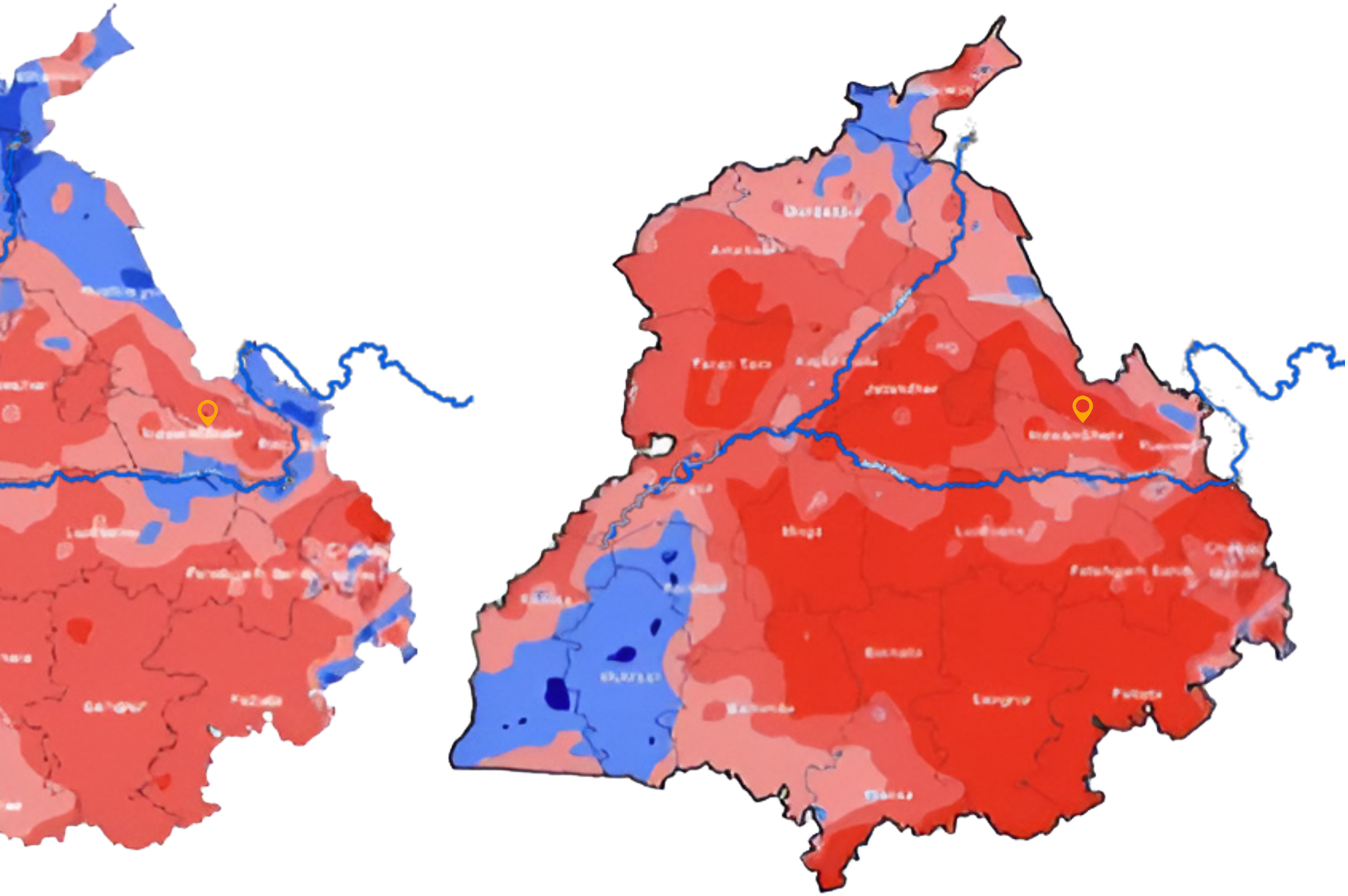


Figure 30: Progression of groundwater depletion over the years

2037



WATER DEPTH
METER BELOW GROUND LEVEL

0-2	10-20
2-5	20-40
5-10	>40

NADALON SITE

0 45 90 km

Original size 1:1,250,000 on 12X24"

3.5 Free Electricity

Free electricity for agricultural irrigation, introduced in 1997, has further entrenched groundwater overuse, making paddy cultivation financially attractive and technically easy for farmers. Although policy recommendations have been made including withdrawing free power for medium and large farmers and offering income support for alternative crops, these have not been implemented, largely due to political reluctance and lack of long-term planning.

3.6 Forest Clearing

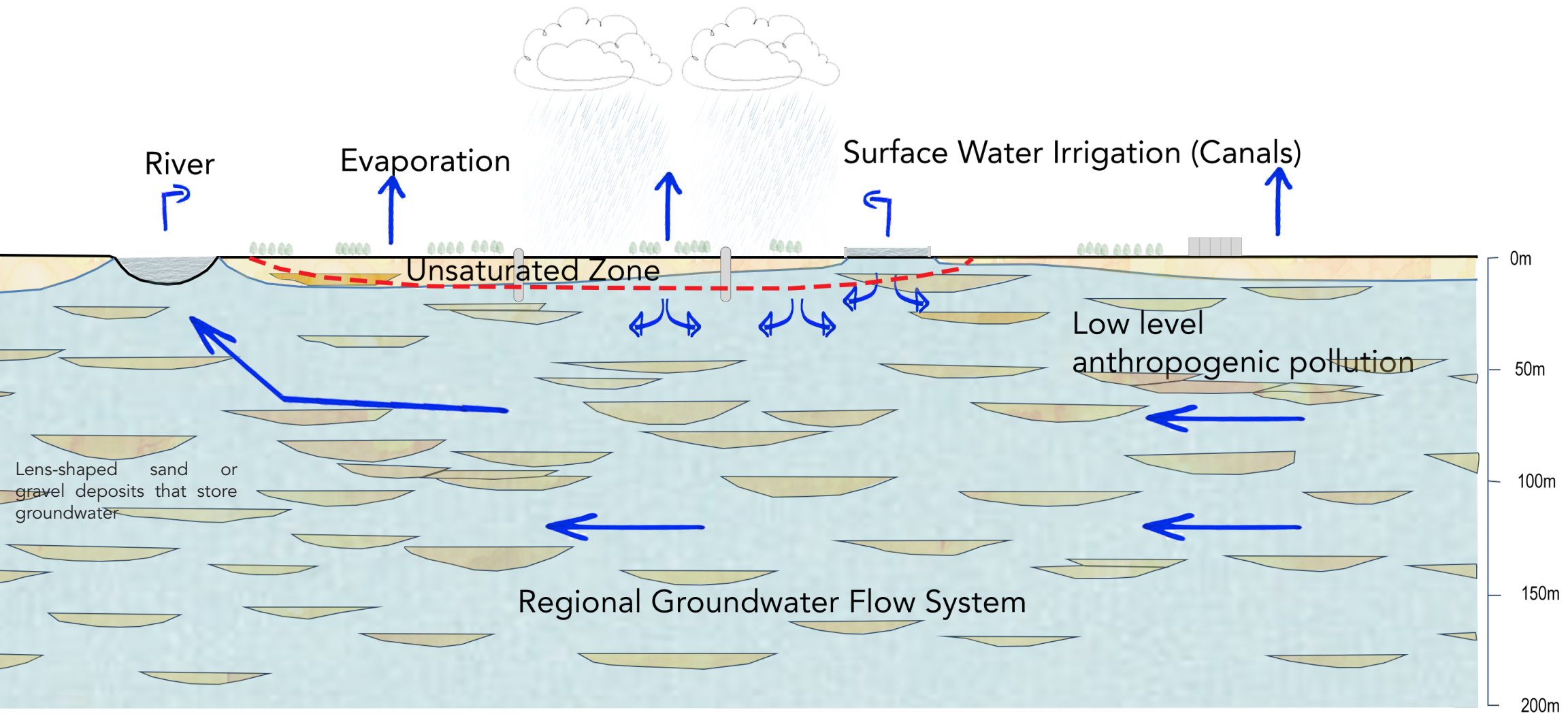
Civilizations have historically developed along riverbanks, where fertile land and water are easily accessible. The riparian forests of these rivers were initially cleared through burning to make space for farming and then for timber. In addition, more parts of the forests were cleared or submerged to make way for hydroelectric dam projects on these rivers. [3]

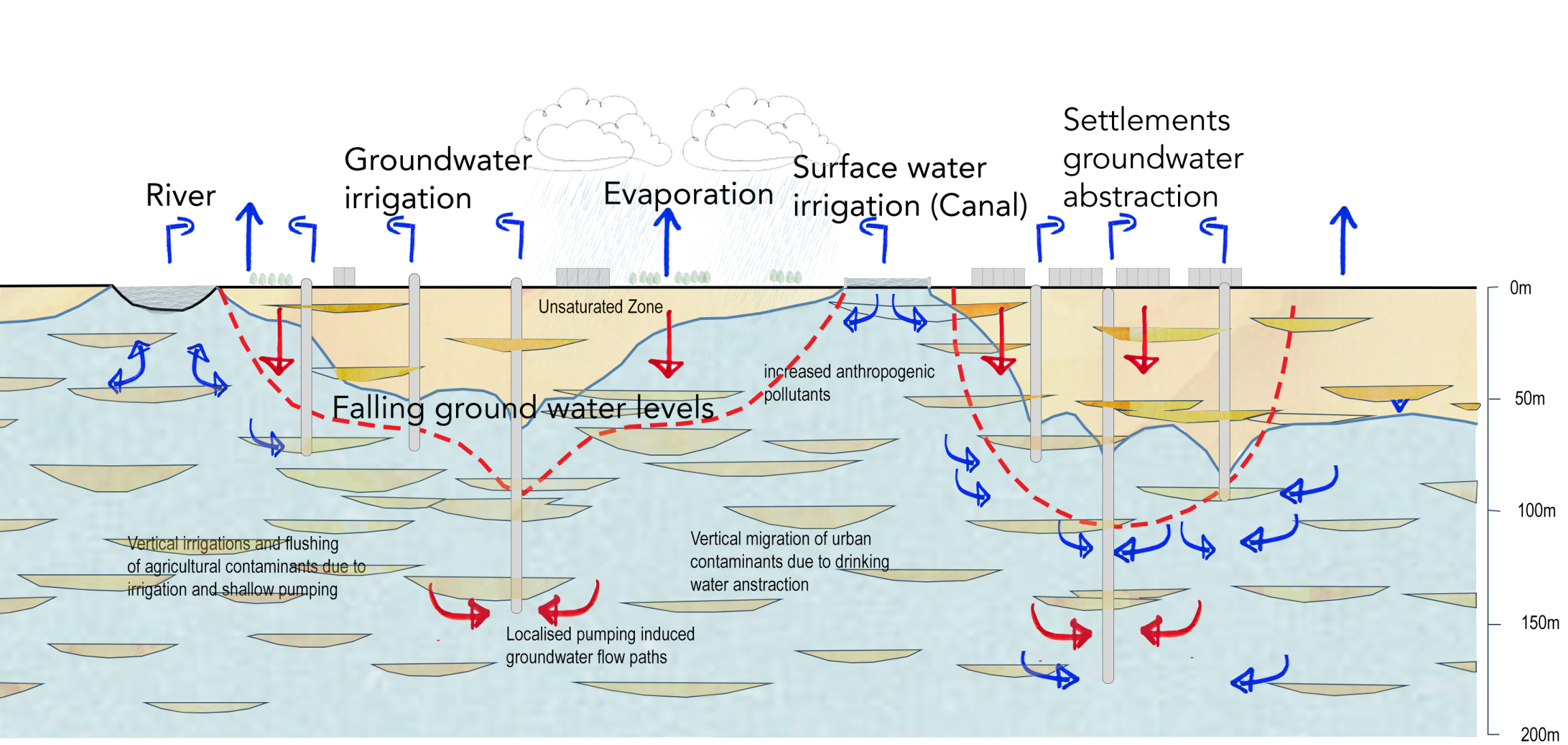
As a result, groundwater recharge has declined because fewer plants and soils are available to absorb and filter rainfall.

In conclusion, the Green Revolution brought major changes to Punjab's agricultural landscape, especially, in the way the water resources were used for irrigation. While the introduction of high yielding varieties of rice helped with food and income security, large scale irrigation led to the overuse of groundwater. The widespread use of tube wells and electric pumps to support rice farming has caused the region's groundwater levels to plummet at an alarming rate. At the same time, the Sutlej River, is drying up, also leading to extraction of groundwater. In addition, as industry and urban settlements expanded, the water demand has grown faster than the nature can supply, causing a serious gap between water use and water availability. Moreover, free electricity for pumping of groundwater contributes heavily towards this.

Once known for its fertile landscapes, Punjab now faces challenges due to groundwater scarcity and soil degradation of intensive agriculture. As a result, it is expected that Punjab will become a desert in 25 years in 2050.[12] While the semi-arid land of Punjab is not a desert yet, if we continue to keep the practices going as they are, it will not be a future problem, but a truth we would live in. Desertification intensifies poverty, food insecurity, and environmental degradation, highlighting the urgent need for mitigating solutions.

Figure 31: Water table drop before the Green revolution and after including the causes (right)


River
Evaporation
Surface Water Irrigation (Canals)
Unsaturated Zone
Low level
anthropogenic pollution
Lens-shaped sand or gravel deposits that store groundwater
Regional Groundwater Flow System
0m
50m
100m
150m
200m


River
Groundwater irrigation
Evaporation
Surface water irrigation (Canal)
Settlements groundwater abstraction
Unsaturated Zone
Falling ground water levels
increased anthropogenic pollutants
Vertical irrigations and flushing of agricultural contaminants due to irrigation and shallow pumping
Vertical migration of urban contaminants due to drinking water anstraction
Localised pumping induced groundwater flow paths
0m
50m
100m
150m
200m

END NOTES

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04 EXISTING POLICY REVIEW

The severity of groundwater depletion in Punjab has prompted several policy documents aimed at promoting more sustainable water management practices in agriculture.

Recent discussions under the new Punjab government highlight crop diversification and resource conservation as policy priorities, but experts stress that meaningful change will require coordinated action from both state and central governments, including guaranteed income for alternative crops and investment in supportive infrastructure like the food processing sector.[1]

4.1 Punjab Preservation of Sub-soil Water Act, 2009

To address the growing problem if groundwater depletion caused by early paddy sowing, policy measures were introduced to regulate the timing of the rice cultivation, These measures restricts the farmers from sowing paddy saplings in nurseries before May 10th and from transplanting the seedlings before June 10th. The delayed transplanting helps reduce water loss by lowering evapo-transpiration, as the crop is exposed less to intense heat during early growth stages.

The report also suggest that these efforts has led to saving approximately 5cm ground water annually. This approach has also helped reduce the severity of groundwater deficits during low rainfall years, showing the potential of regulated agricultural practices. .[2]

4.2 Efforts to shift from Paddy to Alternate crops ⚠

During 2018-19 cropping seasons, government officials in Punjab encouraged farmers in groundwater stressed areas to shift from paddy to maize during the kharif (autumn) season. This effort aimed to reduce water use and promote more resilient cropping practices.
However, most farmers returned to paddy cultivation the following year, mainly due to the absence of minimum support price for maize, which made it economically un-viable option. [3]
This highlights the importance of aligning agricultural policy incentives with water conservation goals to ensure successful crop diversification.

4.3 Free Power Policy and Groundwater Overuse ⚠

Since 1997, free electricity has been provided to support agricultural activities such as irrigation in Punjab. As a result, power consumption in the area nearly doubled.
The rise in electricity use has significantly contributed to the depletion of groundwater resources. Economist S.S. Johl emphasised the need to reform this policy to address its environmental impacts effectively.[4]

4.4 Unimplemented Policy Recommendations 💡

The Punjab State Farmers' and Farm Workers' commission has recommended ending the provision of free electricity for medium and large farmers. The funds saved from this change would be redirected to support income assistance for farmers. However, this policy has not been implemented yet.[5]

4.5 AAP Government's Recent Diversification Initiatives 💡

The Aam Aadmi Party (AAP) government announced incentives to encourage farmers to adopt Direct Sowing of Rice technology, which helps reduce water consumption during rice cultivation. In addition, the government guaranteed the procurement of moong dal (*Vigna radiata L.*) to promote crop diversification. However, moong dal is grown only in the short window between the wheat and paddy cycles and does not serve as a replacement for paddy.

This initiative reflects a step toward sustainable agriculture, but highlights the need for further strategies that directly address the over-dependence on water-intensive crops like rice. [6]

✅ ACTIVE / POSITIVE STEP OR EFFECTIVE CONCEPT

⚠️ PROBLEMATIC

💡 GOOD POTENTIAL WITH MINIMAL CHANGES, NOT YET IMPLEMENTED OR LIMITED IMPLEMENTATION

4.6. Punjab State Farmers' and Farm Workers' Commission recommendations 💡

The objective is to save 30% of the total water demand, equivalent to 20 billion cubic meters(BCM) out of the 66.12 BCM, within in five year period .

The implementation approach is a set of reforms focused on changing cropping patters, improving irrigation methods, managing energy use efficiently, and strengthening overall water management practices.

4.6.1 On Farm Water Management

1. Shift in cropping patterns
- Ban on long duration paddy varieties, as they consume excessive amounts of water.
- Paddy prohibition in over exploited areas. These areas to transition to alternative crops such as cotton, maize, sugarcane, vegetables and orchards. To support this transition, government support needs to be provided for financial security.
- Revival of cotton cultivation with mustard in a crop rotation system is recommended. To achieve this change, a minimum support price, use of drip irrigation and solar powered pumps re recommended. While pumping of water should be stopped, the other criteria can be helpful.
- Cultivation of low water demand variety of Rice such as Basmati Rice.
- Encourage Sugarcane cultivation using drip irrigation systems to reduce water use.

2. Promote Micro-Irrigation Systems
- Drip and sprinkler irrigation systems should be installed on 20% of the total cultivated land to improve water use efficient.
- The initial focus should be on crops that require more water and offer higher returns such as fruits, vegetables, flowers , sugarcane, and cotton.

3. Water Saving within Paddy Cultivation
- Crop Calendar Adjustment should be implemented by enforcing staggered transplanting dates to coincide with monsoon (e.g., PR-126 variety allows July planting).
- Alternate Wetting and Drying (AWD) can help save ~30% water. For success of this method, discourage puddling, encourage direct-seeded rice.
- Public Supply Tubewells should not be used for irrigation for paddy in sensitive areas like Kandi.

4.6.2 Groundwater Management

1. Solarisation of Agricultural Pumps (AP)
- Grid connected solar panels are recommended to be installed in this policy.
- Through this system, farmers can earn income by renting out land or supplying surplus energy to the grid.
- The Punjab State Power Corporation Limited can use this approach to reduce electricity subsidies while promoting the use of renewable energy.
- However, despite these recommended policy efforts, the overuse of pumps for irrigation should ultimately be discouraged and phased out.

2. Paani Bachao Paisa Kamao (Save Water, Earn Money) Scheme

Farmers should be rewarded with cash incentives for reducing their use of electricity and water, encouraging more efficient and sustainable agricultural practices.

3. Urban groundwater regulation
- The use of household submersible pumps to be discouraged to reduce excessive groundwater extraction.
- Groundwater recharge are recommended be promoted through green spaces and community based collective recharge systems.

4. Groundwater Recharge enhancement
- Runoff rainwater should be effectively utilized to enhance water availability.
- Rooftop rainwater harvested to be implemented, the

compliance to be ensured through use of security deposit.
- Surface drains and canals escaped to be equipped with heck structures to promote groundwater recharge, while also ensuring that only clean water enters recharge systems.

4.6.3 Canal Water management

1. Restoration and modernisation
- An immediate overhaul of Punjab's aging canal network is necessary to improve water distribution.
- Special attention to be given to upgrade secondary and tertiary canals to ensure more efficient and reliable water delivery farms.

4.6.4 Water resource management in Punjab's Kandi Region

1. In situ rainwater conservation and harvesting
- This focus is to be on constructing rainwater harvesting structures and promoting solar powered micro irrigation systems to enhance water conservation and irrigation efficiency.

2. Groundwater recharge through seasonal torrents
- Torrents (choes) from the Shiwalik historically recharged groundwater in kandi and non-kandi regions. The construction of dams has disrupted these natural flows, causing lower water table.
- Controlled, stage wise water releases from dams during the monsoon season are recommended to help restore groundwater.
- Designated recharge zones to be identified and protected to support ground water replenishment.

3. Lift irrigation schemes
- Lift irrigation using water from the Maharana Pratap Sagar Dam trhrough the Kandi canal recommended to improve water availability for agriculture.
- Agro-forestry practice to be promoted to enhance environmental resiliency and support farmers' livelihoods.

4. Monitoring and alert systems
- Advanced tools such as sensors, earth observation, and big data analytics should be used for real-time water monitoring.
- Recommended to create enhancements to flood forecasting, climate modeling, and investment in homegrown water technology innovation.

5. Water resource zoning
- Certain areas recommended to be designated as drinking water zones to ensure the protection and sustainable use of clean water sources.
- Regions experiencing significant groundwater depletion to be identified, along with areas suitable for recharge.
- Flood affected, salt affected and drought prone zones to be mapped and monitored.
- Zones with declining water quality to be observed.

6. Capacity building
- Prioritise public training and research through water-related organizations.
- Annual awards to recognize outstanding contributions.

7. Create public awareness [7]

4.7 Recommendations for Sustainable Groundwater Management — Hoshiarpur District 💡

1. Groundwater development
- The district's groundwater development level is at 84%.

2. Mandatory rainwater harvesting
- Rooftop rainwater harvesting and artificial groundwater recharge structures to be made mandatory in building bye-laws, especially in overexploited blocks.

3. Water level monitoring expansion
- Strengthen the groundwater monitoring network, particularly in the central and southern regions of the district.

4. Community awareness
- Educate local residents about the risks of excessive groundwater mining and promote the need for efficient and economical water use.[8]

4.8 National Government Recommended Strategies 💡

4.8.1 Guide on Artificial Recharge to ground water

1. Direct Surface Techniques:
- Flooding: Direct application of water to recharge aquifers.
- Basins/Percolation Tanks: Large basins that allow water to infiltrate into the ground.
- Stream Augmentation: Adding water to streams to facilitate recharge.

- Ditch and Furrow System: A network of ditches or furrows to channel water into the ground.
- Over-Irrigation: Excess water used in irrigation is allowed to recharge groundwater.

2. Direct Sub-Surface Techniques:
- Injection Wells/Recharge Wells: Water injected directly into aquifers via wells.
- Recharge Pits and Shafts: Shallow or deep structures that allow water to infiltrate the ground.
- Dug Well Recharge: Using existing wells to recharge the aquifer by diverting surface or storm water into them.
- Borehole Flooding: Flooding boreholes to increase recharge.
- Natural Openings/Cavity Fillings: Utilizing natural openings in the ground for recharge.

3. Combination Surface-Sub-surface Techniques:
- Basin or Percolation Tanks with Recharge Pits: Combining surface basins with recharge wells to enhance groundwater replenishment.

4. Indirect Techniques:
- Induced Recharge from Surface Water Sources: Encouraging water infiltration from surface water bodies.
- Aquifer Modification: Altering the physical characteristics of aquifers to increase recharge.

5. Additional Groundwater Conservation Structures:
- Bandharas: Sub-surface dams used to control water flow
- Rock Fracturing: In hard rock areas, fracturing the rock to allow water to flow into fractures, increasing recharge.

6. Specific Recharge Techniques:
- Ditch and Furrow Method: A system of ditches or furrows to maximize water infiltration.
- Percolation Tanks: Tanks designed to recharge both shallow and deep aquifers, especially in areas with fractured rock formations.
- Check Dams and Nala Bunds (check dams): Small dams or bunds across streams to slow down water flow and facilitate infiltration into the ground.
- Gabion Structures: A form of small dam made from boulders wrapped in steel wire, typically used across small streams.
- Modification of Village Tanks: Existing tanks can be desilted and modified to act as recharge structures.
- Recharge Shaft: A vertical shaft that allows water to be injected into deep aquifers directly.

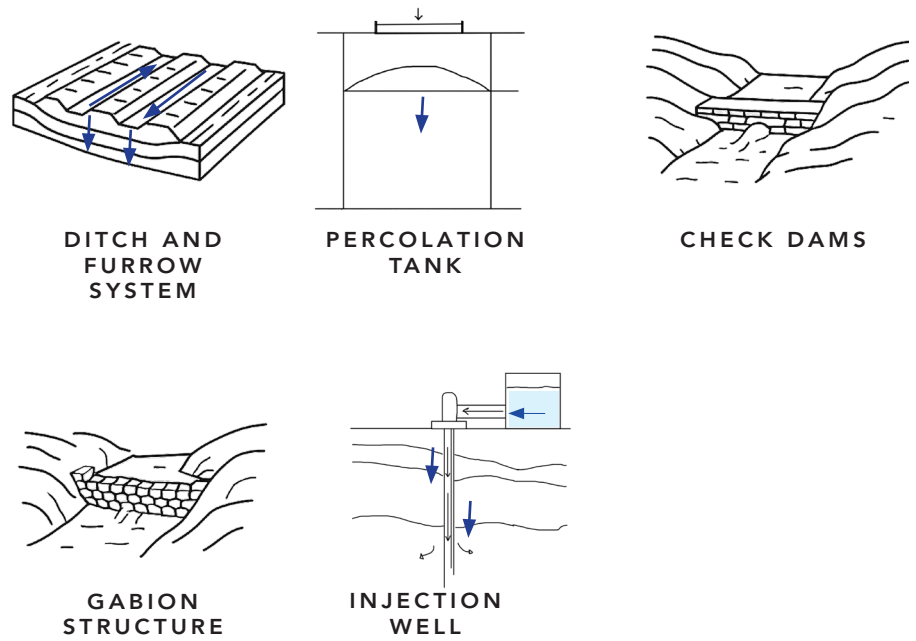

Figure 32: Water recharge techniques

4.8.2 Master Plan for Artificial Recharge, 2020 (Punjab)

1. Uncommitted Surplus Runoff:
- To be managed using check dams and recharge shafts.

2. Surplus Canal Water:
- To be recharged via injection wells.

3. Surface Runoff from Agricultural Land:
- Captured using farm ponds, proposed at 1 farm pond per hectare.

4. Roof Top Rainwater Harvesting (RTRWH):
- Applied to government buildings, institutions, and 55 lakh houses with ~200 sq. m roof areas in the first phase.
- Expected to harvest 52.49 MCM of rainwater, assuming 70% system efficiency.
- Estimated cost: Rs. 30,000 per system (cluster of 4–6 houses).

5. Limitations
- Total Artificial Recharge Cost for Punjab: Rs. 6,773.55 Crore
- Rural Areas: Rs. 5,119.63 Crore
- Urban Areas (RTRWH): Rs. 1,653.92 Crore
- Limited man power[9]

4.9 Punjab State Action Plan on Climate Change ✓

1. Conservation Strategy in Punjab
- Focus on the Shivalik region to conserve biodiversity, wetlands, agriculture and forest diversity.
- Sustain ecosystems and improve climate resilience.

- 2. Solar Energy Potential
- Punjab has 4-7 kWh/sqm of solar insolation.
- 9.325 MW of solar power commissioned as of reporting.
- Increasing solar in the state's energy mix will reduce reliance on fossil fuels.
- Provide incentives for solar thermal water heating systems for urban and rural households.[10]

4.10 Punjab Biodiversity Mission ✓

1. Rehabilitate natural wetlands with community involvement.

2. Continue conservation of man-made wetlands, including:
- Ramsar sites.
- Nationally important wetlands.
- Budget: ₹39 Crore.

3. Rehabilitate natural wetlands by involving the local communities.

4. Continue conservation of manmade wetlands, including:
- Ramsar sites.
- Nationally important wetlands.[11]

In conclusion, there is lack of crop diversification incentives as the existing policies are rewarding towards water intensive crops instead of alternatives such as millet, pulses, or oilseeds. Moreover, farmers also continue to cultivate paddy as well extract water, despite knowing the consequences due to lack of financial stability. Moreover, power and fertilizer subsidies are structured to reduce farmers' input costs rather than encourage efficiency or sustainable practices. Irrigation policies assume groundwater as an unlimited resource. There is insufficient coordination between water-use regulation, crop planning, and groundwater conservation. There is a lack of farmer centric transition support for crops for farmers, while they exist on paper, they are not adopted practically or at a scale that farmers can participate in them.
The Punjab State's Action Plan on Climate change has addressed a lot of important strategies, but their implementation status is unknown.
Therefore, my project focuses on community based initiatives, to discard the issue of finances.

✓ ACTIVE / POSITIVE STEP OR EFFECTIVE CONCEPT

⚠ PROBLEMATIC

💡 GOOD POTENTIAL WITH MINIMAL CHANGES, NOT YET IMPLEMENTED OR LIMITED IMPLEMENTATION

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Figure 33: Present day conditions

Punjab's agricultural landscape is under growing threat of desertification, driven by groundwater depletion, soil degradation, and unsustainable farming practices. This ecological imbalance has also resulted in the erosion of cultural landscape qualities such as shared gathering spaces and shade-providing trees that once connected people to the land. These losses have not only compromised environmental resilience but also weakened the community's relationship with their agricultural heritage, a disconnection I have come to understand more personally through stories from my grandmother.

To address these intertwined issues, my design strategy takes a multi-scalar approach to water and soil restoration by intervening at state, regional, and inter-village levels to enhance groundwater recharge and reduce runoff. Complementing this, the project seeks to reintroduce community gathering spaces under native shade trees, reviving cultural practices and helping people reconnect to the land.

PROBLEM STATEMENT

05

REIMAGINING THE STATE: WATER, ECOLOGY, AND AGRICULTURAL RESILIENCE

STATE SCALE STRATEGIES



INTRODUCTION

Building on the understanding of Punjab's layered landscapes, this chapter introduces strategies at the state scale, where hydrological systems, agricultural practices and settlement patterns intersect. Starting at this broader scale helped develop a perspective for the identification of large scale ecological and cultural systems that inform locally grounded and adaptable strategies later on. These strategies form the framework based on existing policies, for addressing surface water scarcity in rivers, ground water recharge, saving water and creating social-ecological places .

Figure 34: Sutlej Riverbank: A view of the river's edge, highlighting the absence of riparian forest. (Google Street View)

Punjab's water management strategies involve several key state-level interventions aimed at restoring ecological balance and improving groundwater recharge. These include: (1) establishing vegetation zones along major rivers such as the Sutlej and Beas, as well as alongside major canals; (2) reviving and conserving wetlands to enhance natural water storage and biodiversity; and (3) maintaining a balance between the regular flow of rivers and deeper aquifer recharge to ensure sustainable groundwater levels. The following sections explore each of these interventions in detail.

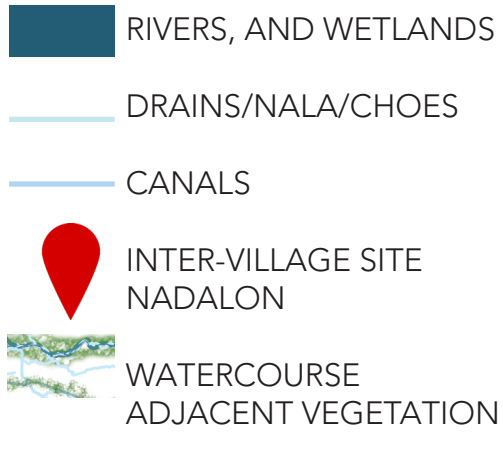
5.1 Establishing the Vegetation Zone on the Major River (Sutlej and Beas River) and Major Canals

5.1.1 Vegetation Establishment

The Vegetation zone is a vital component of the river-aquifer system, positioned within the watershed. Its distinct spatial structure and ecological functions enable it to regulate both the quantity and quality of water exchanged between the river and the groundwater.[1]

5.1.2 Necessity for the strategy

The implementation of the vegetation zones along the Sutlej River and Beas is essential for reinforcing water security as it directly affects the groundwater recharge as mentioned in Chapter 3. Moreover, these forests are an important part of the regional water cycle, the vegetation along riverbanks of canals helps in moderating evaporation, transpiration and precipitation patterns, slowing down the river water to infiltrate, and therefore, creating healthy water systems. The two rivers are known to experience seasonal flooding, and riparian forest function as natural flood buffers by absorbing excess water during peak flows, and eventually helps in riverbank stabilization.[2]



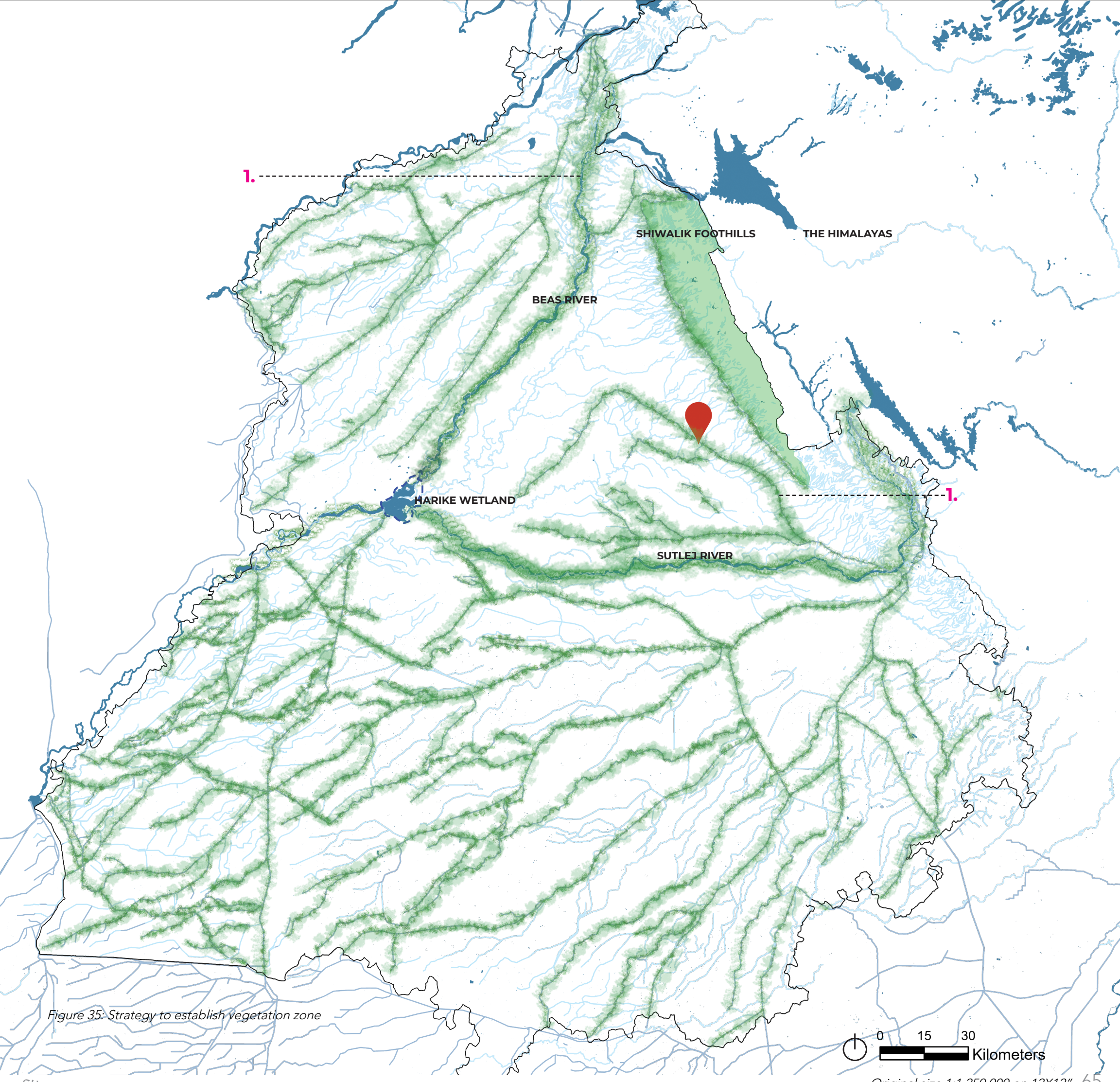


Figure 35: Strategy to establish vegetation zone

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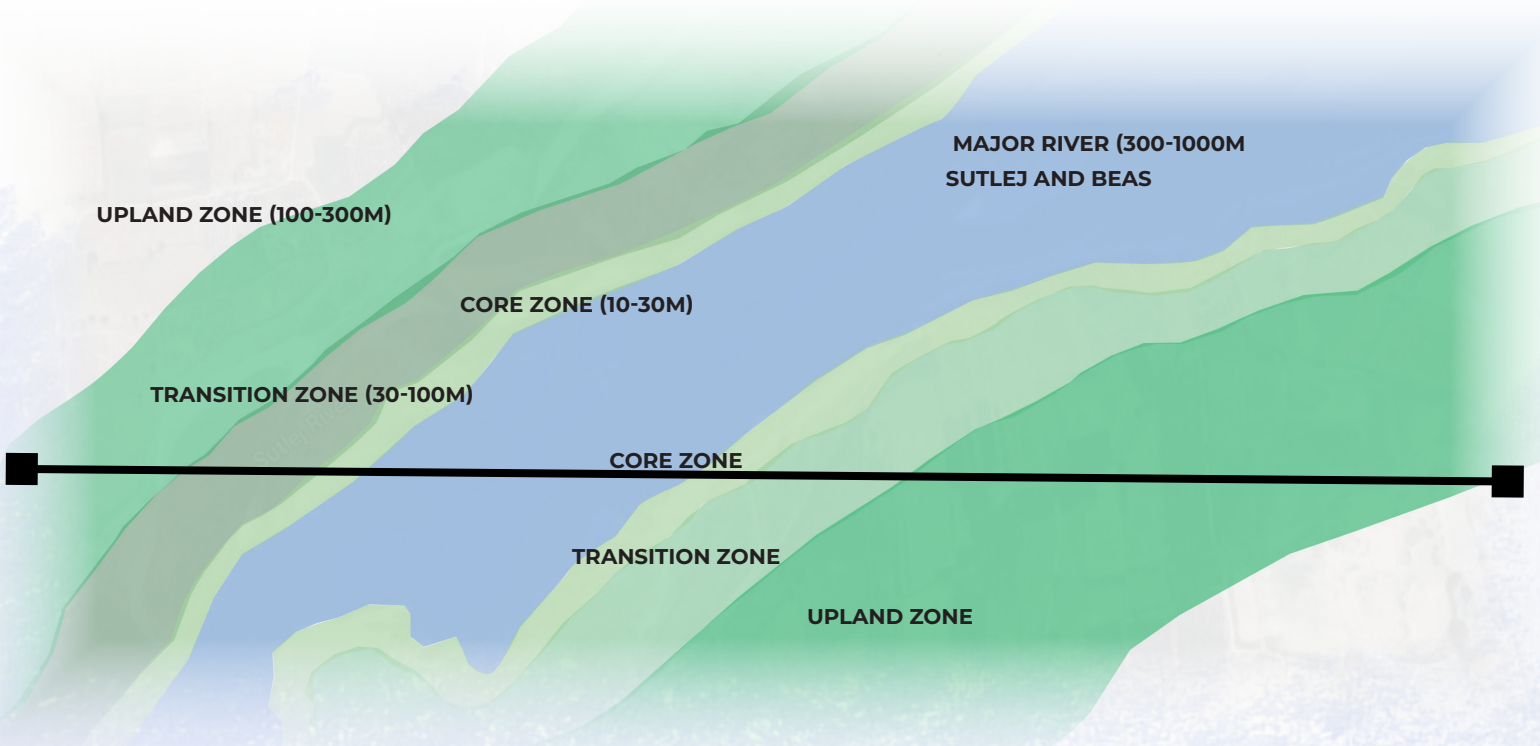


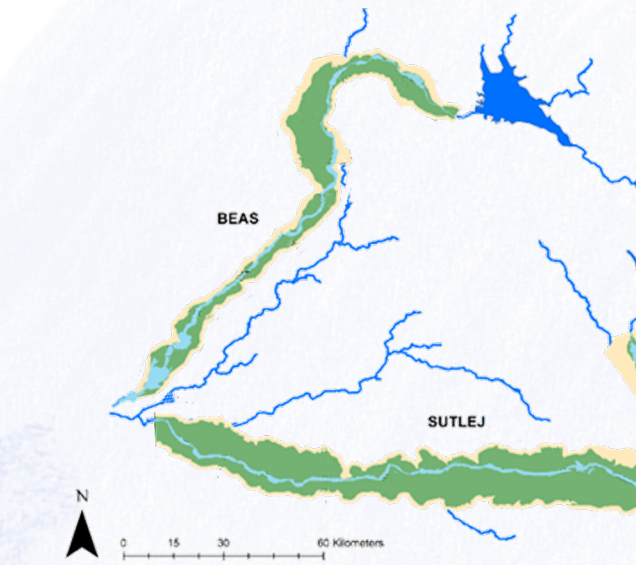
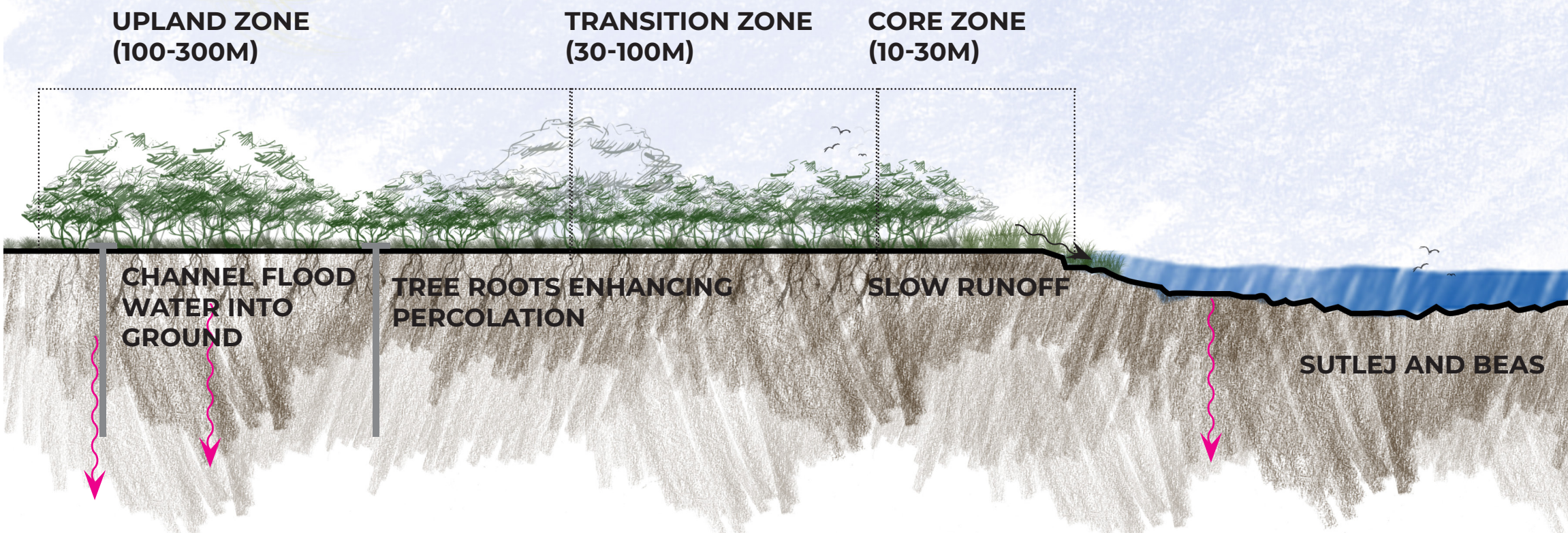


Figure 36 & 37: Average Vegetation Width for the Rivers (left) and Potential vegetation width (right)
Figure 38: Section showing the vegetation zones (below)





5.1.3 How does it refill the groundwater

Vegetated riverbanks contribute towards groundwater recharge by slowing down and infiltrating surface water, which eventually percolates into the ground increasing the water table. The trees and other plants creates porous soil structures to help water infiltrate faster. Moreover it also helps with the filtration of pollutants and trapping sediments before the surface water reaches the ground water table.[3] Increasing vegetation cover along the Beas and Satluj rivers reduces soil erosion and improves soil moisture retention, which supports higher groundwater recharge in the surrounding areas.[4]

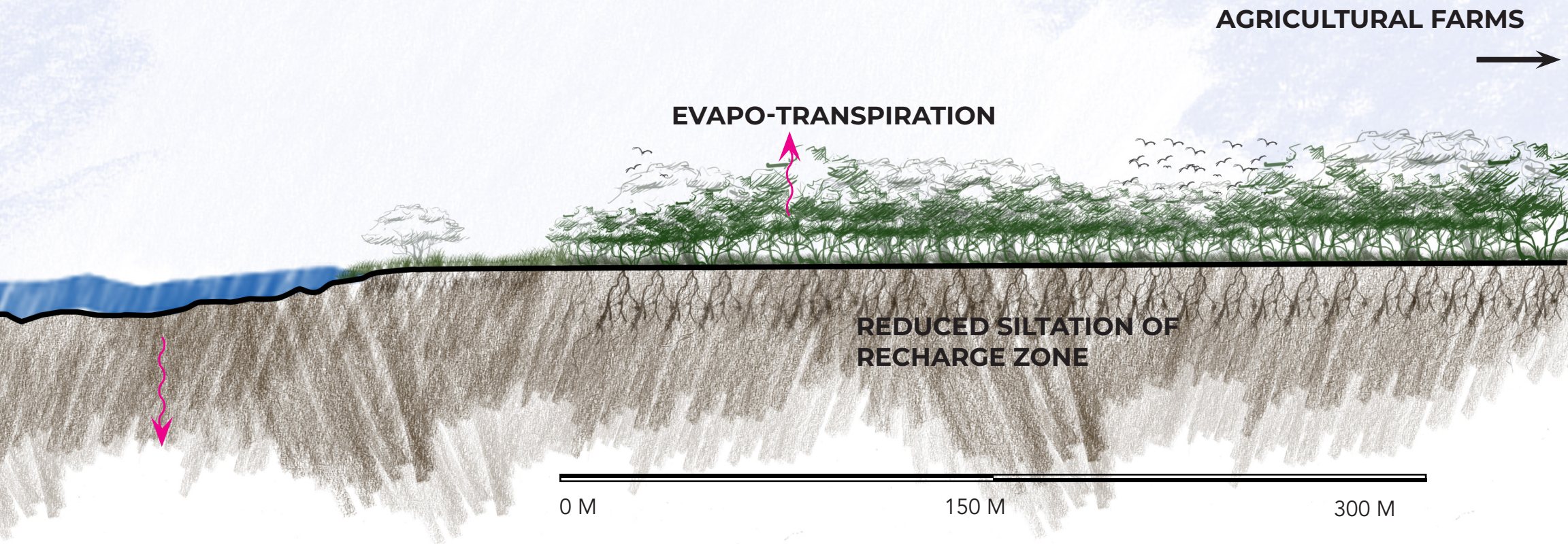
Groundwater recharge is highest when there is moderate tree cover, therefore, 50% of tree coverage is recommended, the rest is prescribed to be native grasses. Areas without trees experience high surface runoff and soil evaporation, which leaves little water to soak into the ground, even though transpiration is low. On the other hand, dense forests reduce surface runoff and evaporation, but high rates of transpiration and interception limit groundwater recharge. Hence, when tree cover is at a moderate level, both surface runoff and evaporation decrease while transpiration remains balanced, allowing more water to reach and replenish the groundwater system.[5]

Trees are planted so that the impact of trees on groundwater recharge is strongest in local-scale aquifers, where hydro-geological conditions are well understood, therefore, it is crucial to consider the amount of plantation at various segments of the riverbanks, tailoring re-vegetation efforts to the specific conditions of each area to maximize groundwater recharge and ecological benefits.[6] (Figure 38)

5.1.4 Area of Vegetation extent for rivers

The width of a vegetated area varies depending on several factors, including the river itself, topography, vegetation and human influence.

As the River valley of these rivers extend as wide as 15-20 km, range from a few meters to several km (figure 37). It will eventually depend on local factors of each segment of the river, including the hydro-geological conditions. The generalized width is selected for the regional scale as shown in the figure.



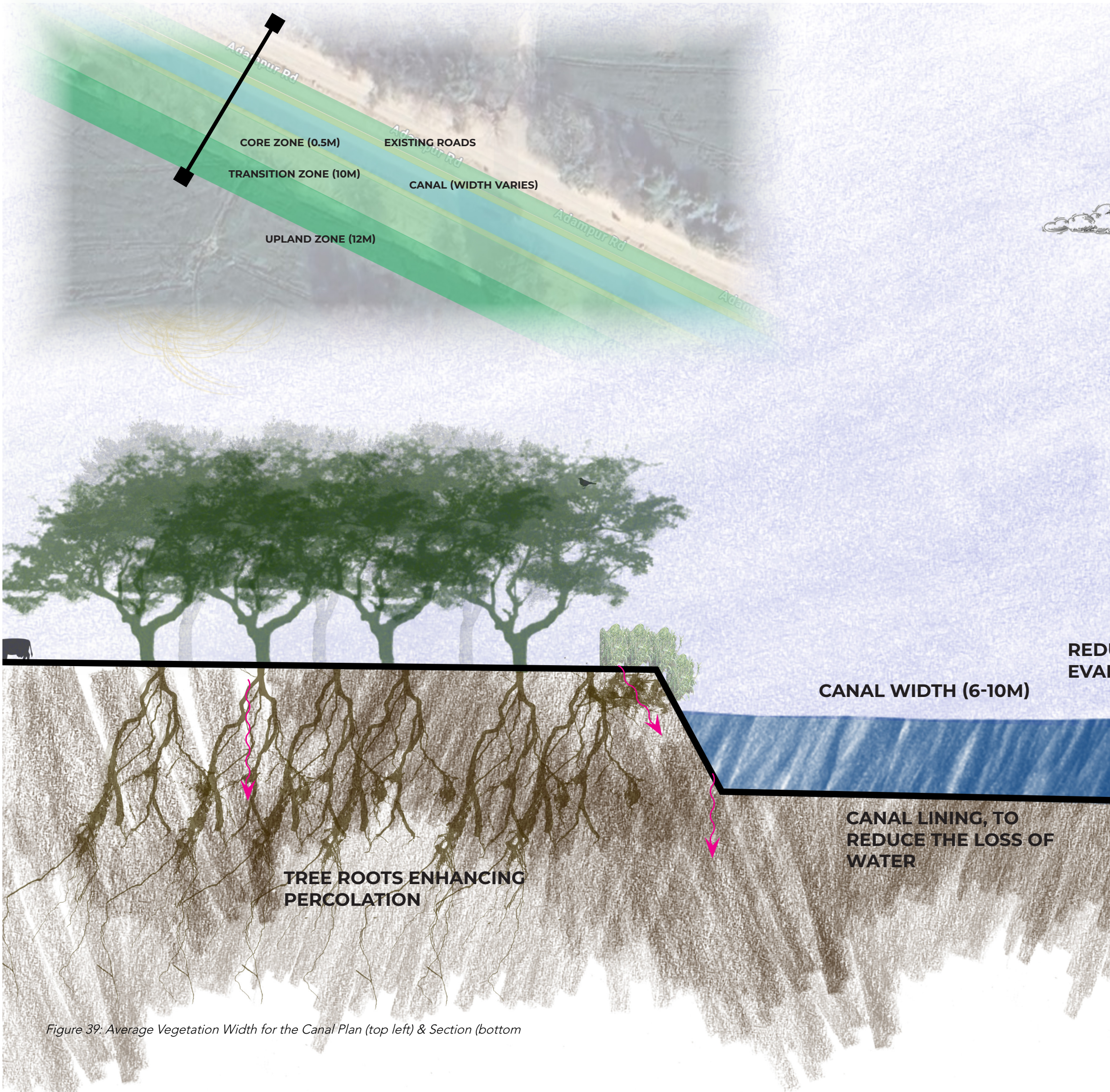
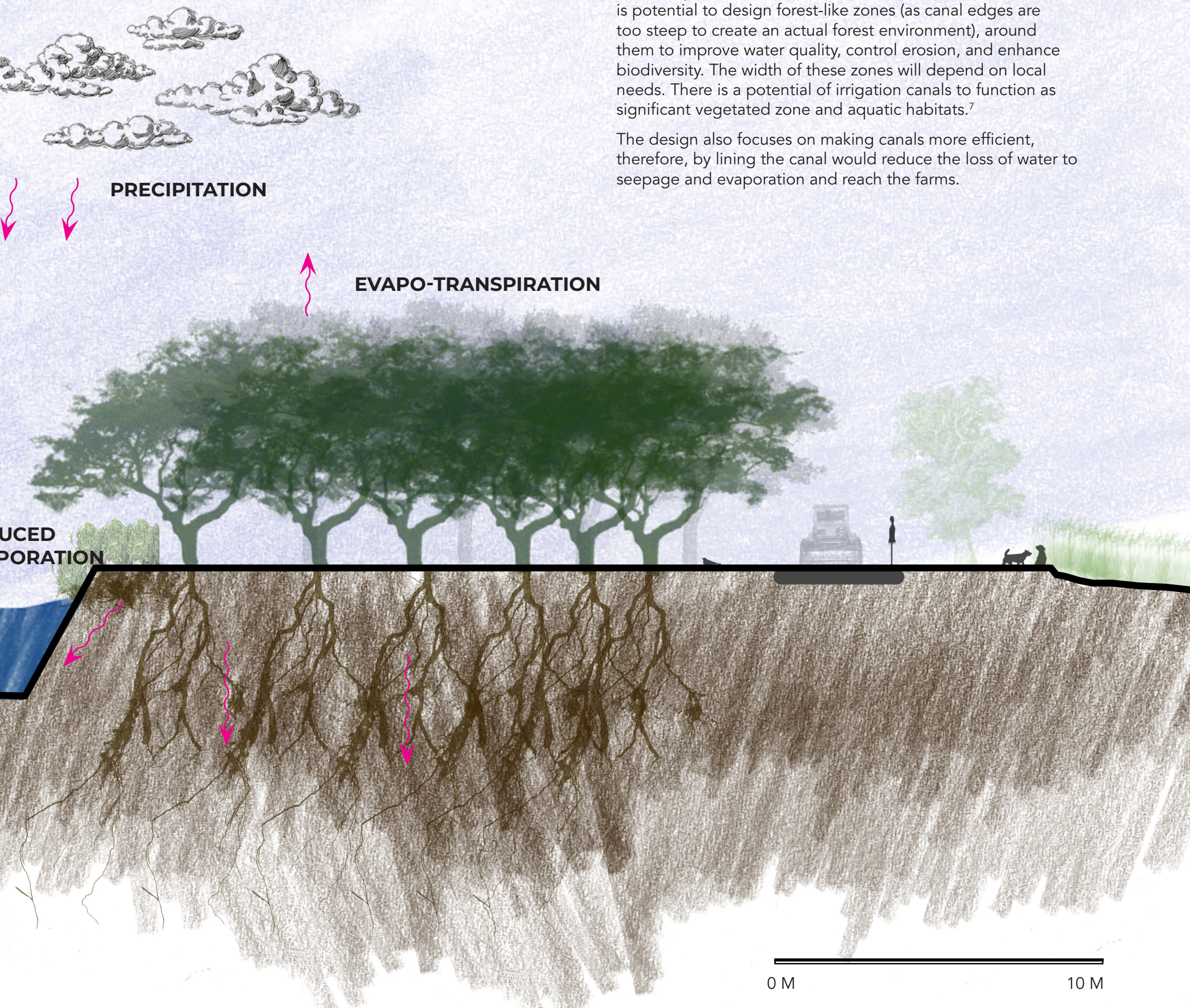


Figure 39: Average Vegetation Width for the Canal Plan (top left) & Section (bottom

5.1.5 Area of Riparian Forest for Major Canals

Canals typically lack natural Vegetation zones, but there is potential to design forest-like zones (as canal edges are too steep to create an actual forest environment), around them to improve water quality, control erosion, and enhance biodiversity. The width of these zones will depend on local needs. There is a potential of irrigation canals to function as significant vegetated zone and aquatic habitats.[7]

The design also focuses on making canals more efficient, therefore, by lining the canal would reduce the loss of water to seepage and evaporation and reach the farms.



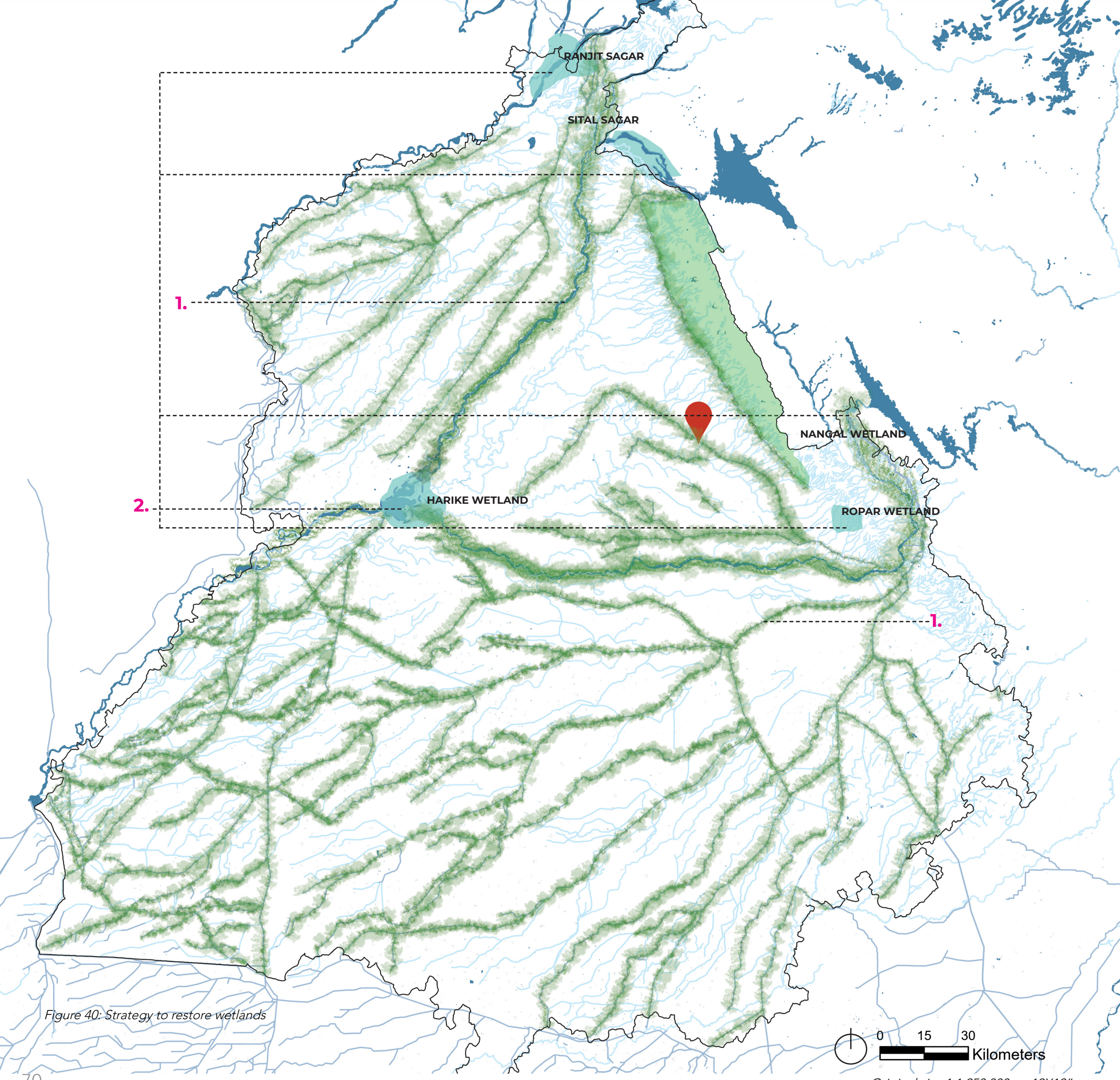


Figure 40: Strategy to restore wetlands

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5.2 Restoration and Conservation of Wetlands

5.2.1 Wetlands

The revival of wetlands is the second strategy for the regional scale. Wetlands collects fresh water on the surface. The water is collected from sources such as rainwater and surface runoff. These water-bodies slowly release it into the ground ultimately recharging the groundwater and also creates rich biotopes.[8]

5.2.2 Necessity for the strategy

As mentioned in chapter 2, the wetland's areas are reducing due to unauthorized agricultural encroachments, the spread of invasive plant species including weed growth, siltation and pollution from industries, agricultural run off and expansion of urban area. Additionally, unsustainable practices such as fishing, poaching, and overgrazing have further degraded the wetland ecosystems. This loss not only affects groundwater recharge, but also severely affects biodiversity of the wetlands and the region. For example, the migratory birds visiting Punjab is declining every year, due to combined effects of climate change, water scarcity and hunting.[9]
Therefore, it is essential to incorporate wetlands in this design to conserve water in water bodies to help with water percolation. As they establish, wildlife population have habitats as well.

5.2.3 Conservation

The revival and conservation of these wetlands is established through the enforcement of existing policies and the current and enhanced legal protection. The necessity of these wetlands is shared through education. The wetlands are embedded in the community by developing them through co-creation with the local stakeholders, the installment of local stewardship and management.



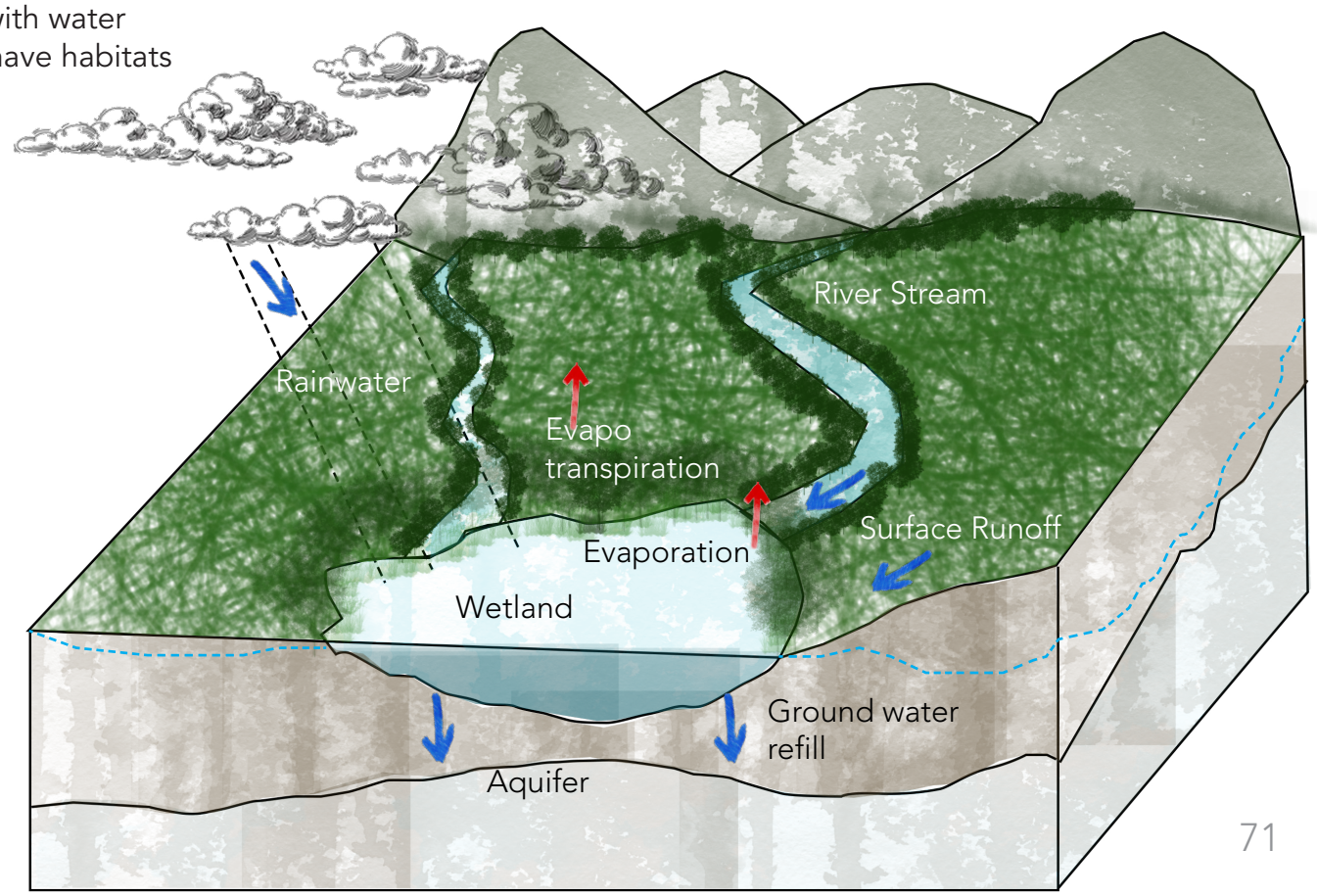

Figure 41: Illustrative depiction of groundwater recharge through Wetlands

5.3 Balance between regular flow of the rivers and deeper aquifer recharge

To ensure the health of wetlands and regular flow in the Sutlej and Beas River, a regular flow of surface water from the source is created by regulating the Dams.

5.4.1 Regulation of Dams

While the dams at the sources of the Sutlej River and Beas river helps infiltrate water into the deeper aquifer, dam release schedules still need to be better regulated so that the wetlands and riparian ecosystems can sustain in the lower areas of the state, and as mentioned in Chapter 2, removing this issue, would fulfill water needs through surface water in due time, and reduces groundwater extraction for agricultural irrigation and daily use.

5.4.2 Regulations and Shifts

Punjab requires stricter operational regulations of dams, including scheduled water releases during the dry season to ensure the continuous flow of rivers like the Beas and Sutlej, that are vital for groundwater recharge, wetland conservation, and sustaining biodiversity. Alongside this, the state shifts towards solar-powered electricity, reducing dependency on hydroelectric dams, as highlighted in Chapter 5's policies for promoting renewable energy alternatives. This combined approach balances energy needs with ecological preservation.

Moreover, the Zone 1 and 2 area, where dams store water, plays an essential role as a prime location for deep groundwater recharge. While maintaining this storage is important for sustaining groundwater levels, it is balanced with the need to allow a regulated, consistent water flow downstream to support river ecosystems.[10]

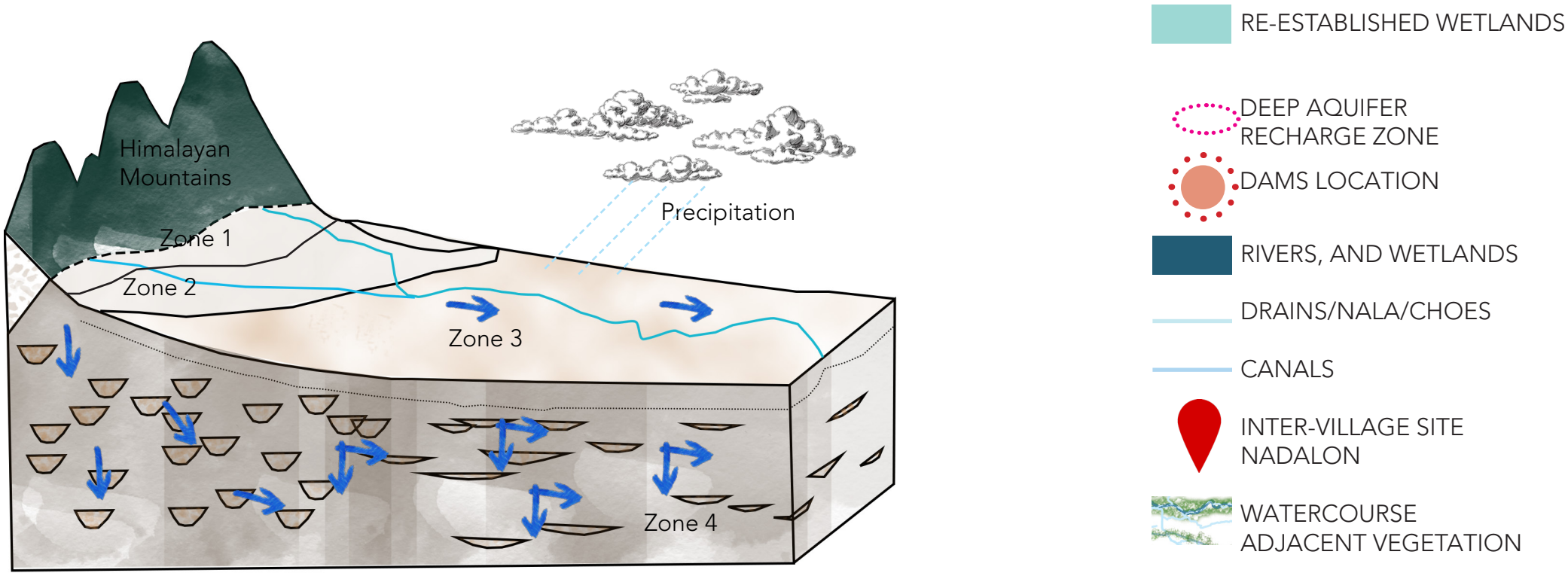

Figure 42: Deeper aquifer recharge in Zone 1 and 2; when water naturally percolates into the soil, it slowly seeps deeper into underground layers, replenishing aquifers. This recharged water doesn't just stay local but it becomes part of the regional groundwater flow system, moving underground over time and supporting wells, springs, and base flow in rivers across a wider area.

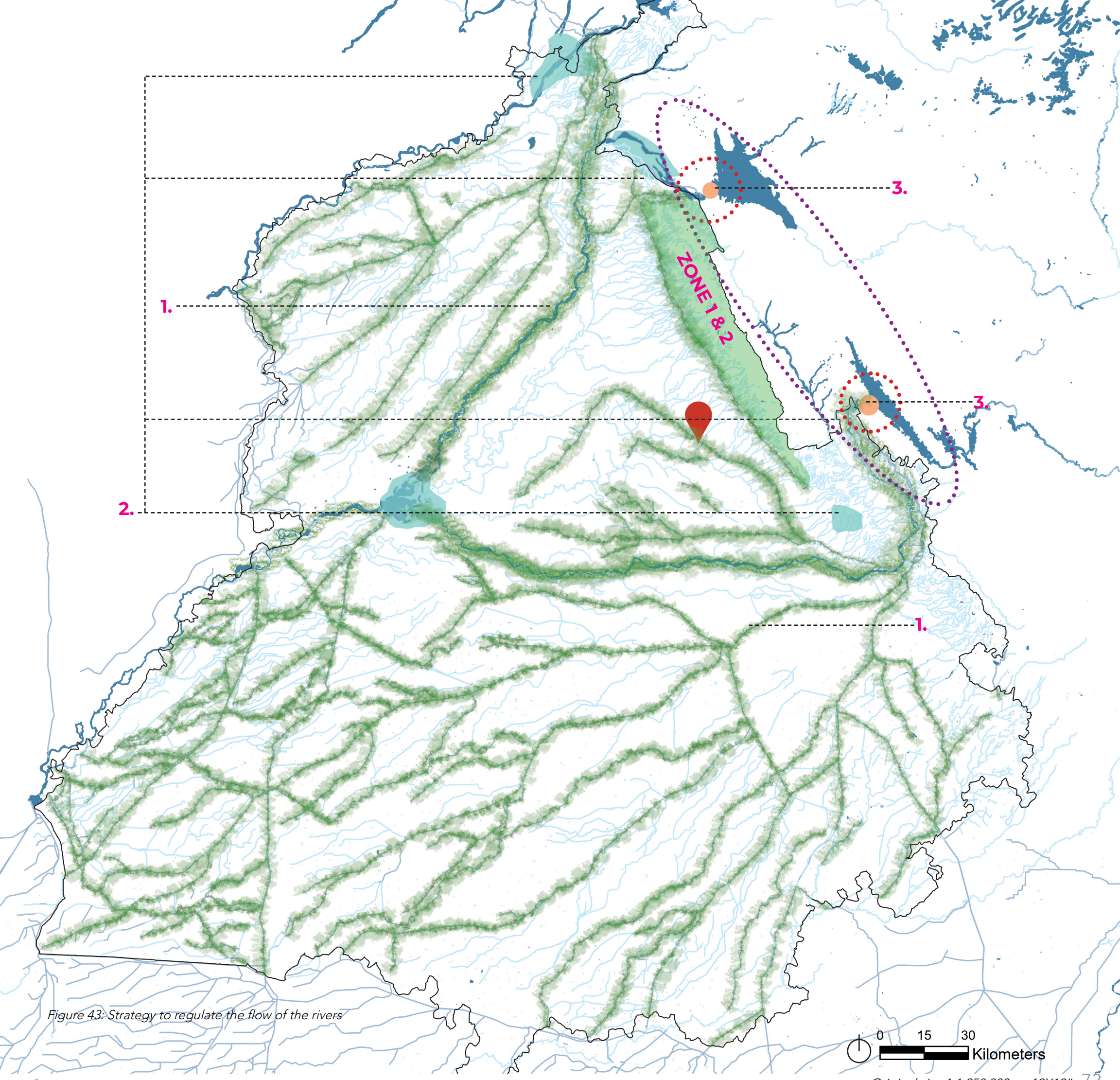

Figure 43: Strategy to regulate the flow of the rivers

Original size 1:1,250,000 on 12X12”

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06 BIST DOAB: THE FERTILE INTERFLUVE OF PUNJAB'S RIVERS

REGIONAL SCALE STRATEGIES

6.1 INTRODUCTION

The Bist Doab translating to the land between two rivers, the Beas river and Sutlej river, is the most fertile land in Punjab due to its location. It is a useful area for an intermediate study. More particularly, this was majorly changed during the green revolution. The region is bounded by Shiwalik hills in the northeast, and the two rivers. The two rivers join at Harike Wetland and thereafter continue as Sutlej River.
The Bist Doab region comprises of 18% of the total area of the Punjab state, and has four districts named, Hoshiarpur, Jalandhar, Kapurthala, and Nawan Shahr. About 87% of the area is plains and 13% with hills.[1]
In this region, most of the original natural vegetation has been cleared with a few remnants surviving on the hills and the foothills. The existing cover, a result of human planting includes following species: trees such as Kikkar (*Acacia arabica*), Shisham (*Dalbergia sisson*), Jamoa (*Eugenia jambolana*), Bohr (*Ficus benghalensis*), Pipal (*Ficus religiosa)*, Ber (*Zizyphus mautiana*), Dek (*Melia azadarachta*), Phalai (*Acasia modesta*), and Wan (Slavodora oleoides).[2]
As for rainfall in this region, overall, precipitation decreases from approximately 900 millimeters in the northeast to around 500 millimeters in the southwest.[3] Additionally the region is dominated by intensive agriculture, especially wheat-paddy cycles, and the landscape is highly fragmented by canal networks, rube-wells and farm roads. The rural settlements are quite dense and often aligned along either roads or canals.

RIVERS, AND WETLANDS

DRAINS/NALA/CHOES/ RIVULETS

CANALS

INTER-VILLAGE SITE



Figure 44 : Context of Bist doab showing major water bodies

Original size 1:550,000 on 12X12”

6.2 Geology and hydro-geology of the Bist Doab region

The region of Bist Doab is composed of alluvial deposits formed by the rivers and streams that originate in the upper Himalayas, primarily Sutlej and Beas and their tributaries.[4]
The Bist doab region has thick layers of alluvial deposits resting on semi-consolidated tertiary rocks or older igneous and metamorphic bedrock from the Precambrian era. Near the foothills of Shivalik hills, the landscape is covered by piedmont deposits, which include coarse materials, like boulders, pebbles, and gravel, along with some other finer sediments such as sand and clay. This area of foothills is also known as Kandi belt.[5]
The region is drained by the white Bein and black Bein rivers, as well as two canal systems, namely Bist Doab canal and Kandi canal. Near the northeastern Shiwalik foothills, the drainage density is the highest, while other areas show medium to low drainage with patterns that are either sub-parallel or sub-dendritic. In the plains, the land slopes gently at 0.5 meters per km towards the south east direction.[6]
The region contains two main aquifer groups. The upper aquifer is confined and made mostly of coarse sandy layers, with a thickness that ranges between 72 to 94 meters. It has alternating layers of sand and less permeable clay. The sloped foothills of the Shiwalik region traditionally acts as a recharge zone for the deeper aquifers in the surrounding plains.[7]

Figure (right) reveals a geologically diverse substrate composed of various deposits. This variation indicates alternating zones of permeability. The heterogeneous geological composition shows the need for site specific strategies in water harvesting based on the characteristics of each are.
The Shiwalik foothills are characterized by podzolic soils and a geological base made up of friable gray micaceous sandstone, along with brown, red, and purple clays, and conglomerates. This combination of soils and rocks shows varied permeability, with the sandstone layers functioning as moderate to high infiltration zones into the deep aquifer.
As for the inter-village scale, located within the alluvial plains, it is primarily loamy soils as can be seen in Figure (soils of Punjab) in Chapter 3. These soils possess moderate infiltration rates, typically ranging between 3.8-7.6mm per hour. This balanced texture allows for sufficient water percolation to support groundwater recharge while also retaining moisture for vegetation, making loamy soils ideal for testing design strategies for infiltration based groundwater recharge systems.[8]

RIVERS, AND WETLANDS

DRAINS/NALA/CHOES/ RIVULETS

CANALS

INTER-VILLAGE SITE

PRIABLE GRAY MICACEOUS SANDSTONE, BROWN, RED AND PURPLE CLAY, AND CONGLOMERATE

RED DRIFT SAND TO LOAM WITH KANKAR, STICKY CLAY, GRAY MEDIUM TO COARSE MICACEOUS SAND WITH KANKAR, SUB GROUNDED TO SUB ANGULAR UNSORTED PEBBLES, GRAVEL AND COBBLE IN ADJOINING FOOTHILLS

BLUE GRAY TO LIGHT GRAY MICACEOUS SAND WITH INTERBANDS OF PURPLE RED CLAY

UNDIFFERENTIATED SEMI CONSOLIDATED AND STABILISED AND STABILISED OLDER DUNES WITH KANKAR, AND SOME CARBONACEOUS MATERIALS

UNDIFFERENTIATED AELOLIAN FLAT/SAND SHEET AND NEWER DUNES

LOOSE GRAY MICACEOUS SAND ALONG WITH THE STREAM COURSES

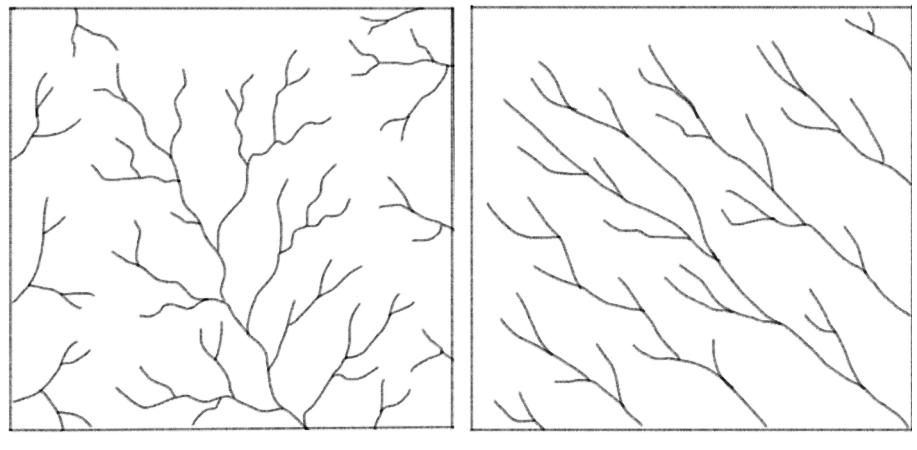

Figure 45: Sub-dendritic flow pattern (left), sub-parallel flow pattern (right) to understand how water moves through the landscape

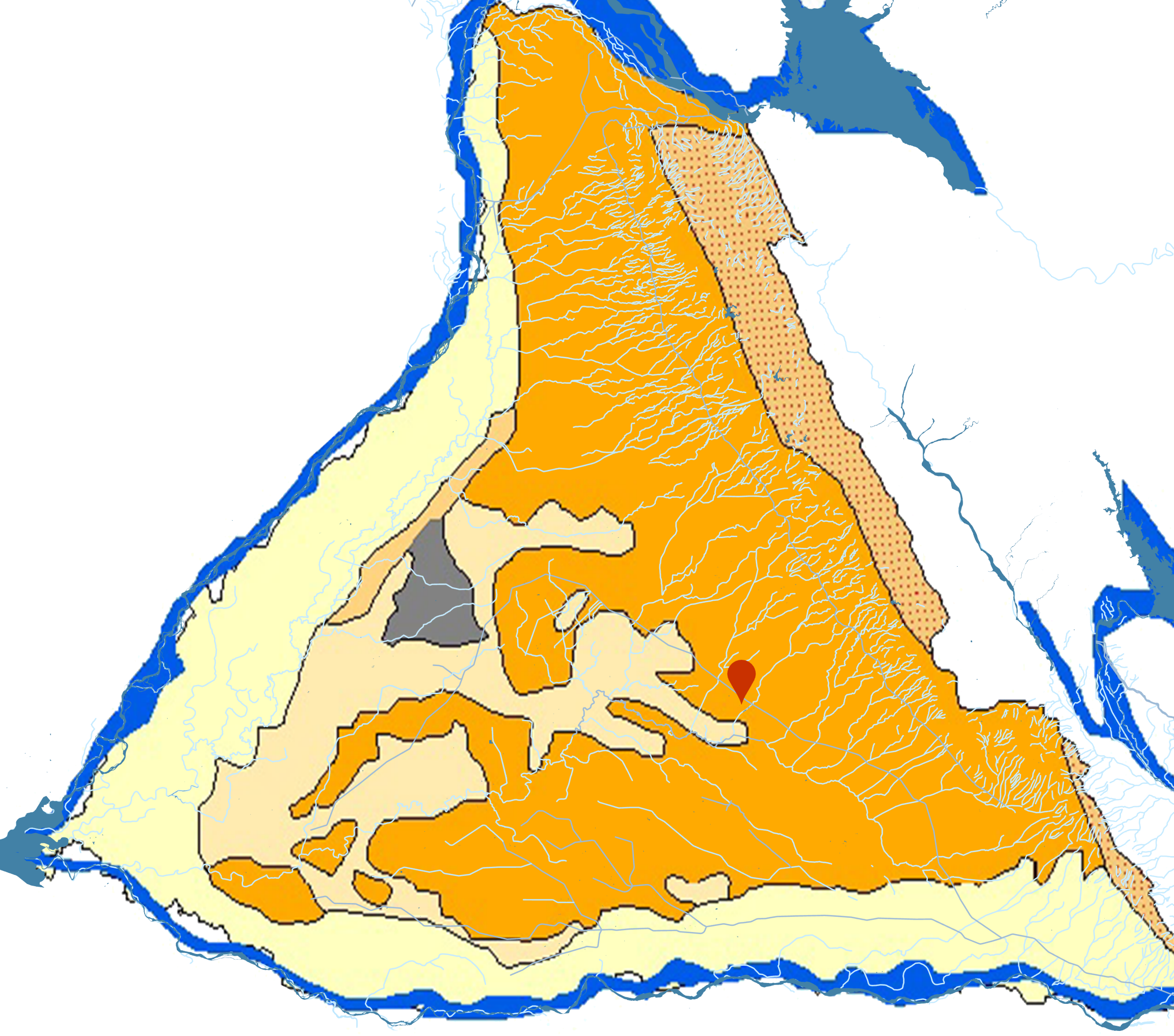

Figure 46: Geology of the Bist Doab region

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6.3 Canal System of Bist Doab Region

The Bist Doab region is supported by an extensive canal network, originally built to support agricultural irrigation. However, as discussed before, the region experienced a significant shift from canal irrigation to submersible tube-wells due to lack of surface water during off season and practice of year round cultivation needed that access. By 2016, tube wells became the primary source of irrigation of rice and wheat cultivation in this region.[9]
Canals in various regions, usually are a source of groundwater aquifer recharge, whereas in this region, there is no link between the groundwater storage and the canal network. This happens due to the short availability of water only during the monsoon season.[10]

6.4 Density of Tube wells in the region

The density of tube wells was more than 30 per square kilometers in the districts of SBS Nagar, Kapurthala, Jalandhar, and around 25 per square kilometers in Hoshiarpur district. The inter-village scale site has 16 tube wells per km2. Before the 1990s, farmers used centrifugal pumps that were powered by electric motors to pump up the water, but as the groundwater levels declined further, farmers started lowering the positions of these pumps into the ground to extract more water and to do that shifted towards submersible pumps.[11]
Many farmers no longer turn their tube wells on or off, as the pumps are cooperated automatically according to the government issues electricity schedules. This reflects the lack of awareness regarding water conservation and over-exploitation of groundwater resources, therefore, suggesting a need to create awareness program and community involvement by providing incentives.[12]
The region's combination of a very well developed canal network and once abundant groundwater resources had made irrigation extremely easy. However, the transplantation of rice during May, when the average temperature reaches 37°C and potential evaporation is about 12mm per day, it increases the demand for irrigation, which is essentially met by groundwater.[13]
To help with that, The Punjab Prevention of Subsoil Water Act, 2009 was implemented to prohibit sowing of rice in May, which reduces the pressure on the groundwater by a minimum amount.

6.5 Recharge Zone in the Bist Doab basin

While the eastern and some middle parts of the region are good for natural recharge, they are not suitable for artificial groundwater recharge in green color(figure 47). The best recharge zones are located in the parts of the central and western areas. There are floodplains, alluvial plains and agricultural farms, all of which have soils with high infiltration potential. Therefore the inter-village site is chosen in the good artificial recharge zone, while the eastern area was chosen for strategic natural aquifer refilling.
About 15% of the Bist Doab region falls into the poor recharge zone, 18% moderate, 37% in the good zone, and very good zone is 30% (refer to map on the right).[14]

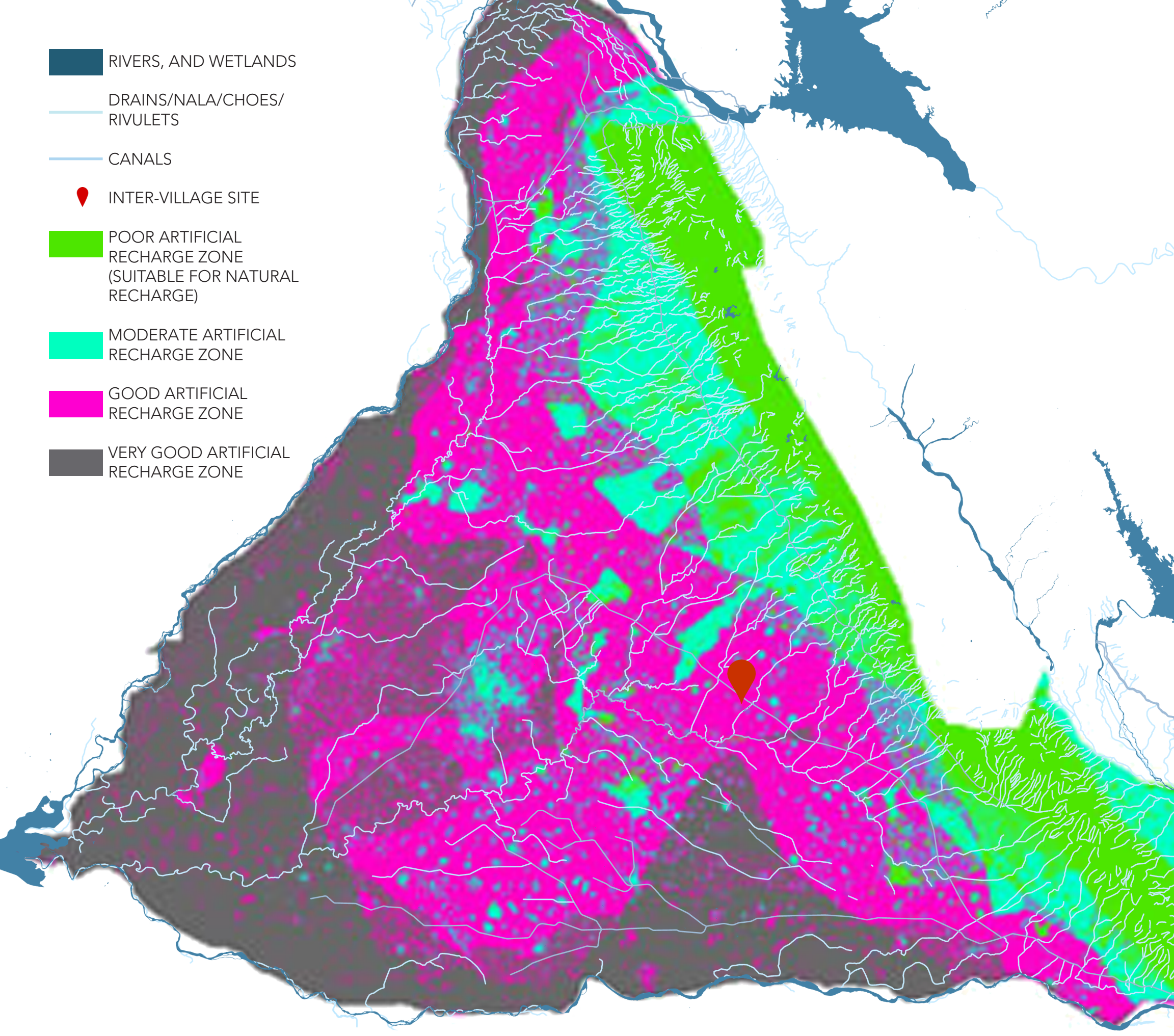

Figure 47: Artificial recharge zones

Original size 1:550,000 on 12X12"

6.6 Regional Level Strategies - Bist Doab

1. Establishing tree vegetation on canals, rivulets and drains for natural filtration

As discussed in section 6.3, Bist Doab region has an extensive canal and drain network. To enhance their effectiveness, these drains are lined with vegetation. This helps with water by slowing down the runoff and reducing evaporation from the water bodies.

2. Addition of bunds and check dams in the Kandi (foothills of Shiwalik hills) for natural infiltration by slowing the flow of the water

Section 6.2 highlights that the foothills of the Shiwalik range provide favourable conditions for recharging deeper aquifers. This area receives higher rainfall, averaging up to 1000 mm, and the natural runoff from the elevated slopes is directed towards lower areas. Bunds and check dams in these foothill zones slow down this runoff, allowing water to infiltrate into the soil and recharge the deeper aquifers. Once replenished, these aquifers will maintain groundwater flow toward the agricultural lands in the rest of the Bist-Doab region.

3. Reforestation in Shiwalik forest

Afforestation is carried out in the Kandi belt and areas adjoining the Shiwalik hills, as these regions are sparsely populated and have available open land for tree planting.[15]

Increasing tree cover in these areas helps improve groundwater recharge by enhancing soil permeability, reducing surface runoff, and promoting infiltration. The root systems of trees create pathways for rainwater to seep into the ground, allowing water to reach deeper aquifers.[16]

4. Change in Faming patterns

The Bist Doab region, where rice and wheat are the primary crops, has experienced significant stress on its groundwater table due to these water-intensive farming practices. To address this issue, cropping is diversified through the introduction of alternative crops. One effective approach is mixed cropping, which helps maintain soil fertility and reduces the reliance on chemical fertilizers. In this area the rice production area is diminished by 60%. For example, pairing leguminous plants with non-leguminous ones, such as maize with red gram, wheat with gram, or pea with mustard, can naturally enrich the soil. These crops also require less water comparatively.
Additionally, allowing agricultural land to lie fallow for one season each year helps conserve soil moisture and restore its fertility. During this fallow period, incorporating organic matter like cow dung, green leaves, and other natural fertilizers into the soil further enhances its health, preparing it for more productive and sustainable crop yields in the following season.[17]

5. Shallow water bodies in local contexts

As mentioned in Guide on *Artificial recharge and Punjab State Policy*, the introduction of small water-bodies aligns with existing government policies aimed at promoting groundwater recharge, biodiversity conservation, and flood control. These water-bodies are integrated into the landscape in a way that respects local agricultural patterns and ecological conditions. While proposed at a smaller scale, these systems gradually extend into local and inter-village contexts, where they contribute to both water management and community resilience.



WATER SAVED
4 TRILLION LITRES
PER YEAR
(ESTIMATED)

Total area: 8,915 km² (891,500 ha)
60% under rice cultivation: 534,900 ha
Changing 60% of rice area: 320,940 ha
Crop shift breakdown:
40% Millets (128,376 ha)
40% Pulses (128,376 ha)
20% Vegetables (64,188 ha)
Water use per hectare:
Rice: 15,000,000 L/ha
Millets: 1,950,000 L/ha
Pulses: 1,600,000 L/ha
Vegetables: 5,000,000 L/ha
Water saved annually:
Original rice water use: 4.81 trillion litres
New crop water use: 0.78 trillion litres
Water saved = 4 trillion litres per year

1.
2.
SHIVALIK HILLS
FOOTHILLS OF SHIVALIKS (KANDI BELT)
3.
4.
5.

Figure 48: Strategies for Bist Doab region

Original size 1:550,000 on 12X12"

0 5 10 20
Kilometers

6.7 Government Support, Community Involvement, and Incentives for Sustainable Strategies

The strategies outlined at the state and Bist Doab scales depend on the assumption that government policies will support their implementation. These policies are crucial for providing infrastructure, and funding.

Community involvement is also essential for the success of these strategies. Local participation ensures the solutions are culturally appropriate and resilient in the long run, but cannot start at this scale or be only carried out by the local, therefore government organization support is essential. Additionally, incentives are necessary to encourage individuals to adopt these practices, whether through financial rewards or other benefits. In addition, education programs need to be implemented.

Overall, the success of these strategies depends on the collaboration between the government, local communities and organizations, and individuals to ensure a resilient landscape in Punjab.

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2. Ranbir Kang and Dhian Kaur, "Spatial Pattern of Ground Water Level Changes in the Irrigated Agricultural Region of Bist Doab, Punjab, India," *Singapore Journal of Tropical Geography* 37, no. 1 (2016): 78.

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7. Anant Gautam, S. C. Rai, and Shive Prakash Rai, "Impact of Anthropogenic Activities on the Alluvial Aquifers of North-East Punjab, India," *Environmental Monitoring and Assessment* 192, no. 7 (2020): 3, https://doi.org/10.1007/s10661-020-08496-8.

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10. Anant Gautam, S. C. Rai, and Shive Prakash Rai, "Impact of Anthropogenic Activities on the Alluvial Aquifers of North-East Punjab, India," *Environmental Monitoring and Assessment* 192, no. 10 (2020): 7, https://doi.org/10.1007/s10661-020-08496-8.

11. Anant Gautam, S. C. Rai, and Shive Prakash Rai, "Impact of Anthropogenic Activities on the Alluvial Aquifers of North-East Punjab, India," *Environmental Monitoring and Assessment* 192, no. 7 (2020): 7, https://doi.org/10.1007/s10661-020-08496-8.

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07 WATER HARVESTING, AQUIFER RECHARGE, AND RESILIENT AGRICULTURE

INTER-VILLAGE SCALE INTERVENTIONS

7.1 Location and background

The site is based in the district of Hoshiarpur, between the village of Nadalon and Todarpur.
This area is considered to be over exploited, which was below 20mbgl (meters below ground level) pre-monsoon and 10-20mbgl post monsoon in 2013. This level has decreased in the present years. The block receives an average annual rainfall of 806 mm. This rainfall was deficient in the year of 2024, while in the year prior to that, it was in the average range. Therefore, it can be assumed that in the coming year, the rainfall is consistent on an average.
The inter-village landscape forms an essential social network through its connectivity between different villages and farmlands, where water systems, agricultural practices, and community life extend beyond administrative boundaries. Addressing groundwater recharge and resilient agriculture at this scale requires coordinated strategies that reflect this shared dependence.
This area also holds personal significance, as one of these villages (Nadalon) is my own where I spent my childhood and is my grandmother's village too, where she spend her youth. This connection informs my understanding of the landscape as a collective system rather than isolated fragments.

**Immediate family includes my father and his siblings' lands*
**Extended family means cousin, etcetera.*

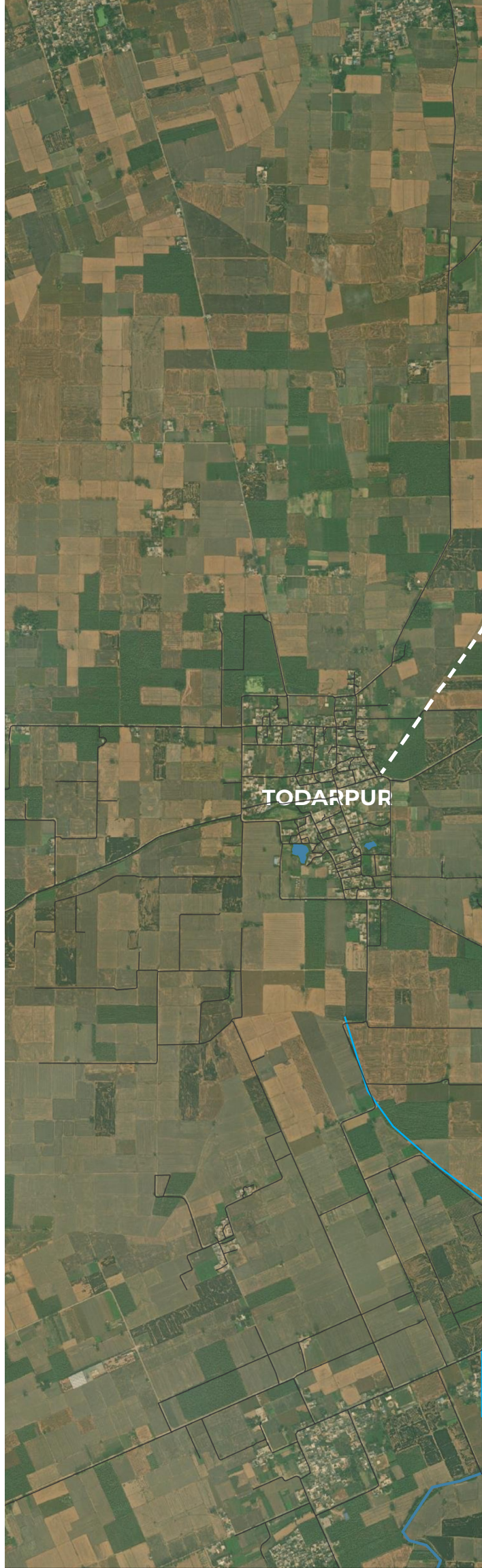
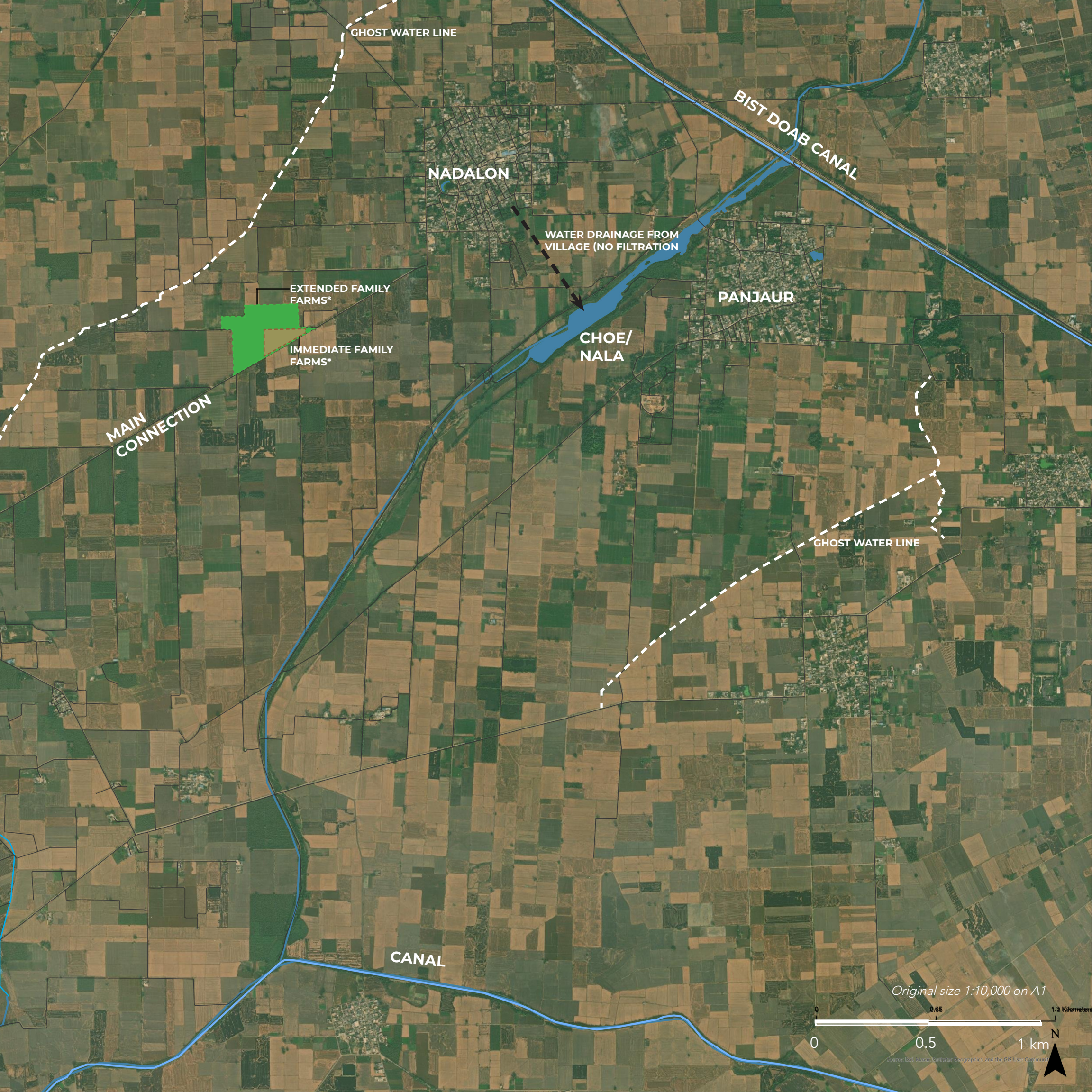
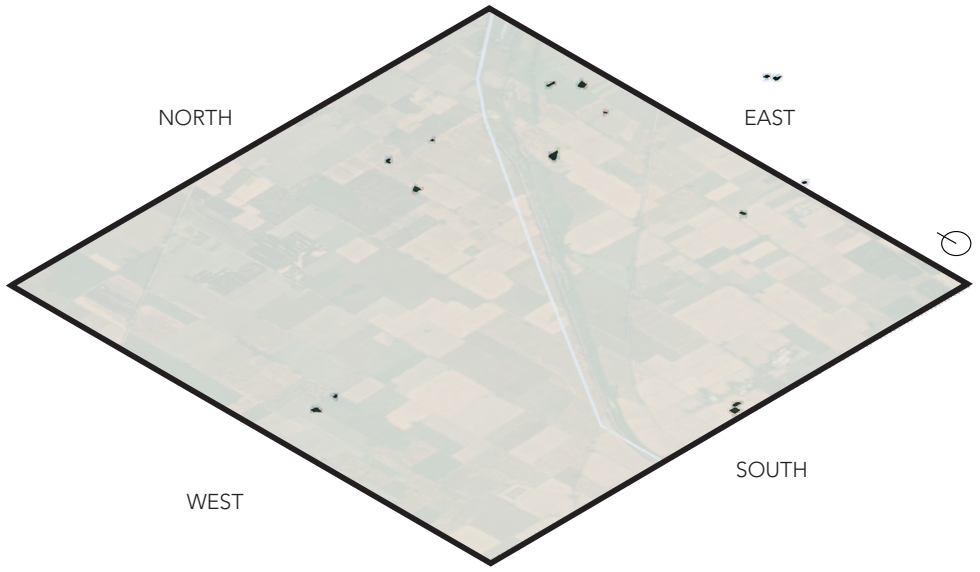
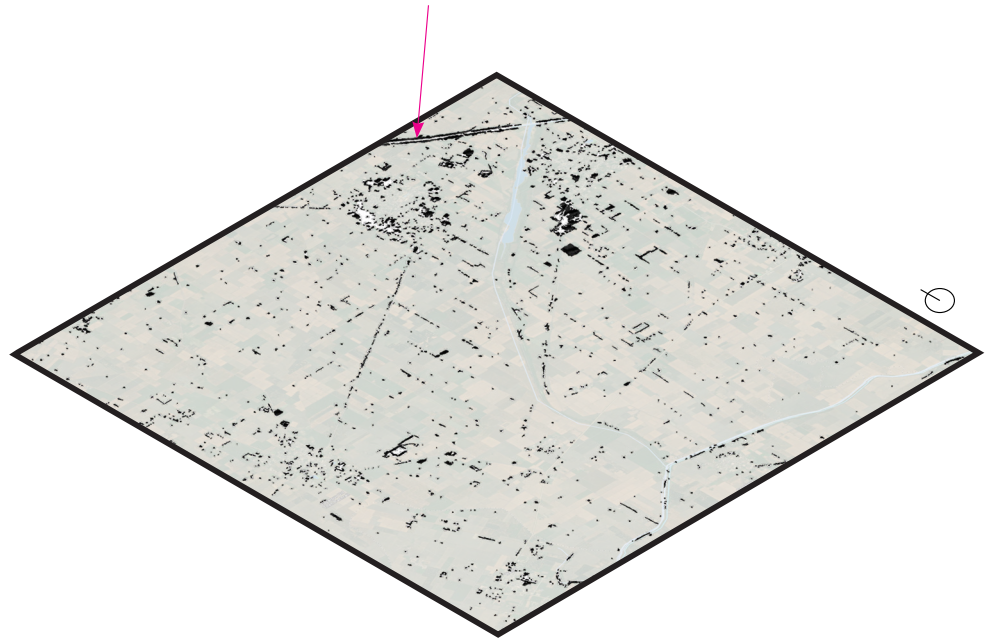


Figure 49: Inter-village site existing conditions

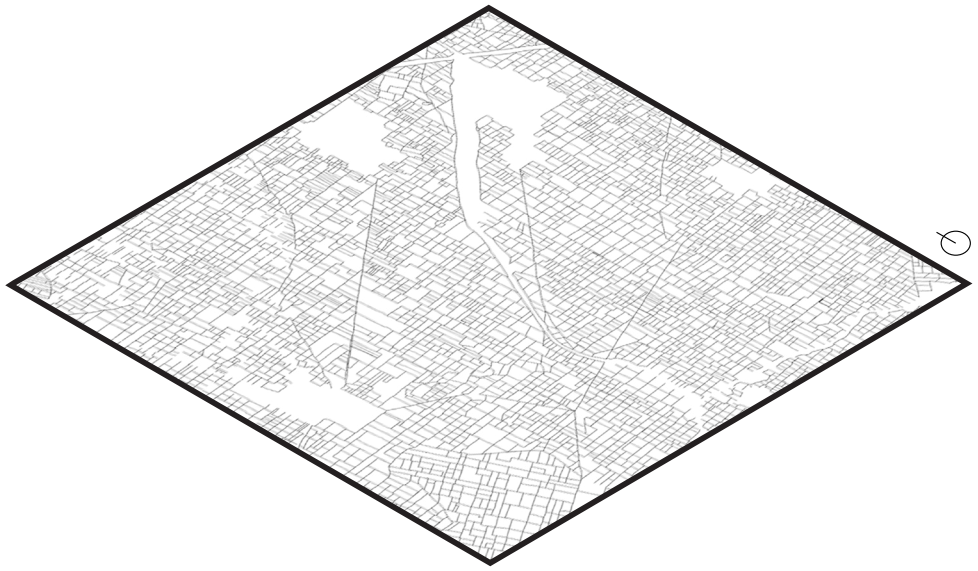

GHOST WATER LINE
BIST DOAB CANAL
NADALON
WATER DRAINAGE FROM VILLAGE (NO FILTRATION
EXTENDED FAMILY FARMS*
IMMEDIATE FAMILY FARMS*
PANJAUR
CHOE/ NALA
MAIN CONNECTION
GHOST WATER LINE
CANAL
Original size 1:10,000 on A1
0
0.65
1.3 Kilometers
0
0.5
1 km
N



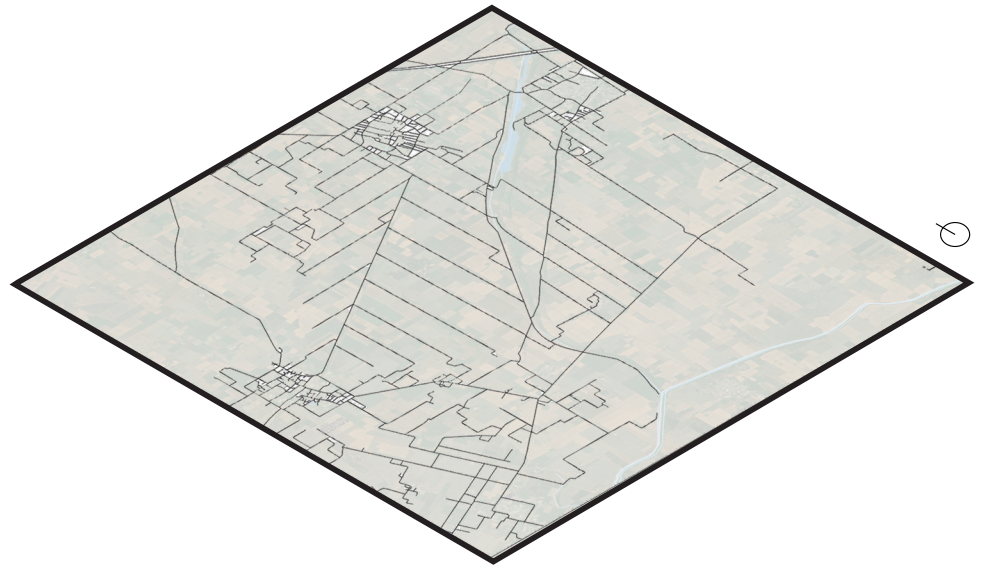
EXISTING PONDS



EXISTING TREES



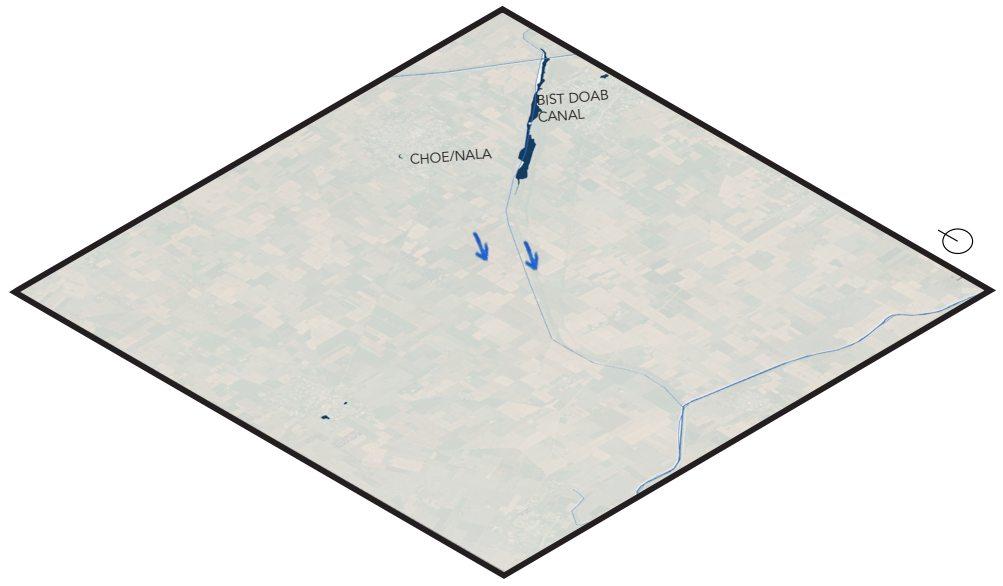
FARM BOUNDARIES



EXISTING PATHWAY AND ROADS

WIND DIRECTION

WATER FLOW DIRECTION



EXISTING WATER-BODIES AND HISTORIC GHOST-LINES

Figure 50: Inter-village site existing conditions (axo)

7.2 Existing Conditions, observations and Analysis

1. Water Storage infrastructures
The inter village landscape depicts the human interventions as well as the natural shifts that have shaped this region over years and years. Currently, water storage infrastructures such as ponds on the site are very limited. Traditionally villages used to have ponds called Toba (ਟੋਭਾ) in the local language used to be common in villages and farms.

2. Tree cover and vegetation
Tree cover across the site is minimal, and where present, it is dominated by Eucalyptus production due to high returns on its wood, but it is a species known for its high water consumption. Other species present on site are Peepal (*Ficus religiosa*), Dek (*Melia azedarach*), Kikar (*Acacia nilotica*) , Shisham (*Dalbergia sissoo*), Mangoes (*Mangifera indica*) as observed on site visits. Historically, Peepal (*Ficus religiosa*), Dek (*Melia azedarach*) and Banyan tree (*Ficus benghalensis*) were commonly planted near water bodies such as ponds for their cultural and religious significance as these places are used for gathering as well as prayers. These traditional planting practices have also declined, leaving the landscape exposed and fragmented. *Arundo donax* (giant reed) was observed along the choe. While this species offers some benefits, such as biomass production and phyto-remediation, it is largely considered environmentally harmful in Punjab due to its highly invasive nature.[1]

3. Farm boundaries (Land ownership)
Land ownership patterns are divided within the families. Farm boundaries are informally defined and it is assumed that the earthen bunds mark the extent of each plot. This unclear division complicates land management and interventions as my design is a community involvement focused design for implementation.

4. Existing road and pathway network
The road network primarily acts as connection between villages, and also to take machinery to the farms. The farms are accessed through a series of mud walkways. These paths don't directly extend to every farm, therefore, the farmers use the bunds as footpaths to navigate between different farms. The absence of tree cover along the roads and walkways leave the landscape very exposed and during the site visits, even in the winter month of November, the lack of shade made it difficult to endure the heat.

5. Waterbodies and canals
The Bist Doab canal runs parallel to the site, although highly under-used as farmers rely directly on groundwater through tube wells, due to free electricity and ease of irrigation. The site also has a seasonal choe and the ghost lines of former streams, which now are dry, but visible in aerials. And due to that, some farms plots have irregular, more natural boundaries at certain spots while the majority farms are laid very geometrically. (Figure 49)

6. Water flow direction
The flow of surface water across the site follows north/northeast to southwest direction, which is the same for groundwater flow.

Overall, the inter village landscape shows signs of ecological degradation and social disconnection. Traditional systems have reduced to a large extent, meanwhile the canal system is under-maintained and therefore underused, eventually all contributing towards exploitation of groundwater. These challenges make it difficult for communities to manage and adapt land sustainability.

Despite the aforementioned issues, the site has potential as the natural water flow, and cultural history provides a strong foundation for design interventions.

7.3 Site Observations and SWOT

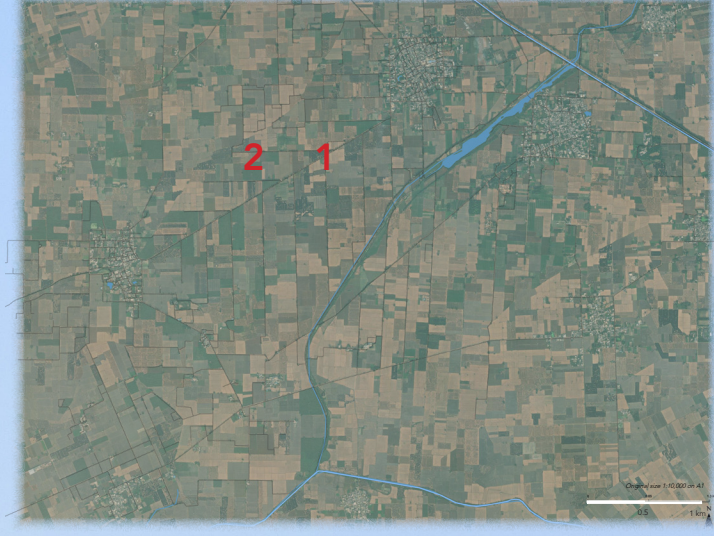
The following photographs document the current conditions observed during site visits in the Winter season in Punjab, India capturing both the visible elements such as sparse vegetation, polluted canals, cropping patterns, traces of traditional structures, etcetera, and the absence of protection from wind, absence of community life. By closely observing these conditions in person, design decisions were made.



Figure 51: Water pump system



Figure 52: Water pump system distribution



Tubewells and pump houses were present throughout the site, with nearly every other farm having one. They play a crucial role in extracting groundwater for irrigation, reflecting the high dependence on groundwater resources in this area.
The electricity pole is present for providing free electricity for groundwater pumps/tube wells.

Electricity pole

Pump house

Tube-well

Figure 53: Electric pole for free electricity for water pumping

The farms were either being prepared for wheat transplantation or had already been transplanted. The lack of rice farms images is due to the time of the site visit being not in the same season as rice cultivation.



3 *Figure 54: Sugarcane crop*



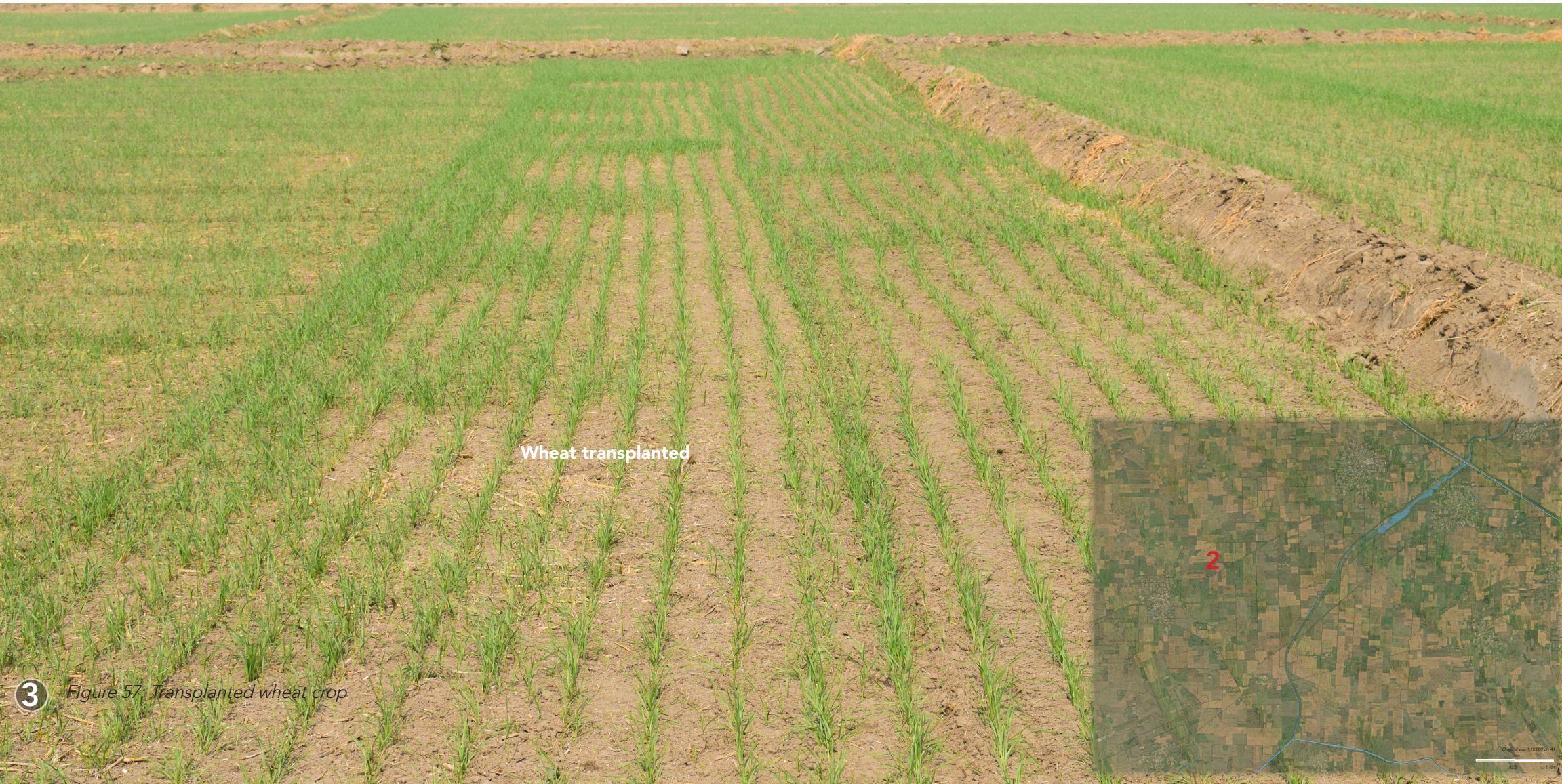
Figure 55: Weeding process of rice crop





Figure 56: Forage crops

3



3 *Figure 57: Transplanted wheat crop*



Figure 58: Walkway exposed to strong sun light



Figure 59: Recently transplanted wheat crop in the farm

There was a lack of shade trees on the farms, with only traces of some native trees.



A freshly prepped and tilled field

Figure 61: Freshly prepped farm, ready for sowing



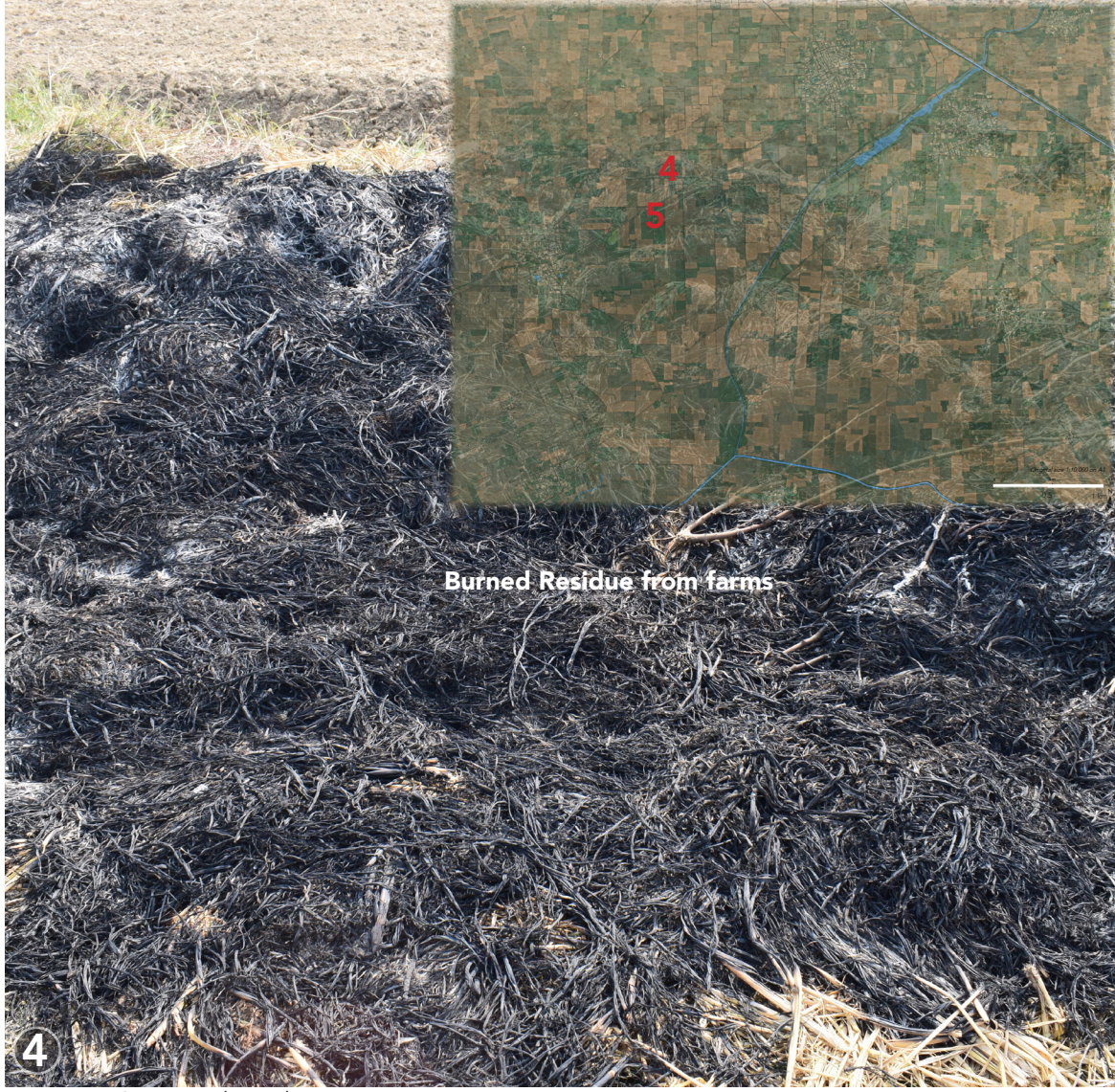


Figure 60: Burned residue



Figure 62: Harvesting and processing of crop

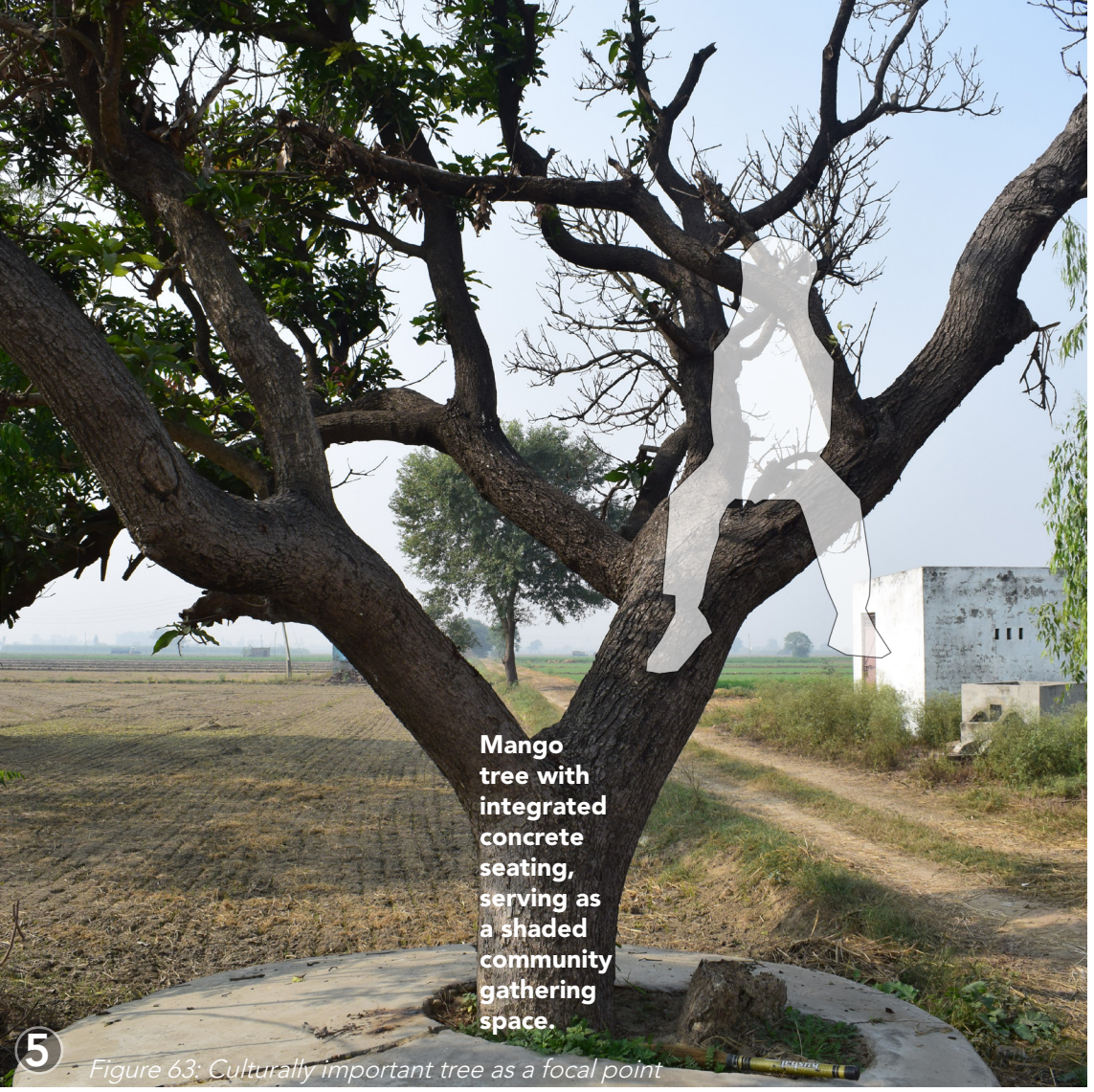


Figure 63: Culturally important tree as a focal point



Figure 66 & 67: Post green revolution landscape (above) (below)



Figure 64: High water demanding Eucalyptus

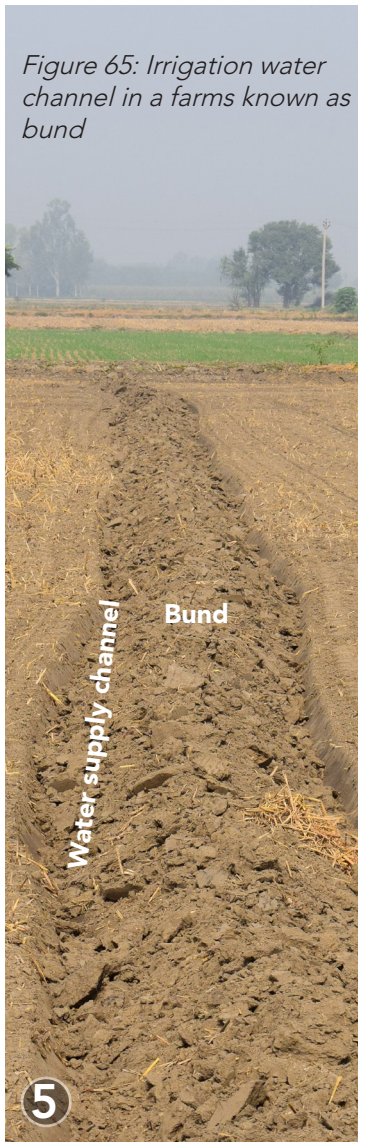


Figure 65: Irrigation water channel in a farms known as bund





Figure 68: Young traditiona tree, showing remnants



Figure 69: Walkway - dirt path lined with trees, but does not continue until the end of the walk



Figure 70: Out of use dug well that can be used to reverse pump



This pond was originally designed to serve as a communal irrigation source for nearby fields, with groundwater pumping supporting its water levels. However, it is no longer actively used for irrigation purposes. Despite this, the pond continues to hold cultural significance as a social gathering spot, shaded by sacred Peepal trees. Additionally, it supports local biodiversity by providing habitat for various wildlife species. This shows how these water bodies are important both for local culture and for supporting wildlife in the area.



Figure 72: Community ground water pumped irrigation pond - not used anymore

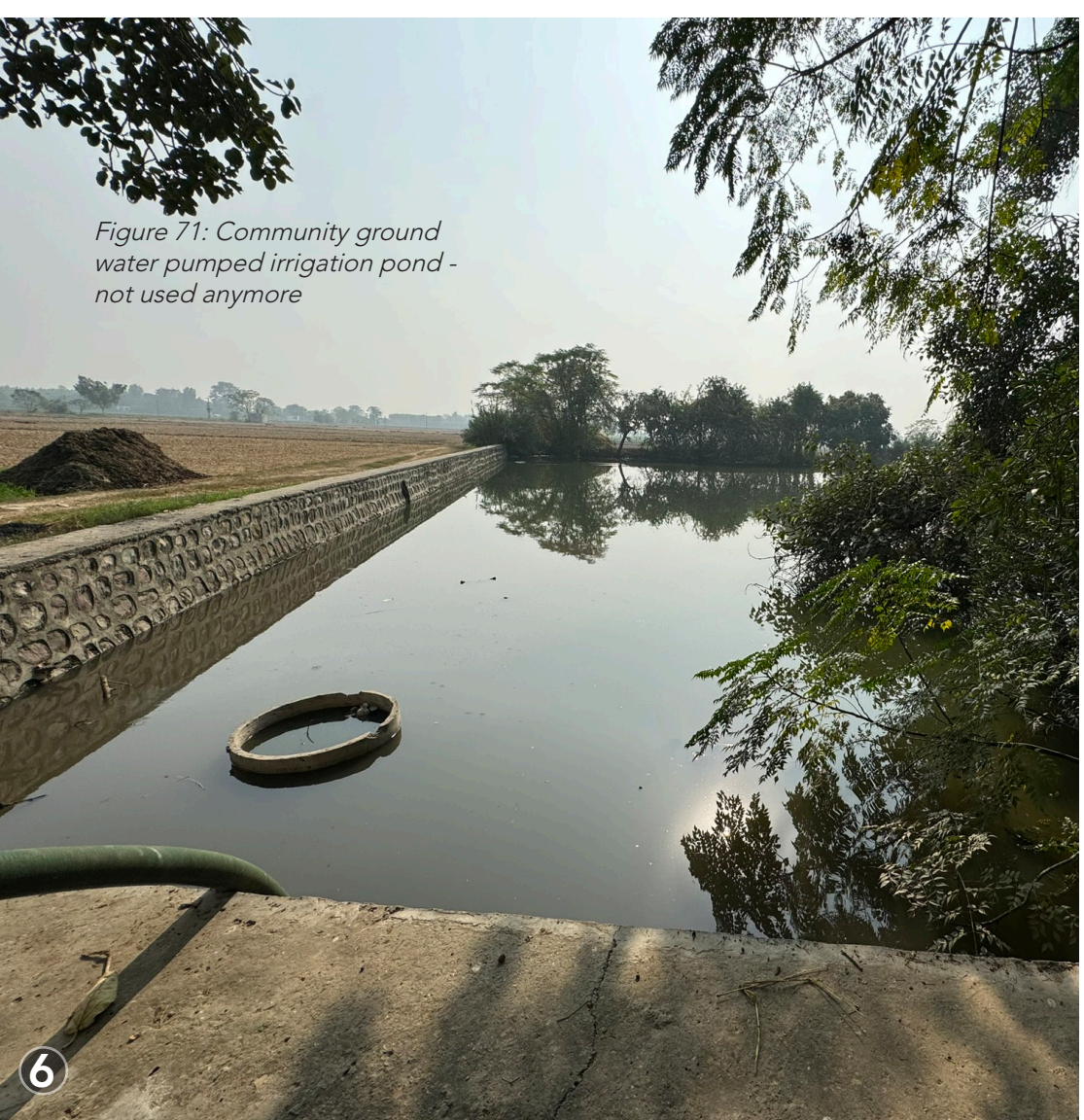


Figure 71: Community ground water pumped irrigation pond - not used anymore

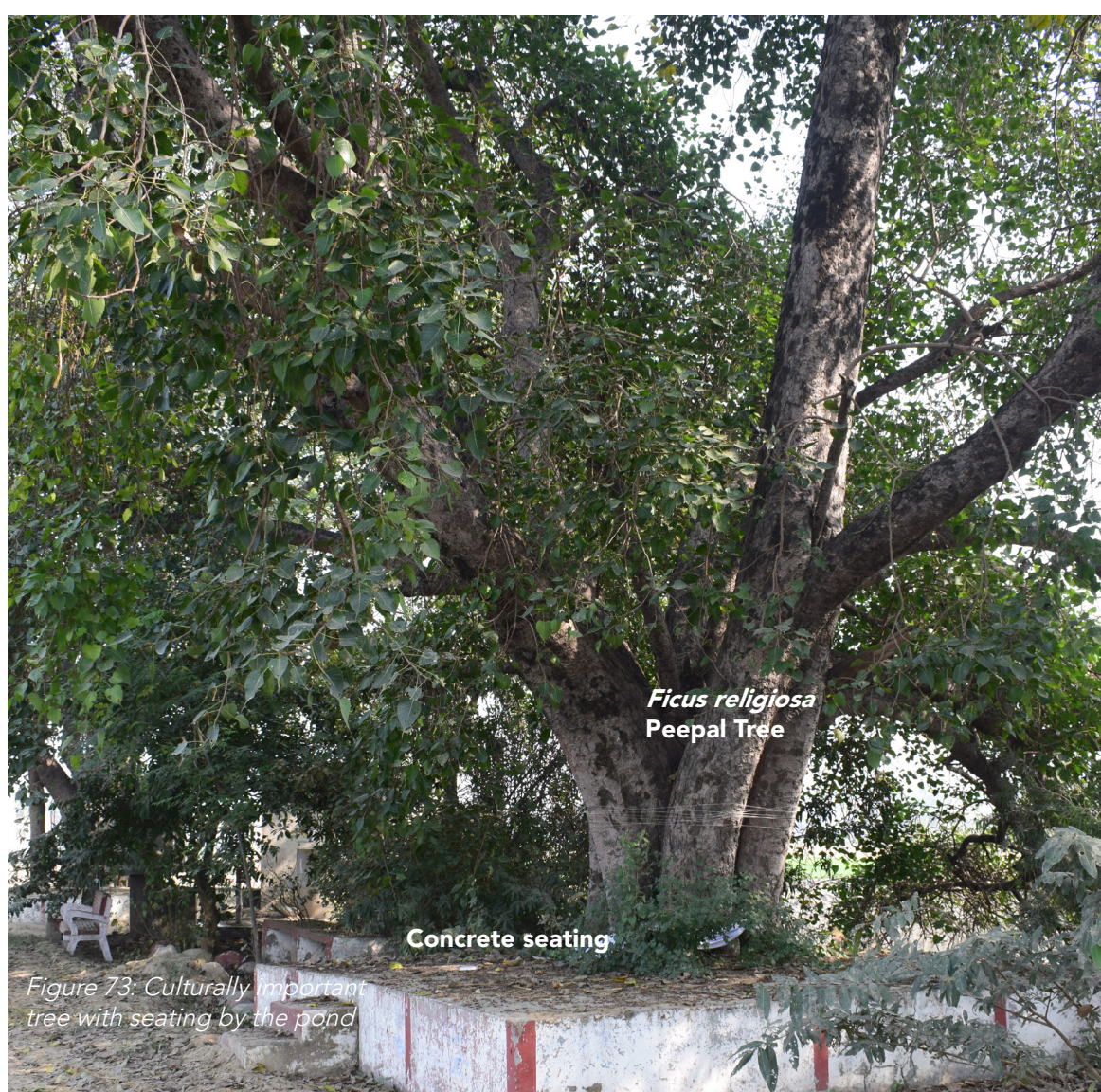


Figure 73: Culturally important tree with seating by the pond





Figure 75: Wildlife settled in the vegetation by the pond



A community waterbody sustained through groundwater pumping.

Figure 74: Community ground water pumped irrigation pond



Figure 76: Storage of the pumped water for drinking (not clean anymore)

The seasonal stream/choe/drain is polluted and overgrown with invasive plants which diminishes its ability to refill groundwater table.
Additionally, the canal is polluted and poorly maintained, leading to water loss and reduced flow. This limits its effectiveness for irrigation.

Base of the choe

Donkey

Figure 77: Middle of the seasonal stream/choe

Figure 78: Polluted choe because of trash dumping

Polluted Choe





Edge of the Choe

***Rundo donax* (Nadde)**

Figure 80: The crossing on the seasonal choe is being made with concrete

7



Figure 79: Invasive vegetation in the choe

Pigeon



Bist Doab Polluted Canal

Figure 81: Polluted canal - reducing the efficiency of use of canal for farming

8

7.4 SWOT

STRENGTHS

- PRESENCE OF NATURAL WATERBODIES
- REMNANTS OF TRADITIONAL FEATURES
- FARMERS STILL USING TRADITIONAL BUNDS AND PATHWAYS
- TRADITIONALLY A DEEP CULTURAL CONNECTION TO TREES AND LAND

WEAKNESSES

- VERY FEW WATER STORAGE STRUCTURES (PONDS)
- PRESENCE OF EUCALYPTUS TREES HAVING HIGH WATER INTAKE
- UNDERUSED CANAL
- POLLUTED SEASONAL STREAM (CHOE), AND CANAL
- LACK OF SHADE
- UNCLEAR FARM BOUNDARIES
- MONO-CULTURE OF RICE

OPPORTUNITIES

- RESTORE PONDS AND TRADITIONAL WATER SYSTEMS
- REINTRODUCE NATIVE TREES
- USE NATURAL WATER FLOW FOR AQUIFER RECHARGE
- SHARED SPACE COMMUNITY FOCUSED DESIGN

THREATS

- CONTINUED DECLINE IN GROUNDWATER LEVELS
- CONTINUED MONO-CROPPING
- DEPENDENCE ON TUBE WELLS AND FREE ELECTRICITY
- CLIMATE CHANGE
- CULTURAL DISCONNECT FROM LAND AND TRADITIONS ESPECIALLY IN NEW GENERATIONS



Figure 82: Collage illustrating the dynamic interplay of flora, fauna, and human interaction within natural landscape.

7.5 Design Intervention Principles

1. SHELTERBELTS
Drought-tolerant, tap, adventitious rooted tree species are introduced to create shelterbelts that reduce wind erosion, help water to be infiltrated into the soil as the roots open up the soil for percolation, offer shade, and improve micro-climatic conditions. In addition, fruit trees are incorporated to maintain productivity.

Benefits
- Reduced Water Loss: Shade from the trees minimizes direct evaporation from soil surfaces.
- Improved Water Retention: Root systems support infiltration and reduce runoff.
- Evapo-transpiration Control: Trees help regulate moisture loss from crops and soil.
- Micro-climate Regulation: Cooler temperatures and reduced wind stress create more favorable growing conditions.

Implementation Strategy
- Configuration: Trees are planted in a grid pattern, spaced every 200–300 meters. To counter hot summer winds, cold winter winds, and monsoon retreat winds, all primarily blowing from the northwest, a grid-based shelterbelt pattern ensures protection from all directions.
- Tree Height: Species selected should grow to approximately 20 meters high.

2. FARMING PATTERN CHANGE
One major intervention is to encourage a shift towards multiple alley cropping systems, agroforestry practices, and orchard-based agriculture to diversify income, improve soil health, and reduce water demand. In addition, the trees in orchard would reduce the surface runoff and help with percolation.

Alternate Crop Rotations
- Orchard trees - Kinnow & other citrus fruits, Mango, Guava, Peach and Grapes
- Kharif Season Crops (Autumn): Arhar (Pigeon Pea), Urad (Black Gram), Moong (Green Gram)
- Rabi Season Crops (Winter): Gram (Chickpea), Masoor (Lentil), Pea, Potato
- Mixed Cropping
  Maize + Red Gram, Wheat + Gram, Pea + Mustard

3. STREET TREES
Street trees are proposed or shade while walking from one village to another.

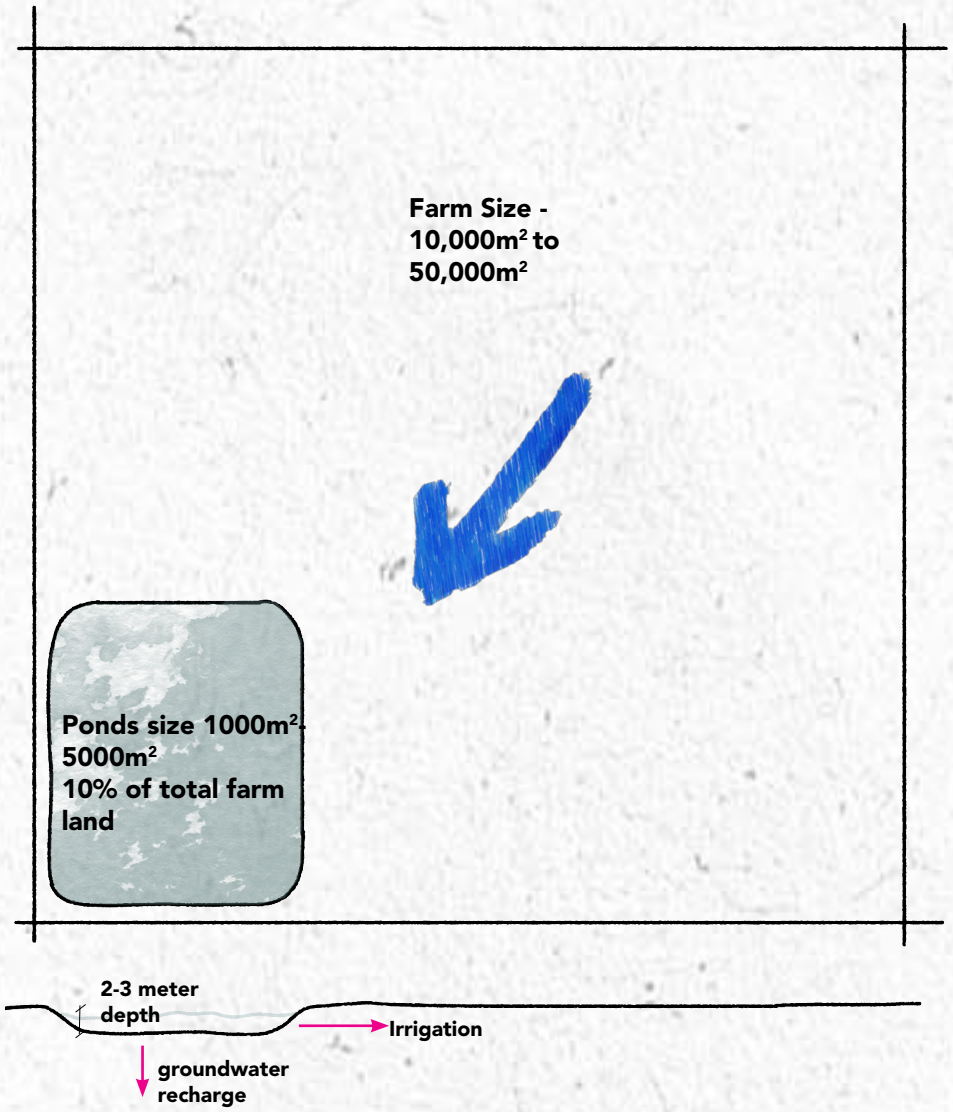
Implementation Strategy
- Roadside plantation - trees are positioned opposite to each other for a tunnel effect.
- Ideal tree size - 1-3+ meter tall saplings at the time of planting for quicker shade development.

4. PONDS
Addition of ponds into the design is the major intervention to harvest rainwater and surface run off, which can eventually be used for irrigation and percolation to refill groundwater table. Ponds sizes are based on 10% of total farm area^2, depending on budget and area range to make sure there is enough productive land left. When designing at very specific fields, the sizes are calculated for storage in accordance to the rain and surface runoff.
Small and medium-sized ponds for rainwater harvesting to reduce the stress on groundwater, and large ponds additionally support groundwater recharge are developed. Existing dug wells are used as injection wells to artificially recharge ground water quickly.

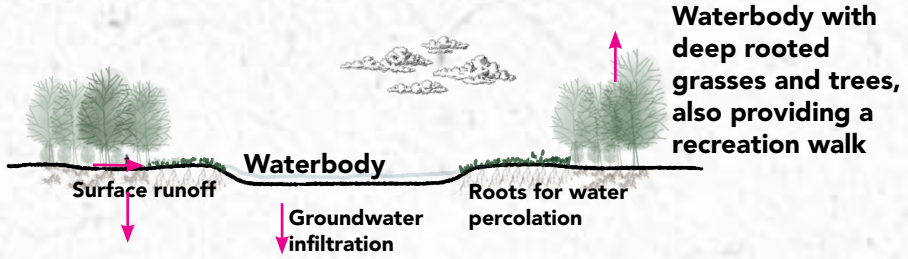
5. WATERBODIES
Water from the Bist Doab canal is diverted into the waterbody area. These water bodies are designed with varying slopes and depths to contain the water.
Implementation Strategy
- 84 hectares based on rainfall availability (no data available for canal input), deep end - 3 meters, shallow end - 0.3m.
- The slowed water flow allows sediments and nutrients to settle, reducing nutrient load.
- Water is filtered naturally as it moves through the wetland system.
- Native grasses is planted to aid in deeper percolation of water. Filtered water percolates down to recharge the aquifer.
- Along the way, the wetland provides habitat for a wide range of native flora and fauna.

6. CHECK DAMS ON EXISTING WATER-BODIES SUCH AS CHOES
The existing waterbodies are used for collection of water and slowing it down so it acts as a wetland

Implementation Strategy
- L shaped bunds/check dams to be added to slow down the water, for the choes to act as a wetland.
- The existing vegetation to be replaced by native species of trees and grasses.







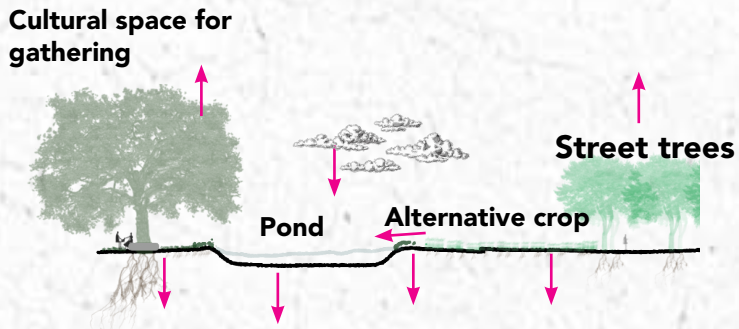


Figure 83: Interventions principles

7.6 Laying the Groundwork: A Detailed Starting Point

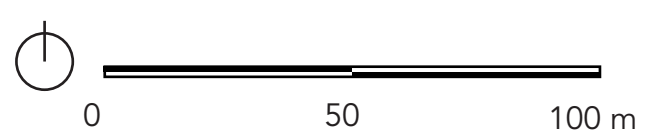


Figure 84: Site for detailed design

The proposed interventions begin at a cluster of farms that hold personal significance, as they are owned by immediate and extended family members. Starting at this location offers a practical advantage, as family relationships make it easier to build trust, encourage participation, and introduce changes.

1. PONDS FOR HARVESTING WATER
2. COLLECTOR TRENCHES
3. EXISTING PUMP HOUSES TO BE USED FOR REVERSE PUMPING
4. ORCHARDS
5. SHELTERBELTS
6. CROPPING PATTERN
7. STREET PLANTING

Figure 85: Detailed design (right)



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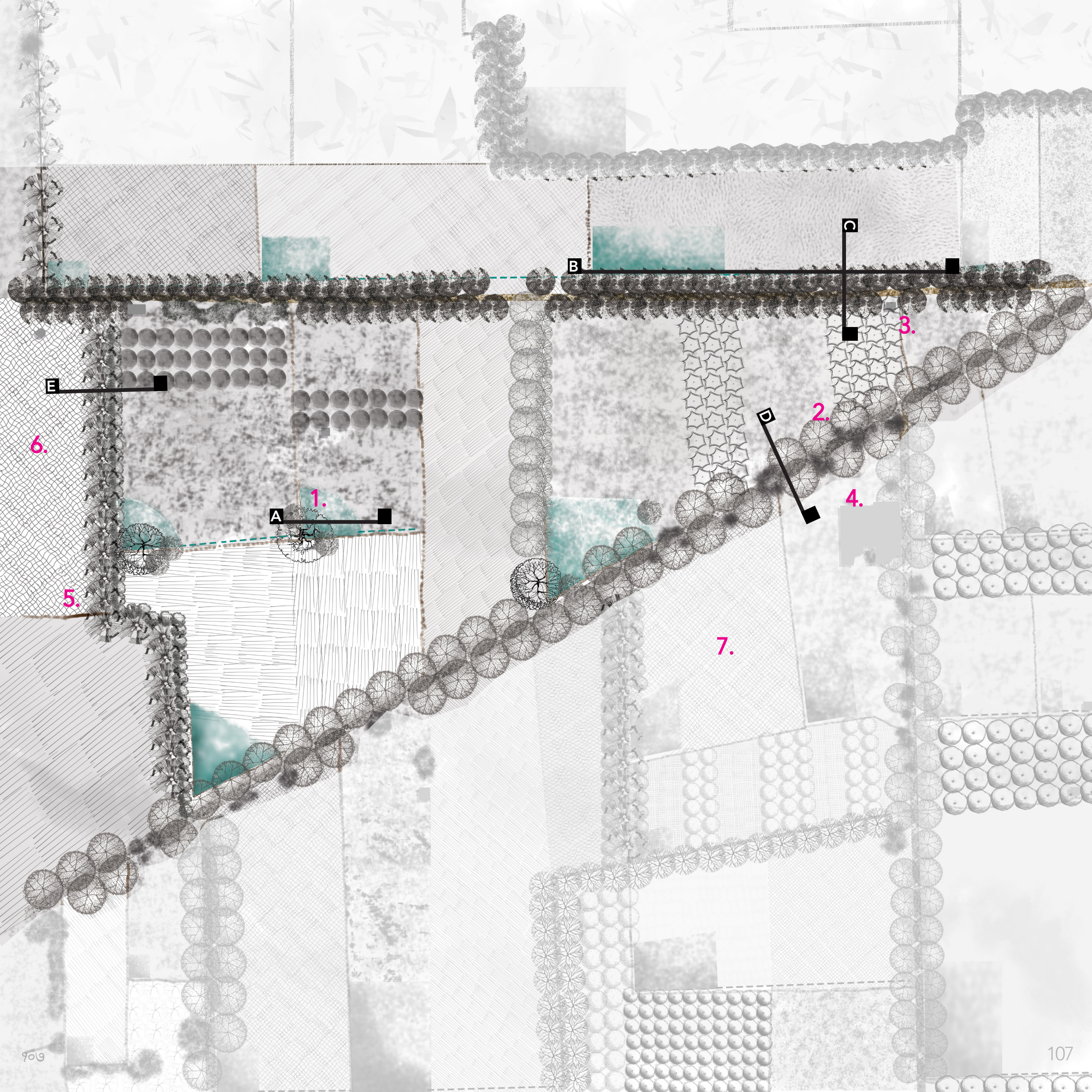
A
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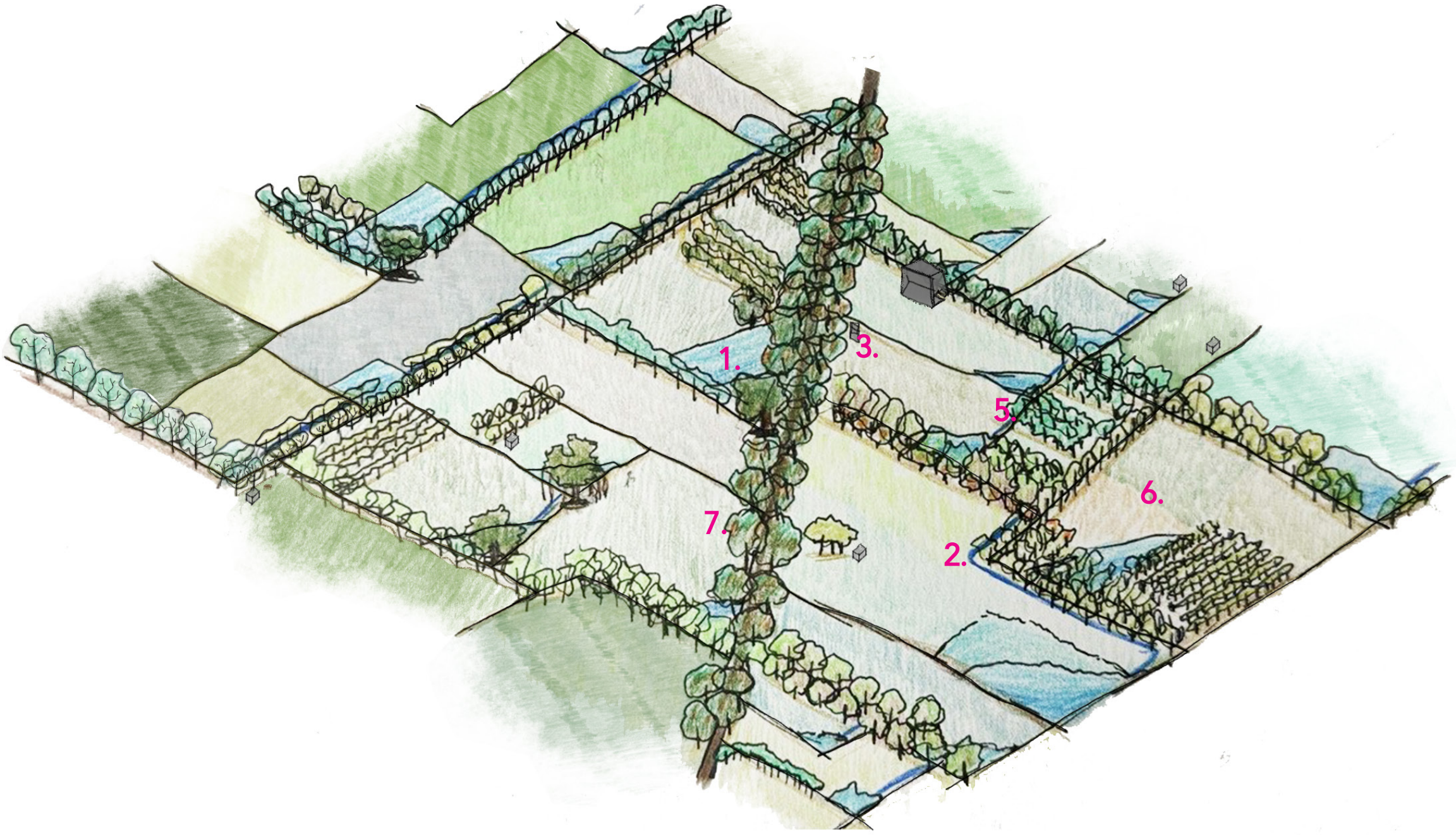


Figure 86: Detailed design (axonometric)

Working with the land

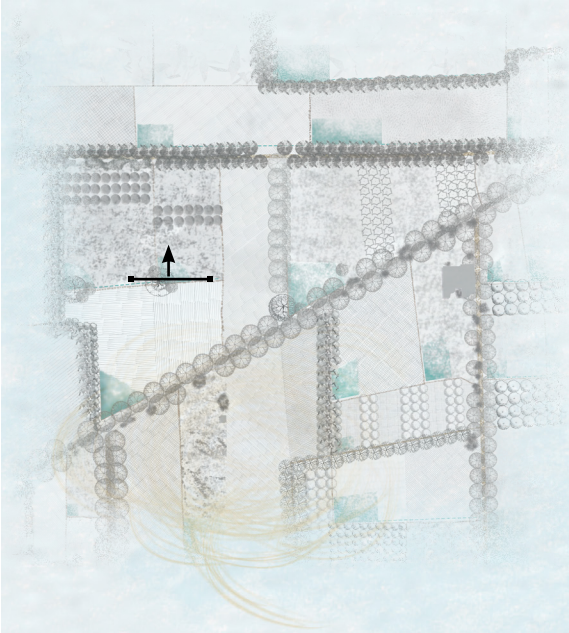
The design integrates a series of interventions that focuses on aquifer refill, water harvesting and supports resilient agriculture. Ponds and collector trenches harvests rainwater, while the existing pump houses are re-purposed for reverse pumping to recharge groundwater. Shelterbelts and street planting provide protection from wind, sun and create micro-climatic benefits, while helping water percolate into the ground. Orchards diversify cropping and enhance resilience, while a revised cropping pattern reduces the use for ground water.

PONDS HARVEST
5 MILLION LITERS
ANNUALLY (ESTIMATED)

Harvested volume (m³) = Rainfall (m) × Catchment area (m²) × Runoff coefficient × System efficiency

Annual monsoon rainfall: ~600 mm
System efficiency: 80%
Field runoff coefficient: 0.3–0.5
Contributing catchment area: ~2.5–3.5 hectares
Estimated annual water harvested: ~5 million liters

1. PONDS FOR HARVESTING WATER
2. COLLECTOR TRENCHES
3. EXISTING PUMP HOUSES TO BE USED FOR REVERSE PUMPING
4. ORCHARDS
5. SHELTERBELTS
6. CROPPING PATTERN
7. STREET PLANTING



During the initial years, the newly constructed ponds (3m deep) are constructed. They have the depth that is enough to store water in the months of surplus. When the rainfall is deficit, the edges of the ponds can still be used for crop production s they are made at a lower slope. After the monsoon season, these ponds retain sufficient water to support irrigation needs for the next non-monsoon season. In addition, they contribute to groundwater recharge by allowing water to gradually percolate into the soil, helping with the recovery of the aquifer.

YEAR 1-5 A

EVAPO-TRANSPIRATION

PRECIPITATION

26 M

SHADED CANOPY GATHERING AREA

OVERFLOW DRAINAGE PIPE

SUBSURFACE CAPILLARY IRRIGATION

3 M

WATER STORAGE

SURFACE RUNOFF

FIELD IRRIGATION CHANNEL

50% SLOPE

15% SLOPE

ROOTS ENHANCING WATER RETENTION

GROUNDWATER PERCOLATION

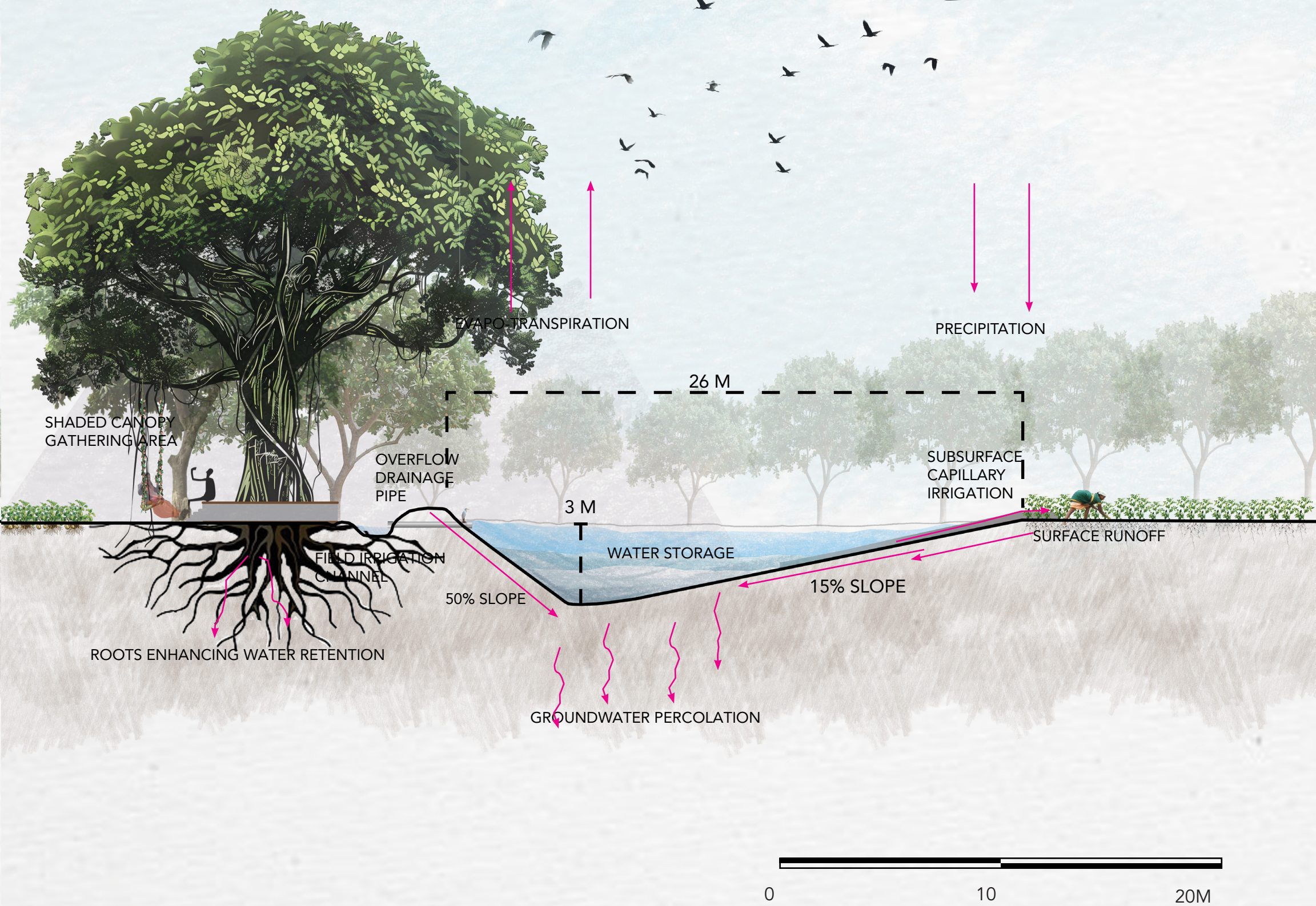
0 10 20M

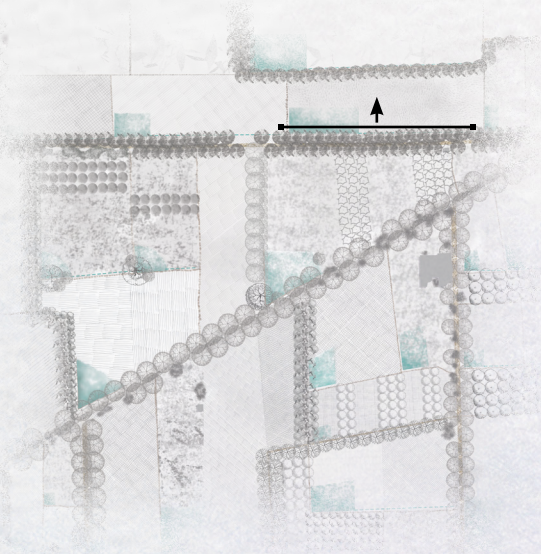
Figure 87: Section A (left & right)

YEAR 25 A

By year 25, the ponds would have developed into stable and reliable water sources that continue to provide irrigation even under varying rainfall conditions. They also maintain their role in recharging groundwater. Around these ponds, established shelterbelts and fruit orchards have formed green corridors that help create a cooler, more sheltered micro-climate, along with reducing soil erosion, wind erosion, retain moisture and support biodiversity.

The ponds act as the central features within the farmlands, accompanied by large trees such as Peepal (*Ficus religiosa)*, or Banyan tree (*Ficus benghalensis*), while trees provide shade and visually break up large, open fields, contributing to a comfortable environment.





The integration of orchards and ponds contributes to a layered spatial experience, where productive farms gradually transitions into spaces that support recreation and social interaction.

YEAR 1-5 B

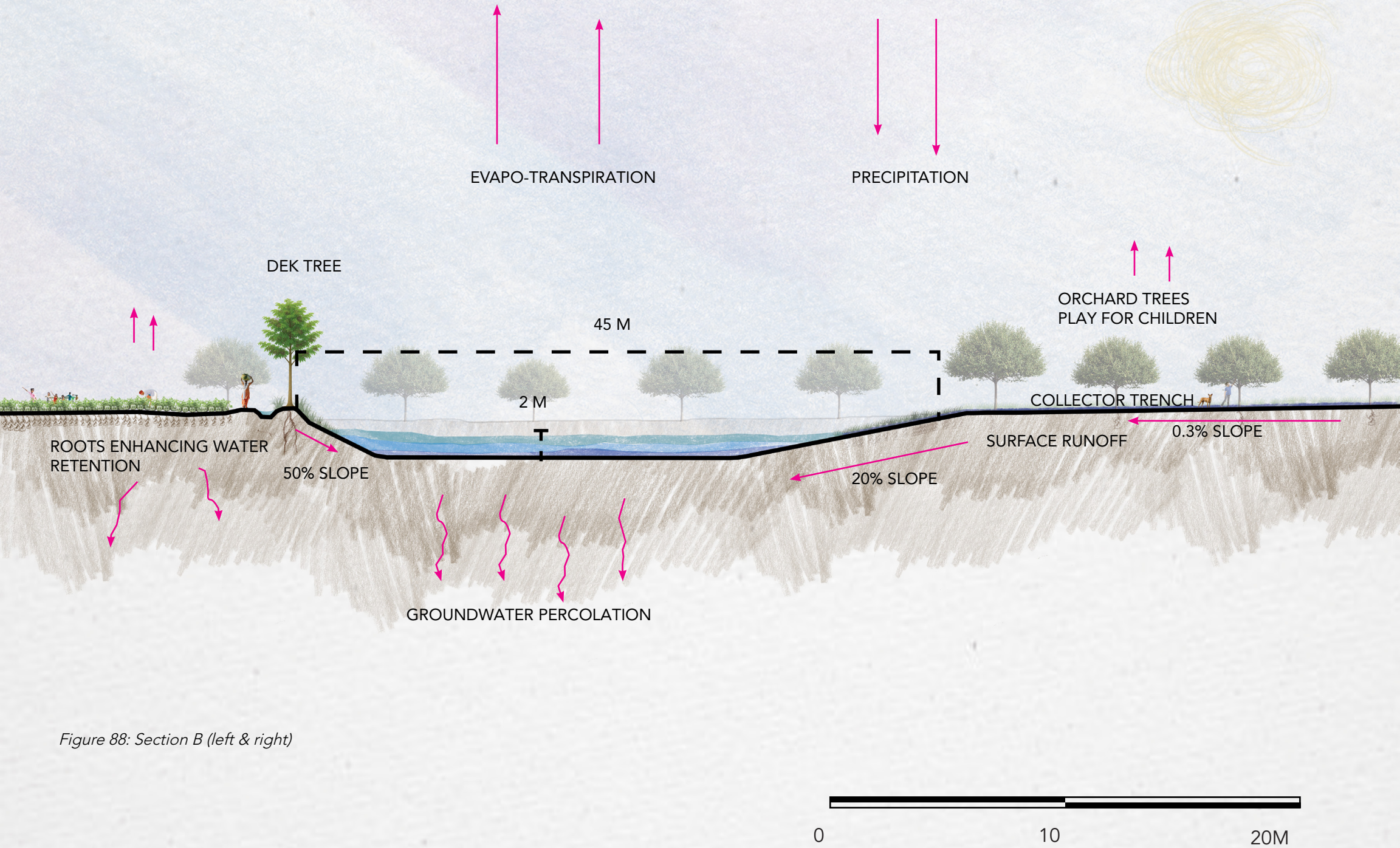
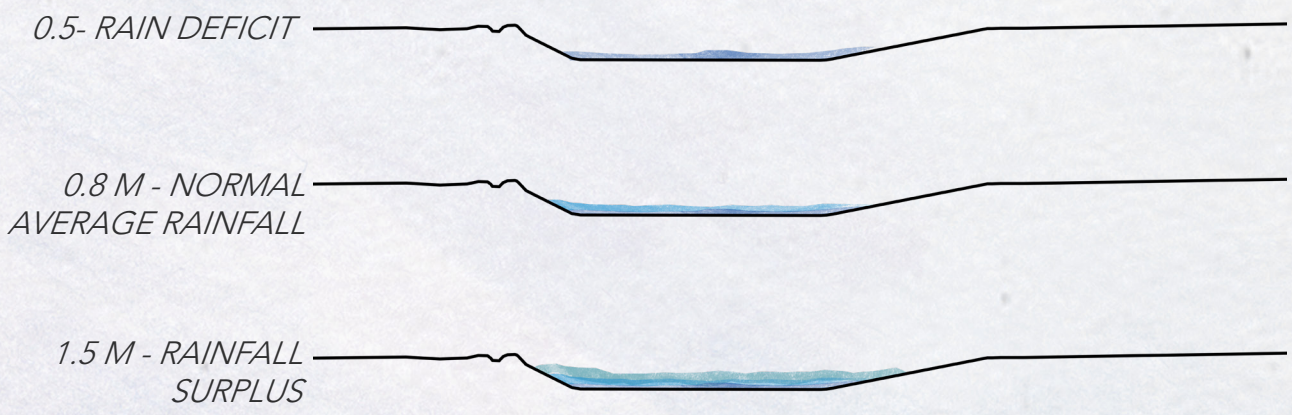
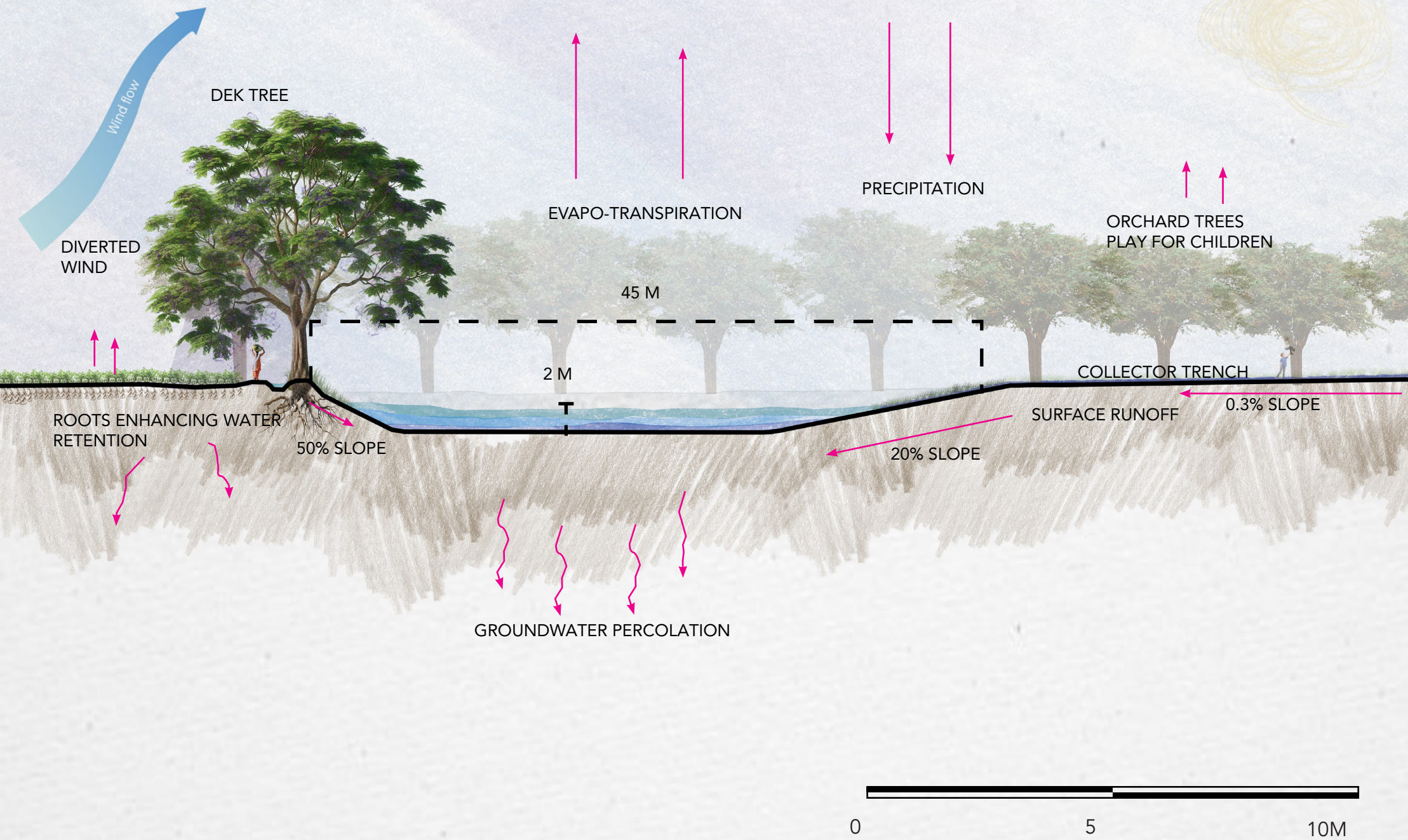


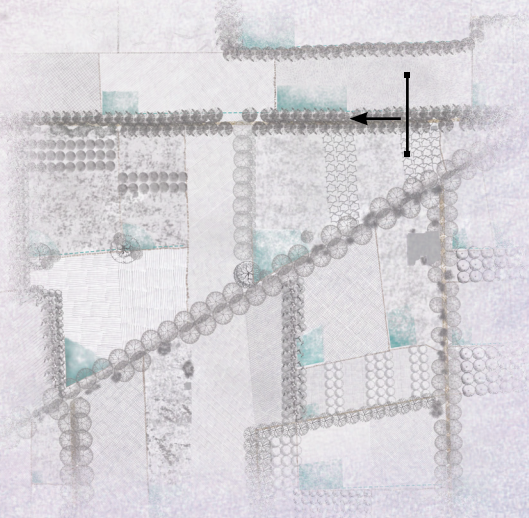
Figure 88: Section B (left & right)

YEAR 25 B

By the year 25, the landscape have developed into a vibrant and resilient system. The orchards have become well established, offering improved micro-climate and productivity. At the same time, they provide spaces for community activities.







In the beginning years, the transition has only just begun. Some farmers have started planting less water intensive crops, marking an initial shift towards more resilient practices to reduce the pressure on the groundwater. Shade trees have been newly planted along pathways, providing the first signs of improved micro-climate and reduced wind erosion.

YEAR 1-5 C

EVAPO-TRANSPIRATION

PRECIPITATION

BOTTLEBRUSH TREE

BOTTLEBRUSH TREE

KINNOW ORCHARD

SUNFLOWER CROP

0.5 M

2% SLOPE

COLLECTOR TRENCH

1.5 M

MUD/DIRT WALKWAY

FIELD IRRIGATION CHANNEL

ROOTS ENHANCING WATER RETENTION

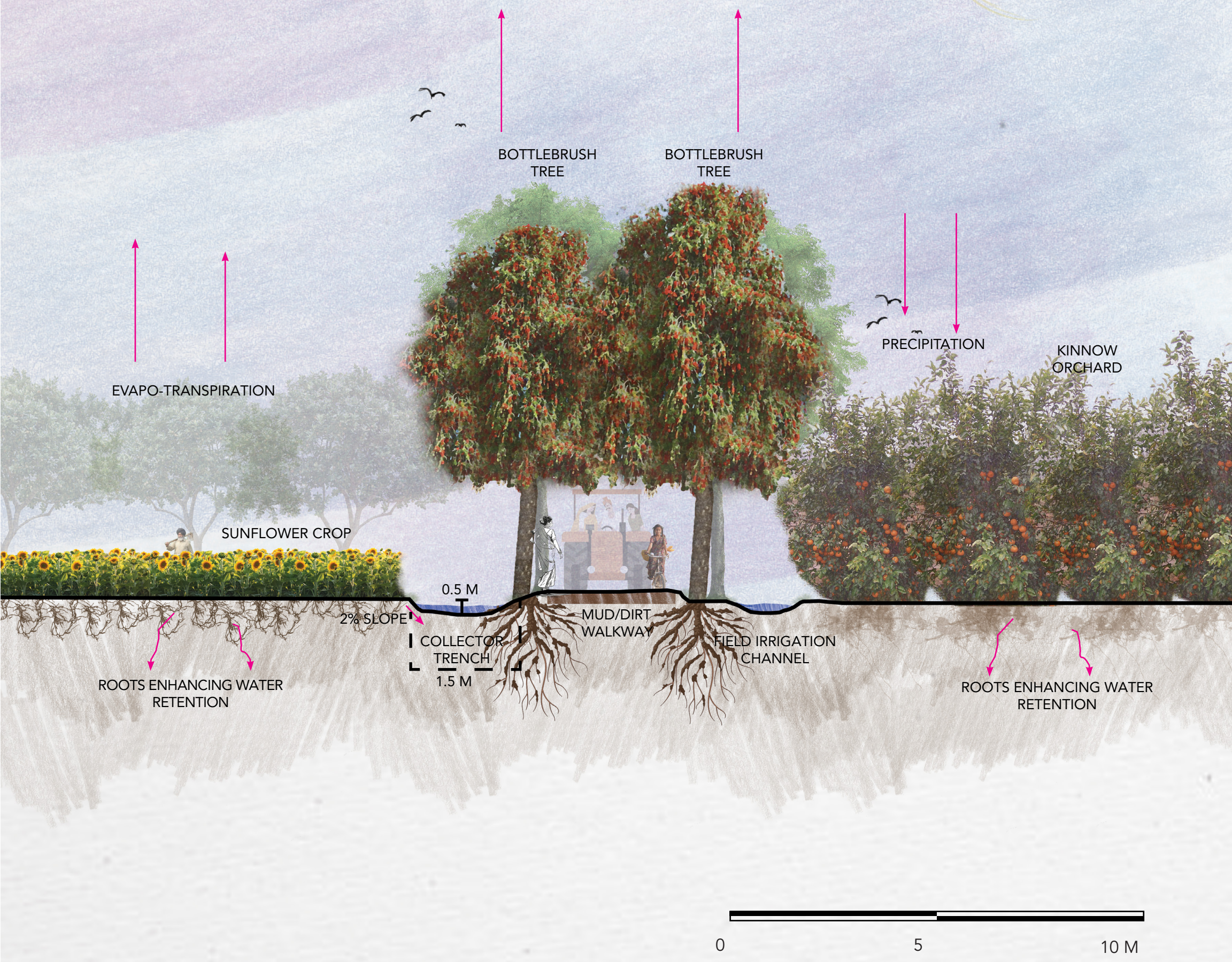
ROOTS ENHANCING WATER RETENTION

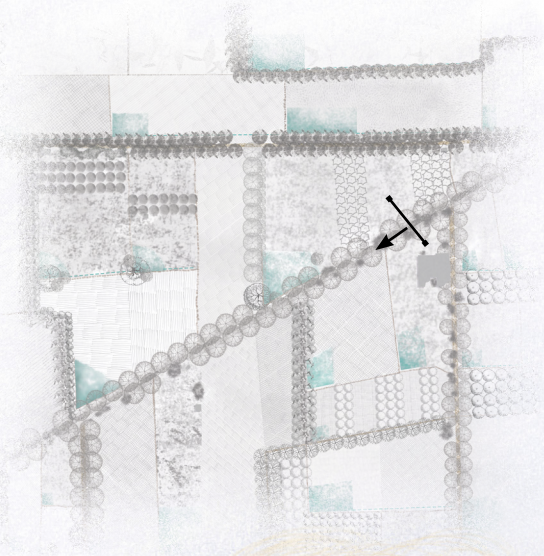
0 5 10 M

Figure 89: Section C (left & right)

YEAR 25 C

By the year 25, these interventions have become fully established. a diverse range of crops is now grown across the fields, which has helped reduce the reliance on groundwater. The shade trees have matured and now form continuous, shaded corridors throughout the farms.





In year 1, newly planted trees begin to define the edges of the routes. Although still young, they provide initial shade along the paths.

YEAR 1-5

D

PRECIPITATION

EVAPO-TRANSPIRATION

AMALTAS
Cassia fistula

AMALTAS
Cassia fistula

PUMP HOUSE

MUSTARD CROP

FORAGE CROP

ASPHALT ROAD

ROOTS ENHANCING WATER RETENTION

ROOTS ENHANCING WATER RETENTION

0 5 10 M

Figure 90: Section D (left & right)

YEAR 25

D

By the 25th year, the trees have matured into a dense canopy, significantly improving the comfort of travel between villages. The shaded paths offer a cooler and more pleasant walking experience enhancing the movement and social interaction. In addition, the root systems of the trees support water infiltration and reduce surface runoff.

EVAPO-TRANSPIRATION

AMALTAS
Cassia fistula

AMALTAS
Cassia fistula

PRECIPITATION

MUSTARD CROP

PUMP HOUSE

FORAGE CROP

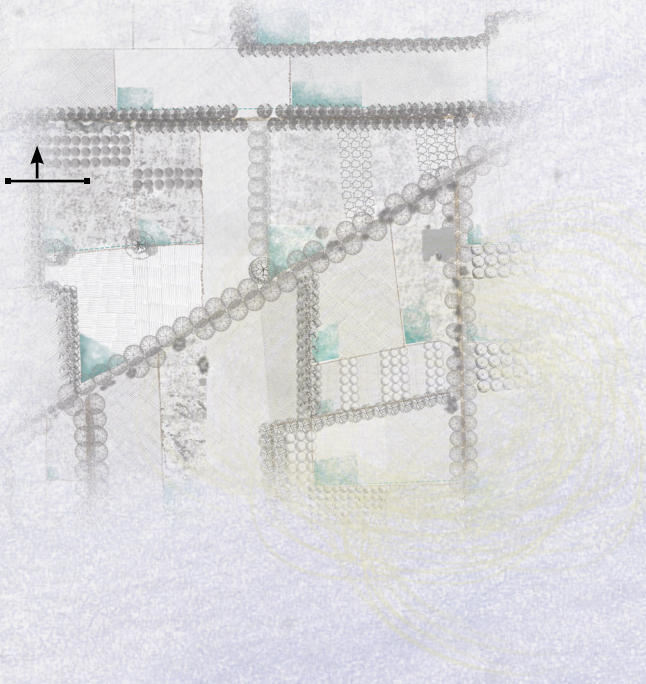
ASPHALT ROAD

ROOTS ENHANCING WATER RETENTION

ROOTS ENHANCING WATER RETENTION

0 5 10 M

YEAR 1-5 E



The shelterbelts are established with a central row of tall, dense, native trees, flanked on either side by fruit bearing productive trees. The trees are spaced strategically to allow adequate sunlight while also creating an effective barrier against strong winds.

PRECIPITATION

EVAPO-TRANSPIRATION

SHELTERBELTS WITH A
SHEESHAM TREE *(Dalbergia sissoo)* +
SHORTER FRUIT TREES
(BER - *Ziziphus mauritiana)*

ROOTS ENHANCING WATER RETENTION

FIELD IRRIGATION CHANNEL

SURFACE RUN-OFF

FIELD IRRIGATION CHANNEL

Figure 91: Section E (left & right)

0 5 10 M

YEAR 25 E

The shelterbelts are fully developed and functioning as intended. The tall native trees significantly reduce wind speed and minimise erosion, while the fruit trees contribute towards additional source of income for farmers.

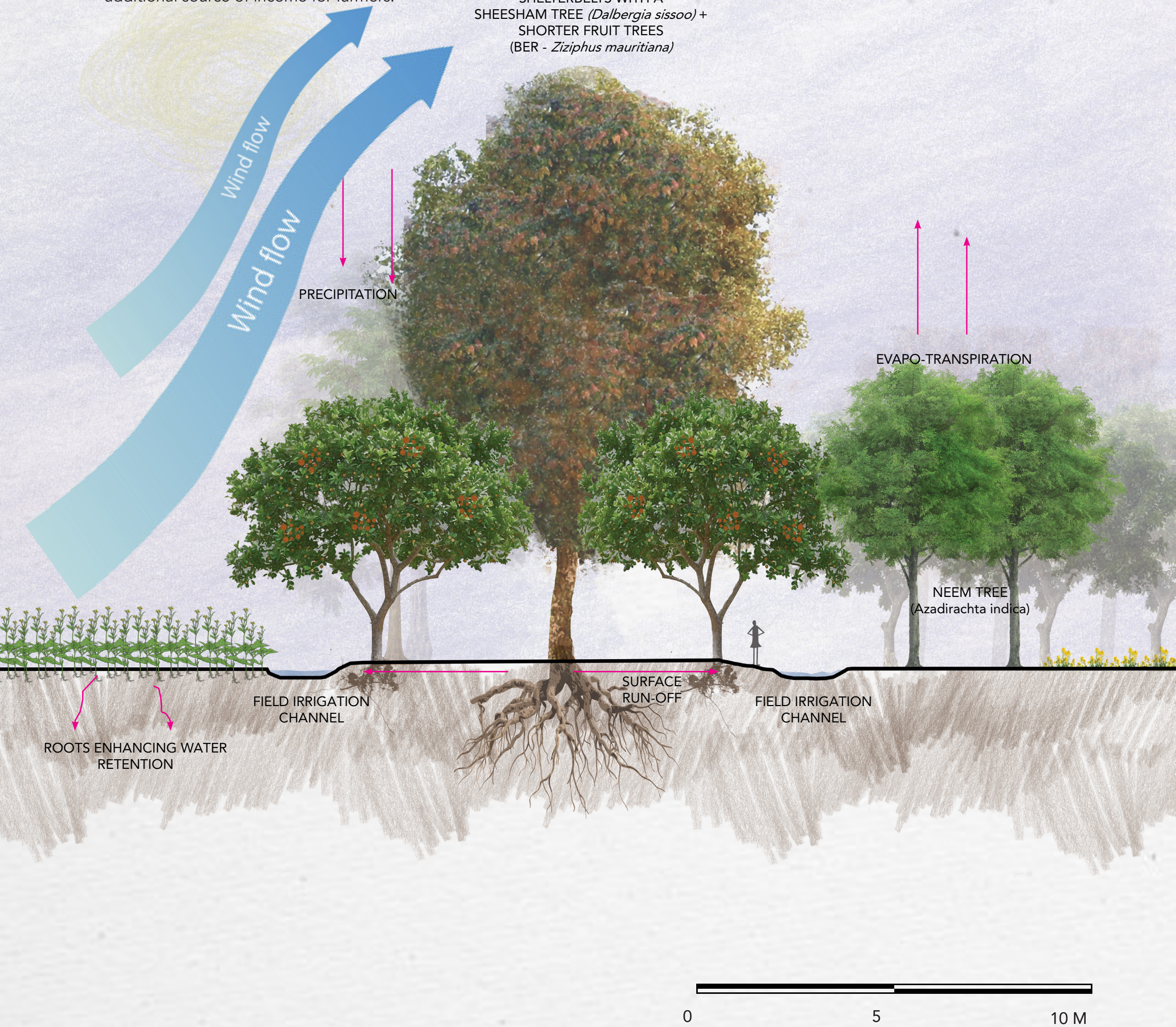




Figure 92: Pre phase1



7.6 Phasing and Implementation

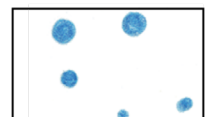
The implementation of interventions into this landscape is envisioned carefully through structured phases, allowing time for ecological systems to establish, community collaboration to grow, and policy frameworks to align. Each phase builds upon the previous one, starting with low-impact interventions and progressing toward more integrated and large-scale changes, ensuring adaptability and long-term resilience.

Pre-phase 1

Year 0: Baseline Assessment & Pond Digging

Initial site evaluation, stakeholder engagement, and detailed planning for interventions. The concept will first be targeted at family-owned farms, which are ready to adopt the interventions, and start with digging the ponds as they only would require manual labour and farmers usually already own digging tools.

LEGEND



PONDS

Phase 1

Year 0-1: Baseline Assessment & Targeting Family Farms

Initial site evaluation, stakeholder engagement, and detailed planning for interventions. The concept will first be targeted at family-owned farms, which are ready to adopt the interventions, ensuring smoother implementation through personal involvement and trust.

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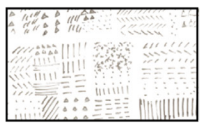
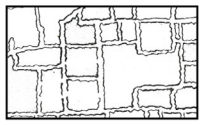
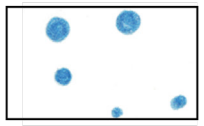


ALTERNATIVE CROP PATTERN



SHELTERBELTS



PONDS



STREET TREES

FAMILY FARMS ADAPTING PONDS, SHELTERBELTS AND CHANGE IN CROPPING PATTERNS

STREET TREES TO BE ESTABLISHED IN YEAR 1 THROUGH FREE TREES SAPLINGS DISTRIBUTION

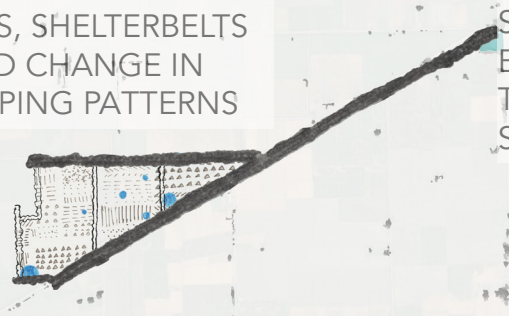


Figure 93: Phase 1

0 0.5 1 km

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Phase 2

Year 01-05: Moving to extended family farms

Phase 2 will be implemented by involving extended family members, neighbours, and the surrounding community. Support from government programs and NGOs will be essential, particularly for sourcing and planting trees. This approach allows the interventions to expand beyond individual farms, making the landscape-level changes more achievable and rooted in local participation.

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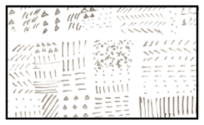
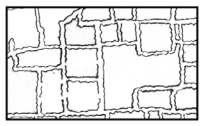
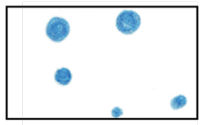


ALTERNATIVE CROP PATTERN



SHELTERBELTS



PONDS



STREET TREES



WATERBODIES



NATURALISED TREE AND GRASS



Figure 94: Phase 2

0 0.5 1 km

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Phase 3

Year 05-10: Enhancing agricultural systems & infrastructure

Application of strategies such as shelterbelts, ponds extended to more farms. Phase 2 focuses on the farms between Todarpur and Nadalon. I have chosen a site for expansion of interventions such as adding ponds, shelterbelts, street trees, and changes to farming patterns. It is easier to plan and manage this area because it involves only two panchayats (village council), which makes coordination more straightforward. While not all farmers may agree at first, most people in this area are either related or have strong connections with each other and with the panchayat. This makes it easier to move the plan forward. The street trees also connects the farms from both villages and create shared spaces for recreation.

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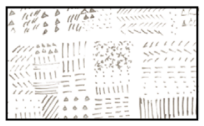
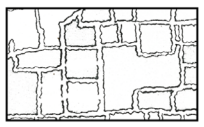
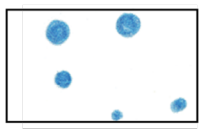


ALTERNATIVE CROP PATTERN



SHELTERBELTS



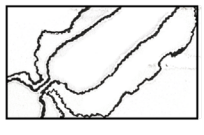
PONDS



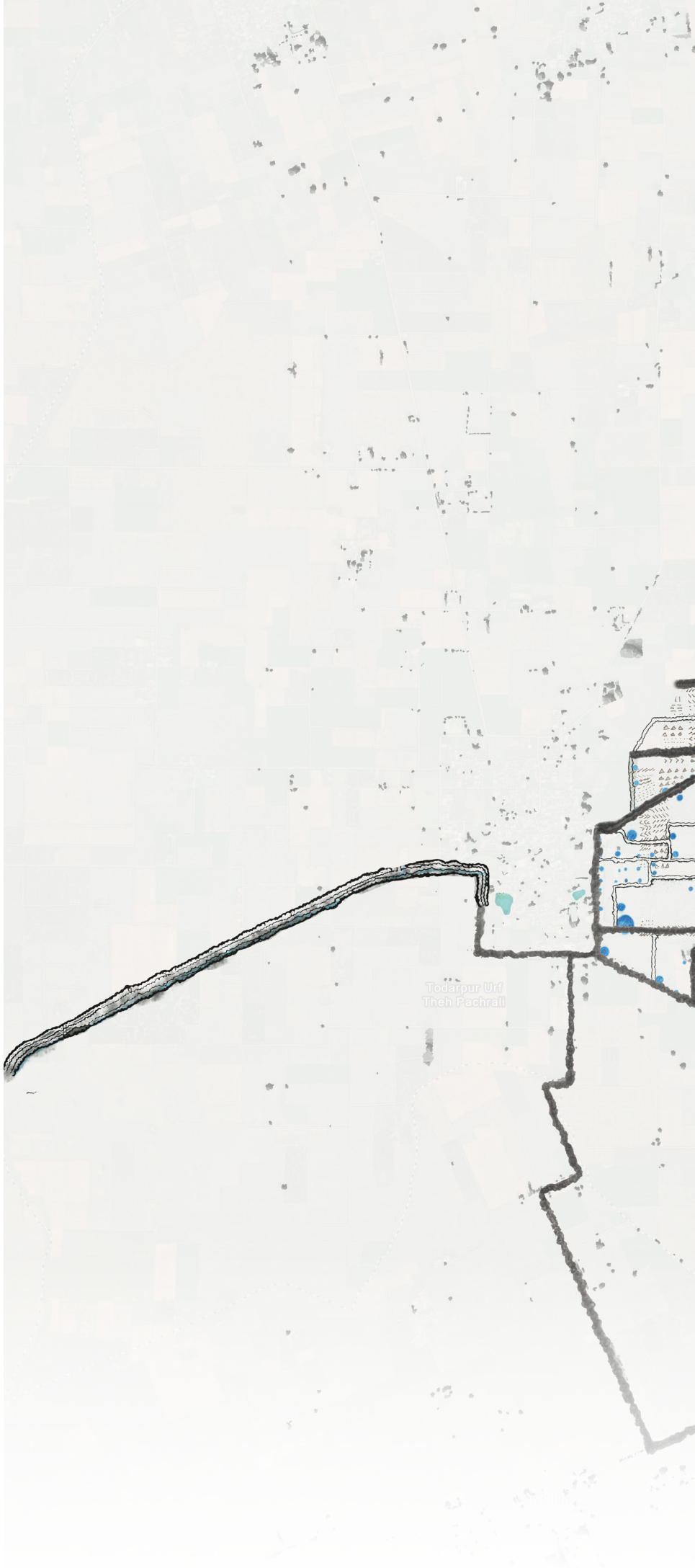
STREET TREES



WATERBODIES



NATURALISED TREE AND GRASS



EXPANSION OF STREET TREES

ESTABLISHMENT OF THE NATURALIZED VEGETATION ON EXISTING WATER CHANNELS

MULTI-CROPPING AND AGRO-FORESTRY

ESTABLISHMENT OF PONDS

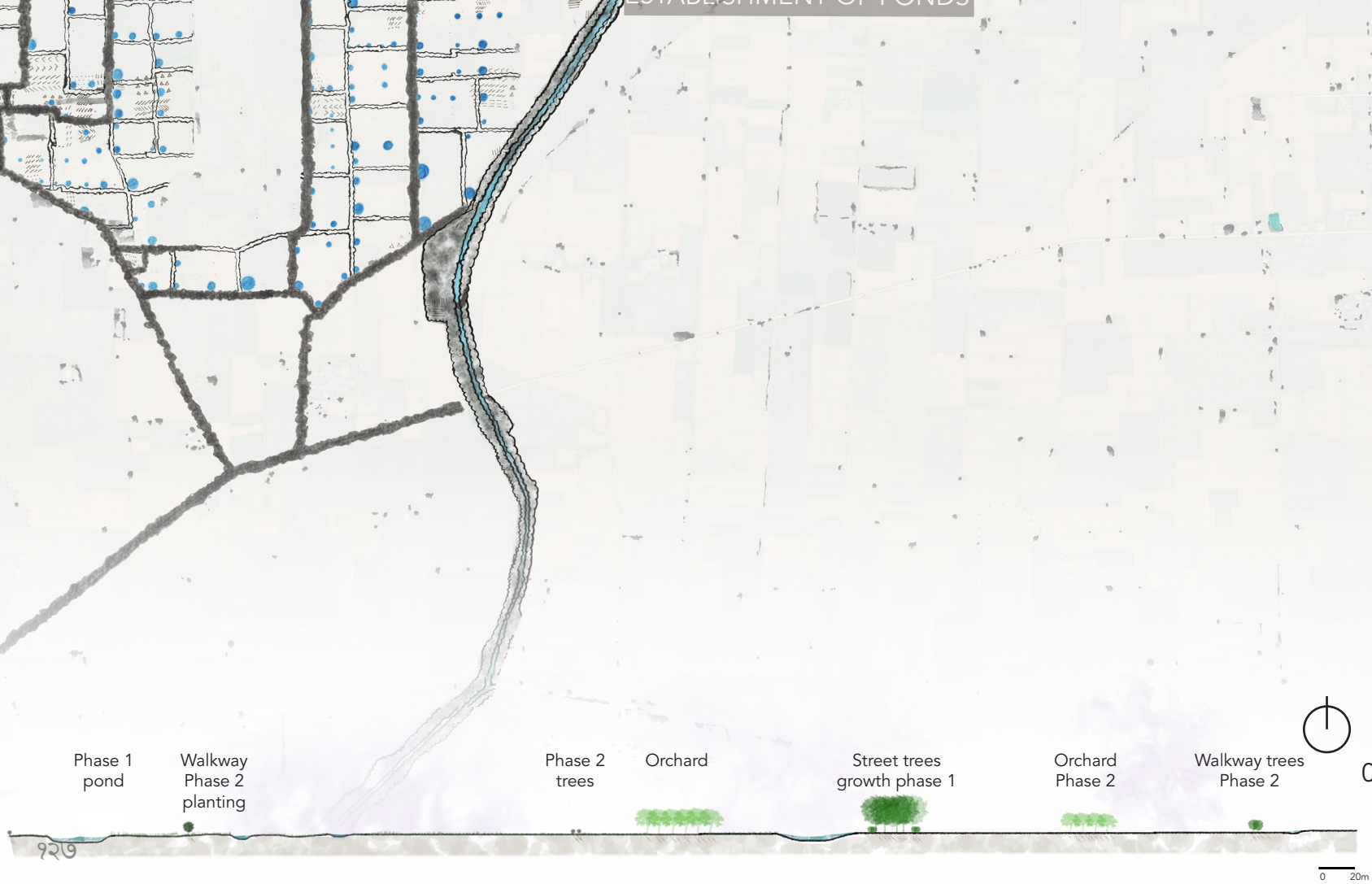


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Figure 95: Phase 3 (plan)
Figure 96: Phasing section

Phase 4

Year 10-15: Ongoing management and community integration

Gradual adoption of successful interventions across adjacent farms and villages. Addition of water bodies and wide crop pattern change is included in this phase.
Since this phase involves converting farmland into ecological zones, such as larger water bodies, policy support from the government will be essential. Farmers are to be compensated for the use of their land, which necessitates formal government involvement. This phase allows a time frame of 10-15 years for the government and non-governmental organizations (NGOs) to build the necessary support systems and policies to facilitate this transition.

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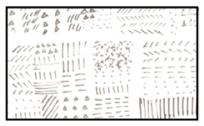
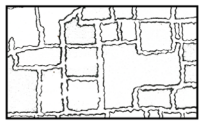
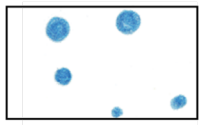


ALTERNATIVE CROP PATTERN



SHELTERBELTS



PONDS



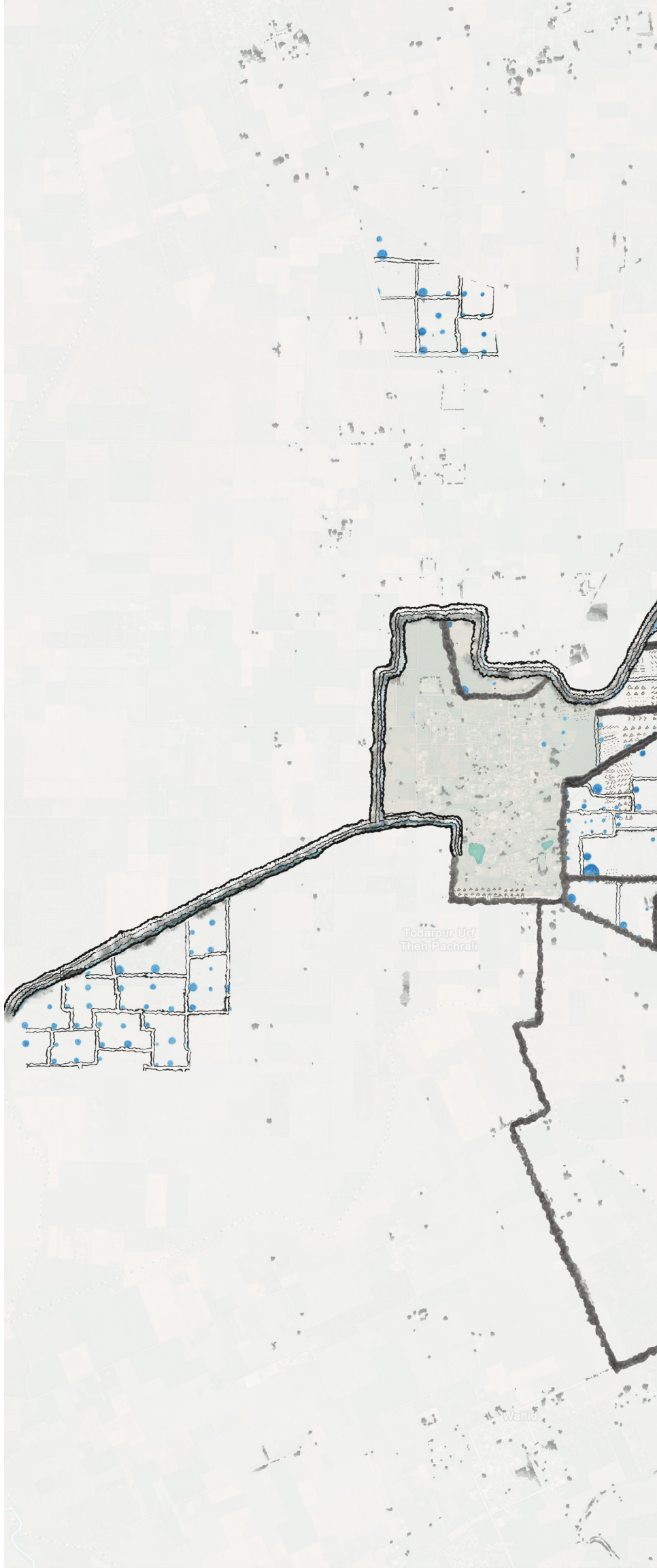
STREET TREES



WATERBODIES



NATURALISED TREE AND GRASS



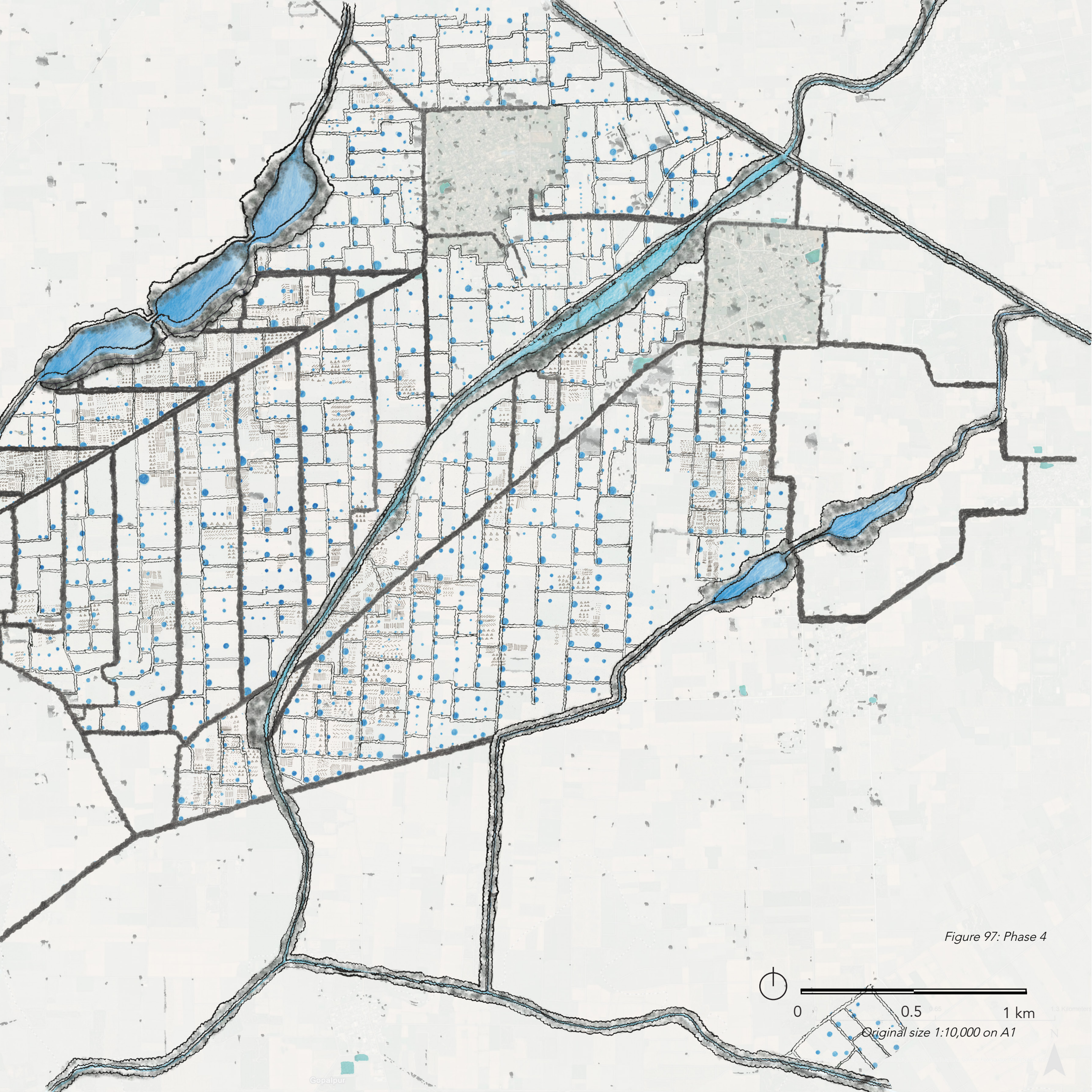


Figure 97: Phase 4

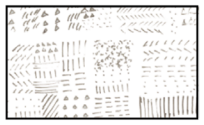
Phase 5

Figure 98: Phase 5

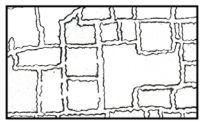
Year 15-25: Realising the vision and navigating challenges

By the end of this phase, the aim is to achieve a 60-70% transition in cropping patterns. However, it is acknowledged that not all farmers will be able to adopt these changes. Therefore, targeted support and incentives are provided to encourage farmers, while efforts are put into understanding and addressing the concerns of those who are reluctant.

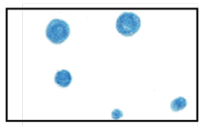
LEGEND



ALTERNATIVE CROP PATTERN



SHELTERBELTS



PONDS



STREET TREES



WATERBODIES



NATURALISED TREE AND GRASS

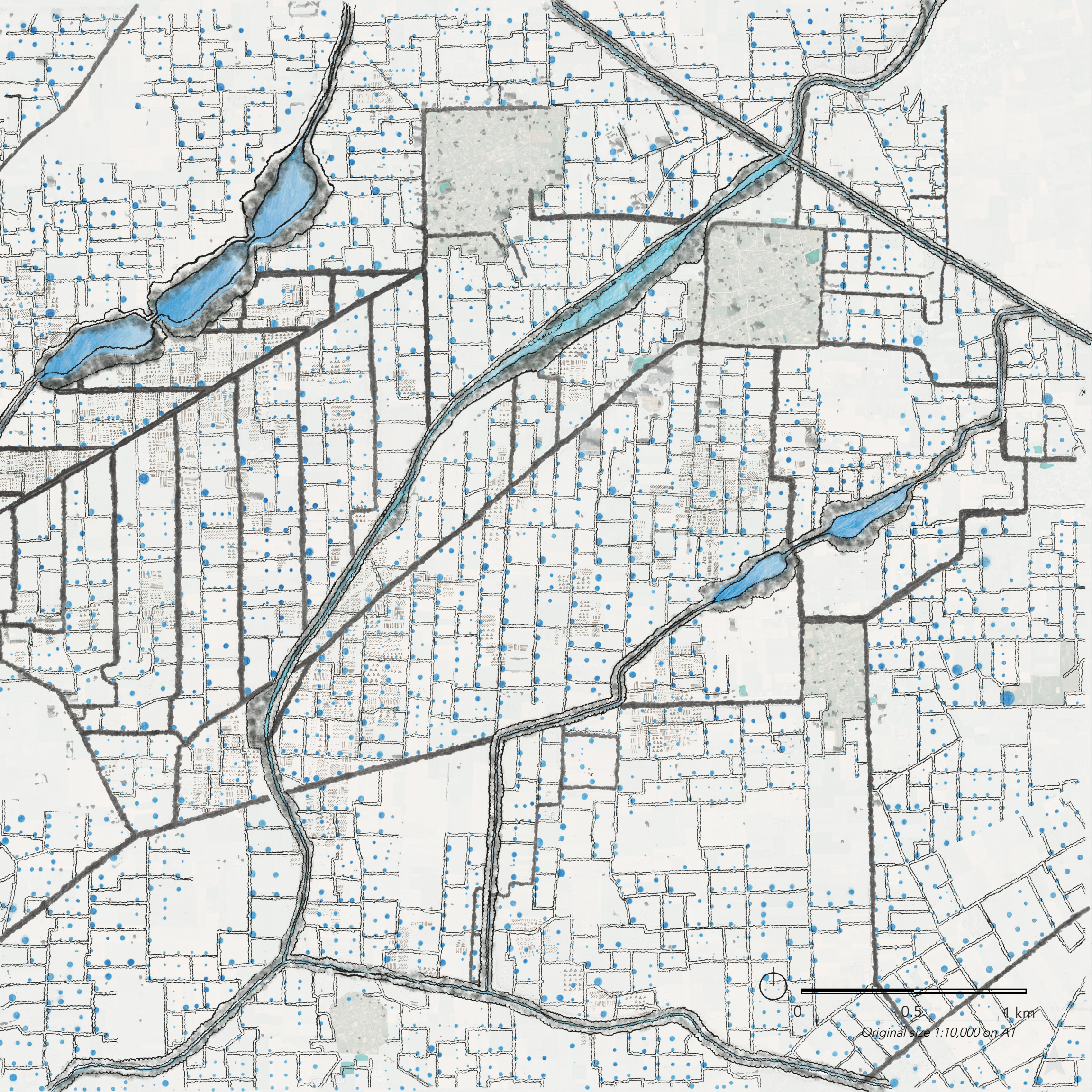

0
0.5
1 km
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Figure 99: Illustration of the design



This is how I re-imagine Punjab - ponds, trees, and new crops that use less water.

Overall, to apply these interventions, help from organisations is be needed, for example, the NGO AgroRangers, based in Maharashtra, has expressed willingness to support the implementation of these strategies. AgroRangers follows a model where the organization supplies farmers with initial resources and planting material, reducing the financial burden of transition. In return, after the successful establishment of agroforestry-based systems, the NGO collects a 10% share of the profits while also acting as a middle agent to secure better market prices for farm produce. Their work primarily focuses on agroforestry and is internationally recognized, with the organization's founder acknowledged by the United Nations Convention to Combat Desertification (UNCCD) for contributions to groundwater restoration and desertification mitigation. Their model demonstrates how shifting cropping patterns can directly support the recharge of groundwater tables while offering economic benefits to farmers.[3]

END NOTES

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08 PLANT PROFILES: SPECIES, TRAITS AND APPLICATIONS

8.1 Exploring the Essence and Role of plants in this landscape

In the heart of every landscape, plants tell stories of resilience, beauty, and purpose. Each species, with its unique form and essence, plays a vital role in shaping the environment, offering both sustenance and strength. This chapter brings together a selection of plants, each carefully chosen for its connection to the land and its potential in supporting the groundwater recharge, resilient agriculture, water-bodies and creation of cultural gathering spaces.

GRASSES SELECTION

For planting grasses in water bodies, native species are chosen because their deep root systems help stabilize the soil, prevent erosion, and allow better water infiltration, which supports groundwater refilling. These grasses are well adapted to local conditions, making them resilient to changes in water levels and climate. Additionally, they require fewer resources like water and fertilizers compared to non-native species.

Scientific Name	Common Name	Punjabi Local Name
Cynodon dactylon	Bermuda Grass	Doob
Typha angustifolia	Narrow-leaved Cattail	Sarey
Scirpus validus	Softstem Bulrush	Saswan
Phragmites australis	Common Reed	Bharb
Schoenoplectus lacustris	Great Bulrush	Sarsowen
Juncus effusus	Common Rush	Jungli
Eleocharis palustris	Common Spike Rush	Chamkora
Nymphaea spp.	Water Lily	Kamal
Sparganium erectum	Bur-reed	Keshar
Vallisneria spiralis	Water Celery	Pani Patta

TREE SELECTION

Trees of Cultural importance

Culturally important trees are chosen for their deep roots that help improve groundwater recharge by allowing water to infiltrate the soil more effectively. At the same time, these trees hold strong cultural significance, serving as important symbols in local traditions, rituals, and community life, thereby connecting people to the land and its natural water systems.

Tree name	Height	Spread	Recommended spacing	Notes
Banyan *(Ficus benghalensis)*	15–25 m	20–30 m	15–20 meters apart	Ideal for cluster of trees or open spaces
Peepal *(Ficus religiosa)*	15–30 m	8–12 m	10–12 meters apart	Sacred, shade, air-purifying.
Dek Tree *(Melia azedarach)*	6–10 m	8–12 m	5–8 meters apart	Cultural, Shallow roots, drought-tolerant, fast-growing, good for soil stabilization
Mango Tree *(Mangifera indica*	10-15m	10-40m	10-12 meters apart	Deep, wide-spreading roots, prefers well-drained soil

Shelterbelt tree and Street tree species

Shelterbelts and street trees are planted for their ability to enhance groundwater recharge by reducing soil erosion and increasing water infiltration through their root systems. They also provide cultural and social value by creating shaded, comfortable spaces for communities

Tree name	Height	Spread	Recommended spacing	Notes
Neem (Azadirachta indica)	12–18 m	10–15 m	6–8 meters apart	Drought-resistant, pest-repellent, fast-growing.
Shisham (Dalbergia sissoo)	15–25 m	8–12 m	7–9 meters apart	Strong timber, nitrogen-fixing.
Babool (Vachellia nilotica)	5–15 m	6-10 m	5–7 meters apart	Strong timber, nitrogen-fixing.
Arjun (Terminalia arjuna)	20–25 m	8–15 m	8–10 meters apart	Deep-rooted, stabilizes soil along water bodies.
Dek (Melia azedarach)	10–15 m	6–10 m	6–8 meters apart	Hardy, erosion control, great for dry slopes.
Ber (Ziziphus mauritiana)	5–12 m	6–10 m	5–7 meters apart	Drought-resistant, strong roots, fruit-bearing.
Jamun (Syzygium cumini)	10–30 m	8–12 m	8–10 meters apart	Wind resistance, shade provider, fruit tree.
Mulberry (Morus alba)	10–15 m	8–10 m	6–8 meters apart	Fast-growing, excellent for soil stabilization.
Bottlebrush (Callistemon viminalis)	10-15 m	3 m	3-5 meters apart	Dense canopy, drought-hardy.
Amaltas (Cassia fistula)	10-20 m	8-10 m	10 meters apart	Striking yellow flower, drought tolerant.

9 LIMITATION AND FUTURE POSSIBILITIES

9.1 Limitations

One key challenge of the limitations is the lack of accurate, high resolution historical or geological maps and detailed records of pre-green revolution landscape, which made it challenging to reconstruct past conditions and is highly based on talking to family members, therefore it is based on oral history.

Additionally, information about specific villages, such as boundaries, farm ownership and farmers capacity to implement new strategies is limited.

Calculations for pond capacity, farming pattern change contributions and water bodies area is based on certain assumption such as efficiency coefficients, and run off coefficients due to lack of concrete data for specifically the inter-village site.

In addition, the project's scope is constrained by the geographic distance to the site. It was not possible to observe the landscape during summer and monsoon cropping seasons, when water related changes are more visible. Community perspectives are drawn from a limited number of engagements.

9.2 Future Possibilities

Although there were some limitations, the practicum offers opportunities for future development. Expanding the project to more areas in the Bist Doab region would help create more water management systems. Access to more accurate data from organizations would be beneficial. In the future, strategies and interventions could be implemented directly with farmers through organizations like Agro Rangers.

There is also potential to work more directly with local farming communities. Collaborating with organizations such as Agro Rangers could help introduce the proposed strategies and interventions in a more practical and community-centered way. These partnerships would allow for on the ground level testing and adaptation of ideas based on farmers' feedback, capabilities and experiences.

The author intends to initiate this design intervention on the farms identified in the detailed design section.



Figure 100: Dirt Walk

FIGURE LIST

Figure 1. Global distribution of dryland subtypes based on aridity index – Punjab is under the category of humid to sub-arid. "Explainer: Desertification and the Role of Climate Change," Carbon Brief, https://www.carbonbrief.org/explainer-desertification-and-the-role-of-climate-change/.

Figure 2. Convergence of land degradation risks based on the third edition of the World Atlas of Desertification. https://wad.jrc.ec.europa.eu/countryreport.

Figure 3. Common combinations of Global Change Issues (GCIs). https://wad.jrc.ec.europa.eu/countryreport.

Figure 4. Projected changes in aridity index for Punjab. https://wad.jrc.ec.europa.eu/countryreport.

Figure 5. Map of India showing Punjab's location. https://mapsforupsc.com/outline-maps-of-india-and-the-world/, edited by author.

Figure 6. Punjab and its major rivers. Living Atlas, ArcGIS Pro.

Figure 7. Transplantation of rice crop in Punjab. By author.

Figure 8. Three different landscape scales. ArcGIS Online and author.

Figure 9. Present-day agricultural landscape of Punjab. By author.

Figure 10. Illustration of a personal story. By author.

Figure 11. Historic Punjab and major rivers. Maemoku et al., "Geomorphological Constraints on the Ghaggar River Regime," Climates, Landscapes, and Civilizations, 2012.

Figure 12. Punjab's water flow direction. Annotated by author, Living Atlas GIS data.

Figure 13. Dams and wetlands of Punjab. Annotated by author, Living Atlas GIS data.

Figure 14. Canal system of Punjab. Annotated by author, Living Atlas GIS data.

Figure 15. Wind direction in Punjab. Annotated by author, Living Atlas GIS data.

Figure 16. Soils of Punjab. https://www.studyiq.com/articles/soils-of-punjab/, annotated by author.

Figure 17. Ficus benghalensis (Peepal tree) in a gathering area (Sathh). By author.

Figure 18. Community irrigation pond. By author.

Figure 19. Temporary resting place and traditional farming illustration. By author.

Figure 20. Punjabi farm with tubewell irrigation. By author.

Figure 21. Surface water irrigation through canal. Redrawn by author.

Figure 22. Groundwater irrigation. Drawn by author, inspired by https://www.montanawatercenter.org/irrigation-efficiency.

Figure 23. Aquifer properties. https://indiawris.gov.in/, overlayed by author.

Figure 24. Aquifer depth. https://indiawris.gov.in/, overlayed by author.

Figure 25. Aquifer material. https://indiawris.gov.in/, overlayed by author.

Figure 26. Aquifer thickness. https://indiawris.gov.in/, overlayed by author.

Figure 27. Water cycle showing groundwater and surface water. Redrawn by author; Keesari et al., "Isotope Investigation on Groundwater Recharge," Applied Radiation and Isotopes, 2017.

Figure 28. Loss of Sutlej River water. https://global-surface-water.appspot.com/map, edited by author.

Figure 29. Rural settlement groundwater use. By author.

Figure 30. Groundwater depletion progression in Punjab. https://savingpunjab.org/2023/03/03/punjabs-water-depeletion-crisis/, annotated by author.

Figure 31. Groundwater table drop before and after the Green Revolution. Redrawn by author; Lapworth et al., "Groundwater Quality in the Alluvial Aquifer System of Northwest India," Environmental Monitoring and Assessment.

Figure 32. Water recharge techniques. By author.

Figure 33. Present-day conditions. By author.

Figure 34. Sutlej Riverbank showing absence of riparian forest. Google Street View.

Figure 35. Strategy to establish vegetation zones. Living Atlas, annotated and designed by author.

Figure 36 & 37. Average and potential vegetation widths along rivers. By author and Beale et al., 2022. https://doi.org/10.5285/9a96e199-34d0-46f9-9a64-140d300a2531.

Figure 38. Section showing vegetation zones. By author.

Figure 39. Canal vegetation width plan and section. By author.

Figure 40. Strategy to restore wetlands. Living Atlas, annotated and designed by author.

Figure 41. Illustration of groundwater recharge via wetlands. By author.

Figure 42. Deeper aquifer recharge in Zone 1 and 2. Redrawn by author; Joshi et al., "Tracing Groundwater Recharge Sources in Northwestern Indian Alluvial Aquifer."

Figure 43. Strategy to regulate river flow. Living Atlas, annotated and designed by author.

Figure 44. Context map of Bist Doab region and water bodies. Living Atlas, annotated by author.

Figure 45. Sub-dendritic and sub-parallel flow patterns. By author.

Figure 46. Geology of Bist Doab region. Gautam et al., "Impact of Anthropogenic Activities on the Alluvial Aquifers of North-East Punjab," Environmental Monitoring and Assessment, 2020.

Figure 47. Artificial recharge zones in Bist Doab basin. Singh et al., "Artificial Groundwater Recharge Zones Mapping," Environmental Management, 2013.

Figure 48. Strategies for Bist Doab region. Living Atlas, annotated and designed by author.

Figure 49. Inter-village site existing conditions. Google Earth, annotated by author.

Figure 50. Inter-village site existing conditions (axonometric). Google Earth, annotated by author.

Figure 51. Water pump system. By author.

Figure 52. Water pump system distribution. By author.

Figure 53. Electric pole for free electricity for water pumping. By author.

Figure 54. Sugarcane crop. By author.

Figure 55. Weeding process of rice crop. By author.

Figure 56. Forage crops. By author.

Figure 57. Transplanted wheat crop. By author.

Figure 58. Walkway exposed to strong sunlight. By author.

Figure 59. Recently transplanted wheat crop. By author.

Figure 60. Burned residue. By author.

Figure 61. Freshly prepared farm, ready for sowing. By author.

Figure 62. Harvesting and processing of crops. By author.

Figure 63. Culturally important tree as a focal point. By author.

Figure 64. High water-demanding Eucalyptus. By author.

Figure 65. Irrigation water channel in a farm (bund). By author.

Figure 66 & 67. Post-Green Revolution landscape. By author.

Figure 68. Young traditional tree, showing remnants. By author.

Figure 69. Walkway – dirt path lined with trees. By author.

Figure 70. Out-of-use dug well that can be used to reverse pump. By author.

Figure 71. Community groundwater-pumped irrigation pond (not used). By author.

Figure 72. Community groundwater-pumped irrigation pond (not used). By author.

Figure 73. Culturally important tree with seating by the pond. By author.

Figure 74. Community groundwater-pumped irrigation pond. By author.

Figure 75. Wildlife in vegetation by the pond. By author.

Figure 76. Storage of pumped drinking water (not clean). By author.
Figure 77. Middle of the seasonal stream/choe. By author.

Figure 78. Polluted choe due to trash dumping. By author.

Figure 79. Invasive vegetation in the choe. By author.

Figure 80. Concrete crossing on seasonal choe. By author.

Figure 81. Polluted canal, reducing efficiency for farming. By author.

Figure 82. Collage of flora, fauna, and human interaction. By author.

Figure 83. Intervention principles. By author.

Figure 84. Site for detailed design. Google Maps, annotated by author.

Figure 85. Detailed design plan. By author.

Figure 86. Detailed design (axonometric). By author.

Figure 87. Section A. By author.

Figure 88. Section B. By author.

Figure 89. Section C. By author.

Figure 90. Section D. By author.

Figure 91. Section E. By author.

Figure 92. Pre Phase 1 diagram. By author.

Figure 93. Phase 1. By author.

Figure 94. Phase 2. By author.

Figure 95. Phase 3 (plan). By author.

Figure 96. Phasing section. By author.

Figure 97. Phase 4. By author.

Figure 98. Phase 5. By author.

Figure 99. Illustration of the design. By author.

Figure 100. Dirt walk. By author.

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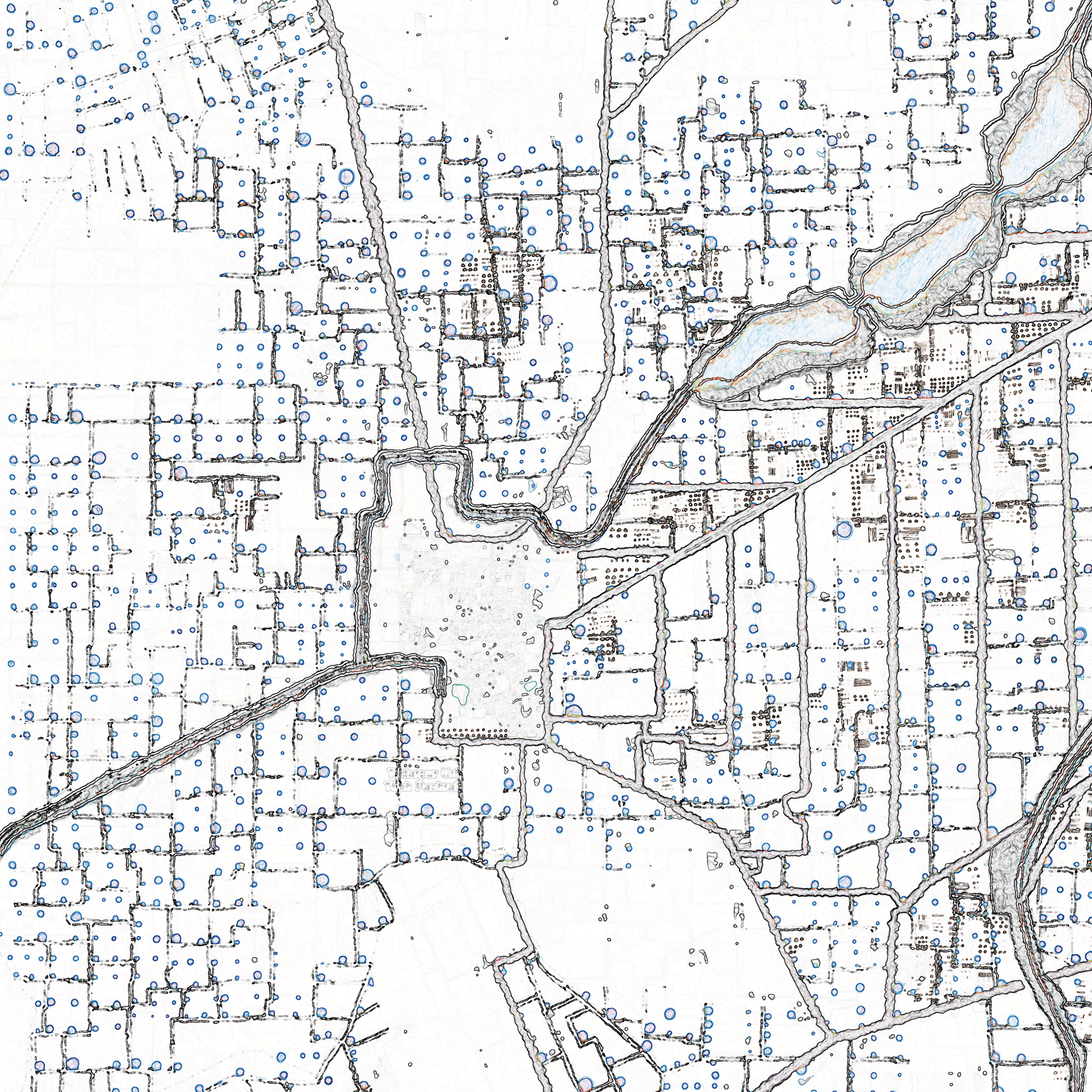

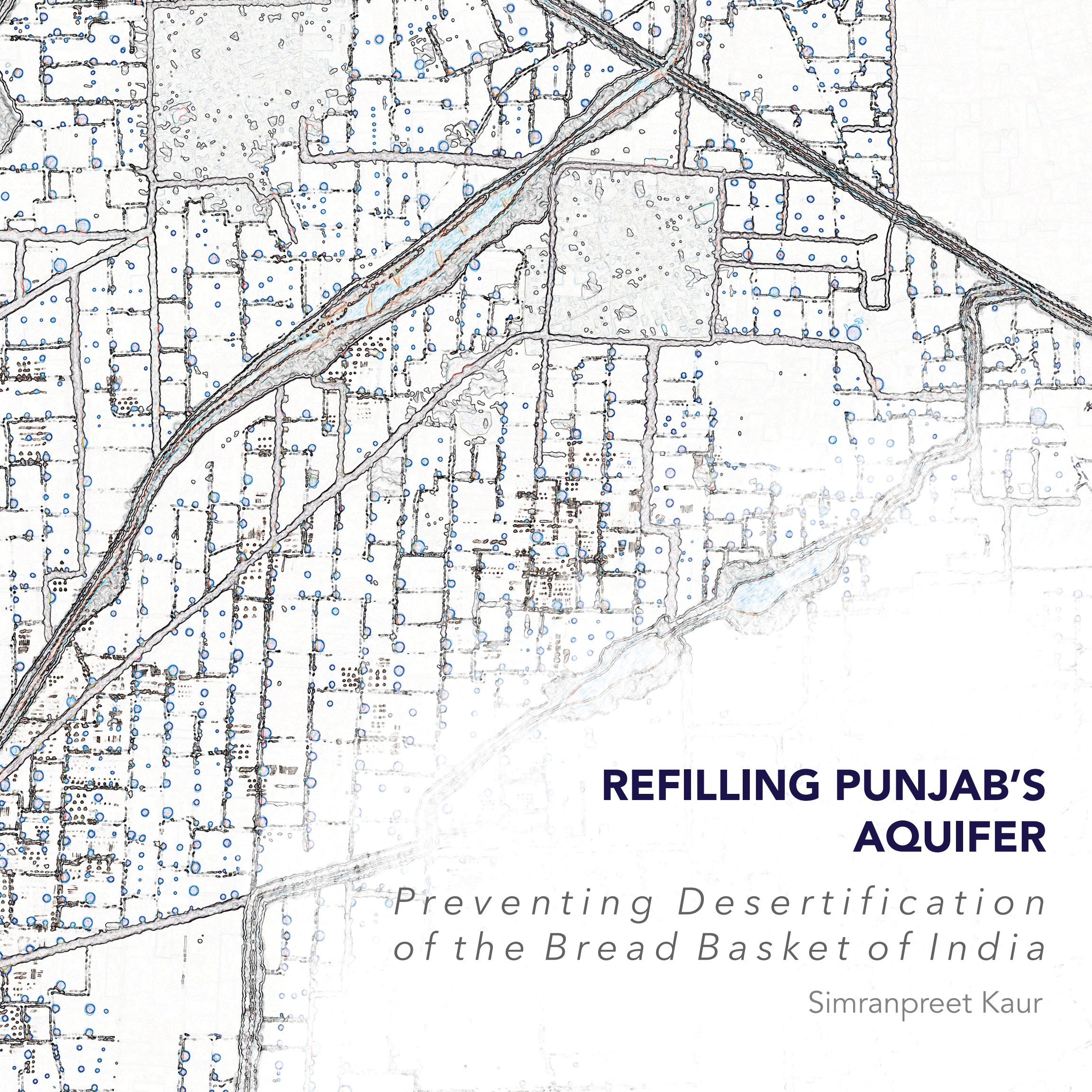

REFILLING PUNJAB'S AQUIFER

Preventing Desertification of the Bread Basket of India

Simranpreet Kaur