PATHWAY TOWARDS A FLOOD RESILIENT ULAANBAATAR

Dutch Disaster Risk Reduction & Surge Support (DRRS) Program
Report

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GEODESY & WATER CONSTRUCTION DEPARTMENT

GOVERNMENT OF THE NETHERLANDS

OFFICE OF GOVERNOR AND MUNICIPALITY OF ULAANBAATAR

Report on behalf of

Netherlands Enterprise Agency (RVO), Embassy of the Kingdom of the Netherlands (EKN)

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List of abbreviations

ADB	Asian Development Bank
CCKP	Climate Change Knowledge Portal
DRRS	Dutch Risk Reduction & Surge
EKN	Embassy of the Kingdom of the Netherlands
FRMP	Flood Risk Management Plan
FS	Feasibility Study
GDP	Gross Domestic Product
GUBB	Geodesy and Water Construction Department
IFRMP	Integrated Flood Risk Management Plan
IFRC	International Federation Red Cross
IGG	Institute of Geography and Geoecology, Mongolian Academy of Sciences
JICA	Japan International Cooperation Agency
MoUB	Municipality of Ulaanbaatar
RHDHV	Royal HaskoningDHV
RVO	Netherlands Enterprise Agency
TA	Technical Assistance
UB	Ulaanbaatar
USD	United States Dollar
UNFCCC	United Nations Framework Convention on Climate Change
WB	World Bank

PREFACE

Ulaanbaatar, Mongolia's capital, is at a turning point in its approach to flood risk management. The severe flooding events of 2023 underscored the urgent need for a more comprehensive and integrated approach to urban flood resilience. In response, the Municipality of Ulaanbaatar (MoUB) requested technical assistance from the Dutch Disaster Risk Reduction & Surge Support (DRRS) Programme, leading to a collaborative effort between Mongolian and Dutch experts to assess flood risks and propose sustainable solutions for urban development.

This report, Pathway Towards a Flood-Resilient Ulaanbaatar, is the result of two DRRS visits to Ulaanbaatar in 2024. The first visit in February 2024 took place under challenging icy conditions, allowing the DRRS team to gain first-hand insights into the city's flood risk challenges not only during the wet season but also under extreme winter conditions. During this visit the team thoroughly reviewed the existing water system in Ulaanbaatar and identified most pressing bottlenecks in the city. The second visit in late 2024 focused on capacity building and laying the foundation for an implementation strategy to operationalize the technical recommendations from the February visit.

This report consolidates the findings from both visits and presents a comprehensive roadmap for enhancing flood risk in Ulaanbaatar. It offers a strategic framework and actionable recommendations at multiple levels—governance, institutional, technical, and planning—to support the Municipality of Ulaanbaatar, directly and through its collaboration with development banks (e.g. WB, ADB, JICA) in implementing flood resilience measures. The report introduces key global concepts for integrated river basin management such as *Retain, Store, and Drain* and *Room for the River,* emphasizing nature-based and integrated solutions tailored to Ulaanbaatar's unique urban and climatic challenges.

The DRRS team extends its gratitude to Mr. Nyambaatar Khishgee, Governor of Ulaanbaatar, and Mr. Manduul Nyamandeleg, former First Deputy Governor of the Municipality of Ulaanbaatar, for their leadership and the Municipality's active engagement in this partnership. Special thanks are also extended to the Geodesy & Water Construction Department (GUBB) for their collaboration and hospitality during the missions. The DRRS team also extends its thanks to other development partners in Mongolia, such as the United Nations (UN), World Bank (WB), Asian Development Bank (ADB), Japan International Cooperation Agency (JICA) and the International Federation of Red Cross (IFRC) for their cooperation and participation during the visits.

The DRRS team was composed of a combined team of experts from Mongolia and the Netherlands. The team composed of Dr. Ayurzana Badarch – Water resources expert, Mongolian University of Science & Technology, Dr. Chinzorig Sukhbaatar – Sediment expert, Institute of Geography and Geoecology, Mongolian Academy of Sciences, Dr. Maarten Bakker – Sediment Management Specialist, Martin te Grotenhuis, Urban drainage expert, and Jacco Breedijk, Urban Drainage Specialist, all Royal HaskoningDHV & Roy Daggenvoorde, Flood Risk Expert, HKV. Team leader for this assignment was Eisse Wijma, sr. Water Resources Management & Flood Management expert, Studio Flow Consultancy. Ms. Delgermaa Byambasuren – Honorary Consul of the Netherlands provided diplomatic assistance to the mission. Lisa Wijkel was responsible for the overall project coordination on behalf of the Netherlands Government, RVO DRRS Program. The team wants to extent a final thanks to the Embassy of the Kingdom of the Netherlands in Beijing, in particularly Ms. Desirée Ooft, for their excellent support to this partnership.

Eisse Wijma,

Team Leader, DRRS Mongolia.

EXECUTIVE SUMMARY

Floods are natural phenomena within river systems and do not inherently pose problems unless assets or human activities are located within flood zones. This principle holds true for most river systems in Mongolia, where human activity remains largely absent from flood-prone areas. For urban rivers, it is necessary to protect the city against floods while providing enough space for the river to safely discharge its floodwaters. Many large global cities have struggled with this balance, as the need for space for urban development often dominates the political agenda. Ulaanbaatar is no different in this regard.

Floods in Ulaanbaatar can be closely linked to past developments, reducing the available space for rivers to accommodate flood water within its channels, floodplains and the catchment. In recent years, the Selbe River has been significantly regulated and its cross-sectional profile narrowed due to the continuous demand for land for construction of buildings and roads. Similar changes have occurred throughout its catchment, with an increasing area of paved surfaces and a loss of natural storage capacity due to the uncontrolled expansion of Ger areas.

The DRRS team concludes that Ulaanbaatar is at a pivotal moment in redefining its approach to flood risk management. Drawing on international best practices, the city is strongly advised to shift course—halting further encroachment on its river system and instead creating more space for the river to discharge floodwaters, enhance urban biodiversity, and serve as a recreational corridor. This presents a unique opportunity to adopt a comprehensive strategy that not only enhances flood protection but also leverages the river's potential to transform Ulaanbaatar into a modern, climate-resilient city.

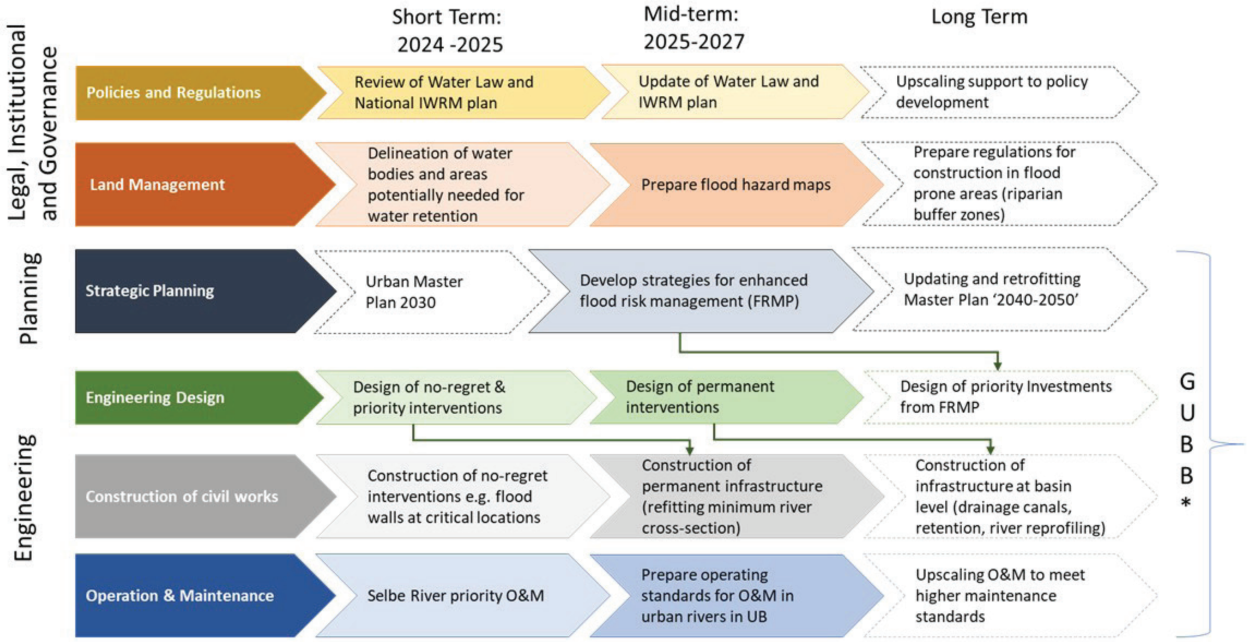
Infrastructure investments alone are unlikely to be sufficient. While mitigation measures—such as rehabilitating local retention ponds, constructing small-scale upstream reservoirs and sediment stilling basins, building levees along the riverbanks, and enhancing maintenance of existing infrastructure as proposed by the DRRS team—may yield short-term benefits, they do not address the broader systemic challenges. This would require 1) upgrading the GUBB to a fully equipped and mandated Water Authority, 2) updating the existing regulatory framework to reflect integrated flood risk management principles, 3) incorporating the interests of multiple stakeholders to ensure inclusive decision-making, 4) and promoting multi-purpose infrastructure investments that serve both flood risk management and urban development needs. By drawing on lessons learned from other global cities, Ulaanbaatar can avoid costly mistakes.

To support this transformation, modern tools such as hydrographic surveys, hydraulic models, satellite imagery, and real-time data acquisition equipment should be employed to deepen understanding in the behavior of the city's river systems. This scientific insight can also inform the establishment of a flood safety standard that reflects acceptable levels of risk, tailored to the city's social and economic priorities. Effective regulations and policies can then be developed - and should be enforced - ensuring that necessary investments in flood protection and maintenance are made, and that the integrity of the river system is preserved against future encroachment.

The recommendations from the DRRS-team can be consolidated into a comprehensive implementation framework for achieving Urban Flood Resilience in Ulaanbaatar. This framework outlines a development pathway toward achieving a flood-resilient city, built on the core principles of Integrated Flood Risk Management. It encompasses the necessary legal, institutional and governance structures, alongside planning, and engineering measures. The framework balances immediate "no-regret" actions with medium- and long-term investment strategies, ensuring that Ulaanbaatar evolves into a resilient and climate-adaptive city. The implementation framework provides a customized financing strategy that can be readily adopted by Development Banks (e.g., World Bank, ADB, JICA) or serve as a comprehensive investment plan for the government.

Implementation Framework for "Enhancing Flood Resilience in Ulaanbaatar"

Developed under the Netherlands-supported DRRS-program Mongolia



**Building capacity of Geodesy & Water Construction Department (GUBB) to support its transitioning into a full water management agency with expanded mandate*

01

GENERAL BACKGROUND

1. GENERAL BACKGROUND

Ulaanbaatar is vulnerable to frequent and severe natural hazards. Urban flooding, storm surges, and severe winter events have a strong impact on the overall urban environment in Ulaanbaatar[1] The construction boom in the city, the rapid expansion of *ger* areas, continuous encroachment of river floodplains and the lack of flood prevention and sediment management facilities have resulted in a drastic increase in flooding risks in the city over the past decades. Changing precipitation patterns due to climate change, are expected to further worsen the flood risk situation. Climate vulnerability is exacerbated by weak planning and management capacity at the municipal level, with inadequate early warning systems, and a lack of an enabling legal environment as well as technical capacity (World Bank, 2021).

1.1 National context

Mongolia is a landlocked, lower-middle-income country located in central-east Asia, bordered by China to the south and east, and Russia to the north and west. Renowned for its nomadic lifestyle, Mongolians traditionally live in round tents, called a 'Ger', enabling them to move with their livestock in accordance with seasonal patterns.

Mongolia has a strongly continental climate, with four distinctive seasons, high fluctuations of temperature, low precipitation and marked regional variations depending on latitude and altitude. Temperature varies dramatically throughout the year, which demonstrates the latest climatology (1991–2020) (see Figure 1). Historically, maximum temperatures have peaked at around 24°C in July, while January minimum temperatures fall to around −28°C. During the period February 24-30, 2024, the week of the first DRRS mission, record breaking cold was observed in Mongolia with temperatures dropping below -35 in Ulaanbaatar.

Annual precipitation rarely exceeds 400 millimeters (mm) and is typically much lower in the south and central desert and steppe regions. Nationally, an estimated 85% of precipitation falls between April and September. Small inter-annual variations in precipitation can lead to severe drought events, with some regions not experiencing rainfall at all. Figure 1 shows observed spatial variation for temperature and precipitation across Mongolia.

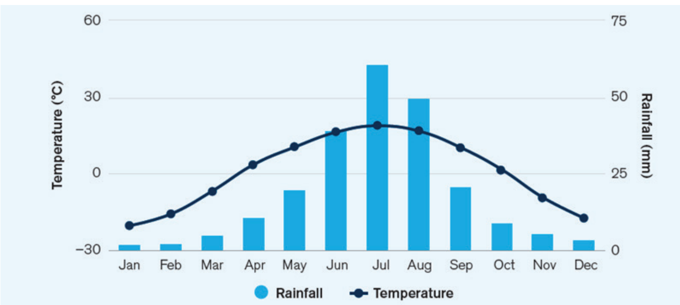


Figure 1: Average monthly temperature and rainfall in Mongolia, 1991–2020 (Source: National Agency Meteorology and Environmental Monitoring)

Mongolia's Third National Communication to the UNFCCC (in the World Bank & ADB, 2021) report a decline in average annual precipitation of 7% over the period 1940–2015, alongside a proportionately large increase in winter snowfall. The number of consecutive wet days and the number of days with heavy precipitation are also believed to have declined over the period 1971–2015. However, as these trends show low statistical significance, and shall thus be approached with caution, local interviews with herders have learned an increase in the frequency of thunderstorms and short high-intensity rainfall events, which could well fit in a climate shifting to an increase in the number of dry days and rainfall concentrating in events with high intensity rainfall. This conclusion is in line with the outcome of ensemble rainfall projections for different climate models. There is reasonable agreement among climate models that Mongolia can expect a slight increase in annual precipitation under most emissions scenarios (World Bank & ADB, 2021). Alongside these annual trends Mongolia is expected to experience an increase in the intensity of extreme rainfall events.

Social, Economic & Political Context

Since 1990, Mongolia has been transitioning to a democratic society with a focus to achieving social development. The country faces numerous social issues, with the most critical being health, education, and employment. While the government supports the health sector, high disease rates due to environmental pollution and low living standards have necessitated greater involvement from the private sector. Public health is hampered by living conditions, the number of health facilities, and environmental pollution.

While Mongolia's mineral resources, livestock, and seasonal agribusiness offer economic potential, political instability and a weak regulatory and planning framework hinder the development of the private sector. The GDP per capita has risen to $5,875, which is still low by international standards, slowing social development. Tax revenue is insufficient to support social development and improve living conditions, compounded by political instability. Mongolia operates a parliamentary government with elections every four years.

Given Mongolia's limited fiscal capacity to support overall social development, it is crucial to consider and implement low-cost solutions to reduce flood risk. In Ulaanbaatar, 38 percent of households live in ger areas, characterized by poor living conditions and a lack of infrastructure. These areas contribute to environmental pollution, including air, soil, and water pollution, and are vulnerable to floods.

Economically, Mongolia largely depends on its neighbors Russia and China. Mongolia depends on Russia for electricity, gasoline, aviation fuel, liquefied petroleum gas (LPG), and diesel, with about 60 percent of these supplies coming from its northern neighbor. China accounts for more than 80 percent of Mongolia's total exports, 60 percent of its imports, and more than 40 percent of its gross domestic product (GDP) .

[1] *Data from https://thinkhazard.org/en/.*
[2] *WBG Climate Change Knowledge Portal (CCKP, 2020). Climate Data: Historical. URL: https://climateknowledgeportalworldbank.org/country/mongolia/climate-data-historical*

[3] *https://www.aljazeera.com/economy/2022/12/14/mongolias-herders-feel-pinch-as-china-russia-squeeze-economy*

Ulaanbaatar City context

Ulaanbaatar – the capital city of Mongolia, has undergone rapid expansion due to the high-levels of rural-to-urban migration. Former nomads have been settling in Ger areas which have developed on Ula er, the development of these Ger areas has far outpaced the planned urban development of the city, leading to various urban planning challenges such as inadequate infrastructure and service provision, as well as an increased risk of flooding . In recent years, there has been a notable surge in urbanization, with 68.5% of the country's population residing in Ulaanbaatar as of 2019. Despite a projected population of 1.4 million by 2030, according to the city's latest Master Plan (2014), this figure was surpassed in 2019 already, with a population reaching 1.45 million (from World Bank - Ulaanbaatar Sustainable Urban Transport Project PAD).

Rapid and unplanned urban development has increased urban flood risk. Over the course of only 18 years Ulaanbaatar has undergone a major facelift. Figure 2 shows a location in downtown Ulaanbaatar where Ger areas and natural river floodplains have transformed into areas with large apartment buildings. At the same time new roads have been constructed and bridges were built. The combination of loss of floodplain area and increasing economic value of the city has made the city increasingly vulnerable to flooding. The lack of appropriate flood protection infrastructure has further exacerbated flood risk, which has materialized during the 2023 floods.

The infrastructure including existing flooding facilities has been deteriorating while maintenance has lagged and is insufficient. Flooding and icing of roads and sidewalks seriously inhibit the mobility of the residents, cause safety issues, contribute to traffic congestion, and damage economic productivity. More frequent flooding of roads during the summer and freezing of the road asphalt during the winter have also resulted in a more rapid deterioration of road pavement (World Bank, 2021).

Climate Conditions in Ulaanbaatar City

Ulaanbaatar has an extreme and harsh continental climate and belongs to the four-season region of the central part of Mongolia. The long-term average of the air temperature in Ulaanbaatar is 0.2°C, and in the last 23 years, the average value has increased to 0.4°C. With an average annual temperature being just above 0 degrees Celsius, the winter season is the most prominent and starts in October and continues to early April of the following year (IGG, 2024). In spring, the air and soil become very dry, and dust and dust storms are a frequent phenomenon, this time of the year.

The average monthly air temperature ranges from -20.7 to 19.6°C. The average temperature of the winter season ranges between -16.8°C and -20.7°C, with extremes reaching -35 degrees in Ulaanbaatar such as the night of February 21, 2024. The average temperature of the summer season ranges from 16.8°C to 19.6°C.

The annual average value of the absolute maximum air temperature between 1999 and 2022 was 33.9°C, and the absolute maximum value reached 38.3°C in 2010. The coldest months of the year are observed in December, January and February, and the long-term average value of the absolute minimum value is -33.1°C, or between -27°C and -37.3°C during 1999-2022. The absolute maximum air temperature has decreased by 4°C degrees in the last 23 years, while the absolute minimum temperature has increased by 2.5°C degrees at the same time.

Long term average total annual precipitation in Ulaanbaatar is 273 mm (1990-2020). The total average annual precipitation for the last 17 years is 271.5 mm, which is close to the long-term average. The regime of precipitation varies within the year. About 70 percent of precipitation falls in the summer season (i.e., June, July, and August). But in autumn, precipitation decreases sharply.

Annual rainfall around Ulaanbaatar has increased by 96 mm in the last 17 years. In recent years, the intensity of rain has increased in Ulaanbaatar, especially during the warm season.

Figure 2: Selbe river in central Ulaanbaatar in 2005 (left) and 2023 (right) showing a remarkable decline in area of natural floodplain area (source: Google Earth).

Table 1: Statistics of precipitation in the Ulaanbaatar meteorological station (Source: National Agency Meteorology and Environmental Monitoring)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
Monthly sum of precipitation	2.1	2.8	4.6	8.3	21.7	47.2	74.5	65.4	28.3	8.6	6.3	3.5	273.2
The maximum rain of day	5.3	5.9	14.3	12.3	33.6	63	46.8	49.8	33.4	29.1	9.5	3.6	63

[3] *https://www.aljazeera.com/economy/2022/12/14/mongolias-herders-feel-pinch-as-china-russia-squeeze-economy*

[4] *Climate Risk Country Profile: Mongolia (2021): The World Bank Group and the Asian Development Bank*

1.2 Ulaanbaatar's rivers

Tuul River

Ulaanbaatar is situated on the alluvial plain of the Tuul River at the confluence of three mountain tributaries: Uliastai, Selbe, and Tolgoit. The Tuul River originates from the Lower Khentii mountains of the Khan Khentii Mountain range. The river flows southwest through the capital of Mongolia, Ulaanbaatar, after which it eventually joins the Orkhon River in Orkhontuul soum where the Tuul River flows in the Orkhon River. The Orkhon River then joins the Selenge River, Mongolia's largest river, just before the border with the Russian Federation. The Selenge River ultimately drains into the large Baikal Lake in the Russian Federation. More than 65% of the Mongolian population lives in the catchment of one of these rivers, which is also where the majority of the country's socioeconomic activities occur (ADB, 2021).

River discharges vary significantly from year to year and fluctuate throughout the year. Snow and ice melting are the main sources of flow during spring. The largest flow is generated by rainfall in July and August. After September, the flows decrease substantially and, in November, the water starts to freeze and the flow stops until the spring melt. Year-to-year variability is large, and important rivers such as the Tuul and the Orkhon rivers show extended periods (from 5 years to more than 10 years) of above or below long-term (i.e., more than 20 years) average flows (ADB, 2021). Major fluvial floods in the Tuul River have occurred in the past, notably in 1934, 1958 (peak discharge of 533 m³/sec), 1966 (peak discharge of 1,120 m³/sec), and more recent years.

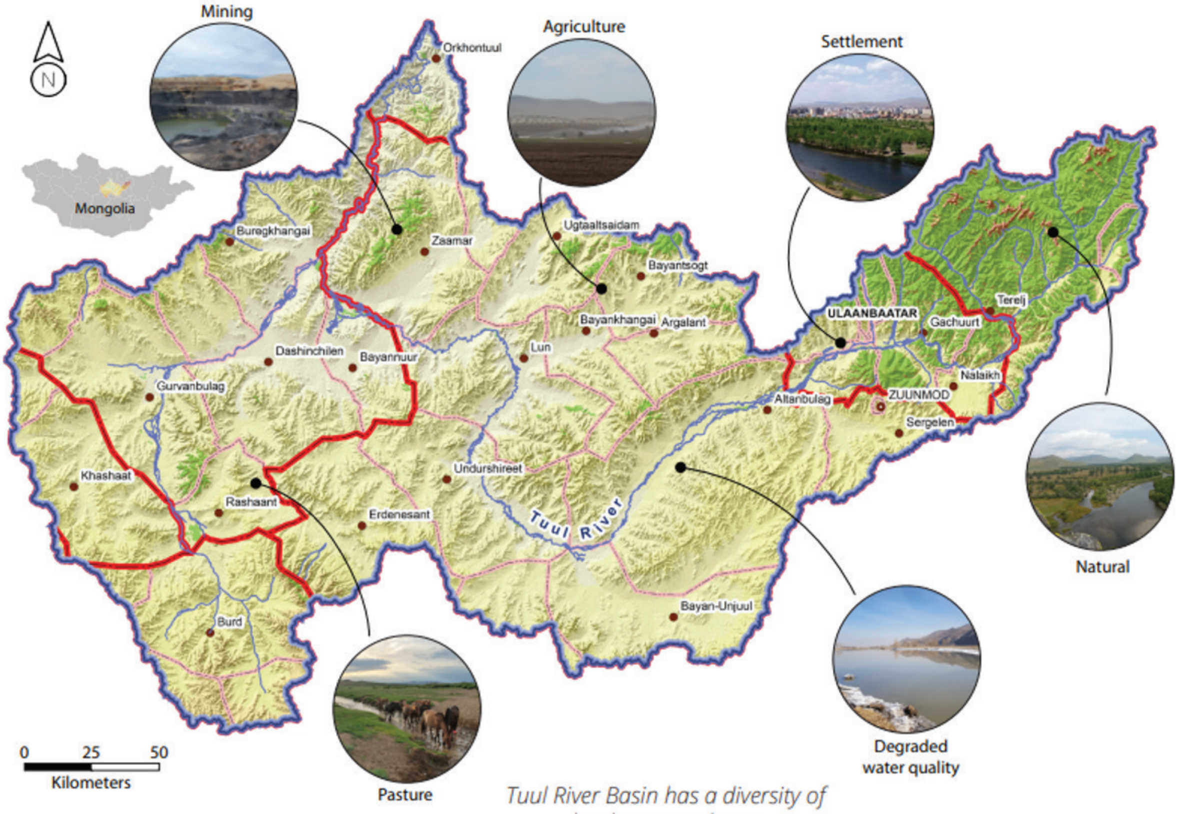


Figure 3: *Tuul River Basin (Source: WWF, 2019)*

The Selbe River

The Selbe River, along with the Uliastai and Tolgoit Rivers, originates in the Khentii Mountains just north of Ulaanbaatar. The Selbe River is 50 km long and the river basin covers 323 square kilometers, which increases to 430.4 km^2 after the confluence with the Baruun Uul canal. The average elevation of its basin is 1,621 m, with a gradient of 14.5‰, and it is classified as a third-order river. The river valley is typically 100-150 m wide, expanding to 400-500 m in some areas, with side slopes about 4-5 m high and covered with meadow vegetation. The channel width along its banks ranges from 20-25 m, with an average water depth of 0.1-0.5 m and banks 0.4-0.6 m high (source: Selbe Revival Plan). The river is at its smallest around 8-10 m near S-Outlet.

The upstream part is characterized by a wide-open river valley which is intensively developed mainly by holiday houses. The active part of the floodplain is roughly 200m in width. In the downstream part, the Selbe River flows through the urban area of Ulaanbaatar. In downtown Ulaanbaatar the Selbe makes a 90-degrees turn (location referred to as S-Outlet), from where it flows to the west until it confluences with the Tuul River. Figure 4 below shows the location of the main course of the Selbe river (left) and a detailed view of the Selbe river for the downstream reach within the administrative boundaries of Ulaanbaatar (right). Past floods, amongst the most severe floods in 1928, 1933, 1966, 1982, and in 2023, prompted the construction of levees in Ulaanbaatar as flood protection measures. Till date, some levees are in a poor condition or of temporary nature, under the ever-existing pressure to maximize land for construction of buildings and roads.

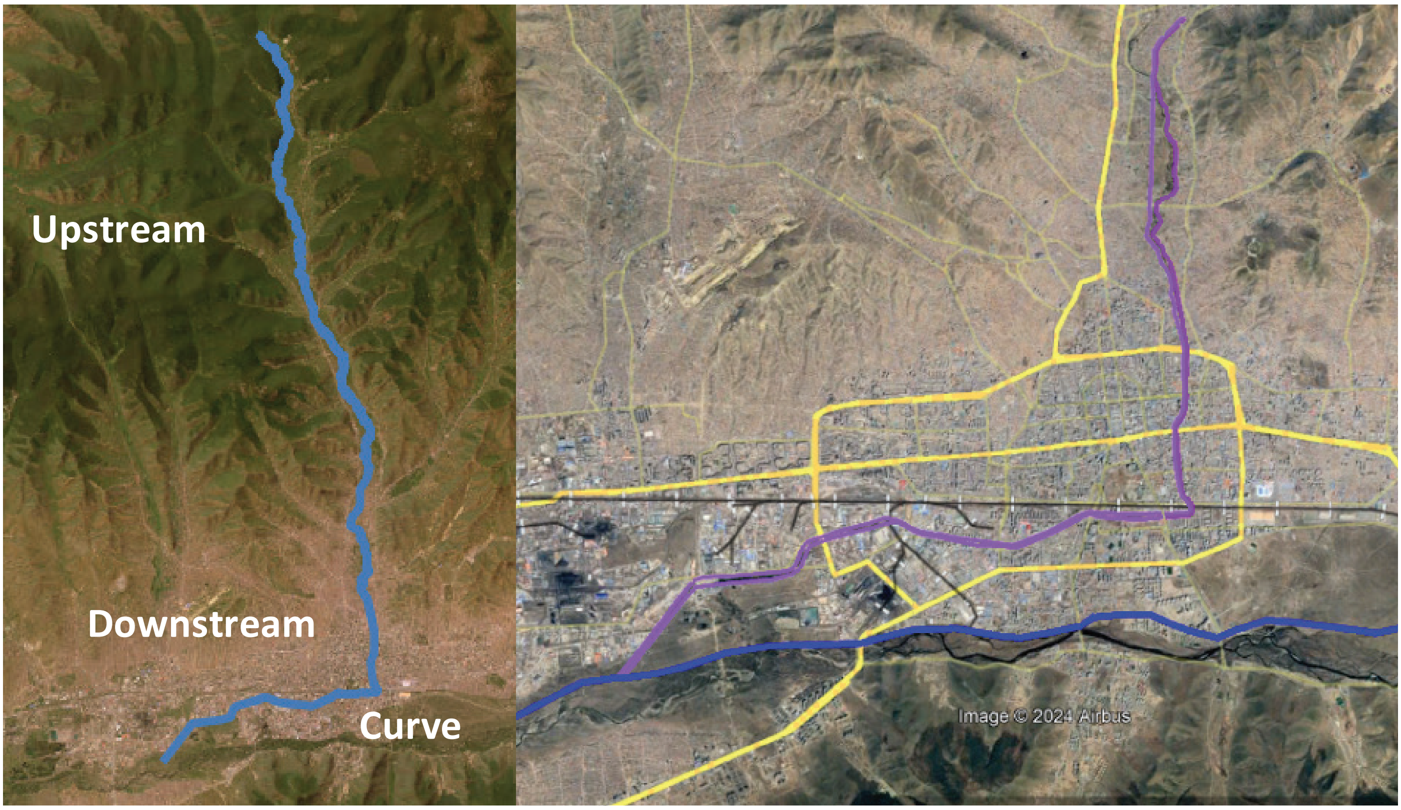


Figure 4: Map of the main river channel of the Selbe River originating in the Khentii Mountains (left). Downstream Selbe River crossing Ulaanbaatar (in purple) and ultimately draining into the Tuul River (blue) (right).

02

A REQUEST FOR SUPPORT FROM ULAANBAATAR'S GOVERNOR

2. A REQUEST FOR SUPPORT FROM ULAANBAATAR'S GOVERNOR

On July 3, July 23 and August 5, 2023, Ulaanbaatar experienced intermittent heavy rain with flash floods, riverbank overtopping and breaching of a levee in downtown Ulaanbaatar as a result. The floods resulted in four deaths and 128,000 people from 31,600 households who were directly and indirectly affected by the flooding. A total precipitation of 41 mm – half of the minimum annual rainfall – has occurred within 72 hours – leading to a peak discharge of 45 m^3/s in the Selbe River equivalent to roughly a 1 in 10 years flood situation. On July 5th flooding was further exacerbated by the collapse of the Selbe river levee, causing flooding of low-lying areas in the city center and resulted in 9.6 M USD of damage and 1.6 M USD of response cost. On August 10, 2023, the Embassy of the Kingdom of the Netherlands (EKN) in Beijing received a request from the Governor's (Mayor's) Office of Ulaanbaatar (UB) for support to the city of UB 'to take urgent actions towards significantly improving the capital city's climate resilience'. The request specified the need 'to strengthening the structure and capacity to prevent and reduce future disaster risks, develop a comprehensive disaster management system, and the ability to quickly undertake response and reconstruction measures.' In October 2023, a DRRS 'reconnaissance' visit was undertaken to Ulaanbaatar to meet with the MoUB, visit some flood affected areas and present at the MoUB - World Bank workshop on urban flood risk.

2.1 Objectives of DRRS visit to Ulaanbaatar

In the period between February 19 – 23, 2024 a delegation of experts from the Netherlands visited Ulaanbaatar as part of a partnership between the Municipality of Ulaanbaatar, Governor's Office and the Netherlands to provide Technical Assistance on Urban Flood Risk Management. The objective of the first visit under the partnership was threefold:

- Develop comprehensive system understanding by conducting field visits to obtain in-depth understanding of the local situation, promote knowledge exchange between Mongolian experts and the Dutch DRRS expert team (technical and institutional aspects of flood risk) and to confirming key flood bottlenecks in Ulaanbaatar.
- Prepare an action plan for short term "no-regret" interventions to reduce flood risk of Ulaanbaatar in the coming rainy season, and lastly,
- To identify promising concepts and strategies to support UB in transitioning to a flood resilient and attractive living environment for the medium and longer term.

A follow-up training visit was held in the period September 10-17, 2024, to assess the ongoing implementation of flood safety measures and provide capacity building for the planning, design and operation & maintenance of water related infrastructure.

Figure 5: The DRRS team held many interactions with the Municipality of Ulaanbaatar and other stakeholders at both political and technical level.

2.2 DRRS program

The Dutch Disaster Risk Reduction & Surge Support (DRRS) program is a special vehicle of the Netherlands Enterprise Agency (RVO), a partnership between the Ministry of Foreign Affairs and the Ministry of Infrastructure and Water of the Netherlands. The DRRS program offers a team of experts to support requesting countries to prevent and reduce the impact of water and climate-related disasters worldwide and increase the resilience of affected areas and populations. Support provided under the DRRS-program is fully demand driven and only offers Technical Assistance (TA).

2.3 Reader's guide

This report serves as the technical background document, outlining key recommendations derived from DRRS visits to Mongolia and addressing topics that have emerged from subsequent interactions with the MoUB. The report comprises four core chapters: Chapter 3 unravels the flood risk problem in Ulaanbaatar, Chapter 4 presents a conceptual framework for managing urban floods, and Chapter 5 offers a set of potential solutions that, together, may shape a long-term flood resilience strategy for Ulaanbaatar. Chapter 6 resembles implementation framework for recommendations presented in Chapter 7, starting with the most urgent recommendations to be implemented in the short term and the proposed implementation framework to demonstrate how to shift from measures towards implementation.

03

PROBLEM ANALYSIS

3. PROBLEM ANALYSIS

Ulaanbaatar is particularly susceptible to three types of flooding: 1) pluvial flooding due to direct rainfall and surface runoff; 2) fluvial flooding along rivers; and 3) ice-jam flooding of waterways. In 2023, after 10 or more years of relatively mild flood events, Ulaanbaatar experienced heavy rainfall upstream, causing devastating pluvial-induced flash floods in the ger areas and flooding of the Selbe River in downtown Ulaanbaatar.

This report addresses most relevant issues related to fluvial flooding, while for a more comprehensive analysis with visual interpretation, please refer to the Selbe Revival Plan (2023) prepared by Prestige Engineering.

The 2023 situation in Ulaanbaatar clearly demonstrates the strong correlation between upstream activities and downstream consequences. The relatively small and steep catchment area of Ulaanbaatar exacerbates the impact of any upstream flood triggers. High rates of erosion in the headwaters, particularly in the ger areas, lead to clogging of drains and siltation in the riverbed, resulting in both flash floods and fluvial flooding. The lack of upstream retention capacity, due to deteriorated retention ponds and encroachment on retention facilities, further worsens the downstream flood situation. Simultaneously, the capacity of downstream reaches has diminished over time due to the ongoing competition for space for road and building construction. The combination of lost retention capacity upstream and reduced flow conveyance capacity downstream highlights the precarious situation Ulaanbaatar currently faces.

This chapter assesses the mechanisms that led to the 2023 floods and uses this knowledge to guide the Municipality of Ulaanbaatar in preparing an action plan to enhance flood safety in the short, medium, and long term.

The 2023 floods were strongly influenced by several changes in the river basin over the past decade, which can be identified as the primary drivers of the 2023 floods:

1. Continuous encroachment on river floodplains in Ulaanbaatar city and upstream catchment areas.
2. Poor construction quality of hydraulic works, exacer bated by a lack of maintenance.
3. Ad-hoc planning and investments for flood safety.
4. Unplanned and uncontrolled construction on steep, sparsely vegetated hillslopes.
5. An imbalance of pervious and impervious areas in urban regions.
6. Construction of bridges and other infrastructure without sufficient under-bridge clearance and water discharge capacity

This chapter addresses most of these drivers of flooding.

3.1 Institutional context

Institutional framework for flood risk management

Effective flood prevention and stormwater management in Mongolia are grounded in constitutional rights and legal mandates. Article 16.2 of the Constitution guarantees citizens the right to live in a healthy and safe environment, while the Water Law empowers provincial or capital governors to plan and implement flood prevention measures. The proposals made by governors are confirmed through meetings with representatives of citizens, with the budget allocated accordingly.

Two government agencies are responsible for planning and operating flood protection: the Urban Development and Standard Department of the Municipality of Ulaanbaatar City and the Office of the Governor. Spatial implications of investments in flood protection infrastructure must align with the Master Plan for Ulaanbaatar, and sectoral plans are developed in accordance with urban development laws.

The design, construction, and commissioning of flood protection structures are governed by the Law on Public Procurement and the Law on Construction. These activities are typically carried out by consultant companies licensed by the Ministry of Construction and Urban Development.

In Ulaanbaatar, the Department of Geodesy and Water Construction (GUBB) is responsible for operating flood control channels, levees, and stormwater drainage systems to protect citizens from floods. GUBB's activities are determined by the Ulaanbaatar city council meeting and following operation and maintenance activities by GUBB to reduce flood risk are prescribed:

- Execute orders/resolutions/decisions on flood control and grading from MoUB;
- Monitoring and technical specifications for development of flood control and storm water system;
- Operate and maintain existing flood control, stormwater, and subsurface drainage systems, including regular cleaning, restoration, and improving the function of structures;
- Regular cleaning of flood control channels and storm drainage network activities to reduce aufeis (scientific name to refer to the specific ice overflow problem) and removing ice in ice flooded areas
- Activities related to flood risk reduction, flood mitigation, early warning, emergency response and buffer of flood zone regulation monitoring;
- Nonstructural measures to flood risk (training, public engagement, flood risk awareness, promotion of regulations etc.)

Institutional barriers to effective flood risk management in Ulaanbaatar

The uncoordinated planning of urban developments and the dominance of influential departments such as the Urban Development Department and the Transport Department in urban developments, have contributed to years of unplanned encroachment on the river and the prioritization of roads over a safe and efficient river system. The DRRS team identified some other important barriers that prevent the government from taking an effective approach to flood risk management:

1. **Flood control measures rank low in terms of governmental hierarchy, resulting in insufficient budget allocation, uncoordinated planning, and poor construction quality.** While the government typically finances the construction of engineering facilities and the improvement of living environments, covering essential utilities such as electricity, water, sewer, and district heating, flood control infrastructure often lacks the same level of investment and prioritization.
2. **The flood situation in 2023 underscores the long-term impact of years of low river discharges on public and political perceptions of the space a river requires.** This has resulted in decreased emphasis on the importance of river maintenance, weakened enforcement, and a lack of attention to surface water in urban planning. Simply put, when people do not experience flooding, there is a diminished sense of urgency to maintain and upgrade the flood protection system to the required standards and more pressure to give up land for road construction and urban developments.
3. **During the DRRS mission, it was noted that GUBB is a highly capable and responsive authority, however, due to budget constraints, the operation and maintenance of flood protection infrastructure is often insufficient.** Additionally, GUBB is frequently excluded as a stakeholder in river-related planning activities, further complicating coordinated efforts to manage and mitigate flood risks effectively.
4. **The cross-ministerial/departmental coordination in Mongolia is often lacking, resulting in deficiencies in prioritizing problems, slow decision-making, and lack of implementation capacity.** The lack of coordination between water management, land use, and urban development sectors leads to uncoordinated development in flood-prone areas and encroachment on floodplains, which subsequently cannot accommodate the required discharge to keep the city free of floods.
5. **Social engagement strategies can be improved.** Despite years of relative silence on flood issues, public interest in the environmental aspects of rivers remains strong. This was evident from the social media unrest following the 2024 river maintenance works. The incident also highlights the opportunity to strengthen public involvement in activities affecting public spaces and underscores the importance of communication as a tool to bridge the gap between government and communities.

3.2 Upstream pluvial floods

Rainfall induced flash flooding significantly disrupts the livelihoods of Ger areas in Ulaanbaatar. According to Mongolia’s Third National Communication, flash floods accounted for 24% of deaths due to natural hazards between 2004 and 2015. These floods are primarily driven by the rapid and poorly planned development of Ger areas on exposed and steep plots of land surrounding Ulaanbaatar City. Due to the steep slopes, surface runoff generates high flow velocities that cause damage to properties and erode poorly vegetated soil, bringing large amounts of loose debris into motion. Deposition of sediments in drains, retention ponds and the river channel are considered one of the biggest drivers of flooding in Ulaanbaatar.

Although flash floods occur abruptly and last for a short period, the damage induced by flash floods can be extensive. On August 5, 2023, a flash flood happened at "Gants Khudgiin am", a tributary of the Selbe River. This event is an illustrative example that was caused by inadequate drainage infrastructure and natural gully formations on the steep, bare slopes of the ger area. The resulting debris flood exacerbated the situation, as drainage channels and culverts became clogged, damaged, or blocked (Figure 6 & Figure 7). A devastating flow of water, sediment, and entrained household items and construction materials surged through the Ger district, causing further damage. Following the flood, more than 1,000 tons of sediment had to be removed from roads, drainage canals, and culverts, and there was extensive damage to personal properties. Damaging flash floods were recorded in 1982, 2003, 2008, 2009, 2011, 2012, 2015 (Janchivdorj et. al., 2017) and August 2023.
Climate change projections suggest an increase in high-intensity, short-duration rainstorm events, which will further aggravate future flash flood risks in Ulaanbaatar in the absence of adequate flood drainage infrastructure.

Figure 6: Flash flood on August 5, 2023 in the "Gants Khudgiin am" eastern watershed of the Selbe River. (Source: mpress.mn).

Figure 7: Damage remained after the occurrence of a flash flood on August 5, 2023 in the "Gants Khudgiin am" eastern watershed of the Selbe River (Source: mpress.mn).

Cause of the problem: high intensity rainfall on a steep, barely vegetated, and densely populated terrain

The occurrence of Figure 7 flash flood completely depends on rainfall intensity and its duration in Ulaanbaatar. According to a previous study by Senjim (2011), rainfall exceeding 20 mm and lasting more than 10 minutes can cause a damaging flash flood in the territory of Ulaanbaatar city. For instance, on August 3, 1982, 44.2 mm of rain occurred in 17 minutes, with a maximum intensity of 2.58 mm/minute. Following this rainfall event, heavy floods occurred in the Tolgoit, Naran and Chingeltei creeks, 87 people lost their lives, more than 80 people were rescued and 262 families were relocated. The country suffered a loss of 13.9 million MNT due to this flood event (Janchivdorj et al., 2017). On July 17, 2009, Ulaanbaatar experienced heavy rainfall during 1.5 hours, with an episode of extreme rainfall that lasted for over 20 minutes. As a result of these heavy rains, flash floods occurred in most Bayanzurkh, Songinokhairkhan, and Khan-Uul districts of the capital, causing severe damage.
Figure 8 below shows rainfall – depth – duration curves at different return periods according to the Gumbel Distribution based on past 32 years observed data measured at 3 different meteorological stations (i.e., University, Takhilt and Buyant-Ukha).

Ulaanbaatar lacks the infrastructure to effectively mitigate flash floods

The failure of retention basins in Ulaanbaatar highlights the long-term risks posed by sedimentation and improper land use. A retention basin designed to collect rainwater from 10 creeks in the Sambalkhundev mountains failed to function properly due to two decades of sediment buildup since its commissioning. As a result, during the summer of 2003, flash floods overtopped the basin's crest, leading to loss of property and lives in the downstream 3rd and 4th districts of Ulaanbaatar City (Janchivdorj et al., 2017). Over the last two decades, dirt was dumped and leveled on the west and east sides of the basin, with gas stations, houses, and roads built on this material. This scenario is typical for many retention basins and natural waterways in Ulaanbaatar, particularly after years when hydraulic works were inactive due to drought.

A significant issue with drainage capacity was highlighted during a heavy flash flood on August 5, 2023, in the Gants Khudgiin Am watershed. Despite the construction of 1.9 km of flood channels, comprising two trapezoidal and two rectangular reaches (Figure 9), the system remains inadequate for extreme events like this flood. The trapezoidal channels have a relatively large capacity of about 33 m^3/s, but the system is constrained by the Dari-Ekh main road culvert, which separates these reaches. This culvert, made up of two pairs of 1.5 m diameter pipes, has an estimated maximum capacity of 10.6 m^3/s, likely reduced further by siltation. Consequently, the culvert cannot manage floods exceeding 10.6 m^3/s, leading to overflow and its associated impacts.

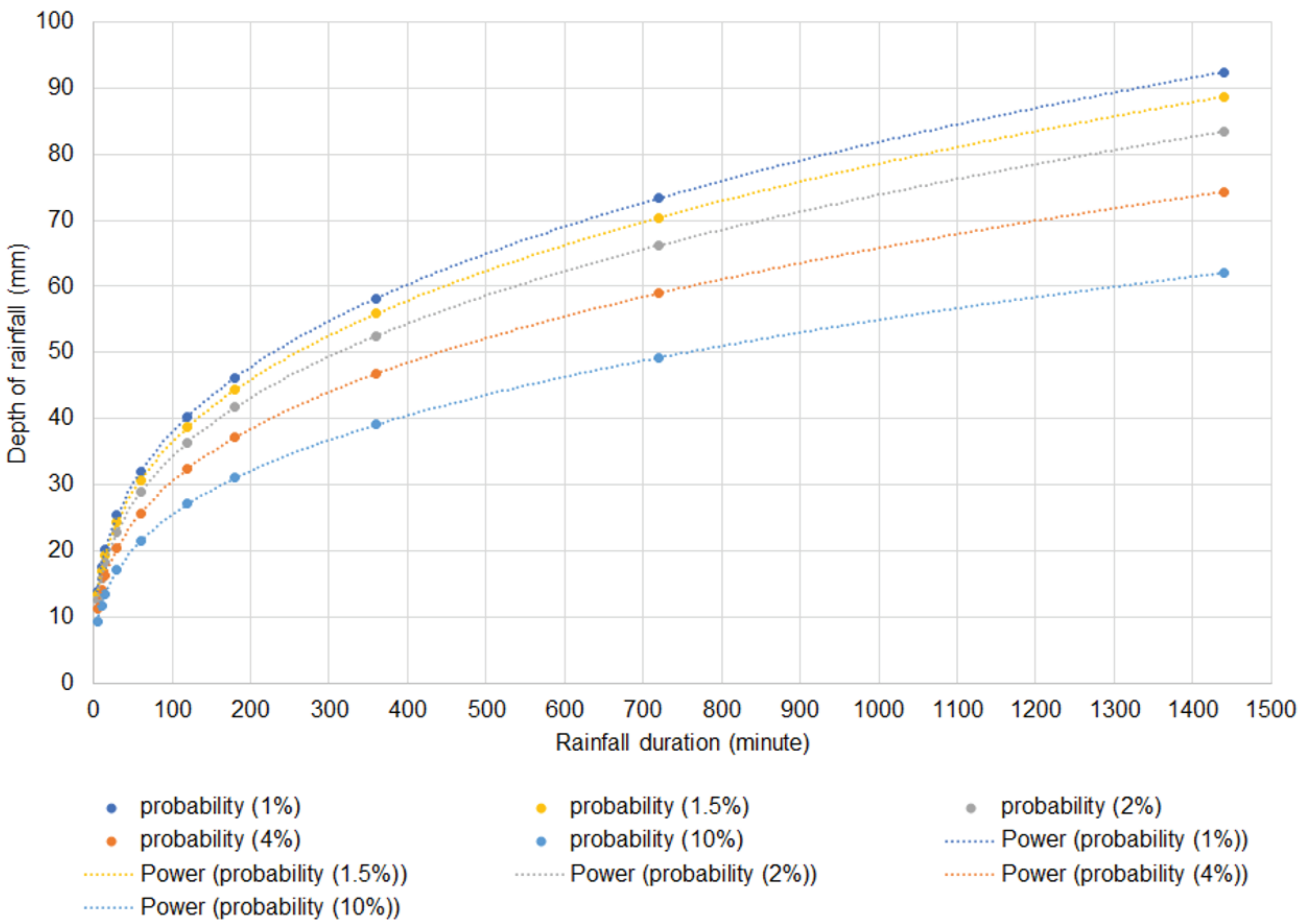


Figure 8: Rainfall depth-duration-frequency curves (Source: DRRS team)

Table 2: Rainfall depth-duration-frequency and intensity in UB according to the Gumbel Distribution based on past 32 years observed data measured at 3 different meteorological stations located in UB.

Freguence, yr	**10**		**25**		**50**		**75**		**100**	
Return period, %	10		4		2		1.5		1	
period	MP, mm	Int, mm/hr	MP,mm	Int, mm/hr	MP,mm	Int, mm/hr	MP,mm	Int, mm/hr	MP,mm	Int, mm/hr
5 minutes	9.4	112.8	11.2	135.0	12.6	151.6	13.4	161.2	14.0	168.0
10 minutes	11.8	71.4	14.2	85.0	15.9	95.5	16.9	101.5	17.6	105.8
15 minutes	13.6	54.2	16.2	64.9	18.2	72.9	19.4	77.5	20.2	80.8
30 minutes	17.1	34.1	20.4	40.9	22.9	45.9	24.4	48.8	25.4	50.9
1 hour	21.5	21.5	25.8	25.8	28.9	28.9	30.7	30.7	32.0	32.0
2 hours	27.1	13.6	32.5	16.2	36.4	18.2	38.7	19.4	40.4	20.2
3 hours	31.0	10.3	37.2	12.4	41.7	13.9	44.3	14.9	46.2	15.4
6 hours	39.1	6.5	46.8	7.8	52.5	8.8	55.9	9.3	58.2	9.7
12 hours	49.3	4.1	59.0	4.9	66.2	5.5	70.4	5.9	73.4	6.1
1 day	62.1	2.6	74.3	3.1	83.4	3.5	88.7	3.7	92.4	3.8

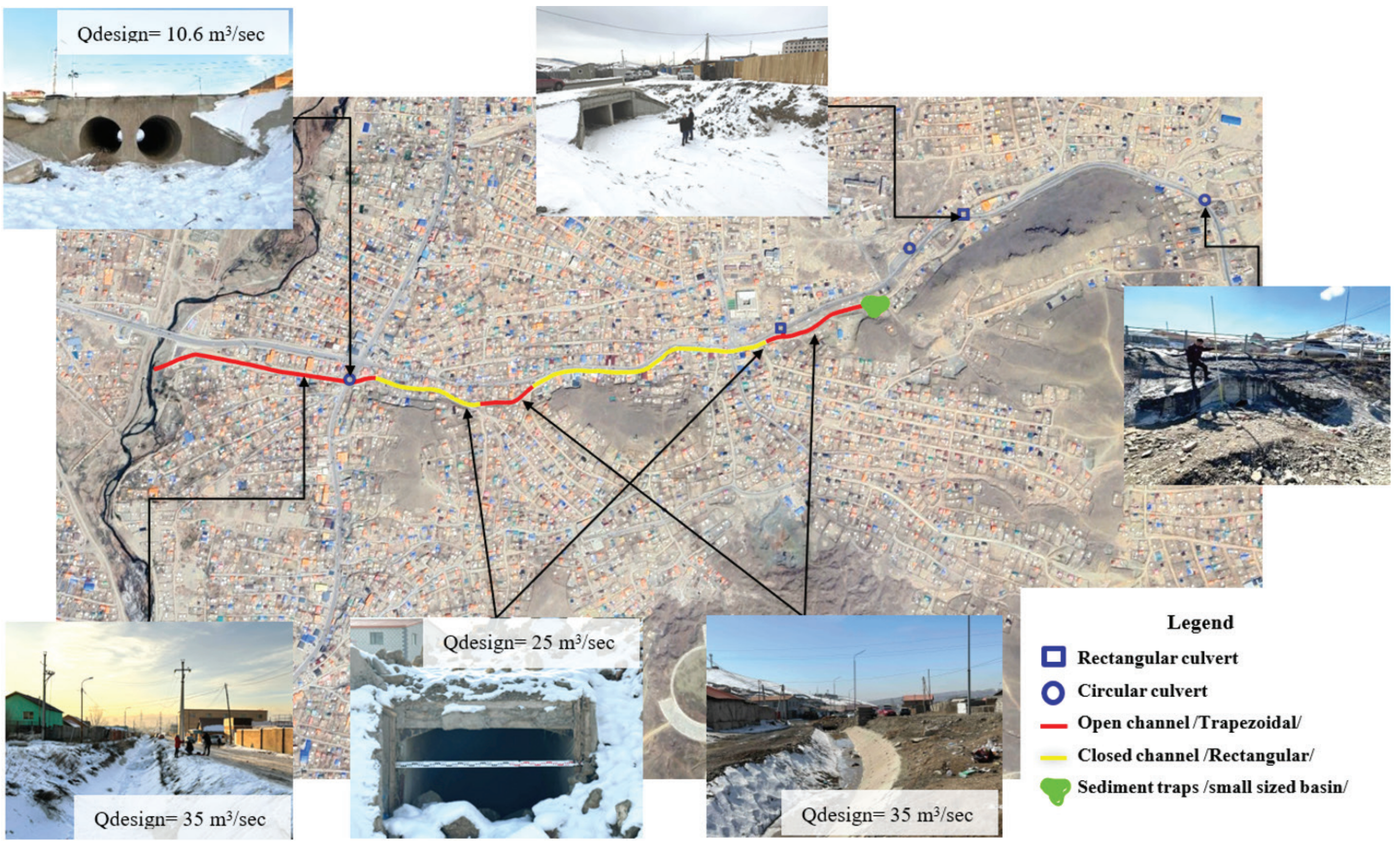


Figure 9: Channels and culverts in the Gants Khudgiin Am watershed – a Selbe River tributary. (Source: IGG, MAS)

3.3 Flooding of the Selbe River

Uncontrolled river floodplain encroachment is considered one of the biggest drivers of flood risk in Ulaanbaatar. Urban planning and growth that were not based on good understanding of flood risks has been a major challenge for Ulaanbaatar. By law, all Mongolian citizens can claim 700 square meters of land for residential use in and around Ulaanbaatar. This has led to tremendous spatial expansion of ger areas into hazardous mountain slopes and flood plains. These areas, often home to lower-income migrants, are largely unplanned and lack basic services and infrastructure, making them more vulnerable to the impacts of flooding (World Bank, 2015) .

Narangerel and Suzuki (2024) identified several flood hazard areas along the Tolgoit, Selbe, Uliastai, and Tuul River valleys. Within the 200-meter buffer zone, they identified 27,970 fences and 12,887 buildings, representing 66.5% of all fence unit areas and 46.3% of all buildings situated within the identified flood risk areas.

Analysing the problem

After a period of relatively low peak discharges in rivers around Ulaanbaatar, in 2023 the Selbe river peaked at discharges up to 45 m³/s at Damba Bridge after a period of intermittent heavy rains. The total precipitation of 41 mm—half of the minimum annual rainfall—occurred within 72 hours. This event led to heavy flooding of the downstream areas where river cross-sections are smallest and hence discharge capacity was most constrained. At the same time, temporary levees were built but appeared of insufficient quality to withstand the flood.

The discharge-frequency curve for the Selbe River highlights the challenges in estimating flood risks. Using data from the Selbe Revival Project (Figure 10 (after Ganzorig, 2023) and Textbox 1), the curve indicates that a discharge of 45 m³/s corresponds to a return period of roughly 1 in 4 years. However, the return periods and discharges in this graph are based on empirical formulas, without considering flow routing, making it unreliable for high-frequency events. Despite its limitations, the graph provides an approximate indication of discharge and return period. Currently, no other reliable return period-discharge graph exists for the Selbe River. The most constrained section of the river, near Narnii bridge (S-Outlet), has an estimated discharge capacity of only ~15 m³/s, explaining the extensive flooding that occurred in 2023.

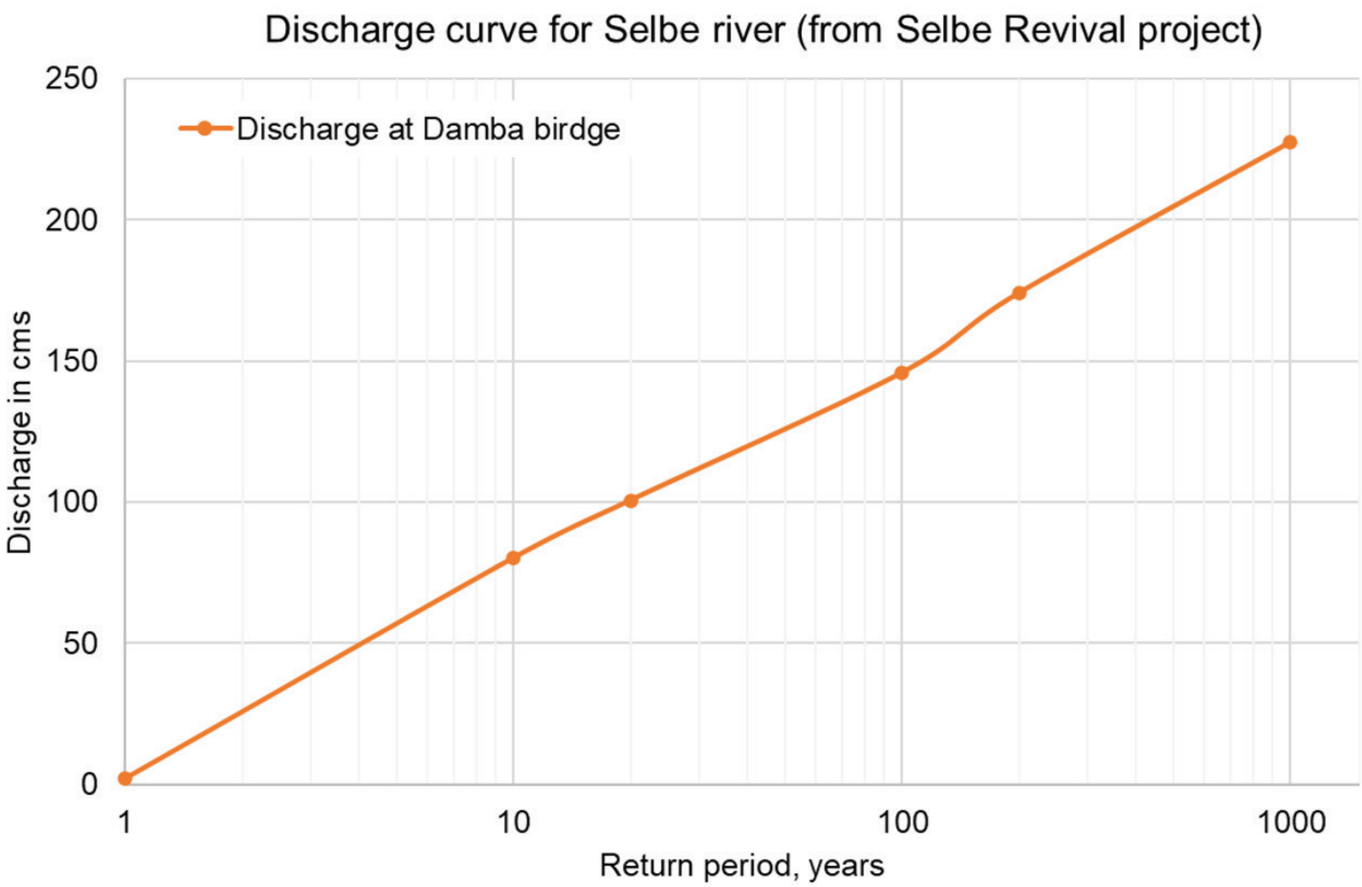


Figure 10: Selbe River flood frequency curve (return periods) (Source: Selbe Revival project, 2023). The more recent World Bank project (2024) shows higher discharges (180 m³/s for T100). (Source: Selbe River Revival Project)

[5] *https://blogs.worldbank.org/en/eastasiapacific/flood-risk-in-dry-ulaan-baatar-of-mongolia*

Textbox 1: Basic principes of the Selbe Revival Plan

In the spring of 2023, the Mongolian government initiated the "Selbe Revival" project to address several urban challenges in Ulaanbaatar, including traffic congestion, public recreation, and flood control. The project has three main components: road network development, a recreation and landscaping plan, and flood control.
The Urban Planning and Research Institute is the general contractor responsible for the project's feasibility study and detailed design, with Prestige Engineering serving as the subcontractor for the flood control component. Key features of the project include:

- Expansion and renovation of a 21.6 km long flood control levee wall along the Selbe and Dund Rivers.
- Construction of a new 15.3 km road, 12 bridges, 4 overpasses, 7 underpasses, 21.6 km of pedestrian and bicycle paths, and a dedicated public transportation road with stops.

The primary goal of the flood control design is to safely accommodate a flood with a 100-year return period in the Selbe River without posing a flood risk. The solution includes a 37.63 km concrete levee (reinforced cantilever wall) for the urban section of the river and a 3.94 km embankment levee for the lower reach of the Selbe River in combination with excavation of the river up to 7 meter in depth. Additionally, retention ponds with a total capacity of 1.3 million cubic meters are planned in the middle part of the catchment.

The flood control structures of the Selbe Revival project are estimated to cost 586 billion MNT (160 million EUR).

Although some elements of the Selbe Revival Project were considered necessary to immediately increase the cities' flood safety level, other design elements are considered a lost opportunity. In a letter to the city Governor on 5 June 2024, the DRRS team has expressed concerns regarding the implementation of the Selbe Revival project in its current form. The DRRS team believes that a more sustainable design for upgrading the Selbe River could yield a broader range of benefits at lower investment costs. To achieve this, an integrated basin-wide planning approach is necessary to find the optimal balance between investments in the upper basin and interventions that create more room for the Selbe River to accommodate flood water (see next chapter), along with necessary governance and institutional improvements to bring water back at the heart of climate resilient urban planning and development.

Figure 11: (left) construction works to the flood wall are ongoing in September 2024 (location left bank upstream of S-Outlet), (right) channel excavation works have enlarged the flow capacity of the channel downstream of S-Outlet. (Source: Photo by DRRS team)

Bankfull discharge versus design discharge

The maximum capacity of a river—or a section of the river—is often referred to as the bankfull discharge (Q_{bf}). The bankfull discharge is the flow that can be accommodated without overflowing the riverbanks. Although the term generally applies to the channel capacity of natural river systems, it is well applicable in the context of this report. The Selbe River is heavily regulated, especially in the downstream reach, resulting in each river section having its unique cross-sectional profile with an associated bankfull capacity (Q_{bf}). The river section with the lowest Q_{bf} determines the critical discharge that initiates flooding.

In the context of the Selbe Revival Plan, the T100 (100 years return period of discharge) is referred to as the design discharge, based on the assumption that the river must be able to accommodate this discharge without overflowing its bank. By Mongolian Law rivers must accommodate a discharge capacity with a T100 return period. According to Figure 4, which comes from the Selbe Revival Plan, the T100 for the Selbe would be roughly 145 m^3/s. A more recent World Bank project estimates 180 m^3/s as T100 for a location slightly further downstream, which is four times more than the 2023 situation. Both the T100 discharge in the World Bank study and the Selbe Revival Plan do not fit in the current river profile and will lead to extensive flooding without taking drastic measures to enlarge the rivers' flow capacity of most constrained river sections (near S-Outlet) ($Q_{des} \neq Q_{bf}$).

Figure 12 below shows assumed T100 discharge values from several studies over the past years, ranging from policy documents to planning and design of hydraulic works. The discharge values show a wide range, and the basis of these values is largely unknown.

The use of the term design discharge varies between policy (or planning) and engineering design, and its application can be very different. In policy, the term "design discharge" is often referred to the target flood safety level of a river or embankment section. When used as a design condition in hydraulic works, a design discharge sets the minimum standards for the civil works to withstand specific hydraulic conditions or hydraulic load, which is basically a geotechnical requirement. In other words, a flood levee/embankment with a design discharge of 180 m^3/s should be constructed in a way that its height and geotechnical stability is sufficient to withstand a discharge of 180 m^3/s locally.

For a small and quickly responding catchment such as the Selbe River or Tolgoit River in Ulaanbaatar, the terms Q_{bf} and Q_{des} do not fully encompass the complexity of catchment hydrology. The upstream catchment characteristics largely determine the shape and magnitude of the hydrograph observed in the downstream part of the river, and. In other words, the shape and magnitude of a theoretical T100 event depend significantly on upstream conditions, where small changes in for instance the amount of impermeable area will have a direct impact on the shape of the incoming hydrograph downstream.

A more accurate approach would be to use the term Flood Safety level, which incorporates the local channel capacity, geotechnical stability of levees as well as the performance of the upstream catchment in retaining floodwater. This approach stresses the need for interventions throughout the basin, including upstream retention and storage measures, as well as downstream enhancements to river capacity and protection of inhabited areas from flooding. This approach would distribute responsibility across various aspects of flood management, which is crucial given the constrained situation in Ulaanbaatar with regards to its river capacity.

Why is the current 'bankfull discharge' capacity lower than the 'design discharge'?
Looking at the consequences of the 2023 floods, the question can be asked whether the urban part of the river has ever been able to accommodate a 100-year river discharge since the construction of its embankments.

While the 2023 floods may not be classified as 'extreme' based solely on river discharge and discharge peak statistics, the vast extent at which flooding occurred in the downtown area of Ulaanbaatar raises questions about other potential contributing factors to the severity of the flooding, in particular in the light of the large difference between the actual discharge capacity of the river and the design discharge mentioned in the Selbe Revival Plan.

The key developments that have reduced the discharge capacity of the Selbe River include:

- **Constrained river width:** The Selbe – and many more rivers and waterways – has experienced continuous encroachment by buildings and roads over time leading to serious reduction of the flow conveyance capacity of the river in downtown Ulaanbaatar. Historically, the river was

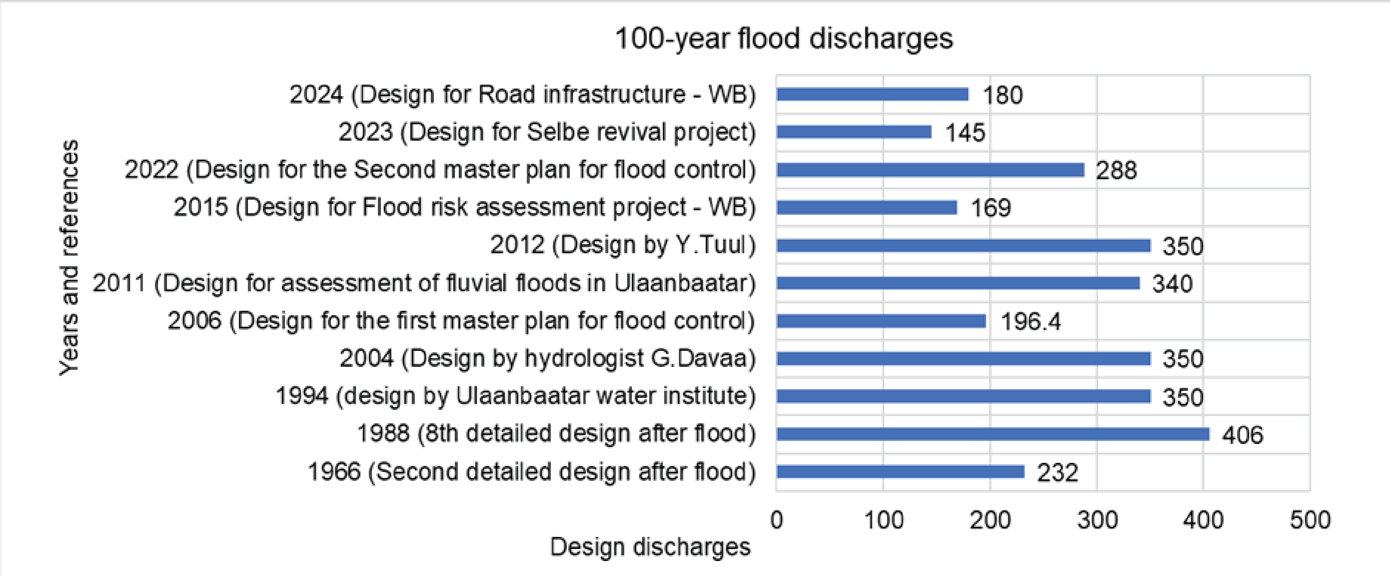


Figure 12: 100-year return period discharges for Selbe river by different sources (Source: DRRS team)

wider and had floodplains. Older satellite images show the Selbe with a width, including floodplains, of over 100 meters. Nowadays, the Selbe is only about 20 meters wide at some locations.

- **Vegetation and siltation:** Siltation and vegetation in the riverbed increase hydraulic roughness, reducing flow velocities and causing a backwater effect that raises water levels. In natural rivers, vegetation and siltation are mitigated by sufficient channel width. However, the extreme narrowing of the Selbe River channel in Ulaanbaatar leaves no room to offset these effects, exacerbating flow issues.
- **Obstructive Structures:** Several bridges and heating pipes cross the Selbe River at low elevations, creating highly constrained under bridge clearances. These structures obstruct the free flow of water, further diminishing the river's flow capacity and leading to a backwater effect.
- **Reduced upstream Storage Capacity:** Encroachment on reservoirs and upstream natural floodplains, sedimentation of reservoirs, and changes in land use (with natural areas storing more water than paved areas) have likely reduced the basin's storage capacity over time. This reduction leads to a faster response to rainfall, increasing the peak discharge for the same return period of precipitation.

Figure 13: Ice accumulation in the Selbe River in February 2024 (top), ice excavation activities in the upper Selbe River to intercept surface runoff (bottom). (Source: Photo by DRRS team)

3.4 'Aufeis': Ice Overflow flooding

The unique winter climate conditions in Ulaanbaatar lead to a distinct natural phenomenon known as "Aufeis," where groundwater seepage freezes on the surface of an already frozen river and may lead to flooding when overtopping embankments. The DRRS support primarily focuses on pluvial and fluvial flood risk; however, during the February 2024 work visit, the team observed the Aufeis situation and heavy maintenance work by GUBB to prevent flooding due to ice overflow. Although the DRRS team did not have the specialized expertise to fully address this issue, they concluded that implementing technical solutions to enhance the river's discharge capacity could simultaneously mitigate the ice overflow problem. Ultimately, these recommendations aim to improve flood resilience in Ulaanbaatar.

Aufeis is the natural phenomenon of the freezing of sub-surface water (ground water) after its exposure to the extreme winter temperatures. Seepage of ground water in Ulaanbaatar's rivers and streams is a natural process. As most of the river is frozen, water is seeping up through cracks in the ice, causing sheets of water to build layers of ice when it freezes. Outflow from drainage pipes into the main rivers, e.g. Selbe river, further worsens the situation. The rate of ice accumulation varies along different stretches of the river, averaging 2 cm per day, which quickly increases the thickness of the ice layer (see Figure 13). During the visit, we observed a section of the Selbe River where the top of the ice layer had reached the levee/embankment crest level, posing an immediate risk of ice overflow flooding.

The 'Aufeis' phenomenon usually starts in late October and early November and reaches its peak between December and February. Melting starts from the end of April and lasts till the beginning of June. In recent years, urban developments have shifted to areas vulnerable to ice overflowing. With the continuous narrowing of the river, the ice overflow problem has become more critical and almost impossible to fully control given the complexity with excavation of ice. Widening the river in combination of drainage enhancing interventions to redirect groundwater flow before it freezes, following the work done by the Institute of Geography and Geoecology, Mongolian Academy of Sciences, would offer some relief.

3.5 Erosion and Sediment Management

Erosion is a significant problem in and around Ulaanbaatar. The geological formations in this area are composed of claystone, which easily breaks down into smaller fractions. The steep and largely unvegetated slopes of the surrounding hills are prone to erosion, especially during rain. Human activities, such as excavations for building construction and the placement of gers, exacerbate the situation by leaving behind steep, unprotected slopes that are prone to slumping or sliding. The sediment from these slopes is transported to areas where surface runoff concentrates, often ending up in drainage facilities. Here, it mixes with construction debris and household waste, clogging drainage canals and culverts (see Figure 14) and ultimately entering the Selbe River.

The average diameter of the riverbed sediment (D50) along the river ranges from 30 mm upstream to 2.0 mm downstream. The grain size of the bed sediment is positively correlated with the longitudinal slope of the river. The slope decreases from i=0.007 at the Dambadarjaa bridge to i=0.001 at the Tuul River discharge. The reaches with the lowest slope, about i=0.00057-0.0006, are found below the "turning point - S-Outlet" of the Selbe River. Upstream, near the Dambadarjaa bridge, relatively large-grained sand and gravel dominate, while sand and clay prevail below the "turning point."

In the part of the river floodplain, sand and clay soils with plant roots are developed, with a thickness of 0.3 to 0.6 m. It is relatively thicker in the area downstream of the "turning point" of the Selbe river (near S-outlet building), where the slope is relatively smaller than upstream.

According to the engineering-geological study carried out by the "Soil Trade" LLC (2013; 2023), brown-browny, dark-gray colored, household and construction waste, man-made technogenic deposits (tQ2), septic deposition filled with sand have been accumulated along the Selbe River. Notably, there is this kind of technogenic deposition about 0.8 m thick near the "100 ail" bridge and 1.7 m thick near the "Nature" bridge. The sediment deposition layer formed after many years of accumulation. As per today, February 2025, GUBB has completed the excavation of vast amounts of sediments in the Selbe River around S-Outlet, which greatly enlarged the discharge capacity.

The existing flood facilities in Ulaanbaatar are poorly operated, serviced, and repaired. For instance, there is a retention basin to collect rainwater from 10 creeks in the Sambalkhundev mountains / mountain range. This retention basin could not fulfill its function to temporarily store water due to two decades of filling with sediment (2.5-3.5 m deposition) since the basin commissioned. In the last two decades, dirt was dumped and leveled on the west and east sides of the basin, and gas stations, houses, and roads were built. However, more waste and dirt have been dumped inside the basin in 2023 and 2024 (Figure 26). Another example, a heavy flash flood occurred on 5, August 2023 in the "Gants Khudgiin Am" watershed. Flood facilities are still unable to operate at full capacity due to the sediment deposition in this watershed. Some small channels along the main road of the "Gants Khudgiin Am" have been filled with sediment and construction water materials (Figure 14). Based on these facts, an accumulation of sediment is one of the reasons that the flood facilities and retention basins are unable to operate their full capacity.

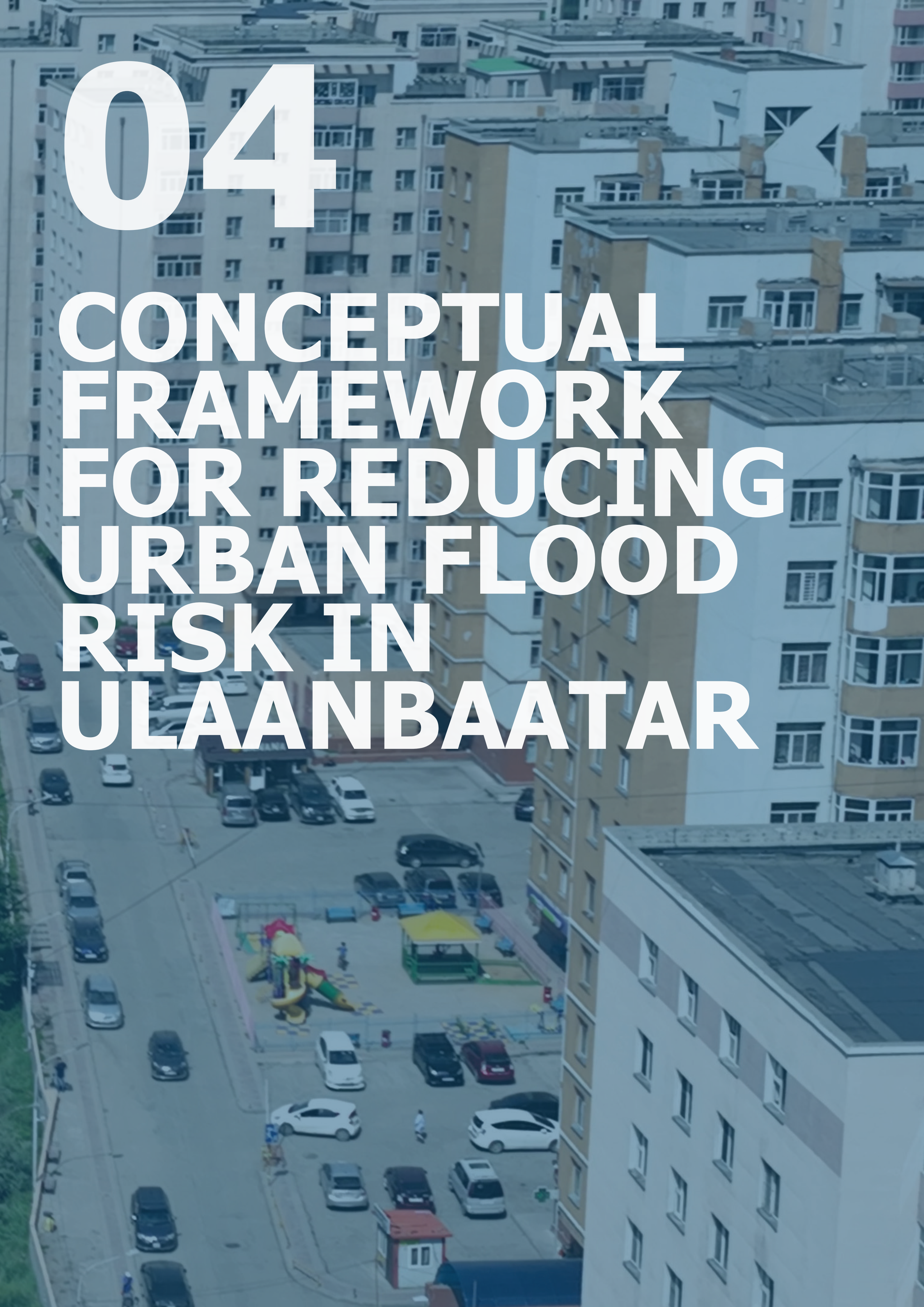
Figure 14a: Flood drainage facilities - A culvert trapped by sediment in "Gants Khudgiin Am" catchment (Source: Photo by IGG, MAS)

Figure 14b: *Flood drainage facilities (culvert and channel) in "Gants Khudgiin Am" watershed (Source: photo by Chinzorig, IGG, MAS)*

Example of drainage channel along the ger district (Source: Photo by DRRS team)

04

CONCEPTUAL FRAMEWORK FOR REDUCING URBAN FLOOD RISK IN ULAANBAATAR



4. CONCEPTUAL FRAMEWORK FOR REDUCING URBAN FLOOD RISK IN ULAANBAATAR

The aim of the DRRS support to the Municipality of Ulaanbaatar is to provide an expert's opinion on the root causes of the 2023 flood situation in Ulaanbaatar and to offer a strategic framework for the analysis of most suitable options to enhance urban flood resilience going forward. Within the context of our efforts to formulate recommendations and preparing a roadmap to enhancing flood resilience in the city, the DRRS team was also requested to undertake a review of the Selbe Revival Plan. This plan has been developed in response to the large scale floodings that happened in 2023 and UB's ambition to reduce traffic congestion. This chapter will present the findings of the analysis and presents an action plan with short- medium and long-term options to enhance flood resilience in Ulaanbaatar.

4.1 Methodology

This chapter focusses on formulating a Conceptual Framework, an approach that provides the basis for decision making by MoUB around the planning of investments required in and along the Selbe River in Ulaanbaatar to reduce flood risk and enhance flood resilience, while offering co-benefits in terms of improved quality of live. The DRRS team acknowledges the complexity of Ulaanbaatar's river and water management system within a harsh climate and under strong spatial limitations in a densely populated city. The DRRS team has a small mandate, and within the available time and financial resources, it is difficult to find one single solution that would serve all needs and solve the current problems. Hence, it is chosen to offer an approach that would guide MoUB in making informed decisions of investment options with most added value in terms of financial viability, technical performance as well as social and environmental sustainability, for the immediate and distant future. This approach is what is referred to as the Integrated Planning Approach.

An **integrated planning approach** refers to a comprehensive and coordinated (urban) planning that considers multiple factors, sectors, and stakeholders to achieve sustainable and balanced development, whether at a river scale or at city scale. This approach integrates social, economic, environmental, and institutional dimensions, ensuring that all relevant aspects and interdependencies are taken into account. Key characteristics of an integrated planning approach include:

1. **Integrated Perspective:** Considers the interconnectedness of different sectors such as transportation, housing, land use, environmental protection, and economic development at river basin scale.
2. **Stakeholder Involvement:** Engages a wide range of stakeholders, including government agencies, private sector, non-governmental organizations, and the community, to ensure that diverse perspectives and needs are addressed.
3. **Sustainability Focus:** Aims for sustainable development that balances economic growth, social well-being, and environmental protection.
4. **Long-Term Vision:** Plans with a long-term perspective, anticipating future challenges and opportunities, rather than focusing solely on immediate needs.
5. **Adaptive Management:** Incorporates flexibility to adapt to changing circumstances and new information, allowing for iterative learning and improvement. This applies for instance to Climate Change as a large uncertainty in city planning.
6. **Evidence-Based Decision Making:** Utilizes data, research, and best practices to inform planning decisions, ensuring that they are based on sound evidence.
7. **Policy Integration:** Aligns policies and regulations across different levels of government and sectors to ensure coherence and avoid conflicting objectives.
8. **Multi-Functional in space and time:** Ensures that spaces and systems serve multiple purposes, maximizing their utility and efficiency, particularly in densely built environments such as Ulaanbaatar. For example, a floodplain can provide recreational opportunities in the dry season and has environmental benefits at the same time. Levees can serve both flood protection and form the foundation for a road or parking space.
9. **Options Analysis:** Facilitates decision-making by comparing different strategic planning options, allowing planners to evaluate potential outcomes and select the most effective and beneficial course of action

By adopting an integrated planning approach, MoUB can create a more resilient, efficient, and equitable river system for the Selbe River that addresses complex issues in a coordinated and comprehensive manner. A similar approach applies to other UB river basins, such as the Tolgoit River and Uliastai River or even the Tuul River Basin.

4.2 Geographical classification

Ulaanbaatar has a distinctive geographical profile characterized by its rugged and largely barren landscape, necessitating a tailored approach to flood risk management. To provide concrete guidance to the Municipality of Ulaanbaatar (MoUB) in applying an Integrated Planning Approach to address the flood risk situation in Ulaanbaatar, this chapter begins with a classification of the city based on geographical characterization. The flood management-related characteristics of the city can be best categorized into four distinct geographical zones (Figure 15):

1. The Upper Hill Area. This zone encompasses undeveloped land predominantly located at higher elevations surrounding Ulaanbaatar. Rainwater naturally flows through gullies in this area, contributing a significant share of the water that flows through the inner city. Due to limited vegetation, the region is highly susceptible to erosion and serves as a major source of sediment.
2. The Upper Ger Area. Extending from the Upper Hill Area, this densely populated zone lacks adequate drainage infrastructure. Gullies often transform into unpaved or occasionally paved roads that turn into torrents during heavy rainstorms, making the area vulnerable to flash floods.
3. The Lower Ger Area. Situated in the valley's lower reaches, this area exhibits more developed water management infrastructure. Roads are typically paved, and some main roads feature stormwater drains and sediment-trapping or water retention ponds. Canalized drains serve as waterways. Despite these improvements, the Lower Ger Area remains highly sensitive to flash floods due to its steep hills and often poorly defin ed water management systems.
4. The River in the City Area. Characterized by a defined river planform with floodplains, the Selbe River is a good example of this zone. As the river approaches Ulaanbaatar's main urban center, its planform becomes increasingly regulated and confined, with levees becoming more prominent. Water management issues in this area are more of a fluvial nature, such as riverbank overtopping, breaching of levees, and channel migration and sedimentation.

This classification enables the identification of a set of customized solutions for each zone.

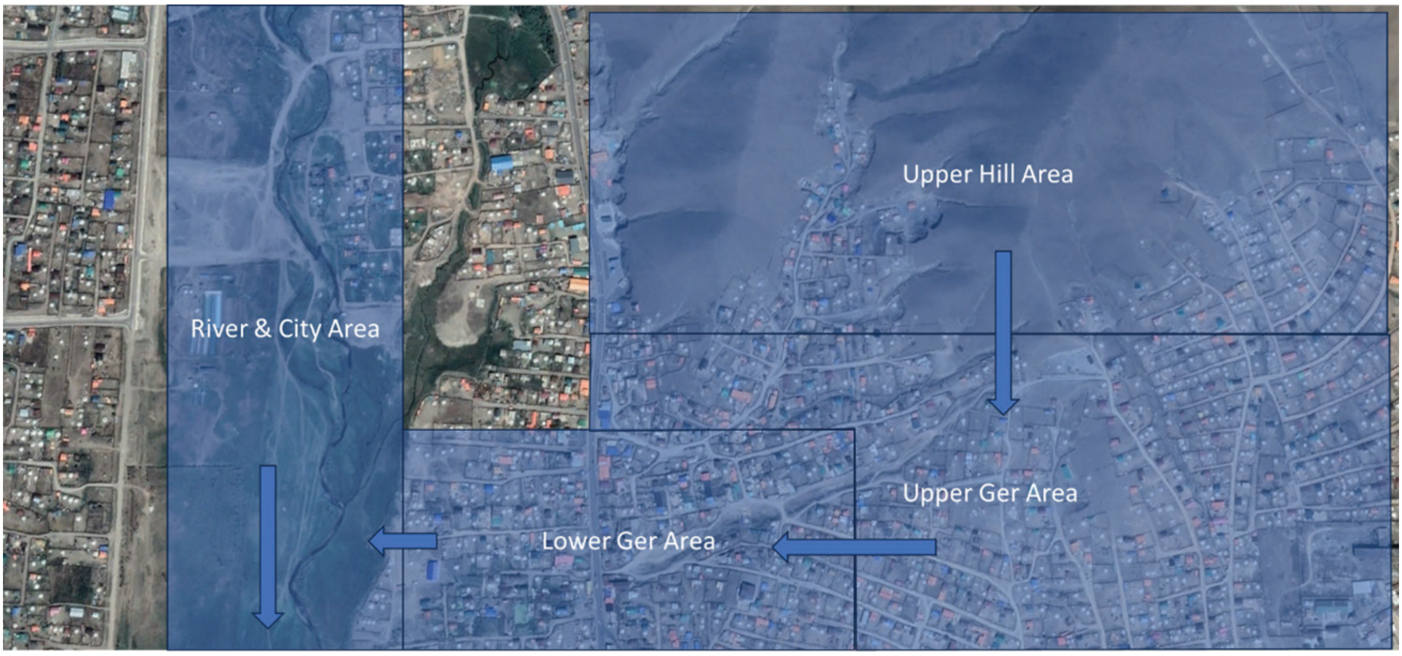


Figure 15: Classification of the city of Ulaanbaatar based on geographic and urban characteristics. (Source: DRRS team)

A view of Ger area transition to the city and river area (Source: Photo by GUBB)

4.3 Retain, Store and Drain

To successfully manage the flood situation in Ulaanbaatar City requires adopting an Integrated River Basin Management Approach. "Retain-Store-Drain" is a concept used in river basin management and urban planning to manage the planning of stormwater drainage infrastructure and mitigate flood risks on a basin scale. This concept focuses on managing water in three subsequent stages:

1. **Retain:** Capturing and holding rainwater where it falls to reduce runoff. Apart from the natural infiltration capacity of a forest cover, this can be further promoted using permeable surfaces, green roofs, and retention basins in built-up environments to slow down water flow and promote infiltration into the ground. "Retain" facilities largely focus on the upper part of the river catchment to reduce peak flows downstream.

2. **Store:** Further reduction of downstream runoff can be achieved by collecting excess water in designated areas to prevent it from overwhelming downstream located drainage systems. This includes the use of detention ponds, rain gardens, and underground storage tanks to temporarily hold water during peak rainfall events.

3. **Drain:** In areas where no more space is available to hold rainwater or river water, water management facilities will focus on efficiently directing excess water to appropriate outflows. This may involve discharging stormwater drains into rivers with sufficient capacity or optimizing the conveyance capacity of urban rivers to safely transport water away from populated areas where it may pose a flood hazard.

By integrating the geographical classification with the "retain-store-drain" conceptual framework, we can create a well-defined approach to identify the most suitable interventions for reducing urban flood risk in Ulaanbaatar. Table 3 provides a comprehensive overview of how various flood and water management principles align with specific geographical areas in Ulaanbaatar and how they fulfill components of the "retain-store-drain" concept. The selection and design of specific measures requires a more comprehensive planning process. This report already fast-tracks some of the design options per geographical area to demonstrate possible results of the planning approach.

The "retain-store-drain" principle is highly applicable across the Selbe catchment and other catchments in and around Ulaanbaatar. In the upper hill and upper Ger areas, implementing small-scale retention measures and enhancing vegetation growth can mitigate immediate runoff. In the Ger areas, creating large retention basins or expanding natural flood plains enhances storage capacity, leading to upstream flood attenuation. Conversely, in the lower city area where space for large-scale storage is limited, enhancing drainage capacity by removing obstacles and channel dredging facilitates efficient water flow toward the main Tuul River, thereby minimizing flood risks. Figure 16 visualizes the concepts that are presented.

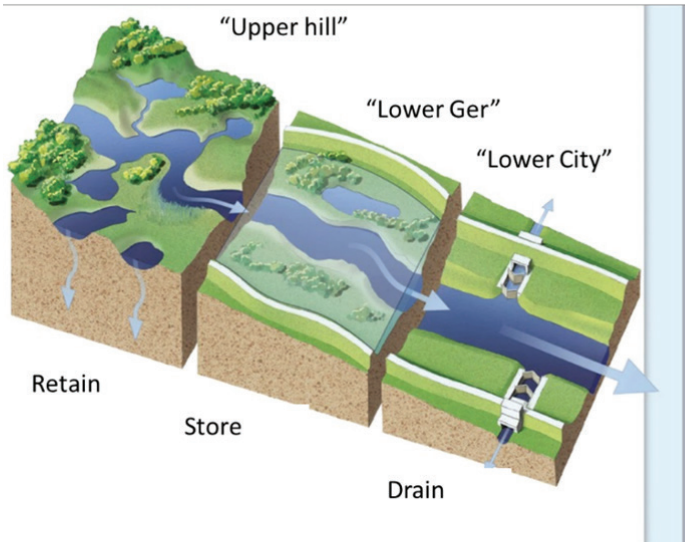


Figure 16: Dutch principle of retain, storage, drain, placed in the context of Ulaanbaatar

Table 3: Planning framework for identification of flood risk reduction interventions in Ulaanbaatar

Geographical Classification	Design principle	Possible interventions
Upper Hill Area	Retain	Implement measures such as reforestation and soil conservation to retain rainwater and reduce erosion. Use terracing and check dams to slow down water flow and promote infiltration through a healthy vegetation cover
Upper Ger Area	Retain	Enhance green spaces and permeable surfaces to retain rainwater at the source
	Store	Install rain gardens, retention basins, and small-scale retention ponds to temporarily store excess water (and locally derived sediment) from heavy rainfall events.
	Drain	Develop a network of effective drainage channels and culverts to manage overland flow and direct water away from residential areas
Lower Ger Area	Retain	Improve green infrastructure to increase water retention within the urban landscape as much as possible in the limited space that is available
	Store	Utilize larger retention ponds, sediment traps, and water retention features along main roads and open spaces to store runoff
	Drain	Enhance the capacity of stormwater drains, smaller canals and the main rivers to improve water conveyance and prevent blockages
River in the City Area	Store	Use floodplains, designated storage areas and restored existing storage basins (large and small) to temporarily store excess water during peak flow events
	Drain	Maintain and upgrade levees, enhance the river channel discharge capacity, and ensure efficient drainage into the downstream river system to manage fluvial flooding risks

4.4 Room for the River

The success of the Room for the River concept has set a new global standard for sustainable flood risk management. Originating after near-flood events in the Netherlands in 1993 and 1995, the program recognized that continually raising dikes was not a sustainable solution, especially with anticipated climate change intensifying peak river discharges. Areas previously encroached upon for urban and agricultural development across the Netherlands needed strategic restoration to return space to the river.

River restoration efforts not only aimed at increasing flood safety by increased flow capacity but also strengthened other functions, providing additional benefits such as economic opportunities, improved living environments, recreational options, and biodiversity. The Dutch government initiated the Room for the River program in 2007, comprising 39 projects, most of which were completed by the end of 2018, totaling 2.3 billion euros in cost. Interventions varied by location and included:

- Relocating dikes/levees to restore natural floodplains.
- Lowering floodplains to increase temporary water storage capacity.
- Creating flood bypasses (e.g., green or blue river corridors) to divert excess flow.
- Removing obstacles in floodplains and river channels, such as cross-dams, vegetation, and groynes, to improve water flow efficiency

How Room for the River helped to reinvent spatial planning

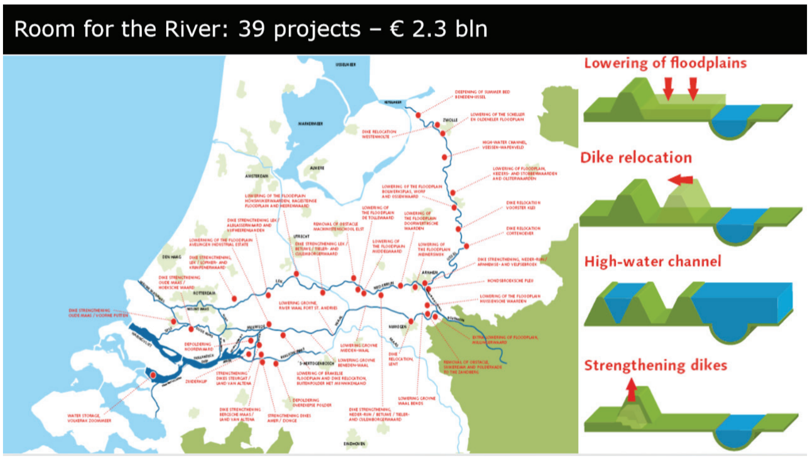
The Netherlands Room for the River concept is not merely an engineering solution but a comprehensive planning framework that integrates hydrological, ecological, socio-economic, and spatial planning considerations. The Room for the River concept is often simplified as an approach that assumes additional space for rivers to accommodate floodwater during extreme events, but there is more.

Beyond its physical interventions, the Room for the River approach is grounded in a sophisticated legal and regulatory framework, ensuring that flood risk management is aligned with long-term land-use planning, environmental conservation, and stakeholder engagement. It involves a multi-level governance structure, where national policies, regional planning, and local implementation are coordinated to balance flood resilience, economic interests, and landscape development. The integration of community participation and cross-sector collaboration further ensures that interventions are socially acceptable, economically viable, and environmentally responsible.

In essence, Room for the River represents a paradigm shift in flood risk management—moving away from rigid structural defenses toward a more dynamic, adaptive, and holistic approach that enhances both flood safety and the long-term resilience of riverine landscapes.

The Room for the River concept presents a compelling framework for Ulaanbaatar, despite the city's distinct character from the Netherlands. Firstly, this concept offers a globally applicable planning approach that emphasizes the multifunctional use of land and optimizes investment capital. At its core, Room for the River advocates for providing more space to rivers to effectively manage floodwaters, a principle universally relevant to urban settings dealing with spatial constraints.

Embracing Room for the River in Ulaanbaatar could transform flood management into an opportunity for socio-economic urban development, improved urban spaces, and environmental conservation, tailored to the city's unique urban and hydrological challenges, while first and foremost enhancing the cities safety against floods.



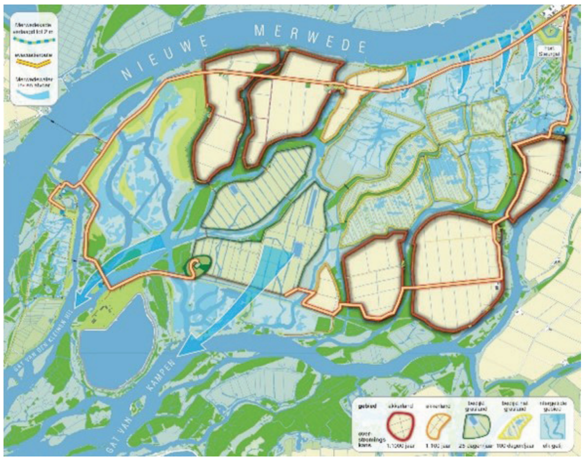


Figure 17: Locations of the 39 "Room for the River" project (left) and an example of the design of the Green River Noordwaard Project (right), Bypass Nijmegen (under).

4.5 An integrated and basin wide approach

In small catchment areas such as those of the Selbe, Uliastai, and Tolgoit Rivers, river discharges respond quickly to changes in rainfall intensity due to the short distance between source and receptor (see Figure 18). Changes in land cover throughout the basin significantly impact how the river system reacts to rainfall events, making it crucial to consider the entire catchment when developing downstream flood safety measures and standards.

Addressing flood risks at the catchment level extends beyond the formulation of technical interventions; it requires an approach known internationally as Integrated River Basin Management (IRBM) or, more specifically, Integrated Flood Risk Management (IFRM) for flood strategies. IFRM is a framework that promotes sustainable, long-term flood resilience by combining social, economic, financial, environmental, and institutional solutions, as well as those involving engineering, disaster preparedness, insurance, and emergency response . While IFRM is comprehensive and extensive, it can be adapted locally into a more customized approach that adheres to IFRM principles, such as integration of various options and multi-stakeholder involvement.

The IFRM-inspired approach for Ulaanbaatar could play a crucial role in determining acceptable flood safety levels for the city, which, in turn, dictate the necessary investments to upgrade the existing water and river system to achieve these targets. Essentially, this approach helps to evaluate the economic feasibility of protecting people and assets against floods. To effectively manage flood risks, the approach should adhere to several fundamental principles:

1. **Potential Flood Drivers:** Assess multiple hydrological and hydraulic (and geomorphological) drivers of flooding. Understanding these drivers, along with their probability of occurrence, is critical for effective flood risk management (Tariq et. al, 2020)
2. **Flood Hazard:** The occurrence of a peak discharge alone does not necessarily result in a flood. Flood hazard is determined by combining the occurrence of a hydraulic event with factors such as levee stability, upstream retention capacity, and river discharge capability.
3. **Exposure:** The exposure of populations and assets to flood hazards is a primary component of flood risk. Effective management strategies require identifying areas where these exposures are highest and implementing measures to reduce the potential impact.
4. **Vulnerability:** Vulnerability is the extent to which a group or individuals or assets are susceptible to the occurrence of a flood and their ability (or inability) to cope, recover, or basically adapt to it. Addressing vulnerability involves enhancing resilience through both structural and non-structural measures.

This structured approach will enable Ulaanbaatar to balance the economic feasibility of flood protection investments with the need to safeguard its people and assets effectively. Additionally, the successful implementation of this flood risk management approach will require supportive policy actions. These policies must facilitate the adoption of new strategies, ensure adequate funding, and encourage multi-stakeholder collaboration to reinforce the city's flood resilience. These policy actions are critical to translating the technical aspects of flood risk management into practical, sustainable solutions for Ulaanbaatar.

Note: This report does not include an assessment of the geotechnical stability of levees / embankments, bridges and other hydraulic works. Mongolia has construction codes (BNbD33-01-03: General Guidelines for Designing Hydraulic Structures) for hydraulic works that must be followed. In addition, there are international standards for the design of hydraulic works that can provide valuable insights and guidance.

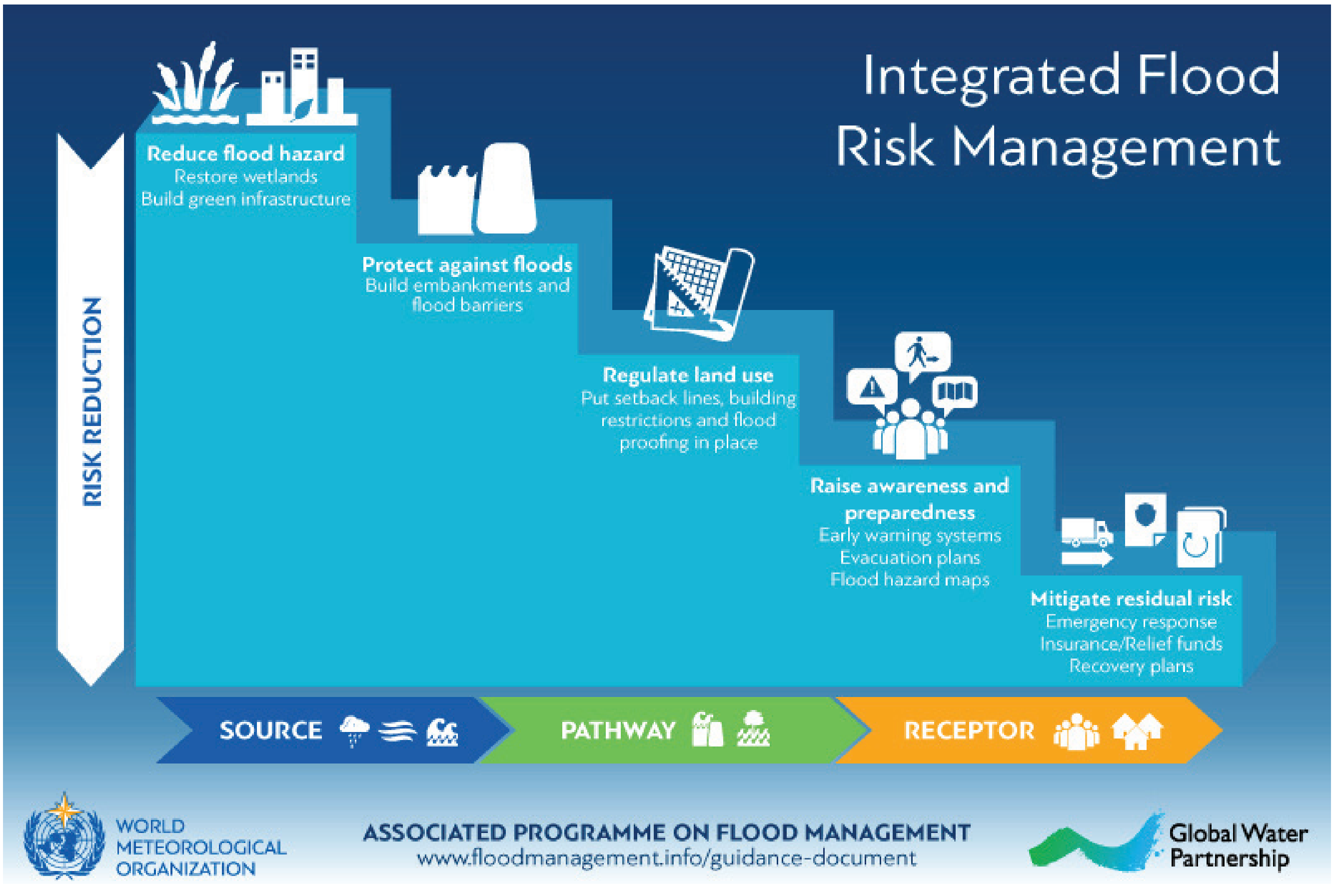


Figure 18: Principles of integrated flood management, arranged in a logical cascading sequence (source Global Water partnership)

[6] *Source: https://hub4r.adb.org/*

[7] *https://www.floodmanagement.info/integrated-flood-risk-management-cascade/*

05

TECHNICAL SOLUTIONS

5. TECHNICAL SOLUTIONS

The DRRS team promotes an integrated, catchment-based approach to improve flood resilience, balancing interventions between upstream retention and storage and enhancing downstream drainage capacity. There are various pathways to enhance flood safety in Ulaanbaatar, each offering a trade-off between pro's and con's in terms of costs, technical performance, socio-economic co-benefits and environmental impacts amongst others. The combination of interventions between upstream retention of flood water and safe passage of floodwater in the downstream reaches of the river crossing the city make the best strategy for the city in terms of return on investments, aligning flood safety with Ulaanbaatar's socio-economic development ambitions.

While the DRRS program is not focused on designing specific interventions, it is deemed valuable to provide a range of options ("menu of options") that the MoUB can use as inspiration when creating a roadmap to enhance urban flood resilience in Ulaanbaatar.

This chapter outlines a series of interventions aimed at mitigating flood risk throughout Ulaanbaatar in the short, medium, and long term. It should be noted that although the interventions proposed by the DRRS team are based on field understanding and information collected during our visit to Ulaanbaatar, they are highly indicative and non-exhaustive, basically meaning that other options may emerge following the results of a thorough planning study. The MoUB remains responsible for preparing a feasibility study and engineering design if they consider the proposed interventions beneficial for Ulaanbaatar.
The following set of measures were considered by the DRRS team:

5.1 Adopting an approach that guides the selection of future investments

Adopting a flood safety approach

The extensive flooding in 2023 served as a wake-up call to the Municipality of Ulaanbaatar, highlighting the urgent need for bold actions to prevent worsening flood conditions. There is a critical necessity for a paradigm shift in addressing urban flood risk—from a reactive response to flood occurrence to a proactive approach that embraces urban water as a means to reduce flood risk, by putting water back at the heart of urban planning.

The MoUB is recommended to adopt a flood safety approach that considers both upstream and downstream characteristics of the river basin, as well as existing facilities that influence the magnitude of an incoming flood wave. Acceptable safety standards should be derived by combining the probability of flood occurrence with its consequences in terms of impacts on people and economic damages. The tradeoff between the probability of occurrence and the consequence of a flood defines the residual 'risk' level acceptable to MoUB. In simple terms; it is not possible to prevent flooding at all costs, and some degree or flood risk remains. The difference is a proper understanding of the residual flood risk levels that can be used in public communication.

Bold actions are needed to ensure a flood-resilient future for Ulaanbaatar, given the anticipated increase in rainfall frequency and intensity, which heightens the exposure and vulnerability of people and property to floods. Although the costs of removing buildings and infrastructure are significant, delaying these decisions in favor of short-term solutions will ultimately prove more expensive. Implementing effective measures early on will reduce investment costs and yield greater socio-economic benefits in the long term. Simultaneously, bold actions necessitate a thorough decision-making process which includes a solid stakeholder and community engagement process.

To achieve long-term flood safety, it is essential to integrate water management and flood risk management into all ongoing and future urban planning activities, ideally within a multi-stakeholder framework. Cross-departmental coordination on an equal footing will be crucial to ensure that all interests are considered and that the full range of co-benefits from investments in flood protection can be realized.

Table 4: "Menu of options"; a selection of interventions to reduce flood risk in Ulaanbaatar.

Proposed Intervention	Geographical Location	Functionality (temporal scale)
Gully Plugs	Upper hill area	Reduce runoff velocity, reduce erosion and trapping sediments
Check dams	Upper hill area	Enhancing upstream siltation
Storage ponds & reservoirs	Upper Ger, Lower Ger, Lower city	Trapping of sediment, flood water retention, reduce peak flow.
Excavation of channel/floodplain	Lower city	Increase discharge capacity, short term
Relocating vegetation	Lower City	Increase discharge capacity, short term
Widening floodplain	Lower City	Increase discharge capacity, long term
Construction of permanent levees/embankments	Lower City	Increase discharge capacity, long term
Remove bridges/increase bridge clearance	Lower city	Increase discharge capacity, long term

Adopting an Integrated Planning Approach

The selection of interventions for the medium and long-term begins with a thorough and comprehensive planning process. As a comparison, the Room for the River Program in the Netherlands initially conducted a quick-and-dirty assessment to gauge the combined impact of a series of concurrent interventions on overall flood safety objectives. The 'Blokkendoos' (translated as 'building blocks') is a program developed by WL|Delft (now Deltares) to aid policymakers at Rijkswaterstaat in assigning sub-projects (site specific interventions) based on the cumulative impact of the total set of interventions. Subsequently, each sub-project underwent a comprehensive planning study. These studies included technical assessments as well as stakeholder assessments, particularly since resettlement could not be avoided.

A comprehensive planning process requires a considerable amount of time. In the Netherlands it took more than 5 years for the planning and design of the program. This shows the need to plan ahead and not wait till emergency interventions are required.

A similar planning process is recommended for Ulaanbaatar. The planning process facilitates a trade-off between upstream and downstream interventions based on the possibilities and limitations regarding available space and potential resettlement issues.

5.2 Interventions to enhance upstream retention and storage of rainwater and sediment

Given the limited space available to increase floodplain capacity in downtown Ulaanbaatar, flood water retention in the headwaters is a proven concept to reduce flood levels downstream whilst reducing the inflow of sediments to the main rivers. Ulaanbaatar has effectively piloted the retention of floodwater during the 2023 floods in the upper catchment, notably through the operation of the Sanzai reservoir.

This section focusses on interventions to retain and store water and sediment before it reaches the downstream stretch of the Selbe in downtown Ulaanbaatar. The following measures were assessed by the DRRS team: 1) measures to reduce pluvial flooding (flash floods in the upper and lower Ger area), 2) measures to reduce erosion and blockage of urban drainage systems by sediment and 3) measures to retain water in the headwaters and store water in retention ponds to attenuate the flood peak.

Headwater gully erosion measures

Actively eroding gullies and headwater streams are an important source of sediment that is deposited in the Selbe floodplain (and floodplains of other tributaries of the Tuul River including the Uliastai, Selbe, and Tolgoit). This sediment settles in urban drainage systems in the Ger areas and further downstream in the river channel in the lower city area. The resulting riverbed aggradation leads to a strong reduction in the flow cross-sectional area of the waterways and thus reducing flood conveyance in Ulaanbaatar city. Figure 19 shows an aerial photograph of a Ger-area where the eroding gullies that supply sediment to the Selbe are clearly visible.

Figure 19: Image with the Selbe River and actively incising gullies on the hillslopes to the East (Google Earth).

For the implementation of effective erosion control measures in the Selbe basin, it is key:

- to identify the headwater basins / gully systems that contribute the most to sediment supply;
- to identify the processes that lead to the largest amount of sediment entrainment (e.g., hillslope processes, gully erosion, human activities); and
- to monitor erosion and sediment transport without measures (basins without measures and prior to implementation) and with measures (following implementation).

More details regarding the strategy to mitigate erosion and sediment transport are provided in Annex II.

During the DRRS mission, two types of measures were identified as most promising in the Selbe basin: (1) planting of trees and stimulating natural forest development as a basin-scale and long-term strategy; and (2) installing grade-control structures, gully plugs in particular, as a local measure to stop erosion in actively incising gullies.

First, during the field visit on 12/09/2024, it was clear that adjacent headwater basins with and without tree cover showed large differences in erosion and sediment transport (Figure 20). This implies a strong control of trees on gully erosion through the stabilization of gully walls. It is highly recommended to verify this stabilization effect in the wider catchment and to align the ongoing national campaign to plant 1 billion trees by 2030 (Mongolia's One Billion Trees Campaign: A Bold Step Against Climate Change and Desertification – Institute for Strategic studies (iss.gov.mn)) with gully-control practices. In addition, the role of grazing on tree establishment in tributary basins is to be investigated. The presence of natural or planted tree cover has an added advantage that the land is less susceptible to urban expansion.

Second, grade control structures, including check dams and gully plugs, serve to dissipate flow energy and limit the hydraulic gradient between structures, thereby reducing flow velocities in headwater channels. The installation of these structures allows the stabilization of gullies, preventing their incision and widening. In addition, just upstream of grade control structures, sediment may be trapped or is deposited due to reduced flow velocities. In the Ulaanbaatar region there is limited to no experience with these structures in headwaters channels and therefore a pilot study to test the installation of 3-4 gabion gully plugs was agreed upon (e.g., Figure 20).

The cross-sectional design and along stream placement of grade control structures depends on gully dimensions and bed slope, (normative) flow conditions and construction material. In Annex II, general guidelines and practical considerations are provided for the (hydraulic) design of gully plugs. For the test pilot a gully channel was provisionally selected in the unvegetated basin that is accessible by dirt road yet at some distance from human the nearest human settlements (Google Maps). It is important to stimulate ownership within the local community, as these structures contribute to erosion and flood control, and to engage them in the monitoring and maintenance of the gully plugs.

Figure 20: Examples of vegetated (top) and unvegetated (bottom) tributary basins and gullies in 15 khoroo, north of UB. (Source: DRRS team)

Figure 21: Examples of gabion gully plugs dams (from gabionsupply.com) (left) and Nile Basin Initiative (right).

Storage ponds & reservoirs: Dambadarjaa retention basins

Currently, the MoUB is planning to build a series of large retention basins named 'Dambadarjaa' just upstream of the Selbe Electrical Substation. The basin will be created by a cascade of five interconnected retention areas, separated by cross-dams. The original idea for the retentions came from the 'Feasibility Study Concerning the Utilization of Ground Water in the Region of Ulaanbaatar' by GAUFF Engineering between 2010-2012 (1.2 million m^3 of volume). After some adjustments, the plans were further designed for the Selbe Revival Plan, with a total volume of 1.3 million m^3. The basin will not only serve as water storage but can also be used as a recreational area during the summer months.

Figure 22 shows the general layout of the system. Besides storing water, the system can trap sediment from upstream parts of the catchment (see textbox below) before it is transferred downstream. It is worth noting that with the siltation of the reservoir its water retention capacity reduces. Therefore, it is extremely important to ensure sufficient maintenance is carried out during the construction season to ensure the effective functioning of the reservoir in reducing flood risk downstream.

Textbox 2: Rough estimation of sediment deposition in the Dambadarjaa basins

> To get an estimate of the sediment trapping capacity of the Dambadarjaa basins, we assume required flow conditions of ~1 cm/s for the deposition of silt and ~10 cm/s for the deposition of sand based on Hjulström's diagram.
> Considering an event similar to that of the Selbe River flood on 05-07-2023 (Q = 45 m^3/s), a filled retention basin with a flow cross-sectional area of ~1000 m^2 (250 m width and 4 meters depth) will result in a mean flow velocity of 4.5 cm/s. This velocity is sufficiently low enough to assume that a large fraction of sand and some silt will deposit, even under high flow velocities.

Apart from the planned Dambadarjaa retention basins, more upstream retention opportunities shall be sought to reduce the pressure on the downstream reaches. Even though these additional retention facilities may be smaller than the Dambadarjaa basins, they can collectively make a significant contribution to reducing flood risk downstream. While the selection of potential locations for these retention facilities is the responsibility of the MoUB, this chapter outlines criteria options for their selection, for further consideration:

- **Minimum Area:** A minimal area of about 10 hectares. Smaller basins will not have sufficient storage capacity or be large enough to induce sediment deposition.
- **Location:** Select locations in or around major waterways to ensure the storage basins can be filled completely under gravity.
- **Resettlement:** Minimize the need for relocation of inhabitants to gain more local support.
- **Number of Basins:** Consider the selection of 5 to 10 smaller basins. Constructing multiple smaller basins at different locations within the upper catchment is more effective than one larger facility in the lower tributaries due to level of development in the lower reaches.

Based on these criteria and following a very straight-forward approach, seven potential sites in different parts of the Selbe river catchment could be identified with a total area of 193 hectares (Figure 23). Assuming an average maximum water depth of 1.5–2.0 meters (comparable to the Dambadarjaa basins), this provides a storage potential of 3.9 million m^3. A hydrological modeling study shall assess the contribution of such retention volume to the attenuation of the downstream flood peak and answer the question whether the investments in upstream storage outweigh the reduced flood damages downstream.

The selection of potential retention facilities requires a thorough planning and technical analysis. In the short term, constructing such facilities is not feasible both financially and technically. A modeling study is required to assess the catchment's hydrological response and adapt the design of retention basins accordingly.

Figure 22: Detailed design of Dambadarjaa retention basins after Selbe revival project (Source: Prestige Engineering, Selbe revival feasibility study report, 2023)

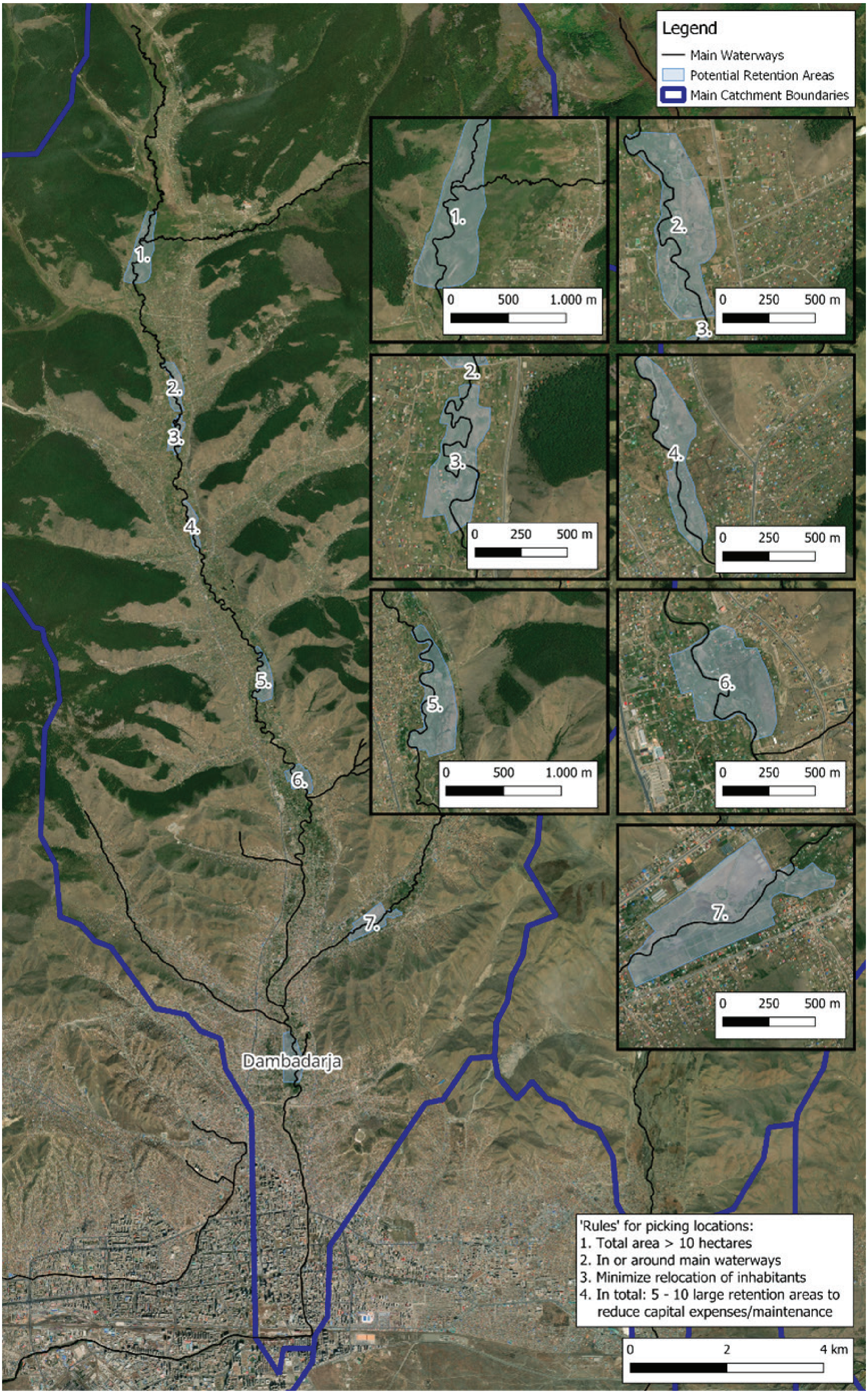


Figure 23: Seven locations as search area for construction of retention basins for the upper Selbe-basin

Rehabilitation of existing retention basins

The largest existing retention basin is Nogoon Nuur. Nogoon Nuur is one of the few remaining retention basins in the downstream section of the West Selbe River (Lower Ger Area), but it is currently not in a good state. The surface area of the retention basin has diminished over time due to encroachment by newly constructed buildings. What remains of the retention basin has undergone significant degradation, rendering it incapable of fulfilling its intended purpose of retaining floodwater and trapping sediment. Furthermore, the downstream weir has experienced extensive damage during the 2023 flood, posing a safety hazard in its current condition.

Due to earlier flood damage, the weir is out of order and demolition of the structure has no major implications for water management. However, to prevent the collapse of the earthen side walls, it is essential to maintain the concrete side walls. Also, the expected instability of the retaining wall of the remaining structure after removal may necessitate installing a crossbeam. Construction of a new outlet structure in the Nogoon Nuur retention basin in combination with the reprofiling of the remaining part of the retention basin to further increase the retention capacity and maintainability, must be done in the 2024-2025 construction season.

Figure 24: Active area of Nogoon Nuur retention basin in 2005 (highlighted area) and encroachment taking place after 2011.

Figure 25: Current size of Nogoon Nuur (in red) and possible extension (in blue) (Source: Google Earth)

Apart from Nogoon Nuur, there are also some smaller retention basins that can be rehabilitated to trap sediment and store rainwater. Figure 26 illustrates a smaller retention basin located in the north of the city. By replacing the outlet structure with a weir that has a smaller orifice and by regularly dredging the upstream deposited sediment, these basins can be used effectively.

Figure 26: Sambalkhundev retention basin: current condition on left and recommendation on right. (Source: DRRS team)

Figure 27: Sambalkhundev retention basin full of sediment (Source: Photo by Chinzorig Sukhbaatar)

5.3 Interventions to enhance downstream discharge capacity and reducing fluvial flood risk

Although the 2023 floods are statistically not considered 'extreme', the large scale at which flooding occurred in the downtown area of Ulaanbaatar demonstrates the extent to which the Selbe floodplains have been constrained over time resulting in an insufficient discharge capacity for the river. We estimate that the bankfull discharge capacity of the Selbe River is locally limited to ~15 m^3/s, corresponding to a return period of 1 in 2-5 years. This basically means that any flood with a return period above 5 years may lead to flooding. Given the social and economic importance of the flood affected areas in Ulaanbaatar, such a flood safety level would seems unacceptable and urgent improvements to enhance the flow conveyance capacity of the Selbe are needed.
This chapter offers a list of options to enhance the flow conveyance capacity of the river (can be the Selbe River or any other river) differentiating between short-term, medium term and long-term implementation period. The short-term measures are directly linked to regular maintenance efforts during the 'construction season' as they must be completed within one construction season. Medium and long-term interventions require a comprehensive planning approach (see 5.1) to ensure that the interventions are fit for purpose (provide required flood safety), are cost-effective, receive community and stakeholder support and sustainable on the long term.

1. **Vegetation management.** Trees and shrubs increase the hydraulic roughness of the river. Removal of vegetation at locations where it blocks the flow most will allow the water to flow faster and reduce water levels locally.
2. **Dredge to deepen the main channel.** The Selbe carries a large sediment load which requires the regular removal of silt to increase the flow capacity of the river.
3. **Widen the main channel.** Over time, the river has been gradually narrowed in favor of road construction, construction of apartment buildings and parking spaces. Relocating embankments outwards as much as possible will provide more room for the river and help to reduce water levels.
4. **Remove low bridges or pipes crossing the river.** There are multiple structures crossing the Selbe River with insufficient under bridge clearance, limiting the flow and causing an upstream backwater effects. Removal or adjustment of the bridges and heating pipes will positively influence the flow capacity of the river.
5. **Build permanent levees, flood walls or dikes:** Ulaanbaatar has installed temporary levees (dikes or embankments) to prevent further flood damage during the 2023 floods. Placing permanent good structures will reduce flood risk and can be combined with roads to make more optimum use of the limited space in the city.

Vegetation Maintenance

Vegetation in river floodplains is part of the natural ecosystem and should be protected where possible. However, where floodplains have been largely confined, vegetation roughness exerts an increasing water level rising effect, necessitating the replacement of vegetation at key bottlenecks. This situation applies mostly to the downstream Selbe River between UNESCO street bridge and Narnii road bridge, as well as the reach of Selbe river near Altai town in Ulaanbaatar center. Vegetation maintenance policies in the Netherlands show a similar approach, with removal of vegetation that is growing perpendicular to the flow direction and regular clearance of bushes with a high vegetation roughness. Vegetation development in wider floodplain areas, especially in flow shelter areas, is promoted as part of the conservation of riparian ecosystems. For Selbe River this applies to more upstream stretches of the Selbe River with higher flood conveyance capacity (and applies as much to other river systems as well).

The DRRS team recommends the following:

- Prepare a vegetation management plan for the Selbe River, including 1) maintenance objectives for vegetation in flood prone stretches of the river, 2) a justification for relocating selected trees and bushes in the most flood prone stretches and 3) a mitigation plan to compensate for the removal of vegetation downstream.
- Set up a communication mechanism with the Ministry of Environment and Tourism and other relevant authorities to agree on the vegetation management plan.
- Install sign boards and prepare social media content to increase communication about the GUBB's work in the Selbe River.

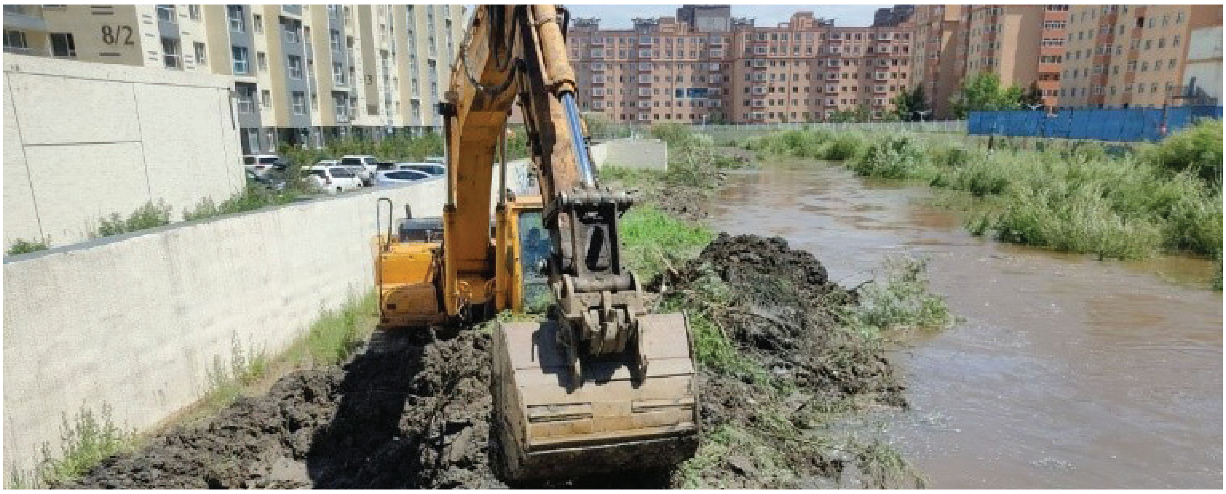


Figure 28: Excavation work in the Selbe River on June 23, 2024

[8] *https://open.rijkswaterstaat.nl/open-overheid/onderzoeksrapporten/@128158/stromingsweerstand-vegetatie-0/*

Silt Removal

The highly erodible soils on relatively bare and steep slopes in the upstream basin, lead to high sediment influx into the city's rivers. Over time, this has resulted in a thick layer of sediment deposits in the Selbe River. Measurements show that the thickness of the silt layer reached 1.5 m and is thickest near bushes.

Figure 29 shows ongoing excavation works by GUBB in May and June 2024 to remove silt from the Selbe River. A number of contractors performed the work based on channel specifications of the Selbe Revival Plan. There has been little to no verification of the current channel dimensions.

Figure 29: Bird-eye view on the Selbe River after excavation works in May-June 2024 (source: photo by GUBB).

A menu of options for Medium and Long-Term Interventions

There are many options available to increase the discharge capacity in a river. The Dutch Room for the River program captures al large number of the possible measures as can be seen in Figure 30 below. As the Room for the River project applies to a typical Dutch situation, the Ulaanbaatar context may bring other opportunities and challenges. Hence a customized approach is needed.

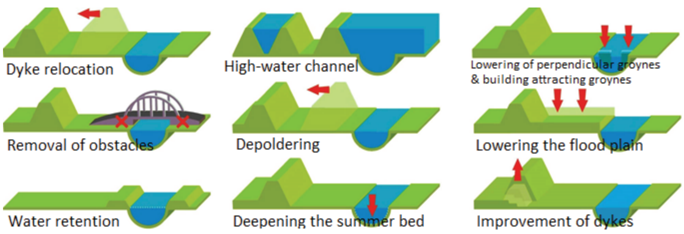


Figure 30: River capacity enlarging options adopted by the Room for the River Program in The Netherlands

Relocation of embankments

The horizontal distance between embankments on both sides of the river reduces in downstream direction in Ulaanbaatar. Upstream the river is roughly 200 m wide, whereas downstream only 20 m remains due to heavy encroachment. Due to a series of relatively dry years, in the past 10 years Ulaanbaatar did not experience significant flooding, which has diminished the government's and public's awareness to the urgent flood risk situation in Ulaanbaatar. In 2023, Ulaanbaatar received a wake-up call with the severe flooding of Selbe River, which to a large extent can be attributed to the encroachment of the river.

The DRRS team highly recommends MoUB to assess all opportunities to widen the river, by for instance relocating existing embankments for the most constrained sections of the river. Additional space can be gained by combining embankments with a road on top. Figure 31 shows an example of the critical bottleneck of the Selbe River in Ulaanbaatar where available space to widen the river is highly constrained.

The DRRS team recommends widening the river at the left bank of the Selbe just downstream of UNESCO bridge by excavating some parking lots and relocating the levee away from the river. This will increase the cross-section area at what is considered to be one of the largest bottlenecks of the river (see Figure 31). The levee should become of a permanent type to not give the impression that flood protection works are of a temporary nature.

More concretely, MoUB has dismantled the S-Outlet building following DRSS recommendations (Figure 31). The building blocks the most constrained part of the Selbe River and widening the river at this location will reduce flood levels significantly in the short term. With the demolition of the building, GUBB has adjusted the design of the flood walls from the Selbe Revival Plan at this location, providing more space for the river.

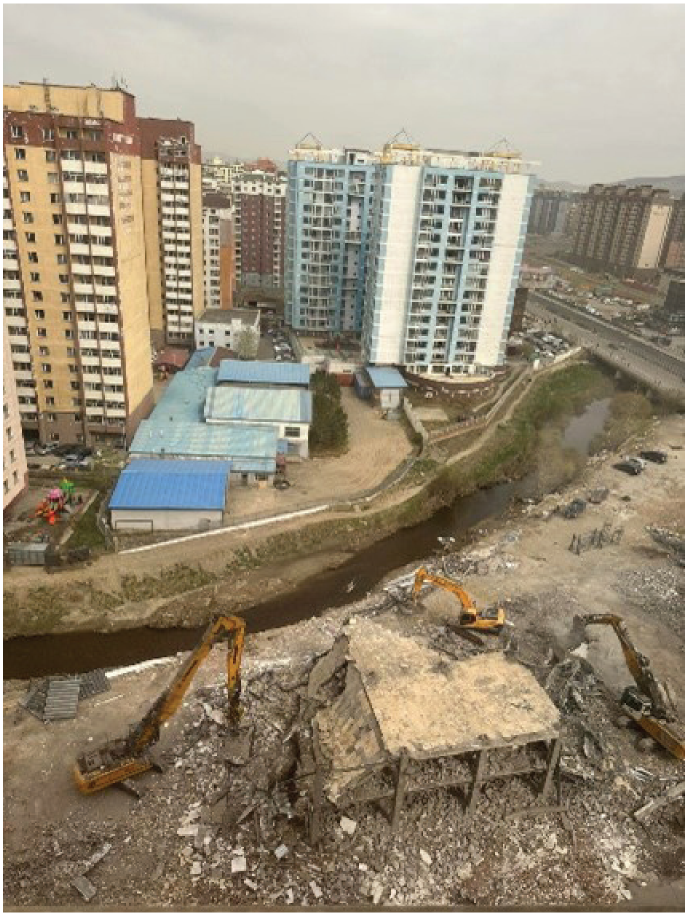


Figure 31: Most constrained stretch of the Selbe River in Downtown Ulaanbaatar, with an aerial view (left) and the demolition of the S-Outlet building on the right at the same location.

Removing bridges and heating pipes with insufficient underbridge clearance

In the Selbe River, multiple bridges and heating pipes cross the river at heights lower than the riverbanks (e.g., the footbridge in Figure 32). These structures reduce the cross-sectional area of the river and decrease the bankfull discharge capacity, causing a backwater effect and significant flood hazard.

The DRRS team recommends MoUB to assess all bridges crossing the Selbe River. For bridges with elements lower than the local bank height, measure the cross-section and determine the discharge capacity. To increase the discharge capacity, either remove the bridge or replace it with a higher one. If this is not feasible, at least raise the heating pipe to the same height as the bridge deck to reduce the blockage of flow and excavate the soil under the bridge.

Furthermore, the DRRS team recommends all future bridges and heating pipes crossing the Selbe River to be constructed with sufficient under bridge clearance. This ensures that new bridges will not become bottlenecks and provides room to raise the banks in the future without obstruction from the bridges.

Figure 32: Photo of the footbridge south of Embassy street, demonstrating insufficient under bridge clearance (Google Maps Streetview August 2023). The top of the bridge is equal to the bank height. The bottom of the bridge deck and the heating pipes are all lower than the banks, largely obstructing the flow.

Systematically increasing discharge capacity

The DRRS team strongly recommends adopting more "Room for the River" Selbe. The following 5 steps guide in the selection of locations and measures to enhance the capacity of the Selbe river:

- **Step 1**: Determine actual discharge capacity at various locations in the river;
- **Step 2**: Identify key bottlenecks that limit flow conveyance;
- **Step 3**: Identify measures to enlarge discharge capacity for key bottleneck locations to improve flood safety on the short term;
- **Step 4**: Set a realistic flood safety standard for the Selbe River which translates into a 'design' discharge capacity to be achieved for the medium and long term;
- **Step 5**: Resolve residual capacity needs with upstream retention to meet target flood safety standards.

Each step is elaborated below, followed by a short example to illustrate the process.

Step 1: Determine actual discharge capacity at various locations in the river;

- Undertake a cross-section survey along the entire stretch of the river, focusing on locations with bridges, culverts and narrow sections.
- Calculate the actual bankfull discharge capacity with flow formulas such as the Chèzy equations (Figure 33) or using a hydraulic model (1D). This will provide an overview of the sections of the river with the lowest discharge capacity. Important in these formulas is the Manning roughness value (n), this value represents the roughness of the river. In rivers with vegetation and debris the Manning value is higher. Higher roughness values lead to higher water levels, which translates into a lower bankfull discharge capacity. Representative Manning values for different rivers can be found online.

[9] In all formulas "i" denotes the part of the cross section and N denotes the total number of parts. The bankfull discharge is the sum of all parts. The figure is an example of a cross section with two parts (N=2). The more parts the better your estimation of Qbf in the measured cross section below it is recommended to treat each part between two measurement points as a single part of the cross section.

$$Qbf = \sum_{i=0}^{N} W_i * C_i \sqrt{R_i * S} \quad (1)$$

$$C_i = \frac{1}{n_i} * R_i^{1/6} \quad (2)$$

$$R_i = \frac{A_i}{O_i} \quad (3)$$

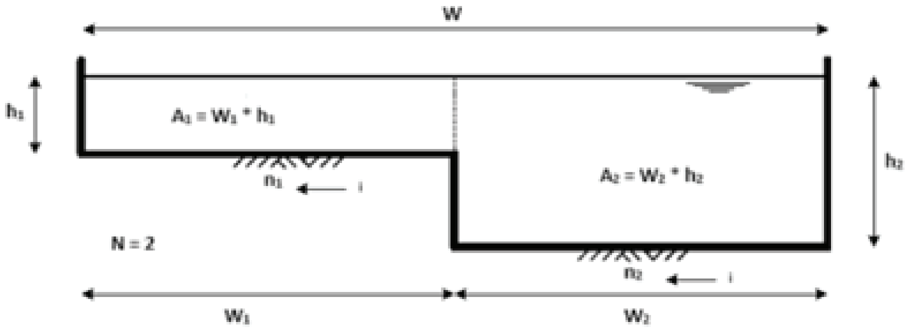


Figure 33: Chèzy-formula (1), Chèzy coefficient from Manning roughness (2) and hydraulic radius (3). Where Q_{bf} is bankfull discharge (m³/s), W the width (m), C the Chèzy formula (m1/2/s), R the hydraulic radius (m), S the slope of the channel (m/m). n is the Manning roughness height (m), A is the cross-sectional area (m²) and O is the wetted perimeter (m) .

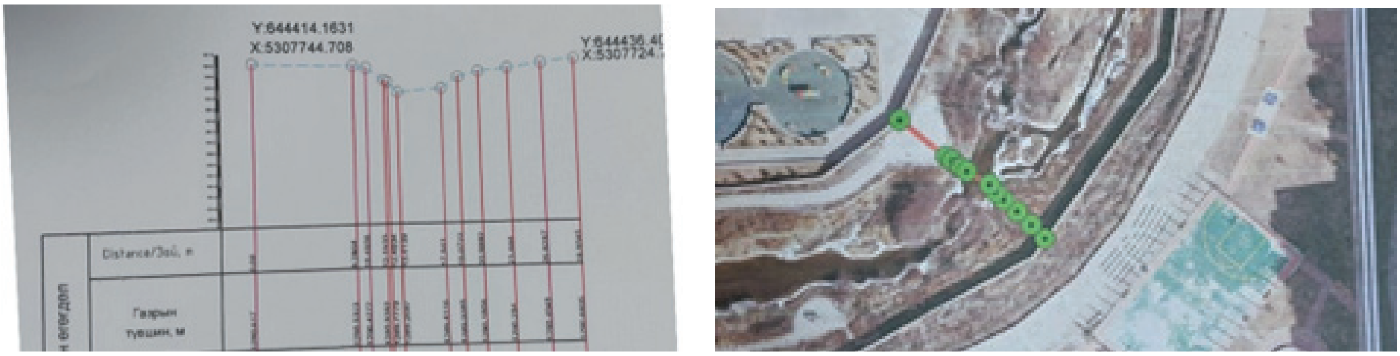


Figure 34: Measured cross sections at the "turning point near S-Outlet" of the Selbe river, measured in 2023. Assuming a clean channel (Manning value 0.04 m and a slope of 0.006) the discharge capacity at this location is roughly 15 m³/s. (Source: Selbe River Revival Project)

Step 2: Identify key bottlenecks limiting flow conveyance

- Based on the results from Step 1, identify the locations with the lowest discharge capacity. These locations are bottlenecks potentially leading to flooding. Start work on the cross-section with the lowest discharge capacity and proceed in ascending order.
- Performing step 1 on multiple cross sections results in figures as shown below. The discharge capacity is determined for each cross section and the lowest capacity is depicted with the red colour (image on the left in Figure 35 below). Currently, the location with the lowest capacity is at the curve of the Selbe river. The second lowest is located just upstream of the curve. The image on the left shows that the discharge capacity of the entire river (blue dotted line) is equal to the capacity of the narrowest cross section (cross-section no 8 in Figure 35 below).
- It must be noted that although the example was applied to the Selbe River, the presented case remains fictitious and needs further elaboration to come to exact numbers.

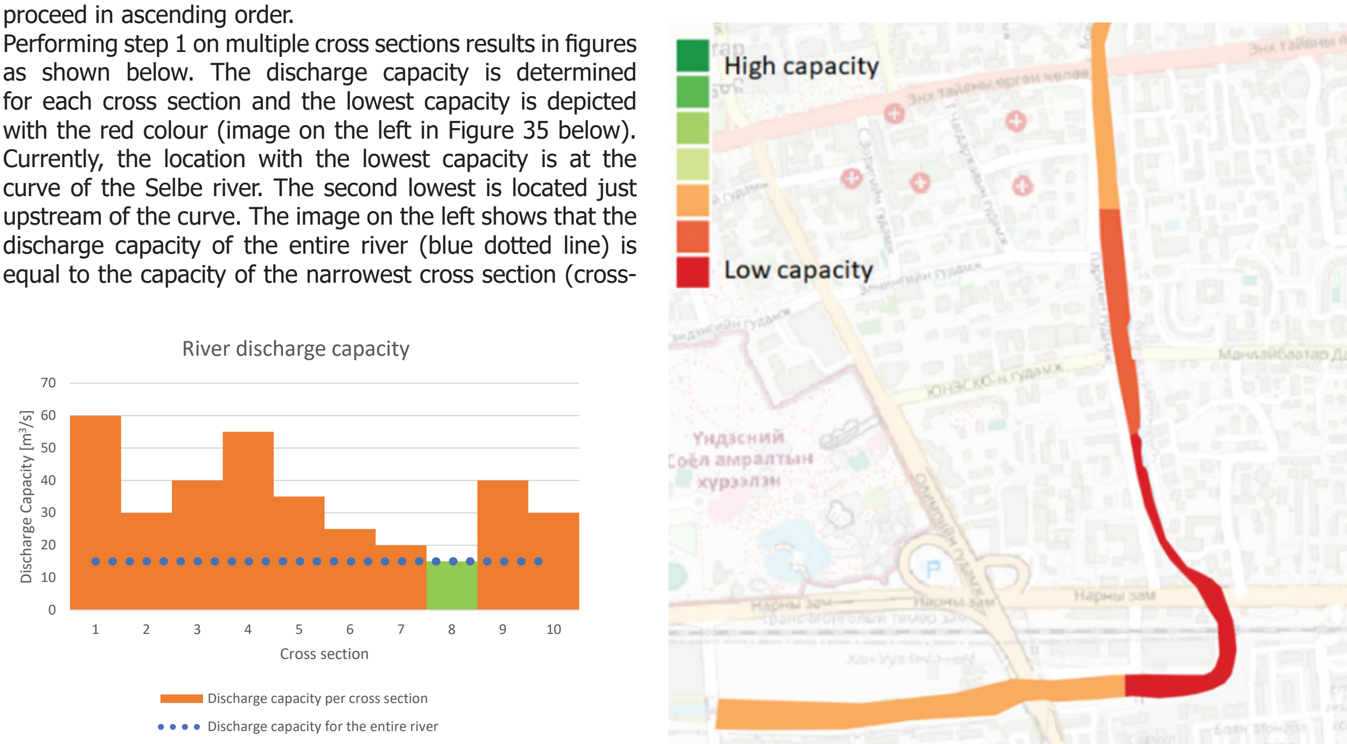


Figure 35: Fictitious example of the approach to identify key hydraulic bottlenecks in the river

Step 3: Identify measures to enlarge discharge capacity for key bottleneck locations to improve flood safety on the short term;

- Information from the Selbe Revival Plan shows that the 2023 event coincides with a 45m³/s discharge in the Selbe river. In this fictitious case, it is assumed that it should be possible to achieve an increased discharge capacity in the Selbe River to safely accommodate a discharge of 45 m³/s.
- Propose multiple measures for each bottleneck and calculate the effect on the discharge capacity (and assess spatial implications). This will provide multiple options per bottleneck, allowing decision-makers to choose the most appropriate measures. Measures can differ in terms of impact on the short, medium, and long term. In the next section, possible measures are discussed. Note that the effectiveness of these measures depends on multiple factors, and the list is not exhaustive.
- All kinds of measures can be taken to increase discharge capacity. The image below shows some examples. For each intervention, the Chèzy formula can be used to calculate the contribution to an increased discharge capacity of the cross section after completion of the intervention.
- In the case of Figure 35, there are 8 cross sections that currently have a lower capacity than the target capacity of 45 m³/s, the river discharge that was assumed to happen during the 2023 floods. This means that a package of interventions (Figure 36) shall be prepared that cumulatively achieves the target flow capacity.
- Start working at the bottleneck with the lowest capacity as this stretch determines the critical flood safety level. Starting at a different bottleneck may even increase flood hazard. An example of this can be found for the bridge just upstream the "turning point - S-Outlet" of the Selbe River. The bridge capacity is highly constrained by the low underbridge clearance. However, when removing the bridge, water arrives faster at the downstream located stretch of the river with an even smaller capacity, causing even more flooding.

Step 4: Set a realistic flood safety standard for the Selbe River which translates into a 'design' discharge capacity to be achieved for the medium and long term.

- This approach distinguishes between short-term and long-term objectives. Short-term interventions, such as dredging, excavation, and vegetation maintenance, are considered no-regret measures that can be accomplished within a single construction season. Long-term objectives involve interventions that require more extensive planning, design, and decision-making.
- A long-term flow conveyance capacity objective will be derived following a comprehensive flood risk assessment, which includes thorough considerations of acceptable levels of flood damage.

Step 5: Resolve residual capacity needs with upstream retention to meet target flood safety standards:

- Achieving sufficient discharge capacity to meet long-term flood safety standards may be challenging due to the limited space available for increasing the channel width and the undesirability of excavating below the siltation level. To address the unrealized discharge capacity, it is necessary to upscale upstream retention and rainwater storage to attenuate the incoming peak flow.
- Section 5.4 below presents a theoretical example on how to calculate the trade-off between upstream retention capacity and downstream increase of the channel's discharge capacity.

Table 5: Calculated runoff coefficient for the Selbe catchment

	Slope	Soil	Share of area	C
Forest	0.5 - 5%	Sandy clay	40%	0.27
Barren soil	0.5 - 5%	Sandy clay	30%	0.57
Barren soil	5 - 10%	Sandy clay	20%	0.63
Urban	0.5 - 5%	Sandy clay	10%	0.9
Runoff factor for Selbe catchment				0.5

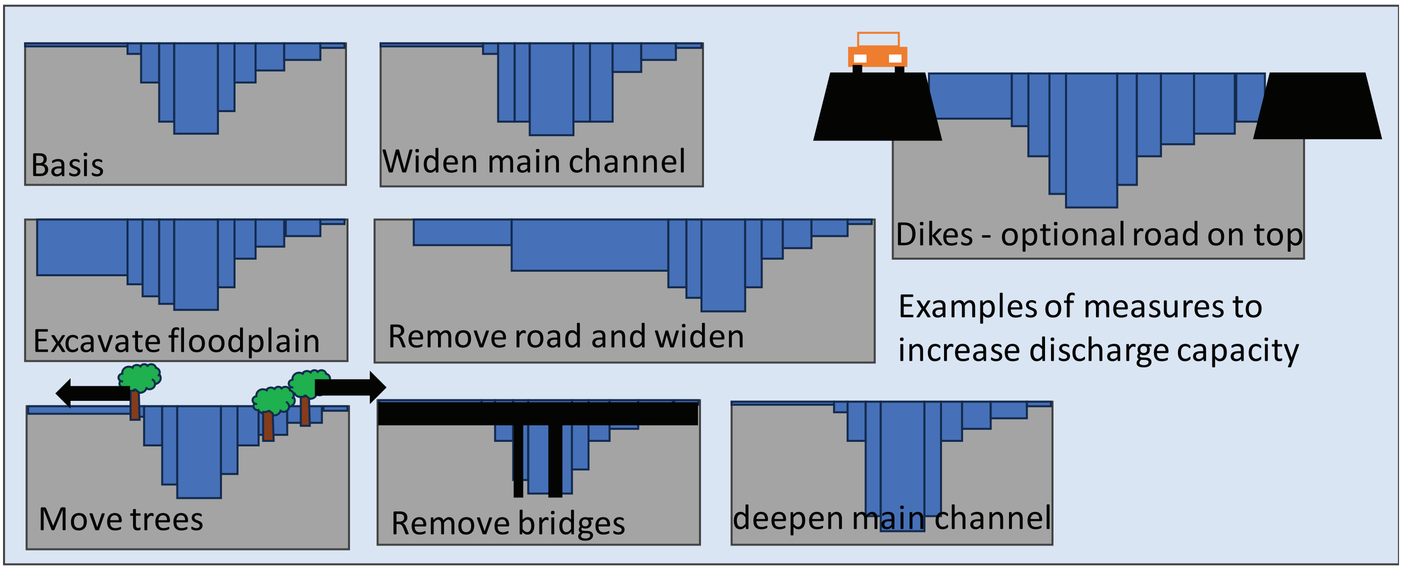


Figure 36: River capacity enlarging options

5.4 Proof of Concept

To demonstrate the possibilities of integrating upstream retention measures and downstream capacity increase, the DRRS team considers a long-term ambition to handle a 100-year return period storm event (T100) in the Selbe catchment without causing significant flood damage. This ambition should not be unrealistic considering the (socio-economic) importance of Ulaanbaatar as capital city of Mongolia. At this moment, the Selbe river cannot cope with such large storm events. It is estimated that the current river system can discharge water from storm events with a return period of 2–5 years and that larger storm events will cause extensive flood damage.

The proposed Dambadarjaa retention basins can have a noticeable impact on the reduction of flood frequency and magnitude, but additional measures are needed. Through a combination of retention, storage and drainage measures, the protection level may be progressively increased to the desired level. Between the different types of measures there is a certain interchangeability: more storage measures grant a larger decrease in peak discharge, thereby reducing the need to enlarge the drainage capacity downstream in the river. Along the same line, many local smaller-scale retention measures in the ger areas or the headwaters may reduce the need for large-scale storage basins. A combination of both may provide the most sustainable and feasible solutions.

Figure 37 below showcases this interchangeability: storage and drainage measures can have a similar effect on the maximum water levels downstream. A combination of both types of measures offers the most flexibility in managing flood risk.

The storage requirements were calculated for three scenarios with increasing drainage capacity measures to prevent large-scale flooding during a 100-year storm event, further highlighting the interchangeability between storage and drainage solutions.

- **Current Situation:** Drainage capacity increase has been managed through annual maintenance of the river system. The discharge capacity of the Selbe River is assumed at 15 m^3/s without causing flooding.
- **Moderate Increase:** The discharge capacity of the Selbe River could be increased to 45 m^3/s through a combination of dredging of the riverbed, removing or adjusting obstacles, such as trees and low bridges and widening the river where possible.
- **Significant Increase:** The discharge capacity of the Selbe River can be increased to possibly 130 m^3/s by taking more drastic measures, such as installing flood retention walls and widening the river, compromising some parking spaces and by integrating permanent levees with local roads.

Note: these numbers are highly indicative and need further justification using detailed 1D/2D hydrodynamic models fed by accurate cross-sectional data after the maintenance work (excavations and vegetation removal) that has been done in 2024.

Estimating the storage requirements for retention basins in the Selbe-catchment

To calculate the required storage capacity to prevent large-scale flooding at a 100-year storm event, we first need to consider the characteristics of the Selbe basin. The total area of the basin is 29,500 hectares. Based on the land use (as estimated from aerial photographs), a runoff coefficient of 0.50 was calculated (as visible in Table 5). This implies that an estimated 50% of the rain that falls on the catchments ends up as runoff in the main river.

Secondly, the rainfall depth needs to be considered. In chapter 3.1.1, depth-duration-frequency curves (DDF-curve) were presented for Ulaanbaatar. From this, a 100-year storm event corresponds to 73 mm of rainfall in 12 hours and 92 mm in 24 hours.

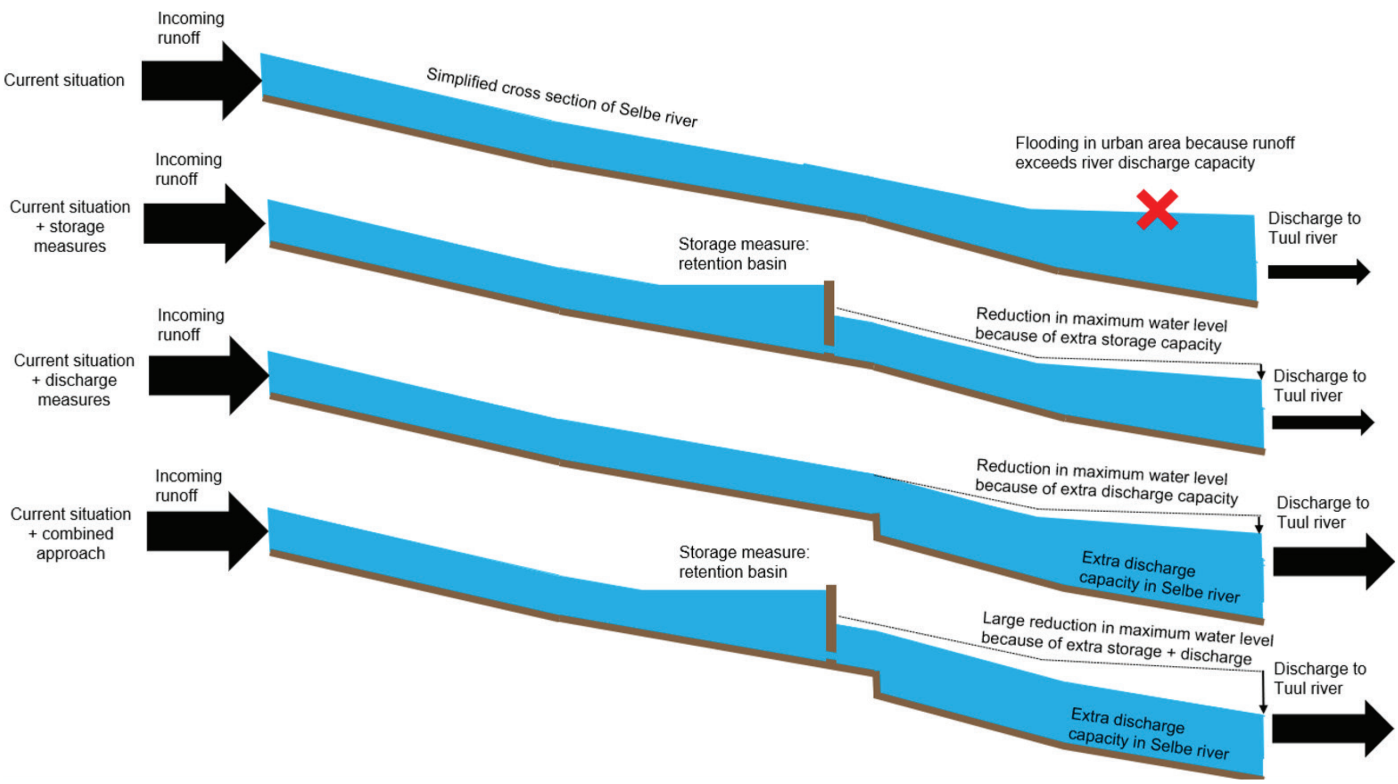


Figure 37: Schematic representation of options for combined storage – discharge capacity increase in the Selbe River

By expressing the river discharge and its storage capacity in terms of rainfall intensity [over time and in mm] using the catchment characteristics that are described above, we can estimate the additional drainage or storage capacity that is needed. For the current situation, the discharge capacity of the Selbe river is estimated at 15 m^3/s. For the two 'future' scenarios, capacities of 45 and 130 m^3/s were assumed. A river discharge of 15 m^3/s corresponds to a rainfall intensity of: 15 [m^3/s discharge] x 3600 [seconds/hour] / (29.5·108 [m^2 catchment area] x 0.50 [runoff coefficient]) = 0.4 mm/hour. This means the Selbe river can discharge 0.4 mm of rainfall per hour, considering the catchment's runoff characteristics and critical cross-sectional capacity of the Selbe River.

Aside from discharge capacity, the current river system also has a certain storage capacity: the main river and its tributaries can temporarily store a certain volume of water before the banks overflow. After the storm events, the river gradually discharges this water into the Tuul river under gravity. This storage capacity of the river basin is impossible to determine accurately without an extensive modelling analysis, but it does play a significant role in the flood protection level.

As a first indicative estimate of this storage capacity, we only consider the storage in the main Selbe River, which is about 40 km long. Based on the cross sections used for the discharge calculations, it is assumed that the average river width is 30 meters and that a maximum water level increase of 1.5 meters causes no major flooding. This grants 1.8 million m^3 of storage capacity in the river during storm events, which corresponds to a rainfall depth of: 1.8·106 [m^3 storage] / (29.5·108 [m^2 catchment area] x 0.50 [runoff coefficient]) = 12 mm.

We can now compute the rainfall depth, river discharge and river storage capacity over time in a graph (such as presented below) to make a rough estimation of the required extra storage capacity for a 100-year storm event.

In the graphs on the next page, if the line representing the storage and discharge capacity of the river system is above the line of the storm event, no major flooding occurs, as the river system will have enough storage and drainage capacity to cope with the amount of rainfall. If the line is below the line of the storm event, the river cannot cope with the amount of rainfall and flooding will occur. For all three scenarios, storage capacity is added until the river system can cope with the 100-year storm event. This results in the following figures:

- **Scenario 1** (current discharge regime): in this case, 72 mm of additional storage capacity is required. The required storage volume is then calculated as: 0.50 [runoff coefficient] * 0.072 [m of rainfall] * 29.5·108 [m^2 catchment area] = 10.5 million m^3.
- **Scenario 2** (discharge capacity of the Selbe river increased to 45 m^3/s): in this case, 54 mm of additional storage capacity is required, corresponding to 7.9 million m^3 of required storage volume.
- **Scenario 3** (discharge capacity of the Selbe river increased to 130 m^3/s): in this case, 25 mm of additional storage capacity is required, corresponding to 3.7 million m^3 of required storage volume.

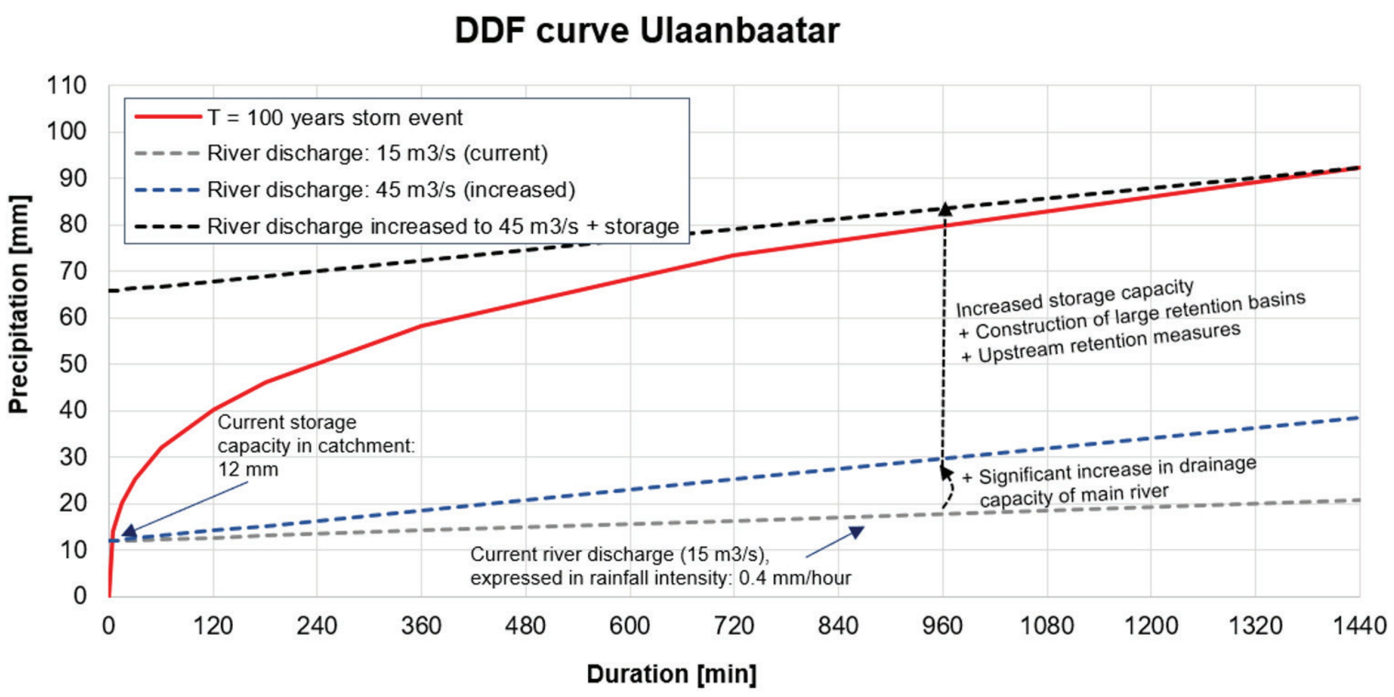


Figure 38: Depth Duration Frequency (DDF) curve for Ulaanbaatar, including the effects of extra storage and discharge capacity on the flood protection level.

In conclusion, the amount of storage capacity needed strongly depends on the number of drainage capacity increasing measures taken downstream. It is estimated that 3.7 – 7.9 million m^3 of extra storage capacity is needed to accommodate a 100- year flood and reduce the peak flow sufficiently such that it falls within the range of 45-130 m^3/s (see section 5.1.1), depending on the extent to which river discharge capacity is increased.

For reference to the required storage volumes, the proposed Dambadarjaa Retention basins have a design capacity of 1.3 million m^3. In case no additional discharge measures are taken in the Selbe river, seven additional series of storage basins of this size need to be built to reach a 100-year protection level. In the scenario with maximum capacity increase downstream, this number reduces to only two. This calculation therefore gives a rough estimate of the required storage capacity for different scenarios, but also showcases the trade-off between upstream storage and downstream discharge capacity increase measures.

It is important to note that natural retention of water in the headwaters of the catchment and increasing the discharge capacity of the river prevail over construction of extra retention capacity of ponds and reservoirs:

- Enhancing the natural storage capacity of the catchment: This can be achieved by reducing the surface area of impermeable surfaces and promoting the planting and natural development of vegetation, a relatively cheap and sustainable solution to reduce floods. These measures help prevent surface runoff and slow down the water flow into the main rivers.
- Increasing the discharge capacity of the river: This approach is advantageous over investing in retention ponds or reservoirs, as it allows a continuous drainage of water, effectively managing a certain volume of water per unit time. In contrast, retention ponds hold water, which requires significant capacity and precise operation. In addition, if a reservoir fills up before the flood peak arrives, it can no longer serve its intended function.

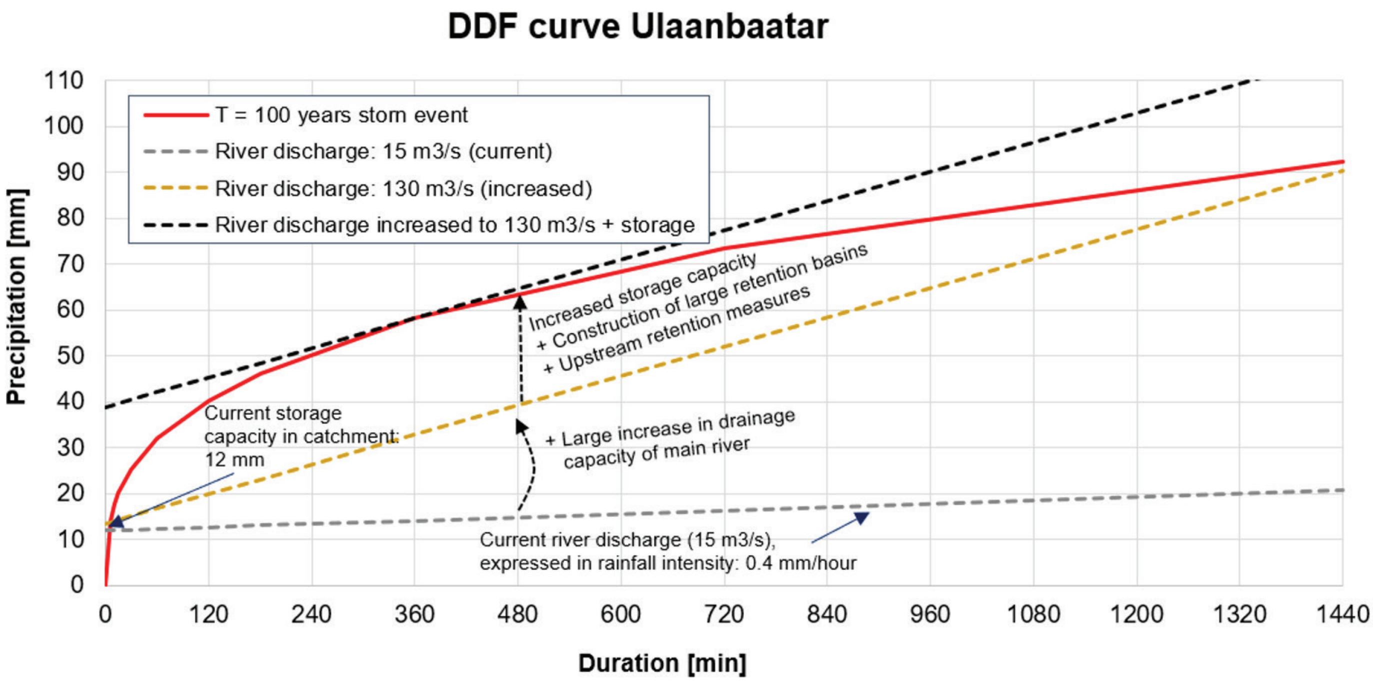


Figure 39: Depth Duration Frequency (DDF) curve for Ulaanbaatar, including the effects of extra storage and discharge capacity on the flood protection level.

06

IMPLEMENTATION FRAMEWORK

6. IMPLEMENTATION FRAMEWORK

The recommendations from the DRRS-team can be consolidated into a comprehensive implementation framework for achieving Urban Flood Resilience in Ulaanbaatar. This framework outlines a development pathway toward achieving a flood-resilient city, built on the core principles of Integrated Flood Risk Management. It encompasses the necessary legal, institutional and governance structures, alongside planning, and engineering measures. The framework balances immediate "no-regret" actions with medium- and long-term investment strategies, ensuring that Ulaanbaatar evolves into a resilient and climate-adaptive city. The implementation framework provides a customized financing strategy that can be readily adopted by Development Banks (e.g., World Bank, ADB, JICA) or serve as a comprehensive investment plan for the government.

Individual recommendations can only be effective when embedded within a broader implementation framework supported by key enabling conditions. For example, preventing river encroachment requires a strong legal and regulatory framework, while infrastructure investments are only sustainable when aligned with urban planning that respects the integrity of the river system. This chapter outlines the key components of the implementation framework and explains how the various steps are interlinked and can be sequenced over time to ensure coordinated and effective execution.

6.1 Legal, Governance and Institutional Strengthening

1. **There is a strong need to revisit the Water Law, in particular the chapter on land management and flood zoning.** The DRRS Team recommends updating the methodology for the identification and management of flood hazard areas. Currently, the law includes a buffer zone of 50 m from the riverbank with restrictions for development, but this zone has no physical basis and is not being enforced. A modeling-based delineation of flood hazard areas is proposed as a more appropriate method for the delineation and management of flood prone areas. The Water Law should impose development restrictions based on these model outcomes and introduce a permitting system for developments in flood prone areas, managed by the respective river basin authorities.

2. **The DRRS team recommends assessing a more prominent role for the Water Agency in developing water related policies and laws.** At the national level, water resources are managed by the Water Agency, which operates under the Ministry of Environment and Climate change. The Water Agency plays a critical role in managing, regulating, and preserving the country's water resources, as outlined in the National Integrated Water Resources Management Plan, developed in 2013 with support from the Netherlands. Its responsibilities encompass multiple aspects of water governance, including monitoring, regulation, and enforcement of water use policies. The agency's role and functions are established under the Water Law of Mongolia.

3. At the basin level, the **Tuul River Basin Authority (TRBA)**, established under Mongolia's Water Law, plays a crucial role in managing water resources within the Tuul River Basin, ensuring the sustainable use and protection of these resources. One of its primary responsibilities is to enforce the Law on Water, including the prevention of illegal encroachment along the riverbanks and other protected areas surrounding the river. Given the many examples of illegal developments in the river floodplain, it can be concluded that the enforcement of the Water Law falls short.

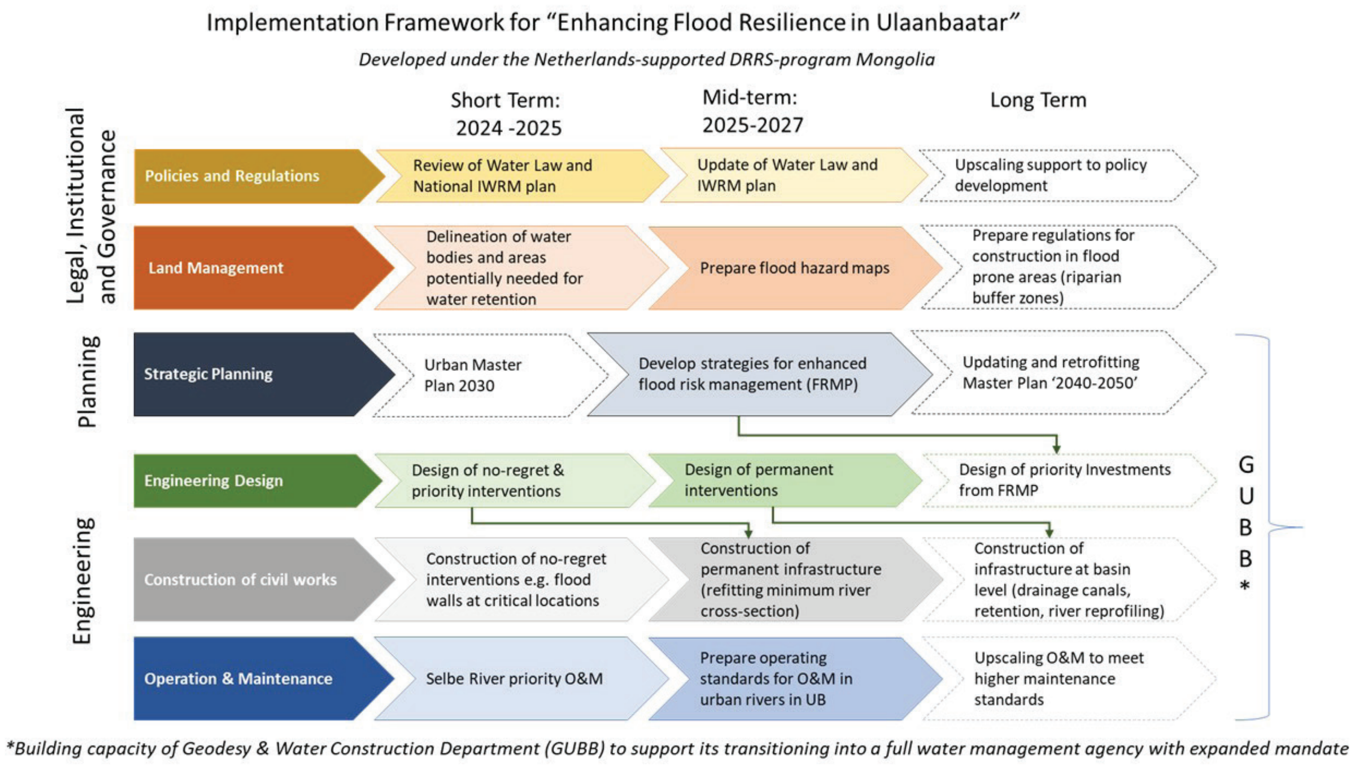


Figure 40: Strategic Framework on Urban Flood Resilience in Ulaanbaatar

4. **It is recommended to build capacity of the Geodesy and Water Construction Department (GUBB) and support the transitioning of the GUBB to become a full municipal water resources authority.** Ulaanbaatar currently lacks a dedicated municipal water authority that can effectively coordinate with key departments such as Transport and Urban Planning on water-related planning, including issuing permits for construction in flood-prone or protected areas under the Water Law. The authority's mandate would encompass a planning wing, a design wing, and a Construction and Operations & Maintenance (O&M) wing. Additionally, a hydro-informatics wing could function as a knowledge broker, processing climate and hydrological data crucial for managing Ulaanbaatar's rivers. Currently, the GUBB partially fulfills the role of a water authority, but its mandate is largely limited to engineering/O&M and, to a lesser extent, design and planning. As a result, departments like the Urban Planning Department lack a counterpart for coordinating urban development in flood-prone areas.

6.2 Planning: Integrated Urban Flood Risk Management Plan

5. **Lack of coordination in the planning of urban areas affecting the functioning of water systems and water related infrastructure is considered one of the largest constraints to the development of UB as a climate-resilient city.** During the visit, the DRRS team observed strong support for developing an Integrated Urban Flood Risk Management Plan (IUFRMP) for Ulaanbaatar. This plan would form the foundation for identifying medium- and long-term flood-resilient development pathways, ultimately leading to a comprehensive investment program. The IUFRMP should adopt a 'catchment-based approach,' addressing not only solutions to increase discharge capacity in the city but also measure to increase the (natural) retention capacity of the upper catchment of the Tuul River's tributaries, such as the Selbe and Uliastai Rivers. This comprehensive approach ensures that measures are implemented at all levels within the catchment, contributing to flood resilience across various zones, from the ger areas to the downtown Central Business District (CBD). This strongly limits the need for very expensive and often disruptive measures in the CBD where limited space is available to accommodate excess flood water.

6. Drawing on the planning principles outlined in the Urban Master Plan 2040, it is recommended to develop a more comprehensive Integrated Urban Flood Risk Management (IUFRM) Plan, similar to other sector plans. While the Urban Master Plan 2040 provides a framework for urban planning, including the role of water in the city, it lacks integration with the river basin management and flood-related management issues. To address this gap, it is advised to prepare basin-wide Integrated (Urban) Flood Risk Management Plans (IUFRMPs), led by a newly established Municipal Water Authority in close collaboration with the Tuul River Basin Authority. The recommendation for an IUFRM plan aligns well with the World Bank's Transport Project technical assistance on flood risk mapping [JBA, 2024], offering a timely opportunity to strengthen coordination and planning across sectors and administrative levels.

6.3 Infrastructure Improvements

7. **The February DRRS visit recommended to scale up the maintenance of critical stretches of the Selbe River where flooding occurred during the 2023 floods.** Years of neglected maintenance has led to the deposition of a thick layer of sediment and uncontrolled growth of vegetation in the river channel, drastically reducing the discharge capacity of the river during flood events. Following the visit, GUBB has excavated approximately 180.000 tons of sediment from the Selbe river in 2024, resulting in a lowering of the riverbed in some stretches by 1.2m. The recent excavation of the channel in the most critical reach of the Selbe River near the former S-Outlet, has undoubtedly enhanced flood safety.

8. **While the urgency of river maintenance is unquestionable, the planning and communication of these works require greater attention and better preparation.** The DRRS team observed extensive excavation activities that lacked a clear plan for achieving (and verifying) the target cross-section, and the use of various individual contractors with limited experience in river environments. Additionally, there was a lack of public communication regarding the necessity of the maintenance, leading to social media backlash over perceived "environmental destruction." While vegetation is a natural part of a river system, Ulaanbaatar's tolerance of vegetation and consequently the excessive narrowing of the river profile has significantly compromised flood conveyance.

9. **MoUB has expressed interest to pilot the installation of anti-erosion structures (so-called Gully Plugs) in active ephemeral channels in the headwaters of the Selbe River.** The construction of 'gully plugs' could provide an effective contribution to the management of downstream siltation, while simultaneously reducing flash flood risks in Ger areas. Ephemeral channels are temporary watercourses that only carry water and sediment during rainfall events. As surface runoff flows downhill, it concentrates in depression areas and forms small streams and gullies, particularly in regions with sparse vegetation and easily erodible soil. Gully Plugs, typically constructed as small, temporary, or permanent cross dams, could play a crucial role in reducing flow velocity and trapping debris and sediment moving downstream in actively eroding headwater basins.

10. For this, GUBB will select suitable locations to pilot the installation of "Gully plugs" and engage with local communities to seek their willingness to participate in the pilot. Community participation can help to raise awareness of the potential danger of flash floods and blockage of drains. The DRRS team can serve as backstopping support to answer questions and review the 'design'. In Annex II, technical recommendations are provided for the installation of gully plugs.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07

RECOMMENDATIONS

7. RECOMMENDATIONS

Floods are natural phenomena in a river system and do not necessarily cause problems if no assets are located in the flood zone. This principle applies to most river systems in Mongolia, where human activity is absent in the river's flood zone. For urban rivers, it is necessary to protect the city against floods and provide enough space for the river to safely discharge its floodwaters. Many large global cities have struggled with this balance, as the need for development space often dominates the political agenda. Ulaanbaatar is no different in this regard.

What sets the situation in many global cities apart from the situation of Ulaanbaatar at this moment is the government decision to change course and halt further encroachment of the river system and shift to providing more space for the river, while embracing the river as a green-blue corridor in an urban environment. Employing modern tools such as hydrodynamic models, satellite imagery, and real-time data acquisition equipment will help to better understand the behavior of the river system and quantify flood risk in terms of the potential social-economic damage in the event of a flood. This understanding can help to establish a flood safety level that aligns with acceptable levels of flood risk, considering the social and economic activities that need protection. Effective regulations and policies can then be developed - and must be enforced - to ensure the necessary investments in flood protection and maintenance are made and to stop further encroachment of the river.

Floods in Ulaanbaatar can be closely linked to past developments affecting the river floodplain and catchment hydrological functioning. In recent years, the river has been significantly regulated and its cross-sectional profile narrowed due to the continuous demand for land for constructing buildings and roads. Similar changes have occurred throughout the river catchment, with an increasing area of paved surfaces and a loss of natural storage capacity due to the expansion of Ger areas.

While mitigating measures such as local retention ponds, reservoirs, and levees along the riverbank have had some success, a larger effort is needed in terms of maintaining existing infrastructure and investing in new infrastructure to improve the flood situation in Ulaanbaatar. However, investments in infrastructure alone will likely not suffice. A course change towards integrating Ulaanbaatar's river and water system within the overall urban planning is needed to provide long-term sustainable solutions.

The DRRS team concludes that Ulaanbaatar is at a crossroads regarding its approach to urban flood risk management. There is a unique opportunity to adopt a new approach to integrating the river within the urban environment and leveraging its potential to help Ulaanbaatar become a modern, flood- and climate-resilient Asian city. This will require a different strategy that incorporates the interests of the entire range of stakeholders, considers the river at the catchment level, and seeks multi-purpose uses for infrastructure investments, among other considerations. Adopting lessons learned from other global cities will help Ulaanbaatar avoid costly mistakes and benefit more from 'single purpose' investments earmarked for city development.

7.1 Recommendation to revisit the implementation of the Selbe Revival Plan

During our visit, the DRRS team was requested to review the Selbe Revival Plan as part of our work. The principles of the Selbe Revival Plan are provided in Textbox 1. On June 5, 2024, a letter was sent to the Governor of Ulaanbaatar City to address the DRRS team's concern with regards to some of the design principles behind the Selbe Revival Plan.

While DRRS commends the MoUB for taking decisive action to immediately improve flood safety in Ulaanbaatar, the selected design raises several serious concerns, which we feel, requiring additional considerations. In short, our main concerns are:

- **Sustainability and effectiveness of the design:** The proposed design's effectiveness is uncertain, due to the rivers natural tendency to return its current state and the associated high maintenance requirements for managing siltation in the riverbed.
- **"Room for the River":** To assure robust flood risk reduction, international best practices in river management advocate for providing more horizontal space for the river to accommodate higher discharges, rather than further constraining the river width for road construction. Such constraining measures increase the risk of sudden and more devastating flood impacts.
- **Loss of multifunctionality of the river:** Upon completion, the proposed design would essentially replace the current natural river system with a 5-7m deep concrete drain, eliminating existing and future opportunities for multifunctional use. This change would deprive urban communities of crucial river benefits such as leisure, biodiversity, and green space.
- **River basin approach:** Solving the flood risk issue entirely within the already limited space of the Selbe River in downtown Ulaanbaatar is unrealistic. A combination of measures at the city and river basin scale is recommended to assure effective and sustainable solutions that meet national and international standards.

In conclusion, the plan is likely to only provide a temporary solution. It does not follow international best practices in integrated (urban) water resource management (IWRM) and planning, which is essential for achieving Ulaanbaatar's ambition to develop into a climate-resilient Asian capital. Examples from other global cities (Singapore, Seoul and Utrecht (The Netherlands) are included in Annex III of this report.

The DRRS team recommends that GUBB conduct a geotechnical stability assessment of the newly constructed flood walls. The team observed potential stability issues due to the absence of a piping screen beneath the structure. The base of the concrete flood walls is in some cases positioned above the level of both the adjacent road and the river channel, raising the likelihood of a net positive subsurface flow between the river and the road during high flow conditions. Piping occurs when small soil particles are carried with the subsurface flow, creating hollow channels or "pipes" underground. When these pipes collapse, they can cause the overlying structure (i.e., the flood walls) to sink. Piping is typically prevented by installing a vertical screen beneath the structure to extend the path of the subsurface flow, but no such screen is installed or currently foreseen. The DRRS team strongly recommends that GUBB assess the risk of piping and implement appropriate technical measures if the risk is found to be significant.

7.2 Recommendations regarding annual river maintenance – short term

What can MoUB do to immediately improve flood safety in Ulaanbaatar?

Flood safety can immediately be improved by undertaking maintenance measures within the riverbed (maintenance dredging/excavation and vegetation maintenance) at low costs. On the longer term, measures such as removal of obstacles (low clearance bridges), the construction of permanent levees and realization of extra storage capacity upstream will further enhance flood safety. Such measures should be integrated with efforts to strengthen sustainable urban planning and resilience.

Following recommendations from the DRRS team in February 2024 to immediately enhance the discharge capacity of the Selbe in the downstream reach, GUBB has taken adequate action by removing silt and relocating trees. While the DRRS team acknowledges the challenges posed by the short construction season, several observations highlight areas needing improvement to prevent social unrest as has happened during the 2024 construction works:

- **Enhance the qualification requirements for attracting construction companies.** The 2024 maintenance work was outsourced to construction companies with limited experience in river maintenance.
- **Interventions appear ad-hoc and lack proper planning.** Silt excavation seems to occur randomly, often during periods of high river discharge, making it difficult to assess effectiveness and resulting in inefficiency and unnecessary damage to the river system. Trees and bushes were removed without prioritizing those causing the highest flow obstruction, leading to unnecessary removal of valuable urban green.
- **The DRRS team emphasized the importance of effective communication regarding maintenance work, particularly concerning the sensitive issue of tree and bush removal.** While communication currently includes newspaper articles and interviews, the rationale behind these activities could be better articulated. This could be achieved through on-site communication panels or by creating a website that provides comprehensive, user-friendly information. Displaying images of indiscriminate vegetation destruction is counterproductive and should be avoided.

Construction activities in the Selbe River ongoing Revival plan

7.3 Recommendations on Governance and Planning aspects – medium term

The DRRS team has formulated the following non-structural recommendations aimed at **enhancing MoUB's effectiveness** in addressing UB's flood risk on the medium term:

1. **Ulaanbaatar must adopt a systematic approach to effectively address flood risk,** moving away from ad-hoc investments and reactive emergency measures (ice and sediment removal, excavation of river) that do not reduce flood risk but only mitigate adverse flood effects. Over the longer term, carefully planned investments in flood adaptation will yield a multitude of economic benefits as compared to ad-hoc investments to mitigate the consequences of a flood.

2. **Immediately halt further encroachment of floodplains to prevent further worsening of UB's flood risk.** The Governor's Office should take an active role to ensure existing regulations on construction restrictions in floodplains are enforced as per the legal provisions on buffer zones in the Water Law. The unprecedented scale at which developments in the floodplain are now tolerated, have already compromised the Flood Safety level of Ulaanbaatar, in favor of short-term financial gains of individual investors. A full stop on further encroachment of river floodplains and retention systems have a higher return on investments through flood reduction but will become exponentially more expensive when available space for implementation is further constrained.

3. **Prepare and endorse a multi-annual investment plan on water, sediment and flood risk management** that facilitates a step-wise implementation of urban flood risk management infrastructure (pluvial & fluvial flooding) and prevents ad-hoc interventions that are costly and have only short-term impact (such as temporary levees).

4. **Establish a coordination entity within MoUB, with the Geodesy & Water Construction Department (GUBB) in the leading role to streamline coordination of developments in the city that affect UB's water system now and in the future.** This entity will streamline collaboration among key departments to oversee developments affecting Ulaanbaatar's water system (roads, bridges, land management), and prevents the cause of lock-ins that compromise possibilities for construction of effective flood management systems in UB.

5. It is recommended to assign an independent governing body such as the Water Agency, or a newly established (technical) advisory board composed of relevant (national and perhaps even international) experts to oversee the activities of GUBB and advise on decision making regarding the planning and management of Ulaanbaatar's flood and water management infrastructure.

6. To maximize the output gained from the DRRS mission, and provide immediate relief with regards to flood risk, the GUBB must get access to funds and professional personnel to implement emergency actions as identified by the DRRS team and agreed by MoUB.

7. **Launching a community awareness campaign to inform people about the implications of throwing garbage in flood gullies and channels.** The MoUB is requested to upscale solid waste management by placing trash bins and/or assign dedicated garbage collection points at locations where it will not cause potential problems in the drainage network.

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ANNEX I: Official Request

МОНГОЛ УЛС
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НИДЕРЛАНДЫН ЭДИЙН ЗАСАГ, УУР АМЬСГАЛЫН ЯАМНЫ ХАРЬЯА ХӨГЖЛИЙН АГЕНТЛАГИЙН ҮЕРИЙН МЕНЕЖМЕНТ "ГАМШГИЙН ЭРСДЭЛИЙГ БУУРУУЛАХ ХӨТӨЛБӨР"-ИЙН АХЛАХ МЭРГЭЖИЛТЭН НОЁН АЙССЭ ВИЖМА ТАНАА

Хамтран ажиллах тухай

Юуны өмнө эрхэм хүндэт Айссэ Вижма таныг манай улсад хүрэлцэн ирж, нийслэл Улаанбаатар хотод болсон үерийн хор уршиг, усны барилга байгууламжийн ажлуудтай танилцаж, "Үерийн сургамж, шийдэл" хэлэлцүүлэгт оролцож үнэтэй саналаа хэлж, илтгэл тавьсанд дахин талархал илэрхийлье.

Та бидний 2023 оны 10 дугаар сарын 27-ны өдөр хийсэн уулзалтын мөрөөр Улаанбаатар хотын инженерийн бэлтгэл арга хэмжээний хүрээнд барилга байгууламж, далан суваг, зам талбайн борооны болон хөрсний усны түвшин бууруулах шугам сүлжээний чиглэлээр урт, богино хугацааны зөвлөмж ирүүлж, хөрөнгө оруулалт шийдвэрлэхэд дэмжлэг, туслалцаа үзүүлэхийг үүгээр дахин хүсье. Бидний хоёр талын хамтын ажиллагаа бодит ажил хэрэг болно гэдэгт итгэлтэй байна.

Мөн цаашид төсөл хөтөлбөр, сургалт зөвлөгөөн, туршлага хуримтлуулах ажлуудын хүрээнд урт хугацаанд хамтран ажиллах хүсэлтэй байгааг энэ ялдамд илэрхийлж байна.

Танд эрүүл энх, сайн сайхныг хүсэж, дахин уулзахын ерөөл дэвшүүлье.

НИЙСЛЭЛИЙН ЗАСАГ ДАРГА
БӨГӨӨД УЛААНБААТАР
ХОТЫН ЗАХИРАГЧ Х.НЯМБААТАР

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ANNEX II: Design principles for erosion control measures "Gully Plugs"

Where is the sediment coming from?

To reduce sediment input into river systems, especially into the confined urban river channels, it is crucial to understand where the sediment is coming from. Effective measures can only be implemented when sediment sources are well identified. This requires a basin-wide approach to assess the contributions of different headwater streams and the dominant erosion processes. Which tributary (sub-)basins contribute most to river sediment input? These basins can be identified by qualitative approaches (considering slope, land cover, etc.), 2D modelling, and, most importantly, field measurements. Measurements of topographic changes (in the form of digital elevation models, or, more simply, gully extent mapping) and sediment loads in the river provide insight into where the sediment comes from and provide a record of changes in sediment supply over time. These changes may be due to the evolution of land use or local mitigation measures, whose effects need to be monitored and verified for maintenance purposes and future implementation (in other subbasins).
Which are the key processes that drive erosion and sediment transport? It is not well known to what extent sediment in the river systems originates from hillslopes, gully systems, human construction activities, etc. During the field visit with experts on 12/09/2024, evidence from active erosion was observed along gully walls and rill/gully formation in unpaved roads that lie perpendicular to the hillslope.
Which measures are appropriate?
To mitigate sediment influx into the rivers the following strategies can be followed:

1. Stopping erosion at its source;
2. Reducing sediment transport capacity and retaining sediment within the tributary basin;
3. Intercepting sediment at the tributary basin outlet.

Although a multitude of measures are possible, we considered the following measures associate with the strategies above: (1) planting of trees and stimulating natural forest development; (2) installing grade-control structures, in particular gully-plugs; and (3) installing sediment retention basins. Which measures are most appropriate depends on a multitude of factors, including locally available space or footprint, costs of installing and maintenance, effect on flood wave propagation and risk of failure, etc.

From the field visit it was clear that the adjacent headwater basins with and without tree cover showed large differences in erosion and sediment transport (Figure 40), implying a strong control of trees on gully erosion through the stabilization of gully walls. It is highly recommended to verify this stabilization effect in the wider catchment and to align the ongoing national campaign to plant 1 billion trees by 2030 (Mongolia's One Billion Trees Campaign: A Bold Step Against Climate Change and Desertification – Institute for Strategic studies (iss.gov.mn)) with gully-control practices. In addition, the role of grazing on tree establishment in tributary basins is to be investigated. The presence of natural or planted tree cover has an added advantage that the land is less susceptible to urban expansion.

For the mitigation of erosion in highly erodible gully systems, a pilot study to test the installation of 3-4 gabion gully plugs was agreed upon. These structures will allow the reduction of the sediment transport capacity of the flow (through the effective reduction of the flow gradient) and capture sediment within the gully (upstream of the plugs).

Figure 41: Examples of vegetated (top) and unvegetated (bottom) tributary basins and gullies in 15 khoroo, north of UB.

Gully plug design

The general design of gully plugs can be broken down into two main steps:

1. Cross-sectional design of gully plugs: The cross-sectional design of a gully plug (typically trapezoidal, Figure 2 left) is set by a design discharge (e.g., based on a runoff formula that accounts for basin size and rainfall intensity) and the discharge capacity of the gully plug spillway (based on the width, height and discharge coefficient of the proposed spillway). For example calculations, see FAO watershed management field manual - Gully control, section 2.6. It is critical that the gully plug has sufficient discharge capacity such that the flow remains in the spillway and does not erode the flanks of the gully at the location of the structure. Geotechnical rules of thumb associated with the construction of gabion gully plugs be found in the previously mentioned field manual, section 3.8; it is recommended to use a robust design for the construction in the pilot study.
2. Along stream placement of gully plugs: Along stream placement of gully plugs: Gully plugs are installed in succession, creating a stepwise long profile (Figure 41 right). The toe of an upstream gully plug is to be located at the same height as the spillway crest of the successive plug (i.e., a gradient of 0%; a minor downstream gradient may be possible in some instances but is discouraged in this case due to the fine nature of the sediment and pilot character of the study). The higher the gully plug spillway, the larger the sediment storage capacity behind the plug and the larger the distance between successive gully plugs. At the downstream toe of the gully plug, scour protection is required over a distance of at least 1.5 times the gully plug height. For along stream placement, individual plugs are preferably located in a straight gully section with constant width and gradient.

For the test pilot of the gully plugs a gully reach was provisionally selected in the unvegetated basin that is accessible by dirt road, yet at some distance from the nearest human settlements (Google Maps). It is important to stimulate ownership within the local community, as these structures contribute to erosion and flood control, and to engage them in the monitoring and maintenance of the gully plugs.

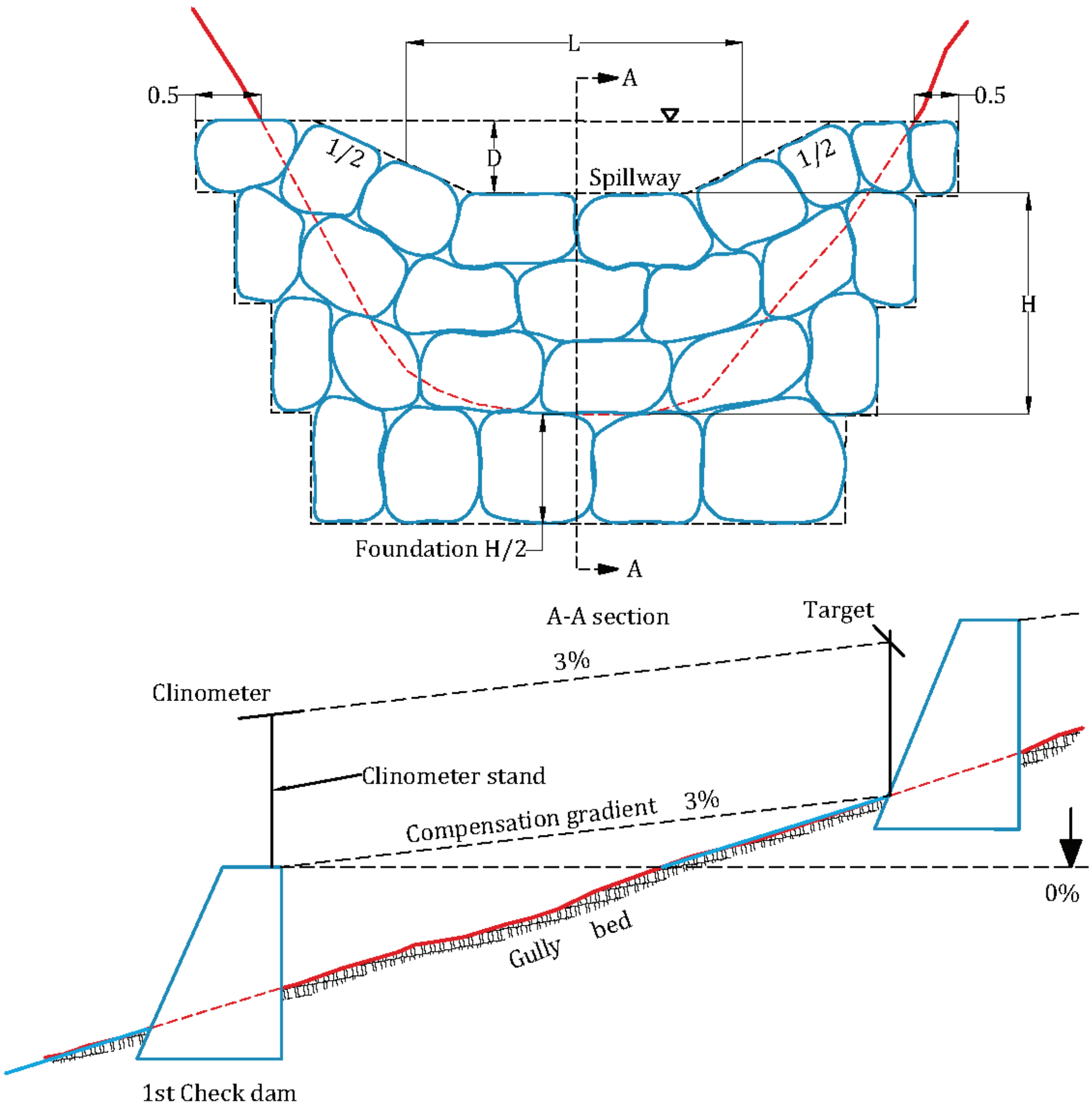


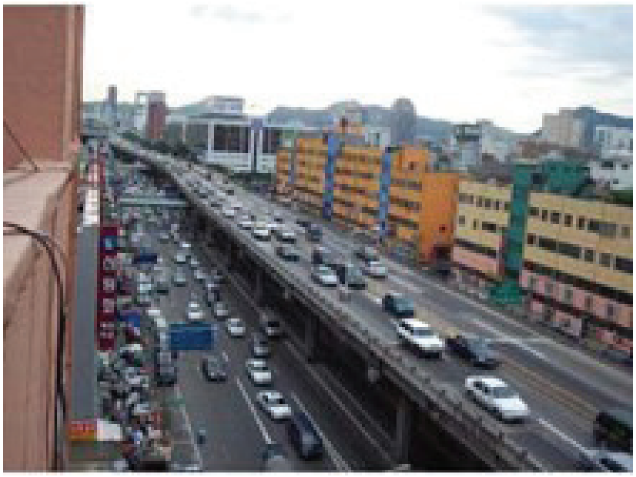
Figure 42: Schematic cross-section of a gully plug (top) and long stream succession of gully plugs (bottom). (Sustainable Sanitation and Water Management Toolbox)

ANNEX III: Examples of river rehabilitation in Seoul, Singapore and Utrecht

Seoul, Korea – Cheonggyecheon stream restoration project

The transformation of the Cheonggyecheon River in Seoul, from an outdated utilitarian highway into a multipurpose, performative infrastructural landmark, stands as a seminal project in contemporary urban design. This remarkable achievement revitalizes the city's biological and social ecology, showcasing the profound ability of urban-scale design to provoke positive transformation across large areas. The project signifies a broader shift in Asian urban design attitudes, moving from a growth-focused quantitative model to a qualitative approach that integrates quality of life, with flood risk management and environmental sustainability into economic development strategies.

https://www.landscapeperformance.org/case-study-briefs/cheonggyecheon-stream-restoration-project
https://udcsa.gsd.harvard.edu/projects/9



Singapore – Bishan Park – stream restoration project

Bishan-Ang Mo Kio Park is one of the most popular parks in the heart of Singapore. Its popularity came after community improvement plans upgraded the park, including transforming its 2.7 km straight Kallang concrete channel along the park's edge into a semi-natural winding river.
The 62 hectares of park space was uniquely redesigned to accommodate the dynamic processes of the river system (including fluctuating water levels), while also providing a relaxing and lush natural environment for visitors to enjoy a break from the bustling city life. To create healthy park ecosystems that provide cost-effective alternatives to traditional 'grey' infrastructure, the Architect used nature-based green and blue infrastructure solutions.

https://www.ramboll.com/projects/water/bishan-park-singapore-nature-for-all
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Utrecht, The Netherlands – Catharijne Singel canal rehabilitation project

Catharijne Canal is the final piece of the restoration of the Utrecht city ring canal. This has undone the controversial transformation of more than 50 years ago into a city highway, after the local population had voted in favor of the proposal for rehabilitation in a referendum in 2002.

Commissioned by the municipality of Utrecht, OKRA landscape architects drew up the design as part of the renovation of the railway station area. In addition to reintroducing water in the city centre, it was also decided to extend the 19th-century city park around the historic city center up to Hoog Catharijne, the busiest shopping mall in the Netherlands. For the design, the office created a strategy for the historic city center in which the canal serves as the basis for making it climate adaptive. Important ambitions were also increasing social and ecological inclusiveness and boosting the mobility transition. (source: https://arqa.com/en/architecture/catharijnesingel-utrecht-channel.html)