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TERESA

Urban Water Management: German Expertise for Kazakh Cities

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Deliverable D2.1

Report of characteristics of study area
Hydrogeological characterisation of the project site
at Taldykol lake system in Nur-Sultan, Kazakhstan

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SUMMARY

Within the TERESA project a virtual city model for an urban Kazakh environment will be developed using numerical simulation software. To develop the virtual city model, the Yesil district as was chosen an exemplary district in the city of Nur-Sultan to be replicated in the modeling environment.

Because of the rapidly growing population of Nur-Sultan, the Yesil district is planned to be used for the expansion of of the city and has been subject to intensive construction work. Historically, the area had been characterised by waterlogging and the formation of temporal and permanent water bodies due to surface runoff from meltwater and storm events. Recently, the area had been partially drained and levelled by discarding solid materials into the smaller water bodies. Only one of the local lake system will be kept according to the development plan of Nur-Sultan.

This deliverable presents a comprehensive summary of the hydrological and hydrogeological characteristics of the chosen district. It comprises information on the topographical and lithological characteristics as well as relevant meteorological data. The local hydrological situation is described by detailed presentation of relevant local water bodies (rivers, lakes and groundwater). This is concluded by an estimation of the local natural water balance as well as a compliation of known technical water balance components.

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ACKNOWLEDGEMENTS

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1. GENERAL

Sustainable urban drainage solutions (SUDS) support urban flood risk management by providing (temporal) water storage and by enlarging the area for rainwater infiltration. Through the intentional recharge of the aquifers (managed quifer recharge = MAR) with the collected and retained water, time-shifted reuse of stormwater for urban needs such as irrigation of green areas during summer can be achieved.

To support Kazakh stakeholders with designing and adopting such sustainable urban water management solutions, the project will develop a virtual city model using numerical simulation software. The model will focus on scenarios-based assessment of engineered and natural water balances in selected areas of Nur-Sultan city by replicating existing urban developments in Nur-Sultan. The expected outcome of the project is a flexible planning tool for conceptualization of “digital twins” of urban water management systems that enables future urban development and sustainable management of water resources.

To develop the virtual city model, the Yesil district in the city of Nur-Sultan was chosen as a a pilot area for exemplary replicaton in the modeling environment. The area was selected as it is partially undeveloped, thus, offering to oppportunity to include SUDS and MAR structures into the cities master plan for urban development. While a model for the wider Yesil district is envisioned in the scope of this project, model development will start with the realization of a smaller pilot area.

The pilot area is located in the capital of Kazakhstan, Nur-Sultan (Figure 1). It is situated in the Yesil district at the left bank of the river Yesil. between the Taldykol reservoir in the West and Turan Avenue in the East The approximate coordinates of the pilot area are 71°23’E 51°05‘30‘‘N. The area is close to the campus of Nazarbayev University and it was planned to be used for future construction of university buildings (Nazarbayev University Science Park). There are plans to landscape the area to the west with the Taldykol reservoir into a park for recreational purposes (Figure 2).

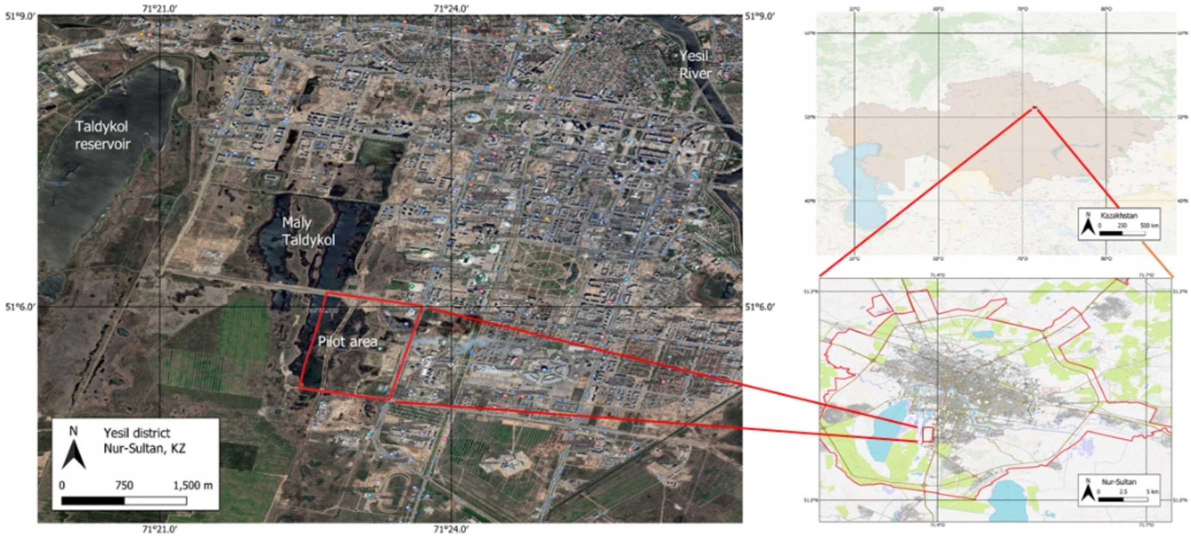


Figure 1. **Pilot area location in the Yesil district, Nur-Sultan, with labelling of Talkdykol reservoir, Maly Taldykol lake system and Yesil river**

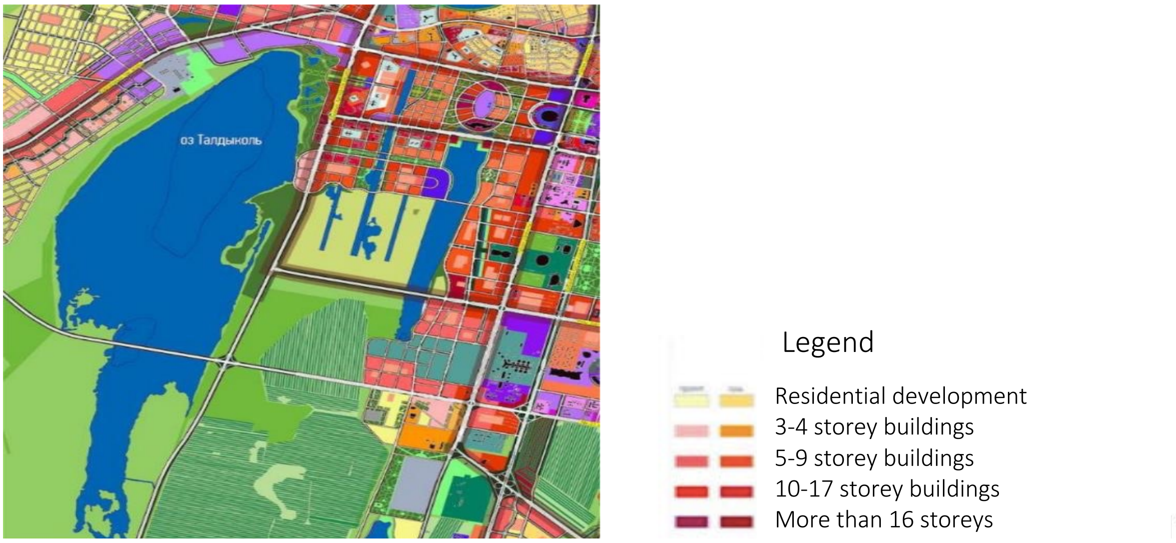


Figure 2. Master plan of the future development of the Taldykol area (Kazakhstani Chamber Environmental Auditors, 2021)

The Yesil district is planned to be used for the expansion of Nur-Sultan and has been subject to intensive construction work. The area has been ongoing some changes in the past years. In 2017/2018 the Turan highway in the east was developed. The Syganak highway in the north of the area has been built in 2020 and diverts the Maly Taldykol into two bigger lake bodies. The area was partially drained and levelled by discarding solid materials into the smaller lakes. Only a minor part of the small Taldykol lake system will be kept according to the development plan of Nur-Sultan (Figure 2). Recently, conflicts have been arising in Nur-Sultan, as parts of the lake area that were planned to be kept (according to the development plan), had already been filled by construction companies. This has been met by wider protests of the local community and scientists of various areas (Kolosovskaya, 2021).

The public concern was driven by the assumption that the lakes have a considerable ecological function in addition to its hydrological one. The Taldykol lake system is a habitat for a variety of animal and plant species. The vast majority of the local invertebrate fauna is aquatic, semi-aquatic and grassland species, in areas with less moisture they are joined by species typical of other landscape zones - forest-steppe, steppe and anthropogenic landscape (Kazakhstani Chamber Environmental Auditors, 2021). During the study in 2020, on the Small and Big Taldykol 55 species of vertebrates, including 2 species of bonefish, 1 species of tailless amphibians, 41 species of birds, 11 species of mammals belonging to 27 families were found (Kazakhstani Chamber Environmental Auditors, 2021). It is worth noting that in addition to the urban fauna (resident), migratory species were recorded in the bird species composition, which is explained by the autumn migration of birds (Kazakhstani Chamber Environmental Auditors, 2021).

While the city council of Nur-Sultan has been open to listen to the public concern about the environmental functions of the lakes, its focus is on housing and infrastructure development. Nur-Sultan is a rapidly growing city. While the population was 1.1 million in 2017, it is projected to reach 2 million inhabitants by 2050 (Asian Development Bank, 2018). Since population and economy have been growing rapidly, there is a big interest in further developing unused areas of the city council. This goes along with enhancing the existing infrastructure to meet the growing demand, thus, the city council has been investing into the water infrastructure since 2009, namely into the construction of flood dykes, wastewater treatment plants and water supply networks.

2. LAND USE AND TOPOGRAPHY

The city of Nur-Sultan is situated in the steppe of Middle Asia. Thus, the vegetation comprises mostly of higher grassland (tussock herbs, motley grass) and in the marshland Cyperaceae vegetation is dominant. The pilot area is located in marshlands in the south-west of the city.

The area is located in a plane part of the city situated between the river Yesil in the north and the Nura River to the south. There are little to no slopes, the soil surface lays between 342 and 344 m above sea level. As shown in Figure 3, there is a gentle slope from the north-west to the east of the city, with the highest elevations being north of the river Yesil and lower terrain towards the eastern part of the city. There is little slope in the north-south cross section. However, the area is characterized by local depressions.

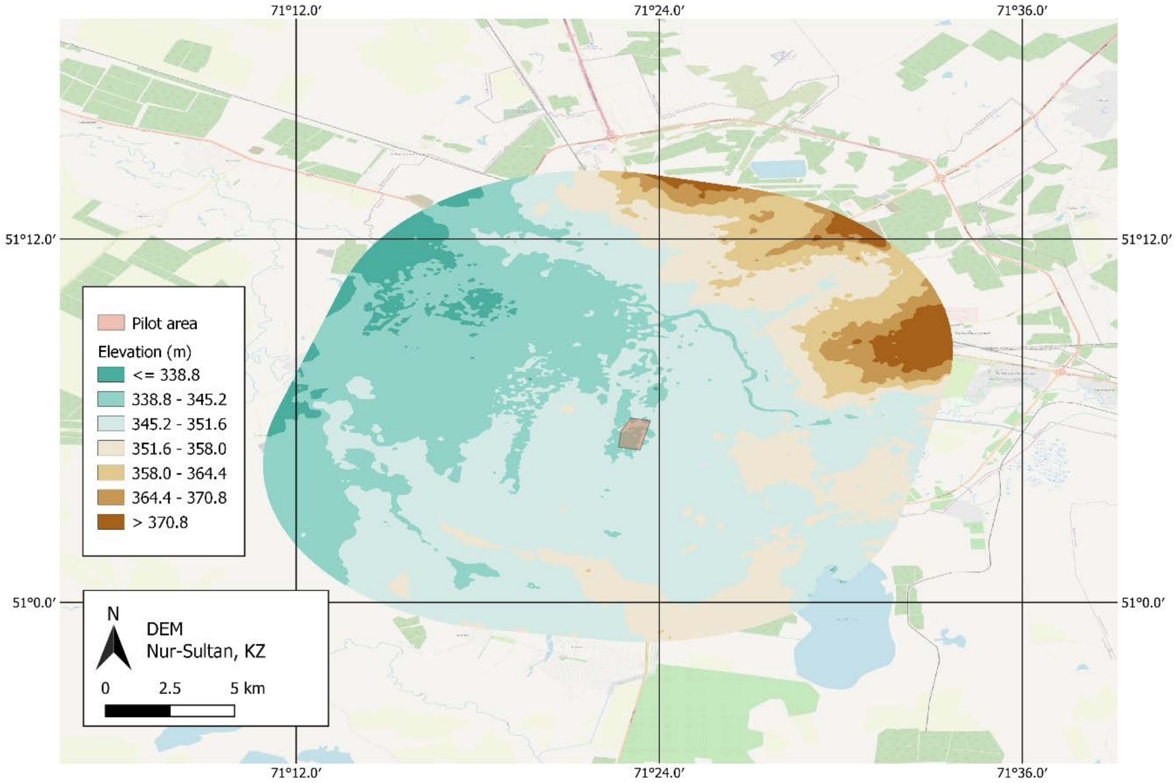


Figure 3. Digital elevation model of Nur-Sultan, pilot area marked in red (in the centre of the figure)

The geomorphology of Nur-Sultan is dominated by flood and peneplain areas. The pilot area lies within the low flood plain of the south-western part of the city, which is characterized by alluvial sand and silt clay and is waterlogged (Figure 4). The eastern part of the area borders with the river terrace geomorphology class which consists of fluvial sediments (middle-upper Quaternary sand, clayey sand and clay) (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001).

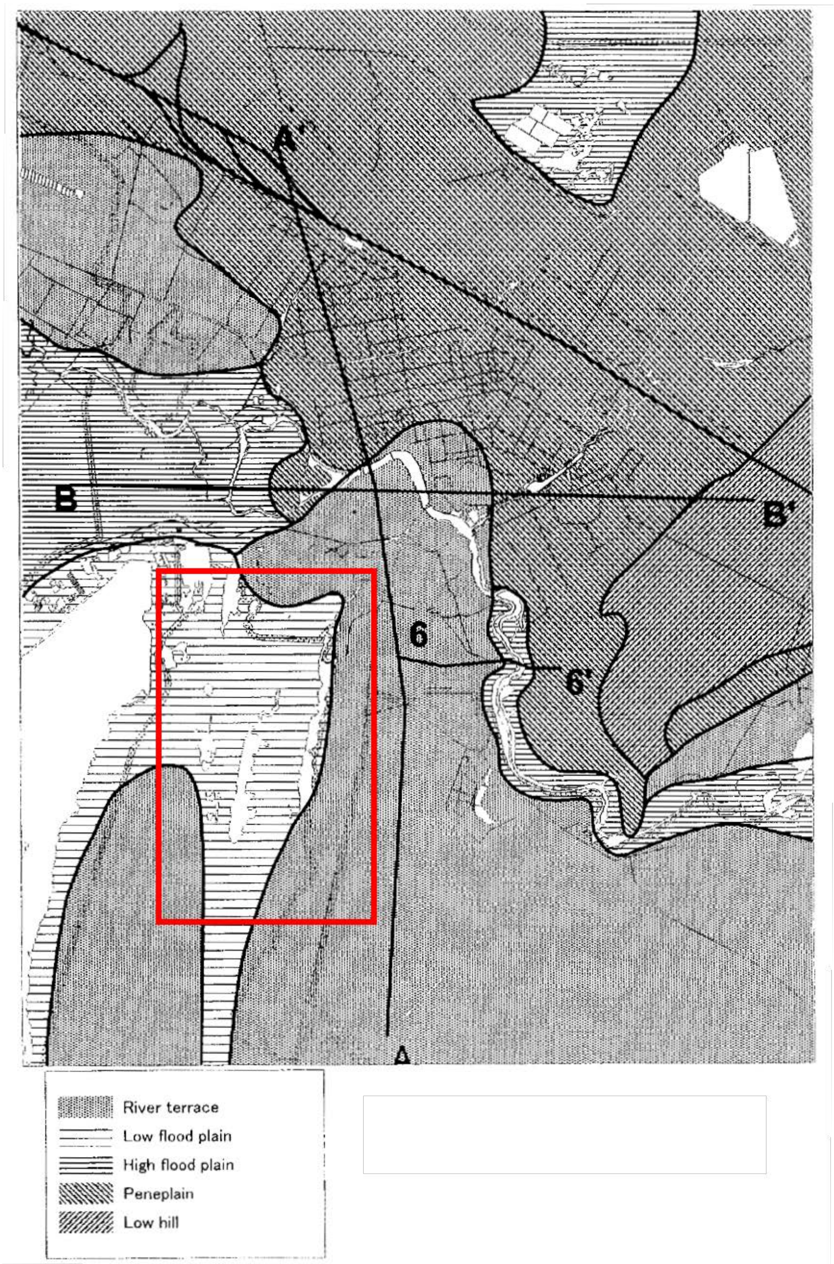


Figure 4. Geomorphological map of Nur-Sultan with pilot area marked in red
(Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001)

3. HYDROGEOLOGY

3.1 GEOLOGICAL STRUCTURE

The area is characterized by a bedrock of siltstone, sandstone and limestone from the Palaeozoic. It is located at a depth of 15-25 m below surface. These are overlain by Palaeogene clays, weathered strata of loam and Quaternary sediments along the river courses (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001).

In Figure 5 the pilot area is characterized further. The lower flood plain, which makes up most of the area, has a lithology comprising quaternary sands and muddy clay. The part of the area that is characterized as river terrace, is partly clay, loam and clayey sand up to a depth of 4-7 m with sand of various sizes below (type a_1^6, Figure 5), partly loam up to a depth of 2.5-4.7 m with underlying sand of various sizes (a_1^2, Figure 5) and partly sand up to a depth of 1.5-3 m with a clayey soil below (type a_1^7, Figure 5).

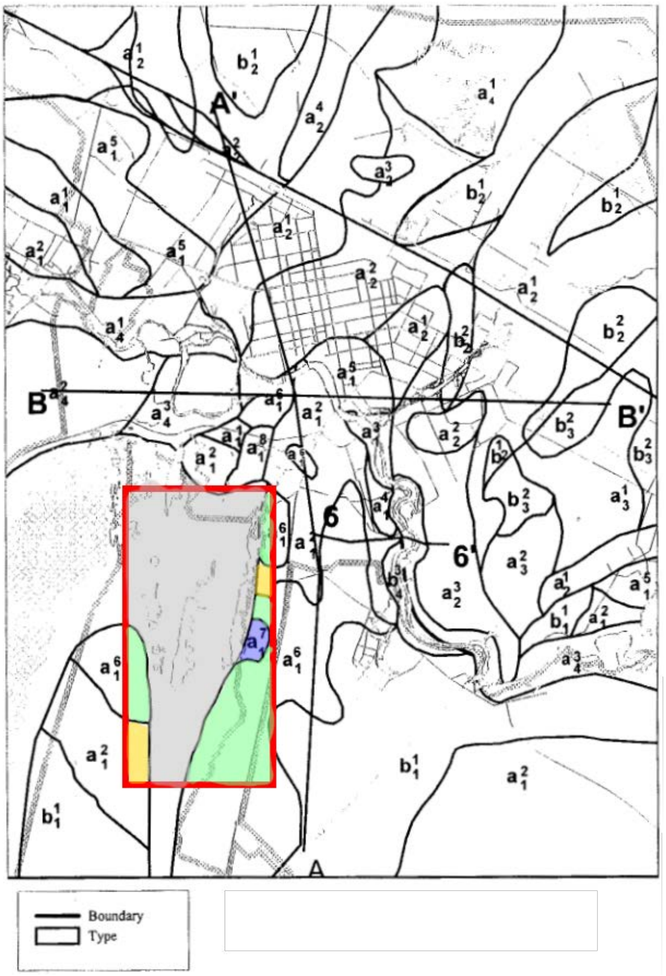


Figure 5. **Geo-technical map of Nur-Sultan with pilot area marked in red and geology type a_1^6 (green): clay, loam and clayey sand up to a depth of 4-7 m with sand of various sizes below, a_1^2 (yellow): loam up to a depth of 2.5-4.7 m with underlying sand of various sizes and type a_1^7 (purple): sand up to a depth of 1.5-3 m with a clayey soil below. Grey areas mark the low flood plain. (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001)**

The low flood plain area has been described as unsuitable for construction from geo-technical and financial viewpoints as its exploitation would require flood control, surface and subsurface drainage as well as reclamation (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001). Nevertheless, recent years have shown intensive construction activity in the area.

The cross sections marked in Figure 5 are shown in Figure 6 and Figure 7 respectively. Part of the cross section A – A’ that is located closest to the pilot area shows that the subsurface is relatively homogenous in this area with a clayey layer up to 5 m depths and underlying sand and gravels layers. Cross section 6 – 6’ indicates that the bedrock in this area is located 25 m beneath the soil surface.

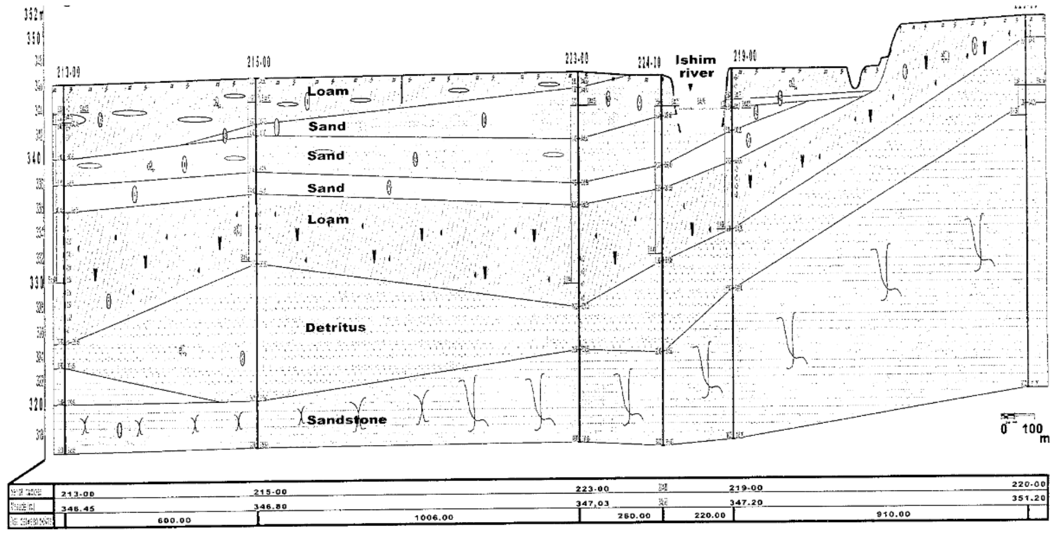


Figure 6. Cross section of line 6- 6' (compare Figure 5) (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001)

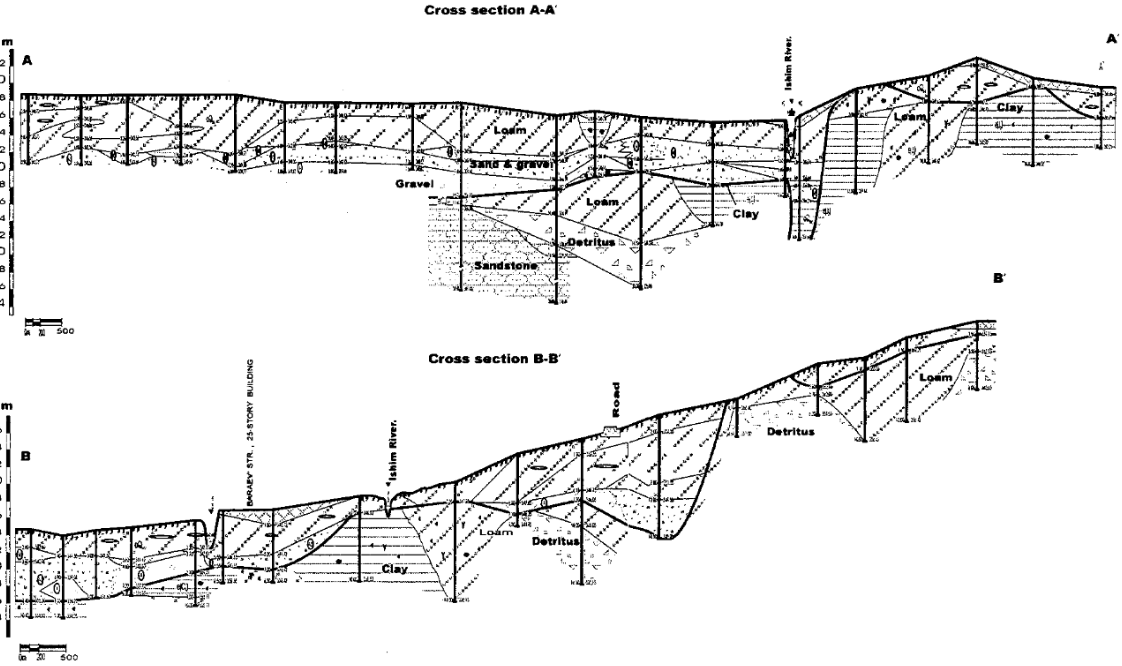


Figure 7. Cross sections of lines A- A‘ and B – B‘ (compare Figure 5) (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001)

A groundwater pumping test conducted on the grounds of Nazarbayev University (location: 51°05’11’’ N 71°23’59’’ E), showed a water flow rate of 0.83 l/s and was able to lower the groundwater table by 2 m during a 2 hour pumping trial. The water table of the shallow aquifer was found to be 7.1 m below surface. A second aquifer was identified between 17.5 and 19 m depth (Table 1). The sandstone identified as the second layer is likely a classification error and should be identical to the sand/gravel layer shown in other geological profiles.

Table 1. Soil profile from a well located at Nazarbayev University

Depth interval (m)	Groundwater	Sediment description
0 – 7		Clay, grey loam
7 – 14	1st aquifer	Sandstone grey, medium sized, water saturated
14 – 15.5		Pebble, water-bearing
15.5 – 17.5		Clay with sand inclusions
17.5 – 19	2nd aquifer	Coarse sandstone
19 – 21		Grey clay

On the pilot site, an engineering survey was carried out in 2015 and 2016 as part of the investigations for draining the area to construct the Nazarbayev University Science Park (Popov, 2016). The upper meters of the soil profile consist of two different layers of loam, below is a layer of sand and gravel.

The first layer, silty loam, has a thickness of 0.80-1.65m. According to the field description, the loam is dark grey to grey coloured, with plant roots and soft plastic fluidity. The loam has interlayers and lenses of sand and an organic content of 4.6-10.4%. Soil density is 2.08 g/cm³, the porosity is 0.51 and the soil moisture at the measurement point was 32%. The second layer, sandy loam has a thickness of 2.00-4.20m. According to the field description, it is brown to dark grey loam. Its stability ranges from firm to compact plastic, with interlayers and lenses of sand and an organic content of 0.1-5.3%. Soil density is 2.07 g/cm³, the porosity is 0.55 and the soil moisture at the measurement point was 28%. The third layer is a gravely sand that was found with a (measured) thickness of 0.5-0.8 m. However, drilling stopped in this layer. Sand and gravel are described as brown, with medium density and this layer was saturated.

In the eastern part of the area, the Turan Avenue has been built. Here, 2 m of bulk materials have been heaped on top of the silty loam, artificially elevating the area.

Table 2. Sieve analyses for three upper soil layers, values are averages from several soil samples at different sampling points (Popov, 2016)

	> 10 mm	10-2 mm	2-0.5 mm	0.5-0.25 mm	0.25-0.1 mm	0.1-0.05 mm	0.05-0.005 mm	< 0.005 mm	Average depth (m)
Silty Loam	0.0	0.1	3.6	9.0	14.5	29.6	21.6	21.7	1.3
Sandy loam	0.0	0.5	3.3	8.8	12.8	25.8	28.1	20.8	3.5
Gravelly sand	2.6	31.5	35.3	11.8	3.7	15.1	0.0	0.0	12

The layering is confirmed by a historic cross section of the area (Figure 8). The loamy layers are combined in the figure and characterize the upper 4-6 m of the area. The gravel/sand layer is depicted with a thickness of 8-10 m in the eastern part of the basin; this is where the Maly Taldykol lake system is located. In 13-16 m depth, another layer of loam/clay was found (Kasmov and Umbin, 1993).

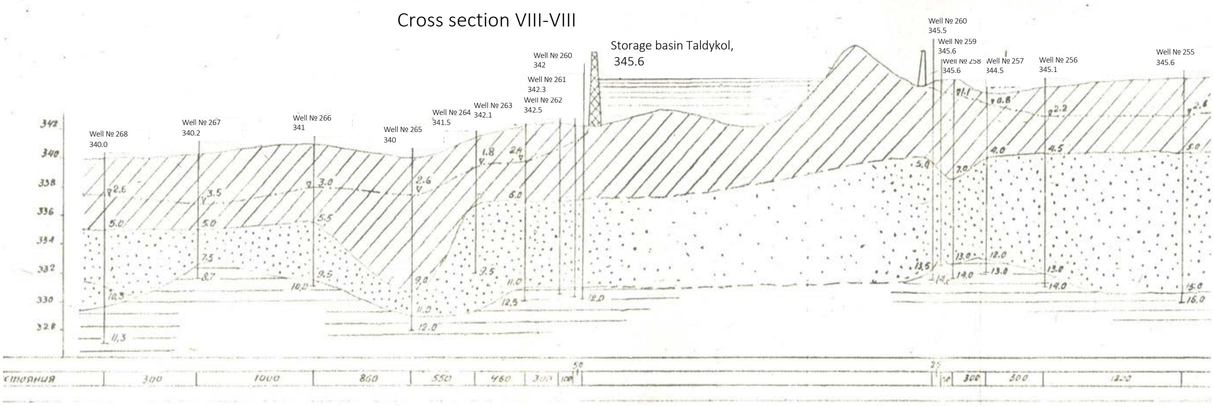


Figure 8. **Hydrogeological cross section of the area around the Taldykol reservoir with historic groundwater levels measured in 1986 (Kasmov and Umbin, 1993)**

3.2 GROUNDWATER

Four groundwater reservoirs are located in the Nur-Sultan vicinity (Figure 9).

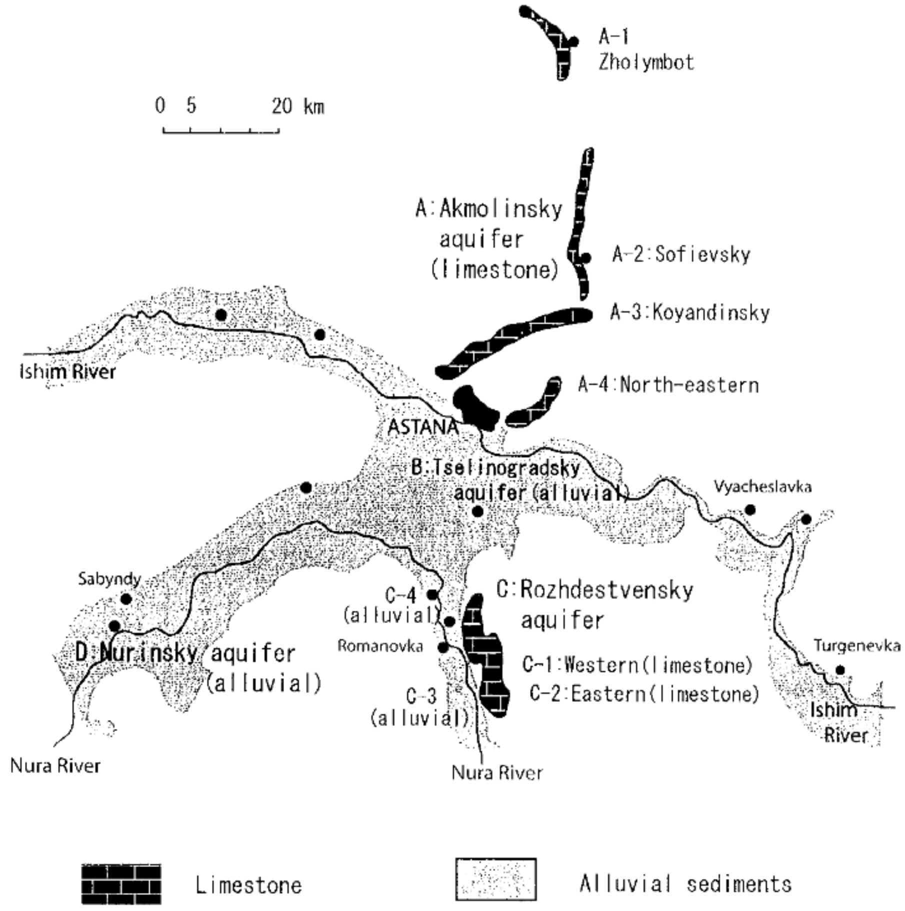


Figure 9. **Groundwater systems around Nur-Sultan**
(Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001)

Close to the river systems of the Yesil (or Ishim) River and the Nura River, the alluvial aquifer systems Nurinsky aquifer and Tselinogradsky aquifer are located, which serve as a subsurface connection of the two rivers. There are further aquifer systems in the weathered limestone: the Akmolinsky aquifer in the North of Nur-Sultan and the Rozhdestvensky aquifer in the south of the city. The groundwater level in the alluvial sediments lays between 0.95 and 3.6 m below surface, in the weathered strata 8-17.1 m below surface. They have a variation in depth of 1-1.5 m throughout the year with a typical minimum in March and a maximum after the snow melt in May (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001).

The Nurinsky and Rozhdestvensky reservoirs are not available for exploitation as the Nura River suffered from chemical pollution with manganese, lead, bromide, lithium and phenol due to industrial wastes being disposed into the river (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001). From 2003-2011, the World bank financed a clean-up project for the Nura river basin, where soil contaminated with mercury has been safely disposed (World Bank Group, 2014). Recently, the government has published plans to exploit the Nurinsky reservoir as a back-up reserve for water supply of Nur-Sultan. The potential of provision was estimated to be 48,000 m³/d.

The pilot area lies within the shallow alluvial aquifer system with groundwater levels being 2-3 meters below ground. Most of the area lies within the water logged part that makes up 10% of the cities aquifer system (Figure 10). In spring, water levels are even higher, being only 1-2 m below ground. The water-logging is described to be of anthropogenic origin as human activities have disturbed the natural dynamic equilibrium of the water balance (BIOSPHERA, 2014). Increased surface runoff and surface sealing due to the city’s expansion combined with the poorly permeable soils and missing drainage from the area have led to extensive waterlogging.

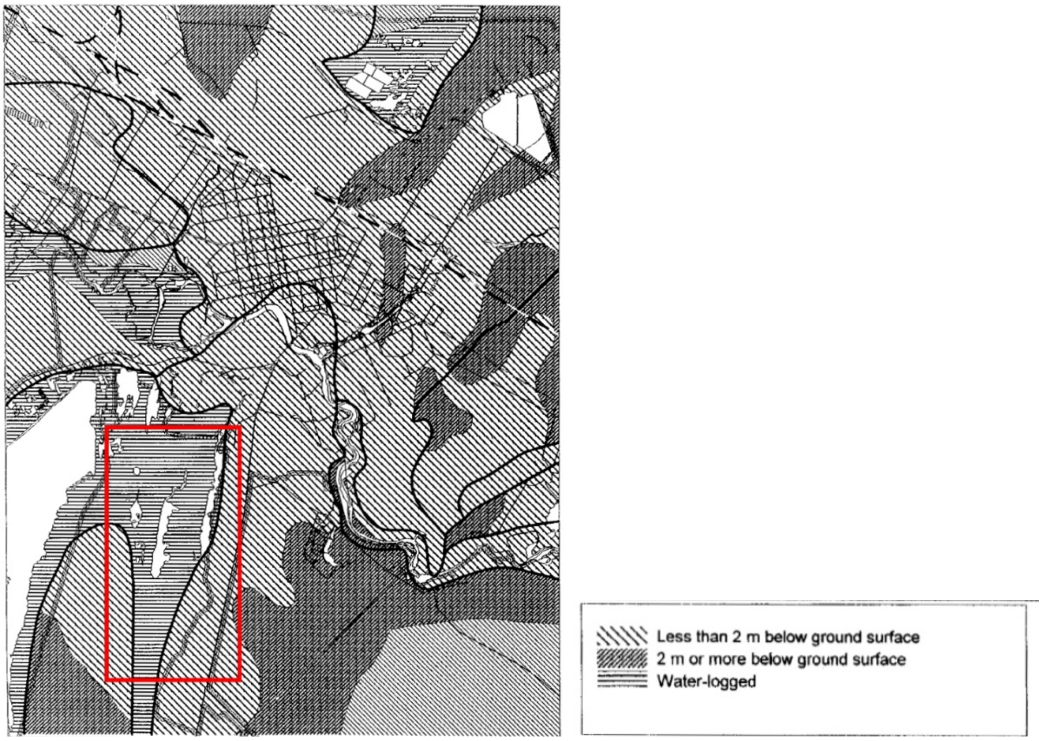


Figure 10. **Groundwater table depth in Nur-Sultan in 2000**
(Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001)

Historic measurements of the groundwater level in the area show that the groundwater level was 2-3 m below the surface and the groundwater height increased towards the Taldykol reservoir (Figure 8). During that time, the level of the Taldykol reservoir was 5 m above ground and it was still in operation for the discharge of treated wastewater. Thus, groundwater inflow from the reservoir could be observed. The main source of groundwater recharge is the snowmelt and precipitation in spring, which supply the groundwater through direct infiltration or by recharge through the river bottom.

In Figure 11, another historic source of groundwater recharge was analysed. Here, a cross section shows the groundwater level between the Nura-Ishim channel and the Maly Taldykol lakes. The channel was constructed in 1970 and in 1972, the groundwater level showed no signs of influence through the channel with the groundwater level being steady throughout the cross section and only little slope towards the eastern boundary. This indicated very small groundwater inflow into the Taldykol area. However, in 1986, the situation had shifted and the groundwater level increased by more than 2 m due to leakage from the channel. It was estimated that 1.4-4.0 m³/day of loss from the channel flowed into the underground (Kasmov and Umbin, 1993). This shows that the groundwater levels are sensitive towards local sources of recharge and that groundwater inflow into the Taldykol lake system would not be negligible under the situation in 1986.

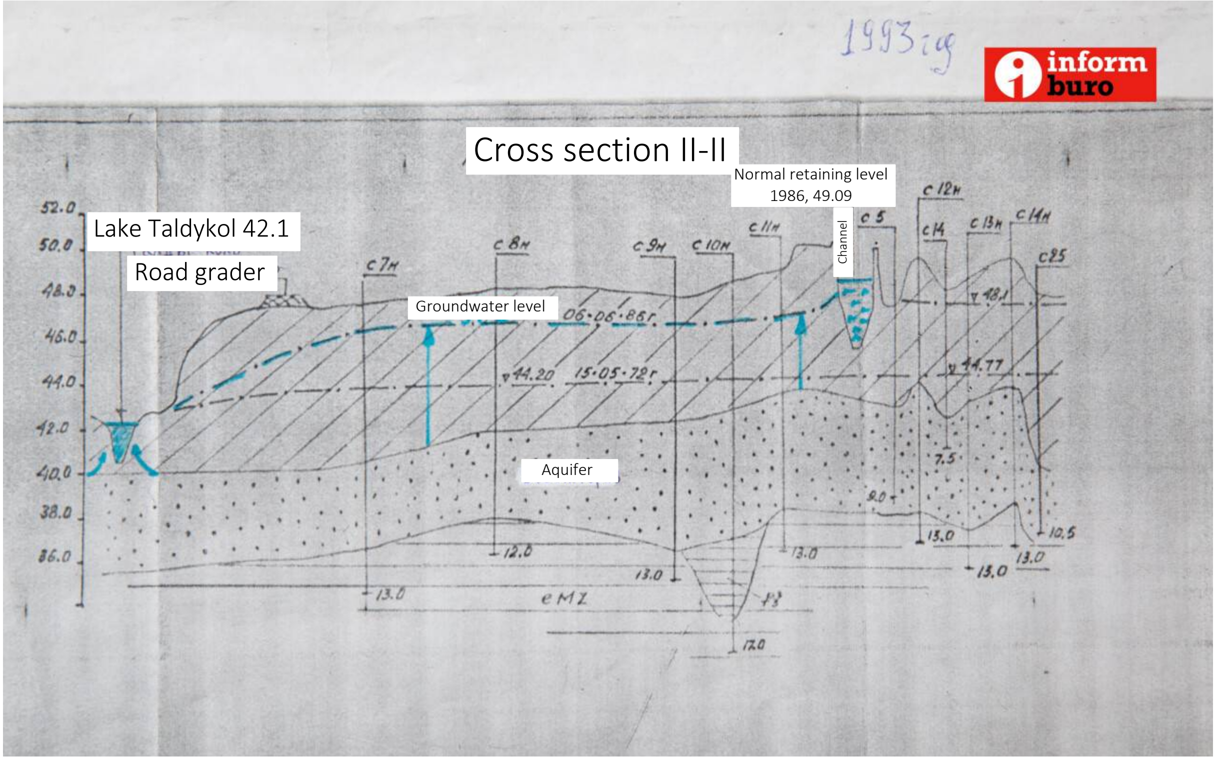


Figure 11. **Hydrogeological cross section of the area between the Maly Taldykol and the Nura-Ishim channel with groundwater levels measured in 1972 and 1986 (Kolosovskaya, 2021)**

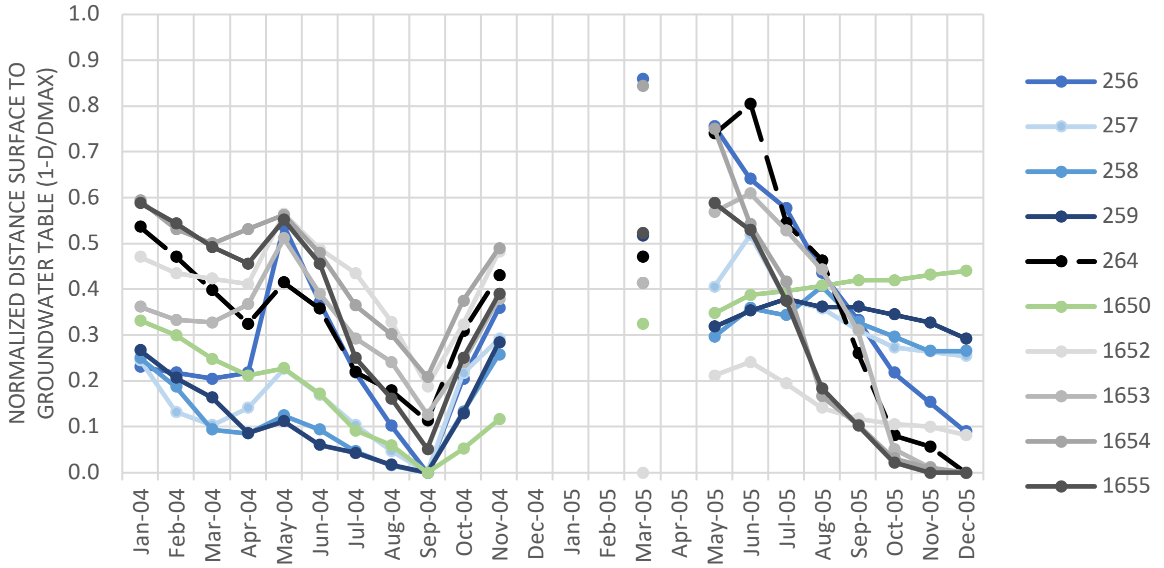


Figure 12. **Normalized distance from surface to groundwater table for the years 2004 and 2005 (locations of groundwater wells locations see Appendix 6)**

While some historic information about the hydrogeology of the area could be retrieved, current measurements were not that easy to obtain. The most recent measurements from the Taldykol area are from 2004-2005, which is from before the start of construction in the area. Figure 12 depicts these more recent measurements of the groundwater table depth for 10 groundwater wells located in the Taldykol area (for locations compare Appendix 6). No absolute values were given but the relative values show the general trend of the groundwater table fluctuations. There is a peak in May in both years, meaning the distance from groundwater to the surface is the smallest – which could be due to infiltrating snowmelt runoff or recharge through the interfluve from the rivers that have their highest discharge in the spring months. Additionally, rainfall in that month could be an influence, as in May 2004 rainfall was 14 mm, whereas in May 2005, rainfall was 49 mm and might have been one reason for the smaller surface-groundwater distance. Since snowmelt is in March/April, this would suggest a 1-month lag of the groundwater table reaction. After May, the depth to groundwater table increases continually over the summer month. It was hypothesized that in the autumn and winter the depth to groundwater table remains constant or increases but at a much slower rate. This behaviour can be seen in 2005; in 2004 however, the groundwater table depth decreases in autumn.

The groundwater monitoring wells marked in grey (1652-1655) are located closest to the river Yesil. During spring, very high groundwater tables characterize them. This could indicate a stronger influence of the river, forcing recharge into the interfluve area. In comparison, the wells marked in blue (256-259) have a less strong annual fluctuation and reaction to spring floods. These are located close to the Taldykol reservoir. In 2004 and 2005, the reservoir still operated as a treated wastewater dump with very high water levels and at the time had a more dominant influence in this area. The hydraulic conductivity of assessed subsurface materials is listed in Table 3.

Table 3. **Hydraulic conductivity of subsurface materials based on pumping tests *1(Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001) *2 (Popov, 2016)**

Layer	Hydraulic conductivity (m/d) *1	Hydraulic conductivity (m/d) *2
Loam	0.006-0.13	0.0001-0.02
Clay	0.001-0.007	-
Sand	3.8-15.7	
Gravel and sand	10.54	10.22 (loose), 22.15 (compacted)
Gravel	17.72	

In (Kasmov and Umbin, 1993) the soil hydraulic parameters were determined for the Taldykol area with a differentiation into unsaturated and saturated properties (Table 4 and Table 5).

Table 4. **Properties of the unsaturated zone in the Taldykol area whose maximum extend is between 0.9-8.8 m (Kasmov and Umbin, 1993)**

Hydraulic conductivity range (m/d)	0.006-0.86
Hydraulic conductivity average (m/d)	0.12
Saturated water content (-)	0.436
Residual water content (-)	0.121

Table 5. **Properties of the saturated zone in the Taldykol area (Kasmov and Umbin, 1993)**

	Upper layer	Lower layer
Average extend (m)	1.5-2.5	4.5-7
Hydraulic conductivity range (m/d)	0.046-0.183	40-120
Hydraulic conductivity average (m/d)	0.11	46
Water yield	0.04	0.15
Transmissivity (m²/d)	-	0.089-0.0047

The soil water in the upper soil layers is described as very hard (30-35 mg Eq total hardness), slightly alkaline (pH 7.2-7.9) and brackish-saline (organic content 14.5-110 mg/l, ionization compare Table 6). The water is considered corrosive to steel and concrete structures.

Table 6. **Chemical composition of groundwater samples in mg/l (16-16 and 18-16 from February 2016 in 14 and 19 cm depth and 43-15 from March 2015 taken in 40 cm depth) (Popov, 2016) (For locations of boreholes compare to Appendix 1)**

Well	Ca^{2+}	Mg^{2+}	$(Na + K)^+$	HCO_3^-	Cl^-	SO_4^{2-}	Salinity	NO_3^-	NH_4^+
16-16	280	252	1635	842	1882	1886	6777	1.7	0.5
18-16	300	180	1546	805	1704	1728	6263	3.4	1.0
43-15	300	228	1681	708	2130	1705	6752	0.3	0.1

In general, there is no citywide groundwater drainage network except for some individual buildings and the more recently developed parts of the city. As the upper 5 m of the subsurface are thick loam with low permeability, it is not easy to drain the area. The high groundwater levels pose a problem to the existing and envisioned city infrastructure. (BIOSPHERA, 2014) estimated that with ongoing construction and proper surface drainage, subsurface water levels in the Taldykol area would drop by 0.5 – 1 m depending on the drainage infrastructure. Recent construction has shown that drainage networks can keep the groundwater level at 3 m beneath soil surface. Interestingly, subsurface drainage used to be discharged into the Taldykol lake system but has now been redirected to discharge into the Yesil river. The exact location of the drainage network and the drained volumes are unknown.

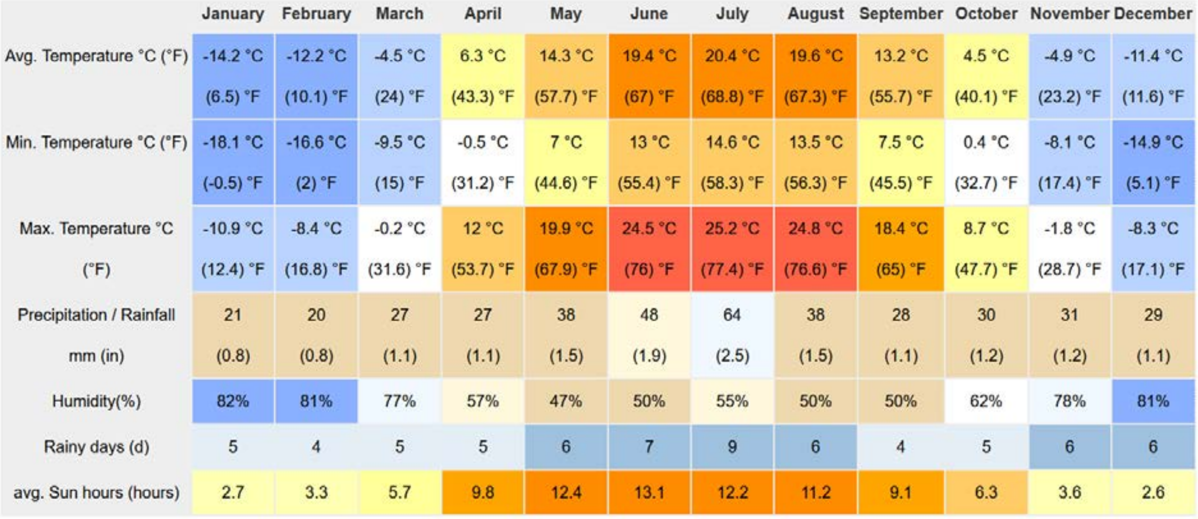
4. METEOROLOGY

Nur-Sultan is located in the continental and steppe climate zone. The temperature range is wide with temperature values recorded between -40 °C to 35 °C. As shown in Table 7 and Figure 13, for 5 months the average monthly temperature is below 0 °C. July has the highest mean temperature and January the lowest mean temperature. The highest variability in average monthly values can be seen in the winter months (December-February), whereas the average temperature in July, August and September is less variable (Figure 13).

The average annual precipitation is 326 mm and is exceeded by an evaporation of 680 mm/a from water surfaces and 280 mm/a from soil surfaces (Popov, 2016). 25–30% of the annual precipitation falls in the cold season with the snow cover varying between 20 and 40 mm/a (Regional Environmental Centre for Central Asia, 2019). The water reserve in the snow is 67 mm (Popov, 2016). Snowfall season lasts from October until April. Storm events with 50-60 mm rainfall can occur in July and August. Since weather observations started in 1932, several multi-year draughts have been recorded (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001). Particularly in the summer months, there is a high degree of variability of rain observed, which can be attributed to storm events with high rainfall volumes that do not occur consistently each year (Figure 13).In contrast to this, the months from September until April are characterized by little annual variation. The highest mean monthly precipitation falls in July, the driest month is February.

The frost penetration depth for Nur-Sultan is 185 cm for clay soils, 225 cm for sandy loam and 241 cm for sandy soils with the greatest penetration usually being in March (Popov, 2016).

Table 7. Monthly averages of climate variables in Nur-Sultan (https://en.climate-data.org/)



	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	-14.2 °C (6.5) °F	-12.2 °C (10.1) °F	-4.5 °C (24) °F	6.3 °C (43.3) °F	14.3 °C (57.7) °F	19.4 °C (67) °F	20.4 °C (68.8) °F	19.6 °C (67.3) °F	13.2 °C (55.7) °F	4.5 °C (40.1) °F	-4.9 °C (23.2) °F	-11.4 °C (11.6) °F
Min. Temperature °C (°F)	-18.1 °C (-0.5) °F	-16.6 °C (2) °F	-9.5 °C (15) °F	-0.5 °C (31.2) °F	7 °C (44.6) °F	13 °C (55.4) °F	14.6 °C (58.3) °F	13.5 °C (56.3) °F	7.5 °C (45.5) °F	0.4 °C (32.7) °F	-8.1 °C (17.4) °F	-14.9 °C (5.1) °F
Max. Temperature °C (°F)	-10.9 °C (12.4) °F	-8.4 °C (16.8) °F	-0.2 °C (31.6) °F	12 °C (53.7) °F	19.9 °C (67.9) °F	24.5 °C (76) °F	25.2 °C (77.4) °F	24.8 °C (76.6) °F	18.4 °C (65) °F	8.7 °C (47.7) °F	-1.8 °C (28.7) °F	-8.3 °C (17.1) °F
Precipitation / Rainfall mm (in)	21 (0.8)	20 (0.8)	27 (1.1)	27 (1.1)	38 (1.5)	48 (1.9)	64 (2.5)	38 (1.5)	28 (1.1)	30 (1.2)	31 (1.2)	29 (1.1)
Humidity(%)	82%	81%	77%	57%	47%	50%	55%	50%	50%	62%	78%	81%
Rainy days (d)	5	4	5	5	6	7	9	6	4	5	6	6
avg. Sun hours (hours)	2.7	3.3	5.7	9.8	12.4	13.1	12.2	11.2	9.1	6.3	3.6	2.6

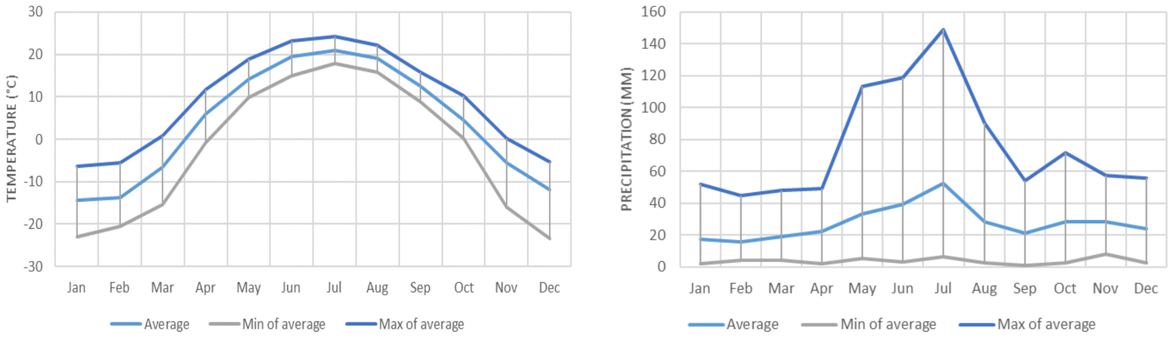


Figure 13. Monthly average temperature and precipitation values for Nur-Sultan (data from 01.01.1981 till 31.07.20). Source: Kazhydromet

Climate change predictions project for the region to become wetter. An increase in temperature (2.5°C increase by 2050) will influence the snowmelt. Consequently, Yesil is projected to have decreased peak flows as spring flooding will occur over two month (March and April) as opposed to its current peak in April (Regional Environmental Centre for Central Asia, 2019).

Analysis of the temperature data from 1981 until 2020 shows a significant increase of nearly 1.5 °C over the 30-year period (Figure 14). This can be particularly attributed to the spring months (March, April, May), which all show a significant trend of increasing temperature values. Precipitation shows a slight increase over the period as well from an annual value of 300 mm to about 350 mm (Figure 15). However, this trend is not significant.

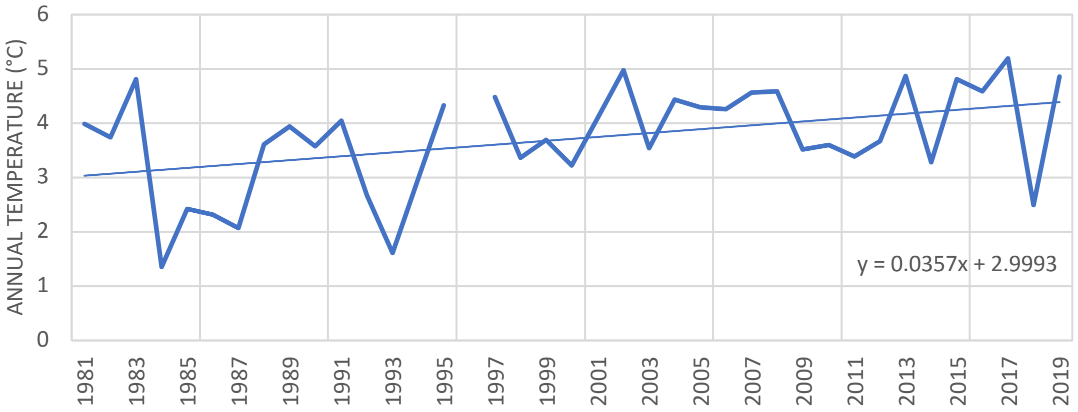


Figure 14. Average annual temperature for Nur-Sultan (data from 01.01.1981 till 31.07.20). Source: Kazhydromet

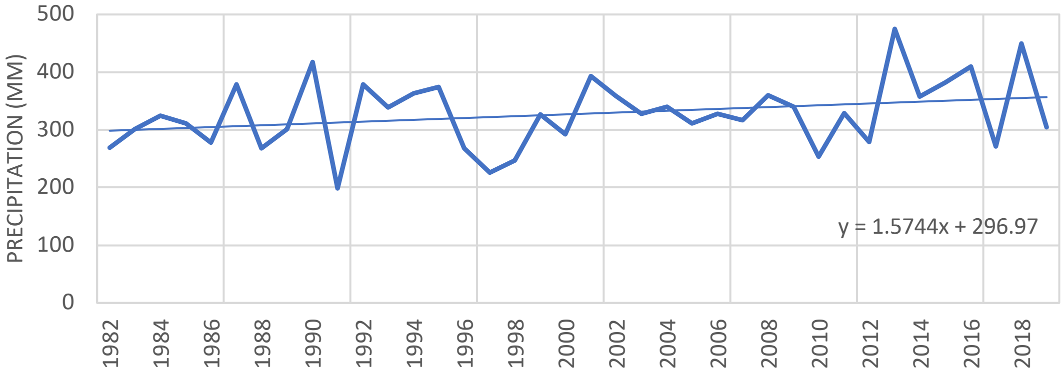


Figure 15. **Average annual precipitation for Nur-Sultan (data from 01.01.1981 till 31.07.20). Source: Kazhydromet**

5. HYDROLOGY

Close to the pilot area, there are two bigger hydrological features that need to be regarded, the Yesil river and the Taldykol lake.

5.1 RIVER YESIL

The Yesil (or Ishim) River divides Nur-Sultan city. In the outer cities boundaries, it flows unregulated with many meanders. Within the city centre, the river has been dammed and has a canal-like shape. Here it is of importance for the landscaping of the city and has a representative function. Since 1998, the Yesil has been actively managed in Nur-Sultan for flood management as well as for maintaining higher water levels in the city centre for recreational and representative purposes. Downstream of central Nur-Sultan, a dam has been built keeping water levels more constant throughout the year. The river bottom has been deepened to discharge floodwaters faster.

The river is mostly snow-fed (85%) and groundwater and precipitation are of less importance. The river discharge decreased over the years, from 7.6 m^3/s (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001) to an average annual flow of 4.2 m^3/s (Akiyanova et al., 2019) measured in Nur-Sultan. This is caused by the construction of the Astana reservoir upstream of Nur-Sultan, which is used for drinking water supply. Yesil discharge is very heterogeneous with 200-300 % difference in between years. Three main flow periods characterize the discharge:

1. the high-water period (April-May, 85–95% of the total annual flow);
2. summer low water (June–October, 3–8%); and
3. winter low flow (November–March, 0–3%) (Akiyanova et al., 2019).

During the snowmelt period, the Yesil River can discharge 1,000 m^3/s or more to Nur-Sultan (Regional Environmental Centre for Central Asia, 2019). A summary of discharge statistics is given in Table 8. An assessment of river discharge of the last 25 years found that the start of spring high-flows has shifted to earlier periods with the overall discharge volume increasing but at the same time the flooding periods have halved (Akiyanova et al., 2019).

Table 8. Discharge statistics of Yesil River (in m³/s), observations from 1936 to 1987 (Source: https://www.r-arcticnet.sr.unh.edu/v4.0/index.html)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	0.40	0.35	1.33	51.04	6.98	1.75	1.12	1.07	0.91	0.89	0.81	0.54	5.57
Standard Deviation	0.57	0.36	2.87	53.26	6.47	1.59	1.33	1.41	1.23	1.14	1.05	0.73	3.86
Min	0.00	0.01	0.00	0.52	0.14	0.04	0.01	0.02	0.04	0.03	0.03	0.02	0.71
Max	2.94	1.51	11.5	242	24.7	5.45	5.59	5.89	5.84	5.51	5.19	3.46	14.64
Coeff. of Variation	1.43	1.02	2.16	1.04	0.93	0.91	1.19	1.31	1.35	1.27	1.31	1.35	0.69

Flooding is a major risk along the Yesil, as the city is expanding into previous floodplains. In order to contain the high flows during the snowmelt, an earth embankment dam has been built east of the city in 2009 with a height of 10 m and a length of 31 km (Figure 16) (Ongdas et al., 2020). The dam collects high flows from Astana reservoir, e.g. in 2017, 600 million m³ of water passed through the Astana reservoir during the snowmelt season, highly exceeding the reservoirs storage capacity (Asian Development Bank, 2018). The earth dam releases a maximum discharge of 40-45 m³/s to the city centre. The Yesil River itself has a maximum discharge limitation of 5 m³/s.

As it begins shortly before reaching Nur-Sultan, there is little opportunity for contamination of the Yesil River from the industrial and agricultural infrastructure upstream. However, as a result of the additional water allocation through the Satpayev canal, pollution in the surface water body has increased and the water quality is assessed as "moderately polluted" and "polluted" with the main pollutants being manganese and copper (Krasnoyarova et al., 2019).

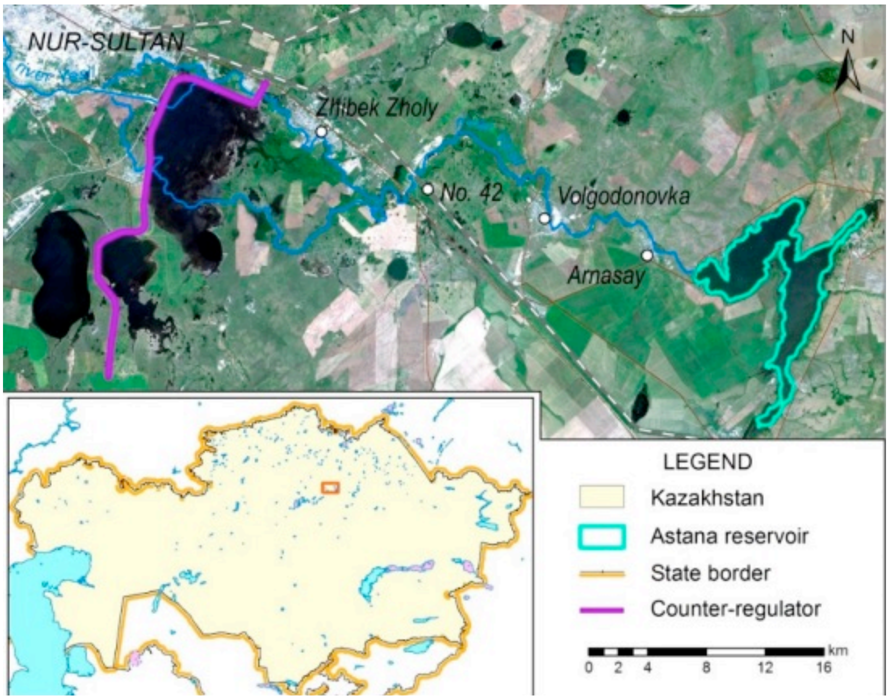


Figure 16. Location of earth embankment dam for flood protection (purple) and the Astana reservoir used for drinking water supply (turquoise) (Ongdas et al., 2020)

In the Yesil district, the Yesil River has its closest distance to the Nura River – 25 km (Appendix 3). Both rivers are connected through alluvial sediments. The Nura river is not as regulated as the Yesil, resulting in a wide river network with multiple temporary watercourses. The Nura river runoff was 19 m³/s on average (1940 – 1974) and increased to 27 m³/s (1975 – 2006) with the maximum runoff occurring during snow melting season (Dostay et al., 2010).

The difference in river management between Nura and Yesil River can be depicted from their annual discharge (Figure 17). Nura is more unregulated than the Yesil, which results in a more natural representation of spring floods that occur annually and are significantly higher than the discharge in the other month of the year. In general, the spring peaks due to snowmelt are dominating the discharge timeline. Responses to storm events during the summer cannot be seen in the discharge pattern even though measurements show high rain intensity in the summer months (Figure 17). The Yesil shows anthropogenic influence in its discharge pattern. In 2004, the spring peaks are cut off partially, which must be related to flood protection measures that had been put in place before the Yesil reaches Nur-Sultan. Further, the discharge of the Nura River is 10 times higher than for the Yesil River, even though the water level in both rivers has a similar height. This is due to the bigger catchment area of the Nura and its multiple watercourses but also due to the fact, that the Yesil is dammed in the Nursultan city centre, artificially increasing its water level.

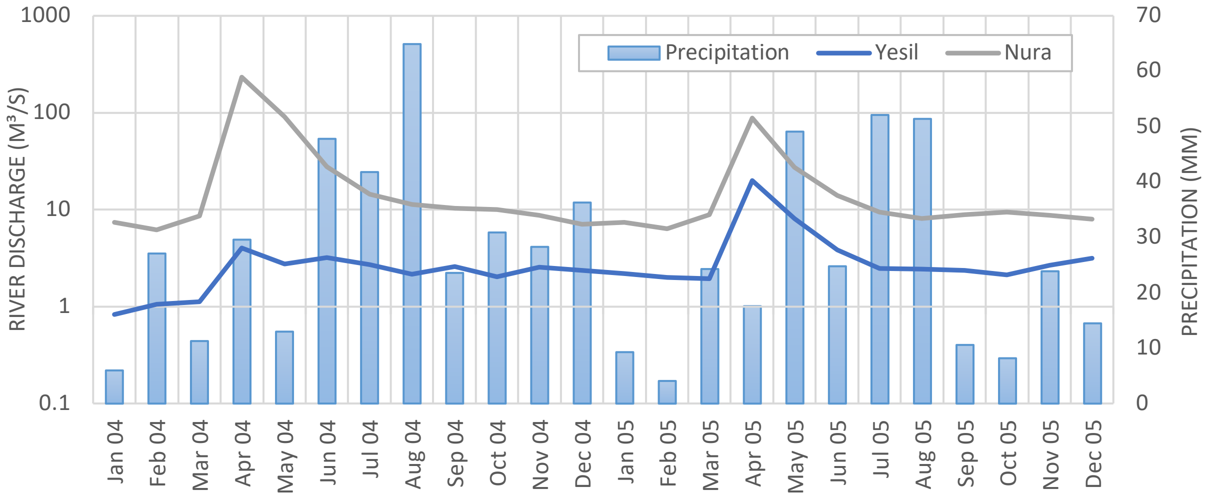


Figure 17. **Discharge of Nura and Yesil rivers in 2004 and 2005 (monthly average in m³/s, y-axis is logarithmic)**

Near Nur-Sultan the Nura river is anthropogenically influenced through the Preobrazhensky hydro scheme, which diverts water from the river into the Nura-Ishim channel that has been built in 1970 (BIOSPHERA, 2014)(Appendix 3). The channel has been constructed in the east of the city centre and in the 90s an analysis showed that substantial loss from the channel raised the groundwater levels in the area by 2.5-4 m (Kasmov and Umbin, 1993). In 2011, it was reconstructed and cleaned to increase its capacity. Furthermore, the channel has been sealed with a layer of loam and clay to disrupt its connection to the aquifer (BIOSPHERA, 2014).

The elevation difference between Nura and Yesil is 10-14 metres. During spring flood events, surface and subsurface flow occurs towards the Yesil River. The Taldykol lake system is located in between these rivers and is recharged consequently. There is a theory that the Taldykol lake system was formed due to the overflow from the Nura to the Yesil River. Since at present the lake bottom is silted, the subsurface recharge is decelerated (ГИПЕРБОРЕЙ, 2021). The construction of dams and highways has further limited the surface runoff towards the lake system that is cause by flood events.

5.2 LAKE TALDYKOL GROUP

The Taldykol lake group consists of the (bigger) Taldykol Lake, the Maly Taldykol (small Taldykol) and further to the south the Tassuat and the Olmes Lake (Figure 18 and Appendix 3). The lakes are estimated to be 13,000 years old and appeared at the turn of the Late Glacial period and Holocene. The lakes are natural, drainless water bodies that have been formed from ancient channels of the Nura River. Surface inflow depends on seasonal water storage in snow and ice, on precipitation, and on stormwater runoff from sealed residential areas. Before the construction of local highways, the smaller lakes would merge into a single water body during spring floods but throughout most of the year, they would divert into several small lake bodies.

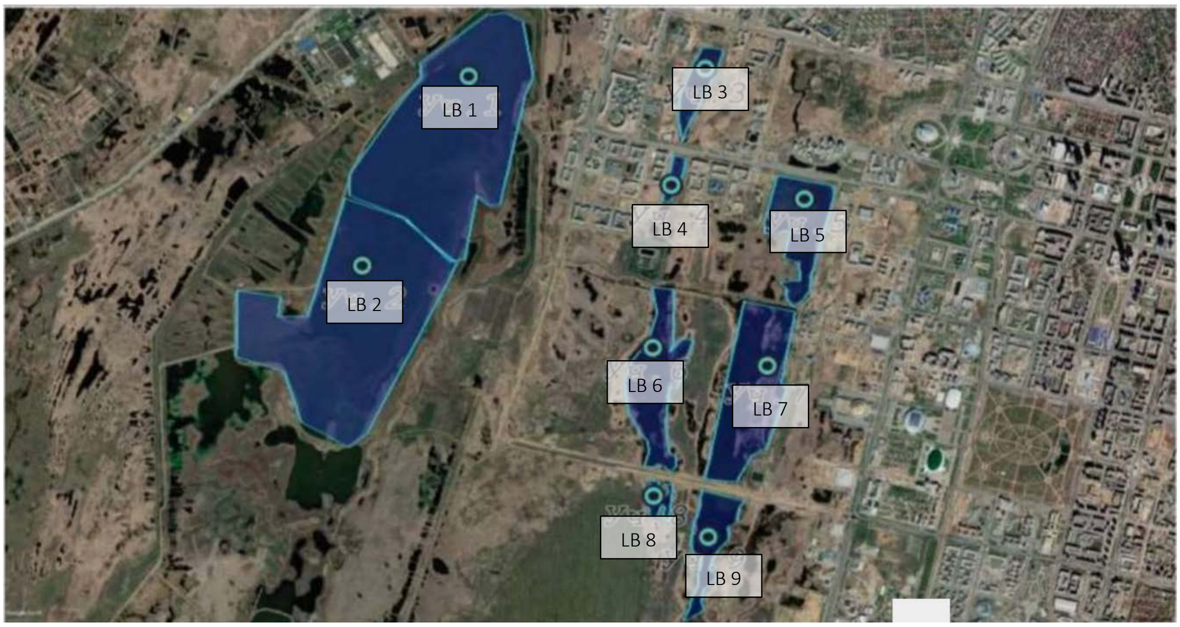


Figure 18. Northern part of Taldykol lake system (LB = Lake Body)
(left water body: Taldykol, all water bodies on the right: Maly Taldykol)

The Taldykol lake

In 1970, the Taldykol lake or reservoir (lake body 1 and 2 in Figure 18) has been adapted to receive the discharge from the Nur-Sultan waste water treatment plant (WWTP), as it was not allowed to directly discharge WWTP effluent into rivers in Kazakhstan (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001). During that time, the water level of the Taldykol reservoir was 5 m above ground (Figure 8,(Kasmov and Umbin, 1993)). However, the law has been changed and, in 2020, 230,000 m^3/d of treated wastewater were released to the Yesil River, leaving the Taldykol reservoir with no significant inflow other than precipitation. Taldykol was constructed on marshland with dykes around the lake. Thus, the water level in the lake used to be higher than the surrounding ground surface level (Figure 19). However, the lake level has dropped significantly in recent years. In 2021, it was found to be equal or even lower than the water level in the Maly Taldykol lake system (Appendix 5). The bigger Taldykol lake had a surface area of 21 km^2 and water levels of the lake had an amplitude of 67 cm, fluctuating between 347 m (March 2012) and 346.33 m (September 2012) above sea level (BIOSPHERA, 2014). The lake freezes from late November until March with an estimated ice thickness of 25 mm.

While the water quality in the lake is generally perceived as polluted, an analysis from 2001 showed that its actual water quality is good due to proper WWTP operation (primary treatment) and additional natural treatment in the lake itself (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001). According to a study from 2020, the lake pollution is moderate, still allowing for recreational use of the lake as well as using the lake water for irrigation. Analysis of the lake sediments indicated only slightly increased concentrations of ammonium und nitrate compared to the Maly Taldykol system that did not receive treated wastewater (Appendix 4). The sanitary situation of all water bodies is good, with none exceeding the limits for bacteria and germs.

The small Taldykol lakes system

The smaller Taldykol lake (Maly Taldykol) comprises seven separate lake bodies, which have a total surface area of 6.02 km² with an estimated water volume of 4.815 million m³ and an average depth of 0.8 m with the maximum depth being 3.41 m (Utepov et al., 2021). The lacustrine basin of the smaller Taldykol lake is located on a depression of the relief, causing its comparatively large depths, which causes the parts of the lake to not fall dry even in dry years. Due to the elevated water levels of Taldykol lake, underground flow from Taldykol to the Maly Taldykol lakes could influence their water balance. (BIOSPHERA, 2014) estimated that 43,000 m³/a underground inflow could potentially be generated along the 4 km long western as well as the eastern boundary of the lakes. However, due to the low permeability, poor drainability and low water yield of the soils surrounding the lakes, the smaller lakes are outside of the hydrological influence zone of the bigger Taldykol lake. In the north-south direction the slope is low (0.00086, (BIOSPHERA, 2014)) so that the inflow from both directions is insignificant. The stable difference of water pollution deposition in the bottom sediments of the lake bodies could indicate a weak or practically absent connection between the water bodies through groundwater flow (Appendix 4). The lake bottom is characterized by an up to 80 cm thick layer of silt and sludge (BIOSPHERA, 2014). Below there is a grey clay with low permeability of 0.005-0.3 m/s. This suggests a weak connection to the underlying aquifer.

Table 9. Chemical composition (in mg/l) of Maly Taldykol lakes (lake bodies from Figure 18, lake * refers to water body north of lake 5 that is almost extinguished in that map). MAC = Maximum allowable concentration (Kazakh standard) (BIOSPHERA, 2014)

		depth (m)	pH (-)	O_2	BOD_5	COD	Ca^{2+}	Mg^{2+}	$Na^{2+}+K^+$	NH_4^+	SO_4^{2-}	Cl^-	$N\text{-}NO_3^-$	$N\text{-}NO_2^-$	Phenols
	MAC		-	4	3	30	180	40	250	0.5	500	350	45	0.02	0.001
Jan 2013	Lake 3	0.5	7.7	0.84	3.4	182.5	520	1163	6898	0.7	6109	9093	79.7	0.004	0
	Lake *	0.4	7.2	0.85	22.2	95.6	219	179	2137	2.3	1153	1594	465	0.008	0.014
	Lake 5	0.7	7.6	1.22	4.2	95	375	621	3438	1.1	3343	4440	44.2	0.004	0
	Lake 7	1	7.2	0.26	6.6	91	416	572	3010	1.3	2709	4254	17.7	0.004	0
Apr 2013	Lake *	0.2	7.7	5.93	1.8	26.8	16	3.6	33	0.7	45.1	34.7	3.2	0.099	0.003
	Lake 5	0.2	8.2	9.89	0.3	16	24	15.8	87.8	0.1	96.1	113	3.9	0.012	0.003
	Lake 7	0.2	7.3	6.65	1.3	38.4	58.1	40.1	194	0.2	260	252	5.3	0.025	0.001
	Lake 6	0.2	7.1	7.1	1.1	11.8	98	99.2	51.7	5.1	310	323	10	0.019	0.018

The lake is reported to be more polluted than the bigger Taldykol, particularly with oil products, organic compounds and rubbish (Table 9, Appendix 4). The lake has been separated into several water bodies, partially due to the construction of highways. According to a study from 2020, the northern parts of the lake (bodies 3, 4 and 5, Figure 18) were assessed as heavily polluted, whereas the central parts (bodies 6 and 7) were moderately polluted and the southern parts (bodies 8 and 9) were clean. Data shows that the pollution of the lakes decreases from the north to the south with the southern lake bodies having clean water (Kazakhstani Chamber Environmental Auditors, 2021). This suggests that the pollution originates from the city through runoff and that the highways built between the lake bodies serve as a barrier that restricts the lake pollution. A study from 2013 showed that the chemical composition of the lakes depends strongly on the time of the year (BIOSPHERA, 2014). After the snowmelt (April) the chemical composition of all lake bodies is much more diluted with less salt ions, higher oxygen concentration and less ammonium and nitrate in the lakes (Table 9). The decision of the local authorities to drain and develop the area of the Maly Taldykol was faced with public resistance urging to conserve the lakes. The lakes have been found to be a habitat for several plant and animal species (Kazakhstani Chamber Environmental Auditors, 2021).

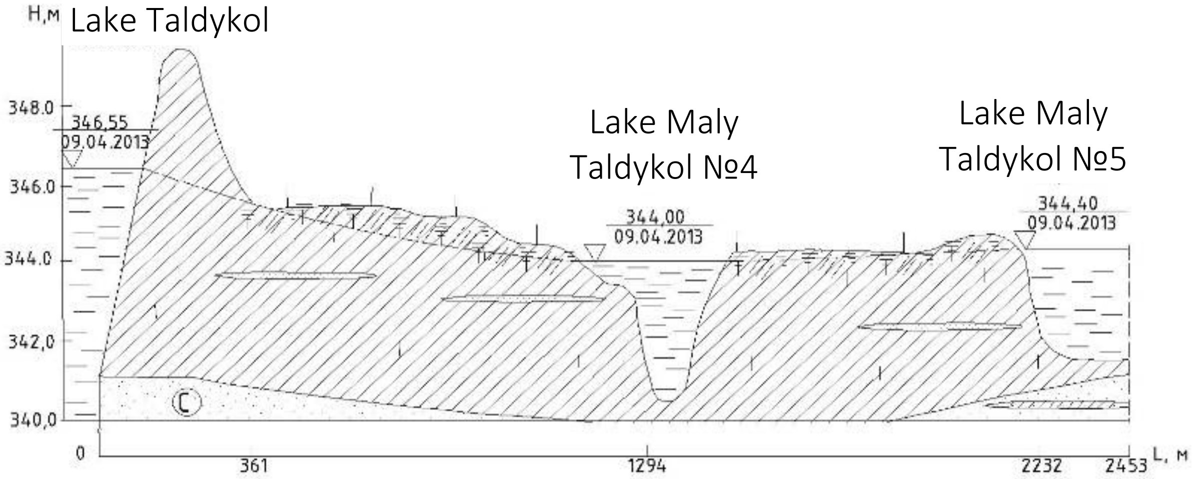


Figure 19. Elevation of Taldykol lake (left) and Maly Taldykol (centre and right) (BIOSPHERA, 2014)

The smaller lakes of the Maly Taldykol group might fall dry in some years, depending on the annual precipitation and evaporation during hot and dry summers. The water occurrence in the Taldykol area was analysed using the datasets from (Pekel et al., 2016). The data shows that the larger water body of Maly Taldykol has persisted from 1984 until 2020 whereas many water bodies are temporal in the pilot area. This means that they either occur seasonally or have vanished over the analysed period.

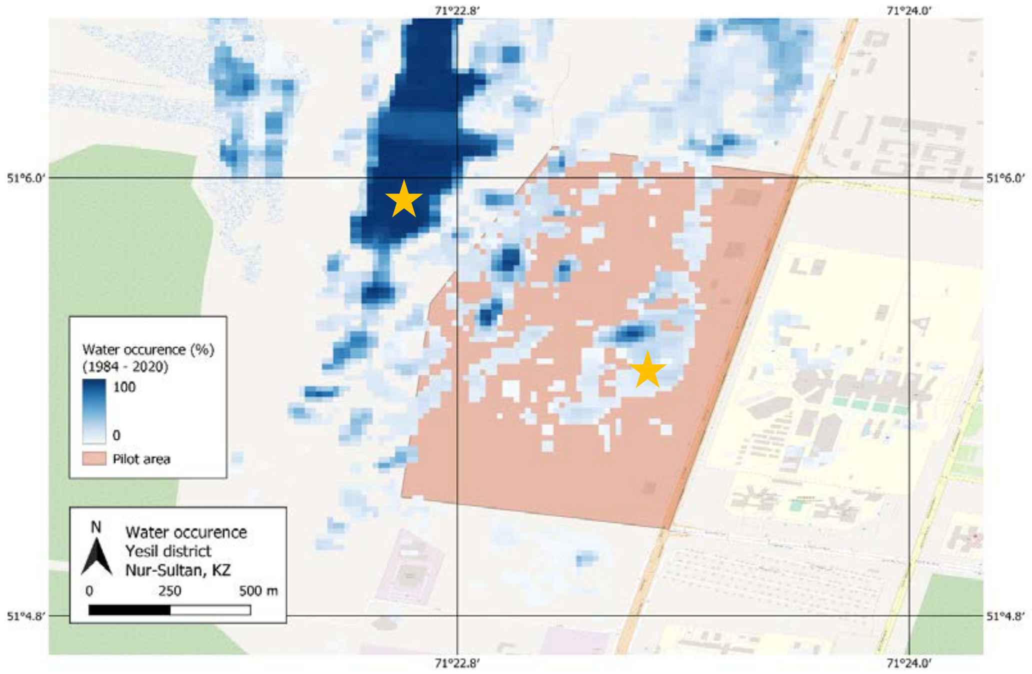


Figure 20. **Surface water occurrence (in %) for the Taldykol area. Darker areas have permanent water; light blue areas have temporal water bodies. Source: EC JRC/Google**

To better understand the variability of the water bodies, time profiles from the main water body and from a location in the pilot area have been obtained from the map (compare stars in Figure 20). In Figure 21, the monthly occurrence of surface water during non-freezing period is shown for both locations. While water in the main water body persists permanently during the observation period, the water body in the pilot area is mostly present during the months influenced by snowmelt (April and May). From June until September the water bodies occur only in a few years, indicating that the water collected from the snowmelt has either evaporated or infiltrated into the soil.

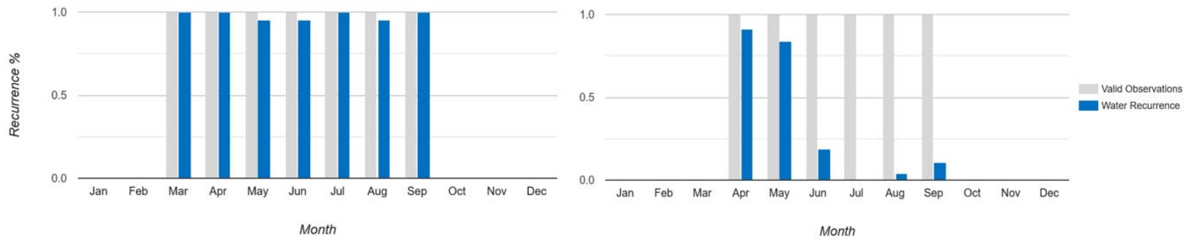


Figure 21. **Monthly reoccurrence of surface water in Maly Taldykol main water body (left) and in the pilot area (right) (compare stars in Figure 20)**

Looking at the annual reoccurrence of surface water reveals another phenomenon characterizing the difference in both water bodies Figure 22. While the main water body persists permanently, the water body in the pilot area changes between seasonal water and no water. This indicated that in years with fewer snow cover or a long melting period, no water bodies form at the marked location.

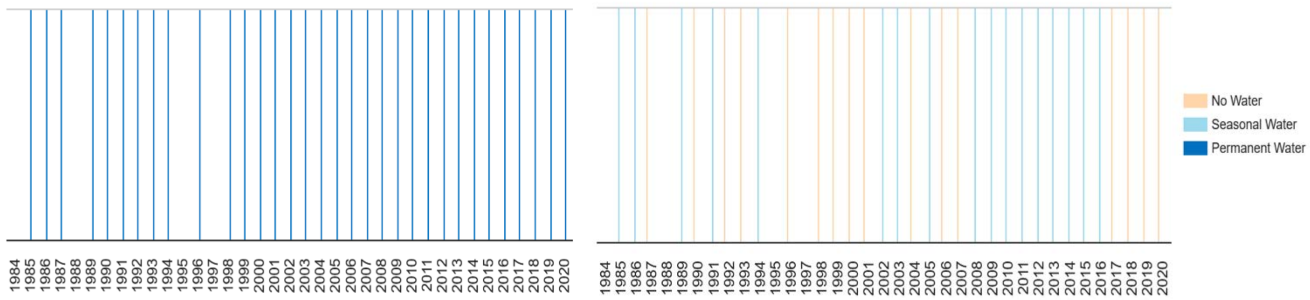


Figure 22. **Annual reoccurrence of surface water in Maly Taldykol main water body (left) and in the pilot area (right) (compare stars in Figure 20)**

The seasonality of the lake levels in the Taldykol area has been described by (BIOSPHERA, 2014). Lakes levels rise between 30 and 50 cm during the snowmelt period (Mid-April). During the summer, the water level drops again by 50-60 cm due to evaporation losses. The difference is in most years balanced out by precipitation during the ice-free month. Due to ongoing construction work in the Maly Taldykol area and the termination of treated waste water inflow into big Taldykol, the lake area for both systems has dropped significantly from 1223 ha (2004) to 379 ha (2020) for big Taldykol and 379 ha to 210 ha for Maly Taldykol (Kazakhstani Chamber Environmental Auditors, 2021). Particularly the lake bodies 3, 4, 5 and 8 show decreasing water levels that are lower than 0.3 m in 2021. Lake bodies 6, 7 and 9 remain with some catchment area as well as discharge of drainage water from the ongoing construction in the area.

5.3 WATER BALANCE

Based on data retrieved from the Water Balance App (Esri Hydro, 2021), an analysis of water balance components was conducted. The app uses data from NASA's Global Land Data Assimilation System (GLDAS-2.1), such as temperature, humidity, and rainfall. The data is fed to the Noah land surface model (Niu et al., 2011), which estimates the water balance components runoff, evaporation, and change in storage. The later comprises changes in snowpack as well as infiltration into the soil (depicted as soil moisture). The data set is available from 2000 until 2021 with aggregated monthly data. The calculations are based on a data resolution of a 30 km grid, thus, it only gives insights on regional trends and does not necessarily reflect local measurements.

The average annual precipitation for Nur-Sultan during the last 20 years is 468 mm, while the average evapotranspiration sums up to 435 mm. In comparison, runoff is small with an average height of 27 mm/a. This means that the water balance is almost even, with a small positive change in storage of 6 mm/a. As it is shown in Figure 23, the annual change in storage can be positive or negative, depending on the year. Particularly the years with an annual precipitation of 400 mm/a or less tend to result in a negative water balance. Looking at the trend of precipitation and evapotranspiration during the 20 years that were analysed, it becomes apparent that precipitation is decreasing and evaporation is increasing. However, the time series are too short to make certain statements about the trends.

The water balance for the seasons is depicted in Appendix 2. Here it is shown that the water balance is positive during winter and fall and negative during summer and spring. In winter, water is stored as snow during as well as to a lesser extend infiltrated into the soil, causing a positive water balance. During summer and spring, evapotranspiration exceeds precipitation so that no surplus water is available for recharge. Runoff is only relevant during winter and spring and is mostly linked to the snowmelt period.

It becomes apparent that the evapotranspiration remains stable in spring, increases in winter and fall and decreases during the summer month. Precipitation decreases significantly in winter and slightly in fall. In summer, it increases slightly and in spring, it stays relatively constant.

To assess the annual course of the water balance components, they have been averaged over the 20-year period (Figure 24). Apart from precipitation, some very distinct annual courses can be seen. Evapotranspiration is mostly relevant from April until August and negligible in fall and winter. Runoff occurs only during the months of March and April, coinciding with snowmelt. Change in storage is negative from April until September, the months with higher evapotranspiration rates. During the other months, a small, yet positive change can be detected. Only precipitation shows no clear course throughout the 20 years. Maximum is generally reached in July and minimum in September but during the other months the course shows a huge noise between the individual years.

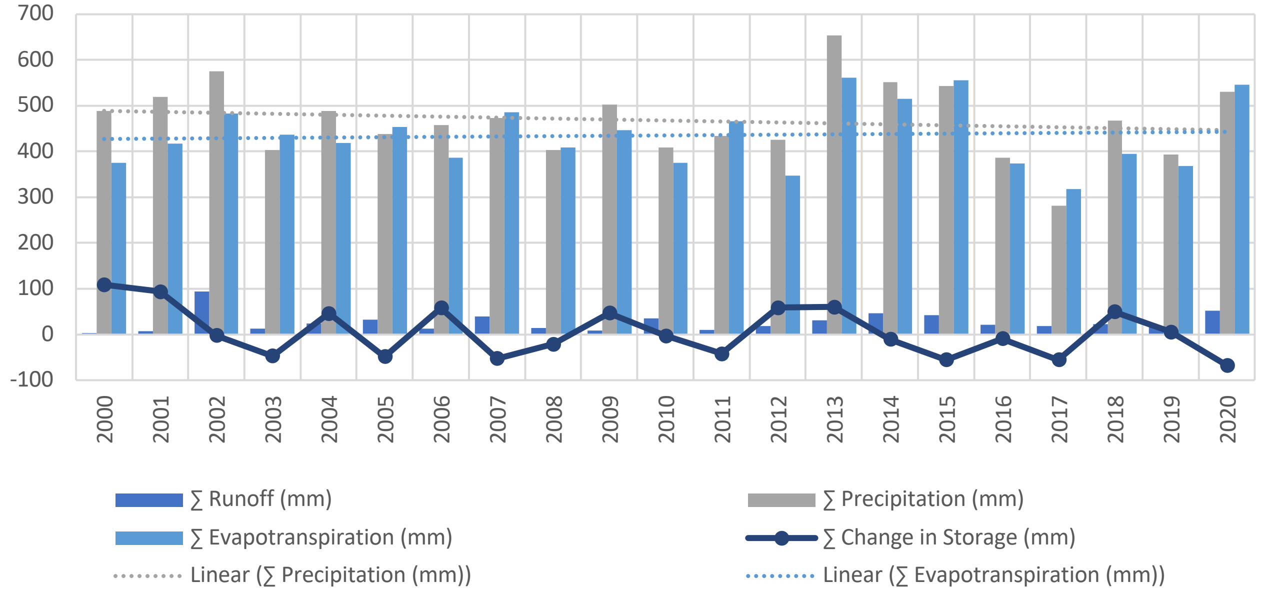


Figure 23. Sums (mm) and trends of annual water balance components for Nur-Sultan

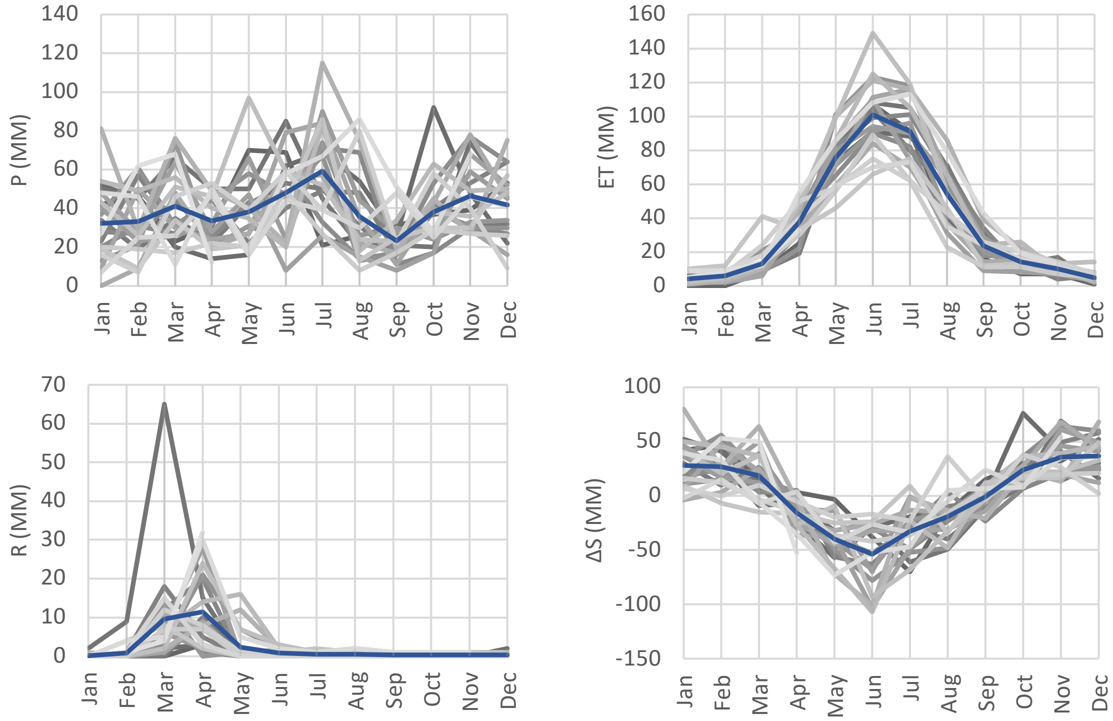


Figure 24. **Annual course of water balance components for each year (grey) and averaged value (blue) with P – precipitation, ET- evapotranspiration, R – runoff and ΔS – change in storage**

Change in storage is partially attributed to water storage in snowpack and to water storage in the soil (groundwater recharge). For the snowpack, the most relevant parameter is the maximum snowpack as this parameter is an indicator of how much water is stored in the snow cover over the winter. Figure 25 shows that the maximum height is variable with years of lower snow cover around 30 mm height (2018, 2019) and a maximum height of 200 mm in 2013. The average height is 106 mm and there is no clear trend of increase or decrease in the past 20 years. In (Regional Environmental Centre for Central Asia, 2019) the snow cover height for Nur-Sultan is stated varying between 200 and 400 mm/a, thus, the satellite data is likely underestimating the maximum height. (BIOSPHERA, 2014) measured the snow height at the pilot location in 2013 and found it to be 0.48 m on average with an average snow density of 0.3 kg/dm³. Nevertheless, the annual course of the snow cover can be obtained from the data (Figure 25). The snow cover starts to grow continuously from November until March and completely melts during April. May until October are snow free in almost all years.

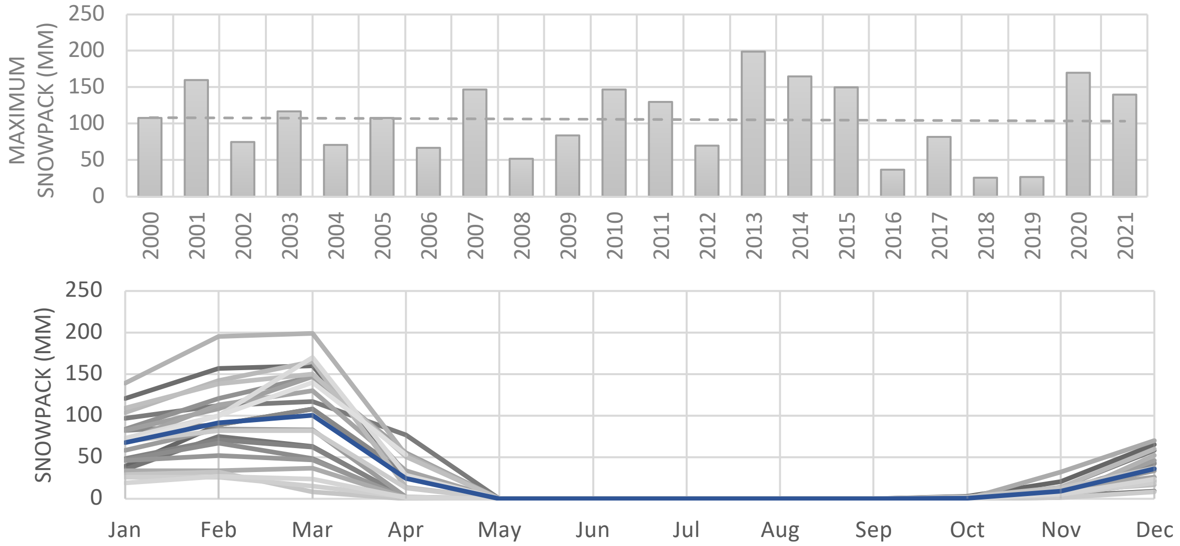


Figure 25. **Upper graph: maximum snowpack (in mm) and lower graph: annual course of snowpack with averaged value over the 20 years**

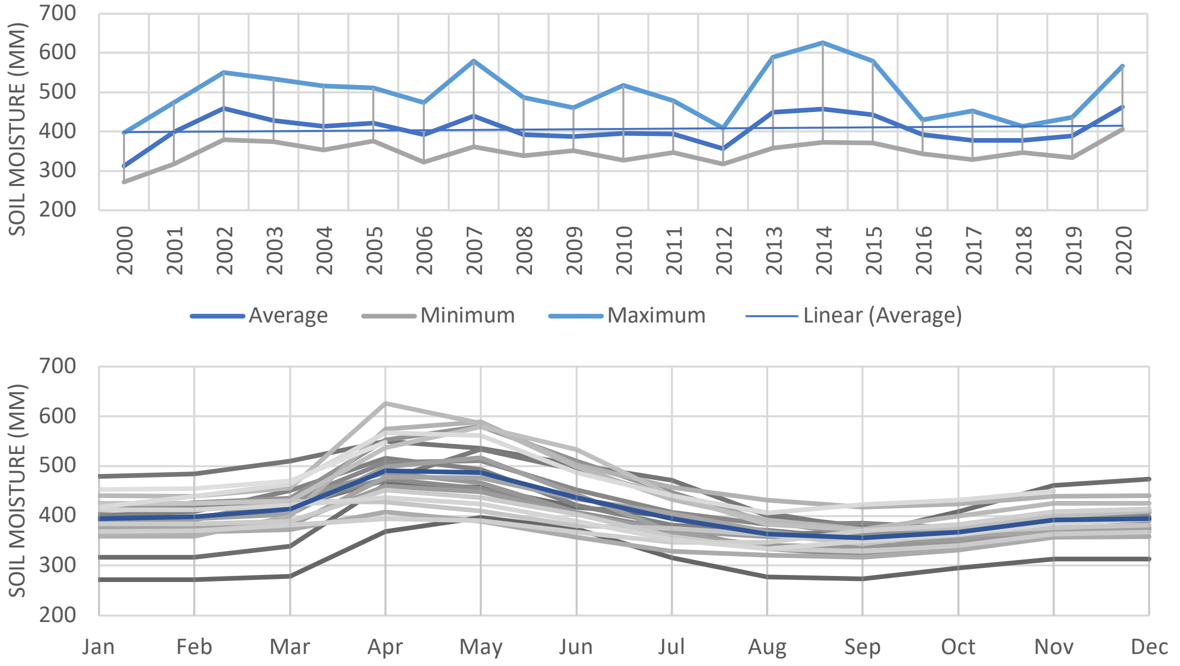


Figure 26. **Upper graph: average, minimum and maximum soil moisture (in mm) from 2000 until 2020. Lower graph: annual course of soil moisture (in mm) with average course over 20 years depicted in blue**

Storage of water in the soil can be depicted as soil moisture (Figure 26). The soil moisture in Nur-Sultan fluctuates around 400 mm with values ranging from 300 to 600 mm. The inter-annual variability of minimum and average soil moisture is low and no clear trend of increase or decrease can be depicted. For the maximum soil moisture, a greater variability is shown with minimum values of around 400 mm (2012, 2018) and maximum values of 620 mm (2014). The annual course of the soil moisture is very distinct (Figure 26, lower graph). With average values around 350 mm it reaches its minimum in August and September. Starting in October, it gradually increases to values around 400 mm, which in March and April increase significantly to 500 mm. While the maximum soil moisture continues to stay as high as 500 mm in May, it afterwards decreases until it reaches its minimum in August.

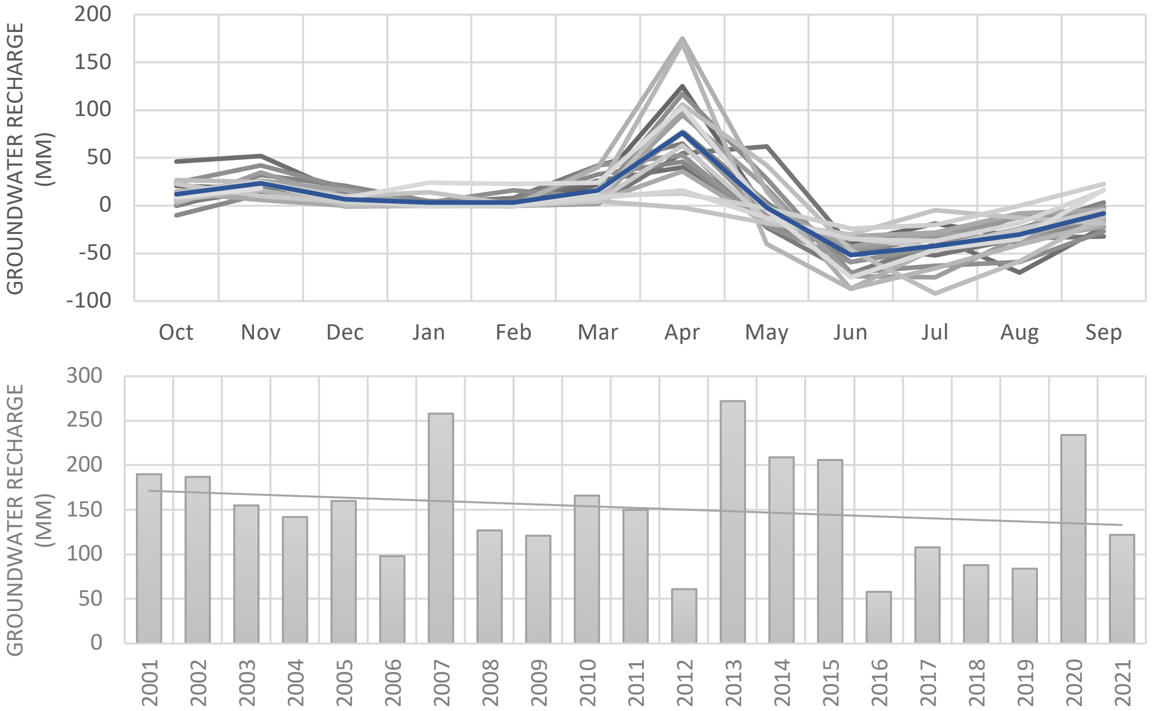


Figure 27. **Upper graph: groundwater recharge course, average over 20 years in blue; lower graph: annual groundwater recharge for hydrological year (starting in Oct of the previous year)**

Groundwater recharge was determined as the soil moisture change between consecutive months (Figure 27). For this, the hydrological year was regarded, beginning in October, when groundwater recharge starts. From October until February, there is little but steady recharge with rates ranging between 0 and 25 mm/month. October and November show slightly higher rates, from December until February rates are generally below 10 mm/month. March and April show the highest recharge rates and contribute the most to the annual recharge. Annual recharge was determined by summing up all positive monthly recharge values. These show recharge rates from 60 mm/a until 270 mm/a. Average annual recharge is 140 mm/a. During the past 20 years, there is a visible trend of decreasing annual groundwater recharge rates with a difference of circa 50 mm/a.

A local water balance assessment has been completed for the Taldykol lake system (BIOSPHERA, 2014). The water balance for the Taldykol lake system can be summarized as

$$\Delta S = I_R + I_P + I_{GW} + I_L - O_{ET} - O_W - O_{Per}$$

With ΔS change in storage, I_R Inflow through Runoff, I_P Inflow through precipitation, I_{GW} Inflow through groundwater, I_L inflow through leakages, O_{ET} outflow through evapotranspiration, O_W outflow through withdrawal and O_{Per} outflow through percolation into the soil. The atmospheric components make up the dominant part of the water balance.

The water balance components have been estimated by (BIOSPHERA, 2014). The catchment area of the lakes is four times as large as the lake surface, thus, the surface runoff is estimated to be 1 – 1.5 million m³/a depending on the precipitation during the year. Precipitation on the water bodies sums up to 233 mm/a. 43,000 m³/a of underground inflow were estimated. Evaporation was 760 mm/a for an overall surface area of 547 ha. 395 ha of that area becomes overgrown by reed during the warm period, making transpiration another factor of concern, which, together with evaporation, sums up to 2,410,000 m³/a. Water losses from leakage (water/heat supply sewerage) are estimated to be 165,184 m³/ for the area with the current infrastructure. A projection for infrastructure losses in the year 2030 with the Taldykol area developed according to the city master plan, losses would increase to 2,145,000 m³/a. Another water balance for lake body 5 from 2021 revealed the overall water balance of the lake system to be negative (Kazakhstani Chamber Environmental Auditors, 2021). Surface water inflow was estimated to be 0 mm, groundwater inflow 90 mm, precipitation on the surface of the lake 318 mm per year. Outflow to groundwater was 0 mm and evapotranspiration from the lake surface 700 mm per year. This sums up to a negative water balance of -219 mm/a. As the reason for the negative water balance the development of the Taldykol area was given. Buildings and infrastructure construction decreased the catchment area of the lake system more than 3 times.

With further development planned, surface runoff will be nearly absent in the area as the surface flow will be diverted to sewer systems. Geotechnical analysis showed that the groundwater level in the area to be at 343 m above sea level. Since the lake bodies 6, 7 and 9 exceed the groundwater level, outflow from the reservoir to the groundwater would be expected, whereas for the lake bodies 3-5 groundwater inflow is anticipated. However, since the surrounding soil has low permeability, no significant inflow is expected. Further construction in the area will decrease the underground flow towards the lake systems. (Kazakhstani Chamber Environmental Auditors, 2021) expected the water bodies 3, 4 and 5 to completely dry out. Lake bodies 6, 7 and 9 could be preserved but need artificial replenishment.

6. WATER MANAGEMENT

At the moment, the water supply system in Nur-Sultan is sufficient to meet the demand but with population growth, the demand is expected to increase beyond the current supply limits (Table 10) (Regional Environmental Centre for Central Asia, 2019). A calculation of water demand increase from 2001 showed that the drinking as well as technical water demand were going to increase by 100% until 2030 (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001).

Table 10. **Projected raw water demand (million m³) for Nur-Sultan in 2030 for different purposes (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001)**

Drinking water	Industrial water	Irrigation	Forestation	City greenery	River base flow	Landscaping and other use	Water loss
96.6	11.2	30.8	10	0.5	5.0	3.0	13.1

The Astana (Vyacheslav) reservoir (50 km east of Nur-Sultan) has a potential volume of 375.4 million m³ and is the main source of potable water supply in Nur-Sultan but it is starting to fail to cover the growing water needs of the city (Krasnoyarova et al., 2019). Water shortages in the reservoir have arisen in the past during times of low recharge through spring floods. For example, in 2000, the volume of water stored in the reservoir dropped to 158 million m³.

Possible sources for additional water supply are the groundwater resources and partially the reuse of treated wastewater. Further water could be allocated through transfer through canals from other watersheds, e.g. since 2001, a daily water volume of 288,000 m³ is transferred through the Satpayev canal to the Yesil river to replenish the Astana reservoir.

It was projected that 50 – 80 million m³/a of treated wastewater will be available for reuse by 2030 (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001). Reuse of treated wastewater for irrigation was practised near Taldykol Lake from 1985 to 1995 but was closed down due to lack of money. It has to be noted that reclaimed water can only be used for fodder crops (or reforestation) and not for crops for human consumption in Kazakhstan.

In the southern part of the city irrigated agriculture is in operation but currently agriculture is mostly rain-fed (Regional Environmental Centre for Central Asia, 2019). If irrigation occurs, it uses water taken directly from the Yesil River. Irrigation water demand has declined in the past due to social and economic changes. Thus, there is only little irrigated agriculture at present. However, there were government plans to restore existing irrigation schemes and to grow agriculture. A potential 5,412 ha of land were dedicated for potential farming (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001). Next to irrigation, forestation is envisioned in the master plan of the development of Nur-Sultan. The plan to increase forestation outside of the urban area would require an estimated 10 million m³ water/a by 2030 for an area of 20,000 ha of forest. Treated wastewater from the Taldykol reservoir was planned to be used for this purpose (Japan International Cooperation Agency and Capital Development Corporation City of Astana, 2001).

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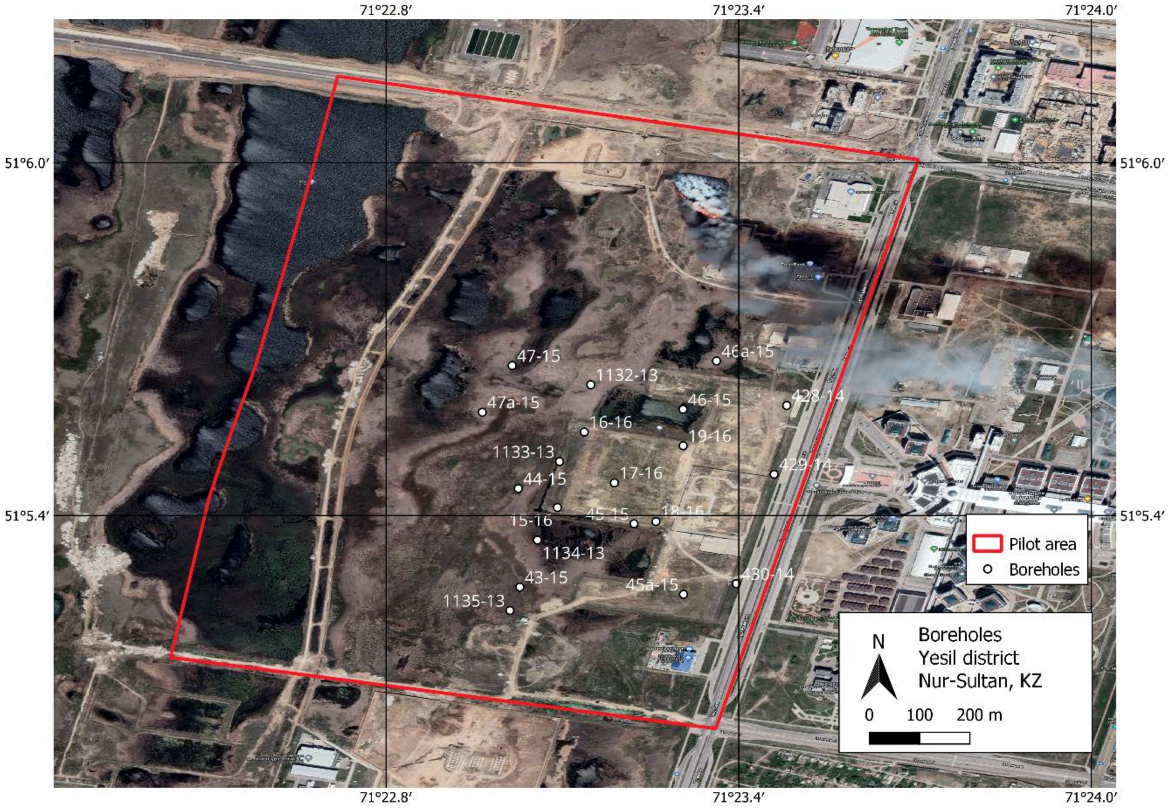
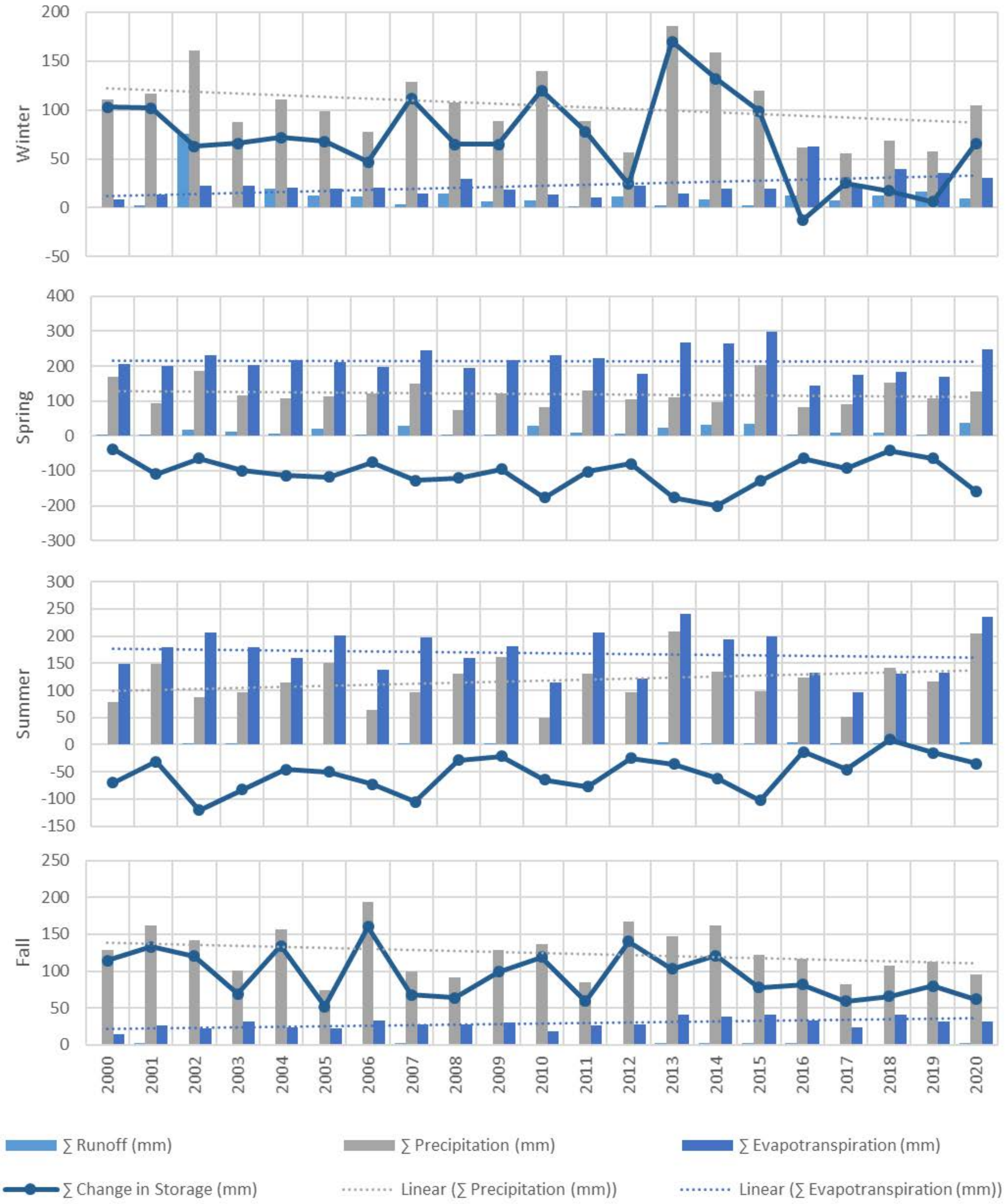
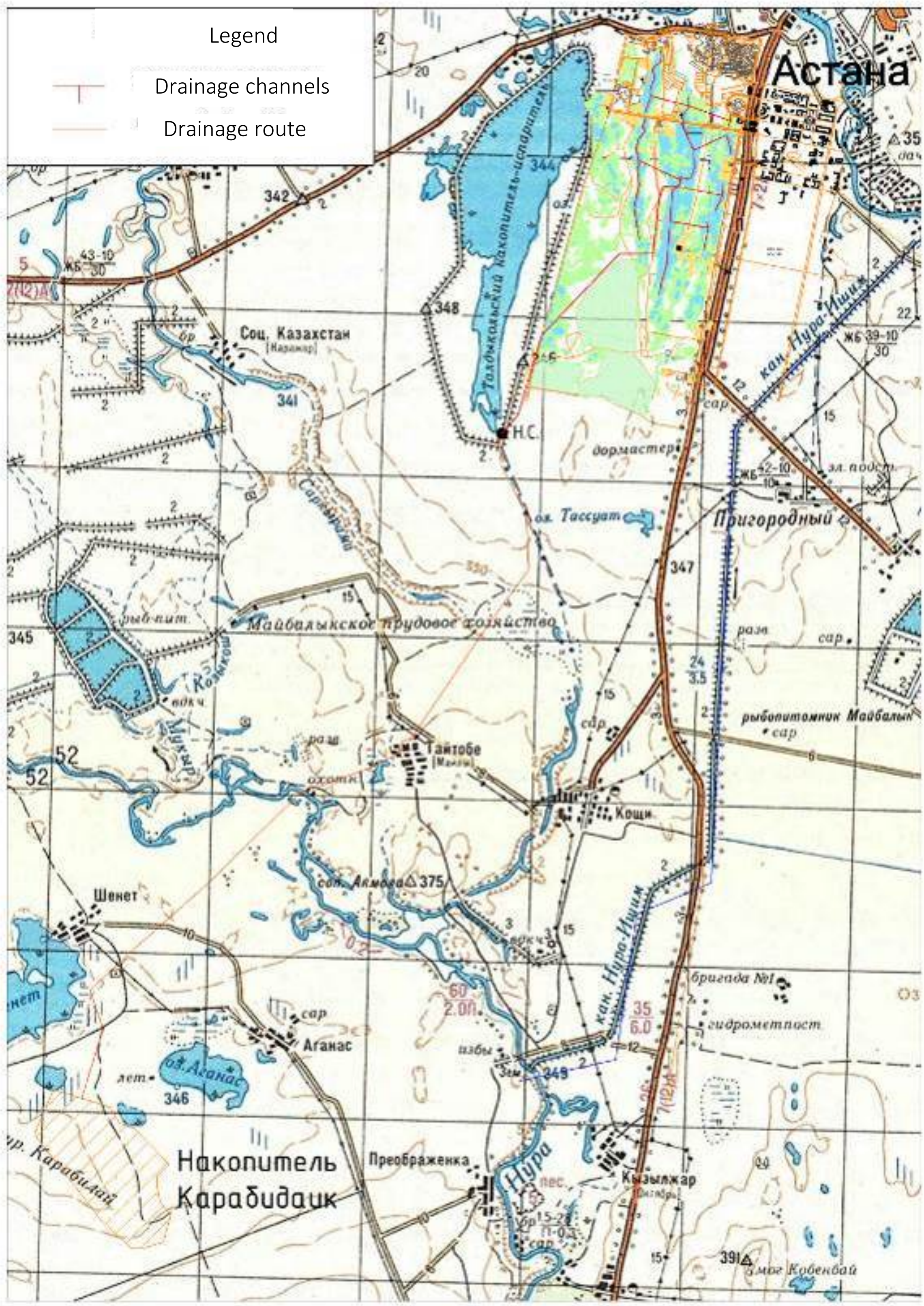


Appendix 1 Location of boreholes in pilot area



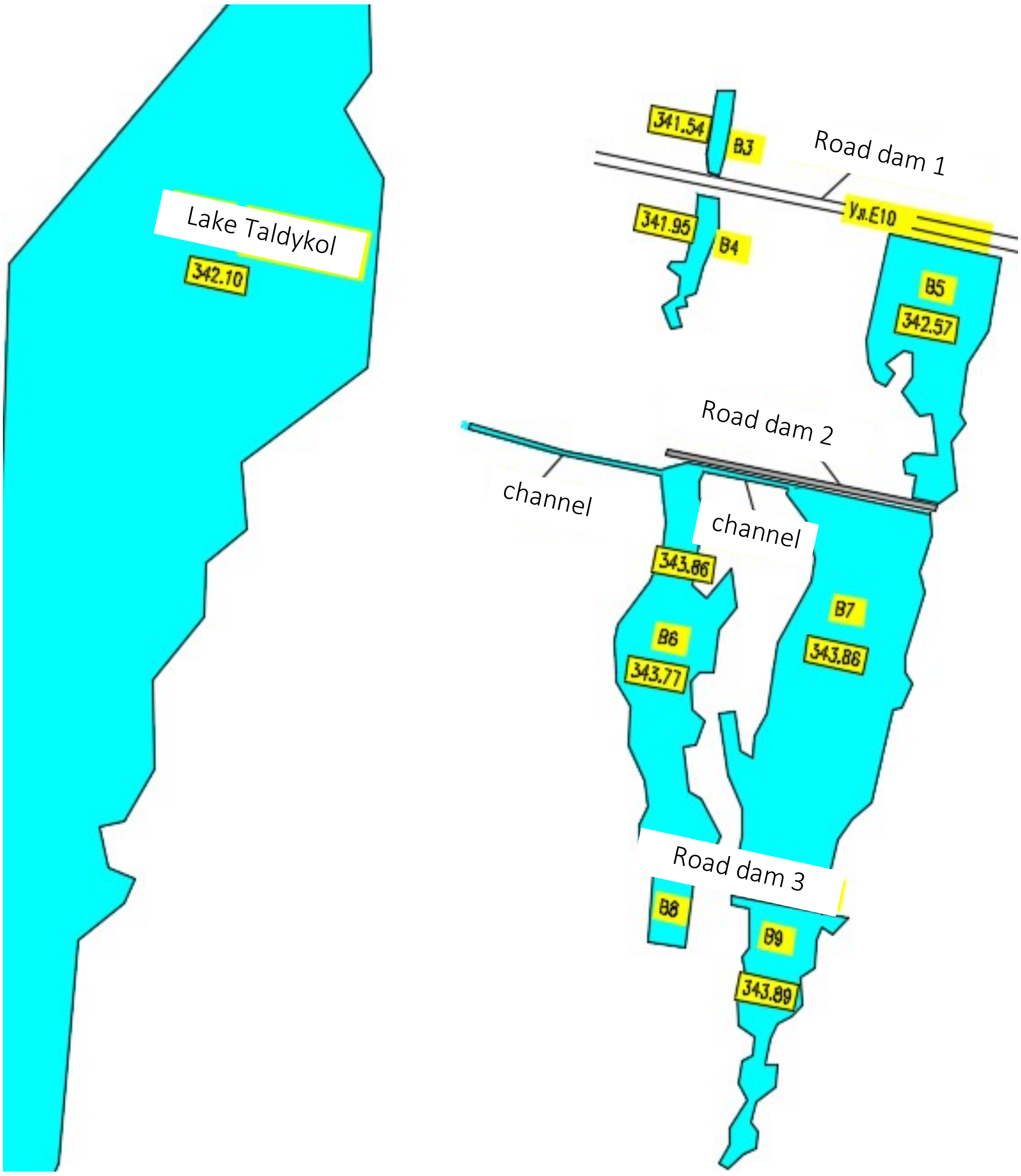
Appendix 2. Sums and trends of annual water balance components (in mm) for Nur-Sultan broken down into winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep) and fall (Oct-Dec)



Appendix 3. Diagram of drainage canals in the water area of the Maly Taldykol lakes and drainage routes

Appendix 4 Chemical composition of bottom sediments of the Taldykol lake system (in mg/l and [1]in mg/kg)

	Lake body 1	Lake body 2	Lake body 3	Lake body 5	Lake body 6	Lake body 7	Lake body 8	Lake body 9
pH	7.9	8.1	8.2	7.8	7.7	7.5	7.6	7.7
Sulphate	58	45	64	124	61	79	58	76
Nitrate	0.6	1.3	0.3	0	0.2	0.8	0.3	0.6
Ammonium	0.25	0.12	0.05	0.03	0.05	0.1	0.04	0.07
Surfactant	0.013	0.011	0.013	0.014	0.017	0.0105	0.013	0.012
Iron	0.42	0.12	0.08	0.05	0.11	0.813	0.09	0.05
Nitrite	0.02	0.008	0.018	0.031	0.004	0.195	0.014	0.008
Phosphate	0.036	0.056	0.23	1.84	0.13	0.029	0.46	0.72
Chloride	522	487	241	429	216	924	378	95
Calcium	2812	1860	4263	3381	4477	1224	2794	4305
Sodium	2083	3246	4377	2770	2770	3410	5510	2343
Magnesium	3040	2280	5134	5680	4860	3870	8270	4779
Potassium	220.9	316.3	169.3	237.7	179.8	192.4	241.6	157.2
Lithium	1.14	2.13	3.06	2.15	1.93	3.05	4.68	3.27
Fluoride	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
α-Hexachlorocyclohexane[1]	<0.0001	<0.0001	<0.0001	0.0393	0.0225	0.0549	0.0456	0.0652
d –Hexachlorocyclohexane[1]	<0.0001	<0.0001	<0.0001	0.11	0.2579	0.1705	0.2792	0.0596
Heptachlor[1]	<0.0001	<0.0001	<0.0001	<0.0001	2.0063	<0.0001	<0.0001	0.3163
4,4-Dichlorodiphenyldichloroethylene[1]	0.3272	0.6409	0.2946	0.4551	0.1589	0.2629	0.3337	0.3676
Kelthane	<0.0001	<0.0001	<0.0001	<0.0001	0.0627	<0.0001	<0.0001	<0.0001
Heptachlor epoxide[1]	0.1747	0.4064	0.5444	0.3576	0.0426	0.1123	0.1332	0.1293
Aldrin[1]	0.1825	0.1919	<0.0001	0.1117	0.0871	0.1243	0.0404	0.023
Endosulfan[1]	<0.0001	0.0021	<0.0001	0.0026	0.0254	0.0194	0.0021	0.0133
Chlorobenzilate[1]	12.2487	23.0817	11.921	8.8763	<0.0001	7.9485	7.4359	<0.0001
Endrin[1]	1.9392	<0.0001	<0.0001	<0.0001	0.4089	1.2593	<0.0001	26.5848
Endosulfan[1]	<0.0001	17.2	10.3113	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Naphthalene[1]	<0.0001	<0.0001	5.6	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Acenaphthylene[1]	7.9	<0.0001	5.3	6.5	5.5	<0.0001	13.7	96.3
Acenaphthene[1]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	26.7
Fluorene[1]	3.2	0.8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Pyrene[1]	1	<0.0001	0.6	0.5	0.7	0.5	0.4	0.5
Benz[a]anthracene[1]	<0.0001	0.9	5.5	2.3		7.6		3
Chrysene[1]	1	<0.0001	0.3	0.5	0.3	0.2	0.4	0.2
Benzo[b]fluoranthene[1]	1	0.6	2.1	<0.0001	<0.0001	<0.0001	0.6	<0.0001
Benzo[k]fluoranthene[1]	0.6	0.4	1	0.2	0.3	0.2	0.4	0.2
Benzo(a)pyrene[1]	0.4	0.1	0.2	0.2	0.3	0.3	0.1	0.2
Arsenic[1]	5.44	14.59	19.99	14.41	<0.01	5.47	9.38	11.24
Mercury[1]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01



Appendix 5. Lake levels of Taldykol lake system in 2021 (Kazakhstani Chamber Environmental Auditors, 2021)

Appendix 6. Locations of groundwater measuring locations from 2004/2005 (locations are estimated)