Temperature regime of the Daginsky thermal springs (Sakhalin Island) during their reconstruction in 2019-2021

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Abstract. The article presents the results of studies of the temperature regime of the Daginsky thermal springs. Daginsky thermal springs are the most famous and visited on Sakhalin Island (Russia). In the fall of 2019, their reconstruction and arrangement of the surrounding landscape began. As a result of the reconstruction of the main thermal springs, their hydrological and temperature regime was violated, the water temperature dropped. In 2020, in the springs most popular with visitors (Aleksandrovsky, Tsentralny, Mechta), the temperature became several degrees lower, which led to the termination of their use. In 2021, after the completion of the design of the spring bath and the surrounding area, the temperatures increased. In April 2021, the temperature of the Patriot spring was 40.5 °C, the Partizan spring 38–39 °C, the Central spring 36–39 °C, the Aleksandrovsky spring 34.6–36.0 °C, the Mechta spring 34.4 °C (at the bottom up to 45.5 °C), Molodost spring 35 °C (at the bottom up to 37–41.3 °C).

1. Introduction
Daginsky deposit of thermal mineral waters is located in the north-east of Sakhalin Island, on the coast of the Nyisky Gulf of the Sea of Okhotsk. Active exploration of the Daginsky deposit began in the 1950s by V.V. Ivanov [1], N.D. Tsitenko [2], M.A. Stein [3, 4], B.T. Komissarenko [5], operational reserves of thermal mineral waters were approved in 1990–1991 [6]. From the 1990s to the early 2000s hydrothermal fluids have practically not been studied. Modern periodic field studies of the Daginsky thermal springs have begun since 2004 [7–11]. In all studies, the main role was assigned to the conditions for the formation of hydrothermal vents, the variability of physical and chemical indicators, and the assessment of the prospects for the use of hydrothermal vents in balneotherapy. The reconstruction of the springs and the improvement of the surrounding territory have begun in the fall of 2019 by the order of the Government of the Sakhalin Region. Six springs were selected for reconstruction (figure 1). The baths of the springs were made of steel (figure 2), they all have the same dimensions (193×193 cm), while the morphometric parameters and the flow rate of certain thermal springs were not taken into account. The bath is mounted on a platform with pontoons measuring 8×8 m; the top is covered with a dome about 6 m in diameter and 3.2 m high, made of an aluminum frame and plexiglass (figure 3).

During the reconstruction of the main thermal springs, their hydrological regime was changed, the water temperature decreased. The purpose of our research is to reveal the features of the change in the temperature regime of the Daginsky thermal springs during the period of their reconstruction. For this purpose, field work was carried out with spring temperature measurements (January 21–22, 2020;
May 19–21, 2020; October 5–6, 2020; April 7–8, 2021). The data obtained were compared with the water temperatures in the springs before their reconstruction.

2. Methodology
The temperature of the thermal springs was measured with electronic thermometers with a KTKhA 01.02R-T310 thermal converter, the operating temperature range of this thermocouple is from -200 °C to +1350 °C, the measurement accuracy is 0.1 °C. When determining the maximum temperature, the duration of the measurements was several minutes. The SAT SDS Hotfind-LXS thermal imager was used to survey infrared (thermal) imaging of the areas with outcrops of hydrothermal vents. The range of measured temperatures of the thermal imager is from -20 °C to + 1000 °C, the accuracy is ± 2 °C, the angular field is 24×18°, the spatial resolution is 1.1 mrad, and the resolution of the active matrix is 384×288 points. We also used the CAT S61 (Flir) portable thermal imager.

Figure 1. The geographical position of the Daginsky thermal springs (a); reconstructed thermal springs (b): 1 – Patriot, 2 – Partizan, 3 – Central, 4 – Aleksandrovsky, 5 – Mehta, 6 – Molodost (satellite image from Google Earth).

Figure 2. The bath of the spring.

Figure 3. Dome of the Central thermal spring.
3. Results
There are three areas of thermal mineral waters discharge at the field: North, Central and South. The springs of the Northern section discharge within the littoral zone of the Nyisky Bay and are flooded with sea waters and the Nelbuta River at the high tide. The springs of the Northern section were not included in the reconstruction project. Four main thermal springs have been reconstructed in the Central section of the Daginsky deposit of thermal mineral waters: Patriot, Partizan, Central, Aleksandrovsky. The hydrothermal fluids of these springs have similar physical and chemical properties. Thermal waters are methane (free gases contain 77–83 % methane), sodium chloride, pH 6.8–7.8, TDS 1.3–2.7 g/l.

The **Patriot spring** had an average temperature of 40 °C and was very popular with visitors before the reconstruction. After the reconstruction, the water temperature in January 2020 was within the range of 34.9–36.5 °C and the spring was practically not used. In May 2020, the average water temperature was 38.3–39.4 °C, and the spring was rarely used by visitors. At the beginning of October 2020 and in April 2021, the temperature has reached 40.5 °C, the spring is actively used by visitors. The water in the bath is relatively clean, the depth to the metal bottom in April 2021 was 88 cm.

The **Partizan spring** had an average water temperature of 39.0–41.5 °C before the reconstruction. After the reconstruction, the water temperature in January 2020 was 38.0–38.5 °C. The average temperature in May 2020 reached 38.5 °C, in October 39.0 °C. In April 2021, the average temperature was 38–39 °C, the water in the bath was relatively clean, the depth to the metal bottom was 104 cm. Today it is the most visited spring.

The **Central spring** (Dikiy, according to [6]; now it was erroneously designated as Pioneer) warmed up to 38–40 °C on average before the reconstruction. In January 2020, the temperature was 30.0–31.8 °C. In May 2020, the average temperature of the water in the bath was 25.2–27.5 °C, in October (after the work had been carried out by the contractor to reduce the flow of groundwater) it reached 39.1 °C. In April 2021, the average temperature was about 36 °C, at a depth it reached 39 °C. The spring was practically not visited, the water in the bath was relatively clean, the depth to the metal bottom was 100 cm.

The **Aleksandrovsky spring** was the hottest and most visited spring before the reconstruction. The average temperature in different years and seasons was within the range of 45 °C, in March 2017 it was 40.0 °C, in October 2019 it was 42.0 °C. After the reconstruction, the water temperature in January 2020 was in the range of 26.5–27.5 °C. In May 2020, the average temperature was 33.6–34.1 °C (figure 4), in October (after the work had been carried out by the contractor to reduce the flow of groundwater) it reached 39.3 °C. In April 2021, the water temperature was 34.6–36.0 °C, the depth to the metal bottom was 96 cm. The water in the bath is peaty, silty sediments are observed on horizontal surfaces, metaphyton mats and foam float on the surface. When mounting the platform of this spring, a surface turf layer of peat with a thickness of 10–50 cm was removed, there is an open peatland with cold surface water around the spring now; the temperature of the cold spring on the south side of the platform in April 2021 was 4.5 °C. Due to the low temperature and turbidity of the water, the spring is currently not used.

In the southern section of the Daginsky deposit of thermal mineral waters, 2 main thermal springs were reconstructed: Mechta and Molodost. The spring fluids have similar physical and chemical
properties. Thermal waters are methane (free gases contain up to 91% methane), sodium chloride, pH 6.8–8.1, TDS 2.5–2.6 g/l.

The **Mechta spring** had an average water temperature in the range of 36–39 °C before the reconstruction, while temperatures of 40–45 °C were recorded in the muddy bottom of the spring. Despite the extremely unsightly appearance, the spring has always been very popular. After reconstruction in January 2020, the average water temperature in the spring was 26.5–27.7 °C, in May 2020 it reached about 32 °C in the near-surface layer, in October (after the contractor's work on changing the design of the hot tub and reducing the flow of groundwater) 35.5 °C in the near-surface layer and up to 39.5 °C at the bottom. In April 2021 (figure 5), the water temperature was 34.4 °C at a depth of 50 cm, the temperature of the sandy bottom (the metal perforated bottom of the bath was removed) reached 45.5 °C in some places, the average depth of the spring was 114 cm. There are practically no visitors at the spring.

The **Molodost spring** was also very popular with visitors before the reconstruction. The water temperature was within the range of 37–39 °C. After the reconstruction in January 2020, the temperature was in the range of 30.1–32.2 °C, in May the average temperature in the hot tub was 35.2–36.1 °C, in October (after the contractor's work on changing the design of the hot tub and reducing the flow of groundwater) was 35.4–37.0 °C. In April 2021, the average water temperature was 35 °C (figure 6), the temperature of the sandy bottom (the metal perforated bottom of the bath was removed) reached 37–41.3 °C in some places, the average depth of the spring was 111 cm. There are practically no visitors at the spring.

**Figure 5.** The Mechta spring (07.04.2021).

**Figure 6.** The Molodost spring (07.04.2021).

### 4. Conclusion

Comprehensive studies carried out in 2019–2021 showed changes in the temperature regime for several springs in comparison [7, 11] with the period before their arrangement had been started: the average water temperature became several degrees lower due to an incorrect design solution and unskilled construction work. It was found that, as a result of the arrangement, the pits of the springs were significantly expanded, the participation of cold groundwater increased, therefore, the hydrothermal fluids entering them with a certain flow rate do not heat the increased volume of water to the previous temperatures. The attempts made by the builders to block the flow of cold groundwater into the trenches of the springs gave a small temporary effect, but at the same time worsened the water exchange in the springs. Today, out of 6 equipped springs, only 2–3 springs are actively visited, depending on the season of the year. For a complete restoration of the temperature regime of the Daginsky springs, it is necessary to carry out their reconstruction based on a scientific approach and modern data. It is necessary to continue routine monitoring of the temperature of the springs. Regular observations will reveal changes and predict the further development of the situation.
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