Impact of Vladivostok’s solid waste landfill for ecological risks formation of nearby rivers pollution

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Abstract. This article analyzes the environmental issues arising from the development and operation of the landfill and the theoretical calculation of the timing and expected output sites with contaminated water into the neighboring valley streams, including Brook Desantny, Brook Rybachy, and River Bolshaya Pionerskaya.

1. Introduction

The new landfill was developed in the city of Vladivostok, Municipal Solid Waste (MSW) Polygon. It locates in the valley of the Brook Bezymyanny and it was constructed in preparation for the APEC Summit 2012. The unnamed old landfill in the town of Gornostai was closed and remediated. The new site is supposed to be designed taking into account all the latest developments in solid waste processing industry. The MSW Polygon is located in the brook valley and includes four sites for waste disposal with waterproof layer, drainage of the contaminated water into the wastewater treatment plants, and discharge of treated water into the Brook Bezymyanny.

Since the construction work was carried out in a hurry to meet the deadlines, the landfill project was carried out in a shortened form and with poor quality of work. Work region was divided by four Sites (part of whole area) - Fig. 1. By the time the APEC Summit 2012 commenced, the waterproofing has not been completed yet at Site #1 and has not been even started at Site #2. However, the old landfill had already been closed. As waste disposal was necessary, the local government made a decision to store waste in unprepared Site #2.

In order to assess the situation at Site #2 after the APEC Summit 2012, the engineering surveys were performed by Izyskatel-2 LLC and Ecoproekt LLC (the firms from the Vladivostok city, which deal with geological and environmental works).

The results of the surveys are as follows:

1. The drainage works of the Brook Bezymyanny were performed poorly. Half of the contaminated water enters the proper drainage channel built of reinforced concrete trays. However, half of it goes directly into the small canyon located at the Site #2. In order, to intercept the stream fully, it is necessary to build a hydraulic structure to collect the water (possibly out of the concrete), as well as cemented partitions across the thalweg (possibly more than one).

2. Site #2 was quickly filled with waste that eventually spread into Site #3. The Brook Bezymyanny freely flows through Sites #2 and 3. At the time of the surveys, the waste thickness at Site #2 was 8-13 meters; 4 meters out of them (on the surface) were in the dry state, and less than 4 meters – in the water-saturated state. Given that approximately 10-20% of waste, including organic
waste, paper, and textiles, has already been dissolved, the relocation of the waste from Site #2 into better-constructed Site #1 is out of question.

3. At the time of the surveys, the sewage treatment plants were not working properly. They were packed with polyethylene and the Brook Bezmyanny, leaving Site #2 through the pipe dumped its waters into the small canyon below the landfill, forming a brown foam of 0.5 meters high.

4. According to the water samples, taken by Ecoproekt LLC from the monitoring wells on the left side of the stream, could see high content of phenols and other contaminants, the contaminated water from Site #2 spreads further down the canyon.

The aims and objectives of the present article is to theoretically calculate the release dates of polluted waters from Site #2 into the neighboring valley streams, including Brook Desantny, Brook Rybachy, and River Bolshaya Pionerskaya. Particular interest is the output of the polluted water into the valley of River Bolshaya Pionerskaya and subsequently – into the Pioneerskoe (Sedankinskoe) reservoir, which is used to supply water to the city of Vladivostok.

2. Geological conditions of the site

The landfill site is located in the contact zone of the Pospelovsky suites with intrusion of the Sedankinsky granitoids. The Pospelovsky suites have regional North-Eastern strike, with the dip at the 40-45° angle in the South-East.

The South-Eastern edge of the landfill is formed by the stratification of the quartz-feldspar sandstones of the lower stacks (possibly the second pack) of the Pospelovsky suite. The bottom or the first pack of the Pospelovsky suite is not exposed at the landfill. The pack is composed of the massive sandstones from fine-grained to fine-grained light-gray platy. There have been bands up to 5 m of the

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**Figure 1.** Study area, sites. Sedimentary rocks: 1 - siltstones, 2 - sandstones; Intrusive rocks: 3 - granites, 4 – diorites; 5 – sites, 6 – fault line
dark-gray thin-slabby siltstone, while the siltstones are of minor importance. On the left side of the landfill there are exposed platy sandstones, and on the right side — platy and massive layers (in the area of the specialized plant). Siltstones in the starboard side have the same bedding. The formation thickness is cut by a valley of the Brook Bezymyanny. This pack contains a weak tectonic disturbances and almost terrigenous composition, while the effusive rock is not observed (Fig. 2).

The bottom sediment (clastic) pack of the Pospelovsky suite meets with the effusive-sedimentary packs (third or fourth) approximately in the middle of the landfill. On the contact with the effusive packs, the layers of the sandstones sometimes bend, creating separate xenolith blocks.

Figure 2. The schematic geological section

The overlying packs, mainly effusive, consist of the layers of andesite, rhyolite, and silicified sandstones. The rhyolites are rare. There is a significant tectonic disturbance of the effusive rocks, which are filled with rhyolites rocks. The tectonic disturbances usually steeply dip at an angle of 60-80°, subparallel to stretch seams. There are rare and dipping disturbances in the form of thrust faults.

On the western edge of the site, in the upper reaches of the glen, on the left side the leucocratic Sedankinsky light granite intrusions were opened. Because of the proximity of the intrusive contact, the volcanic-sedimentary rocks of the upper packs of the Pospelovsky suite silicified due to the contact metamorphism; in some formations the hornfelsing is observed.

The (true) penetrated thickness of the lower (terrigenous pack) at the sides of the gully is about 200 m, thickness of the upper volcanic-sedimentary packs is about 300 m.

The Brook Bezymyanny, as well as the rest of the neighboring streams that cascade into the sea (Brook Rybachy and Brook of the Desantny Bay), struck the bed of its valley on the tectonic fault that is located across the strike formations of the Pospelovsky suite. These tectonic faults abut the edge of the Sedankinsky intrusive massif and disappear.

3. Theoretical calculations pollution from pool neighboring streams landfill
The MSW Poligon is located in the valley of the Brook Bezymyanny. The absolute marks are 145-150 meters (map marker number 2). On the opposite side of the hills surrounding the MSW Poligon, there are valleys of the Brook Rybachy, Brook Desantny, and River Bolshaya Pionerskaya. The Bolshaya Pionerskaya River is a protected water zone and the headspring of the Pionerskoe (Sedankinskoe) reservoir. The Sedankinsky Granite Intrusion separates the landfill from the reservoir. Since the surrounding streams of the valley are located below the landfill level, as a result of filtering of the contaminated water through the hills, it is possible to contaminate by sewage the basins of the Brook Rybachy, Brook Desantny, and River Boljshaya Pionerskaya. This assumption is theoretical, because the polluted water self-cleans when it is filtered through the rock strata. But the self-cleaning process is not infinite, and at some point (after the n-number of years), the contaminated water can reach the outlets of the three neighboring streams. In this paper, the theoretical calculation of the timing of the release of the contaminated water from Site #2 into the neighboring valley streams is presented.
4. Method of computation
Since there are no small-scale maps of the territory, a topographic base was first prepared. Based on the Google maps and 1: 100,000 scale, the 1: 20,000 scale map with drawing contours was created. The shortest (direct) direction to the beds of Brooks Rybachy, Desantny and the river Big Pionerskaya are marked (Fig. 4).

The next stage of computation was hydraulic calculations, under which the following factual and theoretical estimates were made:

1) The water level at Site # 2 - 142.5 m (elevation level of contaminated water at Site # 2) The distance from the surface of Site # 2 and exit points in the creeks of the valley is calculated according to the plan of the indicative scale of 1: 20,000. The distance between Site # 2 and the Brook Desantny is 600 m, Brook Rybachy - 700 m, and the River Bolanjaya Pionerskaya - 1900 m (Fig. 3).

2) The minimum slope of the water flow - 0.006 (adopted from the design of the gravity sewer) [5], then J = 0.006. [3]

3) The rock massif porosity:
The granitoides porosity [4] - (1% <N <10%), taking the average value of 5%.
The sandstones porosity [4] - (3.5% <N <24%), taking the average value of 10%.

Filtration coefficient of intensely fractured rocky soils is calculated based on two values [3]:
Kmin - 0.5 m / day
Kmax - 5 m / day

Figure 3. Diagram of hydraulic calculation.

The 142.5 mark of the water level at Site #2 is used as a primary mark. The absolute marks where the polluted waters reach the valleys of the Brook Desantny, Brook Rybachy and River Bolanjaya Pionerskaya are calculated taking into the account the minimum sewer slope towards the valleys of the streams.

The calculation of flow #1 of contaminated water from Site #2 to the River Bolanjaya Pionerskaya (the total distance of 1900 m) is as follows:

Let us assume the granitoides as averaged porosity rocks considering fractures, tectonics and take N = 5%.

1. Filtering rate:
Vmin = Kmin * J = 0.5 * 0.006 = 0.003 m / day
2. The actual flow rate:
   $U_{\text{min}} = \frac{V_{\text{min}}}{N} = \frac{0.003}{0.05} = 0.06 \text{ m / day}$
   $U_{\text{max}} = \frac{V_{\text{max}}}{N} = \frac{0.03}{0.05} = 0.6 \text{ m / day}$

3. Estimated time of downstream:
   $t_{\text{max}} = \frac{S}{U_{\text{min}}} = \frac{1900}{0.06} = 31666.67 \text{ years}$
   $t_{\text{min}} = \frac{S}{U_{\text{max}}} = \frac{1900}{0.6} = 3166.67 \text{ years}$

The estimated output of polluted water is calculated to be at the abs. mark of 131.1 m.

The calculation of flow #2 of polluted water from the MSW Poligon to the Brook Desantny (the total distance of 600 m) is as follows:

Let us assume the sandstones as averaged porosity rocks considering fractures, tectonics and take $N = 10\%$.

1. Filtering rate:
   $V_{\text{min}} = K_{\text{min}} \times J = 0.5 \times 0.006 = 0.003 \text{ m / day}$
   $V_{\text{max}} = K_{\text{max}} \times J = 5.0 \times 0.006 = 0.03 \text{ m / day}$

2. The actual flow rate:
   $U_{\text{min}} = \frac{V_{\text{min}}}{N} = \frac{0.003}{0.1} = 0.03 \text{ m / day}$
   $U_{\text{max}} = \frac{V_{\text{max}}}{N} = \frac{0.03}{0.1} = 0.3 \text{ m / day}$

3. Estimated time downstream:
   $t_{\text{max}} = \frac{S}{U_{\text{min}}} = \frac{600}{0.03} = 20000 \text{ years}$
   $t_{\text{min}} = \frac{S}{U_{\text{max}}} = \frac{600}{0.3} = 2000 \text{ years}$

The estimated output of polluted water is calculated to be at the abs. mark of 138.9 m.

The calculation of flow #3 of polluted water from the MSW Poligon to the Brook Rybachy (the total distance of 700 m) is as follows:

Let us assume the sandstonex as averaged porosity rocks considering fractures, tectonics and take $N = 10\%$.

1. Filtering rate:
   $V_{\text{min}} = K_{\text{min}} \times J = 0.5 \times 0.006 = 0.003 \text{ m / day}$
   $V_{\text{max}} = K_{\text{max}} \times J = 5.0 \times 0.006 = 0.03 \text{ m / day}$

2. The actual flow rate:
   $U_{\text{min}} = \frac{V_{\text{min}}}{N} = \frac{0.003}{0.1} = 0.03 \text{ m / day}$
   $U_{\text{max}} = \frac{V_{\text{max}}}{N} = \frac{0.03}{0.1} = 0.3 \text{ m / day}$

3. Estimated time downstream:
   $t_{\text{max}} = \frac{S}{U_{\text{min}}} = \frac{700}{0.03} = 23333.33 \text{ years}$
   $t_{\text{min}} = \frac{S}{U_{\text{max}}} = \frac{700}{0.3} = 2333.33 \text{ years}$

The estimated output of polluted water is calculated to be at the abs. mark of 138.9 m.
5. Conclusion
1. Thus, given the different coefficients of filtering rocks, the calculated times of the output of the polluted water from Site #2 to the valleys of the Brook Desantny, Brook Rybachy and River Bolshaya Pionerskaya are as follows:
   \[ K_{\text{min}} = 0.5 \text{ m/day} \]
Kmax - 5 m / day

Repeating the same calculations for the average coefficient of filtration K - 2.75 m / day, the following values are obtained:

Filtering Flow rate:

\[ V = K \times J = 2.75 \times 0.006 = 0.0165 \text{ m / day} \] - for the Brook Rybachy, Brook Desantny and the River Boljshaya Pionerskaya.

The actual flow rate:

\[ U = \frac{V}{N} = \frac{0.0165}{0.05} = 0.33 \text{ m / day} \] - for River Boljshaya Pionerskaya

\[ U = \frac{V}{N} = \frac{0.165}{0.1} = 1.65 \text{ m / day} \] - for the Brook Rybachy and Brook Desantny.

Estimated time of output streams:

\[ t = \frac{S}{U} / 365 = \frac{1900}{0.33} / 365 = 15.8 \text{ years} \] – to the River Boljshaya Pionerskaya.

\[ t = \frac{S}{U} / 365 = \frac{600}{0.165} / 365 = 9.9 \text{ years} \] – to the Brook Desantny.

\[ t = \frac{S}{U} / 365 = \frac{700}{0.165} / 365 = 11.6 \text{ years} \] – to the Brook Rybachy.

2. The Brook Rybachy and Brook Desantny valleys are of no particular interest as they are short streams that flow directly into the sea and are not used for the purpose of water supply. However, the coastal strip is the fishery conservation zone of the Ussuri Bay area, as well as a place of the popular summer vacation site for those living at the city of Vladivostok. Therefore, the pollution of the coastal strip is unacceptable.

The River Boljshaya Pionerskaya flows into the Pionerskoe (Sedankinsky) reservoir that supplies water to the city of Vladivostok. According to our calculations, the average theoretical release of the polluted wastewater from Site # 2 at the abs. mark of 131.1 m. in the valley of River Boljshaya Pionerskaya can occur in 15.8 years.

3. Taking into account that Site # 2 has been filled around 2011, it is theoretically possible that the output of the polluted water from the landfill into the valley of the Sedankinsky Reservoir can occur in 2026. To test this hypothesis, the management of the Primvodokanal Ltd. is recommended to schedule an assessment of the hydrogeological conditions of the Eastern slope of the Pionerskoe Reservoir starting 2020 to assess the possibility of inflow of the contaminated water from the landfill. It is sufficient to carry out annual monitoring (once a year) of the chemical composition of the surface waters from the Boljshaya Pionerskaya River below the absolute level of 130 m.

It is also possible to start an earlier monitoring of the surface water of the Brook Rybachy and Brook Desantny. If the increase of the phenol in the water samples is noted and raises year to year, it will be possible to conclude that the main reason is the contamination from the landfill.

4. Currently, there are sites at the landfill that have already been filled. To increase the capacity of the landfill, the only solution is to build the dams. However, this can lead to automatically raising the level of the contaminated water at the site thus creating an additional hydraulic gradient and increasing the flow rate of the contaminated water through the rock strata.

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