Comparison of computer prognoses given in 1997 with the real sanitation results for the Ilukste oil pumping station, Latvia

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Abstract. The Ilukste oil station pipelines diesel fuel from Belorus to the seaport town Ventspils in Latvia. In 1970-1996, the station also filled railway tanks. Due to oil leakages, groundwater under the railway terminal routes was contaminated. Mobile oil discharged from a steep bank of the nearby Ilukste river. To prevent oil inflow into the river, a special pond was dug for its intercepting. In 1996, remediation of the station area started and followed up until now. The work was supervised and financed by the station owner LatRosTrans Ltd. Since 2000, it was performed by the environmental company VentEko. In 1997, scientists of Riga Technical University (RTU) established the hydrogeological model of the contaminanted area. Due to use of the model and the code ARMOS, a disposition of the oil leakage source was found. The oil plume self-cleaning for about 25 years was predicted due to oil natural run off into the pond. In 2018, RTU assessed results of the sanitation. It was found out that the remediation process had reached its final stage, as productivity of the oil recovery was getting low. Comparison of the real sanitation results with the predicted course of the oil plume natural run off showed that the both processes differed mainly due to a repeated oil leakage in the area of the railway terminal. The case confirmed considerable value of the predictions that were obtained by modelling.

1. Introduction

Migration processes of oil plumes in groundwater differ considerably from the mass transport of dissolved contaminants. For this reason, in 1997, specialised code ARMOS [1] was used by scientists of Riga Technical University (RTU) for simulating oil movement for the Ilukste oil pumping station site in Latvia. The station is located in the south-east of Latvia (figure 1). The station is situated on a steep bank of the Ilukste river (figure 2). For years, diesel fuel has been leaking through the lower part of the Ilukste river bank. To prevent oil inflow into the river, a special pond was dug. Contents of the pond were periodically removed. In 1996, the company Baltec Associates, Ltd. started remediation of the oil contaminated site. In 1997, due to investigations of the company, the area location (figure 3) and the thickness distribution of the oil plume were found.

Figure 1. Location of the Ilukste oil pumping station

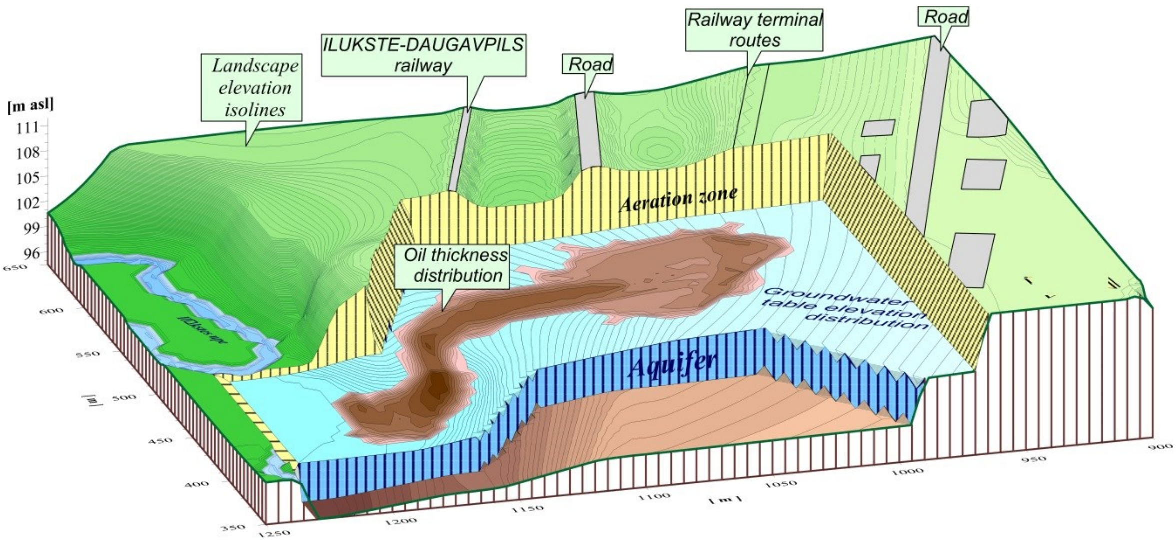

Figure 2. The Ilukste oil pumping station site. The complex isometric diagram with elevation distributions of: the landscape relief, the groundwater table, the clay layer top surface and the simulated oil plume thickness.

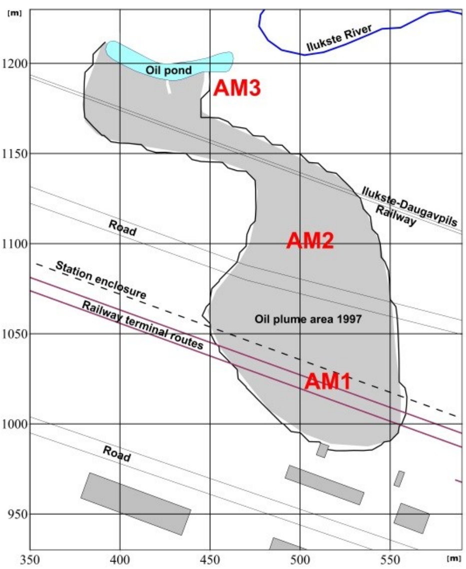

Figure 3. Location of the oil plume area and of the oil recovery modules AM1, AM2 and AM3

In [2] and [3], some hypotheses regarding the oil plume unusual shape were given and the following results obtained by using ARMOS were described:

- to support the steady state oil plume, the oil leakage intensity was about 70-90 litre/day; the leakage was caused by failure of the sewage system of the railway terminal;
- for about 20-25 years, oil plume self-cleaning would take place due to oil natural run off into the pond.

In 2018, it was possible for the RTU team to compare the real sanitation results with the predicted self-cleaning of the oil plume due to natural causes. It was a surprise that the ARMOS predictions satisfactorily matched the real sanitation course.

2. Oil plume self-cleaning simulated by ARMOS

By using ARMOS, natural run off of the oil plume was simulated under the condition that no oil leakages existed in the station area. In figure 4, the results provided by ARMOS are shown. It is visible from the oil plume images for the four elapsed time shots that gradually the plume thickness decreases and the oil flow stops moving. There is practically no difference between the oil plume images after 16 and 24 years. It means that if no oil leakage exists then any oil plume will stop moving. In 1996, this fact was confirmed for oil plumes of the former Rumbula airport site [3].

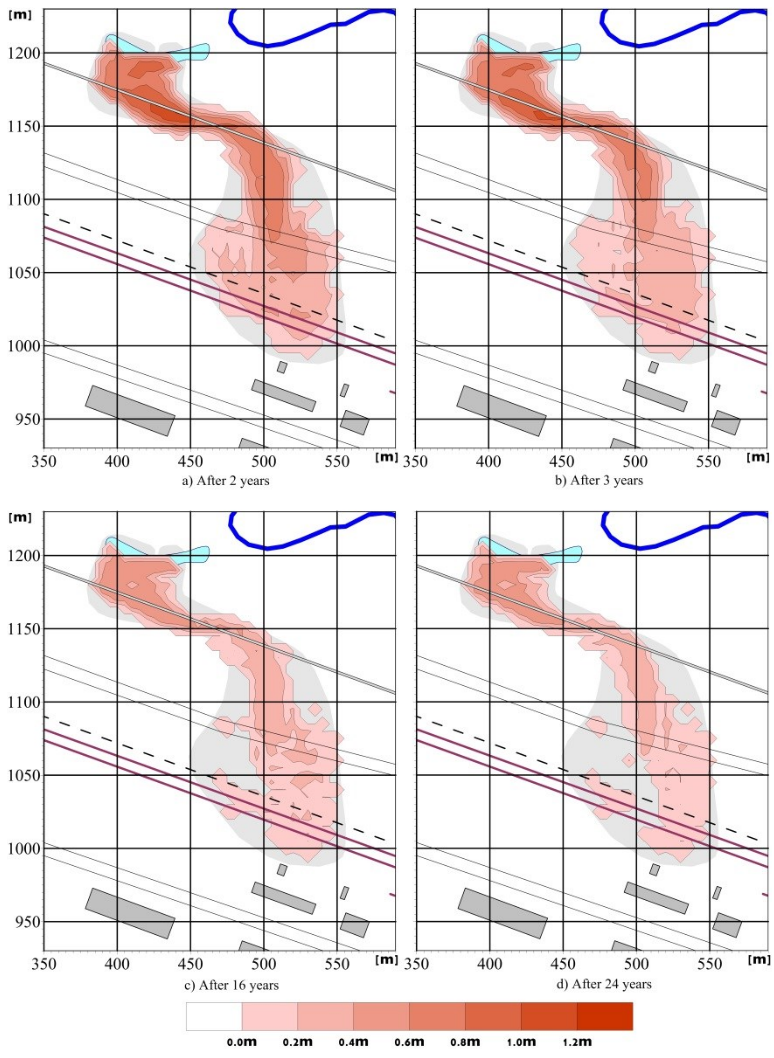

Figure 4. The ARMOS simulated natural run off process of the oil plume

However, the computed movability and a thickness of an oil plume depends strongly on the choice of the Van Guchten's capillary model parameters [4]. For this reason, computed and real oil plumes may be different.
In figure 5, the ARMOS computed volume graphs versus time for total, mobile and trapped oil are exposed. There the trapped oil volume, for the first 4-5 years is not correctly computed, because it must be practically permanent (~105m^3) for the plume. It was shown in [2], [3] that ARMOS failed to compute rightly volumes of trapped oil. Fortunately, the graphs of figure 5 may be used, if the first four year period is eliminated. Then the duration of simulation is 21 years and its start may be associated with 1996.

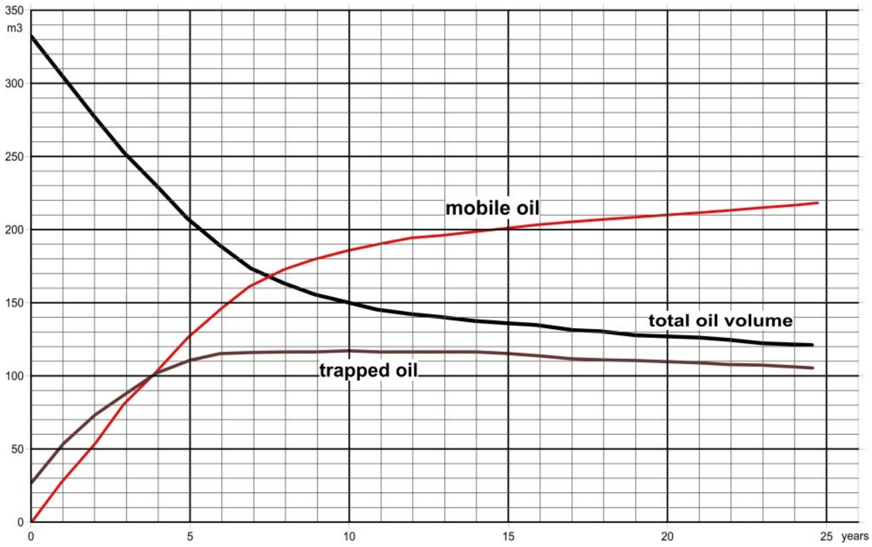

Figure 5. The ARMOS computed cumulative volume graphs for total, mobile and trapped oil

It follows from figure 5 that during the first three years, about 20m^3/year of oil will be discharged into the pond. The area situated at the railway terminal will be cleaned at first. For the last ten years only ~1.6m^3/year of oil may be recovered due to its natural run off.

The plume and trapped oil do not present notable danger to the station site environment, because the aeration zone thickness there is large (in figure 2, 5-9 meters) and oil and its products that are dissolved in groundwater will enter only the pond.

In [2] and [3], it was recommended to apply a clean-up module only at the vicinity of the oil pond (AM3). In reality, the oil recovery modules AM1 and AM2 were also used (figure 3.). About 100m^3 of trapped oil will remain in soil.

3. Sanitation of the station site area

The three oil recovery modules AM1, AM2 and AM3 were applied (figure 3.). The modules AM1 and AM2 pumped oil out from the contaminated aquifer. The set of oil recovery wells was installed there. For the module AM3, a horizontal drain was used that was installed before the oil pond. The drain collected outflowing oil and prevented its inflow into the pond. Therefore, only in the module AM3, the simplest oil recovery option was exploited. In addition, a manual oil skimming from monitoring wells was used, because the method was simple and rather productive. It was applied mostly in the AM2 area. Conditionally, to account for the oil volume recovered by the manual skimming, the fourth module MOB was introduced by RTU in [5].

For the modules AM1, AM2 and AM3, it was necessary to extract recovered oil from a water/oil emulsion. It was done by separating these liquids in cisterns where their stratification took place. During winter, the emulsion froze up and then no clean-up work was done.

4. Productivity of oil recovery

In [5], information regarding productivity of oil recovery for the modules AM1, AM2, AM3 and MOB was arranged. In table 1, information on the oil recovery for the last ten years is provided.

In figure 6, productivity graphs versus time for the oil recovery modules are presented. Considering the graph shape, the following conclusions are obvious:

- productivity depends on climatic conditions; it is high/low if weather is dry/damp, because then groundwater heads are low/ high, accordingly [6];
- since 2004, for the module AM1 productivity increased due to a repeated oil leakage in the railway terminal area; in 2014, underground elements that caused the oil leakage there were removed;
- productivity of the module AM3 represents the natural clean-up process; in 2017, 0.88 m^3 of oil has been recovered (table 1);
- in 2017, productivities for the modules AM2 and MOB were only 0.07m^3/year and 0.23m^3/year, accordingly, (table 1);

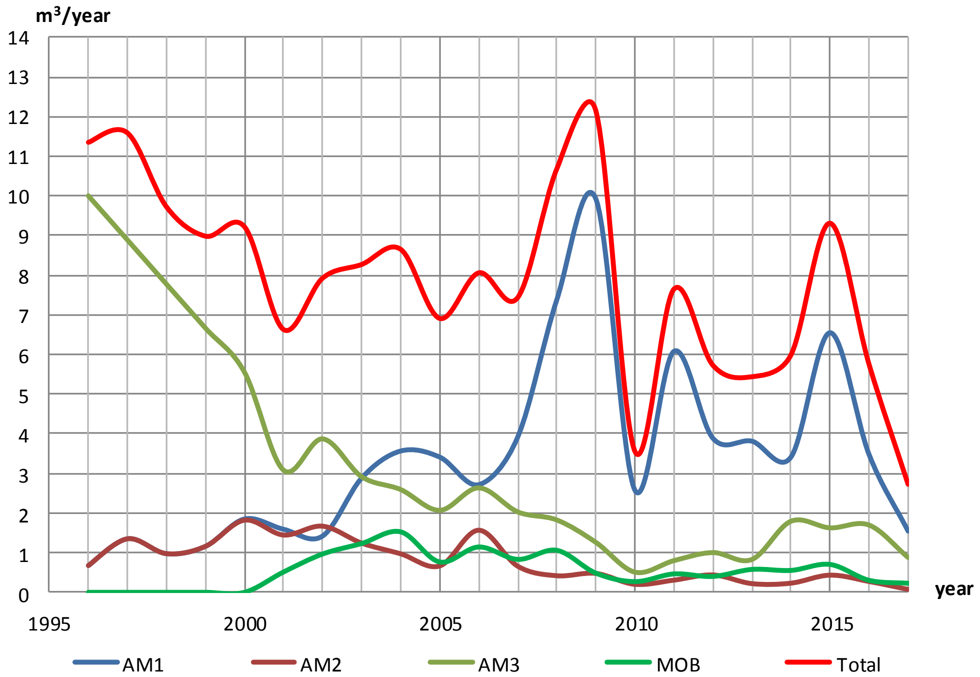

Figure 6. Productivity of the oil recovery modules

Table 1. Productivity [m3/year] of the oil recovery modules

Year	AM1	AM2	AM3	MOB	Total
2008	7.38	0.42	1.83	1.06	10.68
2009	9.93	0.48	1.26	0.48	12.15
2010	2.58	0.20	0.51	0.27	3.56
2011	6.08	0.31	0.80	0.46	7.65
2012	3.89	0.44	1.00	0.40	5.73
2013	3.81	0.22	0.83	0.58	5.44
2014	3.41	0.23	1.79	0.55	5.99
2015	6.55	0.43	1.63	0.70	9.31
2016	3.48	0.27	1.70	0.30	5.75
2017	1.54	0.07	0.88	0.23	2.73

In figure 7, cumulative productivity graphs of the recovery modules are shown; the recovery result is compared with the ARMOS prognosis. In tables 2 and 3 , information for the last ten years is presented.

It follows from these graphs and tables 2 and 3:

- the productivity ~70m^3 is achieved by the modules AM1 and AM3 (table 2);
- the graph for the module AM1 and its mean productivity 4.57m3/year (table 3) indicates a presence of the repeated oil spill ~40m^3 in the railway terminal area; for this reason, the total cumulative productivity has reached 165m^3>128m^3 (ARMOS prognosis).

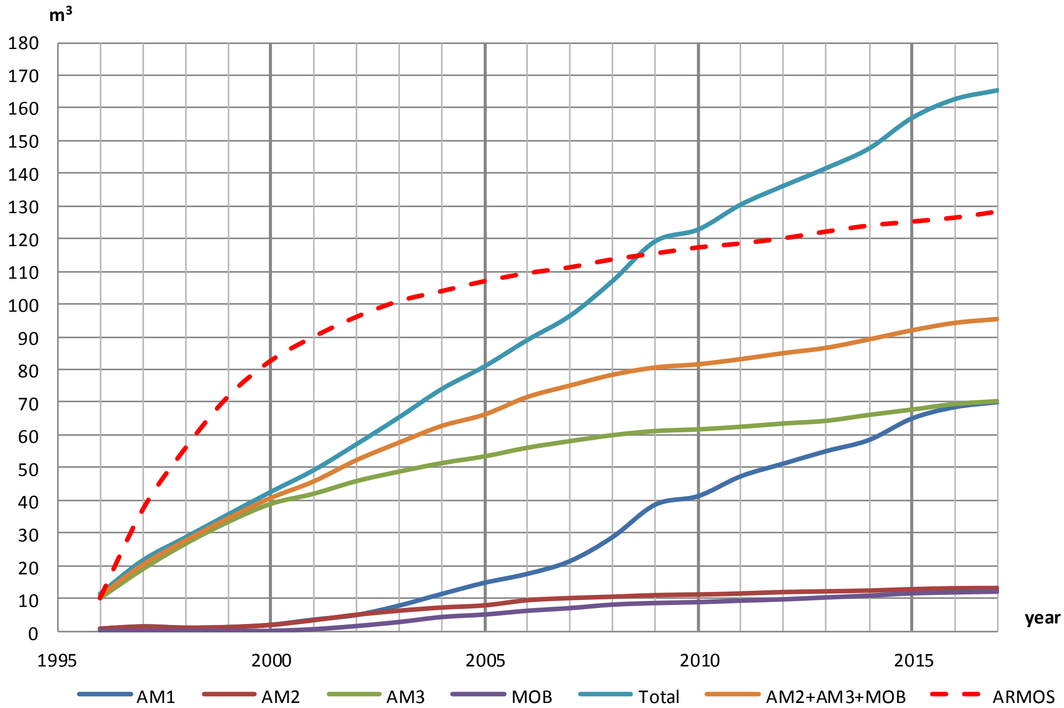

Figure 7. Cumulative productivity of the oil recovery modules; comparison of the total and ARMOS productivities

Table 2. The cumulative productivity [m^3] of oil recovery

Years	AM1	AM2	AM3	MOB	Total	AM2+AM3+MOB	ARMOS
2008	28.73	10.45	59.89	8.03	107.10	78.37	113.68
2009	38.65	10.93	61.15	8.52	119.25	80.60	115.30
2010	41.23	11.13	61.66	8.79	122.81	81.58	116.92
2011	47.31	11.44	62.45	9.25	130.45	83.14	118.54
2012	51.19	11.88	63.46	9.65	136.18	84.99	120.16
2013	55.01	12.10	64.29	10.23	141.63	86.62	121.78
2014	58.42	12.33	66.08	10.78	147.61	89.19	123.40
2015	64.96	12.76	67.70	11.49	156.91	91.95	125.02
2016	68.44	13.03	69.40	11.79	162.66	94.22	126.64
2017	69.98	13.11	70.28	12.02	165.39	95.41	128.26

Table 3. The mean productivity of oil recovery [m3/year] for the last ten years

AM1	AM2	AM3	MOB	Total	AM2+AM3+MOB	ARMOS
4.57	0.29	1.15	0.44	6.45	1.88	1.62

The real oil recovery process differed from the one that was simulated by ARMOS:

- the modules AM1 and AM2 were used where oil was pumped out from the aquifer;
- the considerable oil leakage was present in the AM1 area.

In spite of these differences, the real oil recovery productivity satisfactorily matched the ARMOS prognosis:

- the mean oil recovery 1.88m^3/year for the modules (AM2+AM3+MOB) is close to the ARMOS productivity 1.62 for the last ten years;
- if one assumes that, without oil leakages, the module AM1 may recover ~30m^3 of oil then the total oil recovery 95+30=125 [m^3] is very close to the volume 128m^3 computed by ARMOS.

5. Oil plume thickness evolution

In figure 8, the oil plume thickness distributions in 1996, 2002, 2008 and 2016 are shown. Due to the oil recovery, the oil plume thickness has considerable decreased. In 2002, the area of the module AM1 was rather clean and this fact was predicted by ARMOS (figure 4). However, in 2008, due to the renovated oil leakage, the plume thickness there increased.

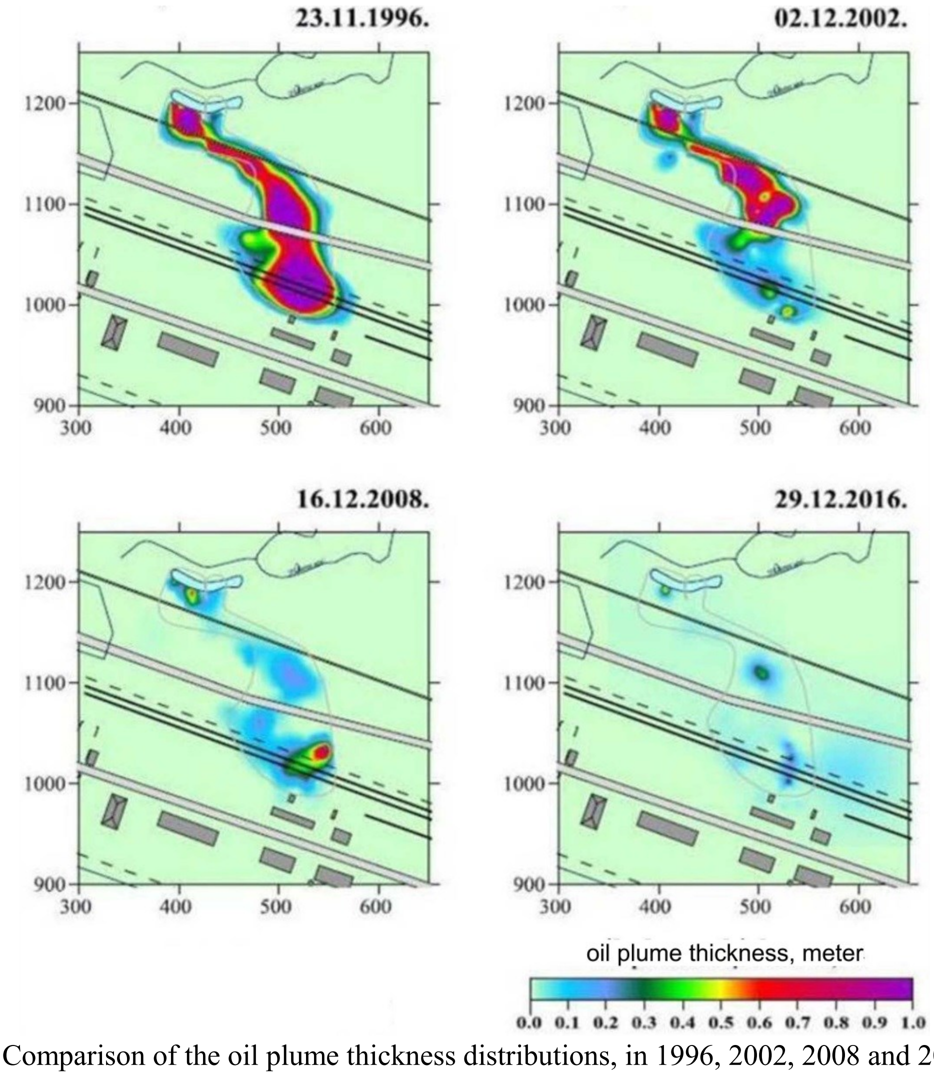

Figure 6. Comparison of the oil plume thickness distributions, in 1996, 2002, 2008 and 2016

In 2016, the plume thickness was only 0.1-0.2 meters. For this reason, the oil flow movement in the AM1 and AM2 areas has stopped. Only slow oil migration towards the drain of the module AM3 may be expected. In 2017, productivity 0.88m^3/year of the module was rather high and its mean productivity 1.15m^3/year (table 3) was notable.

6. Conclusion

The area of the Ilukste oil pumping station site was heavily contaminated due to leakages of diesel fuel. From 1996 up to now, the site remediation process was supervised and financed by the station owner LatRosTrans Ltd. Since 2000, the sanitation process was carried out by the company VentEko. Due to close cooperation of the owner and the performer, the contaminated area of the oil pumping station site was practically cleaned from the mobile oil fraction. About 165m^3 of oil were recovered.

In 1997, the ARMOS prognosis predicted that the contaminated area may be cleaned due to the oil natural run off process. In 2018, it was possible to compare the real sanitation course with the prognosis that was given in 1997. In spite of the differences caused by the additional use of oil pumping and presence of considerable oil leakages, the ARMOS prognosis satisfactorily matched the real oil recovery results. The ARMOS predicted oil natural run off was the most productive oil recovery option.

The oil recovery module AM3 must be preserved, because it also prevents discharge of dissolved oil products into the Ilukste river. The oil dissolution process will continue, because ~100m3 of trapped oil the oil plume leftovers will remain in the contaminated aquifer for a long time.

The case of the Ilukste oil pumping station site sanitation confirmed that mathematical modelling could provide valuable information for remediation of oil contaminated sites.

References

[1] ARMOS, 1988-96, *User and TechnicalGuide*, Environmental Systems and Technologies, Inc.

[2] Contract No 6190/97 report (1997) *Modelling of oil flow movement and recovery for the Ilukste oil storage terminal,* Riga Technical University, 67 p. (in Latvian).

[3] A.Spalvins. Mass Transport Modelling in Groundwater Studies. Achievements of Latvian Scientists / F.Fonnum, B.Paukstys, B.A.Zeeb and K.J.Reimer(eds.), Environmental Contamination and Remediation Practices at Former and Present Military Bases.- NATO Science Series 2: Environmental Security - Vol.48, - Kluwer Academic Publishers, Printed in the Netherlands, 1998 - P.123-142, ISBN 0-7923-5247-5 HB; ISBN 0-7923-5248-3 PH

[4] Van Genuchten, M.Th., A closed-form equation for predicting the hydraulic conductivity of unsatured soils, *Soil, Sci. Soc.Amer*. J., 44, pp. 892-898, 1980.

[5] Contract No L8508 report (2018). *Evalution of oil recovery at the Ilukste oil pumping station,* Riga Technical University, 57 p. (in Latvian).

[6] Kemblowsky, M.W., Chiang, C.Y., Hydrocarbon thickness fluctutions in monitoring wells, *Ground Water*, 28, pp.244-252, 1990.