Verkís

Aloca's Aluminum Plant at Bakki, close to Húsavík in North Iceland. Wet Scrubber Effluent Dilution.

March 2010

Útdráttur á íslensku

Dreifing mengunarefna í sjó frá fyrirhuguðu álveri Alcoa á Bakka við Húsavík hefur verið reiknuð. Sett voru upp tvívíð líkön af straumum og dreifingu af svæðinu utan við Bakkakrók með 50 m upplausn reiknipunkta. Straumalíkanið byggir á upplýsingum úr líkönum sem ná yfir stærra svæði, eru með grófari upplausn og eru keyrð daglega á Siglingastofnun Íslands. Straumalíkanið var stillt af við mælingar sem framkvæmdar voru af Hafrannsóknarstofnun á tveimur stöðum utan Bakkakróks og líkönin voru keyrð yfir einn tunglmánuð.

Í útreikningum sem gerð er grein fyrir í þessari skýrslu er eingöngu horft til afleiðinga þess að nota vothreinsun í fyrirhuguðu álveri enda verður ekki um frárennsli frá iðnaðarferlum að ræða við þurrhreinsun eingöngu. Þau þrjú álver sem nú eru starfrækt á Íslandi, á Reyðarfirði, á Grundartanga og í Straumsvík nota aðeins þurrhreinsun til að draga úr magni mengunarefna í útblæstri og því hefur engin reynsla fengist af notkun vothreinsunar hér á landi.

Niðurstöður voru þessar helstar:

1. Styrkur svifagna og flúoríðs nær bakgrunnsstyrk sjávar í næsta nágrenni útrásar.
2. Styrkur súrefnis fer niður fyrir mettun á aðeins litlu svæði umhverfis útrásina.
3. Að teknu tilliti til dúavirkni sjávar nær frárennsli bakgrunnsgildum fyrir sýrustig (pH) í allra næsta nágrenni útrásar.
4. Gert er ráð fyrir að við 346.000 tonna ársframleiðslu berist 28,3 kg af PAH-16 og 0,57 kg af B(a)P árlega til sjávar. Á botninn setjast 2,8 kg/ári af PAH-16 miðað við stærð agna 10 µm. Miðað við sömu forsendur um stærð agna setjast 0,51 kg/ári af B(a)P á botn flóans. Í báðum tilfellum flyst það magn sem ekki sest á botninn út úr flóanum.

ALCOA´S ALUMINUM PLANT AT BAKKI, CLOSE TO HÚSAVÍK IN NORTH ICELAND

WET SCRUBBER EFFLUENT DILUTION

Project no.: 06156 002 March 2010

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PROJECT NO:	06156 002	DATE:	2010-03-19
WORKPHASE:	7	NO.:	
CLIENT:	Alcoa		
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ABSTRACT:

Alcoa is planning an aluminum smelter with a yearly production capacity of 346,000 tons in an industrial site at Bakki in the vicinity of Húsavík in North Iceland. This study is done in relation to the environmental impact assessment for the plant and is intended to predict the concentration of polluting matters in the sea when the wet scrubber technology is used in addition to dry scrubbers as a means to control pollution from the airborne emissions.

Two dimensional numerical models are set up for Bakkakrókur for the calculations of currents and transport. A 50 m x 50 m resolution model of currents, based on lower resolution models run on daily bases at the Icelandic Maritime Administration, is used to feed a transport model.

The models are calibrated and verified by comparing simulations to measurements at two locations in Bakkakrókur. They are run over one lunar month to predict with sufficient accuracy the variability in velocities and concentration between spring and neap tide.

The transport model simulates dilution, concentration of PAH-16 and B(a)P dissolved and deposited, dissolved oxygen and the pH value in Bakkakrókur.

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1 Introduction

Alcoa is planning an aluminum smelter with a yearly production capacity of 346,000 tons in an industrial site at Bakki in the vicinity of Húsavík in North Iceland. This study is done in relation to the environmental impact assessment for the plant and is intended to predict the concentration of polluting matters in the sea when the wet scrubber technology is used in addition to dry scrubbers as a means to control pollution from the airborne emissions.

Two dimensional numerical models are used for the calculations of currents and transport. A high resolution model of currents, based on lower resolution models run on daily bases at the Icelandic Maritime Administration, is used to feed a transport model.

2 Measurements

The Marine Research Institute (MRI) conducted current measurements at two fixed locations outside Bakkahöfði Cape in November 2008 (**Figure 1**). At the western location the instrument was deployed at a 50 m depth, recording currents in the depth range from about 7 m from the bottom to 7 m below surface, in 5 m bins. The observation period was from November 14th 2008 to January 8th 2009. At the eastern location the instrument was deployed at a 19 m depth, recording currents in the depth range from about 3 m from the bottom to 2 m below surface. The observation period was from November 14th to 30th 2008.

The MRI finds that the currents tend to reflect the topography at the mooring locations. Thus the main direction of the currents at the eastern location is from northeast to southwest and vice versa. The main direction of the currents at the western and deeper location is slightly from northwest to southeast and vice versa.

The MRI conducted sea level measurements at the same locations covering the period from November 14th 2008 to January 8th 2009.

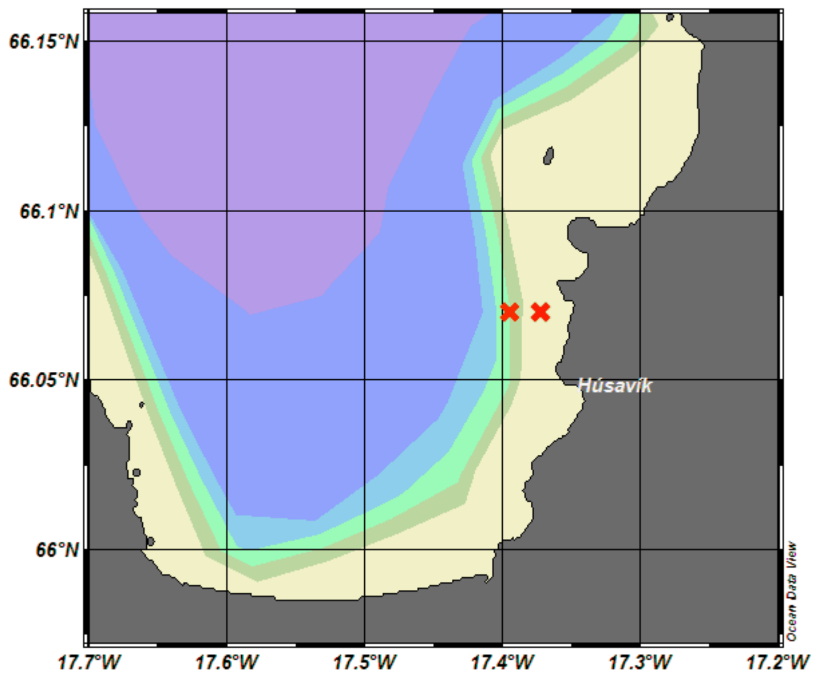

Figure 1 Location of current and elevation meter stations, west of Bakkakrókur. Steps in topography are 20 m, 30 m, 40 m, 50 m and 100 m. (Figure prepared by the Marine Research Institute).

Information on the bathymetry in Skjálfandi is taken from measurements made by the Icelandic Coast Guard, Hydrographic Department. Depth within the transport model area is shown in **Figure 4**.

3 Numerical model of currents

A high resolution 2D tidal model is built to feed the transport model with tidal and weather imposed currents. The tidal model was developed at VST (now Verkís) for the Icelandic Maritime Administration (IMA). It is built on the Princeton Ocean Model, which is a widely used ocean model. It solves the shallow water equations on a Arakawa C-grid, using a finite difference numerical scheme. The domain reaching from Greenland to Norway to Scotland is on a 10 km x 10 km grid (**Figure 2**). Boundary conditions are obtained from global ocean models. A higher resolution 2 km x 2 km model uses boundary conditions from the 10x10 model. These models are run on daily basis at the IMA, to predict sea surface elevation and currents in the North Atlantic Ocean using weather forecasts by the European Centre for Medium-Range Weather Forecasts (ECMWF).

For this project a finer 50 m x 50 m model has been set up, to simulate within an adequate accuracy the currents in Skjálfandaflói Bay. The model domain is 11.25 km x 16.50 km with 50,000 grid points at sea. In order to produce boundary condition for the finer grid model, two other coarser models have been set up. All tidal models used are listed in **Table 1**, model domains are shown in **Figure 2**.

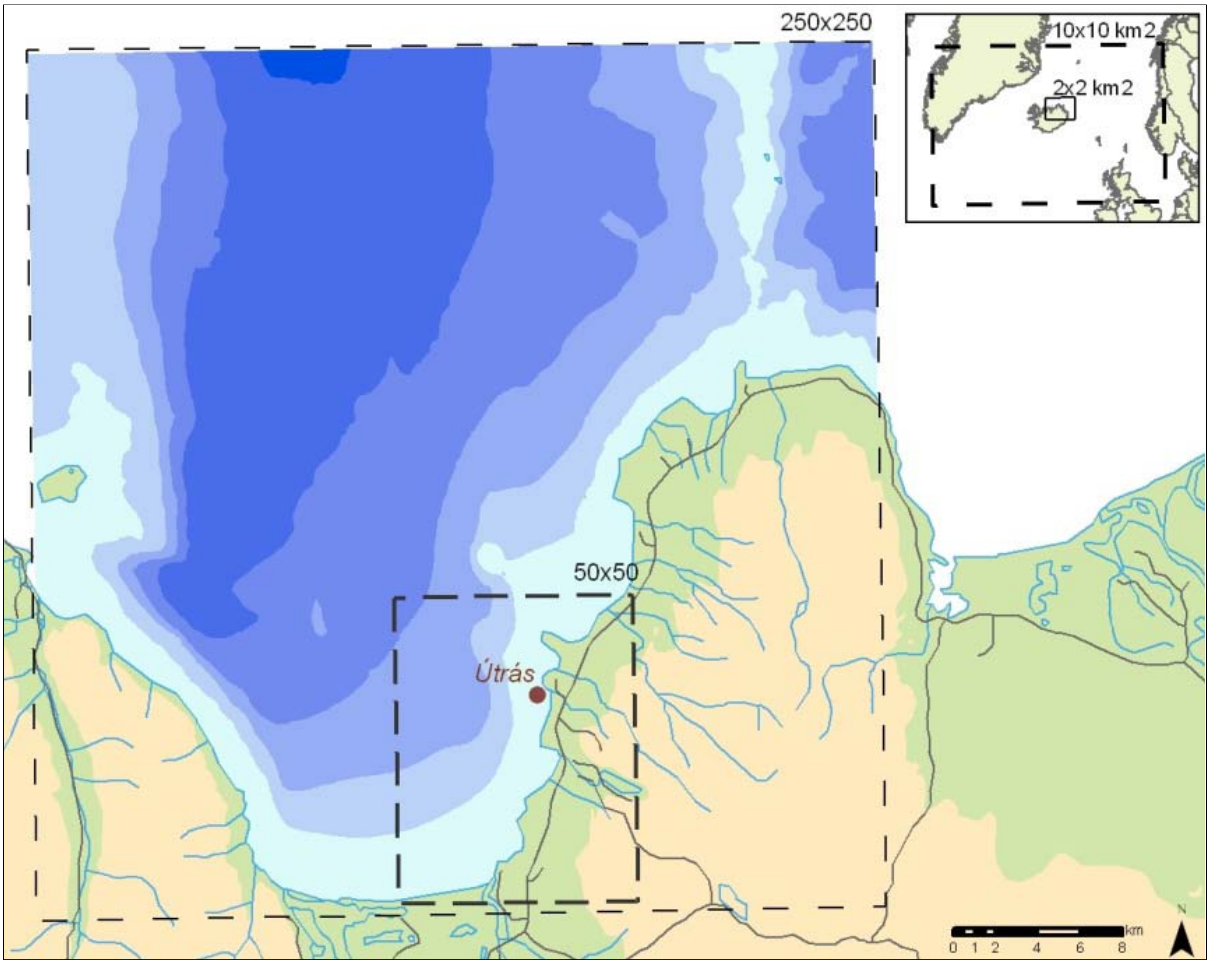

Figure 2 Domain of tidal models, the larger scale IMA model domains in upper right corner.

The coarser tidal models (10x10 and 2x2) have been calibrated using extensive sea level measurements. The finer models set up for this project have as well been calibrated and verified for spring and neap tide using the measurements in Bakkaflói mentioned above (Chapter 2), taking into account weather forcing as well as astronomical forcing.

The model simulates measured sea level well, predicting within a sufficient accuracy sea level variation with respect to time and magnitude of crests and throughs (**Figure 3**).

Table 1 Ocean current model configuration.

Model domain	**Resolution**	**Number of nodal points**	**Time stepping**	**Limits of domain in geographical coordinates**			
	m x m		seconds	°N	°N	°W	°W
North-Atlantic ocean	10,000x10,000	291x199	300/20=15	56.00	71.00	41.00	-4.00
NA-continental shelf	2,000x2,000	186x136	100/20=5	65.00	67.08	19.00	13.00
Skjálfandi & Axarfjörður	500x500	169x201	50/20=2.5	65.90	66.78	18.20	16.40
Skjálfandi	250x250	161x165	10/20=0.5	65.98	66.34	17.88	17.04
Bakki	50x50	226x331	10/20=0.5	66.00	66.12	17.48	17.28

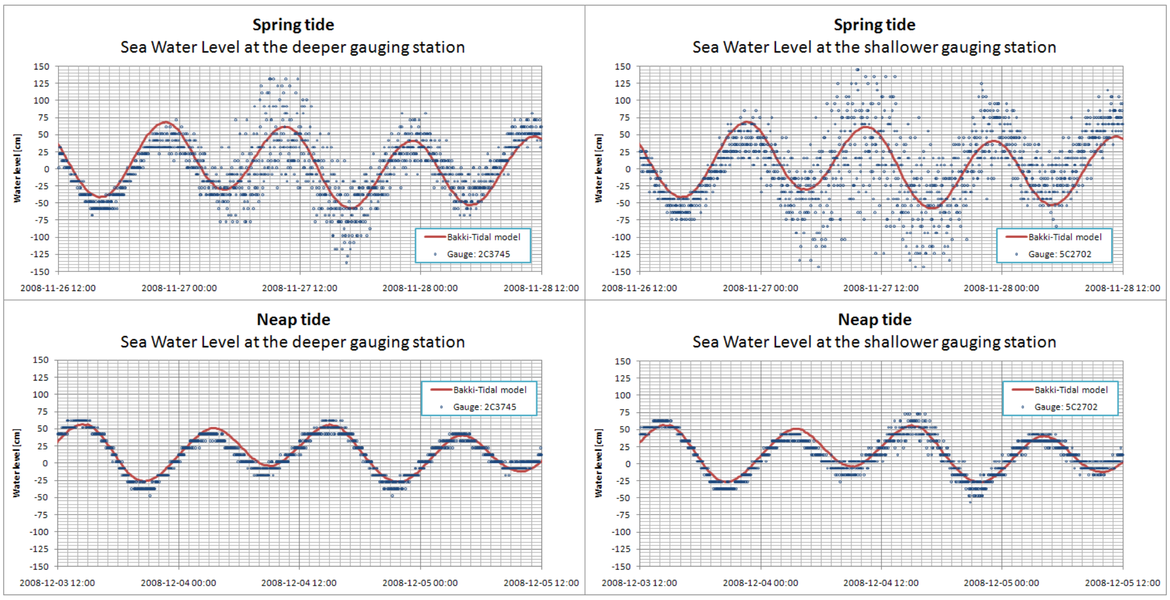

Figure 3 Sea level variation from mean sea level. Model results and measurements at two gauging stations in spring and neap tide. The meter at the deeper location (50 m depth) on left, the meter at the shallower location (19 m depth) on the right.

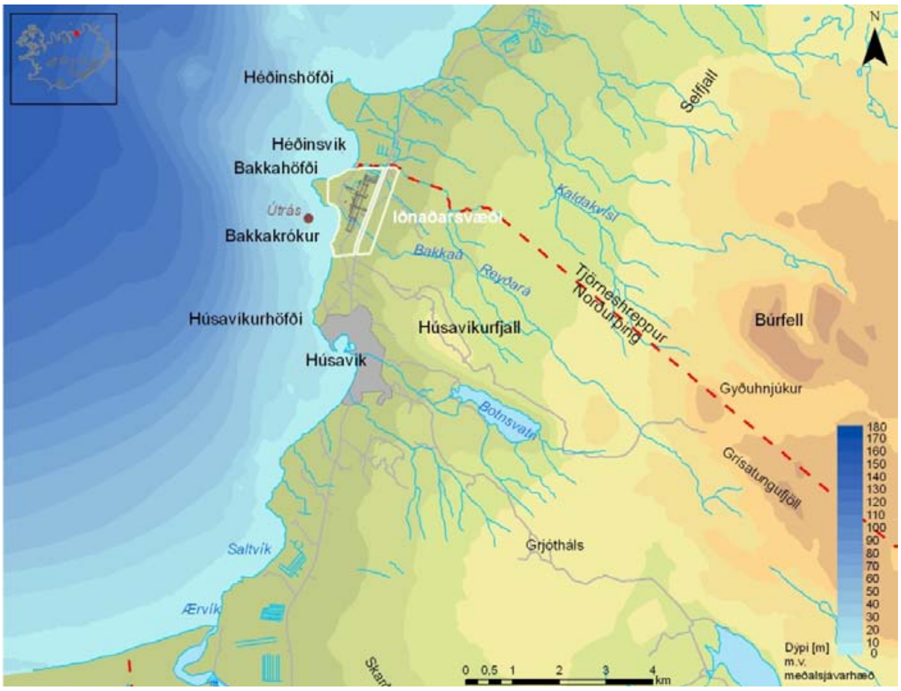

Figure 4 Bathymetry in east Skjálfandi Bay.

4 Numerical model of transport

The transport model uses as input the following variables; depth, sea level, tidal currents, dispersion coefficients, effluent quantity, concentration and properties of each component or pollutant accounted for.

The advection-dispersion equation describes the concentration of pollutant in the sea (C) as a function of location (x,y) and time (t), given the discharge into the sea per surface area ($q=Q/A$), and the concentration of the pollutant in the discharge (C_0).

$$\frac{\partial}{\partial t}(HC) = -\frac{\partial}{\partial x}(HuC) - \frac{\partial}{\partial y}(HvC) + \frac{\partial}{\partial x}\left(HD\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(HD\frac{\partial C}{\partial y}\right) + qC_0 + r$$

where (u,v) denote depth integrated velocity in the x and y directions respectively, D denotes dispersion coefficient, H depth and r denotes fate or transport processes for a given pollutant. Velocities and sea level are extracted from the ocean current model. Further information on the transport model is given in **Table 2**.

Table 2 Transport model configuration.

Effluent discharge (Q)	3.0 m^3s^{-1} (10,850 m^3h^{-1})
Dispersion coefficient (D)	5–10 m^2s^{-1}
Resolution (Δx x Δy)	50 m x 50 m
Domain size	11.25 km x 16.50 km
Effluent location	400 m from shore at 10 m depth, southwest of Bakkahöfði, see Figure 4
Maximum current velocity in the vicinity of effluent location	< 0.4 ms^{-1}

5 Discharge and environmental criteria

Concentration values of different materials in the wet scrubber effluent were provided by Alcoa and are based on concentration values in the air emission and information from the manufactures of wet scrubbers equipment on removal rate.

Table 3 shows concentration of different materials in the effluent, assumed background values and existing environmental criteria from regulations. The environmental criteria is from Icelandic regulations except in some cases where no such criteria exists, then limit values from other countries are applied.

Table 3 Concentration in effluent, background values and environmental criteria.

Material	Quantity	Concentration in effluent	Background value	Environmental criteria
SO_2	7,357 t/year	77 mg/l		
Solids	41.0 t/year	0.73 mg/l	0.3 mg/l	2 mg/l[1]
F	27.7 t/year	1.59 mg/l	1.3 mg/l	5 mg/l[2]
PAH	28.3 kg/year	0.30 µg/l		
B(a)P	0.57 kg/year	0.006 µg/l		
N	2.8 t/year			300 µg/l[3]
P	0.3 t/year			20 µg/l[3]
pH			8.3	0.5[1]

[1] Maximum increase in rivers and lakes according to Icelandic regulation no. 798/1999 on wastewater systems and sewage.

[2] From British regulation on protection of ecosystems in saltwater.

[3] From Icelandic regulation no. 796/1999 on protection against pollution of water.

Table 4 shows five rated categories for the concentration of PAH and B(a)P in sediments and dissolved in seawater, from Norwegian regulations published by SFT (2007), the Norwegian Pollution Control Authority.

Table 4 Norwegian regulation for PAH and B(a)P in sediments and water.

		I	II	III	IV	V
		Background (Bakgrunn)	**Good (God)**	**Moderate (Moderat)**	**Poor (Dårlig)**	**Very poor (Svært dårlig)**
PAH-16	Deposited (µg /kg)[1]	<300	300 – 2,000	2,000 – 6,000	6,000 – 20,000	>20,000
B(a)P	Deposited (µg/kg)[1]	<6	6 - 420	420 - 830	830 – 4,200	>4,200
	Dissolved (µg/l)[2]	$<5\times10^{-6}$	5×10^{-6} – 0.05	0.05 - 0.1	0.1 – 0.5	>0.5

The criteria for deposited B(a)P has been changed in the revised regulations from SFT[1] as the former regulations from 1997[3] had lower values for each category.

[1] SFT, 2007. Tabell 7b Klassifisering av tilstand ut fra innhold av metaller og organiske stoffer i sedimenter.

[2] SFT, 2007. Tabell 7a Klassifisering av tilstand ut fra innhold av metaller og organiske stoffer i vann.

[3] SFT, 1997.

6 Results

The transport model has been set up and run for one lunar month to predict the variation in concentration of pollutants. Due to advection the polluting matter will be transported farther from the outlet in high current velocities during spring tide. During neap tide the current velocities are lower resulting in higher concentration in the vicinity of the outlet, and lower concentration farther from it.

Prevailing wind for a considerable period of time could affect the concentration, the weather imposed current velocities are low in comparison to the tidal currents and the impact on concentration is therefore minor.

The solution method of the transport model assumes that the polluting matter is fully mixed over depth at each grid-point, representing an area of 50 m x 50 m surface. The concentration shown in the immediate vicinity of the outlet (a few tens of meters) is therefore underestimated. The dilution zone should cover a few grid-points from the effluent location, even if the calculated concentration is within given limits.

The results shown in this chapter are based on the highest concentration at each location (apart from the area next to the outlet) found over the whole run period using the range of variables given in Table 2. The results are therefore conservative, meaning that average concentration is less than shown.

6.1 Dilution

Dilution is defined as $X = C_0/C = 1/C_E$ and calculated using a numerical solution of the advection-dispersion equation, excluding fate processes:

$$\frac{\partial}{\partial t}(HC_E) = -\frac{\partial}{\partial x}(HuC_E) - \frac{\partial}{\partial y}(HvC_E) + \frac{\partial}{\partial x}\left(HD\frac{\partial C_E}{\partial x}\right) + \frac{\partial}{\partial y}\left(HD\frac{\partial C_E}{\partial y}\right) + q$$

where $C_E = C/C_0$ denotes unit concentration (assuming concentration of the pollutant in the discharge is unity). **Figure 5** shows the range of dilution in Skjálfandi given the above assumptions of discharge, magnitude and location. The source of effluent is located about 400 m from the coast, at a depth of about 10 m, see **Table 2**.

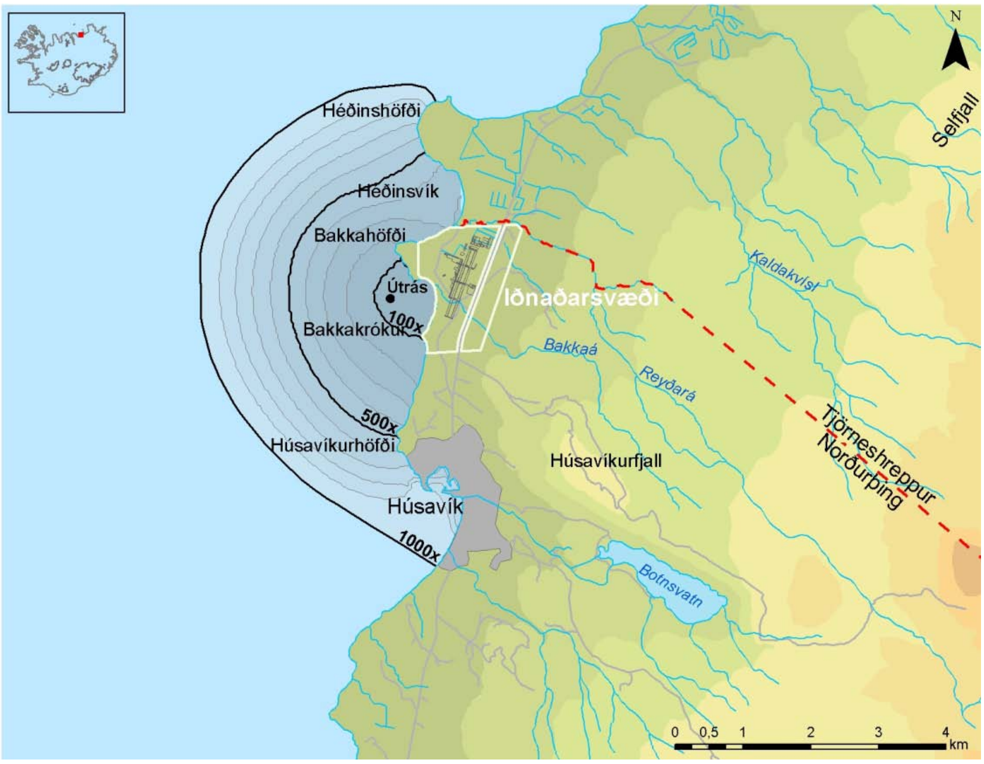

Figure 5 Dilution (*contour lines show lines of equal maximum concentration (minimum dilution), e.g. the concentration on the 1000x line is 0.001 times the concentration in the effluent fluid*).

6.2 PAH Deposited

The concentration of PAH in the wet scrubber effluent is 0.3 µg/m^3 and the assumption made that 90 % of the PAH is dissolved and 10% will be deposited attached to particulate matter with size of 10 µm. This particle size is considered to give conservative results since the coarse grains have higher settling velocities than the finer ones. Each year 28.3 kg of PAH material are discharged to sea and 10 %, or 2.8 kg, are deposited in the bay.

Figure 6 shows the calculated distribution of concentration in sediments, assuming that the rate of sedimentation is 1 mm per year and the dry density of the sediments is 1,150 kg/m^3.

According to Norwegian regulations, see **Table 4**, the condition of an area, which is around 0.6 km^2 in Bakkakrókur, falls in the category "good" but the concentration outside this area is considered to be comparable to background values.

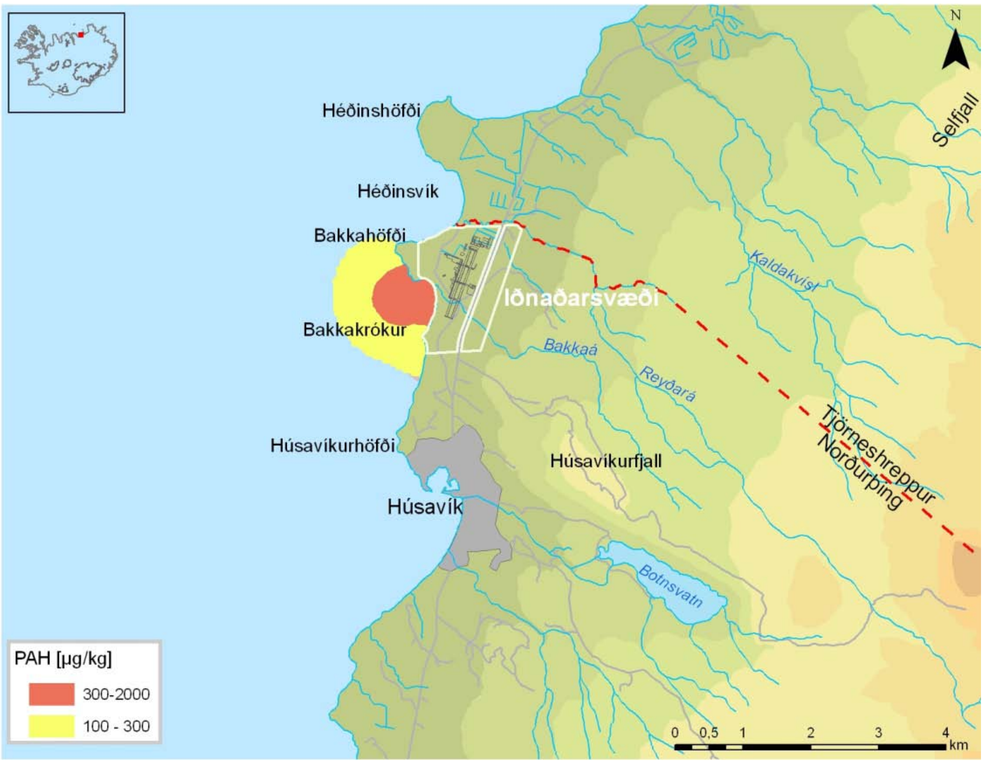

Figure 6 PAH-16 deposited.

6.3 PAH Dissolved

The assumption is that 90 % of the PAH material is dissolved, as described in chapter 6.2. The calculated distribution is shown in **Figure 7**. No environmental criteria for dissolved PAH is available.

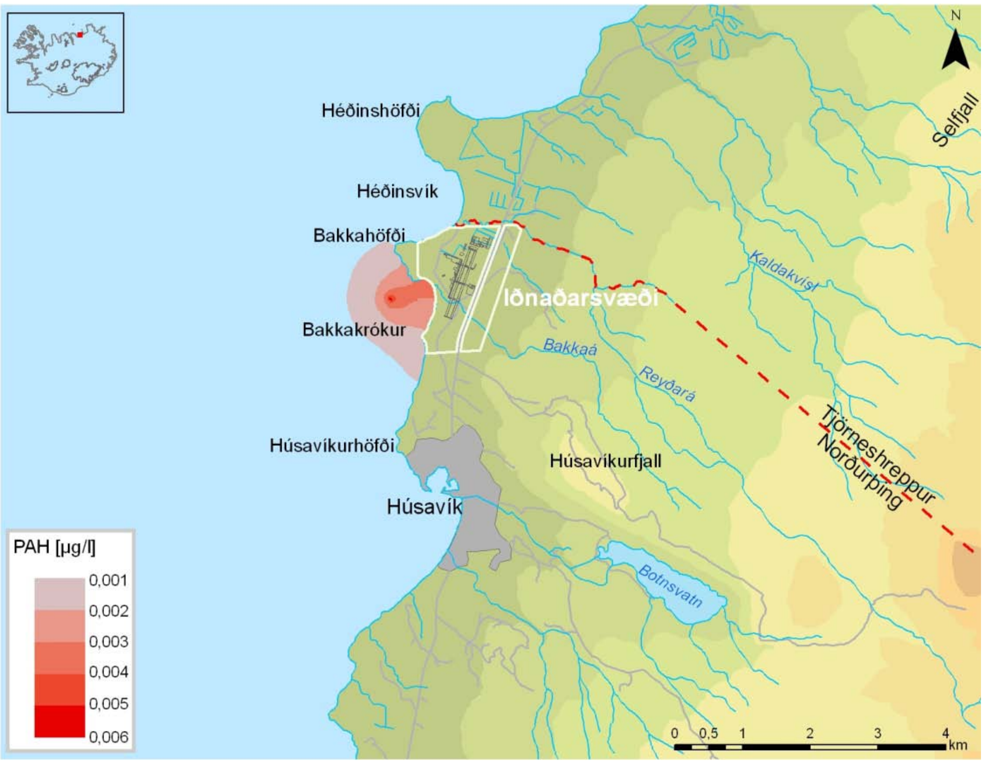

Figure 7 PAH dissolved.

6.4 B(a)P Deposited

One of the PAH materials is B(a)P, which has been related to risk of cancer in humans and is often used as a representative for this type of the PAH materials (cPAH). B(a)P has been estimated to be of the order of 1-2% of the PAH materials in an aluminum plant emission and the effluent here is assumed to have 0,006 µg/l of B(a)P or a total of 0.57 kg per year.

Opposite to PAH, 10 % of the B(a)P material is assumed to be dissolved but 90 % deposited and attached to particles of size 10 µm. About 0.51 kg of B(a)P would then be deposited in the bay on a yearly basis.

Figure 8 shows the calculated distribution of concentration in sediments, assuming that the rate of sedimentation is 1 mm per year and the dry density of the sediments is 1,150 kg/m^3.

The 6.7 km^2 area shown in yellow in **Figure 8** falls in the category "good" according to the Norwegian regulation criteria in **Table 4**. The highest calculated value is around 180 µg/kg.

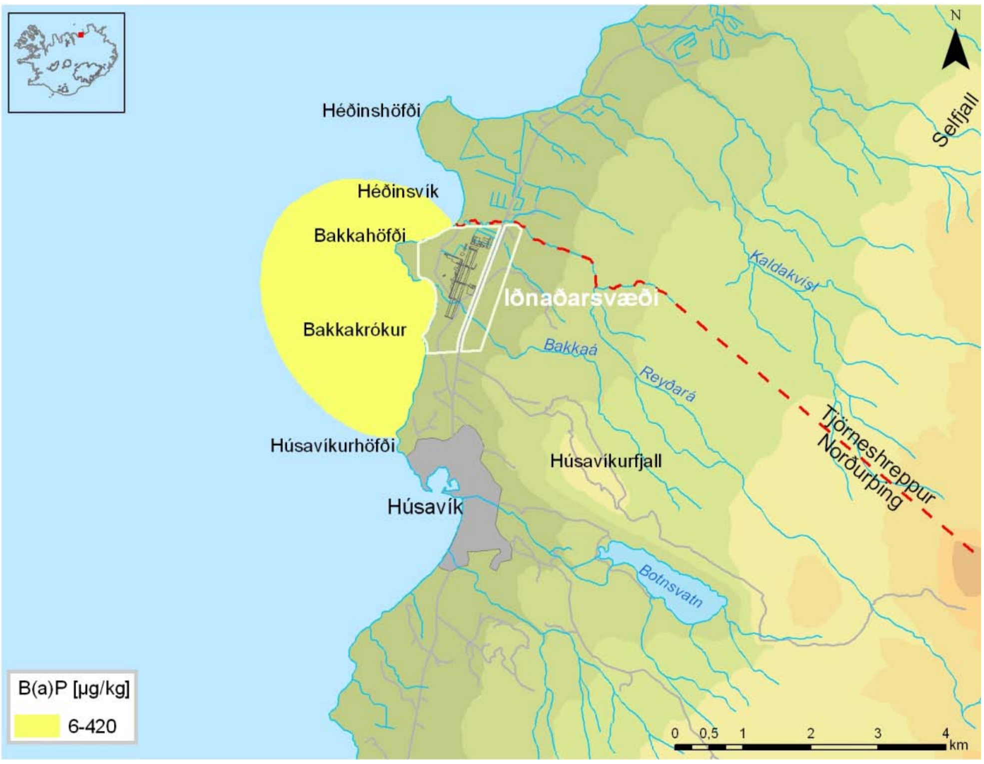

Figure 8 B(a)P deposited.

6.5 B(a)P Dissolved

As stated in chapter 6.4, 10 % of B(a)P is assumed to be dissolved which is about 0.06 kg per year. **Figure 9** shows the calculated concentration of B(a)P dissolved in the sea and the 0.5 km^2 area in Bakkakrókur that falls into the category "good" according to the Norwegian regulation criteria. Outside of this area the concentration is considered to be comparable to background values.

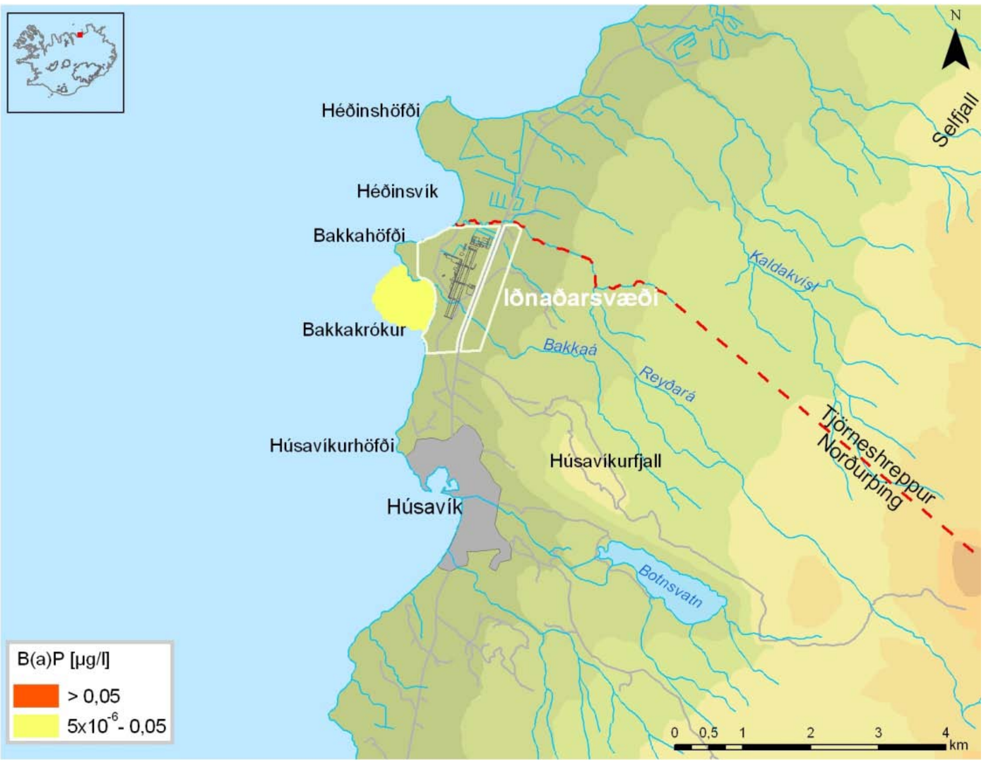

Figure 9 B(a)P dissolved.

6.6 pH

The pH values are calculated based on the distribution of SO_2 concentration, which is 77 mg/l in the effluent. The SO_2 reacts with oxygen in the sea to form sulfurous acid (H_2SO_3), which again by oxidation forms sulfuric acid (H_2SO_4). The sulfuric acid lowers the pH value of the sea but the buffer capacity[4] of the seawater resists the change. The oxidation of SO_2 and H_2SO_3 is assumed to be instantaneous, which is conservative as in reality this will take some time to happen.

Figure 10 shows the calculated pH values in the vicinity of the outfall. The background value is assumed to be 8.3 and a small deviation from this value is only noted in an area close to the outfall in Bakkakrókur.

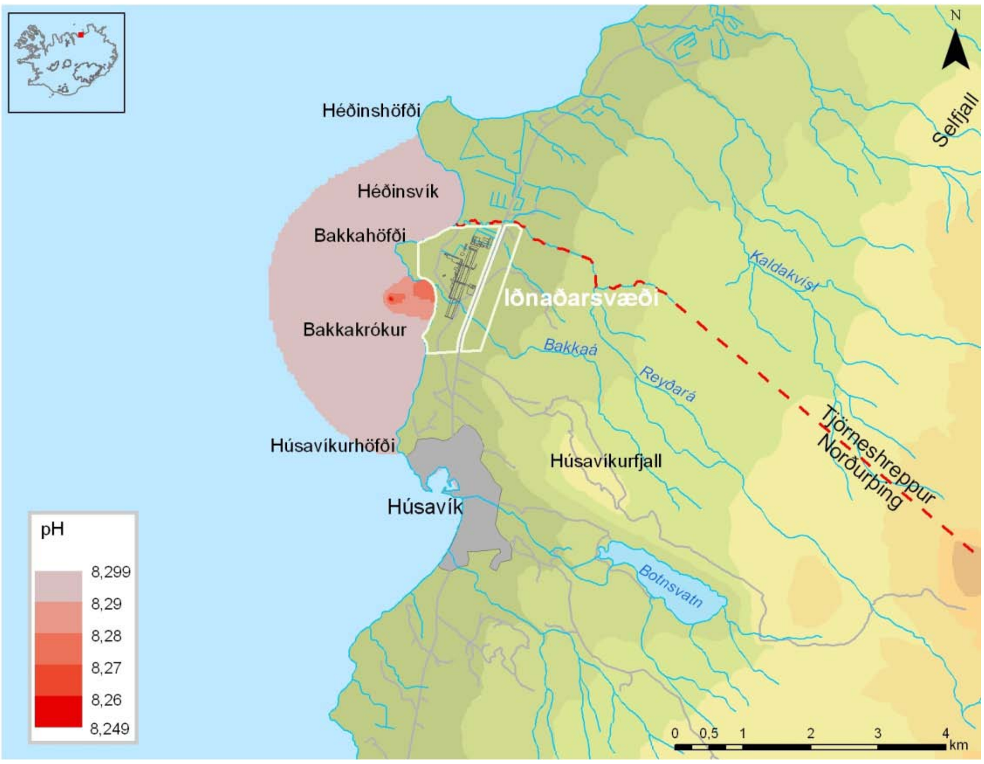

Figure 10 pH, background value is pH = 8.3.

[4] Buffer capacity is a measure of the resistance of a buffer solution to a change in pH on the addition of OH^- ions.

6.7 Dissolved Oxygen

The effect on dissolved oxygen is also an impact of SO_2, as oxygen is consumed in the formation of the acids H_2SO_3 and H_2SO_4. As in the case of pH the conservative assumption is made that the reaction is instantaneous and reairation is ignored.

Figure 11 shows the calculated concentration of dissolved oxygen assuming the background value is 9.0 mg/l. The deviation from the background value is very small and only in the close vicinity of the outfall in Bakkarkrókur.

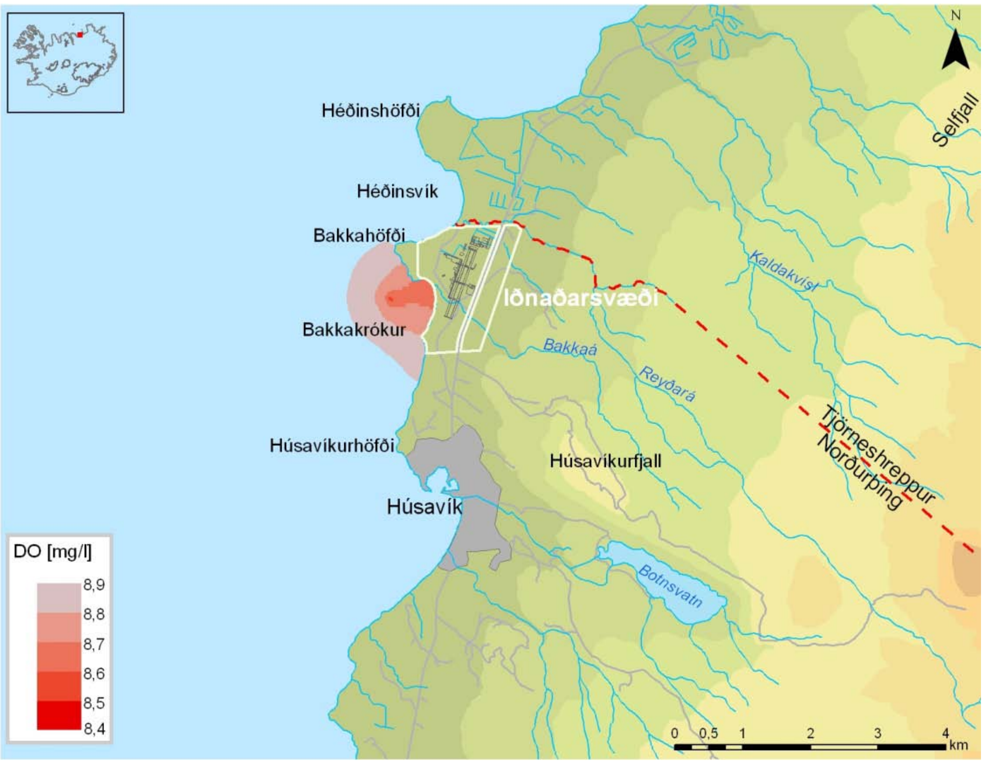

Figure 11 Dissolved oxygen, background value is 9.0 mg/l.

7 Conclusions

The main result of this study is that the calculated concentration of the presented materials, based on the given assumptions, is very close to the background values except in a small area, next to the outfall in Bakkakrókur. Even in the close vicinity of the outfall the deviation from background values is not large. Since the assumption of vertical mixing is applied as the models used are two dimensional, which may not be fully valid in the immediate vicinity of the outfall, it is suggested that the defined dilution zone will be of conservative size.

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