

REYÐARFJÖRDUR

**Dispersion of pollutants in the sea
from a proposed aluminium smelter.**

Prepared for HRV Group

05.09
August 2005

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Dispersion of pollutants in the sea from a proposed aluminium smelter.

According to your request we have performed calculations for the transport of pollutants in the sea at Reyðarfjörður from a proposed aluminium smelter located at Hraun. A similar study was performed by Vatnaskil Consulting Engineers in 2001 for a proposed aluminium smelter at Hraun (Vatnaskil, 2001). The three-dimensional flow and transport model which was designed and calibrated during this previous study was also used for this project.

The calculations in this report focus on the consequences of using the wet scrubber technique for the proposed aluminium smelter. The two existing aluminium smelters in Iceland at Straumsvík and Grundartangi use dry scrubbing methods to reduce the amount of pollutants, and therefore no experience has been obtained in Iceland on the use of wet scrubbers.

The main results are as follows:

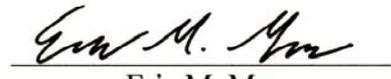
1. The concentration of solids and fluoride reaches background concentration in the sea in the immediate vicinity of the outlet.
2. The oxygen concentration falls below saturation just in a small area around the outlet.
3. Taking the buffer capacity of the sea into account, the wastewater reaches background values for pH almost immediately after it is released.
4. For an annual production of 346,000 tons, 15.8 kg/year of PAH-16 and 0.61 kg/year of BaP are produced. For PAH-16, 0.24 kg/year and 1.48 kg/year are deposited on the bottom of the fjord for particle sizes 1 μm and 10 μm respectively. For BaP, 0.085 kg/year and 0.52 kg/year are deposited on the bottom of the fjord for particle sizes 1 μm and 10 μm respectively. For both cases, the amount that is not deposited on the bottom is transported out of the fjord.

We hope that the results will be to your satisfaction and we will be happy to answer any questions or supply any clarifications that you may desire.

Sincerely yours,



Snorri Páll Kjaran



Eric M. Myer

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1. INTRODUCTION

The purpose of this study was to calculate the transport of pollutants in the sea in Reyðarfjörður from a proposed aluminium smelter located at Hraun. A similar study was performed by Vatnaskil Consulting Engineers in 2001 for a proposed aluminium smelter at Hraun (Vatnaskil, 2001). The three-dimensional flow and transport model which was designed and calibrated during this previous study was also used for this project.

The location of the proposed plant is shown in Figure 1 in the Vatnaskil (2001) report. The outlet for the wet scrubber is located at a depth of 10 m. The calculations are based on a production rate of 346,000 tons per year.

The calculations in this report focus on the consequences of using the wet scrubber technique for the proposed aluminium smelter. The two existing aluminium smelters in Iceland at Straumsvík and Grundartangi use dry scrubbing methods to reduce the amount of pollutants, and therefore no experience has been obtained in Iceland on the use of wet scrubbers.

2. MEASUREMENTS

2.1 Production data

According to information obtained from HRV Group, the components of the wastewater which can be detrimental to the marine environment and therefore should be focused on, are the following:

1. Sulphur dioxide (SO₂)
2. Fluoride (F)
3. Oxygen (O₂)
4. Polyaromatic hydrocarbons
 - a) PAH – 16
 - b) BaP
5. Solids
6. pH

The amount of these components in the outflow is given in Table 1, and the concentration in the outflow is given in Table 2 (background concentration in the seawater has been added to these concentrations). Table 3 gives the actual background concentrations in the sea.

TABLE 1. Amount of components in outflow.

| Production tons/year | Outflow m ³ /hour | SO ₂ kg/hr | Fluoride kg/hr | PAH-16 g/hr | BaP g/hr | Solids kg/hr |
|-------------------------|---------------------------------|--------------------------|-------------------|----------------|-------------|-----------------|
| 346,000 | 10,850 | 840 | 2.25 | 1.8 | 0.07 | 3.71 |

There are no restrictions on the concentration of these elements in the Icelandic water quality standards except for the solids, so in this report the calculated values are compared with background concentrations in the sea.

TABLE 2. Concentration in outflow.

| Production tons/year | Outflow m ³ /hour | SO ₂ mg/L | Fluoride mg/L | PAH-16 µg/L | BaP µg/L | Solids mg/L |
|----------------------|------------------------------|----------------------|---------------|-------------|----------|-------------|
| 346,000 | 10,850 | 77 | 1.51 | 0.17 | 0.006 | 0.64 |

TABLE 3. Background concentration in the sea.

| Fluoride mg/L | Solids mg/L | pH | Oxygen mg/L |
|---------------|-------------|-----|-------------|
| 1.3 | 0.3 | 8.2 | 9 |

2.2 Other measurements

Measurements of bathymetry, tidal elevation, wind, ocean currents, and ocean salinity and temperature were used in the construction and calibration of the flow model. These measurements are described in detail in the Vatnaskil (2001) report.

3. FLOW MODEL

The three-dimensional flow model which was designed and calibrated during the previous study (Vatnaskil, 2001) was also used for this project. A detailed description of the flow model is given in Appendix 2 of the Vatnaskil (2001) report.

4. TRANSPORT MODEL

The transport model described in Appendix 2 in the Vatnaskil (2001) report was used for the calculation of the contaminants. The vertical eddy viscosity coefficient, which was calibrated in the flow model (Vatnaskil, 2001), is used as the vertical mixing coefficient. The horizontal mixing coefficient is set two magnitudes greater because of velocity shearing in the vertical layers. As the injected seawater from the outlet is lighter than the surrounding sea, it is assumed that the pollutants are injected into the surface layer. From there they will be able to disperse laterally and vertically giving a conservative estimate of the distribution.

The results of the transport model for the components given in section 2.1 are as follows:

4.1 Dilution

For an annual production of 346,000 tons, the calculated dilution lines in the surface layer where the concentration is highest are shown in Figure 1. In just a small area around the source the concentration has already diminished one hundred times. This distance from the shoreline to the 100-fold dilution contour is less than 1 km.

4.2 Solids

The concentration of solids in the outflow according to Table 1 is 0.64 mg/L and the background concentration in the sea is 0.3 mg/L. The previously calculated dilution lines show that the amount of suspended solids will only be above background concentration in the immediate vicinity of the outlet.

4.3 Fluoride

The concentration of fluoride in the outflow is 1.51 mg/L and the background concentration in the sea is 1.3 mg/L. The previously calculated dilution lines show that the amount of fluoride will only be above background concentration in the immediate vicinity of the outlet.

4.4 Oxygen

The concentration of SO₂ in the wastewater is 77 mg/L. SO₂ reacts in the sea to form sulphurous acid (H₂SO₃) which again reacts with the oxygen in the sea to form sulphuric acid (H₂SO₄). This process is rather slow (see Appendix 3 in Vatnaskil (2001) report) but it will be assumed for the calculation of the depletion of oxygen that it happens instantaneously when the wastewater comes in contact with the sea, giving a conservative estimate for the depletion of oxygen. For every 64 g of SO₂, 16 g of O₂ are needed. Therefore there is a depletion of O₂ at the outlet. This can be modeled by a sink of oxygen at the outlet of strength 19.25 mg/L. The concentration of oxygen in the sea is at saturation and is given in Table 2 as 9 mg/l.

Figure 2 shows the calculated dissolved oxygen. The concentration of oxygen falls below 8 mg/L just in a small area close to the source.

4.5 pH

As mentioned in section 4.4 for oxygen, the sulphur dioxide reacts in the sea to form sulphurous acid and sulphuric acid and thus lowers the pH in the sea. Because of the carbonate system in the sea, the lowering of the pH is diminished by the buffer capacity (see Appendix 4 in Vatnaskil (2001) report). To calculate the resulting pH in the sea, the transport model calculates the distribution of SO₂ and then the resulting pH can be read from the table in Appendix 4 in the Vatnaskil (2001) report. The results of those calculations for pH are shown in Figure 3 in the surface layer where the pH will be lowest. The pH falls below the background pH in the sea in a small area around the outlet. Sulphurous acid is a weaker acid than sulphuric acid, but the calculations in Appendix 4 in the Vatnaskil (2001) report have been performed assuming instantaneous conversion of all the SO₂ to sulphuric acid. Hence, the calculated pH in the effluent itself and in the immediate vicinity of the outfall is lower than what will be the case in reality.

4.6 Polyaromatic hydrocarbons

Polyaromatic hydrocarbons consist of both PAH-16 and BaP. It is assumed that 90% of PAH-16 is dissolved and 10% is attached to particulate matter. The opposite is true for BaP; 10% is dissolved and 90% is attached to particulate matter. Calculations were performed for both PAH-16 and BaP assuming two different particle sizes, 1 µm and 10 µm. Corresponding settling velocities were used for each particle size. For an annual production of 346,000 tons, 15.8 kg/year of PAH-16 and 0.61 kg/year of BaP are produced.

Figures 4 and 5 show the calculated PAH-16 concentration in the surface layer for particle sizes 1 µm and 10 µm respectively. Figures 6 and 7 show the calculated deposition of PAH on the bottom of the fjord for particle sizes 1 µm and 10 µm respectively. Figures 8 and 9 show the calculated BaP concentration in the surface layer for particle sizes 1 µm and 10 µm respectively.

Figures 10 and 11 show the calculated deposition of BaP on the bottom of the fjord for particle sizes 1 μm and 10 μm respectively.

For PAH-16, 0.24 kg/year and 1.48 kg/year are deposited on the bottom of the fjord for particle sizes 1 μm and 10 μm respectively. For BaP, 0.085 kg/year and 0.52 kg/year are deposited on the bottom of the fjord for particle sizes 1 μm and 10 μm respectively. Figures 12 and 13 show the calculated PAH-16 concentration in the deposited sediment for particle sizes 1 μm and 10 μm respectively. Figures 14 and 15 show the calculated BaP concentration in the deposited sediment for particle sizes 1 μm and 10 μm respectively. It is assumed that the sediment density is 1150 kg/m^3 and the rate of sedimentation is 1 mm/year.

5. RESULTS

The main results are as follows:

1. The concentration of solids and fluoride reaches background concentration in the sea in the immediate vicinity of the outlet.
2. The oxygen concentration falls below saturation just in a small area around the outlet.
3. Taking the buffer capacity of the sea into account, the wastewater reaches background values for pH almost immediately after it is released.
4. For an annual production of 346,000 tons, 15.8 kg/year of PAH-16 and 0.61 kg/year of BaP are produced. For PAH-16, 0.24 kg/year and 1.48 kg/year are deposited on the bottom of the fjord for particle sizes 1 μm and 10 μm respectively. For BaP, 0.085 kg/year and 0.52 kg/year are deposited on the bottom of the fjord for particle sizes 1 μm and 10 μm respectively. For both cases, the amount that is not deposited on the bottom is transported out of the fjord.

REFERENCES

Vatnaskil Consulting Engineers, 2001; **Dispersion of pollutants in the sea from a planned aluminium smelter**. Prepared for Reyðarál hf. Report no. 01.02.

FIGURES

Calculated dilution

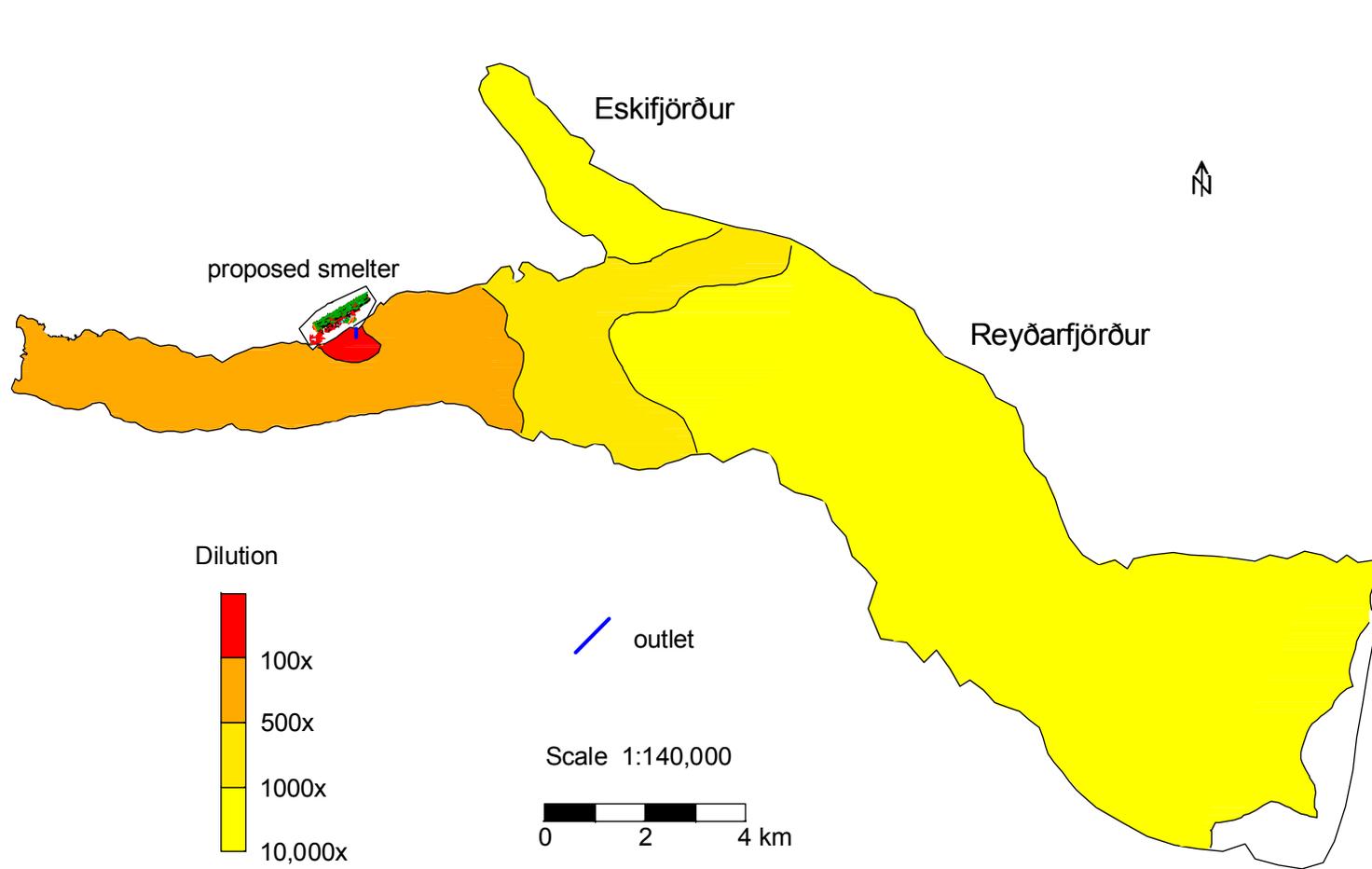


Figure 1

Calculated dissolved oxygen

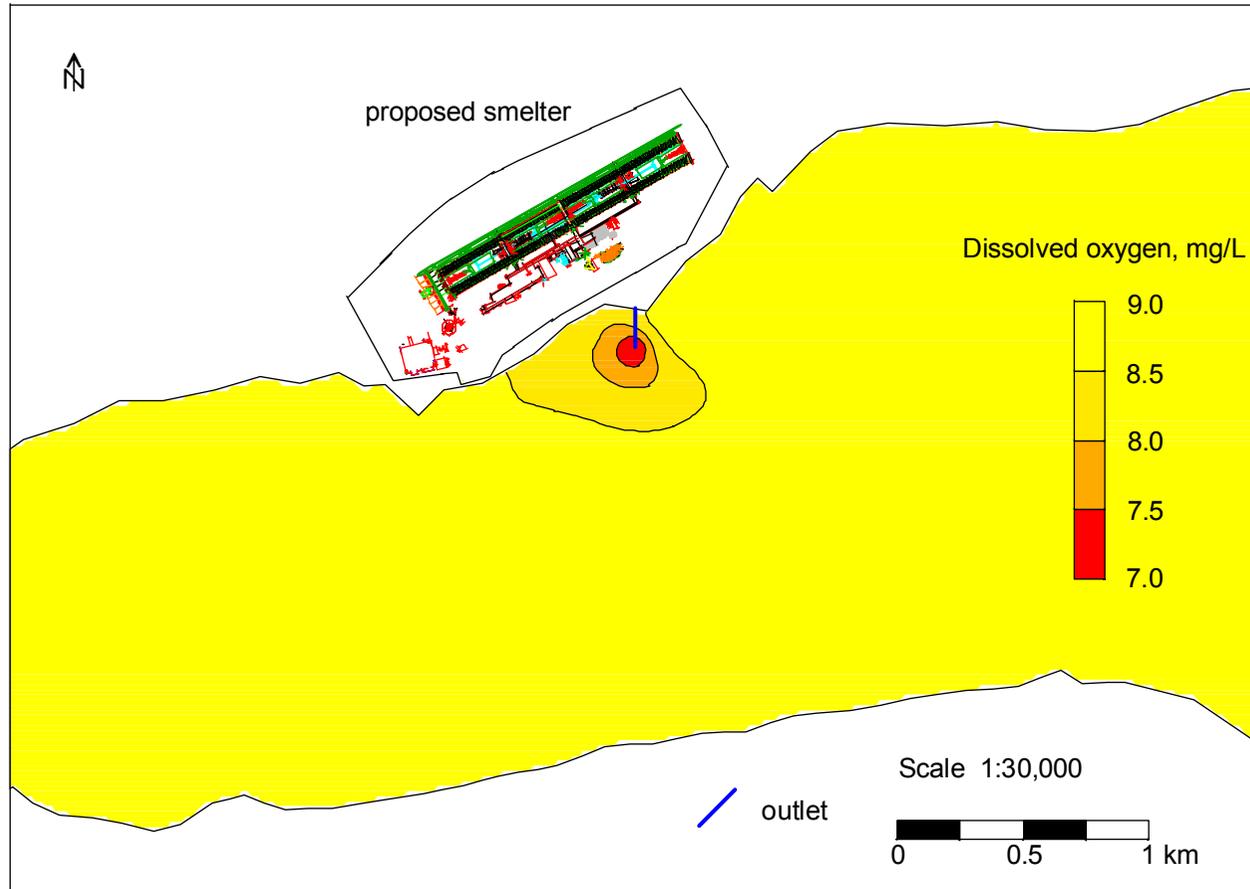


Figure 2

Calculated pH

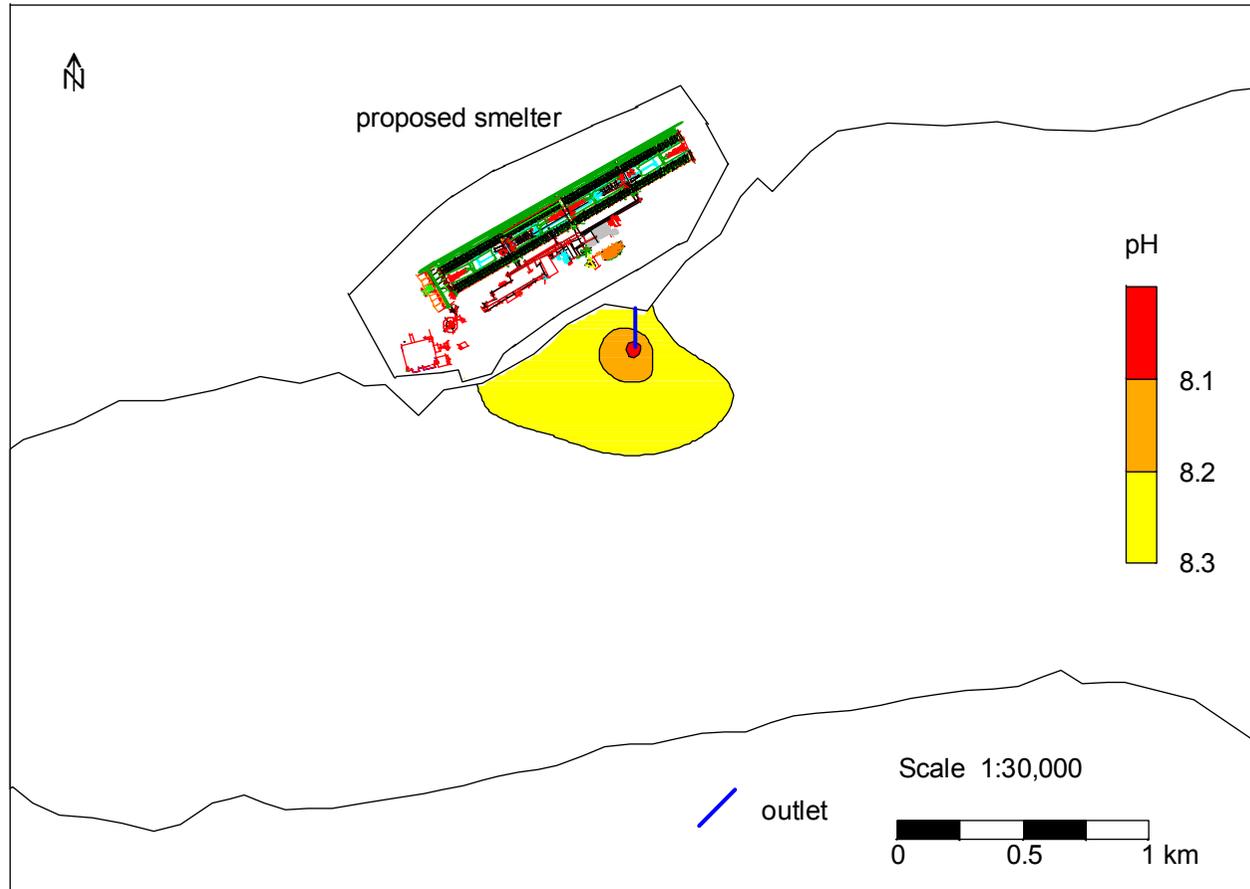


Figure 3

Calculated PAH-16 concentration for particle size 1 µm

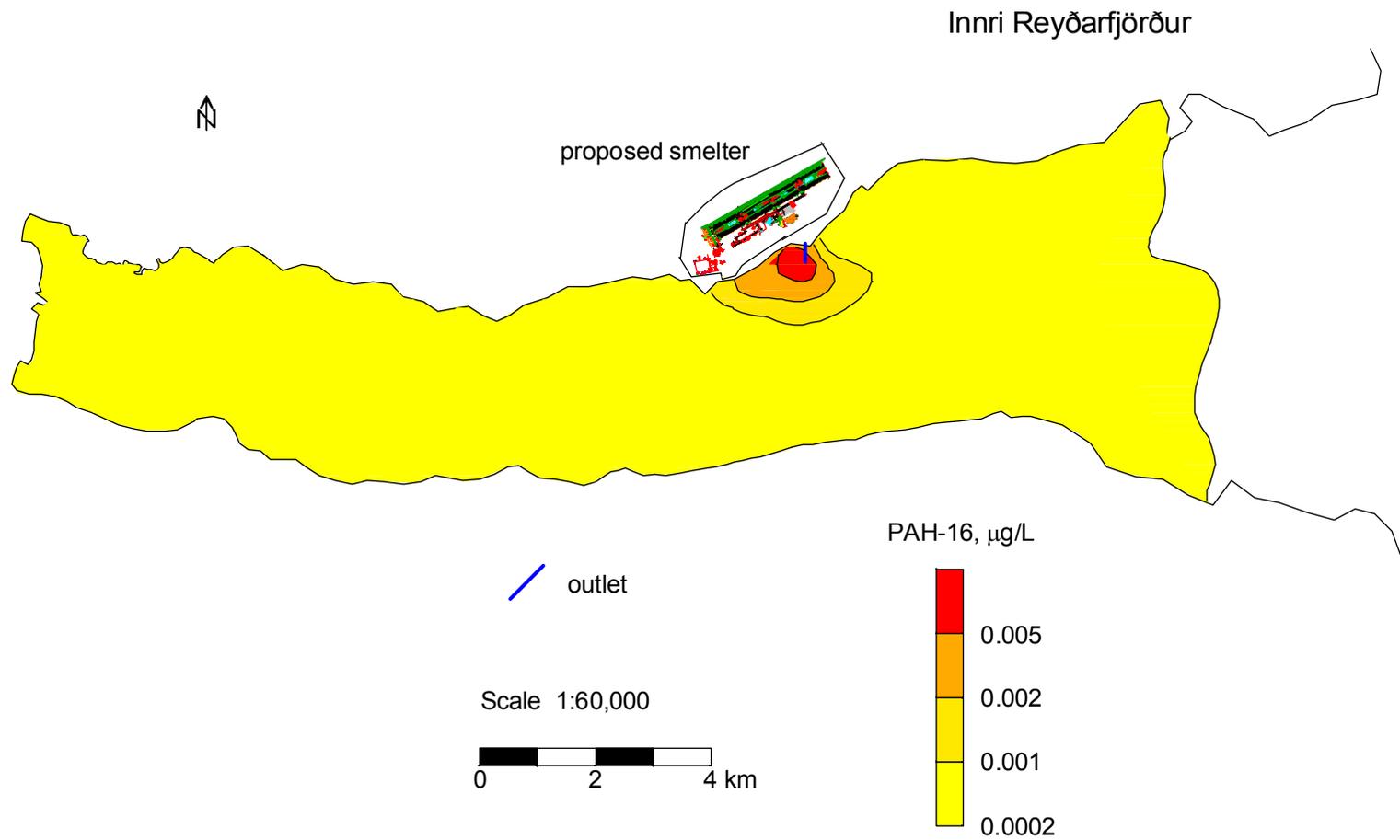


Figure 4

Calculated PAH-16 concentration for particle size 10 µm

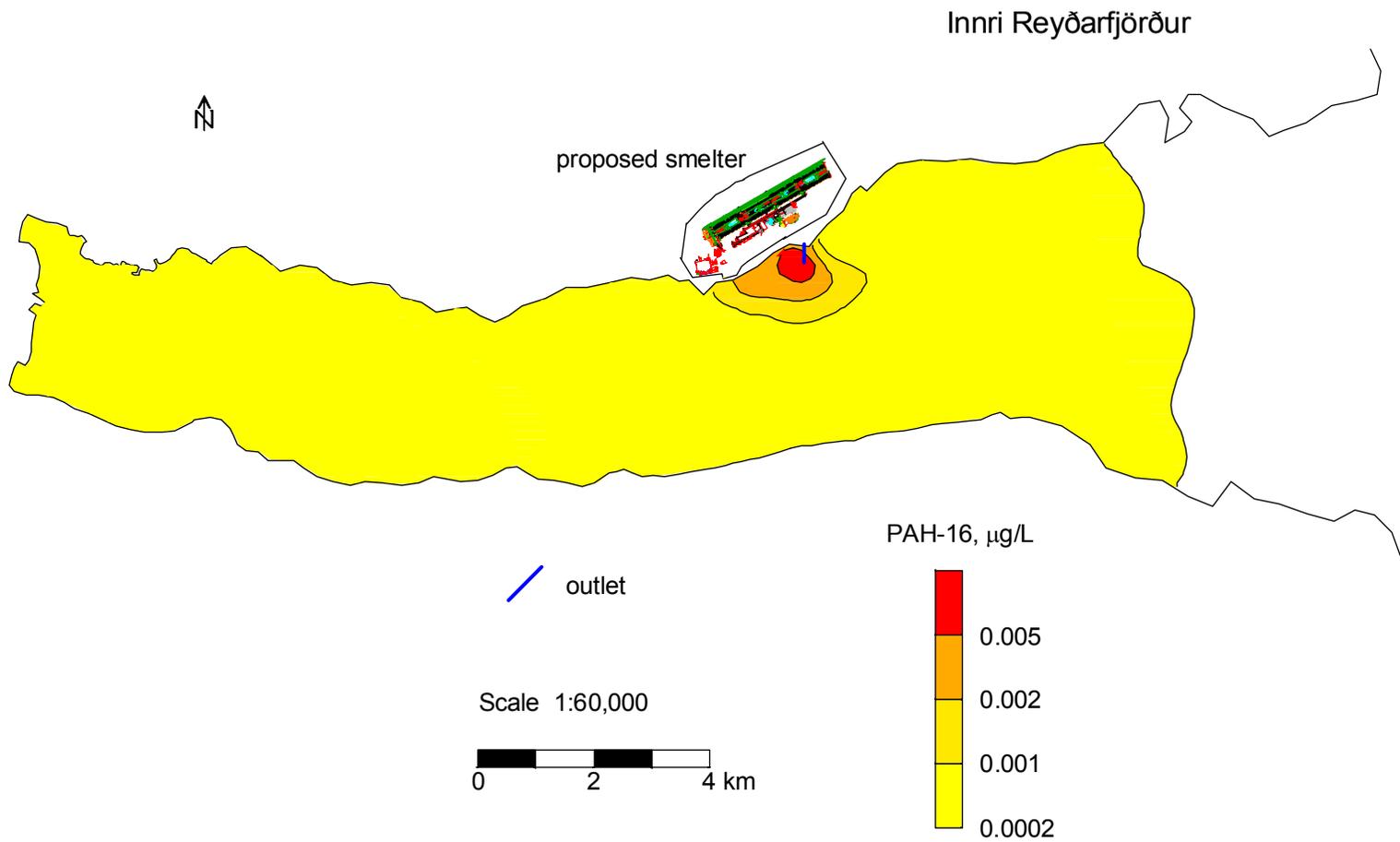


Figure 5

Calculated PAH-16 deposition for particle size 1 μm

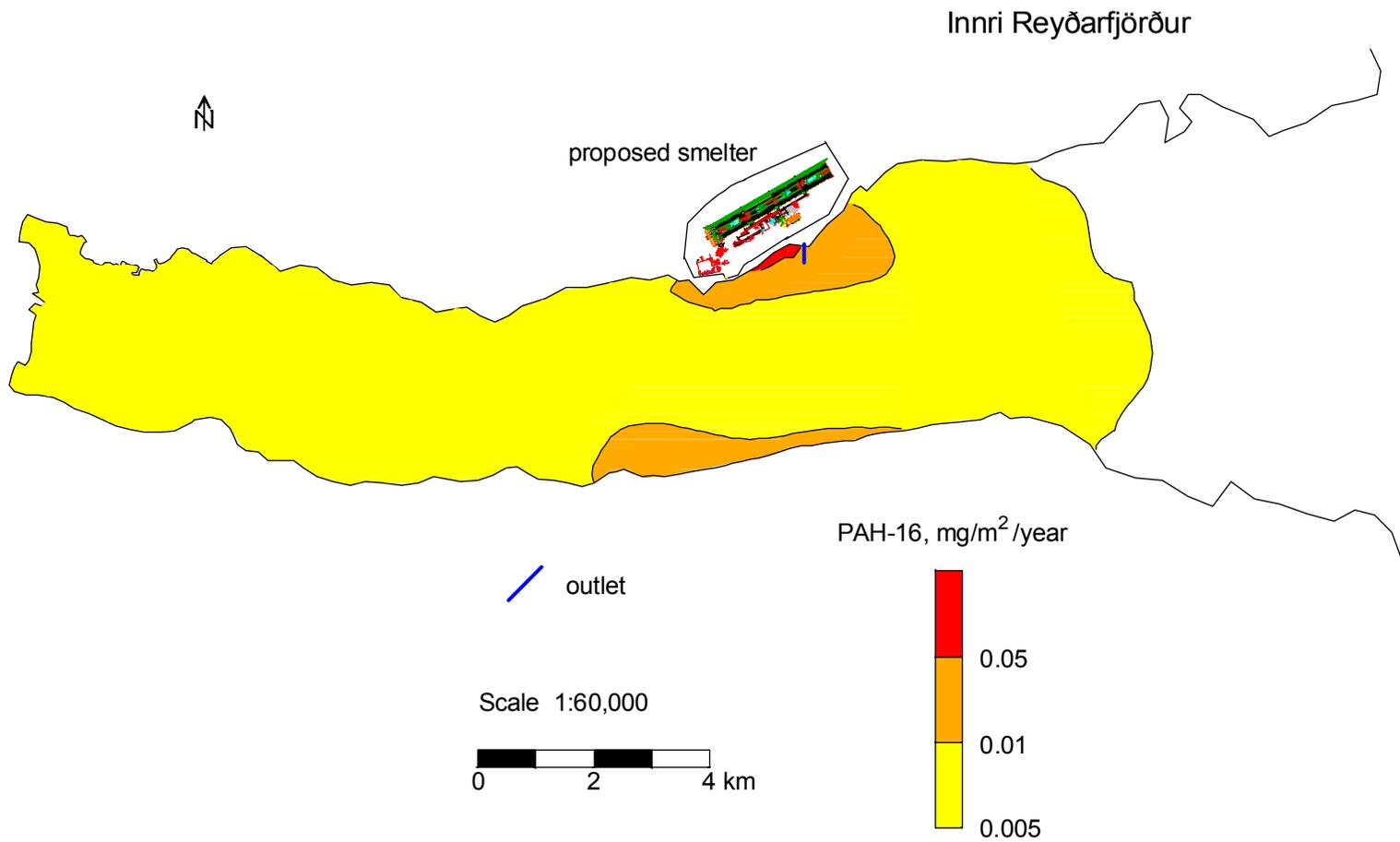


Figure 6

Calculated PAH-16 deposition for particle size 10 µm

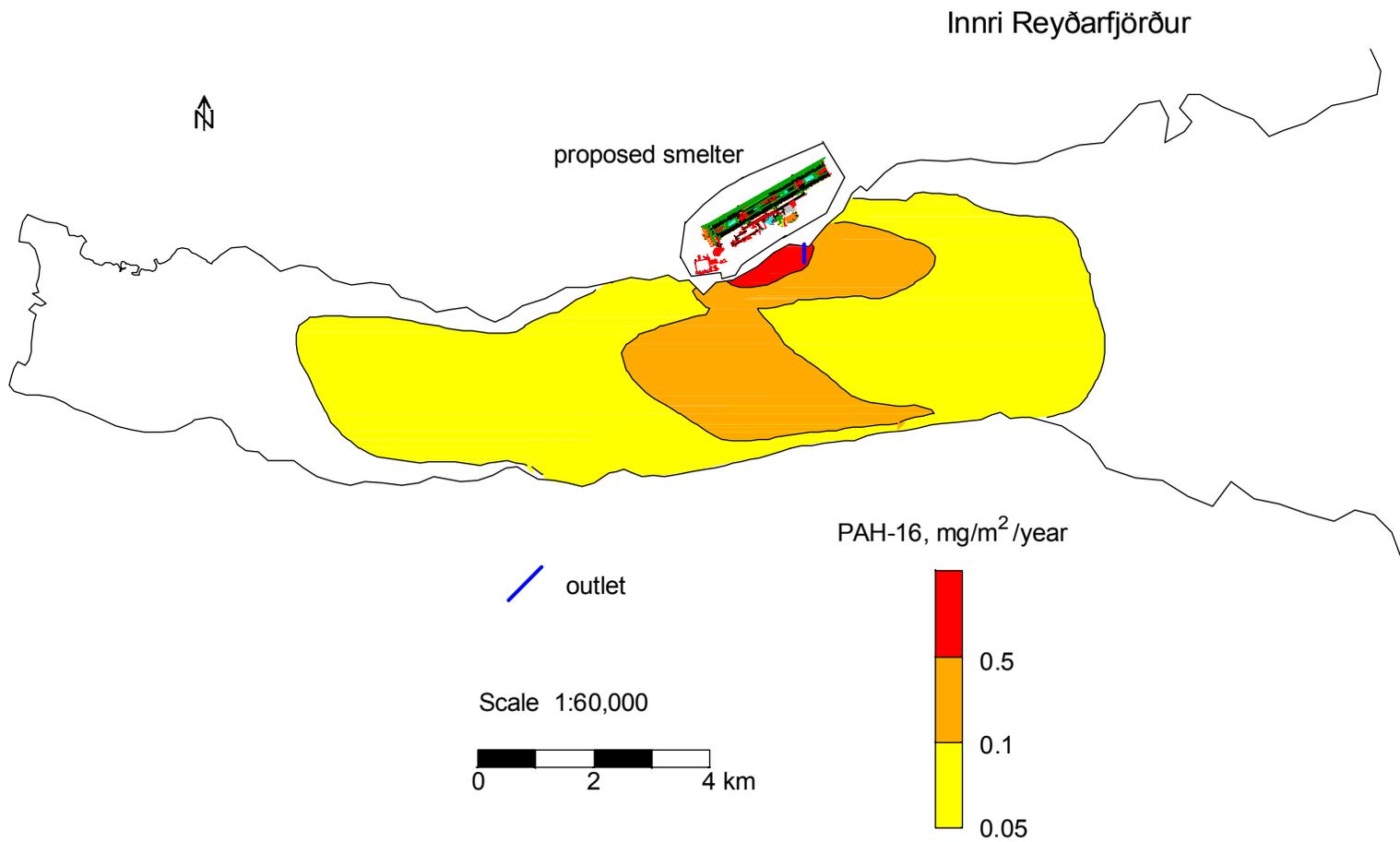


Figure 7

Calculated BaP concentration for particle size 1 µm

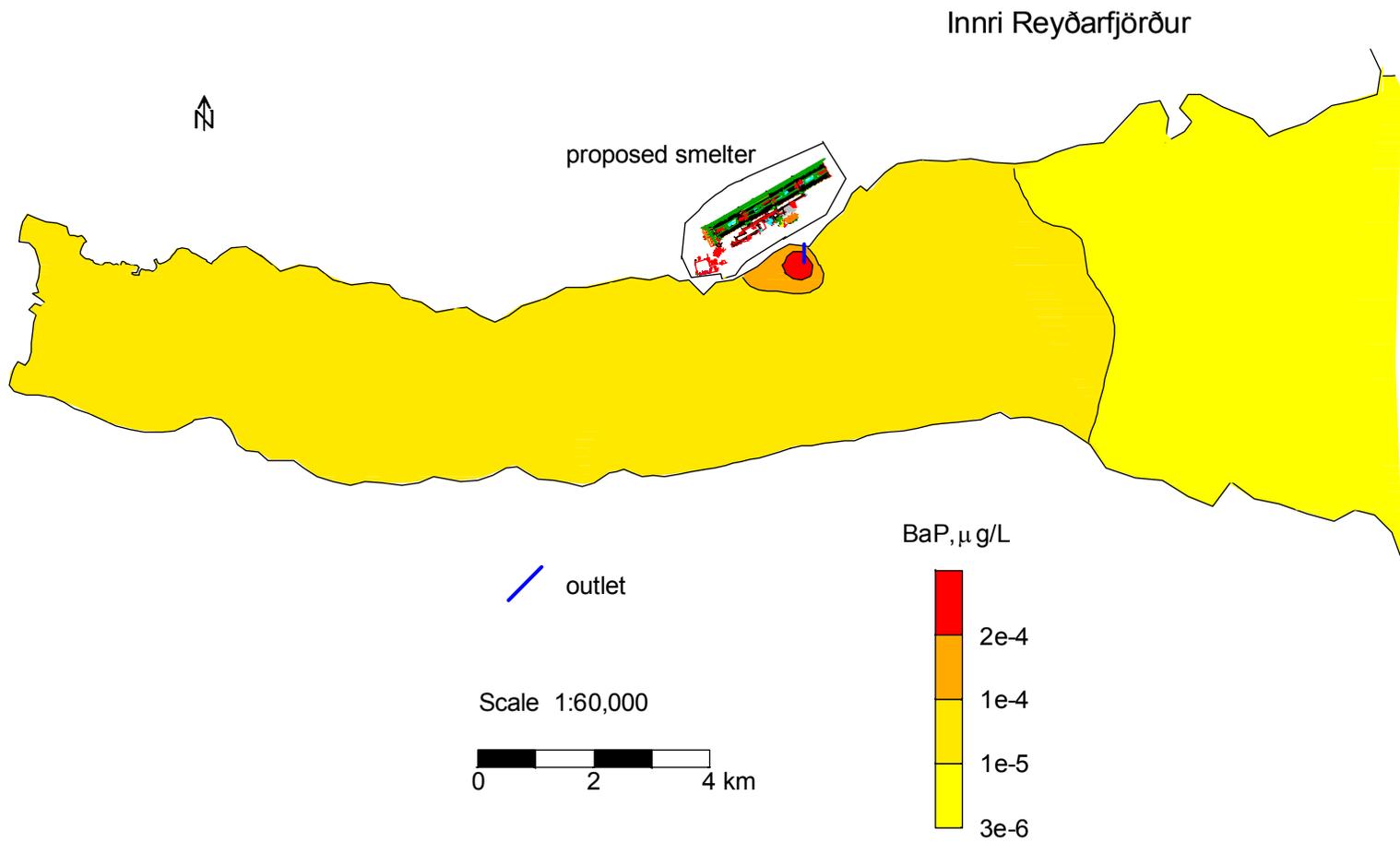


Figure 8

Calculated BaP concentration for particle size 10 µm

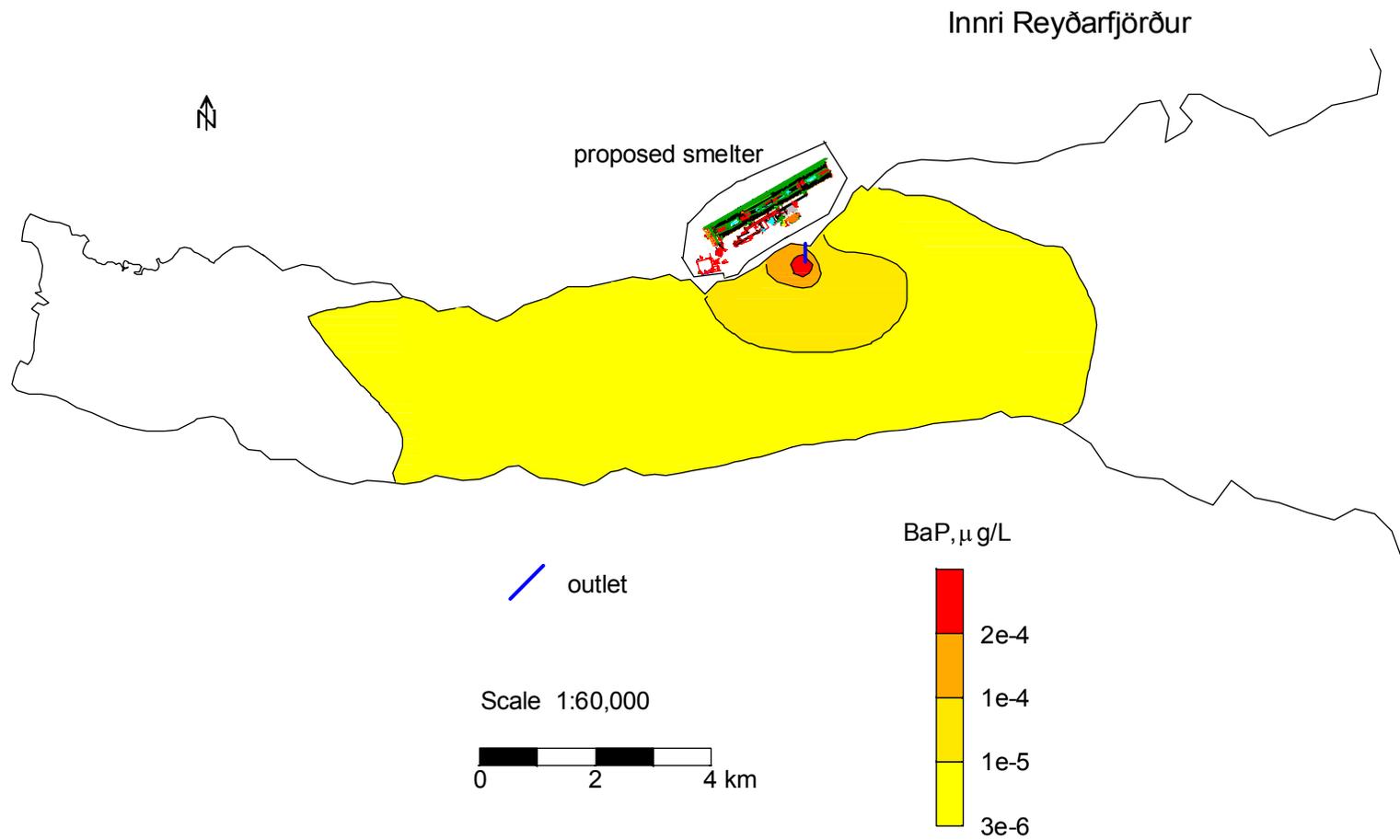


Figure 9

Calculated BaP deposition for particle size 1 μm

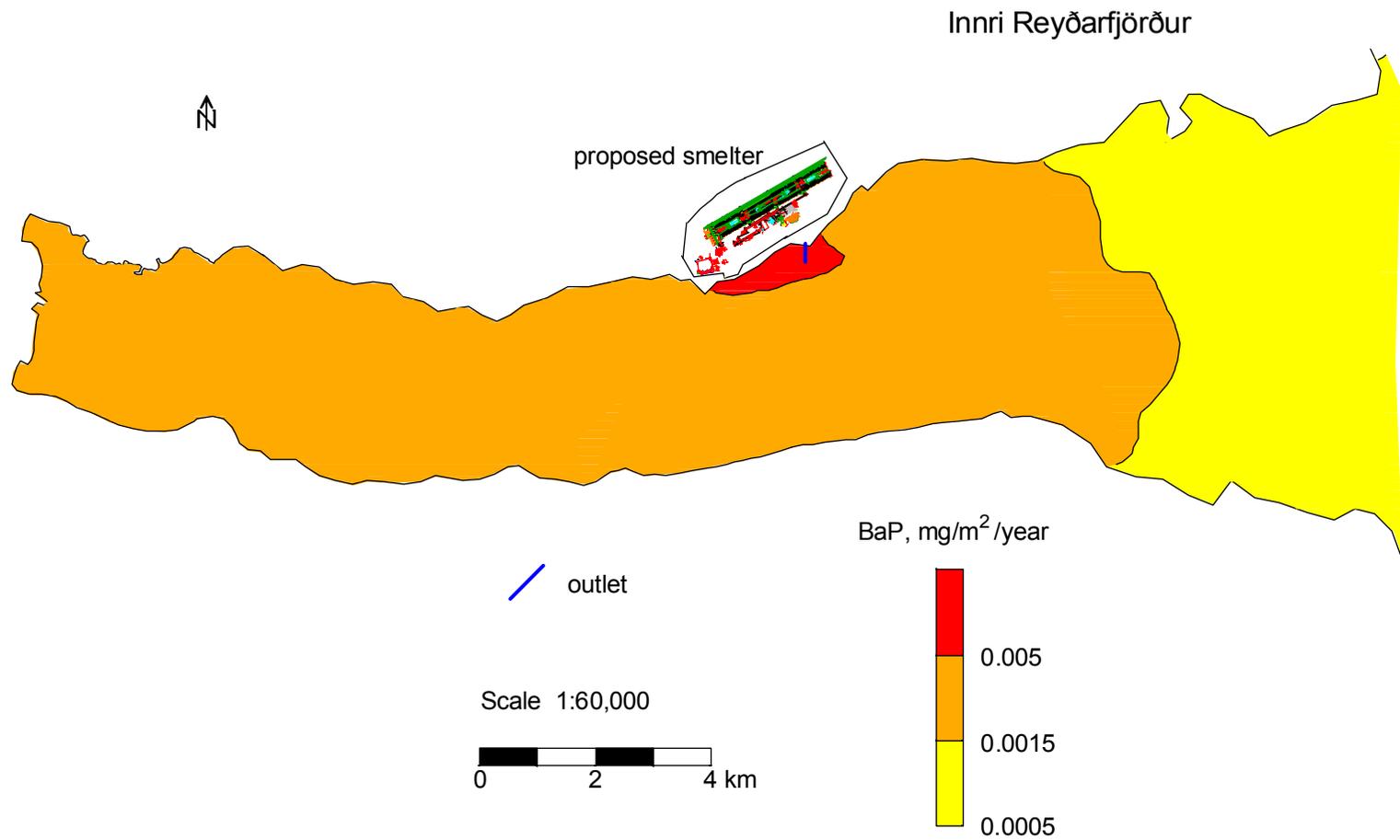


Figure 10

Calculated BaP deposition for particle size 10 µm

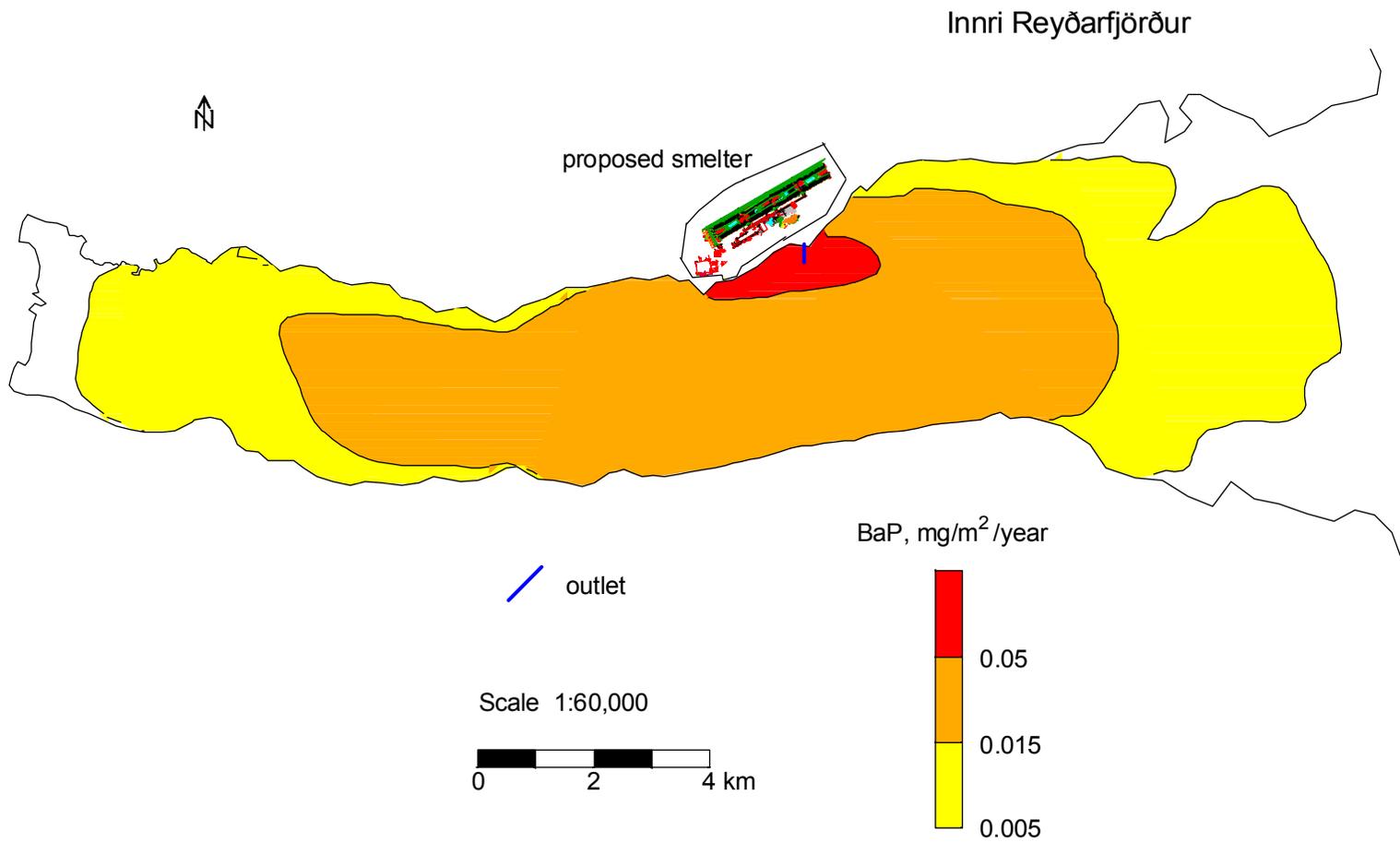


Figure 11

Calculated PAH concentration in deposited sediment for particle size 1 μm

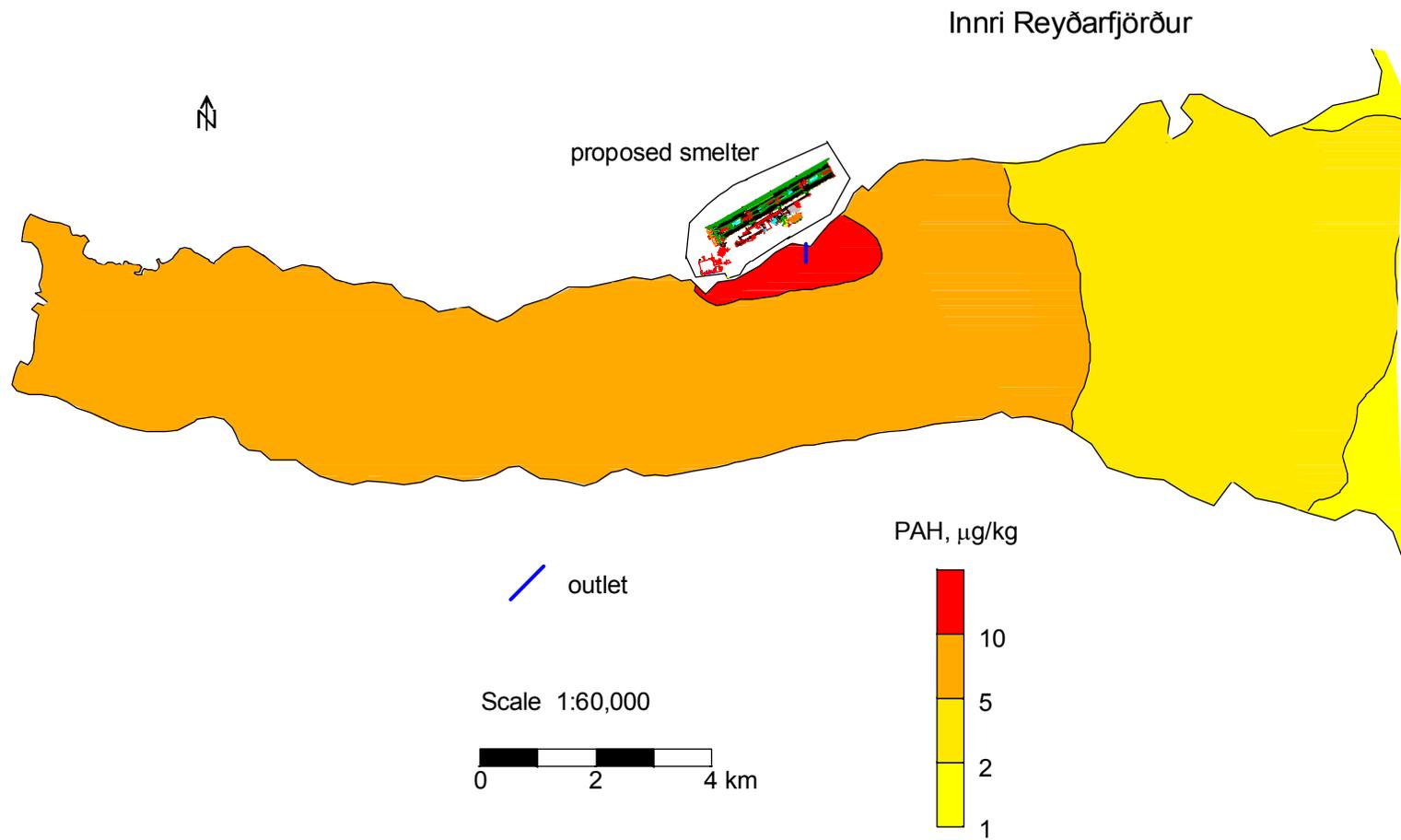


Figure 12

Calculated PAH concentration in deposited sediment for particle size 10 µm

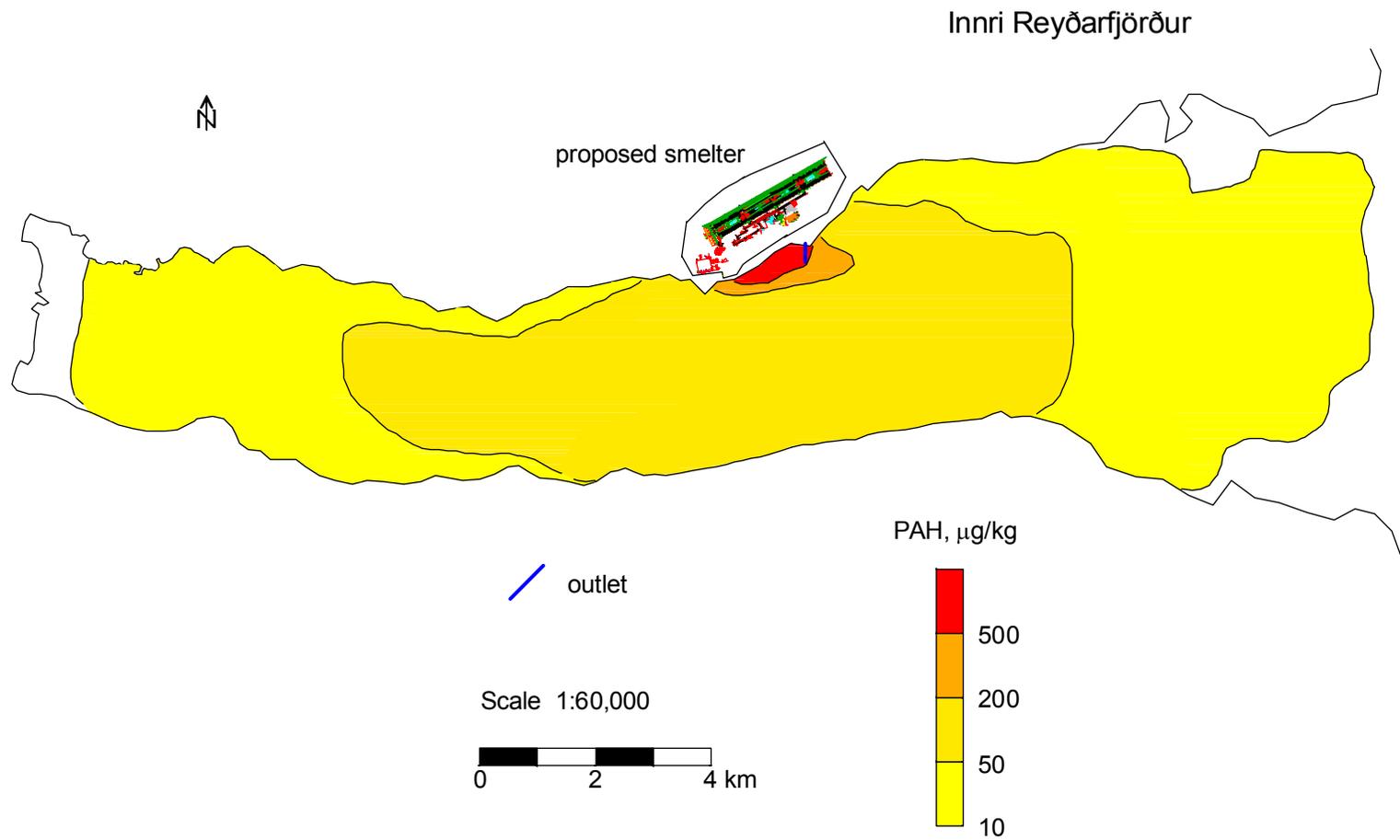


Figure 13

Calculated BaP concentration in deposited sediment for particle size 1 μm

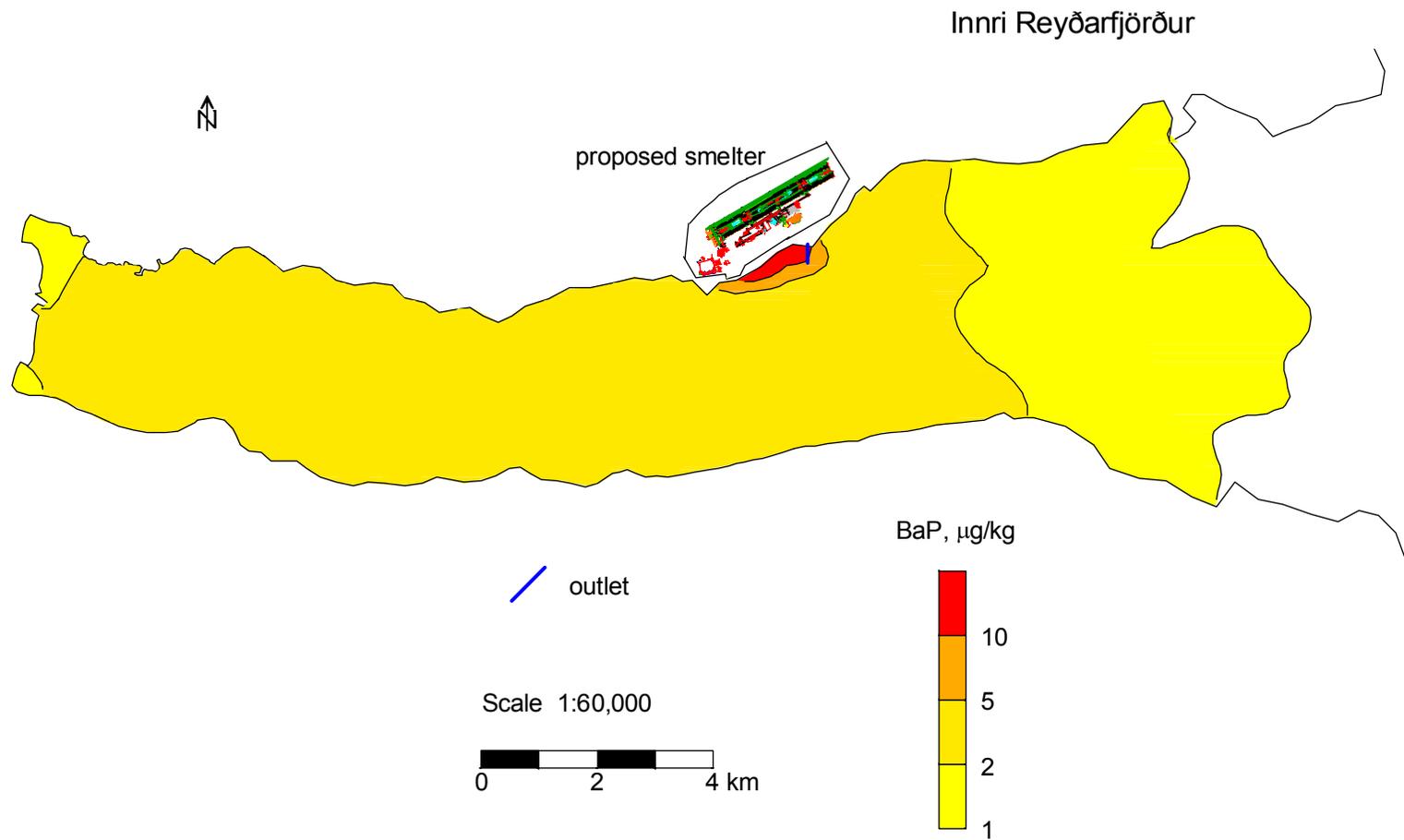


Figure 14

Calculated BaP concentration in deposited sediment for particle size 10 µm

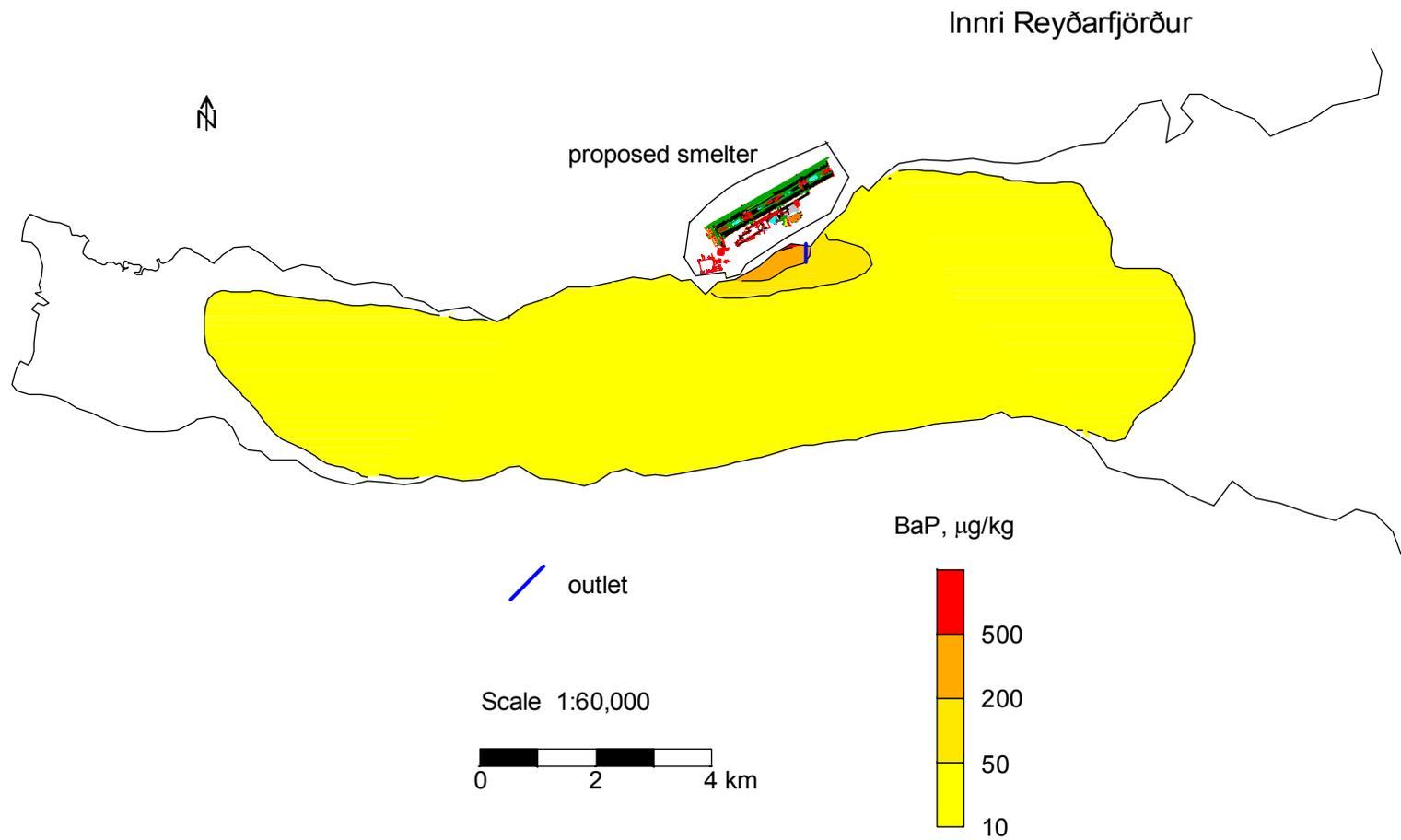


Figure 15