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Environmental geochemistry of a mega beach nourishment in the Netherlands:  
Monitoring freshening and oxidation processes

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1 **Environmental geochemistry of a mega beach nourishment in the Netherlands:**  
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7

8 **Abstract**

9 As coastal lowlands are prone to sea water flooding, sea-level rise might globally increase this risk. To  
10 protect its coastline, the Netherlands adds an average of 12 million m<sup>3</sup> of sand annually, but more is  
11 needed to cope with the expected consequences of global warming. In 2011 a novel approach for coastal  
12 protection was applied near The Hague, consisting of a mega beach nourishment of 21.5 million m<sup>3</sup> of  
13 sand: the Sand Engine – an artificial sand spit rising to 6 metres above mean sea level. It uniquely  
14 combines coastal engineering construction with environmental, ecological and social considerations. To  
15 construct the Sand Engine, material was used from the seafloor, which changed the materials  
16 environment from anaerobic to aerobic, triggering two main hydrogeochemical processes: pyrite  
17 oxidation and groundwater freshening. The objective of this study was to assess the sediment  
18 geochemistry of the Sand Engine and understand the hydrogeochemistry with respect to pyrite oxidation  
19 and freshening. When sufficient buffer capacity is lacking, the mobility of metals and metalloids  
20 originated from the mineral pyrite, can cause local impacts on ecology and environment. Geochemical  
21 and multivariate statistical analyses were performed on 174 sediment samples from the Sand Engine and  
22 from material collected from the seafloor prior to its construction, as well as on 86 samples of pore  
23 water collected from the Sand Engine. First, a cluster analysis was performed, using model-based  
24 (Mclust) and variable clustering. Second, a robust factor analyses (RFA) was used to explain the variation  
25 between the groups and discover relationships between elements and/or soil properties within the  
26 groups. We distinguished three clusters of sediment samples and two clusters of pore water samples.  
27 Sediment cluster 1 was comprised exclusively of surface samples from the Sand Engine; it was  
28 differentiated from the other two clusters by its geochemistry, sorting processes and weathering.  
29 Sediment clusters 2 consisted of shallow samples from the Sand Engine, as well as deeper autochthone  
30 material from the sand pit. Sediment cluster 3 contained deeper samples from the Sand Engine and also  
31 shallow autochthone material from the sand pit. Sediment clusters 2 and 3 show differences in  
32 carbonate content and, especially, in reactive iron, confirming that in the sand pit area a Holocene

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