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Oil permeability variations on lagoon sand beaches in the Patos-Guaíba system in Rio Grande do Sul, Brazil

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ABSTRACT

Permeability is the ability of a sediment deposit to allow fluids to pass through it. It depends on the local types of sediments. When the fluid is oil, high permeability implies greater interaction with the site and more extensive damage, which makes recovery most difficult. Knowledge of permeability oscillations is necessary to understand oil behavior and improve cleanup techniques. The goal is to determine oil permeability variations on lagoon sand beaches. Oil permeability tests were performed at the beach face, using a Modified Phillip Dunne Permeameter and parameters were sampled. Permeability of lagoon beaches is driven by grain diameter and roundness, soil compaction, and depth of the water table. Factors that enhance permeability include: sand sorting, vertical distribution of sediments and gravel percentage. High permeability on lagoon beaches is related to polymodal distribution, to the sediment package, and to the system's low mobility.

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1. Introduction

Permeability is defined as the ability of sediment to allow fluids to flow through it. This is measured by a hydraulic conductivity coefficient, which depends on the fluid and environmental characteristics. When the fluid is oil, permeability determines infiltration and the contaminant's residence time in the substrate. According to Stern (2007), the longer the oil's residence time in an area, the higher its interaction with the environment, and the stronger will be its impact, making recovery more difficult.

High substrate permeability causes subsurface oil deposits, which worsens the situation due to a few factors: First, in the subsurface oil degradation by bacteria is limited, due to low oxygen availability (Rowland et al., 2000). Second, the contaminated volume may be underestimated, since visual measures are ineffective (Owens, 1988). And finally, the variations in the beach sediments package may form interleaved layers of sand and oil, which can be released through time (NOAA, 1992).

Because it depends on sediment characteristics, hydraulic conductivity will vary according to its location (ocean, lake, lagoon, etc). Moreover, sedimentary changes in time may alter permeability, leading to different infiltration rates, causing problems during the cleaning process, besides not corresponding to pre-existing oil sensitivity rankings for the area (Tsouk et al., 1985).

Soil K value can either be measured or predicted. Most natural soils have spatially variable hydraulic properties. This implies that many K data are necessary to adequately characterize the field's K value. Most projects do not have a budget to perform many field and laboratory permeability tests, since those are time-consuming and more costly than predictions. This is why simple methods are used to predict the hydraulic conductivity (Chapuis, 2012).

The official Brazilian method to determine oil sensitivity (MMA, 2007) establishes standard behaviors of oil flow based, mostly, on substrate structure, where permeability is crucial to this definition. However, permeability estimates in the current methodology is based on grain size, which in turn is visually determined by the researcher on the beach, excluding any variation. In addition, oil behavior is based on an ocean beach, but considered the same for beaches located in any other system (like lagoons).

Actual oil behavior does not always match predictions. This is why methodology improvement is necessary and justified. Some efforts to improve oil sensitivity have been proposed by Moe et al. (2000), Castanedo et al. (2009), Fataal et al. (2010), Marques and Nicolodi (2015), and Marinho (2015). In this context, and in order to increase knowledge of oil behavior and permeability and advance the existing methodology, this article aims to determine oil permeability on lagoon beaches, as well as define the main parameters that determine the flow.

2. Methods

2.1. Study area

The area chosen for the study comprises four lagoon beaches in the "Patos-Guaíba" System in Rio Grande do Sul (RS), Brazil, and can be seen in Fig. 1. These beaches are Arambaré Norte (UTM 452819,

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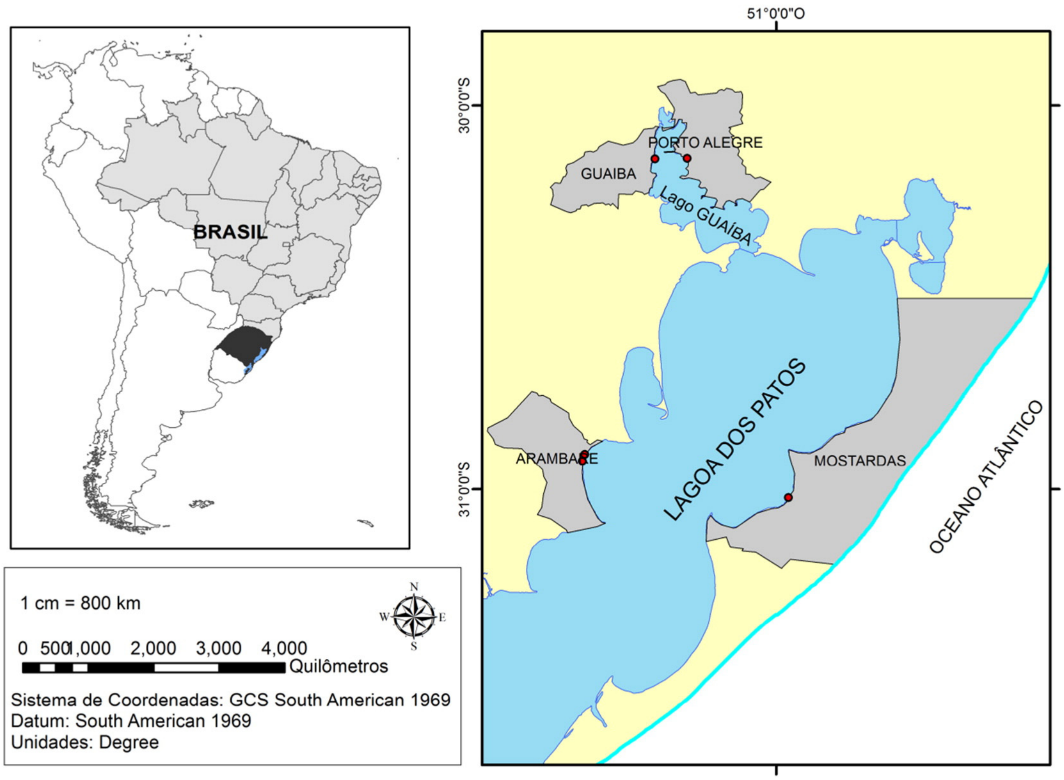

Fig. 1. Location of the studied area in the Patos-Guaíba System, Rio Grande do Sul, Brazil.

6580432), Arambaré Sul (UTM 452250, 6578548), Praia Alegria in Guaíba city (UTM 469869, 6665665), Ipanema in Porto Alegre (UTM 477865, 6665860) and Mostardas (UTM 503033, 6567971). Arambaré was divided in two samples (Norte and Sul) due the differences between the sediments caused by the Velhaco River which flows out onto the beach.

The Patos-Guaíba system is located on the coastal plain of Rio Grande do Sul. On the northern end of the coastal plain the adjacent highlands consist of Paleozoic and Mesozoic sedimentary and volcanic rocks of the Paraná Basin that locally reach 1000 m. On the southern section, igneous and metamorphic rocks of the Pre-Cambrian shield form lower highlands. At present, all sandy sediments eroded from these highlands and carried by rivers to the coast are trapped in the coastal lagoons and other back-barrier environments, and none reaches the ocean shoreline (Tomazelli et al., 2000).

The coastal plain is dominated by a bimodal high-energy wind regime. The dominant wind comes from NE and is more active in spring and summer months. The secondary W-SW wind becomes more important in the autumn-winter months. The coast is dominated by microtidal waves, with semidiurnal tides averaging 0.5 m (Motta, 1969; Calliari et al., 1998; Tomazelli et al., 2000).

The wind pattern has great influence on the velocity of groundwater flow, as it defines the direction of surface flow and the water percolation rate in the sediment. The driving force generated by the lagoon's surface flows moves continental groundwater toward the sea. However, a reverse process, caused by the concentration gradient, transports back toward the lagoon (Machado, 2007).

The Patos Lagoon is described by Toldo Jr. (1994) as a shallow and wide body of water ranging in width from 10 to 60 km. The total length is 240 km. The sediments on the western part of the lagoon are poorly sorted ranging in size from fine sand to gravel, while the sediments along the eastern bank clearly show sorting and fine grain size (Martins et al., 1989).

3. Methods

The methodology adopted included oil infiltration tests and parameters (compaction and water table depth) and sediments sampling. The permeability tests, compaction, and water table tests were performed during a fieldwork on each beach.

The permeability tests were conducted with the Modified Phillip-Dunne Infiltrometer (MPD). The MPD was installed at the beach face of the beaches studied. Six tests were performed for each beach in two perpendicular profiles, named 1 and 2. Point A is located next to the waterline, Point C is on the berm, and Point B is halfway between Points A and C, as shown in Fig. 2. The tests were authorized by the proper Environmental Agency in charge (authorization 127/2015-DL).

The fluid used in the tests was crude oil (API 33.54 and density 0.8549 g/cm^3) donated by Alberto Pasqualini Refinery (REFAP). In each test, the MPD was filled with 750 ml of oil and the fluid dripping time was recorded every 0.5 cm. After infiltration was complete, the MPD was removed and a stratigraphic cut was conducted for subsequent image capture. The infiltration plume (corresponding to the blob formed by the oil in the sand) was photographed and measured. After the test, the contaminated sand was removed and stored in barrels. The barrels were taken to LOG – the Geological Oceanography Laboratory of FURG – Federal University of Rio Grande, where they were stored until final destination.

In the laboratory, dripping time and height variation were input onto a macro to calculate hydraulic conductivity using Philip's (1993) theory. The macro was developed by St. Anthony Falls Laboratory of the University of Minnesota. The macro creation tutorial is available in Ahmed et al. (2011) and Nestingen (2007). The data was also input in other empirical hydraulic conductivity equations in order to identify the effectiveness of each equation in the "Patos-Guaíba" system.

The compaction tests were conducted with a manual penetrometer whereas the penetration resistance to 40 kg/cm^2 and 50 kg/cm^2 loads

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