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Drainage Bed: A Natural System for WTP Sludge Dewatering and Drying with Different Coagulant Chemicals in Tropical Countries

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Abstract

This study seeks to evaluate the mechanisms for dewatering sludge from Water Treatment Plants (WTP) in a natural system that uses nonwoven polyester geotextile blankets named Drainage Bed (DB). Dewatering mechanisms are divided into two stages: Drainage and Drying Phases. For the Drainage Phase, the results showed that the solids content of the Aluminum Sulfate sludge reached 8.9% to 18.3% and the PACl sludge 1.8% to 6.5%, the volume reduction on this phase exceeding 50% and 74%, respectively. The final solids content, after the Drying Phase, was greater than 28%, reaching 90%. In the Drainage Phase the lower the Surface Application Rate—SAR [kg/m^2] is, the greater the drainage flow will be. In the Drying Phase, moisture and insolation were key factors in drying sludge. Thus, the Drying Phase in the DB takes special attention for being virtually nonexistent in dewatering technologies in a closed system (confined) without exposure to solar energy. The use of the DB as a natural system for dewatering WTP sludge in tropical countries proved to be a promising alternative, because of its efficient removal of water from sludge coupled with operational simplicity and low costs, provided there is area available.

Keywords

Sludge, Dewatering, Drying, Drainage Bed (DB), Geotextile Blanket

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1. Introduction

The vast majority of Water Treatment Plants (WTPs) worldwide seek urgent solutions for proper disposal of waste generated in decanters and filters particularly.

In Brazil, as in other tropical countries, it is prohibited to release WTP sludge into bodies of water, according to national legislation [1] and [2]. However, this practice is common in most WTPs [3], making the development of solutions for the proper disposal of this waste an urgent matter.

The method and interval of sludge removal from decanters also pose serious problems in that it is performed manually and intermittently at intervals that can extend for more than 30 days. The time interval for sludge removal from WTPs of full cycle could reach 180 days [4]. The manual operation of sludge removal using jets of high-pressure water and wooden squeegees causes operators to be in direct contact with this material [5] and its solids content to vary considerably.

Efforts to minimize the generation of waste must be a priority. However, it does not eliminate the need for drainage systems, either natural or mechanical, necessary to reduce the volume of sludge generated and to facilitate its disposal. Natural systems include sludge lagoons, drying beds, Draining Bags (BAGs) and Drainage Beds (DBs). Among mechanic systems there are: centrifuges, filter presses, dewatering presses, etc.

After passing through a dewatering system, dewatered sludge can be taken to post-treatment via thermal systems, which promote drying of the material. Thermal systems may be natural or mechanical, such as natural thermal drying, drying ovens, mechanical thermal dryers, incineration, etc.

In sludge lagoons the top layer of sludge exhibits good drying, which does not occur in the lower layers [6] and [7].

Tropical countries, such as Brazil, have advantages in the deployment of nonmechanical dewatering systems, since area availability and climate favor natural methods of water removal [8].

Accordingly, the Drainage Bed (DB) was developed in Brazil [9]—a nonmechanical system (exposed to atmospheric pressure) using as filtering medium nonwoven geotextile blankets, a result of research in laboratories through the evolution of traditional drying beds, which filtering medium is sand [10], as illustrated in **Figure 1**.

The advantages of the Drainage Bed are mainly due to improved efficiency in draining the free water present in the sludge and the possibility of thermal drying of dewatered sludge by evaporation, through the use of natural (solar) energy.

In this technology, the mechanisms of filtration through synthetic blankets should receive special attention. There are two basic mechanisms of filtration through synthetic blankets, based on the different conditions of the solid-geotextiles interaction: filtration of suspended particles and filtration in porous media [11], [12] and [13].

Thus, the efficiency of a filtering system consisting of geotextiles to maintain its draining/filtering capacity over time is closely related to the occurrence of clogging.

Clogging occurs when particles carried in the flow are deposited on the filtering interface, or led into it, creating an area of lower permeability than in the free-flow region before the filter, resulting in alterations on the properties of the geotextile fabric over time. This can occur by blocking, blinding and clogging [14]. The clogging phenomenon directly affects the draining ability of the porous medium where the flow occurs. Nevertheless, about 75% of the pores in geotextile blankets can get clogged without having operability compromised [12].

The dewatering of WTP sludge by DBs through the separation of the liquid phase (free water) and solid phase (particles) can be understood as filtration of suspended particles (**Table 1**). The liquid phase consists of fractions of water: free water, interstitial water, vicinal (or surface) water and bound (or hydration) water [15] and [16]. For the removal of each water fraction, it is required to use a given intensity of energy.

The Drying Phase comprises the step intended to remove the nondrained water in the sludge mass to an unsaturated gaseous medium, such as air, through thermal vaporization [17].

The reduction of sludge volume in two different natural systems, comparing the sludge lagoons system from a conventional WTP of full cycle to the DB developed by Cordeiro [9], was analysed. The investigation showed the difficulties and long-time (months) necessity for water removal in sludge lagoons, while the DB showed a 75% to 85% volume reduction in just seven days [18].

The results of research and implement the DB in real scale, in the municipality of Cardoso, São Paulo State, Brazil, showed high performance dewatering, with a 98% reduction of residue volume and quality of drained (turbidity < 1.0 uT) with satisfactory results [19].

This study seeks to evaluate the mechanisms of dewatering WTP sludge in a natural system that uses geotextile

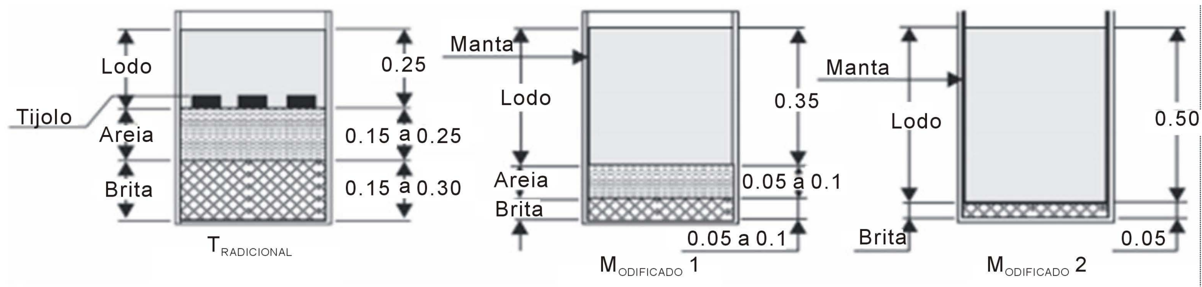

Figure 1. Illustrative schemes of traditional and modified systems 1 and 2 (Drainage Bed) as proposed by Cordeiro (1993 and 2000) [9] and [10].

Table 1. Summary of conditions and results of WTP sludge dewatering tests on Drainage Bed.

Test	1		2	3		4		5A		5B	
Prototype	I		I	II		I		II		II	
Sludge (coagulant)	Al_2SO_4	PACl	PACl	Al_2SO_4	PACl	Al_2SO_4	PACl	Al_2SO_4	PACl	Al_2SO_4	PACl
Volume (L)	25	25	20	8	8	55	55	8	8	8	8
TS_o (%)	2.60	1.40	0.22	7.60	0.04	0.76	0.26	2.70	0.28	4.20	0.21
SAR (kg/m^2)	3.43	1.86	0.23	7.35	0.04	2.20	0.76	2.61	0.27	4.06	0.20
Sedimentation maximum speed (mL/min)	3.5	13	22	0.01	18.9	43	60	-	-	-	-
Drainage Phase											
Drainage time—T_{dra} (min)	300	60	60	480	30	300	60	120	10	120	10
Volume reduction (%)	74.6	73.8	80.0	49.1	95.0	87.9	95.5	58.1	96.3	49.8	96.3
TS_o (%)	2.60	1.40	0.22	7.60	0.04	0.76	0.26	2.70	0.28	4.20	0.21
Final TS (%)	8.9	6.5	5.1	9.7	1.8	12.6	5.1	18.3	-	14.5	-
Δ TS (%)[1]	70.8	78.5	95.7	21.6	97.8	94.0	94.9	85.2		71.0	
Drying Phase											
TS_{1dia} (%)	13.4	8.8	13.0	17.3	13.0	23.4	16.7	18.3	-	14.5	-
Final TS (%)	30.6	28.4	91.8	88.9	53.3	98.0	46.6	50.3	-	42.3	-
Δ TS (%)	56.2	69.0	85.8	80.5	75.5	76.1	64.1	63.6	-	65.7	-
Drying time—T_{dry} (day)	7	7	6	7	2	6	2	7	1	7	1
TS > 30% (day)[2]	7	7	4	4	2	2	2	3	1	3	1

[1]Variation in solids content Δ TS (%) = [TS_o (%)/Final TS (%)]*100; [2]Time in days in which solids content (TS%) of dewatered sludge greater than 30%.

blankets named Drainage Beds (DBs), and to verify the occurrence and efficiency of two distinct water removal phases: free water drainage and drying by water vaporization.

2. Material and Methods

In order to carry out the tests, DB prototypes and samples of raw WTP sludge were used. The blanket used in the tests is the nonwoven polyester geotextile of 600 g/m^2 (surface density 4.5 mm thick, porosity > 90%, normal permeability 3×10^{-1} cm/s and 60 µm opening).

In **Figure 2** we have the schematic of the dewatering tests performed on DB prototypes and the variables involved.

The tests were initiated at time to, with a setting of initial solids TS_o (%) and a measuring of the total volume of sludge applied (V_L). The preset and studied control variables are presented below:

- Total time of dewatering (Δt) = $t_f - t_o = t_{drainage} + t_{drying}$;
- Accumulated drained volume (Δv) = $V_L - V_{evaporation} + V_{preciptation}$;
- Total solids content variation (ΔTS) (%) = $TS_i - TS_o$.

The time t_i, start of the Drying Phase and end of the Drainage Phase, was studied and characterized when the

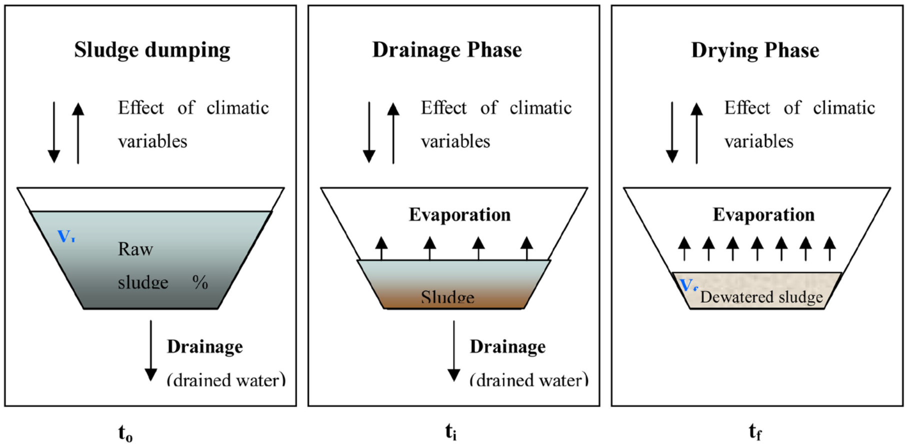

Figure 2. Schematic illustration of the Drainage Bed dewatering and variables involved.

drainage flow rate reached values lower than Q = 0.04 L/mi, equivalent to the volume of 10 mL in the interval of 15min. The time t_f, end of the Drying Phase was studied and characterized either when there was no possibility to collect solids retained in the blanket or when the stipulated deadline of seven days was reached.

Six tests were performed with different samples of conventional WTP sludge which employ coagulants such as aluminum sulfate [$Al_2(SO_4)_3$] and polyaluminum chloride (PACl).

Dewatering times ($t_i - t_o$) were determined during the Drainage Phase and the drying time ($t_f - t_i$), during the Drying Phase of the sludge. During the Drying Phase, climate variables were also monitored in order to provide a better understanding of the mechanisms comprising natural drying.

3. Results and Discussion

For all different conditions of dewatering, with raw $Al_2(SO_4)_3$ and PACl sludge samples, with different solids content and volumes used, the maximum drainage time was approximately eight hours, for $Al_2(SO_4)_3$ sludge, and one hour for PACl sludge, being volume reduction during the Drainage Phase superior to 50% and 74%, respectively, for all tests, as **Figure 3** and **Figure 4** show.

The solids content after the Drainage Phase for $Al_2(SO_4)_3$ sludge ranged from 8.9% to 18.3% and for PACl sludge from 1.8% to 6.5%. Final solids content, after the Drying Phase (2 to 7 days), was greater than 28% to all cases, getting closer to 90% in some tests, regardless of drying time or sludge type.

In the Drainage Phase, the value of Surface Application Rate—SAR [kg/m^2] and/or Total Solids—TS [%] proved decisive in defining the flow of initial free water drainage—the lower the SAR the higher the drainage flow for both types of sludge ($Al_2(SO_4)_3$ and PACl coagulants), see **Figure 5**.

The draining material used in the Drainage Bed made up of geotextile blankets showed a distribution of pore size capable of retaining flocculent, or solid particles, as evidenced by the properties of the free water drained, which showed effective removal of solids and metals from the PACl and aluminum sulfate sludge samples. **Figure 6** illustrates the results of two tests, demonstrating that after five to ten minutes the turbidity of the drained water presented values close to 2.0 uT.

In the Drying Phase, climatic variables, humidity and insolation were determinants in sludge drying, see **Figure 7** and **Figure 8**. Evaporation offered a potential means for monitoring and predicting the drying speed, especially with sludge with higher solids content.

4. Conclusions

The Drainage Bed (DB) was effective in the two distinct phases of sludge water removal (Drainage Phase and Drying Phase), with significant reductions in sludge volume for different sludge samples. The Drying Phase enabled the thermal drying of dewatered sludge by evaporation through the use of natural (solar) energy.

On the DB the Drying Phase takes special attention for being virtually nonexistent in other dewatering technologies, such as the use of sludge lagoons—in which there is the formation of impermeable layers of the material itself (water sandwich effect)—and in the case of Draining Bags which, for being a closed system (confined)

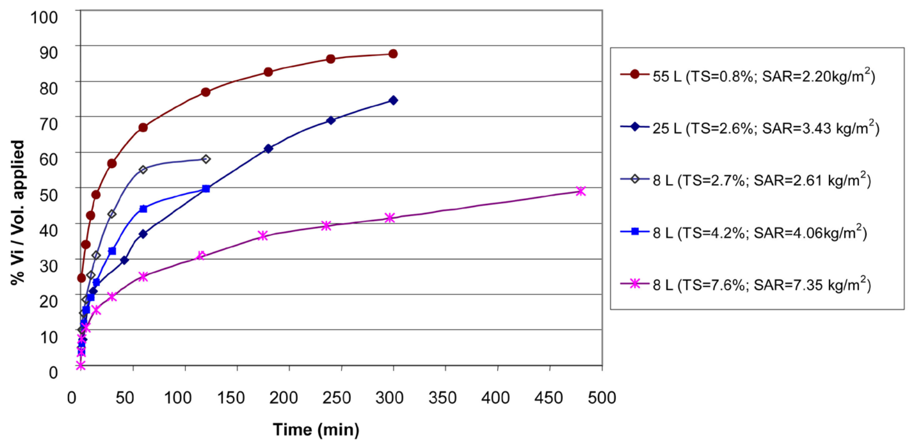

Figure 3. Cumulative volume of drained free water in dewatering tests with $Al_2(SO_4)_3$ sludge samples.

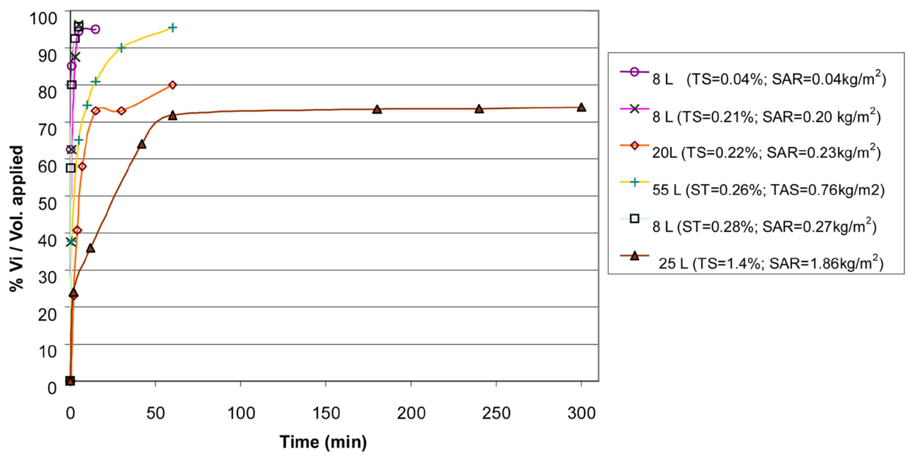

Figure 4. Cumulative volume of drained free water in dewatering tests with PACl sludge samples.

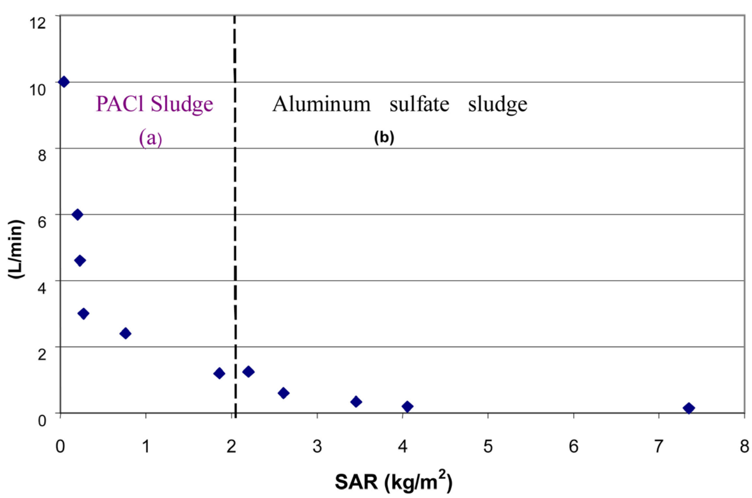

Figure 5. Relation between initial drainage flow of free water (L/min) and the values of Surface Application Rate—SAR (kg/m^2) for tests conducted with a sample of PACl sludge (a) and $Al_2(SO_4)_3$ sludge (b).

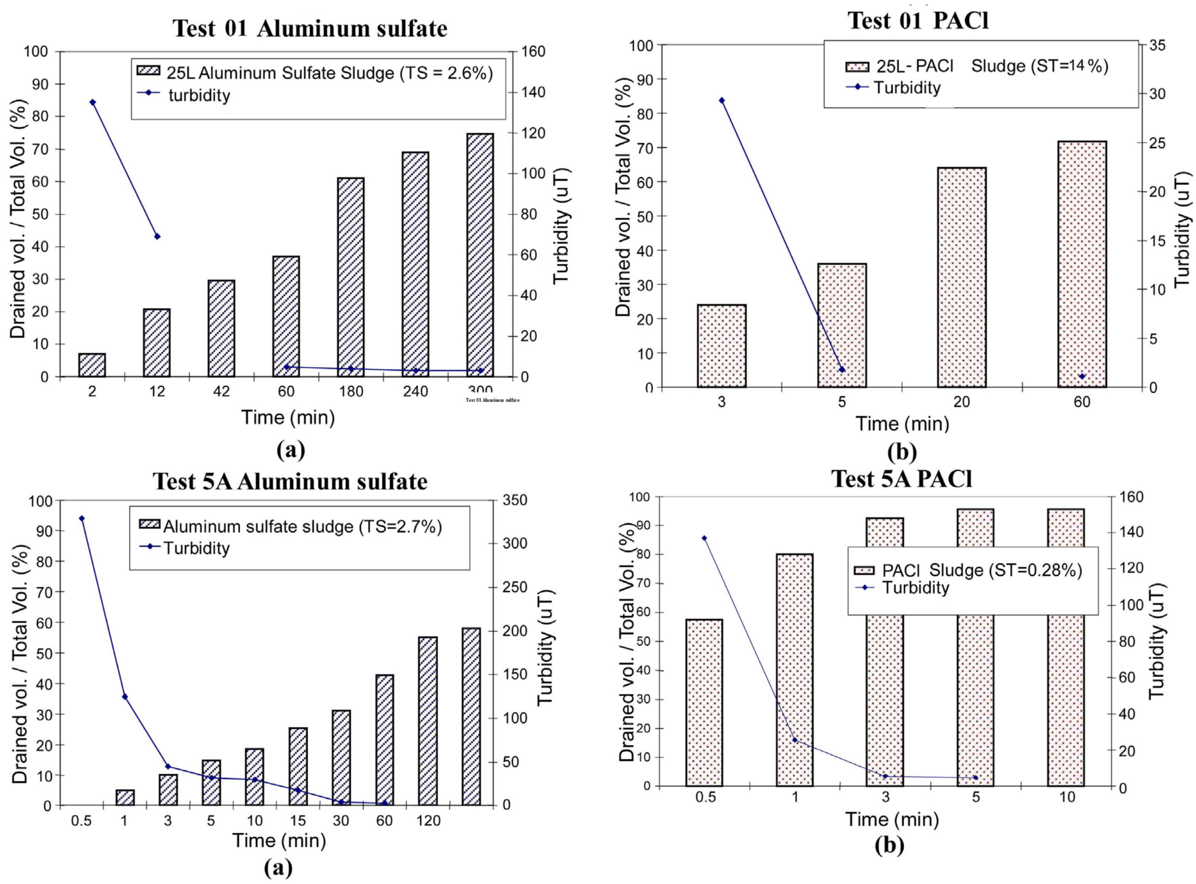

Figure 6. Variation in the values of cumulative volume of drained free water (%) and turbidity during the Drainage Phase, for samples of $Al_2(SO_4)_3$ (a) and PACl (b).

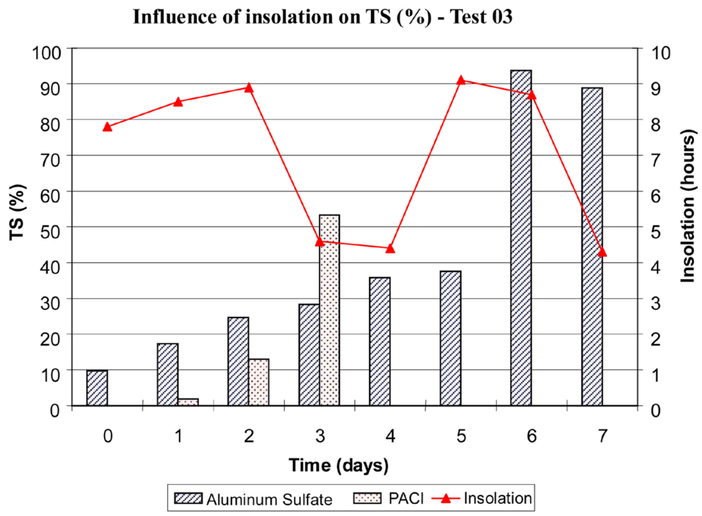

Figure 7. Variation of insolation and total solids content (%TS) for one of the Drainage Bed dewatering tests (Drying Phase).

without exposure to solar energy, prevents the drying of the material and even reuse of the system.

The use of the DB as a natural system for dewatering WTP sludge in tropical countries proved to be a promising alternative, as a result of the efficient removal of water from sludge coupled with operational simplicity

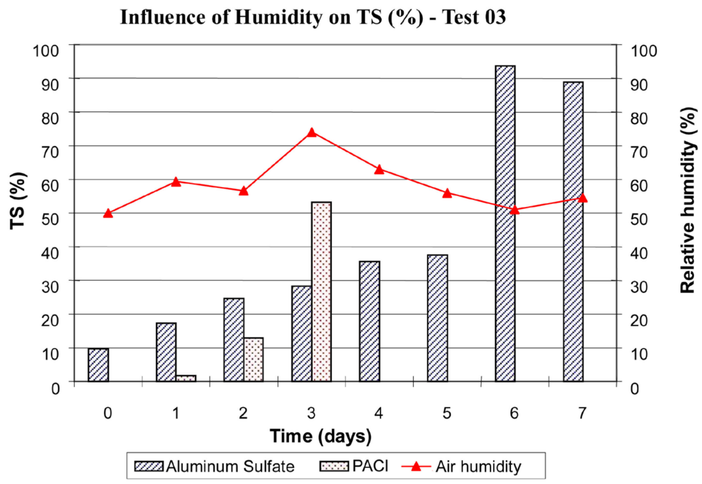

Figure 8. Variation of humidity and total solids content (%TS) for one of the Drainage Bed dewatering tests (Drying Phase).

and low costs, provided there is area available.

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