

Improvement of shrinkage and expansive soil properties using nano-copper

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ABSTRACT

Nanoparticles are now becoming a common material and currently produced in bulk worldwide to warrant possible use in construction and for improvement of infrastructures. This paper presents an experimental study on the use of nano-copper to enhance the shrinkage and expansive behaviour of soils. This behaviour is the result of loss of soil water content which develops matric suction in soil that increases the shrinkage strain in the soil and normally results in cracks. The term desiccation is also normally used to describe this phenomenon which will cause high hydraulic conductivity in soils leading to failure of slopes, retaining walls and landfills. In the past, sand, lime, and fibres were used to arrest shrinkage. However, at the same time hydraulic conductivity increases significantly. Tests were conducted on four types of soils mixed with nano-copper of different amounts. The soil specimens were compacted under the condition of maximum dry unit weight and optimum water content using the standard compaction test. It was found that there was a significant improvement by nano-copper in terms of expansive and shrinkage strain. This is possibly because the particle density of nano-copper is high which increases the specific gravity of the soil–nanomaterial mixture leading to increase in the maximum dry density of the mixture. The results also showed that nano-copper decreases the development of desiccation cracks on the surface of compacted samples without increasing the hydraulic conductivity.

1 INTRODUCTION

In addition to traditional consolidation, volume change in soil can also be due to shrinkage caused by drying (desiccation) or swelling due to saturation of the soil. Desiccation causes clayey soils to shrink. Specifically, this occurs due to the loss of water content which lead to the progress of matric suction in soil that increases the shrinkage strain normally followed by crack development (Nahlawi and Kodikara, 2006). In general, the factors that affect the volume change in soils include clay mineralogy, clay content, compaction conditions, drying process, wetting and drying cycles, soil particle orientation, unit weight, pore fluid, and exchangeable ions. Soils with higher clay content and higher plasticity index generally have a greater volume of water and thus are more prone to large volumetric shrinkage strains during drying. Specimens compacted near optimum water content have less water/unit volume when saturated, and lower volumetric shrinkage strains (Albrecht and Benson, 2001). In relation to shrinkage strain and desiccation in soil, there is another important accompanying parameter, i.e. hydraulic conductivity. Wang and Shibata (2007) show the importance of considering soil permeability (or hydraulic conductivity) and suggest that soils with large permeabilities have the propensity to result in flow slides with higher mobility. In relation to clay liners and caps, soils should be compacted to achieve a hydraulic conductivity of 1×10^{-9} m/s or less

(Daniel and Wu, 1993). One of the methods to reduce the shrinkage strain and hydraulic conductivity is to increase compaction efforts. This however, normally involves high additional cost. The increase in the compaction effort increases the dry density and decreases the water content but for higher water content soils, the increase in the compaction effort does not reduce the shrinkage strain significantly (Osinubi and Nwaiwu, 2008). Moreover, mixing the soil with fibre can reduce the shrinkage strain up to 90% but the fibre increases the hydraulic conductivity up to 50 times the hydraulic conductivity of the original soil (Rifai, 2000).

2 MATERIAL

2.1 Soil

Four types of soils were used in this study, i.e. S1, S2, S3 and S4. S1 is a local soil obtained within the campus of the Universiti Kebangsaan Malaysia in Bangi, Selangor, about 35 km south of Kuala Lumpur, the Malaysian capital. This is a residual soil of sedimentary origin. Soils S2, S3, and S4 are soil S1 with 5%, 10% and 20% bentonite for creating soils with higher plasticity index. The specific gravity of the all the soils were almost the same but their plasticity index significantly differ from each other. The properties of soil are shown in the Table 1.

Table 1: Basic properties of the soil used in this study

Characteristics	Values and descriptions			
	S1	S2	S3	S4
Specific gravity	2.61	2.61	2.61	2.62
Plasticity index (%)	16.96	28.26	36.18	69.01
Linear shrinkage (%)	8.2	12.86	15.9	23.57
Passing No. 200 sieve (%)	47.16	49.80	52.44	57.73
Clay content (< 2 µm) (%)	18	22.9	28.5	38.5
Unified Soil Classification System (USCS)	CL	CL	CH	CH
Compaction properties				
Optimum water content (%)	14.29	16.01	18.63	20.3
Maximum dry unit weight (kN/m ³)	18.05	17.70	16.93	16.12

2.2 Nano-copper

Nano-copper oxide with purity 100% was used in this study. The nano-copper was supplied by Inframat Advanced Materials, Manchester, USA. The specification and the information provided by the company are shown in Table 2.

3 TESTING PROCEDURE

Initially, the soil and nano-copper were mixed by spraying the nano-copper powder over the soil in six layers to prepare the mixtures. The soil and nano-copper were blended together under dry conditions. Then, the dry mixtures were mixed with the required amount of water.

Table 2: Properties of the nano-copper

Property	Nano-copper
Particle density (g/cm^3)	6.3 – 6.49
Formula	CuO
Average particle size	100
Solubility in water (%)	Insoluble

In general, all mixing was done manually and proper concern was taken to prepare homogeneous mixtures. Initially the soil was separated into six portions and each portion was mixed separately with the required amount of nanomaterial. Then all the six portions were combined together and re-mixed by mixing equipment for three hours. The compaction behaviour of unamended soils and soils mixed with various amounts of nano-copper was studied at nano-copper contents of 0%, 0.15%, 0.3%, 0.5%, and 0.7% of the dry soil weight. The compaction curves were determined according to standard test method ASTM D698. Compacted samples were used for measuring the shrinkage and expansive strains in addition to hydraulic conductivity tests. After compaction was completed, some of the soil samples were saturated with water and others left to dry directly under oven temperature approximately $34 \pm 2^\circ\text{C}$. Saturation was conducted by permeating the specimens in flexible-wall permeameters following ASTM D5084. In addition, the crack intensity factor (CIF) was obtained by dividing the surficial dimensions of cracks (cracked area) over the total area of the soil samples (Harianto et al., 2008):

4 RESULTS AND DISCUSSION

The influence of nano-copper on the optimum water content and maximum dry density is shown in Figures 1, 2, 3, and 4. Some measurable changes occurred in the optimum water content as the amount of nano-copper increases. For soil S1 (pure natural soil), the optimum moisture content slightly increases with increasing amounts of nano-copper. However, for soils S3 and S4 (soils with high plasticity index), the trend reverses. Thus, it may be concluded that for higher plasticity soils, addition of nano-copper reduces the optimum water contents of the compacted specimens.

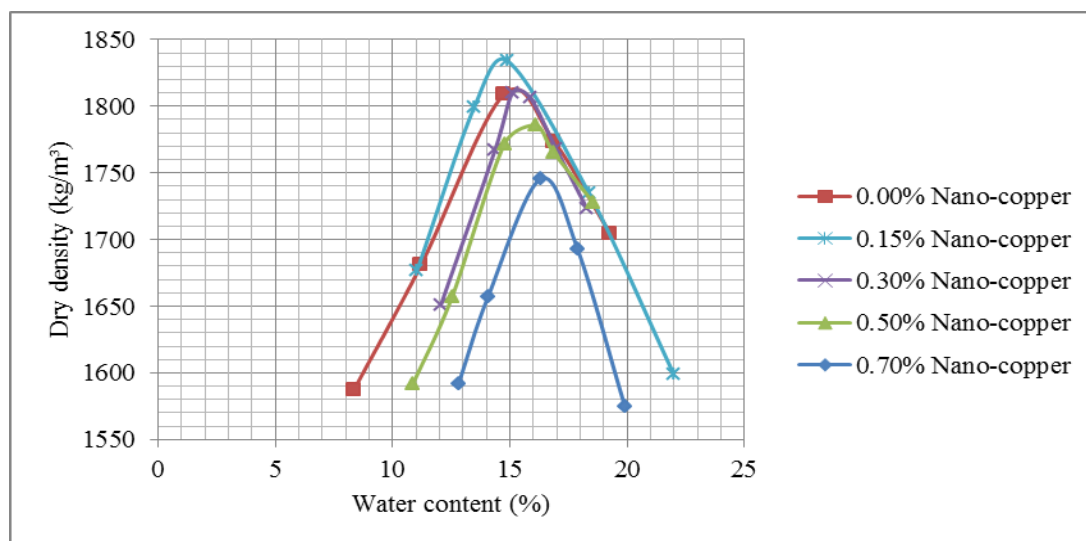


Figure 1: Compaction curves for soil sample S1 with different nano-copper content (% dry soil weight)

In the case of maximum dry density, for soils S1 and S2 (soils with low plasticity index), increasing amounts of nano-copper will initially lead to an increase in its maximum dry density. However, increasing beyond a certain optimum amounts (both roughly about 0.3 %), will cause the maximum dry density to reduce. This is possibly due to the fact that the nanoparticles started to agglomerate and thus increasing the void ratio. In addition, the drop in maximum dry density goes below the maximum dry density for the soil without nano-copper. For high plasticity soils (S3 and S4), similarly, addition of nano-copper up to 0.5 % will increase the maximum dry density after which the maximum dry density then decreases. However, the decrease in the maximum dry density did not go below the maximum dry density of the soil without nano-copper.

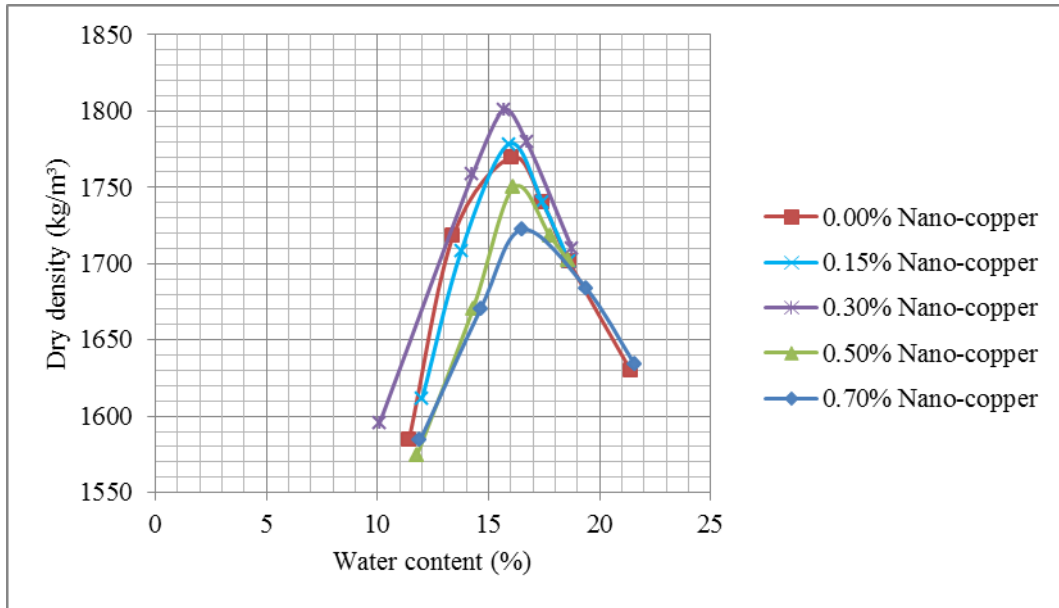


Figure 2: Compaction curves for soil sample S2 with different nano-copper content (% dry soil weight)

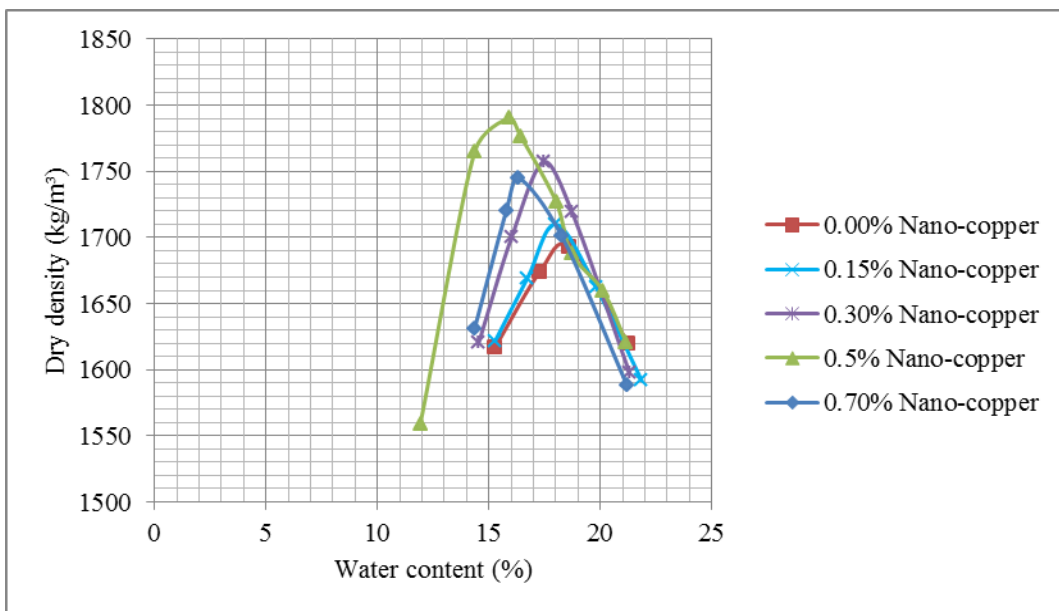


Figure 3: Compaction curves for soil sample S3 with different nano-copper content (% dry soil weight)

The increase in nano-copper content beyond the optimum value causing a decrease in density and increase in water content may possibly result from agglomeration in nano-

copper particles which in turn cause an increase in the void ratio. The agglomeration of nanoparticles increases the amount of necks (contact points) between particles and therefore decreases the density of the soil-nanoparticles matrix (Ferkel and Hellmig, 1999).

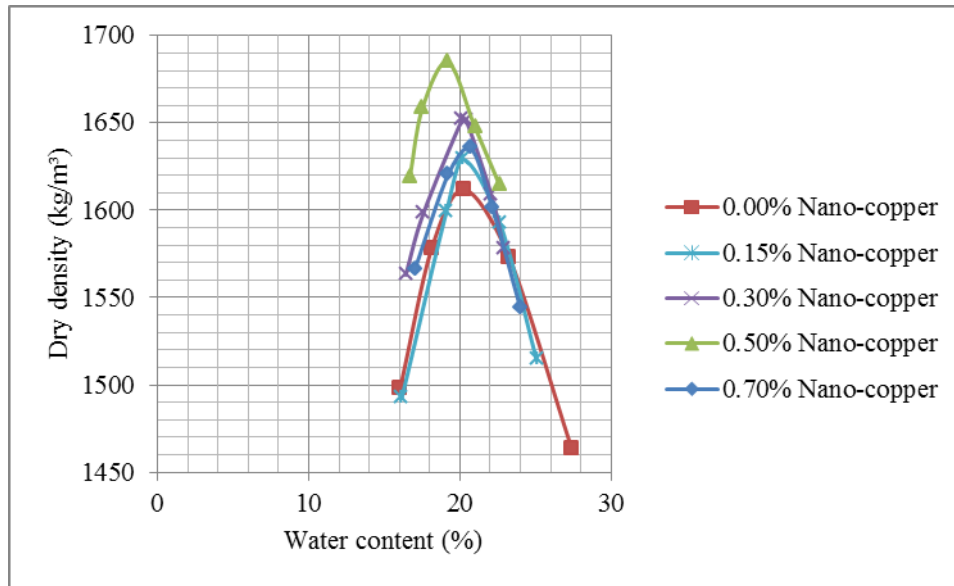


Figure 4: Compaction curves for soil sample S4 with different nano-copper content (% dry soil weight)

The results of shrinkage and expansive strains of soil with nano-copper are shown in Figure 5. For original soil S1, there were no expansive (swelling) strains. The expansive strains for samples without nano-copper were about 5.3 %, 16 %, and 24.25 %, respectively for S2, S3, and S4 samples. For comparison, at 0.5% nano-copper, the expansive strains were 3 %, 4.3 % and 11 % for the respective soil samples.

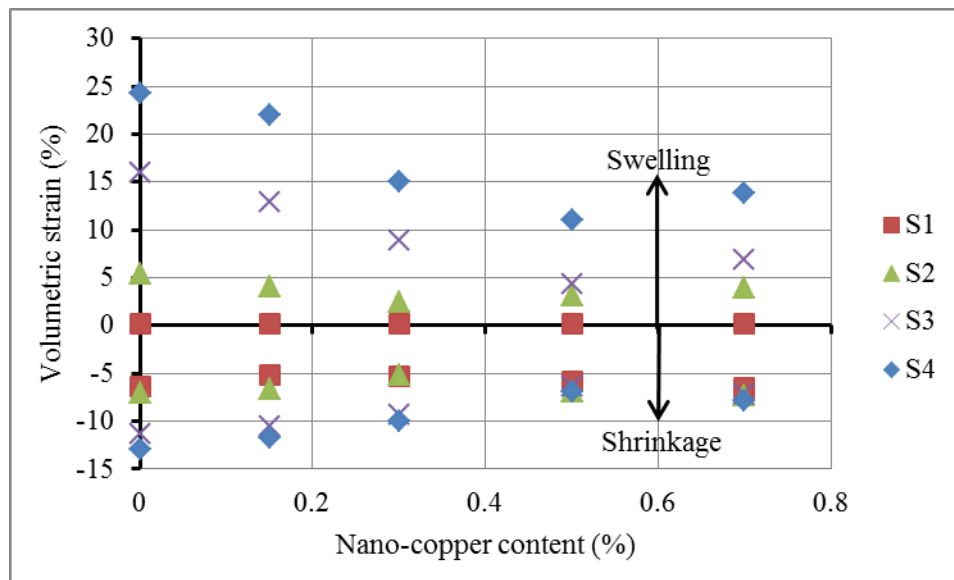


Figure 5: Effect of nano-copper on expansive and shrinkage strains for soil samples S1, S2, S3, and S4

Thus generally, it shows that nano-copper was able to reduce the amount of expansive strains and similarly for shrinkage strains. This is due to the increase in dry density and the reduction in optimum water content. In addition, the reduction in shrinkage and expansive strains by nano-

copper for soil samples S3 and S4 (high plasticity soils) are greater than soil samples S1 and S2 (low plasticity soils). In general, minimum reduction in expansive and shrinkage strains were noted at 0.15 %, 0.3 %, 0.5 %, and 0.5 %, respectively for soil samples S1, S2, S3, and S4. However, the increase in nano-copper beyond 0.5% leads to increase in shrinkage and expansive strains with the latter showing greater change.

The effect of nano-copper on the desiccation crack development is shown in Figure 6. The test results showed that the nano-copper caused some decrease in the desiccation cracks on the surface of soil samples S3 and S4. For S1 and S2 samples, the cracks cannot be measured. This is due to soils S1 and S2 which are low plasticity soils and desiccation cracks were not expected. However, the results showed that the crack intensity factor was reduced by about 70 % and 40 %, respectively for S3 and S4 soil samples. In general, maximum reduction in desiccation cracks were noted at 0.5 % nano-copper content for both S3 and S4 soil samples.

For all soil samples, the addition of nano-copper did not significantly affect its hydraulic conductivity. For example, tests showed that the hydraulic conductivity of soil sample S3 with 0% nano-copper and 0.5% nano-copper were 1.000×10^{-11} m/s and 1.122×10^{-11} m/s, respectively, and the hydraulic conductivity of soil sample S4 with 0% nano-copper and 0.5% nano-copper were 4.567×10^{-12} m/s and 2.408×10^{-12} m/s, respectively. From Figure 7, it is evident that the value of hydraulic conductivity of soil sample S3 with and without nano-copper did not change significantly. However, a slight decrease occurred for soil sample S4 after addition of nano-copper. This means that the nano-copper used in this study will treat the soil for cracks without detrimental effect on its hydraulic conductivity. Similar behaviour was obtained in previous study (Taha and Taha, 2012) using nano-alumina powder. The improvement of soil behaviour using nano-copper is better than that nano-alumina due to the particle density of nano-copper which is greater than that of nano-alumina. The increase in particle density increases the density of the mixtures thus improving the soil by reducing the strain.

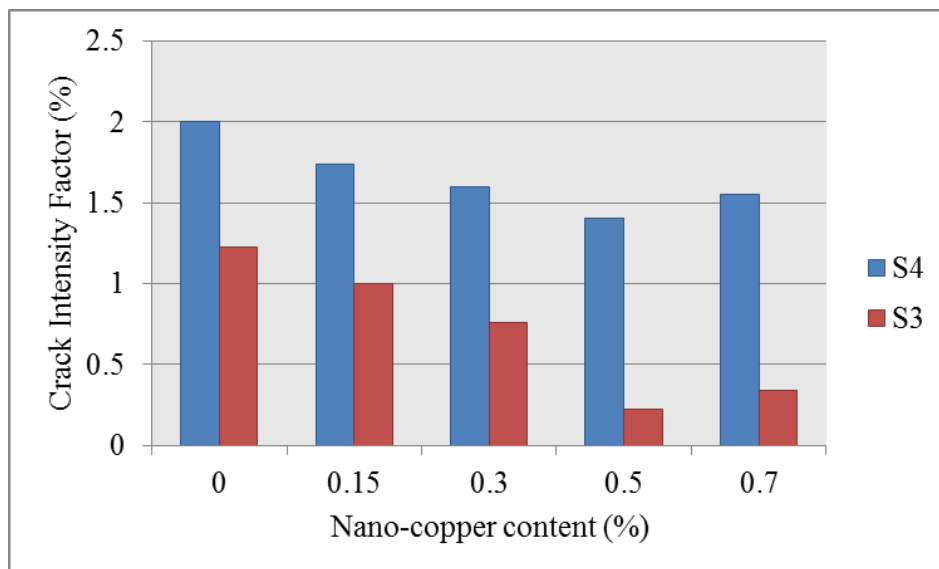


Figure 6: Effect of nano-copper contents on the CIF of soil samples S3 and S4

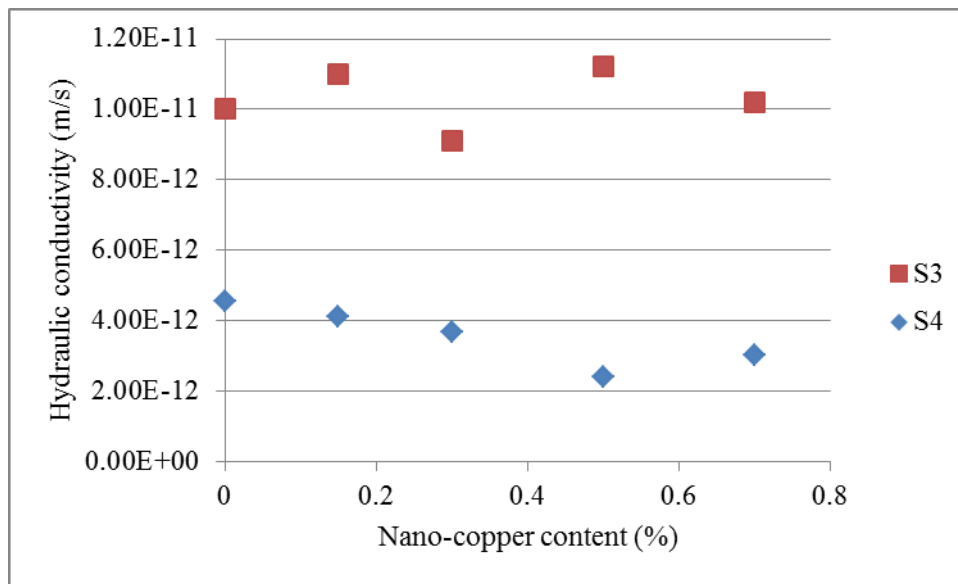


Figure 7: Hydraulic conductivity of soil samples S3 and S4 before and after addition 0.5% nano-copper

5 CONCLUSIONS

In this study, the effects of nano-copper were evaluated on the shrinkage and expansive strains of soils with different plasticity index (PI). The optimum moisture content increases slightly with increasing amounts of nano-copper for pure natural soil with low PI (soil S1 in this study). For soils with high PI (soils S3 and S4) the addition of nano-copper reduces the optimum water contents of the compacted specimens. For maximum dry density, for soils S1 and S2 (soils with low PI), increasing amounts of nano-copper will initially lead to an increase in its maximum dry density. However, increasing beyond 0.3 % nano-copper, the maximum dry density was observed to have a reducing trend. Similarly, for high plasticity soils (S3 and S4), addition of nano-copper up to 0.5 % will increase the maximum dry density after which the maximum dry density then decreases. The shrinkage and expansive strains reduced measurably after addition of nano-copper. Thus, nano-copper improved the compaction condition and reduces the shrinkage and expansive strains of soil. For the desiccation crack development, nano-copper caused some decrease in the desiccation cracks on the surface of soil samples S3 and S4. In addition, the addition of nano-copper does not show detrimental trend to the hydraulic conductivity of the soils.

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