UAV Measurement Methods for Monitoring of Volume Reduction at Dredged Sediment Disposal Sites

Chika ITO[1,*], **Satoshi NISHIYAMA**[1]

[1] *Okayama University, Okayama City, Japan, (pj2u9giw@s.okayama-u.ac.jp, nishiyama.satoshi@okayama-u.ac.jp)*

[*] *corresponding author*

Abstract

In recent years, as ships have become larger and larger worldwide, it has become essential to deepen and maintain channels and anchorage areas. However, there is a shortage of disposal sites for the dredged sediment generated as a result. To further increase the capacity of dredged sediment disposal sites, volume reduction is being conducted to promote consolidation and settlement, and the use of UAV(Unmanned Aerial Vehicle) green laser measurement technology is being considered as a new monitoring method for the remaining capacity. Therefore, in this study, we conducted measurements in test tanks with different turbidity levels and at an actual sediment disposal site, in Okayama, Prefecture, Japan. Based on the results, we were able to summarize the relationship between turbidity and accuracy, the relationship between turbidity and the point cloud acquisition rate of the water bottom, and the measurement conditions suitable for measurement at locations with high turbidity.

Keywords: *Green laser, UAV, Dredged sediment disposal site, Volume reduction*

1 Introduction

As ships continue to grow in size worldwide to reduce transportation costs, it has become increasingly important to deepen and maintain navigation channels and anchorage areas. However, the development of disposal sites for the dredged sediment generated by these dredging operations has been slow due to environmental concerns and challenges in local coordination (Yasuo, 2013). To address this issue, volume reduction is being implemented to increase the capacity of disposal sites. This process promotes the consolidation and settling of clay soils, thereby optimizing the use of the newly created space, which, in turn, allows for the acceptance of larger volumes of dredged sediment. In this context, monitoring the remaining capacity of disposal sites is essential. However, at present, only fixed-point observations using water level gauges are being conducted. Therefore, the use of UAV green laser measurement technology is being considered as a more effective monitoring method for volume reduction at dredged sediment disposal sites. In a previous study (Katsuhiro, 2023), missing bathymetric data was observed in UAV green laser measurements at a sediment disposal site, with turbidity identified as a contributing factor. Further verification of the measurement conditions revealed that the depth measurement capability improved by increasing the beam divergence angle, which is the spread angle of the irradiated laser. However, the extent of turbidity's effect on UAV green laser measurements and its accuracy in underwater environments has not yet been fully clarified. To address this, we conducted measurements using two types of UAV green lasers at the same sediment disposal site as the previous study. We examined the depth measurement capabilities and measurement techniques for locations with high turbidity, such as sediment disposal sites. Additionally, a test tank was installed within the measurement range to quantify the impact of turbidity on the measurements and to validate the accuracy of underwater measurements.

2 Materials and Methods

2.1 Equipment Used

UAV green laser surveying is a method in which a laser is emitted, the distance to the reflected surface is measured using a laser scanner, and 3D point cloud data is obtained. Green lasers have the unique property of penetrating water, making it possible to perform measurements both on land and in water. Additionally, drones offer a more efficient alternative to aircraft for surveying. Their low-altitude, low-speed flight enables the collection of higher-density data. For underwater measurements, multibeam sounding is often used. However, even with small vessels, there are concerns about the risk of grounding when the water depth is about less than 0.5 meters (Dai, 2018). This limitation makes the method unsuitable for areas with shallow depths, such as sediment disposal sites. Therefore, in this study, we conducted measurements using green lasers with the performance characteristics shown in Table 1 and 2. The green laser shown in Table 1 (hereafter referred to as "Laser 1") is specifically designed for underwater measurements (Figure 1). It allows for the adjustment of key parameters, including the beam divergence angle (which controls the spread of the laser beam), the receiver's field of view (which defines the range of the laser receiver detecting the reflected laser), and the pulse rate (which influences the laser's intensity). These parameters can be modified according to the characteristics of the measurement site. On the other hand, the green laser shown in Table 2 (hereafter referred to as "Laser 2") does not allow for adjustments to the beam divergence angle, as is the case with Laser 1. However, it is lightweight, weighing 2.7 kg, which enables longer flight times and more efficient surveying compared to heavier equipment. Additionally, the laser classes in each table are defined for safety based on their potential to harm human eyes and skin. They are categorized in increasing hazard as Class 1, 2, 3R, 3B, and 4. In this study, Laser 1 is classified as Class 3R, hazardous for eye exposure, while Laser 2 falls under Class 3B, considered safe when handled carefully (Lasersafetyfacts, 2025).

Table 1. Specification of Laser 1

Laser Wavelength	532nm
Pulse Rate	Configurable (50-200kHz)
Scan Speed	Maximum 100 line/second
Beam Divergence Angle	Configurable (1mrad~6mrad)
Body Weight	About 12kg
Laser Class Level	3B

Table 2. Specification of Laser 2

Laser Wavelength	532±1nm
Pulse Rate	60kHz
Scan Speed	30 line/second
Beam Divergence Angle	1.5mrad
Body Weight	2.7kg
Laser Class Level	3R

Figure 1. Laser 1 and UAV

2.2 Overview of Measurement

The measurements were conducted at the Tamashima Harbor Island Sediment Disposal Site in Kurashiki city, Okayama Prefecture, Japan on November 30th and December 6th, 2023. The approximate location of the site is indicated by a red circle in Figure 2. At this disposal site, dredged sediment primarily from the maintenance of nearby navigation channels and anchorage areas is being brought in, and volume reduction construction is being carried out to increase the capacity for accepting dredged sediment. The measurement area is shown in Figure 3, with the red-boxed area (approximately 50m × 300m) surveyed using Laser 1 on November 30th, and the yellow-boxed area (approximately 400m × 700m) surveyed using Laser 2 on December 6th.

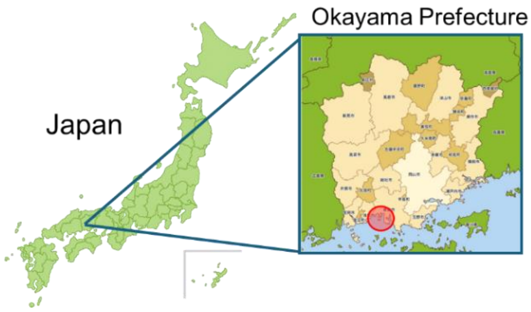

Figure 2. Location of the Tamashima Harbor Island Sediment Disposal Site

Figure 3. Measurement area in yellow and red rectangle

The measurement details are shown in Table 3. For Laser 1, the measurements were conducted at an altitude of 120 m with a beam divergence angle of

2.0 mrad, and the receiver field of view (FOV) was varied across three settings: 6 mrad, 9 mrad, and 12 mrad, with each setting tested once. For Laser 2, the measurement was performed at an altitude of 50 m with a beam divergence angle of 1.5 mrad, conducted once. Additionally, to verify the accuracy underwater and assess the effects of turbidity, test tanks with varying turbidity levels were placed on land within the measurement area. These were surveyed simultaneously with the measurements at the disposal site. To ensure the required point density for underwater accuracy verification, lower altitudes were flown above the test tanks than those set for the general survey conditions.

Table 3. Measurement Condition

Measurement Date	November 30th, 2023	December 6th, 2023
Equipment used	Laser 1	Laser 2
Ground Altitude	120m	50m
Side Lap	50%	65%
Beam Divergence Angle	2.0mrad	1.5mrad
Pusle Rate	50kHz	60kHz
Receiver FoV	6mrad, 9mrad, 12mrad	No setting
Flight Time	12 mins, 3 times	70 mins, once

3 Application to Monitoring of Volume Reduction Construction

3.1 Accuracy Verification for Underwater Measurements

Since the accuracy of underwater measurements at the sediment disposal site was a challenge, this study conducted accuracy verification for underwater measurements by placing circular Ground Control Points (GCP) with a diameter of 50 cm and a height of 10 cm, as shown in Figure 4, in five test tanks with varying turbidity conditions. The test tanks used were of internal dimensions 2000×900×1200 mm, as shown in Figure 5. At the sediment disposal site, a water depth of 1 meter or more allows for sufficient dredged sediment to be deposited, so monitoring of the remaining capacity is required when the water depth reaches below 1 meter. Therefore, test tanks with a height of 1.2 meters were used to ensure a water depth of 1 meter within the tanks.

The summary of the test tanks is presented in Table 4. Turbidity levels varied across five conditions by adjusting the ratio of tap water, seawater, and water from sediment disposal site. Tank 1 contained only tap water, Tank 2 contained only seawater, Tank 3 had two-thirds seawater and one-third sediment

Figure 4. GCP used in the test tanks

Figure 5. Test tank used for accuracy verification

disposal site water, Tank 4 had one-third seawater and two-thirds sediment disposal site water, and Tank 5 contained only sediment disposal site water. Turbidity increased from Tank 1 to Tank 5. The difference in turbidity values between November 30th and December 6th is likely due to the differing elapsed times since the setup of the test tanks. The test tanks were set up on November 29th, and by December 6th, approximately one week had passed. Prior to the December 6th measurement, the test tanks were stirred. However, it is believed that sedimentation of suspended particles occurred between November 30th and December 6th.

Table 4. Summary of the test tanks

	Water Type	Turbidity (NTU)	
		Nov. 30	Dec.6
Tank 1	TW	0.6	1.1
Tank 2	SW	4.8	2.6
Tank 3	SW(2/3)+SDSW(1/3)	9.9	4.6
Tank 4	SW(1/3)+SDSW(2/3)	13.9	7
Tank 5	SDSW	17.8	8.9
※ TW: Tap Water, SW: Seawater , SDSW: Water from a Sediment Disposal Site			

The accuracy of underwater measurements was verified by comparing the results of Total Station (TS) surveying with the coordinate values obtained from UAV green laser surveying. The accuracy verification results for Laser 1 are shown in Figure 6, and the results for Laser 2 are shown in Figure 7. The results from Laser 1 show that the error increases as turbidity increases, reaching approximately 10 cm for the water from the sediment disposal site in Tank 5. For Laser 2, the accuracy verification could not be conducted as the bottom of Tank 5 was not captured. However, like Laser 1, there is a tendency for the error to increase as turbidity rises. These results suggest that as turbidity increases, the accuracy of measurements in the water tends to degrade. One possible explanation is that the water at the sediment disposal site contains a high concentration of suspended particles, which increases the water's density. This could cause delays and refraction of the laser signal. Although certain corrections are usually made to green laser measurements for underwater measurements, the high concentration of suspended particles in the water at the sediment disposal site likely caused the laser to fail in accurately capturing the reflected position. Therefore, to improve the accuracy of water measurements at sediment disposal sites, it is recommended that surveys be conducted during periods of lower turbidity whenever possible.

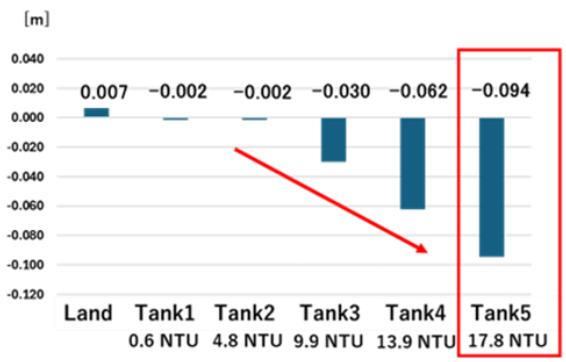

Figure 6. Accuracy verification results for Laser1

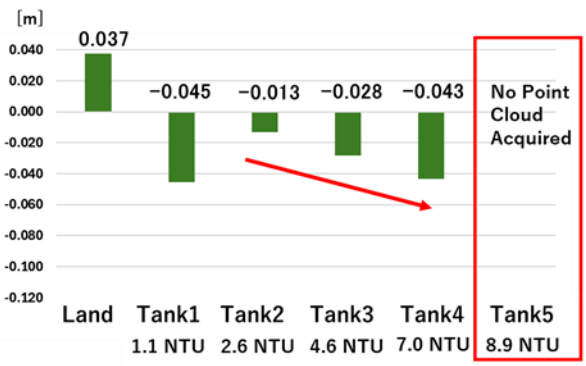

Figure 7. Accuracy verification results for Laser2

3.2 Relationship between turbidity and bottom point density

The sediment disposal site in this study has stronger turbidity compared to rivers and coastlines where green laser measurements have been conducted previously (Katsuhiro, 2023). As a result, it is believed that the scattering effect of laser light due to suspended particles is more significant. Therefore, to quantify the effect of turbidity on UAV green laser measurements, the point density at the bottom of each test tank was compared. Figure 8 shows the point cloud of the bottom of the test tanks, color-coded based on the reflectance intensity. Figure 9 presents a graph showing the relationship between turbidity and point density at the bottom of the test tanks, based on the measurements from Laser 1 and Laser 2. From these results, it is evident that as turbidity increases, both the reflectance intensity and the point density at the bottom tend to decrease. Additionally, in the case of Laser 1, when turbidity exceeds approximately 18 NTU, and in the case of Laser 2, when turbidity exceeds approximately 9 NTU, the laser is no longer able to capture the bottom. Based on this, for measurements at sediment disposal sites with a water depth of 1 meter, it is recommended that measurements using a laser such as Laser 1, which is specialized for underwater measurements, be carried out during periods of favorable weather and when the turbidity is preferably below 18 NTU. For standard green lasers like Laser 2, it is recommended that measurements be conducted when the turbidity is below 9 NTU.

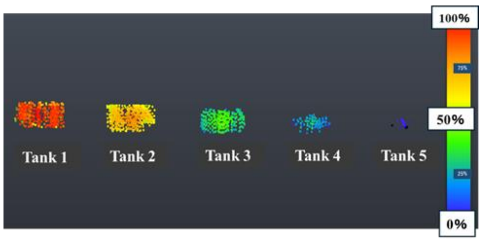

Figure 8. Bottom reflection intensity of Laser 1

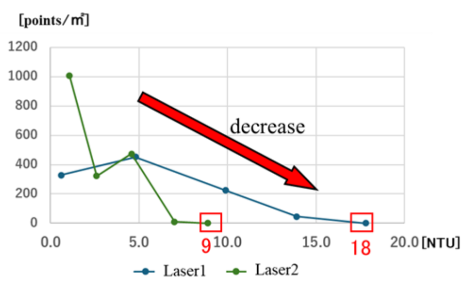

Figure 9. Point density at the bottom of the tanks

3.3 Results and discussion of measurements in the sediment disposal site

The actual measurement results from the sediment disposal site are summarized, and a discussion on the depth measurement capability of UAV green laser surveying is presented. From the field measurement results at the sediment disposal site, it was confirmed that for Laser 1, measurements were made up to the maximum water depth of 0.7 meters at a turbidity of approximately 35 NTU. For Laser 2, the measurement range was broader, and it was able to reach a water depth of 1.0 meter at a turbidity of approximately 12 NTU.To further evaluate the point cloud acquisition on the water bottom, the point cloud within the red box area shown in Figure 10 was extracted. The point density on the water bottom within the red box was calculated to be 447 points/m² for Laser 1 and 27 points/m² for Laser 2.

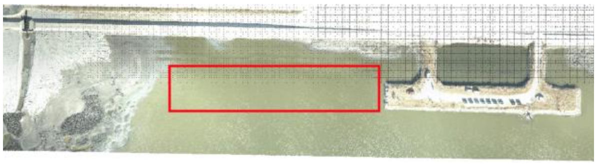

Figure 10. Point cloud extraction area

Additionally, points that are considered to have reached the water bottom were color-coded by depth to represent the water depth of the sediment disposal site. The results for Laser 1 are shown in Figure 11 and for Laser 2 in Figure 12. From these figures, it can be observed, that in both cases, measurements were successfully taken up to approximately 0.7 meters. However, when examining the point cloud acquisition, it is evident that in the case of Laser 2, there were many gaps and variability in point cloud acquisition, whereas Laser 1 was able to capture the water bottom with high density and without significant bias. The factors leading to these results are thought to be related to the size of spot radius of laser beam. The spot radius of laser beam refers to the laser size when it reaches the measurement point. As shown in Figure 13, the spot radius of laser beam is influenced by the flight altitude and the beam divergence angle. A larger the spot radius of laser beam increases the likelihood that some of the laser, even if scattered by suspended particles, will still reach the water bottom, thereby improving depth measurement capabilities. By calculating the spot radius of laser beam for Laser 1 and Laser 2 under the measurement conditions, the respective values were 240 mm and 75 mm, with Laser 1's spot size being approximately three times larger than that of Laser 2. Therefore, the ability to obtain high-density measurements with Laser 1 can be attributed to its larger the spot radius of laser beam. Another factor that might contribute to the results is the scanning method used. Laser 2 utilizes line scanning, and depending on whether the laser is directed vertically or obliquely under the scanner, the strength and shape of the laser beam may vary when it reaches the measurement point.

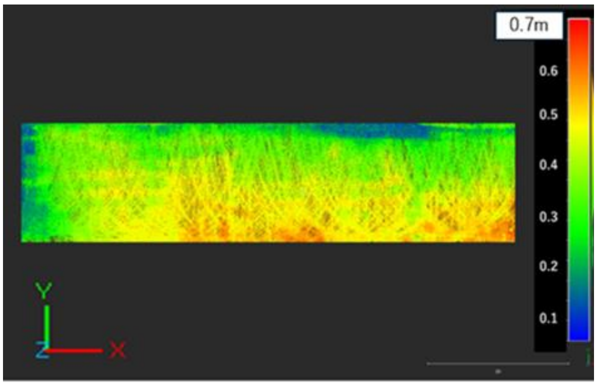

Figure 11. Water depth within the red frame area shown in Figure 10 (Laser 1)

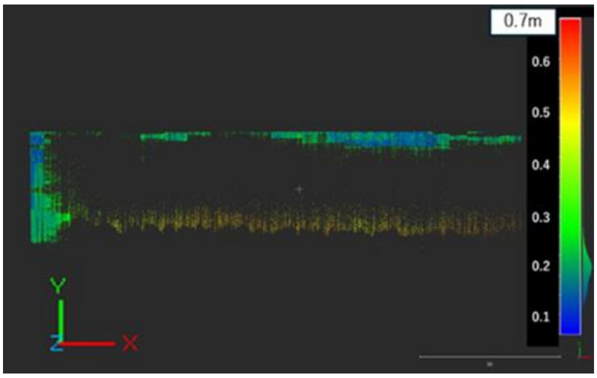

Figure 12. Water depth within the red frame area shown in Figure 10 (Laser 2)

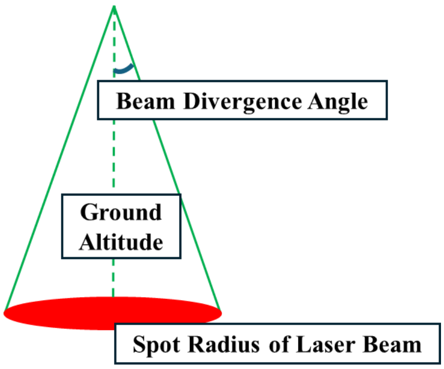

Figure 13. Spot Radius of Laser Beam

However, Laser 1 uses a circular scanning method, similar to Airborne Lidar Bathymetry (ALB), where the angle of incidence on the water surface remains constant. This consistency in the angle of incidence reduces the variability in measurement precision and laser conditions. Therefore, as seen in Figure 11, high-density measurements were obtained uniformly across the measurement range, likely due to the circular scanning method.

3.4 Depth measurement capability based on differences in receiver angle

Finally, the point cloud acquisition status in the field sediment disposal site when the receiver field of view was varied is discussed. According to the specifications of the VQ-840-G (Laser 1), it is stated that increasing the receiver field of view expands the range of the reflected laser that can be received, thereby enhancing depth measurement capability. Consequently, a larger field of view is considered suitable for turbid water (RIEGL Japan, 2025). However, increasing the receiver field of view also increases the number of received light signals, which can result in increased noise. Moreover, if the amount of received light exceeds the capacity of the receiver, the laser scanner may temporarily shut down to protect the receiver. Additionally, since the laser beam spreads out and refracts underwater, the beam spot diameter becomes larger when the reflected light returns from the water bottom. Therefore, it is recommended that the receiver field of view should be at least three times the divergence angle of the beam at the beam divergence angle. In this experiment, a beam divergence angle of 2 mrad was used, and the receiver field of view was varied to 6 mrad, 9 mrad, and 12 mrad for measurement. When examining the point cloud data, it was observed that for 6 mrad and 9 mrad, the point clouds within the measurement range were evenly distributed. However, for 12 mrad, several missing data points were observed. The increased missing data at 12 mrad can be attributed to the larger receiver field of view, which caused the laser to detect additional light sources, such as reflections from sunlight, which led to an excess of received light. Further, Figure 14 is an orthophoto of the sediment disposal site taken from above. The point cloud data within the area outlined in red was extracted, and the point acquisition conditions for 6 mrad and 9 mrad were compared. Figures 15 and 16 show side views of a portion of the extracted point cloud for 6 mrad and 9 mrad, respectively. In the cross-sections, two distinct horizontal lines are visible: the upper line indicates the water surface, and the lower line indicates the water bottom. It is confirmed that for both 6 mrad and 9 mrad, the laser reached the maximum depth of 0.7 m within the measurement range. However, for the 9 mrad case, more noise (indicated by the red circle in Fig.16) was observed between the water surface and water bottom compared to 6 mrad setting. This suggests that, as with 12 mrad, the larger receiver field of view captured additional light from sources other than the water bottom and water surface, such as sunlight or reflections from suspended particles. Based on these findings, we conclude that increasing the receiver angle may not always be effective, particularly in sunny conditions, as sunlight-induced noise could significantly affect the measurements. Nevertheless, within the current measurement range, both 6 mrad and 9 mrad successfully measured the maximum depth of 0.7 m, making it difficult to compare the differences in depth measurement capabilities. Therefore, future measurements in deeper central areas are necessary to clarify the relationship between receiver angle and depth measurement capability.

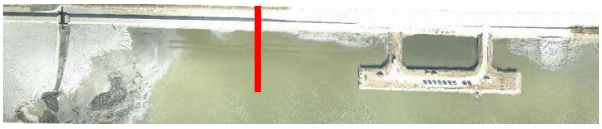

Figure 14. Orthophoto of the sediment disposal site (the extracted area outlined in red)

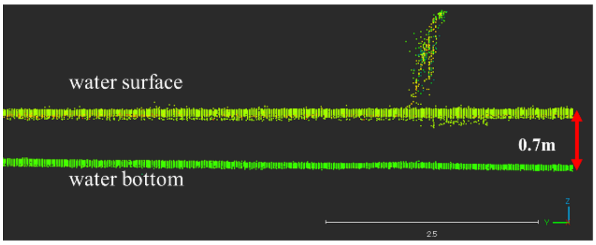

Figure 15. Side view of the extracted point cloud (receiver field of view 6 mrad)

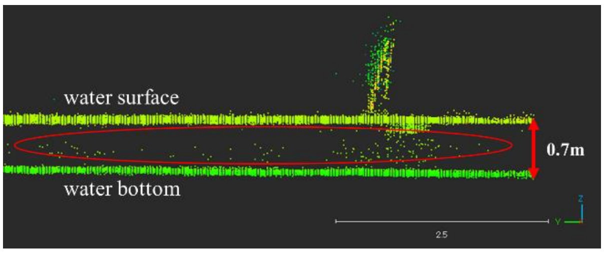

Figure 16. Side view of the extracted point cloud (receiver field of view 9mrad)

4 Conclusion

The aim of this study was to establish methods for monitoring of volume reduction at dredged sediment disposal sites using UAV green laser measurement technology. This was done by performing accuracy verification in underwater environments and evaluating the impact of turbidity using test tanks with varying levels of turbidity. Additionally, actual measurements were conducted at a sediment disposal site to assess the depth measurement capability of UAV green lasers.First, from the results of the underwater accuracy verification, it was confirmed that the measurement error increased with higher turbidity. Furthermore, the measurements from the test tanks, which were adjusted for five different turbidity levels, allowed for the quantification of the turbidity effect.From the results of the measurements at the sediment disposal site, it was found that by increasing the spot radius of laser beam and using a circular scan method, the depth could be mapped across the entire area up to a depth of 0.7 m, even in the high turbidity conditions of the disposal site. A comparison was made regarding the receiver field of view, which is considered effective in areas with high turbidity. However, the effectiveness of increasing the receiver field of view could not be confirmed within the measurement range of this study. Based on these results, it can be concluded that UAV green lasers can be used to map the water bottom up to a depth of 0.7 m in areas with turbidity levels below 35 NTU. From the obtained accuracy and point density of the water bottom, it is considered that measurements should ideally be conducted during periods with lower turbidity.In the future, the relationship between turbidity, depth measurement capability, and point density will be further analyzed by measuring the actual water depth and turbidity at multiple points within the sediment disposal site, and comparing these results with UAV green laser measurements. Additionally, in order to apply this method to estimate the remaining capacity of the sediment disposal site, we aim to determine the required point density and contribute to the establishment of an effective monitoring method.

References

Katsuhiro,I., Satoshi,N., Hiroyuki,I., Noriyuki,S., and Takaaki,N. (2023). *Research on monitoring technology to support volume reduction of dredged soil*. Proceedings of the 58th Geotechnical Society Annual Conference, 11-11-5-04.

Dai, K. (2018). *Bathymetric survey using a multibeam unmanned boat*. Shashin Sokuryo to Remote Sensing, 57(3), 106-110.

Lasersafetyfacts.(2025). *Laser Classes*. Lasersafetyfacts.https://www.lasersafetyfacts.com/laserclasses.html (Accessed: 17 February 2025).

RIEGL Japan. (2025). *UAV Green Laser Scanner Measurement Case Studies*. RIEGL Japan. https://www.riegl-japan.co.jp/about/green.html (Accessed: 17 February 2025).

Yasuo, K., Satoquo, S., Shinya, M., Erina, I., Kouki, Z., and Koji,T. (2013). *Consideration about development of tidal flat and shoal using dredged soil*. Journal of Coastal Zone Studies, 26(1), 39-51