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Classification of the sediments of the Khasa Dam Lake, northeastern Kirkuk, Iraq

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Abstract
Surface storage dams are their most important source of water. They store water from mountains and valleys on the Earth's surface, constituting a vital resource.
Some recent studies have shown that sedimentation can significantly reduce dam efficiency. Unless addressed scientifically, the rapid flow of water from mountainous areas carries with it dirt and small gravel. These materials settle in the lake over time, causing a decrease in the volume of water storage. This problem is observed in many dams in Iraq, especially in the northern regions (Al-Mamoori*et al*., 2019) [2] and has been studied by Iraqi researchers.
This study aims to examine the amount of sediment accumulating in the lake to develop solutions that help preserve water storage for the longest possible period (Hassan, 2018) [1]. Volumetric analysis of sediments within the lake area This study is the first to classify lake sediments
The percentages of the volume fractions of clastic sediments (sand, silt, and clay) were extracted using the methods mentioned above. It was noted that silt and clay represented the dominant fractions in the studied samples, while sand represented the secondary fraction, as shown in Table (2). The percentage of clay ranged between (5.1% - 48.4%), with an average of (22.26%), while the percentage of silt ranged between (40% - 62.3%), with an average of (51.96%), and the percentage of sand ranged between (4.7% - 53.4%), with an average of (25.08%).
It is clear from the results using mathematical relationships to classify sediments that models
We find that most of the samples fall within the quiet water range, indicating that the samples do not move long distances and settle quickly due to the calm water. Samples (9 and 10) also do not follow a specific pattern, indicating that they are deposited by different processes or indicate instability in water movement. Coarse samples (9, 10) have the best sorting and the lowest standard deviation. Fine samples (7, 1, 2) have the worst sorting and the highest standard deviation. This pattern is consistent with sediment transport theories, where long-distance transport processes lead to better sample sorting, and thus the softest and worst-sorted samples.

Keywords: Sediment, dam, lake, geology, grain size, analysis

1. Introduction
1.1 Preface
Surface storage dams are their most important source of water. They store water from mountains and valleys on the Earth's surface, constituting a vital resource. Some recent studies have shown that sedimentation can significantly reduce dam efficiency. Unless addressed scientifically, the rapid flow of water from mountainous areas carries with it dirt and small gravel. These materials settle in the lake over time, causing a decrease in the volume of water storage. This problem is observed in many dams in Iraq, especially in the northern regions (Al-Mamoori *et al*., 2019) [2] and has been studied by Iraqi researchers. The objective of the research on the private dam lake was to determine the sedimentary characteristics of the reservoir in order to provide recommendations for its optimal use (Hawas, 2012) [3].

1.2 The aim of the study
This study aims to examine the amount of sediment accumulating in the lake to develop solutions that help preserve water storage for the longest possible period (Hassan, 2018) [1]. Volumetric analysis of sediments within the lake area This study is the first to To classify lake sediments

2. Study Area and Methodology

2.1 Location of the study area

The study area is located northeast of Kirkuk Governorate, with coordinates of latitude (35°33′30″N) and longitude (44°28′30). It occupies an area of approximately 420 km². The study area is approximately (21) km from the center of Kirkuk city. The study area is bordered to the north and northeast by the northern Jamjamal Fold, to the northwest by the Shwan Sub-Basin, and to the west by the Khasah Dam (Al-Ghuburi, 2020) [4].

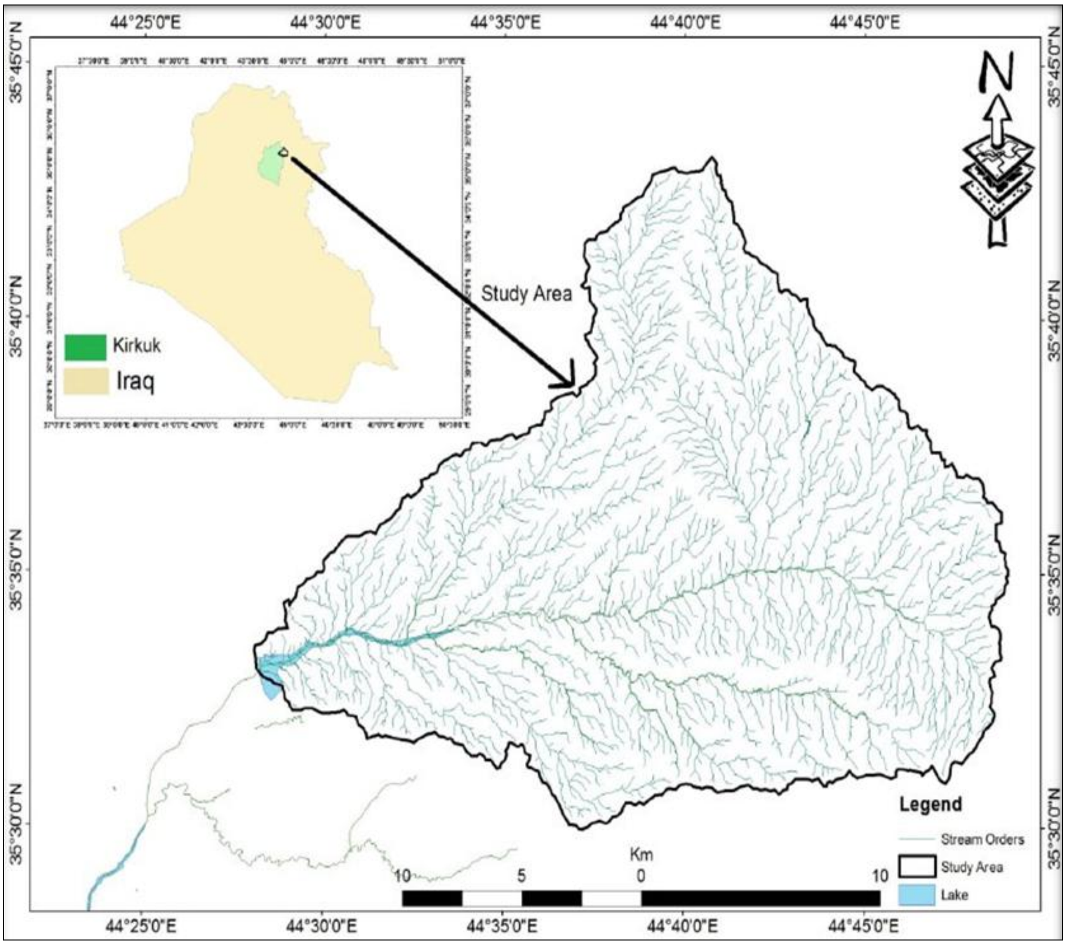

Fig 1: Map showing the study site

2.2 Geology of the study area

Many geological formations are prominent within the study area, covering the region within a different topographic and geomorphological range. All of these formations belong to the Tertiary and Quaternary periods, which extend from the Miocene to the Pleistocene - Holocene. In general, the oldest rocks appear on the edges of the basin in which the study area is located, while modern sediments covered the middle of the basin. 2-3 Stratigraphy of the study area The study area consists of several geological formations and the following is a description of these formations (Sissakian, V.K, 1992) [6].

2.3.1 Injane Formation (Late Miocene)

The Injana Formation (Upper Fas) is part of the Tertiary geological age, and its stratigraphic location indicates an Upper Miocene age (Al-Naqib, 1959) [8]. It consists of mudstone, siltstone, and sandstone in the study area (Sissakian & Al-Jiburi, 2012) [9]. However, according to (Sissakian *et al*., 2017) [24], the thickness of the formation is 398 meters. According to (Kassab and Jassim, 1980) [11], the Injana Formation contains less information than the Muqaddadiya Formation. The Injana Formation comprises 0.94 square kilometers (0.223%) of the study area.

2.3.2 Muqdadiya Formation (Late Miocene-Pliocene)

The Muqdadiya Formation (Lower Bakhtiari) is considered to have formed during the Tertiary geological period. Using the stratigraphic location, deposits of pebbly sandstone, siltstone, and mudstone were found in the study area (Jassim *et al*. 1984) [25] (Al-Rawi *et al*. 1992) [7]. The thickness of the formation is 456 meters (Sissakian *et al*., 2017) [24]. The Muqdadiya Formation covers an area of 30.59 square kilometers (7.26%) of the study area.

2.3.3 Bai Hassan Formation (Pliocene-Pleistocene)

Using stratigraphic location, the Bai Hassan Formation (Upper Bakhtiari) was identified as belonging to the Pliocene-Pleistocene, a Tertiary geological epoch (Jassim *et al*. 1984) [25] and (Al-Rawi *et al*. 1992) [7]. The Bai Hassan Formation consists of sediments that include sandstone and mudstone found in the study area (Jassim *et al*. 1984) [25] and (Al-Rawi *et al*. 1992) [7]. The thickness of the formation is (790) mm, and the study area comprises (354.74) square kilometers (84.46%) of the Bai Hassan Formation.

2.3.4 Quaternary (Middle Holocene)

This period is represented by the Quaternary sediments found in the research area. It is characterized by slope deposits containing fine clastic rock fragments, multiple deposits containing silty clay soils, and river terrace deposits with sandstone and mudstone. Quaternary sediments constitute 10% of the research area, equivalent to 12,272 square meters (Sissakian, 1992) [5].

2.4 Tectonic and structural study area
According to the classification made by (Buday and Jassim 1987) [6], in which the area was separated into a high folded zone and a foothill zone, the research is located within the unstable platform on which tectonics continues in the area. (Bolton, 1958) [12] was the first to propose a foothill zone by virtue of (Doski and Ahmad, 2016).

2.5 Geomorphology of the Study Area
Rainfall is the sole source of water in the study area, falling annually during the winter and spring seasons. The area is characterized by a dendritic drainage system, named after the Greek word for "dendritic pattern" (dendron). The drainage pattern often tapers from the highlands toward the main river, or from the north and northeast to the western part of the study area. Weathering and erosion are also widespread in this area, significantly affecting the region. Sheet erosion affects almost all flat areas covered with various sediments. The degree of weathering varies depending on the rock types, and due to the diverse rock types present within the area, all degrees of weathering are present (Sissakian, 1992) [5].

2.6 Topography of the Study Area
The study area contains several small valleys that flow into the main stream. Part of the surface water flows from the higher elevations in the north to the western part of the area, while the other part flows from the northeast of the study area to the western part, where the two sections of the valley meet at coordinates (3936202 East, 464719 North) near the dam.

3. Collecting Sediment Samples
Traditional methods were used to collect sediment samples from the sides of the lake and dam. Nylon bags were used, and each sample was numbered and recorded, along with the date and time of collection. Sediment samples were collected in polyethylene bags, with their location, number, and date recorded. For samples taken from the center of the lake, a small boat and a large shovel were used to collect samples from as deep as possible. A coring machine was also used on-site to collect samples from depths inaccessible by conventional methods. A GPS device was used to determine sample collection locations. The samples were plotted on a map of the study area using ARCGIS 10.8.

3.1 Sediment Analysis
The laboratory work on the sediment section included a volumetric analysis to separate the different sizes of sediments for later use in petrographic studies. The following is a brief description of the processes and analyses conducted in the lab.

3.1.1 Size Analysis
The percentage of different sizes in dry sediment samples can be obtained by grain size analysis (mechanical analysis). This means analyzing the sediment into different size groups. This analysis can be performed in one or two stages. The total number of samples analyzed by size was 10, consisting of samples taken from the sides of the lake and samples taken from the center of the lake. The method (Folk, 1974; Carver, 1971) [13] was used. In the wet analysis, at least 250 grams of the sample was isolated. After dissolving it in distilled water, at least 250 grams of sediment samples were passed through a 0.0625 mm (200.No) sieve. After this procedure, coarse sand particles are separated from fine clay and silt particles. All components must be dried. Therefore, the sediment was analyzed into particles smaller than 0.0625 mm by the wet analysis method. This method is primarily based on the principle of sedimentation using Stoke's Law (Folk, 1974) [13].

3.1.2 Sieve Analysis
Sieve analysis was conducted for 10 samples distributed over all parts of the lake. Statistical coefficients for grain size were calculated using the Folk scale (Folk & Ward, 1957) [14]. Sieve analysis of sediments is used to calculate percentage values using sieve No. (4) or (200 µ). As for smaller sediments, a hydrometer was used to calculate the percentage of clay in the samples. The program (version) was relied upon to provide statistical coefficient values to describe the grain distribution of sediments and the possibility of providing extrapolation of the trend and direction of the distribution of fine-grained sediments (Poppe *et al*., 2004) [15]. The program inputs are the weight percentages of sand, silt, and clay, using the Phi function (Ø notation), separated from each other by commas. Some analyses were conducted at the College of Science at the University of Kirkuk, and some others were analyzed at the Kirkuk Construction Laboratory. The purpose of analyzing the grain size, whether wet or dry, is to draw the curve. The cumulative use is to determine the percentages of sediments, and the second use is to apply mathematical equations to sediment transport processes.
Table (1) and Figure (2) show the location of sampling from the study area.

Table 1: Coordinates of the study models.

E	N	Model Location	Model Number
44.518	35.563	Source	1
44.507	35.56	Location Lake Sides	2
44.493	35.562	Northern Part	3
44.493	35.559	Middle of the Lake	4
44.474	35.556	Shallow Area West of the Lake	5
44.49	35.557	Center of the Lake	6
44.47	35.551	In Front of the Dam Body	7
44.472	35.547	Spillway	8
44.487	35.553	Southwest Side of the Lake	9
44.494	35.554	Southeast Side of the Lake	10

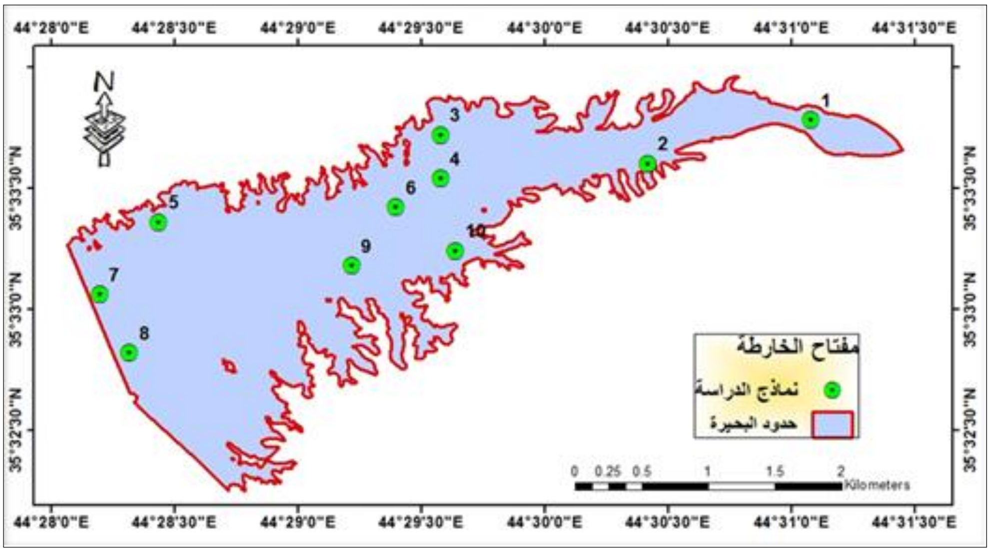

Fig 2: Locations of sediment samples in the study area

4. Results and Discussion

4.1 Classification of Clastic Sediments

The percentages of the volume fractions of clastic sediments (sand, silt, and clay) were extracted using the methods mentioned above. It was noted that silt and clay represented the dominant fractions in the studied samples, while sand represented the secondary fraction, as shown in Table (2). The percentage of clay ranged between (5.1% - 48.4%), with an average of (22.26%), while the percentage of silt ranged between (40% - 62.3%), with an average of (51.96%), and the percentage of sand ranged between (4.7% - 53.4%), with an average of (25.08%).

Table 2: Shows the weight percentages of sand, silt, and clay fractions for the samples of the special dam lake.

Clay fraction %	Silty fraction %	Sandy fraction %	Volumetric fractions Models
33.04	45.7	20.2	1
34.6	54.8	10.4	2
25.8	57.6	15.5	3
20.3	65	14.2	4
6.1	62.3	31.2	5
28.2	50.2	19.8	6
48.4	46	4.7	7
15	54.7	30	8
6.1	40	53.4	9
5.1	43.3	51.4	10

The percentages were projected onto the classification triangle proposed by (Folk, 1954: In Carver, 1971), Figure (3), in order to know the textural characteristics of the sediments that were withdrawn from the lake. We find from the triangle that most of the samples are located in the sandy silt part and are represented by samples No. (4, 5, 6, 8) respectively, and the sandy mud part and are represented by samples No. (1, 2, 3) respectively, while sample No. (9, and 10) were located in the sandy silt part, and sample No. (7) was located in the mud part (Mud).

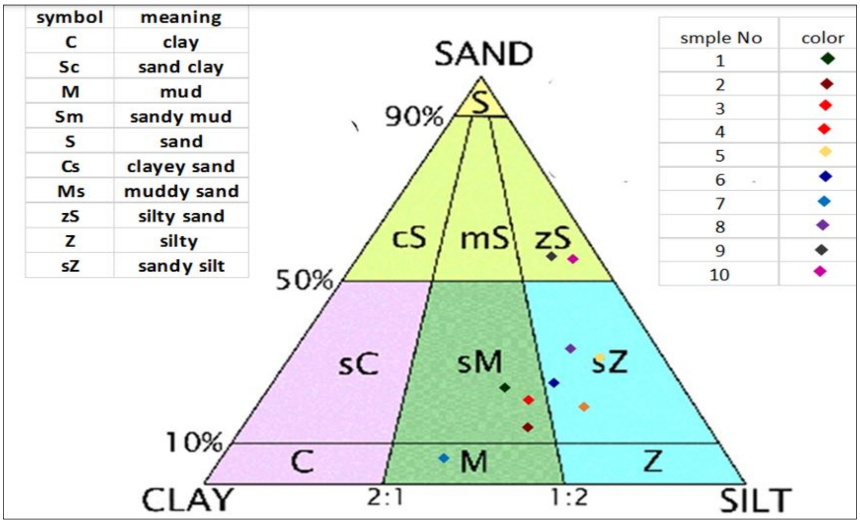

Fig 3: Folk's classification (1954: In Carver, 1971) of soft Sediments

4.2 Size-frequency curve

The size-frequency curve is plotted to provide an idea of the grain size distribution (Figure 4), Figure 5, and Figure 6). It can be plotted in various forms, such as unimodal, bimodal, or polydistributive. It may also provide a spectrum of dispersed sizes (Hartmann, 2004) [16]. The curve also provides an idea of sorting and symmetry (Friedman and Johnson, 1982) [17]. When examining the ten samples studied, we observe a diverse spectrum of distributional patterns that reflect the complexity of sedimentary processes. Samples (2, 3, 4, 7, 8, 9, and 10) exhibit a unimodal distribution, indicating the presence of a single dominant transport and deposition mechanism under relatively stable hydrodynamic conditions. This pattern typically reflects a homogeneous sedimentary environment where a single force, such as a water current, sorts grains according to size and density. In contrast, samples 1, 5, and 6 exhibit a bimodal distribution, a more complex pattern that reveals the overlap of multiple sedimentary processes. This pattern may be attributed to the mixing of sediments from two different geological sources, to cyclic changes in water current intensity, or even to the redeposition of older sediments.

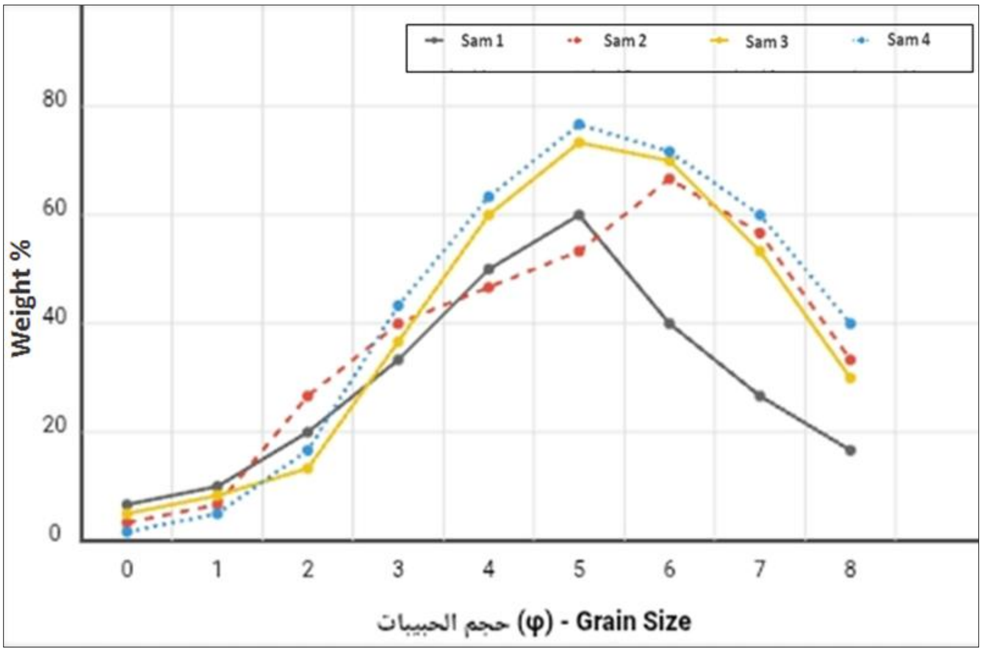

Fig 4: shows the frequency-volume curve for study models (1, 2, 3, 4).

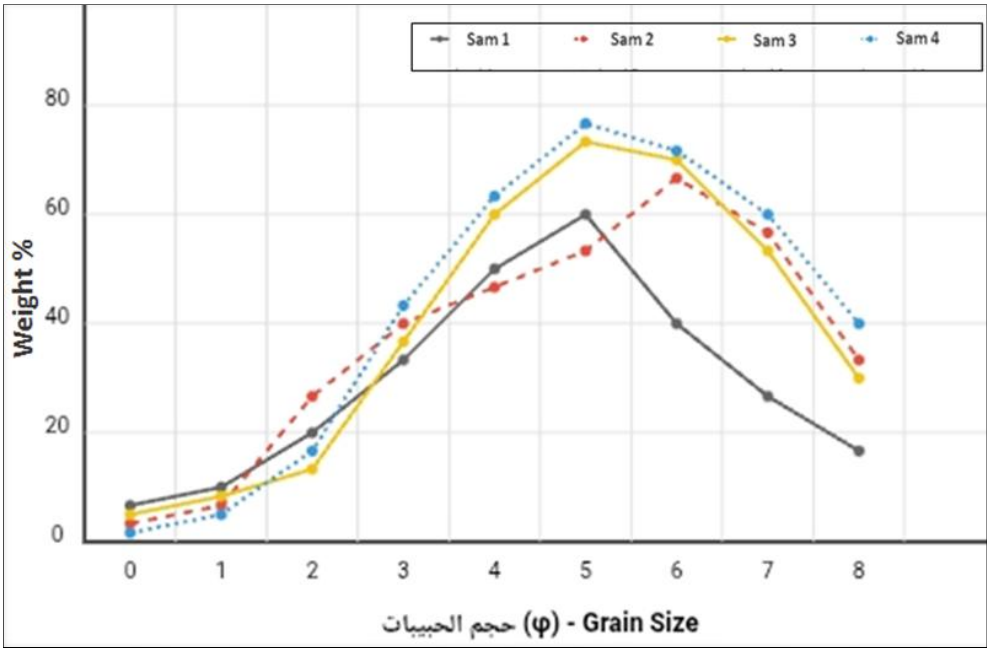

Fig 5: Shows the frequency-volume curve for study models (5, 6, 7, 8).

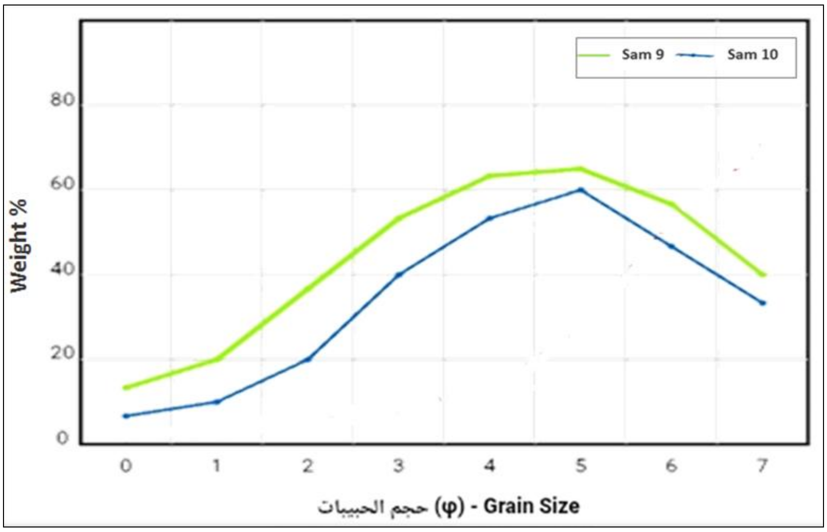

Fig 6: Shows the frequency-volume curve for study models (9, 10).

4.3 Cumulative Frequency Curve

The cumulative frequency curve is an important statistical and sedimentological tool in studying the size distribution of sedimentary grains. It enables the cumulative percentage of grains passing through screens of different sizes to be displayed in the form of a graphic curve. The horizontal axis represents the Phi scale values, which express the grain sizes (Krumbein, 1934) [18], while the vertical axis represents the cumulative percentage of the total sample weight (Folk & Ward, 1957) [14]. The shapes of the curves reflect the mechanical methods of sediment transport, and thus an idea of the energy of the medium through which sediment is transported. The cumulative curve also includes three clusters, and thus the curve consists of three main lines representing the three mechanics (jumping, stuck, and rolling) (Visher, 1969) [19]. Segmented curves indicate that the sediment contains more than one component. It is noted that most of the curves consist of two main lines, one of which is short and has a slight slope, which represents transport by attachment, and this process is common in the transport of clay and silt grains, and the other line has a high and long slope, indicating transport by jumping, and includes sand grains (Mahdi, 2006) [20]. We notice from Figures (7) and (8) that the cumulative frequency curves consist of more than two lines and have a slight slope, and this indicates the presence of more than one mechanical process for transporting sediments in the study area, and the diverse distribution indicates multiple sources or redeposition of materials. Samples from 1 to 5 represent deeper and quieter areas, while we find that samples from 6 to 10 represent a greater diversity from shallow active to deep quiet, and samples (5, 8, 9, 10) indicate shallow areas or close to sediment sources, samples (2, 7) indicate deep quiet areas far from currents, samples (1, 3, 4, 6) These represent intermediate depth transition zones. This diversity indicates a dynamic lake environment with zones of different depths and hydrological activity. (Friedman *et al*., 1982) [17].

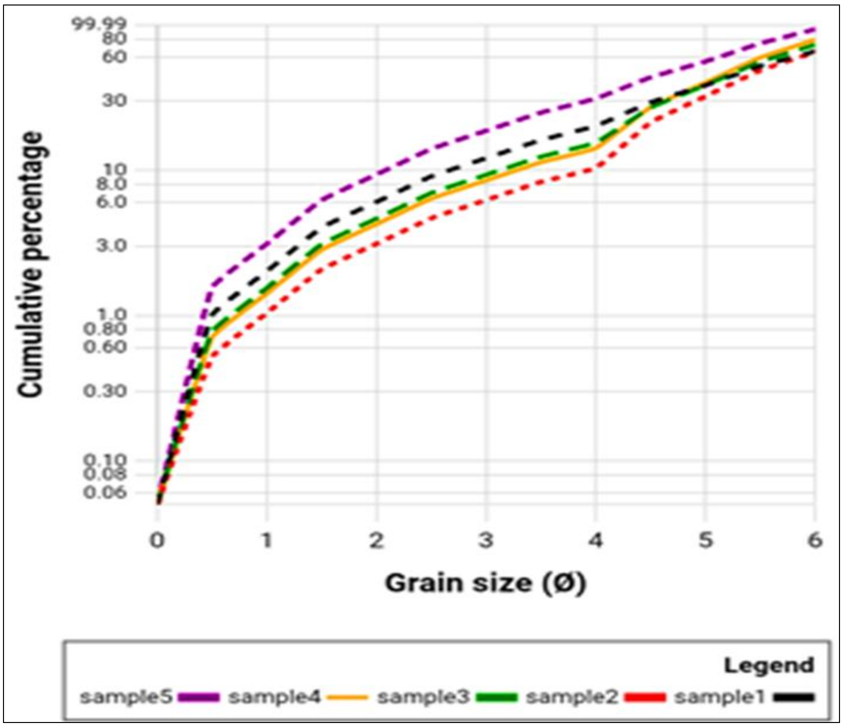

Fig (7): Shows the cumulative frequency curve for study models (1, 2, 3, 4, 5) (Friedman *et al*., 1982) [17].

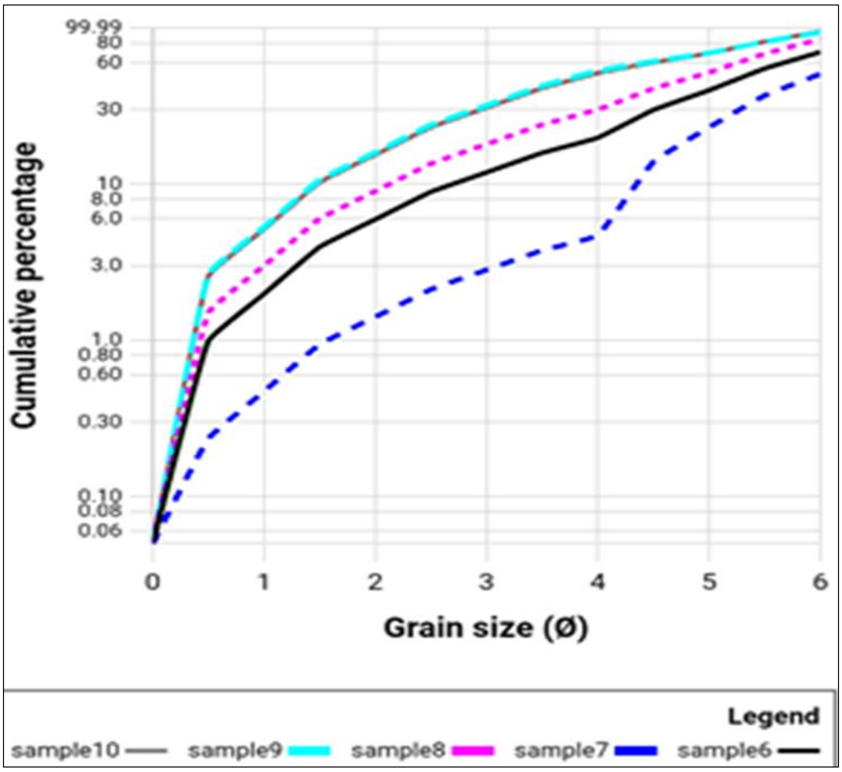

Fig (8): Shows the cumulative frequency curve for the study models (6, 7, 8, 9, 10).

4.4 Statistical Coefficients

The study of statistical coefficients (mean, arithmetic mean, standard deviation, symmetry, and kurtosis) is important in studying sedimentary properties, such as the nature of the source rocks and depositional processes. Statistical coefficients (Folk and Ward, 1957) [14] are used, as they provide better results and include both fine and coarse sizes, using the phi notation function, which was obtained from the previous curves.

4.4.1 Median

It is expressed as the diameter of the grains corresponding to the 50th percentile on the frequency-frequency curve. It can be expressed in mm or as the Ø function. Note that this parameter often does not reflect the total sediment volume, so it is preferable not to rely on it (Folk, 1974) [13]. From the cumulative frequency curves of the studied samples, we find that the median values range between (3.1 - 6.8 Ø), with an average of (4.9 Ø). The classification of the samples taken from the lake reservoir ranges from (fine sand to fine silt), with an average of (very fine sand). These values reflect the nature of the sediments in the dam lake. The median values indicate varying sedimentation rates across the lake. Areas with a low median are susceptible to more rapid sedimentation, which may affect the lake's depth and storage capacity over time. This requires periodic monitoring and possibly sediment removal interventions to maintain the dam's efficiency.

4.4.2 The arithmetic mean

It is a mathematical average of the sediment sizes in samples. It is difficult to determine precisely, as it is difficult to calculate the total number of grains in a sample (Boggs, 2006) [21]. However, it is more useful than the median because it covers most grain sizes. The arithmetic mean is calculated using three values for Ø: 16 Ø, which represents one-third of the coarse sizes; 50 Ø, which represents the boundary between the sizes; and 84 Ø, which represents one-third of the fine sizes. The arithmetic mean is expressed by the following equation:

$$\text{Mean (Mz)} = \frac{\varphi 16 + \varphi 50 + \varphi 84}{3}$$

The smaller the grain size, the larger the value of this coefficient. It provides an overview of the energy of the medium, the amount of force applied to the study area, and the role of both wind and water in transporting sedimentary particles. From the model results, we note that the arithmetic mean values range between (4.193 Ø -6.804 Ø), with an average of (5.607). This indicates that the samples range from fine sand to very fine silt, with an average of (Greenstone). This indicates the large distances traveled by sediments in the study area.

4.4.3 Standard deviation

This coefficient expresses the extent of the force that determines and controls the distribution of sediments. Large values indicate poor and limited sediment sorting during the transport and deposition process, while low values of the sorting coefficient indicate good sorting through the energy of the medium, which plays a role in the transport and deposition processes (Boggs, 2006) [21]. The standard deviation is calculated from the relationship:

$$\text{Standard Diviation} = \frac{Ø84 - Ø16}{4} + \frac{Ø95 - Ø5}{6.6}$$

Where: Ø 5: is the phi value for the percentage 5%.
Ø16: The phi value for the 16% percentile.
Ø84: The phi value for the 84% percentile.
Ø95: The phi value for the 95% percentile.
The standard deviation values ranged between (1.837 - 3.045 Ø) and an average of (2.499). Based on these results, we find that the samples ranged between (poor sorting to

very poor) and an average of (very poor sorting). This indicates variable transport energy, multiple sources of sediments, as well as an unstable sedimentation environment.

4.4.4 Symmetry and Diffraction
This coefficient is used to determine the slope of the curve. If the slope is positive, this indicates that the area tends to be a sedimentary area, resulting in an increase in fine sediments and the selective removal of coarser grains. If the slope is negative, this indicates that the area is undergoing erosion and an increase in coarser sediments. A symmetrical curve indicates the presence of both fine and coarse sediments, distributed symmetrically. The symmetry and diffraction coefficients are determined by the following relationship:

$$\text{Skweness} = \frac{\varphi 5+\varphi 95-2\varphi 50}{2(\varphi 95-\varphi 5)} + \frac{\varphi 16+\varphi 84-2\varphi 50}{2(\varphi 84-\varphi 16)}$$

Where: Ø 5: is the phi value for the percentage 5%.
Ø16: The phi value for the 16% percentile.
Ø50: is the phi value for the percentage 50%
Ø84: The phi value for the 84% percentile.
Ø95: The phi value for the 95% percentile.

Based on the results obtained for the study samples, we find that symmetry values range between (-0.142, -0.578), with an average of (-0.298), indicating that the samples range between (very fine symmetry and coarse symmetry), with an average of (fine symmetry). We find that all samples have negative symmetry, indicating the dominance of coarse grains. This indicates a medium to high energy sedimentation environment with a predominance of coarse grains.

4.4.5 Kurtosis
This parameter is used to measure the separation ratio between the two ends of the curve. It shows the severity of kurtosis in the volume frequency curve ( ). It also represents a quantitative measure describing the deviation from the normal distribution. The following relationship expresses this parameter:

$$KG = \frac{\varphi 95-\varphi 5}{2.44\,(\varphi 75-\varphi 25)}$$

A curve is considered leptokurtic if the middle part of the curve is better sorted than the tail. If the middle part is less sorted than the tail, the curve is flatter, i.e., platykurtic. If the curve has no kurtosis or curvature along its length, the kurtosis is myzokurtic (Folk, 1974) [13]. From the studied models, the kurtosis values for the studied sample samples ranged between 0.872 and 1.275, with an average of 1.08, i.e., they ranged from leptokurtic to flat or platykurtic, with a normal kurtosis (myzokurtic). This reflects the true differences in grain size distribution among the different samples.

5. Conclusions
5.1 Relationships between grain size coefficients:
This relationship represents statistical coefficients to determine the quality of the sedimentary environment of the sediments (Friedman, 1962), as well as the processes responsible for sediment transport and deposition.

5.1.1 Relationship between standard deviation (sorting) and median:
This relationship is used to determine the quality of the processes that led to sedimentation. We find that there are three ranges, which indicate the basic processes in sediment deposition: river processes, wave processes, and quiet water processes. This relationship was used to study the relationship between the arithmetic mean and standard deviation of the study models, Figure (9). We find that most of the samples fall within the quiet water range, indicating that the samples do not move long distances and settle quickly due to the calm water. Samples (9 and 10) also do not follow a specific pattern, indicating that they are deposited by different processes or indicate instability in water movement.

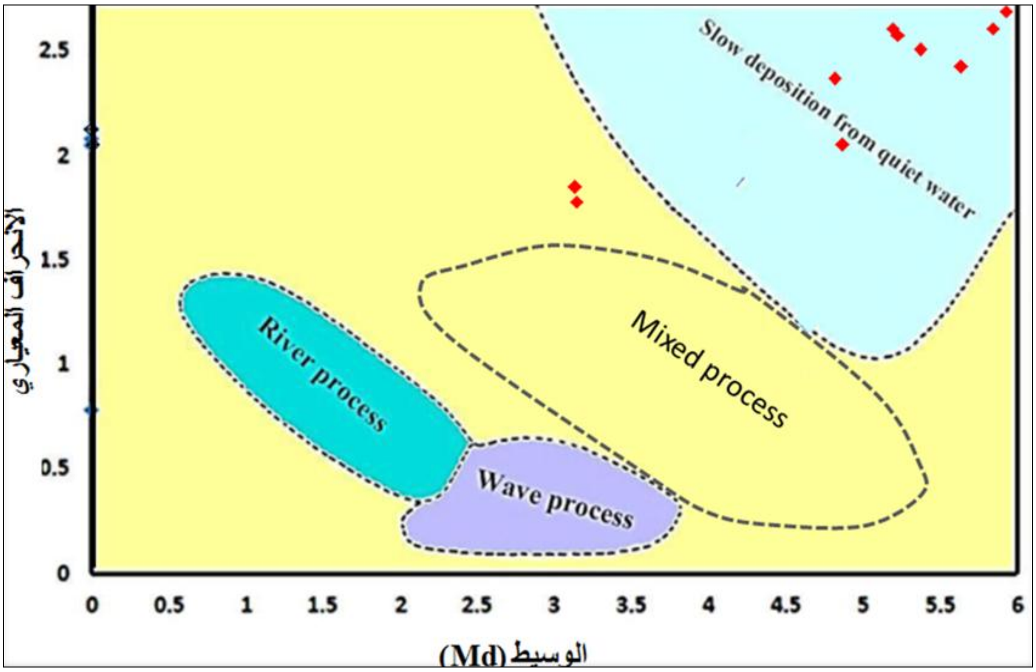

Fig 9: shows the relationship between the standard deviation (sorting) and the median (Stewart, 1958) [22].

5.1.2 The relationship between the arithmetic mean and the standard deviation

This relationship is important for understanding the relationship between sorting and grain size. The lower the arithmetic mean, the higher the standard deviation (Patro, 1993) [23], and vice versa, which leads to increased sorting with the increase in the amount of silt and clay in the sediment (Folk & Ward, 1957) [14]. From Figure (10), we find that the relationship is negative: the higher the arithmetic mean (fineness of the grains), the lower the standard deviation (improved sorting). Since the samples in our study area are predominantly sandy, they are very poorly sorted, with the exception of some samples, such as sample No. (7), which is predominantly silt and clay, and which are well sorted. The negative relationship indicates that geological processes that lead to fine grains (erosion, long-distance transport) are associated with improved natural sorting. Coarse samples (9, 10) have the best sorting and the lowest standard deviation. Fine samples (7, 1, 2) have the worst sorting and the highest standard deviation. This pattern is consistent with sediment transport theories, where long-distance transport processes lead to better sample sorting, and thus the softest and worst-sorted samples.

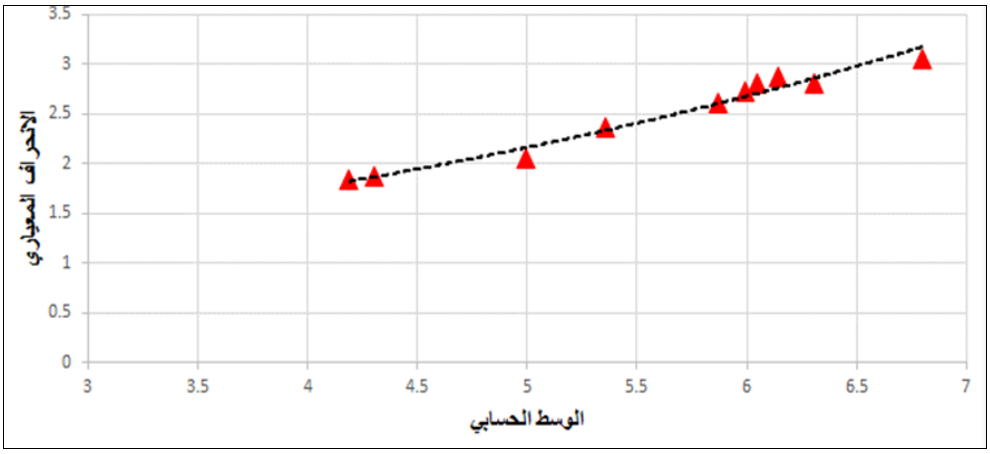

Fig 10: The relationship between the arithmetic mean and the standard deviation of the sediments of the dam lake reservoir (Folk & Ward, 1957) [14].

The relationship between the standard deviation and the arithmetic mean is also used to distinguish between sand of coastal or river origin (Friedman, 1967). From Figure (11), we find that the study models are of river origin.

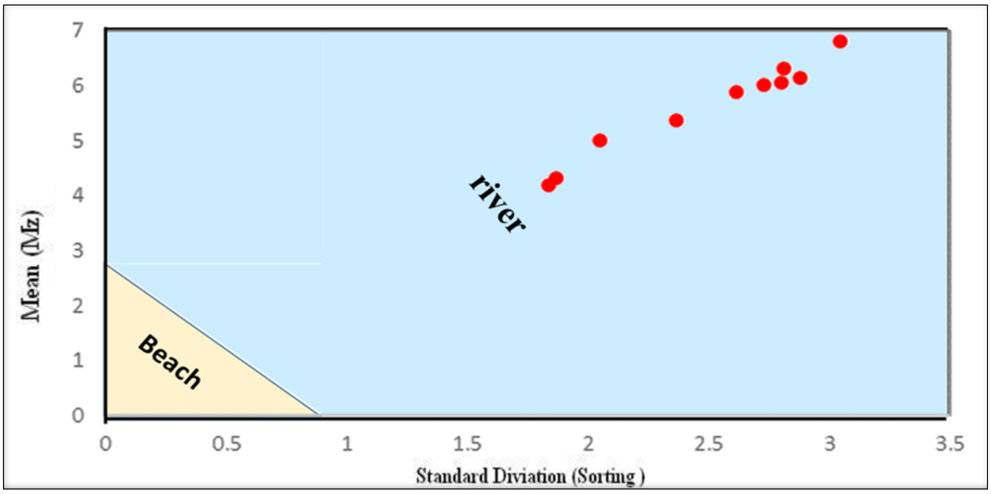

Fig 11: Shows the relationship between the arithmetic mean and the standard deviation of the sediments of the dam lake reservoir (Friedman, 1957).

5.1.3 The relationship between the arithmetic mean and symmetry

The relationship between the arithmetic mean and symmetry is studied to determine the correlation between increasing grain size and symmetry. The relationship between them must be directly proportional (Cronan, 1972). Although symmetry is negative and indicates coarse sizes, these values decrease with increasing arithmetic mean. This means the relationship is inverse, indicating irregularity in the sedimentation mechanism (Figure 12).

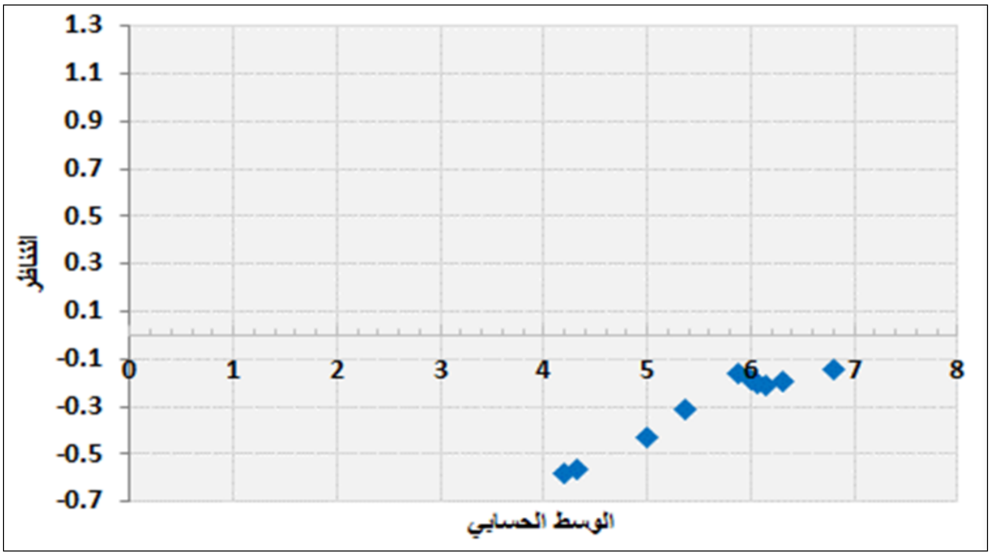

Fig 12: Shows the relationship between the arithmetic mean and symmetry.

5.1.4 The relationship between standard deviation and symmetry

The values of standard deviation and symmetry reflect the relationship and correlation of specific grain sizes (coarse, fine, or both). Figure (5-7) shows samples taken from the reservoir of the Special Dam Lake. It is noted that there is an inverse relationship between standard deviation and symmetry, indicating the presence of different grain sizes in the sediments of the study area.

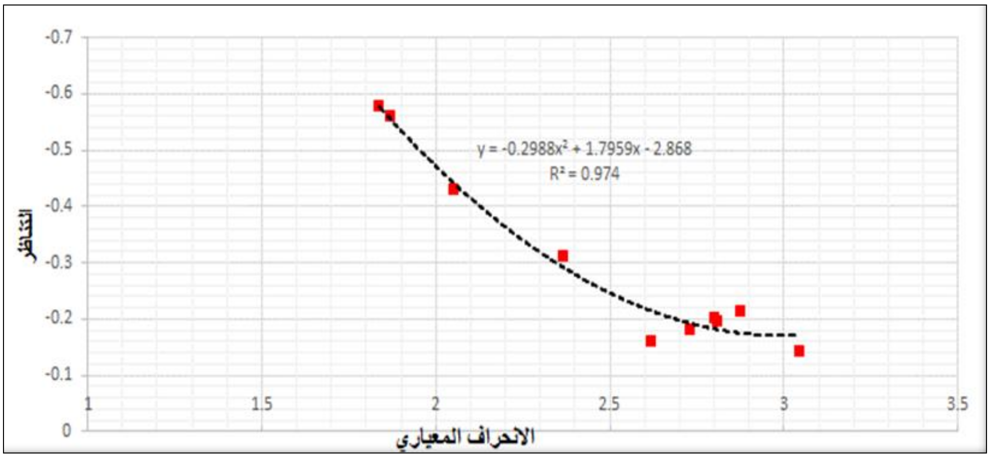

Fig 13: The relationship between standard deviation and symmetry

Table 3: Results of statistical analysis of study area models

Kurtosis	Symmetry,	Standard Deviation	Arithmetic Mean,	Median,	Location	Samples
1.152	-0.214	2.876	6.15	5.2	Source	1
1.218	-0.198	2.81	6.312	5.8	Lakeside location	2
1.134	-0.183	2.729	6.002	5.4	Northern part	3
1.089	-0.162	2.616	5.876	5.6	Middle of the lake	4
0.983	-0.432	2.049	4.997	4.8	Shallow area west of the lake	5
1.146	-0.202	2.8	6.056	5.3	Center of the lake	6
1.275	-0.142	3.045	6.804	6.8	In front of the dam body	7
1.052	-0.312	2.366	5.365	4.9		8
0.872	-0.578	1.837	4.193	3.2	Spillover side	9
0.885	-0.562	1.868	4.313	3.1	Southwest side of the lake	10

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