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Sediment Sampling and Analysis in Rönne å at Ängelholm

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Report 3242
Lund, Sweden

Sediment Sampling and Analysis in Rönne å at Ängelholm

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Summary

This report presents the results of sediment sampling in Rönne å (river) at Ängelholm, located in the north-western part of Scania, which is the southern-most province in Sweden. The sampling and subsequent grain-size analysis were performed primarily to verify hypotheses about main mechanisms controlling local scour at a number of sites where scour holes had been observed in the river during detailed bathymetric surveys. Thus, this study is expected (1) to complement the results from the bathymetric survey where bottom erosion (local scour) was detected in order to establish the main causes of the erosion, and (2) to subsequently employ the information on bottom sediment (grain size) conditions into an existing hydrodynamic model, improving model predictability regarding scour.

Sampling were performed at 8 locations encompassing in total 19 samples that represented parts of the Rönneå river bottom experiencing scour in the city of Ängelholm, covering a stretch from the river mouth to about 8 km upstream. These locations comprised bottom areas with pronounced scour holes due to the presence of bends, bridges, and hard bottom. The samples were subjected to analysis, including sieving and visual inspection and classification, depending on the material composition. A few samples consisted mainly of cohesive material and they have not been analysed yet.

Overall, the sampling and related analysis verified the hypotheses about the mechanisms governing the evolution of the scour holes at the investigated locations. The main causes of the scour were bend scour (locations SH1, SH4, SH9, SH10, and, SH12; see figure 1), bridge scour (SH8), and hard bottom scour (SH5 and SH6). However, at SH8, SH9, and SH10, hard bottom also contributed to the scour. The sediment parameters determined in the grain-size analysis will be useful for calculating the development and equilibrium properties of the scour holes using appropriate formulas from the literature. For the samples where grain-size analysis could be carried out the median grain size approximately varied between 0.6 mm and 15 mm, but larger-sized substrate (*e.g.*, gravel) was observed in the field at hard bottom locations, where no samples could be retrieved by the applied sampling technique.

Table of contents

1. Introduction

1.1 Background

This study on sediment sampling and analysis in the downstream part of Rönne å at Ängelholm was performed in response to an investigation of local scour problems that was initiated by Ängelholm Municipality and undertaken by Water Resources Engineering at Lund University. In 2020, on the request of Ängelholm Municipality, the company MarCon Teknik AB carried out a thorough bathymetric survey along a 12-km stretch of Rönne å, extending from the outlet at Skälderviken to the E6 Bridge using multibeam echo sounding technology (MTE, 2020a). The topography adjacent to the river was surveyed with laser (Lidar). This survey revealed a relatively uneven river bed profile with a large number of pronounced scour holes, as well as eroded banks, at many locations along the river, differing in magnitude (MTE, 2020b).

Subsequently, a Master thesis study was undertaken on the topic (Inamdeen, 2020), involving a comprehensive investigation of local riverbed erosion (scour), combined with simulation of the river hydrodynamics. This thesis work has been followed by a study specifically looking at local scour adjacent to bridges that includes a general state-of-the-art review of bridge scour as well as several case studies, including scour in Rönne å (Das et al., 2021).

These studies identified the lack of information on sediment properties along the river as a seriously limiting factor to determine the cause of the scour holes and to quantify their evolution and equilibrium properties. Thus, Ängelholm Municipality decided to fund a sediment sampling campaign along the river stretch of interest, including analysis of the samples. The sediment properties (particle size and distribution) and the river bed conditions are essential parameters for detailed investigation of local erosion and for the design of proper countermeasures that may be taken in order to prevent erosion and associated risks of slides and structural damage in the future.

1.2 Objectives

The overall objective of the present report is to describe the sediment sampling, and subsequent analysis, from the field campaign in the downstream part of Rönne å at Ängelholm. Some interpretation of the collected data will be provided in the context of mechanisms for scour hole development. All data from the field campaign are presented in this report. Additional information on the interpretation of the data and their relation to the local scour observed in Rönne å is provided in Das et al. (2021) and Inamdeen et al. (2021).

Thus, this study is expected (1) to complement the results from the bathymetric survey where bottom erosion (local scour) was detected in order to establish the main causes of the erosion, and (2) to subsequently employ the information on bottom sediment (grain size) conditions into an existing hydrodynamic model, improving model predictability regarding scour.

1.3 Report overview and procedure

The report starts with a description of the sampling points and their locations as well as the sampling procedure employed. Detailed bathymetric conditions at each sampling point are displayed based on previous surveys carried out by MarCon Teknik AB (MTE, 2020a). Then, the analysis methodology is reviewed, including the sieve analysis carried out for samples were friction sediment dominated. Finally, the results of the sediment analysis are presented together with some interpretations in the context of the scour observed in Rönne å and the prevailing mechanisms.

2. Sample locations

The sediment sampling was performed to provide support in determining the causes of the scour holes observed in Rönne å and their development. Previous studies had tentatively identified three types of scour: (1) bend scour, (2) bridge scour, and (3) hard-bottom scour. For the first two types of scour, knowledge of river geometry and bridge properties can be employed to establish the cause of the scour hole and to facilitate calculations of scour hole characteristics. However, information on the sediment properties are required for such calculations. In order to confirm hypotheses about hard-bottom scour, where non-erodible bottom causes downstream scour, detailed knowledge of the bed conditions is required. Thus, the present sediment sampling was crucial to confirm such a hypothesis as a cause for local scour.

There were 19 locations selected for sediment sampling by considering observed major bottom scour holes in the 12-km long stretch of Rönne å at Ängelholm. An overview map of the sample locations is shown in figure 1, whereas detailed pictures and bathymetric conditions are provided in figures 2-9. Further details on the locations are summarized in table 1, showing the coordinates for the sampling points in the SWEREF99 TM system and remarks on the conditions at the sampling sites together with a motivation for the sampling.

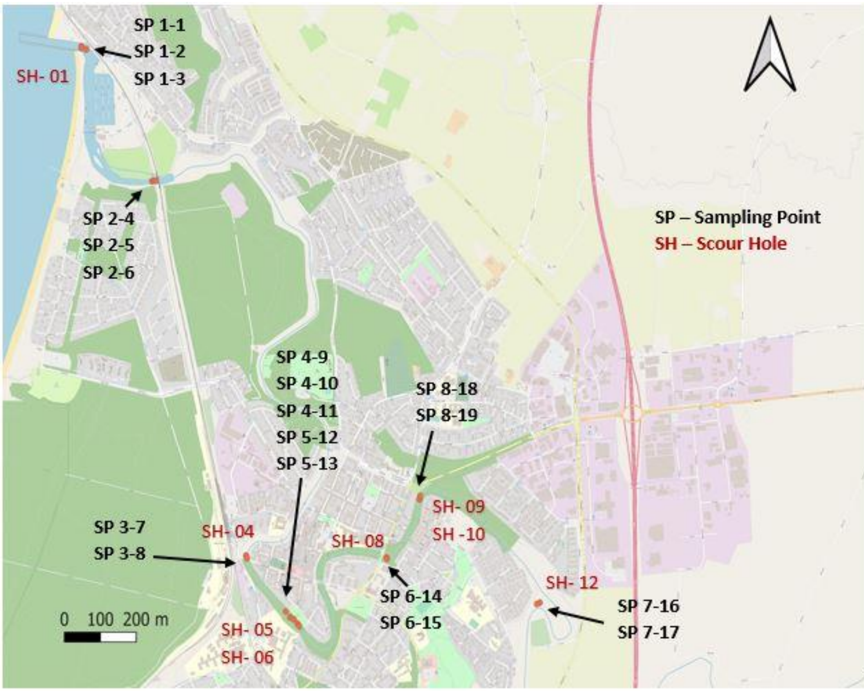

Figure 1. Overview map of the sample locations. SH denotes major scour holes identified in Inamdeen (2020) that were the basis for selecting sample locations.

Table 1. The geographical locations for the 19 sediment samples (KP denotes the distance from the river mouth following the river in the upstream direction; SH refers to major scour holes identified, where there location are shown in figure 1. Coordinates given in CRS: SWEREF99 TM.

Location	Sample points	X-Coordinate	Y-Coordinate	Remarks
Location 1: KP 0 + 425 m	1	366124.8657	6238420.42	Center of hole SH-01
	2	366122.3797	6238409.299	Left side of hole SH-01, where some sediment accumulation was expected
	3	366156.137	6238398.832	Upstream of hole SH-01, where sedimentation could occur due to pool-riffle sequences in bend
Location 2: KP 1 + 575 m	4	366578.06	6237589.413	In the wake zone of Flygarebron; possibility for bridge scouring
	5	366594.0933	6237591.607	In between piers of Flygarebron
	6	366605.5394	6237592.561	Approach section (upstream) of Flygarebron
Location 3: KP 5 + 600 m	7	367145.6507	6235307.131	Center of hole SH-04 (downstream) of Järnvägsbron
	8	367151.0876	6235290.439	Upstream of hole SH-04, just downstream of Järnvägsbron
Location 4: KP 6 + 025 m	9	367405.0904	6234961.6	Downstream of hole SH-05 (at Tullportsbron)
	10	367432.6458	6234924.977	Center of hole SH-05 (at Tullportsbron)
	11	367457.6105	6234912.613	Upstream of hole SH-05 (at Tullportsbron) and downstream of hole SH-06
Location 5: KP 6 + 175 m	12	367483.0753	6234882.952	Center of hole SH-06 (at Carl XV bron)
	13	367493.0334	6234869.303	Upstream of hole SH-06 (at Carl XV bron), where hard bottom is expected
Location 6: KP 7 + 400 m	14	368098.7464	6235264.441	Center of hole SH-08 (downstream) of Kristian II bron
	15	368101.3733	6235257.178	Left side of the hole SH-08, where hard bottom is expected

Location 7: KP 9 + 650 m	16	369131.6591	6234961.133	Center of hole SH-12 (at strongly meandering bend)
	17	369111.6285	6234953.502	Upstream of hole SH-12, where sedimentation could occur due to pool-riffle sequences in bend
Location 8 :KP 7+ 850	18	368332.9315	6235611.549	Downstream of hole SH-10 and upstream of hole SH-09, expecting hard bottom
	19	368339.4941	6235631.237	Center of hole SH-10 (at the bend)

The locations of sampling points 4-9 and 5-13 (notation: location followed by sample point number; *i.e.*, 4-9 means location 4 and sample point 9) were altered by the sampling contractor MTE due to the possible presence of pipes or cable lines passing across the pre-defined locations given in the table 1.

In the following figures (figures 2-9), the detailed locations of the sampling points are given at each location, both on aerial photos and on the bathymetric surveys (MTE, 2020a). With reference to table 1, the motivation for selecting the specific points can be realized. In all cases prominent scour holes had been identified in the bathymetric data prior to the sampling.

Location 1: KP 0 + 425 m

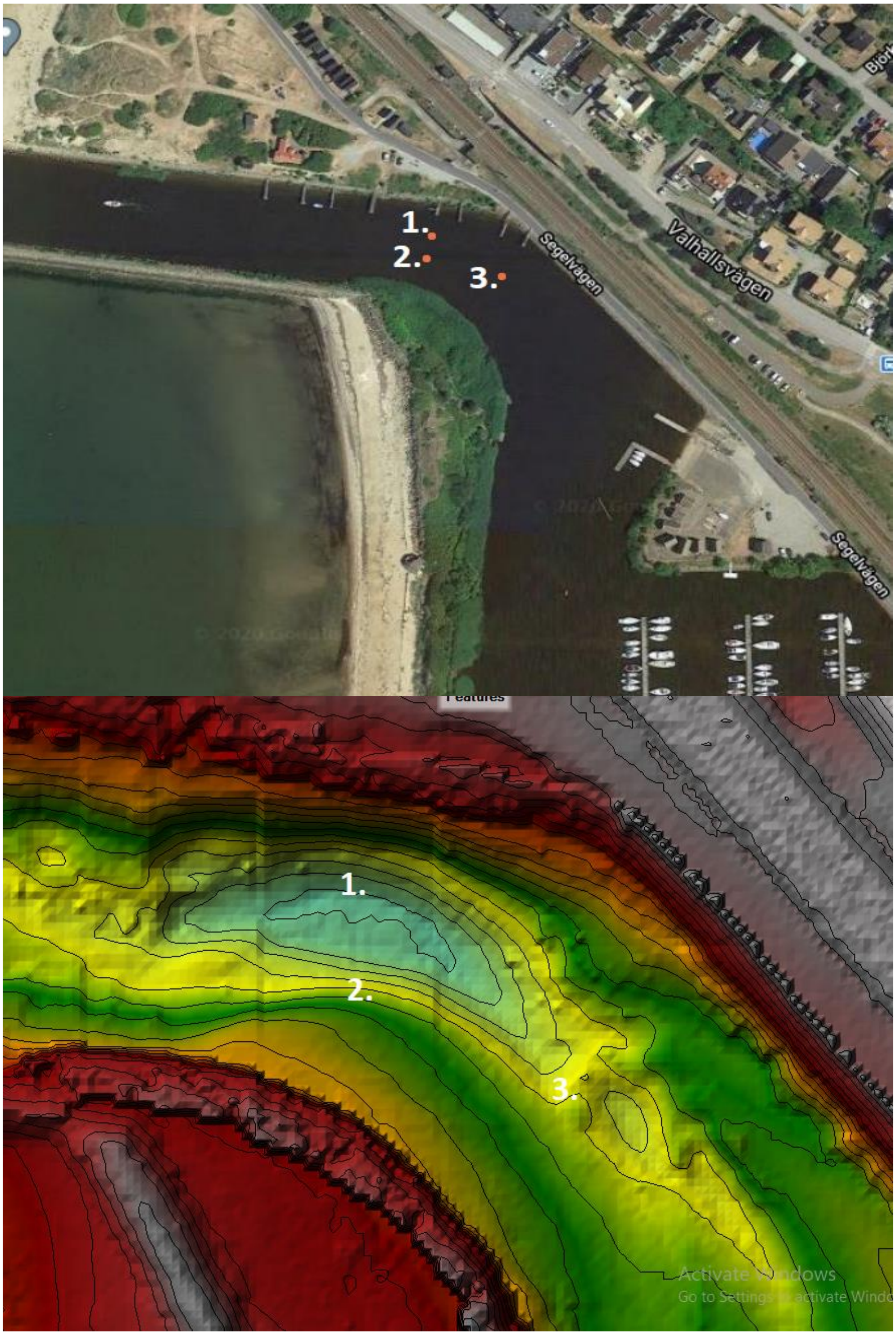

Figure 2. Location 1 with sample points 1 to 3

Location 2: KP 1 + 575 m

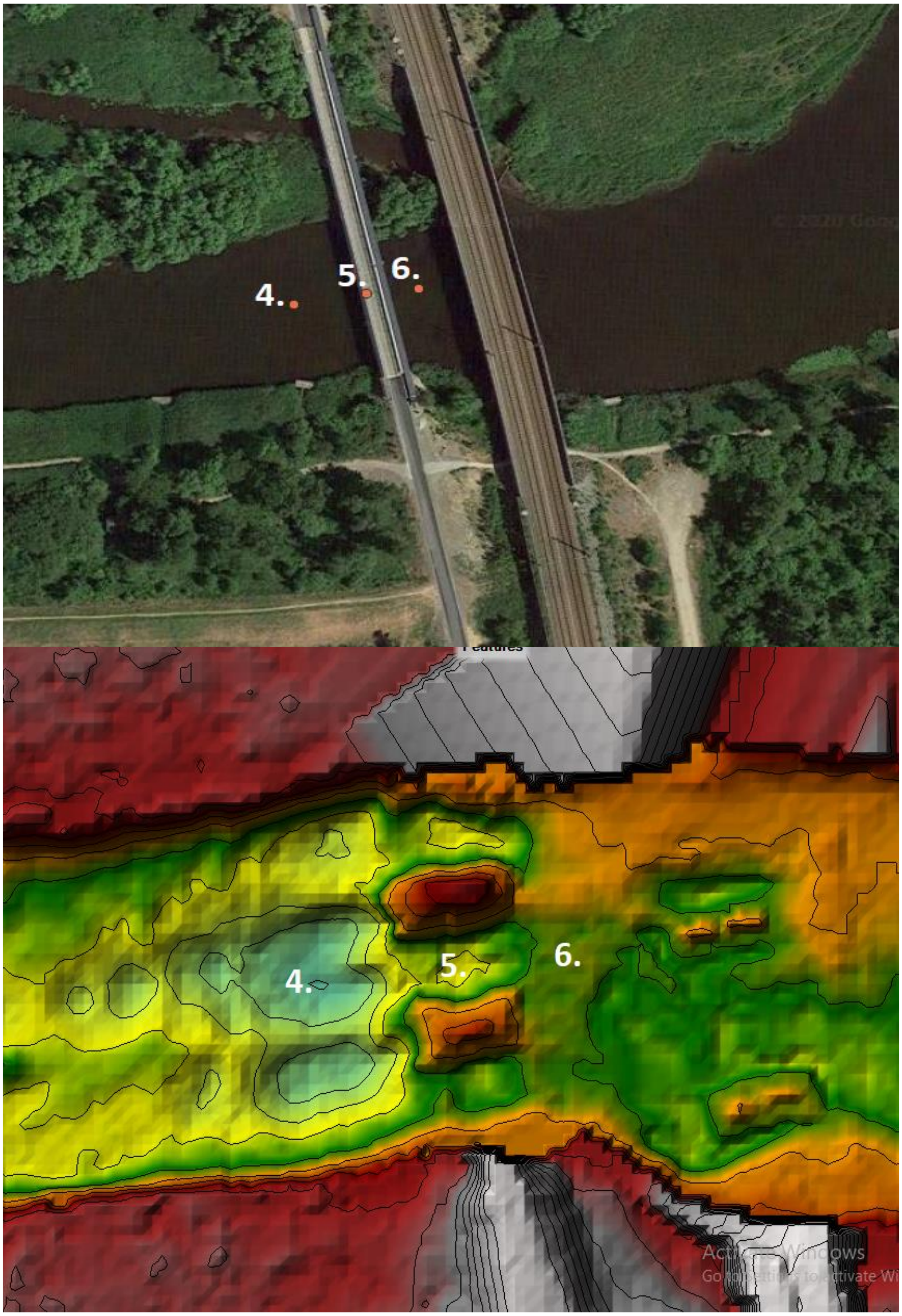

Figure 3. Location 2 with sample points 4 to 6

Location 3: KP 5 + 600 m

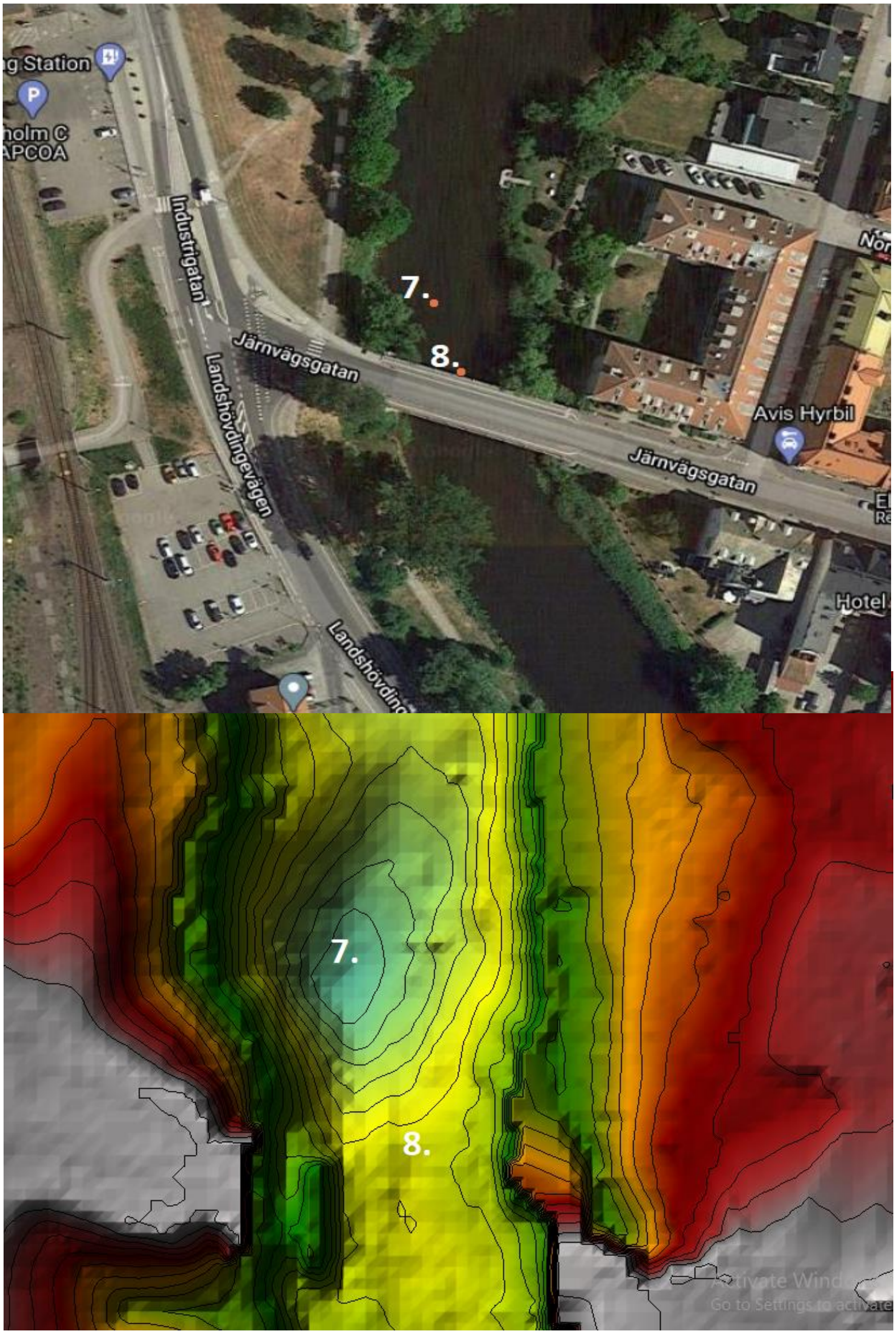

Figure 4. Location 3 with sample points 7 and 8

Location 4 : KP 6 + 025 m

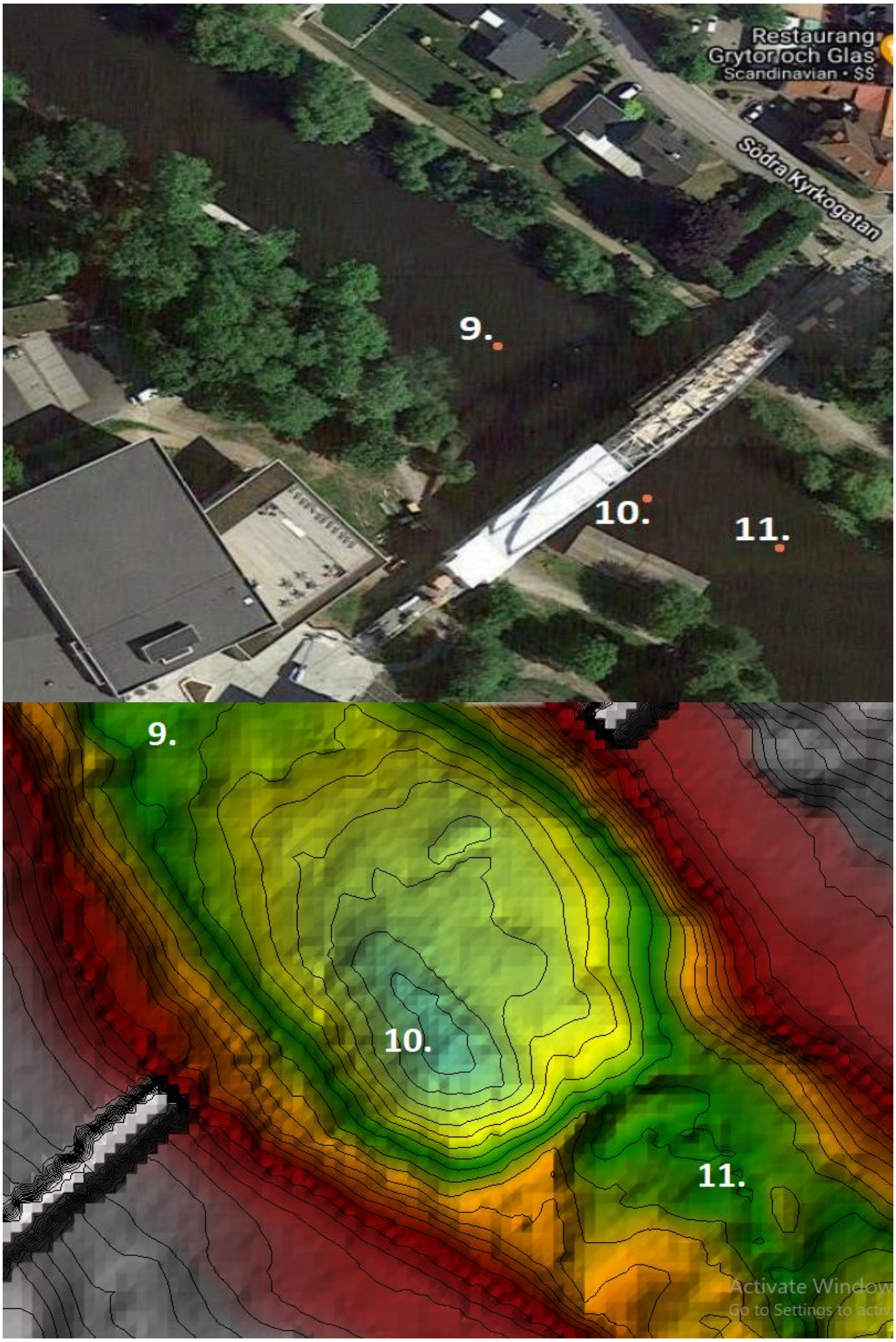

Figure 5. Location 4 with sample points 9 to 11

Location 5 : KP 6 + 175 m

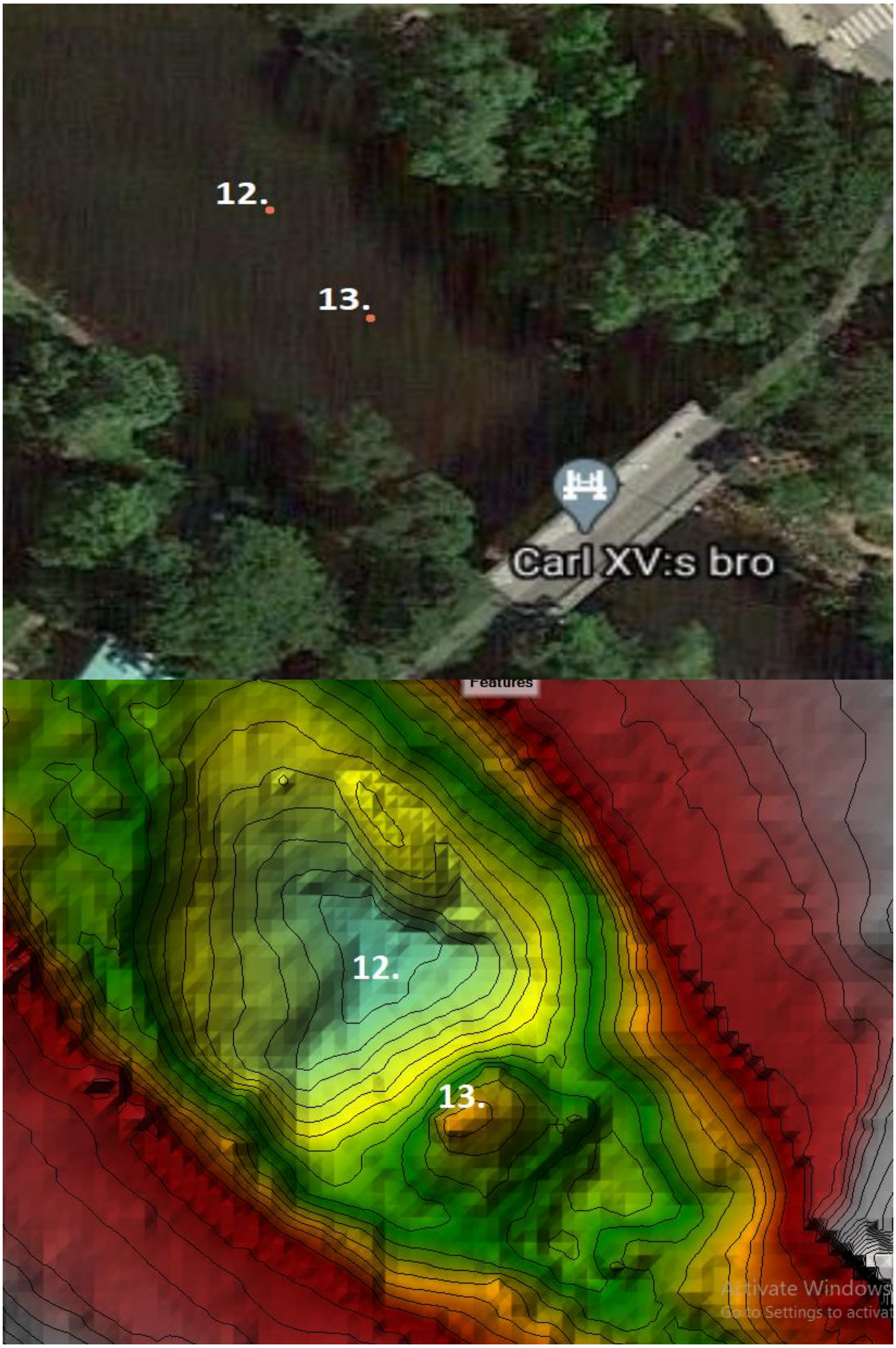

Figure 6. Location 5 with sample points 12 and 13

Location 6 : KP 7 + 400 m

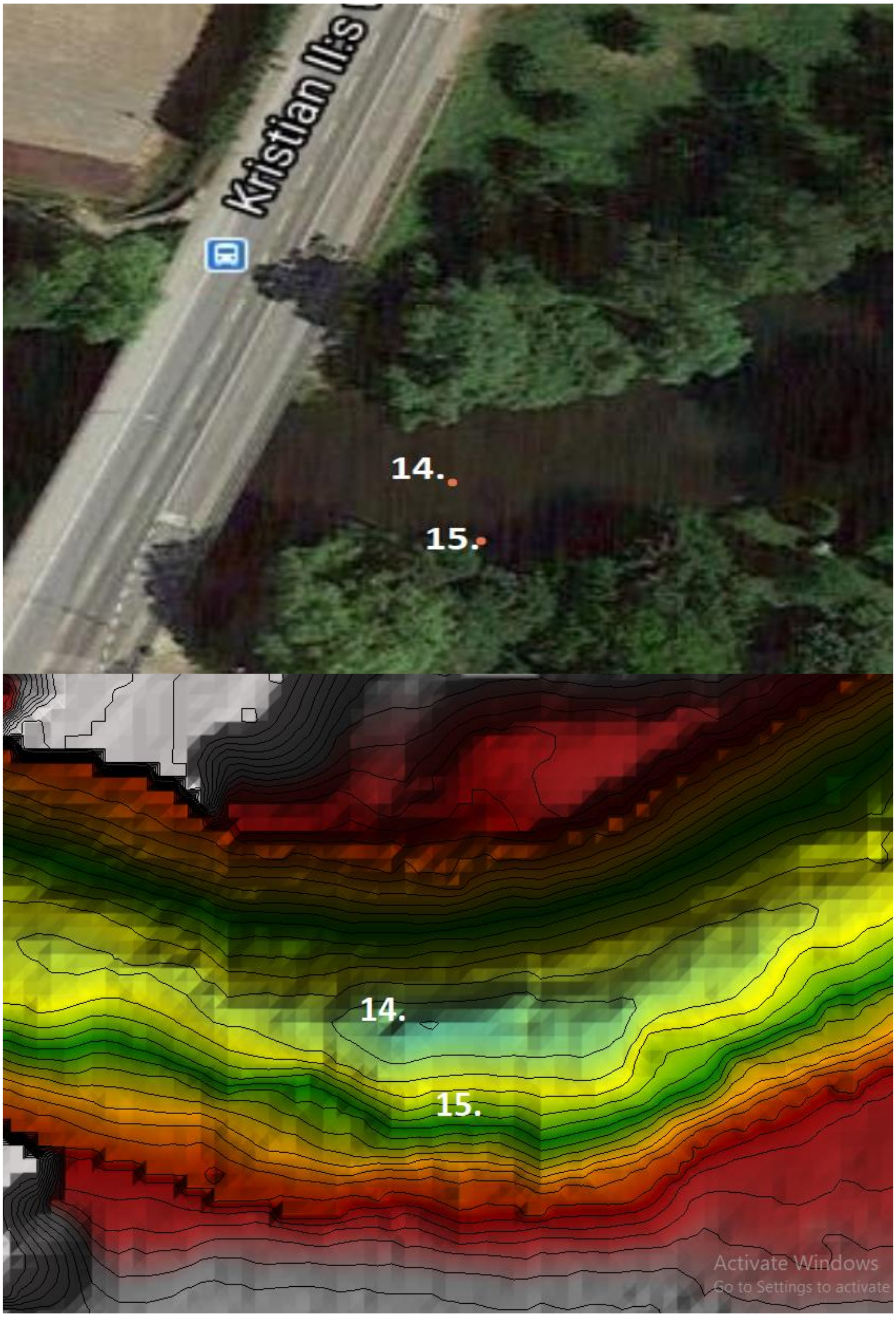

Figure 7. Location 6 with sample points 14 and 15

Location 7 : KP 9 + 650 m

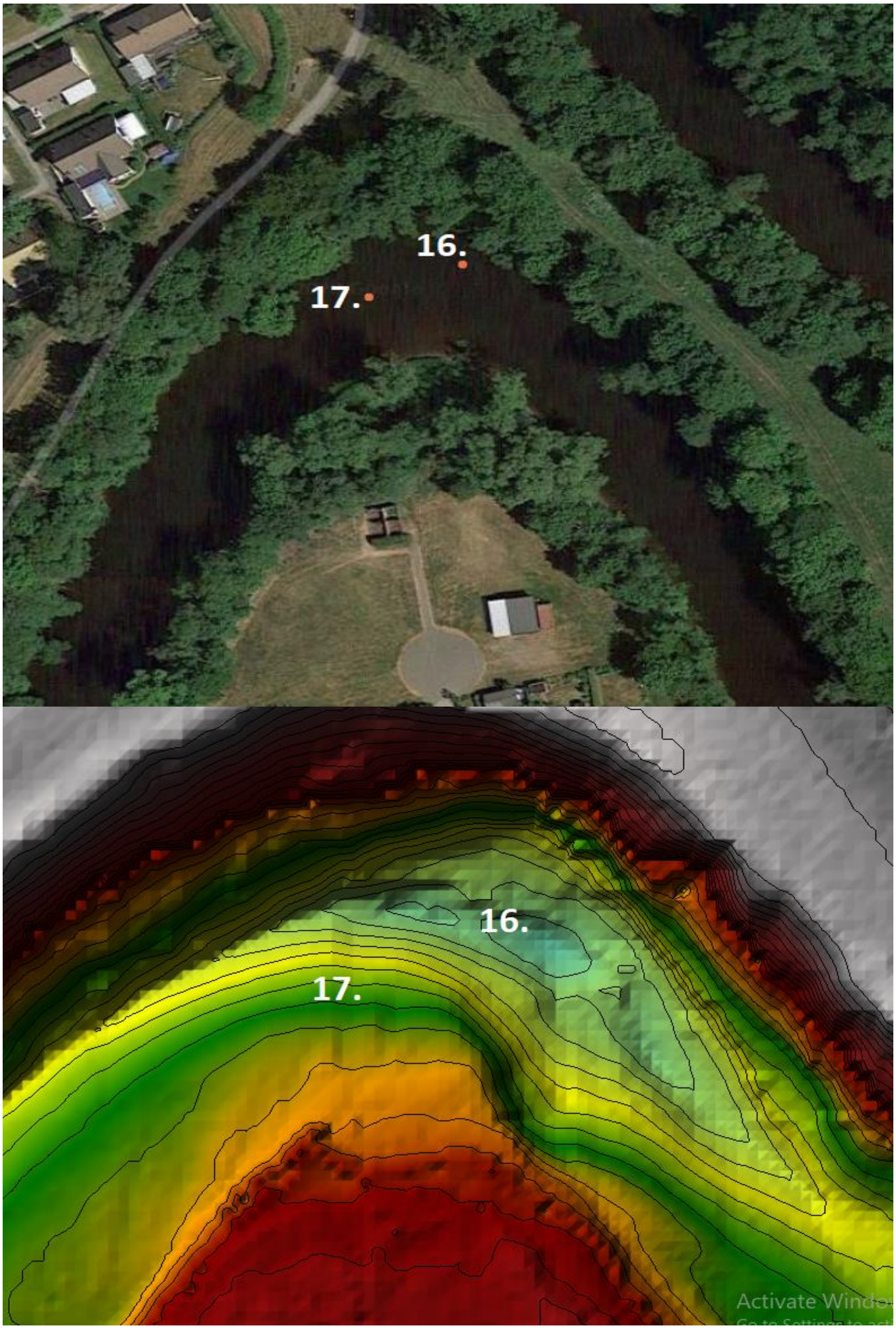

Figure 8. Location 7 with sample points 16 and 17

Location 8 : KP 7 + 850 m

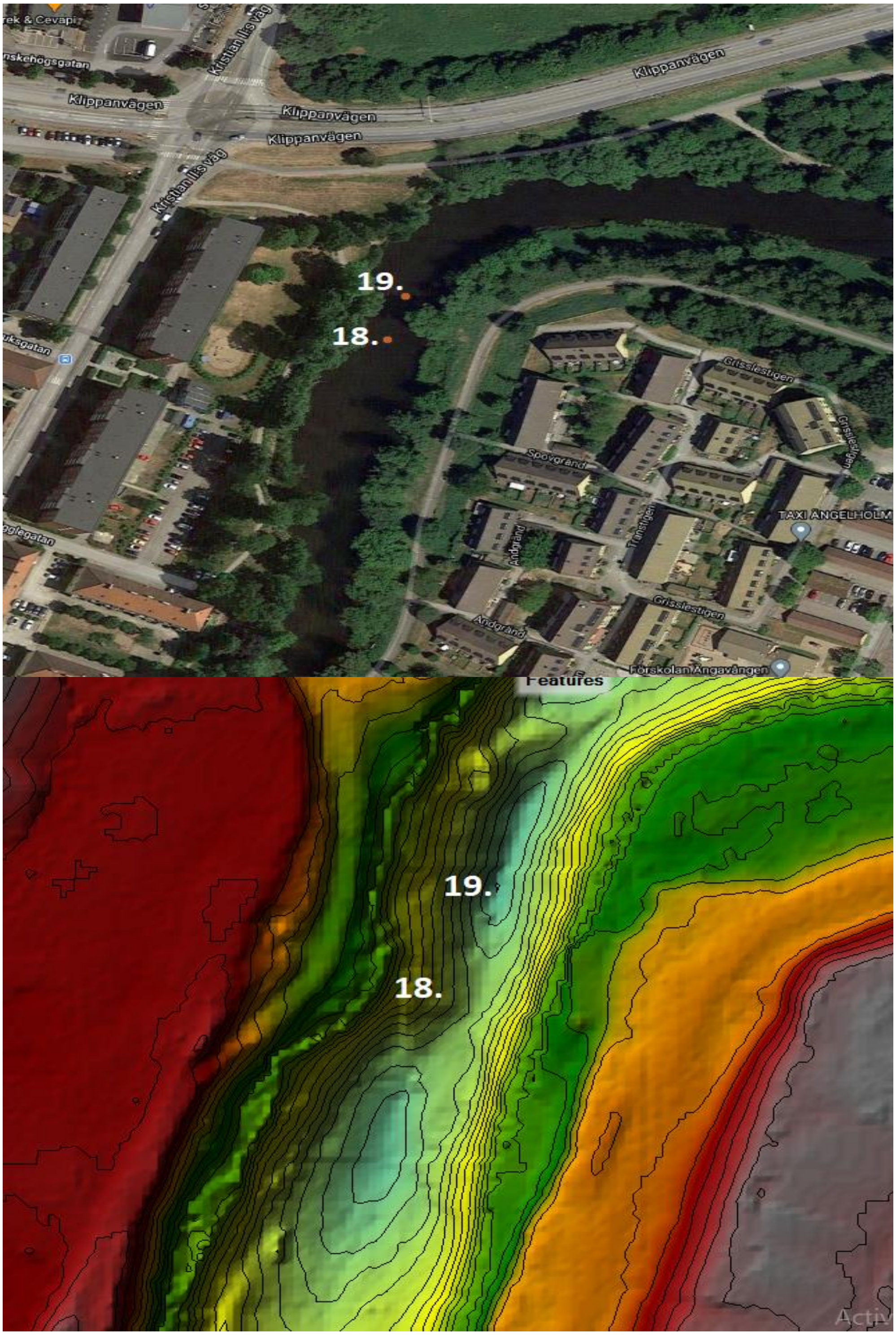

Figure 9. Location 8 with sample points 18 and 19

3. Analysis methodology

As mentioned in section 2, the sampling locations were selected based on bottom erosion conditions along the studied river stretch. The sampling was done by MarCon Teknik AB (MTE) on the 22/10/2020 at the predefined locations using a grab sampler. The conditions at the time of the sampling and other considerations related to the sites obtained from MTE are presented in Appendix 1. Due to the risk of encountering submerged pipelines or cable infrastructure across the river bottom, MTE changed two sample locations slightly as displayed in the figure of Appendix 1. As expected before the sampling, some points were characterized by hard bottom. Thus, samples at 2-5, 4-11, and 5-13 could not be obtained through grab sampling due to hard bottom conditions.

The sampling analysis was conducted in the laboratory of Building Materials in the Department of Building and Environmental Technology at Lund University. Initially, all the samples were dried at room temperature for several days. Then the samples were qualitatively checked and clustered for visual analysis; then grain size analysis were carried out based on sample quantity and initial characteristics. This report covers the results from the particle size sieve analysis as well as the visual analysis. The finer (clay particle) sediment samples should be analyzed through sedimentation techniques, yet to be performed, see section 4. For the particle sieve analysis, ASTM standard sieves from 32 mm to 0.063 mm were used and the testing procedure was adopted with reference to ASTM D 422 standard. There were six samples subjected to particle size analysis. The particle size distribution and associated statistical analysis were performed using GRADISTAT (2021).

Figure 10. Sieve set with sieve shaker

Table 2 summarizes the analysis performed and specifies the samples for which sieving could be done. For some samples a qualitative inspection was performed (visual analysis) and a general assessment of the material characteristics was made. In case hard bottom was encountered, no sampling could be carried out (sample not taken). Finally, some samples yielded fine material for which sieving was not possible; those samples will be subject to hydrometer analysis at a later time.

Table 2. Overview of samples taken and the type of analysis that was performed for each sample.

Sample ID	Analysis	Sample ID	Analysis
1-1	Hydrometer analysis (not yet)	4-11	Sample not taken
1-2	Sieve analysis	5-12	Visual analysis
1-3	Hydrometer analysis (not yet)	5-13	Sample not taken
2-4	Hydrometer analysis (not yet)	6-14	Sieve analysis
2-5	Sample not taken	6-15	Hydrometer analysis (not yet)
2-6	Visual analysis	7-16	Hydrometer analysis (not yet)
3-7	Sieve analysis	7-17	Sieve analysis
3-8	Visual analysis	8-18	Visual analysis
4-9	Sieve analysis	8-19	Visual analysis
4-10	Sieve analysis		

4. Analysis results

Table 3 summarizes the result of the grain size analysis for the samples for which sieving could be done. Median grain size (D_{50}), as well as the grain size for which 90% and 10% by weight is finer than (D_{90} and D_{10}, respectively), is presented in the table.

Table 3. Summary of grain size analysis for the samples for which sieving could be done (D_{50}: median grain size; D_{90}: grain size for which 90% by weight is finer; D_{10}: grain size for which 10% by weight is finer).

Sample ID	D_{50} (mm)	D_{90} (mm)	D_{10} (mm)	Textural group
1-2	0.59	1.36	0.27	Slightly gravelly sand
3-7	14.96	56.92	4.18	Gravel
4-9	0.72	2.99	0.27	Gravelly sand
4-10	0.75	10.51	0.17	Sandy gravel
6-14	1.51	3.33	0.53	Sandy gravel
7-17	0.81	1.69	0.43	Slightly gravelly sand

The sample 1-2 was taken adjacent to a bend scour hole (2.0 m deeper than the normal river bottom), near the river outlet to Skälderviken. This location represents an inner curve of a bend where sedimentation normally takes place (see figure 2). The sample textural group may be characterized as slightly gravelly sand.

Figure 11. Sample 1-2 during the analysis process

SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **Sample 1-2**

ANALYST & DATE: Fainaz Inamdeen, 25/11/2020

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Coarse Sand

	mm	ϕ
MODE 1:	0.75	0.500
MODE 2:		
MODE 3:		
D_{10}:	0.27	-0.443
MEDIAN or D_{50}:	0.59	0.765
D_{90}:	1.36	1.872
(D_{90} / D_{10}):	4.98	-4.224
$(D_{90} - D_{10})$:	1.09	2.315
(D_{75} / D_{25}):	2.30	6.481
$(D_{75} - D_{25})$:	0.49	1.205

GRAIN SIZE DISTRIBUTION			
GRAVEL:	3.8%	COARSE SAND:	45.9%
SAND:	95.8%	MEDIUM SAND:	33.5%
MUD:	0.4%	FINE SAND:	4.1%
		V FINE SAND:	1.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.1%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.1%
FINE GRAVEL:	0.5%	FINE SILT:	0.1%
V FINE GRAVEL:	3.3%	V FINE SILT:	0.1%
V COARSE SAND:	11.1%	CLAY:	0.1%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic µm	Geometric µm	Logarithmic ϕ	Geometric µm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	773.1	580.1	0.786	563.6	0.827	Coarse Sand
SORTING (σ):	648.2	1.981	0.986	1.843	0.882	Moderately Sorted
SKEWNESS (Sk):	3.658	-0.675	0.675	-0.015	0.015	Symmetrical
KURTOSIS (K):	23.47	8.917	8.917	1.043	1.043	Mesokurtic

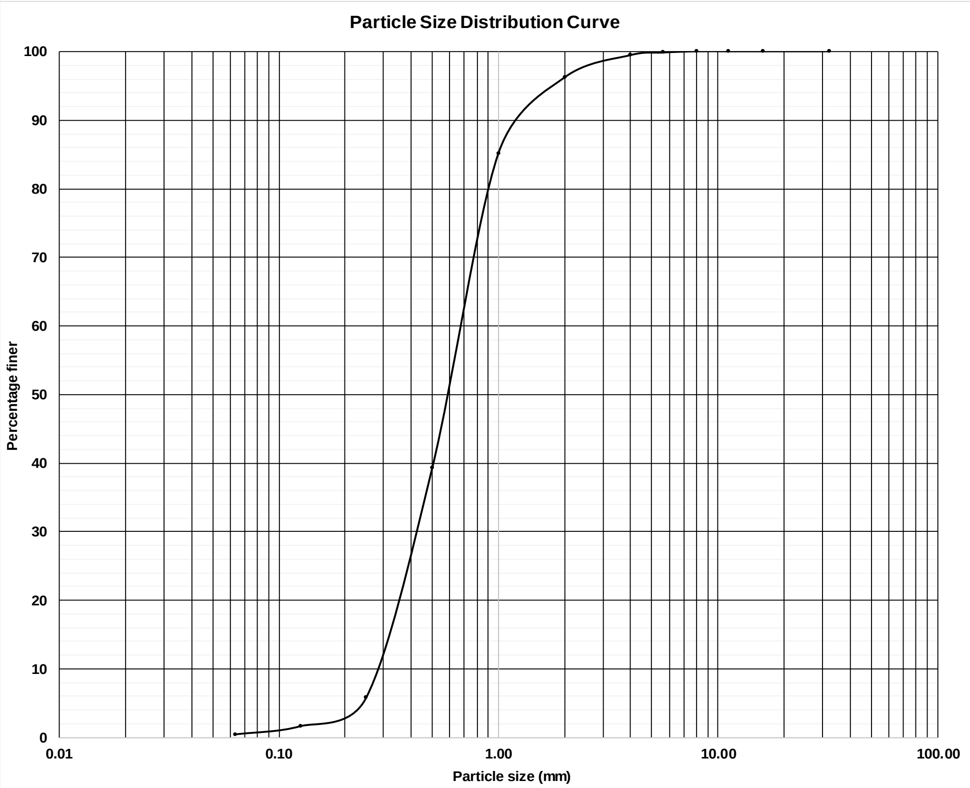

Figure 12. Sample 1-2 sieve analysis results

The sample 2-6 was taken from the approach section to Flygarebron (upstream) and downstream of the Skälderviken bron (see figure 3). The sample contained larger rock pieces suggesting an armored or hard bottom. The sample analysis was performed by visually means due to the sample characteristics and the quantity of material obtained.

Figure 13. Sample 2-6 during the analysis process

The sample 3-7 was taken from the center part of a scour hole near Järnvägsbron (see figure 4). The sample contained mussels and were not subjected to sieve analysis. The sample textural group is characterized as gravel.

Figure 14. Sample 3-7 during the analysis process

SAMPLE STATISTICS

SIEVING ERROR: 0.1%

SAMPLE IDENTITY: **Sample 3-7**

ANALYST & DATE: Fainaz Inamdeen, 1/12/2020

SAMPLE TYPE: Unimodal, Well Sorted

TEXTURAL GROUP: Gravel

SEDIMENT NAME: Coarse Gravel

	mm	ϕ
MODE 1:	13.60	-3.743
MODE 2:		
MODE 3:		
D_{10}:	4.18	-5.831
MEDIAN or D_{50}:	14.96	-3.904
D_{90}:	56.92	-2.062
(D_{90} / D_{10}):	13.63	0.354
$(D_{90} - D_{10})$:	52.74	3.769
(D_{75} / D_{25}):	3.15	0.661
$(D_{75} - D_{25})$:	20.03	1.653

GRAIN SIZE DISTRIBUTION			
GRAVEL:	92.9%	COARSE SAND:	1.6%
SAND:	6.5%	MEDIUM SAND:	1.4%
MUD:	0.7%	FINE SAND:	1.1%
		V FINE SAND:	0.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	45.9%	COARSE SILT:	0.1%
MEDIUM GRAVEL:	35.4%	MEDIUM SILT:	0.1%
FINE GRAVEL:	9.0%	FINE SILT:	0.1%
V FINE GRAVEL:	2.5%	V FINE SILT:	0.1%
V COARSE SAND:	1.6%	CLAY:	0.1%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic µm	Geometric µm	Logarithmic ϕ	Geometric µm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	10677.5	1219.8	-2.483	10837.1	-3.438	Medium Gravel
SORTING (σ):	8954.1	51.40	2.082	1.350	0.433	Well Sorted
SKEWNESS (Sk):	0.291	-1.139	1.203	-3.226	3.226	Very Fine Skewed
KURTOSIS (K):	1.756	2.467	4.617	0.361	0.361	Very Platykurtic

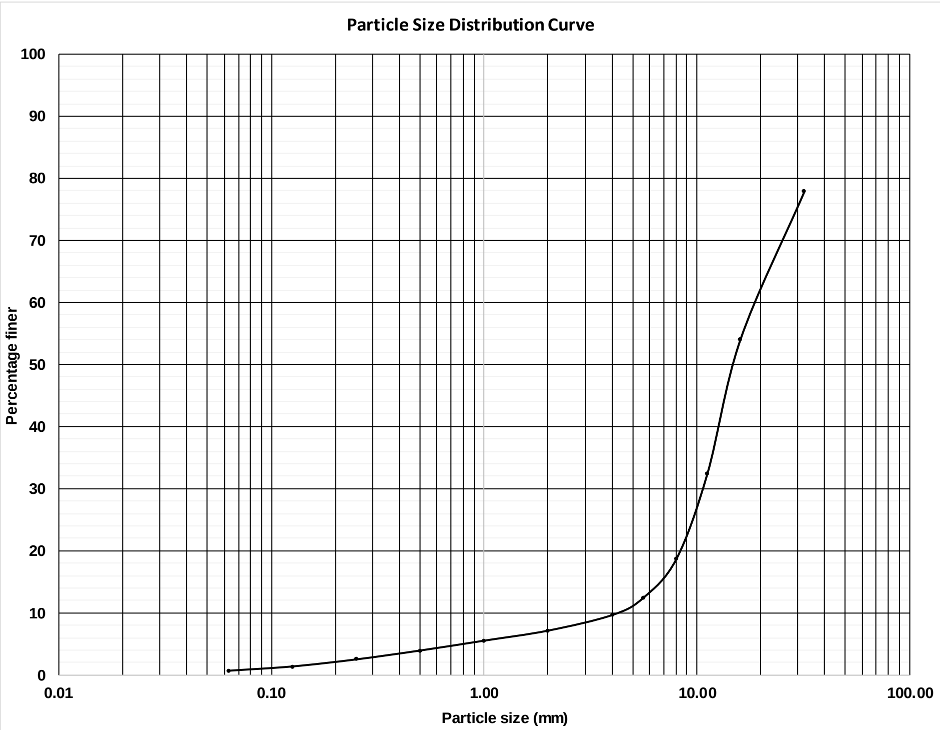

Figure 15. Sample 3-7 sieve analysis results

The sample 3-8 was taken upstream of a scour hole (2.0 m deeper than the normal river bottom), downstream Järnvägsbron (see figure 4). The sample contained larger rock pieces, which suggested hard bottom. The sample analysis was performed visually because of the sample characteristics and obtained quantity of material.

Figure 16. Sample 3-8 during the analysis process

The sample 4-9 was taken in the downstream part of a scour hole (3.5 m deeper than the normal river bottom), near Tullportsbron (see figure 5). The sample textural group is characterized as gravelly sand. The sample was mixed with lots of mussels, as seen in pictures below.

Figure 17. Sample 4-9 during the analysis process

SAMPLE STATISTICS

SIEVING ERROR: 0.1%

SAMPLE IDENTITY: **Sample 4-9**

ANALYST & DATE: Fainaz Inamdeen, 23/11/2020

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

	mm	ϕ
MODE 1:	0.75	0.500
MODE 2:		
MODE 3:		
D_{10}:	0.27	-1.579
MEDIAN or D_{50}:	0.72	0.465
D_{90}:	2.99	1.888
(D_{90} / D_{10}):	11.06	-1.196
$(D_{90} - D_{10})$:	2.72	3.468
(D_{75} / D_{25}):	2.99	-3.054
$(D_{75} - D_{25})$:	0.87	1.579

GRAIN SIZE DISTRIBUTION			
GRAVEL:	14.3%	COARSE SAND:	39.1%
SAND:	85.2%	MEDIUM SAND:	21.5%
MUD:	0.5%	FINE SAND:	5.9%
		V FINE SAND:	1.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	1.6%	COARSE SILT:	0.1%
MEDIUM GRAVEL:	1.9%	MEDIUM SILT:	0.1%
FINE GRAVEL:	3.4%	FINE SILT:	0.1%
V FINE GRAVEL:	7.4%	V FINE SILT:	0.1%
V COARSE SAND:	17.5%	CLAY:	0.1%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1635.7	798.5	0.325	763.0	0.390	Coarse Sand
SORTING (σ):	3290.7	2.777	1.473	2.583	1.369	Poorly Sorted
SKEWNESS (Sk):	5.331	0.391	-0.391	0.140	-0.140	Coarse Skewed
KURTOSIS (K):	34.44	5.773	5.773	1.270	1.270	Leptokurtic

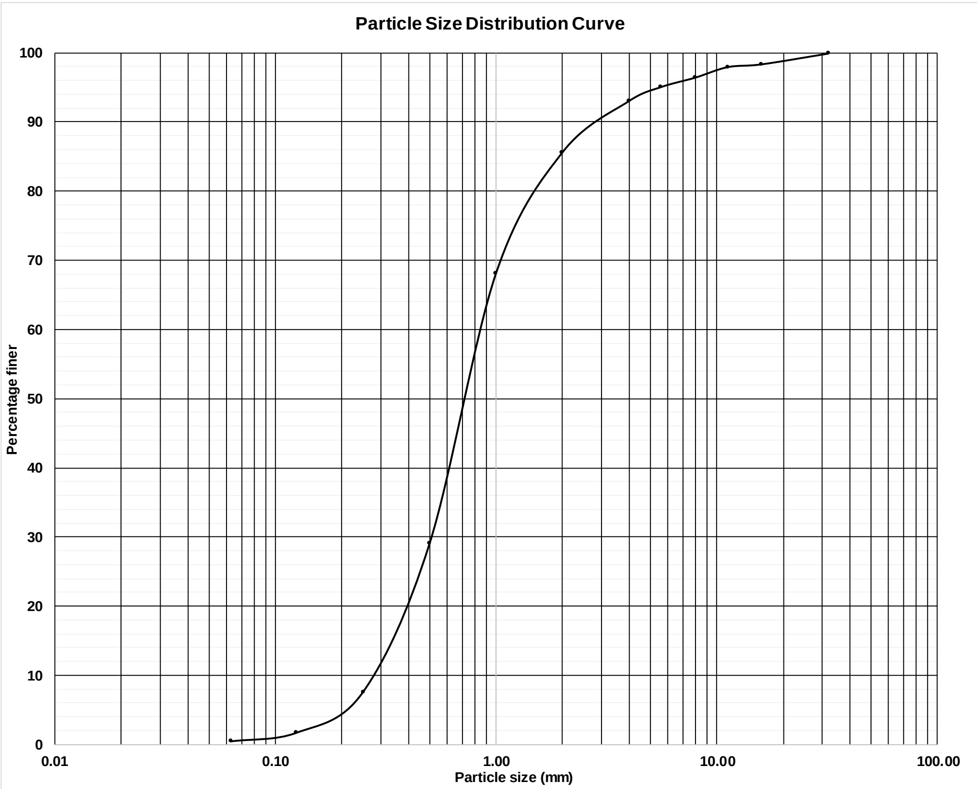

Figure 18. Sample 4-9 sieve analysis results

The sample 4-10 was taken from center part of a scour hole (3.5 m deeper than the normal river bottom), under Tullportsbron (see figure 5). The sample textural group is characterized as sandy gravel.

Figure 19. Sample 4-10 during the analysis process

SAMPLE STATISTICS

SIEVING ERROR: 0.2%

SAMPLE IDENTITY: **Sample 4-10**

ANALYST & DATE: Fainaz Inamdeen, 25/11/2020

SAMPLE TYPE: Trimodal, Very Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Fine Gravel

	mm	ϕ
MODE 1:	0.38	1.500
MODE 2:	3.00	-1.500
MODE 3:	13.60	-3.743
D_{10}:	0.17	-3.394
MEDIAN or D_{50}:	0.75	0.406
D_{90}:	10.51	2.532
(D_{90} / D_{10}):	60.79	-0.746
$(D_{90} - D_{10})$:	10.34	5.926
(D_{75} / D_{25}):	9.34	-0.950
$(D_{75} - D_{25})$:	2.81	3.223

GRAIN SIZE DISTRIBUTION			
GRAVEL:	33.7%	COARSE SAND:	19.5%
SAND:	65.1%	MEDIUM SAND:	23.5%
MUD:	1.2%	FINE SAND:	9.2%
		V FINE SAND:	4.5%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.2%
COARSE GRAVEL:	5.1%	COARSE SILT:	0.2%
MEDIUM GRAVEL:	6.9%	MEDIUM SILT:	0.2%
FINE GRAVEL:	8.3%	FINE SILT:	0.2%
V FINE GRAVEL:	13.4%	V FINE SILT:	0.2%
V COARSE SAND:	8.3%	CLAY:	0.2%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic µm	Geometric µm	Logarithmic ϕ	Geometric µm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	3311.1	1000.3	0.000	1006.0	-0.009	Very Coarse Sand
SORTING (σ):	5762.9	4.714	2.237	4.507	2.172	Very Poorly Sorted
SKEWNESS (Sk):	2.595	0.121	-0.121	0.261	-0.261	Coarse Skewed
KURTOSIS (K):	9.070	3.012	3.012	0.913	0.913	Mesokurtic

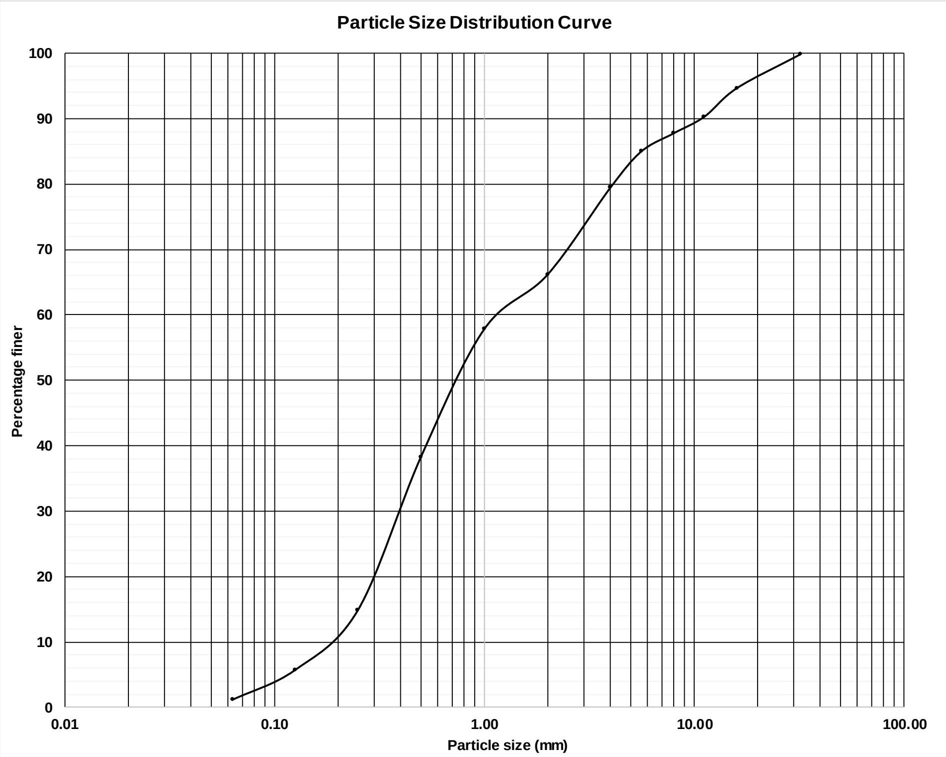

Figure 20. Sample 4-10 sieve analysis results

The sample 5-12 was taken from the center part of a scour hole (3.5 m deeper than the normal river bottom), near Carl XV bridge (see figure 6). The sample analysis was performed visually due to the sample characteristics and sample quantity. The sample suggests that the particular bottom is hard and contains larger rock particles.

Figure 21. Sample 5-12 during the analysis process

The sample 6-14 was taken from the center part of a scour hole (1.5 m deeper than the normal river bottom), downstream to Kristian II bron (see figure 7). The sample textural group is characterized as sandy gravel.

Figure 22. Sample 6-14 during the analysis process

SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **Sample 6-14**

ANALYST & DATE: Fainaz Inamdeen, 23/11/2020

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Fine Gravel

	mm	ϕ
MODE 1:	1.50	-0.500
MODE 2:		
MODE 3:		
D_{10}:	0.53	-1.735
MEDIAN or D_{50}:	1.51	-0.590
D_{90}:	3.33	0.915
(D_{90} / D_{10}):	6.28	-0.527
(D_{90} - D_{10}):	2.80	2.651
(D_{75} / D_{25}):	2.84	-0.154
(D_{75} - D_{25}):	1.60	1.504

GRAIN SIZE DISTRIBUTION			
GRAVEL:	35.5%	COARSE SAND:	21.0%
SAND:	64.2%	MEDIUM SAND:	5.0%
MUD:	0.2%	FINE SAND:	2.1%
		V FINE SAND:	0.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.8%	FINE SILT:	0.0%
V FINE GRAVEL:	34.7%	V FINE SILT:	0.0%
V COARSE SAND:	35.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1795.0	1353.4	-0.437	1421.9	-0.508	Very Coarse Sand
SORTING (σ):	1033.0	2.166	1.115	2.117	1.082	Poorly Sorted
SKEWNESS (Sk):	0.556	-1.506	1.506	-0.190	0.190	Fine Skewed
KURTOSIS (K):	3.898	7.946	7.946	0.961	0.961	Mesokurtic

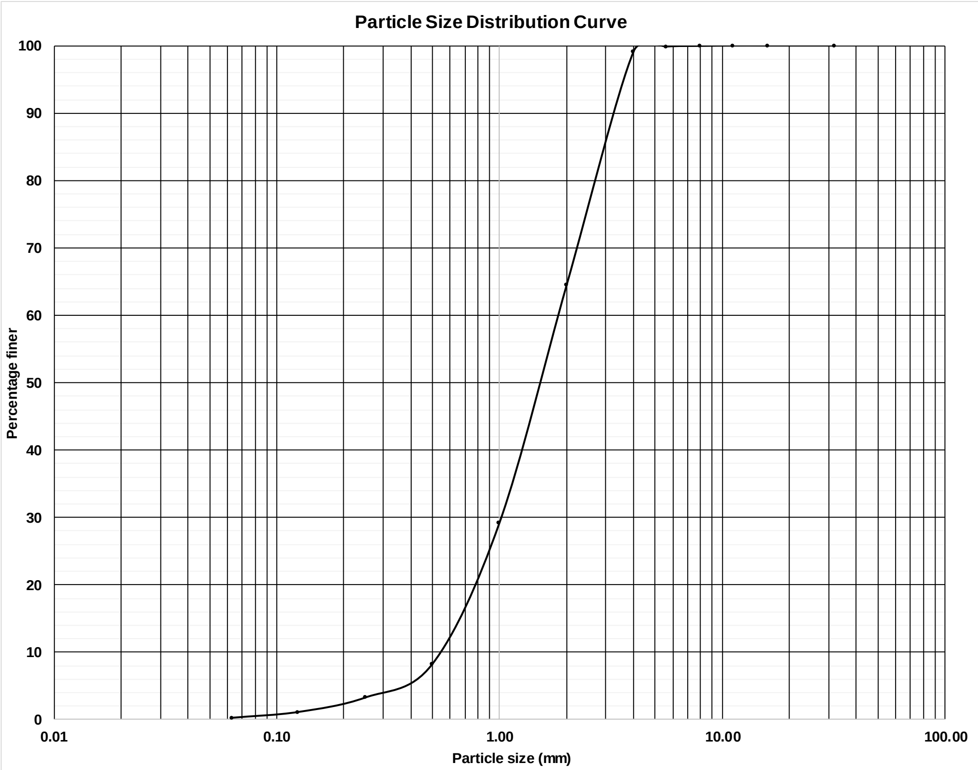

Figure 23. Sample 6-14 sieve analysis results

The sample 7-17 was taken from the upstream part of a scour hole and near a sharp river bend where a riffle feature can be expected (see figure 8). The sample textural group is characterized as slightly gravelly sand.

Figure 24. Sample 7-17 during the analysis process

SAMPLE STATISTICS

SIEVING ERROR: 0.1%

SAMPLE IDENTITY: **Sample 7-17**

ANALYST & DATE: Fainaz Inamdeen, 25/11/2020

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Coarse Sand

	mm	f
MODE 1:	0.75	0.500
MODE 2:		
MODE 3:		
D_{10}:	0.43	-0.759
MEDIAN or D_{50}:	0.81	0.312
D_{90}:	1.69	1.214
(D_{90} / D_{10}):	3.93	-1.600
(D_{90} - D_{10}):	1.26	1.973
(D_{75} / D_{25}):	2.05	-2.925
(D_{75} - D_{25}):	0.61	1.032

GRAIN SIZE DISTRIBUTION			
GRAVEL:	2.7%	COARSE SAND:	54.7%
SAND:	97.0%	MEDIUM SAND:	11.1%
MUD:	0.3%	FINE SAND:	0.5%
		V FINE SAND:	0.4%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.1%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.1%
FINE GRAVEL:	0.1%	FINE SILT:	0.1%
V FINE GRAVEL:	2.6%	V FINE SILT:	0.1%
V COARSE SAND:	30.3%	CLAY:	0.1%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$)	989.7	812.9	0.299	853.6	0.228	Coarse Sand
SORTING (σ):	530.3	1.776	0.829	1.700	0.766	Moderately Sorted
SKEWNESS (Sk):	1.763	-1.920	1.920	0.061	-0.061	Symmetrical
KURTOSIS (K):	8.513	17.15	17.15	1.027	1.027	Mesokurtic

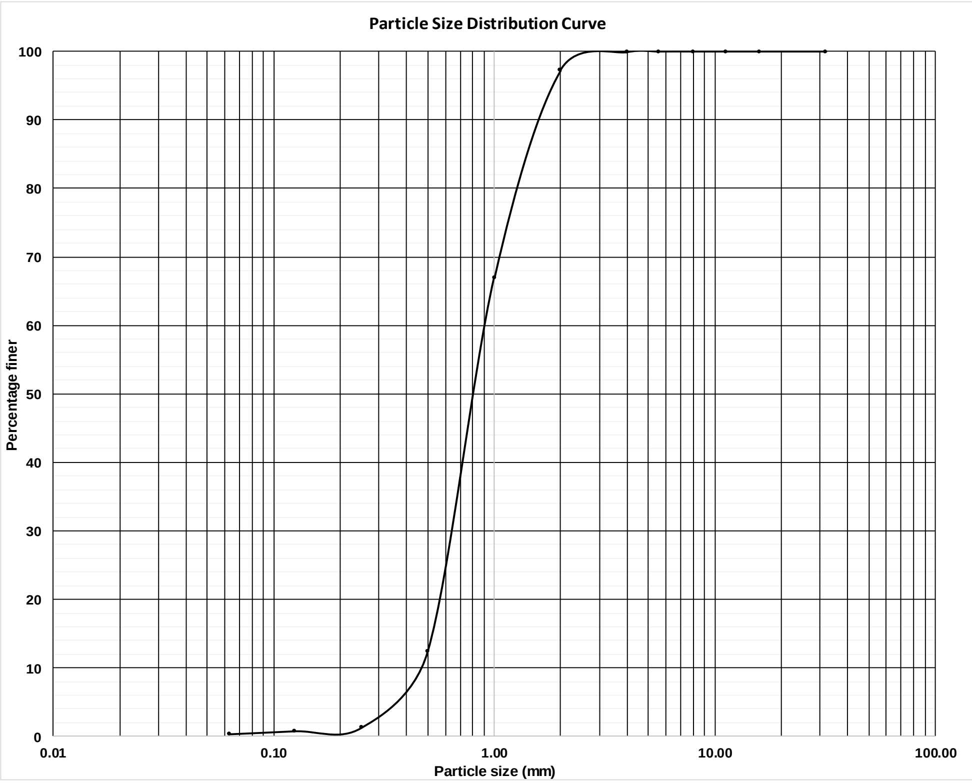

Figure 25. Sample 7-17 sieve analysis results

The sample 8-18 was taken from the upstream part of a scour hole and near a river bend (see figure 9). Hard bottom features were expected before the sample was taken because of the formation of surrounding scour hole and adjacent river bathymetry. The sample analysis was performed visually due to lack of a sufficient sample quantity. The sample suggests that the particular bottom is hard and formed by claystone or siltstone.

Figure 26. Sample 8-18 during the analysis process

The sample 8-19 was taken from center part of a scour hole (1.3 m deeper than the normal river bottom), near a river bend (see figure 9). The sample analysis was performed visually due to the sample characteristics. The sample suggests that the particular bottom is hard and layered by claystone or siltstone. Some eroding features are indicated at the top surface of the hard bottom.

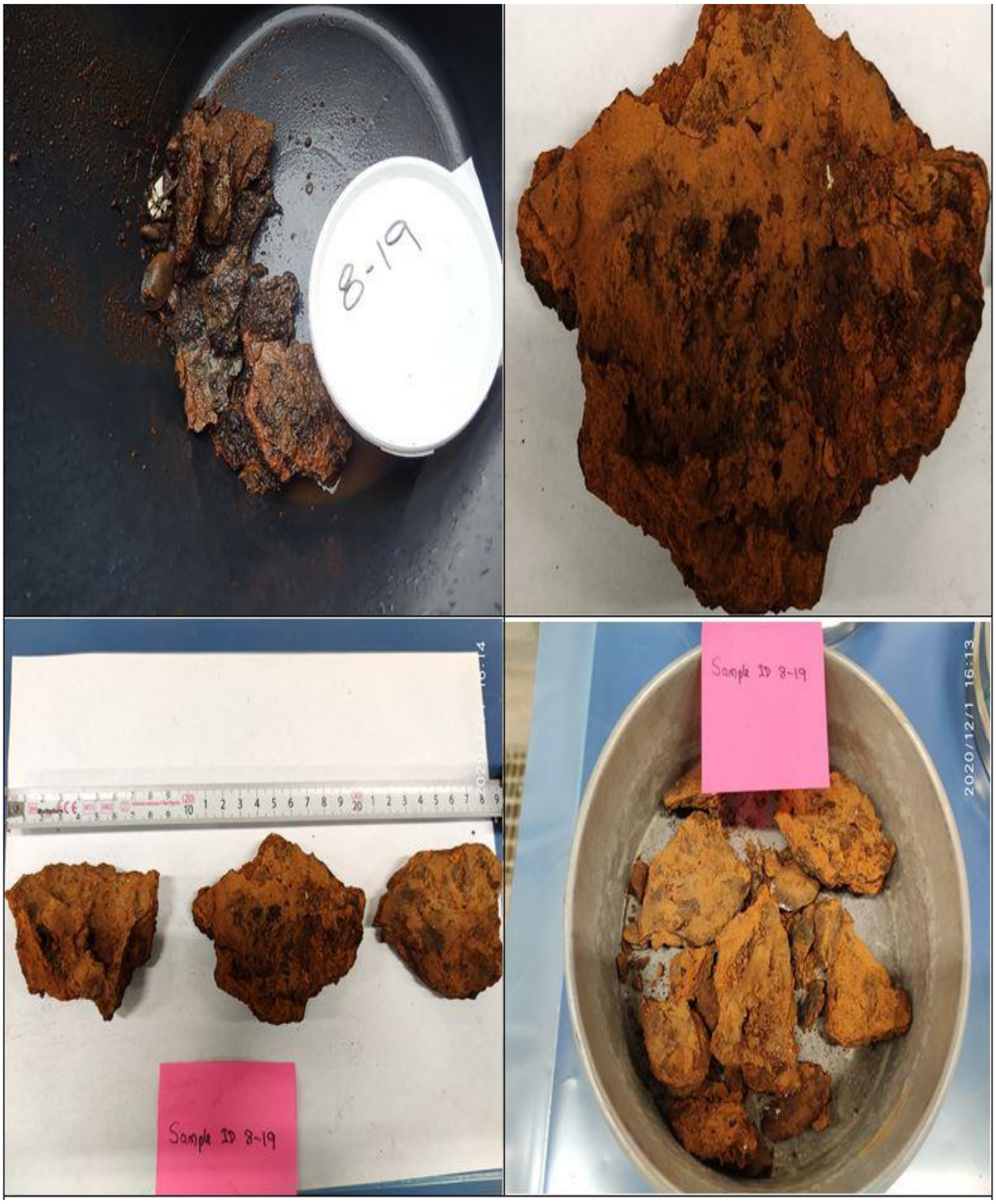

Figure 27. Sample 8-19 during the analysis process

5. Concluding remarks

The sediment sampling in Rönne å was primarily conducted to verify hypotheses about the main controlling factors of local scour at specific locations along the river as observed in detailed bathymetric measurements. Subsequently, the analysis of the samples and the sediment parameter values derived may be used to employ different formulas to calculate the evolution and equilibrium properties of the scour holes. In such calculations the geometric characteristics of the river and bridge structures, together with available information on the flow and sea level from which water depth and velocity may be determined, are important input information as well.

Previous analysis of river bed morphology revealed a number of prominent scour holes that were attributed to river bends, bridges, and hard bottom (or sometimes combinations of these factors). The sediment sampling and analysis, as well as field inspection, confirmed the major hypotheses about the causes of scour at the studied locations. Major scour holes observed were denoted SH and numbered consecutively from the river mouth (see figure 1). Several samples were typically taken at, or adjacent to, each scour hole.

The main causes of the scour at the different holes, confirmed by the present sampling, were bend scour (SH1, SH4, SH9, SH10, and, SH12), bridge scour (SH8), and hard bottom scour (SH5 and SH6). However, at SH8, SH9, and SH10, hard bottom also contributed to the scour.

6. References

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Appendix 1

Table A1.: Sampling protocol with remarks taken during the sampling.

Sample	Smell	Type of bottom material	Remarks
1-1	Sulphur	Soft clay/silt	1 try
1-2	Sand	Fine sand	1 try
1-3	Clay	Clay covered by small mussels	2 tries
2-4	Slight smell of clay	Silt, fin clay	2 tries
2-5		Cobble 10x10 cm	6 tries
2-6		Cobbles	6 tries
3-7		Cobbles + one mussel	4 tries
3-8		5 pebbles, size 1-6 cm	5 tries
4-9_1	Soil	Fine to coarse sand with mussels and small pieces of wood and leaves	3 tries
4-10	Soil	Coarse sand with pebbles	5 tries
4-11			6 tries. Could hear sampler hit bottom, rock.
5-12			6 tries. Could hear sampler hit bottom, rock.
5-12 B		Cobbles	1 try
5-13_1			6 tries. Could hear sampler hit bottom, rock.
6-14		Coarse sand	1 try
6-15		Cobbles, 15 - 8 cm	7 tries
7-16	Soil, mussels	Coarse sand, cobbles, mussels	4 tries
7-17	Soil	Coarse sand	1 try

8-18		Cobble	6 tries
8-19	Metallic	Hard bottom, cobble, mussel, conglomerate of cobble/sand	2 tries

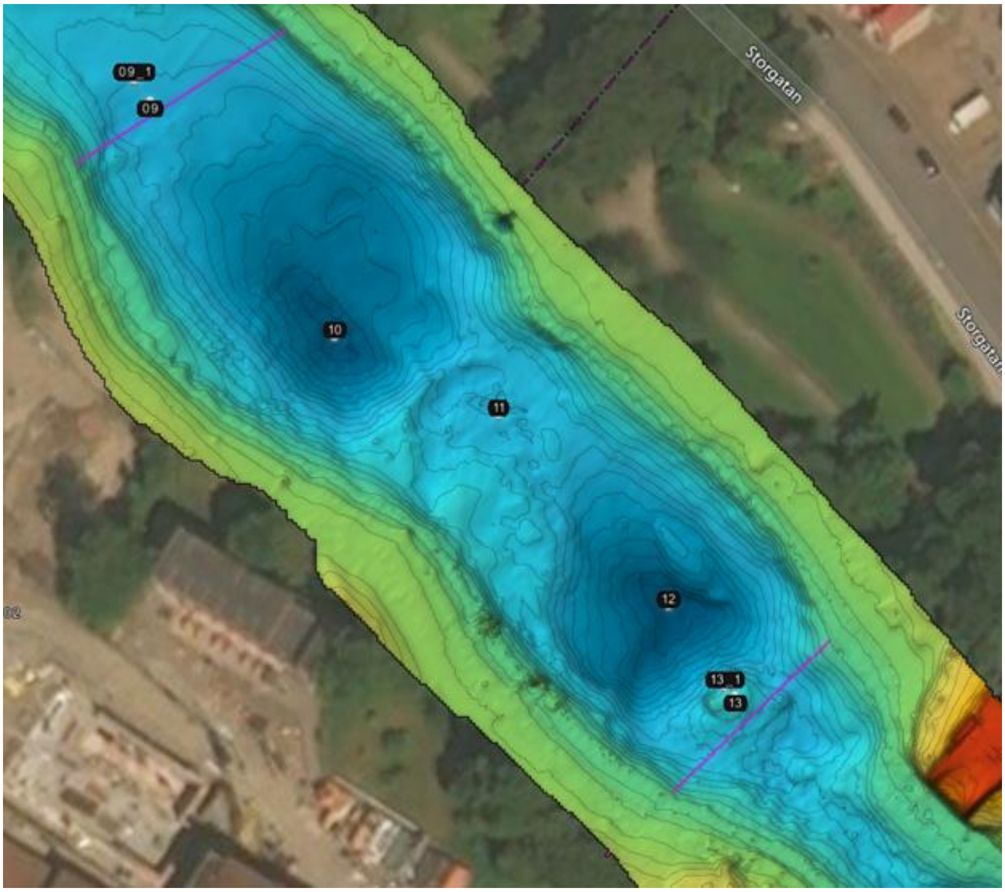

Figure A1. The changed sample locations due to crossing infrastructure (e.g., pipe or cable crossing) over the river as marked. The sampling location was changed with regard to the LTH suggested sampling points as a measure to keep a safe distance to the infrastructure (courtesy Carl Karlsson, MarCon Teknik AB).