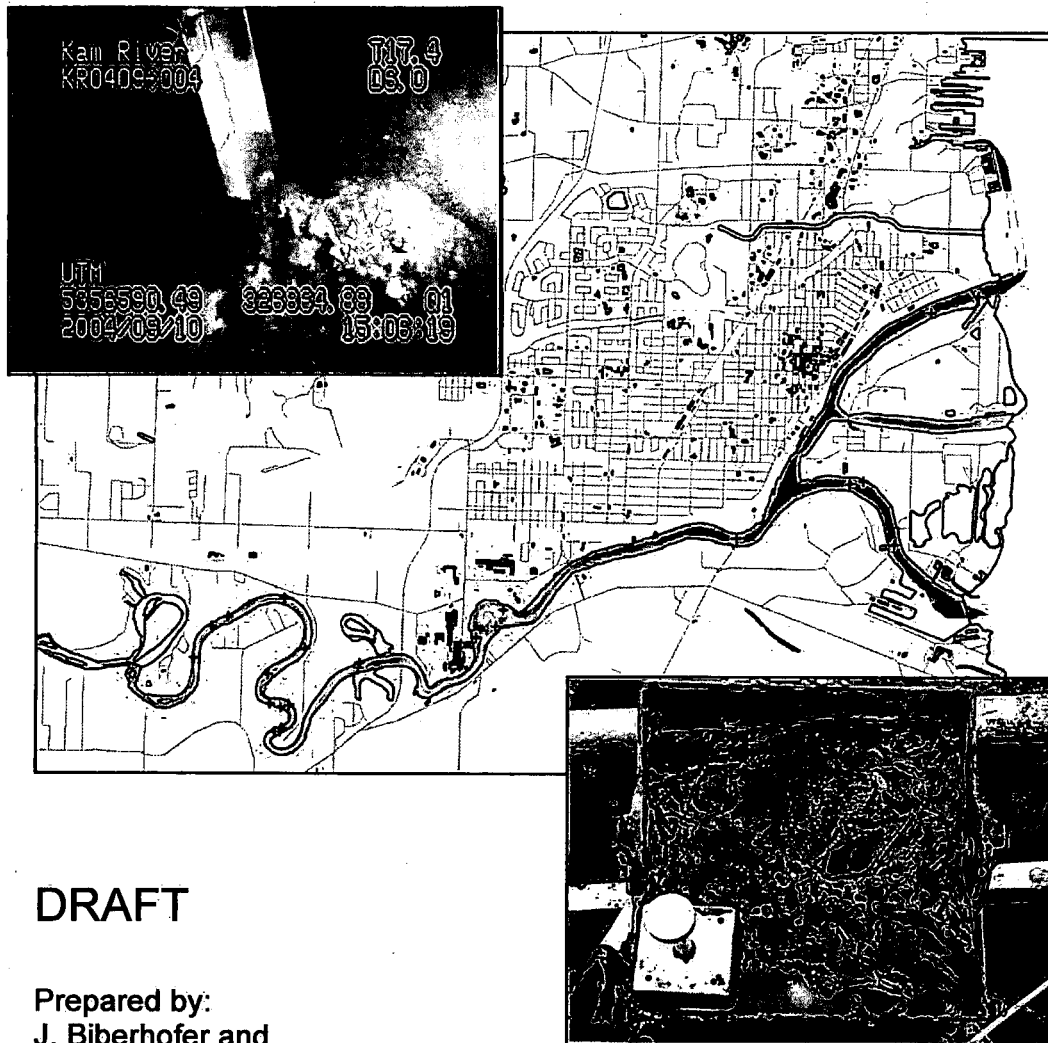


Description and Quantification of the Submerged Aquatic Substrates in the Lower Reaches of the Kaministiquia River, Thunder Bay, Ontario.



DRAFT

Prepared by:
J. Biberhofer and
C.M. Prokopec

Environment Canada
National Water Research Institute
WSTD, AEMR

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Introduction:

The submerged landscape in aquatic systems is an integral determinant for determining the sustainability of many prized fisheries. This landscape, particularly close to urban centres, has been exploited to accommodate human activities and often the results have been and continue to be detrimental to the ecosystem's integrity. A consequence of these anthropogenic perturbations is that habitat suitable for species sustainability has been reduced and in some areas lost completely. Implicit to stewardship of valued species is the protection and enhancement of the remaining habitat to augment, if not ensure, the future viability of the valued fish species.

A critical element for successful management and conservation strategies for these fish species is the description and quantification of available aquatic substrates that can be utilized as habitat features. Acoustic technologies have proven successful in discriminating the attributes of submerged surfaces in river and lake systems. The National Water Research Institute of Environment Canada has advanced and refined this technology in support of aquatic habitat assessments and delineation of contaminated sediment deposits. There is an ongoing research effort to further advance the discrimination of submerged substrates and to further investigations in determining form and function relationships between the substrate and fish species.

This study was undertaken as a scientific partnership initiated by Ontario Ministry of Natural Resources in support of the Lake Superior LaMP aquatic habitat objectives that include ... *to identify and quantify critical habitat for key indicator species by electronically mapping lake bottom substrates...* (Lake Superior LaMP, 2000).

Study Area:

The Kaministiquia River is a major tributary to Lake Superior that terminates in a three channel delta as it flows into Thunder Bay, Lake Superior. The McKellar and Mission Rivers are secondary channels that with the Kaministiquia River define McKellar and Mission Islands respectively (Figure 1). The study area extended from ends of these rivers to the furthest upstream extent possible that was still within the shallow water limits of the acoustic technology employed.

Three arbitrarily defined reaches are used to describe the surveyed sections of the river (Figure 2). The Upstream Reach is a meandering 10 km section of river that is relatively shallow and not navigable by commercial marine traffic. The shoreline varies to include eroded river banks, forest, park land and seasonal and permanent residences where the shoreline is stable.

The Mid-River Reach starts at the upstream extent of the turning basin and continues for 4.8 km to the where the river divides into 3 channels. The water in this section is deeper and was historically used for commercial marine transport of goods from industries located on the river shores. There are few viable industries remaining, the pulp and paper mill located at the turning basin is the most dominant. The remaining buildings appear to be vacant, often in disrepair, and at some dilapidated buildings the adjacent water is littered with structural debris.

The Downstream Reach includes the 3 rivers that form the delta. The north river is a 4.5 km continuation of the Kaministiquia River, the central channel is the Mission River and the southeast channel is McKellar River with lengths of 2.5 and 3.4 km respectively. There is a heavy industrial landscape along the shores of each of these rivers that include railway maintenance, lumber mills, coal-fired power generation and tank farms. There are also marine facilities for commercial and private vessels (Figure 3).

Survey Schedule

The study started September 9, 2004 and had to be suspended on September 10, 2004 due to a failure of a critical sounder component. September 10, 2004 was used to collect underwater video and track radio-tagged sturgeon with Ontario Ministry of Natural Resources personnel.

The study resumed October 23, 2004 and soundings were collected until the afternoon of October 26, 2004. The survey launch was then reconfigured to collect underwater video but there was limited success documenting the substrate due to poor underwater visibility. The video collected September 10, 2004 while not optimum was superior to the video collected in October and did provide some important visual information on the substrate, mainly in the upstream reach of the river. Sediment samples were collected at on October 27, 2004.

Field Procedures

Positioning

A NovAtel 3151W differential Global Positioning System (DGPS) with a 2 carrier signal antenna was used to collect position data for the soundings, underwater video and sediment sampling. The DGPS was enabled to include real-time Wide Area Augmentation System (WAAS) corrections as part of the DGPS solution. Position accuracy was monitored throughout the survey effort by recording the NMEA GPGST output string from the DGPS at 10 second intervals. The GPGST string includes information on the standard deviation of the longitude and latitude of the DGPS solution.

Survey lines for the turning basin and target positions were created and displayed in Hypack © version 2.12 navigation software. The software provides a real-time left-right indicator and target proximity information for the coxswain. Tracklines were generally run within 5 m or better of the planned lines and positioning for video and sediment sampling were typically within 1 m of target position. The main channel survey lines were a combination of planned navigation lines and heads-up positioning by the coxswain using the boat's relative position to previously sounded lines. This afforded the survey better coverage of the river given the meanders in the upstream section and the variable width and obstacles encountered in the lower reaches of the river.

Substrate Mapping - RoxAnn

Acoustic mapping of surface sediment with a RoxAnn™ seabed-classification system (Rukavina 1998, Rukavina and Cadell 1997) has been used at a number of sites in the Great Lakes basin to investigate the distribution of substrate types. This technology has recently been applied to map aquatic substrate to identify and quantify critical fish habitat in Lake Superior (Biberhofer 2003, 2004 and 2005).

The RoxAnn survey efforts were conducted on September 9, 2004 and between October 23 and October 26, 2004 (Table 1). The survey vessel Puffin, a 7 m aluminium launch, was equipped with a dual-frequency (50 kHz and 200 kHz) digital Knudsen sounder (Model 320M) with a combined in-hull transducer. The return signal from each frequency of the sounder transmit was measured and processed with a dedicated RoxAnn seabed-classification system unit (Figure 4). This study will report only on the high-frequency data.

The RoxAnn output signal, G1 (roughness) and G2 (hardness), was converted to an acoustic label based on the position of the G1 and G2 variables on Cartesian plot established in the Microplot™ survey software running on a dedicated rack-mount computer. The Microplot software logs the labels and the corresponding water depth and DGPS positions at 1-second intervals which are displayed in real time on a geo-referenced map (Figure 5).

Survey lines were determined to provide the most efficient coverage of the river and the density of mapping was variable depending on the width and locale of the river (Figure 6). Additional effort was invested in mapping the turning basin which is known to be utilized by the sturgeon during the summer periods (M. Friday, personal comm.).

The integrity and stability of the acoustic data acquisition system was assessed by measuring the RoxAnn outputs in response to a programmed range of simulated sounder transmits. These data were logged at the beginning and end of each survey day to confirm equipment performance and integrity.

Underwater video

An underwater camera mounted on a weighted tripod was used to collect underwater video records of the substrate at 59 sites (Table 2, Figure 7). The legs of the tripod have 10 cm colour gradations useful for comparing substrate size and depth of penetration when the camera is lowered onto the substrate. The DGPS antenna was transferred to a mount on the davit used for lowering the camera (Figure 8). At fixed target sites effort was made to keep the boat stationary, or at very low speeds, to optimize the vertical and position accuracy between the antenna and the camera lowered in the water. Station information, real-time position data and water temperature and depth information was integrated with the video signal from the camera by combining the two inputs with custom software interfacing with a VideoStamp™ processor (Figure 8).

At some sites, particularly those sites that transitioned from sand to cobble or at sites where the substrate was heterogeneous due to debris, it was useful to record video transects as the boat drifted or moved slowly under power. During some instances, the position information was degraded up to 3 metres due to the slope of the line from the davit to the camera's tripod.

The video was recorded in a digital format on 8mm tape. Selected segments of the video were then extracted as computer images and computer video files for portability as well as to be included in a Geographic Information System (GIS) project.

Sediment Sampling

Sediment samples were collected at 24 of the 25 target sites (Table 3, Figure 9) with a Shipek sampler, which is very effective at collecting surface sediment. This layer of sediment has the most effect on the characteristics of the high-frequency return echo recorded with the RoxAnn seabed classification system. The sampler was deployed from a winch and davit setup on the launch with the GPS antenna mounted on the davit, similar to the setup for the underwater video. The collected sediment was described, photographed and sub-sampled for particle size analyses (Duncan and LaHaie, 1979).

Data Analysis

Bathymetric data

The water depth data can be collected over a wider range of vessel speeds and depths than the RoxAnn measurements. The bathymetric dataset includes the depth data logged during RoxAnn sounding lines and during transit when the vessel speed was less than 8 m.s^{-1} . As the river extends many kilometres inland the bathymetric data is reported as recorded rather than adjusted to International Great Lakes Datum 1985 (IGLD85), which would be only be applicable to the lower reach of the river. To confirm that there were no large differences in water level elevation during the survey, the 3-minute water level data for Thunder Bay (Station 10050, Figure 10)) (Fisheries and Oceans Canada, 2005) was summarized for the survey periods of September 9, 2004 and October 23-26, 2004. Elevations at the station varied 16 cm, ranging from 0.21 m to 0.37 m above chart datum.

A spatial raster model of the bathymetric data was generated using the nearest neighbour algorithm of the 3D Analyst extension of ArcGIS © (Environmental Systems Research Institute Inc (ESRI)). The 3D model provides both a spatial context for the substrate data as well as identifying submarine topographical features that may modify the expected acoustic return data. Surfer ® (Golden Software) was used for spatial rendering of the turning basin using the default Kriging algorithm.

Substrate Mapping – RoxAnn

RoxAnn data were edited using spreadsheet macros to remove records for which the actual water depths were less than 2 m; two meters is the shallow-water limit of the high-frequency RoxAnn system. The deep water limit of 40 m for the high frequency was not an issue for this survey. The data was further edited to remove soundings that were collected at boat speeds of less than 2 m.s^{-1} or greater than 5 m.s^{-1} . Vessel speeds outside the 2 to 5 m.s^{-1} range can result in shifts of RoxAnn labels to coarser and harder sediment classes than are actually present (N. Rukavina, personal comm.). Air bubbles or eddies under the vessel's hull compromise the RoxAnn signal integrity and are sometimes encountered when the velocities exceed the upper limit of speed range or when the seas are too rough. This processing resulted in a dataset of 62,630 soundings for the area covered during this survey.

The dataset was further edited to remove soundings when the standard deviation of DGPS position solution, as recorded in the NMEA GPGST string, was greater than 5.0 m for either the latitude or longitude coordinate. As the position data was recorded every second and the quality of the DGPS solution was logged every 10 seconds the data was edited in GIS rather than eliminating matching records. The GPGST dataset was edited to only include positions that had a position standard deviation greater than 5.0 m. A buffer was created around each position of the selected GPGST points that overlapped along the direction of the track line. Soundings that were included within the buffer (n=450) were deleted from the dataset.

The final edited data for substrate mapping resulted in 62,180 soundings. The dataset was imported into Systat ® (Version 11, Systat Software Inc.) a Windows based statistical software package. The records were then clustered using the Systat K-means procedure with Euclidean distance as the distance metric and number of iterations set to 20. Several combinations were tested using G1, G2 as the variables and the number of clusters was varied from 6 to 9.

The dataset and the cluster identifier file were merged and exported into an ArcGIS ArcMap ® (Environmental Systems Research Institute Inc (ESRI)) readable format. The cluster identifier was then mapped as a substrate class in an ArcMap GIS project. The substrate label was determined by comparing substrate class with the images of the substrate, which were extracted from the underwater video records. As previously noted the quality of the video was limited due to the poor visibility; however 59 sites did provide some information with the September video being superior to that recorded in October. Each site was matched to the nearest RoxAnn sounding that was within a 3-5 m radius. The ArcMap "Hyperlink" feature was used to make direct visual comparisons of the substrate label and the substrate image (Figure 11). The grain size analysis from the 24 sediment samples (Appendix 1) was also compared with the substrate labels and the images.

Generally, there was fairly good correspondence between the range of the RoxAnn signals and the substrate types that could be observed and the results of the Shipek samples. The correspondence was further improved when the G1 and G2 values were \log_{10} transformed and then analyzed with the K-means procedure. The best agreement of the groupings of the acoustic values with the video sites and sediment samples was an 8 cluster \log_{10} transformed dataset (Figure 12). Acoustic cluster values were translated to substrate classes based on the

characteristics of the substrate and video information.

Spatial analysis

To quantify the areal distribution of the substrates, the classified RoxAnn data was ingressed into MapViewer® (Golden Software Inc.) as the data source for generating Thiessen polygons. The procedure creates polygon boundaries from point data such that a region is drawn around each point and every element of the boundary of that region is closer to that point than to any other point. The polygons were then assigned the substrate classification of the associated point data. The boundaries of the analysis were limited to the nearshore extents of the edited soundings.

As the extent of an individual Thiessen polygon is an extrapolation to the boundary of the adjacent polygon, the accuracy of the substrate area estimates can be affected by distance offset between track lines and the degree of natural variability of the underwater features. Areas such as the mud and muddy sand regions in the deeper waters tend to be uniform over large areas and are well represented with the Thiessen polygon procedure. The nearshore areas are often more heterogeneous which is often captured with tighter survey patterns and hence smaller polygons and shorter distances to extrapolate. It is possible that there may be features that were not detected, but based on the sounding coverage from this survey, the Thiessen polygon method is expected to provide a reliable estimate of the distribution of the substrate types based on the classification techniques employed. The resulting polygon themes were ingressed into ArcMap for further processing and integration with other thematic data.

Results and Discussion

Bathymetry of the River

The surveyed extent of the river has two very distinct sections, the meandering upstream reach and lower reach, subdivided in this report to middle and lower reaches, that have been modified for commercial marine transport. The meanders of the upstream section essentially double the length of the river reach to 10 km from the straight line distance of 5 km (upstream extent of survey to downstream boundary of upstream section). These meanders have characteristic water depth profiles with deeper water on the outer boundary of the arc (Figure 13).

Water depths (median 3.3 m, max = 8.9) were much shallower than those measured for the middle and lower reaches (median = 6.6 and 7.8, max = 11.8 and 11.4) respectively. It needs to be noted that these values are biased as the minimum survey depth was limited to 2 m that excludes proportionally more area of the upstream reach of the river.

The middle and lower sections of the survey area were typical of an engineered system for commercial marine transport and has industries located along the shores (Figures 14 and 15). There was little variation in the main channel bathymetry. Shoreline sections that had industrial buildings immediately adjacent to the river often had wharves and therefore a maintained depth up to shoreline. Several of the buildings immediately adjacent to the river were in extreme disrepair and it was evident at some sites that building material was falling into the river.

The turning basin, which is the upstream extent for navigation of ship traffic, has a unique bathymetric feature in that there is a submerged bar which extends into the basin from the upstream reach of the river. There is an adjacent deep pool along the west side of this bar (Figure 16).

Substrate Classification

Based on the survey techniques employed the substrate can best be described when divided into 8 clusters that were congruent with the ground-truth sampling results. These classes represent the substrate groups:

1. mud (silt=clay)
2. mud (silt > clay)
3. mud (acoustically hard)
4. sand
5. coarse sand - pebble
6. gravel-sand mix
7. cobble
8. clay

Upstream Reach

This 10 km stretch is characteristic of hydraulic sorting of the river bottom substrate. The deeper scoured regions that would be subject to higher energy during high flow events such as spring run-off, are predominantly coarse sand pebble mix along the outer boundary of the arch. Sand substrate lines the lower energy side of the channel (Figure 17).

Cobble contacts along the outer edge of the large meander are the in-water toe of rock armouring that has been installed at the base of a high river bank that has had substantial erosion in the past (Figures 18). Significant amounts of cobble are also encountered in the main channel further downstream where the river direction changes over 180°. Cobble along the shore in the lower extent of the upstream reach just before the turning basin may be due to shoreline armouring, while the main channel cobble may be attributed to river sorting or transport (Figure 17). The water at the toe of the banks was often littered with trees and other debris that had slid into the water when the banks slumped (Figure 18).

In several locations clay was encountered, generally where the river had cut into the clay banks along the shore and the clay was from either the toe or slump of the river banks (Figure 18).

The Middle Reach

The turning basin marks a rapid transition from the shallow upstream reach to the engineered channel characteristic of the remainder of the river. The basin's dominant feature is a submerged bar of coarse sand and large gravel that extends across the basin (Figure 19). This substrate appears to be bedload material that has accumulated from successive upstream high flow events that would have transported this coarser material. The remainder of this section of the river substrate is mud. While the significance is unknown, there was a consistent discrimination between muds that had approximately equal portions of silt and clay and those muds that had higher silt content. Small isolated patches of coarser substrate were also detected in the immediate vicinity of the bridge abutments indicating a higher energy zone as the water is deflected (Figure 20).

As an aside, it is interesting to note that sediment site KR0410-19 located at the upstream extent of the turning basin (Figure 9) was the only site of the 24 sampled to have visible burrows in the sediment (Site KR0410-19, Appendix 1).

The Lower Reach

This section is also predominantly muds. Acoustically hard mud was a dominant feature of the Kaministiquia River channel and was also encountered to a lesser extent in the Mission River. This is typically the result of the sediment having high gas content which increases the reflectivity of the substrate, making it appear harder. Gas bubbles were noted at the surface for some of the sites in this area when sediment samples were collected. Unfortunately video confirmation was not possible due to poor visibility. The substrate changes to coarser sediment at the mouths of all 3 rivers, consistent with higher wave energy from the lake (Figure 21).

Spatial Analysis

The Thiessen polygon matrix provides an estimate of the quantity of substrate types as defined in this study (Figures 22-24). The data included in table 4 summarizes the distribution of the substrate type by study reach. As previously noted the substrate distribution is very different from the upstream reach when compared to the middle and lower river sections.

Summary

The Kaministiquia River is a very different river in the upstream reach when compared to the middle and lower sections studied during this survey. The natural meanders upstream reach contrasts with the middle and lower reaches that that been dramatically modified to accommodate commercial marine transport. As a consequence, the upstream reach has a range of substrates ranging from sands to coarser material including pebbles, cobble and rock whereas the middle and lower reaches are predominantly muds.

A highlight of the survey was the mapping and description of the submerged bar of sand and coarse gravel in the turning basin. The coarse substrate was found to extend to the opposite shore of the turning basin beyond the extent of the bathymetric profile of the bar. This feature is located in the area utilized by radio-tagged sturgeon during the summer.

This effort is the first undertaken to describe the river bottom substrate for the Kaministiquia River. It is anticipated that it will contribute to the understanding habitat requirements and availability for valued aquatic species.

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Tables:

Table 1: Survey Effort

Table 2: Location of Underwater Video Sites.

Table 3: Location of Sediment Sample Sites

Table 4: Areal Coverage of Substrate Classes for Kaministiquia River Study Area.

Table 1: Survey Effort.

RoxAnn Sounding Tracks								
Collection Date	Raw Start Time	Raw Finish Time	Number of Records			Distance Covered (km)		
			Raw	RoxAnn Edited	Bathymetry Edited	Raw	RoxAnn Edited	Bathymetry Edited
2004-09-09	09:11:22	17:54:58	25081	20068	24288	94.51	76.98	84.80
2004-10-23	09:45:34	16:47:32	18342	16942	18173	83.46	79.11	82.98
2004-10-24	09:16:44	15:41:32	14040	12562	13880	77.26	68.82	76.34
2004-10-25	09:21:20	15:13:22	12628	11731	12536	74.79	63.03	72.36
2004-10-26	09:24:26	13:25:28	4640	4381	4567	27.40	23.51	25.25
		Total:	74731	65684	73444	357.42	311.45	341.73

Video Sounding Tracks								
Collection Date	Raw Start Time	Raw Finish Time	Number of Records			Distance Covered (km)		
			Raw	RoxAnn Edited	Bathymetry Edited	Raw	RoxAnn Edited	Bathymetry Edited
2004-10-26	13:25:30	17:29:58	9797	N/A	N/A	21.69	N/A	N/A
2004-10-27	08:24:10	16:22:51	26095	N/A	N/A	55.70	N/A	N/A
		Total:	35892	N/A	N/A	77.39	N/A	N/A

Table 2: Location of Underwater Video Sites.

Site	Date	Easting	Northing
409-001-1	2004-09-10	329654	5358161
409-002-1	2004-09-10	326624	5356490
409-004-1	2004-09-10	326878	5356608
409-004-2	2004-09-10	326874	5356600
409-004-3	2004-09-10	326865	5356590
409-005-1	2004-09-10	326829	5356587
409-006-1	2004-09-10	326814	5356592
409-006-2	2004-09-10	326820	5356586
409-007-1	2004-09-10	326810	5356599
409-008-1	2004-09-10	326668	5356458
409-009-1	2004-09-10	326632	5356453
409-009-2	2004-09-10	326618	5356454
409-010-1	2004-09-10	326667	5356389
409-010-2	2004-09-10	326664	5356382
409-011-1	2004-09-10	326652	5356354
409-011-2	2004-09-10	326645	5356339
409-012-1	2004-09-10	326763	5356324
409-012-2	2004-09-10	326753	5356275
409-013-1	2004-09-10	326996	5356404
409-014-1	2004-09-10	328547	5357426
409-014-2	2004-09-10	328560	5357435
409-031-1	2004-10-26	324917	5357064
410-01-1	2004-10-26	328617	5357339
410-02-1	2004-10-26	328825	5357098
410-03-1	2004-10-27	334329	5359821
410-04-1	2004-10-27	333820	5360789
410-05-1	2004-10-26	325904	5357927
410-07-1	2004-10-27	326801	5356870
410-08-1	2004-10-27	326636	5357300
410-09-1	2004-10-26	327802	5357383

Site	Date	Easting	Northing
410-10-1	2004-10-27	334726	5358996
410-11-1	2004-10-26	325903	5357929
410-12-1	2004-10-26	326907	5356899
410-13-1	2004-10-26	325671	5357508
410-14-1	2004-10-26	326252	5358041
410-15-1	2004-10-26	329580	5357929
410-16-1	2004-10-26	329963	5358102
410-17-1	2004-10-27	335204	5362014
410-18-1	2004-10-27	335816	5362230
410-19-1	2004-10-26	329321	5357779
410-20-1	2004-10-26	329681	5358147
410-21-1	2004-10-26	330312	5358432
410-21-2	2004-10-27	330310	5358432
410-22-1	2004-10-27	332690	5359072
410-23-1	2004-10-27	335835	5360571
410-24-1	2004-10-27	334153	5359785
410-26-1	2004-10-26	327115	5357637
410-27-1	2004-10-26	326657	5356917
410-28-1	2004-10-26	326617	5356399
410-29-1	2004-10-26	327821	5357445
410-30-1	2004-10-26	328999	5357202
410-31-1	2004-10-26	324918	5357063
410-32-1	2004-10-26	324952	5357026
410-33-1	2004-10-26	327134	5358064
410-33-2	2004-10-26	327129	5358058
410-34-4	2004-10-26	327150	5357689
410-35-1	2004-10-26	326781	5356263
410-35-2	2004-10-26	326781	5356266
410-36-1	2004-10-26	326626	5356389

Table 3: Location of Sediment Sample Sites.

Site	Date	Easting	Northing
3	2004-10-27	334330	5359819
5a	2004-10-27	326116	5358051
6	2004-10-27	326847	5358290
6a	2004-10-27	326849	5358291
7	2004-10-27	326798	5356870
8	2004-10-27	326634	5357301
9	2004-10-27	327802	5357384
10	2004-10-27	334728	5358995
11	2004-10-27	325905	5357926
12	2004-10-27	326906	5356897
13	2004-10-27	325671	5357513
15	2004-10-27	329581	5357930
16	2004-10-27	329963	5358105
17	2004-10-27	335206	5362017
18	2004-10-27	335815	5362233
19	2004-10-27	329325	5357779
20	2004-10-27	329679	5358147
22	2004-10-27	332693	5359073
24	2004-10-27	334155	5359785
26	2004-10-27	327111	5357637
27	2004-10-27	326656	5356917
29	2004-10-27	327820	5357448
40	2004-10-27	326813	5356595
41a	2004-10-27	326788	5356552
42	2004-10-27	326727	5356551

Table 4: Areal Coverage of Substrate Classes for Kaministiquia River Study Area.

Substrate Type	Upstream Reach (ha)	Central Reach (ha)	Tributary Reach (ha)	Total (ha)
Mud (Silt=Clay)	0.097	46.377	39.997	86.471
Mud (Silt>Clay)	0.935	22.011	49.767	72.713
Mud (Acoustically Hard)	1.435	4.292	31.479	37.206
Sand	26.769	2.292	5.374	34.436
Coarse Sand-Pebble	31.069	0.241	4.273	35.583
Gravel-Sand Mix	5.690	6.632	13.706	26.028
Cobble	8.878	0.161	5.474	14.513
Clay Bed	4.616	1.642	7.463	13.721
Total	79.489	83.647	157.534	320.670

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- Figure 8: Underwater video.
- Figure 9: Shipek sample sites.
- Figure 10: Thunder Bay water level gauging station 10050.
- Figure 11: Example of Hyperlink matching in ArcGIS.
- Figure 12: Substrate clusters and classification.
- Figure 13: Bathymetry for upper reach section.
- Figure 14: Bathymetry for middle reach section.
- Figure 15: Bathymetry for lower reach section.
- Figure 16: Detailed bathymetry of the turning basin area, Kaministiquia River.
- Figure 17: Classified RoxAnn point data for upper reach section.
- Figure 18: Riverbank features along the upper reach.
- Figure 19: Substrate collected from turning basin bar.
- Figure 20: Classified RoxAnn point data for middle reach section.
- Figure 21: Classified RoxAnn point data for lower reach section.
- Figure 22: Classified RoxAnn polygon data for upper reach section.
- Figure 23: Classified RoxAnn polygon data for middle reach section.
- Figure 24: Classified RoxAnn polygon data for lower reach section.

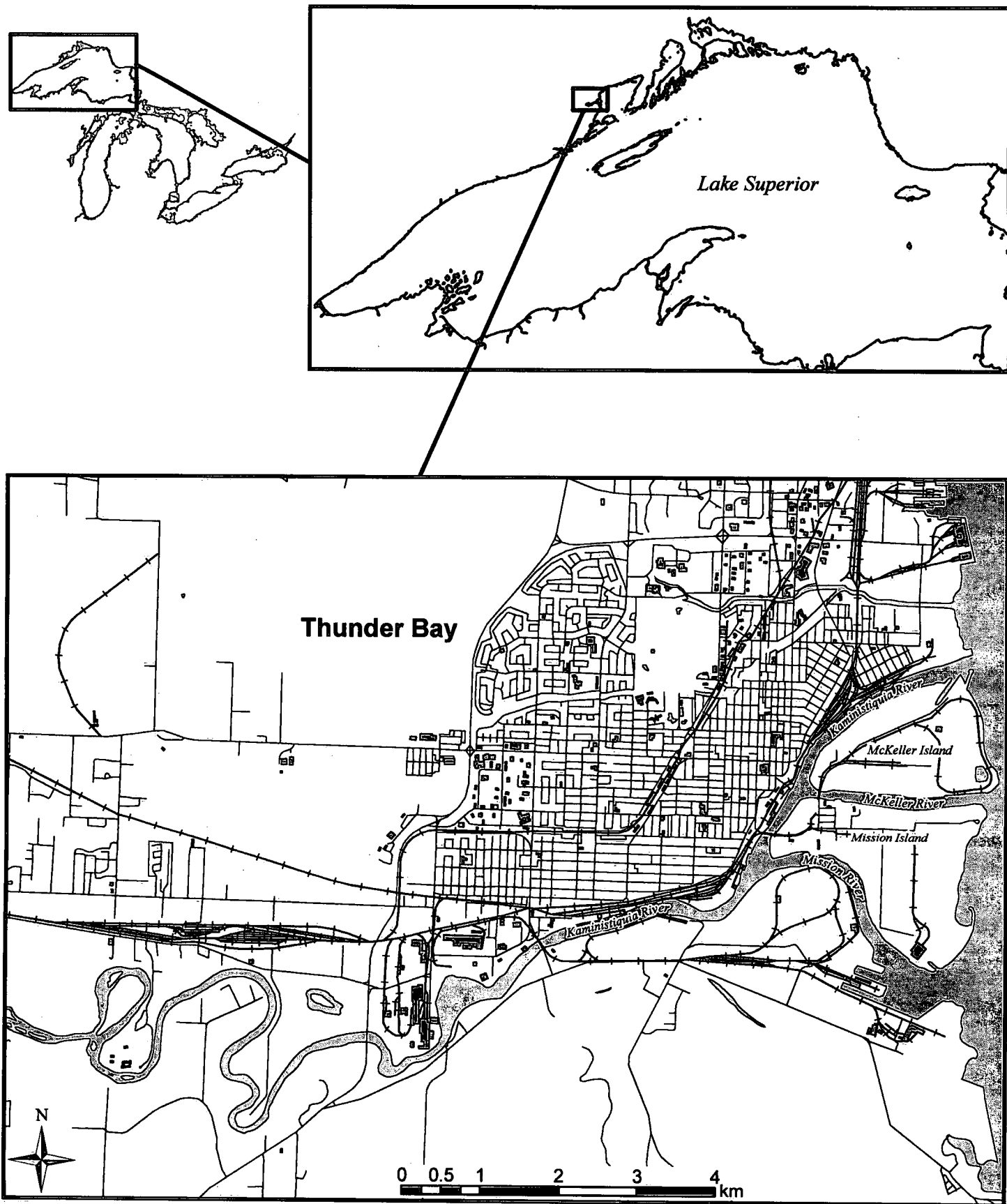


Figure 1: Study Area.

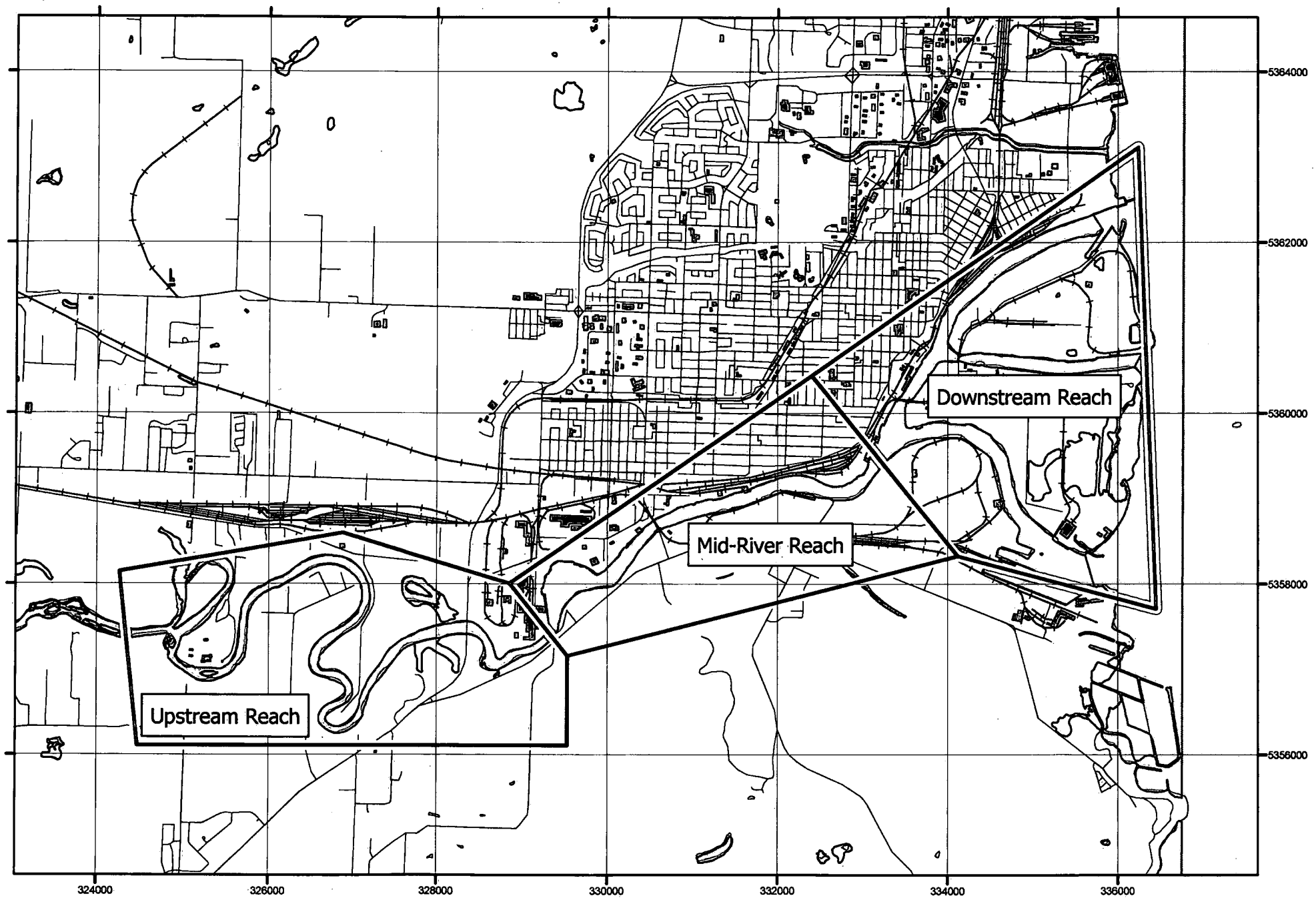


Figure 2: River reaches within the study area.

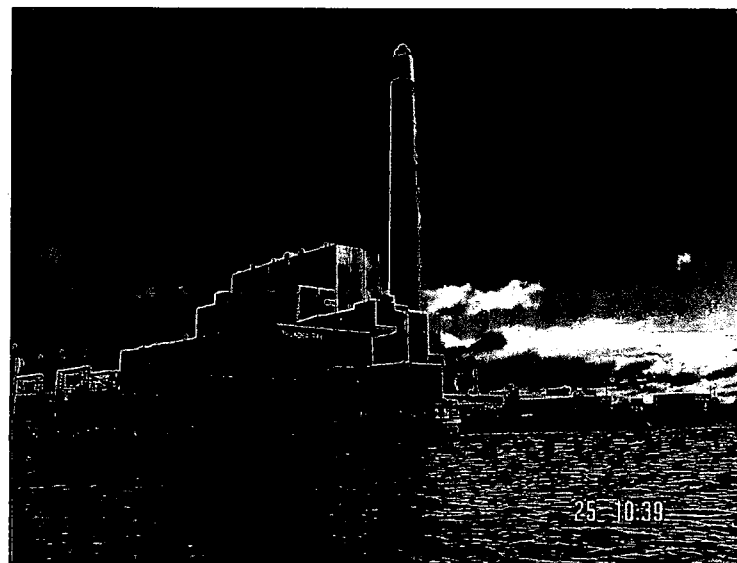
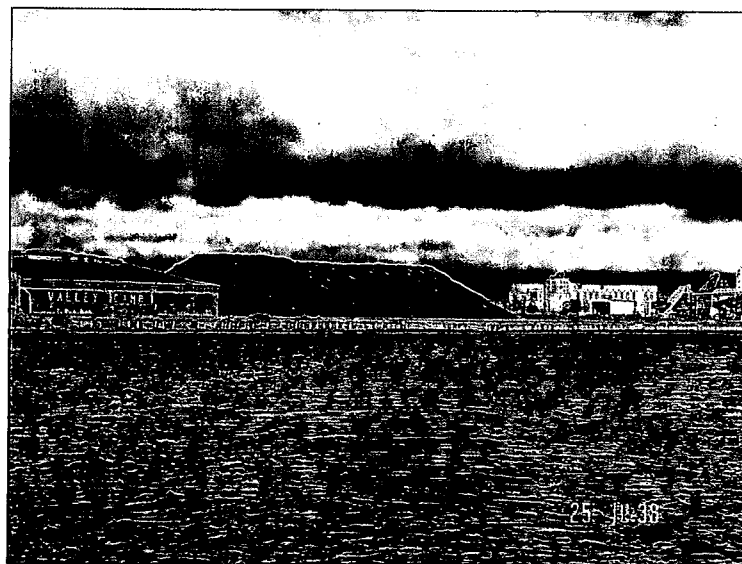
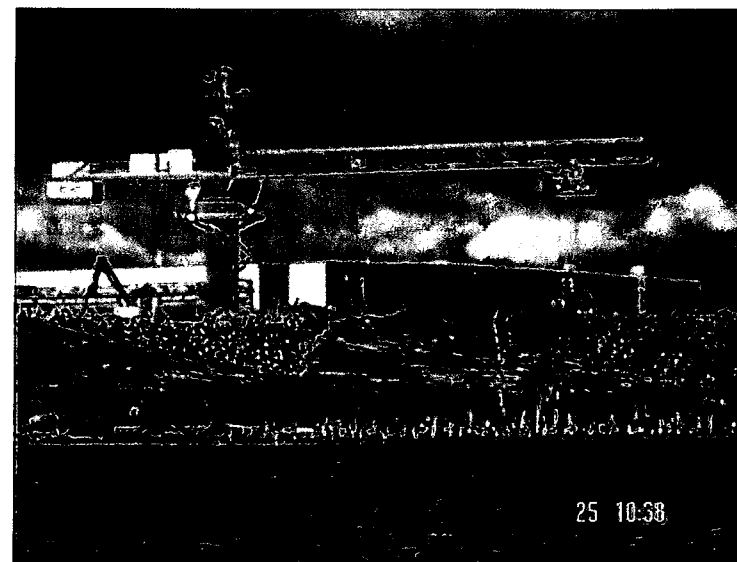
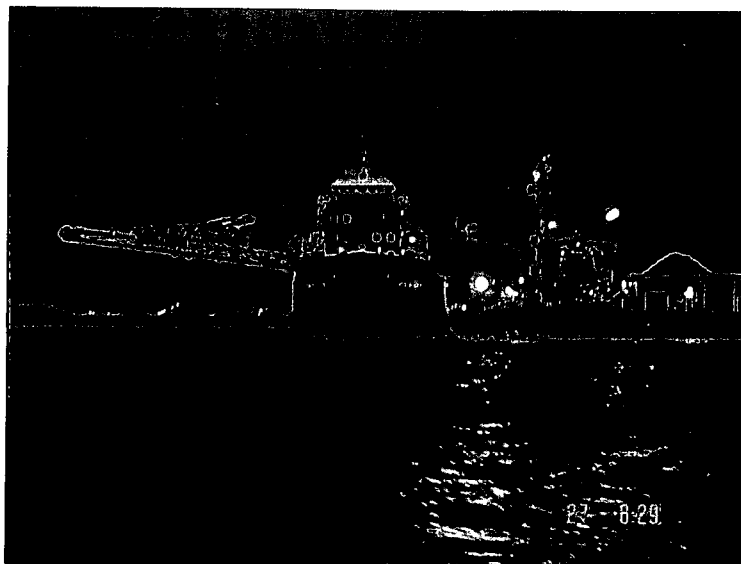
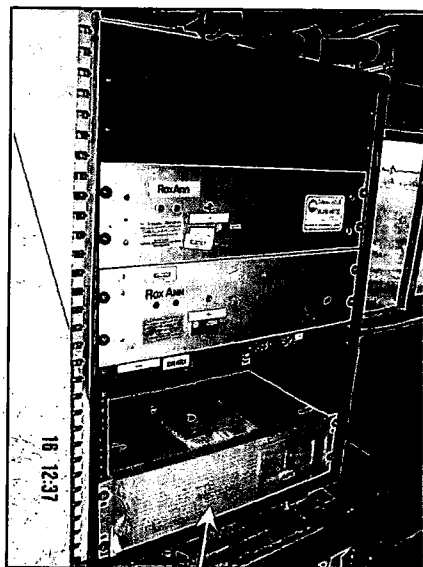


Figure 3: Examples of shoreline activities along the lower reach of the study area.



RoxAnn units
process computer
and stabilized
power supply



Sounder, DGPS and
computers for
navigation and
sounder data
acquisition

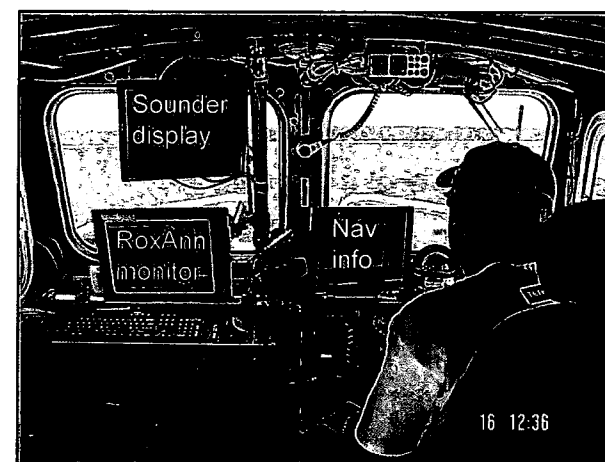
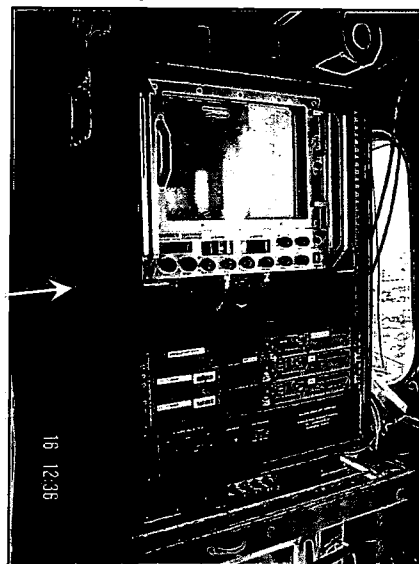


Figure 4: Survey launch configuration

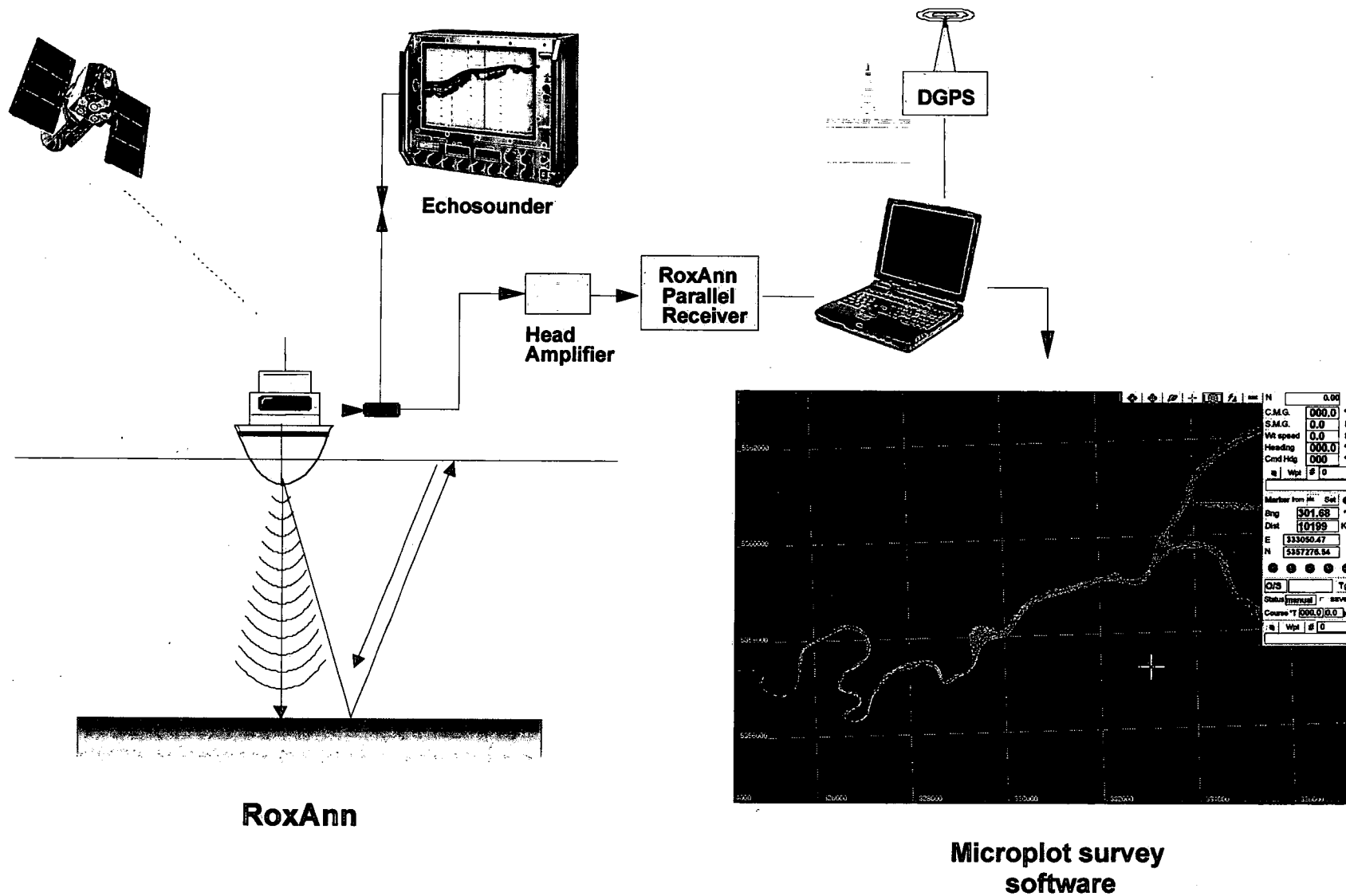


Figure 5: RoxAnn schematic

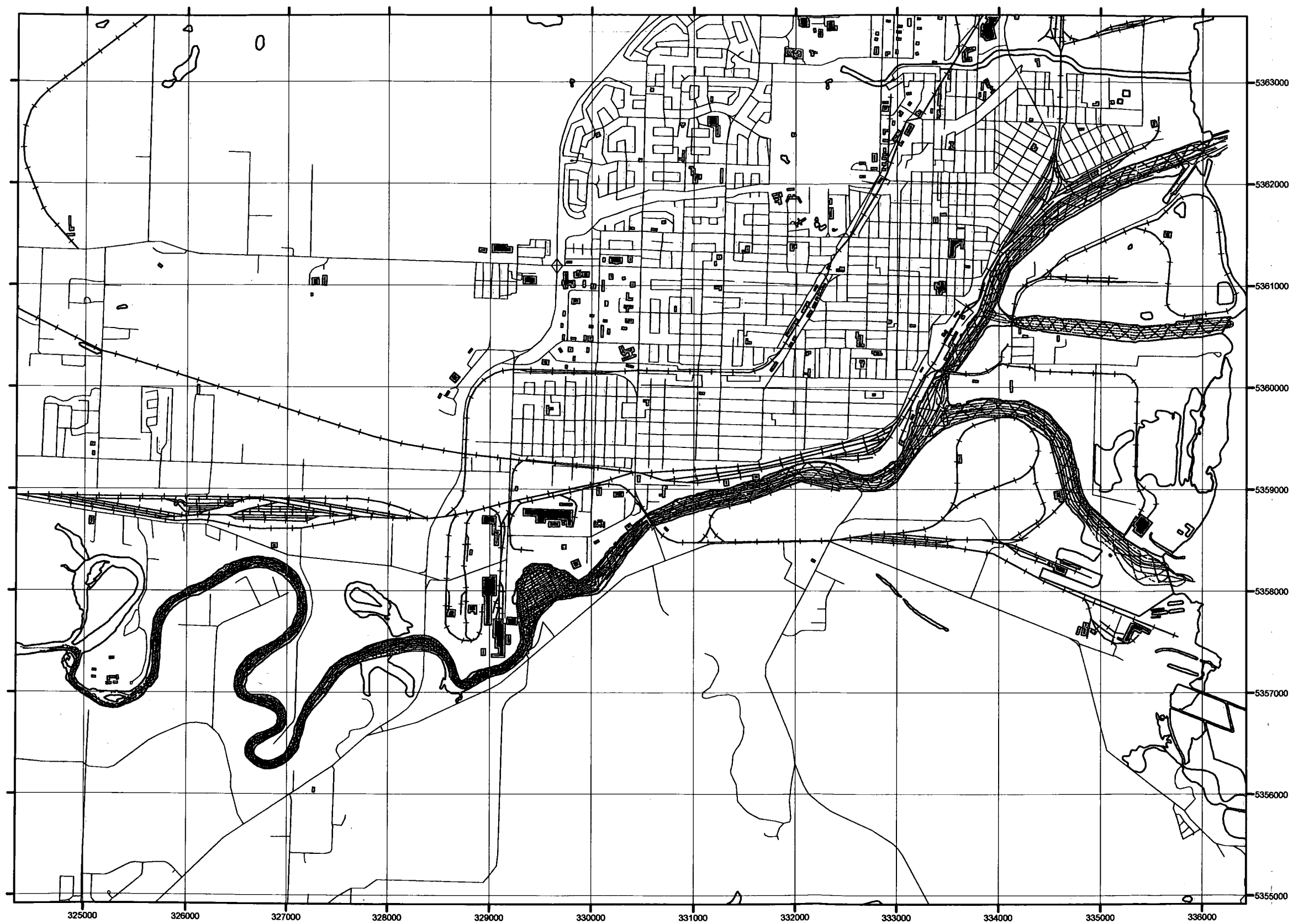
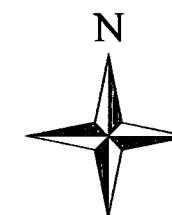
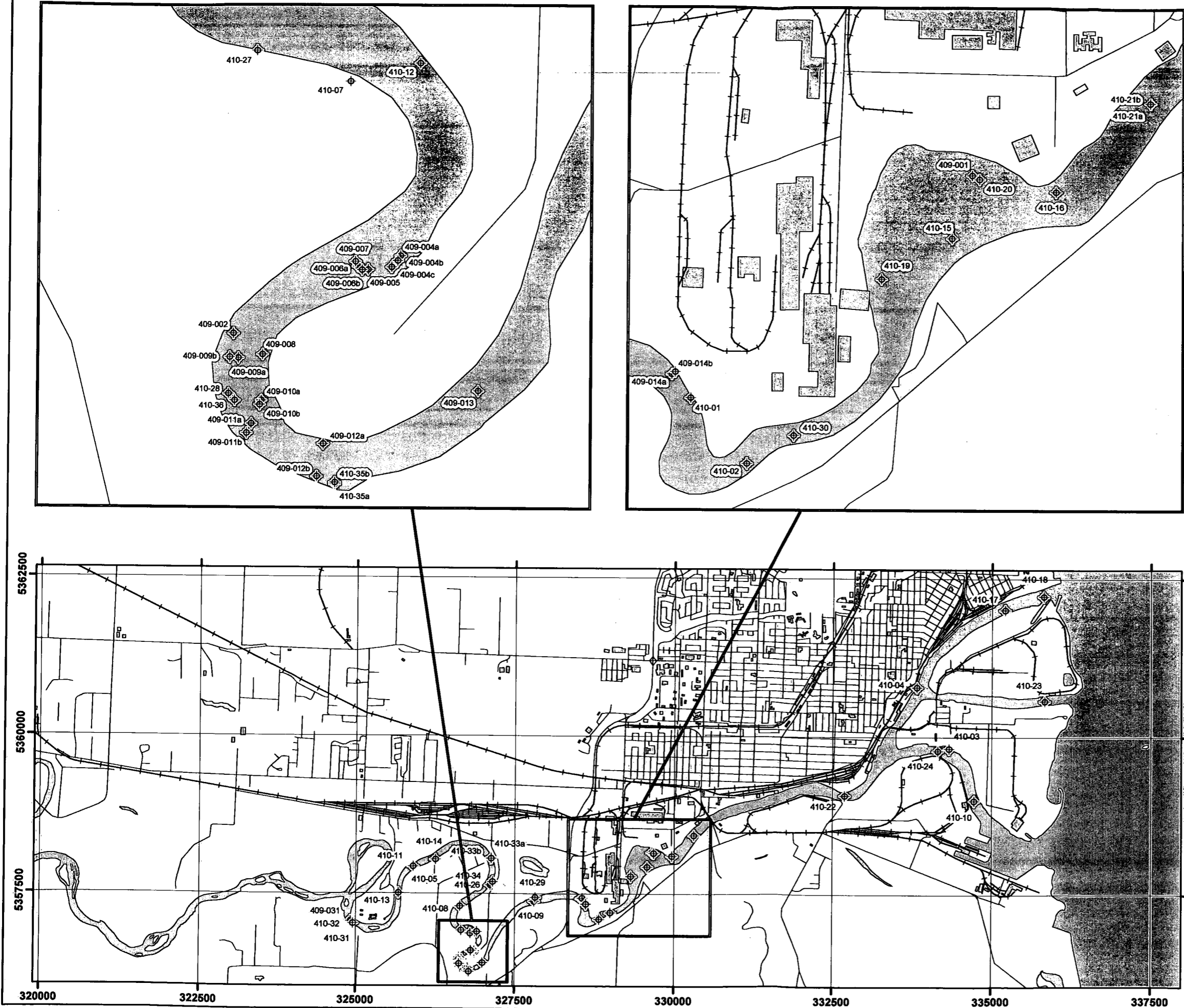


Figure 6: Survey tracklines.



NAD 83 UTM Zone 16

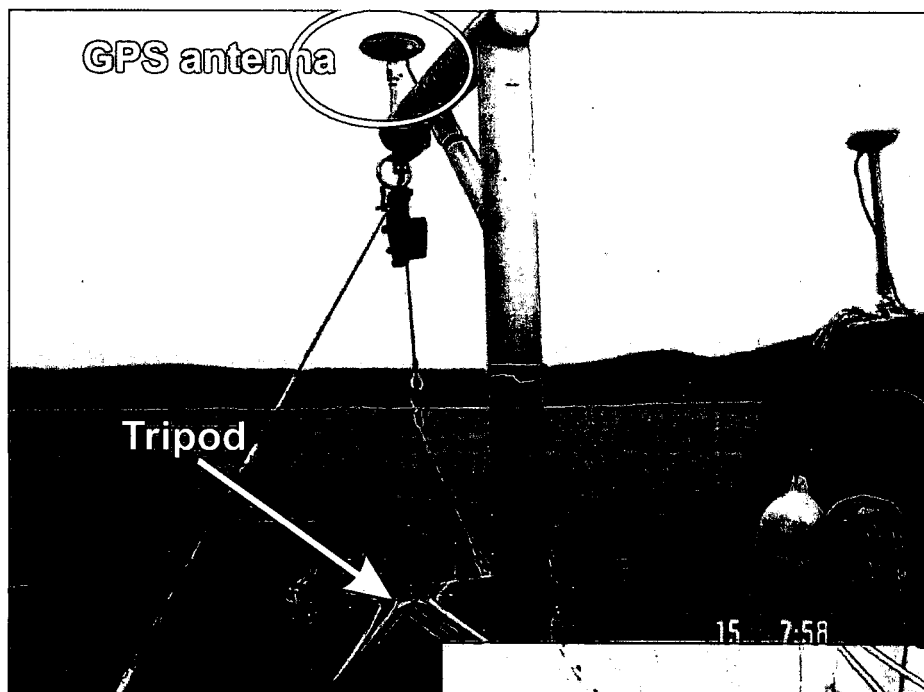
Figure 7: Underwater Video Sites



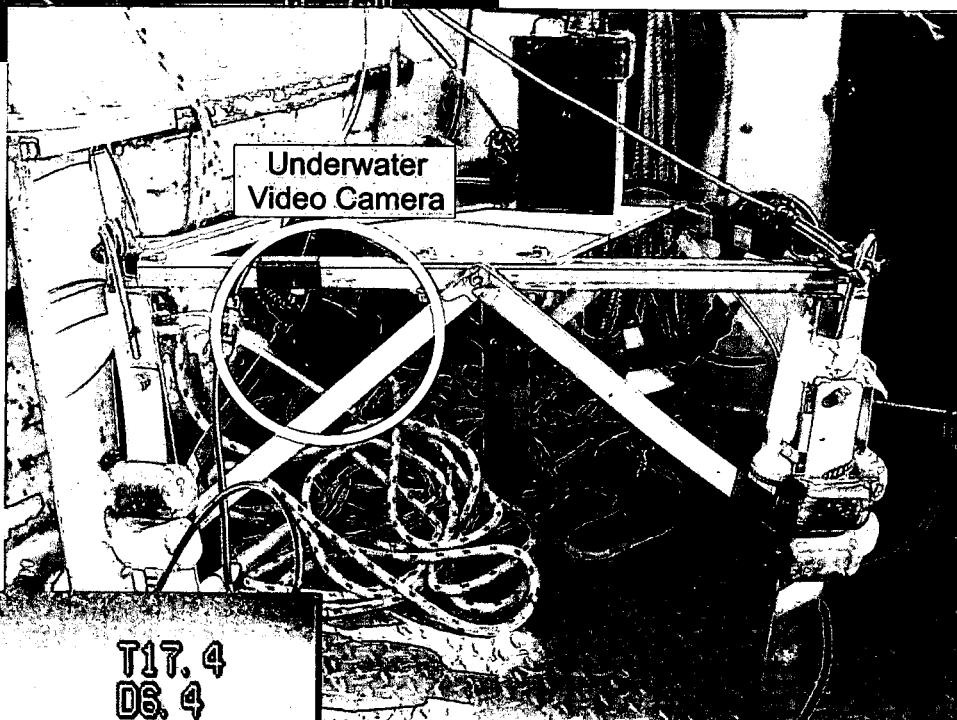
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Legend

- ◆ UWTV Sites
- Roads
- +— Railway
- ▨ Buildings
- Built-up Area
- ▤ Shoreline



Davit setup on Puffin



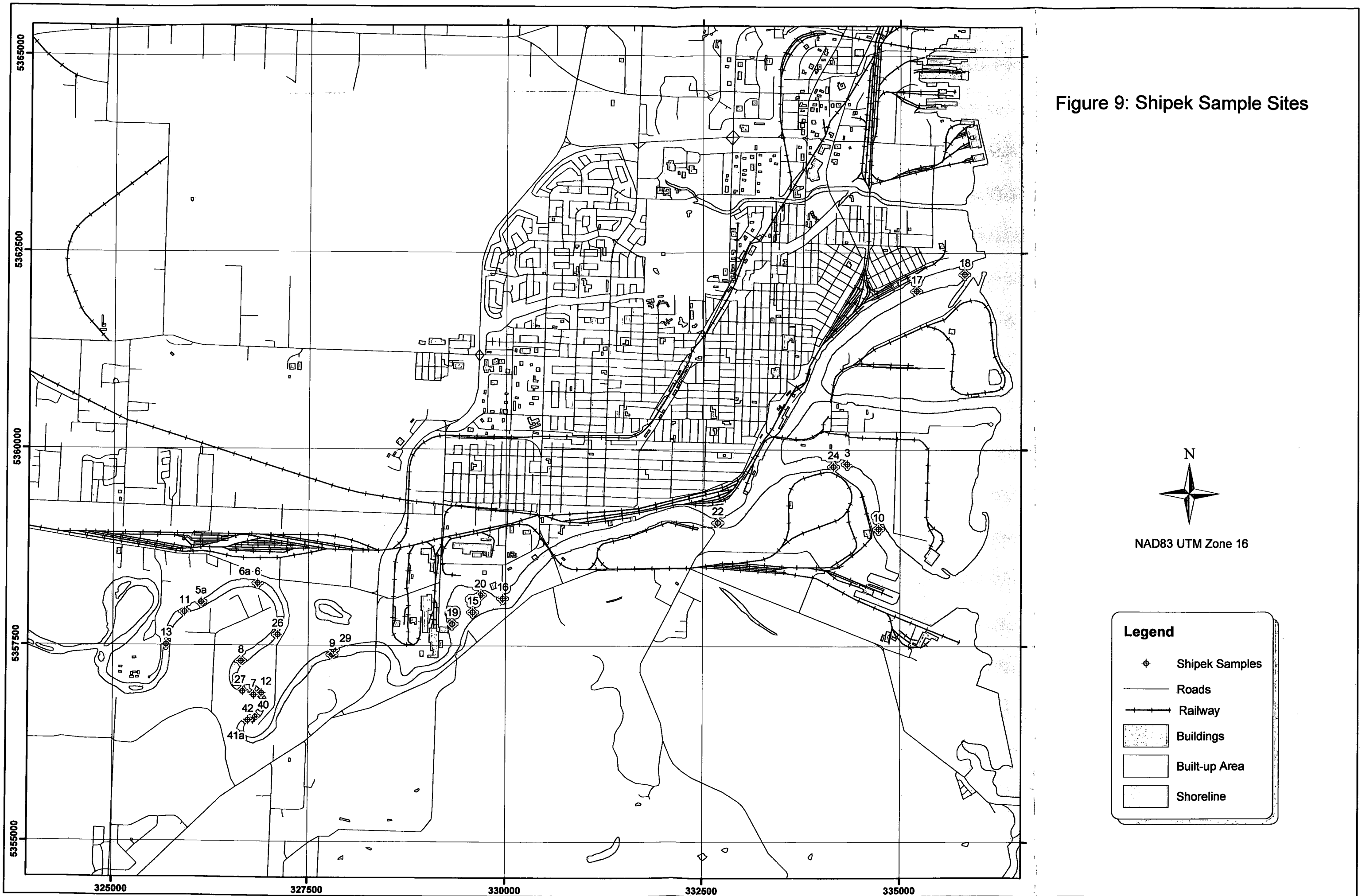
Camera tripod



Video overlay

Figure 8: Underwater video

Figure 9: Shipek Sample Sites



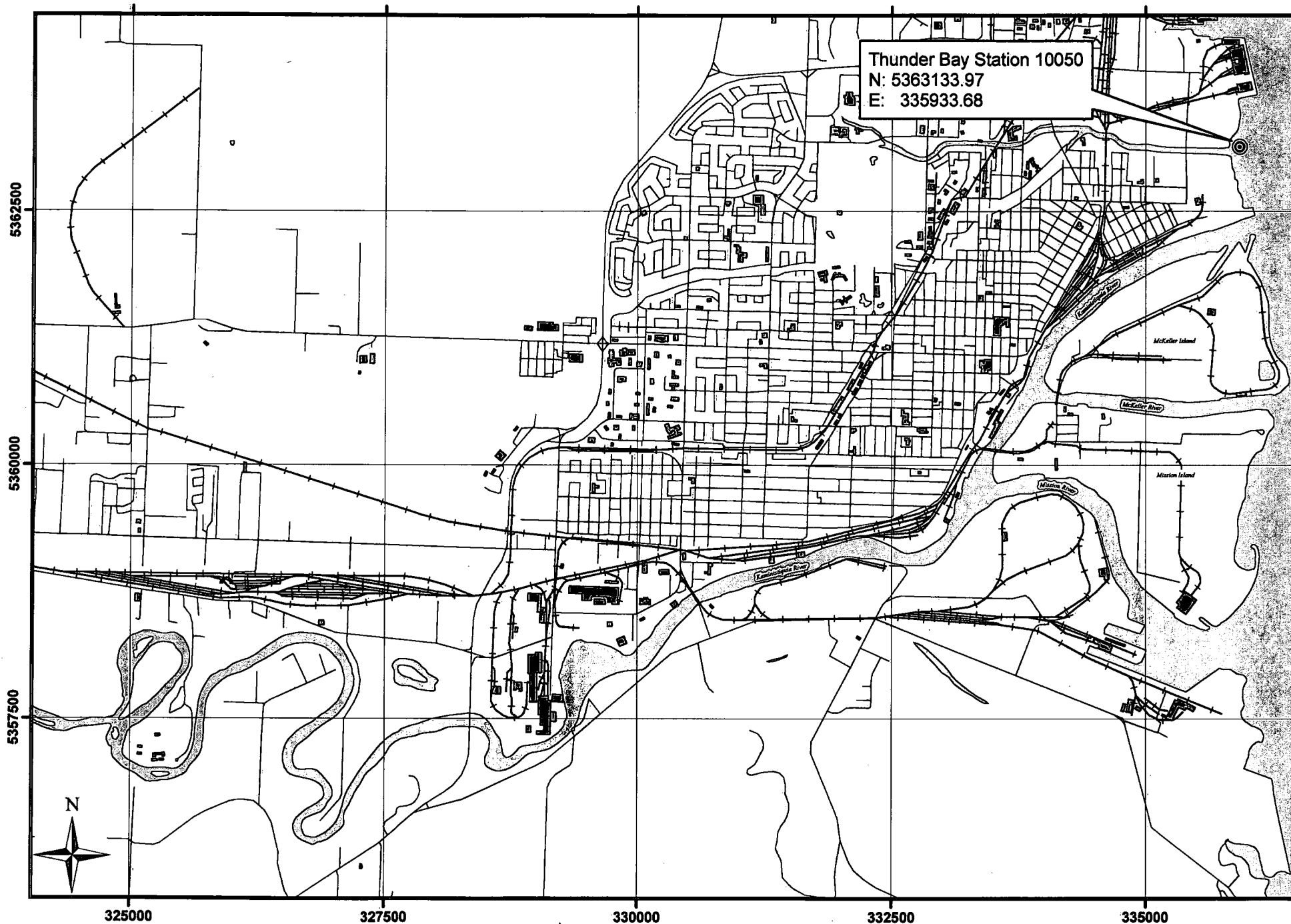


Figure 10: Thunder Bay Water Level Gauging Station 10050.

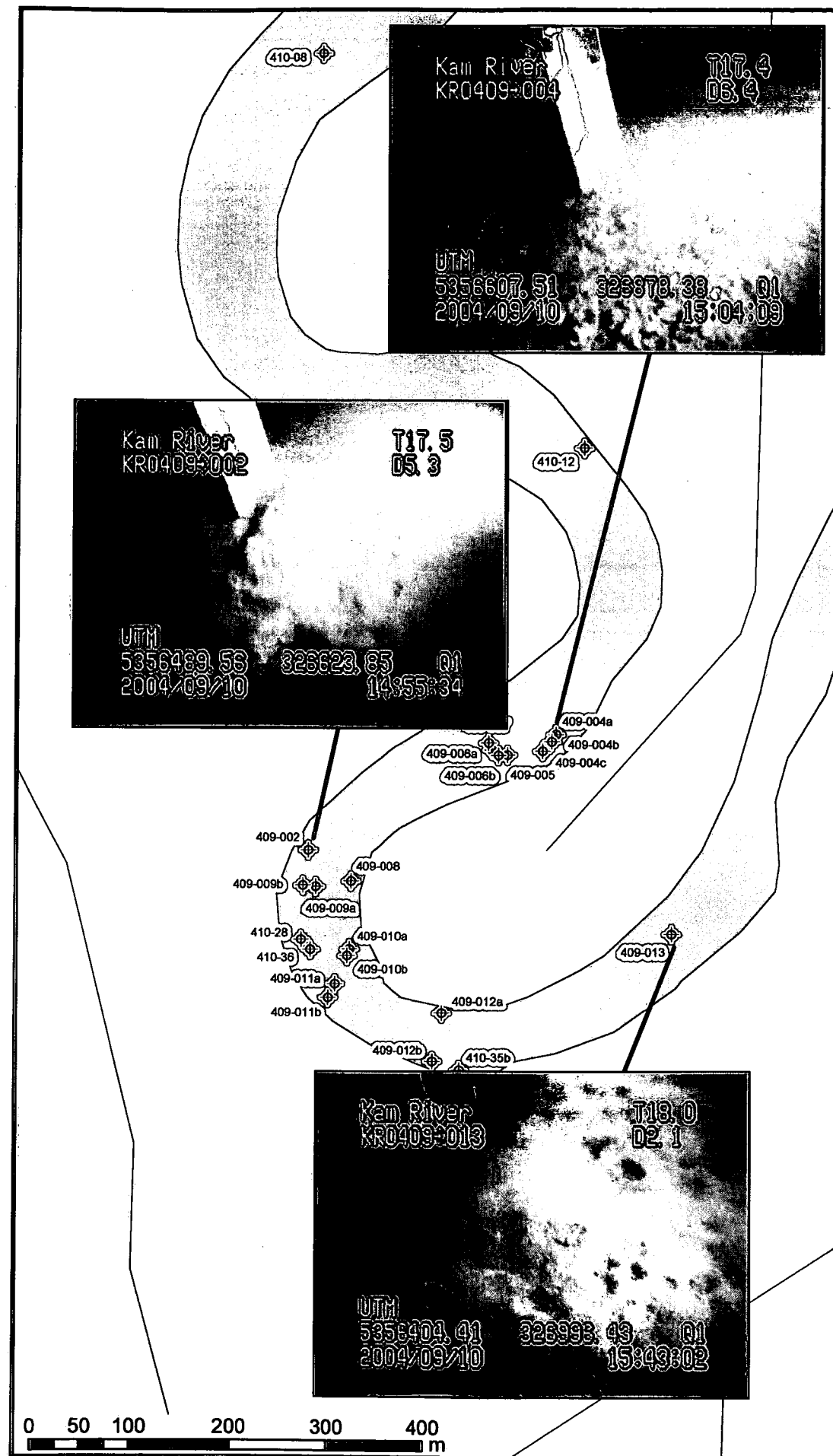

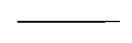
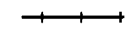





Figure 11: Example of Hyperlink Matching in ArcGIS



NAD83 UTM Zone 16

Legend

-  UWTV Sites
-  Roads
-  Railway
-  Buildings
-  Built-up Area
-  Shoreline

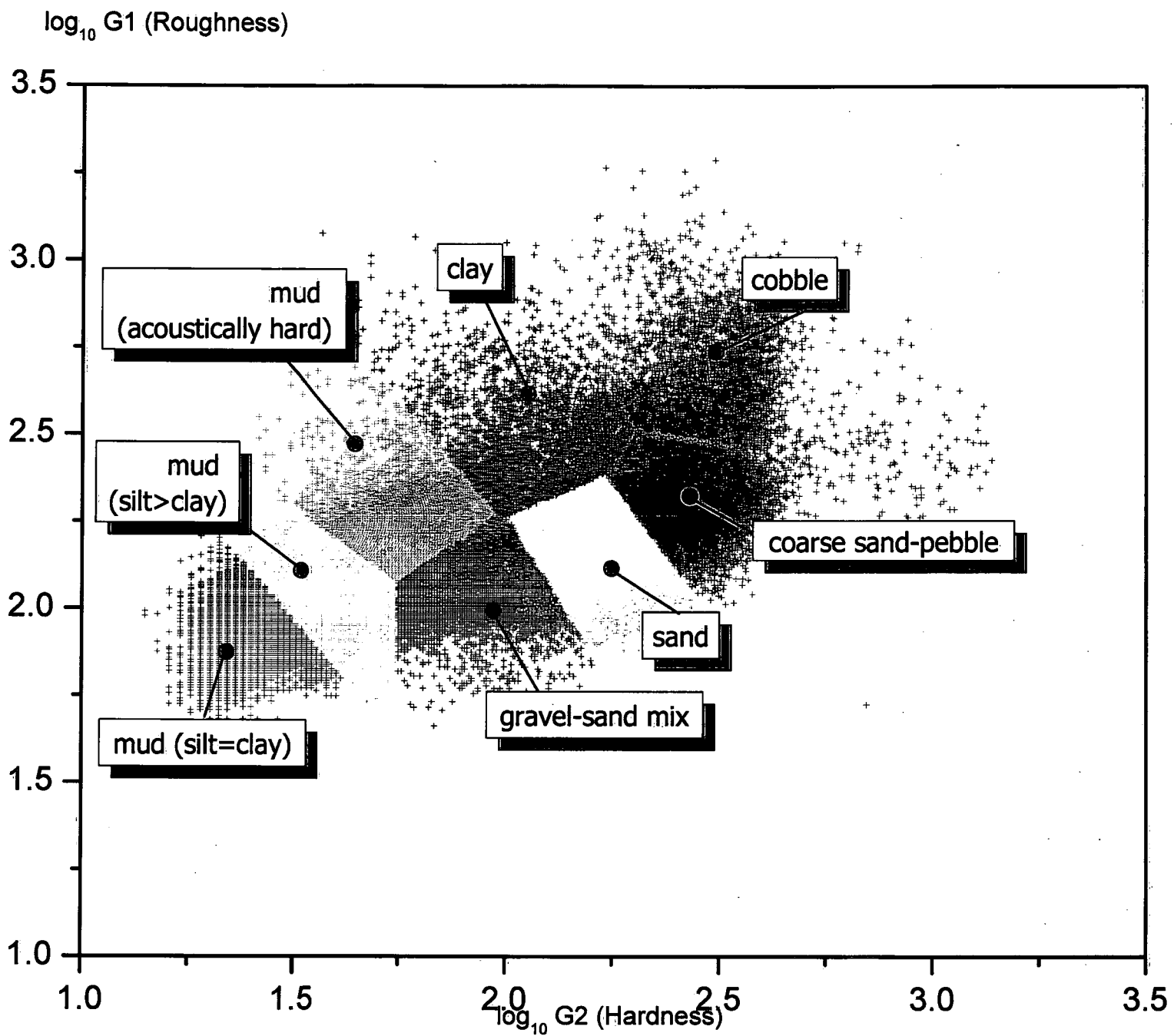
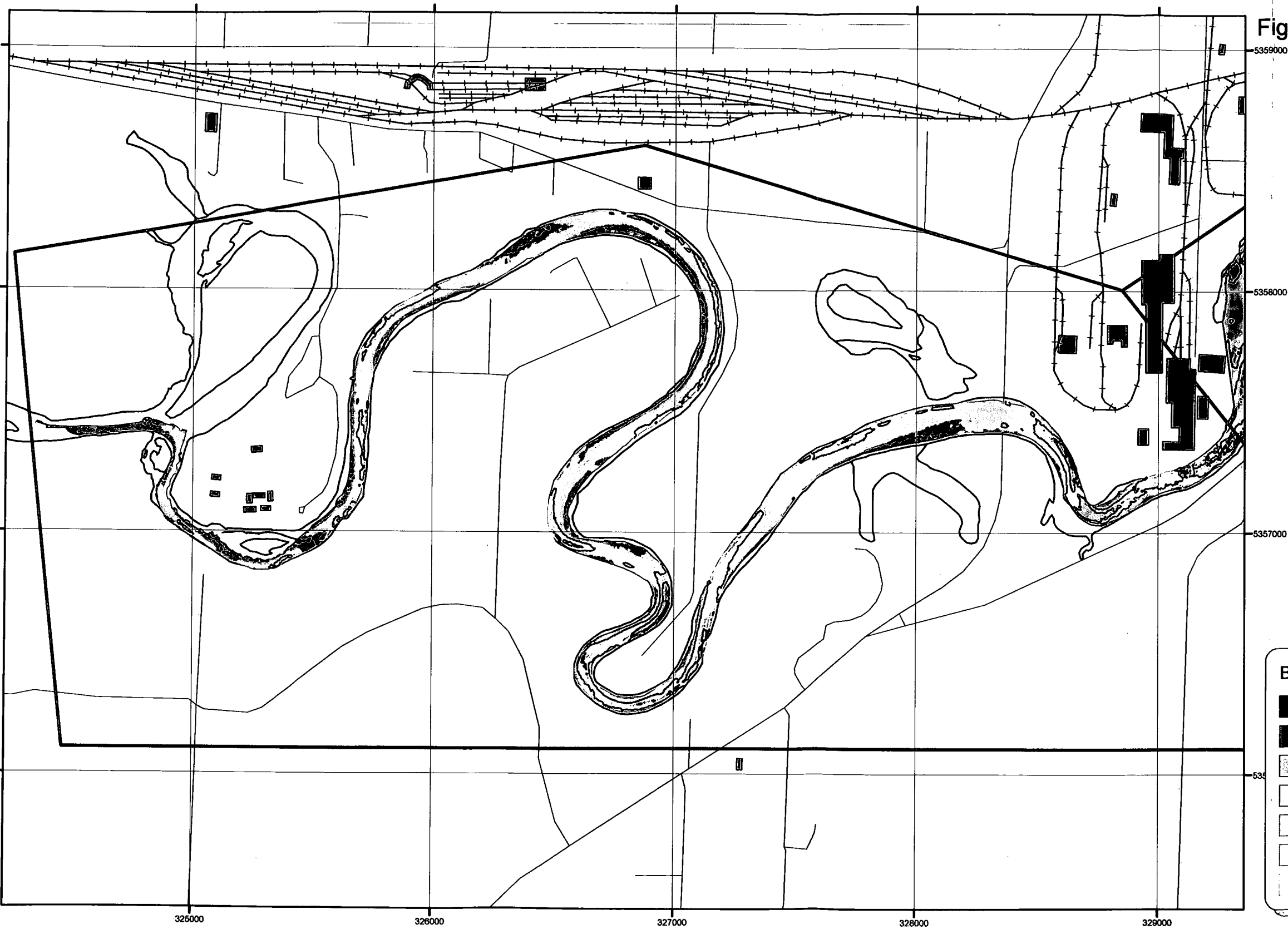


Figure 12: Substrate clusters and classification.

Figure 13: Bathymetry for upper reach section.



NAD 83 UTM Zone 16

Bathymetry

1.5-2.0	5.0-5.5	8.5-9.0
2.0-2.5	5.5-6.0	9.0-9.5
2.5-3.0	6.0-6.5	9.5-10.0
3.0-3.5	6.5-7.0	10.0-10.5
3.5-4.0	7.0-7.5	10.5-11.0
4.0-4.5	7.5-8.0	11.0-11.5
4.5-5.0	8.0-8.5	11.5-12.0

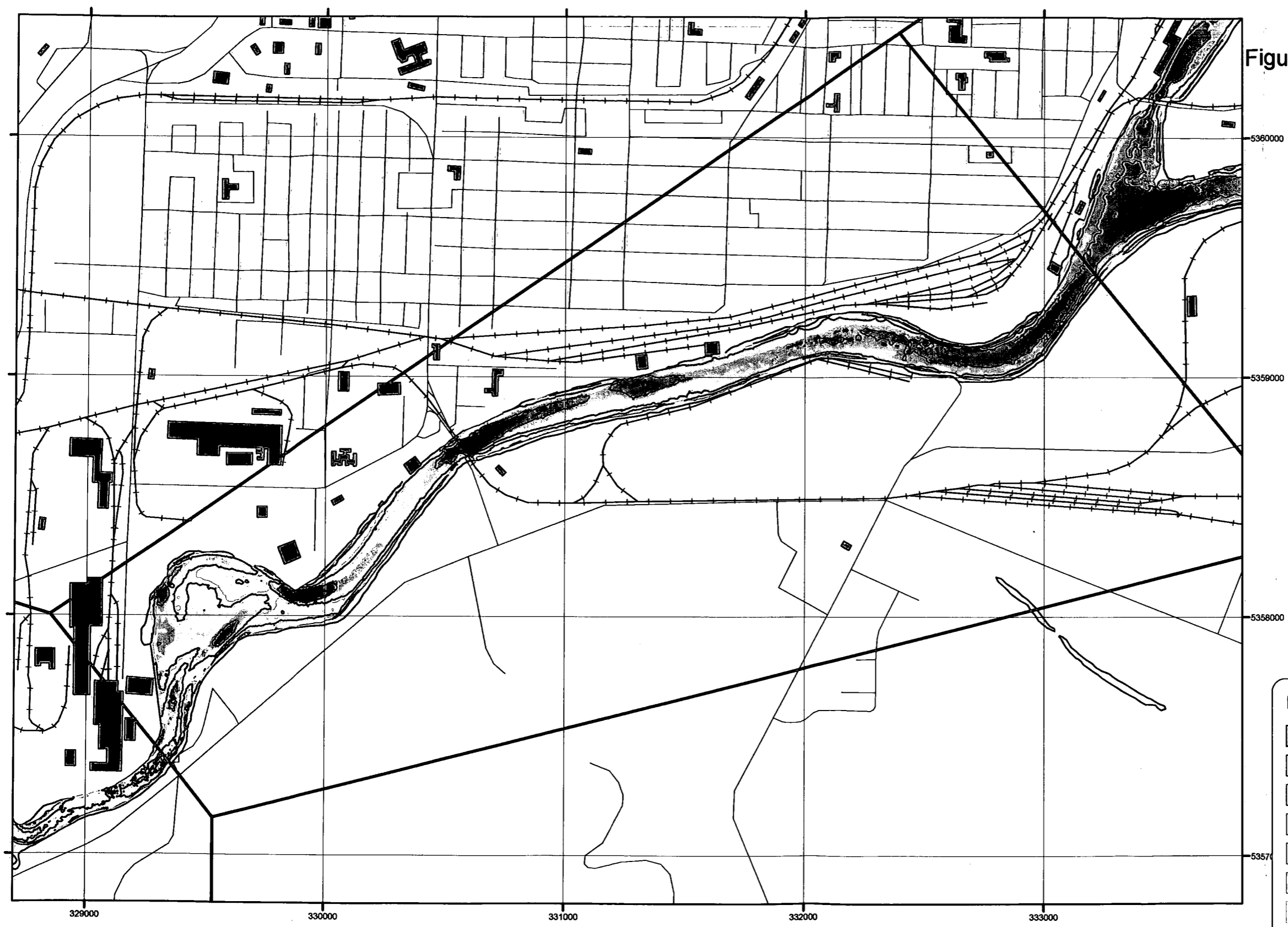
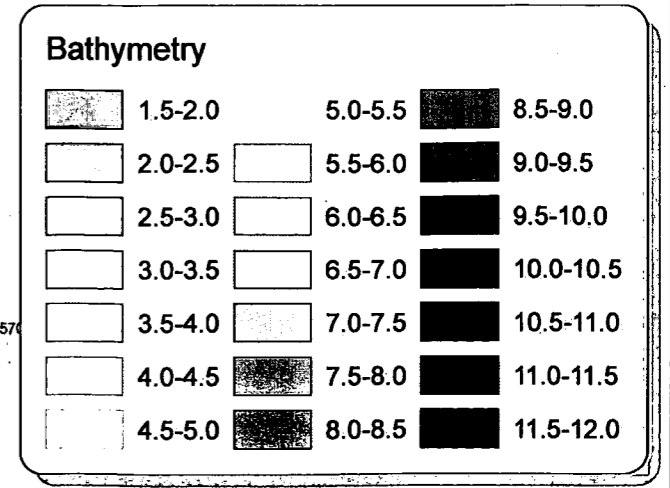


Figure 14: Bathymetry for middle reach section.



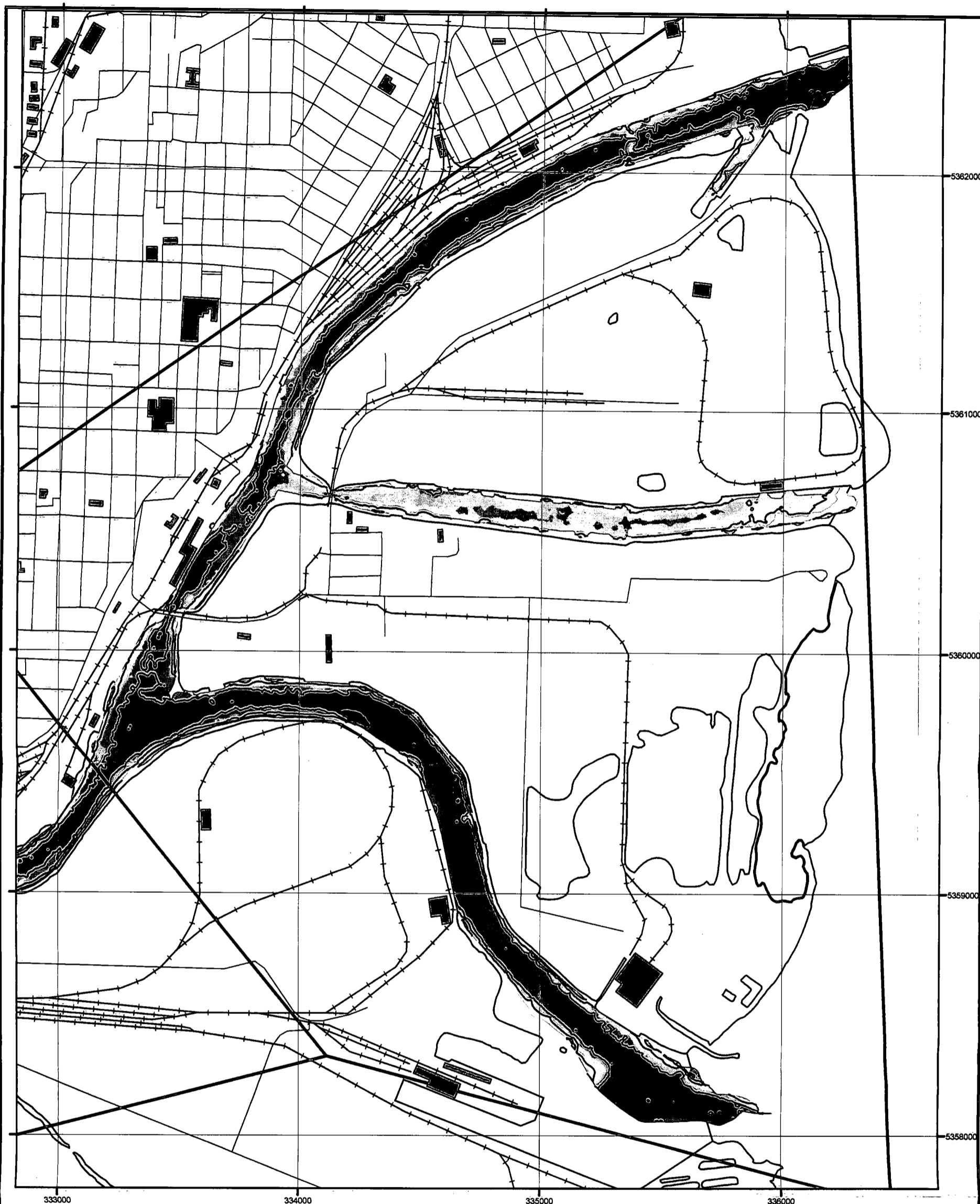


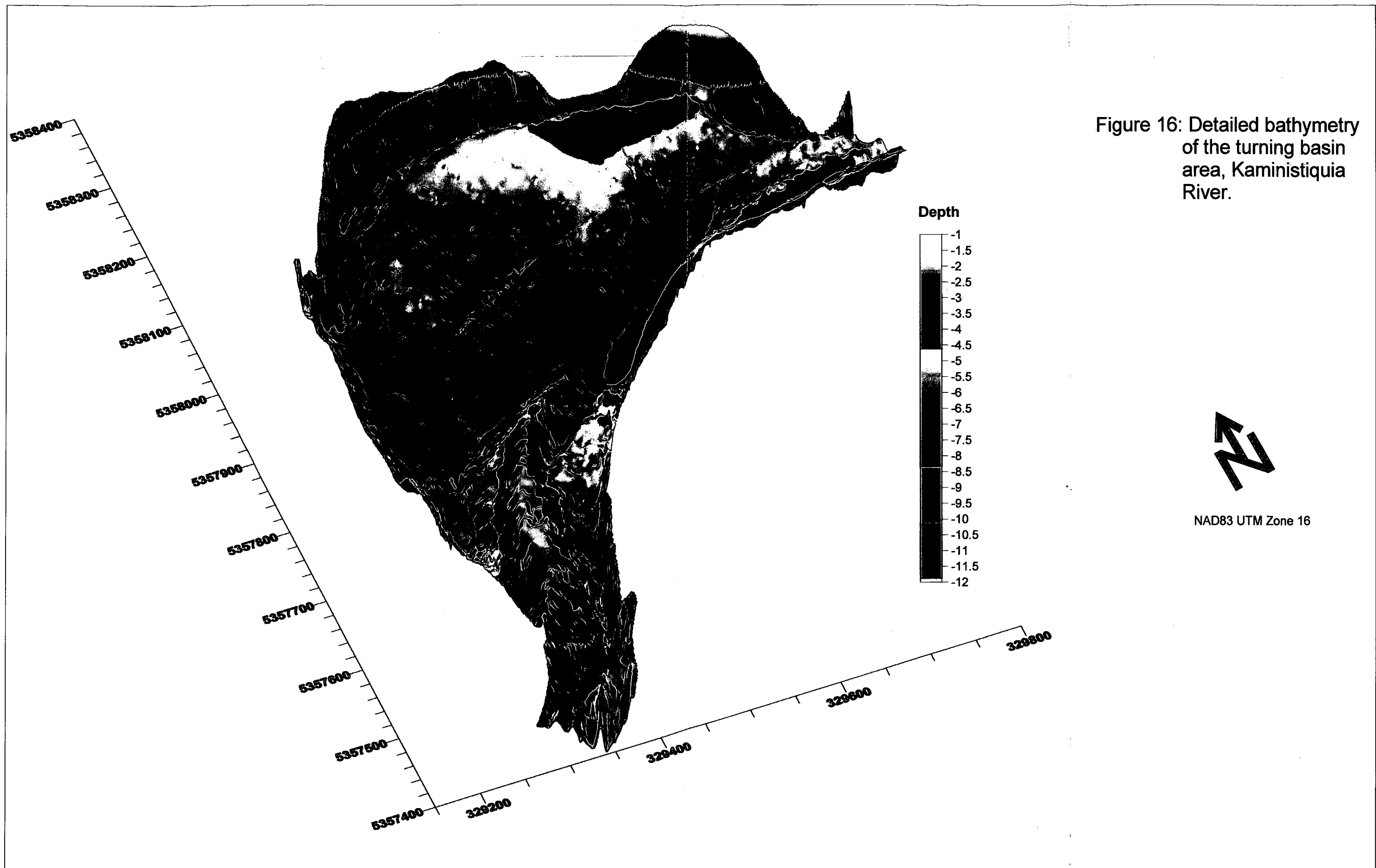
Figure 15: Bathymetry for lower reach section.



NAD83 UTM Zone 16

Bathymetry

1.5-2.0	5.0-5.5	8.5-9.0
2.0-2.5	5.5-6.0	9.0-9.5
2.5-3.0	6.0-6.5	9.5-10.0
3.0-3.5	6.5-7.0	10.0-10.5
3.5-4.0	7.0-7.5	10.5-11.0
4.0-4.5	7.5-8.0	11.0-11.5
4.5-5.0	8.0-8.5	11.5-12.0



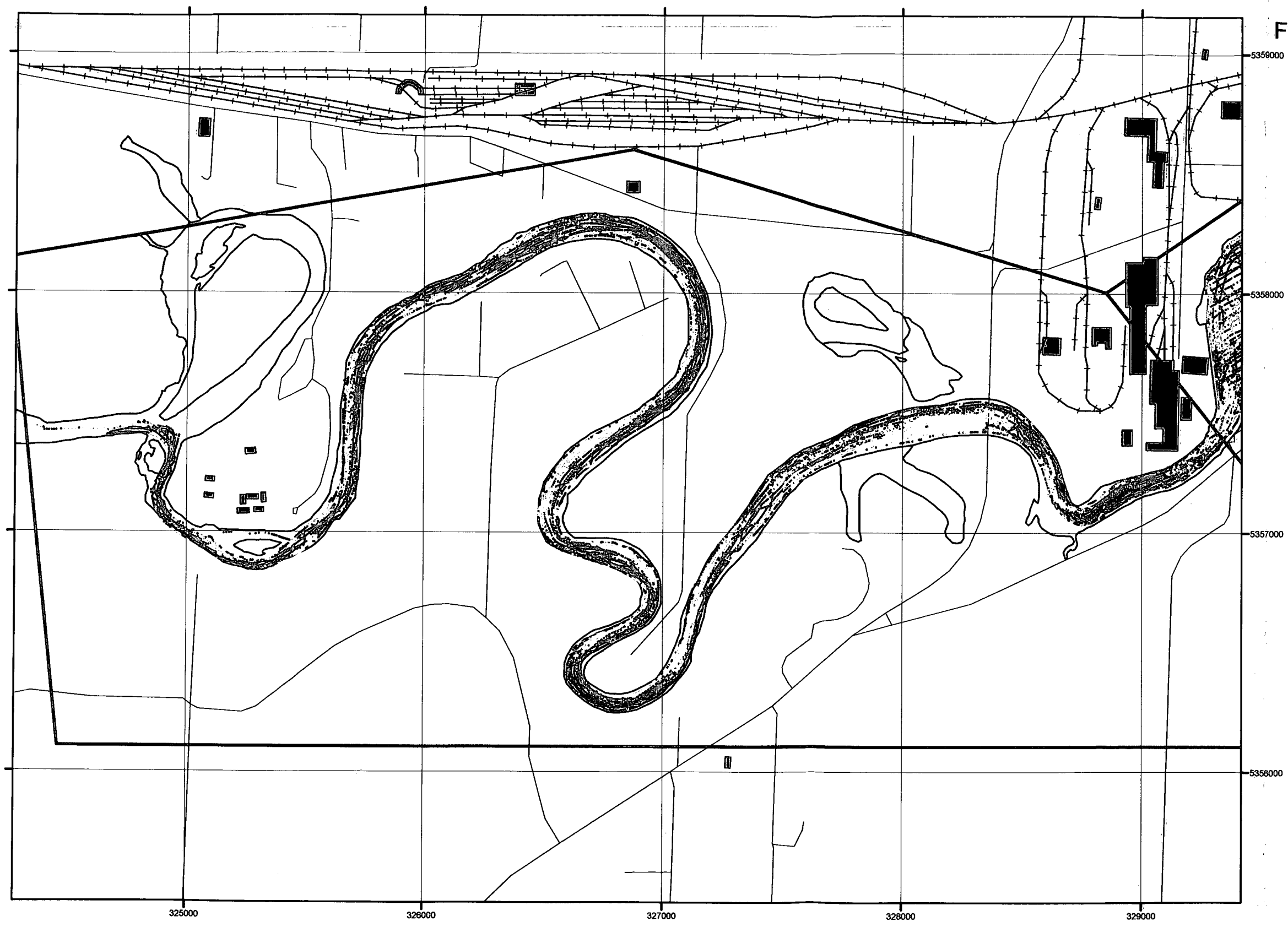
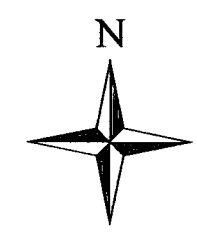


Figure 17: Classified RoxAnn point data for upper reach section.



NAD 83 UTM Zone 16

Classified RoxAnn Point Data

Substrate Classes

- Mud (Silt=Clay)
- Mud (Silt>Clay)
- ⊙ Mud (acoustically hard)
- Sand
- ⊙ Coarse Sand-Pebble
- Gravel-Sand Mix
- Cobble
- Clay Bed

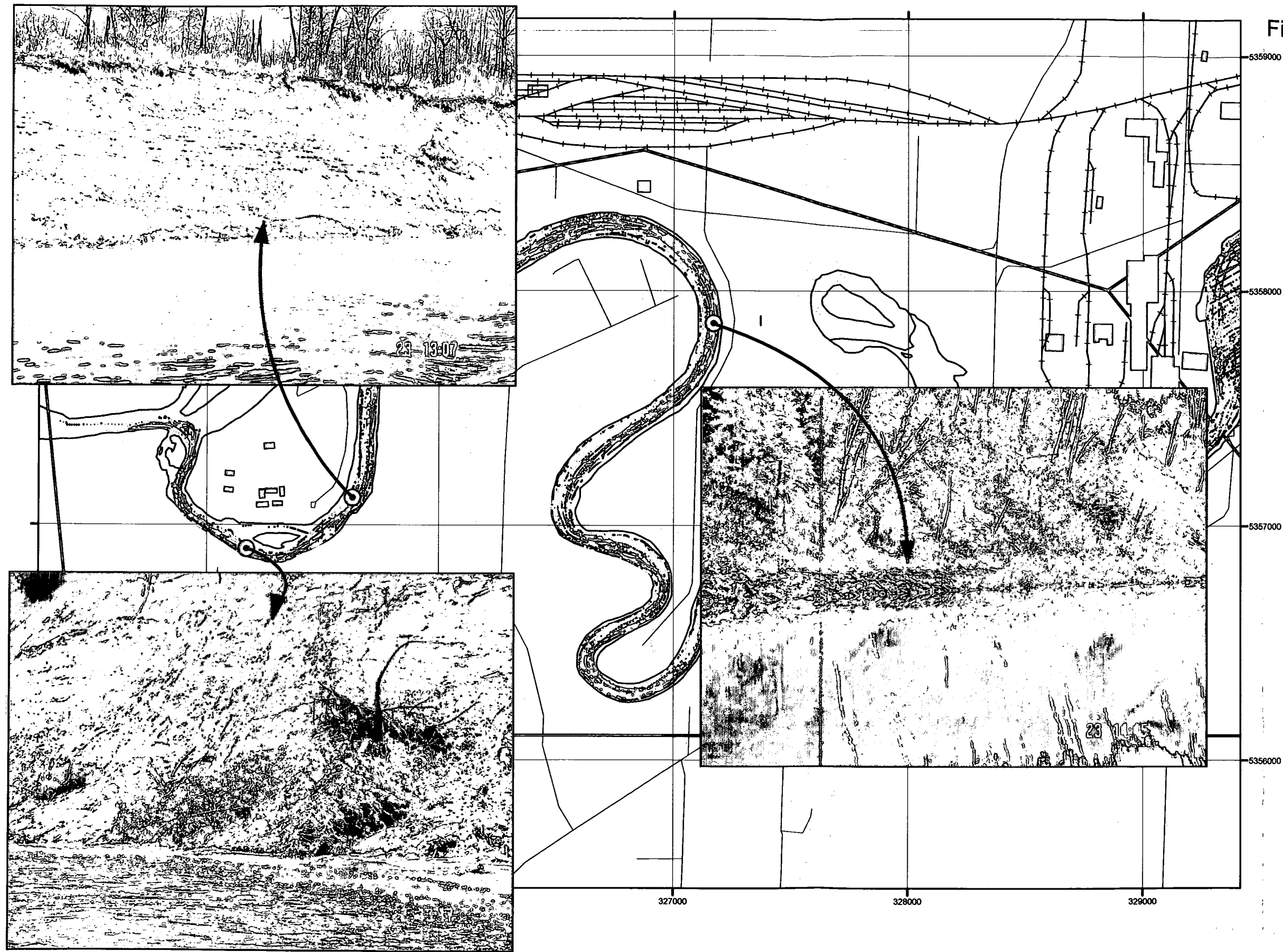


Figure 18: Riverbank features along the upper reach.



NAD 83 UTM Zone 16

**Classified RoxAnn Point Data
Substrate Classes**

- Mud (Silt=Clay)
- Mud (Silt>Clay)
- Mud (acoustically hard)
- Sand
- Coarse Sand-Pebble
- Gravel-Sand Mix
- Cobble
- Clay Bed

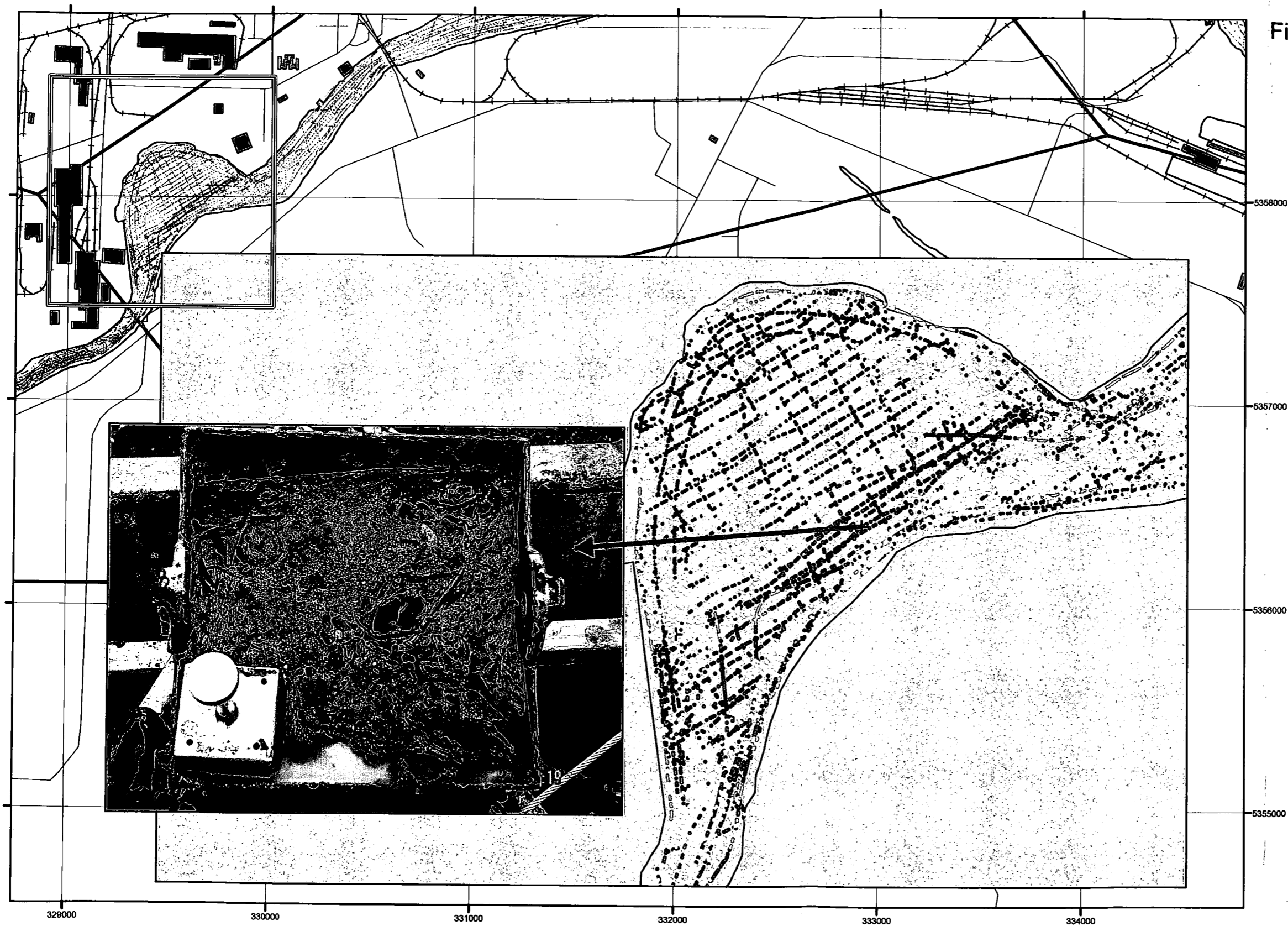
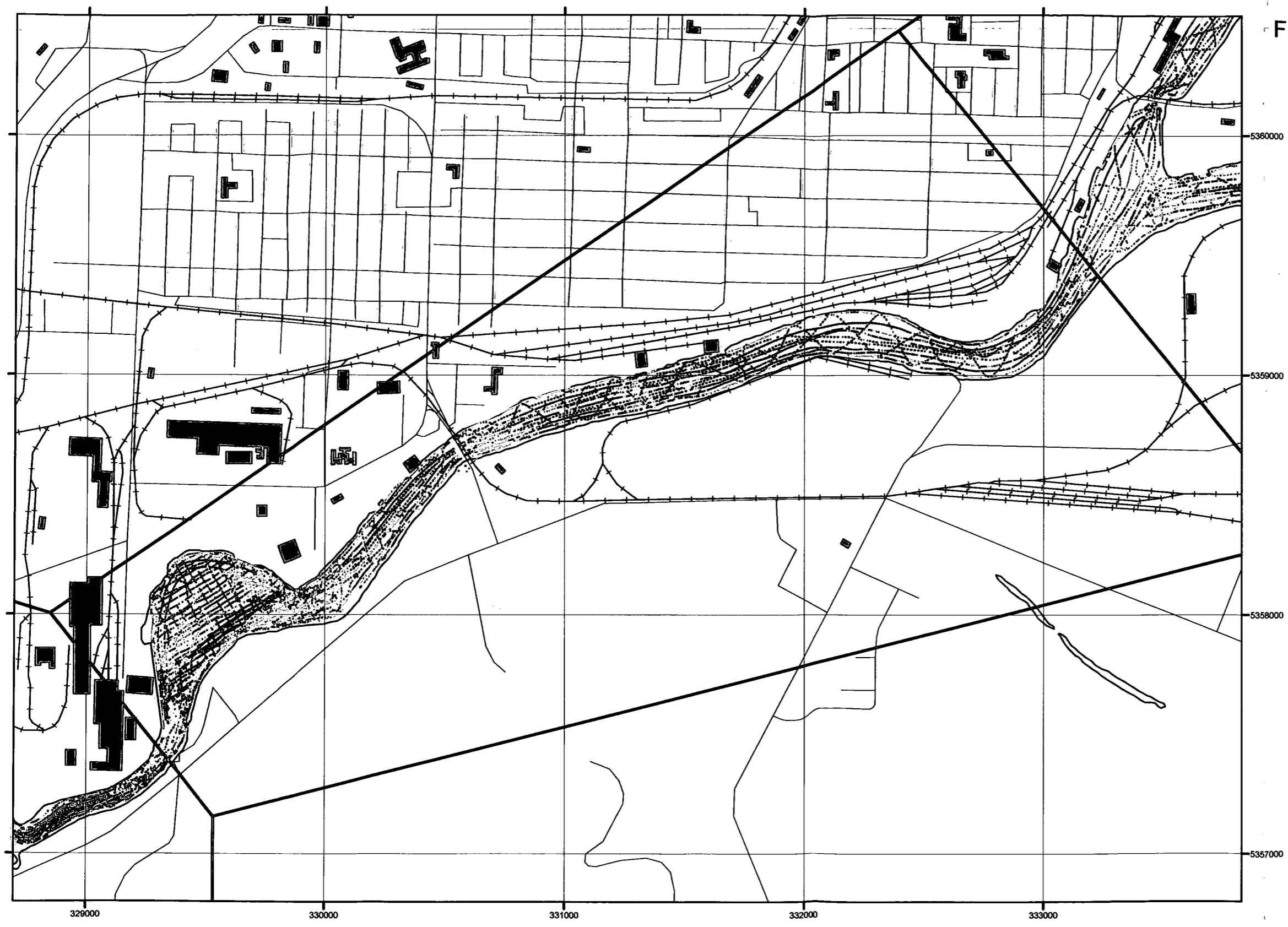


Figure 19: Substrate collected from turning basin bar.

Figure 20: Classified RoxAnn point data for middle reach section.



Classified RoxAnn Point Data

Substrate Classes

- Mud (Silt=Clay)
- Mud (Silt>Clay)
- Mud (acoustically hard)
- Sand
- Coarse Sand-Pebble
- Gravel-Sand Mix
- Cobble
- Clay Bed

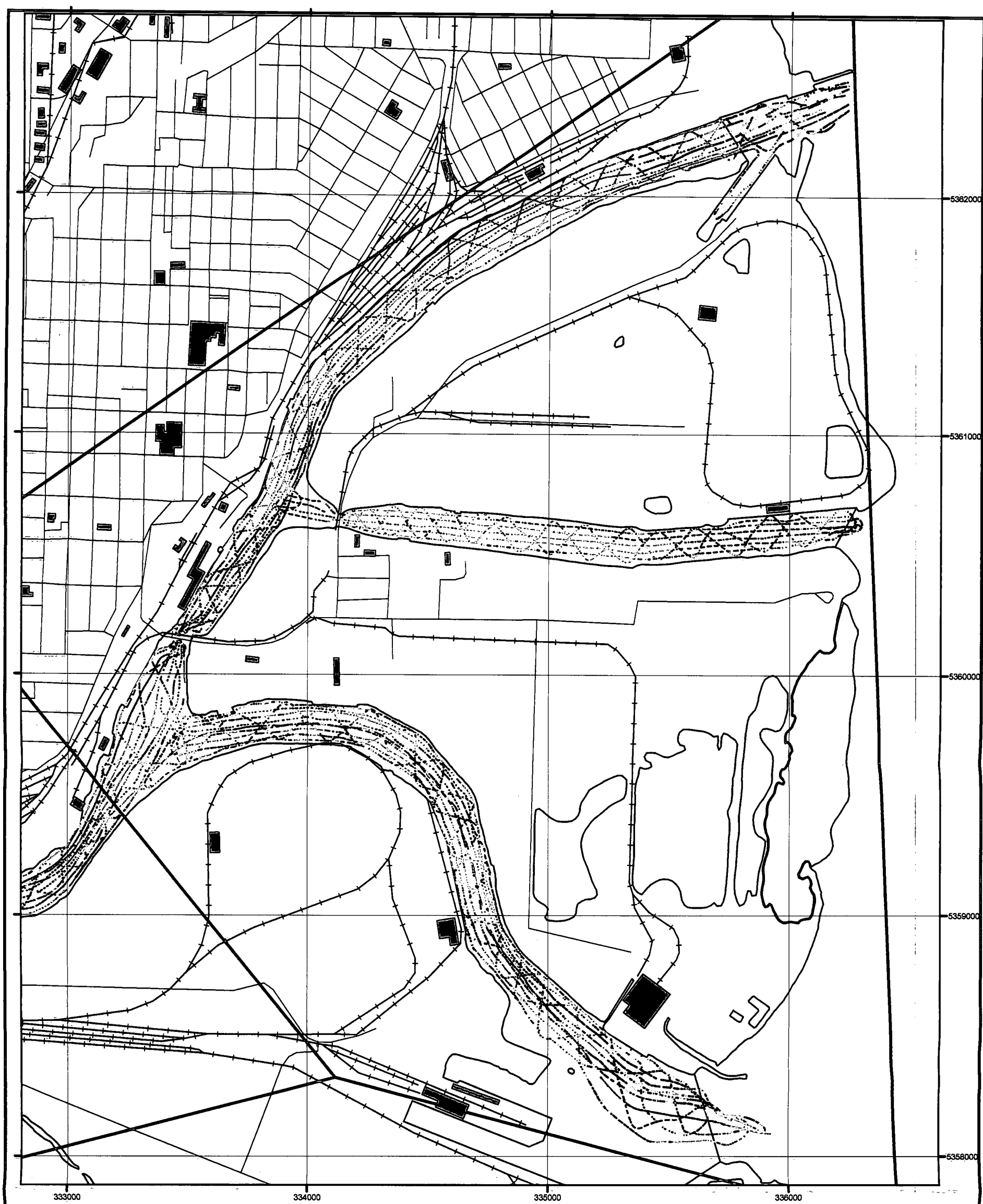


Figure 21: Classified RoxAnn point data for lower reach section.

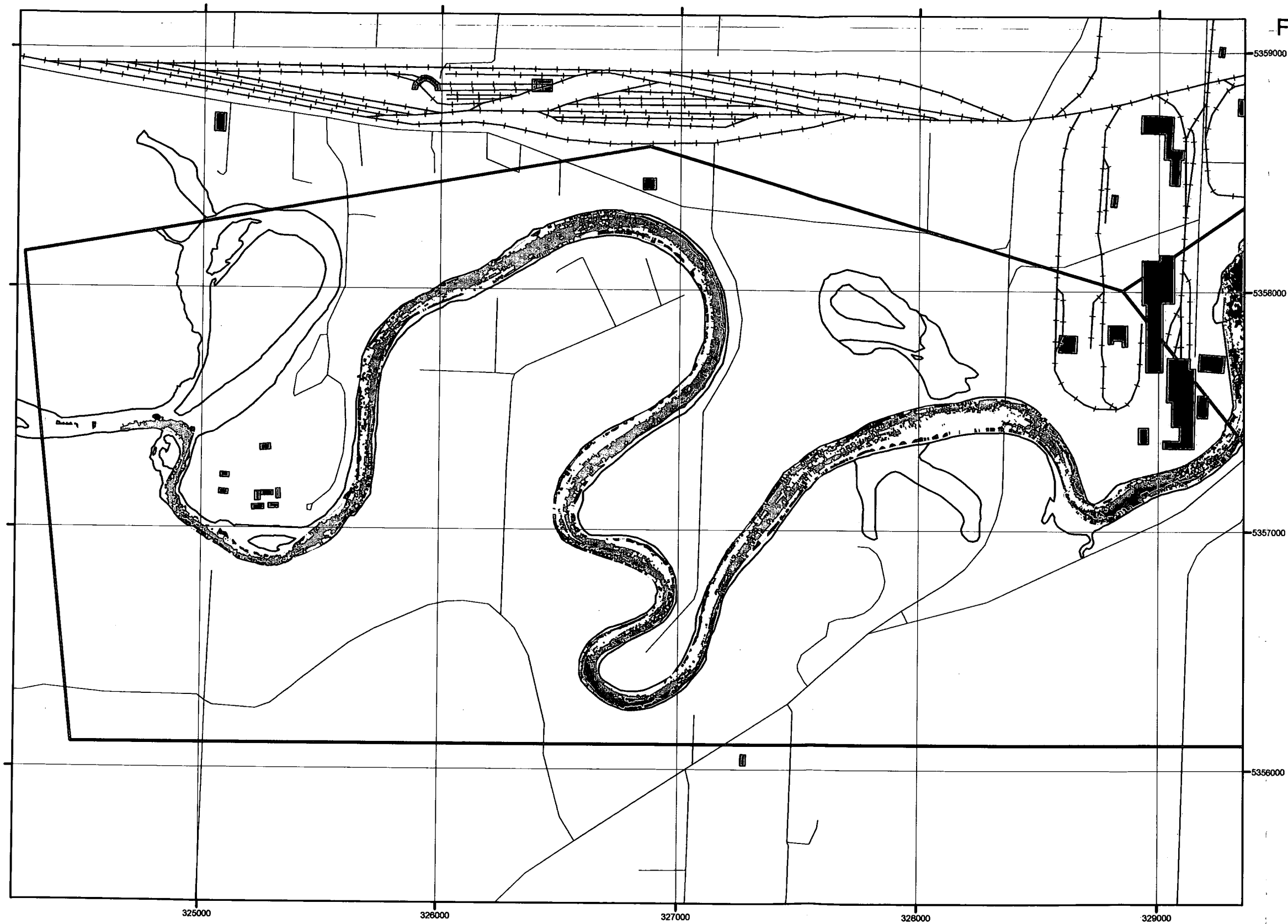


Classified RoxAnn Point Data

Substrate Classes

- Mud (Silt=Clay)
- Mud (Silt>Clay)
- Mud (acoustically hard)
- Sand
- Coarse Sand-Pebble
- Gravel-Sand Mix
- Cobble
- Clay Bed

Figure 22: Classified RoxAnn polygon data for upper reach section.



NAD 83 UTM Zone 16

RoxAnn_Polygons
Substrate Classes









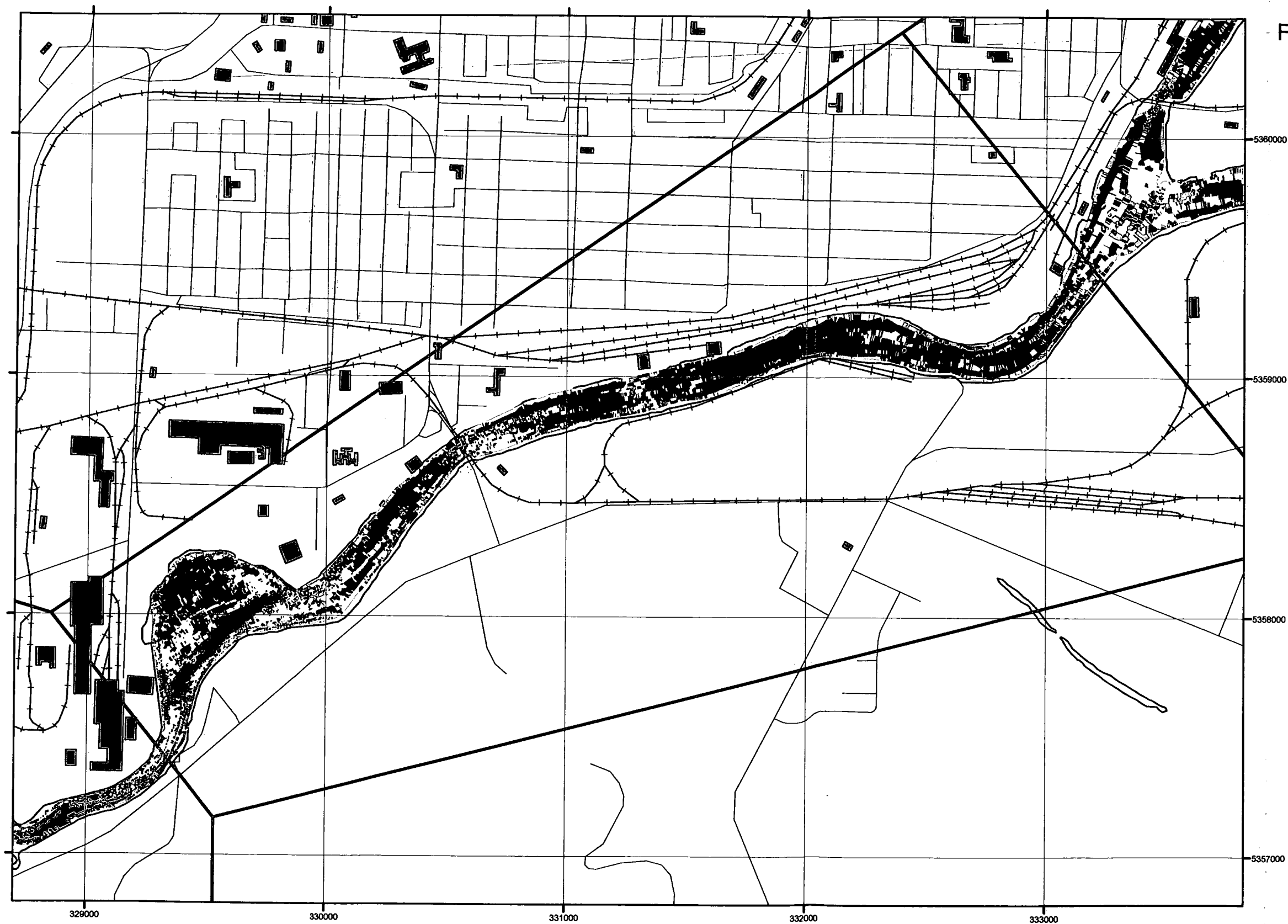
-  Mud (Silt=Clay)
-  Mud (Silt>Clay)
-  Mud (acoustically hard)
-  Sand
-  Coarse Sand-Pebble
-  Gravel-Sand Mix
-  Cobble
-  Clay Bed









Figure 23: Classified RoxAnn polygon data for middle reach section.



NAD 83 UTM Zone 16

RoxAnn_Polygons

Substrate Classes

-  Mud (Silt=Clay)
-  Mud (Silt>Clay)
-  Mud (acoustically hard)
-  Sand
-  Coarse Sand-Pebble
-  Gravel-Sand Mix
-  Cobble
-  Clay Bed

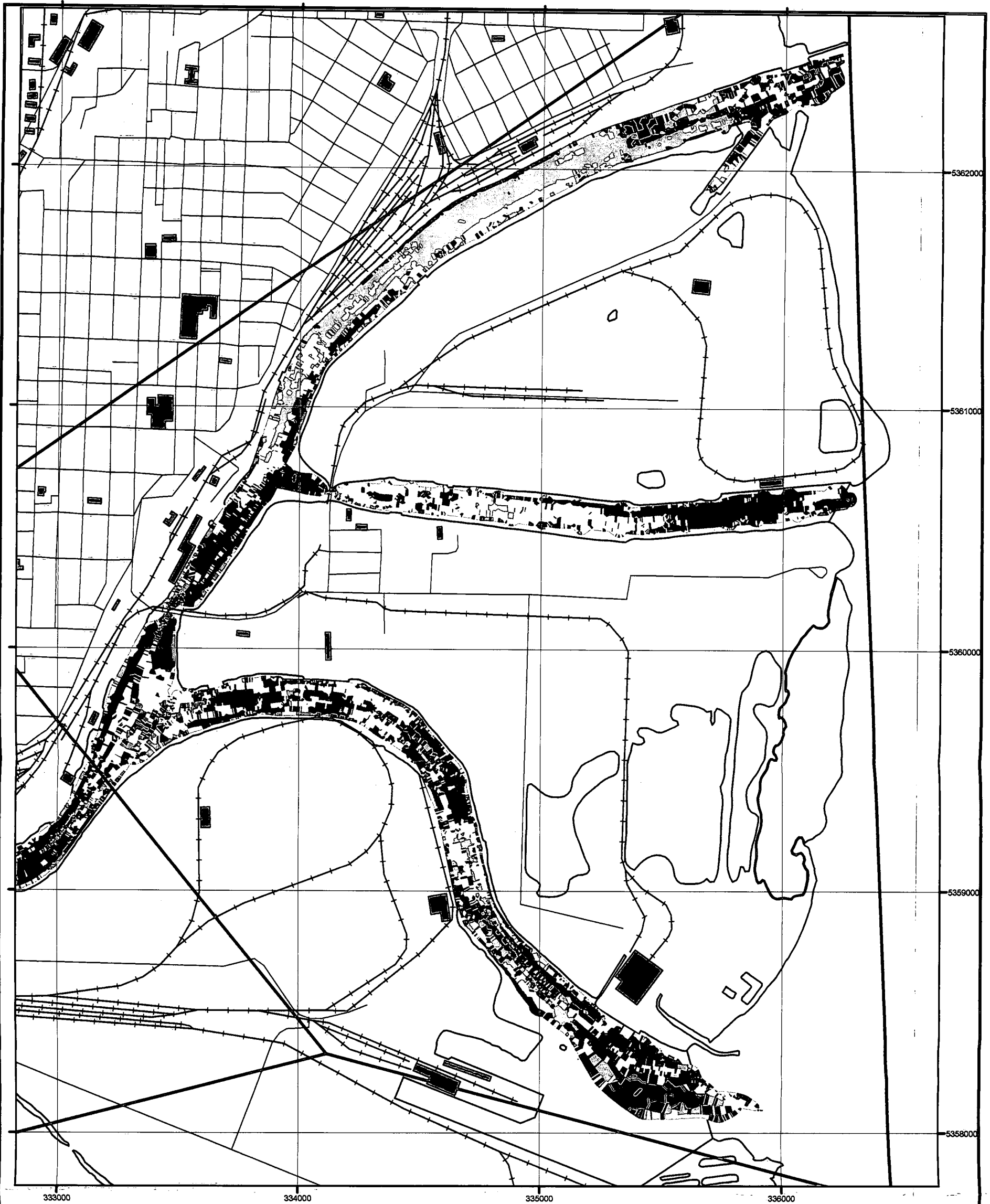
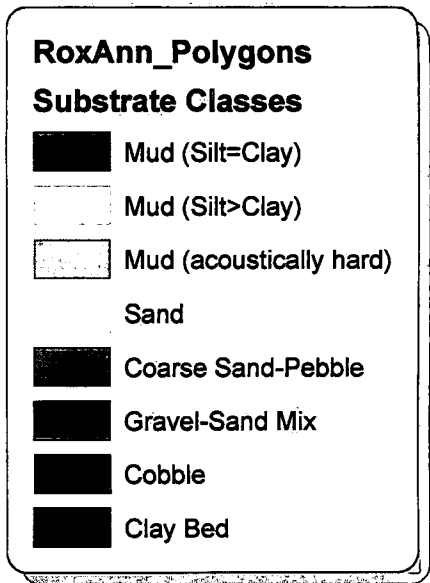
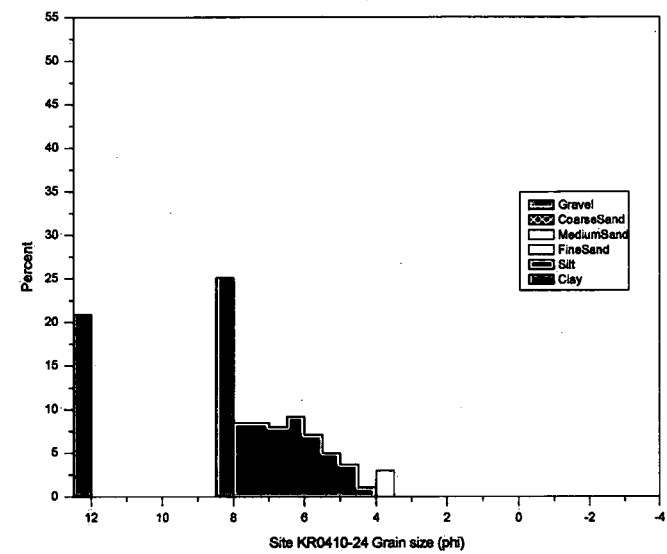
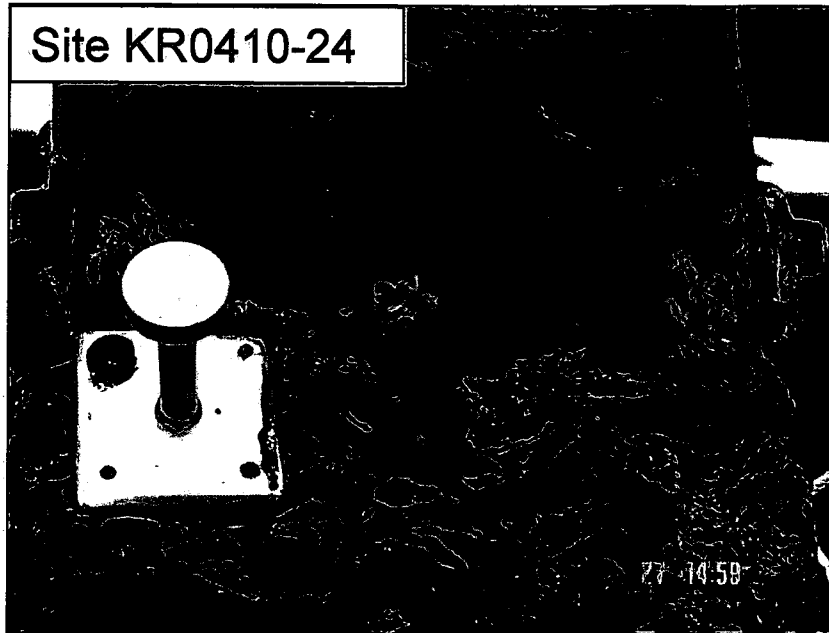


Figure 24: Classified RoxAnn polygon data for lower reach section.

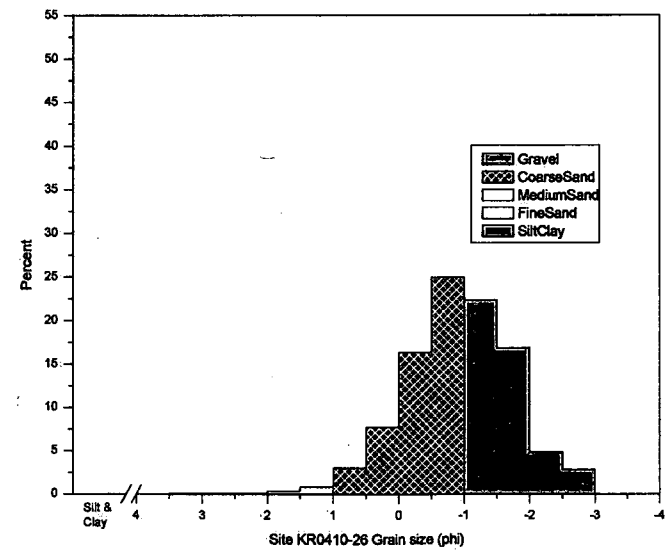
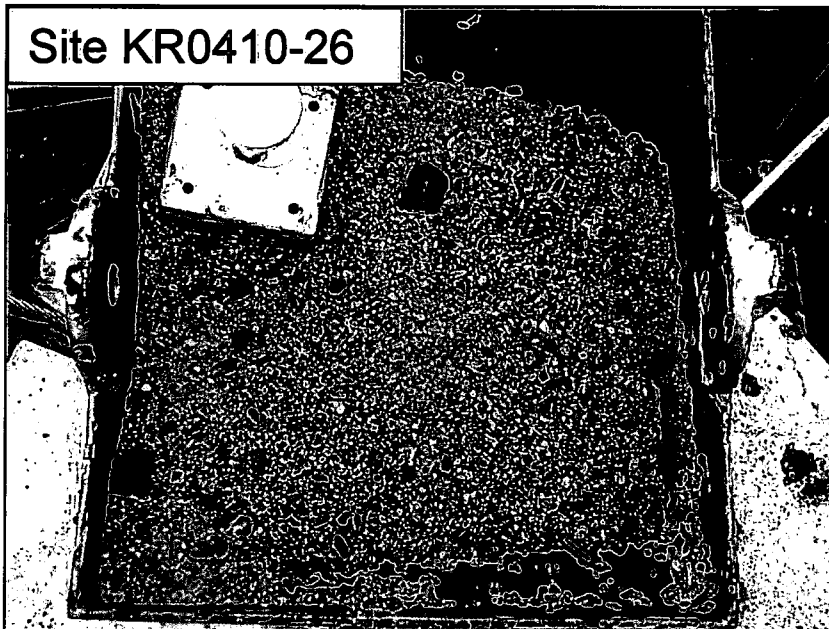


Appendix 1: Shipek Sample Images and Grain Size Analysis

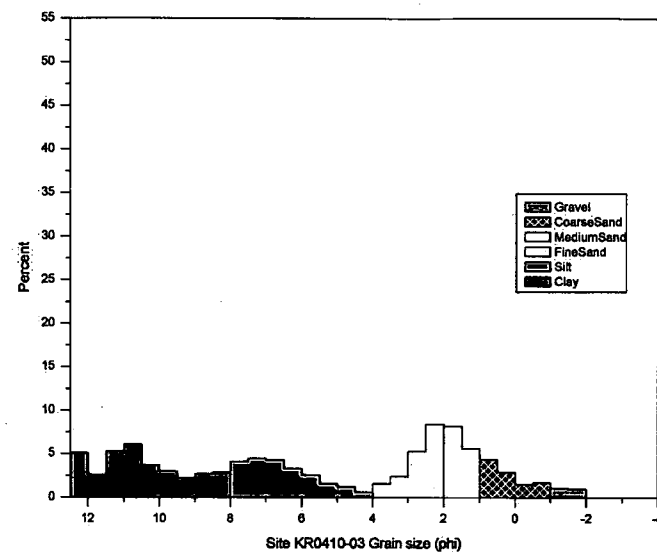
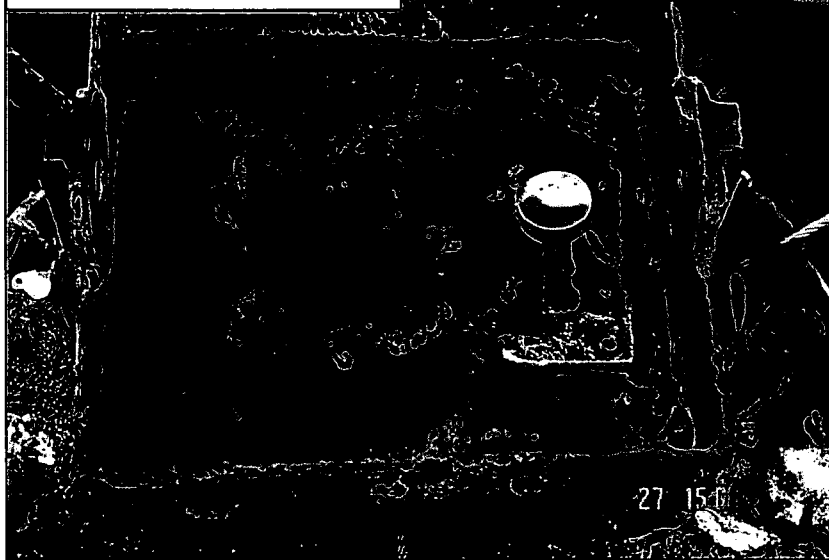
Site KR0410-24



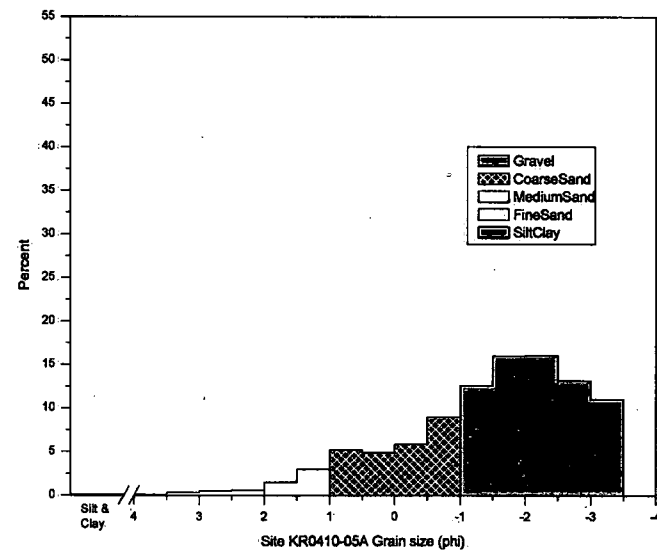
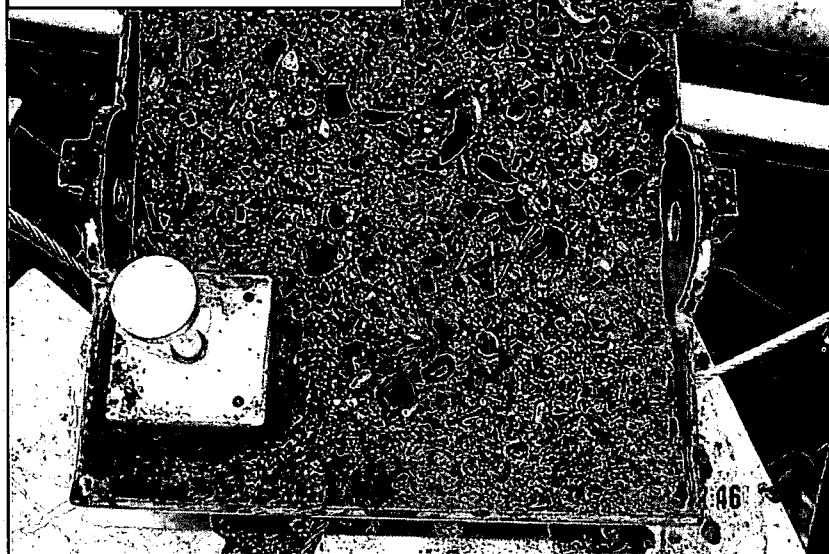
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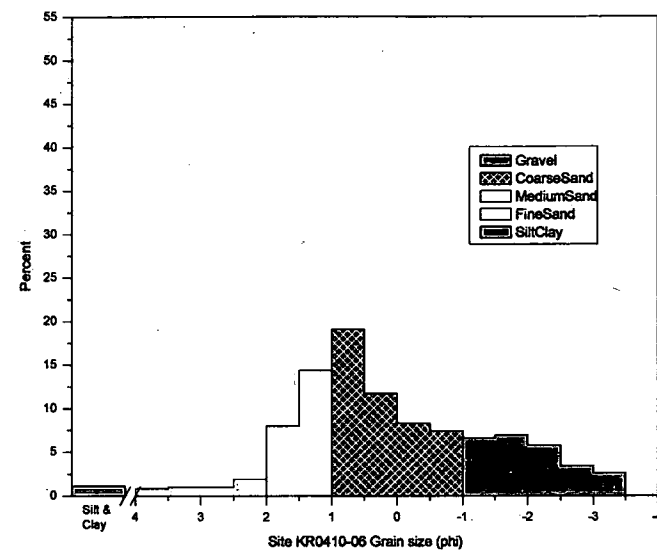
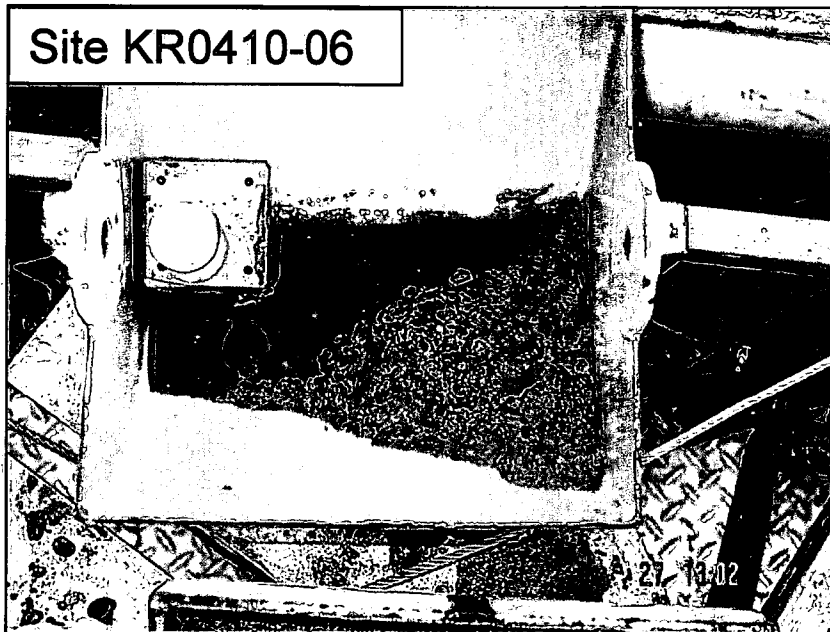
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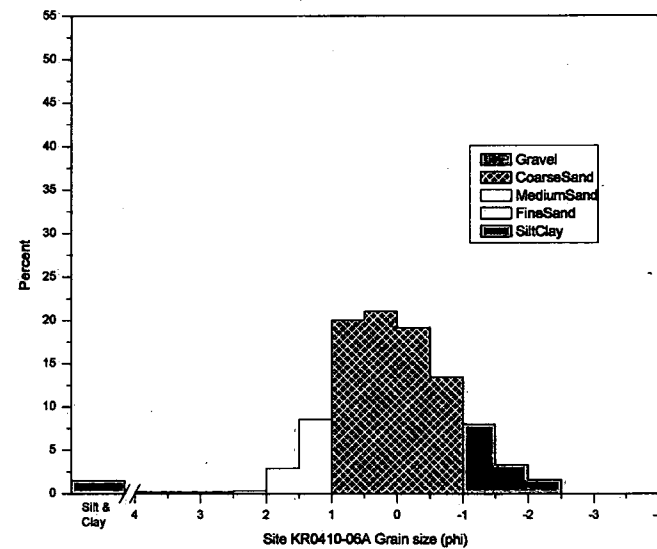
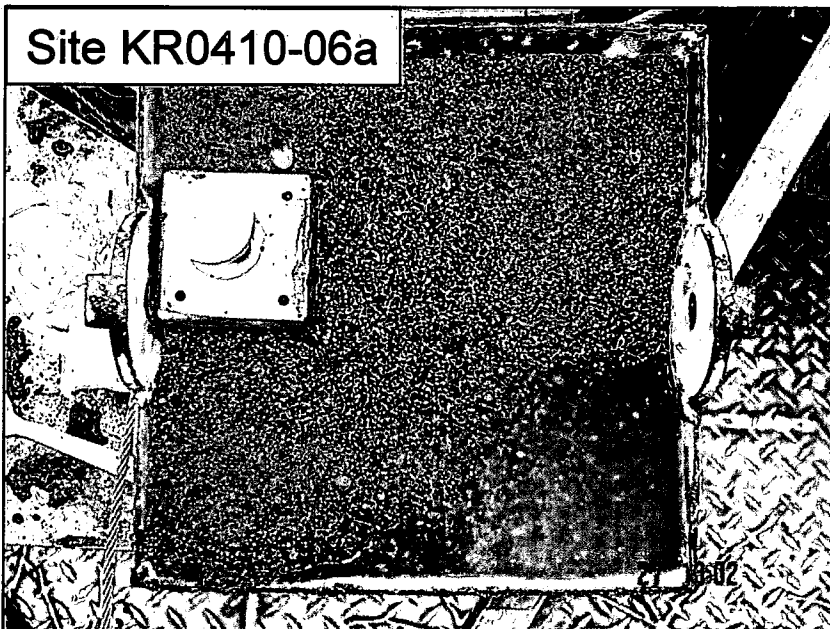
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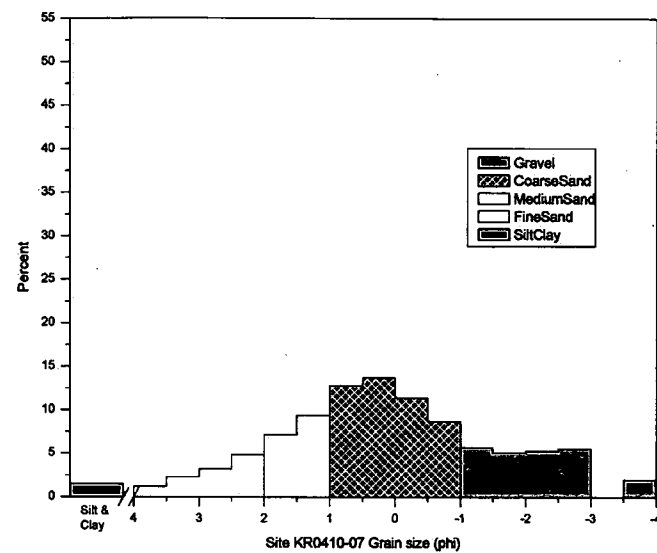
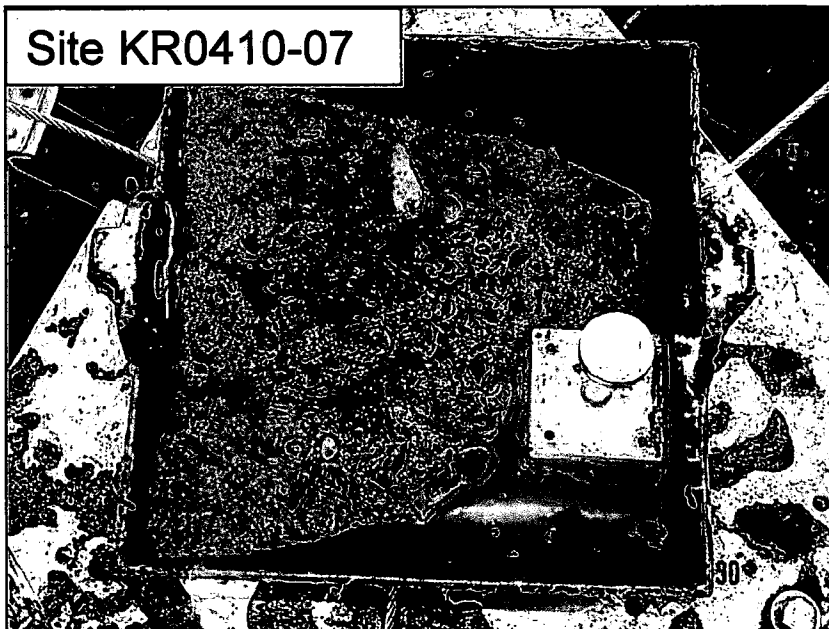
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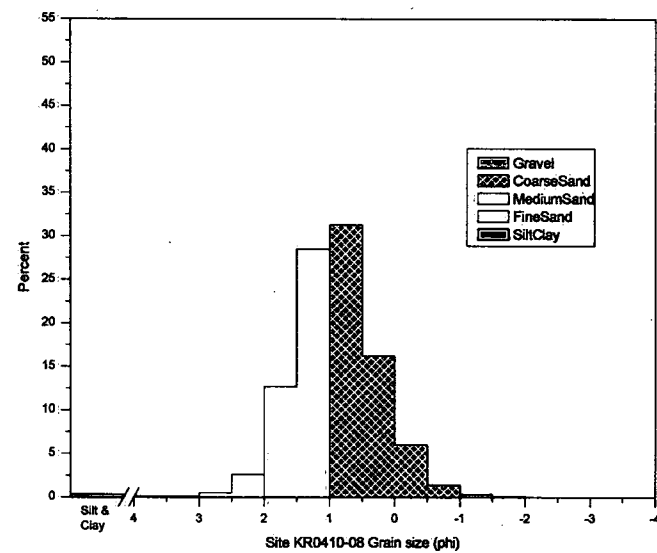
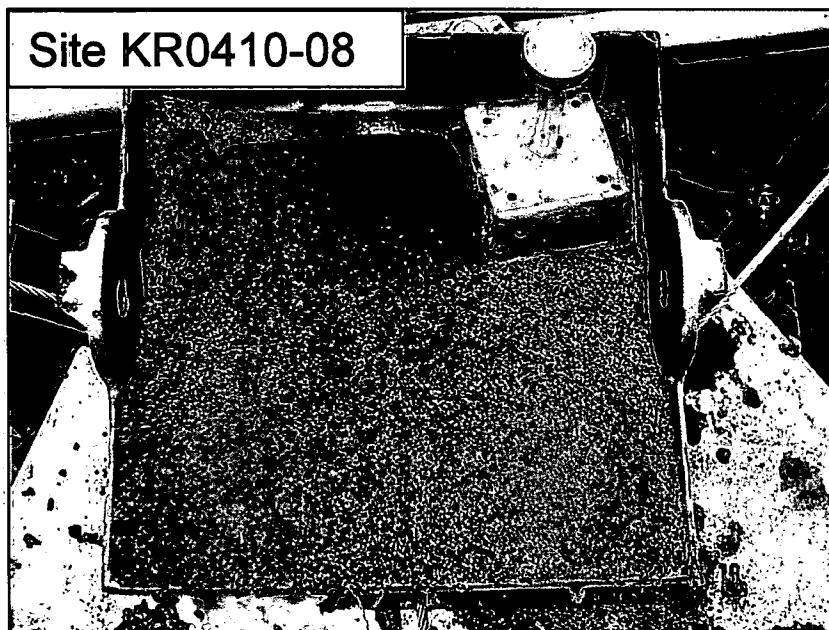
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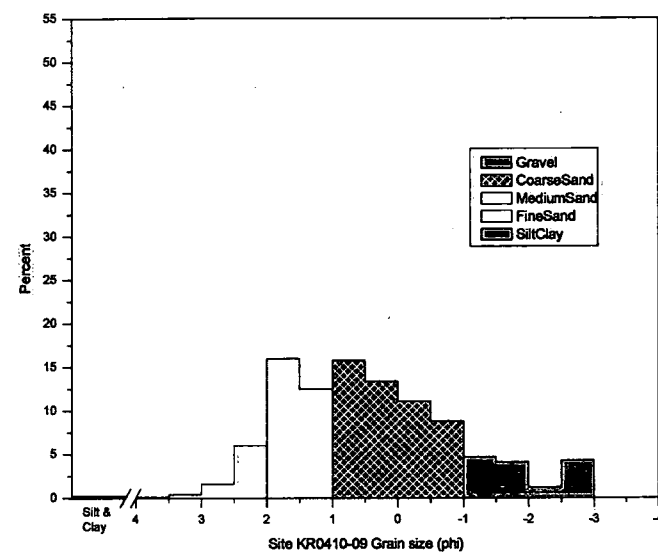
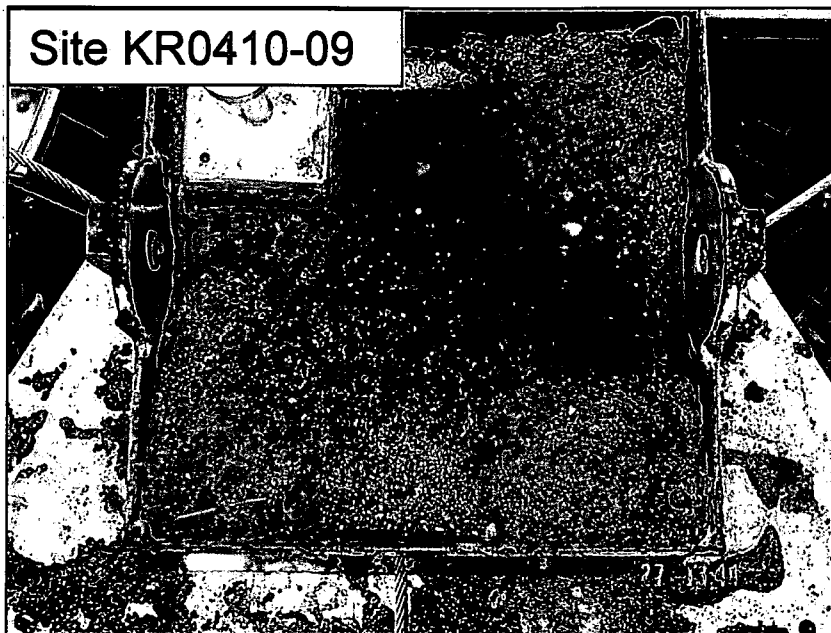
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Site KR0410-08

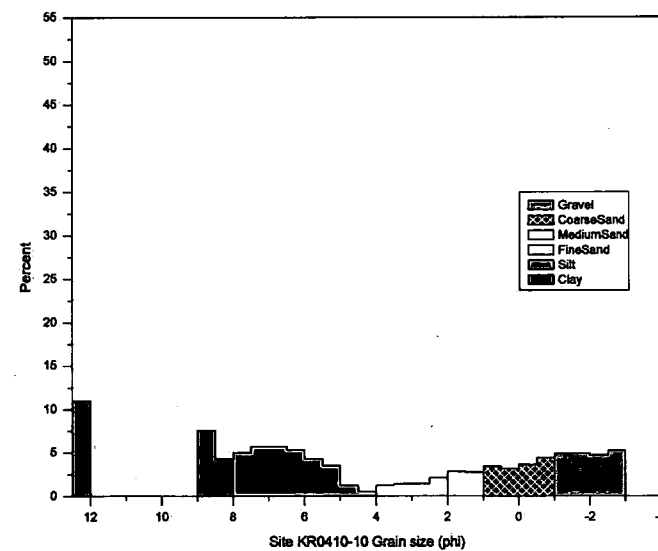


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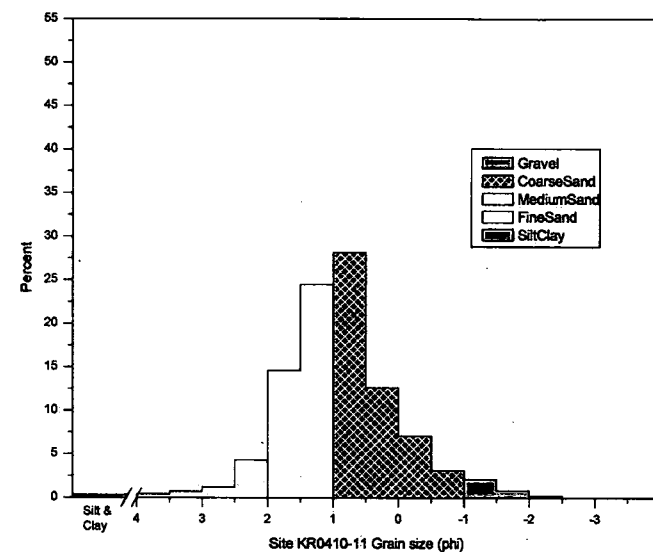
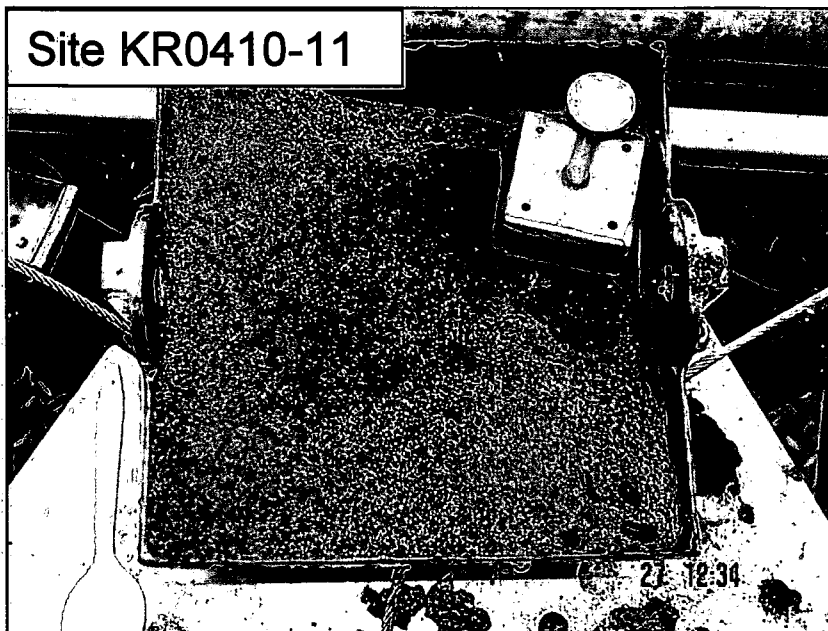


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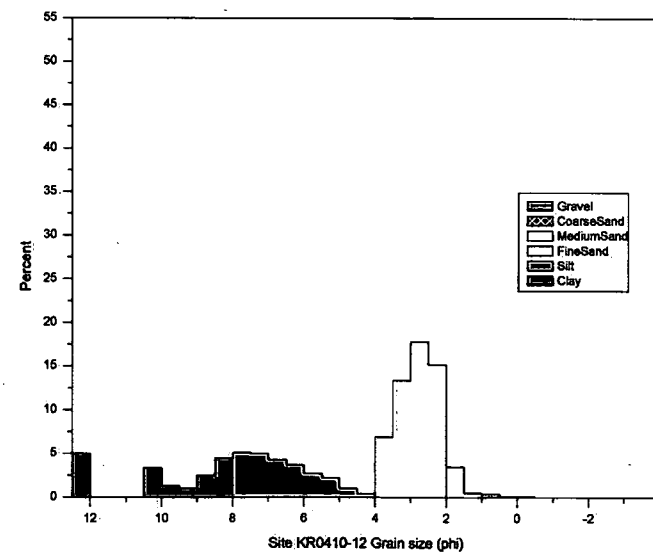
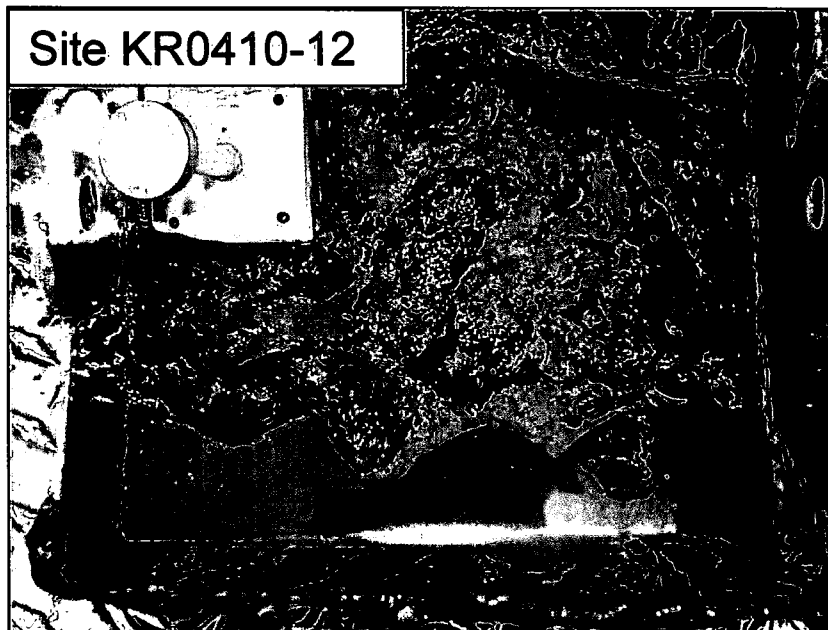
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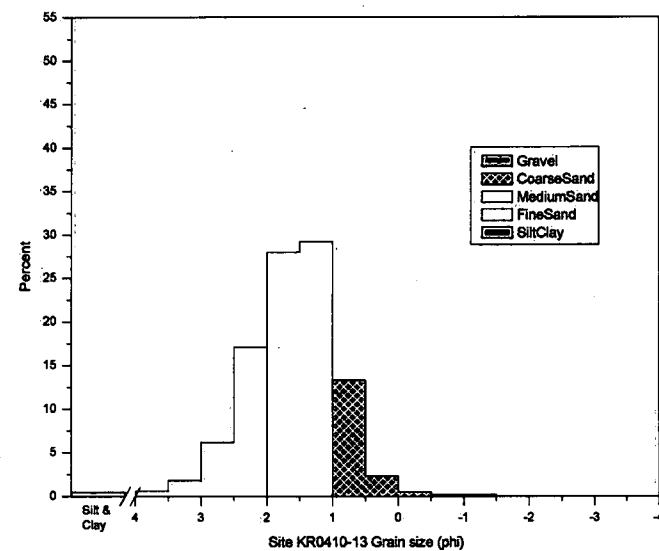
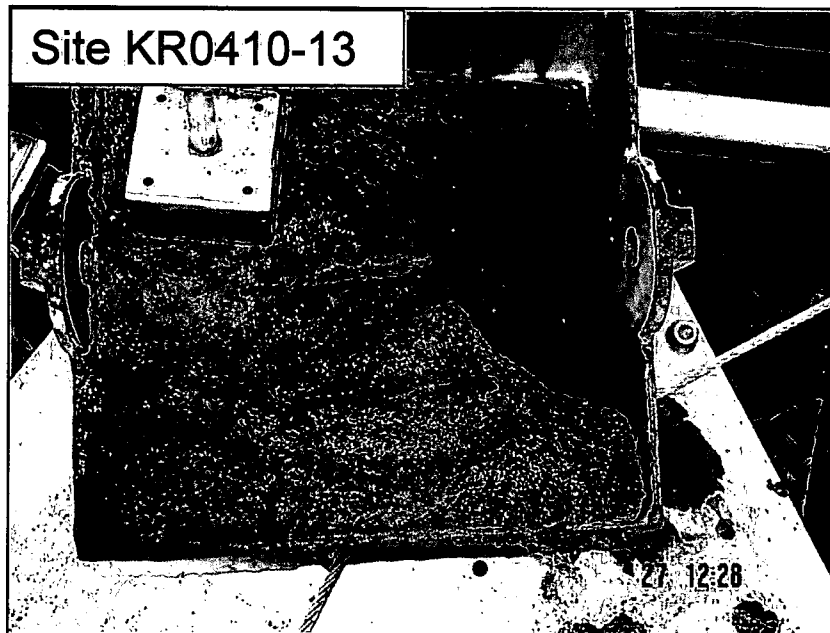
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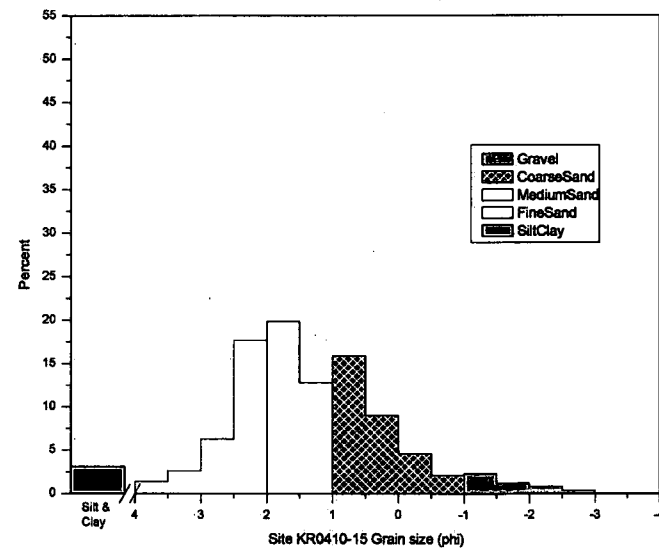
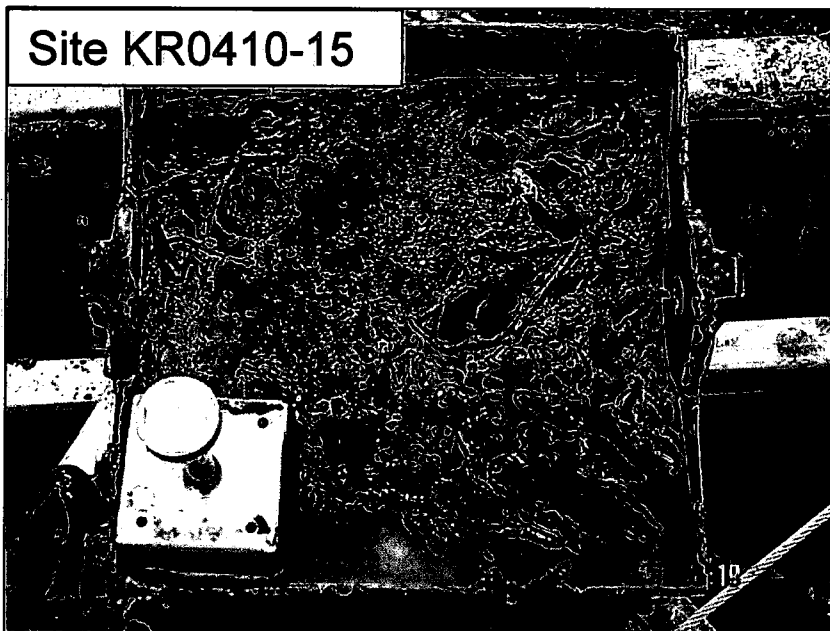
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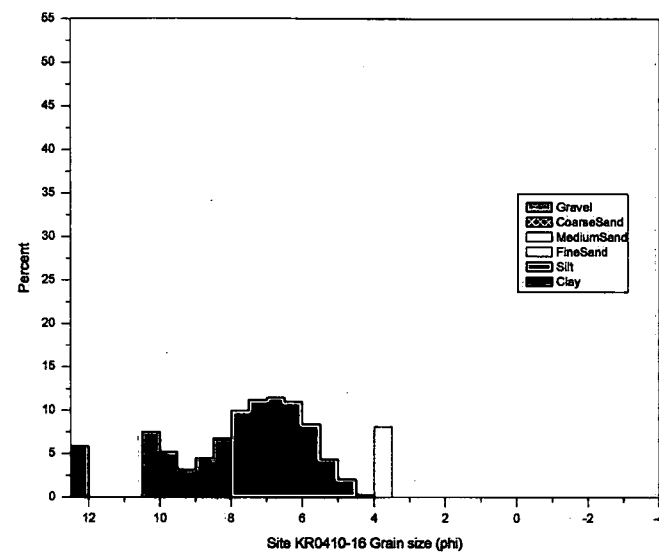
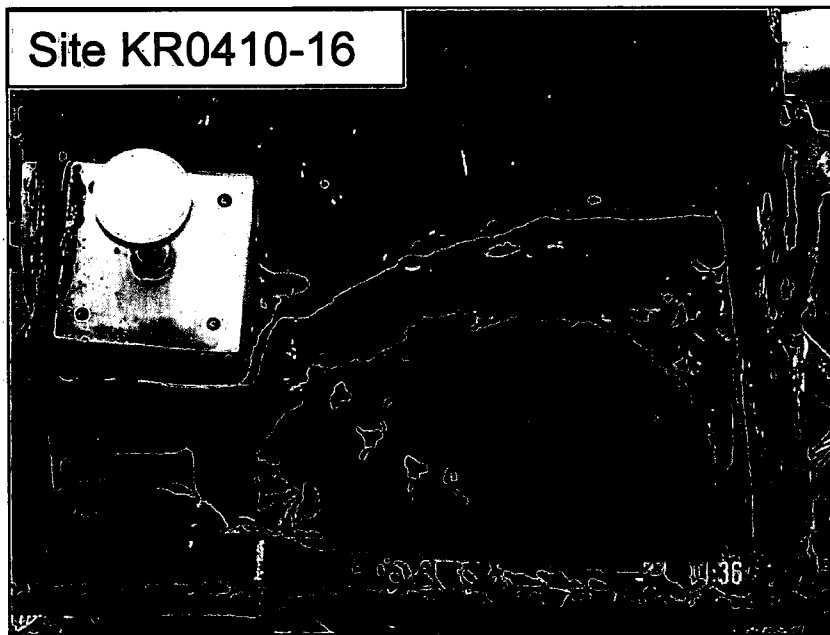
Site KR0410-13



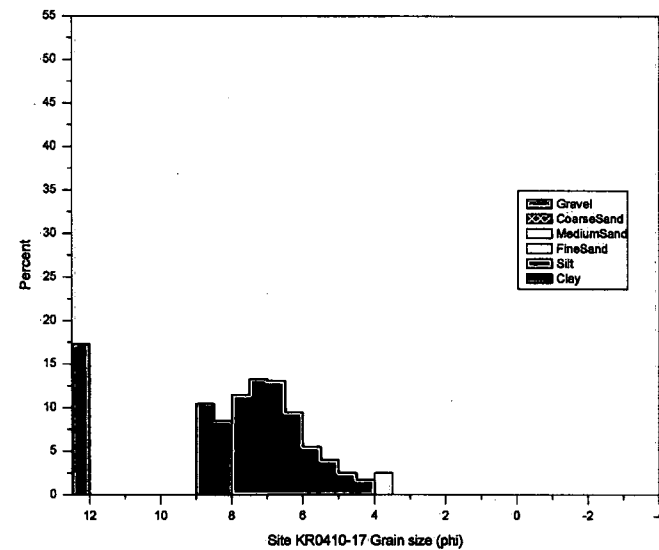
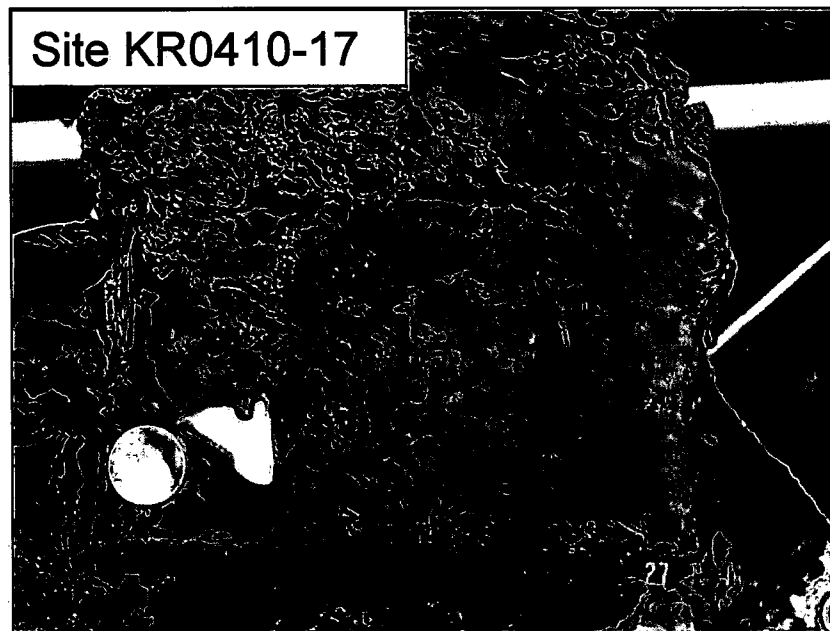
Site KR0410-15



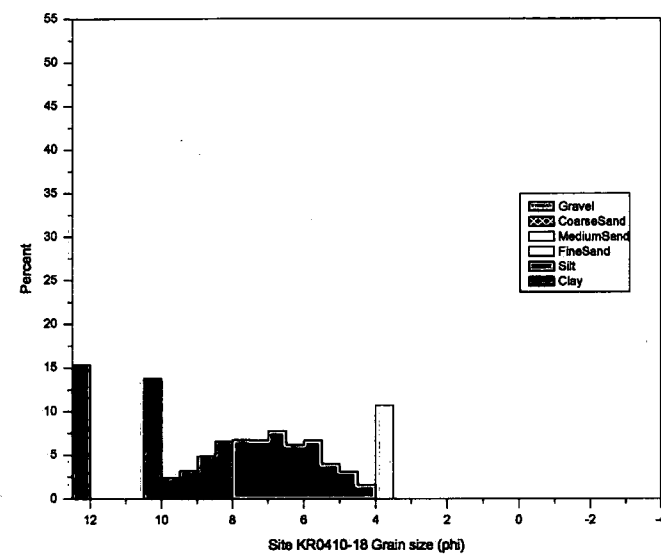
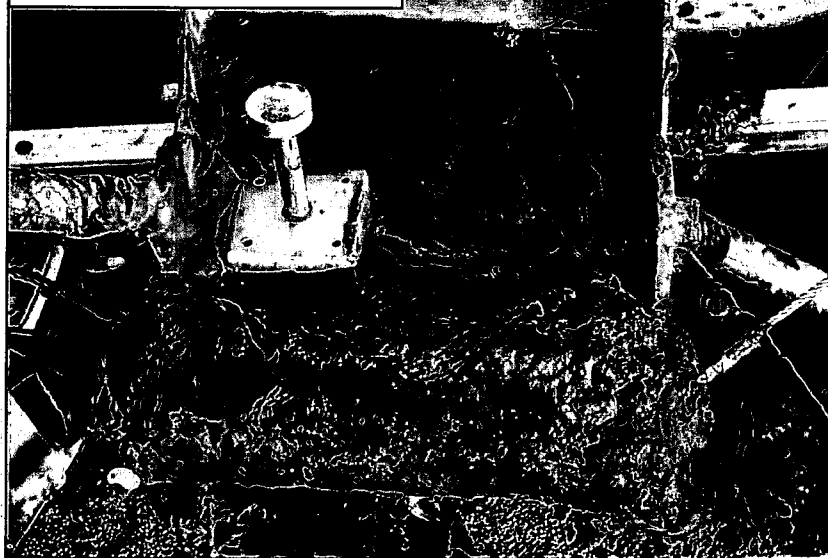
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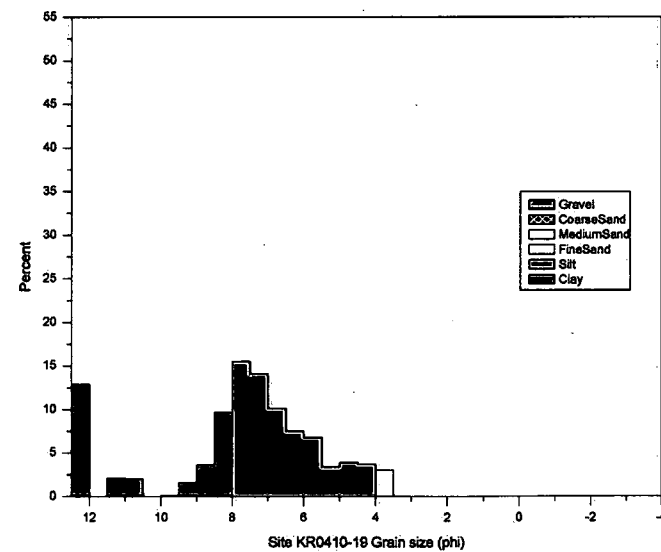
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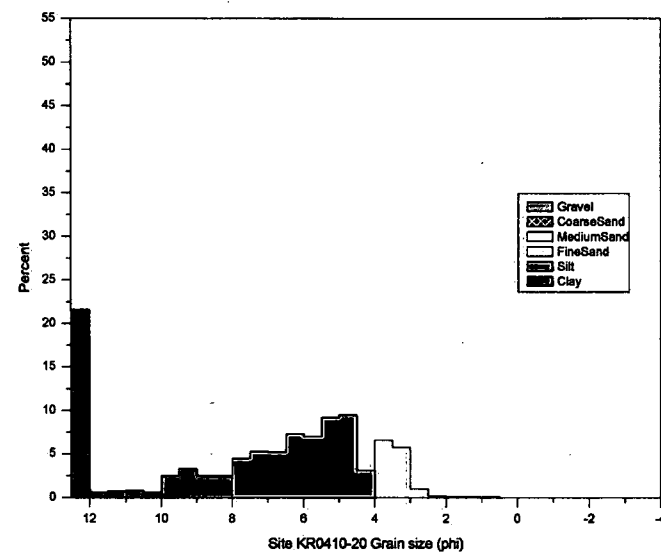
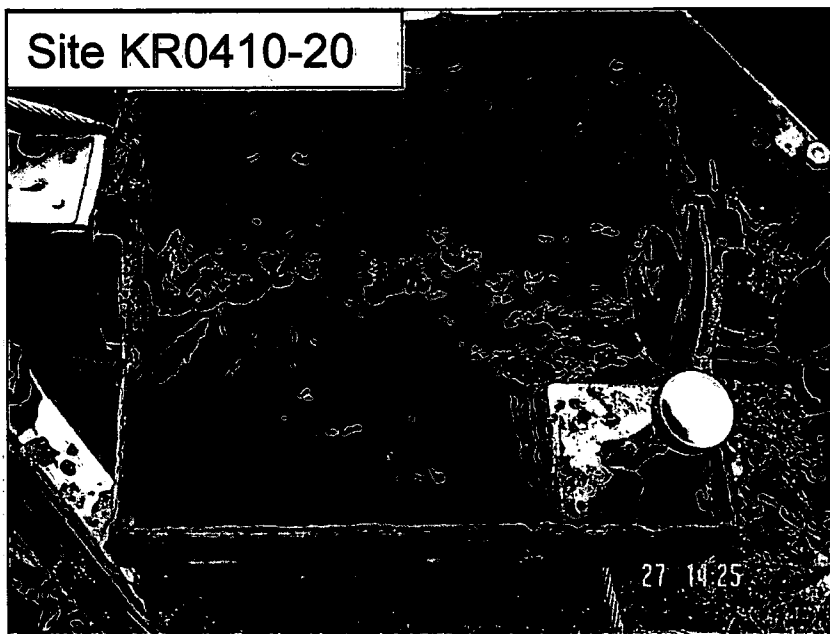
Site KR0410-18



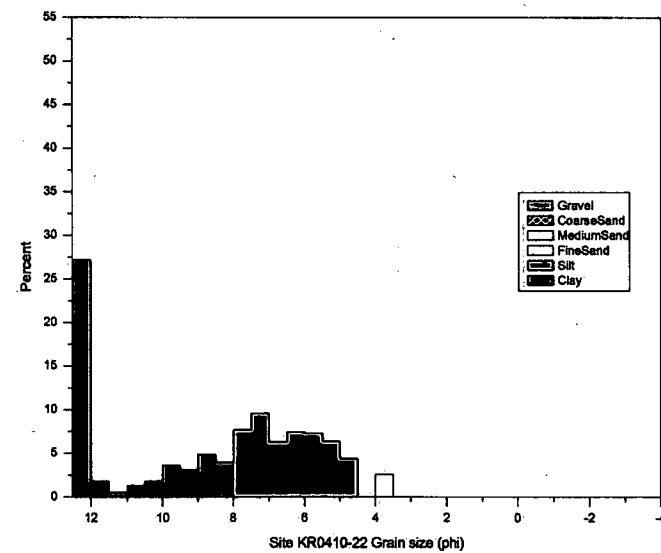
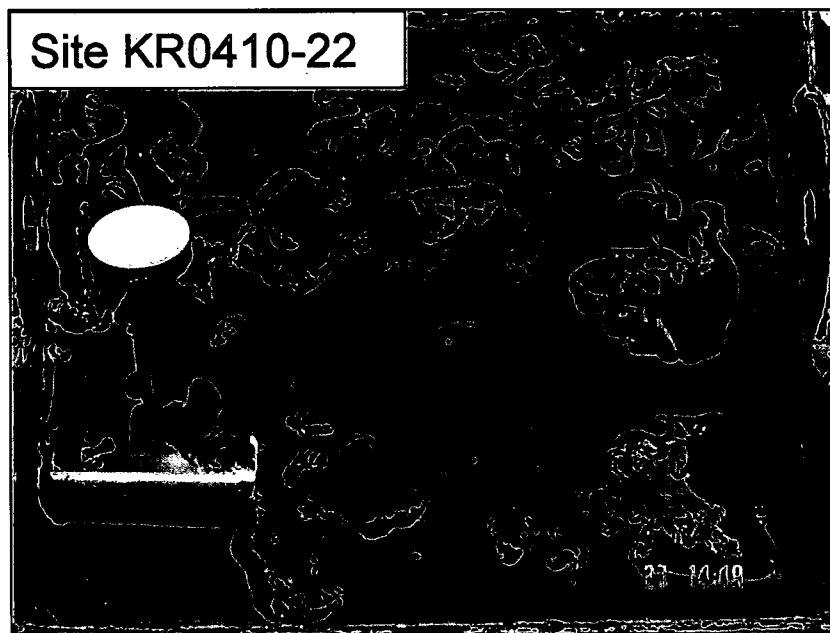
Site KR0410-19



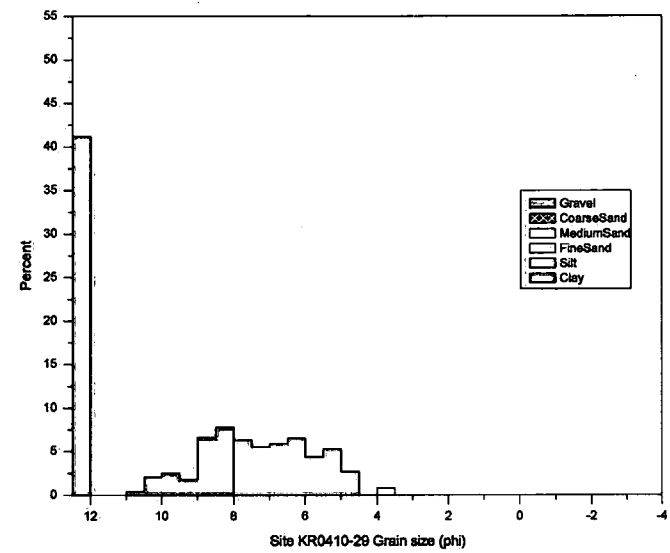
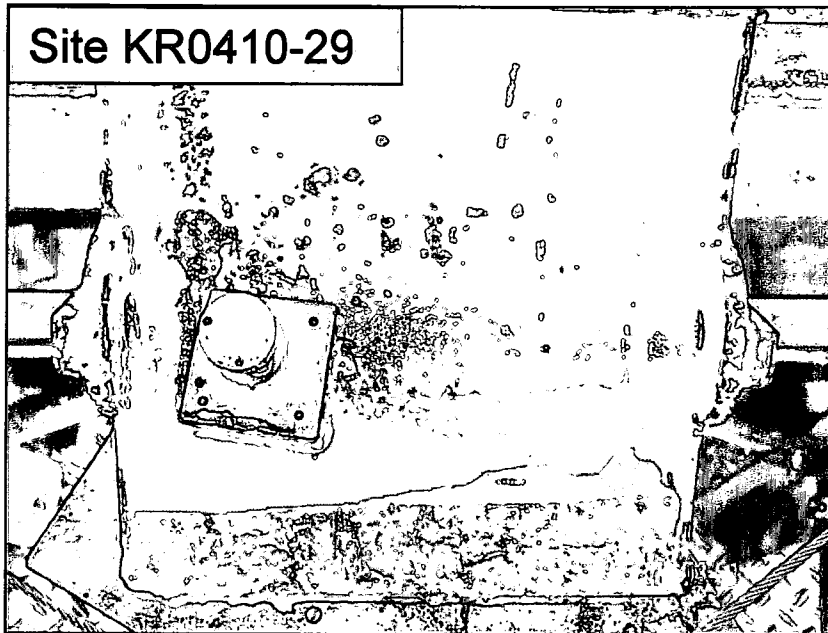
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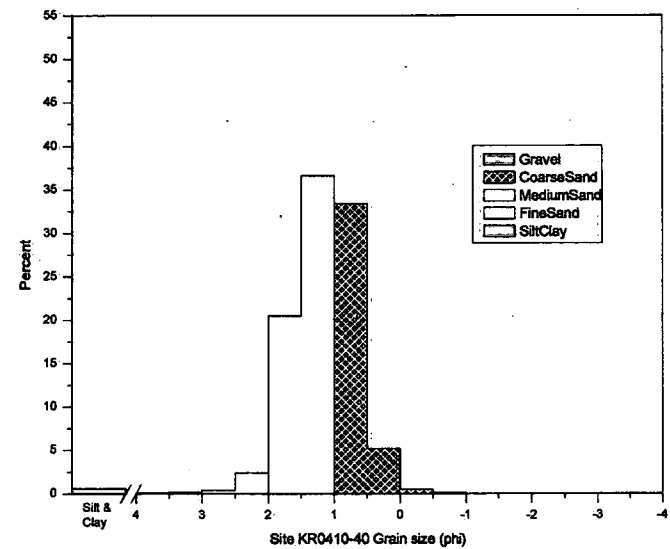
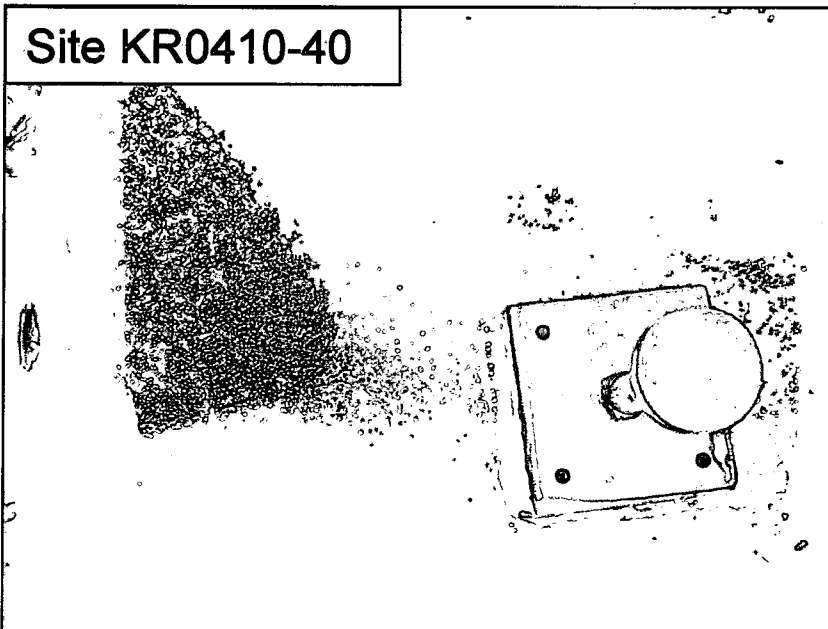
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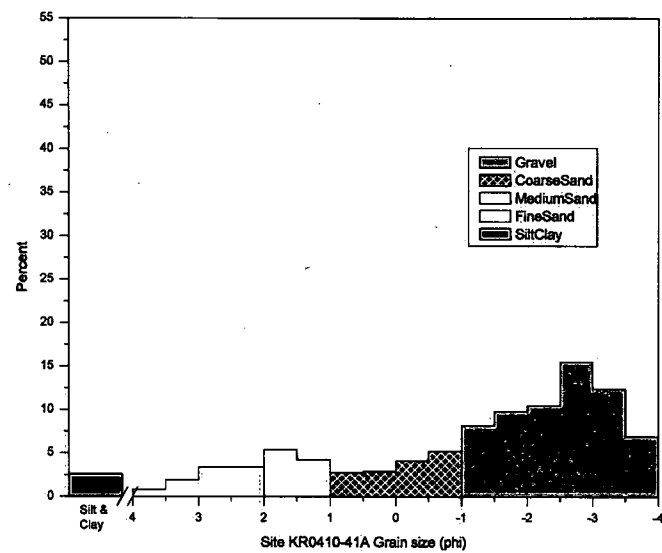
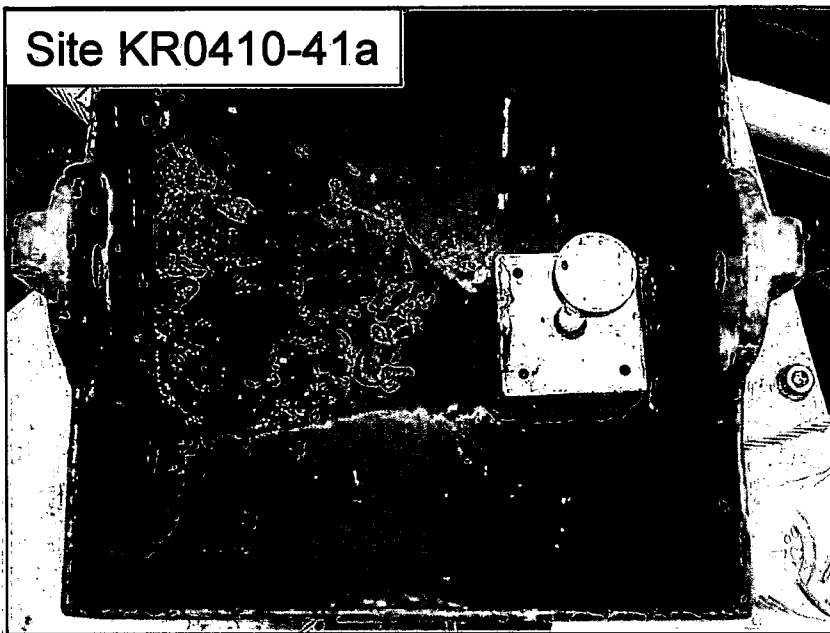
Site KR0410-29



Site KR0410-40



Site KR0410-41a



Site KR0410-42

