RANSOM Consulting, Inc.

Consulting Engineers and Scientists

April 16, 2013

R131.06049.001

Mr. John S. Holt, Chair
Lamoine Planning Board
606 Doughlas Highway
Lamoine, ME 04605

Re: Peer Review of MacQuinn Gravel Pit Expansion Application

Dear Mr. Holt:

In accordance with Ransom Consulting, Inc.'s (Ransom) proposal of March 14, 2013, and the Lamoine Planning Board's acceptance of that proposal in an April 3, 2013 email, Ransom has completed Task 1 of the work scope. This report summarizes our review of written documents submitted to the Board as part of its review of the proposal of Harold MacQuinn, Inc., to expand its gravel pit by moving into the area shown on the attached Figure 1 and apparently part of Lamoine Tax Map 3, Lots 31 and 33. Specifically, Ransom's work includes a review and analysis of a report by Summit Environmental Consultants, Inc. (Summit), of September 2012 (beginning on P. 74 of the Record), a rebuttal by Dr. Willem Brutsaert (Brutsaert) dated January 2013 (beginning on P. 228 of the Record), and a surrebuttal by Summit to Brutsaert's testimony, dated Feb. 1, 2013 (beginning on P. 221 of the record). These three reports contained tables, boring logs, groundwater elevations, maps, and other references and my analysis is based on the data contained in or referenced by these pieces of the record. Ransom's task was to analyze the record and identify, to the extent possible, the potential groundwater impact.

One of the first tasks that we undertook was to assemble all of the data into ArcGIS so that everything could be correctly georeferenced. We noticed that the November 2011 LiDAR GIS products were available from the Maine Office of GIS so we downloaded the new topographic maps and hillshade representations of topography. We georeferenced the data points contained in the three reports by aligning data with identifiable points on the 2003 orthophotograph or the USGS 7.5' topographic map of the area. Therefore, we transferred Summit's "site boundaries, cross section locations, and data points" from the various maps to the ArcGIS environment. A map in the Record that showed the proposed final topographic configuration of the completed pit was on P. 136 of the Record and was a map prepared by Summit called "Post Development Drainage Plan." We assume that this represents the final outcome of the project that is before the Board for approval.

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Using the LiDAR-determined ground surface, we estimated the ground elevation for each geologic data point, and then subtracted the depths to different features of interest to find the depths to such features as: 1) an upper, or perched water table in fine-grained glaciomarine sediments; 2) the position of the uppermost glaciomarine fine-grained sediment; 3) any deeper identified water table in the sand and gravel aquifer; and 4) the top of bedrock. Additional data points were added along the Jordan River, Archers Brook, Blunts Pond, and a few other small unnamed streams and tributaries that were obviously in glaciomarine fine-grained sediments. The purpose of these points was to add additional data points to the top of glaciomarine fine-grained sediments, and a perched water table elevation. Although most of the ground elevations that were surveyed at the Summit data points (after changing from NGVD29 to NAVD88 datum = 0.64' difference) were in close agreement with the LiDAR (95% of LiDAR points are supposed to be within +/- 0.5' of true ground surface), one point, MW-3-2012 has a difference in estimated ground elevation of about 27 feet, suggesting that either the survey data at MW-3-2012 are off either vertically or horizontally or MW-3-2012 was not plotted at the correct location on the Summit maps. We also note that on our maps we abbreviate the name for "glaciomarine fine-grained sediments" to "clay" simply for the purpose of fitting the text easily into the figures. We understand that the glaciomarine sequence is not all clay and that silty fine sands, silts, and clay-silts are stratified to form the unit and the texture is variable from place to place and one depth to another.

We put together all of the viable data for each of the four groups of data—shallow water table; deep water table; top of clay; and top of bedrock—in the program SURFER9 to contour the data using the minimum curvature algorithm, then blanked out large areas of the contour map where no data existed as we did not want to extrapolate far without data. By digitizing the location of the Summit Geologic Sections AA' and BB', we brought those into SURFER as *.bln files and used them to cut "slices" through the four data sets, giving us the elevation profiles of each data set along each of the two cross sections, in the general vicinity of where data existed. These data sets consist of sets of coordinates of distance from the beginning of the section and elevation of the data in NAVD88 feet. These data sets were then combined in EXCEL to show the estimated positions in cross section.

In reviewing the data and comparing the Summit interpretations to those of Brutsaert, the thing that struck us was that there are obviously two different water tables in the vicinity of the proposed gravel pit expansion. Cold Spring, which is located at the intersection of Geologic Cross Sections AA' and BB' and is the source of a small community water supply in Lamoine, is formed by springs that exit at the interface of a sand and gravel layer that pinches out over an underlying glaciomarine fine-grained sediment layer, which we will call "clay" for short, but understand the caveat we gave in the previous paragraph. All indications are that this water table that supplies Cold Spring is a perched or "shallow" water table. Boring logs and monitoring wells MW-1 and MW-3-2012 suggest a deeper water table in sand and gravel underlies the "clay" layer. In other words, the clay layer is sandwiched into the sand and gravel and a monitoring well that has a screen set deep into the clay layer shows up as "dry". Monitoring well OW-1 (the one in the existing Kittridge Pit) finds a groundwater table at about elevation 25' NAVD88. Given the knowledge and approximate inclination and distribution of the "clay" layer in the sand and gravel, the question is how important this clay

layer is to diverting precipitation recharge going down through the gravel pit area from the surface sands and gravels towards the Cold Spring area. As described below, it appears that the clay layer is sloped upward from Cold Springs into the pit area and it is not a stretch to conclude that Cold Spring is recharged by groundwater that percolates into the sand and gravel of the pit area, travels downward and hits the clay layer that slopes toward Cold Spring, and then flows down along this clay layer, concentrating and developing a more defined perched water table as it nears the Spring. How much of this clay layer can be removed before Cold Spring has a "significant impact"?

Figure 1 shows the proposed pit expansion area, the locations of Geologic Cross Sections AA' and BB' (the same as used by Summit), and a contour map of the top of the "clay" unit inferred from a few boring logs, and data points located along streams in obvious glaciomarine sediment terrain. Notice how the clay layer is interpreted to slope upward from the Cold Spring area (at the juncture of the two cross sections) toward the middle of the pit expansion area but remain well below the ground surface**.** **Figure 2** is a color-coded digital terrain model that accentuates with color the differences in the ground surface elevation. Otherwise, the information is the same as on **Figure 1**. **Figure 3** is a shaded relief model developed from the LiDAR data that is quite informative as to what is happening geologically. Notice the rather smoothed ground surface on the southeast side of the large raised mound of sand and gravel on the western end of Cross Section AA'. We interpret this rounded shoulder to be beach deposits in sand and gravel on top of the clay unit. The beach was formed immediately after deglaciation when the relative sea level dropped fairly rapidly from Elevation 240' at the time of deglaciation toward where it is today at 0'.

The important difference between the Summit interpretation and the Brutsaert interpretation has to do with whether or not the clay layer under the beach deposits extends into the gravel pit area and is important to the hydrology of Cold Spring. Summit's Geologic Cross Section AA' as shown on P. 231 of the Record (**Attachment 1**) suggests that the clay layer just laps up on the side of the esker, but does not penetrate into it. Summit's written analysis does not seem to put any weight on a clay layer penetrating into the gravel pit, either, despite boring log descriptions (**Attachment 2**) that suggest some type of fine-grained glaciomarine deposits being encountered at depth in borings near the expansion area. We have attached several pages from a well-known reference on glacial geomorphology by Embleton & King (**Attachment 3**). If you look at pages 475 and 476 of that reference and the figure on page 475, you can see how having an inclined clayey layer embedded in an esker is certainly possible.

It is easier to see what we are talking about by looking at our renditions of Geologic Cross Sections AA' and BB'. In Section AA' (**Figure 4**) we have drawn the topography of the ground surface with great precision, based on the November 2011 LiDAR. Notice that there is a lot of vertical exaggeration, so slopes look much steeper than they would be in a 1:1 scale. The green line is the inferred top of "clay" or the fine-grained glaciomarine sediments that we believe are important to the recharge capability of the springs to the east of the pit. The blue line is the shallow water table that would occur near the top of the "clay" unit. The orange line is the water table in the lower sand and gravel (beneath the "clay" unit under the eastern half

of the pit expansion area). Notice it is annotated within the pit expansion area itself as being a maximum because no water table was found in borings that were terminated at that depth. The estimated top of bedrock is shown by the lower red line. Because of the scarcity of the data points and the broad brush contouring, some of the lines fall above the ground surface lines in places but that is only an artifact of the methodology we have had to use to interpret widely-scattered data points. We know the lines are above ground surface in places but it is not important to the overall point to try to force them down to the ground surface. Cold Spring is located at the distance of about 6250' from the start of the AA' line. Section BB' (**Figure 5**) is not nearly as important to the issue as Section AA', so although we have provided Section BB' here to be complete, we do not need to discuss it here.

On Cross Section AA' we have sketched in the approximate sideways projected position of the bottom of the pit expansion in a black dashed line. The important thing to note here is that if the pit is developed as suggested by P. 136 of the Record, that a lot of the glaciomarine unit that is inferred to slope upward from Cold Spring into the pit area will be removed. If this unit is removed, the effect of this low permeability layer in encouraging downward percolating recharge to flow toward Cold Springs could be lost. If that happens, the flow of the spring could be greatly reduced.

With all of the foregoing in mind, and feeling that there should be some requirement for the applicant to prove as part of the approval process that he can really excavate the pit to the elevations shown on the plan on P. 136 of the Record and maintain 5' of separation to the average seasonal high water table, we have developed a proposed plan of additional exploration that will assist the Board in answering the most important questions pertaining to the groundwater impact of this proposed expansion: 1) where are the shallow and deep water tables within this pit; and 2) would excavation in the eastern half of the pit expansion area significantly affect the recharge for Cold Spring?

Figure 6 shows the location of 4 proposed exploration points. To try to capture the essential information at each point, two monitoring wells may be necessary. The idea would be to advance a boring at each location that would go at least 5 feet into the permanent (deep) water table in sand and gravel beneath any glaciomarine fine-grained sediment units. The boring should be logged continuously as it is advanced. It may be possible to do this through air rotary drilling methods, as we have found that this is a reliable means of drilling through thick esker sediments with boulders in a relatively quick and cheap fashion, provided the driller is experienced in logging surficial material in an air rotary hole and can differentiate the fine-grained units from the glaciofluvial sand and gravel. A monitoring well can then be completed in the hole and the casing either partially or totally withdrawn. Having determined the depth to the glaciomarine unit (if one is encountered), a separate hole should be drilled 10 feet away from the first that penetrates only 5' into that unit and a well installed in that hole. Since the existing data suggest that any glaciomarine units are likely to be relatively shallow, those wells should be installed with hollow-stem auger and continuous split-spoon samples taken as the augers are advanced, then the well installed inside the augers.

At the proposed locations on **Figure 6**, we expect that the glaciomarine unit may only be encountered in PB-3 and PB-4. Regardless of what is found in drilling deep at each of the locations, shallow holes should be drilled at PB-3 and PB-4 with auger borings and wells installed into the top 5 feet of any fine-grained glaciomarine units encountered down to elevation 150'. Shallow wells only need to be installed at PB-1 and PB-2 if glaciomarine units are encountered in those holes above the elevation of the deep water table. The hole locations and elevations should be surveyed upon completion by survey-grade GPS equipment. After completing the borings and taking at least 2 separate water level readings a week apart, the geologic consultant for the Applicant should summarize the new geologic data and water levels and write a report that focuses on whether there is a glaciomarine layer in the eastern part of the gravel pit expansion area that is contributing to Cold Spring recharge, and whether, if that unit were removed, the Cold Spring flow would decrease and the approximate magnitude of that decrease. The exploration program we have suggested here is an absolute minimum. Depending on what is found in the field, the Applicant may want to acquire additional data to support whatever findings his consultants will ultimately make. This work would be better done now at the time of seasonal high water table, than in late summer at time of low water table, because there may not be any measurable water in the top of the clay layer then, although there may be water there at other times of the year. The Applicant's geologist should take into account the time of year the water level data are acquired and adjust for conditions that may occur in other seasons.

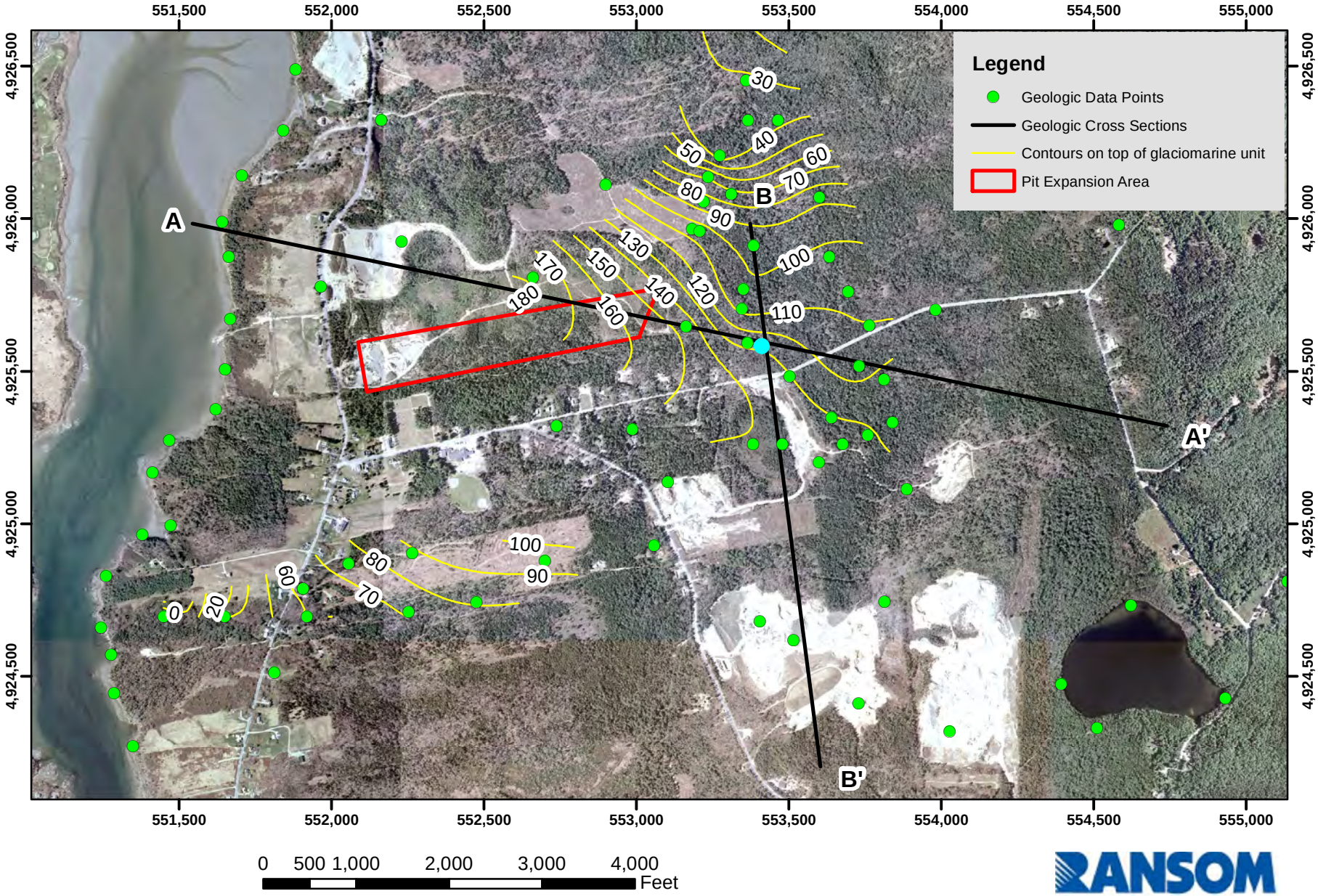
Sincerely,

Ransom Consulting, Inc.

STATE OF MAINE
ROBERT
GRAHAM
GERBER
110
CERTIFIED
GEOLOGIST

Robert G. Gerber, Certified Geologist #110
Senior Engineer & Geologist

Attachments: Figures 1-6; Attachments 1-3



0 500 1,000 2,000 3,000 4,000 Feet

Elevation Contours on Top of Glaciomarine Unit
Town of Lamoine, MacQuinn Gravel Pit Expansion Review
Orthophoto is 2003 2-ft pixel density
Grid is UTM, NAD83, 19N, meters
RGG 4-15-13 131.06066

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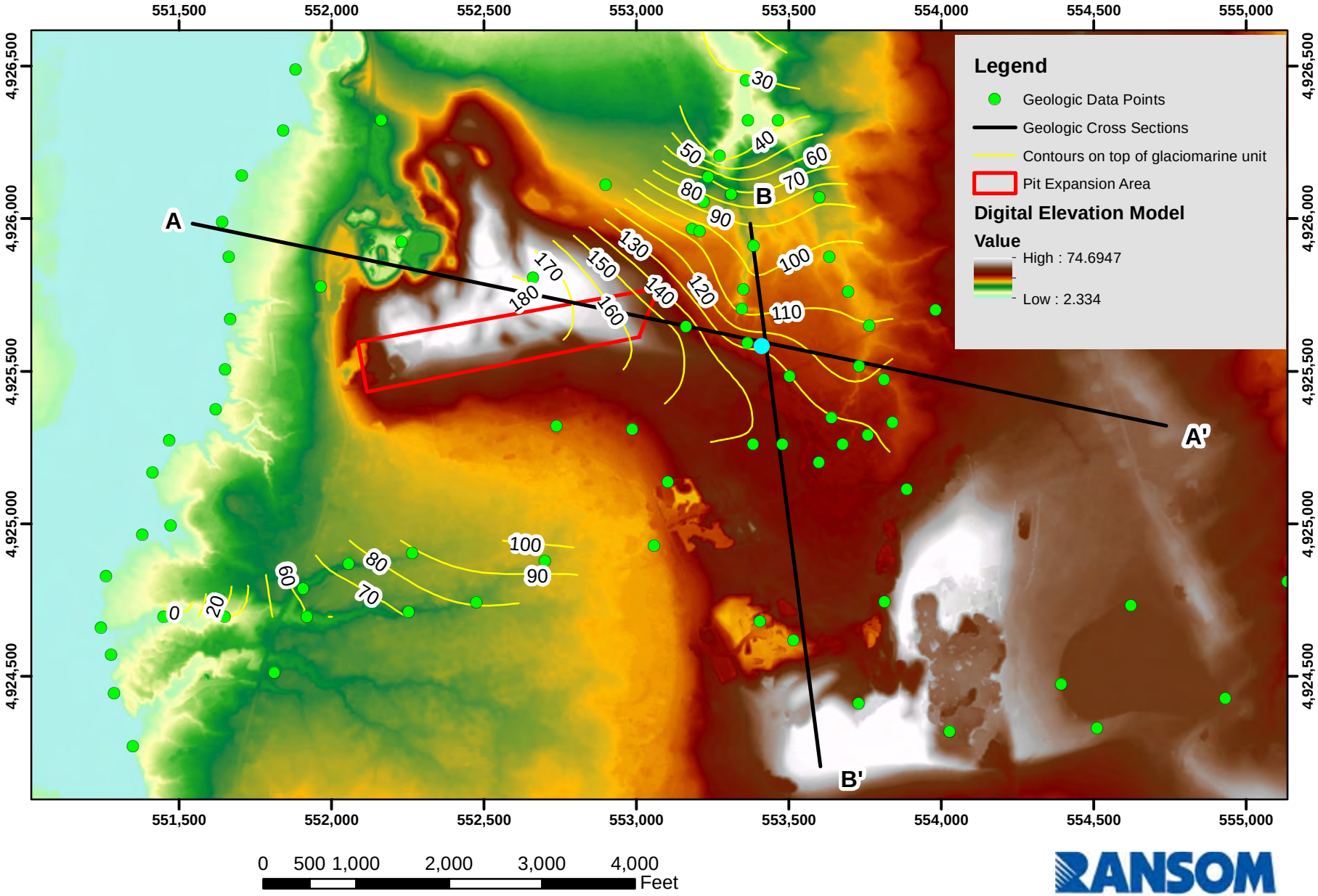
Figure 1



Elevation Contours on Top of Glaciomarine Unit
Town of Lamoine, MacQuinn Gravel Pit Expansion Review
Digital Elevation Model Developed from 2-m LiDAR
Grid is UTM, NAD83, 19N, meters
RGG 4-15-13 131.06066

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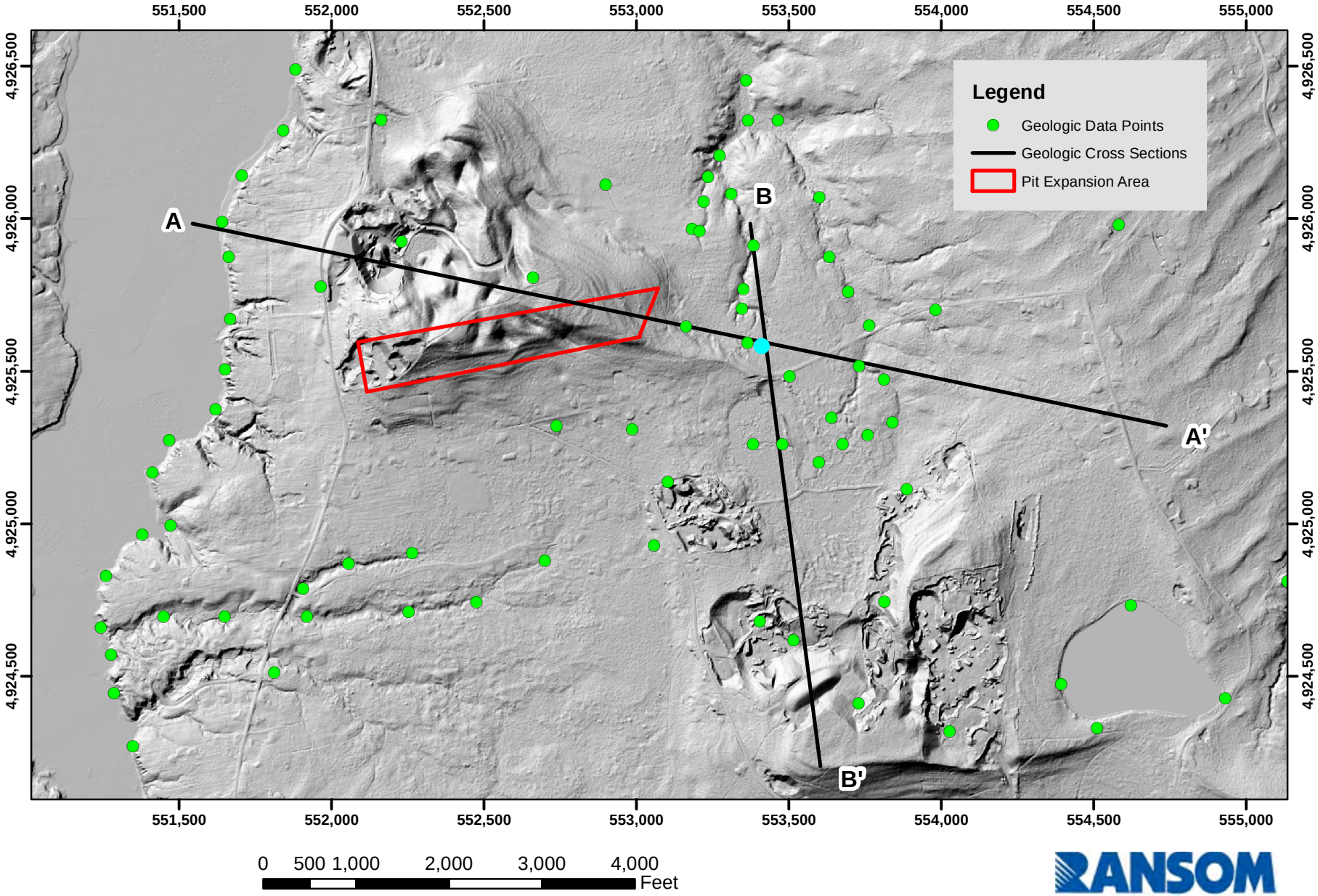
Figure 2



Elevation Contours on Top of Glaciomarine Unit
Town of Lamoine, MacQuinn Gravel Pit Expansion Review
2-meter Hillshade from LiDAR taken November 2011
Grid is UTM, NAD83, 19N, meters
RGG 4-15-13 131.06066

RANSOM Consulting, Inc.

Figure 3

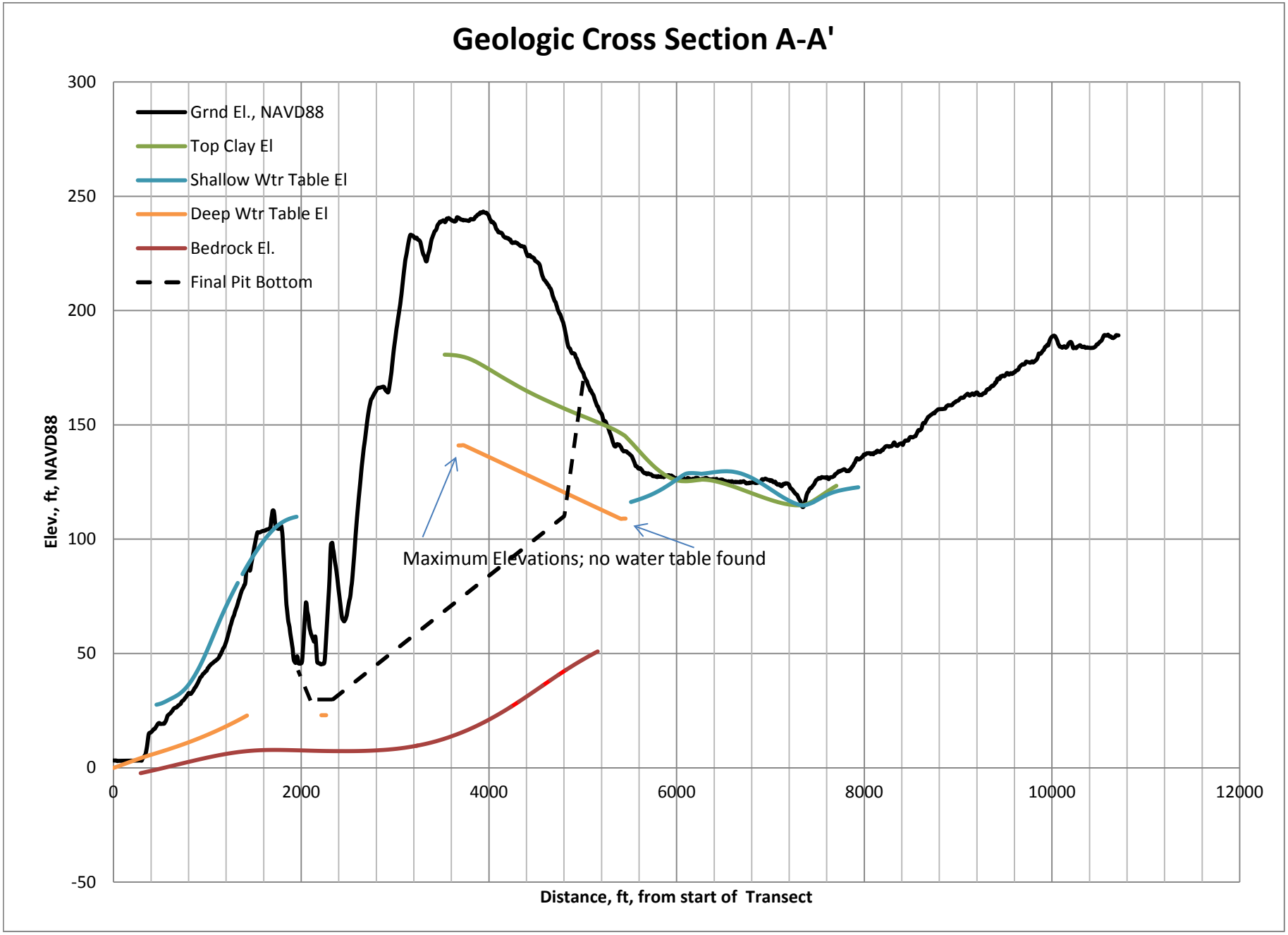

Geologic Cross Section A-A'
Grnd El., NAVD88
Top Clay El
Shallow Wtr Table El
Deep Wtr Table El
Bedrock El.
Final Pit Bottom
Maximum Elevations; no water table found
Elev., ft, NAVD88
Distance, ft, from start of Transect
300
250
200
150
100
50
0
-50
0
2000
4000
6000
8000
10000
12000

Figure 4

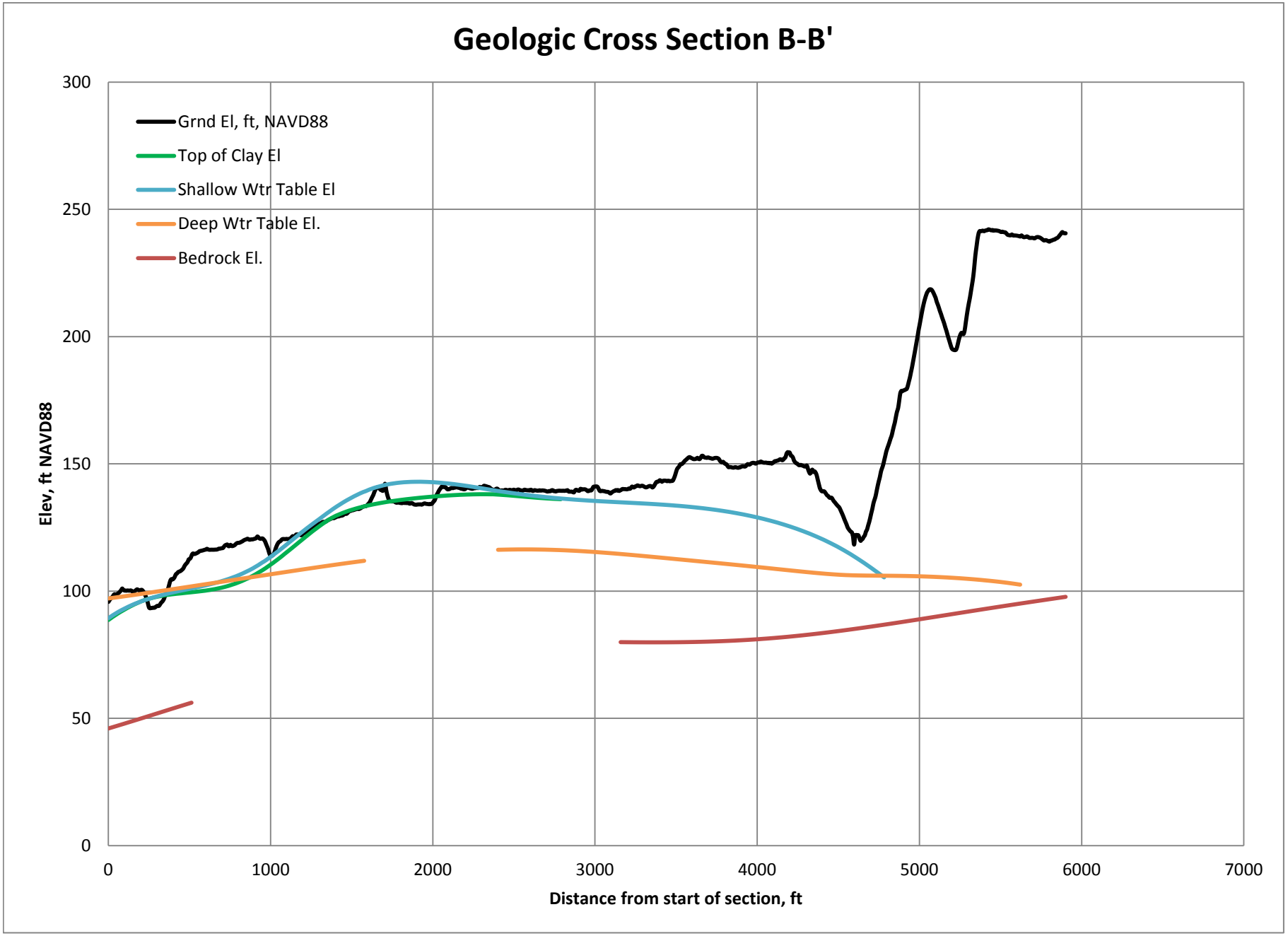
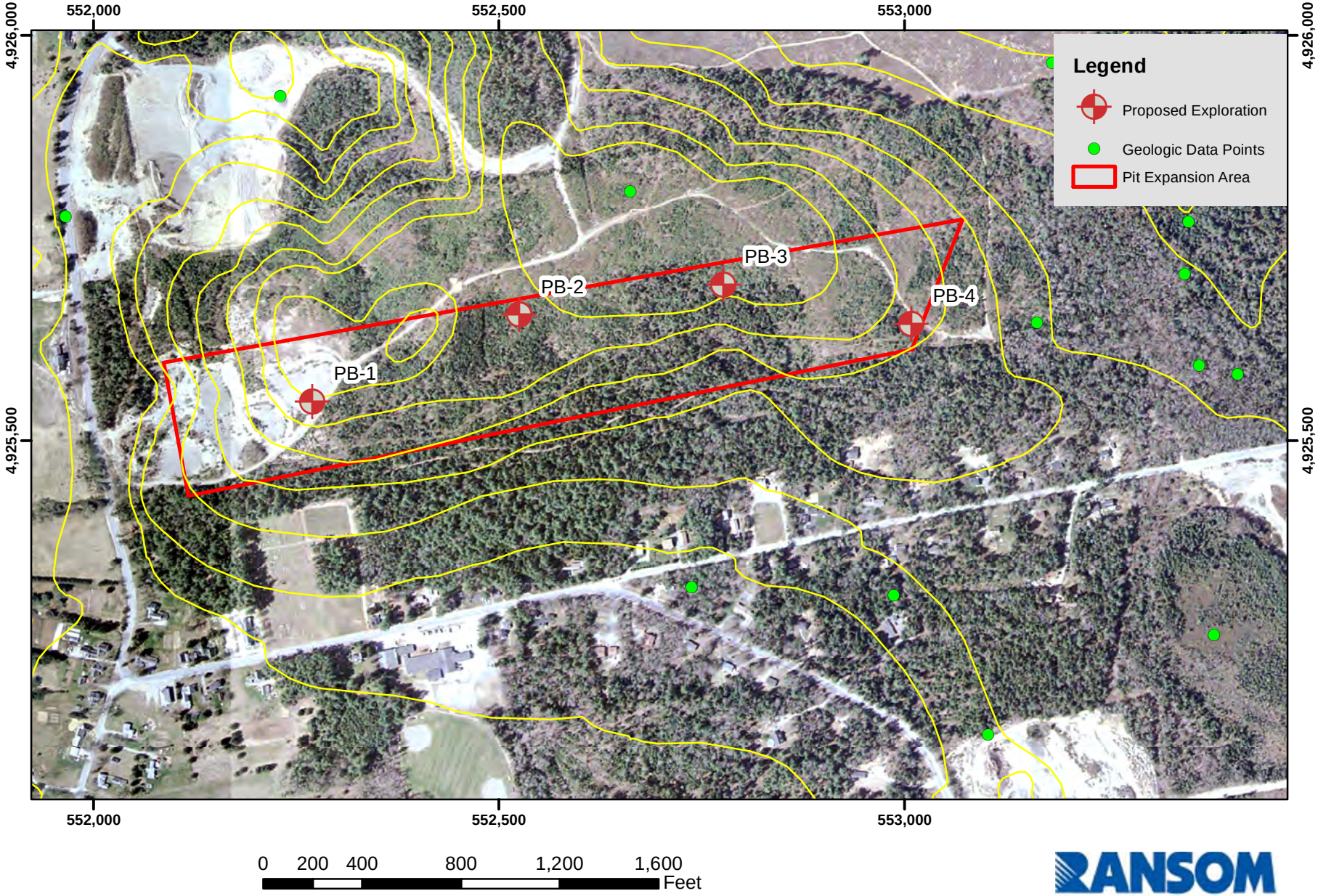

Geologic Cross Section B-B'
Grnd El, ft, NAVD88
Top of Clay El
Shallow Wtr Table El
Deep Wtr Table El.
Bedrock El.
Elev, ft NAVD88
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000
Distance from start of section, ft

Figure 5



Proposed Additional Exploration Points
Town of Lamoine, MacQuinn Gravel Pit Expansion Review
Orthophoto is 2003 2-ft pixel density
Grid is UTM, NAD83, 19N, meters
RGG 4-15-13 131.06066

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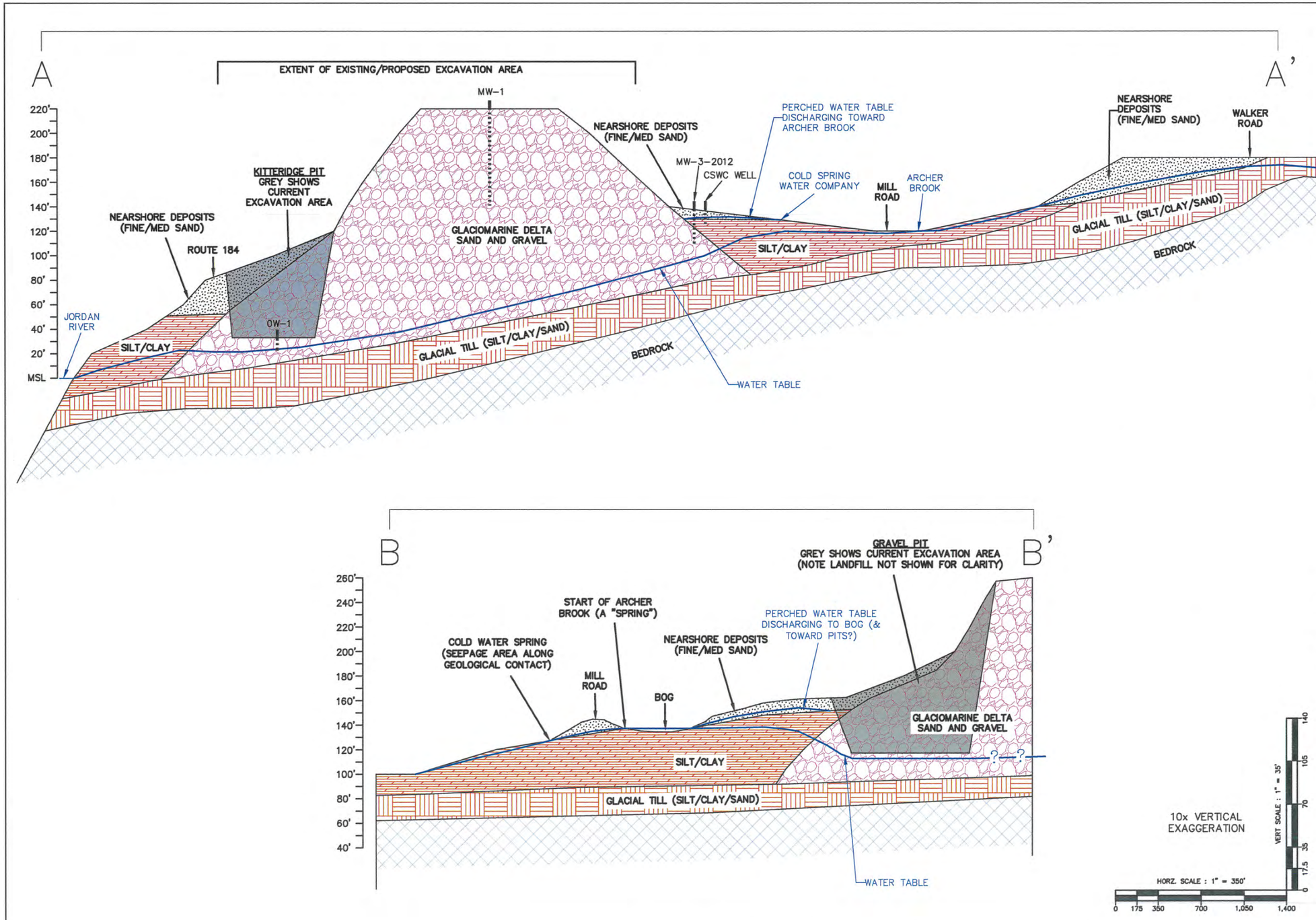
Figure 6



NO.	REVISION	DATE
1	ADDED MONITORING WELLS	2/1/13

SHEET TITLE: SCHEMATIC GEOLOGICAL CROSS SECTIONS

SCALE: AS NOTED
DATE: DEC. 2012
DRAWN BY: SBM
CHECKED BY: MAD

PROJECT: KITTRIDGE PIT
ROUTE 184
LAMOINE, MAINE

CLIENT: HAROLD MACQUINN, INC.
PO BOX 789, ELLSWORTH, ME 04605

640 MAIN ST.
LEWISTON, MAINE 04240
Tel.: (207) 795-6009
Fax: (207) 795-6128
www.summitenv.com
Summit Environmental Consultants,

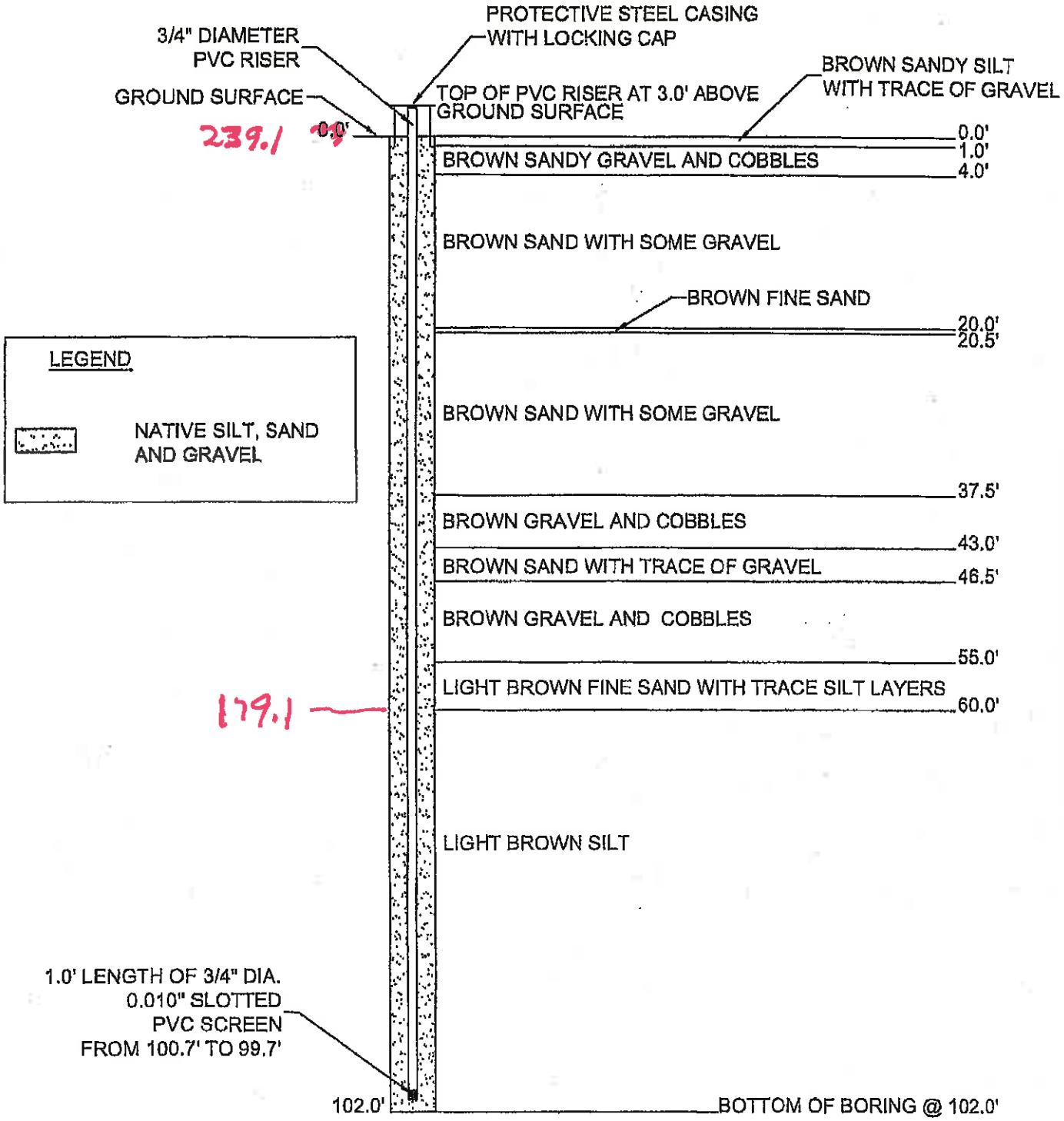
JOB NO: 11-3240.5

FOR PLANNING
BOARD PRESENTATION

Attachment 1

S.W.COLE ENGINEERING, INC.

MW-1
WATER LEVEL MONITORING WELL INSTALLATION DETAIL



SCALE

VERTICAL: 1" = 15'
HORIZONTAL: NOT TO SCALE

Job No : 04-0421 G

Sheet 8

SUMMIT

ENVIRONMENTAL CONSULTANTS, INC.
640 Main Street
Lewiston, Maine 04240

SOIL BORING LOG

Boring #: MW-3-2012
Project #: 11-3240.5
Sheet: 1 of 1
Chkd by: MAD

Project: MacQuinn - Miro Lot
Location: Lamoine, Maine

Drilling Co: Maine Test Borings
Personnel: Mike Porter
Summit Staff: Steve Marcotte, CG

Boring Location: see location map
Top of PVC Casing Elevation: 167.87
Date started: 8/27/2012

DRILLING METHOD		SAMPLER	
Vehicle:	Skidder	Type:	Not Functioning
Model:	CME	Hammer:	
Method:	4.25" HSA	Fall:	

ESTIMATED GROUND WATER DEPTH

Date	Depth (ft)	Reference	Groundwater Elevation (ft)
See Report			

Depth (ft.)	No.	Pen/Rec (in)	Depth (ft)	Blows/6 in.	SAMPLE DESCRIPTION	Stratum
164.9					0 to 2.5 ft bgs - Brown Sand and Gravel	Sand and Gravel Marine Near-shore
					2.5 to 10 ft bgs - Yellow Brown Medium Sand	
10					10 to 11 ft bgs - Gravel lense	
					11 to 20 ft bgs - Yellow Brown Medium Sand	
144.9' 20						
					20 to 23 ft bgs - Moist Olive Silty Sand	Marine Silt and Clay
					23 to 26 ft bgs - Olive Clayey Sand	
30					26 to 36.5 ft bgs - Olive Silty Clay Moist (balling)	
40					36.5 to 65 ft bgs Olive to Brown Silty Very Fine Sand to Silt	Silty Very Fine Sand To Silt Marine Delta
					Dry	
50						
60						
70					Bottom of boring at 65 ft bgs	
80						
90						
100						

Granular Soils		Cohesive Soils		% Composition	
Blows/ft.	Density	Blows/ft.	Consistency		
0-4	V. Loose	<2	V. soft		
4-10	Loose	2-4	Soft	<5%	trace
10-30	Compact	4-8	Firm	5-15	little
30-50	Dense	8-15	Stiff	15-25	some
>50	V. Dense	15-30	V. Stiff	>25	and
		>30	Hard		

NOTES:
1. bgs = below ground surface
2. bottom 15 feet of augers were left in the hole due to driller error
   MW-3-2012 was installed in second boring to 55 ft located 3 ft from this boring
3. split spoon sampler was not functioning. Materials were classified based upon cuttings and inspection of cutting bit every 10 ft

Attachment 2

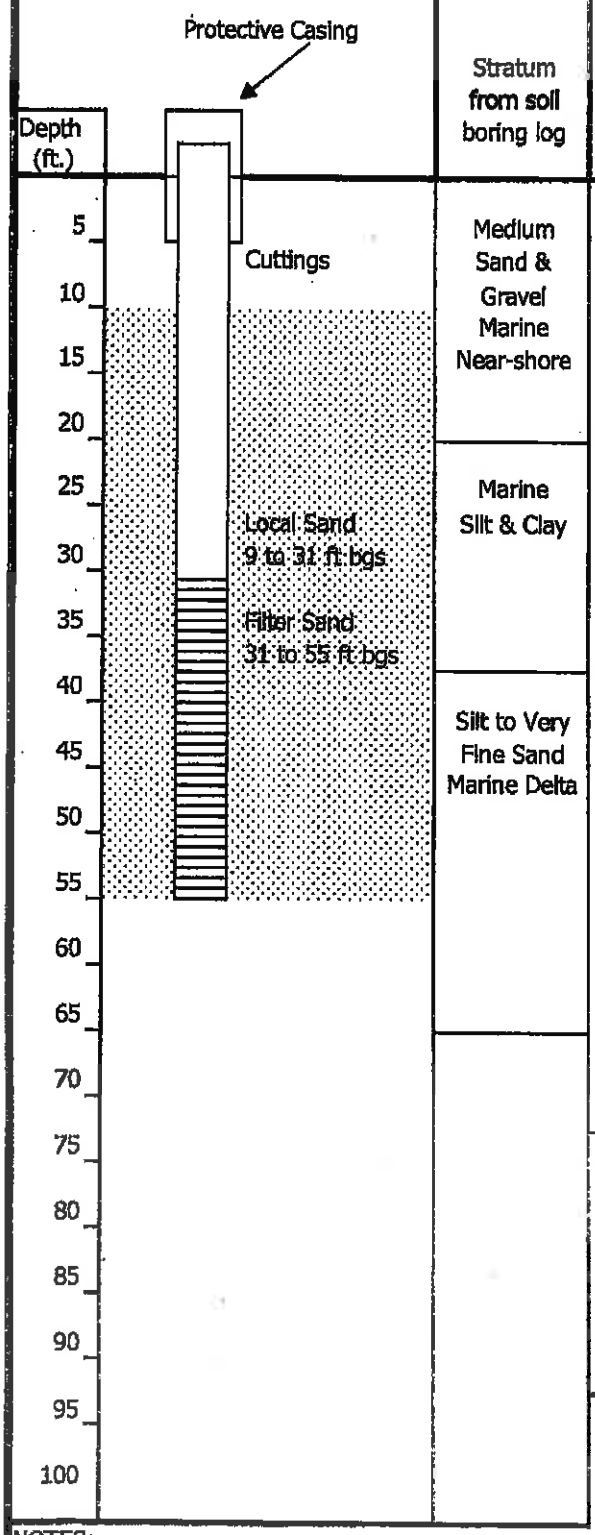
SUMMIT

ENVIRONMENTAL CONSULTANTS, INC.
640 Main Street
lewiston, Maine 04240

WELL COMPLETION LOG

Project:	MacQuinn - Miro Lot	Well #:	MW-3-2012
Location:	Lamoine, Maine	Project #:	11-3240.5
		Sheet:	1 of 1
		Chkd by:	MAD

Drilling Co:	Maine Test Borings	Well Location:	See Location Map
Foreman:	Mike Porter		
Summit Staff:	Steve Marcotte, CG	Date started: 8/28/2012	Date Completed: 8/28/2012



Stratum from soil boring log
Medium Sand & Gravel Marine Near-shore
Marine Silt & Clay
Silt to Very Fine Sand Marine Delta

REFERENCE ELEVATIONS

Surveyor:	Herrick and Salsbury
Reference (MSL or TBM):	NGVD 29
Top of Protective Casing:	
Top of inner casing:	167.87
Ground Surface:	164.9

GW ELEVATIONS

Date	Elevation
8/28/2012	<109.9
9/7/2012	**<109.9**

WELL CONSTRUCTION DETAILS

PROTECTIVE CASING

Type (Standpipe or roadbox):	Standpipe
Diameter (in.):	1 inch
Length (in.):	5 foot
Concrete Seal (gal):	N/A

WELL CASING AND SCREEN

	Riser	Screen
Material:	PVC	PVC
Schedule:	10	10
Diameter (in.):	1 inch	1 inch
Length (ft):	33.0	25.0
Interval below ground surface (ft):	+3 - 30	30 to 55
Slot size (in.):		0.01

FILTER AND SEAL MATERIALS

	Filter	Seal
Type:	Sand	None
Size:	#1	
Quantity (lbs.):	500	
Interval below ground surface (ft):	31-55	

GROUT

Type (filter sand, bentonite, etc.):	
Quantity (gal. or lbs.):	
Interval below ground surface (ft.):	

WELL DEVELOPMENT DETAILS

Water level from measuring point (ft):	
Depth of well from measuring point (ft):	
Total feet of water:	
Volume of water (gal):	
Volume of water evacuated:	
Method of development:	Not Developed

NOTES:

Attachment 2

flow law
p. 126

Glacial Geomorphology

Clifford Embleton

Reader in Geography, University of London King's College

Cuchlaine A. M. King

Professor of Physical Geography, University of Nottingham

A HALSTED PRESS BOOK

John Wiley & Sons
New York

Attachment 3

© Clifford Embleton and Cuchlaine A. M. King, 1975

First published 1975 by
Edward Arnold (Publishers) Ltd
London

This book is a fully revised edition of Parts I–III of
Glacial and Periglacial Geomorphology first published 1968 by
Edward Arnold (Publishers) Ltd
Reprinted 1969, 1971, 1974

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Published in the USA
by Halsted Press, a Division
of John Wiley & Sons, Inc
New York

Library of Congress Cataloging in Publication Data

Embleton, Clifford
Glacial geomorphology

(Their Glacial and periglacial geomorphology; v. 1)
'A Halsted Press book'
Includes bibliographies and index
1. Glacial landforms. I. King, Cuchlaine, A. M. joint author. II. Title
GB581.E452 1975 vol. 1 551.3'1'08s
ISBN 0–470–23892–5 [551.3'1] 75–14188
ISBN 0–470–23893–3 pbk

Printed in Great Britain

Attachment 3

2.3 *Descriptions of eskers in different areas*

R. J. Price (1965) has described eskers left in front of the retreating Casement glacier in Alaska, some of which have been revealed since the glacier became land-ending about 1907. A complex set has been exposed from the retreating ice since 1935. The eskers are ridges 3–9 m high, formed of well-rounded gravel, cobbles and boulders. They occur on ground that slopes both away from and towards the glacier. Those formed on the slope down towards the glacier must either have been formed by subglacial streams under hydrostatic pressure or by englacial streams. In the latter event they must have been let down subsequently on to the reverse slope. A complex series of ridges is thought to have developed supraglacially in lakes, which have since drained, leaving shoreline features on the ridges. The largest ridges were probably on the site of meltwater streams and they appear to be true eskers which were underlain by ice at one time. Some near the glacier have ice cores, and photographs showed them extending on to the ice in places. They could either have formed in englacial tunnels or on the ice. Subsequent melting must have produced the uneven crest line. The lakes must have formed after the ice melted out beneath and around the eskers. Some of the eskers were 40 m high and 33 m wide at their base when they were still on the ice. These eskers have been destroyed by meltwater streams subsequently.

Hoppe (1961) has described some of the eskers of northern Sweden. These eskers occur both above and below the highest marine limit. They often extend for 5 to 10 km between breaks, which normally occur where the relief is highest. The largest eskers have rather flat, broad crests, supporting the view that the deposits were built up in successive layers in subglacial or englacial meltwater channels. Hoppe agrees with V. Tanner (1932) that the sharp-crested narrow variety of esker is the result of subsequent collapse of the sides when the supporting ice walls melt away. The eskers formed above the water-level consist mainly of stratified sand and gravel. Sometimes silt occurs within the esker or on its surface, and occasionally heaps of boulders are found.

One particular esker, Hammesharju, shows some unusual features. It is situated south-east of Gällivare and is over 4 km long, 50 to 80 m wide and up to 16 m high, although its crest is broken by gaps. The esker was formed probably in a subglacial or englacial tunnel; later, a supraglacial stream was let down across it and eroded the gaps that occur along it. Ridges of till flank the esker on either side. These ridges contain stones preferentially orientated transverse to the ridge elongation. It is thought that they were formed by the squeezing of water-soaked till into the area on either side of the tunnel. There are also examples of a similar type of feature that forms when the till is pressed beneath and into the central core of the esker rather than alongside it.

Another interesting example is the Vessö esker in southern Finland. It is in part a continuous ridge, but in places it is broken into separate mounds. It is situated about 50 km east of Helsinki, is 8 km long and varies in width from 300 m to 2 km, with a maximum height of 38 m (Fig. 16.7). It runs south-east to north-west radially to the large Salpausselka moraines to which it is linked. Its outer part consists of several islands, while it has been modified by the sea as it has risen isostatically since its emergence from the ice. The esker as a whole is asymmetrical and has a steeper eastern slope with a stony surface, continuing in places below sea level. In places, there are depressions,

which are steep and circular, along the ridge. Along part of its length, the esker forms a broad ridge with associated boulder-covered mounds. Elsewhere, the esker spreads out and merges into an even, sandy plain. The fluvioglacial material of which the esker is composed lies directly on the rock with no intervening till. The bedrock, an easily weathered granite, was eroded to form a depression along which the esker is situated.

The structure of the esker has been revealed in cuttings at a point where the eastern slope is 13° and the western only 3°. The esker is covered with boulders and its internal structure is shown in Fig. 16.7. The sloping layer of clay (4), with a dip of 8°, runs

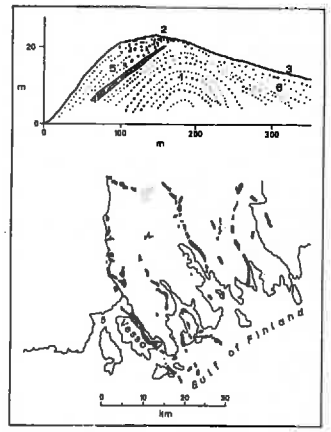

Fig. 16.7
The Vessö esker, Finland (O. Granö, *Fennia*, 1958, by permission of the Johnson Reprint Corporation)

almost parallel to the steeper eastern side. This layer probably formed the original esker surface, and the overlying sand and stones (5) consist of later marine additions. Beneath the clay and silt, sand (1) occurs in alternating layers of finer and coarser particles, showing cross-bedding. In the centre, the material is coarser. Some large angular boulders occur in the silt layer and on the upper surface (2), where the gravel and stone layer is 1–3 m thick.

The form of the esker and its constituent material give indications of its mode of formation. O. Granö (1958) suggests that the fluvioglacial material of the esker was deposited close to the ice margin in deep water. He considers that the character of the esker, particularly its core, agrees with the views of De Geer concerning esker formation in submarine environments. The original core was probably deposited as a small delta at the mouth of a subglacial stream emptying into the sea. A clay and silt layer represents a remnant of the covering of fine material deposited when the esker was still in deep water. It includes large ice-rafted angular blocks. The boulders covering the clay could have been derived from a covering of stony till from which the fine

Attachment 3

material has since been washed away. The sand (6) above the unconformity on the western side of the esker was deposited by the waves as the esker emerged above the sea. The steeper eastern slope is the result of movement of material to the lee side by the waves whose maximum fetch lay to the west. The feature has been considerably modified by the sea since its formation at the edge of the retreating Scandinavian ice sheet.

The Lammi esker, described by E. Wisniewski (1973) stretches north-west from the Salpausselka I moraines. It consists of a series of proglacial deltas linked by short ridges, and lies in a bedrock trough. The deltas formed successively in the Baltic Ice Lake. In places, the esker ridge is 200 m wide and 35 m high, and is composed of gravel and pebbles up to 30 cm in size. Its sides slope at 25° to 30°. Some boulders up to 2 m in size indicate an ice-contact position; they overlie bedded material whose stratification is deltaic. Deformation of the finer layers in places has resulted from melting of buried ice, and there are also kettle holes. The esker now has the form of hillocks of varying size, formed during deglaciation in a sub-aqueous environment. Each delta marks a pause in the retreat of the ice front, and the esker deposits accumulated in crevasses or channels along which fluvioglacial transport was taking place. It is a classic example of a De Geer-type esker. Most of it was submerged on deglaciation, resulting in some loss of fines and abrasion through wave action.

P. Fogelberg (1970) analyses the features of deglaciation associated with the Salpausselka II moraine in an area of southern Finland. In the moraine foreland, there are eskers whose southern ends rise to ridges or hills 135 to 140 m above sea level, northwards from which a lower tail continues at 100 to 110 m. The steep hillock at the southern end was deposited between ice walls where the ice-channelled stream or tunnel opened into a lake. The tail is part of the feeding esker formed in the ice tunnel. In the moraine hinterland, the fluvioglacial deposits include more continuous eskers. No De Geer-type eskers occur either in the foreland or the hinterland of this area.

Farther north in Finland, the deglacial history of the Tana valley provides further illustration of the complex environments with which esker systems are associated. The ice sheet melted rapidly from this area, its margin melting back at an average rate of 230 m/year until it became ice-free in 9500 BP (H. Mansikkaniemi, 1970). Subglacial sedimentation was extensive during this phase, and bottom eskers and subglacial valley trains formed. The largest eskers occur where the valley is narrow and deep; these include bottom eskers 10 to 40 m high that follow the valley floor and that were formed in ice tunnels. They have been trimmed by later marine incursion. During deglaciation, short-lived lakes formed in the narrow parts of the valley and these were filled with fine sediments, at a level above that of the river deposits. The sorted sediments attain thicknesses of 20 to 70 m on the valley floor. There are also 'slope eskers' descending the valley sides, which are smaller and less than 10 m high, the infillings of subglacial chutes (p. 346). Some of the large bottom eskers are continuous for 7 km. Their width varies from 100 to 300 m—25 to 50 per cent of the width of the valley bottom. Deep kettle holes are associated with them. The finest deposits in the eskers are well-sorted, and the stones rounded, having travelled 25 to 35 km. Coarse sediments, on the other hand, are poorly sorted and only slightly stratified. Some of the bedding in the bottom eskers is nearly horizontal. The eskers probably formed under dead ice 100 to 200 m thick, whose downwasting led to the plateaux and uplands being exposed while ice

remained in the valleys. Fine sediments accumulated as melting ice caused blockages in the valley at some places. Coarse sediments were deposited when the flow was rapid in subglacial or englacial tunnels. These were enlarged by melting until the marginal ice walls collapsed, together with the roof, and the fallen blocks of ice were then covered by further sediment. The slope eskers are less numerous because rapid flow of water down the subglacial chutes tended to prevent deposition.

The deglaciation of the Holy Cross Mountain area west of the Vistula in Poland has been discussed by C. Radłowska (1969). The Tarłow esker is associated with the Vistula ice lobe of Riss age. Its roots lie, in part, in a valley, although not at the lowest point. Its crest reaches 192 m where the plateau level is 210 m, and its course is sinuous, consisting of long hillocks and mounds, whose irregular relief is said to be partly the result of subsequent erosion. Coarse material occurs in the esker core, overlain by bands of gravel-pebble mixture and some sand. The structure is complex and in places disturbed, particularly where the material is coarsest in the north. Boulders up to 0·5 m across are tightly packed at the esker base. Material is more uniform towards the south. The lower eastern slope is thinly mantled with till up to 5 m from the crest, suggesting that the esker was formed in a tunnel. Large soft-rock boulders indicate short distances of transport, and there is little sign of sorting. Strong cross-bedding occurs and there are lenses of sand and silt. Three stages of deglaciation are inferred:

1 the esker developed in a subglacial tunnel and was then partially covered by till and ablation moraine as the ice decayed
2 a free space developed between the esker and the dead-ice wall, and water flowing along this channel added a kame terrace to the esker
3 after the dead ice decayed, a valley formed adjacent to the kame-esker, followed by settling and gelifluction on the slopes. Eolian activity finally added some sand dunes.

In central Poland, Z. Michalska (1969) differentiates true eskers from crevasse fillings. Esker materials are well washed but vary in particle size and bedding. Accumulation occurred in a marginal tunnel or, more rarely, in a decay crack near a tunnel outlet. There were probably short breaks in sedimentation, a series of layers representing separate depositional episodes with different sources. Till layers several metres thick are found near the bases of some eskers; at some later stage, channels up to 30 m deep were cut in the till. Following channel erosion, up to 30 m of fluvioglacial sediments were deposited in several episodes, to be overlain in turn by sandy deposits laid down in continuously flowing water. The tunnel then increased in size and deposits 15 m thick accumulated along the channel axis. Finally, the tunnel roof melted, letting down a mantle of till 1–2 m thick.

Mention should be made of some of the eskers of Ireland, as it was from this country that the name 'esker' originated. An interesting series of eskers and associated features has been described by F. M. Synge (1950) in the area around Trim, north-west of Dublin. The area lies in the drainage basin of the River Boyne, which flows north-eastward to the north of the main esker area. The area is drained by streams flowing north-westward to join the Boyne (Fig. 16.8). When the ice sheet associated with the eskers lay over the area, its margin ran roughly from north-east to south-west and was

Attachment 3