PHASE 1 EROSION STUDIES

STUDY 1 – TERRAIN ANALYSIS
FINAL REPORT

Volume I: Text, Tables, & Figures

WEST VALLEY DEMONSTRATION PROJECT AND WESTERN NEW YORK NUCLEAR SERVICE CENTER

Prepared for:

United States Department of Energy, and
New York State Energy Research and Development Authority

Prepared By:

EROSION WORKING GROUP
Enviro Compliance Solutions, Inc. (ECS) Contract Number
DE-EM0002446/0920/13/DE-DT0005364/001

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February, 2018

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February 2018

EXECUTIVE SUMMARY

This report presents the results of Phase 1 Erosion Study 1 - Terrain Analysis, Age Dating, and Paleoclimate for the West Valley Demonstration Project (WVDP) and the Western New York Nuclear Service Center (WNYNSC), referred to as the "Site." A substantial quantity of data and information already existed for the Site. Much of this had been reviewed and incorporated in the Final Environmental Impact Statement (FEIS) erosion studies. The overall goal of Study 1 was to build on this previous work to better delineate and enhance understanding of the postglacial geomorphic history of the site, and the larger Buttermilk Creek watershed for the purpose of reducing the uncertainty inherent in future erosion forecasts.

The specific objectives of the study included the following:

- Establish more precisely or definitively the timing of the last ice sheet recession
- Establish the sequence of major or identifiable events in postglacial time
- Ascertain the past history of postglacial erosion and its relation to prediction of future erosion
- Investigate relations between paleoclimate and erosion rates
- Provide guidance on how these factors should be incorporated in predictive erosion models

A large quantity of field data and information was gathered and analyzed during the course of the study from August 2015 to September 2016. The general types of data and information gathered can be generally summarized as follows:

- Personal expertise, experience, familiarity with the site and regional geology, and insights, of the SMEs;
- Review of published and unpublished literature, reports, data, and information;
- Analysis of maps, satellite imagery, aerial photography, and detailed LiDAR maps;
- Information gathered in the course of numerous geologic reconnaissance visits including traverses on foot with detailed digital photography and LiDAR contour maps, collection of shallow samples for pebble counts, collection of organic samples for ^{14}C dating, and collection of old growth tree cores;
- Non-invasive subsurface information from more than 11,000 lineal feet of ground penetrating radar surveys;
- Geologic logging, sampling, and photography of 112 exploratory pits and trenches;
- Several hundred in situ shear stress measurements;
- Laboratory age analysis of 67 samples by radiocarbon dating, 11 samples by OSL dating, and 5 samples by TCN dating methods;
- Reinterpretation of 10 previous OSL sample results reported in the FEIS using more-recent analytical methods;
- Synthesis and analysis of the various types of data, and estimation of historical erosion rates; and

- Evaluation of uncertainty reduction.

The data, information, and analyses performed support the following conclusions:

1. The age of the last glacial recession can now be confidently dated at circa 13,000 calendar years before present (YBP). This date establishes the starting point for late Pleistocene/ Holocene Buttermilk Creek incision.
2. Sediment yield from Buttermilk watershed significantly exceeds yield from Connoisarauley watershed as seen in 1994 color-infrared air photos. That the two basins produce markedly different sediment quantities is not surprising because the late-glacial ice advance (Lavery) involved sediment trapping in the bowl-shaped watershed of Buttermilk Creek while the watershed of Connoisarauley had meltwater channels positioned to allow maximum disbursement of proglacial waters and sediment westward. Computer modeling would need to account for differences in basin sediment yields between the two basins if comparative studies of sediment loss or yield were done.
3. Historical Buttermilk Creek incision rates have been nonlinear through time. Vertical incision rates immediately following glacial retreat at 13,000 YBP averaged around 0.018 feet per year between approximately 13,000 and 10,000 YBP (55 feet in 3,000 years per Figure ES-1). Between approximately 10,000 and 5,600 YBP, there was little net incision based on data from the abandoned meander area. The incision rate then increased during the period from 5,600 to approximately 2,300-2,500 YBP to an average of 0.030 feet per year (95 feet in 3,200 years) until the existing bedrock thresholds were apparently encountered in the channel. During the most recent 2,300-2,500 years the net incision has been approximately 5 to 10 feet, or approximately 0.002 to 0.004 feet per year.
4. The graphs in Figure ES-1 present two equally-plausible and similar scenarios for incision history on the basis of the available age dates. One curve was derived from data at the abandoned meander, and the other was derived from projecting a longitudinal section through Buttermilk valley that included the Franks-Buttermilk juncture. The bases for the two scenarios are discussed in the report. While various incision rates are tabulated or discussed in the report, the above incision rates were calculated with data estimated directly from Figure ES-1, which is the fairest representation of the report findings and interpretations. Minor differences in incision rates, and other minor variations in interpretations within the report arise from variations in choice of locations for data reduction, varied elevation values, and varied interpretations of terrace surfaces related to channel-bar shapes and sediments. Figure ES-1 also provides a general indication of the relatively low uncertainty in incision history by comparing the two curves.
5. Climate was warmer and drier approximately 10,000 to 6,000 years ago than in the periods before and after. The mild climate coincided with a cessation of incision in the Buttermilk valley as indicated by dates at the abandoned meander (Figure ES-1). The milder climate affected Lake Erie level and consequent base level for the mouth of

Cattaraugus Creek, yielding about 3 meters of incision, followed by a sudden 11 meters of aggradation of the creek mouth; such changes are not likely to be transmitted upstream more than a few miles, perhaps a dozen, and thus would not have affected the Buttermilk drainage. Climate change may have influenced the whole Buttermilk watershed in ways such as sediment transport and mass-movement rates (water contents).

6. While there are no published reports of relative incision resistance comparing rock to sediment, local and regional observations indicate shale erosion resistance ranges from equivalent to many-times the incision resistance of sediments, based on outcrop profiles, valley-widening up-gradient of bedrock reaches, flood effects, seismic velocities, and standard penetration tests (SPT) from drilling. Furthermore, sandstone erosion resistance is many times greater than shale incision resistance.
7. The reason for the slowing of Buttermilk Creek incision rate during the past 2,000 to 3,000 years likely is emergence of resistant sandstone bedrock sections in downstream reaches of Buttermilk Creek. The overall flattening of the gradient of Buttermilk Creek with time (from about 10,000 YBP to present) was from approximately 0.018 to 0.010 as indicated by terrace and modern creek gradients, but data for the steeper old levels is scant. The modern gradient of 0.010 is common among similar size streams in Lake Erie escarpment-face positions. Both resistant sandstone sills and gradient flattening are factors that will continue to be applicable into the future.
8. The Buttermilk Creek channel was pushed westward by fan growth by the westward-flowing Heinz Creek tributary at the confluence of the two streams. The west bank of Buttermilk Creek has been over-steepened leading to active landslides at this location. The westward lateral migration of Buttermilk Creek during Holocene time is estimated to have ranged between approximately 0.09 and 0.16 feet per year. If the current westerly migration of Buttermilk continues into the future at these rates, Buttermilk Creek may remove part of the Franks Creek-Buttermilk divide in the vicinity of the State-licensed Disposal Area (SDA) in an estimated 4,100 to 6,600 years, or sooner depending upon the concomitant rate of widening of Franks Creek.
9. Several hundred, field shear-stress values for a wide variety of in situ materials were measured using a Torvane device. The Torvane data demonstrate that sediment types vary in shear strength by about two or three orders of magnitude. In general, shear strength has an inverse correlation with erodibility, i.e. greater shear strength implies lower erodibility. These data may correlate with erodibility measurements from Study 2. If so, the larger number of Torvane data points may be able to supplement the Study 2 erodibility data by serving as proxies for erodibility in modeling.
10. Landslides have, and will continue to have, great significance to terrain development in the Buttermilk Creek watershed. For example, two of the primary processes key to understanding past landscape development, namely Buttermilk Creek base level control, and westerly channel migration, are at least in part influenced by landslides. The large landslide in the east bank of Buttermilk Creek just downstream from the tree farm site terraces was periodically influential in base level control, while the active landslide in the

west bank opposite the Heinz Creek fan is intimately involved in westward lateral migration of the Buttermilk channel.

11. The current study has produced a significant improvement in our knowledge of the historical processes controlling landscape development and their timing in the Buttermilk Creek watershed. This has enabled a reduction in uncertainty concerning the nature and timing of these processes; although, quantifying the reduction is difficult. The vast quantity of data gathered, and the significant improvements in dating and other measurement technologies, are just two of the factors that enable the dramatic improvement in confidence when compared with the quantity and quality of data available to previous studies. As a specific example, LiDAR with 1-foot contours supplanted older maps with 20-foot contours so that features less than 3-feet in height were identified now where features such as alluvial fans more than 40 feet in height were previously inadequately identified.

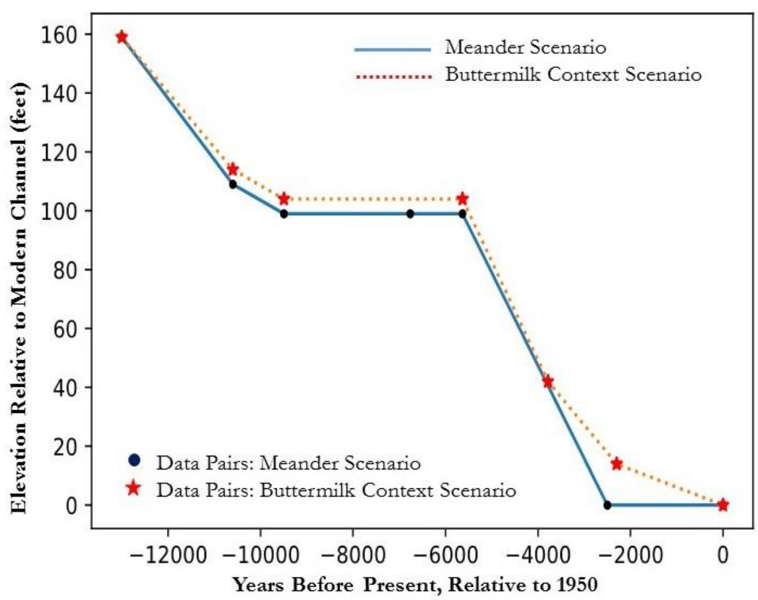

Figure ES-1: Graphs of equally-plausible incision history scenarios in the vicinity of the abandoned meander.

The data, information, findings and conclusions, and expertise of the study participants lead to the following observations concerning future erosion at the site:

- Future erosion within the Buttermilk Creek watershed will be dominated by headward erosion up tributary streams and gullies such as Franks Creek, and valley-widening processes, rather than by significant base-level lowering of the main stem Buttermilk Creek.
- Mid to lower Buttermilk Creek is not likely to significantly incise deeper in the coming millennia because: a) further incision of Cattaraugus Creek (Buttermilk's base level) will take 10,000s to 100,000s of years owing to the great extent its profile has already incised and flattened to date; b) the length of the flow path to the Atlantic Ocean; c) the flat gradients of the Great Lakes Erie and Ontario; d) the expected 11,000 year retreat of

Niagara Falls before beginning to drain Lake Erie; and e) the fact that the current gradient of Buttermilk at 0.010 has been sustained for thousands of years and is typical for similar stream reaches throughout the region; and f) the level of lower Buttermilk Creek has been quasi stable for more than 2,000 years. The threat to site facilities is from gully incisions in the Franks Creek watershed related to head-cuts, knick-points, initiations of new gullies, or in other words the back-wasting or retreating processes of gully gradients and walls.

- Incision of the Franks-Erdman creeks is not likely to reach bedrock in the vicinity of facilities and so the modeling should use parameters for erosion of sediments. Where creek beds currently encounter bedrock, more erosion resistant parameters could be inserted into analysis and as incision proceeds the bedrock parameters could be advanced downstream. Because some bedrock could be as erodible as some till, using only sediment erosion characteristics in analysis would model the worst-case scenario for incision.
- Gulley widening due to Franks-Erdman creeks encountering sandstone layers is not likely in the vicinity of facilities because bedrock will not be reached by incision. If or when resistant sandstones are incised to the west of the facilities area, the effect will be to widen gullies upstream (west) of facilities, leaving facilities unaffected by such widening.
- Westward migration of the Buttermilk Creek channel opposite the Heinz Creek confluence is likely to continue and will likely lead to incorporation of Franks Creek adjacent to the SDA within a time frame of roughly 4,100 to 6,600 years from now, or sooner depending upon the rate of widening of Franks Creek which could hasten the process. This process is illustrated schematically in Figure ES-2 on the following page.
- Unlike the westward migration of the Buttermilk Creek channel at Heinz Creek, the map position (x-y) of the Buttermilk Creek/Franks Creek confluence appears to have changed little in the last several thousand years. The juncture is currently directly in the middle of the Buttermilk flood plain that is 500 feet wide; the juncture will have varied within that location as meanders migrated. The meander patterns (ghost channels or scroll work) indicate that juncture movement up or down the length of Buttermilk valley was tens of feet, less than a hundred feet. The stability of the channel at this location makes it a good candidate location for setting base level boundary conditions for models of the Franks Creek watershed within the limits just described.
- When evaluating the variability of historical vertical incision rates of Buttermilk Creek for use in modeling future erosion, appropriate weight should be given to the most-recent approximately 2300- to 2500-year period during which the incision rate appears to have slowed dramatically to 0.003 feet per year (estimates range from 0.002 to 0.004 feet/year). The reasons for the slowing include emergence of larger resistant bedrock sections in downstream reaches of both Buttermilk and Cattaraugus Creeks, and the overall flattening of the gradient with increasing age. These conditions will continue into the future, as opposed to many of the transient conditions that accompanied variable incision rates during earlier periods.

- Climate change is expected to produce more storms of high precipitation intensity in the relatively near future; although, little reliable information is available to forecast climate change more than roughly 100 years in the future. The erosive energy of runoff from increased future storms will likely enhance Buttermilk valley widening in erodible sediments more than base-level lowering because base-level lowering has slowed due to emergent resistant bedrock. The earlier period of warmer climate (ca. 10,000 to 6,000 YBP) also resulted in slowed incision.
- Patterns of storm water runoff have changed over the last approximately 200 years owing to deforestation, agriculture, and paving of ground surfaces resulting from changes in land use. Concentration of runoff is now greater than prior to homesteading the region and will likely increase further if these trends continue in the future.
- The results of this study have provided a much-improved and well-documented late glacial chronology, as well as a reasonable estimate for when the modern Buttermilk Creek gradient became established at close to its present configuration in the vicinity of the Site. The new glacial chronology requires a significant revision in our understanding of the late glacial events throughout western New York. Historical Buttermilk Creek incision is now reasonably documented as having started approximately 13,000 calendar years before present, which is considerably younger than previously concluded.
- The data and information from Study 1 should enable prediction of future erosion with greater confidence than has heretofore been possible.

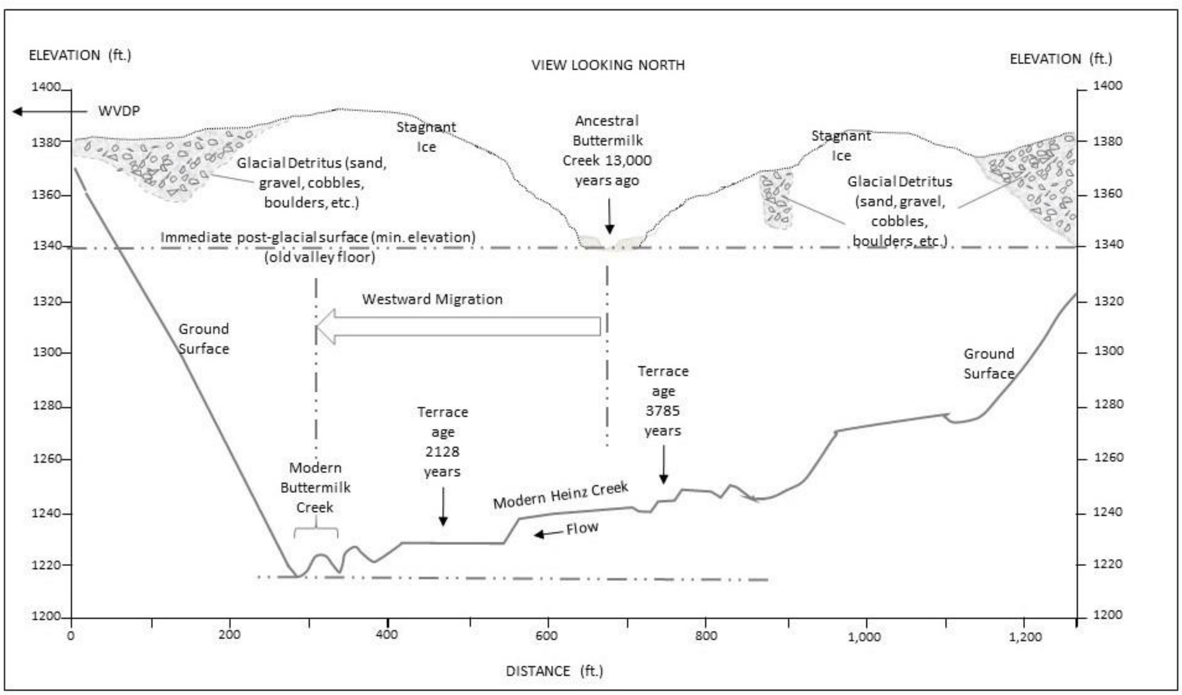

Figure ES-2: Schematic diagram of historical Buttermilk Creek westward migration at Heinz Creek.

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LIST OF ACRONYMS

^{10}Be	beryllium 10
^{14}C	carbon 14
^{14}C years BP	carbon 14 uncorrected years before present (BP defined as before 1950)
%	percent
AD	anno domini
AMS	accelerator mass spectrometry
APA	access prohibited area
BeO	beryllium oxide
ca.	circa ("approximately" when used in time or date references)
CALIB	computer program for calibrating radiocarbon ages
DEM	digital elevation model
DOE	United States Department of Energy
ECS	Enviro Compliance Solutions, Inc.
EWG	West Valley Erosion Working Group
FEIS	Final Environmental Impact Statement
GDPA	ground disturbance prohibited area
GISP	Greenland Ice Sheet Project
GPR	ground penetrating radar
HCl	hydrochloric acid
IACP	Intra-Allerod Cold Period
ISP	Independent Scientific Panel
ka	kilo annum (1,000 years)
kg/cm^2	kilograms per centimeter squared
LiDAR	light detection and ranging
NRC	United States Nuclear Regulatory Commission
NY	New York
NYSERDA	New York State Energy Research and Development Authority
OSHA	Occupational Safety and health Administration
OSL	optically-stimulated luminescence
QA-QC	quality assurance and quality control
SME	subject matter expert

TCN	terrestrial cosmogenic nuclide
TSF	tons per square foot
US	United States
USGS	United States Geological Survey
UTV	utility all-terrain vehicle
WNYNSC	Western New York Nuclear Service Center
WVDP	West Valley Demonstration Project
YBP	years before present - calendar corrected years BP (1950) as used in this report

1. INTRODUCTION

1.1 PHASE I EROSION STUDIES

This report presents the results of Phase 1 Erosion Study 1 - Terrain Analysis, Age Dating, and Paleoclimate.

The Final Environmental Impact Statement (FEIS) presented predictions of future erosion at the facility (DOE/NYSERDA, 2010). The two responsible agencies, the United States Department of Energy (DOE), and New York State Energy Research and Development Authority (NYSERDA) differed in their views of the uncertainty associated with the conclusions of the FEIS erosion analysis. The Phase 1 erosion studies were conceived to enable improved forecasts of future erosion at the West Valley Demonstration Project (WVDP) and the Western New York Nuclear Service Center (WNYNSC) (together the "Site"), to reduce the associated uncertainty, and to assist the agencies in reaching consensus on the likely effects of future erosion. Figure 1-1 illustrates the relative locations of the WVDP and WNYNSC.

To address the study goals, DOE and NYSERDA convened the West Valley Erosion Working Group (EWG) to recommend specific erosion studies that would facilitate the agency goals. The EWG consists of a multidisciplinary panel of experts with prior experience with the Site issues and widely-recognized expertise in the technical subject matter.

The EWG is comprised of the following members:

- Sean J. Bennett, Ph.D. Dept. of Geography, SUNY Buffalo
- Sandra G. Doty, M.S., P.E. Consulting Geological Engineer
- Robert H. Fakundiny, Ph.D. New York State Geologist, Emeritus
- Gregory E. Tucker, Ph.D. Dept. of Geological Sciences, University of Colorado
- Michael P. Wilson, Ph.D. Dept. of Geosciences, SUNY Fredonia, Emeritus
- Richard A. Young, Ph.D. Dept. of Geological Sciences, SUNY Geneseo, Emeritus

Drs. Wilson and Young are the Study Co-Leaders for Study 1 - Terrain Analysis, Age Dating, and Paleoclimate.

The Phase 1 Studies contractor, Enviro Compliance Solutions, Inc. (ECS) was tasked with managing the erosion studies.

DOE and NYSERDA initially tasked the EWG with formulating recommendations for erosion studies that could lead to improvements in erosion prediction. The EWG submitted its recommendations in June 2012. In addition to DOE and NYSERDA, the recommendations were also reviewed by the Independent Scientific Panel (ISP) and other stakeholders including the Nuclear Regulatory Commission (NRC), other regulatory agencies, interest groups, and the public.

On the basis of comments and feedback received on the EWG recommendations, the agencies tasked the EWG in June 2013 with addressing the specific sources of uncertainty in the previous FEIS erosion projections (and predictive erosion modeling in general), and with focusing the Phase 1 erosion study recommendations on tasks and activities having the greatest promise of uncertainty reduction. The EWG submitted its report on uncertainty and prioritization of the recommended erosion studies in October 2013.

The EWG concluded that six categories of uncertainty can be identified with regard to erosion prediction methodologies applied over a range of time- and space-scales. These categories are:

(1) Experimental uncertainty, which refers to error in the measurement of a particular parameter, such as stream discharge;
(2) Estimation uncertainty, which refers to the error in the prediction of a parameter by an equation or a model, such as the prediction of stream discharge;
(3) Temporal estimation uncertainty, which refers to the error introduced in the prediction of a parameter because of unknown future conditions, such as predicting future stream discharge without knowing future rainfall rates, and would include all issues related to future climate change;
(4) Theoretical uncertainty, which refers to error in the underlying theory of a model or how model complexity or simplicity might affect model predictions, such as aggregating all the complex processes of hillslope erosion into a single, simple equation;
(5) Geologic uncertainty, which refers to the error in the interpretation of geomorphic features and surfaces, such as the uncertainty of the stratigraphic age or significance of a geologic landform (constrained by incomplete OSL analyses); and
(6) Cognitive uncertainty, which refers to error in the quality of documentation and clarity in communication, such as the verbal description or identification of a geologic feature.

Some of the uncertainties listed above could be easily addressed and quantified (such as 1 and 2), while others would require additional discussion and research, potentially within the scope of the planned activities (such as 3 and 4), and still others could be reduced by adopting multiple lines of evidence (such as 5 and 6). While categories of uncertainties and their sensitivities within the context of erosion prediction technology could be recognized and qualitatively gauged (see below), definitive statements regarding the magnitude of model estimate uncertainty reduction resulting from additional study could not be made *a priori*; rather, this could be assessed only after the current work was completed.

The EWG critically examined the various sources and potential magnitudes of uncertainty with respect to erosion prediction technology and terrain analysis. A simple qualitative approach was adopted. For every model parameter or geomorphic attribute identified germane to erosion prediction, the EWG used professional judgment to assign an uncertainty and sensitivity measure to each (low, medium, or high), and then combined these measures into an uncertainty index. Sensitivity simply refers to the actual or perceived importance of a parameter or geomorphic feature in parameter estimation. Here, high uncertainty indices offer the greatest potential opportunity for reducing the uncertainty of erosion prediction.

Using this simplified but informed analysis, the EWG created a priority list of those specific studies and study components likely to reduce uncertainties in erosion prediction. The following parameters were identified as the most important for numerical modeling (ranked in order of relative importance):

(1) Bed sediment entrainment threshold;
(2) Soil/till detachment threshold;
(3) Storm depth, duration, and frequency parameters;
(4) Soil/till detachability; and
(5) Soil infiltration capacity.

The following parameters were identified for additional study for a gully erosion model (ranked in order of relative importance):

(1) Soil/till detachment threshold;
(2) Soil particle size and bulk density;
(3) Headcut height (if applicable);
(4) Storm depth, duration, and frequency parameters;
(5) Soil/till detachability; and
(6) Soil infiltration capacity.

The following three tasks were identified for additional study for terrain analysis and age dating:

(1) Construct a geologic and geomorphic history of the WNYNSC;
(2) Relate postglacial climate events to stratigraphy or erosion and deposition, and
(3) Estimate average rates of channel incision since the last glacial maximum.

On the basis of these findings, the EWG recommended fewer, more focused Phase 1 erosion studies to maximize the potential uncertainty reduction focusing only on those having the greatest potential to reduce predictive uncertainty. The EWG submitted the Phase 1 Erosion Study Plan (the "Study Plan") in June 2015 (EWG, 2015). As described in the Study Plan, the individual studies were designed to produce converging lines of evidence toward predicting future landscape evolution at the Site, to improve the scientific defensibility of the results obtained, to supplement existing data, and to strengthen the confidence in short- and long-term forecasts of erosion processes. The collective studies comprised three principal study areas:

(1) Study 1 - Terrain Analysis, Age Dating, and Paleoclimate Evidence
(2) Study 2 - Recent Erosion and Deposition Processes
(3) Study 3 - Model Refinement, Validation, and Improved Erosion Projections

These studies were designed to be independent, but complementary, and synergistically interactive to enhance reduction of erosion-prediction uncertainty.

1.2 PURPOSE OF STUDY 1

A substantial quantity of data and information already existed for the Site. Much of this had been reviewed and incorporated in the FEIS erosion studies. An important objective of Study 1 was to build on this previous work (e.g. LaFleur, 1979, Boothroyd et al., 1979, Fakundiny, 1985) cited in the FEIS or elsewhere, to better delineate and enhance understanding of the postglacial geomorphic history of the Site and the larger Buttermilk Creek watershed. The purpose of many of the earlier studies had been to address specific issues at various areas of the West Valley facilities rather than to predict long-term erosion rates; consequently, data gaps existed in areas needed for predictive erosion modeling. Given the priorities identified above for Study 1, the primary purpose was to better define:

(1) The geologic and geomorphic history of the WNYNSC;
(2) The relation of postglacial climate events to stratigraphy or erosion and deposition, and
(3) The rates of erosion since the last glacial maximum.

As such, Study 1 was designed to provide enhanced context and perspective for calibrating erosion models selected for prediction of erosion.

Data generated from Study 1 are used to constrain the ranges of model parameters, and to perform sensitivity analyses. Data are also used to test the ability of the predictive model or models to reproduce past patterns and rates of erosion.

Specific objectives included:

- Establish more precisely or definitively the timing of the last ice sheet recession
- Establish the sequence of major or identifiable geologically linked events in postglacial time
- Investigate the past history of postglacial erosion and its relation to prediction of future erosion
- Investigate potential relations between paleoclimate and erosion rates
- Provide expert guidance on how these factors should be incorporated in predictive erosion models

The last bullet is a particularly important objective, because it is possible that only a discreet and recent portion of the postglacial history is relevant to predictive modeling. For example, the conditions extant in the early postglacial period, e.g. receding ice sheet, inundation by glacial melt waters, isostatic rebound (though likely small as discussed previously), and immediate post-glacial vegetative succession, are not likely to apply during the next several hundred to several thousand years. On the other hand, relatively recent human-caused conditions such as deforestation, hardening of land surfaces, and concentration of runoff may be relevant to predictive modeling. Issues with large unknowns, such as the effects of future climate change, may also be important for predictive modeling.

1.3 ORGANIZATION OF REPORT

This report is organized as follows. Section 1 is an introduction. Section 2 presents the overall geologic setting of the Site and environs to provide context for the discussion that follows. Section 3 describes the study scope and methodology, and describes each of the individual data gathering activities that were performed. Section 4 discusses the results in the following subsections: 4.1 briefly presents the state of knowledge regarding late-glacial and postglacial history of the Buttermilk Creek watershed prior to the present study, Section 4.2 discusses the findings regarding terrain analysis and postglacial history of watershed development, 4.3 discusses findings regarding chronology and key ages for events in the postglacial history, and imputed incision rates, 4.4 discusses depth to bedrock and implications for incision, 4.5 discusses the elevation of the Kent/Lavery interface in the subsurface, 4.6 discusses relative erosion resistance of the different units, 4.7 describes the results of field shear strength testing, 4.8 discusses landsliding as a key component of terrain development, 4.9 discusses paleoclimate factors, 4.10 presents a summary of Buttermilk Creek incision history and erosion rates, and 4.11 discusses gully initiation versus headward erosion, 4.12 discusses expected impacts from land use changes, and 4.13 discusses uncertainty. Section 5 presents a summary of overall conclusions for Study 1, and Section 6 presents a list of references cited in the report.

Figures follow the text and present illustrations, diagrams, graphs, and maps that identify field investigation locations and summarize data and information that are discussed in the text. Tables are interspersed within the text and provide summaries and compilations of data and information.

Appendices in Volume II provide supporting data, reports of individual data gathering activities, and additional useful resources. The appendices include the following:

Appendix A1: Expanded List of References – includes the references cited listed in Section 6 plus additional references known to the SMEs that provide useful information but were not cited.

Appendix A2: Annotated Bibliography – presents summary information contained in selected key references reviewed for the study.

Appendix B: Pebble Count Data

Appendix C: Reconnaissance Field Summaries

Appendix D: Maps of GPR and Exploratory Excavation Locations

Appendix E: Ground Penetrating Radar Results

Appendix F: Field Progress Reports

Appendix G: Trench Stratigraphic Logs

Appendix H: Field Torvane Data

Appendix I: Radiocarbon Dating Results

Appendix J: Previous Radiocarbon Dating Results by Dr. Lee Gordon

Appendix K: Optically Stimulated Luminescence Dating Results

Appendix L: Re-evaluation of Previous OSL Dating Results by Dr. Harrison Gray

Appendix M: Cosmogenic Dating Results

Appendix N: Summary of Western New York Glacial Chronology

2. GEOLOGIC SETTING

A basic understanding of the geologic setting of the Site and region provides important context for understanding the subsequent sections of this report. The geology of the Site area is presented in detail in the FEIS. The following is a summary adapted from the FEIS discussion.

The Site is located within the glaciated northern portion of the Appalachian Plateau physiographic province. The surface topography is dominated by Buttermilk Creek and its tributaries, which are locally incised into bedrock and the surrounding glaciated upland topography. The maximum elevation on the WNYNSC occurs at the southwest corner of the property at an elevation of 568 meters (1,862 feet) above mean sea level. The minimum elevation of 338 meters (1,109 feet) above mean sea level occurs near the confluence of Buttermilk Creek and Cattaraugus Creek on the floodplain at the northern extent of the WNYNSC. The average elevation across WNYNSC is 435 meters (1,426 feet) with a modal elevation of 423 meters (1,387 feet) above mean sea level. The facility is approximately midway between the boundary line delineating the southernmost extension of Late Wisconsin Glaciation[1] and a stream-dissected escarpment to the north that marks the boundary between the Appalachian Plateau and the Interior Low Plateau Province. The Appalachian Plateau is characterized by hills and valleys of low-to-moderate relief between the Erie-Ontario Lowlands to the north and the Appalachian Mountains to the south. The general topography of the Site and environs is illustrated in Figure 2-1.

The WVDP is located on a stream-dissected till plain west of Buttermilk Creek and east of the glaciated upland. Surface topography at the WVDP declines from a maximum elevation of 441 meters (1,447 feet) in the main parking lot to 398 meters (1,305 feet) near the confluence of Franks Creek and Erdman Brook with an average elevation of 423 meters (1,387 feet) above mean sea level. Erdman Brook separates the WVDP into the North and South Plateau areas (Figure 2.1). The surface topography east of the WVDP declines to approximately 366 meters (1,200 feet) within the Buttermilk Creek Valley.

The terms "North Plateau" and "South Plateau" are specific to the WVDP project premises; however, the general term "plateau" has also previously been used in reports to refer to similar roughly planar surfaces at similar elevations in the surrounding postglacial terrain. In past reports the term "soil plateau" has been used loosely to describe the land surface exposed immediately following the last glacial retreat. In this report we generally refer to "immediate postglacial surface" to distinguish the terrain that existed at the inception of the Buttermilk Creek watershed development. This general term is adopted to avoid implying that the postglacial surface was everywhere planar or soil covered when in fact it had topographic relief and minimal soil development on the glacial sediments. We use terms such as "soil plateau,"

[1] The Wisconsin Glaciation is the name given to most recent major advance of the North American ice sheet that occurred between approximately 85,000 and 11,000 years ago. Late Wisconsin Glaciation refers to the latter portion of this time interval.

"old valley floor," "postglacial valley floor," and "end-of-Pleistocene valley floor," to refer to specific surfaces relevant to specific discussions in following sections.

The WNYNSC is located on the west flank of the Buttermilk Creek Valley, which is a buried, steep-sided, northwest-trending U-shaped valley that has been incised into the underlying Devonian[2] bedrock. A 150-meter-(500-foot-) thick sequence of Pleistocene-age deposits and overlying Holocene (recent age) sediments occupy the valley. Repeated glaciation of the ancestral bedrock valley resulted in the deposition of at least three glacial tills, commonly referred to in previous site reports and regional studies as the Lavery, Kent, and Olean tills (For example, see Photo 2.1). Remnants of additional older tills may also be present at depths as yet unexplored. These comprise the majority of the valley fill deposits. The uppermost Lavery till (as defined by LaFleur, 1979) and younger surficial deposits form a till plain with elevation ranging from 490 meters to 400 meters (1,600 to 1,300 feet) from south to north that covers 25 percent of the Buttermilk Creek basin. The Holocene sediments were primarily deposited as alluvial fans and aprons that were derived from the glacial sediments that covered the uplands surrounding WNYNSC and from floodplain deposits derived from the Pleistocene tills, outwash, and bedrock.

Photo 2.1: Moderately stony till deposit exposed along Buttermilk Creek.

Regional Studies (e.g. Holcombe et al. 2003, Lewis et al. 2005) have evaluated isostatic rebound as a result of glacial recession in the Eastern Great Lakes region. These data indicate that differential rebound over the relatively short length of the Buttermilk basin would have been very small and would have had an inconsequential effect on incision history.

[2] The Devonian is a geologic period spanning 60 million years from the end of the Silurian period, 419.2 million years ago, to the beginning of the Carboniferous period, 358.9 million years ago.

3. STUDY SCOPE AND METHODOLOGY

As discussed above, the following three tasks were identified as necessary for terrain analysis, age dating, and paleoclimate interpretation (ranked in order of relative importance):

- Explore the evidence for postglacial climate events as recorded by stratigraphy or erosion and deposition, and its variability with time;
- Calculate the apparent average rates of erosion from the last glacial maximum; and
- Construct an improved geologic and geomorphic history of the WNYNSC.

Terrain analysis and age-dating studies required a number of individual activities to resolve each key issue. The primary activities were organized to be sequential but overlapping and consisted of:

- Study of background reports, maps and LiDAR imagery
- Geologic field reconnaissance and prioritization of investigation targets from LiDAR
- Geophysical surveys of investigation targets to optimize invasive data collection
- Excavation of exploratory trenches and pits for data and sample collection
- Selection of samples and age analyses using ^{14}C and Optically Stimulated Luminescence
- Data reduction and reporting

The following subsections describe specific activities that were conducted to generate the needed data and information.

3.1 BACKGROUND RESEARCH

The basic objectives of the geologic fieldwork for the Phase 1 studies included reviewing all of the key previously-available geologic information to identify opportunities to improve on the identification of geomorphic landforms with the ultimate goal of improving the late glacial and postglacial chronology. The most-often cited geologic reference is the detailed mapping of the area performed by LaFleur for the United States Geological Survey (USGS) (LaFleur, 1979). LaFleur's mapping of the Ashford Hollow and West Valley 7 ½ Minute and adjacent quadrangles is partially reproduced as Figure 3.1-1 in two sheets. The first sheet is the map, and the second is the accompanying explanation. Color has been added to the map to aid visual interpretation.

Other studies performed and data collected in the past for West Valley were also researched and selected studies were reviewed. Section 6 presents a list of pertinent references cited in this report. An expanded list of references is included as Appendix A1, and a partial annotated bibliography of selected references is also presented as Appendix A2.

3.2 REVIEW OF LIDAR DATA

The Phase 1 studies have been greatly enhanced by the availability of detailed light detection and ranging (LiDAR) imagery, the most recent advance in the detailed analysis of geomorphic landforms. The review of landforms visible on the LiDAR imagery allows at least an order of magnitude improvement in the ability to identify small-scale landforms that cannot be resolved on existing 1:24,000 scale topographic maps, and that were not adequately identified during previous geologic mapping studies. The ability of LiDAR to "see through" the tree canopy and detect small features on the ground surface otherwise hidden to aerial view enables much more detailed geomorphic mapping of the terrain than previously possible.

A basic comparison of the new LiDAR imagery with the historical geologic mapping by LaFleur illustrated in Figure 3.1-1 relied upon in past studies has revealed that many useful landforms exhibiting subtle topographic relief were not adequately depicted on, nor could they be inferred from, the LaFleur maps. This especially includes features such as small individual landslides, numerous fluvial terraces, small alluvial fans, abandoned stream channels, and subtle landforms formed during the last glacial advance and recession that were not apparent or depicted on the topographic base maps used by LaFleur to compile his geologic maps. The extraordinary level of new detail now visible on the LiDAR imagery enabled a refined interpretation and understanding of the glacial and postglacial history. An example of the improved detail is illustrated in Figure 3.2-1. The figure shows a comparison between the standard USGS 7 ½ minute quadrangle topographic map versus a 2015 LiDAR image for a small area around the confluence of Buttermilk and Heinz Creeks immediately east of the WVDP. The new LiDAR data enabled a fundamental re-examination (LiDAR combined with field reconnaissance) of LaFleur's geologic mapping in the Site vicinity.

The initial LiDAR analysis and field reconnaissance enabled the identification of a number of glacial and fluvial landforms in close proximity to the WNYNSC that were the most likely to provide information of chronologic value, assuming that appropriate datable samples had been preserved within the deposits. The landforms considered to be most relevant to such studies were the stream terraces and remnants of former stream channels or deposits, such as alluvial fans, that have been preserved over a significant range of elevations.

These initial targets helped to optimize the field reconnaissance effort described in the following section. Using LiDAR mapping it was possible to plan access routes to features of interest in advance of actually going into the field. This ultimately facilitated the most productive use of the reconnaissance efforts.

3.3 GEOLOGIC RECONNAISSANCE

Uncertainty in the identification of a specific landform must be reduced by field inspection. One of the critical issues for such field validation was the ability to make distinctions among fluvial, mass wasting, and glacial landforms and deposits. All three processes may produce small step-like surfaces along valley margins that may look similar but actually record entirely different events in time and space.

Extensive geologic reconnaissance trips to selected sites were conducted in 2015 and early 2016 on the basis of the LiDAR landform interpretations. Reconnaissance involved three basic strategies:

- Primary trips by foot along lengthy continuous transects, or to specific targets, to investigate and record features on the ground, and to note specific features and areas of interest to return to for more detailed study,

- Secondary trips by foot and utility all-terrain vehicle (UTV) into areas noted for further inspection to conduct specific investigative activities and to evaluate access conditions for geophysical and excavation equipment, and
- Tertiary exploratory trips into more remote and/or upstream areas seeking additional confirmation of features noted in primary and secondary reconnaissance.

The reconnaissance trips were documented in field notes and by extensive photography. Minimally-invasive data collection conducted during reconnaissance events included:

Photo 3.1: Geology assistants collecting reconnaissance surface pebble collection (50 or 100 clasts) to determine potential fluvial vs glacial origin.

- Shallow (<30 inches) hand excavations for the purpose of revealing stratigraphic origins, enabling pebble counts, and collecting samples of geologic materials and potentially datable materials (e.g. wood or other carbonaceous materials);
- Collection of representative pebbles from gravel deposits (Photo 3.1) to conduct statistical analysis of petrology (rock type) and clast morphology to determine the source of the deposit and likely direction, length, and mode of transport (stream, glacial ice, mass wasting); and
- Collection of tree cores from apparent old growth tree stands in areas adjacent to the modern stream channel for potential estimation of minimum terrace age.
- Collection of two wood samples for 14C age determinations obtained from dry specimens that protruded from the stream bed and channel side and that could be collected without disturbance of sediment.

Photo 3.2: Assistants completing pebble analyses and counts in the field.

Pebble counts involved collecting representative samples of either 50 or 100 pebble-size clasts from a discrete lithologic unit. The mineralogy and rock type of each pebble was examined and the percentages of each rock type in the sample were tallied (Photo 3.2). This provided a picture of where the deposit originated, i.e. from what direction (north, south or local) the deposit was sourced based on the predominant rock types of its clasts. From this information, and within the context of stratigraphic sequences and other textural information, one can deduce the nature and direction of the process that transported the materials to their current location. This in turn provides important insight into the geologic history derived from the chronology of dated samples.

Photo 3.3: Till pebble count from meander depression trench T18; contains “bright” clasts of northerly derivation.

The pebble counts revealed that glacial and postglacial fluvial (stream) deposits could be readily differentiated based on examination of representative pebble samples (analysis of 50 or 100 clasts) at most critical sites. These pebble counts showed that the northerly-derived glaciofluvial deposits and tills contain a significant proportion of exotic clasts, derived from bedrock formations that typically crop out only 30 to 60 miles north of Cattaraugus Creek (Photo 3.3). In contrast, the deposits of modern Buttermilk Creek and its predecessors are dominated by the sandstone clasts from bedrock exposed to the south (Photo 3.4). This analysis also revealed that locally-derived landforms, such as alluvial fans, have more complex compositions that can be demonstrably tied to the nearby geology.

Pebble count documentation is included in Appendix B. Reconnaissance field summaries are presented in Appendix C.

Photo 3.4: Fluvial clasts typical of modern Buttermilk Creek, dominated by sandstones.

The LiDAR analysis and reconnaissance activities revealed three promising areas that appeared to record flights of terraced surfaces attributable to fluvial processes, both channel forms (terraces) and low-gradient alluvial fans. These areas were prioritized for further investigation and are referred to in this report as follows:

- The “abandoned meander” area, so named for the presence of a paleomeander of the ancestral Buttermilk Creek channel now preserved as an elevated paleochannel and associated terraces located a short distance south of the confluence of Franks and Buttermilk Creeks on the west side of the modern Buttermilk channel;

- The “Tree Farm” terraces, a flight of terraces on the east side of Buttermilk Creek in proximity to a former tree farm located 1.6 km (1 mile) downstream from the Franks and Buttermilk confluence; and

Photo 3.5: Active landslide on left (west) bank of Buttermilk Creek near Heinz Creek confluence.

Photo 3.6: Glacial outwash sediments located between tills at site of large active landslide of Photo 3.5.

- The “Heinz Creek” fan and terraces, located at the confluence of Heinz and Buttermilk Creeks due east of the WVDP and upstream from the Franks and Buttermilk confluence. The Heinz Creek study area is subdivided into the “lower” Heinz Creek fan and terraces located at the confluence with Buttermilk Creek, and “upper” Heinz Creek terraces located at higher elevations upstream along Heinz Creek. Heinz Creek is an unnamed tributary, informally named for Heinz Road, located on the east side of Buttermilk Creek approximately opposite the large active landslide east of the SDA (Photos 3.5, 3.6).

Photo 3.7: Temporary (yellow tape) and permanent (aluminum tags) markers for locations of ground penetrating radar (GPR) survey lines.

These locations are shown on Figure 3.3-1.

3.4 GEOPHYSICAL SURVEYS

Transect lines for ground penetrating radar (GPR) surveys were laid out in the field at each of the three primary target areas (Figure 3.3-1) (Photo 3.7). The purpose of the GPR surveys was to obtain a rapid non-invasive “picture” of subsurface stratigraphy and to optimize trench locations at each target area. Schnabel Engineering was contracted to perform the GPR surveys. In all, Schnabel conducted a total of 11,407 lineal feet of GPR survey lines in two phases at locations indicated on the maps shown in Figures 3.4-1 through 3.4-5, and in Appendix D (3,192 lineal feet at the abandoned meander, 3,160 lineal feet at

Photo 3.8: Field calibration of ground penetrating radar (GPR) equipment.

Upper Heinz Creek, 2,735 lineal feet at Lower Heinz Creek, and 2,320 lineal feet at the tree farm terraces). The first phase was conducted at the abandoned meander in November, 2015. The second phase was conducted at the abandoned meander, tree farm, and Heinz Creek locations in July 2016 (Photos 3.8, 3.9, 3.10).

The GPR results were successful in revealing near-surface stratigraphy in terms of contrasts in subsurface layer densities, which is what GPR measures. These imputed density contrasts enabled optimization of trench locations to directly-observed lithologic layers and boundaries, and to maximize the opportunities for discovering datable materials. The locations of GPR transects are shown on Figures 3.4-1 through 3.4-5 as well as on the maps in Appendix D, and the individual GPR profiles are shown in Schnabel's reports in Appendix E. A complete discussion of GPR methodology is also presented in the Schnabel reports in Appendix E.

Photo 3.9: Assistants dragging ground penetrating radar (GPR) antenna for 200 MHz data collection.

Photo 3.10: Terrain obstacles encountered during ground penetrating radar (GPR) survey; assistants cleared brush and fallen trees from marked traverse lines.

3.5 EXPLORATORY TRENCHING AND DATA COLLECTION

As discussed in the previous section, a primary purpose of the GPR surveys was to optimize target locations for exploratory excavation. J. D. Northrup Construction (Northrup) was contracted to provide excavation, backfilling and associated services.

Personnel and small equipment access to excavation locations was by UTV (Photo 3.11).

Photo 3.11: UTV vehicle and trailer used to access difficult sites along former logging access roads; some partially regraded during project.

Exploratory excavations included shallow (generally less than ten feet) pits and trenches. Any accumulating water whether from seepage or storm water was pumped from the excavations to avoid creating a hazard. At the conclusion of the excavation work and following completion of sampling and other data collection activities, all exploratory pits and trenches were backfilled and the ground surface around each backfilled excavation was restored as close as reasonably possible to the pre-existing conditions. Photographic documentation of the trenches and the backfilling was maintained. Selected trench photos are included in Appendix B. Photographic documentation of the final condition after backfilling of every excavation at the WNYNSC was provided to NYSERDA on digital media for archive purposes.

A total of 112 exploratory pits and trenches were excavated. These included 37 at the abandoned meander and associated terraces, 49 at the Heinz Creek locations (lower and upper), 26 at the Tree Farm terraces, and one at an offsite location on private property on Simmons Road in an area previously mapped by LaFleur and identified as a portion of the "Kent" terminal moraine marking the southerly extent of the Kent advance in this area (LaFleur 1979). Trench and pit locations are shown on Figures 3.4-2 through 3.4-5 as well as on the maps in Appendix D.

Data collection from the exploratory excavations consisted of four general categories:

- Lithologic and stratigraphic descriptions of exposed geologic materials,
- Collection of samples for age determination,
- Collection of samples for pebble counts, and
- In situ shear stress measurements using a Torvane.

Each of these activities is discussed further below.

3.5.1 Lithologic and Stratigraphic Description

At each pit and trench, careful observation of the geologic materials exposed in the sides and bottom of each pit or trench was made. Loose material was carefully removed to expose the natural (in situ) materials. Detailed notes on the lithology and stratigraphic relations between different materials (layering, organic remains) were recorded where relevant. Structural features such as jointing, and fracturing were recorded as appropriate in natural bedrock exposures such as stream beds and banks. Photography of key exposures was routinely performed. Copies of original field notes are provided in Appendix F. Summary stratigraphic logs of excavations were constructed and are presented in Appendix G. The stratigraphic logs also indicate the approximate stratigraphic positions of ^{14}C and OSL samples collected, plus the location of pebble counts and the existence of Torvane measurements, as applicable.

3.5.2 Collection of Samples for Age Determination

Potentially datable materials (e.g. wood fragments, e.g. as seen in Photo 3.12, or other carbonaceous materials such as leaf mats, for ^{14}C dating and quartz-bearing sediment for OSL dating) were identified if present, and samples were collected. Age analyses are discussed in Section 3.6 below.

For ^{14}C samples, an attempt was made to select carbonaceous samples without obvious intrusive contamination, if multiple fragments were present. For OSL sampling, it was critical to prevent exposure of the sample to ambient light; therefore, OSL samples were collected in metal or solid plastic tubes driven into the side of the trench and retrieved, capped, and sealed with no ambient light exposure. Alternatively, some trenches were covered with tarps and samples too coarse to collect with drive tubes were extracted in the dark using headlamps fitted with bulbs emitting only light in the red wavelength portion of the visible spectrum (Photo 3.13).

Photo 3.12: Example of in-situ wood sample excavated from abandoned meander channel.

Photo 3.13: Collection of optically stimulated luminescence (OSL) sample in darkened excavation under double tarp cover.

3.5.3 Pebble Counts

Pebble counts were conducted on surficial samples collected during reconnaissance trips and have been described above in Section 3.3. Samples of pebble assemblages were also collected from many of the exploratory pits and trenches. During the reconnaissance and trenching phases of the project, 75 bulk samples were obtained for pebble counts. As with those collected on reconnaissance visits, the pebble samples collected from the trenches were used for statistical comparison of clast petrology and sources. As with the reconnaissance samples the pebble counts revealed that glacial and fluvial deposits could be readily distinguished as deriving from northerly sources

Photo 3.14: Ice-contact gravels separating till units (Lavery and Kent?) showing heterogeneous textures, poor sorting, and inclusion of till fragments.

Photo 3.15: Clast imbrication along Buttermilk channel showing direction of current flow (upper left to lower right) as indicated by shingle-like orientation of individual clasts. Imbrication is additional evidence for north or south derivation of gravel units when distinguishing between fluvial and glacial deposits.

(containing a significant proportion of carbonate and other "bright" clasts from bedrock sources north of Cattaraugus Creek) indicating southerly glacial transport and deposition (Photo 3.14), versus southerly-derived sources (mainly gray to brownish sandstones) indicating northerly directed postglacial fluvial deposition (Photo 3.15). Pebble count data are included in Appendix B.

3.5.4 Torvane Measurements

The Torvane is a hand-held vane shear device for rapid determination of shear strength in cohesive soils either in the laboratory or the field. The Torvane allows shear strength to be measured in the sides of test pits, trenches or excavations. For this study, shear strengths were measured with a Torvane apparatus to help compare strata origins and characterize landslide potential and relative erosion resistance. The strength tests were basic field tests requiring no sample retrieval, transport or archiving, and were rapid and inexpensive. The Torvane is a very small, hand-held shear vane with a mechanical spring-loaded dial gauge that registers shear strength at the moment of soil failure. Failure in this test is the inability of the soil to hold the vane teeth against the spring pressure as the researcher twists the device.

Results from a prior study of floodplain sediments in the Piedmont Province of North Carolina provided support for using the Torvane method. In that study Torvane measurements of point-bar and overbank sediment shear-strengths ranged between 0.1 to 0.3 kilograms per centimeter squared (kg/cm^2) in sandy sediments, 0.3 to 0.4 in silty sands, and 0.4 to 0.6 in silty or clay rich mixtures. Some of the clay-rich mixtures were saprolites or soils formed in-situ by deep decay of underlying bedrock. Although of a very different origin, saprolites are generally similar to glacial tills but lack the history of overburden pressure that an ice sheet would convey. Thus similar strength values were expected for the Buttermilk region, with higher values for glacial tills. Regardless of geographic region or study purpose, Torvane values represent the matrix strength within strata, the apparatus teeth are not placed against individual pieces of gravel or rock fragments during testing.

The Torvane has a stress range of from zero to approximately 1 kg/cm^2. This is also the approximate range of torque that can be easily applied by finger pressure. The Torvane works best for saturated cohesive soils whose undrained strength is independent of normal pressure. The stress range permits it to be used for clays varying in consistency from very soft to stiff.

The advantage of the Torvane method is that it permits the rapid determination of a large number of strength values with different orientation of failure planes. It is simple to use and sample trimming is unnecessary, requiring only a reasonably flat surface one inch in diameter.

The primary purpose of performing Torvane shear-strength measurements on the in-place deposits in outcrop and exposed in trenches was to better understand how differences in shear strength may influence modeling of future erosion. In addition, the information was useful for distinguishing similar-appearing lithologies, and correlating horizons between adjacent pits and trenches. Moreover, the shear strength data may be correlated with the erodibility of the near surface materials. The relatively large number of Torvane measurements may be useful as proxies for the fewer numbers of in situ erodibility tests accomplished during Study 2. Erodibility testing is discussed in the separate Study 2 report. Torvane data are presented in Appendix H.

3.6 SAMPLE AGE ANALYSIS

The two initial methods for dating fluvial and glacial landforms assumed to be applicable to West Valley were: 1) radiocarbon dating (^{14}C), applicable for organic materials up to 50,000 years old, and 2) optically stimulated luminescence (OSL), a newer method that has evolved rapidly and gained acceptance over the past two decades, but that has important limitations and is very time consuming and labor intensive. Because organic remains are seldom preserved for very long in near-surface oxidizing environments, the OSL method fills an important gap that has long been unavailable.

A third and emerging method of dating known as terrestrial cosmogenic nuclide (TCN) dating utilizes beryllium-10 (^{10}Be) and aluminum-26 (Al-26) that are produced by the cosmic ray bombardment of exposed quartz in boulders exposed at the land surface. This method requires the existence of large boulders that must not have been moved or rolled over since deposition. This method was initially considered for West Valley but was thought to have doubtful applicability because the limited field information available suggested an absence of large boulders in the Buttermilk watershed. During the course of the fieldwork, however, a potential site for application of this technique to alluvial fan deposits with large boulders was discovered near the apex of the Heinz Creek alluvial fan

Photo 3.16: Example of large boulders encountered near apex of fan deposits at lower Heinz Creek site.

(Photo 3.16). Accordingly, samples were collected for cosmogenic dating. Each of these methods is discussed further below.

3.6.1 Radiocarbon Dating

There are two major issues that are probably most important in the evaluation and dating of organic samples in fluvial and glacial environments.

1) What is the nature of the depositional process and what was the natural environment (i.e. what is the origin and nature of the organic material and how did it arrive at its current burial position?). Is reworking of samples a plausible assumption?

Photo 3.17: Example of wood collected in fluvial terrace deposit that illustrates fragmentation, lack of bark, and clear evidence of abrasion, all indicative of reworking of older wood. Such samples are of questionable value for accurate dating of discrete events.

2) What is the likelihood and potential magnitude of contamination by older or younger introduced carbon (groundwater deposition, rootlet penetration, mold, fungus)?

Some of the contamination issues can be minimized by careful sample treatment and use of the accelerator mass spectrometry (AMS) method; others depend significantly upon the interpretation of the sample context as carefully interpreted in the field.

There are some straightforward observations that can be used to simplify the potential circumstances:

- Old wood samples can be reworked and redeposited in younger sediments (the "reworking" issue – Photo 3.17). However, younger samples cannot be found in truly older sediments (unless contamination has occurred by penetration of rootlets, fungi, impacts of tree falls). The reworking issue is predominantly one where old (dead) trees or branches are initially buried, then re-exposed, broken into smaller pieces, and redeposited one or more times during subsequent flood events. This is common in fluvial floodplain situations. Therefore, this issue is problematic when a relatively small, isolated wood sample (broken fragment) is found or collected, and its decomposition and potential multi-stage burial history are uncertain.

Photo 3.18: Example showing the typical fate of logs that remain on the surface and are exposed to natural decomposition for a couple of decades or less.

- All dead or uprooted wood is susceptible to relatively rapid decay and disintegration when exposed at the ground surface as seen in Photo 3.18, or when buried in permeable sediments that are above the local groundwater table. Conversely, wood samples can be amazingly well preserved for extended times below the water table, especially when the enclosing sediments are fine-grained silt and clay (Photo 4.14).

The reason for the unusual preservation of wood below the water table is the relative absence of air, insects, and fungi, and the relatively slow operation of bacteria in this environment (Photo 3.19). Studies of old wooden construction piles at building sites in Boston, MA, (Lambrechts, 2008) and in European countries have recently demonstrated the significance of above- vs. below-water table environments for wood preservation at the multi-century scale (Klaassen, 2015).

Decomposition is mainly due to fungal, bacterial, and insect activity, as well as normal atmospheric oxidation processes. For these reasons, wood exposed in the open and on the surface is highly unlikely to survive for more than a decade and end up buried in a pristine, undecomposed state. In other words, if an old sample of buried wood (log or stump [e.g. Photos 3.20, 4.14]) is found to be in good to excellent condition (little or no obvious decomposition), it can be assumed that: 1) the sample has been preserved below the water table for most of its history, and/or 2) the specimen did not sit on the surface for a lengthy period of time (probably less than a decade).

Photo 3.19: Example of typical fungi active in the decomposition of wood exposed on the surface for relatively short intervals.

One of the main conclusions to be drawn from this and other similar information is that the cellulose extraction method or treatment, when used with AMS dating, should allow for most contamination issues to be eliminated, or at least better resolved. In addition, AMS dates, unlike the older generation methods, allow discrete counting of individual atomic species (isotopes), such that contamination issues can be better defined. Samples in the milligram size range can be dated accurately, unlike previous methods.

Another factor to be considered is that even when contamination is present, a small amount of contamination does not necessarily mean that a date is grossly incorrect (depending on the age of the sample and the amount of contamination). A sample with small amounts of contamination can still provide a useful approximate age (Example: 1% contamination of 17,000-year-old sample produces a 600-year error, which is not that different from discrepancies encountered along some portions of the ^{14}C calendar-year calibration curve).

Given these considerations, samples for potential ^{14}C dating were carefully screened and selected in the field to minimize the effects of reworking, decomposition, or contamination. Sixty seven samples were collected and sent to Beta Analytic, Inc. of Miami, Florida for ^{14}C dating by the AMS method. The results are tabulated in Appendix I.

Photo 3.20: Decomposition of a naturally rooted stump. Compare with the more "pristine" condition of the dated stump depicted in Photo 4.16.

The sample results vary from contemporary up to a maximum age of more than 28,000 years before present (YBP). The interpretation and conclusions from these results, along with limitations, are discussed in Sections 4.2 and 4.3 below. Unless otherwise noted, ^{14}C ages in this report have been converted to actual calendar years YBP (before 1950) using the online CALIB program (Stuiver et al. 2017) in order to use a consistent conversion program for comparison to older samples referenced in the literature.

In addition, the study considered previous ^{14}C dating of samples collected by Dr. Lee Gordon of NYSERDA in the abandoned meander area and elsewhere. Dr. Gordon collected five samples from the meander area and elsewhere in 2012. These samples were also analyzed by Beta Analytic and ranged in age from relatively recent (AD 1490 to 1610) to approximately 14,600 YBP. Dr. Gordon's data are provided in Appendix J.

3.6.2 Optically Stimulated Luminescence Dating

OSL is a relatively recent age dating method that attempts to determine the length of time since a buried assemblage of quartz and/or potassium feldspar (K feldspar) grains in a sedimentary deposit has been exposed to sunlight (i.e. since deposition occurred). The basic theory is that certain elements in common minerals (quartz, feldspar) undergo atomic alteration when subjected to bombardment by solar radiation, and subsequently by naturally-occurring radionuclides in the surrounding soil. The burial of the sediment eliminates the solar interactions, and thus the age since burial can be measured. After burial, further in situ alteration due to natural radiation from the surrounding sediment may also produce modifications that occur at known rates and can be measured in quartz and K feldspar mineral grains, given accurate knowledge of the background radioactivity. Quartz and K feldspar are particularly useful in this regard owing to their elemental composition and abundance in sedimentary deposits.

Re-exposure to sunlight interrupts the alteration process and "resets the clock" in a process called "bleaching." The best candidates for dating are those deposits that have not been re-exposed since their original deposition. Aeolian (windblown) sand deposits are generally considered to be the best candidates for OSL dating, but water laid or glacial deposits are good candidates for OSL dating depending upon the conditions of burial. "Partial bleaching" is a common problem in OSL dating of some glacial and fluvial deposits (due to their potentially multistage reburial history), but correction factors can be applied to mitigate the effects of partial bleaching if the depositional history of the sediment is relatively uncomplicated by processes such as reworking.

Since exposure to sunlight immediately resets the sample ages, extreme care must be exercised during sample collection to prevent sunlight exposure. As mentioned in Section 3.5.2, some trenches were covered with tarps and coarse-grained (gravel) OSL samples were extracted in the dark using headlamps fitted with appropriate wavelength infrared lamps. However, most sand-sized OSL samples were collected in metal or solid plastic tubes driven 8-inches deep into the sides of the fresh trench walls and retrieved, capped, and sealed with no ambient light exposure. Samples of the surrounding soils were also collected where relevant to determine the variability of natural radioactivity for each contrasting stratigraphic unit.

Eleven OSL samples were delivered to the Illinois Geological Survey laboratory at the University of Illinois for analysis by Dr. Sebastien Huot. The ages for the samples ranged from approximately 1,330 to approximately 18,000 YBP. Dr. Huot's report is presented in Appendix K. Findings and conclusions from the results are discussed in Section 4.3.

In addition to Dr. Huot's report, OSL results for 10 samples previously collected by Dr. Tucker and Ms. Doty at the West Valley Site in 2007, and analyzed by the USGS dating laboratory in Denver, Colorado, were re-interpreted by Dr. Harrison Gray, a post-doctoral student of Dr. Tucker and current employee of the USGS OSL dating laboratory. Dr. Gray's re-analysis of the raw data from the original samples was based on improved contemporary statistical analysis methods and reflects current advances in the technology of OSL dating. Dr. Gray's updated results along with the original 2007 results are presented in Appendix L. Findings and conclusions from these results are also discussed in Section 4.3.

3.6.3 Cosmogenic Dating

As discussed above, cosmogenic dating was initially considered but was not expected to be practical in the Buttermilk watershed because significant numbers (5-10) of large stable boulders exposed on a surface are needed for the method to be successful, and these were observed to be rare during initial reconnaissance. The method involves the natural exposure of minerals in boulder surfaces to bombardment by cosmic rays that form terrestrial cosmogenic nuclides (TCNs). The concentration of TCNs is dependent on the TCN production rate, the local latitude, topographic shading, and the duration of surface exposure. In essence, the TCN concentration is a function of age and determining the TCN concentration provides a means of dating when a boulder was last deposited on a surface. Repeated exposure of such boulders during a potentially complex transport history (glacial and fluvial) is usually dealt with by looking at a larger number of boulders to look for a concentration of younger ages.

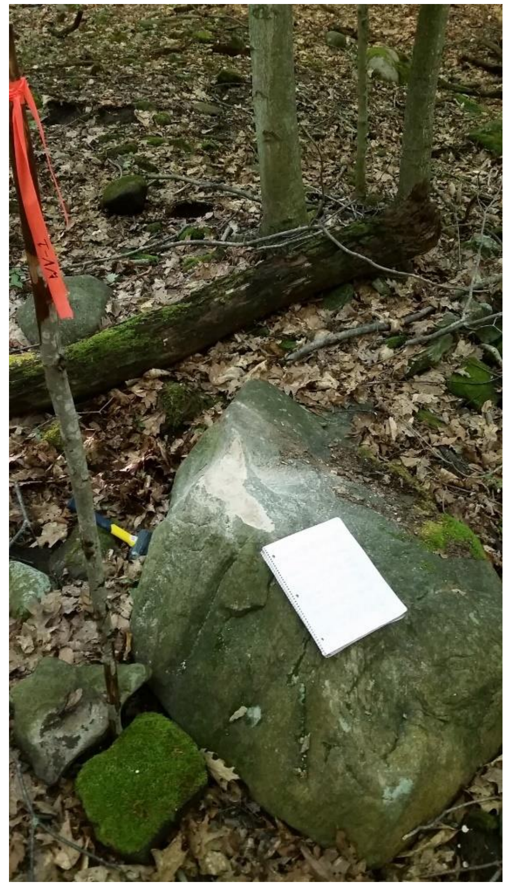

Photo 3.21: Collection of sample from large boulder for terrestrial cosmogenic nuclide (TCN) dating.

TCN dating, therefore, defines the age of alluvial fan surfaces because it may document the timing of deposition of freshly-exposed boulders on the surface being dated. The presence of boulders with multistage depositional histories is problematic. Be-10 (^{10}Be) is the most commonly used TCN because it is forms in quartz, a ubiquitous mineral in most rocks, and its production rate is well known. The youngest ages within a grouping would be assumed to be most representative of the depositional age.

Samples for ^{10}Be dating are usually collected from quartz-rich boulders (Photo 3.21) on individual alluvial fan surfaces by hammering off 400-500 grams of the upper horizontal surface of each individual boulder. These samples are chemically processed for quartz and the quartz is spiked with a low-background $^{10}Be/^{9}Be$ carrier, then is separated by ion chromatography, and precipitated as beryllium oxide (BeO). The $^{10}Be/^{9}Be$ ratio in the extracted BeO is measured in an accelerator mass spectrometer.

A cluster of apparently stable boulders was unexpectedly encountered in the apex area of the Heinz Creek fan. Five boulder samples were collected by Dr. Lewis Owen and shipped to Dr. Owen's laboratory at the University of Cincinnati for ^{10}Be analysis (Photo 3.21). The results ranged in age from approximately 15,000 to 28,000 YBP. Dr. Owen's report is provided in Appendix M. Findings and conclusions from the results are discussed in Section 4.3.

3.7 DATA REDUCTION AND REPORTING

The general types of data and information gathered and used for Study 1 can be generally summarized as follows:

- Personal expertise, experience, familiarity with the site and regional geology, and insights, of the SMEs;
- Review of published and unpublished literature, reports, data, and information;
- Analysis of maps, satellite imagery, aerial photography, and detailed LiDAR maps;
- Information gathered in the course of geologic reconnaissance visits including traverses on foot with detailed digital photography and LiDAR contour maps, collection of shallow

samples for pebble counts, collection of organic samples for ^{14}C dating, and collection of old growth tree cores;

- Non-invasive subsurface information from GPR surveys;
- Geologic logging, sampling, and photography of exploratory pits and trenches;
- Laboratory age analysis of samples by radiocarbon, OSL, and TCN methods;
- Synthesis and analysis of the various types of data, and estimation of historical erosion rates; and
- Evaluation of uncertainty reduction.

These data were used to create and compile working drafts of maps and diagrams to facilitate analysis of the terrain and to formulate working hypotheses concerning the postglacial history of landscape development for further testing and refinement. The working hypotheses were used to direct the types and locations of additional data gathering during the ongoing field work. As additional data and information were received, hypotheses were narrowed and refined. Inherent to this process was evaluation of quality control measures and associated uncertainties applicable to the data. The results are discussed in the following sections.

4. DISCUSSION OF RESULTS

4.1 REGIONAL SETTING

4.1.1 General

The regional geologic setting of the WVDP and WNYNSC is described in the FEIS and is summarized in Section 2. Briefly, the pre-Wisconsin Buttermilk Creek Valley was a northwest-trending valley that was incised into the underlying bedrock. A 150-meter thick sequence of Pleistocene and Holocene deposits now occupies portions of the buried valley. Previous studies concluded that repeated glaciation of the ancestral bedrock valley resulted in the deposition of a minimum of three glacial tills, commonly referred to in previous site reports and regional studies from youngest to oldest as the Lavery, Kent, and Olean tills (Photos 4.1 to 4.3). These comprise the majority of the known valley fill deposits. The uppermost Lavery till and younger surficial deposits are estimated to cover approximately 25 percent of the Buttermilk Creek basin. The younger Holocene sediments were primarily deposited as either individual or coalescing alluvial fans or as flood plain deposits, all derived from the glacial sediments that covered the uplands surrounding the site.

Photo 4.1: Multiple till units exposed in right (east) bank of Buttermilk Creek at upstream edge of Tree Farm site. Site includes Lavery and Kent tills (LaFLeur, 1979, geologic map). Photos 4.2 and 4.3 illustrate fluvial deposition (glacial outwash; erosional hiatus) between major units occurring near center of this view.

Appendix N presents a summary of the current status of Western New York glacial chronology excerpted from the literature for reference.

The age of the Lavery till has been estimated to be between 14,000 years (Droste et al., 1960) and 19,000 years (White, 1982) as cited in Fleeger (2005). The age of the Kent glacial advance is estimated to be about 23,000 years as inferred from a date on pro-Kent lacustrine sediments in Ohio (White, 1968). The Olean till is older.

Photo 4.2: Obvious incised glacial outwash channel occurring near center of Photo 4.1, between two till units.

The well-established Erie Interstade (warm period of glacial recession) lies between the ages of the Lavery and Kent tills. The Erie Interstade was once thought to range from 15,000 to 17,000 years BP by Morner (1971), but was more precisely dated as between 14,500 and 16,000 years BP in the Mohawk Valley region (Ridge, 1997).

Photo 4.3: Glacial outwash deposit between tills at same horizon as Photo 4.2, showing cross-bedded sandy units indicating current flow from north to south (left to right in view).

The reliable establishment of the terminal glacial chronology at the WNYNSC is an important aspect of the current study, as it provides a starting point from which to accurately infer the postglacial incision history of the Buttermilk Creek basin, and therefore the base level lowering history for Franks Creek at its confluence with Buttermilk Creek. Central to this issue, beyond establishment of the age, is the determination of the elevation and configuration of the immediate postglacial surface as the ice receded from the Buttermilk Creek basin, when fluvial and mass wasting processes became the dominant forces in shaping the postglacial landscape.

4.1.2 Previous Studies

Previous studies of the glacial and postglacial history of the WVDP and WNYNSC have resulted in a chronology for the glacial and postglacial history of the Buttermilk Creek basin that is based on a very limited number of radiocarbon and optically stimulated luminescence (OSL) dates in combination with a review of literature sources that correlated the local glacial moraines and till sheets with the better known upper Midwest glacial stratigraphy as projected from Ohio through Pennsylvania into western New York (LaFLeur, 1979, 1980; Gordon et. al 2013). An overview of selected recognized Late Pleistocene glacial moraines is presented in Figure 4.1-1. Very few radiocarbon ages have been published that provide unambiguous ages for the numerous moraines present in western New York.

Previous radiocarbon ages in the existing literature are mostly from logs or wood fragments collected from fluvial or ice-marginal sediments. Dating such materials is problematic because wood fragments are commonly reworked from older parent materials, either by glacial advances across pre-existing organic deposits with uncertain relationships to the younger events, or by postglacial stream flooding events. Some of the radiocarbon ages from previous studies are also subject to alternative interpretations with regard to the sedimentary environment. Previous OSL dating of sediments produced a limited number of data points to compare with the radiocarbon results. The previous interpretation of chronology was therefore limited by the small number of dated samples, uncertainty regarding correlation between the two dating methods, and uncertainty regarding the interpretation of individual samples.

The chronology that has been previously proposed has not provided an unequivocal or generally-accepted age for the last glacial recession and, therefore, the implied beginning of the erosion of the Buttermilk Creek watershed. This in turn has prevented a more precise calculation of the rate of vertical incision of Buttermilk Creek, and an understanding of the variability of the incision rate in response to climatic variability, landslides, and the emergence of bedrock knickpoints as the channel became incised.

The findings of the present study, discussed in the following sections, have provided greater clarity regarding the sequence and timing of late glacial and postglacial events in the site region. As a result, the timing of the inception of Buttermilk Creek incision can now be established with greater certainty than was heretofore possible.

4.2 DEVELOPMENT OF CURRENT TERRAIN

4.2.1 General

The following subsections and associated illustrations present the core methods, analyses, and resulting conclusions for determining the history of erosion of the Buttermilk Creek watershed, particularly related to the WNYNSC. Figure 4.2-1 is a topographic map of the WNYNSC and environs based on portions of the USGS Ashford Hollow and West Valley 7 ½ minute quadrangle topographic maps. Figure 4.2-1 presents a similar representation of topography based on the 2015 LiDAR digital elevation model (DEM). In Figure 4.2-1, color shading has been added to allow a visual comparison of areas of similar elevation on opposite sides of the main stem of Buttermilk Creek. Figure 4.2-2 shows the same area in the form of a LiDAR hillshade image.

The following sections describe the terrain analysis performed.

4.2.2 Glacier Retreat and Inherited Landscape

4.2.2.1 Buttermilk Watershed

Large portions of the Buttermilk Creek area landscape seen today are essentially the same as uncovered by retreating ice and associated waters thousands of years ago. The immediate postglacial terrain has a veneer of soil developed by mineral decay, natural vegetation, agricultural practice of the past 200 years, and both ancient and modern wind-transported silt and organic materials. Most of the deglaciated landscape is well preserved and observable in detail on topographic maps (e.g. Figure 4.2-1) and related images, such as LiDAR hillshade images (e.g. Figure 4.2-2).

Through a process of interpreting the USGS topographic maps and surveying the features in the field by driving and walking, LaFleur (1979) coded the topography for various morphologic and sedimentary features related to deglaciation (Figure 3.1-1). He had a limited number of exposures of strata available to view, such as gravel mines and stream banks. While Study 1 results generally support his findings, the features and history of deglaciation are discussed in greater detail for critical project locations in this report. The USGS topographic maps available to LaFleur had contour intervals of 20 feet, while Study 1 had LiDAR maps with 1-foot contour intervals available (Figure 3.2-1). The U.S. Geological Survey maps available to LaFleur and Study 1 have a scale of 1 inch = 2,000 feet, while approximately 80 LiDAR-based, 20x32-inch topographic maps at a scale of 1 inch = 67 feet were printed for the current project. In addition, customized LiDAR products such as hillshade maps (similar to shaded relief maps) and computer screen images were used in the current project. Synoptic views were used for Study 1 on computer screen images as well as large mosaics of the detailed LiDAR topographic maps.

Figure 3.1-1 (LaFleur's 1979 geologic map) shows reddish-colored areas that represent the end moraine remnants that define the southern edges of the Buttermilk Creek watershed at the lower edge of the Ashford Hollow quadrangle (reddish patches at center bottom of Figure 3.1-1). Also labeled on Figure 3.1-1 are LaFleur's meltwater channels and their interpreted flow directions, as well as additional meltwater channels identified during the current study. The glacial topography that emerges is obvious. The prominent Kent end moraine, along with adjacent high hills of bedrock and till, form the southern, eastern and southwestern edges of the Buttermilk Creek basin. The basin is like a shallow amphitheater that slopes to the north, and whose contents flow into Cattaraugus Creek. Advancing ice (Lavery) was relatively steep and thick (likely 100 or hundreds of feet thick) and blocked northward drainage forming a lake in front of the glacier and accumulating sediments. As the glacier advanced it ran over the clay lake sediments remolding them into clay-rich till. The basin was last filled with glacial ice and underlying sediment to its southern end moraine approximately 13,000 years ago. At that time there was a relatively rapid glacier retreat accomplished by episodes of glacier stagnation interspersed with two short periods of recessional moraine construction. These events are discussed further in the following sections.

4.2.2.2 Meltwater Channels Draining the Early Buttermilk Basin

The positions and elevations of the meltwater channel floors, excavated or re-excavated during glacier stagnation (ice recession), are indicated by arrows in Figure 3.1-1. The directions of the arrows indicate initial predominantly southerly water flow as the ice began to melt or recede. Elevations of channel thresholds range from about 1790 feet to 2000 feet, while hilltops range in elevation from about 1900 feet to 2100 feet. Meltwater channels were cut to depths of tens of feet.

No significant proglacial lake formed between the final retreating ice front and the basin-edge moraine (circa 13,000 YBP). Evidence for negligible proglacial lake area during initial retreat includes:

a) South-flowing channel margins and thresholds that overlap each other in elevation cutting through the basin perimeter and thus allowing free flow southward above approximately elevation 1790 feet.
b) Adjacent valleys to the south, east, and west had lower marginal channels that could accommodate outflow from the 1790- to 2000-foot elevation thresholds of the Buttermilk Creek basin.
c) Stratified ice-margin deposits include very few apparent slack water areas as mapped by LaFleur (e.g. the upland area above the 1790-foot elevation channel that is midway between

Buttermilk and Connoisarauley Creeks that can be seen on Figure 3.1-1, or slack water areas that might be indicated by modern wetlands.

d) Evidence of beaches and deltas of proglacial lakes was not reported by LaFleur or others.

As glacial stagnation and recession continued, negligible proglacial-lake water or sediments formed between the stagnating ice or between two minor recessional moraines and the Buttermilk basin perimeter because there were many westward-draining meltwater channels entering and leaving the northern Buttermilk Creek basin. Elevations of coexisting channels in the neighboring Connoisarauley Creek basin to the west did not restrict the natural hydraulic operation of the Buttermilk basin channels allowing westward flow to be maintained. Elevations of several channel thresholds and channel margins are marked on Figure 3.1-1.

On the east side of the Buttermilk basin northeast of the WNYNSC, there is a set of westward-flowing channels into the Buttermilk watershed with thresholds ranging from 1400 to 1700 feet in elevation, with corresponding channel shoulders of from 1400 to above 1700 feet in elevation. These are matched by channels on the west side of the Buttermilk basin with thresholds ranging from elevation 1400 to 1660 feet. Corresponding channel margins above their immediate thresholds range from approximately 1500 feet to above 1700 feet in elevation. Consequently, the inflow and outflow of meltwater in the Buttermilk basin was accommodated over, under, or around stagnating or receding glacial ice without significant proglacial ponding.

Similar accommodation of westward meltwater flows is apparent continuously for about a hundred miles westward along the north-face of the Allegheny Plateau south of the Lake Erie basin (Muller, 1963). Ages of these channels to the west pre-date the Lake Whittlesey shoreline and post-date the Lake Escarpment Moraine. Those channels could have also been active during Lavery time; some contain till. Those channels to the west are correspondingly lower in elevation and larger than the Buttermilk meltwater channels.

A second area where Buttermilk basin meltwater could have been dispersed was into the Conewango basin, which is the valley of the ancestral Allegheny River south of Gowanda, New York. The Conewango basin drains southward into the Ohio-Mississippi River system.

Another factor in the disbursement of meltwater from the Buttermilk basin is the possibility of flow in the meltwater channels that occurred partially or completely beneath or within glacial ice. During stagnation or recession. Moreover, especially in the environment of glacier stagnation and retreat, more than one channel could have been active simultaneously. While these processes and conditions are a possibility, they are not required to explain the glacial-meltwater incision history.

4.2.2.3 Watershed Sediments: Glacial Accumulation vs. Modern Yield

Previous research on surface and subsurface sediment accumulations in and adjacent to Buttermilk watershed revealed that the distribution of Lavery till included clay-rich sediments and incorporated rhythmites, and that the surface map pattern of the perimeter of clay-till deposition approximately followed topographic contours. Study 1 concluded that Lavery till was deposited by glacial ice advancing into a proglacial lake (for example, quantitative evidence from consolidation tests by Fickies and others, 1979), and the retreating phase was marked by coarse lenses in the upper till and reduced hydraulic conductivity which led to oxidation. LaFleur (1979) mapped stratified drift and other coarse debris often across Buttermilk watershed uplands, but mapped coarse sediments in the Connoisarauley watershed and westward as preferentially in the lowlands. Lavery clay is mapped in Buttermilk lowlands. Study 1 agrees generally with LaFleur's sediment distribution findings and with his mapped interpretations of meltwater channels in the Buttermilk, Connoisarauley and nearby watersheds. Study 1, using both topographic information available to LaFleur and new LiDAR detailed topography checked LaFleur's interpretations of meltwater channels and located several additional channels. All the meltwater channels and their approximate elevations are highlighted on Figure 3.1-1.

In summary, Study 1 concludes that fine sediment was glacially-trapped in the Buttermilk amphitheater or tilted bowl-shaped valley, but not in the more open Connoisarauley valley, and that retreating ice provided numerous meltwater channels forming a sequence connecting most or all elevations. Little to no proglacial lake sediments occur as a veneer over other sediments in either Buttermilk or Connoisarauley valleys from glacier retreat. From the perspective of modern and future erosion and sediment transport, and computer modeling, the Buttermilk watershed is likely to produce more fine-grained sediment yield than the Connoisarauley watershed owing to modern gullying into the Lavery glacial till that was derived from advance into a Buttermilk proglacial lake. Studies of drainage density, numbers of gully heads, measured sediment yields or other sediment transport or morphometric properties may reveal functional differences between the two watersheds, Buttermilk vs. Connoisarauley.

The above measured or implied differences between the Buttermilk and Connoisarauley watersheds have resulted in detectable sediment yield differences between the two watersheds. While Study 1 was searching for best access routes for field data acquisition, air photos were reviewed. Color-infrared air-photos dated 1994 detected sediment-laden water from Buttermilk Creek entering Cattaraugus Creek and forming a very distinct plume in the Cattaraugus Creek water[3]. Buttermilk Creek was sediment laden in the aerial photos for many miles of the trunk stream (much or most of the watershed). In contrast, Connoisarauley carried no apparent suspended sediment and provided no observable plume in Cattaraugus Creek. The contrast in suspended sediment production between the two watersheds is striking. This contrast is shown in Figure 4.2-3.

4.2.2.4 Glacier Down-Wasting

The glacier was melting and receding as the meltwater channels were active. Whenever glacial processes are studied it is a challenge to determine whether the glacial recession was dominated by down-wasting (stagnation being the end member) or by back-wasting (the ice front retreating being the end member, with calving into a lake or sea producing the steepest ice front). During the glacier retreat from the Buttermilk basin, stagnation dominated, but there were several instances of glacial retreat marked by minor still-stands of the ice margin (LaFleur, 1979 Fig. 2). The hummocky terrain produced by glacier disintegration is largely absent from the uplands, which are worn smooth by

[3] available from NYS-Orthos-Online, at www.orthos.dhses.ny.gov/?id=974103

glacier motion, suggesting thin ice, or ice with very little entrained sediment. The hummocky terrain in the southern portion of the Buttermilk basin near, and south of, the hamlet of West Valley is classic end moraine topography.

Northward glacial recession from the area south of the hamlet of West Valley produced kettles in outwash and irregular till mounds, and depressions across the Buttermilk basin and lower valley sides. There are many ice stagnation features west and northwest of Riceville and the juncture of Gooseneck Creek with Buttermilk Creek, including apparent eskers and kettles. Some of these features can be discerned by close inspection of Figures 4.2-1, and 4.2-2. The Riceville vicinity landforms and the position of Gooseneck Creek record a recessional moraine (greenish area denoted as "Wfg" in Figure 3.1-1). Another end moraine, recessional or re-advance, is recorded by the irregular terrain, till and gravel deposits surrounding the abandoned meander study site. Similar features continue eastward adjacent to the Buttermilk valley-wall meltwater-channel mapped by LaFleur at elevations descending southward from approximately 1470 to 1450 feet, as highlighted in Figure 3.1-1 by use of bold black arrows. Other indistinct end moraines have not been specifically named but are present as indicated by LaFleur (1979, p.6, Fig. 2).

4.2.2.5 Lavery Till

The Lavery Till is an important geologic unit referenced in previous site reports that underlies the recessional glacial features of the immediate postglacial land surface within the Buttermilk watershed. The Lavery Till is a thick two-member till that consists of silt- and clay-rich diamict with a thickness of tens of feet. The lower member of the Lavery till is gray with very low permeability while the upper phase is gray or brown with slightly-higher permeability and occasional coarser-grained lenses. Features of the Lavery advance include layered proglacial-lake soft strata that were over-ridden, incorporated, or homogenized, while features of Lavery glacier retreat include coarse sediment lenses, kettle holes, outwash, and a relative lack of rhythmites. Glacier advance was into a proglacial lake in the north-sloping Buttermilk basin. As discussed above, the glacier acted as a dam to northward drainage, and as the ice advanced southward, the glacier encroached into its own ice-dammed lake and homogenized the sediments into a clay-rich till. This is the reason that the areal boundaries of the Lavery till resemble the outline of a lake in the Buttermilk valley.

The upper member of the Lavery till is the ice retreat phase, deposited under moving ice, but during ice thinning, recession, or stagnation. The apparent depth of weathering in the upper phase of the Lavery till as indicated by the brownish color is the result of increased oxidation owing to slightly-greater permeability inherited from ice ablation conditions. Where the groundwater table is high, oxidation is retarded and both advance and retreat phases may appear gray. The Lavery till as mapped in the Buttermilk valley represents the youngest glacial event, however this youngest glacial episode is younger than other glacial tills named Lavery in nearby regions (13,000 YBP in the Buttermilk watershed rather than ca. 15,000 or 16,000 calendar YBP in other regions, as discussed in a later section of this report).

4.2.3 Transition from Pleistocene to Holocene Drainage

4.2.3.1 Deglaciated Valley Topography

As presented above, the late Pleistocene glacially-directed drainage was southward from the Lavery "lobe" defined on LaFleur's (1979, p. 6) map, but subsequently deviated to westward as glacier melting uncovered the low elevations of the northwest rim of the Buttermilk basin (between approximately 1790 and 1400 feet in elevation). The floor of the Buttermilk valley was composed of outwash, ground moraine till (upper phase of Lavery till), stratified drift of eskers and crevasse fillings, recessional moraine mounds, and interbedded clay-tills and gravels from glacier-margin local oscillations during recession. These materials and morphologies formed a high-level surface referenced in older reports as "soil plateaus". The upper soil plateau (highest surface) partially preserved today was the valley floor at the end of the Pleistocene; Buttermilk Creek has incised below this end-of-Pleistocene valley floor.

The end-of-Pleistocene (postglacial) valley floor, composed of its variety of ice-recession debris and subtle morphologies, sloped northward as interpreted from Figure 4.2-1. The floor was at an elevation of about 1410 feet or lower in the Riceville vicinity, and at an elevation of about 1360 feet or lower at the margin of the Cattaraugus Creek valley (shades of olive green in area marked "Tree Farm" in Figure 4.2-1). There are several locations along the valley walls where permanent or temporary streams eroded perpendicularly or obliquely into the valley wall and deposited alluvial fans onto the postglacial valley floor. One of these fans is referenced in previous reports as the Quarry Creek Fan that underlies much of the former reprocessing and adjacent facilities. Another example is the fan at the entry of Gooseneck Creek into Buttermilk valley. These similar alluvial fans likely began to be deposited partially on or near melting glacial ice and continued their deposition onto the 1360- to 1410-foot valley floor during the early Holocene. Sometime after 13,000 YBP their apexes became entrenched by continued evolution of the upstream tributary reaches. Continued erosion of the upland ravines supplied gravel to younger entrenched fan surfaces formed as Buttermilk Creek continued to incise (such as the lower Heinz Creek fan). The large fans on the late-Pleistocene Buttermilk Valley floor (such as Quarry Creek) predate fans that are below the postglacial floor, such as the lower Heinz Creek fan.

Modern tributary ravines in the Buttermilk valley walls began to erode from about 13,000 YBP, following an implied 13,000 YBP glacial advance (Younger Dryas event), that was heretofore undated or unappreciated. Tributary locations were inherited from subtle undulations in the shapes of the original glacial topography, from pre-glacial erosion, and initiated by glacier margin meltwater. Erosion began as soon as the areas were uncovered by ice, ravines became incised, and alluvial fans like the Quarry Creek Fan were deposited onto the postglacial valley floor). Thus the placement of Buttermilk tributaries was inherited from early postglacial ravine and fan development. The growth of alluvial fans on the original valley floor and the depressions in the floor from the irregularly shaped deposits of Lavery glacier recession (or younger 13,000 YBP event) are the features that controlled the initial location of the main stem of Buttermilk Creek.

Evidence from meltwater channel elevations leads to the conclusion that significant proglacial lakes tens of feet deep and covering hundreds of acres were not likely ponded on the Buttermilk Valley floor in late Pleistocene or early Holocene time. Strand line features such as beaches and deltas were sought on LiDAR maps and in field reconnaissance, but were not located during Study 1. However, the evidence would be difficult to find because such strand line features would not be prominent due to lack of prevailing wind fetch and the relatively short time for development. For comparison, the well-developed shoreline features of ancestral lakes in the Erie and Ontario basins had as much as tens of miles of fetch and likely one or more centuries of time to develop. Considering the availability of westward outlet channels at and north of Dutch Hill, large proglacial lakes would not have been maintained in the Buttermilk Creek valley during ice withdrawal.

4.2.3.2 Inherited Features and Stratigraphy of the Postglacial Buttermilk Valley Floor

What exactly did the Buttermilk Creek valley floor look like at the end of the Pleistocene, beginning of the Holocene? Figure 4.2-4 provides a location map and Figures 4.2-5 through 4.2-7, and 3.4-2 contain four representations of the terrain in the immediate postglacial era. Depicting the old postglacial floor of the Buttermilk valley, going from upstream (south) to downstream (north), examples of the old valley floor topography are provided for three locations (Figures 4.2-5, -6, and -7) in the vicinity of Heinz Creek (east side of Buttermilk valley). A fourth example is provided at the abandoned meander (Figure 3.4-2, west side of Buttermilk valley). In Figure 4.2-5, yellow highlights identify channels in the undulating valley floor that suggest a somewhat disorganized stream network ultimately flowing northward. These channels were and are being deepened or captured (green highlight) by the modern Buttermilk tributary network.

In addition to the former valley-floor terrain in Figure 4.2-5 (located approximately 3,000 feet south of Heinz Creek), Figure 4.2-6 displays similar terrain about 2,000 feet south of Heinz Creek. The abandoned early Holocene valley floor contains a misfit channel highlighted in yellow. It is about 5 feet deep and 60 feet wide, with its south end "chopped-off" by modern Buttermilk right-bank erosion and landslides. Its north end is being entrenched by Holocene gulley-headward incision.

The former valley floor topography between 300 and 1,000 feet south of Heinz Creek is shown on Figure 4.2-7. This area is referenced in many of our illustrations and designated as UH for upper Heinz (whereas lower terrain is referenced as lower Heinz, or simply as "HT"); trenches UHT-1 through UHT-10 are trenches located in the upper Heinz terrain.

Trenches UHT-1, 2, 3, and 4 exposed approximately 2 feet of sand over 5 feet of gravel over glacial till, with the intermediate gravel layer fining downwards in each trench and also from trench to trench moving toward the eastern valley wall from trench 1 to 4. The contact within the wall of trench 3, between gravel above and till below, has about 1.5 feet of relief. The gravel in trenches 1-4 is well rounded and poorly to non-stratified. These gravels are ice-contact deposits of the receding glacier and part of the original Buttermilk Creek valley floor.

Trench sequence UHT-11-9-10 exposes fine-grained colluvium (slope-wash sediment deposit derived from mass wasting and overland flow across loess or till in this area) thickening from 1.5 to

2 feet toward the valley wall. This colluvium overlies 5 to 6 feet of glacial till, with the till oxidized to a brownish color in places and with more stony till below the colluvium.

In terms of former-valley floor-topography trench UHT-8 lies roughly between the UHT 1-4 sequence and the UHT 11-9-10 sequence. The walls of trench UHT-8 expose 1 to 2 feet of sandy colluvium over 1 to 2 feet of fine-grained colluvium over 4 feet of sand-and-gravel with interbedded till. The colluvial sand of UHT-8 was dated as 9,400 ± 500 YBP.

Trenches UHT-5, 6 and 7 in Figure 4.2-7 were all excavated to look for datable materials in or under bog soils on the margin of the postglacial Buttermilk valley floor. These trenches generally exposed 2.5 feet of clay and silty colluvium containing 0.1 to 0.3 mm thick, thumb-nail size, accumulations of carbon (possibly leaf fragments) concentrated especially at about 1.5 feet in depth, and numerous small black wood fragments. Below the colluvium in these trenches are 2.5 to 3.0 feet of interbedded silty to sandy fine gravel that gradually decreases in grain size upwards; further down are 2.5 to 3.5 feet of fine to medium gravel. The two small wood fragments found in the colluvium were dated at 10,129 ±40 YBP and 4,922 ±30 YBP, and the leaf-like carbon remains in the colluvium were dated at 10,640 ±40 YBP. These relatively old dates, at their current elevations, are consistent with the progressive operation of mass wasting and colluvial processes following ice recession from the 13,000 YBP advance.

In addition, the orange arrow in Figure 4.2-7 points to the location ("E") of a small, natural cliff that exposes about 11.5 feet of sediment. That exposure was described in a stratigraphic section and was sampled; 8 feet of till overlies a succession of four 1-foot-thick layers of gravel, clay, sand, and gravel between 8 and 12 feet thick. The sand layer was dated using OSL at 12,700 ± 1,100 YBP.

The topographic, stratigraphic, and age data from the areas shown in Figures 4.2-5 through 4.2-7, support rapid glacial recession from the Kent moraine and Lavery "lobe" of LaFLeur (1979. P.6) south of West Valley. These data also support an environment characterized by ice stagnation, little or no lacustrine presence, abundant west-flowing outlets, and a former valley floor that contained approximately 20 to 30 feet of relief. Buttermilk Creek initially connected depressions among ice disintegration features that were lowest toward the valley center (locus of greatest ice thickness).

Another example of the former glacial floor of Buttermilk valley is an area west and south of the abandoned meander (Figure 3.4-2). In this area, the surface of the initial Buttermilk valley floor had about 30 feet of relief from approximately 1340 feet elevation to 1370 feet. This portion of the old Buttermilk "soil plateau" of earlier reports is bounded to the west by Franks Creek and to the east by Buttermilk Creek, and is incised by the abandoned meander. The relief of the postglacial surface here is related to ice disintegration and end moraine development, and is the continuation of the moraine that controlled the meltwater channel of LaFleur on the eastern valley wall (Figure 3.1-1), and also the continuation of upper Heinz features previously discussed (Figure 4.2-7).

Evidence for ice-contact features above (west of) the abandoned meander (Figure 4.2-8) comes from trenches into the old valley floor, in addition to interpretations of LiDAR contours and field reconnaissance. Trenches 8 and 9 in the north segment of this area (Figure 3.4-2) exposed low-relief outwash (18 percent exotic pebbles in T-8); to the south, trench 16 exposed probable crevasse-fill or esker sediments; trenches 13, 14, and 15 exposed outwash (19 percent exotics pebbles in T-13); trenches 11 and 12 exposed diamict thought to be glacial till (24 percent exotic pebbles in T-12). Trench 17 exposed gravel (10 percent exotics) in the base and walls of a small kettle hole (Figure 3.4-2). Trenches 19, 40, 41, and 42 are intermediate in both horizontal and vertical position among the southerly trenches mentioned above (i.e., T-13, 14 and 15 are above and westward, while T-11 and 12 are below and closer to Buttermilk Creek). Trench 19 was about 75 feet in length purposely placed perpendicular to contours to look at the transition between gravelly terrain above and diamict below (to the immediate east). Trench 19, and trenches 40 to 42 all confirm that the transition (gravel above, to the west, and diamict below, to the east) is interbedded gravel and diamict (interpreted to be till). The interbedded gravels and till are repeated at about one to two-foot vertical intervals. Pebble counts were made in two gravel layers at T-19; there were 13 percent exotic pebbles in the upper layer and 19 percent exotics in the lower. There is not enough evidence to determine the exact origin of these interbedded ice-contact deposits, such as: englacial shear planes, oscillating ice margin, or ablation till. However, all the choices are related to ice down-wasting or moraine building, with coarser sediments uphill and finer sediments downhill, with interbedding at shallow depths in the intervening ground. Layer sequences should not be projected laterally, or even locally, due to possible local glacier oscillations and disruption of layers as well as by contemporaneous ice melting.

A kettle in the old valley floor near the abandoned meander was investigated with trenches 18 and P1 through P5. The abandoned meander scar immediately to the north is an excellent example of former Buttermilk channel dimensions. That this kettle feature was formerly interpreted as a Buttermilk meander or "high, early phase" terrace (Boothroyd, et al., 1979, Figure 25) is incorrect, based on our documented stratigraphy, and because Buttermilk Creek would have twisted itself into an unrealistic bowtie pattern to flow in and out of this shallow glacial depression. Shallow bog deposits rest directly on interbedded till and glacial outwash gravels of the dated circa13,000 YBP ice advance at this location. Trench 18 was located to provide an additional check of the kettle interpretation and supports this interpretation; gravel comprised the outer wall of the kettle. Results of two pebble counts in the gravel were 13-percent and 16-percent exotic pebbles. Diamict was also encountered in the bottom of Trench 18.

Pits P1 through P5 were excavated to evaluate Dr. Gordon's lacustrine interpretation of his three ^{14}C dates of 14,170 to 14,380 YBP adjacent to P5A, and to look for additional information supporting the stratigraphic implications of its infilling history. The depression stratigraphy observed does not support either the existence of a postglacial river channel or a shallow lake filling the depression. Rather, the gravelly depression (kettle hole) bottoms in till and, in the bottom of Pit 4, a discontinuous laminated clay. The wood dated by Dr. Gordon (Gordon et al., 2013) is similar to the wood samples we collected in the same vicinity and that have very similar ages. Our 5 wood samples from Pits 1 and 2 (Appendix J, 13,462 to 14,192 YBP) were clearly imbedded in a relatively soft, clay-rich, diamict (till) that is interbedded with glacial outwash or ice-contact gravels. The tamarisk wood samples examined by Griggs (Griggs letter, 2016) show strong evidence of being compressed, impregnated with clay and having their bark removed by rigorous ice erosion and ice loading. Gordon's observations and dates agree well with ours in that the depression is a kettle bordered with ice-contact gravel from ice retreat and the kettle-gravel overlies till with incorporated clay and vegetation from ice advance. The advance is estimated in the vicinity of ages such as 13,500 or 13,400 YBP, incorporating trees up to several hundred years old (ca. 14,100 YBP), and the ice retreat was in the vicinity of 13,100 or 13,000, based on ages in the south end of Buttermilk watershed and at upper Heinz locations.

Boothroyd et al., (1979) previously reported a ^{14}C age of 9920±240 (11,468 calendar years BP) on wood from this depression as being located at a depth of 50 cm in fluvial gravel. Our more extensive excavations and pebble counts imply that there are only glacial outwash gravels present in the shallow subsurface at this depression location. From our new data and analysis we concluded that dates on wood obtained in 1979 (pre-AMS dating availability) could have been affected by groundwater contamination that introduced younger carbon from the bog material immediately above the till and outwash gravel, or, more likely, that Boothroyd et al. collected younger, postglacial wood samples from trees that grew and subsequently died within the depression.

In summary, the morphologies, materials, and ages of materials and events all support construction of an ice advance in the general vicinity of ages 13,500 or 13,400 YBP that overran trees with ages ranging across several hundred years (ca 14,000-plus YBP) and that extended as far south as the Kent moraine position of LaFleur (1979). This advance retreated around 13,000 YBP by intermittent stagnation with recessional moraines, specifically, a minor recessional moraine at Riceville, and another recessional moraine stretching across the Buttermilk Creek valley from the abandoned meander to upper Heinz Creek, and northward along the east wall of Buttermilk valley. The morphologic features and deposits are the same as what previous researchers called Lavery but are assigned a new age of 13,000 YBP.

There are alternative working hypotheses to explain how the dates clustered about 13,000 YBP at the southerly offsite trench location (previously mapped Kent moraine; LaFleur, 1979) relate to past assumptions or publications. For example, the basic recessional topographic features could be assigned to an older (Lavery or Kent age), while the younger dates about 13,000 YBP could be assigned to an unmapped advance and retreat that caused little observable deposition. Using this hypothesis, Buttermilk incision begins at about 13,000 YBP but the incision is primarily in materials that were created more than 15,000 years ago. Regardless of which hypothesis is correct, the 13,000 YBP age for advance and withdrawal of ice and inception of incision provides the most recent date in our data, as well as published data for the Genesee Valley, and results in the fastest (most conservative) incision rates.

4.2.3.3 Adjustment of Early Buttermilk Creek to Cattaraugus Creek

As discussed above, the late Pleistocene, early Holocene floor of Buttermilk Creek valley sloped to the late Pleistocene, early Holocene floor of the Cattaraugus Creek valley beginning ca. 13,000 YBP. Buttermilk Creek became adjusted to Cattaraugus Creek below elevations of 1400 feet. Cattaraugus Creek reworked its valley floor outwash into a terrace that stands today at about 1340 to 1360 feet in elevation. Cattaraugus Creek is a large river with a watershed of 440 mi^2 in a region of high precipitation (50+ inches/ year) due to Lake Erie and local orographic effects. Cattaraugus Creek has the power to mobilize its thick gravel bed during floods, and it has a local channel depth of 10 to 20 feet, or more. Thus the initial Cattaraugus valley floor with elevations of about 1340-1360 feet would have been reworked by the channel with a base at about 1330 to 1340 feet and a floodplain (now terrace) at about 1360 feet. These elevations were initially controlled by the top-of-bedrock at 1320 feet downstream at the shoulder of Zoar Valley near Gowanda, NY. The Franks Creek/Buttermilk Creek confluence elevation was approximately 1340 ± 5 feet. This elevation is good as a relative value relating to other features in the near region, but is not an absolute value at the time of inception due to a small amount of isostatic rebound. Considering the needs for localized computer modeling, differential postglacial rebound is insignificant over a distance of a few miles; therefore, this can be ignored.

Former Cattaraugus Creek valley floor elevations (high terraces in the vicinity of Buttermilk-Cattaraugus confluence) display two distinct levels (now terraces) at about 1290-1300 and 1360 feet. Modern Cattaraugus Creek is at elevation of 1100 feet in this area. Late Pleistocene Cattaraugus valley floor surfaces (now abandoned above modern Cattaraugus Creek) were mapped by LaFleur (1979) as outwash. These distinct gravel surfaces at 1290-1300 and 1360 feet elevation were likely reworked by Cattaraugus Creek, and these surfaces should be described as west-sloping Cattaraugus high terraces. Buttermilk's main-stem channel was adjusted to Cattaraugus Creek terrace levels as evidenced by Buttermilk terraces gradually fusing with Cattaraugus Creek terraces. Buttermilk Creek could not incise more deeply than Cattaraugus Creek.

The 1400-foot-elevation glacial-meltwater channel north of Dutch Hill flowed west into the south-flowing Conewango-Allegheny-Ohio-Mississippi system (refer to the elevation-labeled arrows showing meltwater paths in Figure 3.1-1).). The left bank is still observable today, but the right bank was glacier ice (assumed to mark the Lake Escarpment or Defiance moraine position, LaFleur, 1979). However, the 1360-foot terrace of Cattaraugus Creek near the Buttermilk confluence is difficult to trace into the Conewango valley, and the 1290-1300 foot terrace is not traceable into the Conewango valley. Basically, the very large Lake Escarpment (or Defiance) end moraine south of Gowanda (and paralleling the north margin of Cattaraugus Creek) blocked drainage below 1400 feet, forcing drainage at or above 1400 southward through the Conewango valley. Thus the highest Cattaraugus and Buttermilk terraces below the postglacial valley floor were not formed until after glacier recession from the Lake Escarpment moraine and after Buttermilk Creek westward glacial drainage was terminated. Cattaraugus and Buttermilk Creek drainages below 1400 feet were controlled by Lake Escarpment glacier recession eventually resulting in Cattaraugus Creek incision reaching downstream bedrock obstructions in its channel.

4.2.3.4 Cattaraugus Incision

Over a distance of about 20 miles from the Buttermilk-Cattaraugus confluence westward to Gowanda (Gowanda, Collins Center and Ashford Hollow USGS 7.5' Topo Quads), Cattaraugus Creek crosses two distinct bed types several times. There are seven laterally-contiguous areas where Cattaraugus Creek flows east to west, incised into sediment-filled, north-trending, pre-glacial valleys separated by bedrock ridges, beginning upstream at and above its confluence with Buttermilk Creek, and going downstream toward Gowanda, as follows (zone numbers 1 to 6 in Table 4.2-1):

1) Sediment bed at and east of the Buttermilk confluence;

2) Shale-sandstone bed west from the Buttermilk-Cattaraugus confluence (Rte. 219 area);

3) Sediment bed west of Rte. 219 and east of Connoisarauley confluence;

4) Shale-sandstone bed at and west of Connoisarauley confluence;

5) Sediment bed east of Waterman Brook confluence;

6) Shale-sandstone bed between Waterman Brook confluence and South Branch confluence;

7) Mixed sediment and shale beds downstream to Gowanda.

Cattaraugus Creek flows northward from Gowanda to Lake Erie on sediments filling the ancestral Allegheny River valley to depths of 200 to 300 feet, with about 250+ feet of fill at the Lake Erie shore (Wilson, 1974; Wilson, Peterson and Ostrye, 1981). Zones 2, 4 and 6 contain bedrock canyons with walls between 200 and 450 feet high. This region is known as the Zoar Valley. The approximate top of bedrock in these canyon walls is (downstream to upstream): 1320 feet in zone 6; 1240 feet in zone 4; and 1300 feet in zone 2. Thus zone 6, the furthest downstream, was the control for initiation of incision of Cattaraugus Creek below the Buttermilk confluence. The great difference in valley width between bedrock zones and sediment bed and walled zones clearly demonstrates the greater erosion resistance of the bedrock zones as shown in Table 4.2-1 below.

Table 4.2-1: Cattaraugus Valley Cross-Sectional Statistics

Top Width (feet)	Bottom Width (feet)	Depth (feet)	Area (x 1000 ft^2)	Zone (No.) S - Sediment R - Rock
3,400	1,200	200	460	1 S
1,000	200	170	102	2 R
5,000	2,400	240	888	3 S
4,000	1,200	250	775	4 R mainly on left-bank (south side)
10,000	2,400	450	2,790	5 S
1,100	400	400	300	6 R
Comparative statistics for reaches of lower Buttermilk are:				
1,800	700	140	175	S
2,200	600	120	168	R -rock mainly on left-bank (west side)

Cattaraugus incision of the sediment segments in zone 1 is 4.5 times greater than the cross-sectional area of incision of the bedrock in the contiguous area of bedrock in zone 2, and similarly, the zone 5 area is 9.3 times zone 6. Similar erosion-resistance comparisons occur between bedrock and sediment cross-section areas (zones) elsewhere in southwestern New York, such as along Silver Creek and Chautauqua Creek.

Ages of bedrock canyons provide another perception of bedrock erosion resistance. Using the calendar age of the 13,000 YBP advance at the "Kent" moraine location and the thickest bedrock removal in the Zoar Valley (approximately 450 feet) yields a Cattaraugus vertical incision rate of 0.035 feet/year. By comparison, Chautauqua and Silver Creeks had at least 100 feet and 80 feet, respectively, of bedrock incision after withdrawal of ice from the Lake Escarpment moraine, with a climate and rock types similar to Cattaraugus Creek, but with the Silver Creek section composed of shale only. Dividing by approximate drainage basin areas (Silver Creek at 10 sq mi; Chautauqua Creek at 20 sq mi; and Cattaraugus Creek at 400 sq mi) yields vertical incision rates of:

- Silver Creek 80 ft /13,000 years = 0.0062 ft/yr … 0.0006 feet/year/mi^2
- Chautauqua Creek 100 ft /13,000 years = 0.0077 ft/yr … 0.0004 feet/year/mi^2
- Cattaraugus Creek 450 ft /13,000 years = 0.0346 ft/yr … 0.0001 feet/year/mi^2

The largest stream (greatest discharge) has the largest vertical bedrock incision rate but the least incision rate per square mile of upstream drainage basin area. The vertical incision rate in Franks Creek if it encounters bedrock would be roughly 0.008 ft/yr using Chautauqua Creek for comparison because of similar rock types and predicting that a relatively-thick (4+ feet) resistant sandstone section is not encountered. Using any of the bedrock incision rates will depend on encountering bedrock below projected future locations of modeled gullies, such as Franks Creek. Depth to bedrock information from prior reports, subcrop maps, cross-sections, and similar information could be used to estimate bedrock depths below modeled terrains or adjacent to modeled gully-head advances.

4.2.4 Early Holocene Events: Lower Buttermilk to Cattaraugus Valley

4.2.4.1 Outlet-Area Features

The lower reach of Buttermilk valley above the Cattaraugus valley is composed of several meander-like sinuous reaches (may not be true alluvial meanders) increasing in size downstream, impinging against bedrock on the west valley wall, and hosting terraces and large landslides mostly on the right bank (to the east). The plan-view relationships are indicated in Figure 3.3-1 and details are illustrated in Figures 4.2-9 and 3.4-3. The Tree Farm area contains a set of about ten terraces upstream of a prominent landslide referred to as "giant slide" (Figure 3.3-1). This large landslide has features of a rotational slide 200 feet high, 800 feet deep, and with a top scarp 2,500 feet in arc-length. Sets of multiple terraces occur upstream of the Tree Farm site similar to those at the Tree Farm, but only one terrace above the lower two floodplain levels occurs downstream of the Tree Farm terraces. Meanders diminish in size upstream of Tree Farm, but the modern valley floor remains wide.

On Figures 4.2-9 and 3.4-3, the lowest stream terraces are color coded light and dark blue. Dark blue represents the lowest terrace which is frequently flooded. This level, the modern flood plain, has a flood frequency that is responsive to regional climate change and to local down-cutting rate. The concept of a 2.33-year recurrence for bank-full condition is difficult to apply to streams of southwest New York because spatially-irregular down-cutting reduces bank-full frequency in some stream reaches, while climate change has the effect of increasing flood frequency. Stream bank-full frequency varies from stream to stream and reach to reach. Both climate and soft sediment conditions lead to increased erosion, especially obvious when dealing with practical bank stabilization issues. The dark-blue coded areas are treated as the bank-full floodplains for the current discussion, and these terraces are about 4 to 8 feet above channels on our LiDAR maps (similar to the dimensions of terrace depths estimated for former stream channel sediments in our numerous terrace trenches).

The light-blue shaded areas are much less frequently flooded as indicated by our observations of deeply decayed logs, lack of recent debris in spite of 2009 and 2015 floods (thought to be rare; up to 1 in 200-year events), and flood-deposited railroad-derived coal fragments found in low terraces at the Heinz Creek site. Flood frequencies in the light-blue coded areas are likely 1 in 20 to 1 in 200-year events, because these areas are about 15 feet above the adjacent Buttermilk channels in Figures 4.2-9 and 3.4-3.

Of great significance is the observation that as many as nine terraces occur above flood-plain levels (lowest two terraces) at the Tree Farm site (Figure 3.4-3) versus only one terrace above flood-plain levels at the Outlet site (Figure 4.2-9). The highest terrace (surface from 1192 to 1198 feet elevation) in the series on the east (right) bank at Tree Farm is 51 to 56 feet above the present Buttermilk channel and the terrace at Outlet (with surface from 1165 to 1170 feet elevation) is 40 to 45 feet above the present channel. The elevation of present-day Cattaraugus Creek is about 1100 feet with floodplain at about 1110 to 1120 feet elevation where it receives Buttermilk Creek.

4.2.4.2 Origin of Terraces at Buttermilk Creek Outlet

Two terraces occur near the Cattaraugus-Buttermilk confluence (outlet area, Figure 4.2-9), at elevations of 1295 to1300 feet and another at 1340 feet. The higher terrace is the original valley floor, and it can be accounted for as a response to Cattaraugus incision encountering top of bedrock at about 1320 feet elevation in Zoar Valley upstream of Gowanda. Cattaraugus Creek incision encountering top-of-bedrock at other locations in areas in Zoar Valley or nearer Buttermilk confluence might cause minor terrace fluctuations in the 1340-1350 range.

The lower terrace at the 1295 to 1300-foot level can be explained as a response to resistant sandstone in the bedrock stratigraphic section. There are only two known persistent causes of waterfalls in southwestern New York: 1) resistant sandstone layers such as the Laona Siltstone at Laona, NY, the Shumla Siltstone at Shumla, NY, and the sandstone at Connoisarauley Falls; and 2) hanging streams where the larger trunk stream cut down faster than the small tributaries, resulting in small waterfalls dropping from the sides of canyons, such as many small waterfalls dropping into South Branch Cattaraugus Creek, or as seen in Heinz Creek. Waterfalls in the region have been cataloged online[4], and have been visited by Wilson, who has rafted Cattaraugus Creek and hiked extensive portions of Cattaraugus, South Branch, Connoisarauley, Buttermilk, Silver, Walnut, Canadaway, Slippery Rock, and Chautauqua Creeks.

The elevation of Connoisarauley Falls is about 1100 feet. Using the regional strike of strata as approximately east-west or slightly north of east, the resistant rock unit making Connoisarauley Falls will strike either the bedrock section of Cattaraugus Creek immediately downstream of Buttermilk confluence or the bedrock section of Buttermilk Creek in the Tree Farm to Outlet areas. Adjustment of stream incision to this resistant rock unit accounts for the highest terrace below the old valley floor at each of Tree Farm and Outlet locations. Periodic movement at the giant slide might account for some of the other terraces at the Tree Farm and up-valley, which are missing at Outlet.

Alternatively, some or all terraces at Tree Farm may be from random processes but this explanation does not account for the exceptional change in number of terraces downstream of the giant slide as compared to upstream. Terraces of equal elevation on opposite sides of a valley (paired terraces) could relate to episodic base level variation occasioned by landslide movement, but not finding paired terraces at Tree Farm does not rule-out terrace control by the giant slide. Paired terrace formation at giant slide (and elsewhere) is inhibited by, if not eliminated by, Buttermilk Creek shifting laterally as it laterally impinged upon the interfluve opposite the landslide (in this case, shifting west to east). In summary, the details of exactly how the giant slide influenced terrace development are unclear, but the difference in number of terraces up and down stream is evidence for a major influence.

No waterfalls occur in the main stem of lower Buttermilk Creek or adjacent Cattaraugus valley. A Connoisarauley-equivalent, falls-forming stratum would have migrated up valley (either Cattaraugus Creek or Buttermilk Creek) and been lost as the upper end of either creek's bedrock section was encountered by stream erosion. The resistant sandstone section was lost from the stream's bed by waterfall headward migration into the soft sediment portion of a valley floor, i.e. into buried valley fill.

Considering that regional strike of strata is roughly east-northeast to west-southwest, and corresponding dips are southerly, an erosion-resistant rock unit crossing a north-dipping stream (Buttermilk) will create a v-shaped bedrock outcrop pattern pointing southward. While such strata may disappear upstream from the stream bed, under soft sediments, the same strata will appear in hillsides or tributaries above the primary stream, e.g. Buttermilk Creek. Such conditions can be seen in a tributary ravine south of Tree Farm and west of Buttermilk Creek, where a 14-foot waterfall occurs between 1260 and 1274 feet elevation (lower margin of Figure 4.2-9). This is the rock unit that controlled terrace development at the roughly 1300-foot level (due to its dip, perhaps 1310 or more to north and 1290 or less to south).

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[4] Available at http://falzguy.com

In summary, 1) the Cattaraugus-Buttermilk valley floors first became mutually adjusted at about the 1340-foot elevation; 2) a previously exposed resistant-strata likely in the Cattaraugus valley immediately west of the Buttermilk confluence or in lower Buttermilk Creek accounts for the first (highest) terrace below former valley floors at each of Tree Farm and Outlet areas; and 3) some additional terraces at Tree Farm are accounted by periodic channel-blocking movements of the giant slide. The same logic is used to understand that there are many flights of terraces up-gradient of the Tree Farm throughout the Buttermilk Creek watershed, e.g. Heinz Creek. The extent to which each individual terrace at the Tree Farm and Heinz Creek sites resulted from specific giant slide movements (i.e., a one to one correspondence), as compared to random unpaired-terrace development in response to the giant slide (or other landslides), cannot be absolutely determined. Climate changes, introduction of Native American agriculture, or random events may also have influenced terrace development, but the drastic change in number of terraces above and below the giant landslide imply an important mechanism manner of channel development and incision history.

4.2.5 Terraces below the Postglacial Valley Floor

4.2.5.1 Terraces Chosen for In-depth Study

In the previous sections a process and response model for understanding the late Pleistocene and early Holocene landscape development of Buttermilk valley and related Cattaraugus valley has been constructed. That sets the conditions for initiation of Buttermilk Creek and tributary ravines and gullies beginning ca. 13,000 YBP, as well as an understanding for some of the potential external controls on Buttermilk Creek incision. This section focuses on evaluation of Buttermilk and tributary incision below the postglacial valley floor.

Three areas were chosen for detailed study at the outset of the project; areas which are named for landmarks in their vicinity: 1) The abandoned meander, an abandoned channel feature half-way up the west wall of Buttermilk Creek at the north end of Franks soil plateau and just upstream from the Franks Creek confluence with Buttermilk Creek. This abandoned meander is a rare feature in the region, but is very distinctive in appearance due to its deep lateral incision into the wall of the postglacial surface. Due to its conspicuous "U" shape the abandoned meander also has been referred to as the "race track" in some previous reports; 2) The Tree Farm site, a set of narrow Buttermilk Creek terraces accessed from a former tree nursery; this area is located north of, and downstream from, the abandoned meander, but south of, and upstream from the outlet-area into Cattaraugus Valley and the giant landslide; and 3) Heinz Creek, named for nearby Heinz Road, a set of broad terraces and interconnected alluvial fan deposits, and located south of the abandoned meander.

Together the three areas include a broad range of terrace elevations between modern Buttermilk Creek and the postglacial valley floor, although each individual location does not have a full set of matching or equivalent steps distributed up the valley wall. Another reason for choosing these areas is that they bracket Franks Creek upstream and downstream on Buttermilk Creek. In addition, deposition of the Heinz Creek alluvial fan appears to have pushed or driven Buttermilk Creek westward against the Franks Creek "soil plateau" south of and upstream of Franks juncture with

Buttermilk, which could eventually undermine the lower reach of Franks Creek itself, leading to lateral channel integration and potential increased incision rate of Franks Creek adjacent to the SDA. Lastly, ^{14}C dates were available related to the abandoned meander and Franks Creek sites, as well as several OSL dates at the abandoned meander and in the Buttermilk Creek valley, which provided a starting point for the expansion of field investigations.

Our primary goal was to accurately establish the terraces ages in the three areas to clarify the incision history and to reduce uncertainty for computer modeling of past and future erosion. However, "dating" a terrace involves choosing among several potentially useful age-determination methods, sampling of points in three-dimensional space, and integration of a variety of data to reach realistic and defensible interpretations. From a statistical viewpoint, the problem is n-dimensional, but our data quantity and quality is inadequate to proceed with multivariate techniques such as principal component or cluster analysis. Yet there is much interesting new data. The co-researchers' combined century of experience provides a valid basis for selecting a hierarchy of categories for our observed data; many categories are genetic. Terrace type, gradient, strata level, lithology, and dating methods were chosen as higher-order categories for organizing and comparing (clustering) observations. Further categorization is apparent within the groupings of observed data; in other words, additional analytical relationships become apparent by rearranging or visually scanning data for boundaries, trends, cause-and-effect similarities, or other subtle patterns.

4.2.5.2 Types of Terraces and Former Gradients

Types of terraces and postglacial valley-floor features are categorized in Table 4.2-2 below as: 1) Upper Heinz area and the depression at the abandoned meander for old valley floor features; 2) abandoned meander and south of Tree Farm for high elevation features below the pre-glacial valley floor; and 3) Tree Farm and Lower Heinz terraces and Lower Heinz fan for areas approximately from mid-valley height to floodplain level including Buttermilk bed and bank exposures.

Comparing either elevations of features or heights above nearest-neighbor landforms in Buttermilk (or Heinz Creek, as appropriate), and taking into account the approximately 30 feet of relief in the postglacial valley floor, a broad vertical range of possible features to date was examined (Table 4.2-2). The 2010 LiDAR maps were the principal sources of information used to identify these feature categories. Map mosaics using 1-ft contours and a scale of 1-inch equals 67 feet were studied as a series of transparent overlays illustrating topographic contours, terraces, radar transects, and trench locations. Modern Buttermilk Creek has meander-like curves with large and irregular radii of curvature compared to Heinz Creek, but similar to Buttermilk terrace channels. Where terraces, fans, and channels were sufficiently extensive, the gradients of channel tops were measured on LiDAR contour maps. Reconnaissance undertaken in prior years and concurrently was very important to this work, during which there was field inspection of LiDAR contouring at a contour interval of 1 foot. Gradients for Buttermilk Creek channels in the modern and former floodplain and terrace levels were similar at a slope of about 0.01, while the Heinz Creek and fan, surface and channel gradients were about 0.02-0.04. These gradient data support the identification of alluvial-fan geomorphic elements at the juncture of Heinz and Buttermilk Creeks and suggest they should be a concern for future fan extension and lateral channel migration westward into the modern Buttermilk channel.

Table 4.2-2: Geometric Parameters – Old Valley Floor and Terraces Below

EXPLANATION: in Table 4.2-2 below, "identification" includes location and usually a symbol R for right bank or L for left bank with respect to modern Buttermilk Creek; "elevation" refers to the top of the channel fill within a terrace (a single value may be given if the range along the terrace length is small); "height" refers to terrace height above a nearby point in modern Buttermilk Creek; "comments" include ages (bold **dates** in years before present, YBP).

Identification Location	Elevation Feet	Height Feet	Gradient	Comments
Upper Heinz Area – **Fig. 3.4-5** – Old Valley Floor (soil plateau)				
Bog above gully	1402	160	----	**10640, 10129, 4922** UHT6 colluvium
Gully exposure at "E"	1395	153	----	**12700** OSL in sand over till, below colluvium
Kettle at Abandoned Meander – **Fig. 3.4-2 -** Old Valley Floor (soil plateau)				
Floor bottom	1340	146+	----	**14192, 14155, 14114, 13767, 13462**
[Result of glacier working or reworking lacustrine clay and organics into till w. included logs.]				
Floor fillings	1340	146+	----	**3834, 2756, 2446, 765**
[Result of Holocene bog filling.]				
Abandoned Meander – **Fig. 3.4-2**				
Former Valley Floor	1340-70	146+	----	trenches 8, 9; GPR 7, 11
Highest terrace (L)	1334-36	140	.018	trench 10; GPR 5, 6
Upper old pt. bar (L)	1305	110	----	trench 2, 3; GPR 10; R-bank w.r.t. Abandoned Meander; L-bank w.r.t. Butter.
Upper old pt. bar (L)	1303	108	.010	T-4; GPR 2; R-bank Abandoned Meander
[This terrace is "paired" w.r.t. next terrace in list, which is downstream, L-bank.]				
Upper old pt. bar (L)	1302	107	.012	T-6,7; GPR 3,4; L-bank Abandoned Meander
[This terrace is "paired" w.r.t. previous terrace in list, which is upstream, R-bank.]				
Old channel (L)	1292-94	100	.014	gradient measure from MT 35 to 39;
Dates of logs in deep channel fills: **6764** (MT-37), **6087** (MT-33), **5632** (MT-38)				
Dates of organics in bog fills: **3397, 1544, 697, 103**				
Confounding date from log thought to be in till **9495** (MT-34)				
South of Tree Farm – **Fig. 3.4-3** – south and left bank Buttermilk; abandoned Butter tributary or trunk?				
Left of Buttermilk	1260	118	----	sandstone 14-ft waterfall cap-rock
"	1252	110	----	----
"	1244	102	----	----
"	1240	98	----	----
"	1200-05	60	----	----
Tree Farm – **Fig. 3.4-3** - right bank of Buttermilk				
FT-26	1200-05	60	----	**3785, 3777, 3712, 3712, 2357**; vertical logs & woody debris in landslide terrace.
1	1192-98	51-57	.020-.022	----
2	1190	50	.013	----
3	1181	40	.012	----
4	1176	37	.004-.007	**1857, 1828, 1828**; dates at base of organics filling bog in trench FT-8; lowest ash from fire is base of bog organics in nearby FT-10.
5	1170	30	.006	----
6	1163	23	.006-.011	**604, 604**; clay, channel fill, FT-15
7	1157-60	20	.014	**250**; sand, channel fill, FT-17

8	1156	16	.015	----
9 (high flood plain)	1150-55	13	.006-.016	**1653**, 4.5-ft vertical log in sand-silt channel fill at FT-22; **1165, 116, 107**, base of bog organics at FT-20; **1040, 1040, 210, 130, 130**, in clay channel fill at FT-18
10 (flood plain)	1142-50	4-8	.008-.015	----
modern channel	1137-46	----	.003-.015	----

Lower Heinz Area – **Fig. 3.4-4** – Heinz alluvial fan deposition dominates (height w.r.t. Heinz Cr.):

intra-canyon (R)	1300-10	50	----	unexamined terrace
upper fan (R)	1264-80	30-40	.030-.040	**28658**; varves under gravel at HT-17
intermediate (R, L)	1255-60	15-16	.033	paired terraces: two small terrace remnants on right bank at 1257 ft elevation match larger remnant 1250s on left bank
intermediate (R)	1240-60	10-14	.027	closer to Heinz Cr.
			.035	further from Heinz Cr.
lower fan (R)	1226-36	0-4	.023-.026	----
modern channel	1227-60	----	.018-.034	----

Lower Heinz Area – **Fig. 3.4-4** – Buttermilk Creek deposition dominates (all locations right bank):

1	1260	45	.010	**116, 104, 90**; bog soil at HT-16
2	1252	37	.013	----
3	1238-42	25	.010	**3785**, burnt bark at HT-7
4	1229-37	17	.008	----
5	1227-30	8-10	.008	----
6 high floodplain	1225-29	6-8	.011	**2128, 1225, 1101**; dates decrease going up strata section in floodplain deposit at HT-33
7 fp. below Heinz	1221-24	4-5	.006-.007	**ca. 75-150** YBP railroad coal, HT-24
modern channel	1217-30	----	.007	modern channel gradients such as 0.015 occur sometimes in tight, asymmetric meanders

Note on gradients:
Terrace gradients became a subject of extra interest during trenching operations in 2016. Gradients in the Tree Farm area appeared to be steeper than at the Heinz terraces. Terrace gradients were measured when convenient among other trenching activities; the measurements were not a high priority compared to other data gathering needs, but were easy to do using a long hand level, rod, and tape or laser measurer. The results are: a) at terraces above the abandoned meander, 6 measurements of 3 terraces had a mean of 0.019 and range of 0.015 to 0.023; b) at Buttermilk terraces near Heinz Creek, 14 measurements of 5 terraces had a mean of 0.006 and range of 0.002 to 0.015; and c) at Buttermilk terraces at Tree Farm, 8 measurements of 4 terraces had a mean of 0.006 with a range of 0.002 to 0.008. We concluded the following: 1) making gradient measures from LiDAR contours after seeing the abandoned-channel patterns outdoors is most appropriate and these are the data cited in Table 2 and the report; 2) it is difficult to measure field gradients at the abandoned meander because it is difficult to choose where to stand in the field on the terrace fragments; 3) the field measures of gradients at the abandoned meander are 30% greater than LiDAR measurements but the same order of magnitude; 4) either from LiDAR contours or from field measures the Buttermilk gradients at Heinz and Tree Farm are similar to each other, but a little less by field measures as compared to LiDAR; and 5) in the field, terrace gradients appear visually steeper when the terrace is long and narrow (Tree Farm) compared to terrace remnants that are long but wide (Heinz area); the visual effect is an optical illusion, because each terrace's measured values are similar per the measurement method used.

4.2.5.3 Stratigraphy and Lithology

Using initial perceptions of terraces and other features from LiDAR images, topographic contours, and field reconnaissance, detailed exploration of terrain features was planned. The resulting approach to further exploration was:

1) Based on LiDAR contours and field reconnaissance of each terrace, lines for GPR data acquisition were identified and marked, and paths were cleared for rolling, carrying, and walking the GPR instruments, which require ground contact. Other geophysical probing methods such as seismic reflection or ambient seismic analysis were not used in order to rapidly obtain relatively shallow data, and to look at initial results before further consideration of possible additional electrical, electromagnetic, or seismic methods;

2) Schnabel Inc. was retained in 2015 and 2016 to conduct GPR investigations (Appendix E);

3) Locations were chosen for trenches to be dug with a mechanical excavator by: a) using ground shape during reconnaissance to locate abandoned channels and point bars, b) LiDAR analysis to identify subtle features, c) positioning many of the trenches in locations where GPR reconnaissance showed subsurface strata complexity and continuity, or trenching across places where GPR analysis showed points of discontinuity, d) discussing issues of access, access disruption, and logical pathways for required trench closure, e) discussing issues of proximity to other trenches or features, possible patterns of interconnection or extension, and potential excavation depths, and f) planning work efficiency.

4) Many trenches were purposely located where shallow bog soils were evident in order to maximize the probability for locating dateable carbon (14C) and sand (OSL), and where plant materials would be preserved by water saturation (reduced oxidation);

5) Trench exposures were recorded with field notes and photos, and samples were collected; both Wilson and Young recorded field notes on site-specific printed forms and also transposed field notebook data to such printed field sheets; the overlap in their note taking proved helpful when reviewing trench data; field notes and photos were consolidated into semi-schematic stratigraphic sections (trench diagrams in Appendix G);

6) Sediment samples were collected for lithologic pebble counts from trenches and acquired from shallow, hand-dug surface pits. Surface grab samples were acquired during reconnaissance. During reconnaissance, topsoil and tree roots were removed to examine exposed subsoils and collect surface grab samples of pebbles with 1 or 2-inch diameters. Pebble counts were usually completed in the field on project-specific, printed field sheets. Results of pebble counts are characterized in Table 4.2-3 and raw data are presented in a spreadsheet in Appendix B. .

From the first dozen or so pebble collections it was concluded that ice-contact deposits were relatively enriched in exotic lithologies (sometimes referred to in the literature as "bright") while locally-sourced (upstream bedrock) deposits were dominated by brown or gray sandstone, similar to findings elsewhere in southern New York and adjacent Pennsylvania. Consequently, trench sediment interpretations regarding fluvial or glacial derivation are generally supported by pebble counting. One early consideration was that gravels of uncertain origin could be assigned a source by their relative content of exotic pebbles; another possibility was that exotic pebble percentages would change from higher to lower terraces as the watershed was further incised by fluvial erosion.

Table 4.2-3: Exotic Pebbles as Percent of Sediment in Surface and Near Surface Features

Explanation: ID is unique identification number from the data table in Pebble-Count Appendix (provides details of data, lat.-long locations, etc.). Exotic pebbles are glacial erratics composed of any lithology other than dull shale, siltstone and sandstone (includes all distant provenances such as Onondaga limestone and chert, Lockport dolostone, Medina or Queenston red sandstone, and igneous and metamorphic rocks).

ID	Feature and Location	%
	Samples from active channels:	
36	Buttermilk at WP-20	9
37	“ at WP-2	19
17	Butter-Heinz confluence at “q”	17
13	Heinz at m	16
14	“ n	12
15	“ o	16
16	“ p	16
	Surface grabs on Butter terraces, low Heinz area:	
3	at Heinz “c”	4
4	d	8
5	e	10
6	f	2
7	g	6
8	h	6
10	j	6
	Surface grabs on Heinz alluvial fan:	
1	at “a”	6
2	b	7
11	k	11
12	l	7
18	r	8
	Surface grab at WP-9 to see size dependence:	
20	> 1 cm	6
21	< 1 cm	10
22	> 22 mm	16
23	< 22 mm	15
	Surface grab at Old-Meander trench-10:	
44	surface-grab, area of radar 5 and 6	7
ID	**Feature and Location**	**%**

ID	Feature and Location	%
	Butter terraces at Tree Farm (trench samples):	
71	terrace 2; FT-4	8
72	4; FT-8	9
73	4; FT-9	7
74	7; FT-17	12
75	9B; FT-19	1
	Butter terraces at Heinz area (trench samples):	
	(parentheses contain corresp. value of surf. grab)	
63 (5,6)	terrace 1; HT-15 (11, e,f)	10 (10,2)
62 (4)	2; HT-13 (10, d)	8 (8)
61 (10)	3; HT-8 (12, j)	20 (6)
60 (7)	4; HT-1 (13, g)	12 (6)
68	6; HT-25B (9)	13
70	6; HT-33 (9)	8
	Heinz alluvial fan (trench samples):	
64	fan apex HT-17 (3)	8
65 (1)	fan apex HT-20 (4, a)	10 (6)
66 (12)	near apex HT-21 (4, l)	11 (7)
67 (2)	near apex HT-23 (5, b)	10 (7)
69	mid fan HT-31 (8)	8
	Old-Meander channel gravel (trench samples):	
31	MT-30	12
32	MT-31	12
33	MT-35	7
34	MT-36	12
35	MT-37	17
	Old-Meander trench-10 (highest terrace?):	
48	trench-sample, intersect radar 5-6	21
ID	**Feature and Location**	**%**

Glacial ice-contact features such as basal till, ablation till, inter-till gravel, near-ice outwash-lenses, kettles, eskers or crevasse-fills:

25	till at WP-1	49
26	till at WP-5, 6	36
27	till in gully below end Old-Meander	17
28	till in Old-Meander kettle, Pit-2	21
49	till south of Old-Meander, trench-12	24
53	till “ “ “ “ trench-18	16
38	till on bedrock in Heinz, LaFleur map	38
39	till in Butter bank, WP-25, deep level	37
40	till in Butter bank, WP-25, shallow	39
41	till in Butter bank, WP 5-6, at log #1	36
42	gravel lens in till in Butter trib. gully	42
43	“ “ “ “ “ “ “ “	26
29	Old-Meander kettle-bottom, Pit-1	43
30	“ “ “ “ , Pit-2	31

Old valley floor (top of soil plateaus):

19	upper-Heinz, tree-throw, surf-grab	3
44	highest terrace (?), surf grab above the abandoned meander	7
48	same as 44, but from trench-10	21
45	above Old-Meander, surf-grab	10
46	“ “ “ trench-8	18
47	“ “ “ trench-9	10
50	“ “ “ trench-13	19
51	“ “ “ trench-17	10
52	“ “ “ trench-18	13
55	“ “ “ trench-19, shallow	13
54	“ “ “ trench-19, deep	19
56	above Heinz, away valley wall UHT1	10
57	“ “ mid-distance UHT3	13
59	“ “ close to valley wall UHT4	18

Examples of confounding situations:

24	In Butter Creek, toe slide, WP2	19
9	Heinz terrace at “I”, complex morph	16
76	Tree Farm slide-modify terrace FT26	29
58	above Heinz, under colluvium UHT5	7

Outcrop belts of bedrock in western New York are oriented roughly east-west and dip southward at about 20 to 40 feet per mile. From approximately Interstate-90 southward bedrock lithology is shale grading upward (southward) into younger and ever more interbedded Devonian siltstones and sandstones, almost entirely gray and brown in color. Distinct lithologies such as red sandstone (Medina and Queenston), light-gray carbonates (Onondaga limestone and Lockport dolostone), and bright green-red-purple shales (Vernon) are located 30 to 60 miles to the north of West Valley, and igneous and metamorphic rocks are 100s of miles to the north on the Canadian Shield province. Pebble count data from trenches, streams, and shallow exposures from Appendix B were summed for total percent of exotic pebbles per sample (50 or 100 clasts) and those results arranged into genetic categories in Table 4.2-3. Because Table 4.2-3 is a compilation of percent exotic pebbles, the complementary values are percent local pebbles; a value of 20 percent exotics corresponds to a value of 80 percent local lithologies.

Shales throughout the region break down rapidly when exposed to weathering. Numerous observations of western New York Devonian-age shales show that the shale disintegrates into thumbnail-sized chips upon repeated wetting and drying. These observations are made from weathering responses at outcrops, in stream banks, from core-logs, and especially from flood-deposited shale blocks. Flood blocks usually disintegrate in less than a year; very large blocks such as 1x4x8 feet lasted into a second year (personal observation, Wilson). Study 1 identified three field situations where shale was more common in exposures or pebble counts: 1) glacial till (especially where immediately above shale bedrock, e.g. base of trench FT-13); 2) active deposits such as point-bars in modern stream channels that are a short distance down-stream from channels actively eroding shale bedrock (Table 4.2-3 entry ID Nos. 13 through 17; Appendix D map locations Heinz m, n, o, p, and q); and 3) places of channel avulsion (sudden shift in channel location during flood event or caused by natural channel blockage, such as log jams) in Heinz alluvial fan channels (e.g. HT-20 and HT-21).

Conclusions from analysis of results in Table 4.2-3 are: about 15 percent of pebbles transported in modern streams in the area were northerly-derived carbonates, red sandstone, quartzite, and chert, igneous and metamorphic clasts from reworking of glacial deposits. Fluvial terraces preserved fewer, about 12 percent exotics, in their subsurface but 7 percent exotics in the near surface or topsoil; trench values of fluvial exotics were slightly higher percentages than corresponding surface grab samples. Chemical weathering of exotics was indicated by 5 percent and 10 percent hydrochloric acid (HCl) testing in trenches of several soil profiles of terraces that produced no observable acid fizz (carbonates lost), and Munsell color changed (iron oxidation) from deep red-brown to light red-brown with increasing depth. Carbonate pebble counts resulted from glacial till as a source, and from weathering dissolution in terraces, with high counts in till, outwash, and chemically-protected environments (e.g., wet low-permeability bogs). In addition to chemical weathering, physical weathering also could have slightly reduced carbonate exotics found in the coarse sizes sampled for pebble counts as indicated by size response data (left side of Table 4.2-3).

Exotics typically comprise up to one quarter to one half of the pebbles in local tills or interbedded outwash gravel lenses (left side of Table 4.2-3). Most of these samples are thought to be the Lavery map units of current and past investigations, largely the result of a diamict formed by glacier advance into a proglacial lake confined to the Buttermilk valley. Trench samples of pebbles from the postglacial valley floor deposits (soil plateaus) contained 10% to 20% exotics (right side of Table 4.2-3). Shallow grab samples contained fewer exotics. Thus pebbles of the old valley floor (Pleistocene-Holocene transition) were of similar composition to Holocene terraces with similar degrees of weathering.

4.2.5.4 Ages of Features below the Postglacial Valley Floor

Approximate absolute ages of terraces or other features numerically define the timing and rates of landscape processes affecting the Buttermilk Creek watershed. The relative temporal relationships among regional geomorphic features and strata based on discussions or implications of figures and maps in previous sections of this report, are not changed by adding absolute dates. Absolute ages simply more accurately define the temporal spacing of events and rates of changes.

The Simmons Road site ca 13,000 YBP ages from logs in apparently younger till draped over the mapped Kent moraine (LaFleur, 1979) (including one ^{14}C date obtained independently by Wilson , Young, and Zerfas at the location) clearly defines the age of a ca. 13,000 Younger Dryas ice advance. However, it is uncertain whether this age specifically marks the exact time of glacier advance and whether the end moraine position could have been occupied for several hundred years. We also cannot be certain exactly when or where the apparent ca. 13,000 advance ended and subsequent ice withdrawal was completed. The simplest explanation is that the 13,462 to 14,192 dates from the Kent moraine site and from the glacial kettle at the abandoned meander represent slightly older forest and organic debris incorporated into till either by an over-riding Lavery glacier (whose age is not accurately known at the type locality west of New York State) or by a younger 13,000 event (Younger Dryas climatic cooling) advancing into a proglacial lake (produces clay-rich till), or possibly, from forest growth that has been observed to occur on modern stagnant, till-covered ice as well as on actively moving glacier margin ice. Obviously the ages of trees incorporated in glacial till will always be slightly older than the actual age of the advance that buries them. In addition, logs buried by an older event can be reincorporated into a younger deposit, similar to the problem of the reworking of wood fragments in the fluvial environment.

The 12,700 OSL date at the gully outcrop below trench-UHT5 at upper Heinz agrees well with a date of approximately 13,000 for glacier retreat from the Kent moraine site. The date of 13,000 YBP could be used for initiation of erosion of the Buttermilk system for computer modeling, The dates in the colluvium at UHT6 (10,640 and younger) support using the date of 13,000 as reasonable times of the inception of glacier down-wasting in the central portion of Buttermilk valley.

The deeper portions of channel fill at Old Meander date from 6764 to 5632. This is the likely period of abandonment of the abandoned meander.

The oldest YBP dates of bog fillings are:

1) 3834 in kettle above Old Meander; Beta-437411;

2) 3397 in Old Meander channel; Beta-442967;

3) 3785 at slide terrace at Tree Farm FT-26; Beta-441594;

4) 3785 at Lower Heinz HT-7, terrace #3; Beta-439758.

4.2.6. Buttermilk Creek: Down-Wasting vs. Back-Wasting

In the beginning of Study 1 and during previous Study 1 writing, the concern was raised about the over-arching behavior of the Buttermilk trunk stream. Was Buttermilk's trunk incision dominated by back-wasting, e.g. gully-head retreat, or by down-wasting, e.g. lowering of an initially gentle gradient in the mid- to lower basin?

At first this question was qualified or intensified by field observations that Tree Farm terraces looked steeper than Heinz terraces, but comparing gradients (as per text within Table 4.2-2) provided evidence that the steeper appearance of narrower terraces such as at Tree Farm, relative to wider terraces such as at Heinz, was an illusion. Gradients were equivalent between Heinz and Tree Farm when quantitatively measured in the field and on LiDAR. The conclusion from this is that equivalent gradients in a narrow field of view appear steeper than in a wide field of view. With this visual illusion removed, one can concentrate on the hard data.

Previously during Study 1, it was measured from LiDAR maps that Buttermilk terrace gradients (Tree Farm Figure 3.4-3 and Heinz Figure 3.4-4) are the same as modern Buttermilk Creek gradients. Nearly all gradient measurements, modern and past, fall between 0.005 and 0.015; using a value of 0.010 is reasonable for discussion. In contrast, Heinz Creek modern and past gradient-values near the juncture with Buttermilk are commonly around 0.030.

The initial post-glacial, valley-bottom gradient can be measured from the soil-plateau surfaces (old valley floor at glacial retreat) using LiDAR maps; however this gradient of 0.003 has two flaws. First, the soil plateau-surface gradient measured today is likely steeper than the gradient was of a sinuous stream formed in the ground surface 13,000 years ago by connecting or avoiding glacially-inherited irregularities in that surface; so the gradient 13,000 years ago was less than 0.003.

Comparing these opposing early-Holocene process-impacts is difficult. There is not enough information from terraces in the Abandoned Meander area and elsewhere in the Buttermilk valley to reasonably sort historic events throughout middle to lower Buttermilk valley prior to 3,785 YBP, but there is enough information to understand a portion of the history. In Figures 3.4-4 and 4.10-2, the apex of Heinz fan and nearby Buttermilk terraces are significantly above Trench-7 (3785 YBP) in Terrace-3. Do these features occupy the time-gap above Heinz Terrace-3 (3785 YBP) and below the youngest age in the Abandoned Meander (ca 5,600 YBP)? Or are the fan apex and high Buttermilk terraces at Heinz juncture temporally coincident with or even older than the floor of the Abandoned Meander? The answer depends on how many millennia Buttermilk had a gradient similar to the 0.003 of the earliest-Holocene soil-plateau tops vs. how many millennia earlier than 3785 YBP Buttermilk had a gradient similar to its modern gradient of 0.010.

The middle to late Holocene terraces of Buttermilk Creek at Heinz and Tree Farm are easier to analyze and understand than the early to middle Holocene features. The Buttermilk terraces at Heinz and Tree Farm have the same gradients as modern Buttermilk Creek. The oldest dates so far collected on terraces at Heinz and Tree Farm are 3785 YBP (Figures 4.10-2 and 4.10-3). Buttermilk has had its current gradient of approximately 0.010 for at least 3,785 years (3785 YBP (Heinz trench-7), and longer as confirmed by the gradients of higher Buttermilk terraces (terraces 1 and 2 near the Heinz juncture).

In review, Buttermilk's initial terraces (soil plateaus) had an unknown gradient (interpreted as likely more than 0.003) at termination of glacier-ice cover at ca 13,000 YBP. Buttermilk's gradient was unknown between 13,000 YBP and 10,600 YBP. Buttermilk terrace gradients above and within the channel of Abandoned Meander are or were approximately 0.010 to 0.018 between 10,600 and 5,600 YBP. Buttermilk terrace gradients are or were approximately 0.005 to 0.015 (centered on 0.010) between 5,600 YBP (at least 3,785 YBP) and present day. Furthermore, referring to Figure 4.10-3 and recalling that the date 10,600 is at similar elevation and geographic location to the date 5,600 YBP (rounded to 6,000 in that figure), large amounts of volumetric loss (erosion) of Buttermilk valley occurred between 13,000 and 10,600 YBP and again between 5,600 and 3785 YBP.

In conclusion, the Buttermilk profile is clearly steeper today than it appears to have been 13,000 years ago as evidenced by soil plateau surfaces (Figure 4.10-3). The Buttermilk profile has been at the same gradient for at least 3,785 years and likely 5,600 years, regardless of Abandoned Meander incision rates. The Buttermilk profile has not changed gradient, not increased its degree of flattening, in the last 4,000 years, and maybe 10,600 years, as evidenced by terraces with little or no gradient changes. Overall, the Buttermilk trunk stream has been down-wasting (i.e., maintaining its gradient) for likely 10,600 years and at most has transitioned from an average gradient of 0.014 to 0.010 during those 10,600 years. Buttermilk's gradient, modern or ancient, is in line with other stream gradients (0.010) for similar stream sizes and conditions in the region.

4.3 CHRONOLOGY OF EVENTS

4.3.1 Present Study Approach

The present study attempts to improve the late glacial and postglacial chronology by mapping and dating a series of obvious postglacial fluvial terraces and key glacial units. All radiocarbon dates mentioned in this preliminary report (unless otherwise noted) are expressed as calendar years before present (1950) as YBP (1 sigma [Σ] mean), and were corrected using the online CALIB program (Stuiver et al. 2017); actual measured radiocarbon dates (^{14}C years BP) by BETA Analytic and calendar correction information are included in the Appendices. The CALIB program was utilized because it was necessary to convert and compare many ^{14}C BP ages from older reports, so that it is preferable to use the same program for these comparisons, rather than the very slightly different corrected ages provided by BETA Analytical for their analyses.

Photo 4.4: Excavation on Kent moraine showing one of many logs imbedded in gray glacial till, which underlies peat composed of well macerated wood and plant remains.

The present study also has the advantage of access to a high-resolution LiDAR survey that has permitted more precise identification and targeting of subtle glacial and fluvial landforms as described in Section 4.1. This opportunity, combined with expanded resources for excavating the targeted landforms, has provided a much-improved sampling record for both the glacial and postglacial sediments. The acquisition of 67 radiocarbon samples has allowed the establishment of a much improved chronology for the timing of the last glacial advance and an estimate of when the Buttermilk Creek basin became incised at close to its current gradient (circa 2300-2500 BP).

4.3.2 Revised Glacial Chronology

The discovery of buried wood samples that confirm the late glacial history was a fortuitous occurrence at one of the localities (abandoned meander site), in addition to the excavation on the presumed older mapped Kent moraine located on Simmons Road approximately 3.3 miles (5.4 km) south of the southern WNYNSC boundary (Photos 4.4, 4.5, 4.6). The prominent moraine (Figure 4.1-1) was designated as being of "Kent" age by LaFLeur (1979, 1980) and by Muller(1977), a recognized regional glacial event that predates the well-established Erie Interstade (warm period of glacial recession). The Erie Interstade was once thought to range from 15,000 to 17,000 YBP by

Morner (1971), but was more precisely dated as between 14,500 and 16,000 in the Mohawk Valley region (Ridge, 1997). The age of the actual Kent glacial advance is estimated to be about 23,000 years old as inferred from a date on pro-Kent lacustrine sediments in Ohio (White, 1968).

Photo 4.5: Multiple logs embedded in same glacial till as Photo 4.7 at Kent moraine. Ages of logs in calendar years are clustered in the range from approximately 13,000 to 14,000 YBP. Logs show effects of severe abrasion, complete loss of bark, and are imbedded with small stones, which suggests exposure to extreme pressure (ice loading).

Our current six ^{14}C ages (converted to calendar years) in the range of 12,955 to 14,438 YBP on logs in till close to the surface of LaFleur's (1979) so-called "Kent" moraine and five similar ages (13,462 to 14,192 years BP) on wood in till deposits near the abandoned meander (Photos 4.7, 4.8) clearly demonstrate that either the presumed pre-Erie Interstade age of the so-called "Kent" moraine as mapped in western New York is grossly in error (which seems highly unlikely), or that there was a much younger late glacial advance in western NY that reached at least 25 miles (40 km) southeast of Lake Erie in the Buttermilk Creek basin and overrode the older Kent moraine and other preexisting glacial landforms at the WNYNSC. Evidence for such younger advances (thin tills) overriding older morainal topography, without destroying the underlying morphology, is described by Fleeger (2005) for the Kent till resting on Titusville morainal deposits, as well as for the Lavery till in Ohio and Pennsylvania. There is strong complementary evidence of a 13,000 YBP ice advance in the Genesee Valley to the east (south of Rochester, NY) from multiple logs buried in glacial till exposed in the banks of the Genesee River near Avon (Young, 2012, Young and Owen, 2017), as well as from a carefully dated peccary skeleton buried on a moraine in quicksand near the front of an active glacier at the same latitude (Young, 1978). The Genesee Valley site near Avon was originally considered to be a potential landslide (Young, 2012), due to its unusually young age, but the wood-bearing till is

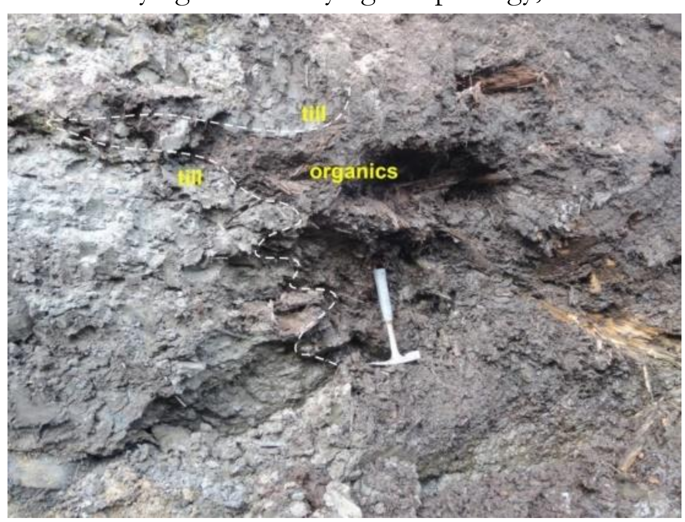


Photo 4.6: Till and organics intricately entwined at Kent moraine trench near Photos 4.4 and 4.5. The intertwined nature of the organic-rich debris and the till indicate a dynamic glacial origin, not a simple burial of glacial deposits by younger bog debris.

Photo 4.7: Excavation of wood-bearing till in pit at glacial depression adjacent to abandoned meander. Pit exposed interbedded till and outwash deposits suggestive of either an ice re-advance or slight oscillation of the ice front.

clearly sandwiched between two sets of undeformed glacial varves. This age corresponds to the well documented climatic cooling known as the Younger Dryas event (Appendix N).

This field evidence now places the postglacial erosional development of the Buttermilk Creek valley within a more recent and more tightly constrained but somewhat complicated time frame. The postglacial landforms in the Buttermilk Creek basin now can be assumed to have been overridden by a previously unrecognized ice advance within the last 13,000 years, and the current basin morphology is a result of erosion following the recession of this now well-dated glacial advance. The presumed southerly boundary of the circa 13,000 YBP glacial advance, as marked by LaFLeur's apparently overridden "Kent" moraine, suggests that either a Lavery or Hiram ice advance could explain that geologic setting. However, either the inferred Lavery or Hiram till is the glacial deposit associated with the ice advance that must have occurred circa 13,000 YBP (clearly younger than the youngest wood buried in the prominent moraine and meander site tills), or an entirely separate ice advance occurred following the recognized Lavery and Hiram events as currently understood. The latter appears to be more likely. Recent papers by Sharp and Russell (2016) and by Boyce and Eyles (2000) provide alternative models for the Lake Ontario basin where floating ice shelves might explain how younger tills become spread over older glacial landforms.

Photo 4.8: Collection of compressed wood samples from distinct organic horizon in glacial till at glacial depression adjacent to abandoned meander site. Impregnated Tamarack wood specimens are shown in Photo 4.20. Griggs (2016)

The choice of which one of these possibilities is correct is complicated by the fact that the precise ages of the Lavery and Hiram advances in Ohio and Pennsylvania are still uncertain (Fleeger, 2005). The age of the Lavery till was estimated to be between 14,000 years (Droste et al., 1960) and 19,000 ^{14}C years BP (White, 1982) as cited in Fleeger (2005). The Hiram advance was estimated to have occurred at about 17,000 years ago (White, 1982), but has a minimum (bog bottom) date on peat in a kettle in Ohio of 14,050 ^{14}C years BP (Totten, 1976). The dates cited in Fleeger are apparently uncorrected ^{14}C YBP ages, which even if converted to calendar years BP, all appear to be older than our recently obtained WNYNSC depression site till and "Kent moraine" (Simmons Road locality) radiocarbon dating results for the most recent ice advance into the Buttermilk Creek drainage basin..

A minimum age for the newly recognized young ice advance in the Buttermilk Creek basin also can be inferred by the position and age of the glacial Lake Whittlesey shoreline along the southeastern edge of Lake Erie (Figure 4.1-1). This shoreline is considered to be of Port Huron age (circa 13,000 YBP; Barnett, 1979, 1984), but has published ^{14}C ages ranging from 12,730 to 13,600 YBP Barnett (1979, 1984). If our inferred 13,000 YBP (calendar year) re-advance to the older Kent moraine had occurred following the strandline development of glacial Lake Whittlesey, its till deposits or erosive effects would have been superimposed on that shoreline and any similarly young features. This implies that the numerous moraines in the Buttermilk Creek basin shown on the maps of LaFleur (1979) are either older landforms that have been overridden, or that many of them formed during a relatively short interval as an oscillatory ice front retreated from the basin between 13,000 BP and prior to the formation of Lake Whittlesey. Published ^{14}C ages for Lake Whittlesey (converted to calendar years) appear to be slightly too old compared to our revised chronology for the Buttermilk Creek basin. However, shorelines are generally dated based on wood fragments found within the strandline deposits, which can obviously be portions of older logs reworked from prior events.

As discussed in Section 4.1.1, the reliable establishment of the glacial chronology at the WNYNSC is the most important aspect of the current study, as it provides a starting point from which to accurately infer the postglacial incision history of the Buttermilk Creek basin, and therefore the base level lowering history for Franks Creek at its confluence with Buttermilk Creek. Central to this issue, beyond establishment of the age, is the determination of the elevation and configuration of the immediate postglacial surface as the ice receded from the Buttermilk Creek basin, when fluvial and mass wasting processes became the dominant forces in shaping the postglacial landscape. This topic is discussed in Section 4.1.

4.3.3 Radiocarbon and OSL Dating Results from Fluvial Terraces and Alluvial Fans

4.3.3.1 Issues Relating to ^{14}C Samples in Fluvial Sediments

The radiocarbon ages of fragmentary wood samples buried in fluvial sediments on former floodplains (terraces) are always subject to uncertainty for the following reasons. Trees or other organic debris are constantly growing, dying, and falling onto the floodplain surface, or directly into the active channel (Photo 4.9). Such debris rapidly decays when left exposed to surface environments, but is occasionally incorporated into channel and overbank stream sediments either by transport and rapid burial during in-channel flood events, or by overbank burial during more extreme events. However, the lateral migration of channels, such as is obvious at Buttermilk Creek, will eventually erode, uncover, and reincorporate some of this older debris into younger fluvial deposits further downstream. The preservation of ^{14}C samples for lengthy periods requires their relatively rapid protection from oxidation as well as the action of insects, bacteria, mold, and fungus. The critical conditions that generally preserve wood located below the water table are described in the publications of Lambrechts (2008) and Klaassen (2015). Wood samples that remain exposed to the elements and bacterial or fungal decay on the surface are unlikely to be adequately preserved in pristine condition and reburied. Therefore, intact logs that preserve bark (e.g. Photo 4.9) or show no strong evidence of deterioration can be inferred to have been covered by sediment shortly following their initial deposition. Significant organic decay occurs relatively rapidly (probably 1 or 2 decades at most), as evidenced by the advanced decay seen in fallen trees scattered on the surfaces of existing Buttermilk Creek terraces (Photos 4.10, 3.20).

Photo 4.9: Wood specimen excavated from postglacial landslide site (trench FT26) exhibiting preservation of bark, unlike glacially transported wood, which generally lacks bark and has been smoothed by subglacial transport. (Age circa 3700 YBP)

Photo 4.10: Recently felled logs lying on organic-rich terrace channel. Similar sites were considered prime targets for excavation due to the obvious high groundwater table and indications of a reducing (not oxidizing) environment, which favors preservation of organics.

Many of the ^{14}C ages acquired from terrace excavations during the present study represent young events, such as development of the modern organic soil profile, local landslides, or trees and limbs that appear to have fallen onto fluvial terraces at some time after their abandonment by ancestral Buttermilk Creek. As an example of reworking, the Genesee River modern floodplain contains wood from a few tens of years old to >12,000 YBP, all within the same sedimentary environment (Young, 2003).

4.3.3.2 Issues Relating to Optically Stimulated Luminescence (OSL) Dating

OSL is a relatively new dating technique that must be carefully applied to each sample acquired (Arnold & Roberts, 2009; Cunningham & Wallinga, 2010; Duller, 2008). The ongoing improvements in applying this technique to the dating of sediments promise to make this technique a powerful companion to ^{14}C analysis, especially where adequate ^{14}C samples are rare, such as on many of the abandoned and oxidized Buttermilk Creek terraces.

4.3.4 Fluvial Chronology and Incision History

Figure 4.3-1 presents a schematic diagram of terrace ages across Buttermilk Creek. Given that the postglacial erosion cycle can now be confidently assumed to have begun approximately 13,000 years ago, it is important to determine whether the current Buttermilk channel has been actively incising in the recent past, or whether most of the vertical incision may have occurred over a shorter postglacial time interval, either at a gradual rate, or erratically in response to climate variability, randomly located bedrock impediments, or other unspecified base level controls, such as major landslides.

The results of ^{14}C dating of key wood samples at and near the current stream elevation in Buttermilk Creek are important to the evaluation of the incision history in the recent past. In this regard, there are two major issues that are probably most important in the evaluation and dating of organic samples in fluvial and glacial environments:

1) What is the nature of the depositional process and what was the natural environment (i.e. what is the origin and nature of the organic material and how did it arrive at its current burial position?). Is reworking a plausible assumption?

2) What is the likelihood and potential magnitude of contamination by older or younger introduced carbon?

Some of the contamination issues can be minimized by careful sample treatment and use of the AMS method; others depend significantly upon the interpretation of the sample context as carefully observed in the field.

There are some straightforward observations that can be used to simplify the potential circumstances of burial and preservation:

Photo 4.11. Spruce wood preservation in Genesee Valley, NY (~48,000 calendar years). Young & Burr, 2006.

A) Old wood samples can be reworked and redeposited in younger sediments (the "reworking" issue). However, younger samples cannot be found in truly older sediments (unless contamination has occurred by penetration of rootlets, fungi, etc.). The reworking issue is predominantly one where old (dead) trees or branches are buried, re-exposed, broken into smaller pieces, and redeposited one or more times during major flood events. This is common in fluvial floodplain situations. Therefore, this issue is problematic when a relatively small, isolated wood sample (broken fragment) is found or collected, and its decomposition and potential multi-stage burial history are uncertain. Leaf mats generally avoid these issues, as leaves are too fragile to remain intact after fluvial reworking.

B) All dead or uprooted wood is susceptible to relatively rapid decay and disintegration when exposed at the ground surface, or when buried in permeable sediments that are above the local groundwater table. Conversely, wood samples can be amazingly well preserved for extended times below the water table, especially when the enclosing sediments are fine grained (silt and clay). Proof of this is shown in Photo 4.11, a circa 48,000-year-old sample of spruce wood preserved in mid-Wisconsin clay-rich glacial till in the Genesee Valley (Young and Burr, 2006). Many similar, bark-covered samples were collected at that site.

The reason for the unusual preservation of wood below the water table is the relative absence of air, insects, and fungi, and the relatively slow operation of bacteria in this environment. Studies of old wooden construction piles at building sites in Boston, MA, (Lambrechts, 2008) and in European countries have recently demonstrated the significance of above vs below water table environments for wood preservation at the multi-century scale (Klaassen, 2015).

Personal experience (R.A. Young) with firewood cutting, storage, and use indicates that hardwood trees disintegrate rapidly when exposed to air. Even when carefully stacked above ground, hardwoods such as oak decompose significantly in this climate in 4 to 5 years, to the extent that the wood loses much of its heating value. Decomposition is mainly due to fungal, bacterial, and insect activity, as well as normal atmospheric oxidation processes. For these reasons, wood exposed in the open and on the surface is highly unlikely to survive for more than a decade and end up buried in a pristine, relatively undecomposed state. In other words, if an old sample of buried wood (log or stump) is found to be in good to excellent condition (little or no obvious decomposition; bark attached as in Photo 4.12), it can be assumed that: 1) the sample has been preserved below the water table for most of its history, and/or 2) the specimen did not sit on the surface for a lengthy period of time (probably less than a decade).

Photo 4.12: Wood sample with bark attached excavated from fluvial gravels at abandoned meander site. Such bark preservation is assumed to indicate that the sample has not been reworked by two or more cycles of deposition, and therefore may provide a more accurate indication of its original time of growth and deposition.

One of the main conclusions to be drawn from this and other similar discussions is that the cellulose extraction method of treatment, when used with AMS dating, should allow for most contamination issues to be eliminated, or at least better resolved. In addition, AMS dates, unlike the older generation methods, allow analysis of very small samples and discrete counting of individual atomic species (isotopes), such that potential contamination issues can be better defined.

Another factor to be considered is that even when contamination is present, a small amount of contamination does not necessarily mean that a date is totally incorrect (depending on the age of the sample and the amount of contamination). A sample with small amounts of contamination can still provide a useful approximate age (Example: 1 percent contamination of 17,000-year-old sample produces a 600-year error, which is not that different from discrepancies encountered along some portions of the ^{14}C to calendar-year calibration curve).

The buried stump sample from Buttermilk Creek channel (WV-BC-C14-S1; age 1960±30 ^{14}C BP) shown in Photo 4.13 appears to be in a normal growth position, well preserved, and was as "hard" as modern wood, inferred by the strength required to detach a sample with a sharp-edged mattock. From these conditions it can be inferred that the ca. 2000-year-old specimen was not exposed to the atmosphere (uprooted) for any significant period of time (as inferred from discussion above). This implies that it has been beneath the water table (at or near stream channel elevation) throughout its burial/growth history. The most logical way to interpret the environment is that of a rooted tree

Photo 4.13: Buried stump (Sample S1) in Buttermilk Creek (1911 ± 30 YBP; 1960 ± 30 ^{14}C BP).

stump in its original growth position. Only further excavation could verify this reasonable assumption.

Consider the alternative possibility. Suppose such a tree were growing on the adjacent flood plain some distance upstream. Such a large tree would either be toppled by the wind, by a major flood event, by disease, or by gradual encroachment of the channel so as to undercut the root ball. Regardless of how such a relatively large tree might eventually fall, the root would likely be attached to the trunk at that time (in order that the roots be lifted from their original growth position, as seen in locally uprooted trees; see Photo 4.14). If such an exposed rooted stump somehow were to be separated from the trunk, carried further downstream, and reburied, the following would have to occur. The root and stump would have to become quickly separated from the trunk and rapidly buried. This is difficult to envision without allowing the entire tree to be exposed to the elements and the natural decay process described above for several years. However, the separation of the stump somehow would have to occur in a manner such that the stump is still well preserved (not compatible with several years of weathering above ground or above the water table) prior to any subsequent burial.

The normal position for stumps seen along such floodplains is: 1) attached to a significant portion of the original trunk and caught in a tangle of other flood debris as in Photo 4.14; or 2) present as a stump (often debris left from logging or clearing operations), but typically tipped on its side with the top end tilted downwards (due to larger diameter of attached root structure). It seems unlikely that a stump with a large root system could be uprooted, separated from the trunk, transported a short distance, and reburied without noticeable "weathering or decomposition" in such an upright position. If such conditions were to be met, it certainly would have to occur over a short time frame following the tree's demise, in order to explain the relatively

Photo 4.14: Logs recently fallen on low terrace. Storms during the winter of 2016 felled many such trees, and may be one of the common ways that such tangles of trees form. The likelihood that such large trees could be transported far from their points of origin along the modern floodplain is slight. The probability that a root structure, as seen here, could be disconnected and reburied in an upright position is low (as discussed in text with regard to dated stump sample downstream from Tree Farm).

pristine condition of the wood comprising the stump.

Alternatively, if the stump (and trunk) were originally buried for some unknown time (possibly above the water table), then re-exposed and/or reburied by another flood, there would have to be more significant effects of decomposition evident. So, reworking and/or gradual reburial do not seem to be reasonable assumptions for this well-preserved specimen (in addition to its upright position).

If the above analysis is reasonably accurate, it implies that the channel of Buttermilk Creek was lowered to near its current elevation at this location by approximately 2,000 years ago, perhaps even earlier (2300-2500 YBP?) if vertical incision has been slowed effectively by the bedrock knickpoint immediately downstream.

Photo 4.15: Buried log at contact between till and overlying fluvial sediments (~1796 calendar years old).

Another buried log (WV-BC-C14-S2; Age: 1860+30 ^{14}C BP; 1796 YBP) shown in Photos 4.15 through 4.18 has a less certain interpretive and "weathering" history than the stump sample in Photo 4.13. The log is preserved resting at the contact between glacial till and overlying fluvial sediments, which varies from 4 to 8 feet above the local stream level. The log is in a state of intermediate decomposition (not completely decomposed or disintegrated). Its total length and connection to an original root structure is undetermined. Although it is above the current water table at present, it has been gradually exposed by the lateral (westward) migration of the Buttermilk channel. When it was located further from the channel, the till directly below may have served to maintain a perched water table, which could have slowed the rate of decomposition of the log for some unknown period of time.

Photo 4.16. Contact of fine-grained fluvial sediment over glacial till. Log in 4.15 is located immediately to the left of this view.

The visible portion of the partially buried log is a minimum of 10 feet long, and it is estimated to have been 8-10 inches in diameter at its largest preserved end. The downstream root end is missing, and the best sample (no visible rootlet penetration) was extracted from this lower end. It was possible to extract and submit a smaller sample from relatively deep within the collected specimen to the Beta lab (Photo 4.18), so that external contamination is even less likely.

Photo 4.17: Well-preserved wood sample dislocated from downstream (north) end of main log.

The elevation of the log sample above the modern channel appears to be at or close to the approximate elevation of the modern floodplain elsewhere along Buttermilk Creek (occupied during moderate to high flood stages). The working assumption for this location is that the log was deposited during a flood-stage event on a surface that had been scoured down to the till, either during the same flood or during an unknown earlier event. Because the log is not totally decomposed it is assumed that it died or was felled and could not have remained exposed on the surface for much more than a decade. It must have been transported onto the till surface during a flood event. The fluvial sediment was either deposited at nearly the same time or somewhat later. As it must have been buried at or near the local water table at the time, it did not totally disintegrate during the approximately 1863 years since its measured growing period (corrected for 1950 ^{14}C conversion).

Trees of this size are moved by extreme flood events, but generally do not travel far (not miles) before becoming entangled with other similar obstacles in the floodway channel, or getting lodged against other trees still standing on the floodplain (see Photo 4.14). For these reasons, and the relatively well preserved condition of the relatively large log, it can be assumed that it has not been exhumed, exposed, and reburied two or more times. Based on these reasonable assumptions, it is assumed it came to rest in its present position not more than a decade or so after its demise.

Photo 4.18: Collected log sample from Buttermilk Creek floodplain after drying at 90°C (WV-BC-C14-S2).

Based on these simplistic assumptions, and the evidence from the downstream stump (Photo 4.13), it can be assumed that Buttermilk Creek was near its present channel elevation by 2300-2500 years ago (or possibly earlier). It is reasonable to surmise that this log is additional evidence for the elevation of the Buttermilk channel close to the time of the log's "death" and original burial. This must have been soon enough that the log did not entirely disintegrate. So it is reasonable to assume (conservatively) that the burial situation occurred within 100 years or less of the tree falling. Otherwise, if left on the surface for several decades, the log should have disintegrated and not been moved as a large intact object by flood conditions.

An alternative hypothesis, that the tree simply fell and was buried (in place) on a vegetated floodplain shortly thereafter by a large flood event, is excluded because it is resting on an apparently fluvially-scoured till surface, which is unlike the nature of the vegetated floodplain surface seen across the adjacent terrain. Limited transport and burial of the recently fallen tree, more than 1863 YBP (added 77 years for1950 ^{14}C convention), without significant time elapsing for decomposition seems to best fit the observed conditions. Even if slightly more time might have elapsed prior to transport and/or burial, the circumstances imply that the modern creek was near its present channel elevation within this approximate time frame.

The log and glacial/fluvial contact are 6 feet above the modern channel exposed in the side of the first fluvial terrace, the present surface of which is 12 feet above the modern channel. An OSL age on the sediment at the same horizon is 2,500 ± 0.23 years BP, which is assumed to be a more realistic estimate of the time of incision to current base level (as suggested throughout this report). A log of this diameter and length, if reworked, probably could not have moved very far from its original location.

A similar site in the same terrace sediments 200 feet further downstream provided four ^{14}C wood ages ranging from 853 ± 30 to 1,305 ± 30 years BP. The younger wood horizon is located 9 feet below the terrace surface and 2 feet above the fluvial/till contact, and within 3 feet of the modern creek level (Photo 4.19). An OSL age on the enclosing fluvial sediment at the level of the buried wood samples is 1,330 ± 0.12 YBP. The position of the wood samples within the fluvial sediments, and their range of ages indicates that they were deposited by fluvial processes sometime after the river eroded the glacial till to within 3 feet of the channel's current elevation, and that they include a range of reworked wood fragments, some of which are obviously younger than the time at which the channel reached its current elevation. This is supported by the OSL age of the enclosing sediment. The wood and OSL ages for these locations are compatible with the 1,911 YBP age for the rooted stump in the channel immediately downstream from the Tree Farm site.

Photo 4.19: Second log site in modern floodplain near old Buttermilk Road crossing. Dark organic horizon can be seen in right half of view at level of geologist's hands. Below the organic layer is a section of brownish oxidized fluvial gravel, which is underlain by gray till. Water at creek level is at the lower left.

Given that the trees from which the wood was derived had to grow on a local floodplain (near the channel) for some time prior to their subsequent death and initial transport, the approximate age of 2,000 years as a minimum age for establishment of the channel near its current elevation is reasonable. The incision of the channel to this current level could be an older event, but not significantly younger, based on the existing data. From these data, Gordon's date of 2300 YBP in Connoisarauley Creek, and the 2500 OSL age, the assumption of a 2300- to 2500-year period of relative elevation stability for Buttermilk Creek near the WVDP should be considered a reasonable estimate. The incision to the current level could have been completed at an earlier time, due to uncertainties in the history of sedimentary deposition events (reworking of sediment), as well as the potential reworking of some of the available wood samples. Gordon et al. (2013, Fig. 4) obtained a buried log date of 2300 YBP at the till/fluvial contact in Connoisarauley Creek, supporting the idea that local grade could have been reached regionally approximately 2300-2500 years ago. We have therefore chosen an age of approximately 2300-2500 YBP as the estimated age for establishment of the current grade.

If the channel were close to its current elevation at least 2300-2500 years ago, then any younger ^{14}C ages on abandoned terraces located at a significant height above the modern channel (25+ feet?) must not accurately reflect the true terrace age. Therefore, in our limited current analysis of the terrace ages and implied history for the highest and intermediate level terraces, it is logical to question the validity of ages that are significantly less than 2000 years old. Disregarding these data points greatly reduces the number of relevant ^{14}C ages we have determined for the critical flights of terraces at the Heinz Creek and Tree Farm sites. The best incision data from the ^{14}C perspective are those sample ages from wood embedded in gravel that have been determined for the abandoned meander channel, which has only a single OSL age for comparison.

The evidence based on the data discussed above suggests that the erosion of Buttermilk Creek was moderate at first (0.014 ft/yr), but stabilized between roughly 8500 and 5632 YBP, and then increased to 0.026 ft/yr until 2300-2500 YBP when the rate slowed to 0.002 ft/yr, presumably due to reduction in gradient and associated development of equilibrium conditions along much of the channel, and associated with one or more bedrock knickpoints. This implies that valley widening and tributary erosion (headward erosion) probably are currently more important processes than main channel incision (with regard to the expenditure of available energy and flood events).

4.3.4.1 Abandoned Meander Site

The abandoned meander site, which has been the subject of previous trenching and OSL dating activities reported in the FEIS, was divided into three general areas of investigation during the present study: 1) the abandoned meander itself along with seven potential terrace surfaces north and south of the meander (trenches T-1 through T-16, T-19, T-40 through T-42), 2) a glacially-related kettle depression immediately south of the meander (pits P-1 through P-5B), and 3) the lowest , most recently active meander channel (trenches MT-30 through MT-39). OSL samples were analyzed from one of the depression pits (sample WV-D1-S1), from trench MT-36, and from trenches T1, T-3, and T-7 (Refer to Figures 4.3-1, and 3.4-2).

Five ^{14}C wood ages were obtained from wood in glacial till at Pits 1 and 2 at the adjacent kettle depression (Photos 4.7, 4.8). The 1Σ mean calendar corrected ages from the till pit samples (P-1, P-2) range from 13,462 years BP to 14,114 years BP. The wood samples showed evidence of compression (ice loading) and contemporaneous impregnation with fine clay (Photo 4.20). These

Photo 4.20: Clay-impregnated sample of compressed Tamarack wood from till excavated in glacial depression next to abandoned meander (Calendar age circa 13,400 to 13,800 YBP). (Refers back to Photo 4.8)

observations support the identification of the enclosing sediments as glacial till, as do the related pebble counts (see spreadsheet, Appendix B).

Analysis by Dr. Carol Griggs (2016) of the Cornell Tree-Ring Laboratory provided the following information for one large wood sample: "Following standard laboratory methods the wood was identified as Larix laricina (Du Roi) K. Koch (tamarack). It is a species common to the boreal and northernmost temperate climatic zones, and one of the first tree species to return to this region following the retreat of the Laurentide Ice Sheet."

Pebble counts from the till and interbedded outwash or ice-contact gravels contain a significant percentage of carbonate and red sandstone clasts (Photos 4.21, 4.22), indicative of a northerly glacial derivation (Appendix B). The tightly-grouped ages of the wood from the till support a glacial advance around 13,000 YBP. This suggests that the 18,000 ± 1.1 YBP OSL age on sand from pit 1 (if correct) can only be explained as resulting from reworking of a subglacial deposit that was last exposed to sunlight during an earlier glacial advance or interstadial event.

Photo 4.21: Glacial outwash pebble count from pit in glacial depression adjoining the abandoned meander at dated wood site. Note "bright" clast content of limestones, chert, and red sandstone, as contrasted with drab Milkweed Creek clasts seen in other illustrations (such as Photo 3.4).

Photo 4.22: Till clast count from same excavation site as Photo 4.21. Note slightly more angular aspect of till clasts, which are less subjected to fluvial rounding, except when pebbles are sometimes incorporated from older fluvial units.

The lowest, youngest, meander channel trenches provided the most abundant samples for ^{14}C analysis of any area examined. However, a significant number of large logs (obvious post-meander tree falls) were evident at shallow depths below the present surface (Photo 4.23), as well as in the

Photo 4.23: Example of several large logs encountered from the surface to shallow depths (1 foot) at trench sites along the abandoned meander channel. Such logs are recent additions to the modern soil (bog) horizon and do not provide useful information on the age of when the channel was last active. Tree falls such as these could drive their branches as much as 2 or 3 feet into the accumulated muck deposits.

shallow organic-rich sediments that overlie the older sand and fluvial gravel deposits. The seven ^{14}C ages completed from these 10 trenches (MT-30 to MT-39) provided a range of ages from essentially modern to 9,495 YBP. Two of these samples, from trenches MT-37 (Photo 4.9) and MT-38, are the only ones that were entirely enclosed in fluvial gravels at depths between 4 and 8 feet. These samples are considered to be the most relevant to establishing a time when the channel was still active, and they had 1Σ mean calendar corrected ages of 6,764 YBP and 5,632 YBP. The 6,764 YBP sample had its bark still attached, indicating a lower probability of significant reworking in a high-energy, gravel-transport environment. These samples appear to encompass the most likely age range for the last significant fluvial events within this channel. Because the sample with bark attached is likely the least reworked, it could be assumed that 6,764 YBP is a realistic time for the incision interval from the surrounding plateau surface, which is at an approximate elevation of 1,370 feet. The modern channel of Buttermilk Creek below the meander site is at 1,200 feet. If that modern elevation was reached approximately 2300-2500 years ago, the 6,764 YBP intermediate channel datum (1285 ft) would imply that approximately 50 percent of the total incision at the abandoned meander occurred after the passage of 61 percent of the 11,000 years assumed available for incision. If the younger 5,632 YBP age were assumed to be more correct, it would imply that 50 percent of the incision occurred after the passage of only 51 percent of the 11,000 available years.

The oldest (9,495 YBP) sample (trench MT-34) is a foot-long vertical log segment encased almost entirely in till, but projecting 1 inch into the overlying gravel. The log fragment was terminated (broken) at both ends, with no root structure. Its stratigraphic position and age could be explained as follows. At some time during incision down to the 1,287 foot elevation (current till/gravel contact) a dead tree fell into the channel, resulting in one of its broken limbs being driven an unknown distance into the existing till. As time progressed, some tree remains and some overlying thickness of till were eroded by fluvial action that subsequently deposited the gravel across the protruding end of the broken branch segment.

The consistency of the till excavated within the current channel is relatively unconsolidated and water saturated, a texture that could facilitate driving of such a log (branch) a foot or more into the subsurface. However, even if this explanation is plausible, there is still the alternative possibility that the meander channel was close to its current elevation at 9,495 YBP (MT-34), suggesting that incision rates could have varied through time. For example: a more rapid incision from 13,000 YBP to 9,495 YBP, followed by relatively stability from 9,495 to 5,632 YBP, an interval of approximately 3,863 years. One OSL age from trench MT-36 was taken at a depth of 2 feet (sample elevation 1,291 ft) and gave a result of 8,400 ± 0.9 years BP. The 8,400 ± 0.9 years BP OSL age of the sand sample from trench MT-36, if accurate, must be the age of sand that was deposited during the incision between 13,000 YBP and the intermediate ^{14}C ages of 6,764 and 5,632 YBP from trenches MT-37 and MT-38.

The OSL age range (7,500-9,300 YBP) nearly overlaps the 1Σ range of the 9,495 YBP ^{14}C sample (9,477-9,917 YBP), also implying that a variation in incision rates is a reasonable possibility. Acceptance of the 9,495 YBP ^{14}C age and the similar 7,500-9,300 YBP OSL ages as the most likely age for incision to near the 1,291-ft elevation would imply that postglacial erosion was moderate (0.014 ft/yr) during the first 3,500 years then stabilized for some 3863 years thereafter, before nearly doubling (0.026 ft/yr). However, an OSL age at trench T-3 (surface elevation 1,308 ft, depth 32 inches) of 3,100 ± 0.3 YBP, if taken at face value, indicates the point bar and meander were active for an even longer period. However this would require that 100 feet, or ~60 percent, of the incision from the meander down to modern stream level would have occurred in 1,000 years or less. This seems unlikely. An OSL age at trench T-7 (Elevation 1,298) has an age of 10,600 ± 1.0 YBP. This sample from trench T-7 nearly overlaps the OSL age range of the MT-36 OSL sample (9,600 to 11,600 YBP vs 7,500 to 9,300 YBP) and is only 7 feet higher, supporting the older age for the abandoned meander being incised to close to its 1,291-ft present day elevation (ignoring soil thickness) closer to 9,500 years ago (Table 4.3-1).

4.3.4.2 Heinz Creek Sites

Despite the existence of at least 10 terrace-like or alluvial fan surfaces scattered across the upper and lower Heinz Creek area (Figure 4.3-1), few ^{14}C samples were found that can be confidently assumed to provide a detailed or plausible chronology for the rate of incision from near 1400 feet elevation down to the modern channel at 1220 feet. Two radiocarbon ages (10,129 and 10,640 YBP) and two OSL ages (12,700 ± 1.1 YBP and 9,500 ± 0.5 YBP) at UHT-8 and UHT-6 at elevations between 1392 and 1395 feet are reasonably compatible with the chronology that assumes the ice retreated from the region around 13,000 YBP. However, all but the youngest of these 4 ages (sand from UHT-8) appear more likely to have been associated with burial by mass wasting and colluvial activity, rather than fluvial processes attributable to ancestral Buttermilk Creek.

Photo 4.24: Sample of varves with thin layer of datable carbon from trench HT17. Yellowish rectangular highlight at upper left indicates location of barely visible black layer.

At an elevation of 1275 feet (trench HT-17), a thin layer of carbon, located within a small lump of glacial varves incorporated in till, has an age of 28,658 YBP, recording an event clearly unrelated to the more recent basin erosional history. This varve sample, seen in Photo 4.24, is probably the result of much older lacustrine sediments deposited during the Cary glacial stage (La Fleur, 1979, 1980) and later reincorporated into the till during a subsequent ice re-advance.

A terrace near elevation 1240 feet (trench HT-7) contained a thin carbon deposit (charcoal from burned wood?) that provided an age of 3,785 YBP (Photo 4.25). This terrace is 40 feet above the modern channel, and this date appears to represent a plausible time when Buttermilk Creek could have eroded to 85 percent of its current depth. This would leave the last 15 percent of incision to have occurred in the approximately 1,800 years remaining prior to reaching the current channel position at the 2300-2500 YBP age representing the minimum time that the modern gradient was reached.

Trench HT-33 at an elevation of 1224 feet, 4 feet above the modern channel, has several ^{14}C sample ages (856, 1,101, 1,225, & 2,128 YBP) , the oldest of which is compatible with other evidence that the channel reached its modern grade more than 2,000 years ago. Samples S1 and S2 with ages of 1,101 and 1,225 YBP were located in sands 0.3 feet above a coarser gravel unit. Samples S3 and S4 were at the sand/gravel contact, both at the same elevation. If the 2,128 YBP sample was preserved sometime during an unknown interval of gravel deposition, and the 856 YBP sample was introduced into the same channel more recently, then this would provide additional support for the channel being near its current grade for at least the past 2,000 years.

The rate of incision near Heinz Creek can be estimated by using the 3,785 YBP sample from trench HT-7 and its position below the estimated level of glacial fill. If the elevation of glacial fill is taken as approximately 1400 feet, based on the preserved topographic relief, the drop in elevation to trench HT-7 is 164 feet. Given the difference in age (13,000 – 3,785 = 9,215 YBP), this implies an average incision rate of 56 years per foot, or 0.0178 feet per year. This incision rate is intermediate between rates estimated for the abandoned meander and Tree Farm (0.013 ft/yr) sites. Using a similar calculation for the remaining incision of 20 feet from HT-7 down to the modern channel, and assuming the channel was at its current elevation by 2300-2500 YBP, the time available for incision is: (3785 – 2500 = 1285 years) and a change in elevation of 20 feet is equivalent to an average incision rate of 64 years per foot, or 0.0.016 feet per year, a rate not greatly different from the rates calculated for the abandoned meander and Tree Farm sites (Table 4.3-1).

Photo 4.25: Discrete charcoal layer (possible burnt log?) excavated from Heinz Creek site trench HT7.

The TCN results of Owen (Appendix M) on the Heinz fan boulders are equivocal. The four oldest TCN boulder ages fall in the time interval when late Wisconsin ice extended southward into Pennsylvania and eastward to Long Island, so cannot be recording true postglacial exposure ages. Their ages are probably the result of complex exposure histories during one or more late glacial events. The youngest age (15.2 ± 1.4 ka) at it lower limit (13.8 ka) comes close to agreeing with the evidence for the last ice advance occurring ca. 13,000 YBP. If correct, this would confirm that the Heinz fan and other similar postglacial landforms began to form in association with the youngest ice advance, and that the Heinz boulder has been continuously exposed at the surface. However, basing this assumption, however appealing, on a single boulder age is probably not scientifically defensible.

4.3.4.3 Tree Farm Terraces

The highest of the nine Tree Farm terraces (trench FT-26, elev. 1,200 ft.) produced several small log samples within a till-like deposit that was initially assumed to record the same glacial advance seen at the abandoned meander site. However, the age range of wood specimens (2,357 to 3,777 YBP) indicated that the location is the site of a landslide at the base of a slope where a failure of the original till buried woody debris long after the last glacial ice retreated. However, the elevation of this landslide and its age provide a minimum limit for the time at which the valley would have to have been eroded down to an elevation of 1200 feet at that location, 60 feet above the modern channel. Based upon the age of the youngest FT-26 trench sample (2,357 YBP), this locality provides further support for the inference that Buttermilk Creek had eroded much of the glacial fill by 2300-2500 years ago. The 1200 foot elevation of trench FT-26 is 69 percent of the distance from the valley margin (1335 ft) down to the modern channel (1140 ft). The 2,357 YBP age at the 1200 foot elevation also makes it unlikely that the OSL date at the abandoned meander point bar (T-3, 3,100 ± 0.3 YBP) is a valid age. Given the modern gradient of 32 feet per mile, and assuming a similar gradient 2,357 to 3,100 years ago, the elevation of the channel near the meander point bar probably would have been 25 to 35 feet lower than its current position at the inferred time.

If one assumes that the landslide at FT-26 is the age of the youngest dated sample (2,357 YBP), and that the landslide occurred due to undercutting by Buttermilk Creek when it was close to the FT-26 elevation (1200 ft), it is possible to estimate the rate of downcutting from the valley edge (1335 ft) down to the F-26 location. A 135-foot change in elevation over the difference in ages (13,000 – 2,357 = 10,643 years) gives an average incision rate of 78 years per foot or 0.013 feet per year. This is very close to the estimated range of the initial incision rate indicated for the abandoned meander site. The only other consistent series of ^{14}C ages on the remaining lower terraces at the Tree Farm site are the three similar ^{14}C dates (1,828, 1,828, 1,857 YBP) at trench FT-8 (elevation 1175 feet), 35 feet above the modern channel. Given that several other localities have ages near 2,000 YBP within 10 feet of the modern channel, it seems unlikely that ages in this range are an accurate measure of the channel elevation at the Tree Farm site. It seems more likely that these dates represent wood and organics that were carried onto the surface by events unrelated to the Buttermilk Creek channel, such as falling tree limbs, mass wasting events, or downslope overland flow during severe precipitation events.

4.3.4.4 Old Buttermilk Road to Landslide Reach of Buttermilk Creek

The multiple ^{14}C and OSL ages at sites 1 and 2 immediately downstream from the old Buttermilk Road bridge (Photos 4.15 and 4.19) support the inference that the position of the Buttermilk channel was close to its present elevation by approximately 2,000 YBP. Two logs (1,796 and 1,134 YBP) and several younger wood fragments dating from 853 to 1,305 YBP support this assumption, in addition to the two OSL ages of 2500 ± 0.2 YBP and 1330 ± 0.12 YBP. These OSL ages are presumed to be more reliable than those at the abandoned meander terraces T-1, T-3, and T-7 because of the more preferable grain size distribution of the sandy sediments collected within the lower Buttermilk terrace. However it is clear that the range of younger ages would have to be explained as a result of the continuing flooding and reworking of the lowest terrace deposits from circa 2300-2500 YBP to the present as the channel underwent lateral migration and concurrent reworking of the fluvial materials.

Calculating the rate of incision for this site provides the following average rate. The age difference (13,000 – 2500 = 10,500 years) for the elevation change of 125 feet gives an average incision rate of 84 years per foot or 0.012 feet per year, similar to the rates calculated for the Tree Farm and the initial rate at the abandoned meander, as well as one of the Heinz Creek estimates. Overall, the average incision rates estimated for the four study sites have a surprisingly narrow range, the majority falling between 0.011 and 0.018 feet per year (Table 4.3-1), with the possible exception of the last phase of incision at the abandoned meander. However, if one uses the 6764 age rather than the 5632 age to begin the last incision increment (5632 sample had no bark; reworked?) at the abandoned meander, the incision rate there drops to 0.018 ft/yr.

4.3.5 Conclusions Regarding Chronology

The results of this study have provided a much improved and well documented late glacial chronology, as well as a reasonable estimate for when the Buttermilk Creek gradient probably became established at close to its present configuration at the WNYNSC. The new glacial chronology requires a significant revision in our understanding of the late glacial events throughout western New York, especially between Lake Erie and the Genesee Valley, as currently described in the existing published literature and less formal fieldtrip guidebooks (LaFleur, 1979, 1980; Gordon et al., 2013). Several precise ^{14}C dates for the age of till at the so-called "Kent" moraine site (Simmons Road) and in the shallow tills at the abandoned meander depression require a reevaluation of the nomenclature that has long been in use, terms such as Lavery and Kent till. The stratigraphic units and old mapping studies may still be relevant and reasonably accurate, but the actual time frame for the associated events is obviously in need of revision (Appendix N).

The last glacial event in the region is now reasonably documented as having occurred approximately 13,000 calendar years before present, which is considerably younger than previously assumed. The age of this relatively young glacial event is consistent with the improved radiocarbon chronology for the well-known "post-Two Creeks" glacial advance in the upper Midwest (Mickelson et al., 2007), as well as by supporting evidence for a similar glacial advance in the Genesee Valley, 53 miles (85 km) northeast of the WNYNSC. This may simply be a previously unrecognized ice advance that overrode some of the older glacial landforms without significantly changing the basin morphology (Sharpe and Russell, 2016). The limited OSL data concur with the radiocarbon results for the glacial event at one key site.

The circa 13,000 YBP wood ages obtained at multiple locations here in New York and in the upper Midwest (Mickelson, 2008) are within the established range of the abrupt cooling interval in late glacial time known as the Younger Dryas event (Carlson, 2013). This late glacial event is estimated at between 600 and 1200 years in length, but has a slight ^{14}C calibration uncertainty (Muscheler, 2008). However, the magnitude of the uncertainty is well within the range of ages on the similarly dated 12 wood samples we have collected from tills in the Buttermilk Creek basin. In any event, wood samples buried by a glacial advance must always be somewhat older than the age of the advance itself, due to the time elapsed for the growth of the trees, and the possibility that slightly older dead trees lying on the surface could be incorporated in the subglacial debris. However, the more restrictive bone and collagen AMS ages on the Genesee Valley peccary skeleton (13,002 and 13,043 YBP; Young, personal fieldwork), and its demonstrable association with an active ice front (moraine crest and associated quicksand; Young and Scatterday, 1978; Young, 2006) indicate that the best estimate for the timing of the Younger Dryas-related ice advance in western New York is most likely very close to 13,000 YBP (Young and Owen, 2017).

Photo 4.26: Bedrock knickpoint in Buttermilk Creek below Tree Farm site, as viewed looking upstream.

Another major improvement resulting from the current study is the demonstration that ancestral Buttermilk Creek terrace gravels are readily discernible from glacial outwash and more northerly derived sediments. The major difference in bedrock sources along a north-south profile results in the glacial sediments having a significant proportion of carbonate and red sandstone clasts (sometimes described as "bright" lithologies), in direct contrast with the high percentage of drab sandstones in the fluvial gravels derived from bedrock cropping out in the southerly headwaters of Buttermilk Creek. Numerous pebble counts during early phases of the study permitted the clear differentiation of fluvial terrace deposits, as compared with glacial outwash gravels and more local alluvial fan deposits.

The revised chronology and estimated incision rates for the development of the Buttermilk Creek basin at the WNYNSC (0.011 to 0.018 ft/yr; possibly as high as 0.026 ft/yr) are generally compatible with those previously described in publications such as Albanese et al. (1983). That review of earlier estimates of erosion rates quotes rates of erosion in the major drainages in the 0.5 to 2.0 feet per 100 years range (0.005 to 0.02 feet per year) for glacial drift. In addition, there is preliminary evidence that the rate of erosion may have slowed significantly during the past 2300-2500 years, as Buttermilk Creek approached its current grade. This may be due, in part, to the resistance of knickpoints, such as the bedrock confined channel a short distance downstream from the Tree Farm site (Photos 4.26, 4.27). This also might imply that valley widening and tributary erosion (headward erosion) are currently more important processes than main channel incision.

Photo 4.27: Same bedrock knickpoint as in Photo 4.26, view of left (west) bank looking downstream.

Table 4.3-1: Buttermilk Creek Incision Rates

FEATURE Location	AGE		ELEVATION (feet)	ORIGINAL SURFACE ELEVATION (feet)	BUTTERMILK CHANNEL ELEVATION (feet)	UPPER INCISION RATE (or total) ft/year	LOWER INCISION RATE ft/year End: 2000 YBP
	^{14}C (Calendar) YBP (1950) Start: 13000 YBP	OSL YBP					
Abandoned meander Channel MT37*	6764		1288	1370	1200	82/6236 = 0.0131	88/4764 = 0.0184
Abandoned Meander Channel MT38*	5632		1290	1370	1200	80/7368 = 0.0108	90/3632 = 0.0248
Abandoned Meander channel	9495		1287	1370	1200	83/3505 = 0.0236	87/5295 = 0.0164
Abandoned Meander channel		8400 ± 900	1291	1370	1200	79/4600 = 0.0171	91/6400 = 0.0142
Terrace T7*		10,600 ± 1000	1299	1370	1200	71/2400 = 0.0295	99/8600 = 0.0115
Surface? UHT-6*	10129		1400	1400	1220	180/8129 = 0.0221	

Table 4.3-1: Buttermilk Creek Incision Rates

Surface? UTH-8*		9500 ± 500	1391	1400	1220	171/7500 = 0.0228	
Terrace HT-7*	3785		1236	1400	1216	164/9215 = 0.0178	20/1785 = 0.0112
Landslide FT-26* (Minimal incision to landslide)	Ca. 3750 2357 (youngest date)		1200 1200	1335 1335	1137	135/9250 = 0.0145 135/10643 = 0.0126	

* Indicates trench no.
Incision rates based on presumed best ages (or alternative ages) of nine dated surfaces. Incision rates are measured from the original (estimated) postglacial surface down to the dated surface (next to last column), and/or from the dated surface down to the modern Buttermilk Creek (last column), using both ^{14}C and OSL data. Assumption: Erosion started ca. 13,000 YBP and ended when the modern channel reached current grade ca. 2000 YBP.
Incision rates are closely grouped with an average of: 0.016 ± 0.008 feet /year with an overall range of 0.0108 to 0.0248 feet/year. If one includes the total erosion at the buried stump in the channel below the Tree Farm site (170 ft/11040 years) the total rate there is: 0.0153 feet/year. There is a slight tendency for the rates to be faster during the initial time intervals and to slow through time, but the data are probably too limited to realistically calculate the changing rate through time with any degree of confidence.

4.4DEPTH TO BEDROCK

Depth to bedrock is in excess of 200 feet below most of the South Plateau including the lagoons, the SDA and part of the NDA, and about a hundred feet depth below most other facilities. Thus bedrock is mostly below the stream base-level of the Franks watershed. The report by Zadins (1997), and its underlying documents that treat depth information (LaSala, 1968; Miller and Staubitz, 1985; Prudic, 1986; U.S. Department of Energy, 1996; Vaughan, 1994; West Valley Nuclear Services Company, 1993; and Wilson, 1990), provide key understanding of depth to bedrock for analysis of erodibility and modeling Franks-Erdman landscape development. Zadins' Figures 1, 2, 6, and 7 are especially helpful for evaluating erodibility and depth to rock. Projecting recent 2,300 years of incision at rates of 0.002 or 0.003 feet/year will only lower the Franks base level (Franks-Buttermilk juncture) into its sediment substrate 20 to 30 feet in 10,000 years.

Bedrock outcrops on the west and east sides of Buttermilk valley are shown on maps by LaFleur (1979), Prudic (1986, Figure 5; reproduced in Zadins, 1997, Figure 1), and Vaughan (1994; reproduced in Zadins, 1997, Figure 2). The Prudic 1986 map is based at least in part on a map by Albanese (1981) which was based on seismic sections and drill data from New York State Public Works (1962). These maps will aid modeling by identifying the bedrock-sediment contacts where stream beds to the west are rock incised and beds to the east of the contacts are sediment incised. The contact between bedrock and sediment will dip as per illustrations such as Zadins (1997) Figure 7.

LaFleur (1979) mapped several bedrock outcrops on his Plate 7 and also mapped "thin stony till over rock" on the west side of facilities, approximately along Rock Springs Road. The east side of the thin stony till in contact with other sediments can be used along with drill data to define the location and elevation (depth) of the sediment-bedrock contact for modeling purposes better than only using a few scattered bedrock outcrops. LaFleur's mapped eastern boundary of "thin stony till over rock" partly connects bedrock outcrops. These stony tills are found throughout southwestern New York and are less than 10 feet in thickness over bedrock. Sometimes referred to as local "lodgement" tills, they contain no exotic rocks, only local shales and sandstones. In Study 1, this type of till was found in Tree Farm trench-13, where its presence indicated about 25 feet of bedrock was incised as lower Buttermilk Creek reached its current level.

4.5 ELEVATION OF KENT-LAVERY INTERFACE IN THE SUBSURFACE

The elevations of the Lavery/Kent tills interface vary from approximately 1260 feet in the north facilities area to about 1300 feet in the SDA area and southerly (Zadins, 1997, Figures 6 and 7). The interface is formed by the intervening Kent recessional deltaic sands and lacustrine silts-clays that thicken eastward toward the Buttermilk valley center. LaFleur (1979, Plate 7) mapped Lavery-Kent contacts at eastward-projecting cliff faces along the west valley wall of Buttermilk at six locations; one contact was traceable for 1,000 feet laterally. He had sufficient confidence to project those contacts further by use of dashed lines, north-south, along the length of the valley wall for about a mile adjacent to facilities.

Study 1 reconnaissance tested LaFleur's map by examining part of his data at the recent large landslide (left [west] bank of Buttermilk opposite Heinz Creek) and by examining gulley exposures at five locations in the west bank of Buttermilk, and two locations in the east side of Buttermilk valley. Although Study 1 gulley exposures were often more covered by vegetation or debris compared to the promontory cliff outcrops used by LaFleur, there were exposures of Kent recessional deposits at 4 of 5 gullies examined in the west Buttermilk valley wall and one of the two east side gullies. Results of Study 1 gulley-recon support Zadins (1997) Figure-7 and LaFleur (1979) Plate-7, and indicate the base of Lavery till and top of Kent recessional deposits occurs at approximately 1300-feet elevation on both sides of Buttermilk valley in the region of Franks Creek and the SDA. Depending on the outcomes of Study 2 and Study 3 materials evaluations, modeling may benefit from using an erosion-resistance interface based on an elevation of 1,300 feet, or on Torvane strengths.

4.6 RELATIVE EROSION RESISTANCE

While we know of no published studies of relative erosion resistance, Study 1 can share information that frames the issue for the agencies and for modeling.

Zadins (1997) citing Rickard (1975) noted that bedrock near the facilities consisted of interbedded shale and sandstone of the Canadaway and Conneaut Groups. Tesmer (1975) also traced these bedrock groups into northern Cattaraugus County. The sub-horizontal Gowanda Shale and higher units are thought to form bedrock in the mid to lower Buttermilk watershed and adjacent

Cattaraugus and Connoisarauley watersheds and their buried valley walls. These units range from more than 90 percent shale with a few percent sandstone (or siltstone) to higher quantities of sandstone in higher stratigraphic positions such as hillsides. Limestones and dolostones do not occur in these units (Tesmer, 1975; Gordon Baird, personal communication, 2016; Gary Lash, personal communication, 2016; Wilson's personal observations, 1968 to present).

Southwestern New York lacks the thick resistant layers such as the Lockport Dolostone that makes-up the Niagara Escarpment and Onondaga Limestone that makes the Onondaga Escarpment, both traceable across New York, adjacent areas, and across Michigan. The Niagara Escarpment lies 11 km north of Niagara Falls and the Falls are estimated to have receded those 11 km in 11,000 years; the resulting 1m annual headward-erosion rate matches the modern rate from studies of maps and photos of the last few hundred years. From these data it will take another 11,000 years before Niagara Falls reaches Lake Erie, another 11 km.

While southwestern New York has several sandstone-controlled waterfalls such as Connoisarauley, Arkwright, Shumla and Laona Falls, precisely-dated positions of retreat are not available to measure their retreat-rates as we can for Niagara Falls. That the sandstones forming these waterfalls have a pronounced resistance to erosion is confirmed by their effect on up-gradient stream profiles (flattening). From revisits to these sandstone-capped waterfalls and study of historic photos, these falls are retreating at less than a foot per year.

In contrast to a small number of 10- or 20-foot-high, sandstone-capped waterfalls in southwestern New York, there are places where shale is equivalent to till in profile relief. These relatively flat vertical profiles occur where shale is especially fissile and weathered below or next to till, or where shale is broken and deformed below or next to till from previous glacier over-riding. In some of these instances no profile variation is seen. Thus the erosion resistances of the shale and sediment (till) can be relatively equal.

A case study of shale erodibility adjacent to till and sandstone was made along Heinz Creek for the current report. LaFleur (1979) mapped a bedrock outcrop in a portion of Heinz Creek. Wilson and Butzer investigated this outcrop and photographed the shale streambed (Photo 4.28). The lower portion of this streambed outcrop changes with flood events while the upper portion is relatively static. The lower portion of streambed outcrop has shale with few, very thin sandstone beds while the upper section has a 7-foot waterfall topped with an approximately 0.5 to 1.0 foot sandstone cap-rock.

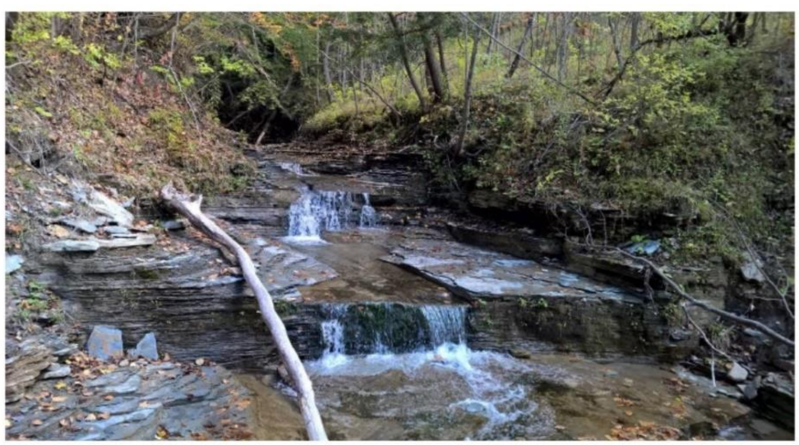


Photo 4.28: Waterfalls located on Heinz Creek upstream of the bedrock-sediment contact.

Figure 4.6-1 presents a side-by-side comparison of the 2015 LiDAR channel contours versus the 2010 LiDAR channel contours for a portion of Heinz Creek. The base map is the 2015 LiDAR contour map with an inset strip map that reproduces the 2010 LiDAR channel contours at the same scale. The apparent offset of the 2010 right-margin compared to the 2015 right-margin in Figure 4.6-1 is lost when the 2010 inset is laid directly over the corresponding area of the 2015 map. The lettered knickpoints (waterfalls) can be compared directly. Point A is the 7-foot waterfall with sandstone cap, which supplies a point of geographic reference both on the LiDAR images and in the field setting. Points C, D, and E are small knickpoints, observable in photography, composed of shale joints with or without very-thin sandstone caps. The 2010 LiDAR was collected after the 2009 flood and the 2015 LiDAR followed the 2015 flood. Photo 4.28 also followed the 2015 flood. The "R" in the LiDAR map is where shale bedrock is lost from view westward, below the streambed gravel. No large shale blocks were deposited downstream in the Heinz channel in the flood of 2015, but erosion is evident at points B, C and D, while not at A.

Other observations of lower Heinz Creek bedrock exposures are available by comparing published maps. LaFleur mapped one continuous bedrock exposure (1979) but Prudic's map from 1986 (Figure 1 in Zadins, 1997) shows a second streambed exposure of bedrock a short distance downstream. Next, the Study 1 field-work for 2015 found just one bedrock reach of stream bed. Thus sometimes parts of the Heinz Creek bed is scoured of gravel and sometimes not, sometimes bedrock is gravel covered and sometimes not.

Other types of available data are the seismic velocities from the 1962 seismic sections (New York State Public Works, 1962). The seismic velocity-calculated cross-sections show use of velocities from 5,400 to 5,800 feet/sec. for Buttermilk-valley sediment fills and 6,300 to 6,900 feet/sec. for thin accumulations of sediment or weathered or disturbed bedrock along valley walls and draped over hills (typically tills). The available seismic sections are two layer cases with depths to bedrock shown, but bedrock velocities used in depth calculations are not presented. Bedrock velocities for SW New York Devonian shales and sandstone-shale mixes (Gowanda Shale and adjacent stratigraphic units) are known from several sources such as petroleum exploration, landfill evaluation, and various university studies. The range of bedrock velocities can overlap with till and firm clay, supporting the notion that till strength and erosion resistance may at times be similar to shale bedrock but is usually less.

Another type of data that could be used to further evaluate resistance to erosion is Standard Penetration Test (STP) results from split-spoon sampling during test borings (drilling or augering). This information could be used to compare sediment vs. bedrock character and well as comparing different kinds of sediments. Bedrock is usually defined as refusal of the split-spoon sampling device in SPT analysis, and confirmed by core drilling, but sometimes (rarely) glacial till will result in refusal (Kulhawy and Wilson, unpublished, confidential data, ca 1974).

A different aspect of erosion resistance is stream bed armoring. This topic was discussed previously in internal reporting to the EWG and in correspondence with the Engineered Barriers Group, and in Wilson (2008, Alliance report Appendix-1). To summarize: a) relatively few shale joint blocks are lifted during floods and they typically disintegrate to thumb-nail size chips within one year, rarely two years, due mainly to wetting and drying cycles; b) the largest local sandstone fragments are typically a foot or two in long dimension in local streams (rarely larger in fan deposits or ice contact deposits) and can be transported in less than bank-full flows; such fragments are transported intermittently, frequently, and are ineffective as armors; c) except for Lake Escarpment moraines which are north of Buttermilk, natural sources of large boulders are lacking especially in Lavery till.

In summary, the above comments suggest: 1) that southwestern New York sandstone is much more resistant than shale when sandstone thicknesses exceed 1.0 foot; 2) that sediments vary widely in strength and erosion resistance (Torvane data in Table 4.4-1); 3) that till or dense clay may equal shale in erosion resistance; and 4) that armoring is inconsequential.

4.7 SHEAR-STRENGTH TESTING

As discussed in Section 3.5.4, field Torvane measurements were collected from trench exposures and outcrops to better understand how differences in shear strength may influence modeling of future erosion.

During initial periods of trenching, a Torvane device was used to test whether there would be a significant range of values that could help identify characteristic values for materials having different origins. High values did occur in clay-dominated strata, and low values occurred in sand dominated strata. Additional values were measured as the trenching continued and it was determined that many additional measurements could be obtained inexpensively while trenches were closed at the end of field work in early autumn 2016. Study 1 shear strength data are provided in Appendix H, with a summary presented in Table 4.4-1. While values are given in kg/cm^2, note that a kg/cm^2 is approximately equal to a ton per square foot (TSF).

Sand or gravel strata (Table 4.4-1), regardless of trench location, had shear strengths of 0.00 (zero) to 0.25 kg/cm^2. These results reflect the inability of clean granular materials to resist shear; their strength comes from friction among sliding particles. Sand-silt-clay mixtures had wide variation in strengths from 0.10 to 0.70 kg/cm^2; however, the higher values were associated with strata that were fine-grained mixtures, such as having a clay portion that smeared on fingers. Very clay-rich strata, especially diamicts considered to be glacial tills, had strengths ranging from 0.43 to 1.28 kg/cm^2, with a single instance of 1.64 kg/cm^2. Overall, the strengths ranged across an order of magnitude, with clay tills generally ten-times stronger than sands. The results agree with field observations such as erosion of sand undercutting clay-till blocks in the 2009 storm, leading to translational failures of Lavery till blocks temporarily blocking Buttermilk Creek flow. Gully erosion yielding knickpoints occurs when clay strata overlie sand layers.

Table 4.4-1: Summary of Shear-Strength Measurements

Location	Sand-Gravel	Sand-Silt-Clay	Clay-Diamict	Woody-Peat	Other
		(all measurements in kg/cm^2)			
UHT (22)	0.04 – 0.25		0.43 – 0.94		colluvium 0.34 – 0.62 0.08 – 0.14
HT (60)	0.00 – 0.09	0.10 – 0.50	0.50 – 1.08	0.25 – 0.47	
FT (48)	0.00 – 0.20	0.30 – 0.70	1.10 – 1.30	0.20	

Table 4.4-1: Summary of Shear-Strength Measurements

MT (13)	0.25	0.45	0.73 – 1.20	0.12 – 0.43
40-42 (6)		0.49	0.74 – 1.28	0.14 – 0.21
Log-2 (3)	0.18	0.55	0.58	

Explanation

Locations are: UHT upper Heinz; HT lower Heinz; FT tree farm; MT abandoned meander; 40-42 three trenches numbered 40, 41 and 42 above and to the south of the abandoned meander; Log-2 is the Buttermilk Creek bank exposure designated Log 2. For each location, values in parentheses are the total number of trench-wall strata measured with the Torvane device; e.g. 22 strata in trenches at Upper Heinz.

The values in this table were taken from the spread sheets in the Torvane shear-strength appendix. Approximately 650 measurements were made, 5 each in 130 strata. The appendixes provide the individual measurements, the means of each set of five measurements, descriptive information on each stratum, and photographs of the strata in the trench walls (usually showing individual holes from use of the Torvane). Most strata conditions, and all fine-grained strata conditions, were moist to wet at times of measurements.

The table above was compiled by visually scanning the Appendix spreadsheets and choosing a range of shear-strength means that best represented the strata types. When the table above does not provide a range, there were data available for only one stratum in the category.

In addition, rotational failures of landslides will be expected to be at least partly controlled by clay shear strengths. Some landslide failures should be expected by translation along sand strata, possibly aggravated by erosive seepage. While these relations of erosive or sliding phenomena to strengths are already well-established ideas, the Torvane results underscore the large differences between sand and clay strata strengths that should influence computer modeling of erosion and engineered barriers as responses.

When gully incision encounters sandy materials such as Kent recessional deposits, irregular profiles, increased erosion rates and changes in landslides should be expected. While paired terraces are not obvious in the Buttermilk trunk valley, one or two sets of paired terraces occur in the lower Heinz Creek valley at the approximate level of the Kent recessional deposits. Variation in sediment strengths could account for terraces such as in the Heinz Creek valley upstream of the Heinz fan rather than base-level or climate changes. Thus the great variation in Torvane-measured shear-strengths provides context for computer models and their outcomes.

Organic horizons were also tested; these were best described as woody-peats. Mean values ranged from 0.14 to 0.47 kg/cm^2. Peat strengths are more diverse and stronger than expected, may impart more slip resistance to sliding than expected, but have the disadvantage of low density against stream erosion, and high potential for decay.

Colluvium was available for testing at several upper Heinz Creek trenches. Clay-rich colluvium tested at 0.34 to 0.62 kg/cm^2 (trenches UHT 5, 7, 9, 10) while sandy colluvium tested at 0.08 to 0.14 kg/cm^2 (trenches UHT 1, 2, 4). Colluvium strength values were similar to corresponding values for non-colluvium strata, but relatively low (Table 4.4-1). Shear strength was not a particularly useful method to distinguish colluvium from similar non-colluvial soils. Soil color, structure and other features were more helpful.

4.8 SIGNIFICANCE OF LANDSLIDING

Active and incipient landslides and landslide scarps are abundant all along the hillsides bordering Buttermilk Creek at all scales, from small individual slumps to major landslide scars with multiple rotational slide blocks. LaFleur (1979) hinted at their abundance with the appropriate slope mapping units used on his geologic quadrangle maps (e.g. Figure 3.1-1). However, the abundance of slumps and landslides at all scales cannot be truly appreciated without completing extensive field reconnaissance and LiDAR imagery of the area as was done in this study. The complex morphology of these active slope processes cannot be appreciated on the 20-foot contour USGS topographic maps, but the individual landforms are very apparent on LiDAR hillshade images or when viewing LiDAR-generated 1-foot contour maps.

The hill slopes along Buttermilk Creek in many locations are characterized by a series of small slumps that may form a nearly continuous mass-wasting veneer over much of the surface. The smallest slumps and minor landslides are too numerous to show on a map at any reasonable scale. The importance of these widespread mass wasting processes and their contribution to landscape evolution cannot be overemphasized.

Figures 4.8-1 through 4.8-5 depict representative examples of incipient and active landslides along Buttermilk Creek, with Figure 4.8-1 serving as a location map for the following figures. Figures 4.8-2 through -5 display 4 maps (numbered from north to south) on a LiDAR hillshade base that indicate the approximate positions of the most obvious landslides, both active and presumably inactive at the present time. Although the maps cannot accurately indicate the true number of individual landslides, they do provide a visual approximation of how significant landslide activity is in the Buttermilk Creek drainage basin. Obvious slide scarps that are interpreted solely from the LiDAR hillshade images are indicated by white dashed lines, while features that were clearly visible or inspected in the field are shown as yellow dashed lines. Many of the larger slides are undoubtedly more complex than is suggested by the single lines that serve to mark the approximate locations of the most obvious landslide head scarps.

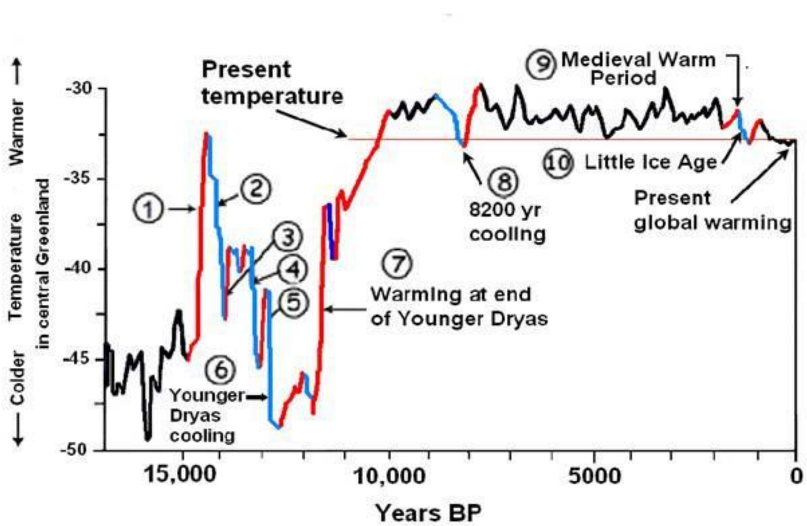
One of the earliest efforts during the current study was the sampling of a number of the flatter slope elements that could have been created by glacial (moraines, kame terraces), fluvial (terraces), or mass wasting (landslides and slumps) processes. This was necessary in order to develop a method to distinguish between glacial and fluvial features, and was accomplished using pebble counts, as described in Section 3.5.3. Landslide activity played a significant role in the analysis of a key trench at the tree farm site. Trench FT-26, chosen for its terrace-like location, first appeared to contain a series of logs embedded in till that might have matched the wood-bearing till section excavated at the depression near the abandoned meander (Pits 1 and 2). However, ^{14}C dates eventually indicated that the buried vertical logs that were sampled represented a much younger landslide (ca. 3700 YBP) that merely had the appearance of a glacial deposit, most likely till remobilized by the mass wasting event. On the positive side, the age of the landslide provided additional evidence of the minimum amount of incision that had to have occurred within the larger Buttermilk Creek valley at that time.

Landsliding has, and will continue to have, enormous significance to terrain development in the Buttermilk Creek watershed. For example, two of the primary processes key to understanding past landscape development, namely Buttermilk Creek base level control, and westerly channel migration, are at least in part influenced by landslides. The "giant" landslide in the east bank of Buttermilk Creek just downstream from the tree farm terraces appears to be influential in base level control, while the active landslide in the west bank opposite the Heinz Creek fan is intimately involved in westward lateral migration of the channel.

4.9 PALEOCLIMATE FACTORS

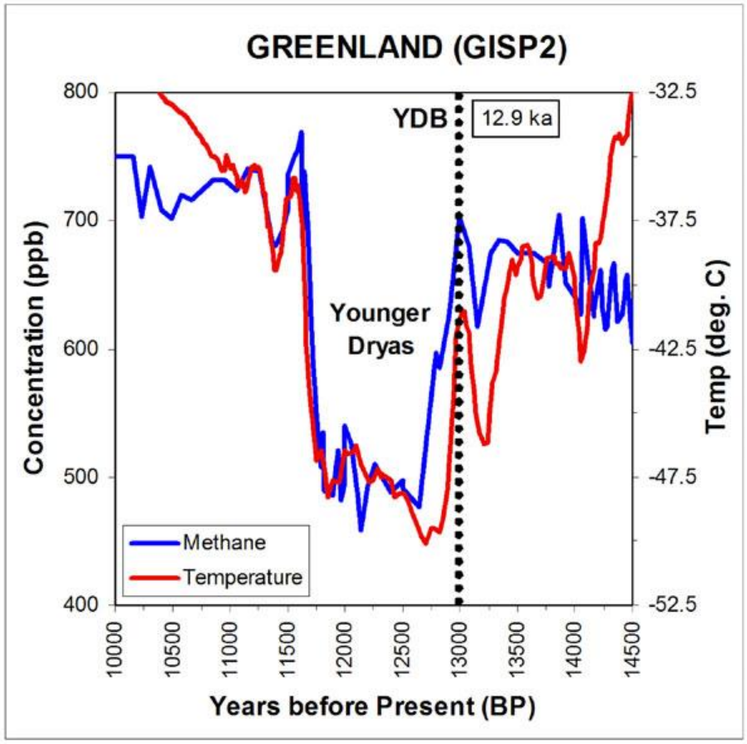
The late glacial climate, as measured by the temperature records from the well-studied Greenland Ice Sheet Project cores (GISP2), deteriorated about 14,500 YBP when continental glaciers began to melt dramatically. There are several signature events that have been directly associated with the northern hemisphere, especially from the North Atlantic Ocean cores and the Laurentide ice sheet chronology. These events are shown on the diagram below compiled by Esterbrook (2008) and appearing in numerous related publications.

The diagram is a graph of the last 15,000 years of northern hemisphere temperature trends recorded in Greenland ice cores (time proceeds forward from left to right in the graph). Blue indicates cooling events, and red indicates warming events. Point 1 is initiation of late glacial warming; 2 is Older Dryas cooling; 3-4 is the Allerod interval, including the Intra-Allerod Cold Period; 5-6 mark the sudden Younger Dryas cooling event (warming at 7), all expressed in calendar years before present (YBP).



A second diagram (following page) shows the changes associated with the Younger Dryas cooling period in greater detail. In this diagram, time proceeds forward from right to left. The diagram shows expanded detail of the types of data developed from the Greenland ice core project (GISP2) for the Younger Dryas cooling event. Note the sharp cooling trend marked as beginning suddenly at 12,900 YBP and the approximately 1100-year length of the event.

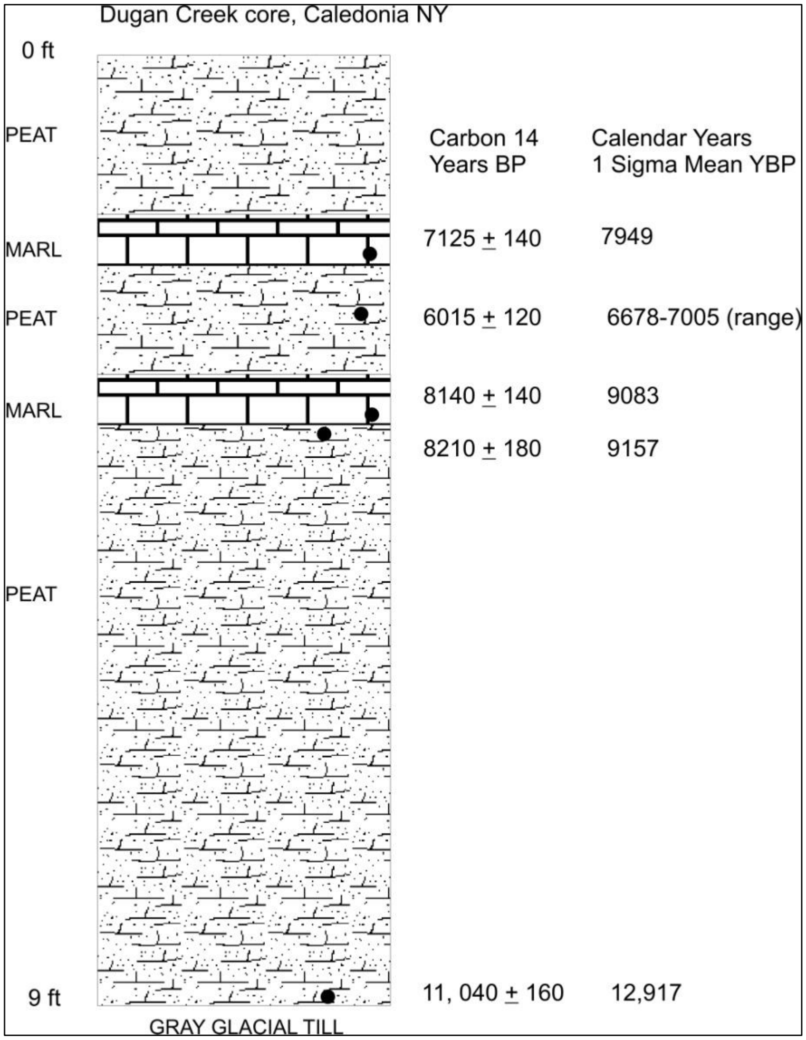
The obvious connection between the major temperature changes shown on the two diagrams (previous page and this page) is the apparent link between the ^{14}C wood ages at West Valley in this report, combined with the comparable age data from the Genesee Valley Avon and peccary sites (Young 2006, 2012, Young and Owen 2017) for the Younger Dryas cooling period. Anomalous oscillations in the local climate around the 8200 YBP cooling event in the Genesee Valley are also recorded in a 9-foot boring in the large glacial outwash channel (Lacey Road at Dugan Creek) near Caledonia, NY (Young, 1988a, b; Mansue et. al, 1991, p. II-30). As shown on the diagram at right, the Caledonia site indicates a period of climatic instability, marl indicative of cooler and wetter conditions (standing surface water, calcareous algae growth), as contrasted with the intervening peat deposits. Note also that the basal age of 12,917 YBP is consistent with a last ice advance and withdrawal coincident with the proposed Younger Dryas ice advance. This assumes that vegetation growth immediately followed ice withdrawal, as is often seen at modern glaciers.



The dates in the stratigraphic diagram (following page) were compiled from a shallow hand cored location in the Dugan Creek outwash channel near Caledonia, NY. Marl dates can be problematic, as they may include calcium carbonate ($CaCO_3$) derived from the local limestone (Onondaga Formation). Climatic oscillation through the 8200 YBP interval is nonetheless indicated.

Ellis et al. (2004) obtained and studied a series of half meter cores from Seneca Lake that record the last 16,000 years of late glacial and postglacial time. They report finding evidence for the Older Dryas cold period at 14.1 ka as indicating a greater ratio of winter to summer precipitation and/or greater lake-effect snow, as well as a shorter growing season. They found that the Intra-Allerod Cold Period (IACP) appears as a precursor of the Younger Dryas cooling event, as it does in the Canadian Maritimes.

They also report that the Younger Dryas event is recorded in the Seneca Lake sediments as extending from 12.9 to 11.6 ka (1300 years). Their data support an abrupt climatic reversal that took less than 140 years at the start of the Younger Dryas. The most often cited explanation for this abrupt cooling is the sudden drainage of the large glacial Lake Agassiz into the North Atlantic.



Their data characterize the Younger Dryas event as having a high amplitude beginning, followed by a more gradual recovery. They define a "post-Younger Dryas climate interval" from 11.3 to 10.1 ka as potentially a regional (more localized) event. The interval from 11.6 to 10 ka (possibly 11.9 to 9.9 ka) is interpreted to be a period of relative climate instability. They suggest that the instability was associated with a large southward expansion and eastward migration of the winter polar front jet stream over the northeastern US. From the Seneca Lake data, Ellis et al. define the end of glaciation and the beginning of Holocene time as occurring at approximately 10.3 ka. From 10.3 to 6.0 their data suggest that relatively low amplitude, but significant climate variations occurred; 9.0 ka also marks the time of maximum Holocene summer insolation as controlled by the Earth's precession and obliquity. Anomalies in the Seneca Lake record occur at 8.2, 7.8, 7.1, and 6.6 ka, with the 8.2 cold event (8.4 to 8.0 ka) being "particularly well defined." The 8.2 ka cooling is also attributed to the discharge of glacial lakes into the North Atlantic. They note that warmer and cooler summers in the northeastern United States have varied during mid Holocene time approximately every two to three centuries. They conclude that the U.S., Greenland, and central Europe experienced synchronous, hemisphere-wide climate variations during the last deglaciation, but that the Younger Dryas event is stronger and more regional (local) in the U.S.

There is enough currently known about westerly winds and mid-continent influences on Lake Erie history and Buttermilk valley climate to offer a balanced understanding of the major climate trends during the Holocene. Holcombe et al. (2003) reviewed late Pleistocene and Holocene history of the

Lake Erie basin. They defined or evaluated influences of glacier withdrawal, isostatic rebound, diversions of inlets to Lake Erie from the upper Great Lakes, and climate changes that at times dried Lake Erie and altered Cattaraugus Creek base level. Holcombe et al. concluded that Lake Erie levels varied greatly during and shortly after glacier withdrawal from the Erie basin. Events included several particularly low levels, however these early low levels of Lake Erie predated Buttermilk glacier recession (ca. 13,000 YBP) and so had no influence on Buttermilk incision.

Lake Erie levels from about 13,000 YPB onward reported in Holcombe et al. (2003 - Figure 9b-upper) are presented in Figure 4.9-1. Also shown in Figure 4.9-1 are two equally plausible graphical incision histories for buttermilk Creek. The derivation of these incision histories are introduced and discussed later as Figure 4.10-4, but are shown in Figure 4.9-1 for comparison with the Lake Erie data.

An explanation of the derivation of this figure follows, followed by a discussion of implications. The graph of Lake Erie levels was taken from Holcombe et al. (2003) Figure 9b-upper, which represents conditions in the eastern basin of Lake Erie. Lake Erie level is displayed as a red line in Figure 4.9-1 (as it was also color-coded in the original Holcombe et al. graphs).

The Holcombe et al. (2003) horizontal axis was originally given in carbon years before present (personal communication with Holcombe, December 6, 2017). In preparing this report's Figure 4.9-1, the Holcombe et al. horizontal axis was recalibrated (stretched) to generally match the calibrated dates of Figure 4.10-1. A precise recalibration of their graph and discussion of dates was not done because it would not have affected analysis or conclusions from this report, but would have necessitated calibration of numerous publications underlying their work. There is enough variation in data quality from their varied information sources and from our data sources that minor fluctuations in lake levels should not be interpreted for our uses. Nevertheless, major attributes are significant as interpreted below.

Holcombe et al. discussed late Pleistocene lake-level fluctuations such as the Ypsilanti low level, however these perturbations occurred prior to Buttermilk valley ice-out and are too early in the lake history to show in the Figure 4.9-1. Likewise, discussions earlier in this section or related to published reviews of late Pleistocene events (e. g., Muller and Calkin, 1993) are mostly irrelevant to Holocene time and not discussed below.

Lastly, the Holcombe et al. graph (their Figure 9b-upper) was right-left reversed and inverted to help compare similarities between lake level and incision graphs in Figure 4.9-1. A non-inverted version of the lake-level graph is shown for comparison in the inset figure (inset to lower left of the figure).

Holcombe et al. interpreted that Holocene levels of Lake Erie were controlled by overall climate warming from about 10,000 to 6,000 YBP with especially high evaporation rates from about 9,000 to 6,000 YBP. They concluded that the Erie basin operated as a hydraulically closed basin (no outlet) from about 10,300 YBP carbon years or about 11,000-plus YBP calendar years to about 5,400 YBP carbon years or 6,000 calendar years and lake level rose, starting 18 meters below current level (this variation should not be taken as a Cattaraugus Creek base level change, as discussed further in a later paragraph below). Holcombe et al. also cited Lake Winnipeg as a closed basin due to dry mid-continent climate during the same time frame as the Lake Erie aridity.

Between roughly 6,000 and 4,000 YBP the Erie level curve was influenced by variability in disbursement of upper Great Lakes water among several upper-lakes outlets (Chicago, North Bay, and Port Huron). These variations of inflows to Lake Erie were sometimes insufficient to overcome evaporative lake losses, and minor Erie level changes occurred.

The Holcombe et al. findings impact the understanding of Buttermilk valley history in two ways. First, Cattaraugus Creek base level dropped for several thousand years during early to mid-Holocene. Second, there was climate change (increased aridity) across the mid-continent that included the eastern Erie basin, and apparently reached central New York as well (previous discussion of Ellis et al., 2004, and related information).

Regarding Cattaraugus Creek base level change in response to Lake Erie level change, that change is insufficient to affect the Buttermilk drainage system. The Cattaraugus base level change is a change relative to the historic lake level curve, not a change relative to modern lake level. Relative to the vertical axis of the Figure 4.9-1 graph, lake level rose several meters after Cattaraugus-Buttermilk ice-out, then declined about 3 meters and stabilized in the general time frame of approximately 10,000 to 6,000 YBP, and then rose abruptly by approximately 11 meters. The lake level curve shows a few meters variation between roughly 6,000 and 3,000 YBP and flattening from about 3,000 or 2,000 YBP to present. The Cattaraugus base level history is primarily a history of aggradation at the mouth measured as about one or two meters per thousand years interspersed with a period of aridity yielding Cattaraugus incision at the mouth of about 3 meters over 4,000 or 5,000 years in early to mid-Holocene. Base level incision at the mouth ended with a very abrupt aggradation of about 11 meters (35 feet) at roughly 6,000 YBP. While it is tempting to translate these changes at the mouth of Cattaraugus creek directly into causative agents for Cattaraugus-Buttermilk long-profile responses, such responses have a negligible probability of being transferred 30 to 60 miles (50 to 100 kilometers) upstream. The lower dozen miles of the Cattaraugus were likely more influenced by lake level changes.

In contrast to base level changes, the major Holocene climate changes supported by Holcombe et al., from more humid to more arid and back to more humid, cover the entire Cattaraugus-Buttermilk watersheds. The climate changes envisioned for the Erie basin, and westward and eastward, are not envisioned as extremes (jungles to deserts to jungles) The warmer period (roughly 10,000 to 6,000 YBP) was mild and roughly coincident with, or prior to, Buttermilk-erosion equilibrium (watershed sediment input equaled sediment yield) for about 4,000 years. There was less runoff during this mildly arid period and Buttermilk incision ceased. A factor contributing to reduced erosion may have been slowed or reduced mass movements due to drying. In conclusion, the major inflection points in Buttermilk incision history (roughly 10,000 to 6,000 YBP) in Figure 4.9-1 correlate with climate changes, with mildly warm and dry conditions leading to reduced incision under a likely continuous tree canopy and other vegetative soil protection.

4.10 SUMMARY OF BUTTERMILK CREEK INCISION THROUGH TIME AND IMPLIED EROSION RATES

4.10.1 Buttermilk Creek Incision

Buttermilk Creek incised into the landscape of its watershed after glacier retreat, beginning about 13,000 YBP. This date comes from analysis of C-14 dates from the southernmost Simmons Road (Kent end moraine) site with respect to glacier withdrawal discussed in Section 4.2.2. In addition, the C-14 and OSL dates at the abandoned meander and the OSL date at upper-Heinz confirm the glacier withdrawal history. At 13,000 YBP the old Buttermilk valley floor consisted of irregular topography formed by approximately 30-feet of ice-contact sediments between elevations 1335 to 1365 feet near the tree farm area, elevations 1340 to 1370 feet in the abandoned meander and Heinz areas, and elevations 1350 to 1380 feet in the area of the dated logs in the Buttermilk Creek cut-bank (Figure 4.10-1). A longitudinally-continuous terrace associated with these deposits and occupying most of the valley floor occurs from 1335 or 1340-feet in the north at the low end of Buttermilk valley and grades southward to 1350-feet at the sites of the logs dated from Buttermilk cut banks. At that time (13,000 YBP), the Cattaraugus Creek and Buttermilk Creek valley floors were controlled by the ice-contact deposits and outwash at approximately elevations 1340 to 1360 feet in the Cattaraugus valley (Cattaraugus and Buttermilk terraces join at about 1335-1340 feet). The elevations of the old valley floors (now terraces) were likely a result of Cattaraugus Creek incision encountering top-of-bedrock at approximately elevation 1320 feet in the Zoar Valley to the west, near Gowanda, New York. The extensive valley-centered terraces at about 1335-1340 feet elevation record an integrated buttermilk Creek trunk stream reaching Cattaraugus Creek.

The first terrace (elevation 1295-1300 feet) below the old valley floor (1335-1340 feet) at the confluence of Cattaraugus and Buttermilk Creeks is likely controlled by erosion resistant sandstone near the confluence or westward. There is a 14-foot waterfall topping at 1274-feet in the west slope of Buttermilk valley across from Tree Farm; this sandstone might have been a base-level control for the abandoned meander, but climate change discussed in section 4.9 accounts better for the several thousand-year formation of the abandoned meander. Also, when stream gradient is considered the terraces above the abandoned meander are more in elevation alignment with the Cattaraugus-Buttermilk 1295-1300 terrace. The 1274-foot sandstone unit may be the same as the unit that forms Connoisarauley Falls near the confluence of Connoisarauley and Cattaraugus Creeks downstream to the west of Buttermilk Creek. While resistant strata control of terracing in response to base level was active and significant, the maintenance of elevation for thousands of years was likely from climate conditions as discussed in the preceding paleoclimate section, but base-level control from sandstone at 1274-feet could assist terrace development.

The outlet of Buttermilk Creek into the Cattaraugus valley has only two prominent terraces, at about elevations 1340-feet and 1295-feet. In contrast, the Buttermilk Creek reach at the Tree Farm area just upstream from the outlet area has approximately ten terraces (Figure 3.4-3). A significant landslide feature is present in the east bank of Buttermilk Creek between these two locations (Figure 3.1-1). This large landslide is referred to in this report as the “giant slide.” This multi-scarp rotational landslide is an order of magnitude larger than the recently re-activated landslide in the west bank of Buttermilk Creek that temporarily impeded flow in Buttermilk Creek upstream at the Heinz Creek confluence during the 2009 flood. The existence of a flight of ten separate terraces upstream of the giant slide, versus only two terrace elevations downstream of the slide, is strong evidence that repeated re-activation of the giant slide created an episodic series of temporary dams in Buttermilk Creek at the giant slide location. Such episodic periods of slide re-activation might have imposed episodic base-level controls for upstream reaches of Buttermilk Creek, including the tributary Franks Creek watershed.

The change in number of terraces from two terraces downstream of the giant slide to ten terraces upstream of the giant slide evidences temporary landslide control of fluvial base level. The soil plateaus that form the initial postglacial valley floor are paired surfaces, whereas the fluvial terraces incised below the old valley floor are not (although the terrace record is incomplete for opposite walls). Paired aggradational terraces that might result from landslide blockage raising fluvial base level have not been identified, but in a drainage system of incising meanders paired terraces are not anticipated. Unpaired terraces are more likely in a situation of incising meanders; incising meanders just slip down one side of the interfluve. The evidence for giant slide causing temporary but responsive base-level changes is powerful.

Below the old valley floor are: (a) terraces and channels from approximately elevations 1335 to 1292 feet at the abandoned meander area; (b) Heinz fan apex above elevation 1280 feet and fan and terrace remnants from elevation 1280 feet to the modern Buttermilk Creek at elevations of 1217 to 1235 feet (modern creek level) in the Heinz area; and (c) terraces from elevation 1198 feet to the modern creek level at elevation 1137 feet.

The highest postglacial terraces are on the west side of the valley, and intermediate to low terraces characterize the east side of the valley. The incised portion of the valley below the old valley floor has a top width of approximately 1,200 to 1,500 feet. Buttermilk Creek eroded laterally several hundred feet while it eroded vertically only 150 feet.

Figure 4.10-1 shows the top of the old valley floor in olive green shades, incised valley walls in deep green, and modern floodplain or lowlands in ivory or very light green. Elevations in white boxes are approximate lowest levels of the old valley floor; S for stump, M for abandoned meander, L for logs, and numbers for cited trenches. Related information is given in Tables 4.2-2 and 4.2-4. Figure 4.10-2 is geologic cross section A-A' at the location indicated on Figure 4.10-1. Figure 4.10-3 is a graphical depiction of a longitudinal cross-section constructed from the above-referenced information. The numbers indicated on the longitudinal section are age dates in calendar YPB.

Table 4.10-1 shows key reference points that provide the basis for interpreting Buttermilk Creek historical incision.

Table 4.10-1: Incision Reference Points

<u>Explanation</u>: points in space are given for plotting or computing incision history of Buttermilk Creek; location is the common name used in field work and reporting for sites; distance is measured from the Log #1 site south-to-north; the first elevation is nearby Buttermilk Creek at each location; the second elevation is for the age-sample site at the location; the height is above the creek (elevation 2 minus elevation 1); age is C-14 calendar years before present (or OSL date as noted); terrace numbers increase downward, #7 lowest at Heinz (#6 and 7 are floodplain) and # 10 lowest at Tree Farm (#9 and 10 floodplain); southerly moraine date of 13,100 YBP is used to estimate old valley floor at time of glacier withdrawal (approx. 1340 elevation in central to northern Buttermilk valley).

Location	**Distance** Ft.	**Elevation** Ft.	**Elevation** Ft.	**Height** Ft.	**Age** years	**Comments**
Log #1	0	1250	1256	6	1796	base of sandy oxbow silts
Log #2	180	1250	1256	6	1305, 1134 933, 853	[OSL 1240, OSL 452] wood for C-14, sand OSL
Heinz UHT-6		3900	1235	1402	167	13,000 estimated from So. Moraine site
Heinz "E"	3900	1235	1395	160	12,700	OSL date in fine-med. Sand
Heinz GPR-30	4250	1225	1230	5	120	two oldest sycamore trees
Heinz HT-33	4400	1221	1228	7	2128	terrace-6 (high floodplain)
Heinz HT-24	4700	1219	1223	4	135	date estimated from rail-road coal at depth 2.5 feet in wall of trench HT-24
Heinz HT-7	5000	1217	1242	25	3785	terrace-3 burnt wood sheet
Meander	8500	1192	1340	148	13,000	estimated from So. Moraine site
Meand-MT-33	8500	1192	1296	104	6000	meander is abandoned
Franks Cr.	11000	1185	1340	155	13000	estimated from So. Moraine site
Tree Farm FT26	18500	1137	1201	64	3785	as discussed in text
Tree Farm FT22	18500	1137	1153	16	1653	terrace #9
" " FT20	"	"	1152	15	1165	"
" " FT18	"	"	1150	13	1040	"
Stump	19500	1133	1135	2	1911	stump in active gravel bar

4.10.2 Major Processes and Ages Related to Buttermilk Longitudinal Section: 13,000-3,785 YBP

Although Buttermilk likely oscillated laterally it was apparently laterally stable at the abandoned meander area between approximately 13,000 and 6,000 YBP as indicated by various dates, such as at approximately 9,000 and 6,000 years (Figure 4.10-3). Older dates, such as OSL 17,000 or 15,000, are from Buttermilk erosion or modern gullies exposing sediments between Kent and Lavery tills or from sediments from Lavery advance. Buttermilk began lowering toward its modern gradient ca. 13,000 YBP; gully heads advanced as suggested by Figures 4.2-5 through 4.2-7, the likely small amount of glacial rebound was countered by incision, and the volume of erosion was potentially greater in this early phase. Buttermilk incision may have been influenced by dry climate impacts from several thousand years (ca. 10,000 to 6,000 YBP).

The process of lateral erosion of a valley is complicated by incision with remaining interfluves. Those interfluves may restrict meander growth. The results of this interaction can be seen at the abandoned meander for Buttermilk Creek and in modern times at a similar-size feature on Chautauqua Creek, to the west. From observations made during its last 45 years before breakthrough, the Chautauqua incised-meander interfluve (about 50 feet vertical) likely took millennia to cut downward and centuries to breakthrough laterally.

For the Heinz alluvial fan to begin to form its apex at elevation 1280 feet on the east wall of Buttermilk valley, its source gully had to first cut down to that level and the Buttermilk valley be incised and widened to that level. Not far below the Heinz alluvial fan apex there are Buttermilk Creek terraces on the east valley wall of Buttermilk valley. The third Buttermilk terrace below the fan apex contains burnt wood as a several-millimeter-thick charcoal deposit retaining its wood structure in a rectangular pattern. This delicate material was in trench HT-7 at depth 2.5 feet in a wet, fine-grained Buttermilk-channel fill, about 25 feet above modern Buttermilk Creek. The charcoal was 14C dated at calendar 3785 YBP and its position is shown in the longitudinal section of Figure 4.6-3. Comparison of the abandoned meander and Heinz terrace dates indicates a period of relatively rapid erosion of a large volume of Lavery or older sediments between 6,000 and 3,785 YBP.

4.10.3 Processes and Ages from 3,785 YBP to Modern

Several ^{14}C dates define rates of landscape development in the last 2,300 to 2,500 years (Figures 4.10-1 and 4.10-3, Tables 4.2-2 and 4.2-4). From north to south: (a) stump in the modern flood plain gravel dated at 1,911 YBP; (b) sequence of terraces at Tree Farm with terrace 9A trench FT22 at 1,653 YBP, between 9A (higher) and 9B (lower) trench FT20 at 1,165 YBP, and terrace 9B trench FT18 at 1,040 YBP; (c) vertical section at Heinz trench HT33 in the upper floodplain terrace 6 (similar position to terrace 9 at Tree Farm relative to elevation of modern Buttermilk) contained four dates, from lowest to highest in trench wall: 2,128, 856, 1,225, and 1,101; and at (d) logs in Buttermilk cut-bank dated at 1,796 and 1,305 YBP. While all of these dates have uncertainty regarding potential reworking, such as the 856 YBP date at HT33 being out of sequence or the stump being in an active point-bar gravel following a major flood, the overall sequencing and spread of locations within 13 feet or less of the modern Buttermilk channel supports a conclusion that the modern channel has been close to its current elevation for about 2,000 years.

Other evidence also leads to the conclusion that modern Buttermilk is currently eroding slowly. The vegetative assemblage near the base of the Heinz fan is dominated by sycamore trees in the floodplain ecosystem. Through tree coring and ring counts the oldest sycamores are estimated to be more than 120 years old. Another kind of evidence was found at Heinz trench HT24 in lower floodplain deposits (terrace 7). At depth 2.5 feet the strata contained coal fragments for the nearby railroad. The rail line has not been coal-fired for about a century and a date of 135 YBP was placed on Figure 4.10-3.

4.10.4 Incision Rates through Time

Buttermilk Creek incision rates may have initially been moderate during the early Holocene between approximately 13,000 and 6,000 YBP. The incision rate may have stabilized during the middle to late Holocene between approximately 8,500 and 6,764 or 5,632 YBP, and then appears to have increased during the last approximately 2300-2500 years. Data points are presented graphically in Figure 4.10-4. This figure presents two equally plausible interpolations of the age data. Both interpolations suggest an initial period of downcutting, followed by an intermediate period of apparent leveling-off of the incision rate, followed by renewed downcutting, finally followed by a dramatic slowing of the incision rate in the last approximately 2300-2500 years. This pattern is consistent with the estimated average incision rates shown in Table 4.10-2 on the following page.

Table 4.10-2: Buttermilk Creek Incision Rates

FEATURE	SAMPLE AGE		ELEVATION	MODERN CHANNEL ELEVATION	INCISION RATE (ft./year)		
	^{14}C	OSL			UPPER INCREMENT(1)		LOWER INCREMENT(2)
	Calendar YBP (1950)	(YBP)	ft. (MSL)	ft. (MSL)	Orig. Surface 1370' El.	Orig. Surface 1340' El.	
Abandoned Meander Channel MT37*	6764		1288	1200	0.0131	0.0083	0.0185
Abandoned Meander Channel MT38*	5632		1290	1200	0.0109	0.0068	0.0248
Abandoned Meander Channel MT34*	9495		1287	1200	0.0237	0.0151	0.0116
Abandoned Meander Channel MT36*		8400 ±900	1291	1200	0.0172	0.0107	0.0142
Terrace T7*		10600 ±1000	1299	1200	0.0296	0.0171	0.0115
Surface? UHT-6* (not terrace?)	10129		1400	1220	-	-	0.0221
Surface? UTH-8*		9500 ±500	1391	1220	-	-	0.0228
Terrace HT-7*	3785		1236	1216	0.0145	0.0113	0.0112
Tree Farm Terrace FT-26* (base of landslide)	2357-3750		1200	1137	0.0126-0.0145(3)		-

EXPLANATION: Incision rates based on presumed best ages (or alternative ages) of nine dated surfaces. Incision rates are measured from the original postglacial surface (estimated elev. 1340-1370) down to the dated surface, and/or from the dated surface down to the modern Buttermilk Creek (last column), using both 14C and OSL data. Assumptions: Erosion started ca. 13,000 YBP <u>and ended when the modern channel reached current grade ca. 2000 YBP</u>.

NOTES:

* Iindicates trench number from which sample was collected

(1) "Upper Increment" indicates rate from original surface down to sample point

(2) "Lower Increment" indicates rate from sample point down to modern channel

(3) Original surface assumed at elevation 1335-1340ft.

4.10.5 Lateral Erosion, and Franks and Buttermilk Stability

4.10.5.1 Valley Widening: Franks

Other than the preceding qualitative discussion of sandstone-caused, valley-widening to the west of the facilities, gully-top widening can be estimated for Franks Creek at the juncture with Buttermilk Creek. The lack of evidence for variation in valley-wall, slope-angle (approx. 22-degrees) through time in the Franks-Erdman and other Buttermilk tributaries allows an estimate for top widening.

The top width of lower Franks Creek valley widened approximately 900 feet in 13,000 years, or 0.07 feet/year. This rate is a uniform rate that implies a uniform incision rate of Franks at the juncture with Buttermilk Creek, however we have proposed that the incision rate was not uniform at the Abandoned Meander (upstream of Franks-Buttermilk juncture) and was not likely uniform at the Franks juncture. A problem for analysis is that there are no Franks or other gully-side terraces to relate to the Abandoned Meander.

Applying a gross rate of widening of 0.035 ft/yr divided by 2 to accounts for individual widening of each gully side, and gives a westward or eastward plateau retreat rate of 0.035 ft/yr from Franks incision. Using a soil plateau-top distance from Franks gully-top westward to waste trenches of 200 feet, yields a calculated time of 5,700 years until waste exposure, with the actual episode of exposure commencing by land-sliding. Maintaining a gully-wall slope of about 21 or 22-degrees (38 or 40%; or ratio of 2.5 horizontal per 1 vertical) and using a distance of 200 feet, Franks Creek would need to incise about 80 feet below the soil plateau surface to threaten waste trenches, i.e. from plateau surface 1380-ft to 1300-ft elevation (about 55-ft below current Franks Creek elevation near waste trenches).

The above calculations use a hill-slope value of 2.5-to-1 for currently dynamic processes of equilibrium between slopes and stream erosion. The slopes are not stable; the slopes are in dynamic equilibrium with incision. If incision stopped, then the slopes would adjust to 3-to-1 or less before slope failures ceased. There will be a time lag effect.

Breaching of waste containment by slope or other processes and the relationship of these processes to exact depth of Franks incision was not investigated in Study-1, nor was incision related to other facilities locations. Computer modeling of Franks erosion will help to more precisely examine details of deep-time erosion of waste and facilities in Franks watershed. Computer modeling will also account for a portion of potential, future non-uniformity of Franks incision rate, and facilities and waste exposures.

4.10.5.2 Valley Widening: Buttermilk

A gross rate of valley-top widening of Buttermilk valley can be estimated from Figure 4.10-1 for the area that includes the Franks-Buttermilk juncture and up Buttermilk valley (southward) to the Buttermilk log-date sites (south of the SDA). The valley top width varies between 1,200 and 1,500 feet and the soil plateau top width (the interfluve between Buttermilk and Franks Creeks) varies between 500 and 800 feet. The gross rate of valley-top widening thus varies between 1200-feet/ 13,000-years (0.09 ft/yr) and 1500-feet/13,000-years (0.12 ft/yr). This rate is a uniform widening rate that implies a uniform incision rate of Buttermilk Creek, however Study 1 proposes that the incision rate was not uniform at the Abandoned Meander. A problem for analysis is that there are no terraces to relate to the several-thousand year period of apparent channel stability within the Abandoned Meander.

Using an average widening rate of 0.10 ft/yr and dividing that rate by 2 in order to account for the west valley wall by itself, yields a plateau top loss of the interfluve between Buttermilk and Franks of 500 to 800-feet divided by 0.05 ft/yr, or 10,000 to 16,000 years.

A projected interfluve loss in 10,000 or more years is inappropriate for the Buttermilk-Franks interfluve (soil plateau) because more precise information is available as basis for calculations: Buttermilk has been eroding westward in response to the growth of Heinz fan for at least 4,000 years; a westward rate of Buttermilk lateral erosion can be measured by using mapped and dated Buttermilk Creek terraces and Heinz alluvial fan positions; and there is no indication that Heinz fan will stop growing westward. The following section evaluates westward migration of Buttermilk Creek in detail.

4.10.5.3 Heinz Fan as a Mechanism Driving Buttermilk Creek Westward

Westward shift of the Heinz-Buttermilk juncture in response to the growth of Heinz Fan is a more important concept than gross Buttermilk-valley widening (discussed above) because the westward shift is well documented and its rate reasonably established. Feature locations are found in report Figures 3.3-1 and 4.10-1, including the location of the longitudinal-section shown in Figure 4.10-2. Figure 3.4-4 presents details of locations of trenches sampled for C-14 dates with respect to geomorphic features (such as Buttermilk terraces and Heinz fan) at and near the Heinz-Buttermilk juncture. The distance from Heinz Terrace-3 (Figure 3.4-4) to the west valley wall of Buttermilk, either using Heinz trench T-7 relative to its immediately-opposite valley wall or using a correlative Terrace-3 fragment with respect to its valley wall near trench T-33, is approximately 460 feet. Using the C-14 date from Heinz trench T-7 of 3785 YBP yields a westward shift of the west wall of Buttermilk valley of 460-feet/3785-years, or 0.122 ft/yr. The distance from Heinz trench HT-33 in Terrace-6 to the west valley wall of Buttermilk is approximately 200 feet. Using the C-14 date from Heinz trench HT-33 of 2128 YBP yields a westward juncture shift (or west valley-wall, retreat rate) of 200-feet/2128-years, or 0.094 ft/yr.

Using these data for westward migration of Buttermilk's location is reasonable but has limits. For example, the rates taken at face value indicate that the rate of westward Buttermilk shift is slowing, which could be the result of Heinz watershed delivering less sediment for alluvial fan growth or that fan growth requires ever more sediment to expand its arcuate perimeter. A worst case scenario is that the 0.122 ft/yr rate continues unabated into the future. Then an interfluve width (soil-plateau top-width between Buttermilk and Franks drainages) of approximately 800 feet (close to Heinz juncture) will be eroded in approximately 6,600 years, or an area of interfluve width of 500 feet (further from Heinz juncture) in 4,100 years. When Buttermilk captures Franks Creek, either south or north of the SDA, then the captured portion of Franks Creek will have a very steep gradient near the SDA and NDA facilities, increasing the Franks incision and gully-top widening rates. This may be a moot point if Franks has already exposed waste at 5,700 years, before Buttermilk captures Franks. In conclusion, Buttermilk or Franks are likely to expose trench waste by approximately 4,100 to 6,600 years in the future. Computer modeling may help refine these estimates, especially concerning Franks gully erosion.

4.10.5.4 Geographic Stability of the Franks-Buttermilk Juncture

The terminus of Franks Creek has not been geographically stable, and won't be in the future, but does essentially vary around a point. A discussion of Buttermilk Creek stability along its valley from Riceville in the south to Cattaraugus Creek in the north frames the issue of Franks-Buttermilk juncture stability. That discussion (below) relates to Figures 3.3-1, 4.10-1, 4.10-2, and 4.10-4 informed by detailed terrain analysis using LiDAR, and further evaluated in some locations by reconnaissance walk-overs or trenching.

Buttermilk Creek is a meandering stream, typically eroding on the outside of its curves and depositing gravel on the inside of the curves. Several terraces (former higher floodplains) contain abandoned point-bar gravel deposits on the inside of curves, sloping toward former channels; those channels are mostly-filled with fine-grained sediments. The location (Figure 3.3-1) named "Abandoned Meander" is one of several abandoned meanders identified during Study 1; there are point-bars and abandoned meanders in terraces of Buttermilk above and near or downstream (north) of Heinz juncture, observable both in the field setting and on LiDAR. All the abandoned Buttermilk meanders have gradients approximately matching modern Buttermilk, unlike the steeper gradients of features related to Heinz Creek (Figure 3.4-4). Middle to lower Buttermilk and its terraces have gradients of approximately 0.01 that are typical of similar-size streams in southwestern New York that flow generally northward to Lake Erie, such as Connoisarauley, Walnut, Canadaway, and Chautauqua Creeks to name a few.

Buttermilk's meanders (eroding on the outside and depositing on the inside) are of three types: 1) constricted; 2) incised; or 3) deflected. Most of Buttermilk's meanders from Riceville to Cattaraugus Creek are constricted by lateral shifting against valley walls. Consequently many of these meanders have asymmetric curves.

Several meanders have shapes that are inherited by incision. The most obvious incised meanders occur at the Buttermilk outlet, Giant Slide, and Tree Farm areas and just upstream (Figure 3.3-1). The interfluves on the inside of the curves indicate a mostly, lateral, meander-shift in one direction during incision downward from the approximately 1340-foot old valley floor level (soil-plateau; glacier-withdrawal). The presence of lodgement till in Trench-13 at Tree Farm indicates that these incised meanders have been eroding through rock during the most recent 25-feet of incision (vertical component). In addition to bedrock incision, these meanders are eroding landslide toes at the outside of their east cut-banks, Giant Slide being especially noteworthy.

The third type of Buttermilk meander is one whose growth is partly or fully controlled by being deflected. Two types of deflecting processes occur locally: landslide deflection and alluvial fan deflection.

Deflection from landslides is discussed here first; this process is usually a relatively short-term, lateral-deflection of Buttermilk Creek and therefore of secondary importance regarding meander-generated valley-widening. For example, the 2009 slide in the west valley-wall of Buttermilk (adjacent to Heinz juncture and vicinity of SDA, Figure 3.3-1) deflected Buttermilk Creek eastward, which was recorded photographically by Gordon. That landslide was partly eroded as seen on 2010

LiDAR; ultimately it was removed by natural erosion soon after (before the 2014 reconnaissance for this project, and before the 2013 NYSGA field trip). Also an example, the movement of Giant Slide has not stopped the long-term incision of the adjacent Buttermilk meander that undercuts the valley wall, however the many more Buttermilk terraces that occur upstream of Giant Slide (Tree Farm) than downstream indicate that periodically the slide acts as a temporary base level. In conclusion, regarding landslide deflection, the velocity and discharge of Buttermilk Creek are sufficient to remove slide masses such as the 2009 slide near Heinz juncture in months or a few years, but it takes much longer to keep pace against the Giant Slide, terraces are formed upstream at Tree Farm, and that meander does not migrate downstream.

Alluvial-fan deflected meanders occur at two relatively large fans in lower Buttermilk valley (Figures 3.3-1 and 4.10-1), one at Heinz Creek and one at the unnamed fan about a half mile upstream of Tree Farm. Each location is fed by a relatively large drainage system and fans deflect meanders westward, especially at Heinz. Interestingly, Franks Creek drainage has larger basin size, similar stream-order and stream-density and would thus be expected to make a similar fan, but Franks drainage cuts more bedrock terrain. Franks Creek shows evidence of very-minor, fan-deflection of Buttermilk meanders by fan growth at the mouth of Franks Creek (LiDAR at scale 1"=67' with 1'-contours; viewed close-up and synoptically). Alluvial fan topography at the mouth of Franks is nearly absent, but Buttermilk terracing is present at low-heights on both sides of Buttermilk Creek valley near Franks juncture. The conclusion is that Buttermilk sediment removal has kept pace with Franks Creek sediment delivery, at least in recent millennia. So the juncture of the two creeks, Buttermilk with Franks, may have moved a few hundred feet periodically or cyclically between valley walls, but negligibly along the length of Buttermilk valley. Computer-modeling the juncture through time as horizontally-static but vertically-dynamic seems reasonable for the planned gully-incision modeling.

4.11 GULLY INITIATION OR HEADWARD EROSION

At Buttermilk's soil plateaus the initiation and advancement of gully heads can be described as having inherited their initiations or bifurcations, and directions of growth, from: a) antecedent channels, typically in the soil plateau surfaces remaining from glacial recession; b) ground water sapping related to antecedent conditions; c) random bifurcations; or d) human modification of terrain.

A finding of Study 1 is that several major gullies have eroded head-ward by following (incising into) antecedent channels in the soil plateaus; these older, gentler channels were inherited from glacier retreat about 13,000 YBP (Figures 4.2-5 and 4.2-6 for examples). Franks Creek is another one of these circumstances. Such antecedent channels captured overland and tributary flow and supplied that flow to gully heads advancing up the old channels for millennia. Franks Creek will continue to advance up its associated late-Pleistocene channel indefinitely (1,000s of years), if not artificially modified. Franks internal gully head was artificially reinforced against rapid incision as a temporary, emergency measure several years ago.

Another antecedent condition giving rise to gully heads is sapping, i.e. erosion by ground water where it exits from a slope. The faces of slopes in Franks watershed that intersect the contact between overlying Quarry Creek alluvial-fan gravel and underlying Lavery till exhibit sapping and gully heads at that level.

While landscapes are often perceived as an effect of some cause such as incising an older, gentler channel or from sapping, the initiations or status of erosional features can also be perceived as random processes. Wilson (2008) reported on landscape erosion in the Buttermilk watershed from a random process perspective by fitting current landscape elements into order-of-magnitude progressions.

Wilson (2008) found that Buttermilk and its sub-basins near the facilities had drainage densities of approximately 6 miles per square mile regardless of basin area, reflecting the relatively short time since glacier retreat, locally uniform climate, and generally similar vegetation and soils across the area. The number of first order streams (Strahler method) was approximately >50 per square mile across the region, but Wilson used $64/mi^2$ to allow for possible undetected streams (gullies) on 1:24,000 scale maps with a 20-foot contour interval. Study 1 determined a similar number of first-order streams ($>50/mi^2$) using LiDAR. Study 1, as already mentioned, has determined more details of terrain elements and dated history than were available in 2008; there were likely more than a few streams per square mile at 13,000 YBP. If there were 12 gullies per square mile at 12,000 YBP, then $24/mi^2$ at 6,000 YBP and $48/mi^2$ today, then that progression would yield $96/mi^2$ at 6,000 years in the future, and $192/mi^2$ at 12,000 years. The purpose of this analysis is not to achieve a precise rate, which cannot be done without data from long-past intervals; it is to demonstrate that many more gully heads are likely in the future until the quantities of drainage water are too small to sustain new gully formation. As the number of gullies per square mile rises to hundreds (orders of magnitude) the soil plateaus are etched and facilities lost in a period of millennia. Forested land will decrease the runoff and paved land will increase the runoff, delaying or advancing the rates of gully formation.

Ruhe (1952) observed drainage networks on four ages of glacial tills and determined that drainage density increased with time. Maximum density occurred in about 20,000 years. Parker (1976, 1977) experimented with physical models using clay-silt-sand mixes. Wilson (2008), using Ruhe's and Parker's results, estimated that approximately 20 percent of today's plateau tops will be eroded in the next 10,000 years. Base level drops would likely increase gully advancement rates (Parker 1977 and Schum et. al. 1983), however the Study-1 suggestion that Franks Creek juncture with Buttermilk Creek will have minor down-cutting would tend to support the 20 percent-loss estimate. Nevertheless, current site conditions such as deforestation, impervious surfaces and hydraulically efficient structures would tend to speed the loss of plateau tops. Without intervention, a 20 percent loss of plateau tops may occur in a few thousand years, rather than 10,000 years.

Other kinds of calculations of Franks erosion, such as future extension of gully heads based on extrapolations from historic photos, are not presented in Study 1 because Study 3 modeling is anticipated to provide better-based and better calculated estimates of gulley incision and erosion.

4.12 EXPECTED IMPACTS FROM LAND-USE CHANGES

4.12.1 Introduction

Section 4.12 mainly treats the possibility of reforestation impacts on future erosion and includes recent observations of land use impacts. Reforestation will significantly reduce runoff and erosion rates in the Franks Creek and Erdman Brook gullies due to reduced runoff from rainfall (reforestation causing increased interception, transpiration, depression storage, and infiltration) as would be predicted by models such as the Rational Method, or more sophisticated models. The effect of log jams on erosion is less clear, but from observations in the region their net effect is to retard erosion. Reforestation thus would also lead to reduced erosion from more log jams. Reintroduction of beavers into the old valley floor channels (soil-plateau-top, glacier-recession and immediate-post glacial drainages) should decrease incision rates. The prior presence of beavers was indicated by beaver-chewed, several hundred-year-old logs buried in sediments along Franks Creek above the gulley-head (Gordon, personal communication, and his C-14 dates).

In the sections that follow, first will be descriptions of 2015 flood conditions and resulting discharges, and then a discussion of implications of those discharges for future land uses, particularly reforestation. Lastly will be a discussion of anticipated reforestation effects on logjams and related erosion.

4.12.2 Lessons from the Flood of July 2015

The flood of July 2015 was widely considered a rare event by scientists, engineers, the public and the media, as was the flood of August 2009. The flood of 2015 has been described as a 1 in 200-year event. This flood resulted from an intense rainfall across the Gowanda, Perrysburg, and West Valley region that caused extensive infrastructure damage and overtopping of many hydraulic structures. Wilson participated in a site reconnaissance with Drs. Zintars Zadins and Lee Gordon on 9-17-15 where he reviewed stream flood-responses at lower Erdman Brook and mid Franks Creek. We looked at stream restoration project results at both sites. The Franks site was located where the current Franks gulley-head begins within the wide channel that was developed into the end-of-Pleistocene old valley floor (soil plateau top). The Erdman Brook site is generally similar. Wilson also looked at 2015 flood effects during field reconnaissance that included Heinz Creek on 10-20-15.

Regarding Erdman Brook. Grade control structures such as artificially reinforced or constructed knickpoints remained intact after the flood, but channels lined with Onondaga boulders and cobbles were rearranged into pool-riffle sequences containing clasts up to 1.5 feet long; this new arrangement indicated a more stable pattern under high-flow conditions. The box culvert in this location was not over-topped and there were no high-water marks above the culvert. A few large blocks of Onondaga rip-rap (3x2x1.5 feet) in one short reach had been undermined by flow and slid downward into the stream channel, but the blocks had not become entrained in the flood flow, as indicated by their position immediately below their starting point. The high-water marks indicated that the artificial channel was over-topped in places with a complex cross-section of flow, such as an upper water layer with 25-foot top width and 2.5-foot depth that was over an artificial channel that was 12 feet wide and 3.5 feet deep. The erosion in the sub-layer (the 12x3.5 foot channel) was apparent while the erosion above was negligible.

The Manning Equation is used for "paleo-hydraulic" calculation here: velocity = 1.49/n (R to 2/3 power) x (S to ½ power). For Erdman Brook, n = 0.04 and 1.49/n = 37, R is approximated by depth for combined layers as 3.5 = 2.5 = 6 ft, and S = 0.01 for the local conditions. The coefficient 1.49 is used for length measurements in American units. Velocity = 37 x .3.3 x 0.1, or velocity = 12 ft/sec. Discharge = area x velocity = 12 ft wide x 6 ft deep (neglecting areas of slow overbank flow), then multiply by 12 ft/sec, yielding a discharge of 860 cfs (cubic feet per second). The observed erosion features and moved-particle sizes are reasonable for the calculated flows.

Regarding Franks Creek, erosion controls were simpler than at Erdman's Brook. There is a headcut control with keys (wing walls) that angle upstream; this drop structure was placed where the headcut was located after the 2009 storm. This structure is composed of two drops with cobbles over fabric between. The keys are several feet vertically into the subsurface soil. The keys were not affected by the July 2015 flood; they were not under water. Many of the cobbles were removed from over the fabric while the fabric remained intact. The downstream drop of the drop structure lost a slab of concrete from its spillway. That rectangular slab, about 4x2.5x1 feet in size, was removed by the flood and carried approximately 25 feet downstream.

Cobbles were also used downstream to continuously armor the bed and banks. The "cobble" armor was composed of a wide variety of sizes including small gravel to small boulders (such as 1.5 feet in diameter). The armor was mobilized throughout the whole reach. A pool-riffle sequence was established with approximate spacing of 30-to-50-foot wavelength. A large cobble bar was created downstream at the exit point of the armored reach.

By coincidence, Franks Creek values for the Manning Equation were the same as the values at Erdman Brook: n = 0.04, width = 12 feet, depth = 6 feet, and slope = 0.01. Thus, the Franks velocity is also calculated at about 12 fps, and the discharge calculated at about 860 cfs.

Regarding Heinz Creek, sediment vs. bedrock erosion observations are presented elsewhere in the report and paleo-hydraulic observations are presented here. Paleo-hydraulic information adds to the understanding of 2015 flood conditions presented above for Franks Creek and Erdman Brook.

High-water marks were examined, such as flotsam, lag-gravel, and erosion scars along Heinz Creek between the upstream bedrock section and the downstream railroad bridge on October 20, 2015. These high-water marks were lower than expected from a storm reputed to be a 200-year recurrence-interval rainfall event, but no higher water marks were found. For a location in Heinz Creek channel approximately 200 feet upstream of the abandoned railroad bridge, the high-water marks and channel bed indicated a transverse channel cross-section composed of two adjacent but contiguous subsections. The left-bank subsection was 15 feet wide and 2 feet deep, while the right-bank subsection was 3 feet deep and 15 feet wide. The upstream sediment bar was somewhat mid-channel rather than only on the inside of the upstream curve. The bar was composed of cobbles and boulders, and the boulders were mostly gray-brown sandstone slabs one or two feet across. The bar character was different than its appearance on the 2010 LiDAR; its shape and position was mid-channel and so indicated that the 2015 storm rearranged the 2009 storm features.

Again, the Manning Equation is used to calculate paleo-hydraulic character of the 2015 flood. Left side and right-side subsections are treated separately for velocity, but calculated separately and added together for discharge. Roughness is estimated as n = 0.04. Left subsection R = 2 feet and right subsection R = 3 feet. To aid understanding degree of certainty of the results, the calculations are done twice, first using a slope S = 0.02 and then using a slope S = 0.03. Slope estimates are taken from LiDAR contours and agree with rough estimates from field recon; there were no artificial erosion controls, unlike at Franks and Erdman channels. The resulting velocity is 8.3 fps in the left subsection and 10.9 fps in the right subsection, using S = 0.02; and 10.1 fps in left subsection and 13.2 fps in the right subsection, using S = 0.03. The lower slope (0.02) results in a measure of discharge of 740 cfs (250 cfs on the left and 490 cfs on the right), while the higher slope (0.03) results in a measure of discharge of 890 cfs (300 cfs on the left and 590 cfs on the right).

About Manning roughness, there are several reasons for choosing 0.04. First, many researchers have chosen 0.04 as the go-to value for paleo-hydraulic calculations. Second, the value is appropriate relative to the US Geological Survey book of field-derived Manning "n" values (USGS Water Supply Paper #1849). Third, the value is appropriate to the special volume of US Geological Survey field-derived values for New York State. Fourth, Wilson's experience using the Manning Equation for many studies suggests 0.04 is a good value for the site characteristics. And fifth, one is not likely to choose a value below 0.03 or above 0.05, and those values result in only about a 10 percent difference in velocity or discharge from that calculated.

Discussion and implications of paleo-hydraulic estimations follow. The use of the Manning Equation for paleo-hydraulic calculations of the peak velocity and peak discharge at three locations was described above. Peak velocity was 12 feet/sec and discharge was 860 cfs at Erdman Brook and at Franks Creek, while velocities were 8 to 11, or 10 to 13, feet/sec in Heinz channel subsections and Heinz total discharge was 740 cfs to 890 cfs. Research for basic runoff models such as the Rational Method of runoff calculation has found that forested land reduces peak flows by 5 to 20 times the flows from areas dominated by artificial impervious surfaces. The Heinz Creek watershed above the location of paleo-hydraulic observations was approximately 1,000 acres while the areas above Erdman and Franks hydraulic-observations were about 100 acres each. Although the Heinz watershed was (is) dominated by forest and a trace of impervious surfaces, and the Erdman and Franks watersheds contained extensive impervious surfaces, the three watersheds yielded similar peak flows during the 2015 flood. While several factors combine to influence runoff from rainfall, similarities in soil materials and climate conditions across the Franks-Heinz area support a finding that land use accounts for some or all differences in flow per unit area during the "natural experiment" flood of July 2015. Conclusion: if the project premises and other Buttermilk watershed areas were heavily reforested, peak flows could be expected to decline by an order of magnitude per unit area of existing Franks-Erdman impervious surfaces, and less for grassed surfaces.

4.12.2 Observations of Logjams and Gully and Stream Erosion in Soft Sediments

Velocity and discharge are important factors for erosion, along with bed or bank irregularities that create vortexes in flow (Wilson, M. P., 1983, "Erosion of banks along Piedmont urban streams": available as pdf at the North Carolina Water Resources Research Institute web site as Report #189). It is common engineering and scientific knowledge that velocity is a major factor related to size of particles entrained in stream or gulley flow. An increase of in-channel average-velocity and discharge will tend to increase the particle sizes entrained and then, once entrained, transported in channel flows. Vortexes from local obstructions will aid entrainment. While conversion of grassed and artificial areas to forest will reduce flows and thus erosion, logjams consequent to reforestation could be counterproductive. Jams might cause erosive vortexes and provide localized vertical drops that increase local velocity and size of entrained particles, however a tangle of logs can also trap sediment, reducing sediment transport. Observations throughout the Buttermilk watershed and other drainages in the region indicate nearly all log jams are associated with landslides, including slides of many scales. Based on observations of logjams and landslides in the region, the aggregate role of log jams in gullies and small streams is to retard flow, trap sediment, and decrease erosion. For comparison, a highway culvert, in contrast to a logjam, focuses water flow and increases vertical drop through time. The down-stream, end-of-culvert erosion is self-enhancing when there is no energy dissipation structure below the drop. The downstream end of several highway culverts in the West Valley region currently display ten or fifteen feet of vertical channel erosion below culverts, with short-reach, gradient-flattening that occurs above culverts. In conclusion, reforestation is expected to increase logjams, trap sediment and small landslides, and reduce gulley incision and erosion generally.

4.13 UNCERTAINTY

Several quantitative and qualitative measures of the reduction in uncertainty of incision history were achieved through Study 1. This discussion focuses on the advantages achieved from LiDAR contouring, from stratigraphic and lithologic exposures made possible by trenching, and from age determinations.

4.13.1 LiDAR

When using the LiDAR available to this project, terrain features were routinely identified such as flights of terraces with 3-foot steps in elevation using 1-foot contours that were not previously recognized on 1:24,000-scale US Geological Survey topographic maps. In the previous studies, steps from terrace to terrace of as much as 30 feet were not observed with the 20-foot contours available. A fundamental principal of identifying remotely sensed patterns is that curved features are more difficult patterns to recognize than are straight patterns; consequently, terraces with curved outlines were even more difficult to identify than straight ones in prior work. Significant-sized and important curved features such as many rotational landslides and alluvial fans were not identified in past studies, but are now recognized from the LiDAR contours and further evidenced from field reconnaissance. For example, there were many years of intermittent investigations before the Heinz

Creek alluvial fan was recognized from 20-foot contour intervals on topographic maps, but now LiDAR contours allow measurement of fan attributes in addition to simply identifying their presence. These findings are evidence that the routine reduction of uncertainty in feature identification, or discovery, and measurement of attributes, found in Study 1 is equivalent to a 10- or 20-fold improvement in terrain analysis. Features less than three feet in height are discerned where features 40 or 60 feet in height were previously inadequately recognized.

Another measure of reduction in uncertainty is that gradients of most terraces were not previously determined because most terraces were not identified in the first place or views of detailed contours were not available. In contrast, terrace gradients were measured to three decimal places in Study 1 from LiDAR contours as well as field measurements.

Separating fan morphology from fluvial terrace shapes, i.e. determining the coexistence of the two and separating them, was possible using LiDAR. Identification of fan surface shapes included measuring gradients that were typically twice that of terraces. Viewing mapped contours allowed identification of abandoned channels, point bars, and cut banks as individual features with radii of curvatures similar to modern Buttermilk Creek, and which cross-cut fan morphology and deposits such as the large Heinz fan.

Measurement of incision rates and lateral erosion rates were profoundly affected by use of LiDAR. In terms of three-dimensional shape, features important to incision measurement changed from unidentified or poorly-measured, to well-identified and measured to two or three decimal places. Regardless of whether the rates themselves are different from the diversity seen in previous studies, the uncertainty in rates of incision and lateral erosion are improved by about two to three orders of magnitude with respect to vertical distances in particular.

4.13.2 Trenches and Outcrops

Reduction in uncertainty of another attribute or statistical variable concerned composition (lithology and stratigraphy). One-hundred twelve trenches were excavated in the Tree Farm, Heinz and abandoned meander areas. As an immediate precursor to this work, NYSERDA had excavated several exploratory trenches in the abandoned meander area. Further in the past, both DOE and NYSERDA had excavated many exploratory trenches and drill holes throughout the developed portion of the property, and these reports were considered by the Study 1 team. The primary uncertainty improvement from the Study 1 trenching is a much-improved understanding of how Site area lithology and stratigraphy relate to locations at greater distances from the Site, and a much-improved understanding of how Site area lithology and stratigraphy relate to base-level controls exhibited near the mouth of Buttermilk Creek (Tree Farm), and the continuity of those controls indicated by sites near Heinz Creek (which brackets the mouth of Franks Creek upstream on Buttermilk Creek). Also much improved is the understanding of lateral erosion from the westerly growth of the Heinz Creek fan towards Franks Creek.

Information from LiDAR and reconnaissance traverses was used to specify trench locations in preference to random sampling (i.e. random trench location) or systematic sampling such as locating trenches on a grid. Thus, 112 trenches were located to effectively test 112 tentative hypotheses about expected lithology and stratigraphy, one trench per hypothesis.

The exploration approach followed the sequence:

(1) use the mode of origin of materials to reduce areas of investigation;

(2) further reduce areas of investigation by analyzing genesis of LiDAR shapes and locations to hypothesize concerning the likely composition of the shallow subsurface;

(3) test hypothetical subsurface conditions with GPR transects parallel or perpendicular to expected lithologic trends or boundaries and thus further reduce the dimensions of exploration;

(4) excavate trenches using trench shape and orientation (such as parallel or perpendicular to apparent flow directions) that promote the analysis of incision or lateral erosion history or that further reduce exploration dimensions required to find dateable samples;

(5) control or modify the rates and orientations of excavations while excavating parallel or perpendicular to hypothesized and encountered materials, especially to reduce the areas of detailed analysis of organics and sands in real time; and

(6) lastly, choose sample locations in trench faces or floors for analysis of pebbles, organics, sands, or other materials, including saving duplicates for quality control.

In summary, reduction of uncertainty in erosion history comes from several sources of trench excavation information. First, uncertainty was reduced by following a pattern of area reduction and increasing precision similar or superior to that commonly used in highly-developed subsurface-exploration industries such as aggregate supply, water supply, and petroleum or minerals exploration. Second, the exploration hierarchy allowed for feedback loops in exploration. Third, the findings demonstrated that in Study 1 detailed lithologic and boundary information was detected and measured.

Most previous evaluations of areas distant from the Site involved use of scattered natural outcrops for sampling. In the three principal Study 1 areas (abandoned meander, Tree Farm, and Heinz Creek), natural outcrops involved about 20 exposures in gullies, slopes or Buttermilk Creek banks, with about 30 feet of lateral exposure each (range of approximately 10 to 100 feet each). That amounts to a total length of approximately 600 lateral feet of exposure. Additionally, there were 112 trenches in Study 1 with typical side face rectangular dimensions of about 10x20feet with several trenches larger, up to 75 feet long. The trenches totaled well over 6,000 lateral feet of exposed lithology and stratigraphy. The trench exposures have an advantage over natural outcrops in that they were peeled open or sectioned while actually being observed, and orientations were contemporaneously controlled. The effect was that the trenches exposed tens of thousands of feet of lateral surfaces for observation. Thus both the qualities of natural outcrops (such as weathering character) and the improved extent of trench exposures were superior in Study 1 as opposed to the more limited and random scattered natural outcrops available to many previous studies. It is estimated that the quantity of information available to Study 1 regarding Site incision or lateral-erosion was two or more orders of magnitude greater than the quantity available before the study.

4.13.3 Age Determinations: Overview

Reducing uncertainty of information from age measurements was also achieved. Critical positions (features and locations) were dated between 14,000 and 200 YPB, with most precise numbers such as 3,785 YPB considered exact to approximately ± 30 years (within the understood constraints of 14C chronology and methodology). These discrete time data allow for measurement of the progressive development of the landscape and stream incision history. Values are supported by independent measures of quality such as repeated ^{14}C samples and companion OSL samples.

Several decades ago site reports had a limited quantity of dated features, due to the large sample size required, and resulting dates often were projected from distant locations or were related to weakly identified local features. Then about two decades ago, more-accurate dates from ^{14}C and OSL became routinely available, but their use was not generally combined with information from LiDAR, GPR, or extensive trench measurements. The new Study 1 dates, as well as several of the previous dates, are enhanced by better relating the dates to their locations and to the surrounding materials. In a quantitative sense, there are many more dates available, there are an order of magnitude more critical dates for constructing graphs depicting temporal relationships, the dates are better related to calendar ages, the dates have been more-precisely determined in the laboratories with narrower margins of uncertainty, and specimens were extracted, handled, packed and shipped using strict quality assurance and quality control (QA-QC) protocols.

Independent experts in dating (Drs. Sebastien Huot[5], Lewis Owen[6], and Harrison Gray[7]) were brought to the Site for consultation and extensive discussions. While providing a quantitative estimate of uncertainty or the reduction in uncertainty is difficult, there is at least an order of magnitude better analysis of time dependent data due to less uncertainty in dates.

4.13.4 Age-Dates by C-14: Review of Concerns, Especially Recycled Organic Materials

All of the C-14 dated organic materials encountered in the West Valley region in Study-1, in studies supporting various research such as Muller and Calkin (1993), or supporting agency activities or impact statements such as LaFleur (1979), or in previous studies such as Gordon, Andrzejewski and Bembia (Gordon and others, 2013), share four over-arching concerns: a) how certain are the laboratory results; b) were the lab results modified from carbon-years to calendar years and how; c) how certain are the representations of stratigraphy (relative ages) to which C-14 dates are assigned; and d) how certain is it that the carbon sources were not reworked. The first two concerns can be quickly diminished for this report, but the latter two require some discussion, especially concern "d", reworking of organics prior to C-14 measurement.

[5] University of Illinois.
[6] University of Cincinnati.
[7] USGS OSL Laboratory

a) One lab, Beta Lab, was used exclusively for Study-1 and for the study conducted by Gordon and others (2013). All samples were analyzed by the AMS method. The lab was interviewed intensively before and during Study-1. The lab provided extensive historic documentation of its QA-QC. Beta provided intensive documentation of our project materials, their preparation and results, including their photography of our carbon materials responses to their treatments. On our part, our samples were carefully transferred to Beta in foil; closed, dark, dry containers; coolers with ice packs; and were transported rapidly by shipping services from western New York to the lab in Miami, FL. Sample acquisition and transfer (chain of custody) was documented throughout. Beta reported the uncertainty in its findings as typically +/- 30 years (1 sigma), with approximately 20% of dates up to +/-60 years. Thus the C-14 dates are very precise relative to the needs of Study-1.

b) Beta provided results for both conventional and calendar ages and followed standard practices for conversions. The Beta conventional carbon dates are given in our report Appendix. Beta calendar dates (conversions) are provided in Beta's original reports. Young provided a second set of conversions using the CALIB program (with values provided in the report appendix adjacent to the Beta conventional carbon dates); this allowed uniform and comparable presentations in the report text for both Beta results and dates acquired from the literature, i.e. one set of calendar values from CALIB throughout the report text and appendix. While the appendix to our report provides two sets of C-14 age results (Beta conventional and CALIB calendar), discussions in this report uses only CALIB calendar ages to keep clarity for communication, and to simplify and add transparency to calculations of process rates and determinations of events histories.

c) Stratigraphy is the study of relative characteristics and ages of layered rocks or sediments, but since nearly all rock types or sediments are wide compared to their thicknesses the concepts and expressions of stratigraphy are applied to many natural materials and situations. There is litho-, chrono-, hydro-, morpho-, and other stratigraphy. A common scientific method is to study one or more types of stratigraphy in an outdoor area and to determine relative ages of materials or features, and then attempt to assign "absolute" ages to features in the stratigraphy if appropriate samples can be discovered. The degree of uncertainty of results varies in this multi-step activity. It is exceptionally difficult to predict the degree of uncertainty prior to collecting data, but reasonable to qualify uncertainty in hind-sight. Consequently, a phase of study referred to as reconnaissance is often injected into the sequence of investigative activities to improve certainty as a study progresses. It is also common for any terrane to be reinvestigated at multi-decadal intervals as new instruments and techniques are made. In the case of Study-1, new stratigraphic methods included: LiDAR for morpho-stratigraphy and litho-stratigraphy; ground probing radar for detecting shallow litho-stratigraphic discontinuities; better-adaptable excavating equipment for litho-stratigraphy; and AMS-dating for chrono-stratigraphy; among other methods. Resulting certainties of stratigraphic studies are partly summarized as follows.

Highly certain are the Study-1 descriptions, analyses and relative dating (sequencing) of terraces such as within each Buttermilk terrace set at Outlet, Tree Farm, lower Heinz, and Abandoned Meander locations (Figures 3.4-2, 3.4-3, 3.4-4, 4.2-8, and 4.10-4). For example, point-bar sand and gravel litho-stratigraphy was confirmed by excavations and trench-wall analyses beneath point-bar morpho-stratigraphy. Abandoned Buttermilk channels adjacent to point-bar features were also confirmed.

If organics were discovered in features whose stratigraphic origin had high certainty, then they were often C-14 dated; examples are:

1) in the Abandoned Meander channel (such as trench #MT-34 or #MT-38 in Figure 3.4-2) the stratigraphy is highly certain because the LiDAR-based morphology, trench-based lithology, and natural outcrops show the abandoned channel shape and location, including that the point-bar shape became reoriented as it was incised; also discernable is where the northeast end of the Abandoned Meander became more recently incised by the "modern" gully head growing westward into the Buttermilk valley wall;

2) Buttermilk terrace #3 at lower Heinz, channel trench HT-7 in Figure 3.4-4; this trench exposes fine-grained channel fill in a LiDAR defined channel which is appropriately positioned adjacent to trench HT-6 exposing the corresponding point-bar gravel to the immediate west;

3) Buttermilk terrace #6 at the lower Heinz area, channel trench HT-33, in Figure 3.4-4; this trench exposes layered floodplain (or low terrace) sediments that are remarkably similar to the flood sediments (also called vertical accretion deposits) in Photo 4.15 and 4.16 from across the Buttermilk floodplain (west side of Buttermilk valley) at Log-Site-1; these deposits at the two, C-14 dated, log sites are also remarkably similar to recent floodplains or terraces across western New York, and dissimilar to the more massive and often less structured channel fills of all of the channel trenches in all of the higher terraces (channel fills at Tree Farm, Heinz and Abandoned Meander areas);

4) the stump in point-bar gravel of Buttermilk Creek near Tree Farm in Figure 3.4-3;

5) the log site in floodplain (or low terrace) sediments, shown in Photos 4.15 and 4.16, as mentioned above.

Additionally, sites of alluvial fan morphology and litho-stratigraphy at lower Heinz (Figure 3.4-4) are of high certainty concerning their origin and relative ages; they have distinct slopes, shapes, and sediment coarseness. Also, comparing alluvial fan features to Buttermilk terrace features allows high certainty in separating the two sets of features.

In contrast, determining relative ages of Buttermilk terraces vs adjoining alluvial fans varies in degree of certainty. For example, at the site called Outlet (Figures 3.3-1 and 4.2-8) the separation of fan and terrace is obvious from LiDAR maps, but their relative age is not as certain because we have no evidence that the distal portion of the fan lies over or under or coincident with the high terrace. The fan, however, does have decreasing slope as the terrace is approached; the fan is graded to the terrace, which indicates the fan is at least partly contemporaneous or younger than the terrace. We lack trenching evidence to establish relative ages at the Outlet site, although LiDAR evidence detects their existence.

In further comparison, Heinz terrace-fan junctures (Figure 3.4-4) have LiDAR evidence of abandoned channel gradients on terraces and fans, radar probe evidence, long-trenches dug across terrace-fan junctures, and sediment sample examinations. This extensive data supported certainty that while some Heinz fans may be inter-layered with more than one Buttermilk terrace, higher terraces are not inter-layered with lower fans.

An example of moderate to weak certainty concerning stratigraphy is the relationship between Buttermilk terracing and slope stability at Tree Farm trench FT-26. The Buttermilk terrace is undulating as if landslide disturbed from below, or having suffered runoff erosion, or having received landslide debris onto the apparent terrace from above. All three conditions may be present at once. A C-14 date (3785 YBP, similar to the Heinz HT-7 location) of this surface determines either the date Buttermilk was at the terrace, or the most recent date Buttermilk was at this surface.

d) All the C-14 dates from Study 1 and published reports of nearby samples can be challenged as from reworked organic materials, such is the typical situation of working with wood as a source of C-14 age determinations, but we were careful to assess uncertainty of reworking throughout Study 1. Only the C-14 date from Buttermilk terrace #3 in the lower Heinz area (trench HT-7) is discussed here in order to simplify the response and to focus the response onto a very informative absolute date. Other carbon-reworking issues, such as interlayered sediments at Heinz trench HT-33 in Buttermilk terrace #6 or the occurrence of a stump in a point-bar deposit in contrast to a cut-bank exposure, were considered elsewhere.

The date 3,785 YPB from trench HT-7 is as fortuitous as it is critical. Fortuitous because the thin carbon sheet was recognized by the excavator operator and he immediately stopped digging and called attention to what he saw from his vantage point. Critical because this date is important for measuring Buttermilk Creek incision history, Buttermilk terrace development, Franks Creek base level change, and lateral erosion by Buttermilk westward toward facilities.

The 3785 YBP date from HT-7 is one of the best quality dates obtained in Study-1; it has very high certainty concerning not being reworked by erosional processes. The sample for the date came from an isolated 1 to 3-mm thick sheet of charred wood that was approximately rectangular 0.5 by 1.0 foot. The sheet of charred wood was horizontal within silty-clay sediment (note that the trench diagram in the appendix is generalized and does not capture the correct sediment type of the C-14 sample as per the original field data sheet or photographs). The C-14 sample from HT-7 was taken at depth 3.3 feet in clayey strata, laterally away from the OSL sample that was taken at depth 3.7 feet in sand strata. The clay-over-sand contact was at depth 2.3 feet on the side of the trench where the OSL sample was located while the contact was much deeper on the C-14 side of the trench. Adjacent trench HT-6 was located in the associated point-bar, interlayered sand and gravel approximately 60 to 75 feet westward of trench HT-7 (both trenches were approximately 15-feet long). So this Buttermilk terrace (terrace #3 in Figure 3.4-4) is composed of a portion of an abandoned meander with its cut-bank at the east Buttermilk valley wall (HT-7) and point bar immediately westward (HT-6), and the C-14 sample represents clay fill in the abandoned channel next to the cut-bank. Buttermilk terrace #3 is about 25 feet above the modern Buttermilk channel; terrace #3 is immediately adjacent to Buttermilk terrace #2 which is south and west of terrace #3. Thus the sample stratigraphic context and relative ages of local features are well established through LiDAR, trenching and reconnaissance.

Certainty is very great that the sample for date 3785 YBP (from Buttermilk terrace 3 in the area of lower Heinz, i.e., sample # Beta 439758 or Study-1 # HT7GPR18B) was not reworked. This sample was from an isolated, horizontal, single, very thin, delicate carbon sheet that could not be reworked without fragmentation or disintegration. The sheet had to be deposited in quiet water, as also attested to by the clay and the stratigraphic setting. Photo 4.25 shows the carbon sheet below the approximately thumb-nail size clods of sticky clay that lay upon it after exposure by trenching. The photo does not capture the centimeter-scale, rectangular crack pattern in the sheet. The sheet was sampled with adjoining clay pieces, while removing as much clay as possible. The Beta lab photo shows clay-carbon fragments prior to treatment; these small clods had clay sheeting parallel to carbon sheeting, making the carbon sheeting mostly, visually undiscernible from the clay. The Beta post-treatment photo shows the visual nature of the carbon; the layering is evidence of wood structure and so the best description of the field occurrence is "a sheet of charred wood, 1 to 3 mm thick". The charred wood layers within the charred fragments in the BETA test-tube, post-treatment, pre-analysis photomicrograph may be either tree-ring structure or tree-ray structure. Description or discussion of tree rings and structure can be found in Speer, 2010, Fundamentals of Tree-Ring Research and at the U.S. Forest Service web site. The carbon sheet (charred wood) sampled in the trench (HT-7) is either the remnant of a thin wood sheet transverse to trunk or limb and showing rings, or an arcuate peel, parallel to rings and circumference, showing rays. Tree types in the region have a variety of ring- and ray-dominant appearances; either dominance in our sample is possible. So . . . a fire burned a tree and a piece of wood 0.5 sq. ft. or larger split-off or popped-off transverse to trunk or limb (preserving ring structure), but more likely split sheet-parallel to circumference (preserving ray structure), and the sheet fell into quiet water along with quiet-water sediments (i.e., clay) in an oxbow setting. Reworking the carbon sheet is very unlikely, and would be analogous to leaves falling, being deposited under sediment, and then exposed by erosion and reworked and redeposited. The charred wood sheet is even a more delicate material.

4.13.5 Age Uncertainty Summary

In summary, reduction of uncertainty in Study 1 has led to recognition that most Buttermilk Creek incision (down-cutting) occurred over approximately 7,000 years (13,000-10,000 and 6,000-2,000) rather than over a much longer duration. Downcutting of Buttermilk Creek was controlled by: a) Cattaraugus Creek as base-level, b) intermittently by large landslides in Buttermilk Creek upstream of the Buttermilk Creek/Cattaraugus Creek confluence, and c) by climate change reducing erosion during a warm, dry period roughly between 10,000 and 6,000 YBP. The Buttermilk Creek trunk stream had a history largely achieved by down cutting rather than headward erosion (knick-points retreating for many miles up-valley). Gully heads at Franks Creek continue to retreat along lines inherited from glacier landforms. Buttermilk Creek (as well as landslides and Beaver dams) controlled gully base levels, and the Heinz Creek fan continues to force Buttermilk Creek westward toward eventual merger with Franks Creek. Reductions of uncertainty in several measured attributes of these historic changes are on the order of two to three orders of magnitude, in addition to greatly improving the understanding of events through time.

5. CONCLUSIONS

As discussed in Section 1.2, specific objectives of the study included the following:

- Establish more precisely or definitively the timing of the last ice sheet recession
- Establish the sequence of major or identifiable events in postglacial time
- Ascertain the past history of postglacial erosion and its relation to prediction of future erosion
- Investigate relations between paleoclimate and erosion rates
- Provide guidance on how these factors should be incorporated in predictive erosion models

A large quantity of field data and information was gathered and analyzed during the course of the study from August 2015 to September 2016. The general types of data and information gathered can be generally summarized as follows:

- Personal expertise, experience, familiarity with the site and regional geology, and insights, of the SMEs;
- Review of published and unpublished literature, reports, data, and information;
- Analysis of maps, satellite imagery, aerial photography, and detailed LiDAR maps;
- Information gathered in the course of numerous geologic reconnaissance visits including traverses on foot with detailed digital photography and LiDAR contour maps, collection of shallow samples for pebble counts, collection of organic samples for ^{14}C dating, and collection of old growth tree cores;
- Non-invasive subsurface information from more than 11,000 lineal feet of GPR surveys;
- Geologic logging, sampling, and photography of 112 exploratory pits and trenches;
- Several hundred in situ shear stress measurements;
- Laboratory age analysis of 67 samples by radiocarbon dating, 11 samples by OSL dating, and 5 samples by TCN dating methods;
- Reinterpretation of 10 previous OSL sample results reported in the FEIS using more-recent analytical methods;
- Synthesis and analysis of the various types of data, and estimation of historical erosion rates; and
- Evaluation of uncertainty reduction.

The data, information, and analyses performed support the following conclusions:

1. The age of the last glacial recession can now be confidently dated at circa 13,000 calendar years before present (YBP). This date establishes the starting point for late Pleistocene/ Holocene Buttermilk Creek incision.
2. Sediment yield from Buttermilk watershed significantly exceeds yield from Connoisarauley watershed as seen in 1994 color-infrared air photos. That the two basins produce markedly different sediment quantities is not surprising because the late-glacial ice advance (Lavery) involved sediment trapping in the bowl-shaped watershed of Buttermilk Creek while the

watershed of Connoisarauley had meltwater channels positioned to allow maximum disbursement of proglacial waters and sediment westward. Computer modeling would need to account for differences in basin sediment yields between the two basins if comparative studies of sediment loss or yield were done.

3. Historical Buttermilk Creek incision rates have been nonlinear through time. Vertical incision rates immediately following glacial retreat at 13,000 YBP averaged around 0.018 feet per year between approximately 13,000 and 10,000 YBP (55 feet in 3,000 years per Figure 4.10-4). Between approximately 10,000 and 5,600 YBP, there was little net incision based on data from the abandoned meander area. The incision rate then increased during the period from 5,600 to approximately 2,300-2,500 YBP to an average of 0.030 feet per year (95 feet in 3,200 years) until the existing bedrock thresholds were apparently encountered in the channel. During the most recent 2,300-2,500 years the net incision has been approximately 5 to 10 feet, or approximately 0.002 to 0.004 feet per year. The graphs in Figure 4.10-4 present two equally-plausible and similar scenarios for incision history on the basis of the available age dates. The bases for the two scenarios are discussed in the report. While various incision rates are tabulated or discussed in the report, the above incision rates were calculated with data estimated directly from Figure 4.10-4 which is the fairest representation of the report findings and interpretations.
4. Climate was warmer and drier approximately 10,000 to 6,000 years ago than in the periods before and after. The mild climate coincided with a cessation of incision in the Buttermilk valley as indicated by dates at the abandoned meander (Figure 4.10-4). The milder climate affected Lake Erie level and consequent base level for the mouth of Cattaraugus Creek, yielding about 3 meters of incision followed by a sudden 11 meters of aggradation of the creek mouth; such changes are not likely to be transmitted upstream more than a few miles, perhaps a dozen, and thus would not have affected the Buttermilk drainage. Climate change May have influenced the whole Buttermilk watershed in ways such as sediment transport and mass-movement rates (water contents).
5. While there are no published reports of relative incision resistance comparing rock to sediment, local and regional observations indicate shale erosion resistance ranges from equivalent to many-times the incision resistance of sediments, based on outcrop profiles, valley-widening up-gradient of bedrock reaches, flood effects, seismic velocities, and standard penetration tests (SPT) from drilling. Furthermore, sandstone erosion resistance is many times greater than shale incision resistance.
6. The reason for the slowing of Buttermilk Creek incision rate during the past 2,000 to 3,000 years likely is emergence of resistant sandstone bedrock sections in downstream reaches of Buttermilk Creek. The overall flattening of the gradient of Buttermilk Creek with time (from about 10,000 YBP to present) was from approximately 0.018 to 0.010 as indicated by terrace and modern creek gradients, but data for the steeper old levels is scant. The modern gradient of 0.010 is common among similar size streams in Lake Erie escarpment-face positions. Both resistant sandstone sills and gradient flattening are factors that will continue to be applicable into the future.

7. The Buttermilk Creek channel was pushed westward by fan growth by the westward-flowing Heinz Creek tributary at the confluence of the two streams. The west bank of Buttermilk Creek has been over-steepened leading to active landslides at this location. The westward lateral migration of Buttermilk Creek during Holocene time is estimated to have ranged between approximately 0.09 and 0.16 feet per year. If the current westerly migration of Buttermilk continues into the future at these rates, Buttermilk Creek may remove part of the Franks Creek-Buttermilk divide in the vicinity of the State-licensed Disposal Area (SDA) in an estimated 4,100 to 6,600 years, or sooner depending upon the concomitant rate of widening of Franks Creek.
8. Several hundred, field shear-stress values for a wide variety of in situ materials were measured using a Torvane device. The Torvane data demonstrate that sediment types vary in shear strength by about two or three orders of magnitude. In general, shear strength has an inverse correlation with erodibility, i.e. greater shear strength implies lower erodibility. These data may correlate with erodibility measurements from Study 2. If so, the larger number of Torvane data points may be able to supplement the Study 2 erodibility data by serving as proxies for erodibility in modeling.
9. Landslides have, and will continue to have, great significance to terrain development in the Buttermilk Creek watershed. For example, two of the primary processes key to understanding past landscape development, namely Buttermilk Creek base level control, and westerly channel migration, are at least in part influenced by landslides. The large landslide in the east bank of Buttermilk Creek just downstream from the tree farm site terraces was periodically influential in base level control, while the active landslide in the west bank opposite the Heinz Creek fan is intimately involved in westward lateral migration of the Buttermilk channel.
10. The current study has produced a significant improvement in our knowledge of the historical processes controlling landscape development and their timing in the Buttermilk Creek watershed. This has enabled a reduction in uncertainty concerning the nature and timing of these processes; although, quantifying the reduction is difficult. The vast quantity of data gathered, and the significant improvements in dating and other measurement technologies, are just two of the factors that enable the dramatic improvement in confidence when compared with the quantity and quality of data available to previous studies. As a specific example, LiDAR with 1-foot contours supplanted older maps with 20-foot contours so that features less than 3-feet in height were identified now where features such as alluvial fans more than 40 feet in height were previously inadequately identified.

The data, information, findings and conclusions, and expertise of the study participants lead to the following observations concerning future erosion at the site:

- Future erosion within the Buttermilk Creek watershed will be dominated by headward erosion up tributary streams and gullies such as Franks Creek, and valley-widening processes, rather than by significant base-level lowering of the main stem Buttermilk Creek.
- Mid to lower Buttermilk Creek is not likely to significantly incise deeper in the coming millennia because: a) further incision of Cattaraugus Creek (Buttermilk's base level) will take

10,000s to 100,000s of years owing to the great extent its profile has already incised and flattened to date; b) the length of the flow path to the Atlantic Ocean; c) the flat gradients of the Great Lakes Erie and Ontario; d) the expected 11,000 year retreat of Niagara Falls before beginning to drain Lake Erie; and e) the fact that the current gradient of Buttermilk at 0.010 has been sustained for thousands of years and is typical for similar stream reaches throughout the region; and f) the level of lower Buttermilk Creek has been quasi stable for more than 2,000 years. The threat to site facilities is from gully incisions in the Franks Creek watershed related to head-cuts, knick-points, initiations of new gullies, or in other words the back-wasting or retreating processes of gully gradients and walls.

- Incision of the Franks-Erdman creeks is not likely to reach bedrock in the vicinity of facilities and so the modeling should use parameters for erosion of sediments. Where creek beds currently encounter bedrock, more erosion resistant parameters could be inserted into analysis and as incision proceeds the bedrock parameters could be advanced downstream. Because some bedrock could be as erodible as some till, using only sediment erosion characteristics in analysis would model the worst-case scenario for incision.
- Gulley widening due to Franks-Erdman creeks encountering sandstone layers is not likely in the vicinity of facilities because bedrock will not be reached by incision. If or when resistant sandstones are incised to the west of the facilities area, the effect will be to widen gullies upstream (west) of facilities, leaving facilities unaffected by such widening.
- Westward migration of the Buttermilk Creek channel opposite the Heinz Creek confluence is likely to continue and will likely lead to incorporation of Franks Creek adjacent to the SDA within a time frame of roughly 4,100 to 6,600 years from now, or sooner depending upon the rate of widening of Franks Creek which could hasten the process. This process is illustrated schematically in Figure 4.10-2.
- Unlike the westward migration of the Buttermilk Creek channel at Heinz Creek, the map position (x-y) of the Buttermilk Creek/Franks Creek confluence appears to have changed little in the last several thousand years. The juncture is currently directly in the middle of the Buttermilk flood plain that is 500 feet wide; the juncture will have varied within that location as meanders migrated. The meander patterns (ghost channels or scroll work) indicate that juncture movement up or down the length of Buttermilk valley was tens of feet, less than a hundred feet. The stability of the channel at this location makes it a good candidate location for setting base level boundary conditions for models of the Franks Creek watershed within the limits just described.
- When evaluating the variability of historical vertical incision rates of Buttermilk Creek for use in modeling future erosion, appropriate weight should be given to the most-recent approximately 2300- to 2500-year period during which the incision rate appears to have slowed dramatically to 0.003 feet per year (estimates range from 0.002 to 0.004 feet/year). The reasons for the slowing include emergence of larger resistant bedrock sections in downstream reaches of both Buttermilk and Cattaraugus Creeks, and the overall flattening of the gradient with increasing age. These conditions will continue into the future, as opposed

to many of the transient conditions that accompanied variable incision rates during earlier periods.

- Climate change is expected to produce more storms of high precipitation intensity in the relatively near future; although, little reliable information is available to forecast climate change more than roughly 100 years in the future. The erosive energy of runoff from increased future storms will likely enhance Buttermilk valley widening in erodible sediments more than base-level lowering because base-level lowering has slowed due to emergent resistant bedrock. The earlier period of warmer climate (ca. 10,000 to 6,000 YBP) also resulted in slowed incision.
- Patterns of storm water runoff have changed over the last approximately 200 years owing to deforestation, agriculture, and paving of ground surfaces resulting from changes in land use. Concentration of runoff is now greater than prior to homesteading the region and will likely increase further if these trends continue in the future.
- The results of this study have provided a much-improved and well-documented late glacial chronology, as well as a reasonable estimate for when the modern Buttermilk Creek gradient became established at close to its present configuration in the vicinity of the Site. The new glacial chronology requires a significant revision in our understanding of the late glacial events throughout western New York. Historical Buttermilk Creek incision is now reasonably documented as having started approximately 13,000 calendar years before present, which is considerably younger than previously concluded.
- The data and information from Study 1 should enable prediction of future erosion with greater confidence than has heretofore been possible.

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Figures

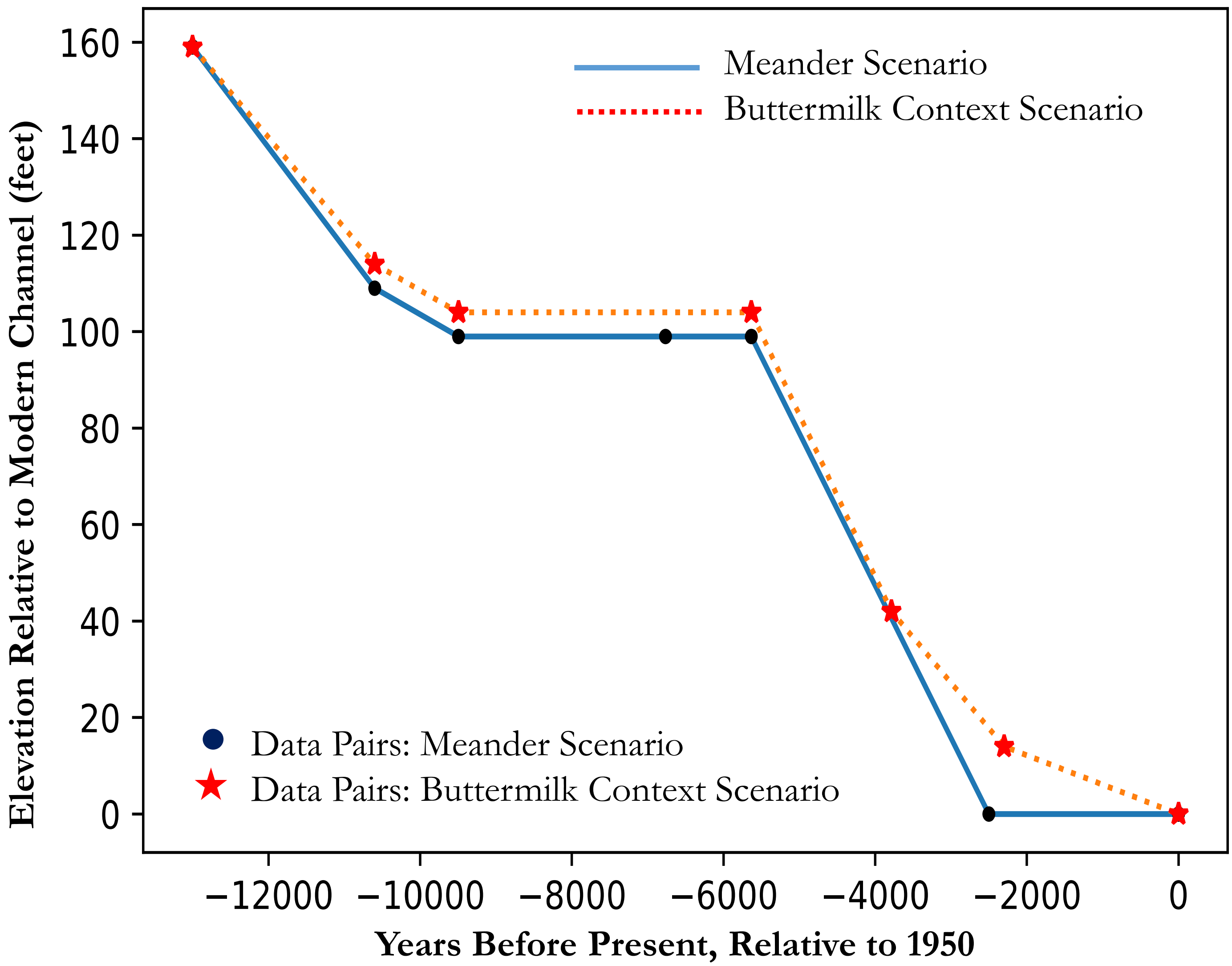


Figure ES-1: Graphs of equally-plausible incision history scenarios in the vicinity of the abandoned meander.

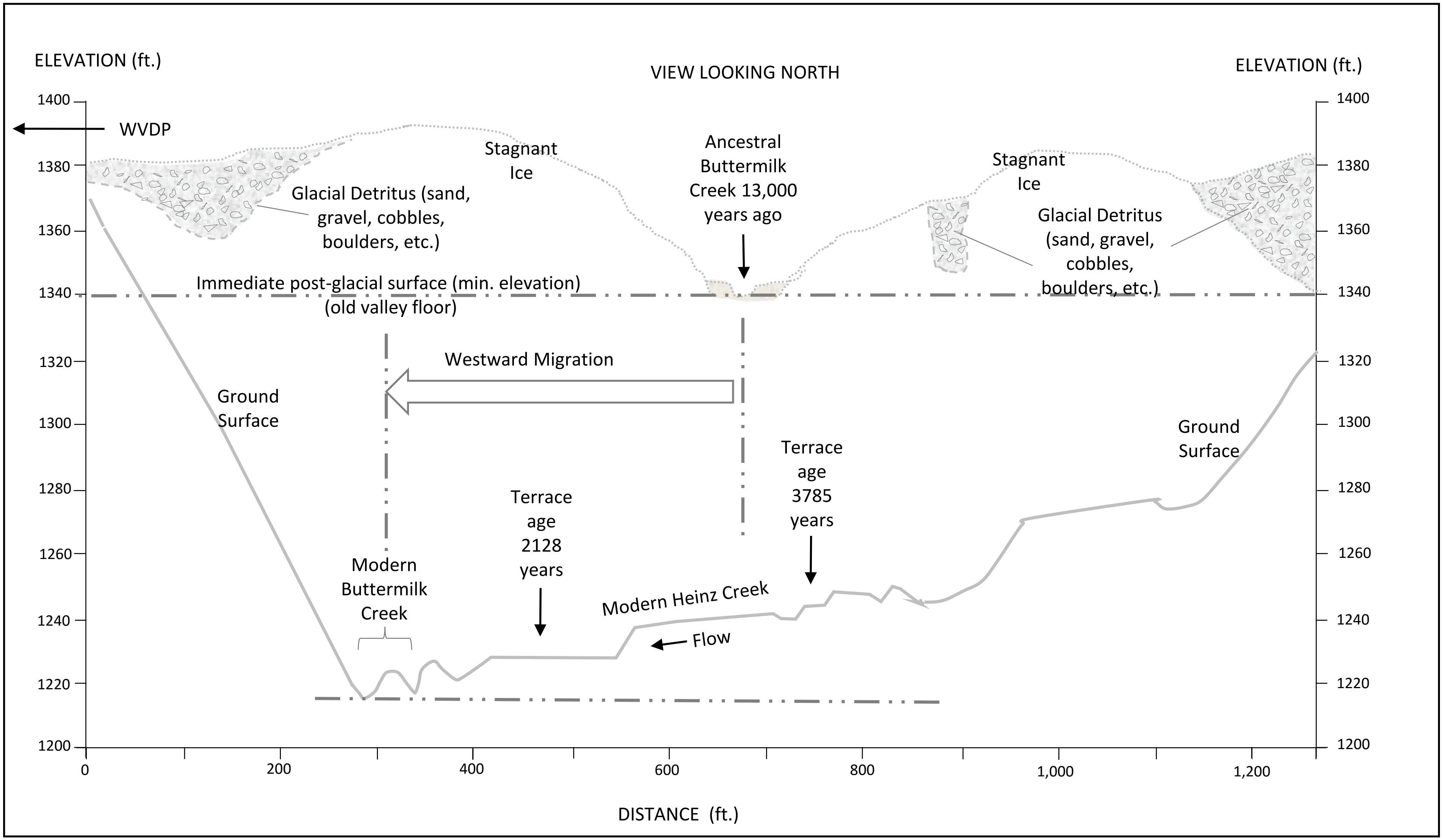


Figure ES-2: Schematic diagram of historical Buttermilk Creek westward migration at Heinz Creek.

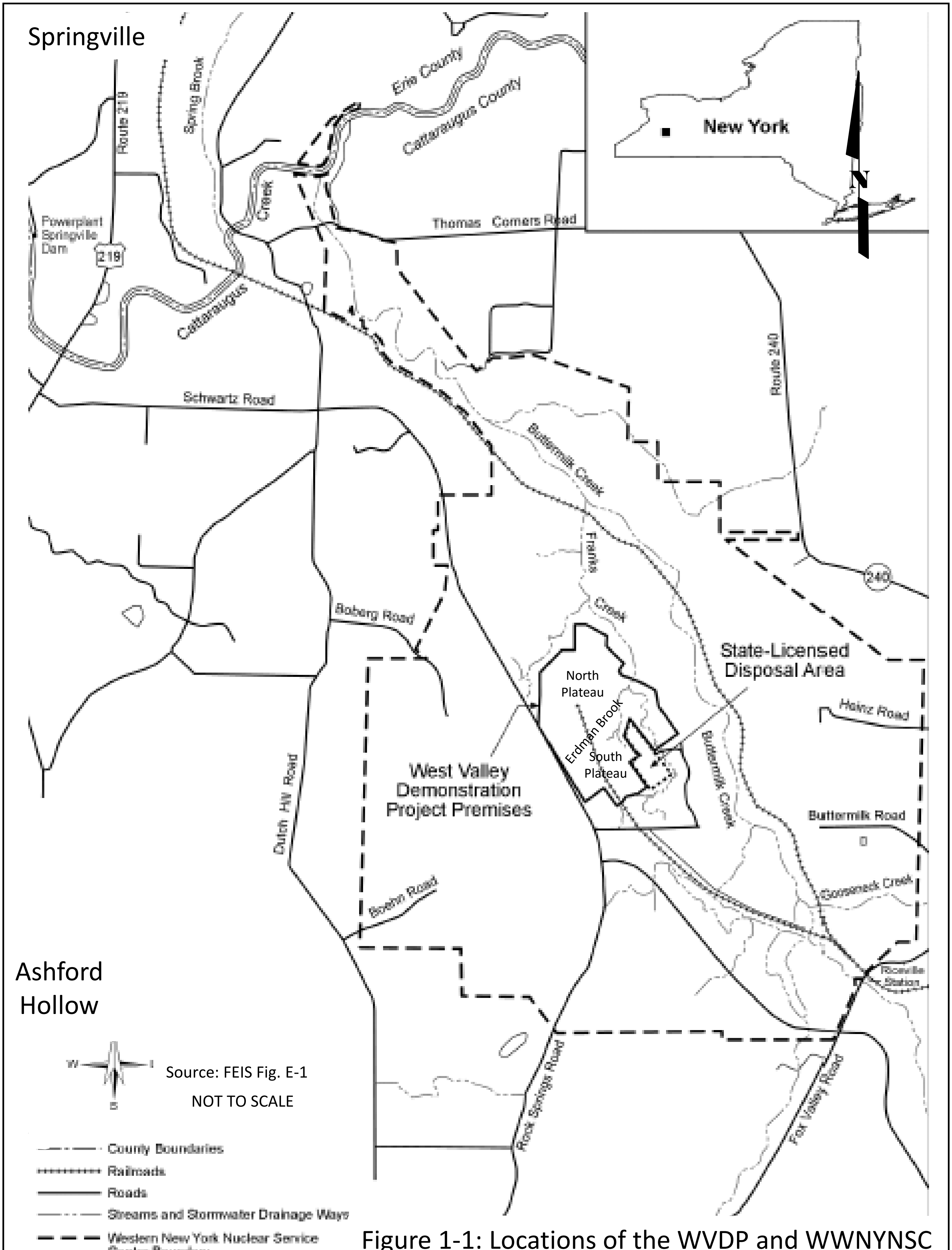


Figure 1-1: Locations of the WVDP and WWNYNSC

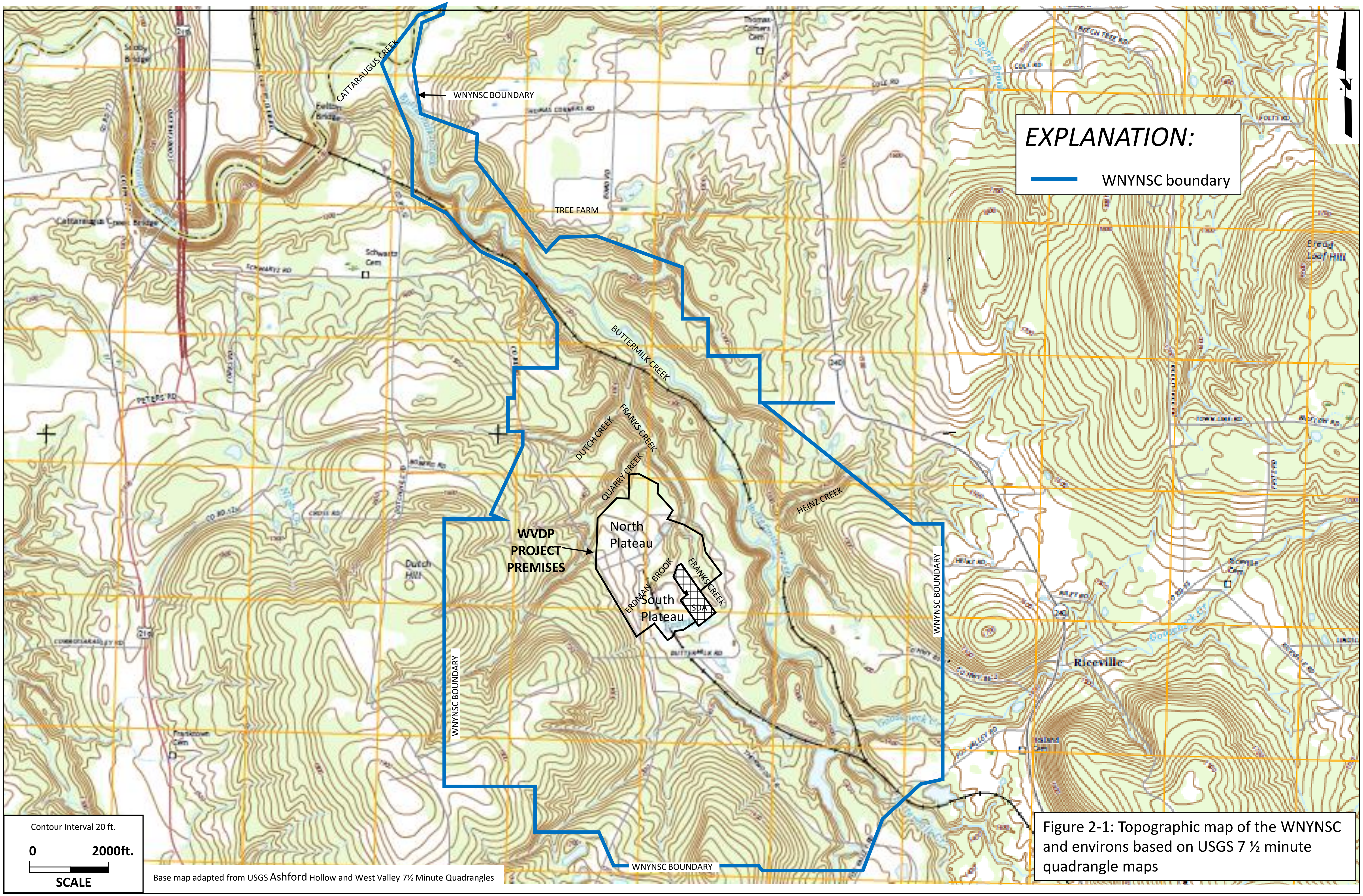


Figure 2-1: Topographic map of the WNYNSC and environs based on USGS 7 ½ minute quadrangle maps

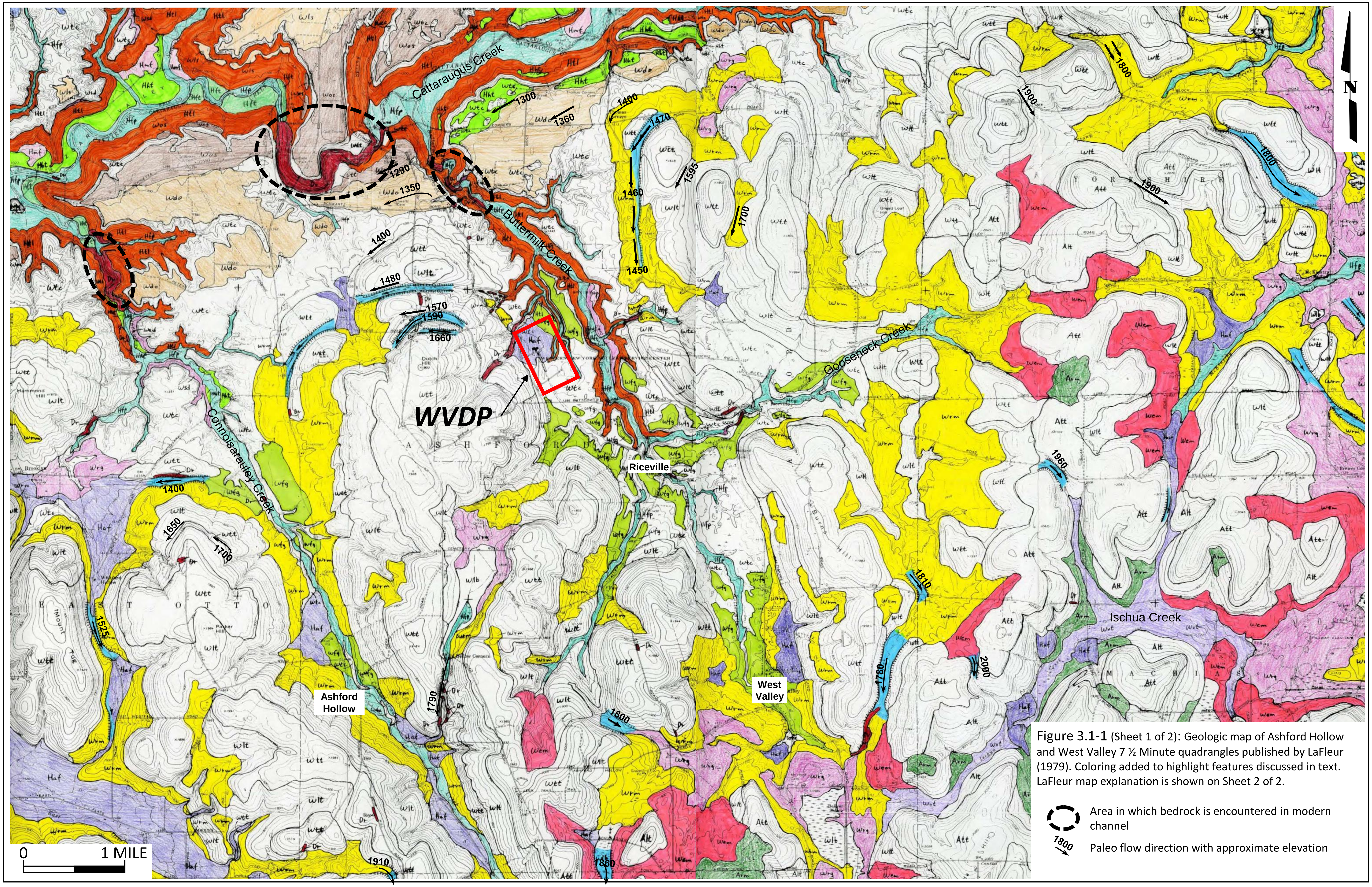
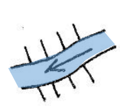


Figure 3.1-1 (Sheet 1 of 2): Geologic map of Ashford Hollow and West Valley 7 ½ Minute quadrangles published by LaFleur (1979). Coloring added to highlight features discussed in text. LaFleur map explanation is shown on Sheet 2 of 2.

	Series	Glaciation	Substage	Moraine or Drift sheet	Symbol	EXPLANATION
QUATERNARY	HOLOCENE				Hfp	Flood plain; gravel, silt alluvium
QUATERNARY	HOLOCENE				Hmf	Mudflows; pebbly silt, marginal to flood plains, derived from clayey till (Wtc)
QUATERNARY	HOLOCENE				Htl	Landslides, slumps; developed on exposures of clayey till (Wtc)
QUATERNARY	HOLOCENE				Hft	Low terraces of Cattaraugus Creek and tributaries; ferruginous gravel and silt, wood bearing
QUATERNARY	HOLOCENE				Hht	High terraces of Cattaraugus Creek and tributaries; younger terraces underlain by ferruginous gravel and silt alluvium, wood bearing; older terraces, commonly developed on dissected outwash gravel, are in part of Woodfordian age.
QUATERNARY	HOLOCENE				Haf	Alluvial fans; channery gravel, sand
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	LAKE ESCARPMENT	Wos	Late outwash; pebble gravel, sand; incised into earlier outwash
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	LAKE ESCARPMENT	Wog	Outwash; cobble gravel, sand
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	LAKE ESCARPMENT	Wls	Lacustrine sand, silt, some pebble gravel
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	LAKE ESCARPMENT	Wkg	Ice-contact cobble gravel, sand; kamic
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	DEFIANCE	Wdo	Outwash; pebble gravel, sand; along ice margin, westward draining, overlying clayey till (Wtc)
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	DEFIANCE	Wfg	Fluvial gravel, sand, derived from upland drainage, hummocky where laid over thin ice; overlies clayey till (Wtc)
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	LAVERY	Wtc	Till, clayey with pebbles and cobbles; deformed silt stringers, minor over-ridden pebble gravel, sand; mainly reworked lacustrines. May include Hiram equivalent till in upper few feet
				Erie Interstade		
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	KENT	Wrg/ Wsd	Ice-contact gravel, sand; kame terraces (Wrg). Recessional kame delta sand, silt, clay (Wsd) beneath clayey till (Wtc)
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	KENT	Wrm	Ground moraine; mixed stony till, stratified drift; ice marginal
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	KENT	Wem	End moraine; mixed gravel, sand, till; distal limit of bright stratified drift
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	KENT	Wvt	Valley train; outwash gravel, sand; distally from bright drift limit
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	KENT	Wlb	Lacustrine silt, clay; bordering end and recessional moraines; includes later bogs
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	KENT	Wlt	Lodgment till, >5' thick; stony, silty, variously bright and drab
QUATERNARY	PLEISTOCENE	WISCONSINAN	WOODFORDIAN?	KENT	Wtt	Lodgment till, <5' thick; occasional rock outcrop
QUATERNARY	PLEISTOCENE	WISCONSINAN	ALTONIAN?	OLEAN	Atc	Colluvium; till, talus
QUATERNARY	PLEISTOCENE	WISCONSINAN	ALTONIAN?	OLEAN	Als	Lacustrine silt, clay; marginal to ice-contact deposits
QUATERNARY	PLEISTOCENE	WISCONSINAN	ALTONIAN?	OLEAN	Arm	Ice-contact gravel, sand; ground moraine; drab
QUATERNARY	PLEISTOCENE	WISCONSINAN	ALTONIAN?	OLEAN	Alt	Lodgment, ablation till, stony, silty; >3' thick, drab
QUATERNARY	PLEISTOCENE	WISCONSINAN	ALTONIAN?	OLEAN	Att	Lodgment, ablation till, <3' thick; frequent rock outcrop
DEVONIAN					Dr	Bedrock outcrop; shales, siltstones, sandstones of the Canadaway and Conneaut Groups (Fisher and others, 1970)



Melt-water channel, with direction of flow

Figure 3.1-1 (Sheet 2 of 2): Explanation of La Fleur symbols depicted on Fig. 3.1-1 Sheet 1 of 2 (From La Fleur 1979).

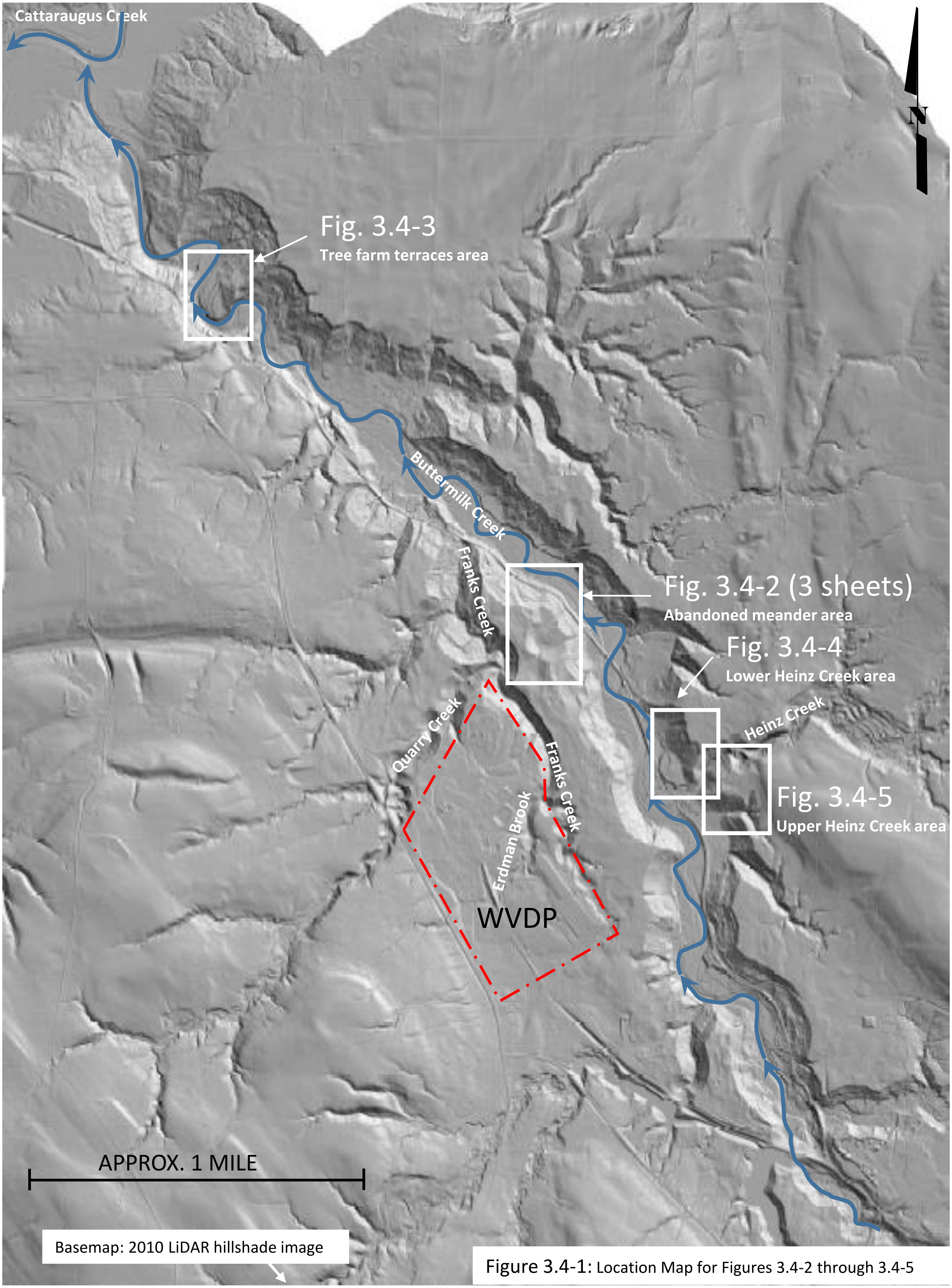


Figure 3.4-1: Location Map for Figures 3.4-2 through 3.4-5

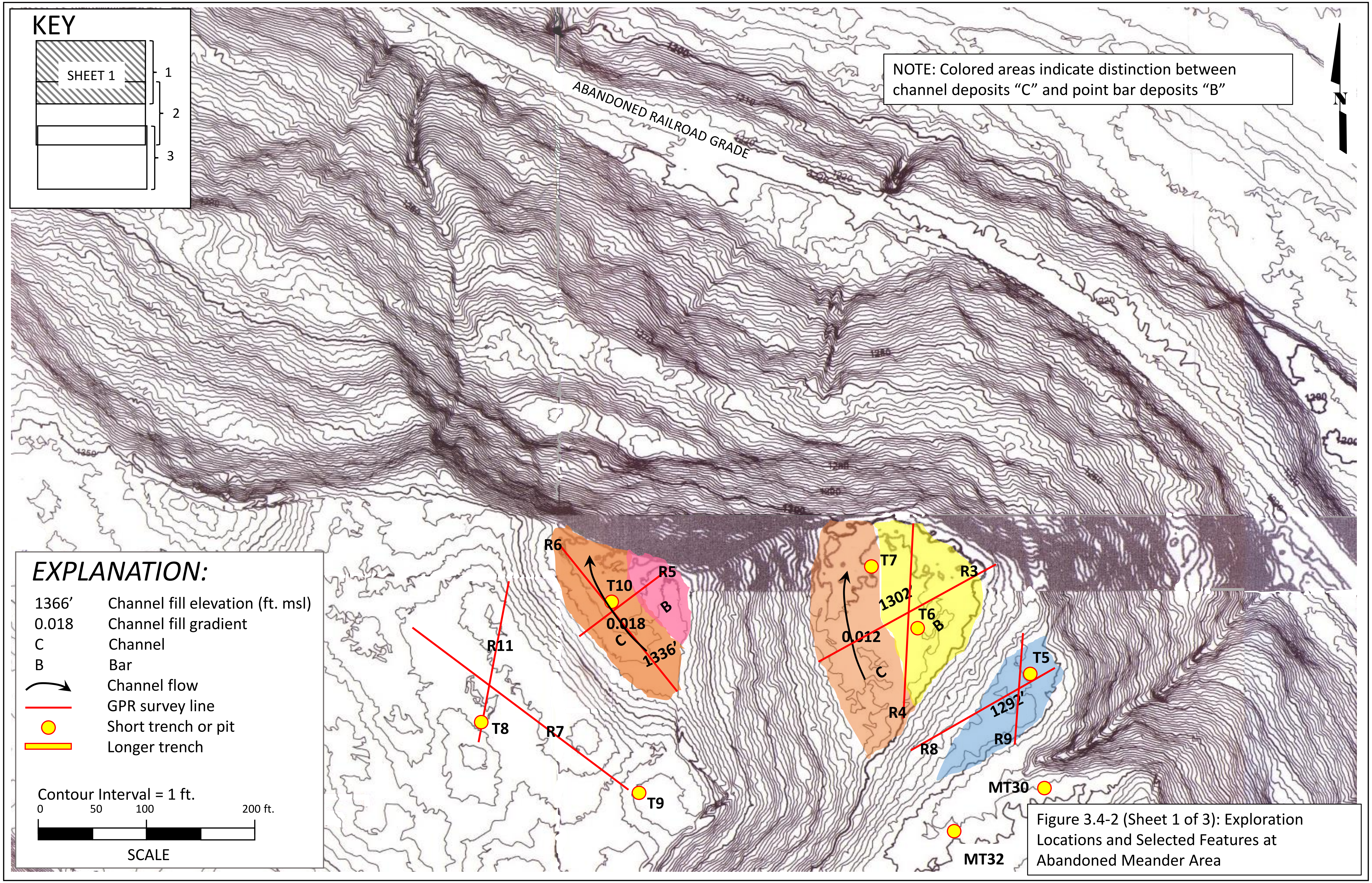


Figure 3.4-2 (Sheet 1 of 3): Exploration Locations and Selected Features at Abandoned Meander Area

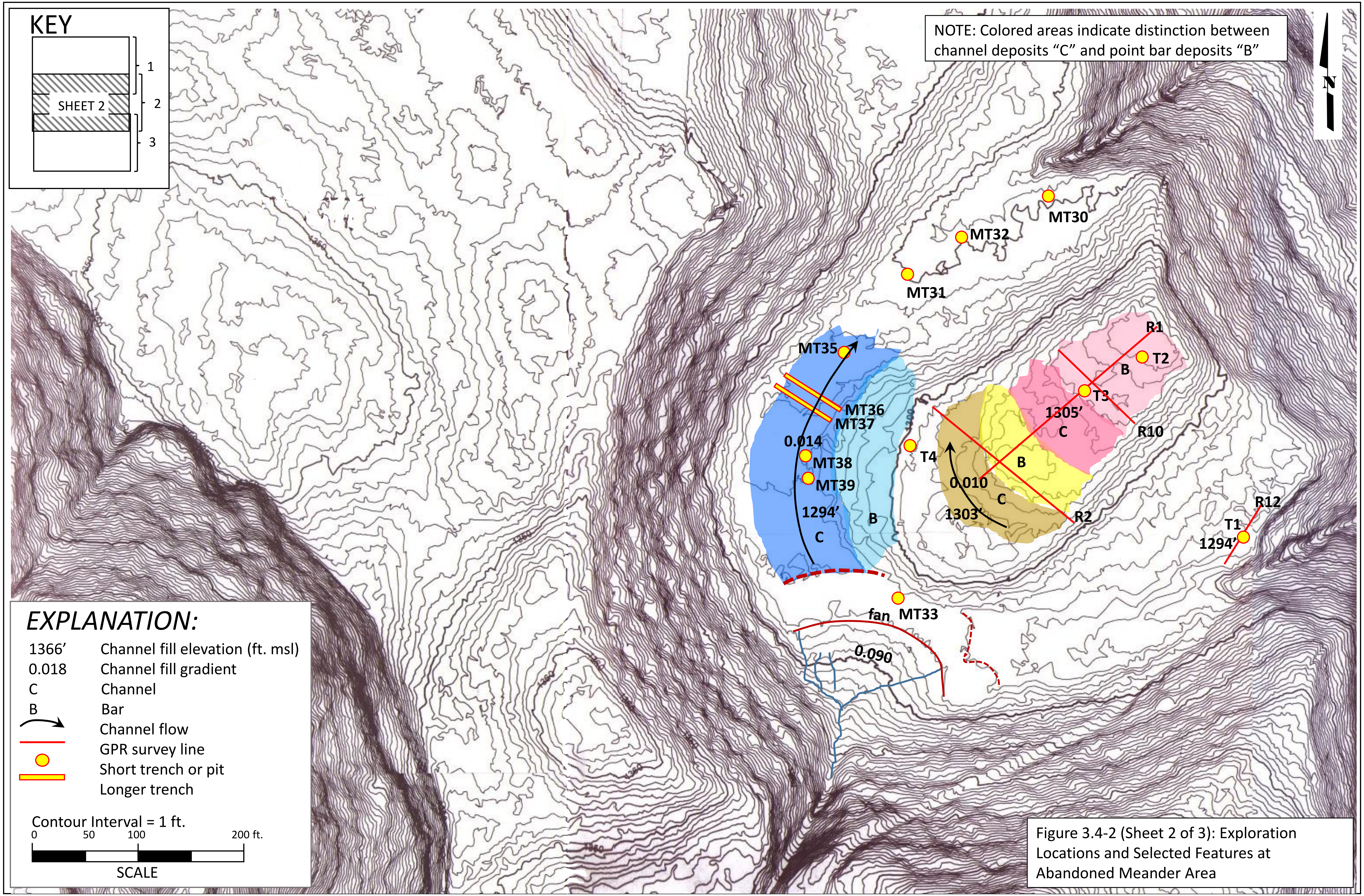


Figure 3.4-2 (Sheet 2 of 3): Exploration Locations and Selected Features at Abandoned Meander Area

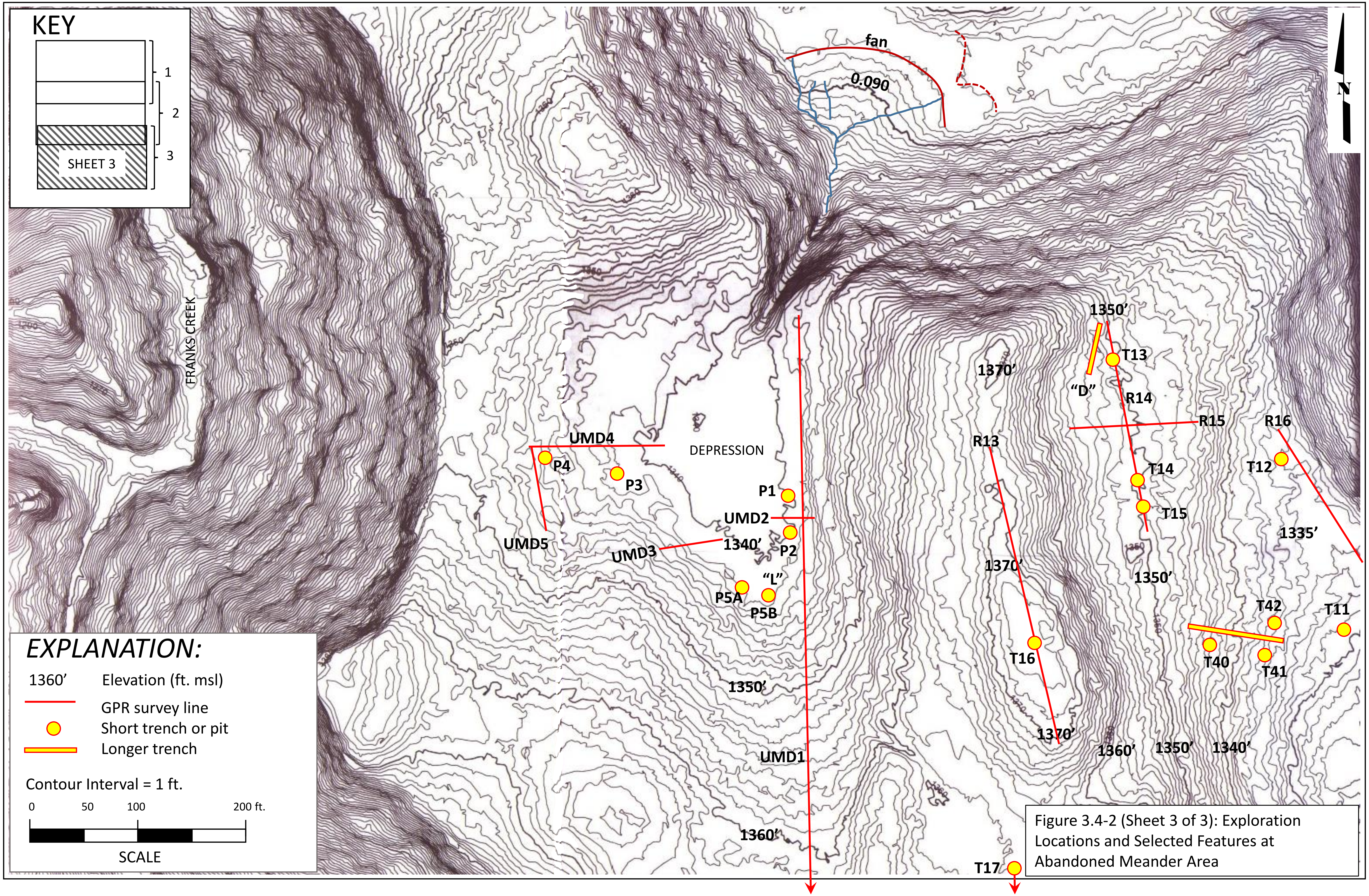


Figure 3.4-2 (Sheet 3 of 3): Exploration Locations and Selected Features at Abandoned Meander Area

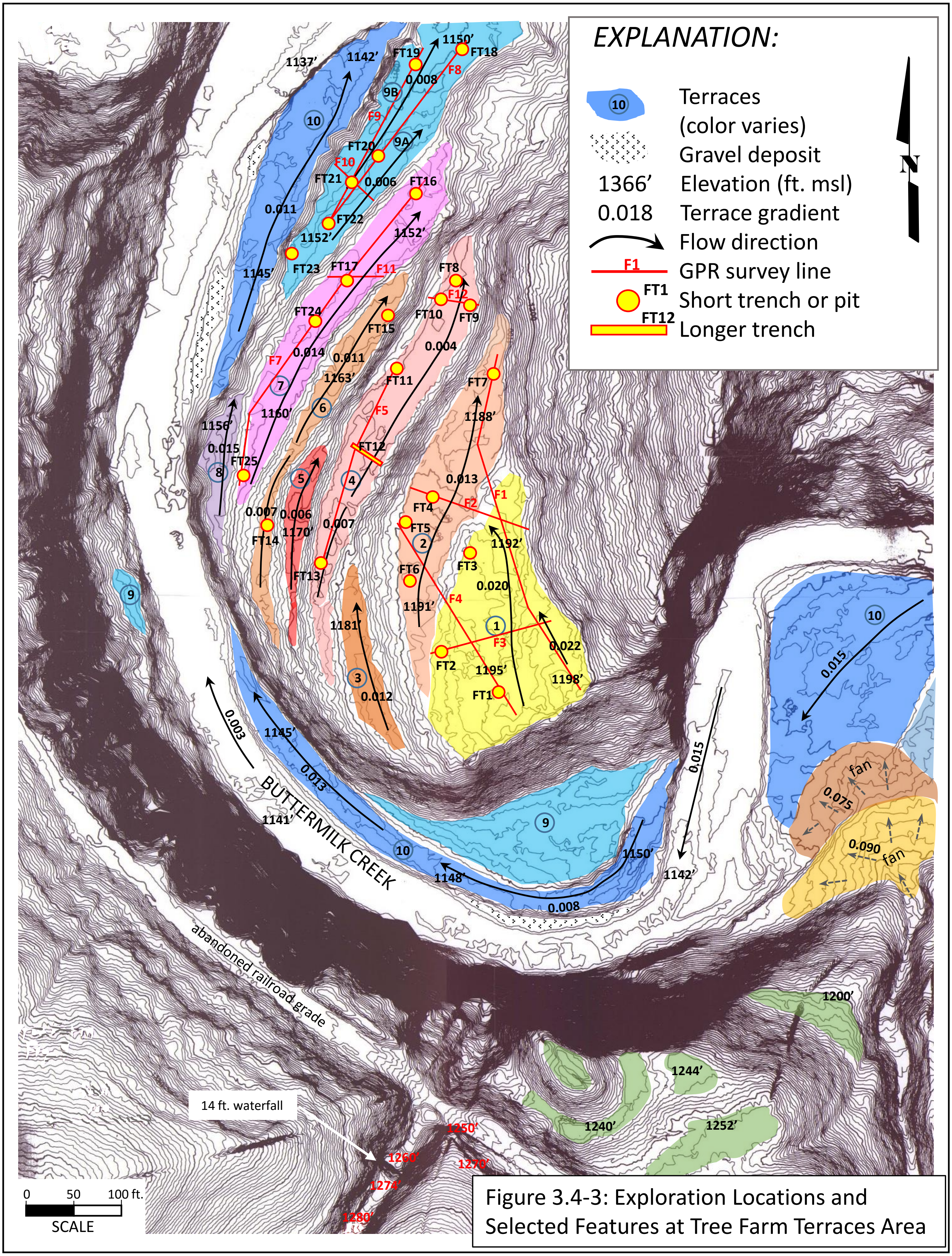


Figure 3.4-3: Exploration Locations and Selected Features at Tree Farm Terraces Area

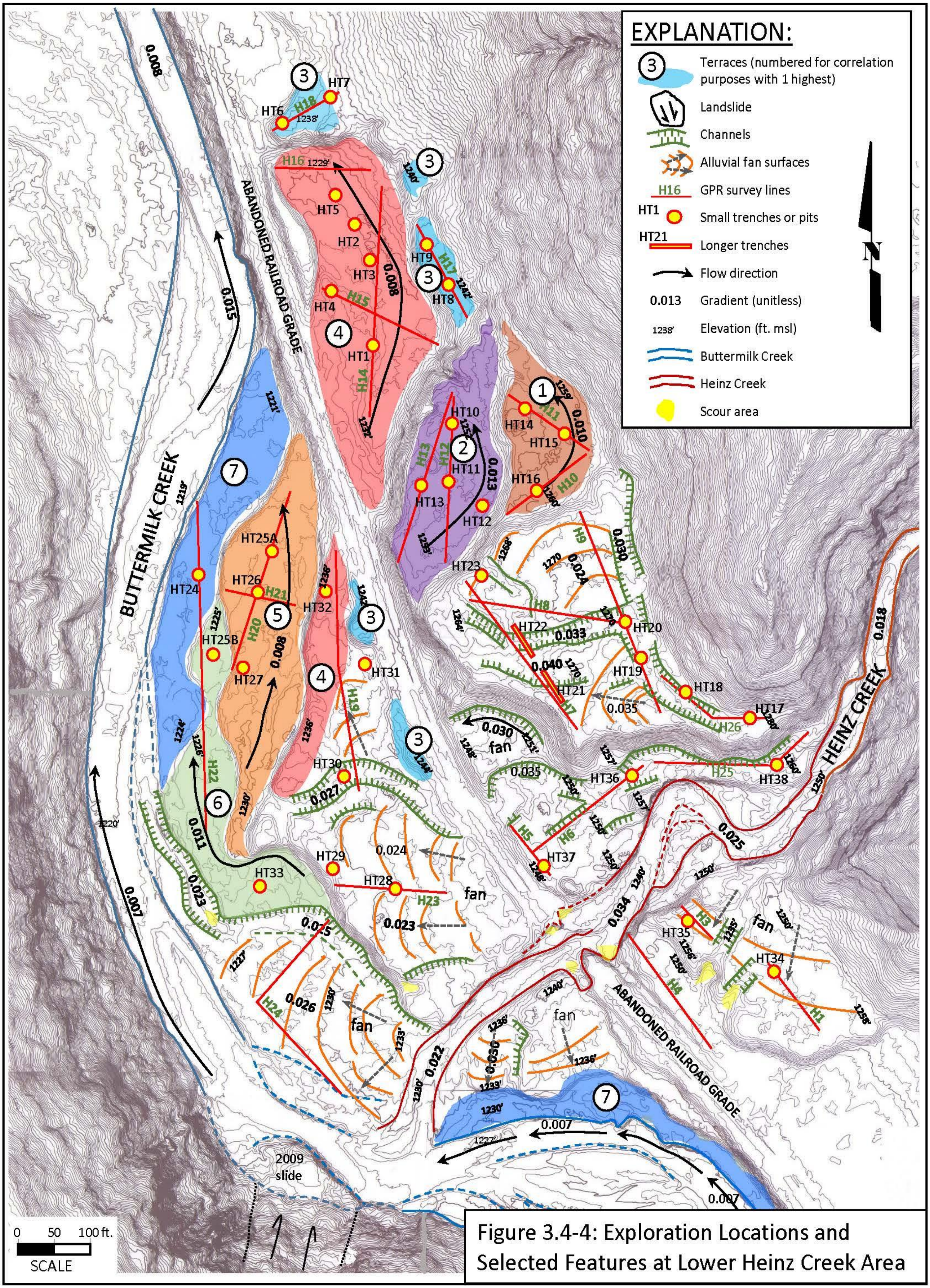


Figure 3.4-4: Exploration Locations and Selected Features at Lower Heinz Creek Area

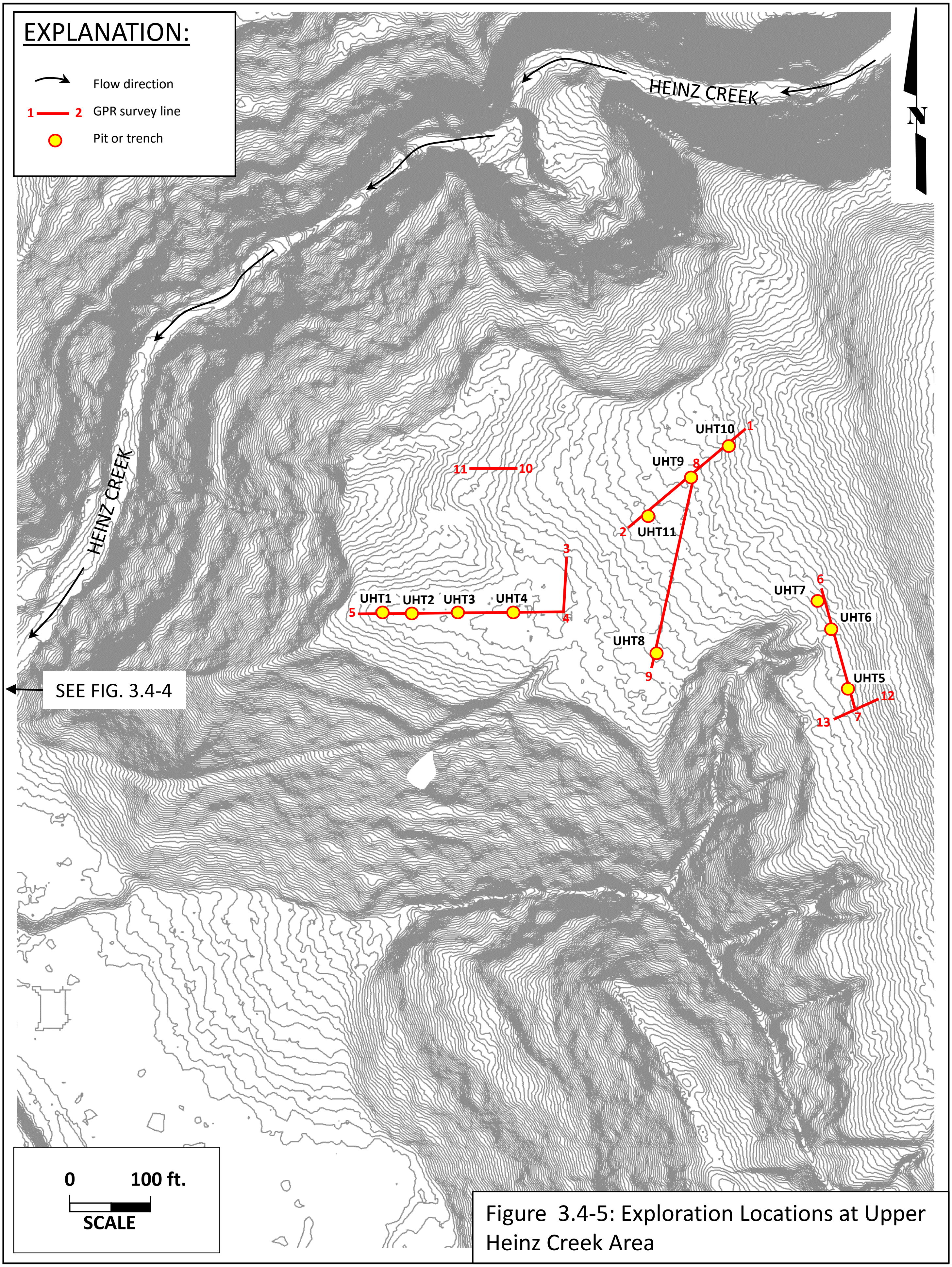


Figure 3.4-5: Exploration Locations at Upper Heinz Creek Area

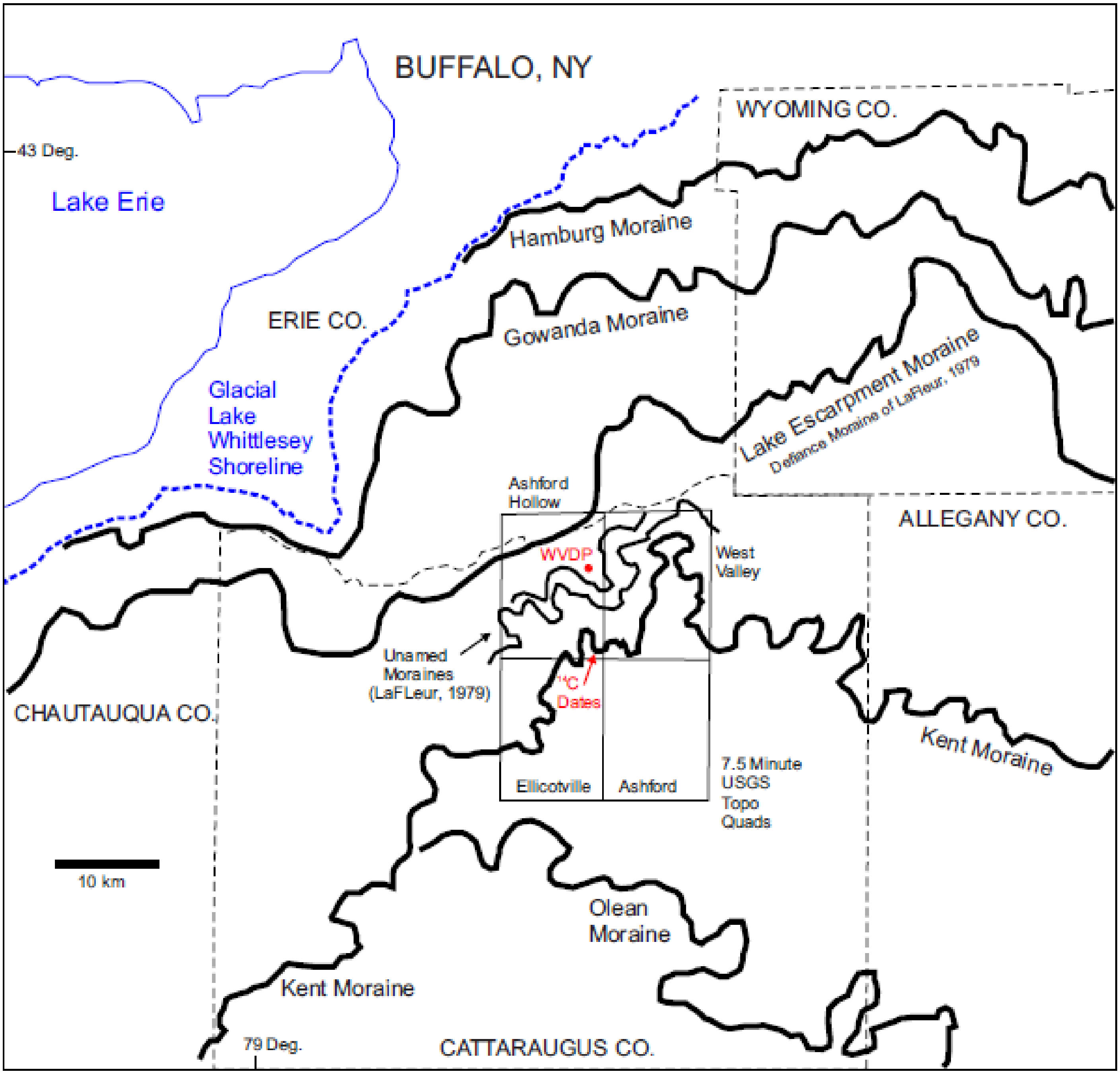


Fig. 4.1-1: Generalized locations of selected glacial moraines and related features modified from Muller (1977), Calkin (1970), and LaFleur (1979) with locations of West Valley Demonstration Project (WVDP) and site of recently discovered logs dated as circa 13,000 kya (calendar years) excavated on the presumed Kent moraine located in the southeast corner of Ashford Hollow Quadrangle. Similarly dated wood samples were collected in a glacial depression near the abandoned meander at the WVDP site. Issues: The Kent till in PA and OH is considered to be approximately 23,000 years old and to predate the Erie Interstade (circa 16,000), as well as being older than the Lavery till. The Hamburg Moraine has previously been considered to be equivalent to the Port Huron advance to the west, which is considered to be between 12,000 and 13,000 years old.

Figure 4.1-1: Pleistocene Glacial Features of Western New York

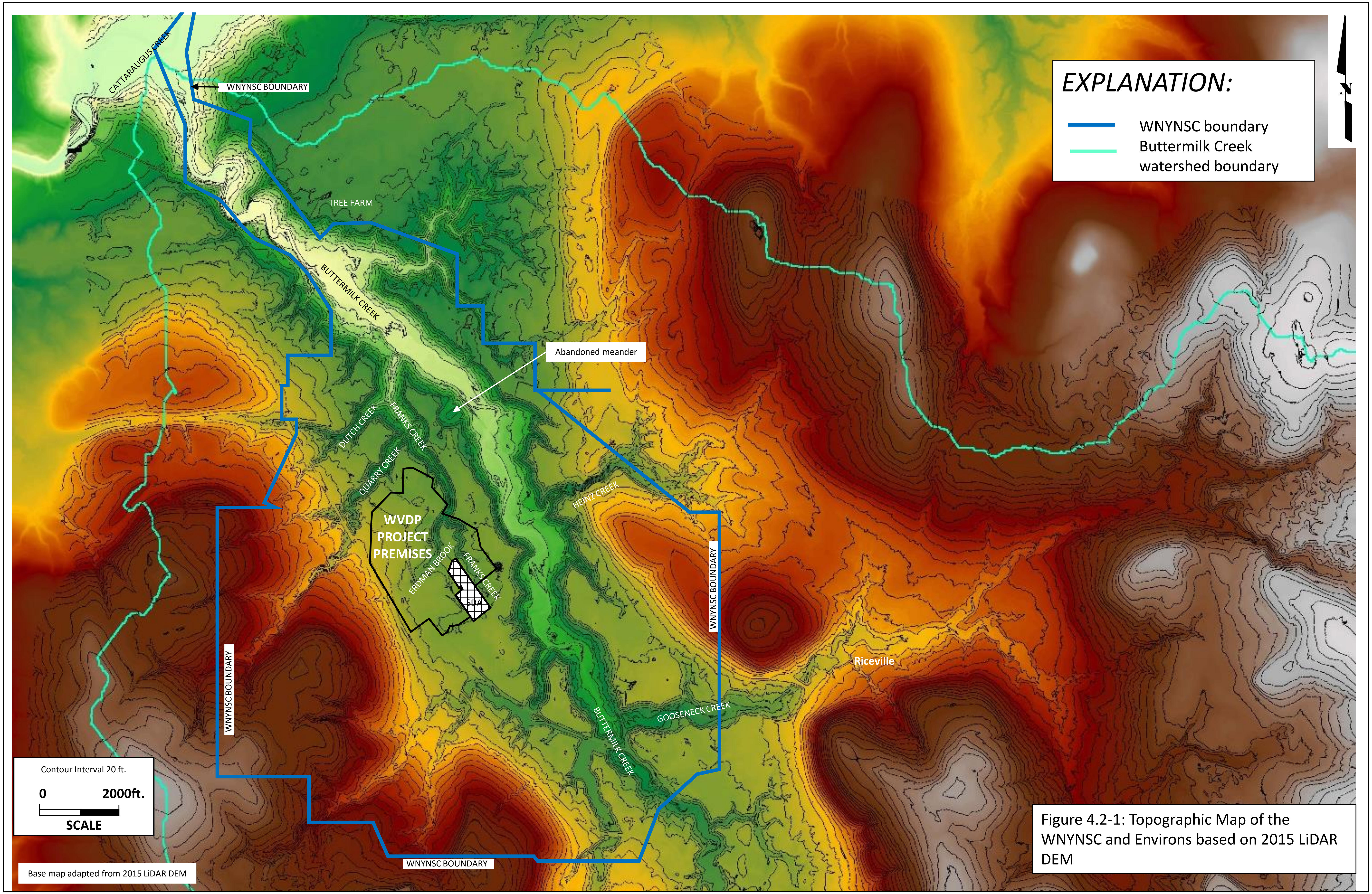


Figure 4.2-1: Topographic Map of the WNYNSC and Environs based on 2015 LiDAR DEM

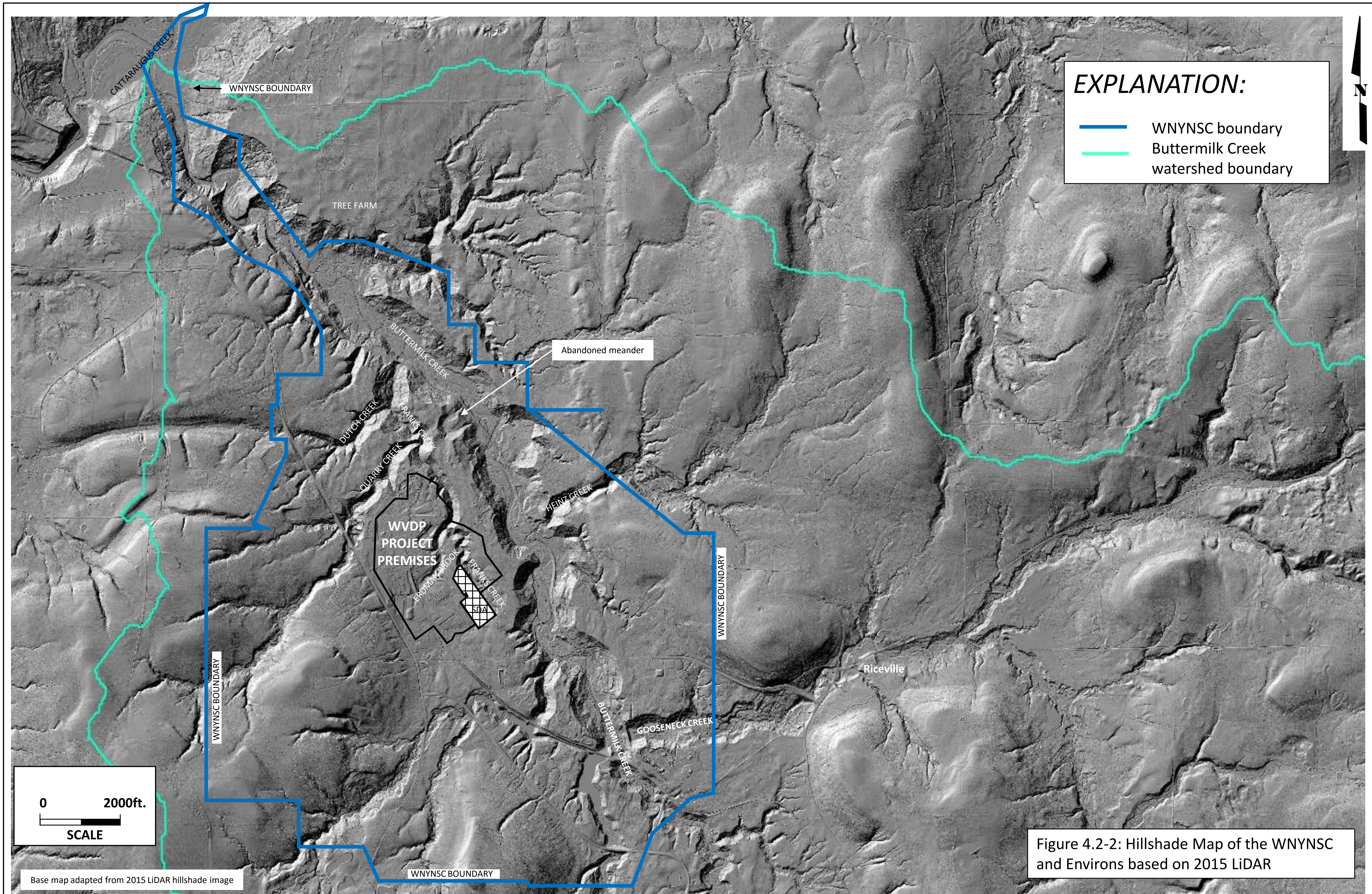


Figure 4.2-2: Hillshade Map of the WNYNSC and Environs based on 2015 LiDAR

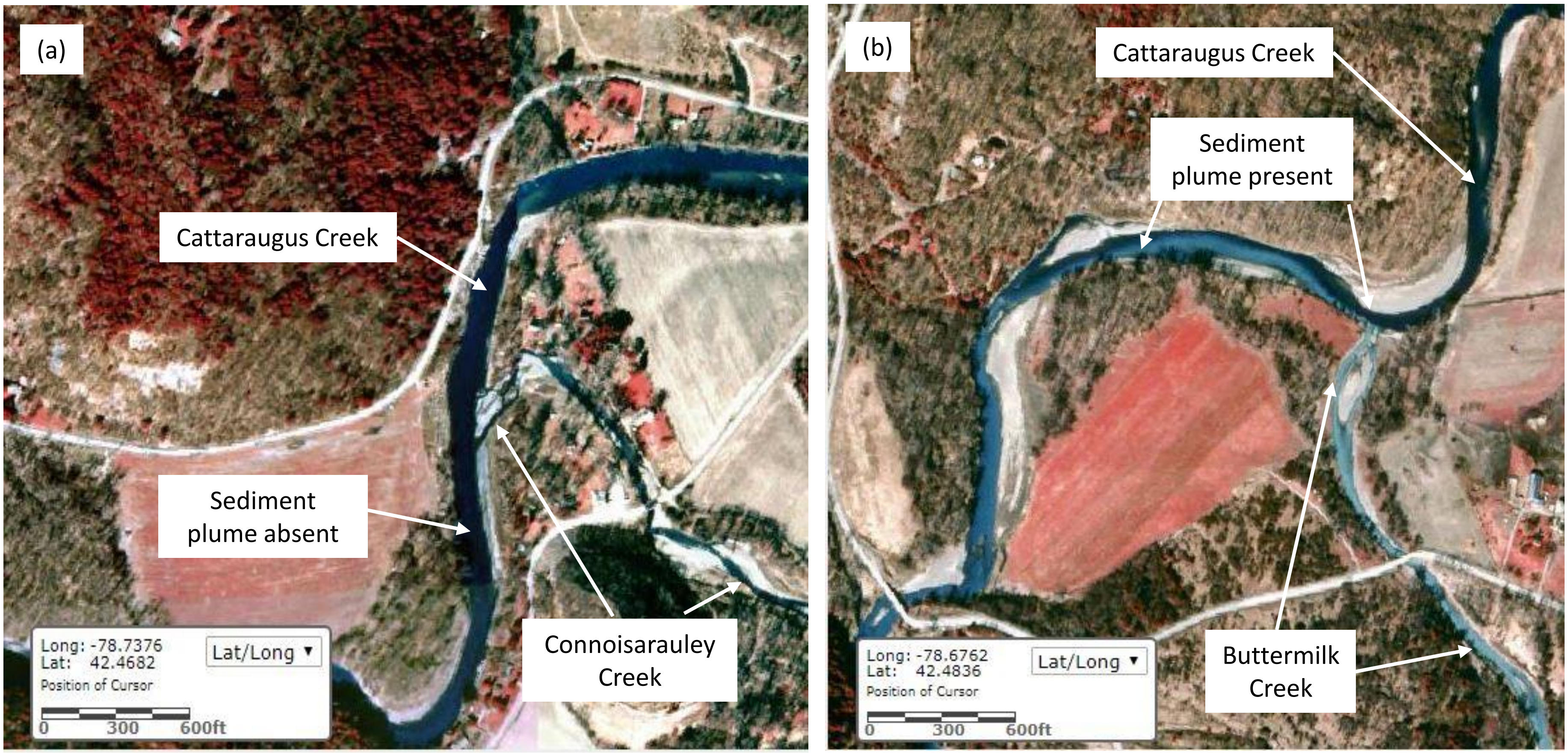


Figure 4.2-3: Color Infrared Images of Contrasting Sediment Load – Connoisarauley Creek (a) versus Buttermilk Creek (b). Both images dated 1994.

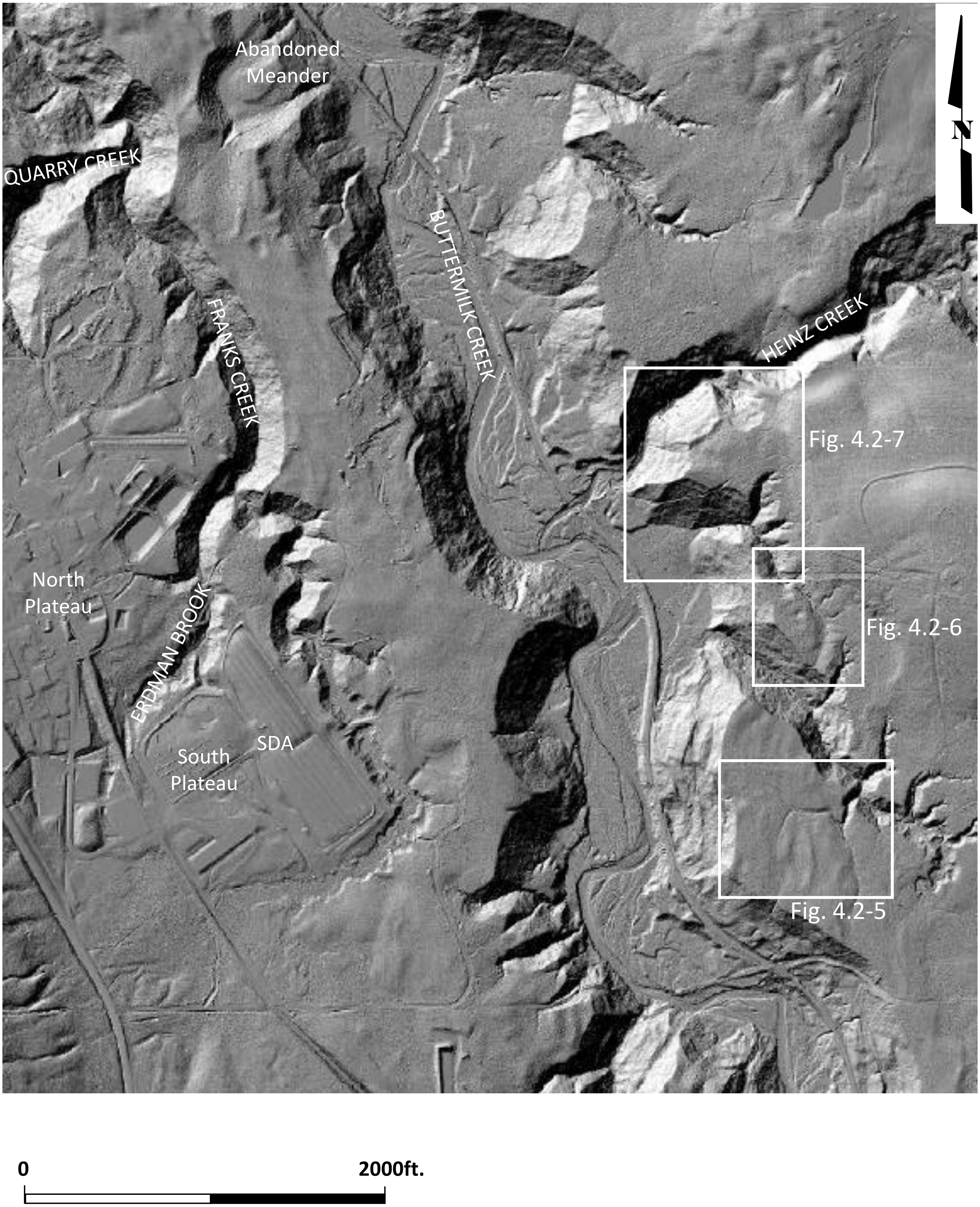
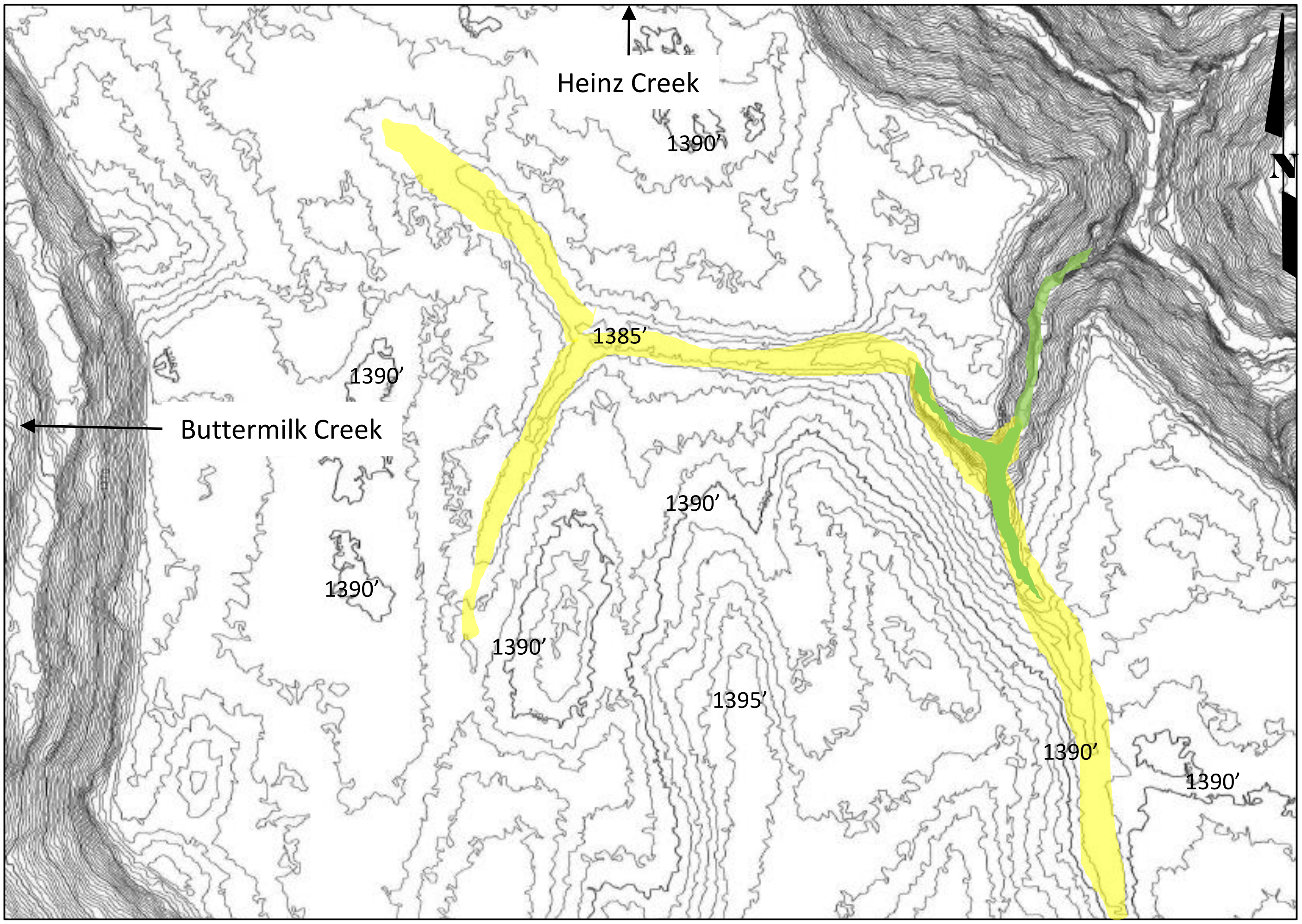


Figure 4.2-4: Location Map for Figures 4.2-5 through 4.2-7



EXPLANATION:

Late Pleistocene drainage

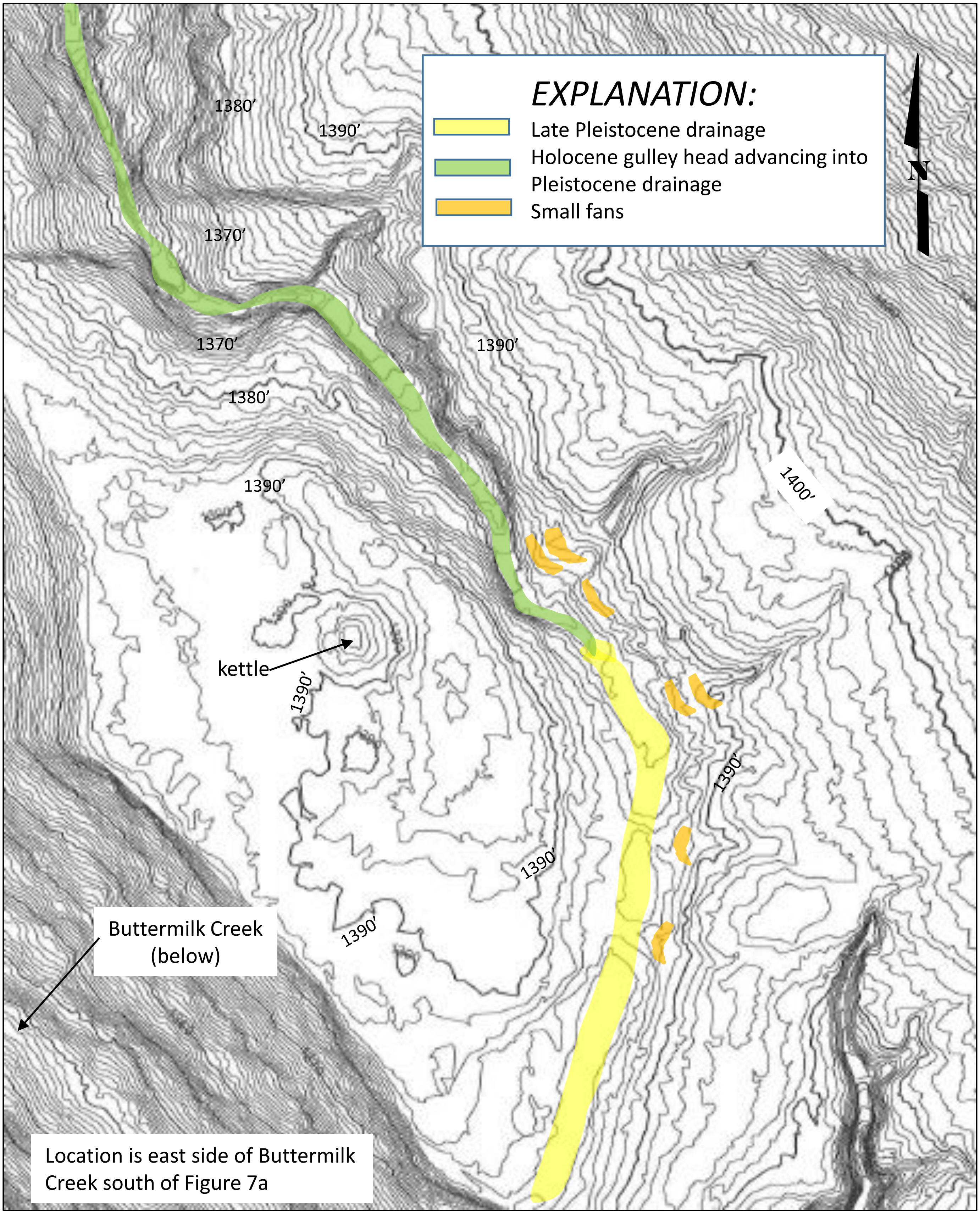
Holocene gulley head advancing into Pleistocene drainage

See Figure 4.2-3 for location of figure

0 **200ft.**

APPROX. SCALE

Figure 4.2-5: Example 1 of Remnant Late Pleistocene Valley Floor Drainage with Holocene Gully Head



See Figure 4.2-3 for location of figure

0 100ft.

APPROX. SCALE

Figure 4.2-6: Example 2 of Remnant Late Pleistocene Valley Floor Drainage with Holocene Gully Head

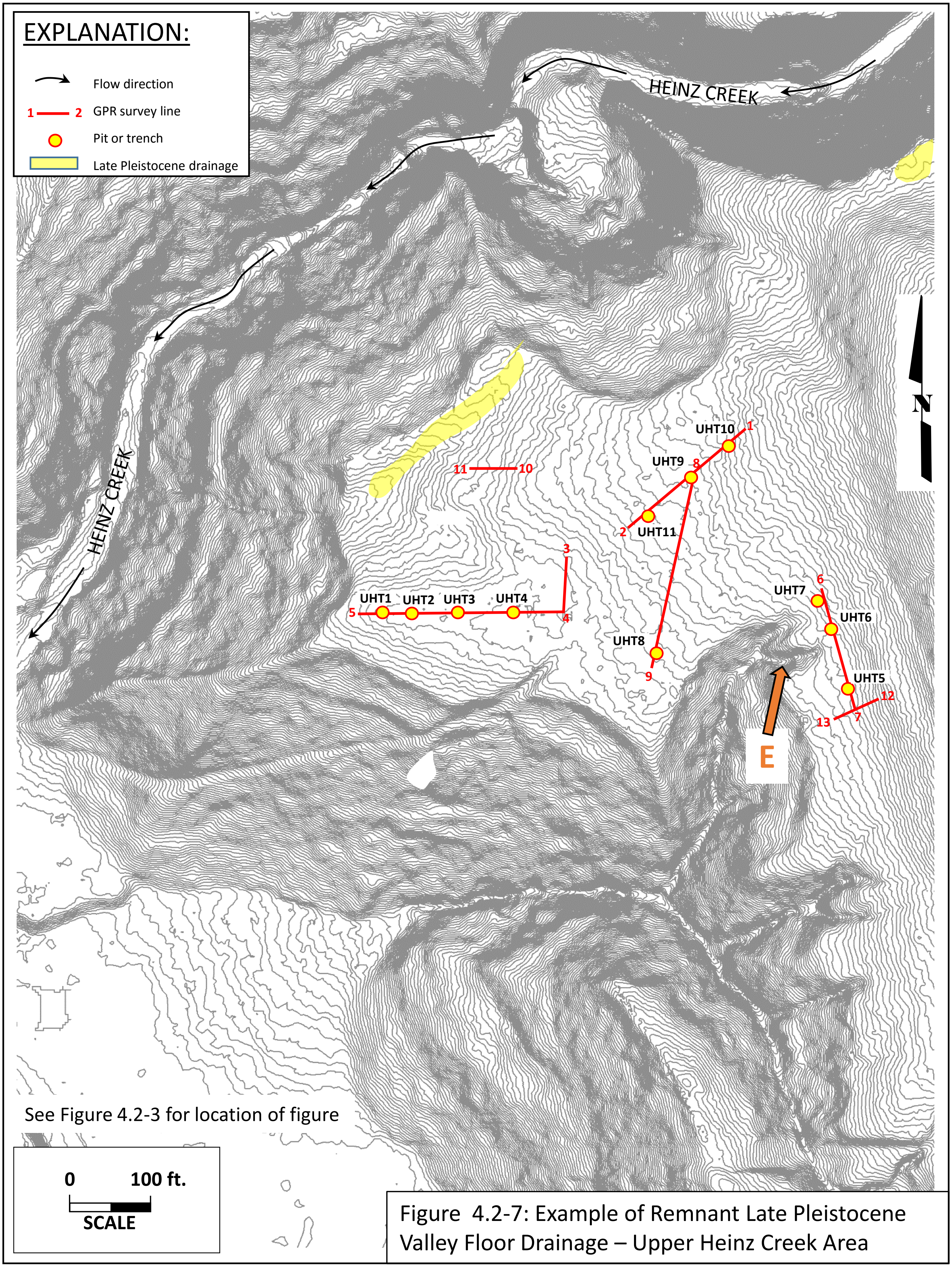


Figure 4.2-7: Example of Remnant Late Pleistocene Valley Floor Drainage – Upper Heinz Creek Area

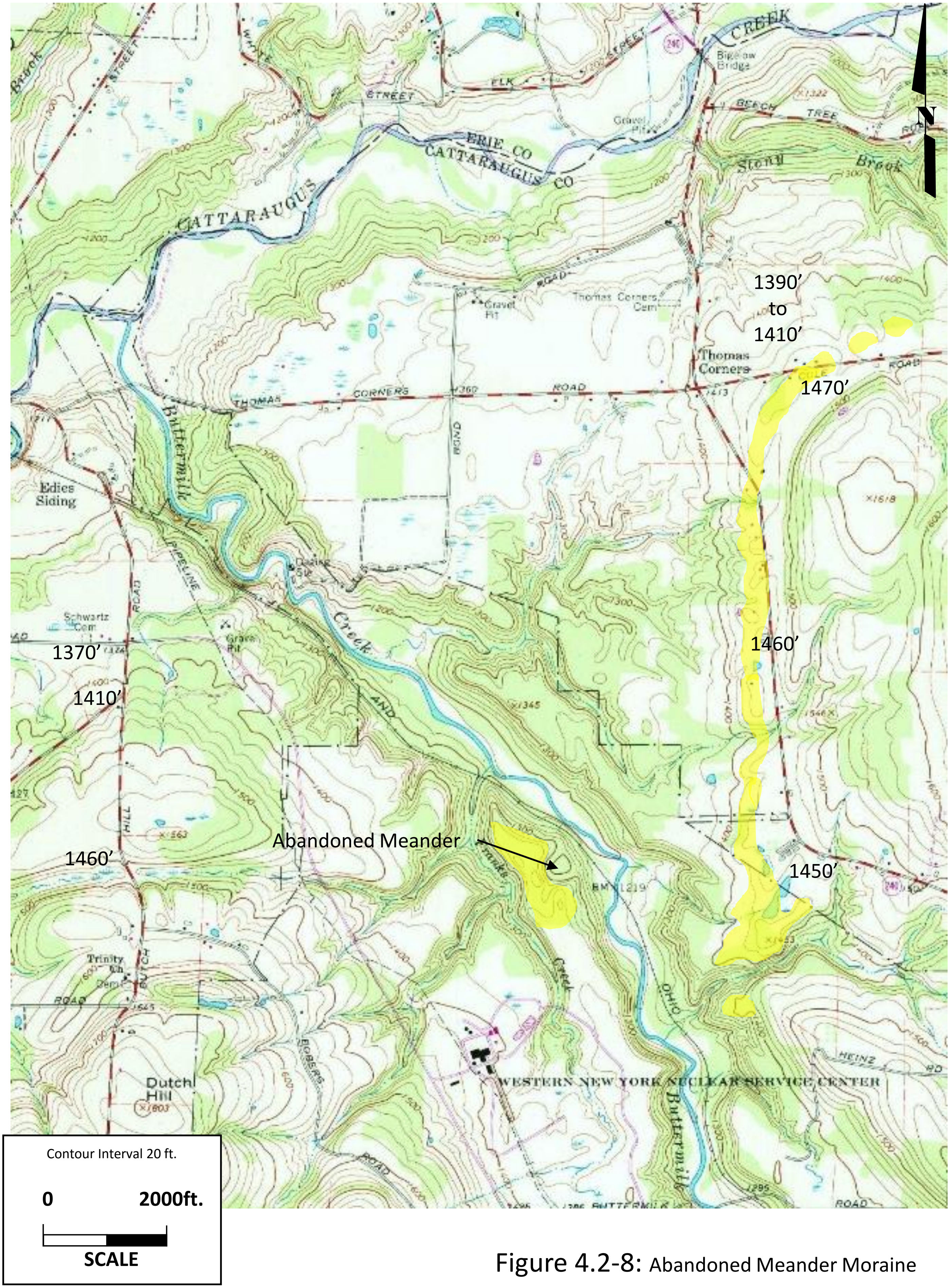
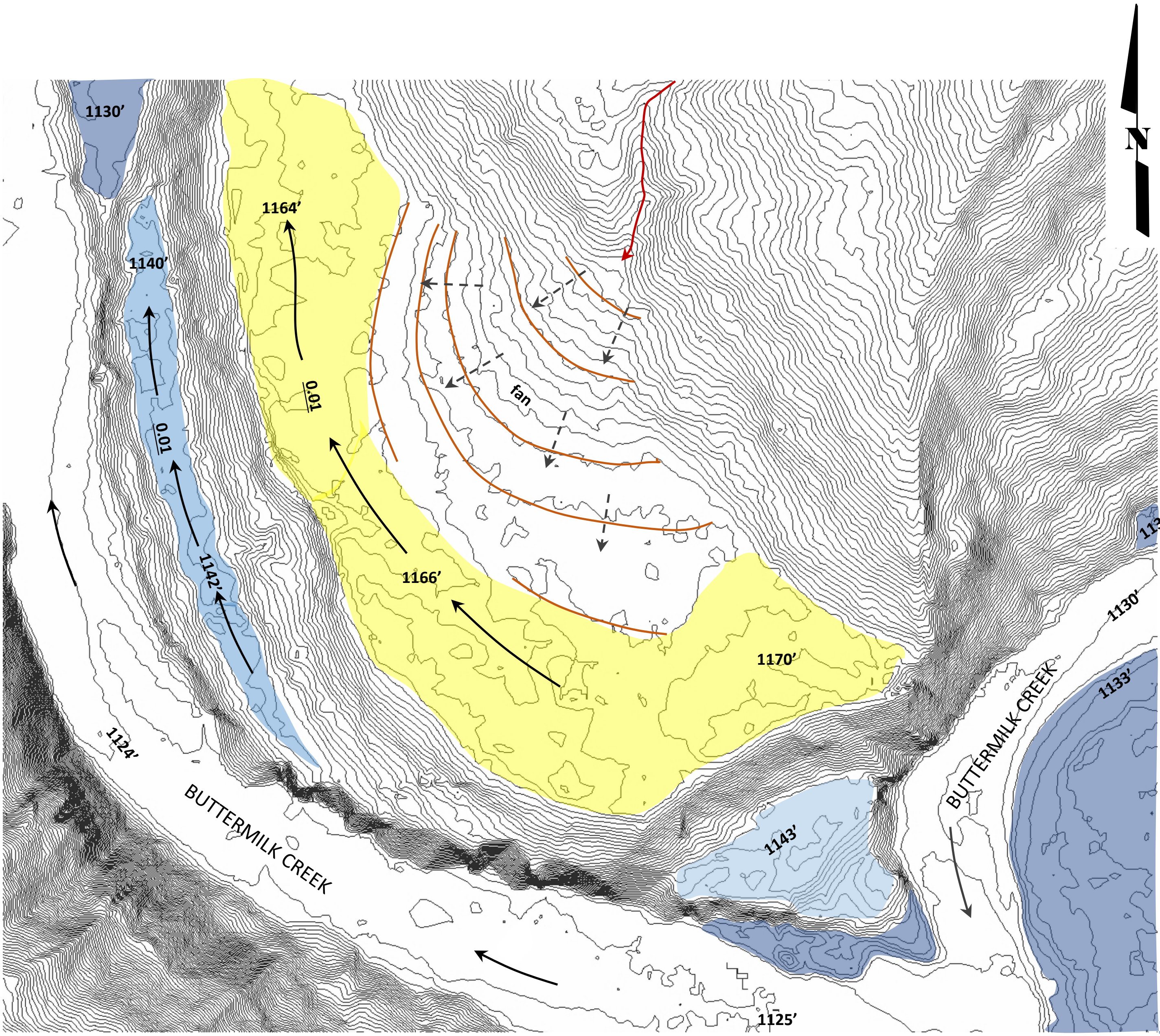


Figure 4.2-8: Abandoned Meander Moraine



EXPLANATION:

Terraces (color varies)
Alluvial fan surfaces
Flow direction
1164' Elevation (ft.)
0.013 Gradient (unitless)

See Figure 3.3-1 for location of Buttermilk Creek outlet terraces

0 **100 ft.**
SCALE

Figure 4.2-9: Selected Features at Buttermilk Creek Outlet Terraces Area

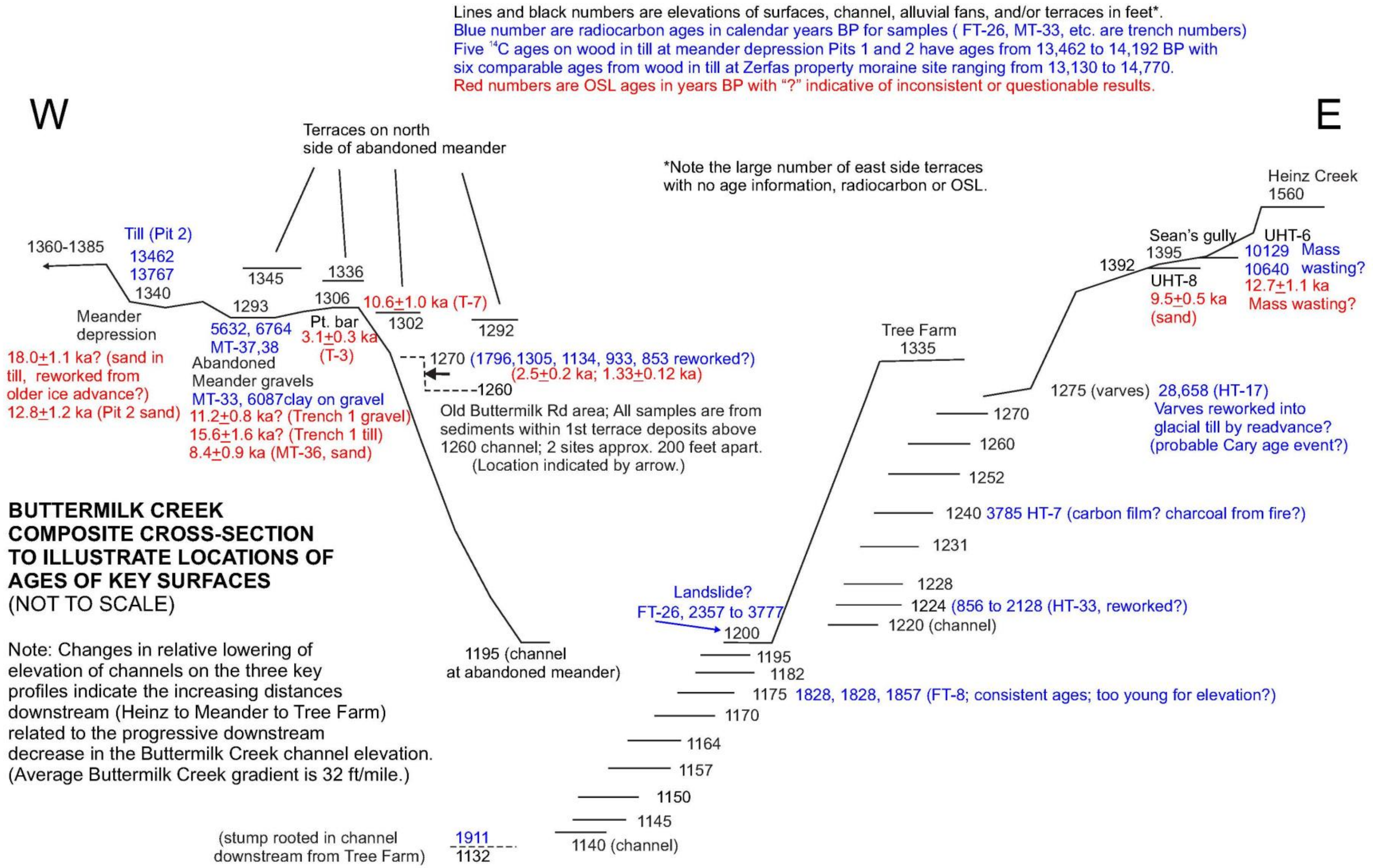


Figure 4.3-1: Schematic Cross-Sectional Diagram of Terraces

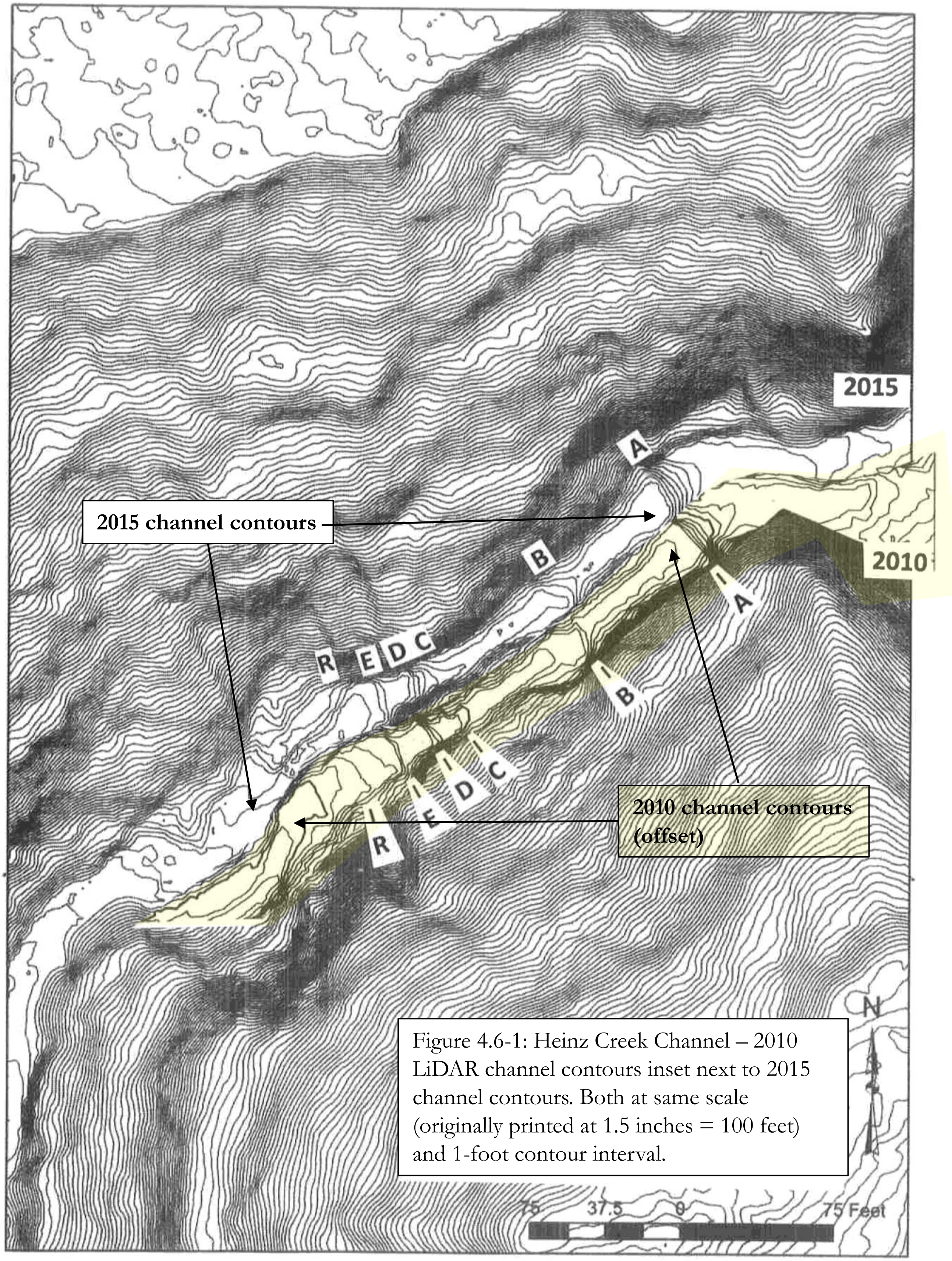


Figure 4.6-1: Heinz Creek Channel – 2010 LiDAR channel contours inset next to 2015 channel contours. Both at same scale (originally printed at 1.5 inches = 100 feet) and 1-foot contour interval.

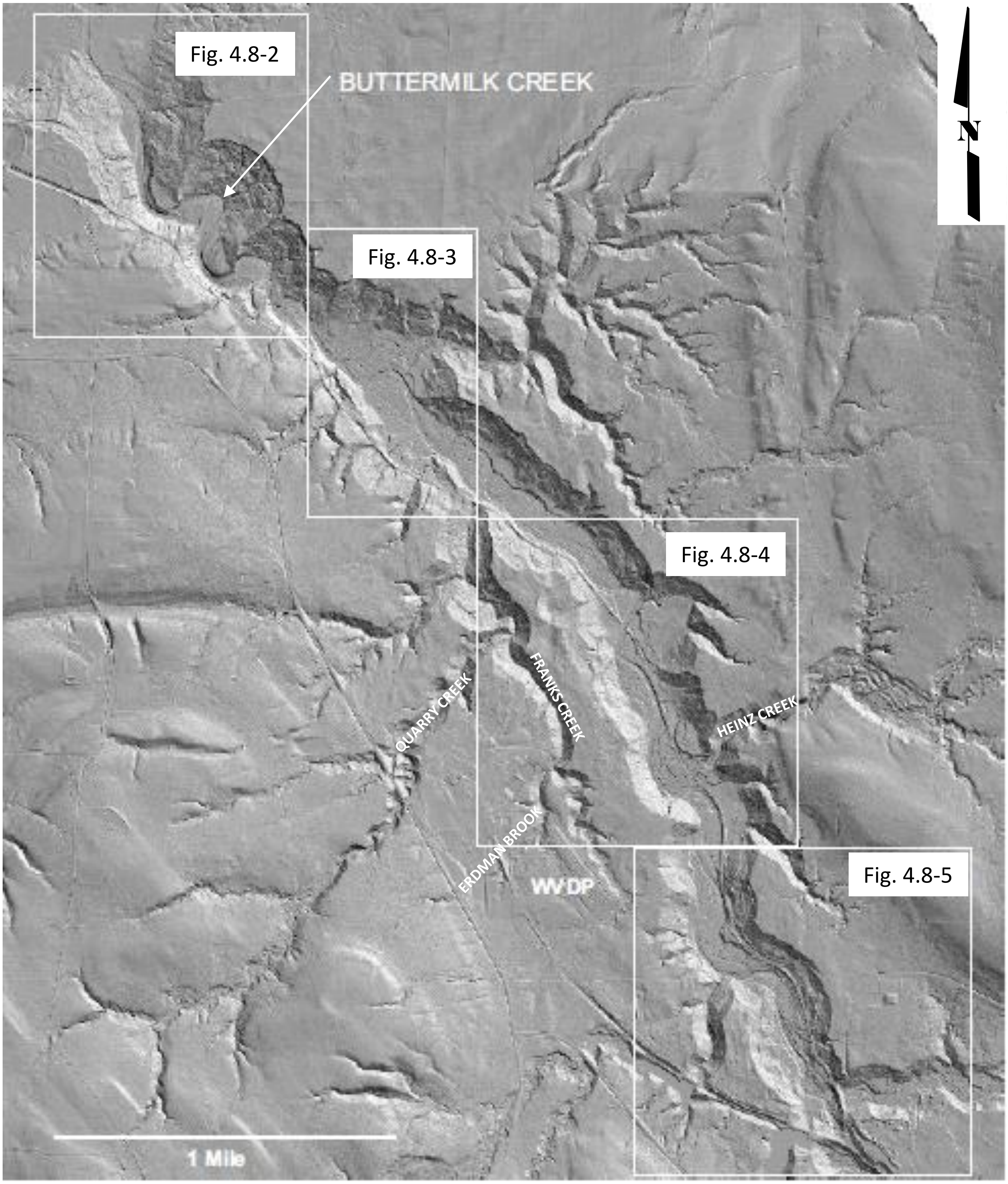


Figure 4.8-1: Location Map for Figures 4.8-2 through 4.8-5

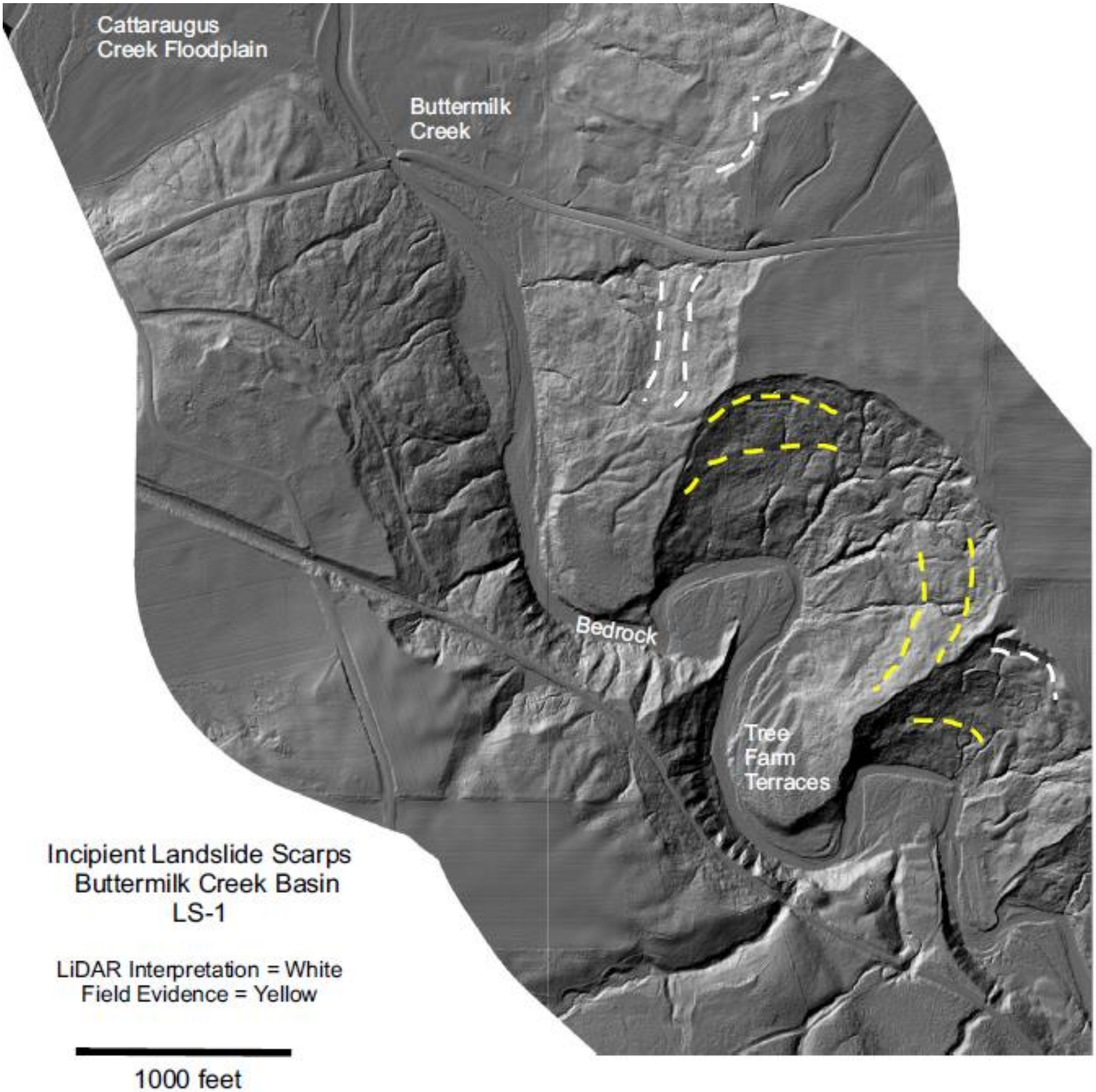
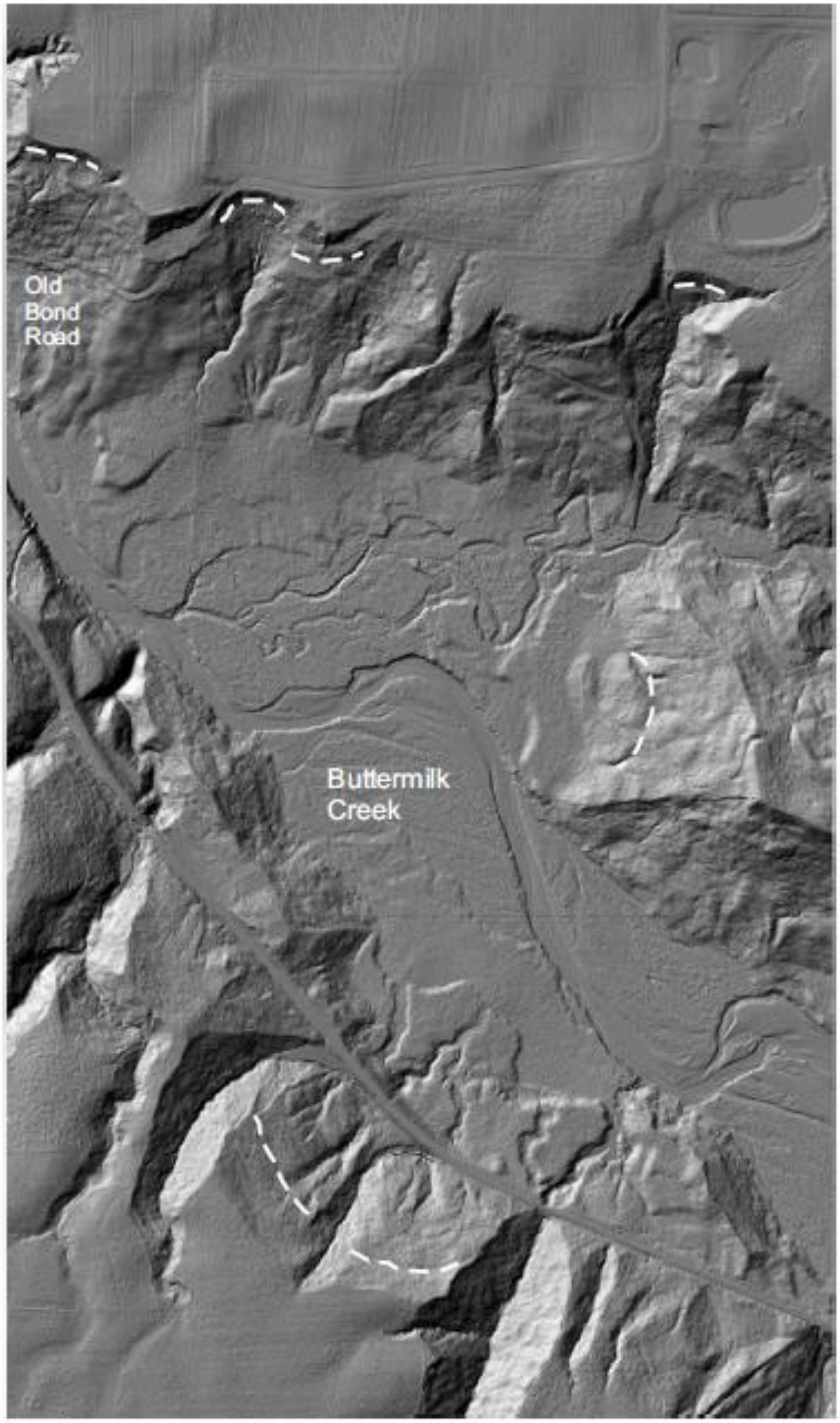


Figure 4.8-2: Incipient Landslide Scarps (1 of 4)



Incipient Landslide Scarps
Buttermilk Creek Basin
LS-2
LiDAR Interpretation (White)
Field Evidence (Yellow)

1000 feet

Figure 4.8-3: Incipient Landslide Scarps (2 of 4)

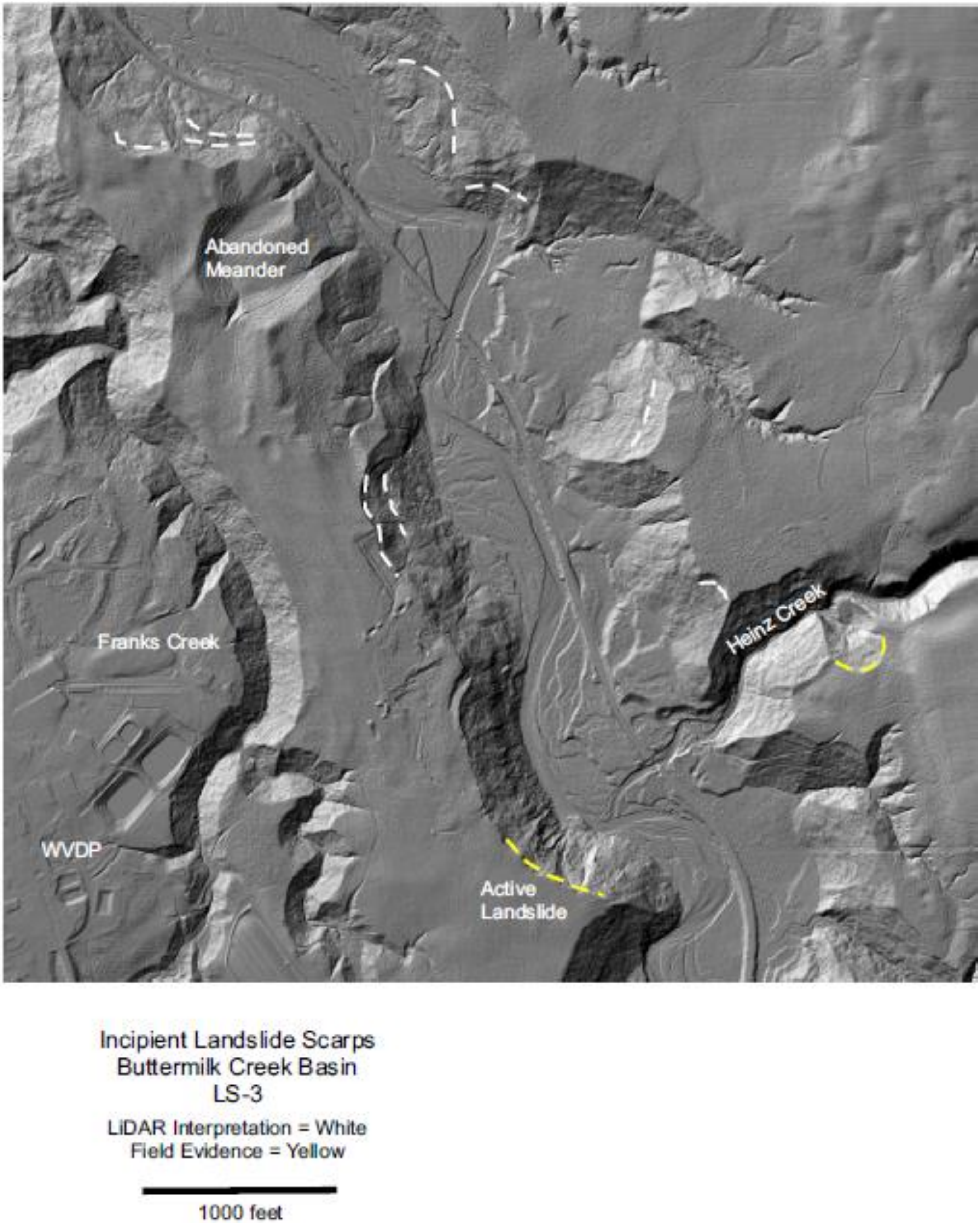
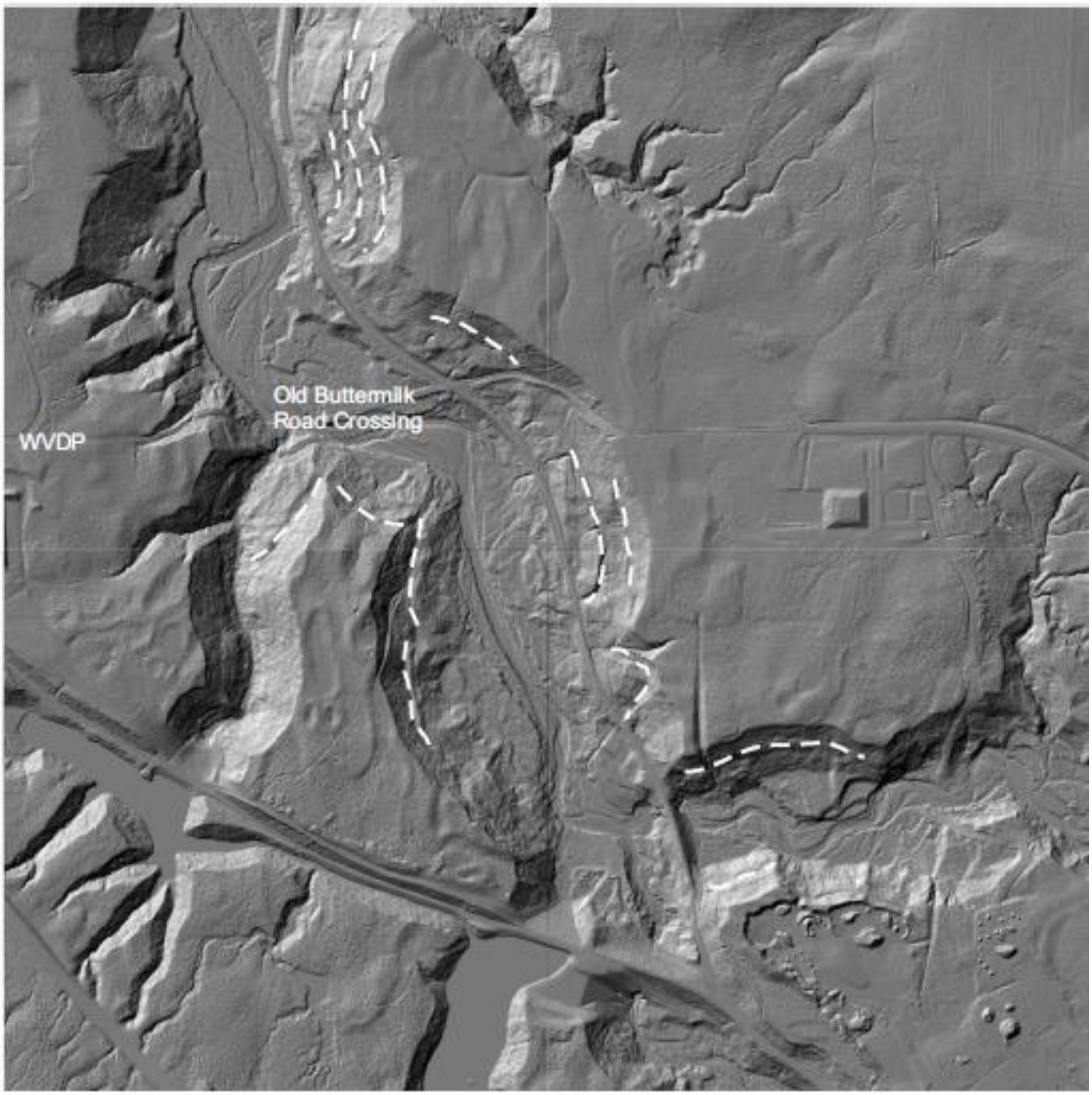


Figure 4.8-4: Incipient Landslide Scarps (3 of 4)



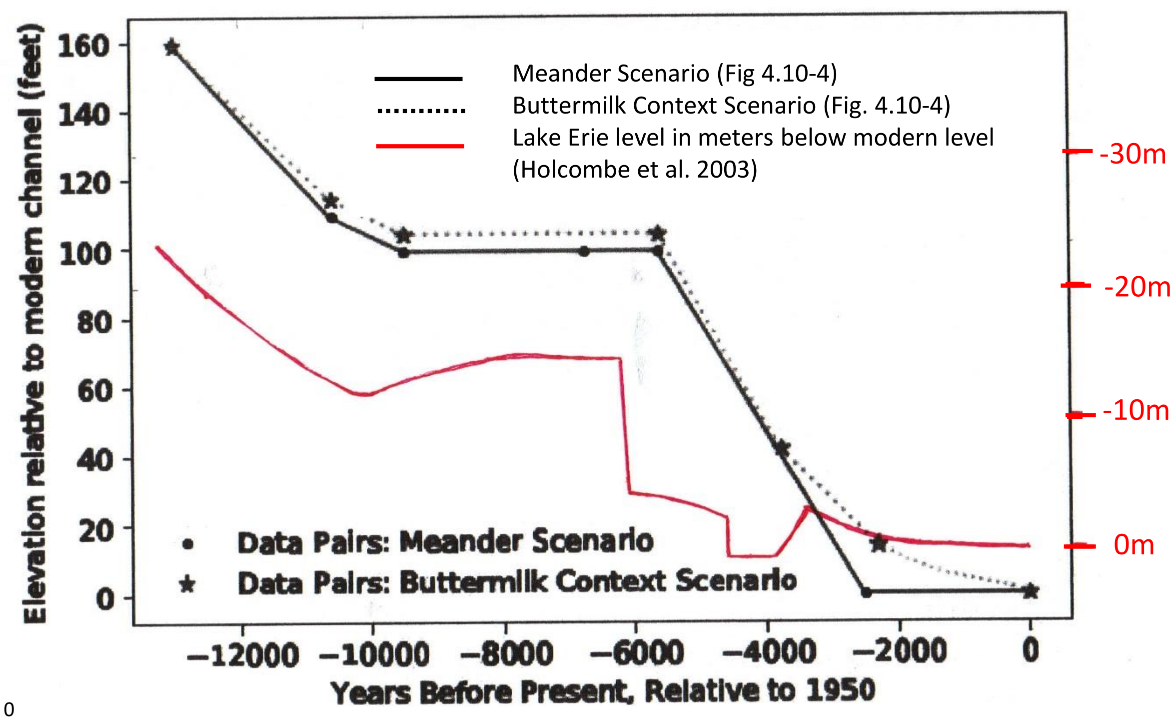
Incipient Landslide Scarps
Buttermilk Creek Basin
LS-4

LiDAR Interpretation = White
Field Evidence = Yellow

1000 feet

Figure 4.8-5: Incipient Landslide Scarps (4 of 4)

Vertical incision rates have been variable since last ice recession at 13,000 years before present (YBP)



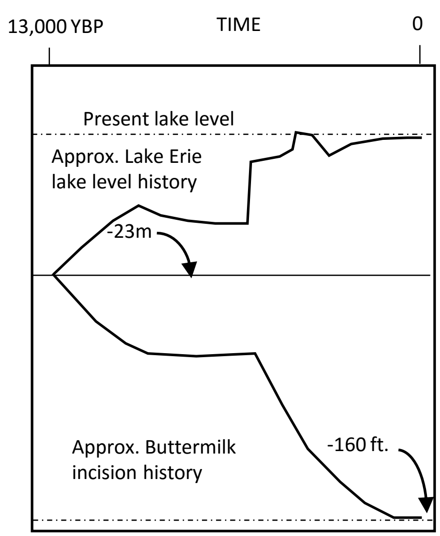


Figure 4.9-1: Lake Erie Levels versus Buttermilk Incision.
Graphs of equalLy-plausible incision history scenarios in the vicinity of the Franks-Buttermilk juncture (from Figure 4.10-4) with a graph of the history of Lake Erie level (discussed in text section 4.9) adapted from Holcombe, et al., 2003 Fig. 9b – upper). The insert at lower left presents an alternative view of the same information with the Lake Erie level graph inverted with respect to the above. Mid-continent, early to mid-Holocene climate change (warmer, drier) lowered eastern Lake Erie level (lowering Cattaraugus Creek base level), and potentially contributing to slowing Buttermilk incision from roughly 10000 to 5600 YBP.

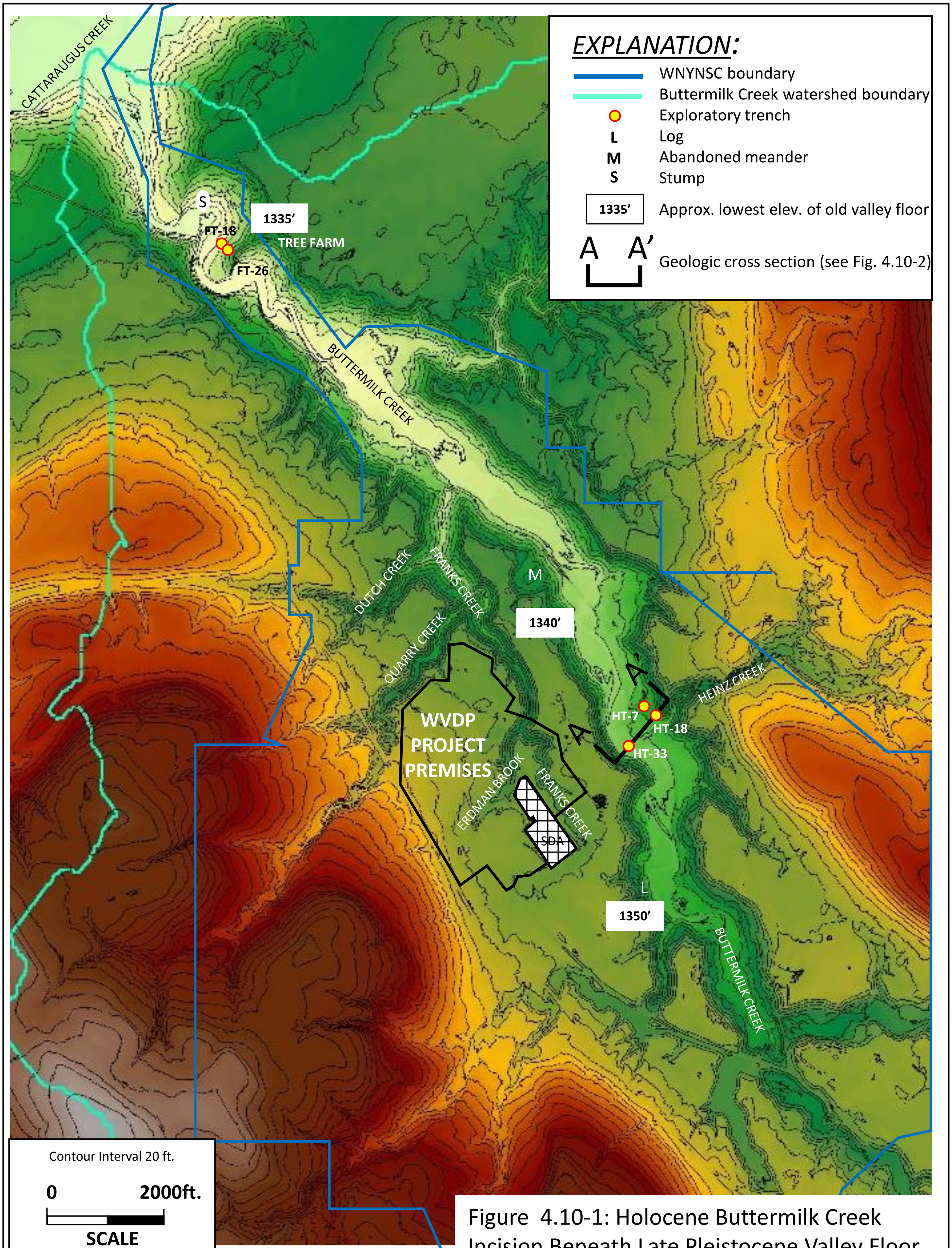
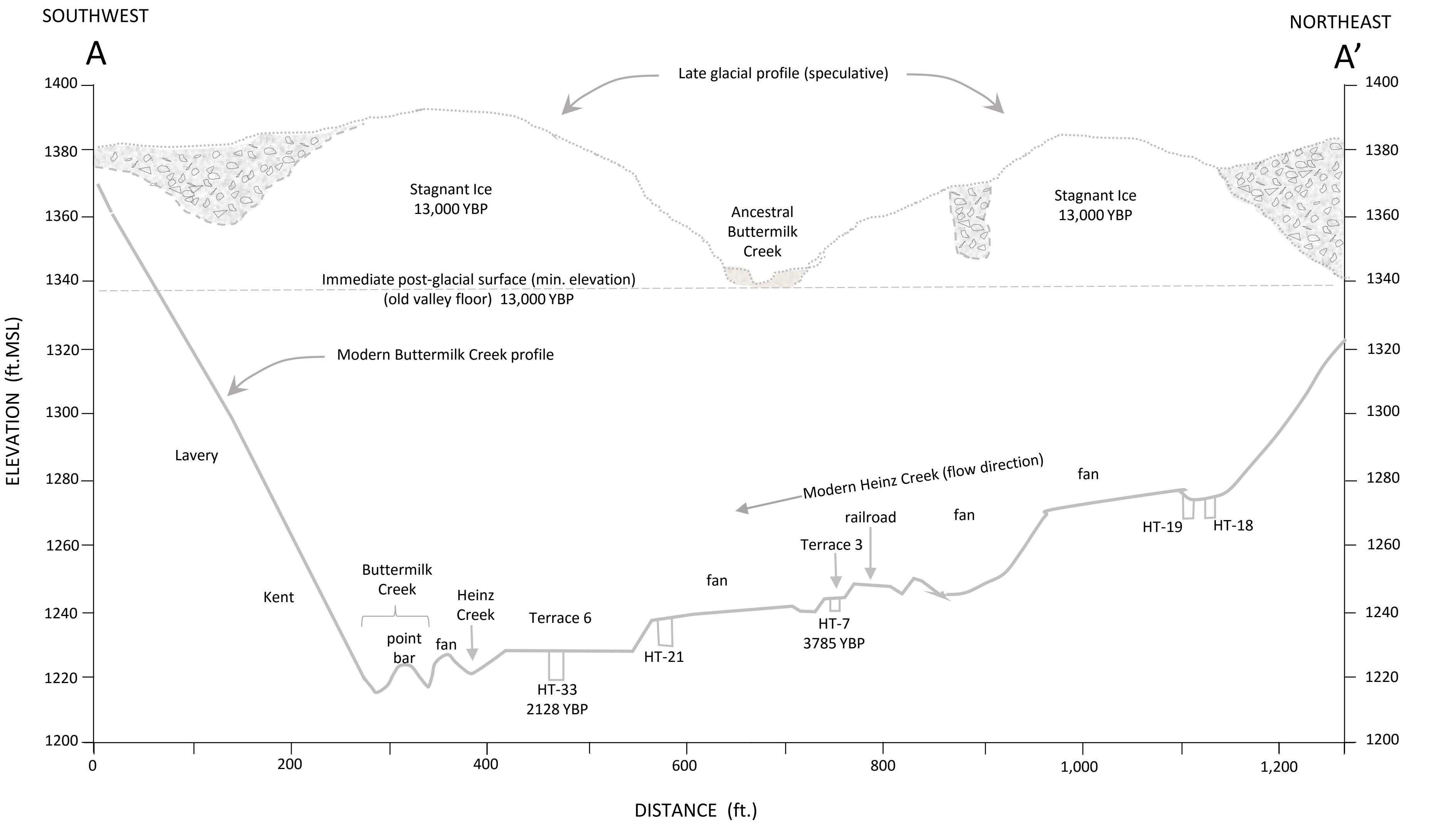
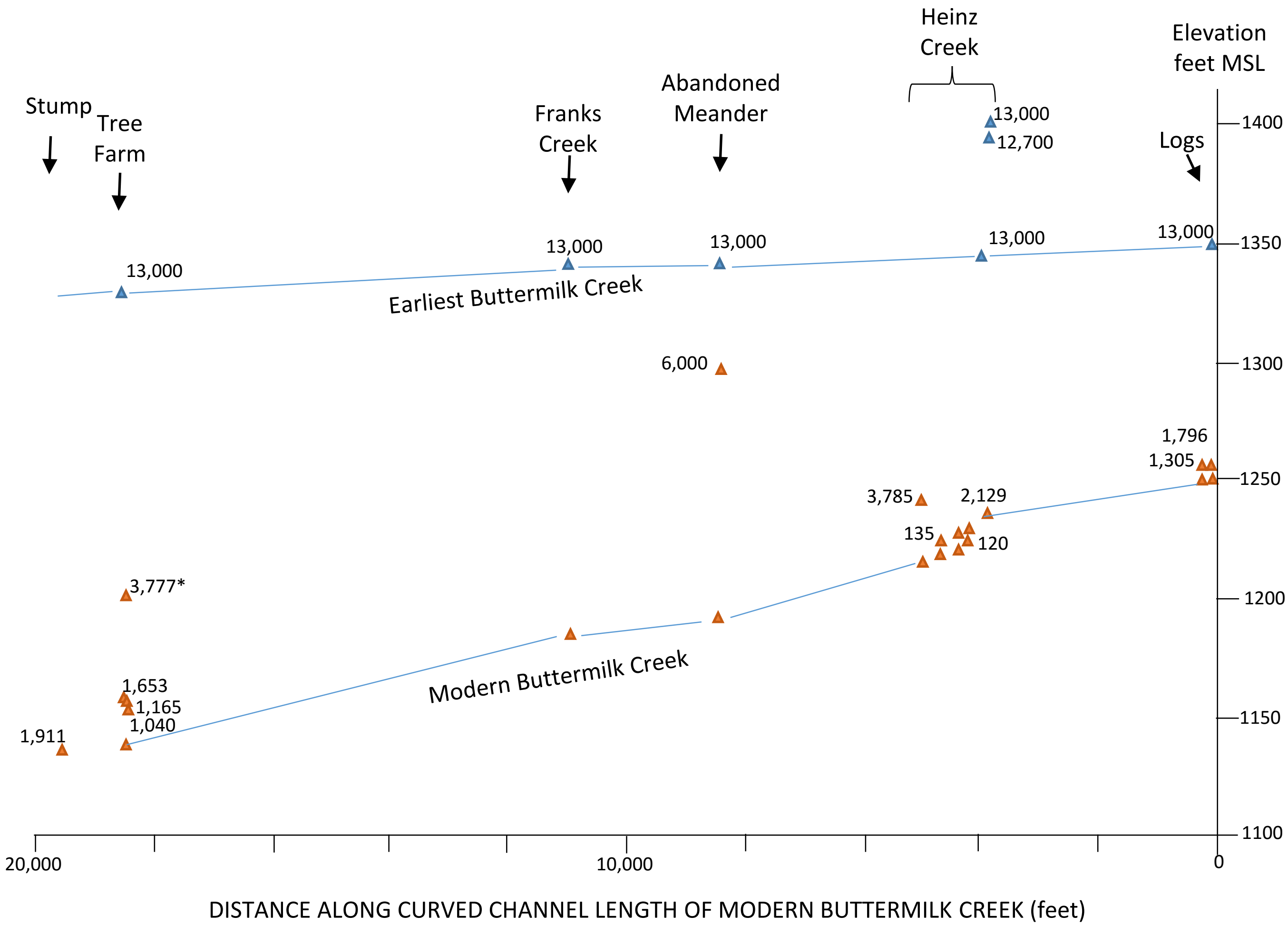


Figure 4.10-1: Holocene Buttermilk Creek Incision Beneath Late Pleistocene Valley Floor



See Figure 4.10-1 for location of cross section

Figure 4.10-2: Geologic Cross Section A-A' across Buttermilk Creek at Heinz Creek



* This sample likely reflects landsliding rather than an accurate terrace age

Figure 4.10-3: Spatial Relationships between Age Dates Along Buttermilk Creek

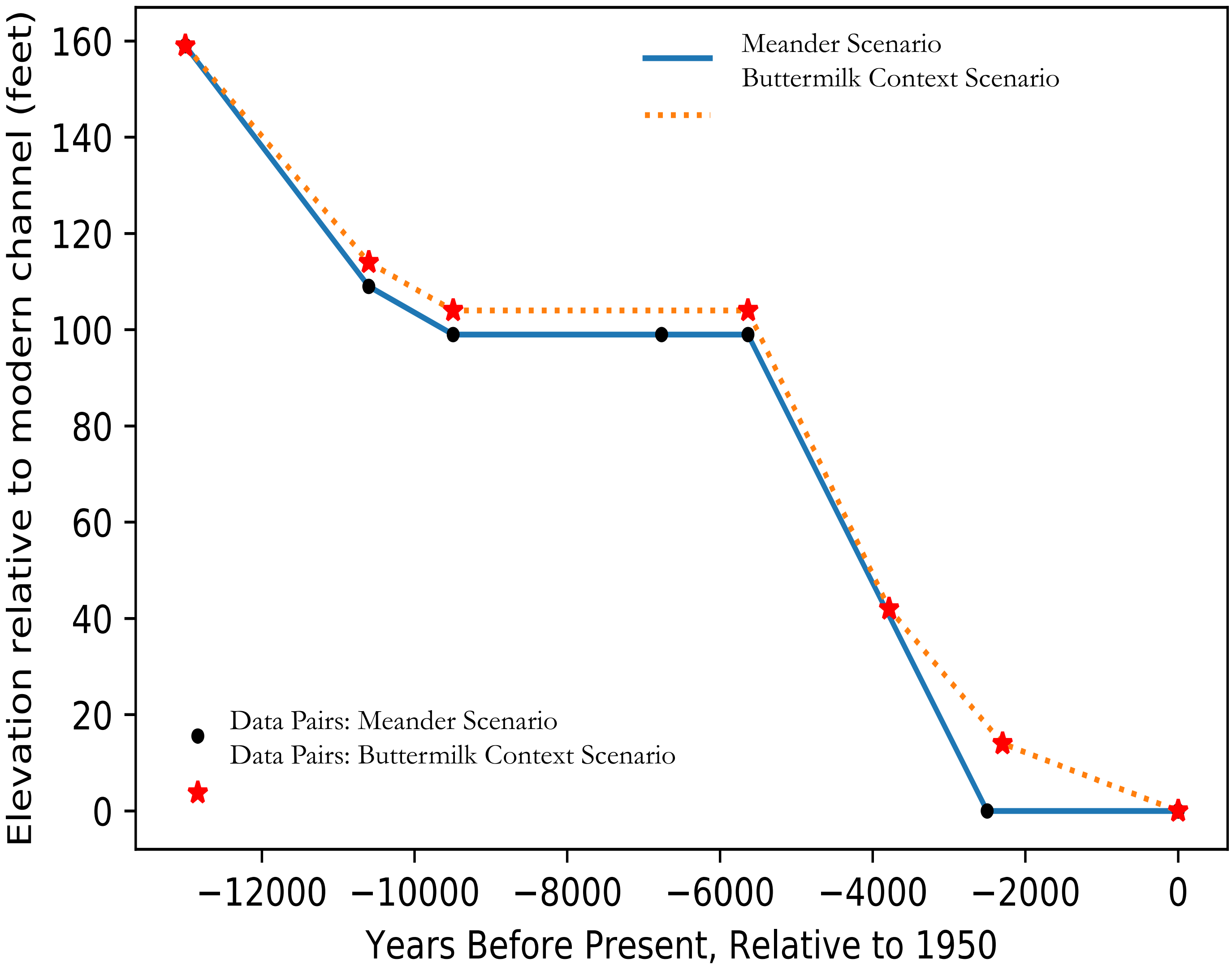


Figure 4.10-4: Graphs of equally-plausible incision history scenarios in the vicinity of the abandoned meander.