# PHASE 1 EROSION STUDY PLAN

***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:


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

**4795 Blue Mountain Drive,**
**Yorba Linda, CA 92887**


**June 19, 2015**

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**WVDP EROSION WORKING GROUP:**

| | |
|---|---|
| Sean Bennett, Ph.D. | *Dept. of Geography, State University of New York at Buffalo* |
| Sandra Doty, M.S., P.E. | *Consulting Geological Engineer* |
| Robert Fakundiny, Ph.D. | *New York State Geologist, Emeritus* |
| Greg Tucker, Ph.D. | *Dept. of Geological Sciences, University of Colorado* |
| Michael Wilson, Ph.D. | *Dept. of Geosciences, State University of New York at Fredonia* |
| Richard Young, Ph.D. | *Dept. of Geological Sciences, State University of New York at Geneseo* |

ECS Study Area Manager:

Michael Wolff, P.G., C.E.G.


**June 19, 2015**

# Phase 1 Erosion-Study Plan

West Valley Demonstration Project and Western New York Nuclear Service Center

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# Acronyms & Abbreviations

| | |
|---|---|
| ± | plus or minus |
| $^{14}C$ | radiocarbon (age date) |
| ArcGIS | proprietary brand name of GIS software |
| ATV | all-terrain vehicle |
| CEG | Certified Engineering Geologist |
| DEM | digital elevation model |
| DQO | data quality objective |
| DOE | United States Department of Energy |
| ECS | Enviro Compliance Solutions, Inc. |
| EPA | United States Environmental Protection Agency |
| EWG | West Valley Erosion Working Group |
| FEIS | final environmental impact statement |
| GIS | geographic information system |
| GPS | global positioning system |
| hr. | hour |
| Hz | hertz, or cycles per second |
| IPCC | Intergovernmental Panel on Climate Change |
| LEM | landscape evolution model |
| LiDAR | combination of “light” and “radar” |
| m | meters |
| mm | millimeters |
| NDA | NRC licensed disposal area |
| NP | north plateau |
| NRC | United States Nuclear Regulatory Commission |
| NTU | Nephelometric turbidity units |
| NYSERDA | New York State Energy Research and Development Authority |
| OSL | optically-stimulated luminescence |
| PG | Professional Geologist |
| QA/QC | quality assurance/quality control |
| s | seconds |
| SDA | State licensed disposal area |
| SME | subject matter expert |
| TIP | task implementation plan |
| WNYNSC | Western New York Nuclear Service Center |
| WVDP | West Valley Demonstration Project |

# I. Summary-Level EWG Study Plan

Enviro Compliance Solutions, Inc. (ECS) and the West Valley Erosion Working Group (EWG) have prepared this Study Plan to describe the recommended erosion studies to be performed as part of the Phase 1 Studies at the West Valley Demonstration Project (WVDP) and Western New York Nuclear Service Center (WNYNSC). The Plan presents the objectives, scope, estimated level-of-effort, and schedule for the studies.

The EWG prepared and submitted initial recommendations for Phase 1 erosion studies to the United States Department of Energy (DOE) and the New York State Energy Research and Development Authority (NYSERDA), the joint sponsoring agencies (agencies) for the studies (Bennett et al., 2012). At the agencies' request, the EWG prepared a report on uncertainty in erosion prediction, and presented a prioritized list of recommended studies focused on reducing uncertainties in the modeling process (Bennett et al., 2013). This Study Plan presents details of the prioritized studies.


Figure 1-1 West Valley Demonstration Project (WVDP) and a part of the Western New York Nuclear Service Center (WNYNSC). View looking southwest. WVDP project premises are at the upper left. The Buttermilk Creek drainage flows from the upper left to lower right of the figure. This image displays the profound effect of drainage and erosion patterns on the development of the landscape.

The Phase 1 erosion studies are planned to be implemented over approximately-three years. This Plan focuses on studies in the first year; therefore, the plan will be revised periodically to reflect study progress and to anticipate follow-on studies as plans for subsequent phases take shape. This plan is a 'living' document, designed to allow for adjustments and corrections as knowledge is gained. It is anticipated that further detailed implementation plans will be created as required to address details of health and safety requirements, training, site security, logistics, subcontracting, and other management aspects of study implementation. This plan presents an overview of the studies themselves but does not include the level of detail that will be addressed in implementation plans.

The Plan is organized in four sections. Section I (this section) provides an introduction, and states the purpose and objectives of the studies. It explains how the EWG has prioritized the Phase 1 study process to focus on those areas holding the greatest promise for reducing uncertainty in long-term erosion prediction technology. The section also summarizes the project management approach, needed resources, reporting, deliverables, estimated level of effort, and schedule objectives for the combined studies.

Section II presents details of the planned terrain analysis, age dating, and paleoclimate studies (Study 1), with a focus on first-year activities. Section III presents details of the planned studies of recent erosion and deposition processes (Study 2), with a similar focus on first-year activities. Section IV presents details of the planned first-year activities in support of model refinement, validation, and improved erosion projections (Study 3).

Figures and tables are included throughout the Plan to illustrate the discussion.

## A. Purpose of Collective Studies

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 basic purpose of the collective Phase 1 erosion studies is to enable improved forecasts of future erosion at the WVDP and WNYNSC, reduce the associated uncertainty, and assist the agencies in reaching consensus on the likely effects of future erosion. The main study problem can be stated as:

> *Future erosion processes across varying temporal and spatial scales may be predicted with sufficient confidence that, when combined with other factors, enable the agencies to make informed Phase 2 decisions about the WVDP*.

The studies described in this plan are designed to produce converging lines of evidence toward predicting future landscape evolution at the WVDP, 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 studies are designed to be independent, but complementary, and will interact synergistically to enhance reduction of erosion-prediction uncertainty.

## B. Scope and Prioritization

The collective studies comprise three principal study areas:

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

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 (low, medium, or high) to each 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 provide the greatest potential opportunity for reducing the uncertainty of erosion prediction, should additional analysis be conducted. The EWG created a priority list of those specific studies and study components likely to provide refined data that will reduce uncertainties in erosion prediction using this simplified, but informed analysis in the landscape-evolution model (LEM) (ranked below in order of relative importance):

- Bed-sediment entrainment threshold
- Soil/till-detachment threshold
- Storm depth, duration, and frequency parameters
- Soil/till detachability
- Soil-infiltration capacity

The following parameters were identified as necessary to reduce uncertainty in a gully erosion model (ranked below in order of relative importance):

- Soil/till-detachment threshold
- Soil-particle size and bulk density
- Headcut height (if applicable)
- Storm depth, duration, and frequency parameters
- Soil/till detachability
- Soil-infiltration capacity

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

- Construct a geologic and geomorphic history of the WVDP
- Relate postglacial-climate events to stratigraphy or erosion and deposition, and its discrete history
- Calculate average rates of erosion between discrete morphologic, stratigraphic or other temporal events

Terrain analysis and age-dating studies require a number of individual activities to resolve each key issue.

## C. Data Quality Objectives

The technical approach for the studies follows the United States Environmental Protection Agency (EPA) data quality objectives (DQO) process (EPA 2006). The DQO process provides a useful mechanism for specifying technical assumptions on which to base the scope of the investigation, and involves the following seven steps:

1. **State the Problem:** Clearly describes the problem(s) to be studied
2. **Identify the Goals:** Identifies the questions the study will attempt to resolve
3. **Identify Information Needed:** Identifies data inputs required to answer the study questions
4. **Define the Study Boundaries:** Establishes the spatial and temporal boundaries of the problem(s); also establishes boundaries on data collection, as appropriate
5. **Develop the Analytic Approach:** Identifies the decision logic that will be employed to meet study goals
6. **Specify Performance or Acceptance Criteria:** Defines the allowable variability related to sample collection, parameter measurement, etc.
7. **Develop the Plan for Obtaining Data:** Defines the program for collection of data

Not all steps will apply equally for each study. For example, Study 1 will rely on expert judgment for interpretation of geologic features, stratigraphic relations, etc. to a greater degree than the other studies. Quantitative limits on decision error are more difficult to apply to these types of parameters because they are not based on measurements. Studies 2 and 3 are inherently more quantitative in nature than Study 1, and better lend themselves to the DQO process.

It should also be noted that DQOs will need to be refined as additional information is gained through the Phase 1 Study process. For this reason, initial DQOs are in some cases necessarily high-level, and will be supplanted with more focused task-specific DQOs as the studies progress.

DQO considerations are discussed further under each study.

## D. Project-Management Approach

The central feature of the project management approach will involve the presence of an on-site coordinator, or site project manager, to assist the ECS Study Area Manager by coordinating day-to-day activities at the WVDP and larger WNYNSC. The site project manager will act as a central point of contact for communications with the agencies, logistics, scheduling, training, site security, arranging for site access, and other day-to-day needs that arise in the course of the erosion studies.

The site project manager will assist with subcontracting arrangements for equipment and operators that will be required to support the studies. The site project manager will also assist in identifying persons needing WVDP access so that necessary training can be scheduled.

## E. Collective-Resource Pool

Resources that will be employed to execute the erosion studies include, as appropriate to specific tasks:

1. Subject matter experts (SME) of the EWG

2. Enviro Compliance Solutions, Inc.[1] (ECS) personnel
    a. Study Area Manager – Michael Wolff, PG, CEG
    b. Site Project Manager - (to be identified)
    c. Support personnel
3. NYSERDA and DOE resources
4. University resources including students, facilities, and equipment under the supervision of SME
5. A supercomputing facility
6. Subcontracted services (e.g. excavation and drilling contractors, surveying, age dating laboratories, etc.)

## F. Routine Reporting

Routine reporting will include weekly progress updates, monthly technical progress reports with budget and schedule status. During the course of field activities, any safety incidents will be immediately reported to the appropriate Facility management personnel, and any observations of unusual or suspicious conditions or activities will also be immediately reported.

## G. Deliverables

Deliverables will include technical memoranda on specific study topics as requested by the agencies, and draft and final reports on the study results. The focus of the first year of studies will be on data collection. Most data interpretation and analyses, including predictive modeling, will occur in later stages of the project. Deliverables anticipated in Year 1 are described further in the sections below.

## H. Overall EWG Study Resource Needs and Level of Effort

Table 1-1 presents a summary-level overview of the estimated level-of-effort for the first year of the combined studies. As noted above, the studies have been prioritized and are planned to be implemented in an iterative fashion so that individual activities can be tailored, as needed, on the basis of data and information generated by other activities. The resources and level-of-effort will, therefore, be refined as the study proceeds.

Table 1-1. Overall Erosion Studies Year 1 Labor Hours Estimate

| Element | Category | Estimated Labor Hours[1] |
|---|---|---|
| Study 1 | EWG SME | 784 |
| | Support personnel | 436 |
| Study 2 | EWG SME | 362 |
| | Support personnel | 1982 |

[1] ECS is the Phase 1 studies contractor retained jointly by DOE and NYSERDA.

Table 1-1. Overall Erosion Studies Year 1 Labor Hours Estimate

| Element | Category | Estimated Labor Hours[1] |
|---|---|---|
| Study 3 | EWG SME | 1,532 |
| | Support personnel | 640 |
| Studies 1,2,3 | Total SME | 2,678 |
| | Total support personnel | 3,058 |
| | Total Studies 1,2,3 | 5,736 |
| Project Management<br>(includes site project manager for 8 months in 2015) | ECS | 1,832 |
| Note:<br>1. Labor hour estimate has large potential variance and will be updated on an ongoing basis to reflect changes | | |

# I. Comprehensive Milestones and Summary-Level Schedule for EWG

The Phase 1 Studies schedule is an independent stand-alone document that will be continuously updated throughout the study process. The schedule is dependent upon many factors, including but not limited to: agency authorization, access restrictions, logistical factors, changes to the plan resulting from study findings, weather delays, etc. The project schedule will be updated on a continuing basis as the project proceeds.

# II. Study 1 - Terrain Analysis, Age Dating, and Paleoclimate

## A. Purpose

The objective of Study 1 is to build on the previous work (e.g. LaFleur, 1979, Boothroyd et al., 1979, Fakundiny, 1985, etc.) cited in the FEIS or elsewhere, to better delineate and enhance understanding of the post-glacial geomorphic history of the site and the larger Buttermilk Creek watershed that may enable more confident projections of future erosion processes. The purpose of these earlier referenced studies was not to predict long-term erosion rates, but to provide insight on trench-water infiltration at the SDA. The purpose of Study 1 is to better define the locations, ages, thicknesses and shapes of sediment and rock surfaces and layers. Study 1 will make maximum use of existing data. Another purpose of Study 1 is to establish historical information ranging from Anthropocene through Holocene into Pleistocene times that may help to project landscapes or landscape characteristics into the future or identify current attributes of erosion and deposition.

This study will provide enhanced context and perspective for calibrating erosion models selected for prediction of future erosion at the WVDP. Data generated from Study 1 will be used to constrain the ranges of -model parameters, and to perform sensitivity analyses. For example, one important model input is the distribution of subsurface materials having different erodibilities and other key properties. Such input essentially specifies what portions of the model domain have erodibility parameter values representative of resistant geologic horizons, and what portions have parameter values appropriate for more easily-eroded geologic materials.

The study will also provide data to enable testing the ability of the model or models to reproduce past patterns and rates of erosion. For example, models should be able to capture the transition from early alluvial-fan deposition to later stream incision. To make such a test useful, it is necessary to obtain information about (1) when the transition occurred, and (2) roughly how much deposition occurred between the time of glacial retreat and the time of fan abandonment. Model tests using this information would lead to more precise calibration of the key parameters, such as the erodibility of geological materials. If, for example, the bedrock or glacial deposit erodibility were tuned too low, the predicted fan deposition rate should be less than what is observed, and vice versa.

The overall purpose of Study 1 is, therefore, to provide data that will allow predictive erosion models to project effects of future erosion at the WVDP with less uncertainty than has been heretofore possible.

Specific objectives include:

- 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 post-glacial erosion (approximately 17,000 years) and its relation to prediction of future erosion

- Establish better carbon 14 ($^{14}C$) and optically stimulated luminescence (OSL) agreement for dating specific features
- Resolve 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 portion of the post-glacial history is relevant to predictive modeling. For example, the conditions extant in the early post-glacial period, i.e. receding ice sheet, inundation by glacial melt waters, isostatic rebound, are not likely to apply during the next several hundred to several thousand years. On the other hand, relatively recent conditions during the Anthropocene[2] (deforestation, hardening of land surfaces, concentration of runoff) may be very relevant to predictive modeling.

In addition, issues with large unknowns, such as the effects of climate change, must also be factored in. The geologic record of specific paleoclimate cycles that can be correlated with periods of increasing or decreasing erosion rates may be evident. This knowledge will be important for predictive modeling.

Data quality objectives for Study 1 involve minimizing chances for errors in interpretation and judgment, because expert judgment is critical to achieving the study objectives. Drs. Young and Wilson are both recognized experts in the post-glacial geology of western New York and will co-lead Study 1. Having two experts intimately involved in the fieldwork will enable Study 1 to benefit from the checks and balances inherent to constructive scientific collaboration.

Study 1 will involve quantification of age dates on the basis of sample analysis. Here, an important data quality objective is to resolve outstanding discrepancies between $^{14}C$ dates and OSL dates for the same features. This will be addressed by collecting co-located samples for both types of analyses where possible. Another purpose of Study 1 is, therefore, to provide more samples than actually needed for analysis so that some may be archived and available for later analysis if needed to help resolve discrepancies.

## B. Scope and Prioritization

### 1. General

Information about the past history of erosion at the WVDP is essential to any analyses of potential future erosion. The simplest potential-erosion model for the site is one that extrapolates the past history of erosion forward in time. To do this, the past and present rates of erosion must be estimated, and doing so requires dates of key geomorphic markers in the landscape. Furthermore, a long-term erosion model should be both tested and calibrated on the basis of past geomorphic evolution. Therefore, data for model calibration and erosion-rate extrapolation are considered here.

[2] The period of time in which human activity has affected the landscape. In Eastern North America, this is generally considered to include the last several hundred years.

A wide range of information and modes of analysis could be used to portray a clearer picture of the area's geomorphic history and rates of erosion. Among these are five pieces of information that are particularly important to erosion analysis and model calibration, and, therefore, will form the core of the study:

1. The date of the last glacial retreat from Buttermilk Creek watershed;
2. The rate history of base-level lowering (stream incision) near the confluence of Buttermilk and Cattaraugus Creeks;
3. The rate history of downcutting on Buttermilk Creek in the vicinity of the confluence with Frank's Creek;
4. The rate history of downcutting or deposition along other reaches of Buttermilk Creek and other nearby streams; and
5. The subsurface distribution of materials and surfaces that may influence modeling, such as modeled incision rates.
6. The influence of Anthropocene (geologically recent) processes on erosion or deposition to aid knowledge of process rates, influences, modeling parameters, and erosion control possibilities.

Here, the phrase "rate history" encompasses both the average rate since the last glacial recession to the present and changes in rate over time. Correct interpretation of diagnostic geomorphic features and measuring their absolute ages is imperative to obtain this information.

Measuring the ages of geologic events at the WVDP involves locating appropriate datable materials associated with geologic features, surfaces, or horizons that can be accurately linked to erosional, depositional, or climatic events. Some of the obvious geologic features typical of landscapes in western New York are: glacial moraines, glacial-outwash sediments, glacial-lake sediments, kettle-hole bogs, postglacial-river sediments, river-terrace surfaces, alluvial fans, and landslides. The basic types of materials normally sought for dating include organic debris suitable for $^{14}C$ analysis (especially wood, leaf mats, and similar materials that can be inferred not to have been reworked), quartz-bearing sands suitable for OSL methods, or tree-ring sequences sufficiently lengthy to enable construction of partial or extended local climatic records. Under the best of circumstances, two or more of these methods can provide converging evidence for the timing of major events in the postglacial geologic history.

Ranking of tasks was conducted for terrain analysis and age dating of critical geomorphic features by the EWG. On the basis of these rankings, the following three tasks are identified for additional study (ranked in order of relative importance):

1. Relate postglacial climate events to stratigraphy or erosion and deposition, and their discrete histories;
2. Calculate average rates of erosion for discrete morphologic and stratigraphic features; and

3. Formulate a geologic and geomorphic history of the WVPD.

Unlike the recent erosion and deposition studies discussed in Section III, or the modeling studies discussed in Section IV, both of which focus on unknown or poorly quantified parameters, the terrain-analysis and age-dating studies require a number of individual tasks that will be used to resolve key issues. For example, calculating average rates of erosion since the last glacial maximum would include field work and reconnaissance, geomorphic mapping and feature identification, securing samples for age dating, and integrating and correlating these age dates into the local and regional glacial stratigraphies and landscapes. The scope of this study will incorporate these activities at prioritized locations of specific interest to the WVDP.

## 2. Technical Approach

This section describes the general investigative approach. The approach will be an iterative one, with the highest priority target site(s) investigated first, followed by successively lower priority sites. Remaining sites will be re-prioritized, with some target sites likely moving up in priority, while others may be dropped on the basis of initial data and results. Following sections describe how initial target study locations (sites) will be prioritized for site-specific investigation.

Subsurface investigations will be coordinated in three concurrent phases: (1) shallow (trenching or augering); (2) intermediate (trenching or split-spoon drilling); and (3) depth to bedrock (drilling with continuous or selective recovery). The shallow phase answers questions about the nature and ages of exposed surfaces of terrain elements or materials, while the deep phase investigates rates of gulley or terrace development from accumulation of deposits. The depth-to-bedrock phase evaluates the top-of-bedrock. Small, mobile investigative methods will be used for the near-surface studies while deeper investigations will require larger drilling equipment and may be more logistically restricted. The terrain analysis and dating phase of investigations will create geologic, geographic, and temporal contexts for other information, past and future, that will significantly decrease uncertainty. Such studies of context will require on- and off-site studies, in Buttermilk Valley and analogous drainages such as Connoisarauley Creek, and use of expert overview.

Where drilling or augering is done, we will pursue all three subsurface investigative goals to depths of approximately 10 to 20 feet, if possible. Information may be extended from or among these map points by interspersing additional shallow investigations (especially where logistics hamper drill rig transport), and by interspersing geophysical studies. Tentatively, ground penetrating radar (GPR) and seismic reflection or refraction will be used for shallow-depth and bedrock-depth investigations, respectively. Any and all disruption of these sites will be repaired to the extent that they do not affect the integrity of the WVDP site and the agencies' ability to perform their required operations.

Early stages of investigation will include evaluation of the three-dimensional distribution of available subsurface data from past studies, and the logistical advantages and disadvantages of new locations, in the context of the study goals, e.g. age-date samples or computer modeling of erosion at bedrock contacts.

A preliminary evaluation of LiDAR topographic mapping from the NYSERDA-sponsored 2010 survey, shows many candidate sites for subsurface sampling. Some examples include: (1) the "race track" (incised meander remnant perched in the Buttermilk Valley wall) that offers access for multiple investigative methods; (2) several asymmetric incised meanders of Buttermilk Creek near the confluence of Cattaraugus Creek; (3) Quarry Creek with small incised point bars that might be accessed from the road in front of the WVDP; (4) small fans on the outside of former meanders (cut-bank meander scars), east-southeast of the State licensed disposal area (SDA) along Franks Creek; and (5) numerous terrace segments and fans in Buttermilk Valley.

## 3. Prioritization Approach

The first year of Study 1 will focus on data collection and interpretation. The target study locations, will be prioritized and investigated using the following general approach.

Prioritization of sites will give highest priority to the sites that appear to have the greatest apparent morphological complexity, and the greatest age span, both within the site itself and between the terminal glacial event (surface) and the active modern or recent postglacial landforms. Morphological complexity implies that a correspondingly greater number of events or processes are represented. Other factors in prioritization may include site access, relations to concerns such as current erosion threats to facilities, identifying past or recent rapid-erosion events, or testing diversity of investigative methods.

An example is Site #1 - high-elevation abandoned meander loop. This site has the highest priority and will be the initial focus of the work. The site elevation is such that it represents the best intermediate topographic location at which to acquire primary information that is reasonably separated in time and space from both the last glacial hiatus and the modern channel. The surface morphology indicates that the site contents should be relatively shallow (~10 ft.) and potentially contain: (1) an obvious abandoned-meander channel, which might contain buried logs (for tree ring chronology); (2) an extended point-bar feature, which implies a protracted interval of lateral channel migration, potentially containing a coherent series of datable horizons, such as leaf mats, or root horizons; (3) a cut bank scarp that could reveal older vertical stratigraphic units, such as former overbank, channel, and abandoned point bar horizons, or a glacial/postglacial contact; (4) several adjacent strath terraces, which might contain datable horizons that document vertical incision intervals, or temporary bedrock thresholds; (5) a fluvial/bedrock thalweg along the main channel, which may contain information concerning the nature of past channel-bedload conditions, as well as the local bedrock gradient; (6) post-glacial modification in the form of a small alluvial fan and companion channel, which could shed light on the timing of a period of climatic change (or extreme runoff event); (7) gully incision migrating from Buttermilk Creek, which can provide a measure of gully-excavation rates from the date of the meander being abandoned; (8) a measure of the active-channel dimensions compared with the active modern channel of Buttermilk Creek in the same reach; (9) a comparative measure of the natural hillslopes originally created at the meander site compared with the active slopes on the modern Creek where the channel is actively eroding; and (10) the depth of incision of the channel into the abandoned glacial surface as a function of the percentage of postglacial time represented (potentially indicating a change in average incision rate).

For Site #1, the EWG plans to investigate discrepancies between 14C dates and OSL dates obtained for the 2010 FEIS analysis. The EWG notes that random pieces of wood collected from fluvial deposits are notoriously unreliable due to “reworking” of buried logs, etc. Carefully documenting the specific context and history of the sedimentary sequence to the degrees possible will be critical.

The EWG plans to incorporate QA/QC measures such as analysis of blind duplicates, and OSL-14C comparative analyses to decrease uncertainty in interpretation of age dates. In addition, the EWG will investigate and incorporate “lessons learned” from reported results by other researchers where OSL dates appeared stratigraphically inverted by about 5,000 years under apparently excellent sampling conditions.

## C. Data Quality Objectives

DQOs for Study 1 are as follows:

1. **Define the Study Problem:**
   The history, rates, and nature of post-glacial erosion of the WVDP and WNYNSC region is not well understood; therefore, improved confidence in prediction of future erosion includes the collection of additional age dating information to supplement existing data that will reduce uncertainty in erosion modeling.

2. **Identify the Goal(s):**
   a. Establish more precisely the timing of the last glacial recession.
   b. Establish the sequence of major post-glacial erosion and depositional events.
   c. Ascertain the past history of post-glacial erosion and its relation to prediction of future erosion.
   d. Establish better carbon 14 ($^{14}C$) and optically stimulated luminescence (OSL) agreement for dating specific features.
   e. Resolve relations between paleoclimate and erosion rates.
   f. Provide expert guidance on how these factors should be incorporated in predictive erosion models.

3. **Identify Information Needed:**
   a. Information on stratigraphic relations between geologic units at study locations (e.g. relative ages)
   b. Information on geologic processes responsible for observed features (e.g. glacial deposits, alluvium, colluvium, landslide, etc.)
   c. Absolute ages of geologic features from laboratory analysis of samples
   d. Information on relations between features at spatially-separated study locations
   e. Information on relations between paleoclimate proxies (e.g. tree rings) and geologic processes

4. **Define the Study Boundaries:**
    a. Lateral: Buttermilk Creek watershed (a companion drainage such as Connoisarauley Creek could be added to demonstrate regional reproducibility or to fill in potential data and/or chronologic gaps)
    b. Vertical:
        i. Topographic – from bottom of Cattaraugus Creek channel near Buttermilk confluence to top of hills surrounding WVDP
        ii. Lithostratigraphic – from bedrock to recent alluvium
        iii. Time stratigraphic – from early post-glacial deposits to Anthropocene deposits
    c. Temporal: from onset of last glacial recession to present (~17,000 yrs.)
    d. Data Collection:

        To meet the listed goals it is estimated that at least 30 $^{14}C$ age dates and 30 OSL age dates, but not more than 50 of each, will be needed. It should be noted that the number of age dates does not relate directly to cost because the difficulty of collecting samples will vary widely from location to location on the basis of conditions encountered (e.g. access for excavation equipment, depths, presence of groundwater seepage, etc.).

5. **Develop the Analytic Approach:** (Identifies the decision logic employed to meet study goals)
    a. If age dating of early post-glacial deposits establishes a definitive age for onset of glacial recession, then goal 2a will be met; otherwise, additional study may be warranted.
    b. If mapping and age dating of key features resolves the sequence of post-glacial erosion, then goal 2b will be met; otherwise, additional study may be warranted.
    c. If mapping and age dating of key features identifies events or periods that are relevant to future erosion, then goal 2c will be met; otherwise, additional study may be warranted.
    d. If a consistent and statistically-significant quantitative relationship can be established between $^{14}C$ and OSL dates for the same features, then goal 2d will be met; otherwise, additional study may be warranted.
    e. If paleoclimate proxies (tree rings, other) can be confidently correlated with relative erosion rates, then goal 2e will be met; otherwise, additional study may be warranted.
    f. If 5a through 5e enable best professional judgment to resolve how past erosion should inform prediction of future erosion, then goal 2f will be met; otherwise, additional study may be warranted.

6. **Specify Performance or Acceptance Criteria:**
    a. Ages of early post-glacial features resolved to $\pm$ 1,000 yrs.
    b. Ages of Holocene features resolved to $\pm$ 500 yrs.
    c. Ages of Anthropocene features resolved to $\pm$ 50 yrs.
    d. Agreement between $^{14}C$ and OSL dates for same feature resolved to $\pm$10 percent

7. **Develop the Plan for Obtaining Data:**
    a. Mapping
    b. Excavation/drilling key features
    c. Collection of samples for $^{14}C$ and OSL dating (up to ~30 samples each)
    d. Laboratory analysis of $^{14}C$ and OSL samples
    e. Tree ring analysis (as needed)
    f. Reporting

## D. Tasks

Specific details of each of the following tasks will be developed in TIPS that will specify the task scope, deliverables, estimated cost, schedule, and other pertinent task-specific details.

### Task 1.1: Mapping

Dr. Richard Young and Dr. Michael Wilson will create landform-geomorphic map(s) of key areas (both onsite and offsite) from the new LiDAR imagery with ArcGIS software to better categorize key glacial (moraines, kettle holes) and postglacial landforms (alluvial fans, terraces, landslides). This task will utilize existing mapping products and former geologic studies and focus more on accurate discrimination of morphologic details that might better delineate morphostratigraphic units most productive for 14C and OSL dating. Map products will be distributed to other EWG members and input from other EWG personnel will be sought as mapping advances.

### Task 1.2: Field Reconnaissance

Drs. Young and Wilson will examine potential field sites chosen from maps and images produced in Task 1.1 to: (1) confirm initial LiDAR analyses; (2) prioritize site selection; and (3) to assess practical site accessibility. Hand-probe sampling will be attempted to supplement preliminary LiDAR and geologic classifications. Photographic images and global positioning system (GPS) locations will be obtained during this reconnaissance to document site conditions and initial findings for distribution and discussion with other EWG members, and potential contractors. Field assistants will be involved at this stage to assure their familiarity with site conditions, and to help manipulate field equipment. Reconnaissance may include readily accessible portions of the Connoisarauley basin as a means to eventually test the comparability and reliability of the data set obtained from Buttermilk Creek.

Site #1 is used as a continuing example. Site #1 has an obvious, and tested, abandoned access road and is relatively open with a moderately high tree canopy and a minimum of obstructing brush or boulders. The nature of the fluvial materials suggests that reconnaissance by hand auger probing and GPR would be practical at this potentially shallow site. Both of these methods could be relatively easily applied to the meander and higher terraces. Shallow-seismic exploration by a hand operated portable unit is feasible. Electrical-resistivity probing for the bedrock contact or local groundwater table is also feasible. It should be noted that geophysical identification of buried till/bedrock contacts may be difficult owing to insufficient density contrast; however, identification of alluvium/till or alluvium/bedrock contacts may be achievable using geophysical techniques. Minimal site preparation would be required to begin work at this location.

On-site decisions will be made to extend diversity of data collection when opportunities are created or discoveries are made, for examples: coring modern trees that may be old growth to help identify terrain element ages, or examining constructed works that may show temporal relationships to terrain elements or stratigraphic features.

### Task 1.3: Site Prioritization

Investigation will proceed in an iterative fashion, with the highest priority sites addressed first. Drs. Young and Wilson will distribute and discuss data acquired and field criteria for site prioritization with other EWG members. Written justification for site selection will be finalized, and a file for each site developed. Files will include preliminary estimates of equipment, personnel, and time needed to explore and sample each site. Plans will be submitted to EWG members for input or suggestions.

Results from Tasks 1.1 and 1.2 for Site #1 would be shared with EWG members to obtain general agreement for prioritization of this site, and to choose the order and methods of recommended testing.

### Task 1.4: Site "Walkover"

Drs. Young and Wilson, with the potential assistance of additional EWG members, will work with ECS and proposed contract firms to plan field sampling activities, including practicality of access, type of equipment suited to tasks, and time estimates for sampling activities. Issues and plans resulting will be distributed and discussed with the EWG.

Site #1 would be visited by potential contractors to discuss the plan, practical approach, and realistic schedule for required site activities.

### Task 1.5: Site Sampling

Drs. Young and Wilson will begin sampling of sites for 14C and OSL dating, on the basis of site prioritization. The first site(s) to be selected should have ready accessibility, so that work can concentrate on demonstrating that sampling methods are adequate and practical, as well as productive. The abandoned meander feature is a good example of such a site, and there is a reasonable chance that abundant organic material will be recovered from a range of elevations (geomorphic features and/or horizons of different ages).

Site #1 will be first to be investigated. Site #1 would be inventoried by: (1) hand augering; (2) ground penetrating radar; and possibly (3) hand-held shallow-seismic or resistivity surveying. This would be followed by large-diameter augering, shallow backhoe trenching, if feasible, and/or use of a drilling rig with split-spoon sampling to delineate depths, thicknesses, and characteristics of deeper horizons to fill data gaps as needed.

Site investigation and sampling must involve senior researchers (Wilson and Young) to carefully document, interpret, record, and validate the geologic nature and significance of the exposures and sampled horizons. Recording will include both still photography and videography. Avoidance of cross contamination of materials, or introduction of contaminants, is an important issue that must be the subject of careful onsite quality assurance and quality control (QA/QC). Careful preliminary packaging, labeling, and storage of samples for final dating selection will be conducted in the field.

On-site decisions will be made to extend diversity of data collection when opportunities are created or discoveries are made, for examples: coring modern trees that may be old growth to help identify terrain element ages, or examining constructed works that may show temporal relationships to terrain elements or stratigraphic features.

### Task 1.6: Sample Preparation and Selection for Dating

Drs. Young and Wilson, in cooperation with other interested EWG members, will prioritize and prepare sample materials for submission to commercial labs. This activity should include drying and preserving 14C samples so that problems, such as mold growth, etc. do not occur if samples need to be stored for prolonged periods. Appropriate sample-location identification and geologic interpretations of sample-site geology will be completed, on the basis of excavation data. Sample splits, where possible, will be made in case later verification, re-dating, or alternate lab comparisons are necessary or desirable QA/QC measures. Photo and video files will be organized and documented to assure that proper sample interpretations are possible, should alternative personnel have to work with the collected materials at a later date. Log samples deemed suitable for tree-ring climatic records will also be adequately documented and saved for submission to Cornell Tree Ring or other suitable lab.

Tree ring studies may prove useful for indicating the potential for short-term variability in climate over longer periods, potentially over a period approaching 17,000 years. Tree-ring studies could be done for both living trees in the nearby region, as well as buried logs (which have been found in several excavations). These data may provide important information concerning the long-term stability of climate (or lack thereof), especially when compared with other climate data from previously completed studies in New York, or broader regions of the northern hemisphere.

Dendrochronology and dendroclimatology could also be useful to fully understand events and contexts of the past, such as incursion of European settlement or timing and movement of landslide blocks that deformed trees.

Tree-ring studies, like other specialized techniques, will be further evaluated in the context of actual target-study locations, and will be recommended if they have a good potential to resolve questions about reducing uncertainty.

### Task 1.7: Sample-Age Analysis, Geologic Interpretation

A revised and improved geologic history of the site will be attempted on the basis of 14C and OSL results. This will emphasize the evidence for the date of the last glacial recession, as well as estimates of postglacial erosion rates at individual sites along various gullies and streams. Data and preliminary findings will be shared with all EWG members for input. Samples intended for such analysis will be selected, and additional dating of individual tree rings will be considered, if sufficient data are collected to indicate that a climate-proxy study is feasible on the basis of excavated logs and/or local tree data.

### Task 1.8: Report

On the basis of all the above activities, a report of findings and geologic interpretations will be developed. This report will emphasize the reliability of the age determination of the last glacial recession, as well as an evaluation of the preferred interpretations and/or alternative interpretations for the documented events in the postglacial history. Any potentially useful tree-ring data will be evaluated by appropriate expert(s) and compared with similar climate proxy studies (including lake or bog cores) for western New York and contiguous regions. The report will also present recommendations for additional work in the subsequent years of the project.

## E. Resource Needs

### 1. Personnel

Drs. Richard Young and Michael Wilson from the EWG will co-lead Study 1. Both Drs. Young and Wilson have extensive personal experience with the geology of the site and environs, as well as the post-glacial geologic history of Western New York. Their personal involvement in the data collection and interpretation is critical to the success of this study. Drs. Young and Wilson will be assisted as needed by other EWG SME such as Sandra Doty and Dr. Greg Tucker to assure that the data collected meet the needs of Study 3. Dr. Robert Fakundiny will provide general oversight and peer review for Study 1. These individuals all have extensive institutional knowledge of the site from prior involvement.

Drs. Young and Wilson will be assisted by various support personnel supplied by ECS, possibly including students, and special subconsultants such as Dr. Carol Griggs of Cornell University, who is a nationally-recognized expert in tree-ring analysis and dating. Subcontractors will also supply specialty services such as geophysical services, drilling, excavation, surveying, and laboratory age dating.

DOE and NYSERDA personnel will play key roles in Study 1 on the basis of their institutional knowledge of the site and its history. Agency personnel will also provide key support in areas of logistics, safety and security training, and other areas.

### 2. Equipment

The following equipment will likely be required at many of the sites:

- Mobile vehicle access, ATV with small trailer (or similar). Depending upon whether onsite or offsite activity is required.
- Auger-excavation equipment (as per previous discussions, diagrams), including a portable water pump for dewatering
- Hand augering equipment (sampling backup)
- Chain saw and other brush-removal equipment.
- Miscellaneous supplies, tools.
- Appropriate personnel with approved clothing
- Sampling preparation and storage equipment ($^{14}C$ and OSL)
- Still camera and video capability
- Field “microscope” for examining small samples?

- Field recording material, notebooks, tape recorder, hand-held radios
- Portable GPS

This list is not inclusive and will be revised as needed.

### 3. Subcontracted Services

The following subcontracted services will likely be needed to support Study 1:

- Storage facility for field equipment, drill cores, samples, supplies, etc.
- Grading for access, excavation of test pits and trenches, backfilling
- Geophysical surveys for utility clearance, depth to bedrock, and location of buried objects
- Shallow auger drilling
- Deep-core and/or auger drilling
- Surveying
- Age-date laboratories (more than one for different techniques and for QA/QC purposes)
- Tree ring studies (Cornell University)

## F. Estimated Level of Effort

The estimated level of effort in labor hours for the first year will be based on several factors including but not limited to:

- Agency authorization
- Logistics
- Weather
- Findings of the initial tasks
- Availability of key resources (e.g. age-dating laboratory sample turnaround times, specialty subcontractors, etc.)

Table 2-1 presents a summary estimate of labor hours for the scope of work described in Section IIC above.

Table 2-1. Study 1 Estimated Labor Hours

| Category | Estimated Labor Hours[1] |
|---|---|
| EWG SME | 784 |
| Support Personnel | 436 |
| Note:<br><br>1. Labor hour estimate has large potential variance and will be updated on an ongoing basis to reflect changes | |

## G. Milestones and Schedule

It should be noted that the schedule is dependent on many factors, including but not limited to: agency authorization, weather, access restrictions, changes to the plan occasioned by findings, or other factors. The project schedule will be revised and updated on an ongoing basis to reflect such changes as they occur. The agencies will be notified of potential effects of schedule changes on the overall study timeline objectives as they occur.

# III. Study 2 - Recent Erosion and Deposition Processes

## A. Purpose

The overall objective of this study is to quantify and characterize recent rates of surface and near-surface erosion and temporary sediment storage occurring on hillslopes, in regions of concentrated flow, and in stream channels at and near the facility. The initial locations of these studies would be the regions surrounding the Nuclear Regulatory Commission (NRC)-licensed disposal area (NDA), the State licensed disposal area (SDA), and the rim of the North Plateau. Subsequent study locations may be recommended within the larger Buttermilk Creek watershed and, if appropriate, within a companion drainage.

A priority listing of specific studies and components has been identified on the basis of further consideration of uncertainty in erosion-prediction technology, and these will be the focus of the initial activities. The specific studies can be grouped into three categories: (1) hydrologic parameters, which include storm depth, duration, and frequency parameters, and soil-infiltration capacities; (2) erodibility parameters, which include stream-bed sediment entrainment thresholds, soil/till-entrainment thresholds and erodibility coefficients, and soil/till-particle sizes and bulk densities; and (3) gully geomorphic parameters, which include the morphometric characteristics of all gullies and the morphodynamics of any headcuts or knickpoints.

Study 1 will aid Study 2 by contributing information about possible stratigraphic or other influences on gulley and headcut characteristics.

## B. Data Quality Objectives

The DQOs for Study 2 are as follows:

1. **Define the Study Problem:**
   Current rates of surface and near-surface erosion and temporary sediment storage occurring on hillslopes, in regions of concentrated flow, and in stream channels at and near the facility, have not been well characterized; therefore, improved confidence in prediction of future erosion includes the collection of additional hydrologic, erosion, and geomorphic data to supplement existing data to reduce uncertainty in erosion modeling.
2. **Identify the Goal(s):**
   a. Quantify rainfall rates and snow depths
   b. Quantify infiltration capacity or rate and soil moisture for all surficial geologic materials
   c. Quantify the flow rates and total suspended solids in select gullies
   d. Quantify the flow rates and total suspended solids at select stream-locations
   e. Quantify the erodibility of the surficial geologic materials
   f. Quantify the entrainment thresholds for all bed and bank materials within select gullies and stream channels

g. Quantify the topographic characteristics of select gullies

h. Provide expert guidance on how these factors should be incorporated in predictive erosion models

3. **Identify Information Needed:**
   a. Measurements of rainfall rates and snow depths
   b. Measurements of infiltration capacity and soil moisture
   c. Measurements of flow rates and total suspended solids
   d. Measurements of erodibility
   e. Measurements of entrainment thresholds
   f. Measurements of gully geometry

4. **Define the Study Boundaries:**
   a. Lateral: WVDP premises and surrounding area bounded by Quarry and Franks Creeks
   b. Vertical:
      i. Topographic – from surface grade of WVDP to bottoms of adjacent creeks and gullies
   c. Temporal: three years from authorization to proceed (may be extended if authorized)

   d. Data Collection:

Task 2.1 A database will be constructed so that meaningful statistics can be derived from the collated distributions of rainfall and snowfall. This would require a minimum of three years of continuous data, capturing approximately 30 to 60 storm events (or about 10 to 20 storms per year).

Task 2.2 To adequately quantify infiltration rate and soil moisture content, at least 20, but not more than 60, measurements are proposed.

Task 2.3 A database will be constructed so that meaningful statistics can be derived from the collated distributions of runoff and suspended sediment concentration in the select gullies. This would require a minimum of three years of continuous data, capturing approximately 30 to 60 storm events (or about 10 to 20 per year).

Task 2.4 A database will be constructed so that meaningful statistics can be derived from the collated distributions of runoff and suspended sediment concentration in the select stream channels. This would require a minimum of three years of continuous data, capturing approximately 30 to 60 storm events (or about 10 to 20 per year).

Task 2.5 To adequately quantify the erodibility of the surface materials, at least 20, but not more than 60, measurements are proposed.

Task 2.6 To adequately quantify the erodibility of the bed and banks of stream channels and gullies, at least 20, but not more than 60, measurements are proposed.

Task 2.7 To quantify adequately the time-evolution of gully morphology and localized erosion and deposition within these geomorphic features, up to 10 gullies will be surveyed each year for a minimum of three years.

5. **Develop the Analytic Approach:** Identifies the decision logic employed to meet study goals.
    a. If three years of rainfall rate and snow depth data are obtained, then goal 2a will be met; otherwise, additional study may be warranted.
    b. If data are collected on infiltration capacity or rate, and soil moisture, for all surficial materials, then goal 2b will be met; otherwise additional study may be warranted.
    c. If three years of data on flow rates and total suspended solids in select gullies and streams are obtained, then goals 2c and 2d will be met; otherwise additional study may be warranted.
    d. If erodibility of the surficial materials is quantified, then goal 2e will be met; otherwise, additional study may be warranted.
    e. If entrainment thresholds for bed and bank materials are quantified for selected gullies and streams, then goal 2f will be met; otherwise, additional study may be warranted.
    f. If the topographic characteristics of selected gullies are quantified, then goal 2g will be met; otherwise additional study may be warranted.
    g. If a through f enable best professional judgment to resolve how current erosion and deposition processes should inform prediction of future erosion, then goal 2h will be met; otherwise, additional study may be warranted.

6. **Specify Performance or Acceptance Criteria:**
    a. Experimental measurement uncertainty: ±10 percent
    b. Infiltration measurements:
        i. std. dev. for multiple (up to 10) measurements at specific location variability ±30 percent
        ii. spatial variability – each geologic unit sampled at 3 locations
        iii. temporal variability – key locations re-sampled with variability ±30 percent
    c. Erodibility and entrainment threshold measurements:
        i. variation for multiple measurements at specific location ±30 percent
        ii. spatial variability – each geologic unit sampled at 3 locations
        iii. temporal variability – key locations re-sampled with variability ±30 percent

7. **Develop the Plan for Obtaining Data:**
    a. Measure rainfall rates and snow depths
    b. Measure infiltration capacity or rate and soil moisture for all surficial materials
    c. Measure flow rates and total suspended solids in select gullies
    d. Measure flow rates and total suspended solids at select stream locations
    e. Measure erodibility of surficial materials
    f. Measure entrainment thresholds for bed and bank materials
    g. Measure topographic characteristics of select gullies
    h. Reporting

## C. Scope and Prioritization

The scope of this study initially is restricted to one year, from approximately June 15, 2015 to June 14, 2016. For this period, the following tasks have been identified to address the focus studies noted above. Specific details of each of the tasks will be developed in TIPS that will specify the task scope, deliverables, estimated cost, schedule, and other pertinent task-specific details.

### Task 2.1: Quantify Rainfall Rates and Snow Depths

Precipitation, infiltration, and runoff will be monitored discretely in space and time. A rainfall gage will be installed at the West Valley site. This will be a tipping-bucket rainfall gage, wherein its surface orifice funnels precipitation into a mechanism that tips when filled to the calibrated level (Figure 3-1a). The gage is capable of recording 0.25 mm increments at intensities up to 700 mm/hr. (±3%) and at sampling frequencies of up to 1 Hz when connected to a data logger (Figure 3-1b). This technology would be supplemental to the meteorological station currently in operation at the WNYNSC. Additional rainfall gages may be installed at strategic locations within the Buttermilk Creek watershed to provide additional information at larger spatial scales.

Snowfall can be an important contributor to the total water budget in western New York. Coupled to each rainfall gauge, a sonic sensor (Figure 3-1c) will measure snow depth as a function of time. This sensor will measure the distance from the probe to the snow surface to within ±10 mm at sampling frequencies of up to 1 Hz.

Location 1 on Figure 3-2 has been identified as a potential location for the installation of the rainfall gage and snow depth sensor. This location should be unobstructed by trees or buildings, it should be near a road for easy access, and the site should be within the restricted area of West Valley. Please note the following. First, all proposed equipment will be self-powered. Second, locations for all monitoring equipment will assessed by preliminary, on-site field reconnaissance, and these will be discussed with and vetted by agency representatives before purchase and installation. The procedure proposed will optimize data collection opportunities and complement allied activities and/or previously collected data.

A database will be constructed so that meaningful statistics can be derived from the collated distributions of rainfall and snowfall. This would require a minimum of three years of continuous data, capturing approximately 30 to 60 storm events (or about 10 to 20 storms per year).

For Task 2.1, the data-quality objectives shall focus on database construction and experiment uncertainty. First, a continuous database will be established for rainfall rates and durations for storm events and for snowfall depths at one location, captured at very high temporal resolution (1 Hz). All surface erosion assessments depend heavily, if not entirely, on rainfall-runoff relations established for the site. As such: (1) no time limit is placed on the acquisition of rainfall and snowfall rates, as much variation can occur annually; (2) modest resources are required to maintain and operate the equipment and to process the data, once installed; and (3) a longer monitoring program increases the chances of observing high-magnitude, low-frequency events of great importance to assessing erosion processes and erosion prediction technology. An initial 5-year monitoring program is recommended, depending on availability of resources.

Second, all equipment will be calibrated semi-annually, both on- and off-site, to verify all experimental measurement uncertainties. No tolerable limit has been established for experimental uncertainty, but $\pm$10% would be acceptable. Any devices displaying greater uncertainty, or temporal drift in the uncertainty, will be recalibrated and/or replaced.

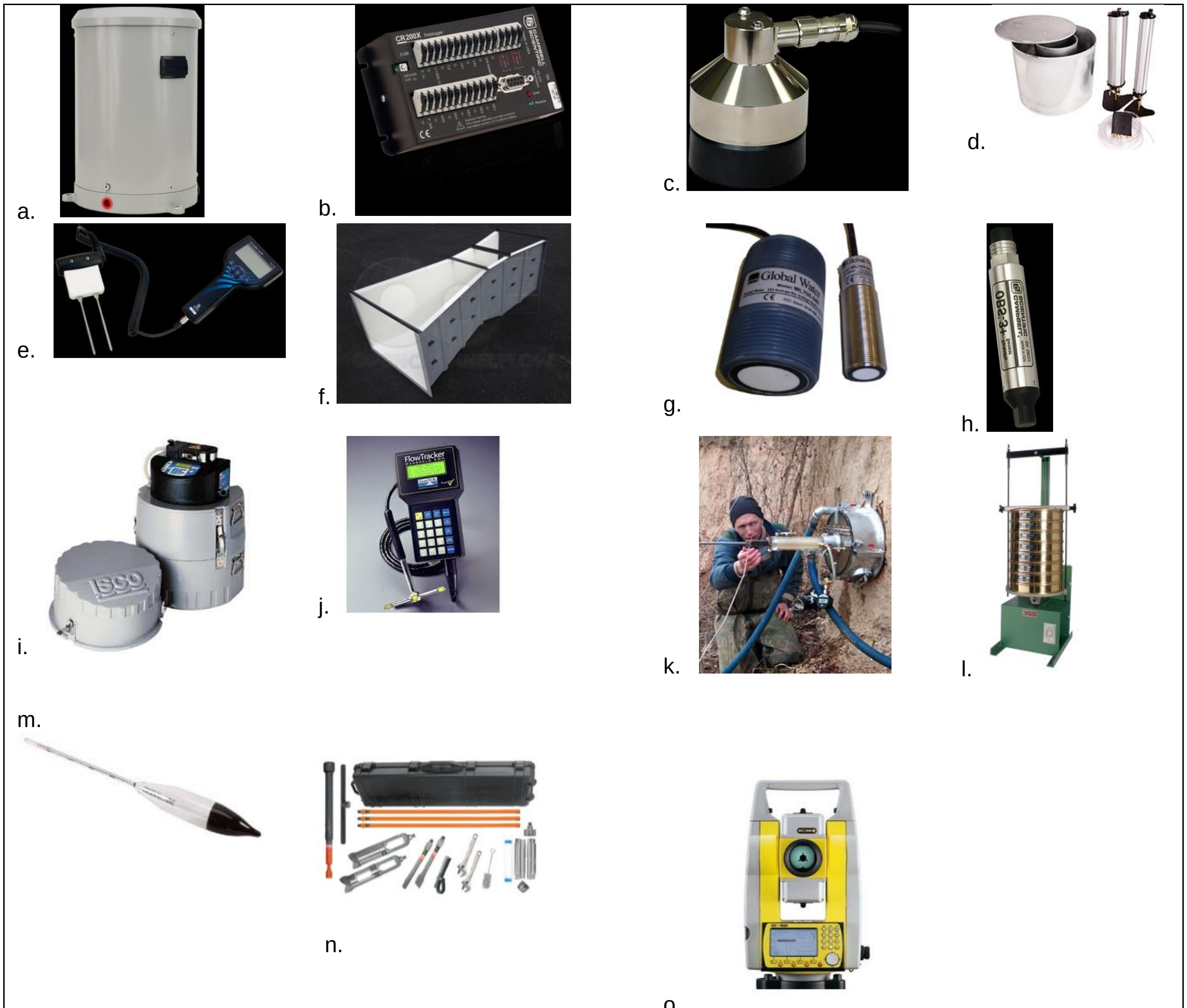


Figure 3-1: Images of suggested equipment: (a) Campbell Scientific tipping bucket rain gage CS700, (b) Campbell Scientific data logger CR200(X), (c) Campbell Scientific snow depth sensor SR50A-L, (d) Humboldt double ring infiltrometer, (e) Campbell Scientific soil moisture probe HS2, (f) Open channel flow 24" Parshall flume, (g) Global Water ultrasonic water level sensor WL705, (h) Campbell Scientific optical backscatter probe, (i) Teledyne ISCO 6712 portable sampler, (j) SONETK 2D Flowtracker current meter, (k) jet test device (Greg Hanson), (l) Humboldt large, motorized, economy sieve shaker, (m) hydrometer, (n) AMS soil sampling kit hydrometer, and (o) Geomax total station.

### Task 2.2: Quantify Infiltration Capacity or Rate and Soil Moisture for all Surficial Materials

Infiltration capacity or rate can be measured directly using a double-ring infiltrometer (Figure 3-1d). This method can measure the steady-state infiltration rate (or saturated hydraulic conductivity) of the surface layer, in this case soil, sediment, or till. The device consists of an inner and outer ring inserted into the ground, where each ring is supplied with a constant head of water, and the saturated-infiltration rate is derived by monitoring infiltration as a function of time. Saturated infiltration rates will be measured at the same locations as the erodibility analyses (see Task 2.5 below), and measured again periodically (monthly, quarterly, biannually). Soil moisture contents also will be measured at the same time using a handheld probe at a depth up to 0.1 m below the ground surface (Figure 3-1e). This probe can measure real-time volumetric water contents up to 50% with a resolution of less than 0.05% and with a measurement accuracy of ±3%. All security and safety policies and procedures for on-site activities, as required by the agencies, will be established before any such activities take place, and these procedures will be strictly followed.

For Task 2.2, at least 20, but not more than 60, measurements should be sufficient to adequately quantify infiltration rate and soil moisture content. The data-quality objectives shall focus on experimental uncertainty, spatial variability, and temporal variability. First, experimental uncertainty will be assessed by measuring infiltration rates and moisture contents at a single location for the same geologic formation up to 10 times in a single day. From this, a standard deviation for measurement uncertainty *in situ* will be calculated. Second, spatial variability will be assessed by sampling each geologic formation of interest in at least three (3) locations, where sample locations will be based on a geostatistical framework (i.e., stratified systematic sampling). Additional infiltration tests will be conducted if the standard deviation of the measurements for a given geologic formation exceeds a tolerable amount to be determined (ca. ±30%). Third, temporal variability will be assessed by re-sampling a subset of previously collected data at least three (3) times during the year. Additional information tests will be conducted if the standard deviation of the measurements at a specific location exceeds a tolerable amount to be specified (ca. ±30%).

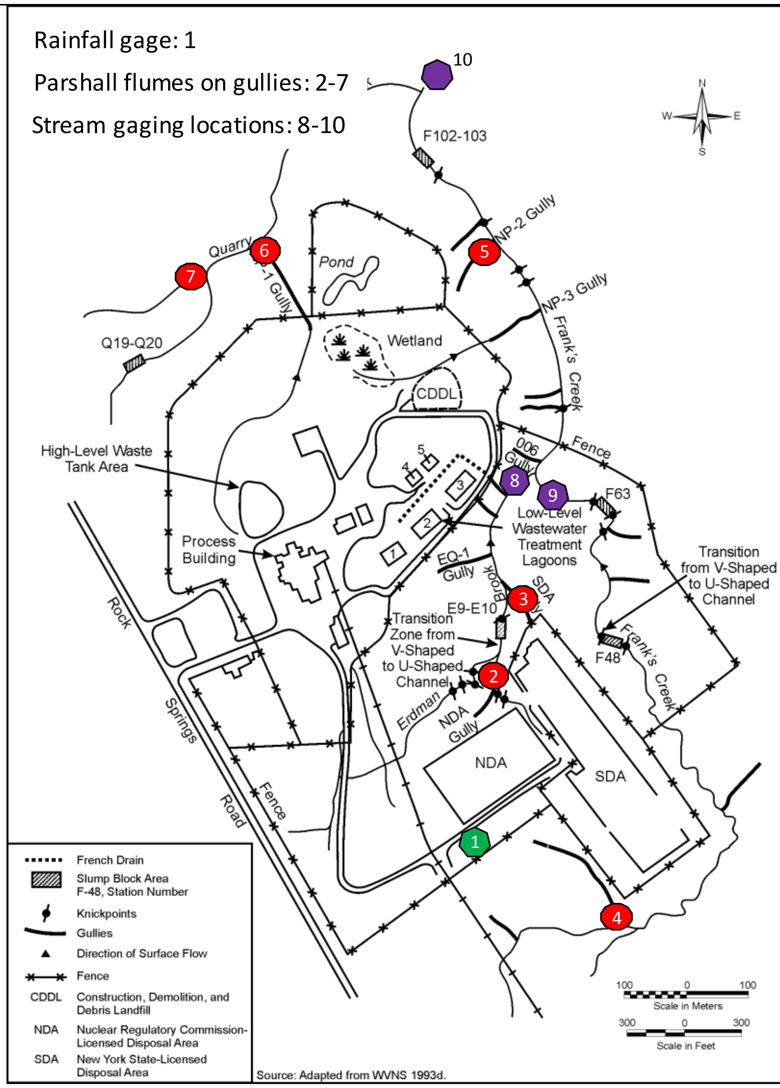


Figure 3-2: Potential locations for the installation of rainfall gage and snow sensor (location 1; green), Parshall flumes (locations 2-7; red), and gaging stations (locations 8-10; purple). This original figure appears in the EIS.

### Task 2.3: Quantify the Flow Rates and Total Suspended Solids in Select Gullies

Flow rates and total suspended solids in select gullies will be monitored. Select small gullies will be equipped with a Parshall flume (Figure 3-1f), an ultrasonic water-level sensor (Figure 3-1g), and an optical backscatter probe (Figure 3-1h). Parshall flumes are fixed in place and are specially designed to accurately measure flow rate from a single measurement of flow depth. A range of Parshall flumes are available commercially to measure any anticipated flow rates. Each flume will be of the appropriate size to address the range of expected flow rates for the channel in question, and each will be calibrated by the manufacturer and verified by an SME. An ultrasonic, water-level probe will be affixed above and orthogonal to the channel, so that flow depth with be monitored continuously. The ultrasonic, water-level sensor will employ a focused probe that has dynamic ranges of 0.1 to 0.9 m (resolution of 2 mm), 0.1 to 3.7 m (resolution of 10 mm), and 0.3 to 14.6 m (resolution of 43 mm), depending on the flume to be installed, with accuracies of 0.5% of its dynamic range. Each ultrasonic probe will be connected to a data logger (Figure 3-1b) that has a sampling frequency of up to 1 Hz. Lastly, an optical backscatter probe also will be mounted into the Parshall flume, and monitor turbidity up to 4000 NTU at-a-point at a frequency of 1 Hz. This probe will be calibrated on-site using a Teledyne ISCO portable sampler (Figure 3-1i), that is capable of obtaining water and sediment samples *in situ* during runoff events (up to 24 individual samples) at a wide range of sampling frequencies. These ISCO-captured samples will be processed in the laboratory to measure total suspended solids (mass) per unit volume, and will be used to calibrate the optical backscatter probes. As such, the ISCO sampler will be installed at each instrumented waterway for discrete periods. All security and safety policies and procedures for on-site activities and for collection and removal of sediment samples, as required by the agencies, will be established before any such activities take place, and these procedures will be strictly followed.

Logistical issues to be addressed include installation and operation. Parshall flumes would be carried to locations using trailers or sleds pulled by trucks or ATVs. All flumes would be placed in-line with a gully on level ground (some grading might be required, by hand or mechanical device), and secured with stakes or the flume's sides back-filled using in situ sediment. Flume installation will not disrupt any current or planned erosion control protection. The flume will be situated either upstream or downstream from such infrastructure, or an alternative site and/or method will be proposed in consultation with agency representatives. All proposed equipment will be self-powered. Finally, locations for all monitoring equipment will assessed by preliminary, on-site field reconnaissance, and these will be discussed with and vetted by agency representatives before purchase and installation. This would include determining accessibility for installation, operation, and maintenance. The procedure proposed will optimize data collection opportunities and complement allied activities and/or previously collected data.

Six gullies have been identified as potential monitoring sites (locations 2-7 on Figure 3-2). Locations 2 (NDA gully on Lagoon Road Creek), 3 (SDA gully), and 4 (southwest corner of SDA). All were selected because these are critical areas of concern for gully erosion and they are located just downstream from stormwater outflows. Locations 5 (North Plateau [NP]-2), 6 (NP-1), and 7 (western upstream gully of Quarry Creek) also were selected because they are critical areas of concern for gully erosion. These flumes will be installed at the toe of the gullies and just upstream from their confluences with Erdman Brook (gully locations 2 and 3), Frank's Creek (gully locations 4 and 5), and Quarry Creek (gully locations 6 and 7).

Of these six locations, gully locations 2, 3, and 4 potentially will be instrumented first, and these installations will exclude the optical backscatter probes and required ISCO sampling. These more modest activities will provide three immediate benefits: (1) data on flow rates within discrete gullies will be measured and monitored for the first time at West Valley, thus providing key input into the erosion prediction technology (Task 3), (2) the efficacy of the instrumentation will be assessed at a much lower initial cost, as opposed to instrumenting all six gullies without such demonstration, and (3) the results obtained will be used to resolve whether additional gully monitoring is warranted.

A database will be constructed so that meaningful statistics can be derived from the collated distributions of runoff and suspended sediment concentration in the select gullies. This would require a minimum of three years of continuous data, capturing approximately 30 to 60 storm events (or about 10 to 20 per year).

For Task 2.3, the data-quality objectives to be employed are identical to Task 2.1. First, a continuous, high temporal-resolution database will be constructed, initially for a 5-year period. Second, all equipment will be calibrated semi-annually to detect measurement uncertainties, and any deficient devices will be recalibrated and/or replaced on the basis of acceptable uncertainty ranges to be established.

### Task 2.4: Quantify the Flow Rates and Total Suspended Solids at Select Stream Locations

A simple stage recording system will be installed for those streams that are too large for a dedicated Parshall flume. Here, an ultrasonic water-level sensor (Figure 3-1g) will be installed above the creek or river, orthogonal to the water surface, and an optical backscatter probe (Figure 3-1h) will be placed into the flow. Both flow stage and turbidity will be monitored continuously using a data logger (Figure 3-1b). On-site stream gages will be required to convert flow stage to flow rate by means of standard techniques. A given stream discharge will be measured manually using a hand-held digital current meter (Figure 3-1j) and stadia rod; thus, an adequate range of flow rates will be measured over time. The hand-held current meter will be a three-component, acoustic-Doppler current meter that is able to measure flow rates from ±0.001 to 4.0 m/s at a resolution of 0.1 mm/s and with an accuracy of ±2.5 mm/s. The optical backscatter probe will be calibrated using the ISCO sampler (Figure 3-1i; see above).

Three locations have been identified for the potential stream gages (locations 8-10, Figure 3-2). Location 8 is on Erdman Brook and Location 9 is on Frank's Creek just upstream from their confluence. Location 10 is just downstream from the confluence of Quarry Creek and Frank's Creek. Consistent with Task 2.3, locations for all monitoring equipment will assessed by on-site field reconnaissance, they will be discussed with and vetted by agency representatives before purchase and installation, and all accessibility issues will be addressed.

Of these three locations, location 10 potentially will be instrumented first, and this installation will exclude the optical backscatter probe and required ISCO sampling. These activities will provide three immediate benefits: (1) data on flow rates within Frank's Creek will be measured and monitored for the first time, thus providing key input into the erosion prediction technology (Task 3); (2) the efficacy of the instrumentation will be assessed at a much lower initial cost, as opposed to instrumenting all three gaging gullies without such demonstration; and (3) the results obtained will be used to resolve whether additional streamflow monitoring is warranted.

A database will be constructed so that meaningful statistics can be derived from the collated distributions of runoff and suspended sediment concentration in the select stream channels. This would require a minimum of three years of continuous data, capturing approximately 30 to 60 storm events (or about 10 to 20 per year).

For Task 2.4, the data quality objectives to be employed are identical to Tasks 2.1 and 2.3. That is, a continuous database will be constructed initially for a 5-year period, experimental errors will be quantified, and any problematic devices will be recalibrated/replaced as necessary.

### Task 2.5: Quantify the Erodibility of the Surficial Materials

The erodibility of the surface materials, whether on hillslopes or within gullies and stream channels, is a function of the geologic and geomorphic attributes of the sediments. Figure 3 displays the surficial geology of the WVDP and nearby environs. Three geologic units are of particular importance here: (1) unit 4, termed sand and gravel (alluvial fan and floodplain deposits), which lie atop much of the North Plateau, (2) unit 5, termed Lavery Till, which forms the top till on much of the North and South Plateaus and has been observed in both weathered and unweathered states, and (3) units 7 and 8, termed the Kent Recessional sequence of sands and gravels, which lies stratigraphically below the Lavery Till. Unit 10, the Kent Till, is exposed in Buttermilk Creek. The composition, origin, and thickness of these units have been summarized in the EIS. The erodibility of the units and their temporal and spatial variability have yet to be quantified; in these regards, Study 1 will aid Study 2 by helping to reduce the uncertainty of geologic layer boundaries, layer thicknesses, soil fractures, etc.

Erodibility indices for all surficial materials will be quantified both *in situ* and in the laboratory. A jet-test device will be used to assess soil, cohesive sediment, and till-entrainment thresholds and erodibility coefficients. This device uses a submerged, circular-impinging jet under a constant head that is directed at the soil/till surface (Figure 3-1k). This jet creates a scour hole, whose depth can be monitored as a function of time using a point gauge. The entrainment-threshold and erodibility coefficient of the sediment then can be measured by the time-variation in erosion rate, with the assumption that the apparatus conforms to classic jet-impingement theory. Erodibility indices will be measured for soils, cohesive sediments, and tills at numerous locations at the WVDP, and repeated periodically (monthly, quarterly, biannually) to assess their temporal variability and limits of uncertainty. Clastic and non-cohesive sediments will be assessed by particle size analysis discussed in Task 2.6. All security and safety policies and procedures for on-site activities and sample analysis and removal, as required by the agencies, will be established before any such activities take place, and these procedures will be strictly followed.

For Task 2.5, at least 20, but not more than 60, measurements should be sufficient to adequately quantify the erodibility of the surface materials. The data quality objectives to be employed are identical to Task 2.2. First, experimental uncertainty will be quantified by multiple tests at a single location. Second, spatial variability will be assessed by sampling each geologic unit in at least three (3) locations employing a geostatistical framework and applying an acceptable level of variation (ca. $\pm$30%). Exceeding this level would require additional sampling. Third, temporal variability will be assessed by re-sampling key locations and also applying an acceptable level of variation (ca. $\pm$30%).

### Task 2.6: Quantify the Entrainment Thresholds for all Bed and Bank Materials within Select Gullies and Stream Channels

The entrainment thresholds for the beds and banks of all critical gullies and creeks will be assessed by three methods. The jet-test device will be used to assess the erodibility of the material, as described above for channels with beds composed of soil, cohesive sediment, or till. Representative grab samples will be obtained and a sieve analysis (Figure 3-1l) will be conducted in the laboratory for channels with beds composed of relatively fine-grained unconsolidated sediment (sand), as described above.

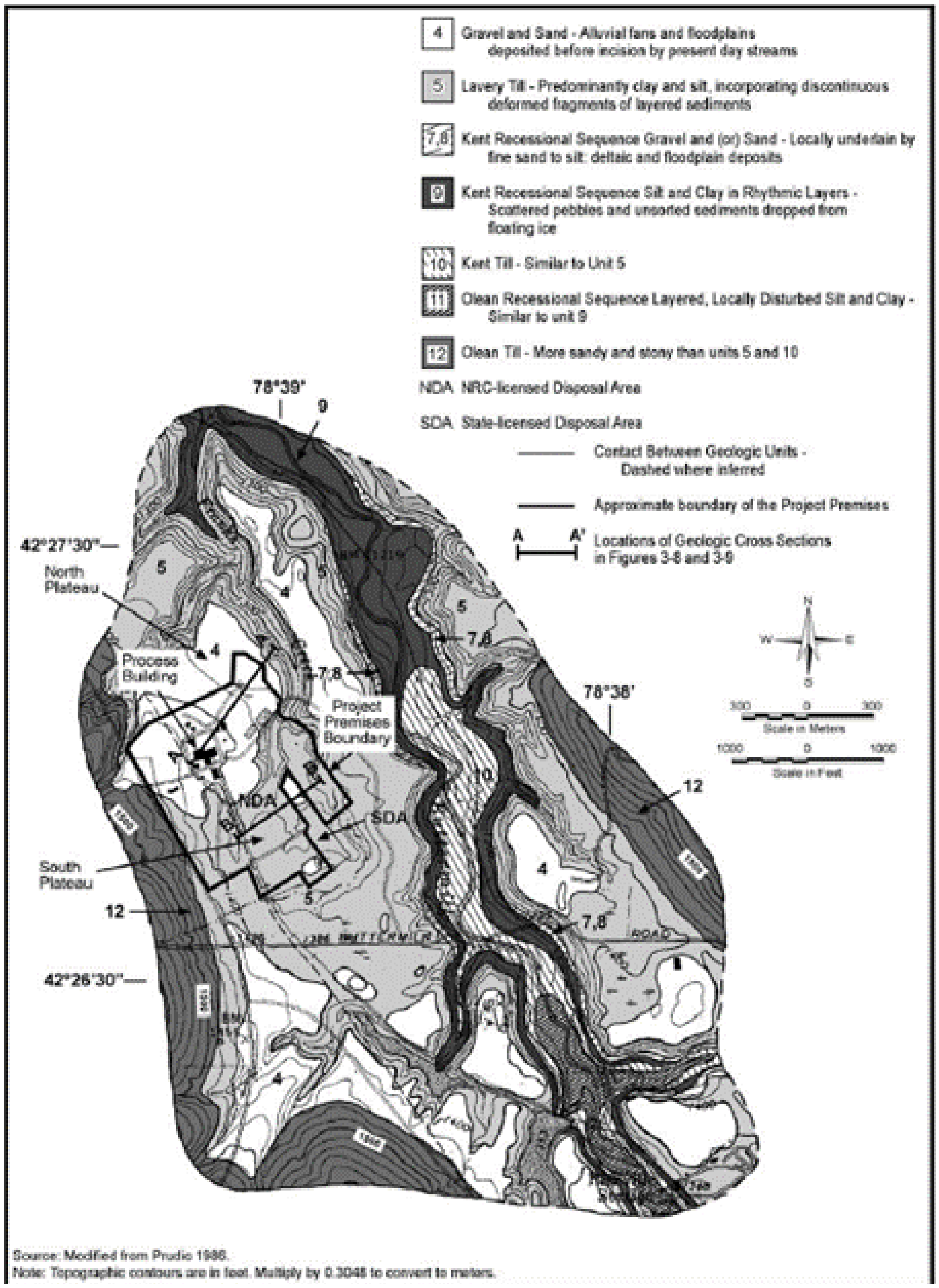


Figure 3-3: Surficial geologic map of the WV Demonstration Project. (This figure appears in the EIS).

The Wolman pebble-count method will be used for those channels with beds composed of relatively coarse-grained unconsolidated sediment, such as sand and gravel. This technique requires the observer to measure the shortest axis of up to 100 random particles on the bed. Entrainment thresholds for the clastic sediments will be quantified using analytical techniques. The fractional percentage of sand, silt, and clay will be measured for all soils, cohesive sediments, and possibly tills, using the hydrometer method (Figure 3-1m), which measures the increase in water density due to the suspension of silt and/or clay in agitated samples.

Bulk density also will be measured for all samples that are assessed for erodibility, where *in situ* cores will be obtained by using either a slide hammer (Figure 3-1n) or a hand-held, hollow-stem power auger. Erodibility indices and entrainment thresholds again will be measured for soils, sediments, and tills for all channels of interest at the WVDP, and repeated periodically (monthly, quarterly, biannually) to assess their temporal variability and limits of uncertainty. All security and safety policies and procedures for on-site activities and sample analysis and removal, as required by the agencies, will be established before any such activities take place, and these procedures will be strictly followed.

For Task 2.6, at least 20, but not more than 60, measurements should be sufficient to adequately quantify the erodibility of the bed and banks of stream channels and gullies. The data-quality objectives to be employed are identical to Task 2.5 (see above).

### Task 2.7: Quantify the Topographic Characteristics of Select Gullies

The topographic characteristics of all gullies will be measured and monitored for gully-geomorphic parameters. Gullies surrounding the SDA and NDA will be identified in the field and surveyed using a total station device (Figure 3-1o). The exact number of gullies to be surveyed currently is not known, but these will include the three gullies to be monitored for flow (see above), and may eventually include up to ten gullies on-site. These surveys will include longitudinal profiles and multiple gully cross-sections, with dedicated benchmarks. These geomorphic attributes will be measured one or more times each year. The existence of headcuts within gullies and nearby streams, as well as the location of the gully heads, also will be noted. Migrating headcuts or knickpoints represent areas of intense erosion, and their important morphodynamic characteristics would include their heights and widths, their migration rates, and their stratigraphic controls. Study 1 will aid Study 2 by describing the location and character of gulley features across portions of the WDVP and improving understanding of regional context. These headcuts will be identified through on-site reconnaissance, and their attributes will be monitored using survey techniques.

For Task 2.7, up to 10 gullies will be surveyed each year for a minimum of three years to adequately quantify the time-evolution of gully morphology and localized erosion and deposition within these geomorphic features. The data quality objectives to be employed are similar to Tasks 2.1, 2.3, and 2.4. First, a database of gully topography with time will be assembled, initially for a 5-year period. Second, experimental uncertainty for the survey equipment and procedures will be assessed on a semi-annual basis.

### Task 2.8: Reports

Technical memoranda or other technical communications will be prepared, as requested by the agencies.

## D. Resource Needs

Study 2 will be led by Dr. Sean Bennett, with the assistance of his students from the State University at Buffalo. Student support will be accessed through a subcontract with the university.

DOE and NYSERDA personnel will play key roles in Study 1 on the basis of their institutional knowledge of the site and its history. Agency personnel will also provide key support in areas of logistics, safety and security training, and other areas.

The required resources include instrument, construction and installation, and operation, maintenance, and data collection. Table 3-1 summarizes these key components.

Table 3-1: Summary of the priority activities focused on recent erosion and deposition processes and the necessary resources. Resources required for instrumentation, construction, and data collection are identified for each parameter.

| Task | Parameter | Instruments Required | Construction Resources | | | Data Collection Resources | |
|---|---|---|---|---|---|---|---|
| | | | Installation | Equipment | Personnel | Equipment | Personnel |
| 1 | Rainfall rate | Rainfall gage | Pole placed into ground | Pole-digger (power auger) with cement footer | Contractors with students | Laptop; ATV/car | Students |
| 1 | Snowfall rate | Sonic depth measurement | Pole placed into ground | Pole-digger (power auger) with cement footer | Contractors with students | Laptop; ATV/car | Students |
| 2 | Infiltration rate | Double-ring infiltrometer | Placed onto ground for test; need a water source | NA | NA | Source of water; ATV/car | Students |
| 2 | Soil moisture | Soil moisture probe | NA | NA | NA | ATV/car | Students |
| 3 | Flow rate (small channels) | Parshall flumes with ultrasonic water level and optical backscatter probes, plus an ISCO sampler | Flume placed at grade, emplaced into soil or cemented | Back-hoe, skid-steer loader, cement mixer | Contractors | Laptop; ATV/car | Students |
| 4 | Flow rate (large channels) | Ultrasonic water level and optical backscatter probes, plus an ISCO sampler | Cantilever arm with pole placed into ground | Pole-digger (power auger) with cement footer | On-site contractors | Laptop, hand-held current meter, stadia rod, ATV/car | Students |
| 5, 6 | Erodibility of cohesive sediment | Jet test device | Placed onto ground for test; need a water source | NA | NA | Source of water; ATV/car | Students |
| 5, 6 | Erodibility of clastic material | Sieve analysis | NA | NA | NA | Sieves and shaker; ATV/car | Students |
| 5, 6 | Soil bulk density | Soil sampler | NA | NA | NA | Slide hammer and power auger; ATV/car | Students |
| 5, 6 | Soil texture | Sample analysis | NA | NA | NA | Hydrometer, glassware; ATV/car | Students |
| 7 | Gully geomorphic parameters | Total station and survey gear | NA | NA | NA | ATV/car | Students |

The required instrumentation has been discussed in Section B - Scope and Prioritization. The proposed instrumentation to be installed on-site is expected to provide high-temporal resolution data (seconds to minutes) at discrete locations in space (critical locations) for very long periods (years). Other equipment is needed for on-site measurements and for sample processing.

Installation is required for dedicated instruments on-site, including installing mounts for weather sensors, and installing Parshall flumes, and other instruments along select gullies and streams. These activities may require construction machinery and authorized personnel. All equipment requirements and additional personnel, if needed, will be addressed by ECS.

Installation, operation, and routine maintenance of instruments, as well as all data collection, will be accomplished by undergraduate and graduate students from the State University at Buffalo under the direct supervision of an SME. These students will assist in the installation of all facilities, and will be responsible for collecting data at regular intervals, securing any necessary samples for analysis, and processing all secured samples in the laboratory. Additional resources would be required to process, reduce, and interpret all collected data, to archive these data into acceptable formats, and to provide the necessary analysis of these data for delivery to the agencies and their cooperators. It is anticipated that student assistants also will be engaged in these activities. All necessary security and safety policies and procedures for on-site activities will be followed. Finally, graduate students will be on-site only when necessary, and only during times that have been approved by the agencies.

All instrumentation purchased for the project will become the property of DOE and NYSERDA and will remain at the facility following the conclusion of the project, or will be deployed elsewhere at the discretion of DOE and NYSERDA.

## E. Estimated Level of Effort

This task requires the installation, operation, and maintenance of specialized equipment as well as the on-site characterization and measurement of materials and surface processes and landscapes. A complete list of necessary equipment has been provided. On the basis of professional judgment, this task requires approximately 1982 hours of student assistance, which includes fulltime commitments in the summer and part-time commitments for the rest of the fiscal year (or about two graduate students working approximately 20 hours per week for a calendar year), and 362 hours of SME time (or about 9 weeks working 40 hours per week). These efforts are applicable only for the period from June 15, 2015 to June 14, 2016.

The estimated level of effort in labor hours for the first year will be based on several factors including but not limited to:

- Agency authorization
- Logistics
- Weather
- Findings of the initial tasks
- Availability of key resources (e.g. age-dating laboratory sample turnaround times, specialty subcontractors, etc.)

Table 3-2 presents a summary estimate of labor hours for the scope of work described in Section IIC above.

Table 3-2. Study 2 Estimated Labor Hours

| Category | Estimated Labor Hours[1] |
|---|---|
| EWG SME | 362 |
| Support Personnel | 1982 |
| Note:<br>1. Labor hour estimate has large potential variance and will be updated on an ongoing basis to reflect changes | |

## F. Milestones and Schedule

Procurement and installation of all equipment will occur in the summer of 2015. For Tasks 1, 3, and 4, installation of the facilities is expected to be completed by September 1, 2015, under the assumption that all equipment will be ordered and delivered in a timely fashion. Data collection for these tasks is expected to commence by this same date. For Tasks 2, 5, 6, and 7, data collection is expected to begin by June 15, 2015. The primary milestones to be achieved this year are: (1) the successful installation, operation, and maintenance of all facilities; and (2) the compilation of annual reports summarizing all data collected.

It should be noted that the schedule is dependent on many factors, including but not limited to: (1) agency authorization; (2) weather; (3) access restrictions; and (4) changes to the plan occasioned by findings, or other factors. The project schedule will be revised and updated on an ongoing basis to reflect such changes as they occur. The agencies will be notified of potential effects of schedule changes on the overall study timeline objectives as they occur.

# IV. Study 3 - Preliminary Erosion Modeling

## A. Purpose

The main purpose of this study is to contribute to reducing uncertainty in estimates of future erosion. This study will attempt to achieve this objective through evaluation of new data and formulation of modeling approaches at various time and space scales, together with uncertainty estimates. In this section, the term "model" or "models" is intended to mean any physical or numerical representation of the processes that occur in nature to modify topography at various scales from individual gullies to broad areas of the landscape, and over various timeframes from short (tens to hundreds of years) to long (thousands of years). Broad objectives of erosion modeling are listed below. Effort in Year 1 should begin to address these objectives.

General erosion-modeling objectives include the following:

1. Establish a quantitative estimate of present-day uncertainty in erosion predictions and its variation across time and space scales to use as benchmarks for evaluating the reduction in uncertainty to be achieved by the planned additional modeling.

2. Establish the most appropriate governing equations to describe erosion at the site, across a range of space and time scales, taking into account recent literature and site data (e.g., LiDAR).

3. Select and configure erosion modeling program(s) that implement solutions to these equations and algorithms. Note that some modeling programs allow the user to select a particular set of equations and algorithms from among a menu of options, and therefore can be tailored to suit the needs of the project.

4. Identify justifiable ranges for the parameters in these governing equations on the basis of comparison between observed and computed erosion patterns. This objective will be met in part through data collection in Study Areas 1 and 2, and in part through comparison of observed and computed erosion patterns.

5. Identify potential "erosion hot spots" at the site. Model sensitivity analysis can help reveal likely locations of active erosion, and the degree to which management actions (such as storm-water drainage routing) might influence such patterns.

6. Perform calculations of potential future erosion under alternative parameter sets and scenarios. Such calculations could be either deterministic or probabilistic or both; they could also provide input to, or components of, probabilistic performance assessment.

7. Provide quantitative estimates of confidence level in predictive erosion model results, relative to magnitude of time and space scales.

Newly collected data will play a key role in meeting the objectives of this study. Age dates collected through Study 1 will provide tighter constraints on the estimates of timing of past landscape evolution for use in model calibration and validation. Terrain analysis conducted in Study 1 will support this study both directly by providing additional insight into processes that should be represented in models, and defining an initial landscape surface for erosion-model testing and calibration, and indirectly by providing information needed to identify and interpret features for age dating, and thereby improve understanding of the geomorphic history for calibration and validation. Data collected in Study 2 will support this study by providing better constraints on model parameters, as well as additional data for model testing. Although the new data collected in Studies 1 and 2 are essential to completing the ultimate objectives of Study 3, several important tasks should be carried out during year 1 in parallel with Studies 1 and 2. Completing these tasks during year 1 will effectively lay the groundwork for the modeling effort in subsequent years, so that this effort can be performed efficiently and without setup and planning delays once the data have been collected.

## B. Data Quality Objectives

Defining the DQOs for Study 3 will follow an evolutionary process. The DQOs identified below represent the initial high-level DQOs that will provide the framework for the Study 3 modeling effort. As the early tasks produce additional information, the DQOs will be refined to reflect the additional information. Later tasks will be guided by refined task-specific DQOs that will enable focusing the effort. The initial high-level DQOs are as follows:

1. **Define the Study Problem:**

   Future erosion processes across varying temporal and spatial scales may be predicted with improved confidence utilizing existing data augmented with additional data to be developed through Studies 1 and 2.

2. **Identify the Goal(s):**

   a. Establish quantitative estimates of present-day uncertainty in erosion prediction across various time and space scales to benchmark the current understanding of uncertainty in erosion predictions
   b. Establish the most appropriate governing equations to describe erosion at the site across a range of space and time scales
   c. Select and configure erosion modeling program(s) that implement solutions to these equations
   d. Identify justifiable ranges for the parameters in the governing equations
   e. Reproduce post-glacial configuration of topography using Lidar imagery
   f. Identify an analog site that is appropriate for model calibration purposes
   g. Identify an appropriate balance between model grid resolution and spatial extent so as to compute gully formation in the upper portion of the watershed at the spatial scale of the facilities.
   h. Evaluate and characterize a model’s ability to predict the timing, location, and evolution of such gullies (if formed).
   i. Assess reduction in uncertainty resulting from models that take advantage of additional data developed through Study 1.

j. Assess reduction in uncertainty resulting from models that take advantage of additional data developed through Study 2.
k. Establish quantitative estimates of the confidence level in predictive erosion model results across various time and space scales.

3. **Identify Information Needed:**
   a. Erosion model calculations that have been completed to date
   b. Age dates from Study 1
      (will provide tighter constraints on the estimates of timing of past erosion and depositional processes for use in model calibration and validation)
   c. Terrain analysis from Study 1
      (will provide additional insight into processes that should be represented in models, and define initial conditions for erosion-model testing and calibration)
   d. Information on correlation of paleoclimate with erosion rates from Study 1
   e. Statistical topographic metrics calculated from 2010 LiDAR
      (will enable comparison of real and computed surfaces)
   f. Measurements of current erosion and deposition processes from Study 2
      (will provide better constraints on model parameters, and provide additional data for model testing)
   g. Climate projections
   h. Access to a supercomputing facility

4. **Define the Study Boundaries:**
   a. Lateral: spatial scales varying from individual gullies to entire Buttermilk Creek watershed (and potentially a companion watershed such as Connoisarauley Creek)
   b. Vertical: spatial scales varying from bedrock surface to modern surficial units
   c. Temporal: various time scales from tens of years through multi-decadal periods

5. **Develop the Analytic Approach:** (Identifies the decision logic employed to meet study goals)
   a. If further evaluation of previous erosion modeling results enables benchmarking of present-day uncertainties in erosion predictions, then goal 2a will be met; otherwise, additional study will be needed.
   b. If it is the consensus opinion of the EWG that the addition of a governing equation yields a significant contribution to describing the erosive response as determined from acceptable goodness of fit between computed and observed topography or other metrics, then goal 2b will be met; otherwise, additional governing equations may be needed.
   c. If existing computer programs are identified that solve the most appropriate governing equations identified in 5.a., then goal 2c will be met; otherwise new programs may be developed.
   d. If the governing equation parameters are measured during the data collection activities (Studies 1 and 2), then goal 2d will be met; otherwise additional data collection and/or analysis may be needed.

e. If it is the consensus opinion of the EWG that remnant plateaus are adequate to define the post-glacial topography, then goal 2e will be met; otherwise additional data and/or analysis may be needed.
f. If it is the consensus opinion of the EWG that the geomorphologic conditions in a nearby valley are similar enough to use as an analog site, then goal 2f will be met; otherwise additional searching may be needed.
g. Computer simulation runs will be conducted to assess the technical feasibility of computing gully formation using two approaches: (1) high-resolution, site-wide modeling, and (2) nested modeling in which particular areas of interest are represented at suitably high resolution while others have coarser resolution. Goal 2g will be met by demonstrating the ability to model gully features of similar scale and extent to those observed on site. EWG is confident, based on prior experience, that a nested approach or its equivalent will be technically feasible; the issue here is whether nesting is required, and in what form. More generally, the goal is to identify an appropriate balance between grid resolution and spatial extent. If it is the consensus opinion of the EWG that the selected gridding is appropriate to the on-site processes, then it will be adopted; otherwise, additional refinement of grid geometry and resolution may be needed.
h. Model performance in predicting short-term erosion patterns will be assessed by comparing observed and predicted locations of particularly active modern gully erosion. If the locations with the highest predicted erosion coincide with observed areas of active modern erosion, and do not coincide with areas known to have had negligible modern erosion, then goal 2h is met; otherwise, additional study may be needed.
i. Uncertainty reduction resulting from new data and findings from Study 1 can be assessed by executing erosion-model runs that compare (1) parameter ranges estimated from the erosional history as it was understood prior to the Phase 1 studies, and (2) reduced parameter ranges estimated on the basis of new mapping and geochronological data obtained through Study 1. Goal 2i will be met if an assessment of the comparison results in a better understanding of the types and magnitudes of the uncertainties involved in the analysis; otherwise, additional study may be needed.
j. Uncertainty reduction resulting from new data and findings from Study 2 can be assessed by executing erosion-model runs that compare (1) parameter-value ranges as they were known prior to the Phase 1 studies, and (2) narrower parameter value ranges as provided by Study 2 activities. Goal 2j will be met if an assessment of the comparison results in a better understanding of the types and magnitudes of the uncertainties involved in the analysis; otherwise, additional study may be needed.
k. If the evaluation of planned additional erosion modeling results enables the estimation of a confidence level in erosion predictions, then goal 2k will be met; otherwise, additional study will be needed.

6. **Specify Performance or Acceptance Criteria:**
   a. Acceptance criteria for estimation of present-day uncertainty: Estimates will be considered acceptable if the number of measurements collected in time

and space from output of existing modeling calculations is sufficient to characterize the present-day uncertainty.

b. Acceptance criteria for model selection and configuration: a model will be considered acceptable if it proves to be capable of reproducing erosional forms and properties observed at the site, such as the magnitude of plateau-to-valley relief; longitudinal stream profiles with convex segments; average valley side-slope gradient distribution; and metrics that reflect gully initiation, location, downcutting, and headward advance, as determined through Task 3.4.
c. Acceptance criteria for erosion modeling computer programs: a program will be considered acceptable if it includes all of the governing equations that provide a significant contribution to describing the erosion response, as determined in analytical approach 5.a.
d. Acceptance criteria for input parameter ranges: if field data from study areas 1 and 2 meet their respective Data Quality Objectives, they are considered acceptable for use in defining parameter ranges.
e. Acceptance criteria for reconstruction of post-glacial topography: acceptability will be assessed using a split-sample test in which a portion of the LiDAR data are used to interpolate topography, and a portion are used to compare with the interpolation. Reconstruction is acceptable if the interpolated topography has a root-mean-square (RMS) uncertainty on the same order as that of the LiDAR RMS (0.3 m), or if tests show a level of sensitivity to interpolation uncertainty that is lower than other sources of uncertainty.
f. Acceptance criteria for identification of a test site: plateau-to-valley relief is within +/-30% of the calibration watershed; stream longitudinal profiles contain convex-upward segment; similar stratigraphic sequence exposed from plateau top to valley floor; similar gully density and geometry.
g. Acceptance criteria for high-resolution gully modeling: numerical model is able to predict the formation of gully features at the appropriate scale, using either a site-wide high-resolution model grid or a nested grid.
h. Acceptance criteria for model reproduction of erosional forms: predicted areas of active modern erosion qualitatively match actual locations of recent erosion.
i. Acceptance criteria for assessing uncertainty reduction: use of new data in model calculations leads to a better understanding of the types and magnitudes of the uncertainties involved in the analysis.
j. Acceptance criteria for estimation of confidence level: Estimates will be considered acceptable if the number of measurements collected in time and space from output of planned additional modeling is sufficient to characterize the confidence level.

7. **Develop the Plan for Designing and Building Numerical Model(s):**
    a. Collaboration in Studies 1 and 2 data collection
    b. Preparation for model selection and component testing
    c. Design calibration and testing strategy
    d. Select, extract, and analyze topographic metrics from 2010 LiDAR imagery

e. Generate model grids
f. Design strategy and select site for model validation
g. Reporting
h. (Additional tasks following Year 1 will be specified later)

The DQO process for modeling is closely related to the level of quality assurance (QA) that will be required for the modeling effort. The modeling activities in Study 3 will be conducted in accordance with the QA approach described in EPA QA/G-5M titled "Guidance for Quality Assurance Project Plans for Modeling" and the EWG guidance for the treatment of uncertainty described in the report titled "*Uncertainty Considerations and Prioritization of Recommended Phase 1 Erosion Studies"* for all Study 3 activities (EPA 2002). QA is discussed further below in Section D.

## C. Scope and Prioritization

During Year 1, this study will support the data collection and evaluation activities (Studies 1 and 2) and focus on preliminary modeling tasks that do not require the use of new data. Specifically, the study will focus on: benchmarking the uncertainties inherent to previous predictive modeling efforts, working with the 2010 LiDAR topography data to produce the necessary digital database for model initialization and for model-data comparison, and completing preparatory work for ingesting the new data and performing calibration and uncertainty analysis. The preparatory work includes designing and testing workflows, and writing and performing quality control on supporting computer programs, among others. These tasks will follow current best practices, including the production of clear documentation, version control, and use of unit tests to ensure reproducibility and transparency.

Performing these preparatory tasks concurrently with the new data-collection actions (Studies 1 and 2) is important to facilitate timely completion of the overall study, and will increase the efficiency of the overall erosion study by allowing the modeling team to "hit the ground running" as the data from Studies 1 and 2 become available. The following subsections describe details of the preliminary tasks to be completed in Year 1. Specific details of each of the tasks will be developed in TIPs that will specify the task scope, deliverables, estimated cost, schedule, and other pertinent task-specific details. As additional information is gathered, subsequent tasks will have refined task-specific DQOs that will reflect the additional information, and will enable the tasks to be better focused.

### Task 3.1: New Data-Collection Support and Evaluation

The modeling team leaders (Dr. Tucker, Ms. Doty, and Dr. Bennett) will work closely with the leaders of Studies 1 and 2 in planning data-collection activities, performing quality control, and interpreting and processing data. Therefore, although data collection is not an activity under Study 3, the project budget includes support for the modeling team to participate in the Study 1 and 2 data collection and analysis.

### Task 3.2: Preparatory Work for Model Selection and Component Testing

The initial element of this task is to benchmark the current understanding of uncertainties inherent to previous erosion predictions to provide a basis for evaluating uncertainty reduction achieved by the planned modeling. This exercise is designed to support the characterization of general uncertainty in the model results. It will quantify present-day uncertainty, the degree to which uncertainty in future erosion estimates grows with increasing time frame, and the distribution of uncertainty in space. To accomplish this task, the team will examine the erosion-model calculations that have been completed to date. The examination of differences among these calculations will provide a simple measure of the degree of uncertainty associated with the previously-used model and its configuration. Because models are spatially distributed, the analysis will also provide insight into how uncertainty in projected erosion varies in space. Note that these calculations will represent a minimum level of uncertainty, because they do not factor in uncertainty due to imperfect understanding of the governing processes (structural uncertainty) or uncertainty in future conditions (such as climate and land cover). This exercise will be repeated in subsequent years to characterize the change in uncertainty as the model evolves.

An iterative process of model refinement will be employed that will involve refinement of DQOs to focus the modeling effort, and to provide a sound basis for model design criteria. This refinement process will help to demonstrate to stakeholders that the selected erosion modeling approach is indeed an appropriate choice. In this approach, elements of reality (model components) are switched on incrementally in a modeling program, so that each contribution can be assessed individually and added (or deleted) on the basis of response, resulting in a model that is as simple as is realistically possible, and thus computationally efficient. A variety of different elements can be evaluated in this manner. The results of this exercise would then help to address stakeholder concerns regarding particular events and processes that may be perceived by laypersons as being especially important. In Year 1, the requisite workflows and computer codes to support this exercise will be constructed and tested. The modeling team members will also perform quality-control measures on the codes using synthetic data, and will document the process.

The Quality Assurance Project Plan (QAPP), described below in Section D, will be created in this task, and refined as required in subsequent tasks.

### Task 3.3: Design Model Calibration and Testing Strategy

This task involves choosing a method for optimizing model parameters through iterative model-data comparison, and calculating uncertainty bounds. After an appropriate calibration/optimization method, such as Markhov-Chain Monte Carlo, has been identified, supporting computer codes will be obtained and/or created, and testing and quality control will be performed on these codes using synthetic data. The team members will also prepare the supporting documentation.

### Task 3.4: Select, Extract, and Analyze Topographic Metrics

The recommended model-calibration strategy takes advantage of the 2010 LiDAR data by comparing observed and calculated topography. This approach requires that various statistical measures of the terrain be calculated from the LiDAR data, and translated into a file format that is suitable for comparison with model output. In this task, the necessary workflows and computer codes will be created, and quality control performed. The statistical data will be extracted from LiDAR data. Tests will be conducted to ensure that the model-data comparison process is robust and error-free. A method for quantitatively scoring the metrics, in terms of a goodness-of-fit value, will be derived and tested. As additional information becomes available, the DQOs will be refined to include the types of "goodness of fit" measures that will be used to assess changes in a variety of landforms and at a variety of scales.

### Task 3.5: Generate Model Grids

LiDAR data obtained in 2010 represent a digital image of the site terrain that has considerably higher resolution and greater accuracy than was previously available. These data will be used to generate input grids for erosion-model calculations. Grids will be constructed for the Frank's Creek, Quarry Creek, Upper Frank's Creek and Buttermilk Creek watersheds, as well as for unnamed gullies of interest, using a variety of grid spacings on the basis of a preliminary design for modeling. In addition, DEMs and grids of these watersheds will be created in their approximate post-glacial configuration by mapping and interpolating remnant plateau surfaces.

Following grid generation, the modeling team will complete tests to calculate the computational speed associated with each of the different grid resolutions and catchment sizes. This will include tests of the ability of the model to predict gully formation in the upper portion of the watershed at the spatial scale of the facilities. As additional information becomes available, task-specific DQOs will be refined to describe the details required to carry out these tests and to assess their results.

### Task 3.6: Design Strategy and Select Site for Model Validation

A useful way to assess uncertainty associated with erosion-model projection is to use a model to calculate erosion at a site that is different from the one from which calibration data were obtained. This task involves identifying an appropriate test site or sites, identifying the data that would be needed to carry out a validation test, and working with the data collection teams to prepare a study plan and obtain such data.

### Task 3.7: Report Progress to Agencies and Stakeholders

This task consists of time spent reporting progress on Year 1 modeling actions. Reporting mechanisms includes inter-group communications (email correspondence, telephone conferences, and occasional face-to-face meetings of sub-groups), as well as preparation of reports for the agencies, including year-end reporting.

### Additional Tasks (contingent on time and budget constraints)

If it turns out that the level of effort required to accomplish tasks 3.1 through 3.7 is less than anticipated, the modeling team will take advantage of the opportunity to begin work on the following tasks that would otherwise be slated for Year 2.

### Task 3.8: Identify, Obtain, and Become Familiar with Computing Resources

Model calibration, uncertainty analysis, and erosion projection will require large numbers of model calculations, which necessitates use of multi-processor computers. After being granted permission to access the computing facilities, the modeling team will become familiar with their use and complete mandatory security training requirements. -It is important to begin this process early because delay is likely while a request is assessed.

### Task 3.9: Create Preliminary Design for Future-Erosion Projection

An important goal of the overall project is to develop a set of scenarios for future erosion, and perform model calculations and uncertainty analyses for those scenarios. A number of questions regarding the high-level design need to be addressed before this step can be accomplished, such as: What will the overall strategy for future projection look like? What lessons can be drawn from other long-term forecasting efforts, such as the Intergovernmental Panel on Climate Change (IPCC) climate projections? How many scenarios will be used? What will be the basis for these scenarios? How will uncertainty be assessed? These questions will not be fully answered in Year 1, but the EWG considers it important to begin the design process early so that in later years a basic foundation on which to build exists. This task, therefore, involves the following sub-tasks: (1) inventory and review other long-term projection projects to ascertain "lessons learned;" (2) formulate a preliminary outline for scenarios to be examined; (3) inventory and review methods for uncertainty analysis in projections; and (4) create a working outline for the most appropriate approach in the context of the WVDP.

### Task 3.10: Compile and Analyze New Available Climate/Hydrology Data and Define Parameter Ranges

This task involves reviewing the recent literature, regional climate/hydrology databases, and newly collected site-characterization data to identify any new constraints on the key erosion-model parameters identified by the EWG. The modeling team will compile and evaluate the updated data and define appropriate parameter ranges for use in the models.

## D. Quality Assurance Protocols

As discussed above in Section B, the modeling team will follow the QA approach described in EPA QA/G-5M titled "Guidance for Quality Assurance Project Plans for Modeling" for all Study 3 activities (EPA 2002). The guidelines call for a "graded" approach to identifying the appropriate level of QA for a modeling project. Higher standards of defensibility and rigor are set for projects that involve potentially large consequences, such as Congressional testimony, development of new laws or regulations, or the support of litigation. The higher standard of quality assurance will be applied to the Study 3 activities.

The QA approach uses a systematic planning process to assure that any models applied are scientifically sound, robust, and defensible. The three steps of the process are: 1) modeling needs and requirements analysis, 2) modeling design, and 3) model application. Step 1 includes the development of the data quality objectives, qualitative and quantitative model performance criteria, and needs for model output. Step 2 develops the model design (i.e., theoretical development, mathematical formulation, identification of needed input data and parameter values, and science peer review), model coding (i.e., development of data management and hardware/software configuration) and model testing (i.e., evaluating uncertainty, determining whether the chosen model meets performance criteria, and calibrating the model). Step 3 involves running the computer code, testing and analyzing the model output, and documenting and summarizing the results. The tasks identified within Study 3 will be grouped into these three general steps for completion during the first year of the project. However, because the process is iterative in nature, some of these tasks will be revisited in subsequent years as reviews and checks occur within the process to ensure that the model output will address all necessary project objectives and meet necessary performance criteria.

The modeling team will develop a QA Project Plan (QAPP) to guide them through the model development and application process. It will be the “blueprint” by which the Study 3 tasks are implemented and assessed. Each of the Study 3 tasks within the three steps will be mapped to one or more elements of the QAPP according to the types of procedures conducted and the data quality issues that need to be addressed within each task. The mapping process will ensure that data used for the characterization of environmental processes and conditions are of the appropriate type and quality for their intended use (i.e., the choices made are consistent with the established objectives and project-specific requirements). The team members will also use the QAPP to ensure that the quality assurance aspects of all Study 3 tasks are fully documented throughout the duration of the project.

## E. Resource Needs

Dr. Greg Tucker will lead Study 3 with the assistance and support of Sandra Doty. Dr. Tucker and Ms. Doty are EWG SME with extensive technical expertise in landscape-evolution modeling and multiprocessor computers. The SME leads will be responsible for completing the majority of the planned work. We anticipate that student assistants also will be engaged in these actions where possible.

## F. Estimated Level of Effort

The estimated level of effort in labor hours for the first year will be based on several factors including but not limited to:

- Agency authorization
- Availability of key resources (e.g. supercomputing resources)

Table 4-1 presents a summary estimate of labor hours for the scope of work described in Section IIC above. Table 4-1 does not include labor hours for additional Tasks 3.8 through 3.10 described above. These tasks are planned for the second year but may be able to be moved up into the first year if time and budget permit.

Table 4-3. Study 3 Estimated Labor Hours

| Category | Estimated Labor Hours[1] |
|---|---|
| EWG SME | 1532 |
| Support Personnel | 640 |
| Note:<br>1. Labor hour estimate has large potential variance and will be updated on an ongoing basis to reflect changes | |

## G. Milestones and Schedule

Task 3.1 (New Data Collection Support and Evaluation) will run concurrently with the field data collection tasks of Studies 1 and 2. Tasks 3.2 through 3.6 will follow in sequential order, because the activities are mostly independent of one another. Some may run concurrently as needed, however, to assure their completion during Year 1. Task 3.7 will run intermittently throughout the year as needed.

The primary milestone to be achieved in the first year is the completion of an interim report summarizing the model-selection process and setup of the necessary cyber-infrastructure for model testing, quality control, and application.

It should be noted that the schedule is dependent on many factors, including but not limited to: (1) agency authorization; (2) availability of appropriate computing resources; (3) changes to the plan occasioned by findings; (4) or other factors. The project schedule will be revised and updated on an ongoing basis to reflect such changes as they occur. The agencies will be notified of potential effects of schedule changes on the overall study timeline objectives as they occur.

# V. Summary and Conclusions

In summary, the primary purpose of the Phase 1 erosion studies is to enable improved forecasts of future erosion at the WVDP and WNYNSC, reduce the associated uncertainty, and assist the agencies in reaching consensus on the likely effects of future erosion. The collective studies comprise three principal study areas:

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

Together these studies are designed to:

- produce converging lines of evidence enabling improved prediction of future landscape evolution at the WVDP,
- improve the scientific defensibility of the results obtained, and
- strengthen the confidence in short- and long-term forecasts of erosion processes.

The studies are designed to be independent, but complementary, and will interact synergistically to result in a greater reduction of erosion-prediction uncertainty than would the sum of the individual studies.

As discussed in Section I, the EWG critically examined the various sources and potential magnitudes of uncertainty with respect to erosion-prediction technology and terrain analysis. The EWG then created a priority list of those specific studies and study components likely to reduce uncertainties in erosion prediction using models. It is the EWG's opinion that the studies outlined in this Plan provide the best opportunity for reducing uncertainty and assisting the agencies in reaching consensus on the likely effects of future erosion at the WVDP and WNYNSC.

# VI. References

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