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Appendix A: Erosion and Control of Erosion at the West Valley Nuclear Site

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Erosion and Control of Erosion at the West Valley Nuclear Site

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PART I EROSION

Introduction

The purpose of this report is to evaluate erosion, and predictability of erosion, of soil plateaus that underlie existing and proposed facilities at the West Valley Nuclear Site in western New York (Part I). Additionally, control of erosion is evaluated and associated costs predicted (Part II).

The West Valley Nuclear Site (Figure 1) is located in western New York State, in a mostly forested region with some agriculture such as dairy farms. The site lies on a plateau of soil on the west side (left bank) of north-flowing Franks Creek, a tributary to (also north-flowing) Buttermilk Creek. Buttermilk Creek is tributary to west-flowing Cattaraugus Creek, which enters Lake Erie about 20 miles south of Buffalo, N.Y. In Lake Erie, longshore transport from the mouth of Cattaraugus Creek is dominantly toward Buffalo, the Niagara River, Lake Ontario and the St. Lawrence River. Studies by Joshi (1988a, 1988b) demonstrate movement of Cs-137, Pu-238, 239, 240, 241 and Am-241 via this longshore route from West Valley past Niagara region drinking water intakes and into Lake Ontario.

The soil plateau is split into three areas. The east plateau is about 600 to 1,000 feet wide by 7,000 feet long, oriented roughly north-south, and lies between north-flowing Franks Creek (on the west) and the north-flowing Buttermilk Creek (on the east).

Erdman Brook, a tributary to Franks Creek, divides the west plateau into north and south sections (often referred to in reports as the North Plateau and South Plateau).

Figure 2 presents a cross-section showing the veneer of soil covering the shale bedrock on the uplands, and showing the thick sediment that fills the Buttermilk valley. The Lavery till (poorly-sorted clay and silt with a small portion of coarser debris such as sand or cobbles) occupies most of the volume of the soil plateaus. Below Lavery till are sands and gravels of Kent glacier recession on top of Kent age till, and within the clay-rich Lavery till are lenses of sand from the lake deposits that were over-ridden to form the Lavery till (LaFleur, 1979; Dana et al., 1979). Above the Lavery till on the North Plateau is a discontinuous veneer of fine-sands from the glacier-margin lake(s) that formed during glacier retreat from the Lavery till (West Valley Nuclear Services, Inc., 1995). Following glacier retreat and during or after the decline of marginal lakes, Quarry Creek deposited alluvial fan sand and gravel across the North Plateau (Dana, et al., 1979).

Franks Creek can be seen splitting the plateaus west of Buttermilk Creek (Figure 2). A corresponding soil plateau occurs east of Buttermilk Creek, here referred to as Heinz Plateau. While the vertical exaggeration (used to make layers observable) is large, it is also appropriate because it helps to convey the steep west wall (left bank) of Buttermilk Creek. The soil plateau between Franks Creek and Buttermilk Creek (east plateau) is about 600 to 1,000 feet wide and 160 feet high (Figures 1 and 2).

Referring to Table 1 and Figure 1, several basic aspects of morphometry are quantified. Buttermilk Creek is high order and large basin compared to the other streams in the area. The other streams are all sub-basins of the Buttermilk basin. All basins have relatively low drainage densities (a high density would be 10s or 100s of miles of channels per square mile of basin; Strahler, 1952 and 1965). The heavy forest cover, mixed soils and humid climate lead to low drainage density, but how recently the terrain was deglaciated also plays a role.

Most of the Earth's surface in this region is as it was when the glacier and its adjacent lakes receded. Most of the soil plateau surfaces and the upland surfaces (eg. drumlins, swales, moraines, etc.) remain unchanged. There has not been enough time for stream incision into these surfaces and resulting high drainage densities to develop. Higher drainage densities are expected in the future as new gullies, ravines and streams form between existing lines of drainage. Features such as the soil plateaus will inevitably become dissected, and erode away.

Timing of Glacial Events

The ages of soil plateau and upland surfaces in the vicinity of the West Valley nuclear site are less than 19,000 years old. Muller and Calkin (1993) summarize carbon-14 dates and other time indicators for the region and demonstrate glacier retreat from the Wisconsinan terminal moraine at 19,000 years before present (BP). They suggest that the glacier continued to withdraw to a “minimum” size (Erie Interstade) at approximately 16,000 BP. During this retreat, glacier-margin lakes accumulated clays and silts. Readvance of the glacier on those lake deposits created clay-rich soils (Lavery and Defiance tills). They place the age of the Lavery till as approximately equivalent to the Angelica moraine and thus imply an age of about 16,000 BP. This fine-grained till forms much of the upper layers of the soil plateaus underlying the nuclear site (LaFleur, 1979; and EID, 1993, Volume 1, part 2, figure 2-6). A few miles north of the plateaus lies the Defiance moraine (LaFleur, 1979; and EID, Volume 1, part 2, figure 2-6), thought by Muller and Calkin (1993) to be approximately equivalent to the Arkport moraine which dates at 15,300 BP. The West Valley region’s upland features such as drumlins and moraines became exposed to erosion beginning between 19,000 and 16,000 BP. At 16,000 BP the irregular margin of Lavery ice (LaFleur, 1979) stuck down the Buttermilk valley like a tongue. The soil plateaus of the nuclear site were uncovered by ice (but not ice-margin lake water) between 16,000 and 15,300 BP.

The Lavery till under the West Valley nuclear site is considered glacier re-worked lake deposits, thus accounting for its very fine-grained texture. Fickies and others (1979) determined that the Lavery till had “been preconsolidated to loads substantially greater than the weight of the present overburden”. This result of laboratory consolidation tests is quantitative support for the notion of glacier over-riding and the reworking of Erie Interstade lake clays by the Lavery glacier.

Northward glacier recession from the Lavery moraine (16,000 BP) to the Defiance moraine (15,300 BP) and then to the Lake Escarpment moraine (14,000 BP) likely maintained continuous or intermittent glacier-margin lake water covering West Valley's plateaus. As the ice receded northward and westward, ever-lower lake-outlet channels were uncovered and lake levels dropped (Fairchild, 1932). Muller and Calkin (1993) make the case that the glacier retreated from the north-most of the Lake Escarpment moraines at about 13,360 BP. Thus glacier retreat controlled lower Buttermilk valley (nuclear-site soil plateaus) lake levels between about 16,000 BP and 13,360 BP.

Muller and Calkin (1993) concluded that Lake Whittlesey existed by 13,000 BP in the eastern Lake Erie basin (this low lake outlet was across Michigan). Consequently, glacial deposits blocking Cattaraugus Creek west of Buttermilk were free to be breached, lower the level of former ice-margin lakes and uncover the soil plateaus of the West Valley Nuclear Site beginning between 13,360 BP and 13,000 BP. How much later in time the lake water receded off the Buttermilk-area plateaus is not clear.

Buttermilk Creek and its tributaries contain terraces on the valley walls that are remnants of former floodplains; these flood plain remnants were abandoned as the streams eroded downward through the 13,000 (or younger) to 19,000-year-old till and lake-bottom surfaces. Numerous stream terraces were mapped (LaFleur's Appendix F in Albanese et al., 1984; Boothroyd, Timson and Dunne, 1982). A large terrace of Buttermilk Creek can be seen as an abandoned meander loop in Figure 1 about 2,000 feet south of the confluence of Franks Creek. A high small terrace of Franks Creek was dated about 9,920 BP. LaFleur (Appendix F in Albanese et al., 1984) suggested that erosion rates were rapid after glacier uncovering (down-cutting rate of 10 to 20 feet per 1,000 years) and then slowed in recent millennia (4 to 10 feet per 1,000 years). He thought younger terraces formed more slowly than older terraces. This kind of thinking is logical as long as processes are quasi-steady-state stream down-cutting with parallel slope retreat. However, the stream will eventually convert to aggressive side cutting as either local or regional base levels are reached. Additionally, these are complex and episodic processes, commonly proceeding at irregular rates (Wilson and Boria, 1999).

Lastly, much of the above discussion emphasizes stream down-cutting through time, beginning between 19,000 and less than 13,000 BP (depending on the uncovering of surfaces), and leaving unpaired terraces. However, much of the erosion was accomplished by initiation and advancement of gully heads. As lakes receded, upland tributaries would supply stream flow across featureless or undulating drained lake beds. As these few streams cut down, new gullies would diverge from them. The drainage networks of the soil plateaus of central and northern Buttermilk valley are thus perceived as partly inherited from pre-lacustrine upland topography and lake bed undulations, and mostly from formation of new gully heads.

Erosion at the West Valley Nuclear Site

As mentioned previously, stream erosion has proceeded during the past 19,000 years or less to carve uplands next to Buttermilk valley, and 13,000 years or less to carve lower Buttermilk valley and tributary ravines such as Franks Creek and Erdman Brook. The intervening surfaces such as uplands and soil-plateau tops remain essentially unchanged.

The processes of erosion operating on the soil plateaus at the nuclear site at West Valley beginning after 13,000 BP are gully head advancement, stream down-cutting with knickpoint migration, stream side cutting, landslides from stream down-cutting and side cutting, and sapping. Sapping is erosion by groundwater exiting a slope, sometimes from natural holes in the soil ("piping"). Knickpoints are waterfalls; at West Valley and elsewhere in western New York, knickpoints can occur in unconsolidated sediments with little or no varying layer resistance, as well as at boundaries. Most of these processes have long been recognized at West Valley and throughout western New York by many scientists and engineers. These processes combined with convex-up longitudinal stream profiles and un-paired stream terraces are evidence of rampant erosion at West Valley.

Gully Heads

Gully heads can be seen forming today at the site. Gully heads at the site have not been observed to self-heal. From general theory, the number of gully heads will increase with time; from my personal observations, new gully heads are now forming. The relative importance of overland flow versus sapping (erosive seepage) for gully initiation and gully head advancement is not known. However, currently one may observe gully extension or initiation at an elevation consistent with the common depth of cracking at top of Lavery till in the tops of the soil plateaus, or at an elevation consistent with the top of Lavery till under alluvial fan deposits on the North Plateau.

Slope Processes

Landslides at West Valley include (mostly) translation of tree-root bound blocks (EID, Volume III, part 3, p. 61) and (less frequently) a variety of sizes of rotational failures. Large rotational landslides tend to occur adjacent to stream floodplains; in other words, stream side cutting is or has occurred at the stream bed and this side cutting is responsible for large-slide initiation.

Contrary to the findings in the EID, slopes of gullies are not stable but are generally in stick-slip motion, on time frames of annual to decadal, often in concert with episodes of seasonal wetting; I reached this conclusion by observing conditions at the site and discussing these conditions with site personnel, and comparing the conditions to other sites in similar materials in western New York, and by looking at block conditions and tree conditions in and of themselves (tilt, trunk curvature, etc.). The 1993 EID (Volume III, part 3, p. 62) concludes that stable slopes have an angle of 21 degrees (38% grade). However, as already stated above, the slopes are not stable. Rough measurements made by me in summer 2006 approximately agree with the 21-degree slope in the EID as do precise measures made at the same time (same day 2007) by

Richard Young (2007, personal communication). Slope angles are stable, but slopes are in motion.

A state of dynamic equilibrium exists between gully down-cutting, knickpoint migration, tree-debris jams in the gullies, and slide rotation and block glide on the slopes, such that a 21- or 22- degree slope angle is maintained. The slope angle is apparently a steady-state phenomenon in spite of the episodic nature of the mutually adjusted variables listed above. It's a matter of scale; the slope angle grossly includes ("averages") the minor phenomena. From an engineering design perspective, a 21-degree slope here represents a Factor of Safety of less than 1.0.

Paired terraces (not reported for West Valley) are terraces along both sides of a valley at the same elevation and result from long time periods of stream stability (equilibrium). Streams may achieve equilibrium between the sediment washing or sliding or otherwise moving into the stream from slopes and the stream's ability to transport that sediment. Equilibrium might be achieved for a year or a decade or even a century without leaving a detectable imprint on the landscape. However, equilibrium achieved for centuries or millennia might leave paired terraces or laterally and longitudinally extensive terraces. Paired terraces have not been reported in southwest New York that date from post-glacial time. A few are suspected that may relate to base level controls such as former levels of the Great Lakes.

The large number of small unpaired terraces that exist in the Buttermilk valley and the thousands in southwest New York are attributed to aggressive stream down-cutting and landslides.

Longitudinal Streambed Erosion

It is generally agreed that bedrock substrates control down-cutting rates. Buttermilk's ability to widen its valley upstream of its bedrock channel supports the notion that the bedrock channel absorbs stream energy.

However, neither bedrock nor sediment streambeds are particularly resistant to erosion in this region. Forty years of observations across southwestern New York reveal several basic facts.

1) The shale bedrock when exposed in the beds of streams erodes partly by abrasion and weathering, and partly by flood-lifting of joint blocks. Blocks up to 10 x 10 x 1 feet are commonly lifted in floods with recurrence intervals of one to several years. However, the shales are extremely sensitive to cycles of wetting and drying and most shale blocks disintegrate into thumb-nail size chips in one year, two years at the most. Thus streambed armoring by shale bedrock does not happen.
2) The siltstone or sandstone layers in the shales are more resistant than the shales to erosion; siltstone or sandstone forms the waterfalls. Siltstones may form streambed armoring, but such armor is small enough (a foot or two in long dimension) to be transported in less than bank-full flows. Quarry Creek

shows local armoring by siltstone when its bed changes from bedrock channel to sediment substrate. The siltstone armoring extends upstream of the substrate material boundary, partly covering the upstream shale bedrock, as well as extending downstream. Such armors are likely in flux, added from above and removed from below.

3) Self-armoring of gullies is somewhat ineffective in southwest New York, even though many glacial boulders are granites, gneisses and sandstones capable of enduring thousands of years of weathering. First, except for the Lake Escarpment moraines, there is a lack of large boulders in the glacial deposits and a lack of large, durable-bedrock joint blocks south of the Onondaga limestone outcrops. In the immediate areas of the soil plateaus, opportunity for armoring is diminished because the Lavery till that is being eroded lacks large particles. Secondly, observations of artificial armoring (half meter or meter size rip rap) suggest that in western New York effective armors of beds do not occur because headcuts (or knickpoints) consume (transport) the coarse debris downstream.

Longitudinal profiles of streams in the Buttermilk watershed show minimal concave-up shape, the common traditional form for natural streams (Figure 3). Worse yet, streams or portions of streams show convex-up form when cutting soil plateaus (Figures 3a and 3b; and Boothroyd, Timson, and Dunne, 1982, Figure 8 and Plate 9). Convex-up is considered unstable and associated with rampant erosion. Thus, profiles of streams such as Franks Creek are compound: convex in their lower reaches where they cross Lavery plateaus, concave overall, and otherwise irregular in their upper reaches reflective of slopes inherited from glacial or other processes.

Lateral Erosion

While gullies such as Frank's Creek and its tributaries are aggressively down-cutting, Buttermilk Creek adjacent to the nuclear site is both down-cutting and shifting toward ever-more side cutting. Looking at a standard topographic map (such as Figure 1) reveals the near-absence of a flood plain where Buttermilk Creek is trapped within a bedrock canyon near its confluence with Cattaraugus Creek. However, where Buttermilk is unconstrained by bedrock walls, it has developed a flood plain. Future flood-plain widening is imminent because the meanders have yet to reach their potential symmetry and size.

One or more very large landslides on the left bank of Buttermilk Creek in the vicinity of the Nuclear Service Center have likely been chewing into the east-soil-plateau for centuries or longer. These landslides are particularly persistent (in a repetitive sense) and aggressive because Buttermilk Creek is forced against its left (west) bank. One control of Buttermilk's position is alluvial fan deposition by Heinz Creek (arbitrarily named) where Heinz Creek enters the valley floor and right bank of Buttermilk Creek (Figure 1 and Table 1). Heinz Creek or its alluvial fan force Buttermilk to remove the toe area of slide deposits.

LaFleur (1979) mapped extensive terrace deposits on the east side of Buttermilk valley opposite the above-mentioned area of landslides and downstream. The extent and position of the long terrace suggests that Buttermilk has been shifting down and westward for centuries or a few millennia. This terrace (east wall of Buttermilk) is approximately at the elevation of the Kent-age recessional deposits (Figure 2) found in the west wall of Buttermilk valley.

Deposition

Erosion may be interrupted, spatially or temporally, by deposition. For example, in early post-glacial time (after ca 16,000 BP) Quarry Creek deposited an alluvial fan over the Lavery till of the North Plateau. Quarry Creek today and for thousands of years has cut down through the fan into the Lavery till. LaFleur (1979) and Boothroyd et al. (1982) and others identified dozens of Buttermilk terraces as alluvial fan remnants at mouths of gullies entering former higher levels of Buttermilk Creek.

Episodic Rates of Erosion

On the timescale of 10,000 years, erosive processes described above are the result of numerous episodes of erosion that often occur at decadal or annual intervals. The result is gully and valley cutting through undulating approximately 13,000 to 19,000-

year-old landscape surfaces. Lack of rounding at the edges of the tops of soil plateaus attests to erosional dominance by gully down-cutting and Buttermilk Creek side cutting, with attendant parallel slope retreat caused by landslides.

Looking at landscape features formed during 10,000 year or 1,000 year time frames, effects of episodic, cyclic and continuous erosion are very difficult to separate. In contrast, erosion observed by scientists or engineers in western New York on time frames of a century, decade or year are clearly episodic. Individual knickpoints migrate upstream, and may disappear as quickly as individual storms or removal of a tree or debris jam. Landslides begin, move and leave the hillside in a more stable, gentler slope. Landslide processes continue when stream down-cutting or side cutting removes the base of the slides. Movements of knickpoints and slides are often seasonal, fastest in spring.

Half a century of observations of an entrenched meander of Chautauqua Creek in western New York (Muller, 1963; Wilson and Boria, 1999; and recent observations) demonstrated that episodes of erosion on either side of the interfluve (high ground) alternated; several years to a decade on one side, then the other, back and forth. The cut off occurred during one or a few storms in December 2005. This feature is of similar size, composition, and otherwise analogous to the high terrace (oxbow) of Buttermilk Creek about 2,000 feet south of the juncture of Franks Creek (the east side of the East Plateau).

Thus, erosion proceeds throughout southwestern New York by numerous recurrences of episodic events. Annual or decadal events (movements of landslides, knickpoints, gully heads, and sapping) chip away at the margins of the remnant ice-age landscape. The landscape is old in the sense that much of it is inherited from ice age glaciation, but young in the sense that post glacial stream erosion has yet to recarve most features into river-related scenery.

Aberrant Processes

The evolution of landscape at the West Valley Nuclear Site and throughout southwest New York is more complex than described above because there are spatially or temporally aberrant features or processes in the landscape system. Concerning West Valley erosion, known aberrant processes worsen the prognosis.

An example is climate change. As reported at the 2006 New York City Watershed Conference, precipitation is expected to increase between 9 and 30 percent in the next few decades, with increased portion as storm flow. Such conditions will likely increase erosion at West Valley.

A second example of an aberrant process may be the increasing number of instances of sapping near tops of gully walls and top of the west valley-wall of Buttermilk Creek. Across the approximately eight years of my visits to Franks and

Buttermilk Creeks I noticed more and larger instances of sapping. Changing groundwater flow directions should be expected as time proceeds because, as gullies erode and banks landslide, positions of lowest hydraulic pressure change, and groundwater flow paths follow. Increasing locations of sapping may be a natural semi-continuous process or related to European settlement (paving, roofing, hydraulic structures and deforestation).

A third aberrant process example is the previously mentioned lateral erosion of Buttermilk Creek into the easily-eroded sand and gravel (Kent-age recessional deposits) exposed in the west wall of the valley.

Temporal Predictions of West Valley Erosion

Exact erosion forecasts are not possible for the West Valley Nuclear Site soil-plateaus, because of the vigor of erosion in this relatively early stage of gully dissection of glacial landscape, because of processes such as Buttermilk flood plain widening and the Heinz Creek fan pressing Buttermilk Creek westward, and because of climate change. Retreat of west-bank Buttermilk landslides is as important as gully initiation and growth. Serious impacts including undermining or sapping of waste or redirecting of groundwater plumes could occur in decades (30 or 50 years?) if facilities are placed near edges of plateaus. Serious impacts could occur in centuries (in 300 or 500 years?) if placed in centers of plateaus.

Temporal prediction involves extrapolation of spatial processes into the past (hind casting) or future (forecasting). In previous sections of the report several spatial processes were identified as integrated process-response systems. The key spatial process systems at West Valley that predict erosion response are:

1. underflow and sapping at the base of Lavery till dessication cracks or at the base of the early-Holocene Quarry Creek alluvial fan causes gully head initiation and growth;
2. maintenance of a 21^{o} gully wall slope via dynamic equilibrium among processes of down-cutting and landslides (rotational and tree-block translation) causes retreat of soil-plateau edges between gully heads (i.e., gully wall back-wasting with maintenance of sharp-edged plateaus);
3. erosion of the toe of Buttermilk Creek landslide causes headscarp and plateau edge retreat.

Predictions

1. *Gully-Head Initiation*. The answer to the question "what is the rate of bifurcation (gully initiation) needed to yield 64 gully heads per 3,000 years" can be addressed by counting the bifurcations during the last 15,000 years. More than 50 first order streams per square mile of soil plateaus are shown in the lower Buttermilk watershed by topographic v-shapes in contour lines on the 1954 topographic map (USGS 7.5 minute). Sixty-four first order streams per square mile are estimated to occur, including new gullies in the past 53 years and those not observable on the topographic

maps. At most 15,000 years were available, so the rate was one "set" of bifurcations per 3,000 years. This prognosis assumes bifurcation of the lower Buttermilk soil plateaus began with two streams and the rate of formation of new gullies was geometric (Table 2). If future erosion was left uncontrolled, about 500 new gullies per square mile would form in the next 10,000 years. This analysis argues for gully head breaching of a trench or tumulus during the next 10,000 years or sooner. There is uncertainty in the exact number of initial gully heads and the rate of bifurcation.

2. *Gully Growth (Drainage Basin Expansion)*. Theoretical studies (Glock, 1931) suggested that drainage networks evolve rapidly to fill a region by headward erosion (Figure 4), then lose drainage density (total drainage length per area) as time proceeds and interfluves are reduced.

Ruhe (1952) compared drainage networks developed on four ages of glacial tills in an observational study (Figure 5). The observations supported theory in that drainage density increased with age of deposits. I infer from Figure 5 that maximum drainage density was achieved in about 20,000 years.

Parker (1976, 1977) conducted experiments using a stream table approximately 30 ft by 50 ft with controlled rainfall. Results (Figure 6) demonstrated that available space becomes filled with drainage channels, at first rapidly and then slowly. The total drainage density and the number of first order streams increase with total precipitation (time) until the available plateau top is occupied, and subsequently they diminish with further total precipitation (time). Parker's (1977) soil was a clay-silt-sand mix.

I reorganized Parker's results into a graph of time vs. basin-perimeter-growth (Figure 7); then measured the remaining soil plateau tops in middle to lower Buttermilk valley (40 to 50%). 50 to 60% of soil plateaus were removed in about 13,000 to 10,000 years (rounding off dates of withdrawal from Lake Escarpment moraine and C-14 age of high terrace). A value for eroded area of 50 to 60% yields a time of 4 to 6% of that needed for complete basin loss of plateau surfaces, based on Figure 7. Then (from Figure 7) I can infer that in another 10,000 to 13,000 years another 4 to 6% of time will go by and plateau-top losses will increase within these bounds of uncertainty: "60% eroded tops today will change to 70% in 13,000 years" to an upper range of "50% today will increase to 63% in 10,000 years." In other words, a range of an additional 8 to 13% of total original plateau tops will be lost in 10,000 years; or about 20% of the tops that remain today across lower Buttermilk watershed.

Several uncertainties in the above analysis lead to a much faster rate of denudation. First, Parker (1977) and Schumm et al. (1983) found that lowering base level caused knickpoints to stimulate erosion in experiments. The base level at Buttermilk has dropped about 200 feet and will decline further in the future; for example, if Springville Dam were removed from Cattaraugus Creek then in coming decades headcuts totaling about 25 feet would move up-stream into Buttermilk Valley. Second, the initial condition of Parker's basin was such that approximately 30% of the area was eroded immediately or quickly (his time zero). Third, deforestation, ditches and impervious surfaces are likely aggravating erosion at the West Valley site today. Fourth, increased storm flow resulting from climate change is expected to aggravate erosion in the future.

3. *Gully Growth (Direct Measurement of Franks and Erdman Head Cuts).* The knickpoint (headcut) on Franks Creek that several researchers (1993, EID, Vol. III, Part I) have identified as transition between V- and U-shaped channel segments were identified by Bembia (2006, 2007, personal communications) as the head of the Franks gully where the gully is advancing into an inherited ice-age channel. Bembia suggests this knickpoint is advancing several feet per year. Personal observations by me agree. In addition, the 1993 EID (Vol. III, Part I, pages 11 and 12) concluded from 35 years of repetitive air photos that the head cut on Franks Creek advanced an average of 7.5 feet per year and on Erdman Brook advanced 10.5 feet per year. Such rates will open the adjacent plateaus to damaging bifurcating gullies during a several hundred year period in the future. Uncertainty, however, comes from not knowing how much these rates should be extrapolated.

4. *Gully Down-Cutting and Side-Slope Retreat.* Loss of the soil plateau tops occurs from gully widening in response to gully deepening and gully-head advance. Side slopes retreat as the longitudinal profile lengthens and deepens. LaFleur (1983) estimated long-term average, longitudinal-profile down-cutting from a high-terrace age of 9,920 BP and from numerous recent ages (less than 4,000 BP) in the Cattaraugus basin. His estimate was in the range of 0.5 to 0.7 feet per 100-years for Buttermilk Creek. McKinney (1986) estimated Buttermilk Creek down-cutting at 1.8 feet per 100-years. McKinney then used this rate in Franks gully; he estimated the rate from the depth of cutting at the lower end (Bond Rd. bridge) of Buttermilk Valley and transposed it

uniformly up gradient to and into tributaries. This method caused him to transpose longitudinal profiles laterally to reflect his down-cutting rate. The 1993 EID (Vol. III, Part 3) used McKinney's down-cutting and slope retreat rates to project gully erosion and provided plateau-edge retreat maps for 50 years (EID Figure 5-6 p. 128) and 500 years (EID Figure 5-4 p. 126). Figure 8 reproduces the 1993 EID (Fig. 5-4, p. 126) map projections of the range in positions for plateau edges 500 years into the future. Initiation of new tributary gully heads by erosive seepage, or otherwise, will enhance the risk indicated by the mapped future edges.

While both LaFleur's recent terrace age approach and McKinney's transposition approach have merit, their methods' applications beyond Buttermilk Creek into Franks Creek have a fatal flaw that will grossly underestimate future erosion. The flaw is that the Franks longitudinal profile will not only shift while down-cutting proceeds, but the longitudinal profile will also convert sooner or later from convex into a concave-up shape. Whether this transformation of shape will take several hundred or a few thousand years is not clear, but great down-cutting is implied (Figure 3), with attendant side-slope retreat.

Re-surveying Franks Creek over a ten year period yielded a downcut rate of 20 feet per 100-years (1993 EID, Vol. III, Part I, page 23). This rate seems consistent with change from convex to concave profile.

Uncertainties in these rates come from extrapolation of short-term studies far into the future, use of long-term average rates for phenomena that may be initially more aggressive, and use of either short-term or long-term rates for episodic phenomena. The rates are reasonable for Buttermilk locations, but should be an order-of-magnitude greater for the convex-up profile of Franks gully, such as the rate from re-survey of Franks Creek.

Gully side slopes at the West Valley site are about 21 or 22 degrees. Presumably, if down-cutting were arrested, slopes less than 21 degrees will be stable for mass movements (but not necessarily stable for slope wash, creep, frost heave, tree throw or side-cutting into softer layers). Plateau edge retreat will thus approximately correspond to projecting a 20 degree angle (or less) from gully beds (Buttermilk or other large landslides are a separate case and will be treated in the next report section). Roughly 3-feet or more of edge retreat will occur for each foot of down-cutting. For down-cutting rates ranging from 2 to 20 feet per 100-years, the corresponding plateau edge retreats would be at least 6 feet to 60 feet per 100-years, with the higher rates more likely associated with Franks Creek.

5. *Landslides.* Large landslides adjacent to the West Valley Nuclear Site along the west wall of Buttermilk Valley appear to be progressive, rotational slides about toe circles initiated and maintained by westward erosion by Buttermilk Creek. There may also be face circles above Kent-age, coarse-grained sediment layers in the valley wall, translating blocks in Kent sand and gravels, and trees traveling both as translating root mats and as passive tops of rotational masses. Sapping gives rise to top-of-slope (plateau edge) gullies and, possibly, face-of-slope gullies. Slopes are about 160 feet high.

The 1993, EID, Vol. III, Part 3, section 4 deals with “slope stability evaluations;” treats conditions as isotropic, homogeneous (section 4.2); and emphasizes Lavery-till slope stability. How the overlying sand and gravel was included in the analyses for North

Plateau sites is not clear, but it is implied such weights were added to slide masses. Also not clear is whether or not hand calculations were done to check computer models. Most critical, though, was the lack of any mechanical stability investigation of Buttermilk landslides. Buttermilk landslide mechanisms need investigation before uncertainties regarding eventual backwasting and capture of Franks Creek can be fully estimated.

However, much of the slope should, at a minimum, reach a dynamic equilibrium condition similar to that already discussed for Franks Creek, i.e., about 20 degrees or less, or 3 horizontal for 1 vertical. This slope adjustment over a period of decades or a couple of centuries will consume a third or more of the distance between Buttermilk and Franks Creek.

An important issue for consumption of the East Plateau by Buttermilk erosion is the westward lateral migration of Buttermilk itself. For example, if Buttermilk moved another 1,000 feet westward in 3,000 years, then the stream and plateau edge would shift westward at 0.33 feet per year. The value is reasonable, but hypothetical.

Piracy of Franks by Buttermilk is imminent on the scale of decades or centuries, and will lead to sudden increases in erosion rates of Franks. The capture process and events leading to it will alter groundwater flow patterns and sapping rates and directions. While not meaningful in a detailed or specific manner, future computer modeling of the range of possible groundwater flow patterns related to piracy could be instructive. Capture of groundwater flow paths may precede actual Franks surface water capture. It is easy to imagine this capture in timeframes of 500 or 2,500 years, but difficult to know if Franks and its probable added tributary gullies will already have consumed so much of the plateaus that little ground will remain available to be pirated.

Probabilistic Models

The 1996 Draft EIS presents probabilistic modeling in Volume II, Appendix L. In Appendix L, several erosion measurement methods are described and reasons given for their limited usefulness in making future projections. However, section L.3.3 presents the 1996 DEIS preferred method, which is probabilistic and uses HEC and SAM computer codes for sediment transport modeling for storm events with recurrence intervals ranging from 2 to 500 years. Erosion was then related to rim widening by referring to the 21 degree slope angles at the site as the dynamic equilibrium condition. Figure 9 is the map (1996 DEIS, vol. 2, page L-12, figure L-2) of resulting, projected, retreat of plateau edges for 1,000 years of erosion. This probabilistic result is in accord with the five conceptual methods results as presented previously above.

Computer Complex-Model Predictions

The SIBERIA model (the preferred erosion indicator in the 2005 Draft EIS) predicts serious erosion impacts at West Valley, but the SIBERIA model incorrectly predicted soil-plateau rounding (like a maturing Davisian plateau over 10 to 100 million years) instead of gully incision of glacial terrain with slope back-wasting. However, the SIBERIA model is helpful to understanding West Valley erosional processes because in its failure to predict backwasting without rounding it stimulates our insight and helps us to focus on more manageable questions and predictive approaches, and on aberrant processes such as episodic erosion, Buttermilk landslides, and climate change. The SIBERIA model is also helpful because it causes one to ask if future erosion will include both gully growth by parallel slope retreat (as in the past) and added erosion from plateau surfaces in response to continued deforestation, and farm-like or urban-like practices (Haff, 2003). Evidence for relative contributions of slopes vs. channels to sediment supply is available for the glaciated Allegheny Plateau in nearby central New York. Nagle et al. (2007) found that eroding of streamside glacial deposits, especially glacial lake sediments, dominates sediment yield today, and that deforestation and channelization lead to further impacts.

Complex computer models like SIBERIA are best used for relatively simple geomorphologic processes. Even the best attempts at combining scaled lab models or computer models with extensive field data often lead to inaccurate predictions of river channel, shoreline, landslope, or other behaviors on short time intervals. Modeling complex landscape-process interactions over long periods is much more problematic, especially when we forget that computer models are best used to stimulate our insight into landscape processes and not to predict definitive outcomes (Haff, 1996). For example, Tucker and Bras (1998) used computer models to examine interactions among small groups of variables, not to predict (forecast and hindcast) landscape evolution. Their models are used to predict simple generic forms, not actual landscapes. To obtain better generalized forms, Tucker and Bras (1998) recommended "a combination of analysis of high-resolution DEM data, dating of geomorphic features in specific landscapes, and modeling of transient landscape states and process interactions." With respect to their statement, conversion of a convex longitudinal profile to concave in Franks Creek but not Buttermilk qualifies as a profound "transient landscape state" and effects of trees and sapping as profound "process interactions." Also, I agree with their above statement about modeling research needs, and suggest the modeling process include conceptual, physical and experimental, as well as computer-based, approaches.

Conclusion

The 1993 EIDs, 1996 DEIS, and 2005 DEIS have flaws such as: 1) no estimate of potential adverse or helpful impacts of global climate change or other climate change issues; 2) avoidance of inclusion of rapid-rate episodic phenomena such as rapid landslide removal of slopes (1993 EID Volume III, part 3 p. 70 for example); 3) insufficient comparison or integration of erosion estimation approaches (McKinney-1986 approach, Draft EIS of 1996; Draft EIS of 2005 "SIBERIA model," and other conceptual approaches presented herein); 4) no estimate for increased erosion in future due to farming-caused or other loss of tree cover, sod cover, etc.; 5) insufficient appreciation of the impact of sapping (groundwater erosive seepage); etc.

Earlier sections of this report, especially the section on "Temporal Predictions," lead to dire assessments of the fate of the facilities on the plateaus at the West Valley Nuclear Site. Plateau conditions are estimated for various times in Table 3. All five factors indicate system failure (facilities breached or sapped by erosion) in less than 10,000 years and two factors indicate system failure in less than 1,000 years. However, the factors will act in concert with each other and likely lead to some facility failures in as little as decades at plateau margins or centuries at plateau interiors. These results (Table 3) agree with the conditions presented in the 1996 DEIS map (here Figure 9), or worse.

Several grave mistakes have occurred in 2005 and 1996 DEIS and underlying documents, regarding conceptual and quantitative analyses or models of erosion. First, there were no estimates or worst cases given for gully head initiations. Second, gully heads are initiating today at an alarming rate. Why do we see a dozen or dozens initiating in recent decades rather than over several hundred or thousand years?

Third, gully slopes at 21 degree angles have been referred to as stable which caused designs of slopes and analyses of slopes and slope processes to assume that 21 degrees produced an acceptable factor of safety. But the 21 degree slopes are actually in a state of movement, of failure, of dynamic equilibrium responsive to down-cutting. Thus, the 21 degree slope angle is in response to a factor of safety of less than one!

Fourth, a most grievous error of conceptualization and quantification of past scientific and engineering analyses is the misunderstanding that gully longitudinal profiles (such as Franks Creek) are convex-up. These convex-up sections of streams are essentially tied at their downstream ends by their base levels such as bedrock sections or trunk streams (such as lower Buttermilk). The upstream ends of these convex sections are maintained at high elevation by upland topography or high bedrock. Thus the middle portion of the length of the stream must erode greatly to establish a concave-up longitudinal profile.

PART II CONTROL OF EROSION

Review of Methods of Erosion Control

Erosion control (stabilization of canals, streams, aqueducts, qanats, etc.) extends back thousands of years to Roman and middle-Eastern cultures. That the Code of Hammarubi (Section 53, 1760 BC) deals out punishments such as slavery for those abusing maintenance of local farm dams acknowledges awareness of the fragility of man's water control infrastructure. For example, Romans were concerned for conveyance of sediment through channels and aqueducts. During the past 150 years or so, many scientists and engineers were interested in erosion control. In recent decades several guidance methods or documents were championed by various agencies or authors. Royster (1979), for example, reviews landslide remediation, as does Turner and Schuster (1996); and Clarkin et al. (2006) reviews designs for low-water crossings. The next few paragraphs review guidance for stream erosion control.

Many specific gully and stream stabilization practices are presented in "Stream Processes" (Thigpen, 2006). This volume lavishly illustrates stream stability problems and human responses. However, durability of the methods is only very generally discussed. For example, it is suggested on p. 30 that "Bridges are relatively permanent structures;" but the design life of culverts is 10 or 20 years and large bridges is only decades or a century. It is also stated (p. 39) that "well-established vegetation is one of the best long-term protections against bank erosion and channel migration;" but long term studies of artificial vegetative protection are lacking and comparable old growth areas commonly look radically different than bioengineered sites.

The “New York Guidelines” (NYS Soil and Water Conservation Committee, 1991, 2005) begin with a summary of erosion control practices in Table 2.1. The column headed “Estimated Design Life” provides good insight into modern erosion control thinking about durability of practices. Many practices have a design life of a few years or less. Practices with design lives of approximately 10 to 25 years include: debris basins, diversions, grade stabilization structures (drop structures), concrete lined channels, retaining walls, and riprap linings. The only longer duration actions are described as permanent and all involved revegetation of floodplains or slopes. The annual maintenance costs for riprap is estimated (Table C.2 in the 2005 edition) as 10% of installation cost, which equates to approximately a 10 year design life. And maintenance of a rock outlet structure as 20% of installation would be about a 5 year design life. Another indicator of the fragile nature of stream erosion control is the suggestion (2005, p. 5-B-38) that riprap needs to be checked for damage and immediately repaired “after every highwater event.”

In an attempt to improve habitat and lower costs while maintaining durability and flood control Ed Keller and Nelson Nunnally published 10 papers about “restoration” of stream channels culminating in Nunnally and Keller, 1979, “Use of Fluvial Processes to Minimize Adverse Effects of Stream Control Channelization” (a guidance document), Keller and Hoffman, 1976 (“Channel Restoration…”), and Nunnally, 1978 (“Stream Renovation…”). Their work focused on projects with design lives of years to decades.

Thousands of scientific and engineering research papers and reports were written about stream erosion reaching conditions of natural stability. William Morris Davis (Davis, 1909) is credited with the concept that extensive terraces can result from long times of streams meandering laterally in response to a base level such as sea level. Hoover Mackin (1948) further refined the concept. He referred to a stream experiencing long term equilibrium as “graded” (suffering neither aggradation nor degradation). Rosgen (1994, 1996, 2006) has taken the graded river paradigm and extended it to shorter time frames such as decades. Rosgen’s classification of streams aids designers and researchers by providing the characteristics of graded (or somewhat graded) streams relative to temporal scales of decades or centuries and spatial dimensions of 1,000s of feet to 10s of miles. An unstable reach of stream can be designed for stability by comparison to a Rosgen reference reach, i.e., a stable reach of similar properties. There are two difficulties in using the “Rosgen method” at West Valley: first, there are no comparable stable reference reaches, and second, design at West Valley is needed for deep time (episodic and aberrant processes will change the conditions over long times that are used to assess both local problem reaches and reference reaches). Simon et al. (2007) recently criticized the Rosgen method and also concluded that bank stabilization in degrading reaches is not likely to succeed.

It may be argued that erosion control experts only need to “try harder” or have plenty of funds and they will be able to achieve better durability. In one discussion I had with experts, they suggested a 10,000-year durability could be met without maintenance. However, frequently and typically, erosion control experts will not state design lives for their works, contracts may not call for or imply design lives, and most important, the completed works fail or need significant renovations within months to a few years. While inspecting and assessing erosion control for about thirty miles of designed stream banks Wilson (1983) found that instability was common and frequently instigated by anything that created localized vortices in storm flows. Another bothersome factor is that professions that design erosion control devices are highly competitive and yet profit or other competitive issues have not driven the practitioners to achieve routine durable designs. It is obvious that durable erosion controls are difficult to achieve, especially in western New York’s erodable glacial soils.

In sum, modern methods of erosion control emphasize a temporal framework of decades and inclusion of natural processes and habitats. However, erosion control will be needed at West Valley for millennia because of long-lasting radioactive threat, and the scale of that threat if wastes are left onsite dwarfs the needs of local habitat conservation. In a later section of this report, results are discussed of a field review of performance of western New York erosion controls, and suggestions are made for erosion control at the West Valley site.

Deep Time – The West Valley Erosion Control Dilemma

Because radioactive catastrophe will be in a state of imminence on the West Valley soil-plateaus for several hundred or a thousand years, extreme measures are warranted. Exhumation of wastes is the obvious, prudent choice.

For sake of discussion, let's outline a plan for erosion control if wastes were retained. The 2005 draft EIS and underlying CERs develop part of the needed erosion control plan. Much of the plan in the CERs seems reasonable from a short term perspective (a few decades), but very inadequate for deep time.

Issues of Site Conditions and the 2005 EIS

The following issues need resolution or partial resolution for erosion control planning or actions:

1. The site contains a substantial radioactive groundwater plume whose future dimensions and paths are uncertain and could be altered by sapping or gully formation impacts on hydraulic gradient.
2. The location of previously contaminated stream sediment is uncertain (contrary to CER for Draft EIS-2005 Alt-2 section 1.3.12.5) because the named radionuclides when sorbed to clay or silt would thus be sorbed to a size particle likely to travel far under normal stream flow conditions, such as to Springville Dam or Lake Erie

or to be deposited on floodplains of Buttermilk Creek or Cattaraugus Creek and there be retained or moved further as wind-blown dust.

3. Because all burial sites are not known for WMA #7, the use of geophysics to locate burial holes (CER Alt-2 section 3.2.7.1) needs cost estimation. The suggestion that one geophysical technique may be sufficient is poor because standard geophysical exploration for shallow targets emphasizes the need for comparative information from multiple methods.
4. Sites of waste need to be pulled-back from gullies (CER Alt-2 pages 131-135). This issue of waste proximity to gullies is underscored in that erosion control was already undertaken at the site to compensate for lack of space on soil-plateaus.
5. More detail is needed regarding use of riprap for gully head mitigation. This approach is not likely adequate and a more robust approach such as flexible concrete and steel cable mats (already in use at West Valley) will be needed. CER Alt-2 p. 148 section 3.2.8.5.2.
6. The excavation of streams planned for WMA 12 as per CER Alt-2 sections 3.2.12 and 3.2.12.1 needs great cost contingencies and planning. Are 100s or 1,000s of samples to locate stream-bed areas for contaminated soil removal anticipated as far downstream as Springville Dam? How will excavation be impacted by global climate change…disrupted by more frequent storms?
7. Plans for streambed restoration (CER Alt-2 section 3.2.12.5) are very inadequate.
8. Why won’t controls be installed for the leading edge of the groundwater radioactive plume? (CER Alt-2 section 3.2.13)

9. The following list of concerns relates directly to 2005 draft EIS CER Alt-2 section 3.2.15 Erosion Control

   a) the CER explains that final designs of erosion controls will be in accordance with appropriate government regulations and guidance, but an earlier section of this report demonstrated that appropriate guidance is not available from standard sources. Appropriate guidance will be provided in a later section of this report.
   b) erosion control strategies do not provide for erosive seepage (sapping), which appears at this time to be common near the edge of soil plateaus.
   c) stabilization of minor gullies or diversions with flexible concrete and steel-cable mats will be better than with grass and riprap.
   d) water control structures and drop structures (grade stabilization) need to be designed for 500 year return intervals, or longer.
   e) add 30% to flows in order to account for global climate change
   f) stream bed armoring will not work without numerous drop structures (grade stabilization).
   g) drop structures will need to be wider because streams in the region that have been prevented from down-cutting show increased side cutting upstream of culverts, box culverts, etc.
   h) drop structures will need to be wider to accommodate 500 year recurrence intervals plus 30% for global climate change.

i) the statement on CER Alt-2 p. 159 that drop structures “would create a minimum drop in the streambed of four feet” should be changed from “minimum” to “maximum.”

j) what are the contingency procedures and costs if radioactive water or sediment taints the drop structures, riprap, or other engineered features?

10. The following list of concerns relates directly to 2005 draft EIS CER Alt-2 sections 3.5 and 5.2 <u>Monitoring</u>:

a) how were the monitor well locations chosen (based in prior piezometric contours; based on computer hydraulic models)?

b) on Figures 3.5-1 and 5.2-1 in CER Alt-2, where are the up-gradient and down-gradient wells?

c) contaminant monitoring at waste sites, including relatively benign sites, usually has a period of continuous, weekly, monthly or quarterly, but the CER Alt-2 sections 3.5.1.1 and 3.5.1.2 suggest semi-annual for 15 years followed by annual thereafter and section 5.2.1 suggests semi-annual for West Valley.

d) the CER indicates that NRC and NYSDEC will approve parameters for monitoring; such a statement implies that the number of parameters needed were not known when writing the EIS, this is no trivial matter when it comes to cost estimation.

e) the percent of samples that will be used for QA/QC is not given.

f) surface water monitoring needs to include base flow and storm flow events.

g) during ground water sampling or maintenance or reconstruction or hydraulic testing, wells are purged. What contingency costs were estimated if the water is contaminated? Section 5.2.1.1 (p. 256) implies this was not factored into costs.

11. The maintenance schedule for erosion control structures (CER Alt-2 section 5.2.2 p. 261 for example) implies an approximately 100-year design life for those structures. A 100-year design life is at odds with common experience as manifested in existing guidance documents such as the “New York Guidelines” (NYS Soil and Water Conservation Committee, 1991, 2005), mentioned earlier in this report.
12. The replacement schedule for monitor wells and piezometers (CER Alt-2 section 5.2.1.1 p. 257) suggests replacement at 25-year intervals, which will create space problems. If a location was monitored for 3,000 years at a 25-year replacement interval, then 120 wells will be needed per location. A 10 by 12 well grid will evolve during the 3,000 years. At a 5-foot spacing the grid will occupy a space about 45 by 55 feet. Thus, the wells themselves will interfere with measurements and hydraulic behavior of the aquifers.

A Better Approach to Erosion Control

Under any conditions it is questionable that the West Valley site will survive erosion for a thousand years. A much more robust approach to erosion control is needed than stated in the 2005 draft EIS if the soil plateaus at the West Valley Nuclear Site are to survive for centuries or millennia. The discussion can be simplified and made effective by focusing on adding to the draft EIS proposed methods and structures (CER Alt-2) because these structures are reasonable but insufficient. Four causes of failure of erosion controls need to be addressed: 1) insufficient grade stabilization, 2) too low a recurrence interval, 3) evolution of new gullies such as by sapping (erosive seepage), and 4) Buttermilk Creek landslides.

Grade Stabilization: Franks and Tributaries

I observed stream instability or stability at numerous sites, for example, in recent years I searched several hundred sites for stable places to locate continuous water-level recorders in Chautauqua County and found none. I searched during 2006-2007 numerous field sites, searched literature, reviewed FEMA records for disasters in SW-NY, attended conferences and short-courses, and inquired of colleagues, regarding durability of stabilization methods. Sheet pile drop structures (Figure 10) show potential to be durable for half century or longer periods if placed successively with small drops.

Grade stabilization could be attempted by adding drop structures to Franks Creek beyond those already planned in CER Alt-2. The approximate additional structures needed are: 1) Franks Creek between elevations 1180 feet and 1340 feet will need 160 feet of elevation divided by 4 foot drops equals 40 structures; 2) lower Quarry Creek, elevation 1240 to 1340 feet, will require 100 feet divided by 4 foot drops equals 25 structures; 3) lower Dutch Creek, between elevations 1210 and 1300 will need 90 feet of elevation divided by 4 foot drops equals 23 structures; 4) lower Buttermilk (above bedrock section) between 1140 and 1180 foot elevations will require 40 feet divided by 4 foot drops equals 10 structures. Total of 98 structures.

Upstream drop structures may need to be 50 feet wide and downstream drop structures may need to be 200 feet wide, and constructed of 20-foot long sheet piles. These recommended structures may be deemed too small after debating the need to base construction on recurrence intervals greater than 100 years and add 30% for global climate change. For sake of discussion, use 98 drop structures that average 100 feet-wide and utilize 20-foot sheet piles. Thus 196,000 square feet of sheet-pile-face is needed. Construction companies that install sheet piles in western New York quoted prices ranging from \$30 to \$50 per square foot depending on transportation and set-up costs and on-site access. Using \$50/ft^2 times 196,000 ft^2 yields \$9,800,000; not including riprap, geosynthetic fabric, or contingencies for working on a radioactive site, etc. Mobility within the gully itself will also create costs. Thus it is estimated that required drop structures will be added to those in CER Alt-2 and will cost between \$10M and \$20 M with design life of 50 years and replacement of 2% of structures annually (\$200,000 to \$400,000 replacement annually).

Gullies on South Side of the South Plateau

On the south side of the South Plateau (which contains the NDA and SDA) there are currently (Ashford Hollow topographic map) at least five gullies (including the gully that contains the northern of the two reservoirs). The concern for any of these gullies is their ability to capture ("pirate") Franks Creek or otherwise affect the erosion of the nuclear sites. Each gully extends from the top of the South Plateau at about 1395 ft to Buttermilk Creek at about 1255 ft elevation. Using 20 ft sheet piles to block 50 ft widths (1,000 ft^2 of sheet face) for 4 ft drops within elevation changes of 130 ft for each gully (33 structures per gully) for 5 gullies equals 165,000 ft^2 of sheet pile face at $50/$ft^2$ equals $8,250,000; not including rip-rap, geosynthetics, concrete, etc., as needed. Thus these costs would add an amount to CER Alt-2 similar to the above analysis for Franks Creek, i.e., $10M to $20M initial plus $200,000 to $400,000 annual replacement. Because some of these gullies are so steep, initial structures might be other than sheet piles, but will likely have similar costs and maintenance.

Recurrence Interval

Double the costs for erosion control and replacement in CER Alt-2 p. 248-249 because larger structures will be needed for greater recurrence interval floods and global climate change.

Erosion Control:	$29,565,000 x 2 = $59,130,000
Replacement (phase 1):	$17,301,000 x 2 = $34,602,000
Replacement (phase 2):	$17,301,000 x 2 = $34,602,000
Annual Replacement after year 218 (CER Alt-2 Table 5.2-18 p. 274):	
	$191,330 x 2 = $382,660

Retarding the Initiations of Gullies

Several years ago an easily-accessed area of gully initiation at the West Valley site was treated fairly effectively using a flexible concrete and steel cable mat at a cost of $17,000. These mats require pregrading, filter fabrics, occasional post-construction brush removal and periodic replacement. If 64 mats (Table 2) with 50 year design lives were maintained then two mats per year would be replaced. Estimating 64 mats at $20,000 each yields installation costs of $1,280,000 and annual replacement costs of $25,600. These values double per 3,000 years due to the number of new gullies expected.

The above discussion of erosive seepage remediation is a bit naïve because erosive seepage is a self-increasing phenomenon. As sapping proceeds the hydraulic gradient often steepens, leading to ever-worsening conditions. Costs may be higher.

Buttermilk Creek Landsides and Grade Stabilization

This is a fantastic problem. Very large Buttermilk landslides need stability in order to mitigate erosion of the soil plateaus. The procedure will include stabilization of lower Buttermilk Creek. Heinz Creek needs treatment to either deflect its alluvial fan away from Buttermilk, or to grade-stabilize the entire Heinz Creek watershed and thus prevent its building an alluvial fan.

Stabilize the Buttermilk landslides (up to 160 feet vertical) by stopping erosion at the base of the slides and allowing the slides to reach a stable slope configuration of less than 20 degrees. This approach will yield a position of the plateau edge more than 500 feet west of the current Buttermilk Creek location (more than 200 feet of additional edge retreat from current location). Dewatering the slide masses would be problematic because altered hydraulic gradients may result and thus change contaminant plume shapes and directions, or alter gully head initiation or have other unforeseen consequences.

Stabilize Buttermilk Creek from Bond Road to Buttermilk Road with sheet-pile drop structures with widths of 600ft and 30 foot piles. Using 4-foot drops between 1150 and 1260 feet above sea level yields 28 drop structures at 18,000 square feet each, which yields 504,000 ft^2 of sheet face at $50 per square foot installed, which equals $25,200,000. Replacement costs with a 50 year life span will be $504,000 annually. Depending on rip-rap, filter fabric and other needs, these initial and annual costs could be twice as much as above.

Armor the left bank of Buttermilk Creek for 10,000 feet from Franks Creek to Buttermilk Road. Add 10,000 ft x 30-ft-sheet-piles equals 300,000 ft^2 of sheet face; at $50/$ft^2$ the cost will be $15,000,000. Because of landslide movements, replace 5% annually at a cost of $750,000/year. Again, these initial and annual costs could double due to need for rip-rap, filter fabric and other costs.

Especially Difficult Erosion Control Evaluations

First, should drop structures or other methods be used to stabilize Heinz Creek basin so that Heinz Creek alluvial fan does not pin Buttermilk Creek against the base of the landslides? This preventative action offers added erosion control but at great cost. Ignoring most first order streams and counting the number of 20-foot contour lines that cross streams in the Heinz Creek drainage network yields estimates of between 50 and 100 contour intervals that could use drop structures. For sake of this discussion, use the minimum and maximum number of intervals (ie, 50 and 100) as limiting values. Multiplying 20-foot contour lines times 50 and 100 yields the total relief to be managed as 1,000 to 2,000 vertical feet. That would be 250 to 500 4-foot drop structures. If these drop structures average 100 feet wide and use 20-foot sheet piles, then the total sheet face needed is 500,000 to 1,000,000 square feet and total cost at $50/ft^2 will be $25 M to $50 M. Replacement costs using a 50 year design life will be $500,000 to $1 M per year. These values will double if rip-rap, fabric and other contingencies are needed. Thus these added costs range from $25M to $100M initially and replacement costs of $500,000 to $2M annually.

Second, should bedrock stream reaches be armored? If half of the Heinz drainage drop structures mentioned above were to be placed in bedrock reaches would they be needed or could they even be built? Should the bedrock section of lower Buttermilk Creek be armored? Should Cattaraugus Creek below Buttermilk confluence be protected? Should Springville Dam on Cattaraugus Creek be maintained as a grade control?

While considering answers to these questions I reviewed or revisited several dams and bridge abutments on shale bedrock in southwest New York, including Springville

Dam. I also interviewed Mr. Kurt Warmbrodt (Dunkirk, NY, February 2008) regarding his experiences constructing many concrete sea walls on Lake Erie shale bedrock exposures. In all situations shale erosion occurs adjacent to the structures, but even small or thin veneers of concrete protect underlying shale from dessication or spalling. As mentioned early in this report, local shale is very susceptible to disintegration by cycles of wetting and drying.

An example of a concrete shale-protective drop structure would be as follows: 13 yards wide, 2 yards deep and 1 yard high containing coated rebars and anchored with rebars drilled and grouted into bedrock; costing about $5,000 in materials as 25% of project costs. Total costs are thus about $500 per foot of width for a small stream, but $1,200 per foot of width for the larger structures (1 yard high but 4 yards deep) needed on lower Buttermilk Creek. In conclusion, the costs for concrete gravity drop structures to protect shale rock will be similar to sheet pile drop structures to protect sediment streambeds.

Adverse Impacts of Proposed Stabilization (above)

The erosion controls suggested above are far more realistic than the insufficient controls estimated in the 2005 draft EIS. However, ecologic resources will be damaged by the proposed erosion control structures (in addition to ecological damages from those structures proposed in the 2005 draft EIS). Fish, and possibly other organisms (such as macroinvertebrates), will be prevented from traveling along lower Buttermilk Creek or interacting with Cattaraugus Creek. It is difficult to estimate this ecological damage as economic loss. Likewise, economic loss from disturbance of scenic views is difficult to quantify.

DeBrun (see Lynch, 2007) recently edited a summary of economic benefits of land conservation for the Trust for Public Land. Lynch (2007) cited studies where residents of eastern Canada valued farmland preservation at $123 per household per year per 1,000 acres in order to preserve water quality, habitat and scenic quality. Making this analogy complicated is that building sheet-pile drop structures will inhibit erosion and preserve water quality against disbursement of radioactivity, and at the same time, diminish water quality by increasing temperature in pools behind and below the drop structures.

To obtain a rough estimate of habitat and scenic value for the West Valley site, value is estimated approximately as $120 per household per year per 1,000 acres. Stream channels involving several square miles of Franks, Heinz and lower Buttermilk drainages will be impacted, approximately 3,000 acres. If the nearest 500 households felt impacted, then the dollar loss would be $120/house x 500 houses x (3,000 acres ÷ 1,000 acres) equals $180,000 per year.

Another adverse impact of sheet pile stabilization, and possibly any other form of stabilization, is the likelihood of artificially widening the gullies of Franks Creek and its tributaries (causing plateau-edge retreat) by cutting roadbeds or widening stream beds for access of construction equipment. While many gully beds may be accessible to small equipment (e.g. backhoe) that will suffice to build sheet-pile dams, there will be difficulties when large rip-rap or sheet piles need cranes or trucks. Access methods could cause cut-slope instabilities, road runoff erosion, or other problems that are so counter-productive as to nullify the erosion control benefits of the actions.

Another adverse impact of sheet pile stabilization, and any other form of stabilization, is the possibility of causing erosive seepage or contaminant plume alteration due to the sheet piles intersecting natural ground-water bearing sand lenses in the Lavery till or other layers. Previous studies concluded there are positive upward hydraulic pressures in these subsurface layers.

Additional Monitoring Costs

Until some of the questions posed earlier in this report are answered, a full appreciation of the effort needed to monitor the West Valley nuclear site is not possible. However, the answers are only likely to increase monitoring costs.

For sake of immediate discussion, several monitoring issues can and will be reviewed here for their cost implications. The CER Alt. 2 p. 178-180 emphasizes annual monitor well sampling, for parameters yet to be approved, for an unknown QA/QC program, and a similarly vague surface water program. Sampling a stream only once per year is ridiculous. Sampling stream base-flows and storm-flows seasonally would be the minimum frequency desired. Seasonal sampling for groundwater would also be the minimum desired. Monthly sampling would be appropriate to detect seasonal impacts. Seeps at the edge of the plateaus should be included. Background values in up-gradient and off-site wells and streams should be monitored. Monitoring background values will help detect or measure unanticipated, episodic, and aberrant conditions affecting the region including the site and thus provide context.

Increasing sampling frequency from annual to quarterly, increasing the number of parameters measured per sample, increasing the percent of samples used for QA/QC, and sampling surface waters for both base flow and storm flow will have a dramatic impact. Costs x 4 [for frequency] x 1.5 [for parameters] x 1.1 [for QA/QC] x 1.5 [for surface flow types] equals an order of magnitude (≈ x 10) cost increase in monitoring. If frequency is changed to monthly, seeps are added as sample locations, and background sites are added, then annual costs of sampling and analytical lab services escalate to 60 times original estimates.

The CER Alt. 2 p. 248 indicates monitoring costs at about $800,000 per year and on p. 274 indicates about $520,000 of that is for environmental costs. Similar proportions would result in 65% of monitor installations ($6.4 M) being environmental ($4.2 M). Because of need for more locations (seeps and background locations), the initial costs approximately double. Thus initial costs rise $4.2M (i.e., from $4.2M to $8.4M). The effect on annual costs is much more dramatic.

Annual costs occur as two separate categories: installations and sample measurements. Doubling the sample sites will double the annual installation replacement costs, that is, if $220,000 of the $520,000 were for installations, then the costs will rise $220,000/year. Also, if the sampling and analytical laboratory services cost $300,000 annually, then these fees rise to $18M/year, an increase of $17.7M/year.

Added Costs Summary

In Table 4, costs are summarized that need to be added to those in the 2005 draft EIS and underlying CERs. Costs of erosion control and monitoring are severely underestimated in the 2005 draft EIS and CERs. Because of lack of information in the CERs it is difficult to suggest the exact underestimation of annual monitoring costs, and impossible to construct a cost estimate from scratch without knowing lists of analytes and other site specifics agreed to by DOE, NRC, EPA, NYS-DEC, etc. When you look at issues such as sampling frequency it is very easy to sense the great underestimation of sampling costs, but difficult to offer final cost estimates. The best estimate now is that $17.7M needs to be added annually for monitoring (other than monitoring installations).

Loss of Institutional Control

Loss of institutional control would be disasterous for any erosion control scenario. The control devices themselves will create large and small waterfalls and otherwise redirect energy against easily eroded materials which will enhance erosion. The critical concept is that higher velocities will be achieved as compared to velocities for the same fall distance with uniform bed slope. Once the cohesive sediments are dislodged, modest velocities will maintain them in transport (Hjulstrom, 1935).

Failing rip-rap or sheet-pile or detention dams or disjointed pipes, and so on, and so on, would provide unintended, uncontrolled erosive energy. Thus loss of institutional control will result in many stream base-level drops (knickpoints, head-cuts, waterfalls, or other equivalent features). Chorley and others (1984, p. 334-335) concluded that base-level drops travel as knickpoints upstream throughout an easily eroded system.

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TABLE 1. Drainage Morphometry

Stream Name	Order	Basin Area (square miles)	Drainage Density (miles per square mile)
Buttermilk Cr.	6	28	6
Franks Cr.	4	2.2	6
Dutch Cr.	3	0.4	7
Quarry Cr.	3	1.2	5
Erdman Br.	3	0.2	6
Heinz Cr.	4	1.6	5

Notes: Creek names Dutch and Heinz were arbitrarily given by the author because these streams were not named in U.S. Geological Survey topographic maps; locations as per Figure 1. Stream orders were determined according to the Strahler method where two streams of like order join to form the next larger order, and first order streams often have only intermittent flow. First order streams are the topographically highest tributaries and are identified using detailed maps or air photos such as at scales of 1 inch equals 2,000 feet or better. Dutch, Quarry and Erdman constitute most of the Franks Creek basin.

TABLE 2. Gully Head Initiations

Time	Number of first order streams per square mile	Gully Formation rate
15,000 BP	2	
12,000 BP	4	
9,000 BP	8	
6,000 BP	16	
3,000 BP	32	
Present	64	1 per 47 years
3,000 AP	128	1 per 23 years
6,000 AP	256	1 per 12 years
9,000 AP	516	1 per 6 years

TABLE 3. Erosion of the West Valley Nuclear Site

Time (years)	Number of New Gullies (# per mi^2)	Additional Future Basin Expansion (Plateau Loss)	Extension of Franks Head-cut (feet)	Franks Plateau-edge Retreat (feet)	Buttermilk West-bank Plateau-edge Retreat (feet)
10	0	0.02%	75	6	3.3
100	2	0.20%	750	60	33
1,000	20	2.0%	7,500?	600?	330
10,000	500?	20%?	------	------	3,300?

? Question marks indicate values likely exceeding limits of available space of the tops the North and South Plateaus; such values are not likely to be reached because the plateaus will be gone first.

TABLE 4. Added Costs Summary

	$ millions Initial	$ thousands Annual Replacement or Other Cost
Franks Creek (and tribs) Grade Stabilization	$10-20	$200-400
South Plateau Gullies Grade Stabilization	10-20	200-400
Impact of Recurrence Interval on Erosion Control	29.5	191
Gully-Head Mats*	1.3	26
Buttermilk Grade Stabilization	25-50	500-1,000
Buttermilk Left-Bank Stabilization	15-30	750-1,500
Proximal Stabilizations**	25-75	500-1,500
Habitat and Scenic Losses	---	180
Monitoring costs: Installations (e.g. wells, etc.)	4.2	220
Monitoring: Sampling, Lab Fees, Reports	---	$17,700
Total	$120M-$230M	$20.467M-$23.117M
Additional labor (25%)***	$40M-$76M	$6.8M-$7.7M

** Costs for gully-head mats should be projected into the future as approximately double per 3,000 years due to rate of gully head initiations.*

*** See discussions under Part II, A Better Approach to Erosion Control, subheading "Especially Difficult Erosion Control Evaluations." The values for costs used above in Table 4 for stabilization proximal to the soil plateaus and central Buttermilk Creek are a rough estimate for partly stabilizing lower Buttermilk and lower Heinz Creeks including some bedrock sections, a compromise between full and partial stabilization, and not including any Cattaraugus Creek stabilization.*

**** Surveying, permits, safety, security, engineering design, administration, etc., projected as 25% of project costs.*

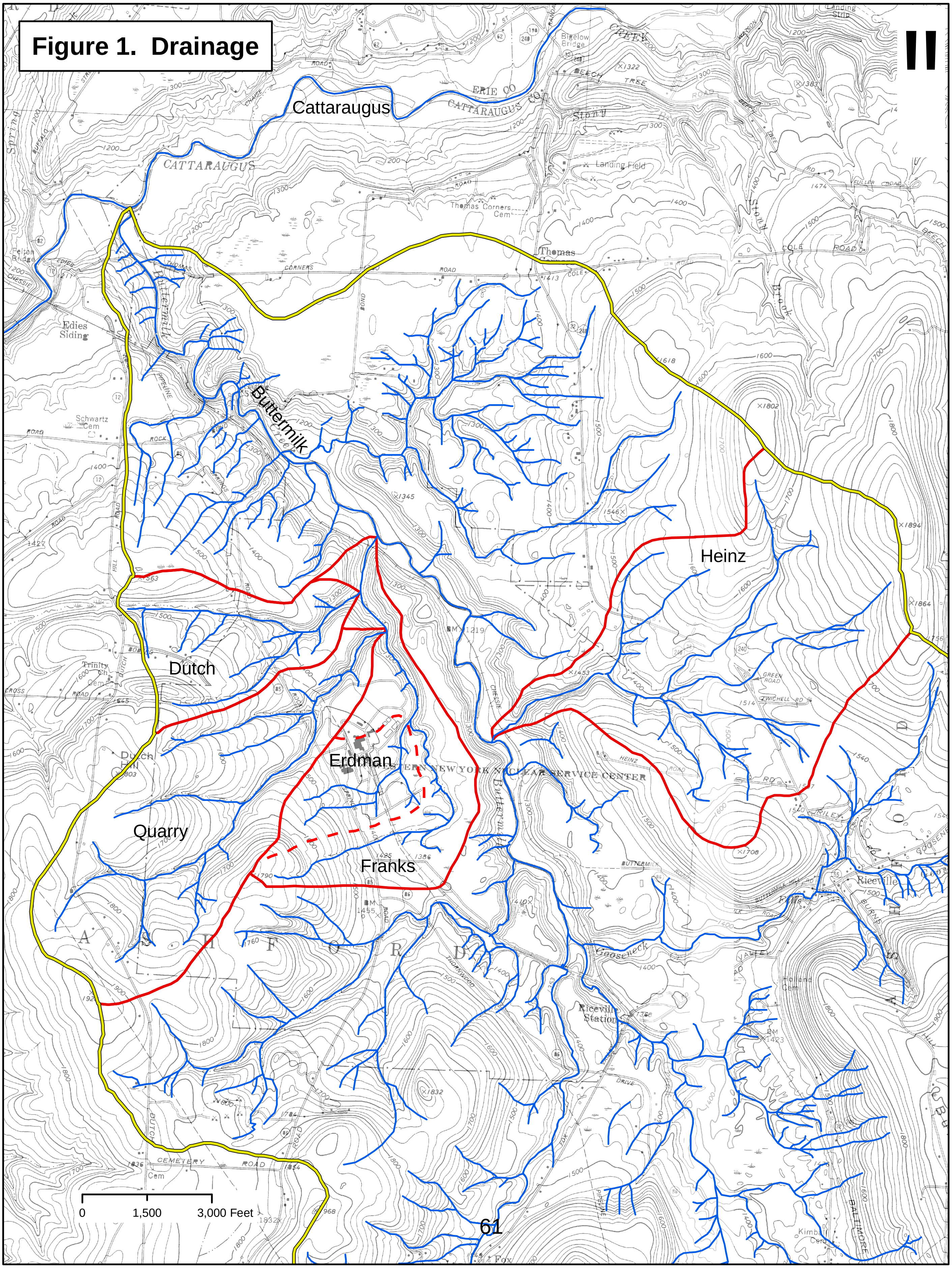


Figure 1. Drainage

Figure 2. Cross-section of Buttermilk Valley at West Valley Site (from EID, vol. 2, part 2, figure 2-15)

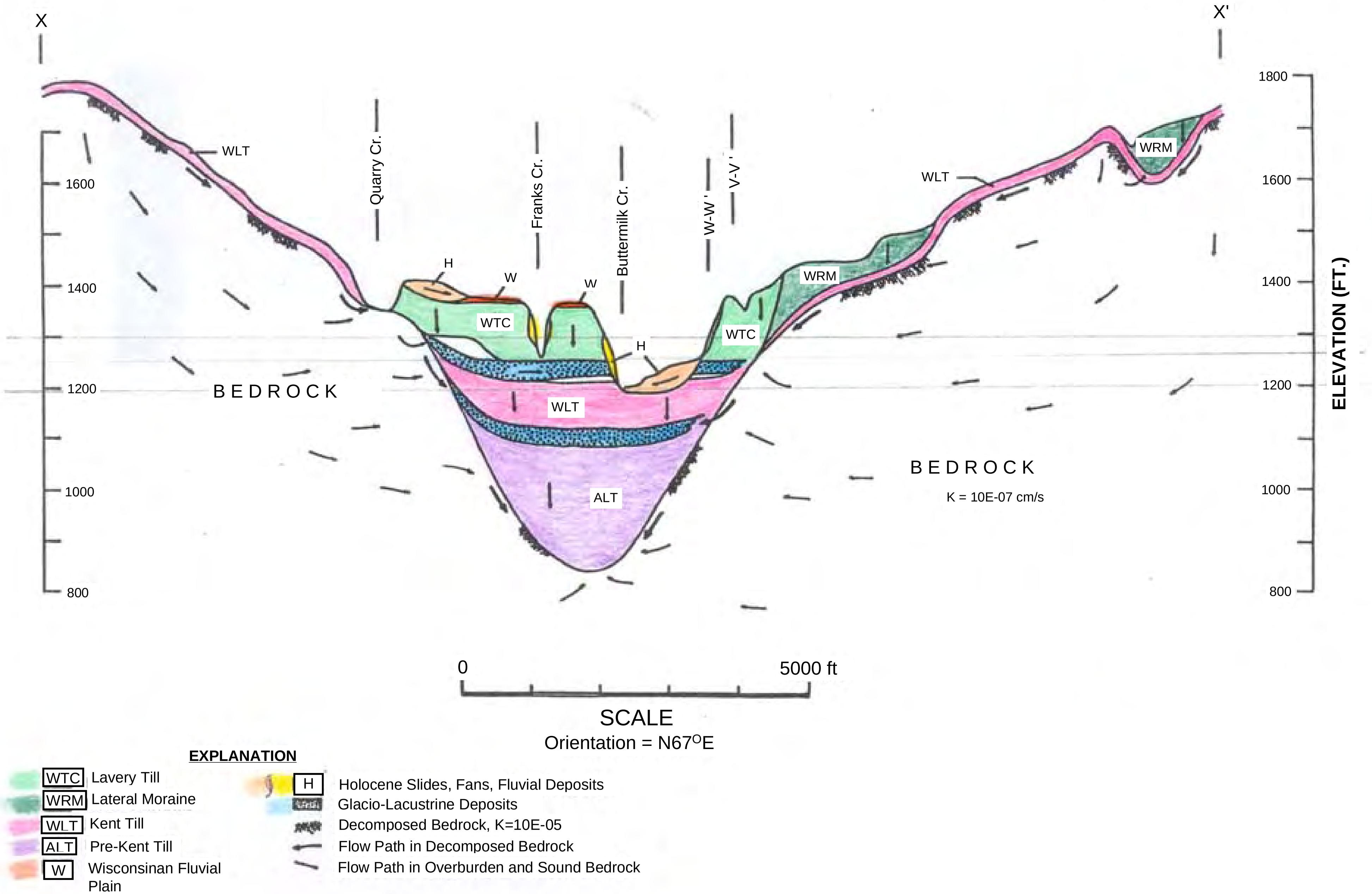


Figure 3a. Profile Segments

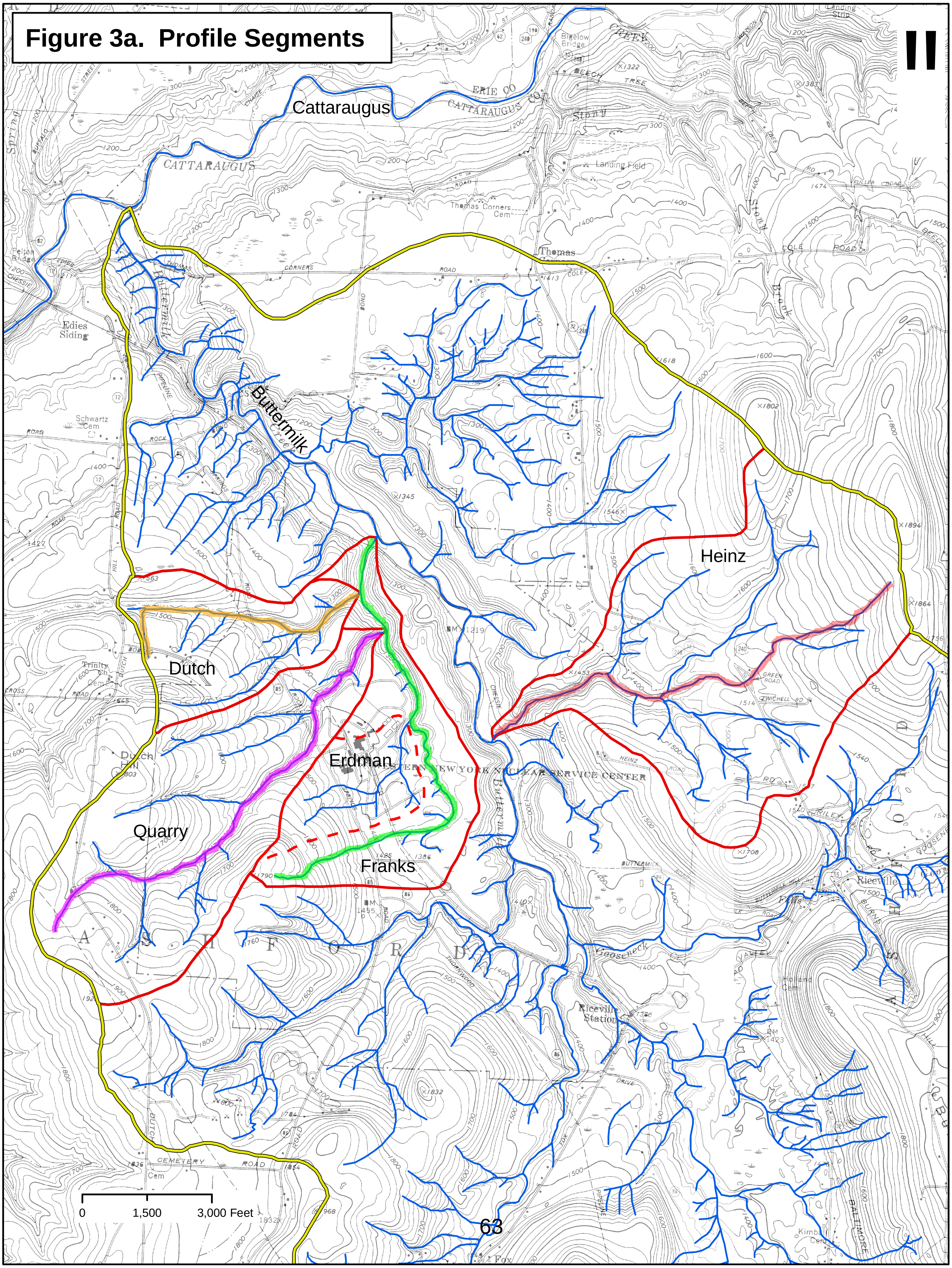


Figure 3b. Longitudinal Profiles of Stream Segments as highlighted in Figure 3a

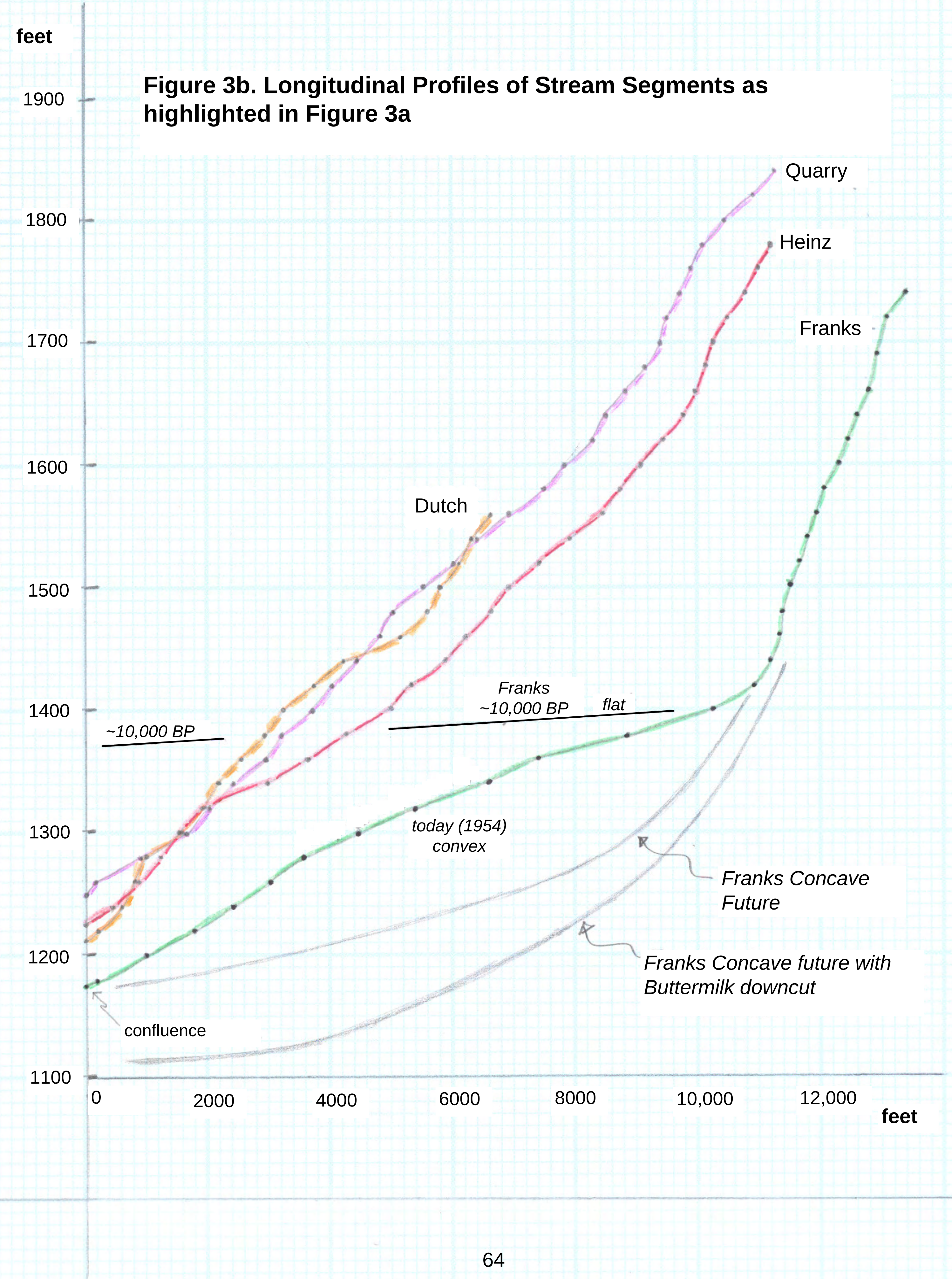


Figure 4. Glock's (1931) Theory of Drainage Extension.

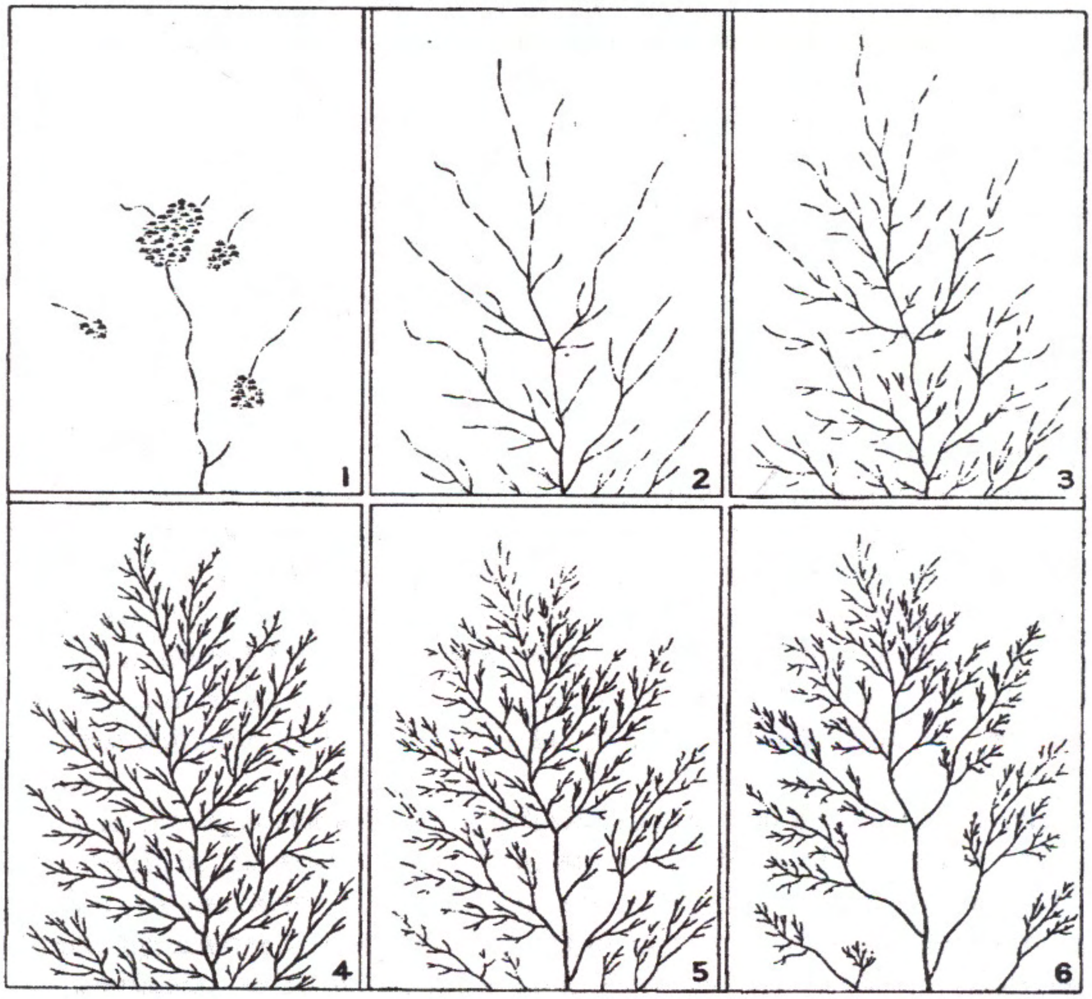


FIG. 8—An ideal diagrammatic summary of the development of a drainage system given for purposes of comparison only. The first four parts show extension, thus: 1, initiation; 2, elongation; 3, elaboration; and 4, maximum extension. Parts 5 and 6 represent steps during integration.

Figure 5. Ruhe's (1952) Observations of Drainage Extension in Glacial Tills.

A) Top: A copy of Ruhe's original illustration.
B) Middle: Ruhe's maps as printed in Chorley and others (1984, p. 329) showing more recent relative-time nomenclature.
C) Bottom: Absolute ages for Chorley's names.

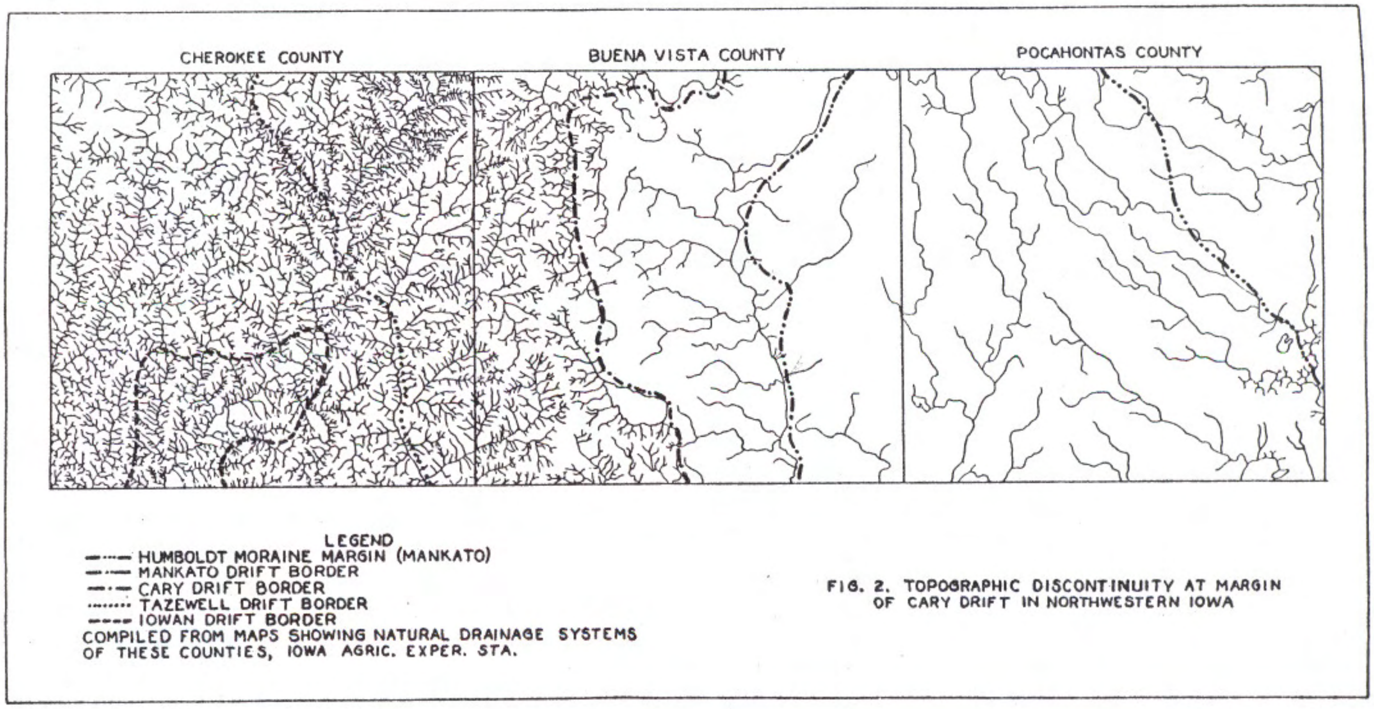
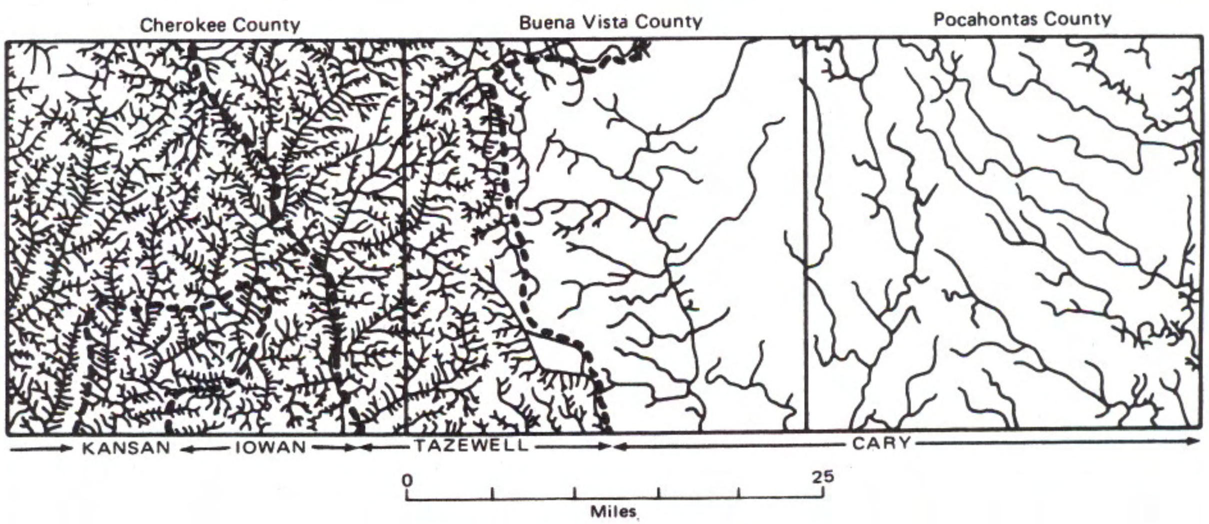


FIG. 2. TOPOGRAPHIC DISCONTINUITY AT MARGIN OF CARY DRIFT IN NORTHWESTERN IOWA



Absolute ages in years BP from Lemke et al., 1965, p. 20:

Cary	**12,800 – 15,200**
Tazewell	**16,300 – 18,300**
Iowan	**18,700 – 22,200**

[Kansan approximately 550,000 BP]

Figure 6.
Parker's Experimental Results as Reorganized and Presented in Chorley and others, 1984.

Cases A – E in Figure 6 represent progressive erosion with essentially 0% of original surface remaining at time E. The lower left and right corners were not available to erosion in the experiment. Time in Parker's experiments was estimated as quantity of runoff.

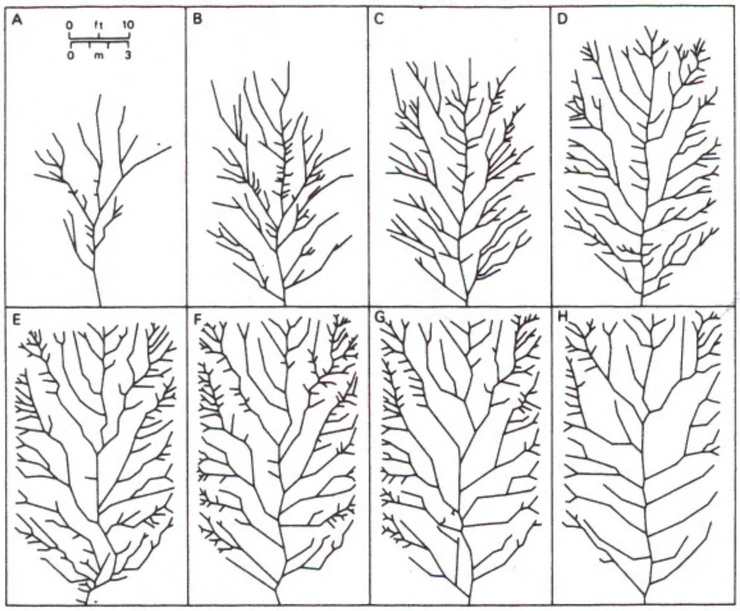


Figure 13.24 Map of growth of a drainage network developed by spraying a model catchment of 3·2 per cent slope with artificial rainfall: A.–D. show a progressive increase, E. and F. show maximum extension and G. and H. integration and channel loss
Source: Parker, 1977, pp. 54, 55.

Figure 7. Relationship Between Time and Drainage Extension from Parker's Experiment.

The percent of available area that was eroded was measured by Wilson and plotted with respect to time (runoff) within Parker's experiment.

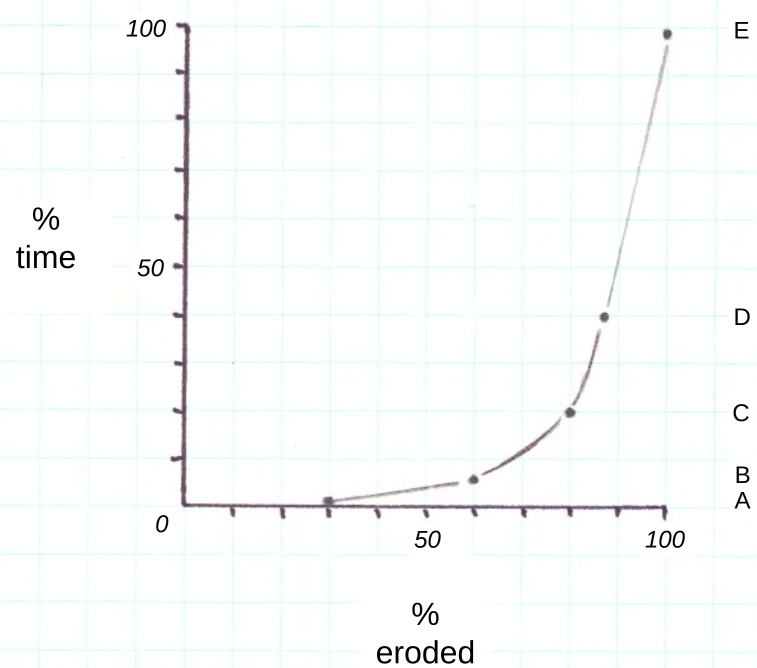


Figure 8. Projected Erosion Fronts at 500 years
(maintaining McKinney's convex longitudinal-profile retreat)

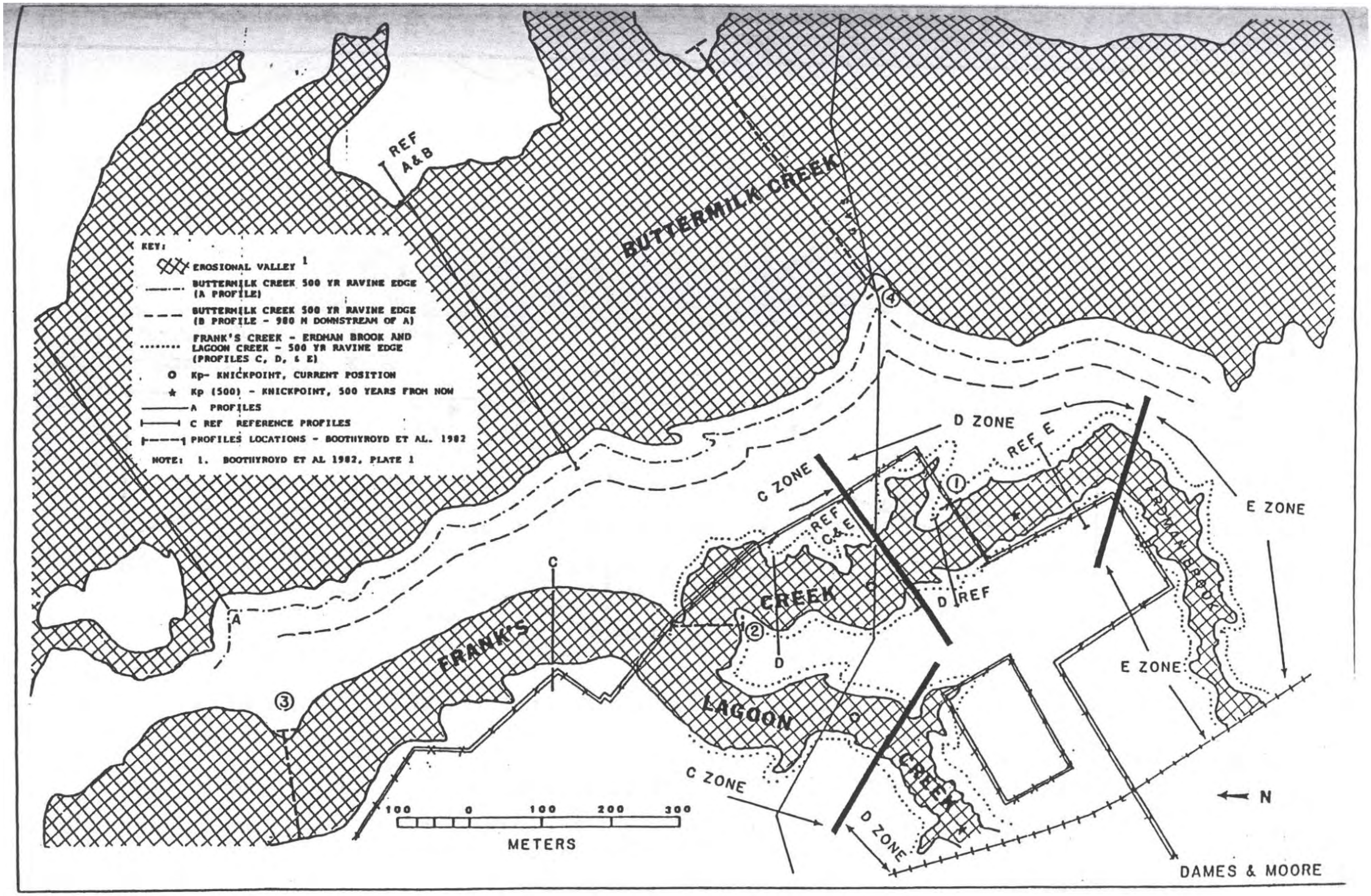


FIG 5-4. 500 YEAR STREAM VALLEY GROWTH

Figure 9. Projected Erosion Fronts at 1,000 years
(using 1996 DEIS probabilistic sediment transport)

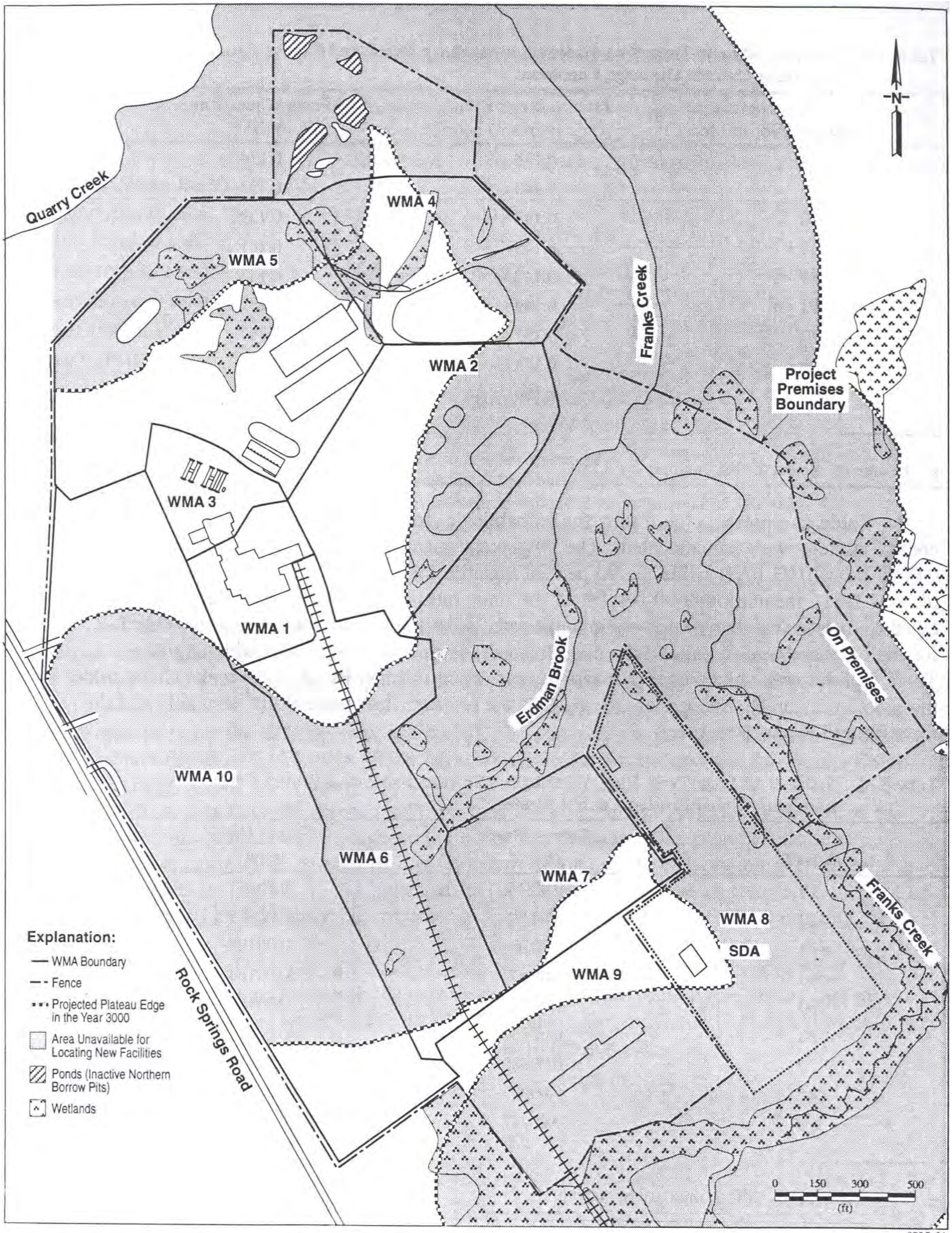


Figure L-2. Projected Erosion Front After 1,000 Years at 90 Percent Quantile Rate.

Figure 10. Sheet-pile Drop Structures