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ieomorphic Processes and Evolution f Buttermilk Valley and ielected Tributaries Vest Valley, New York

ıvial Systems and Erosion Study
ıase II

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GEOMORPHIC PROCESSES AND EVOLUTION OF BUTTERMILK VALLEY AND SELECTED TRIBUTARIES WEST VALLEY, NEW YORK

Fluvial Systems and Erosion Study, Phase II

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ABSTRACT

Repetitive bar and channel mapping at several scales, clast size and movement measurements, suspended-sediment sampling, and stream gaging of a 5 km reach of Buttermilk Creek and selected tributaries at West Valley, New York, have been carried out to determine short-term depositional and erosional processes as well as long-term valley changes adjacent to the low-level nuclear waste disposal site and other areas of the Western New York Nuclear Service Center.

Changes to bar-and-channel geometry in Buttermilk Creed are the result of migration of large transverse bars in equilibrium with large floods, such as occurred during Hurricane Fredric, September 1979. Large amounts of lower terrace gravel are also recycled during these events.

Downslope movement of landslides by slumping and earthflow appears to be a continous process (1.5 m^3yr^{-1}). Volumetrically it is a small sediment source exept when sudden failure by block gliding deposits a large mass in Buttermilk Creek.

Quantitative values of bedload transport, suspended-load sediment transport, and reservoir infill rates compare well with a simple denudation rate (6600 m^3yr^{-1}), a preliminary estimate, was calculated by dividing the volume of sediment removed by the number of years since initial incision (9920 $\pm$ 240 BP).

The middle-to high-level fluvial terraces in Buttermilk Creek are either adjacent to tributary confluences and preserved by an excess of bedload over transport capacity, or survive because the channel is stable on the opposite side of the valley for unknown reasons.

The convex longitudinal profile of Franks Creek/Erdman Brook suggests that it is unstable and will continue to downcut rapidly. Valley widening will occur by parallel retreat of slopes.

The future lowering of Buttermilk Creek is controlled by bedrock floors in Cattaraugus Creek and lower Buttermilk Creek. However, tributary lowering and widening will continue independent of a change in base-level of Buttermilk Creek.

SUMMARY

The major objectives of the fluvial system and erosion study at West Valley are: 1) Determine the seasonal, annual, and long-term modification of Buttermilk Creek and tributary drainage adjacent to the waste burial, lagoon, and other areas of the Western New York Nuclear Service Center; 2) Develop a dunudation rate for the Buttermilk Creek drainage basin.

The specific objectives of Phase II are to: 1) Reexamine and remeasure parameters outlined during Phase I (1978) as reported by Boothroyd and others (1979); 2) Examine the new parameters outlined below under work elements and information products; 3) Describe the proposed structure of an assessment of denudation rate.

The major difference between this work and Phase I was expansion of work area to include the western tributaries of Buttermilk Creek and the Nuclear Fuel Services reservoirs.

Changes in bar-and-channel geometry of Buttermilk Creek are the result of migration of large transverse bars in equilibrium with very large floods. Bar slipface migration up, to 60 m, occurred during Hurricane Fredric flooding in September 1979.

Singnificant movement of large clasts occurred on bar-complex margins during one-year floods (peak flow, 60 $m^3 sec-1$). The movement rate of large clasts is .003-.006 km yr^{-1}.

Topographic mapping established that a large amount of gravel from the low-active terraces is recycled to active bars by channel sweep in response to bar migration.

Suspended-sediment discharge of Buttermilk Creek during a one-year flood event was equivalent to 69 percent of the estimated yearly erosion of till in Buttermilk Valley. Discharge was equivalent to an in-place till volume of 3000 m^3.

Downslope movement of landslides by slumping and earthflow appears to be a continous process with 90 an average rate of 1.5 $m^3 yr^{-1}$. The yearly amount of material delivered to Buttermilk Creek is volumetrically small except when sudden failure by block gliding may deposit a large mass onto bars and into the channel.

Sedimentation in the NFS reservoirs since 1963 has been dominated by fluvial processes on delta plains, density underflow on the delta front and lakefloor, and by slumping of the valley walls. Accumulation rates of fluvially-derived sediment is a function of drainage basin area.

A sediment-loss rate calculated for the reservoir drainage basins ($0.89\ m^3ha^{-1}yr^{-1}$) corresponds well to other estimated transport and denudation rates.

A simple denudation rate was calculated for Buttermilk valley by dividing the volume of sediment removed by the number of years since initial incision and beginning of downcutting (9920 ± 240 BP). The denudation rate, $6600\ m^3yr^{-1}$, should be considered a preliminary estimate.

Many preserved middle-to-high level fluvial terraces in Buttermilk Creek are adjacent to the confluences of tributaries. The excess of gravel supplied over transport capacity aids in their preservation by retarding the sweep of the Buttermilk channel. Other terraces, including the set that contained the dated wood fragment, have been preserved because the Buttermilk channel has remained stable on the opposite side of the valley. Reasons for the stability are unknown.

The convex longitudinal profile of Franks Creek/Erdman Brook suggests it is unstable and will continue to rapidly downcut. Valley widening will occur by parallel retreat of slopes because of slumping of wall material and rapid removal by flood events.

The future lowering of Buttermilk Creek is controlled by bedrock floors in Cattaraugus Creek and lower Buttermilk Creek. However, tributary lowering and widening will continue independent of a change in base-level of Buttermilk Creek.

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1.0 INTRODUCTION

1.1 Purpose of Study

The major objectives of the fluvial system and erosion study at West Valley are:

1) Determine the seasonal, annual, and long-term modification of Buttermilk Creek and tributary drainage adjacent to the waste-burial, lagoon, and other use areas of the Western New York Nuclear Service Center;

2) Develop a denudation rate for the Buttermilk Creek drainage basin.

The specific objectives of Phase II were to:

1) Reexamine and remeasure characteristics outlined during Phase I (1978) and reported by Boothroyd and others (1979);

2) Examine the new characteristics outlined below under work elements and information products;

3) Describe the proposed structure of an assessment of denudation rate.

The major difference between this work and Phase I was the expansion of work area to include the western tributaries of Buttermilk Creek and the Nuclear Fuel Services reservoirs.

1.2 Work Elements and Information Products

Work elements and information products proposed at the initiation of this phase of the study are listed in Table 1. Some were later modified or dropped as detailed in Section 1.3.

The Buttermilk Creek work elements include:

1) Topographic remapping for bar complexes 4-6;

2) Establishment of new clast movement stations;

3) Retrieval of large bulk sediment samples of valley-wall till, bar gravel, and terrace gravel;

4) Correlation of earlier mapped terraces;

5) Mapping and staking a valley-wall alluvial fan at bar complex 5;

6) Resurvey the landslide at bar complex 6;

Table 1

Work Elements	Minimum, Expected Information Products
1. Remap bar complexes 4-6 and map complex 11.	A. Bar complex maps. B. Data with interpretation on rates of mass gravel movement.
2. Continue and/or re-establish measurements at clast movement stations.	A. Data with interpretation on small area bedload transport rates as well as a frequency of bedload movement assessment.
3. Obtain bulk sediment samples of valley wall till. Determine rates of potential bedload to suspended load. Sample existing gravel bars and determine the size distribution of this bedload.	A. Data from both measurements. B. Discussion and analysis of data.
4. Correlate mapped terraces downstream and across valley. Describe the early valley dimensions.	A. Discussion with figures of early valley dimensions. B. Discussion of significance or applicability, in any, of early valley development to future valley development.
5. Devise a system to monitor and measure sediment transport on, and changes of alluvial fans.	A. Summary of quantitative data collected. B. Description of sediment transport on and changes to alluvial fans. C. Assessment of the significance of these processes to the total geomorphic picture.
6. Resurvey landslide at BC 6. Determine slumping rate.	A. Slumping rates with a qualitative description of the modes of slope failure, with illustration appropriate.
7. Continue the velocity-cross-sectional area measurements and relate this curve to stage heights at the clast movement sites, then compute sediment transport rates.	A. Stage-discharge curve with discussion and interpretation, including an assessment of "slugs" from NFS reservoir excess dumping. B. Sediment transport rates.
8. Review and report on all velocity/area measurements, together with all stage recorder and pumping station data.	A. Data summary. B. Hydrologic and sedimentologic analysis of existing data.
9. Sample suspended sediment with a pumping station at Thomas' Corners Road.	A. Data on suspended sediment transport. B. Suspended sediment transport rate. C. Correlation with the records of stage.
10. Attempt to sample bedload during a flood event.	A. Sediment transport rates during flood event. B. Description of the method used, precedents in the literature, and suggestions for its future applicability.
11. Place a screen across the channel at Bond Road bridge to sample total bedload above a given size over a given time.	A. Rate of total bedload movement greater than size X during flood event. B. Description of the method used, precedents in the literature and suggestions for its future applicability.

12. Measure longitudinal profiles of tributaries.	A. Longitudinal profiles of tributaries. B. Analysis of longitudinal profiles' significance to sediment transport.
13. Assess tributary development, including topographic characteristics, fluvial and geomorphic processes and gradient. Construct a tributary drainage area map.	A. Tributary drainage area map. B. Description of tributary characteristics including topography, fluvial and geomorphic processes and gradient. C. Preliminarily identify, describe and assess headward migration processes.
14. Construct cross sectional profiles at selected locations of tributaries. Assess nature of valley development.	A. Cross sectional profiles of tributaries. B. Discussion of valley structure and its relation to mass movement and sediment transport process.
15. Measure sediment volume impounded in NFS reservoirs and compute volume/year deposited.	A. Sedimentation rates for NFS reservoirs. B. Discussion of significance and implications of A.
16. Compute the sediment volume removed from the Buttermilk system as a function of the ages of the terraces.	A. Volumes of sediment removed from the Buttermilk valley as a function of age. B. Relevance, if any, of past rates of future valley development.
17. Report Writing.	Minimum Report Requirements. A. Presentation, analysis, and interpretation of all data collected. B. Integration of A with results of previous reports. C. Summary of total expenditures (for this report) D. Presentation of a preliminary format for denudation rate computation supplemented by a detailed description of its utility, limitations, and the measurements necessary to refine its construction. This should include a description of how all work tasks "fit" into the total picture. E. Recommendations for final phase of study.

7) Continuation of velocity/depth/discharge measurements at Thomas Corners Road bridge.

Expanded work on the tributaries and reservoirs includes:

1) Measure longitudinal profile of Franks Creek/Erdman Brook;

2) Construciton of selected tributary cross profiles;

3) Construction of tributary drainage area map;

4) Measure cross and longitudinal sections in the NFS reservoirs by bottom profiler.

Overall work elements included:

1) Computation of sediment volume removed from Buttermilk Creek and Franks Creek;

2) Computation of fluvial sediment volume deposited in the reservoirs.

1.3 Changes to Information Products

The following work elements were not completed or attempted. Other work was substituted for these tasks.

1) Map bar complex 11 (Task 1) - Flooding associated with Hurricane Fredric (September, 1979) altered the bar so that it is now similar to bar complex 4-6 in morphology, rendering mapping to delineate differing bar morphologies not applicable.

2) Alluvial fan sediment transport (5) - Additonal work constructing a topographic map was substituted for work deleted in (1).

3) Sample suspended sediment with a pumping station at Thomas Corners Road bridge (9) - Station was unavailable, thus this task was deleted.

4) Bedload sampling during a flood event (10) - We monitored two flood events, one (October 12) that was of insufficient discharge to move many clasts; and another (October 25-26) with a peak that occurred during darkness, and was of such high discharge that it was dangerous to work in the channel. These problems are elaborated on in the discussion section.

5) Place a screen at Bond Road bridge to sample total bedload over time (11) - Logistical problems prevented the screen installation, thus this task was deleted.

6) Measure longitudinal profiles of tributaries (12) and assess tributary development (13) - This task consumed a much larger amount of time than first anticipated because of the extreme difficulty of working (movement and vision) with the tributary channels. Additional work on this task was substituted for tasks 9, 10, and 11.

1.4 Scope and Conditions of Study

The field area was expanded over that of Phase I to include the western tributaries of Buttermilk Creek, the plateau area containing the burial trenches and lagoons, and the Nuclear Fuel Services reservoirs (Fig. 1, 2). Also see the updated environmental geologic map (Plate 1) and the NFS plateau site map (Plate 2). Work was also done within Buttermilk Creek and on the valley walls, concentrating on the upper part of the Buttermilk - Bond reach. Velocity-area and stage-discharge measurements were carried out at Thomas Corners Road bridge.

Most bar and channel mapping, profiling, and clast measurement was carried out during low-flow conditions in the summer and fall of 1980. Buttermilk Creek is highly accessible, whereas Franks Creek and the smaller tributaries are difficult to work in because downed trees create log jams that block the main channel of the creeks. We were on site for two storm discharge events, including the substantial flood of October 25-26, 1980. High stage and high flow velocities prevented access to most bar complexes and the velocity-area cross-section during floods.

1.5 Previous Work

We will refer to the Phase I report of the geomorphic and erosion study (Boothroyd and others, 1979) and integrate our new results with the prior study. LaFleur (1979) summarizes the glacial geology and stratigraphy of the Nuclear Service Center site and surrounding drainage basins. A continuing series of technical reports issued by the New York State Geological Survey (NYSGS) on various aspects of site geology, chemistry, and engineering have proved useful (Hoffman and others, 1980; Dana and others, 1979; Dana and others, 1980).

Groundwater properties of till underlying the low-level burial site are contained in reports by Prudic (1979) and Prudic and Randall (1979).

FIGURE 1
LOCATION MAP

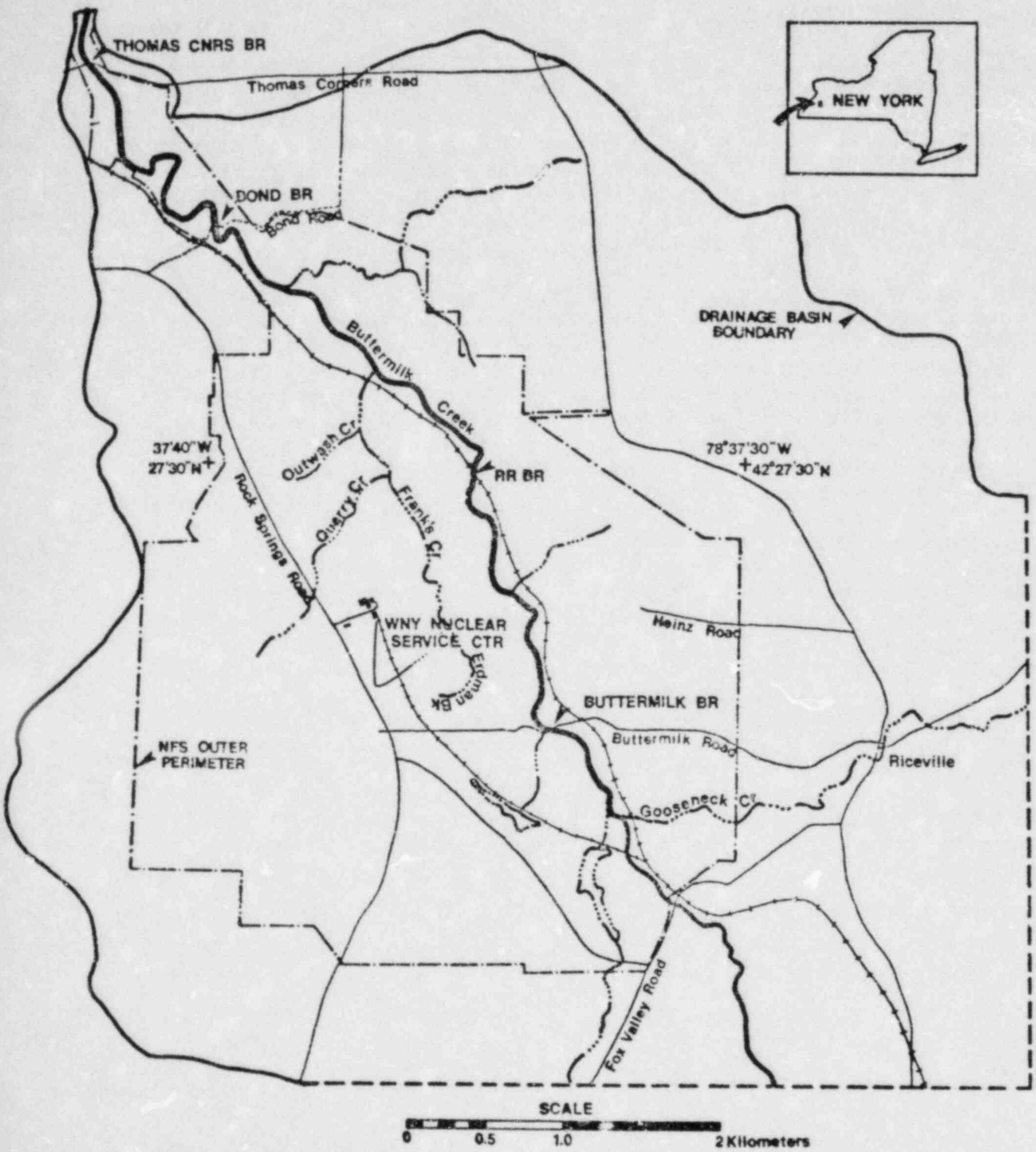


Figure 1. Location map of the northern part of the Buttermilk Creek drainage basin. Note the location of the Western New York (WNY) Nuclear Service Center.

Figure 2. Vertical aerial view of the Nuclear Fuel Services facilities, the waste-burial sites, and the general plateau area. A section of Buttermilk Creek is shown at the top of the photograph (taken April 22, 1980 by Erdman, Anthony Associates).

2.0 CONCLUSIONS

1) Changes to bar and channel geometry in Buttermilk Creek are the result of migration of large transverse bars in equilibrium with very large floods. Bar slipface migration, up to 60 m, occurred during Hurricane Fredric flooding in Sept. 1979.

2) Significant movement of large clasts occurred on bar complex margins during one-year floods (peak flow, 60 $m^3 sec^{-1}$). A movement rate of .003 - .006 km yr^{-1} was established for large clasts.

3) Topographic mapping showed that a large amount of gravel from the low-active terraces is recycled to active bars by channel sweep in response to bar migration.

4) Suspended-sediment discharge of Buttermilk Creek during a one-year flood event was equivalent to 69 percent of the estimated yearly erosion of till in Buttermilk valley. Discharge was equivalent to an in-place till volume of 3000 m^3.

5) Downslope movement of landslides by slumping and earthflow appears to be a continuous process measured at an average rate of 1.5 $m^3 yr^{-1}$. The yearly amount of material delivered to Buttermilk Creek is volumetrically small except when sudden failure by block gliding may deposit a large mass onto bars and into the channel.

6) Sedimentation in the NFS reservoirs since 1963 has been by fluvial processes on delta plains, density underflow on the delta front and lakefloor, and by slumping of the valley walls. Rate of accumulation of fluvially-derived sediment is a function of drainage basin area.

7) A sediment-loss rate calculated for the reservoir drainage basins (0.89 $m^3 ha^{-1} yr^{-1}$) corresponds well to other estimated transport and denudation rates.

8) A simple denudation rate was calculated for Buttermilk valley by dividing the volume of sediment removed by the number of years since initial incision and beginning of downcutting (9920 $\pm$ 240 BP). The denudation rate, 6600 $m^3 yr^{-1}$, should be considered to be a preliminary estimate.

9) Many preserved middle-to-high level fluvial terraces in Buttermilk Creek are adjacent to the confluences of tributaries. The excess of gravel supplied over transport capacity aids in their preservation by retarding the sweep of the Buttermilk channel. Other terraces, including the set that contained the dated wood fragment, have been preserved because the Buttermilk channel has remained stable, for unknown reasons, on the opposite side of the valley.

10) The convex longitudinal profile of Franks Creek/Erdman Brook suggest it is unstable and will continue to downcut rapidly. Floods will continue to rapidly remove slumped valley wall material and produce valley widening by parallel retreat of slopes.

11) The future lowering of Buttermilk Creek is controlled by bedrock floors in Cattaraugus Creek and lower Buttermilk Creek. However, tributary lowering and widening will continue independent of a change in Buttermilk Creek's base-level.

3.0 PROCEDURES

3.1 Field Methods

General Location - Bar complex and longitudinal profile stake locations installed during Phase I were replaced and resurveyed for this study phase in the Buttermilk-Bond reach. Specific locations identified by name follow the Phase I nomenclature (Boothroyd and others, 1979). The environmental geologic map (Plate 1) has been reproduced with added information as a reference guide. In addition, a new (1980) NFS site map provided by the NYSGS has been used to plot information and as a location guide (Plate 2).

Bar Mapping - A topographic survey of bar complex 4-6 was completed using standard transit and rod techniques. Twenty Phase I transects were reoccupied and other bar-edge elevations obtained for a total of 809 stations. Instrument stations at each transect were tied by survey to the USGS benchmark at the B&O railroad bridge over Buttermilk Creek, at the bar complex 10.

Clast Movement Stations - The three transects (5, 11, 16) on bar complex 4-6 chosen as clast movement stations were picked for geographic location on the bar complex, upstream, mid-bar, and downstream, and for difference in bar morphology. Each line extended from the edge of the terrace (west side) to the base-flow channel margin (east side). The marking procedure, similar to that employed in Phase I, was as follows: 1) each transect line end point was marked with a special stake (green) 2) all average maximum-sized clasts (>25 cm L-axis) within several clast lengths of the transect line were painted green; 3) selected medium-sized clasts (<25 cm L-axis) were painted blue; and 4) the transect line was marked with yellow paint to identify smaller clasts. A total of 285 clasts were marked (97 Green, 188 Blue).

Some clasts at a station location from Phase I were recovered in place (see bar map, Plate 4) and repainted. One clast from that station was found downstream of transect 11 and incorporated into the new line.

Bulk Sediment Samples - Eleven bulk sediment samples were collected for grain-size analysis. They include two in-place basal tills; three terrace samples, two gravel and one sand-silt: and six gravel samples from bar complex 4-6. The bar samples were chosen to reflect a range of bar-top morphologies and subenvironments. An attempt was made to collect a sample cube measuring 50 cm on a side, or 0.125 m^3. Each sample weighed 150-225 kg.

Terrace Correlation - Limited field checking was done to verify terrace locations mapped during Phase I of the study.

Alluvial Fan Profile and Mapping - A topographic survey and longitudinal profile was done on the Buttermilk valley-wall alluvial fan adjacent to both bar complex 3 and the till borrow area used for recapping the low-level waste-burial trenches. Standard transit and rod techniques were used. Twenty eight instrument station stekes and backsight/-foresight stakes were placed for later monitoring. A total of 136 elvation points were measured. The instrument stations were tied to the railroad bridge benchmark and the base-flow channel elevation at bar complex 3.

Landslide Mapping - The landslide on the west valley wall above bar complex 6 was resurveyed by transit and rod method. Elevations of twenty stakes emplaced during the Phase I study, as well as forty-seven newly installed stakes, were determined. This control net was tied to the benchmark at the railroad bridge.

Discharge Measurements - Seven sets of velocity/area/discharge measurements were made on Buttermilk Creek at Thomas Corners Road bridge. Three low-flow data sets and one small flood set were obtained at a man-modified trapezoidal section. The section was 22 m upstream from the bridge. A moderate flood event (October 25-26, 1980) was monitored and 3 separate discharge measurements were made using surface flow velocitites at the bridge. This was done because it was not possible to enter the creek and suspension gear was unavailable. Price type AA, Price pygmy, and Marsh-McBirney electromagnetic current meters were used with a topset wading rod for the low-flow and small flood events. Measurements were made at 0.6 depth every 0.5 meters across the section.

Suspended Sediment Sampling - One suspended sediment sample was obtained from the midpoint of the channel during each discharge measurement. A depth-integating, hand-type (DH 59) sampler was used.

Tributary Gradient - The gradient or longitudinal profile of a 2.9 km reach of Franks Creek/Erdman Brook was measured by standard transit and rod leveling techniques. Part of the profile was determined from the 1980 plateau site map (Plate 2). The distance (2.4 km) from the confluence of Buttermilk and Franks Creeks to the security fence at the southern end of the low-level burial area was measured by transit and rod. The distance from the fence, upstream to a small wetland adjacent to the NFS railroad spur, was measured from the map. Precision was 0.3 cm vertically and 15 cm horizontally. Backsights and foresights were restricted to a maximum of 45 meters because of dense vegetation and bends in the channel. Stations were chosen at the water's edge of the base-flow thalweg. Stage height did not appear to vary during the 4 days the profile was run. The profile was tied to the benchmark on the railroad bridge.

Reservoir Sediment Volume - A total of 26 cross profiles and two longitudinal profiles were run between shore stakes in the two NFS reservoirs. Shore stakes were placed along the reservoir edge by tape and pace methods. Locations were plotted on the 1:2400 scale (1 inch= 200 feet) topographic base map of NFS property. A Bludworth Model ES-130SS Portable Echo Sounding Survey Recorder was used. The recorder is accurate to 5 cm vertically at a depth of 100 meters. Horizontal distances were checked where possible by paying out a 20 m line and recording the distance directly on the strip chart.

Photographic Documentation - Approximately 450 color slide photos of bar-surface features, bar-and-channel geometry, tributary channel and valley geometry, and landslide morphology were taken during the field season. Clast movement stations were documented in detail.

3.2 Office Work

Bar Mapping - A topographic map of summer, 1980 morphology of bar complex 4-6 (Plate 4) was produced at the same scale as the Phase I map (1979, Plate 4) to facilitate comparison. The scale of these maps is approximately 1:235.

Map Updating - Drainage basins of the western tributaries were delineated on the environmental geologic map, Plate 1 (1979, Plate 1) and the glacial geology map. (Plate 3) (LaFleur, 1975) (1979, Plate 3). They were also delineated on the 1980 plateau site map (Plate 2). Drainage divides were determined by inspection of map topography, by field checking, and consultation with NFS and USGS representatives for the area within the NFS security fence. Terraces are identified by number on the environmental geologic map (Plate 1).

Volume Computations - Volumes were determined from a surface area multiplied by an approximate horizontal or vertical distance. All surface area measurements were made with a LaSico N1250S1 rolling-disk, auto-scaling, digital planimeter.

Reservoir measurements were made using the cross-sectional area differences between the depth recorder cross-profiles and original profile derived from the 1:2400 scale map. Longitudinal distances between cross-profiles were determined by depth recorder and map distances. Volume calculations were by the double-end area method. Surface area of the delta plains was determined from the 1:2400 scale map.

Buttermilk Creek and Franks Creek/Erdman Brook valley volumes were determined by measuring surface area at the midpoint between two given elevations on the valley wall and multiplying by the elevation difference. Total volume was determined by measuring a series of volume blocks extending "down-elevation" and along the valley in a downstream direction.

Tributary drainage areas were measured on the appropriate scale map. Those included either the plateau site map (Plate 2), environmental geologic map (Plate 1), or the glacial geology map (Plate 3).

Sediment samples - Each bar and terrace sample was air-dried, and a 1/8 split taken to give a workable-sized sample. Splits weighted from 10-30 kg. Gravel and sand-sized material, at 0.25 phi intervals, was sieved on a Ro-tap for 20 minutes. Round-hole gravel sieves and standard sand sieves were used. Clasts with L-axis greater than 5 cm were measured in the field. All three axes were measured. Specific gravity of representative clasts was determined in the lab (average was 2.6). Weights were assigned to these clasts assuming a rectangular shape and using the determined average specific gravity.

A better method would have been to weigh the large clasts in the field. Weights of large clasts were combined with the sieve weights to determine a total weight. Results were plotted on cumulative probability paper following Folk (1974).

Both till samples were split into segments and visually inspected for size and number of clasts. Because the clasts were small in size and number, a 0.5 kg sample was adequate to determine representative grain size. The samples were split by hand and dissolved in distilled water and dispersant to separate out the gravel-sized material. The sample was then wet-sieved and split into size fractions at the 63μm break. The fraction greater than 63μm was dry-sieved and the fraction less than 63μm was pipetted (Folk, 1974). Results were plotted as above.

4.0 RESULTS

The following discussion will make use of the environmental geologic map (Plate 1), the NFS site map (Plate 2), and the glacial geology maps of the Buttermilk drainage basin (LaFleur, 1975) (Plate 3). Please refer to them for location and details. An aerial view of the NFS high security area and surrounding plateau is shown in Figure 2.

4.1 Bar Mapping

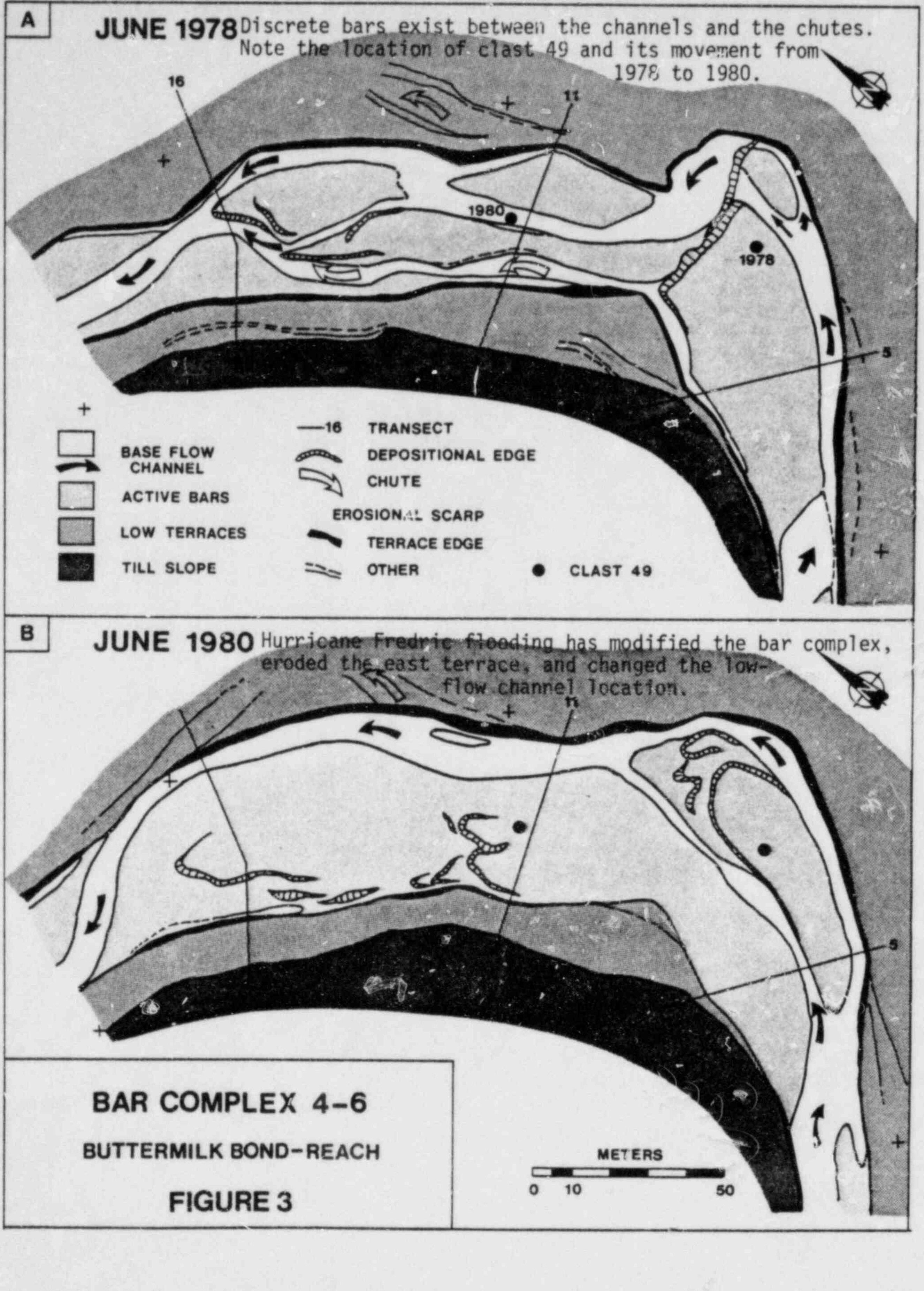
Topographic Mapping - The purpose of remapping bar complex 4-6 was to document changes that have occurred in bar-and-channel geometry and bar surface features since summer, 1978. Field reconnaissance revealed that the 1978 geometry was vastly changed by the large flood event accompanying Hurricane Frederic on September 8-9, 1979. The completed topographic map is shown (Plate 4). Simplified morphologic maps derived from the topographic maps are shown in Figure 3. Volumetric changes, determined from differences in topography from 1978 to 1980 of selected locations on the bar complex are listed in Table 2.

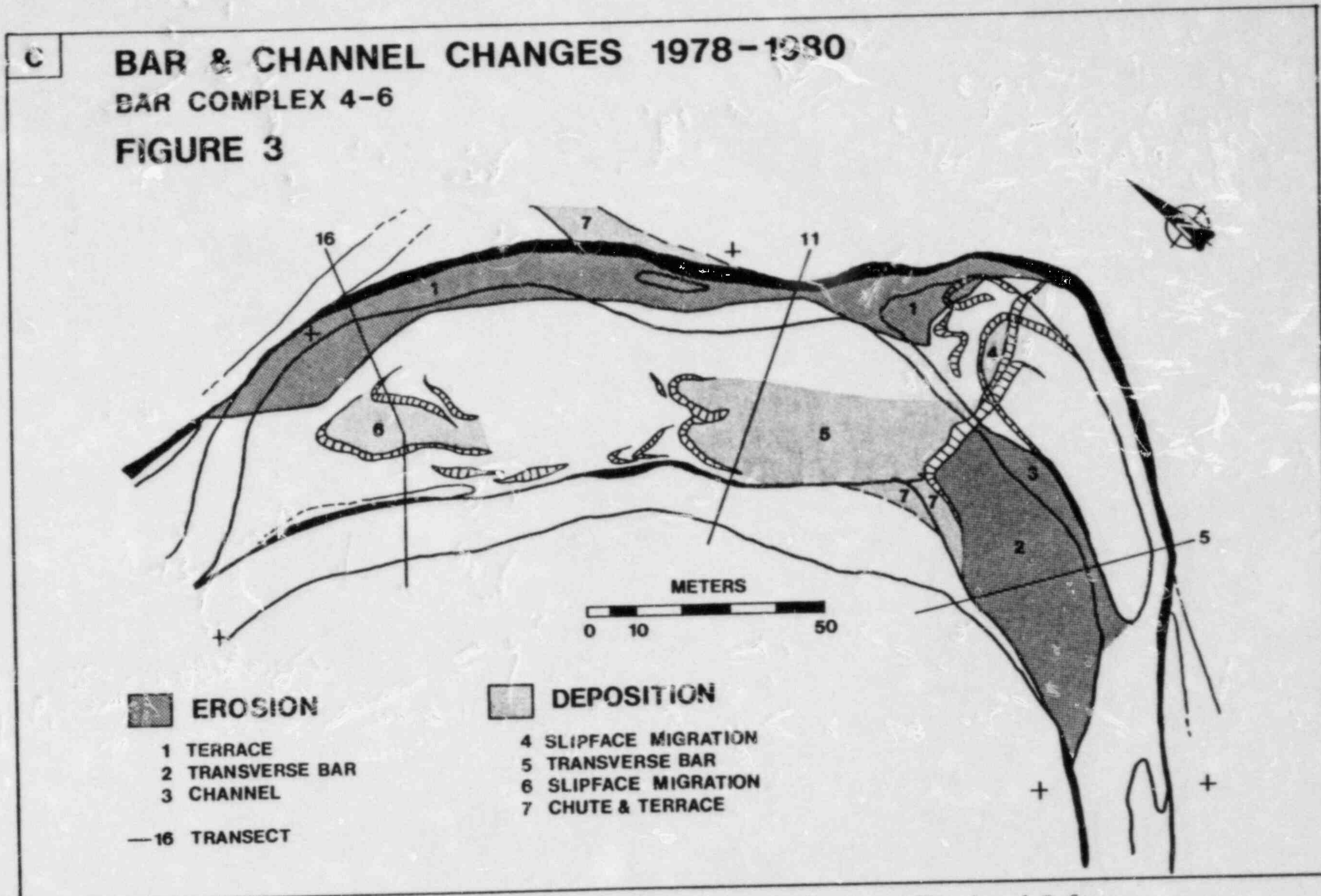
Bar-and-Channel Pattern Changes - The pre-Frederic bar and channel pattern (Fig. 3a; Fig. 6, Boothroyd and others, 1979), upstream to downstream, consisted of a large transverse bar (bar complex 4) with a well-developed slipface as well as a series of smaller longitudinal bar complexes cut by erosional channels and several small transverse bars with low (30 cm) gravel slipfaces. The downstream part of the bar complex was cut by a number of small, erosional, base-flow channels. Both east and west margins of the bar-and-channel system were separated from adjacent, vegetated, low terraces by a 1 to 2 m erosional scarp. The only exception was at the west margin of bar complex 4, where the upstream end of the bar merged with the lowest terrace.

The bar-and-channel pattern mapped in 1980 (Fig. 3b) shows great changes from 1978 (Fig. 3b,c). The upstream transverse bar (complex 4) has been cut by an erosional channel with lowering of the western surface by 20-40 cm (Table 2). The eastern slipface migrated downstream about 8 m. The greatest changes are in the mid-reaches of the bar complex.

A terrace section, 10-15 m wide and 150 m long, on the east has been removed. A large transverse bar has been deposited on the west side (Fig. 4). The base-flow channel now runs against the eastern terrace scarp. The 1978 west-side chute has been filled and gravel longitudinal bars have been deposited on the low, vegetated terrace. The bar surface has been raised 60-100 cm by bar-top and slipface gravel deposition. The lower-complex transverse bars have migrated downstream, approximately 10-15 m, diagonally across the complex surface (Fig. 3, Table 2).

Figure 3. Morphologic maps of bar complex 4-6.





Selected erosional and depositional changes. Use A and B for comparison.

TABLE 2

Bar Complex 4-6 Volume Changes

		Dimension Changes		Volume Change
		Distance (m)	Elevation (cm)	(m^3)
1)	Terrace	avg. width 10-15 m, length 150 m	lowered 100 cm	-1871.3
2)	Old Transverse Bar		lowered 30 cm	- 357.6
3)	Old Channel		lowered 80 cm	- 214.2
4)	Slipface Migration	moved 8 m	height 200 cm	+ 180.6
5)	New Transverse Bar	moved 60 m	raised 80 cm	+ 857.7
6)	Slipface Migration	moved 10-15 m	height 80 cm	+ 240.4

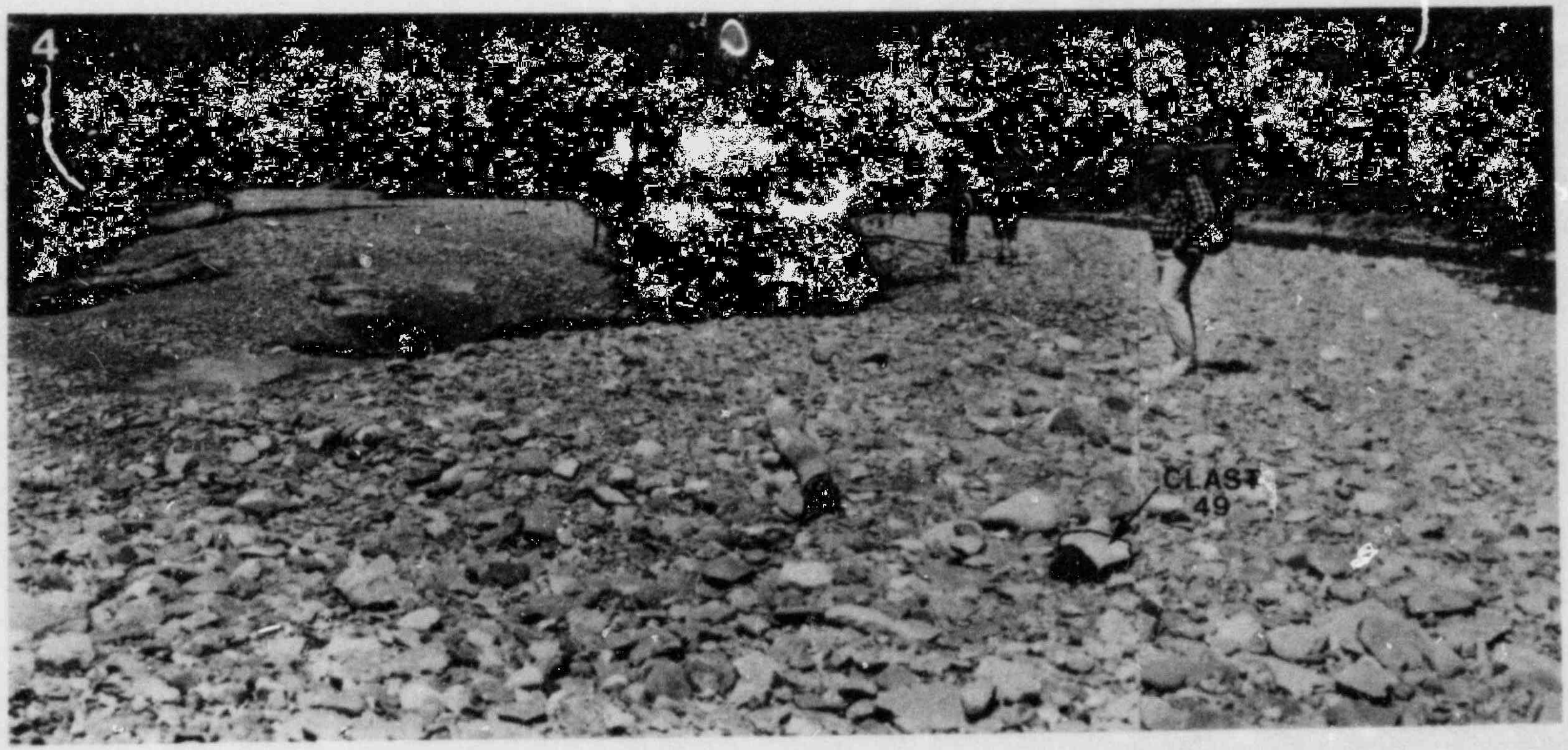


Figure 4. View downstream of bar complex 4-6 from transect 11. The person is standing just off the bar top of the large transverse bar deposited during Hurricane Fredric flooding. Relocated clast 49 is in the right foreground.

4.2 Bulk Sediment Samples

Cumulative curves and a percentage plot for the sediment samples are shown in Figure 5. The plotting procedure follows that of Folk (1974). A photographic log of sample localities is illustrated in Appendix A.

Till - Two samples were collected of silt-rich till with contorted silt lenses and few large pebbles (Fig. 5). This material is in the stratigraphic position of Kent till (LaFleur, 1979, 1980). Sample GS-11, collected below the base of the BC-6 landslide, may be transported Lavery till.

The till samples are silt-rich with 80-85 percent silt and clay which constitutes the suspended sediment load of the fluvial system. Visual inspection of till cropping out at landslide localities and at the base of a scarp slope along the Buttermilk channel reveals that few large clasts are contained in the till. The observed low overall gravel percentage is in agreement with our two analyses. LaFleur (1979) and Dana and other (1979, 1980) report similar findings at other outcrop localities and in research trenches cut in Lavery till on the plateau adjacent to the low-level, waste-burial site.

Bar Gravel - Six samples were analyzed from various locations on bar complex 4-6 (Fig. 3, Table 3, Plate 4). All samples contained 75-95 percent gravel with little sand matrix and very little silt and clay. Some sand and all silt and clay, originally deposited as a falling-stage drape over the gravel, infiltrates downward into available pore space. GS-6, taken from the highest point of the mid-bar complex, contains the greatest percentage of large cobbles. GS-9, the finest-grained sample (pebble gravel) is from a transverse bar on the lower complex.

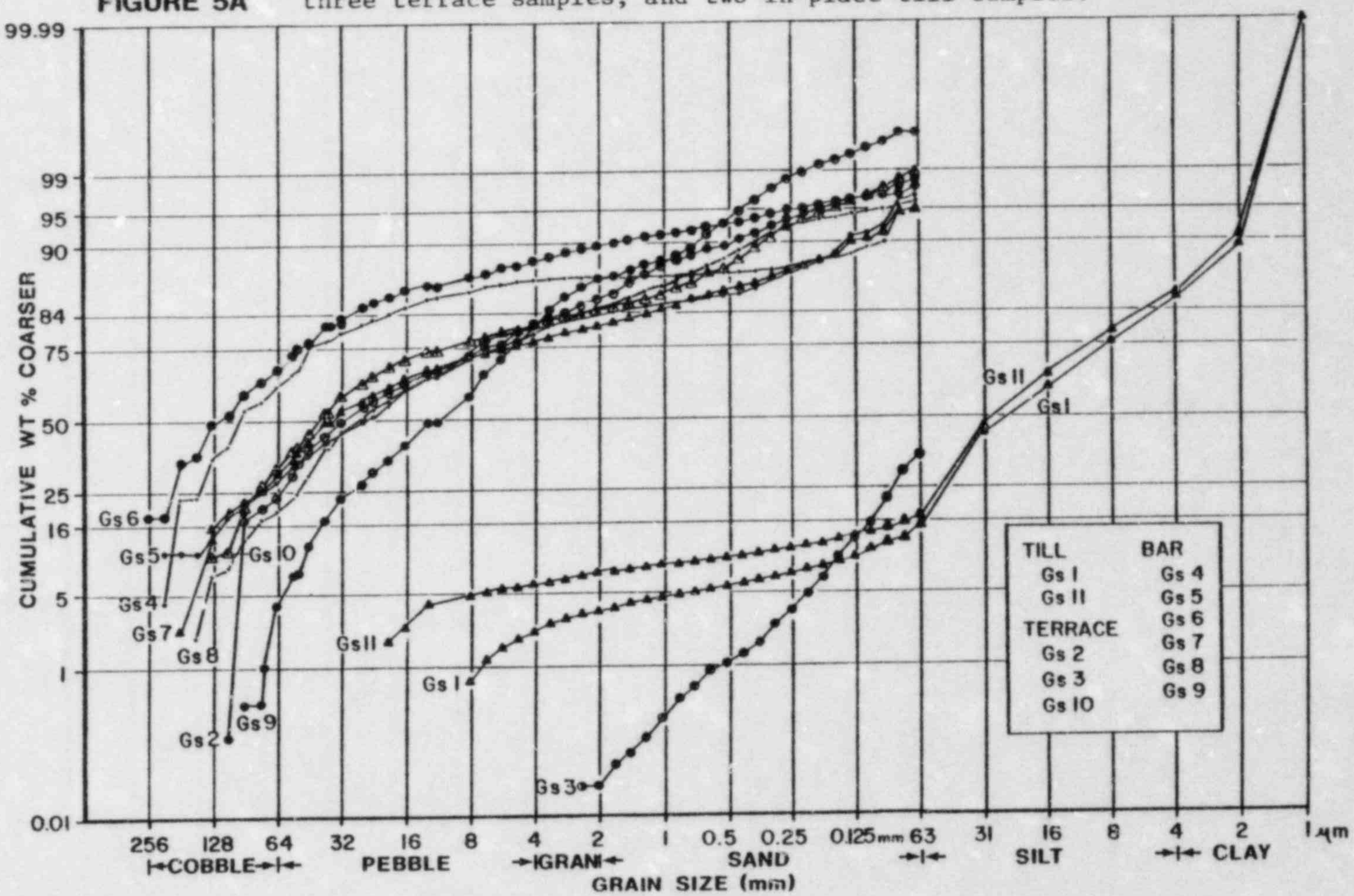
Terrace Samples - GS-2 is from the west side, upstream of transect 1. GS-10 is from the east side at transect 16. They are similar in gravel percent and overall grain-size distribution to the bar samples. These two samples represent previously deposited bar complexes resulting from the cross-valley channel sweep documented by Boothroyd and others (1979; Plate 5).

The third sample, GS-3, is a fine-grained sandy silt with little gravel. It was obtained from the topmost unit in the stratigraphic section upstream of transect 1, opposite bar complex 3 (Fig. 6). This unit was deposited in a small depression (pond) on the gravel terrace at the base of the BC-3 alluvial fan. It was then exposed by channel sweep.

4.3 Alluvial Fan

A longitudinal profile (Plate 5) and topographic map (Plate 6) were constructed for the incised channel and alluvial fan on the west

FIGURE 5A Cumulative curves for six bar complex 4-6 gravel samples, three terrace samples, and two in-place till samples.



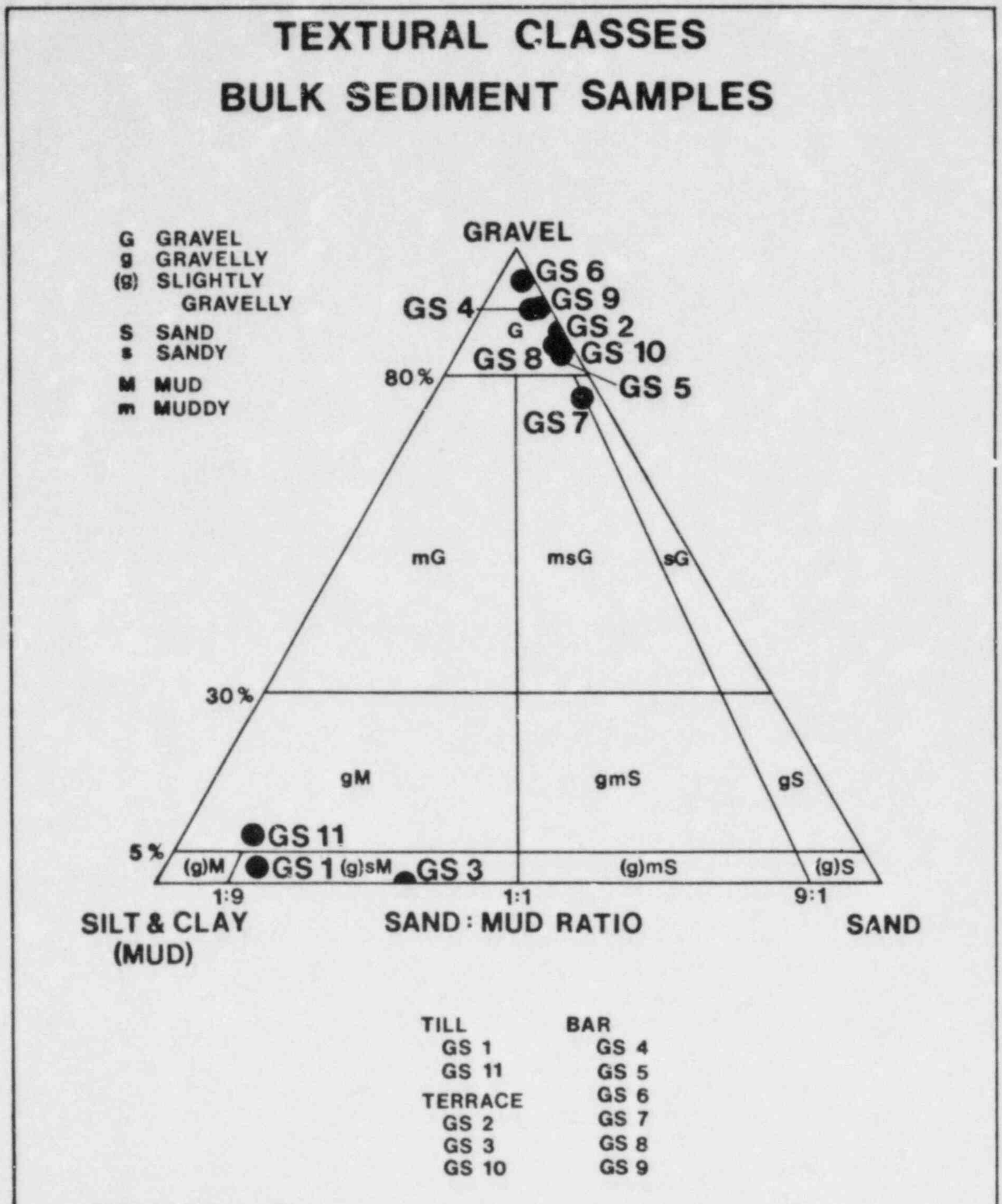


FIGURE 5B

Textural class plot illustrating the high gravel content of the bar samples and the high silt and clay content of the till samples. Nomenclature from Folk (1974).

TABLE 3

Grain Size, Bulk Samples

	Location	Transect	%Gravel	Sand	Silt	Clay
Till						
GS-1	BC-3, west bank		2.3	12.9	70.3	14.5
GS-11	below BC-6 landslide		7.4	9.9	69.2	13.5
Terrace						
GS-2	BC-3 west bank		87.0	12.6	0.4	
GS-3	BC-3 pond, toe of fan		0.03	34.5	65.5	
GS-10	east bank	16	84.2	14.7	1.1	
Bar Complex 4-6						
GS-4	bar top unit bar	6	90.4	6.9	2.7	
GS-5	bar top, transverse bar	8	83.3	14.7	2.0	
GS-6	high point large transverse bar	11	94.8	3.6	1.6	
GS-7	shoulder large long. bar, sand drape	12	76.4	21.0	2.6	
GS-8	large longitudinal bar	15	84.8	13.0	2.2	
GS-9	transverse bar crest	17	90.5	8.1	1.4	

Figure 6. Stratigraphy exposed in the western terrace scarp opposite bar complex 3. The units are: 1) Kent till; 2) bar and channel gravel; 3) slit and clay deposited in a ponded depression at the base of alluvial fan BC-3. Bulk sediment samples GS-1,2,3, correspond to the numbered units.

side of Buttermilk Creek, opposite bar complex 3. The fan is mapped as unit A_{ab} on the environmental geologic map (Plate 1).

Longitudinal Profile - The upper profile is a steep, incised channel with a mean gradient of 288.7 m km^{-1}. The inner channel is incised 2-3 m below the general level of the valley wall (Plate 6). The profile is flattened where slumps have partially filled the channel.

This slumping process probably triggers the formation of the knickpoints present along the reach. The incised channel debouches onto an alluvial fan with a convex depositional bulge at the fan head. The channel profile shows a series of irregular changes as it drops over several terrace levels and then onto a wide terrace approximately 4 m above the level of Buttermilk Creek. A pond forms on this terrace during rainfall and flow events. Overflow is channelled down another incised channel into Buttermilk Creek.

Topographic Map - The inner incised channel is shown in dark shading on Plate 6 and the fan in a lighter tone. An outer, V-shaped channel is also apparent along the upper profile. The single channel bifurcates into three distributaries. Two on the south intersect the fan surface on the convex bulge. The third continues across the bulge to the north and along the edge of the fan. This third distributary connects the presently-active fan head with an older, main-channel segment at the edge of the fan. The segment is part of a now beheaded channel that began further up the valley wall.

The northern distributary is being abandoned with more of the flow feeding sediment onto the southern part of the fan. Events such as Hurricane Frederic flooding may be the mechanism that causes increased fan head incision and channel avulsion.

Some fine-grained sediment that bypasses the fan is deposited in a shallow pond on the 40 m wide terrace at the toe of the fan. These sediments are exposed in the upper section of an erosional scarp created by the migration of the Buttermilk channel (Fig. 6). The scarp is opposite bar complex 3. An unknown amount of fine-grained sediment probably bypasses both the fan and pond. It is led directly into Buttermilk Creek through the lower, incised channel.

4.4 Landslide (BC-6)

Active landslides occur in areas where the channel impinges on, and cuts, the valley wall over a period of at least tens of years. The channel sweep documentation provided by Boothroyd and others (1979, Plate 5) showed that the Buttermilk channel was at, or near, the large landslide area on the west valley wall at bar complex 6, from 1939 to 1977. The latest panoramic view was taken on July 28, 1980 (Fig. 7). Similar views taken in April 1977, 1978, and 1980 by D. Prudic (written communication) are included as Appendix B.

Figure 7. Large landslide on the west wall of Buttermilk Creek at BC-6. The slide is a complex of coherent slump blocks (SB) and hummocky, earthflow deposits (EF). Horizontal movement up to 32 m, and vertical movement up to 10 m occurred between 1978 and 1980. Photograph taken July 28, 1980.

Monitoring Stations - The landslide complex was marked with a series of 1.5 m steel fence posts and shorter wooden stakes in October 1978. A resurvey in July 1980 recovered 20 of 35 original stations. All the recovered stations were steel posts. These stations, as well as the new monitor posts, are shown on Plate 7 with movement tabulated in Table 4 and Appendix C.

Downslope horizontal, 8-32 m, and vertical, .8-10 m, movement was measured. The movement occurs as a series of coherent slumps, 20-50 m wide at the top of the slide, which change to a hummocky, tension-cracked, earthflow mass at the toe of the slide. Downslope trajectories of the upper slide slumps are steeper than the lower earthflow (Table 4). This contributes to a pile-up of material at the base of the slide. This material can rapidly flow out onto Buttermilk bar-and-channel areas as shown in Figure B1 (Appendix B). The earthflow accumulation of material had been removed by April, 1980 (Fig. B3) and was probably eroded by Hurricane Frederic flooding.

4.5 Buttermilk Terraces

The fluvial terraces mapped in 1978 (Boothroyd and others, 1979) are plotted on the environmental geologic map (Plate 1) and on a longitudinal section of Buttermilk valley (Plate 8). Plate 8 depicts the terraces projected from a position on the valley wall to a vertical surface that intersects the thalweg of Buttermilk Creek. The precise elevations and distances down valley are given in Appendix D.

The 1978 mapping assigned numbers to the terrace levels ranging from: (1) 1 m above presently active bars (FA_{b1}, Plate 1); to (14) 35 m above the bar surfaces (FI_{b3}, Plate 1). The terrace levels were grouped into three categories according to general elevation above the bar surfaces: 1) low (FA_{b1}), up to 3 m; 2) middle (FI_{b1}), 3 to 8 m; and 3) high (FI_{b2}), all higher terraces. Plotting of the terraces in longitudinal section (Plate 8) revealed that they should be redivided as follows: 1) low active (0-3 m); 2) low inactive (3-8 m); 3) middle (8-35 m); and 4) high (>35 m).

Low, active terraces are present on both sides of the valley except in areas where the channel has been adjacent to the till slope over the time span of the photo documentation (Boothroyd and others, 1979; Plate 5). An example is the west side of the valley that includes the BC-6 landslide. Low, inactive terraces and most middle terraces are adjacent to tributary confluences with Buttermilk Creek. The western middle-level terraces at the lower end of the reach are protected by bedrock cropping out at creek level. The other middle and high terraces show no affinity to tributaries or bedrock.

4.6 Franks Creek/Erdman Brook

Longitudinal Profile - The longitudinal profile of Franks Creek and

TABLE 4

Downslope Movement, BC-6 Landslide

Oct. 1978

Monitoring Station	Horizontal Movement (m)	Vertical Change (m)	Downslope Trajectory $(m \cdot m^{-1})$	Monitoring Station	Horizontal Movement (m)	Vertical Change (m)	Downslope Trajectory $(m \cdot m^{-1})$
1C NC				4UD NC			
1S NC				4UE	12.20	- 0.82	.067
1N NC				5S	15.80	- 3.34	.211
2N	14.0	- 1.17	.083	5C	13.08	- 3.21	.245
2C NC				5N	14.20	- 1.22	.085
2S NC				6N	14.94	- 2.79	.186
3S NC				6C	11.63	- 1.48	.127
3C	13.97	- 2.31	.165	6S NC			
3N	15.87	- 1.29	.081	6UA	8.80	- 1.20	.136
4N	14.96	- 1.87	.125	6UB NC			
4C	18.06	- 5.0	.276	6UC NC			
4S NC				7S	15.61	- 3.33	.222
4DA NC				7C	20.35	- 6.82	.335
4DB	32.90	-10.38	.315	7N	15.31	- 5.46	.356
4DC NC				8N	13.12	- 3.70	.282
4UA NC				8C	13.75	- 3.64	.265
4UB	12.85	- 3.55	.276	8S	16.31	- 4.45	.272
4UC NC							

NC: Not Recovered

Mean gradient of landslide: 0.438 $m \cdot m^{-1}$

Erdman Brook is shown on Plate 9. It extends from a wetland at the outer edge of the burial-site plateau to the confluence with Buttermilk Creek. A comparison of profile geometry with Buttermilk Creek and the BC-6 alluvial fan is illustrated in Figure 8. The comparative profiles are plotted at the same scale and intersect Buttermilk Creek at the proper location within the reach.

The profile is convex-up with a mean gradient of 19.92 m km^{-1}. The Erdman Brook segment adjacent to the low-level waste-burial trenches has a less steep gradient of 12.46 m km^{-1} (see Plates 1 and 2). This pitches to the mean gradient downstream of the knickpoints. This gradient continues along the central part of the reach to approximately 150 m above the confluence of Quarry Creek. At this point it steepens to 41.27 m km^{-1} for some 250 m before reverting once again to the mean gradient. The gradient flattens and a narrow floodplain develops 400 m upstream of the confluence with Buttermilk Creek.

Bar-and-Channel Pattern - The basic channel pattern of Franks Creek is an entrenched meander system of several wavelengths, ranging from approximately 90 to 200 m, separated by short straight segments. The channel floor exhibits a well-developed pool-and riffle system. The tops of small gravel longitudinal bars constituting the riffles. The bar-to-bar spacing is 15-20 m. The bars occupy the complete channel width and may be overlapping in a downstream direction (Fig. 9a). In a few places, low fluvial terraces are preserved, but they are not common (Fig. 9d).

Undercutting of the steep valley walls is a constant occurrence at high-stage flow. This causes failure by slumping on the walls and mass wasting of the till (unit Tb_{1s}, Plate 1) down the slope and onto the channel bottom (Fig. 9b). The till is then transported as suspended sediment down and out of the reach by succeeding flood events. Heavy forest growth on the valley walls is also transported to the channel on slump blocks, where the large trees create log jams. This results in trapped bedload gravel in temporary storage behind the jams (Fig. 9c).

Cross-Profiles - Four cross-valley profiles were constructed using the 1961 topographic map at the scale 1 inch = 200 feet. Shown in Figure 10, they are: 1) Erdman Brook, at the security fence (also shown in Fig. 11); 2) Erdman Brook, above Lagoon Creek confluence (also see Fig. 9d); 3) Franks Creek, above Quarry Creek confluence; and 4) Buttermilk Creek, just above the BC-6 tributary. Also see Plate 1 for locations.

There is a marked change in Erdman Brook from a flat-bottomed valley (1) (Fig. 11) to the steep V-shape with no flood plain (2) (Fig. 10). This V-shape is maintained through the rest of the reach of Franks Creek (3) to the confluence with Buttermilk. The area from the knickpoints above the NYSGS gage, to 100 m below the gage, is a transitional

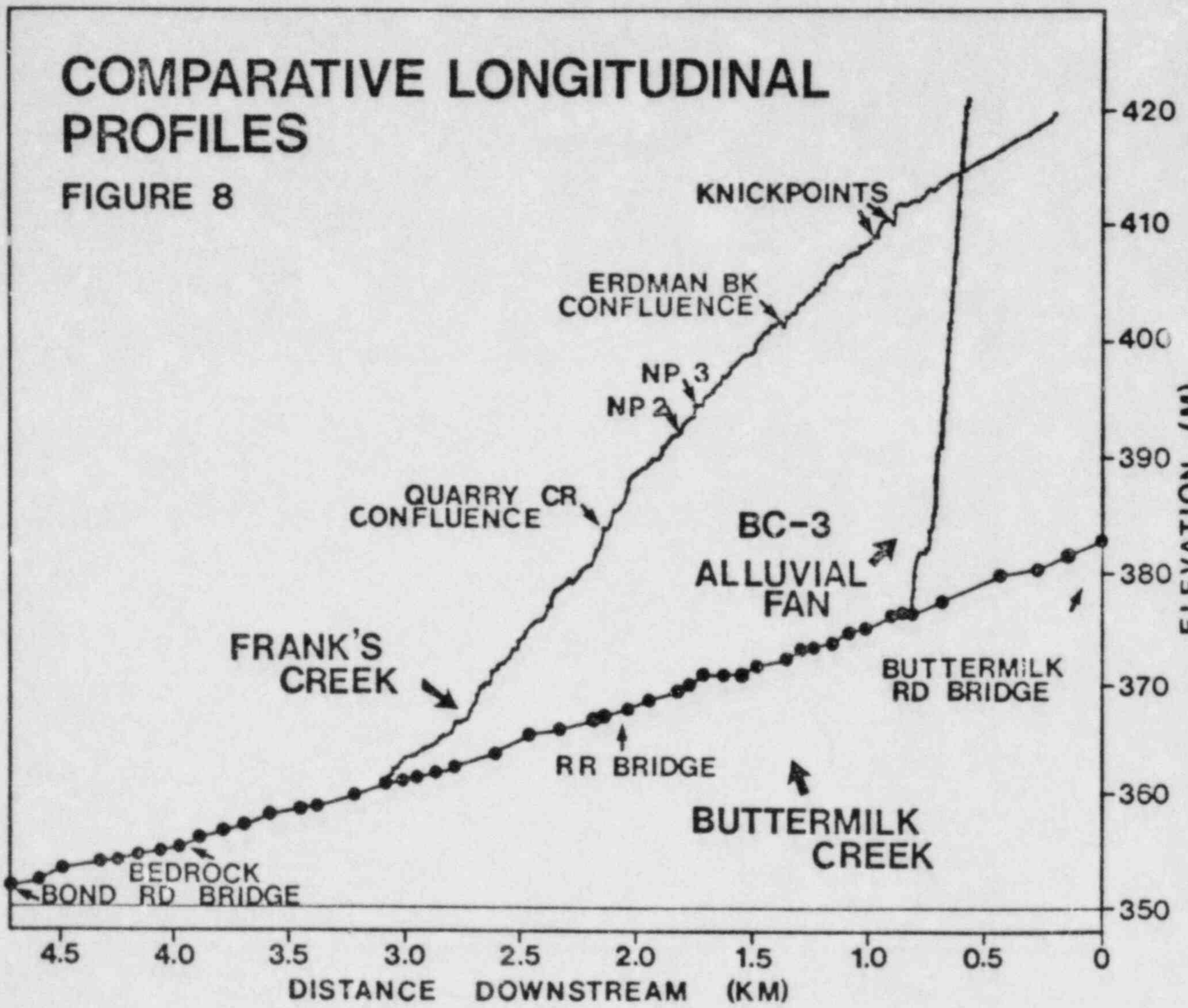


Figure 8. Comparative longitudinal profiles of Buttermilk Creek (mean gradient = 6.76 m km^{-1}), Franks Creek (19.92 m km^{-1}), and BC-3 alluvial fan (288.7 m km^{-1}).

Figure 9. Franks Creek/Erdman Brook geomorphic subenvironments.

A. Small longitudinal bars fill the channel and function as riffles in the pool-and-riffle sequence. Transit operator is on the high point of a bar. View is upstream.

B. Undercut slump block extending over and into the base-flow channel. View is downstream.

C. Log jam created by flood pileup of trees transported to the valley bottom by slumps. Rod person (arrow) is standing on gravel accumulated behind the jam. View is upstream.

D. Fluvial terraces preserved near the valley bottom of Erdman Brook. View is upstream.

TRIBUTARY VALLEY CROSS-SECTIONS

FIGURE 10

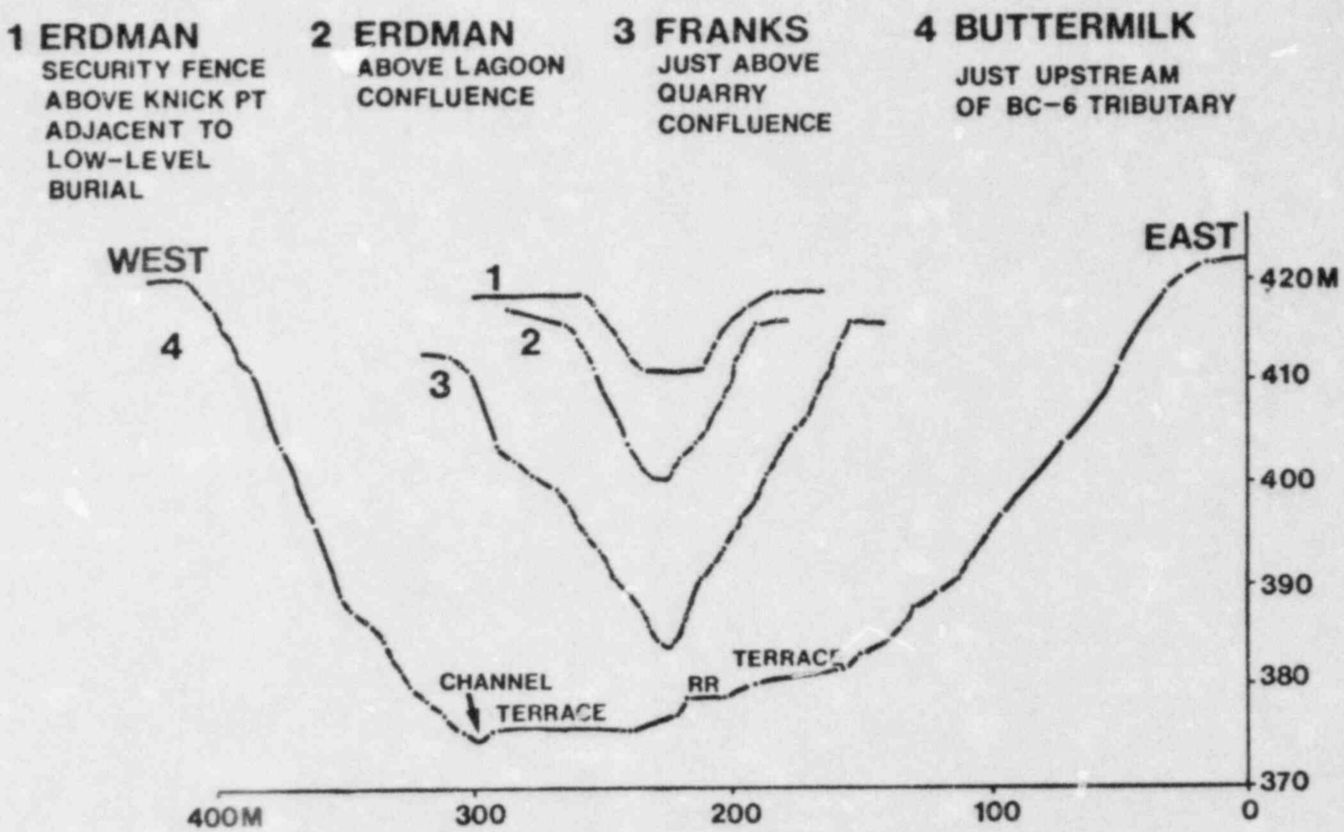


Figure 10. Constructed cross-sections of Erdman Brook (1,2), Franks Creek (3), and Buttermilk Creek (4).

Figure 11. Erdman Brook valley morphology. Area shown is at cross-section (1) (Fig. 10). Arrow points to the NFS security fence.

zone from the flat (1) to the V-shape (2). In the V-shaped zone, it appears that valley widening is proceeding by parallel retreat of slopes.

4.7 Drainage Basin Area

Drainage basin areas of Buttermilk Creek, Franks Creek and streams flowing into the NFS reservoirs are shown on Plates 1, 2, 3, and in Table 5. Franks Creek is further subdivided into a number of smaller basins shown on the Plates and Table 5. The boundaries were first determined by inspection of drainage divides on the largest scale map (Plates 1 and 3 respectively). Boundaries were field checked, particularly on the plateau site area, by one of us (L. Dunne) and by written and personal communication with W. Harding (USGS, Ithaca), L. Wagner (USGS, Albany), S. Potter (NYSGS, West Valley), and A. Bockelman (NFS). The areas were then determined by digital planimeter methods as discussed elsewhere (3.2).

Figure 12 is a simple, descriptive, stream-ordering diagram. This diagram is useful in determining flow paths, particularly of the Franks Creek tributaries. Table 5 illustrates that Quarry Creek is probably the master trunk stream, but that the longitudinal profile was run for Franks/Erdman. This was done because it is adjacent to the low-level waste burial trenches and it receives a large share of all north plateau runoff. Traditional names were used for the lower trunk (Franks) from the Quarry confluence to Buttermilk Creek.

4.8 Reservoir Sediment Volumes

Location maps for bottom profiles in the two NFS reservoirs are shown in Figure 13. Tabulations of cross-sectional areas of the profiles, amounts of fill, and percent reservoir volumes are given in Table 6. The reservoirs which are located in the Buttermilk fluvial system are illustrated on Plates 1 and 3.

The reservoirs are contained by earth dams constructed across separate tributary streams. Water accumulation began in 1963. The full stage for both is 412.4 m (1353 ft). A dredged channel connects the reservoirs allowing free flow and stage equilibrium between them. Flood discharge is released through a pipe beneath the north reservoir, down the tributary, and into Buttermilk Creek just south of the Buttermilk Hill Road bridge. Extreme flooding results in overflow across a wide sluiceway east of the south reservoir and directly into Buttermilk Creek. Stage height when the bottom profiles were obtained was 411.2 m and 411.0 m for the south and north reservoirs respectively. A beaver dam in the dredged channel produced this uneven stage.

Reservoir No. 1 (South) - The pre-reservoir valley cross-eections show a V-shaped form eroded in Lavery till, probably not unlike the present Franks Creek. Sedimentation from 1963-1980 has been by: 1) progradation of a delta at the south end of reservoir; 2) density under-

TABLE 5
Drainage Basin Areas

	m^2	km^2	ha
Buttermilk Creek		78.41	7841.5
Franks Creek Total		5.92	591.75
Lower Trunk			8.47
Middle Trunk			8.64
Upper Trunk			14.65
Outwash		1.35	135.29
Quarry		2.95	294.79
NP-1	217,184		21.72
NP-2	25,157		2.52
NP-3	112,072		11.21
Lagoon		0.53	53.03
Burial	47,839		4.78
Erdman		0.89	88.96
North Reservoir		4.36	435.82
South Reservoir		8.07	806.77

DRAINAGE ORDERING SCHEMATIC

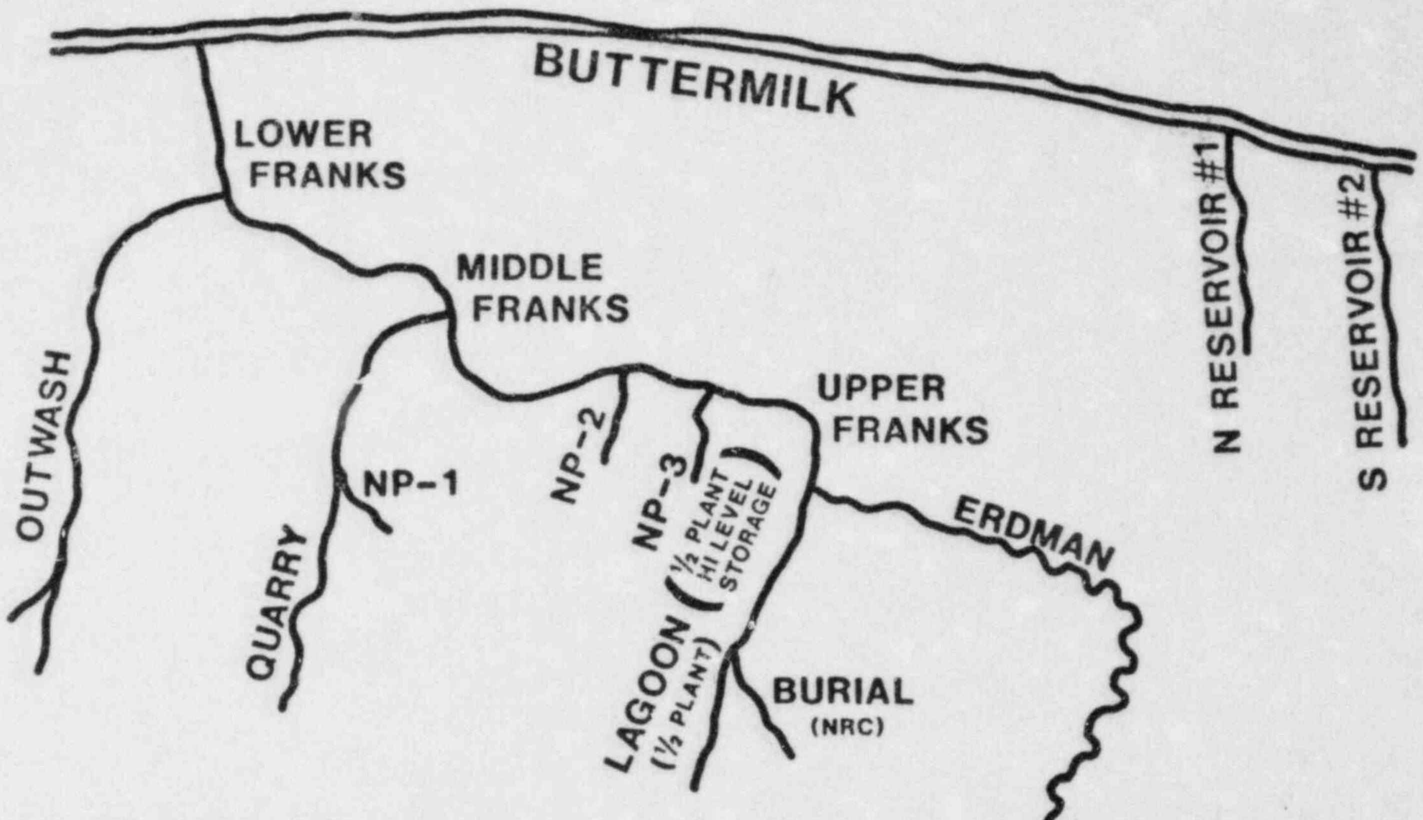
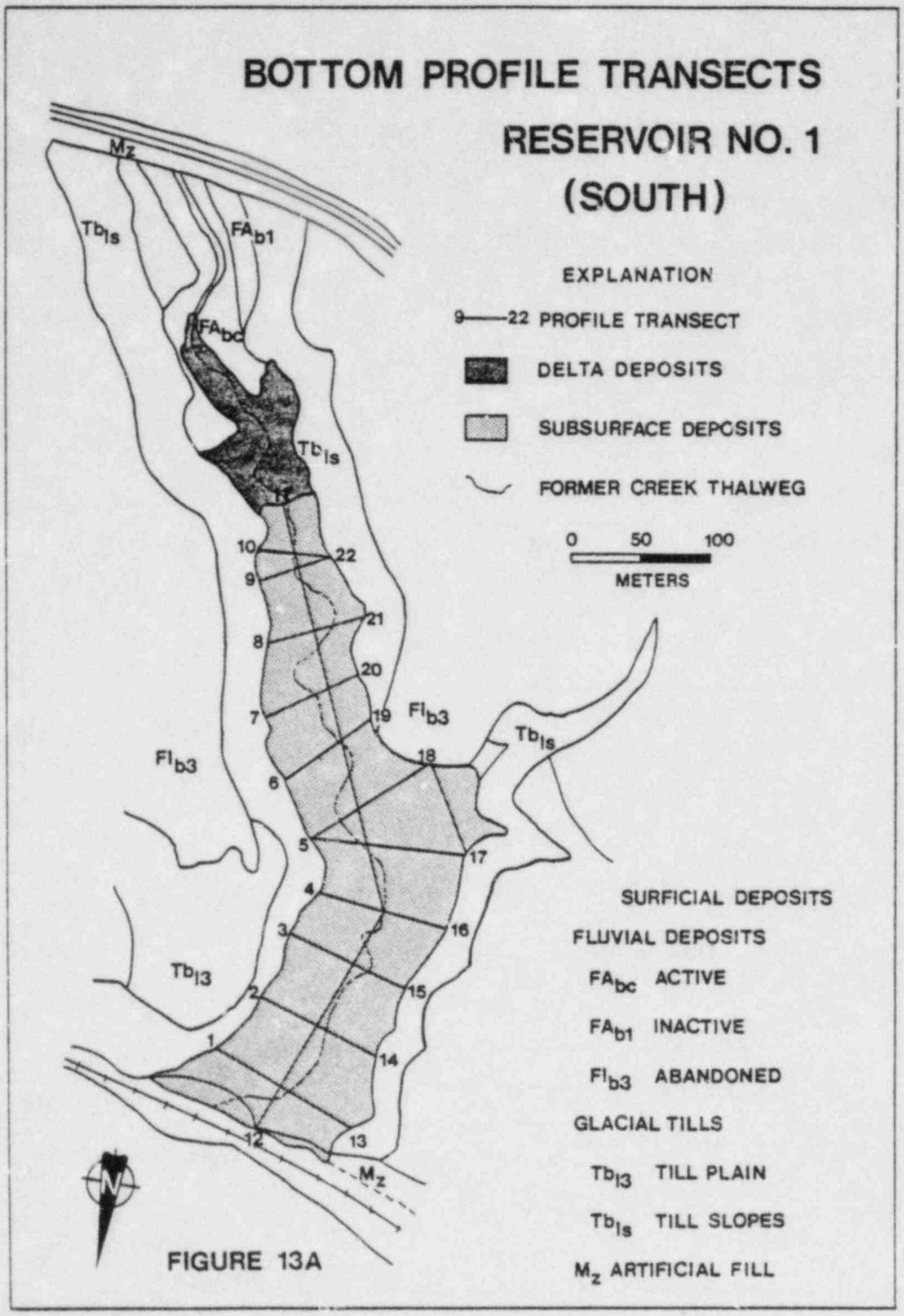
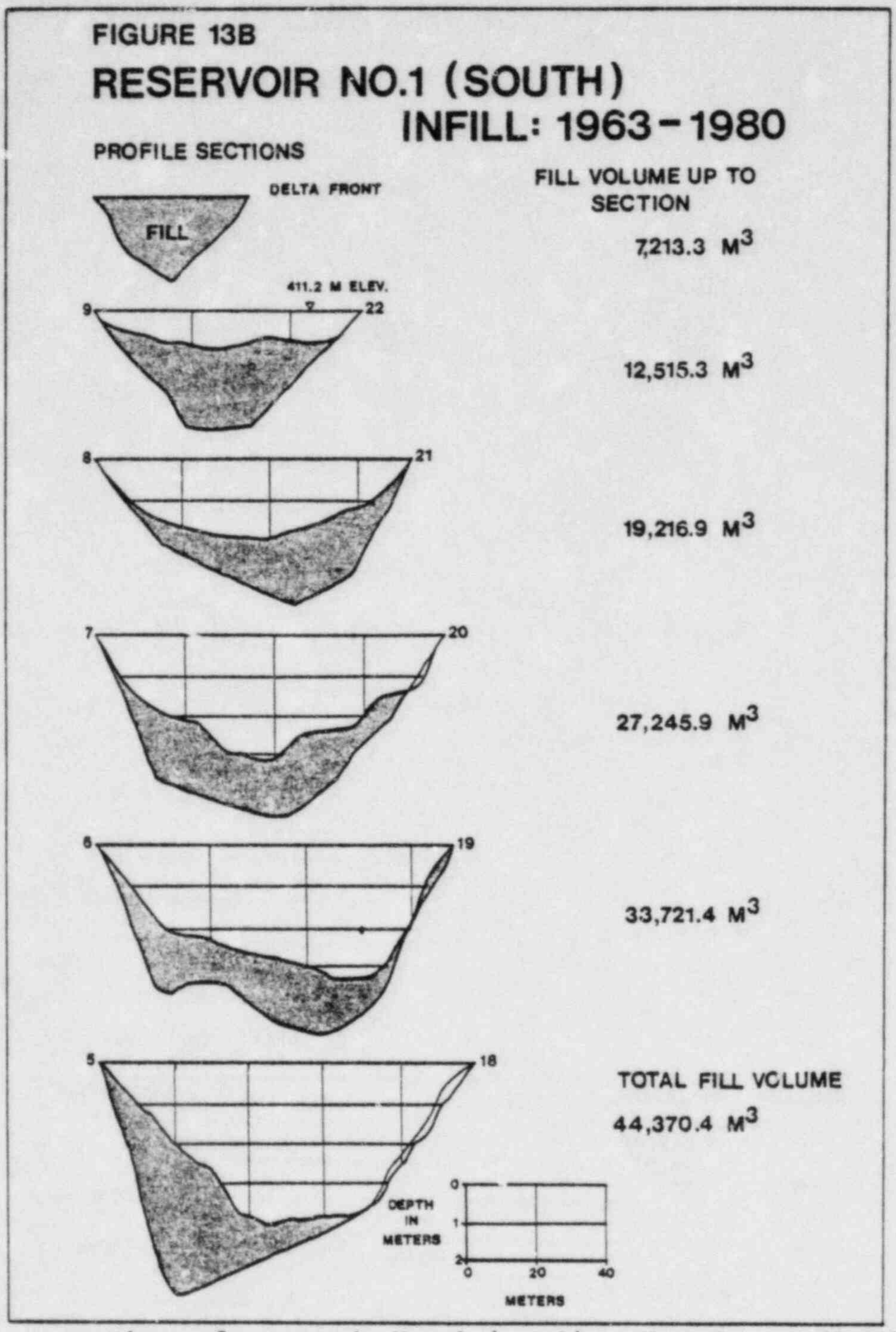


FIGURE 12

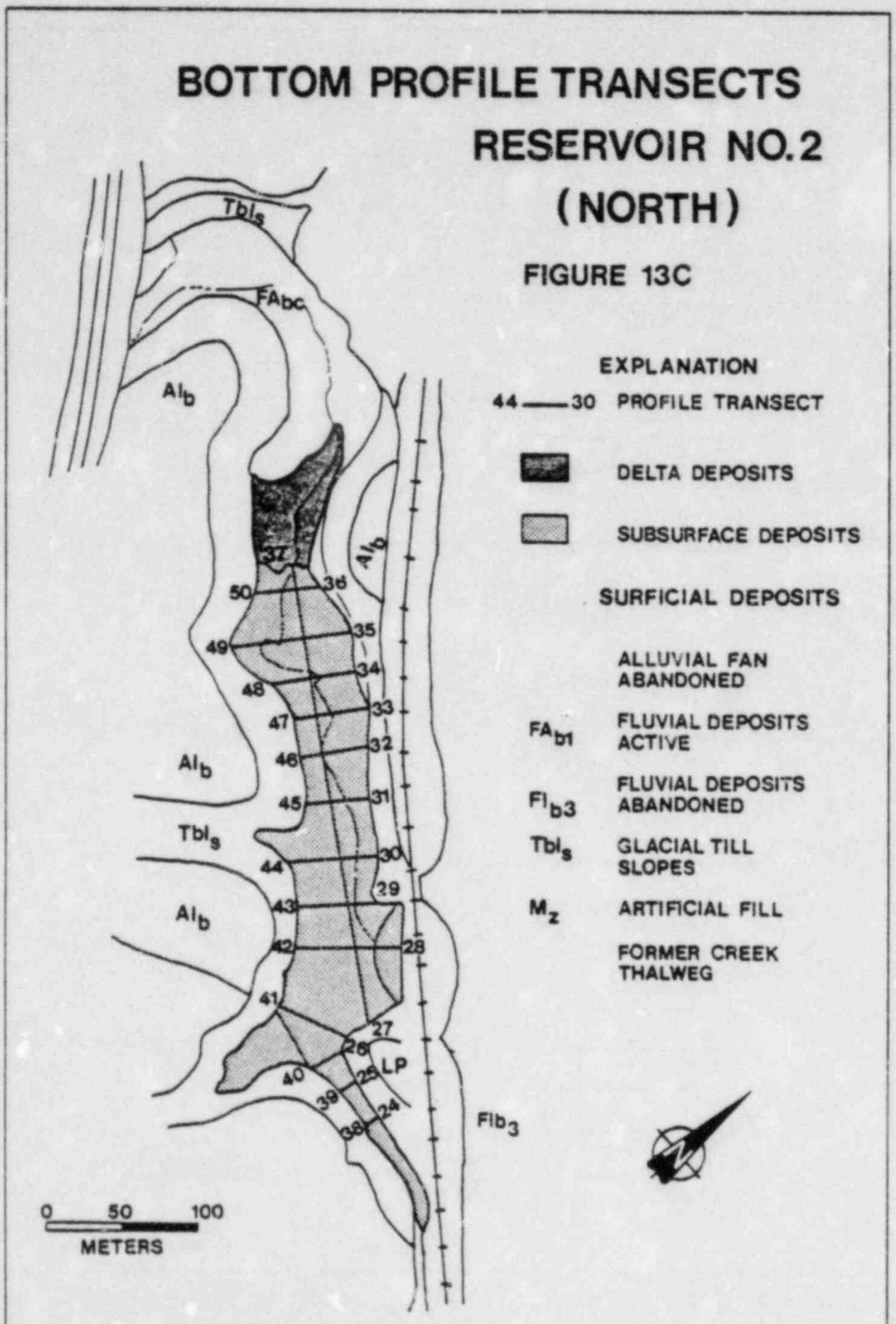
Drainage ordering schematic for the western tributaries of Buttermilk Creek.



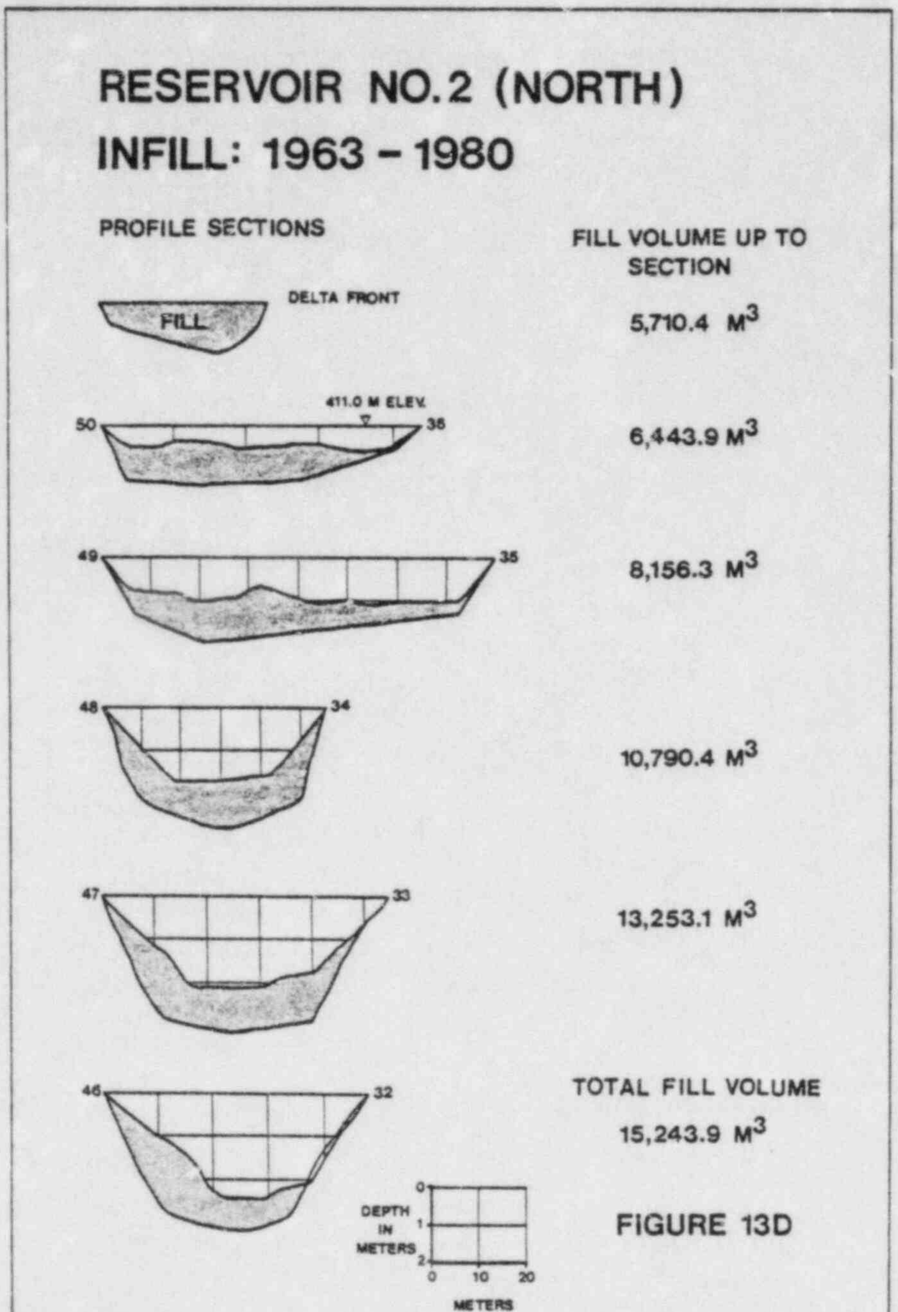
Map of reservoir No. 1 (south) showing bottom profile transects. Delta of inflowing tributary is at the top of the diagram (station 11); dam is at the bottom (station 12).



Cross-sections of reservoir No. 1 (south). Shaded area (fill) divides original section (1963), from measured section (1980). Grid pattern delineates the present reservoir. Section 8/21 to the delta front contains fluvially-derived sediment. Other infill is due to slumping.



Map of reservoir No 2 (north), showing bottom profile transects. Delta of the inflowing tributary is at the top (station 37), dam is at the lower right (station 28).



Cross-sections of reservoir No. 2 (north). The flat floor of the reservoir from the delta front out to profile 46/32 is indicative of density underflow sedimentation, although evidence for slumping is present on the last three profiles.

TABLE 6a

Reservoir Volumes

South Reservoir, No. 1

Delta plain	Surface area	Volume (m^3)
	9757 m^2 (.96 ha)	7213.35

Transects	Cross sectional area (m^2) Fill	H_2O	% Fill	Longit. distance (m)	Volume m^3 Fill	H_2O	% Fill	Total Fill
Delta front	100.30		100.0					
				47	5301.99	1718.84	75.5	12515.34
9/22	125.32	73.14	63.1					
				51	6701.65	6887.73	49.3	19216.98
8/21	137.49	196.97	41.1					
				53	8028.93	13334.42	37.6	27245.91
7/20	165.48	306.22	35.1					
				41	6475.46	13115.56	33.1	33721.37
6/19	150.39	333.56	31.1					
				59	10649.02	24405.87	30.4	44370.39
5/18	210.59	493.75	29.9					

Present Reservoir H_2O Volume 361,658 m^3
Area 46,049 m^2 (4.6 ha)

TABLE 6b

Reservoir Volumes

North Reservoir, No. 2

	Surface area	Volume (m^3)
Delta plain	6247 m^2 (.62 ha)	5710.4

Tran-sects	Cross sectional area (m^2) Fill	H_2O	% Fill	Longit. distance (m)	Volume m^3 Fill	H_2O	% Fill	Total Fill
Delta front	56.42		100.0					
				13	733.56	231.98	76.0	6443.96
50/36	56.44	35.69	61.3					
				21	1712.39	1805.32	48.7	8156.33
49/35	106.65	136.25	43.9					
				25	2634.1	3461.16	43.2	10790.43
48/34	104.08	140.65	42.5					
				25	2462.67	3661.17	40.2	13253.10
47/33	92.93	152.25	37.9					
				25	1990.8	3687.06	35.1	15243.89
46/32	66.33	142.72	31.7					

Present Reservoir H_2O Volume — 55,698 m^3

Area — 23009 m^2 (2.3 ha)

flow of fine-grained material down the delta front and prodelta slope onto the reservoir floor; and 3) slumping and debris flow of the submerged valley walls down the side slopes.

Inspection of Figure 13a indicated that the delta plain has prograded about 140 m into the reservoir. The cross-profiles near the delta front (8/21 and 9/22, Fig. 13b) show a flat to gently concave-up reservoir floor. Cross-profiles further away show a more U-shaped section with terraces and uneven filling. The flat profiles probably reflect fill by density underflow, and the others, fill by a combination of slumping and underflow. The total fill values (Table 6a) calculated from profiles closest to the delta better indicate sedimentary infill of material delivered by fluvial processes.

Reservoir No. 2 (North) - The north reservoir is about one-half the surface area, but only 15 percent of the volume, of the south reservoir as a result of differences in depth and valley form (Fig. 13c, d). The pre-reservoir valley, where dammed, was not incised as deeply and had not developed an extreme V-shaped cross-section. The drainage basin for this reservoir is about one-half the size of the basin area of the south reservoir (Table 5).

The delta plain has prograded approximately 90 m into the reservoir. The cross-profiles show a flat floor adjacent to the delta front similar to the south reservoir. Side wall bulges, presumably slumps, are not as pronounced but are present (46/32, Fig. 13d).

4.9. Buttermilk Stage and Discharge

Stage-height records are available from July 18, 1980 onward for this phase of the study. The stage recorder installed at Thomas Corners Road bridge by the NYSGS in August 1978 was removed by Hurricane Fredric flooding in September 1979 and was reinstalled on July 18, 1980.

Selected stage-height records for the summer and fall of 1980 are shown in Figure 14. Velocity-area information and suspended sediment samples collected during the summer and fall period, and shown on the stage-discharge, suspended sediment concentration-discharge plot (Fig. 15 and Table 7). Regression lines were not computed for these data because there are too few readings to give a meaningful result. However, the stage-discharge plot can be used in a non-statistical, but geologically meaningful way to evaluate stage-heights for which there are no accompanying discharge data sets.

Flood Events - The hydrographs of three flood events are illustrated in Figure 14 and include a relatively low-discharge event (Oct. 12), a moderate event (Aug. 11), and a high-discharge event (Oct. 25-26). The moderate and high events show the "spikey" nature of the flooding as described by Boothroyd and others (1979), particularly the rapid rise in stage to peak flow in a matter of hours.

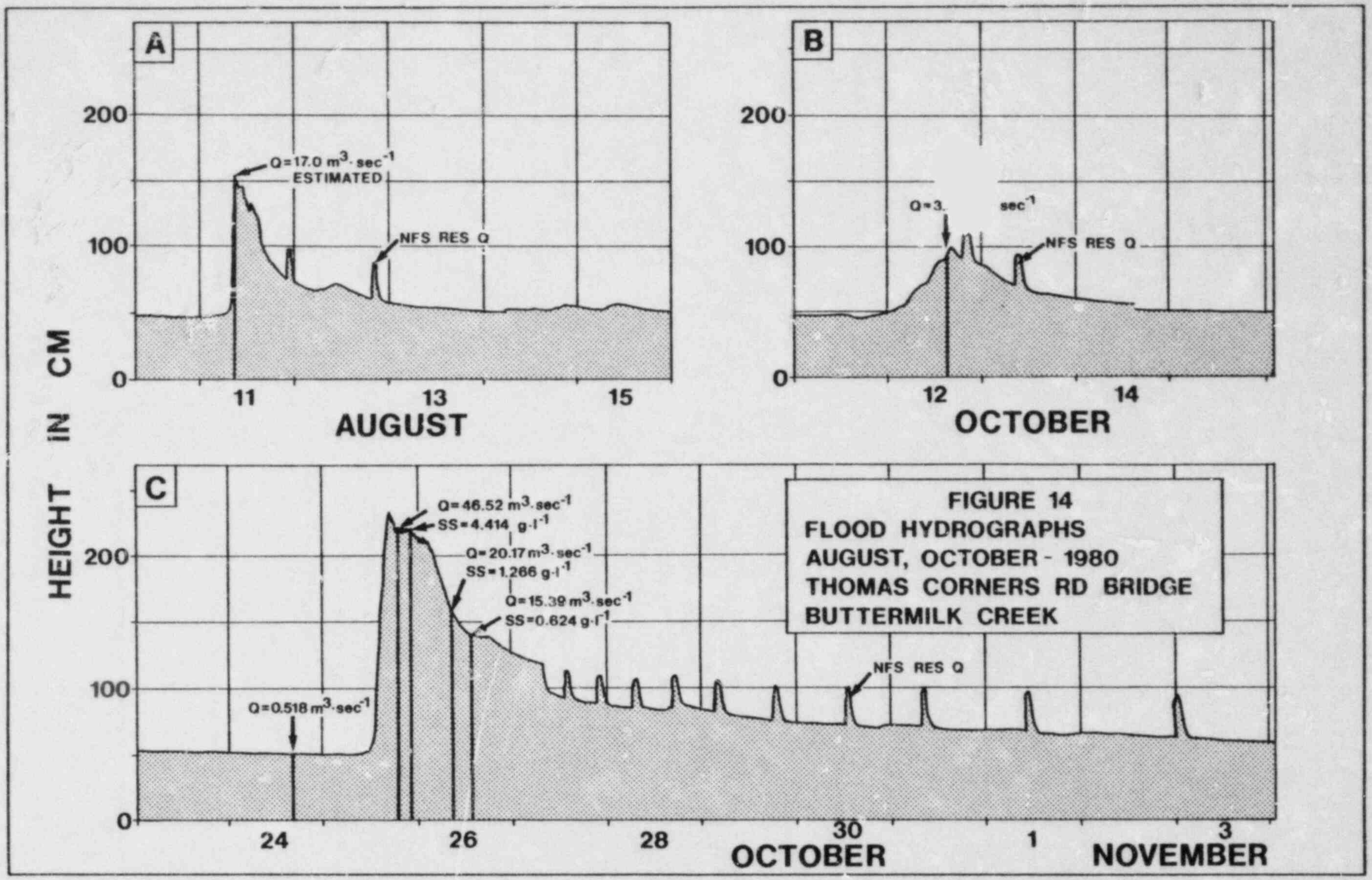


FIGURE 14
FLOOD HYDROGRAPHS
AUGUST, OCTOBER - 1980
THOMAS CORNERS RD BRIDGE
BUTTERMILK CREEK

Figure 14. Stage-height records, Thomas Corners Road bridge (NYSGS), 1980.

A. August 11, 1980 flood hydrograph. A moderate event with peak flow estimated at 17.0 m^3sec^{-1}. Movement of small clasts occurred on bar complex 4-6.

B. October 12, 1980 flood hydrograph. A small event with a measured peak flow of 3.57 m^3sec^{-1}.

C. October 25-26, 1980. A large flood event with peak flow estimated at 60 m^3sec^{-1} (the first high spike). Times of discharge measurements and suspended sediment sampling are shown.

Stage/discharge and suspended sediment concentration, Thomas Corners Road bridge, 1980. Consult Table 7 for details.

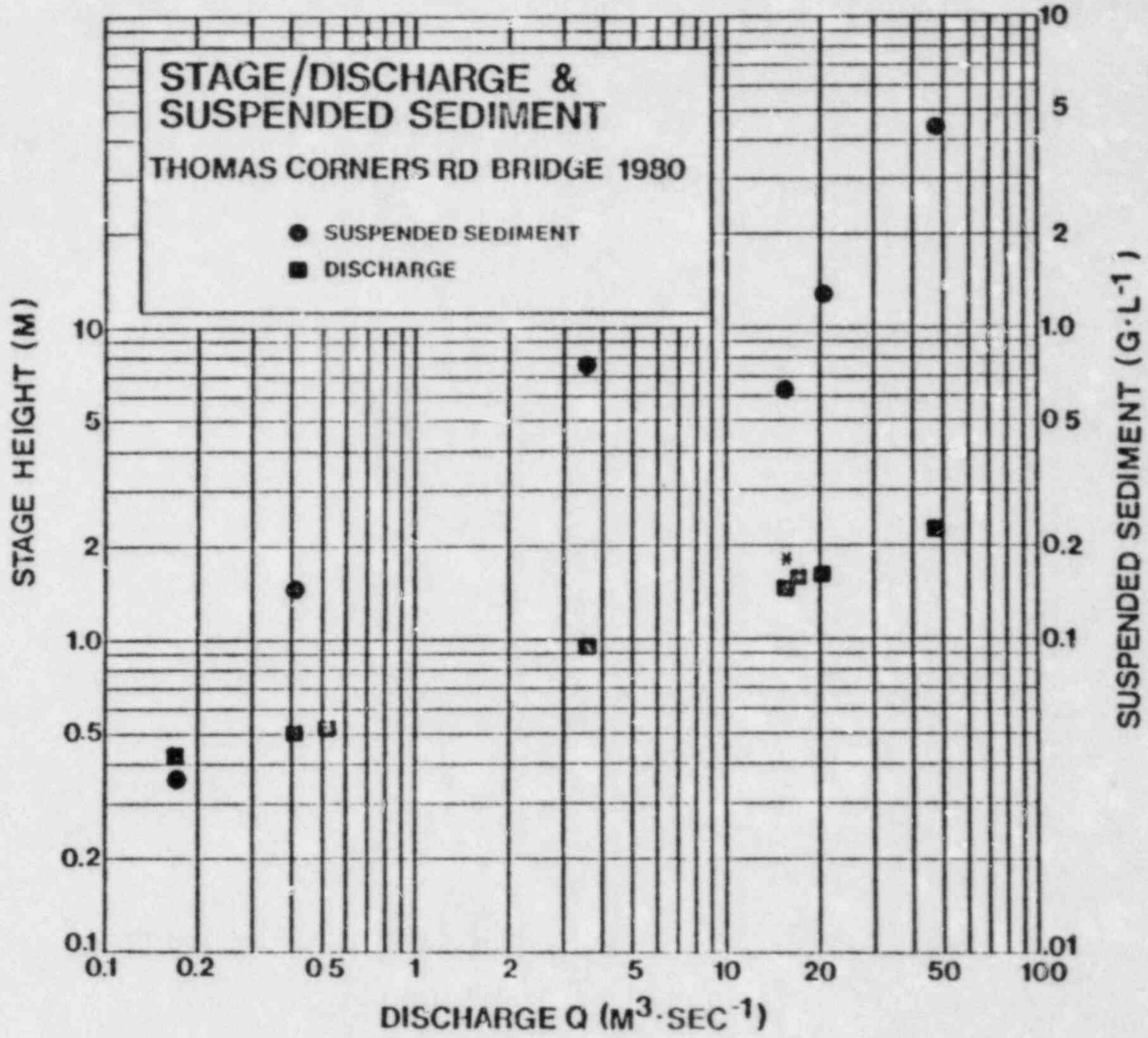


FIGURE 15

TABLE 7

Stage, Discharge, Suspended Sediment

Thomas Corners Road Bridge

Date (1980)	Time	Stage Height cm	Discharge $m^3 \cdot sec^{-1}$	Suspended Sediment $g \cdot liter^{-1}$	Remarks
July 18	16:15	042	0.175/0.169	0.035	Under bridge/ 22 m upstream
July 22	14:54	050	0.410	0.142	
Aug. 1	12:30	042		0.046	
Aug. 11	8:45	158	*17.0		* Estimated
Oct. 12	13:45	094	3.57	0.752	
Oct. 24	16:15	051	0.518		550 Class
Oct. 25	18:14	224.5	46.52		From Bridge
	21:38	223.5		4.414	From Bridge
Oct. 26	7:11	160	20.17	1.266	From Bridge
	12:08	142.5	15.39	0.624	From Bridge

A review of the USGS stage-discharge data and rating curve (USGS, 1968; in Boo royd and others, 1979, Fig. 17) reveals that the October 25-26 flood is within the range of the yearly maximum discharge event as determined by the USGS for 1962-1968. Direct comparisons of stage cannot be made between NYSGS records and the USGS data because the no-flow, stage-height calibration has not been determined for the NYSGS gage.

The Hurricane Fredric flooding that carried away the stage recorder was probably equal to, or greater than, the indirect measurement of 110 m^3sec^{-1} determined by the USGS (1968) for a large flood in 1967. Flood levels, as determined by debris levels in trees, is shown in Figure 16 for three, bar-complex 4-6 transects. Also shown are the base-flow, water-surface elevations and the flood flow of October 25-26, 1980.

Suspended Sediment - Suspended sediment concentration at a given discharge increases rapidly with increase in discharge during a flood event, peaks early, and then falls off more rapidly than a proportional decrease in discharge. This relationship is common to small streams with rapid runoff and little infiltration (Gregory and Walling, 1973). Three suspended sediment samples were obtained during the October 25-26 event. One was taken just past peak stage and the other two during falling stage (Fig. 14c, 15; Table 7). Note the rapid decline in sediment concentration during the falling stage. Compare the last value to the much lower discharge, but similar sediment concentration, at the peak of the October 12 event.

NFS Reservoir 'Slug' Discharge - The sharp spikes on the hydrograph of about one-hour duration represent controlled releases from the NFS reservoirs. The gate at Dam No. 2 (north) opens automatically when the reservoir stage rises 30 cm (1 ft) above 412.4 m (1353 ft), which is the full level. Discharge is released through a 91 cm (36 in) pipe at a rate of 5.66 m^3sec^{-1} (200 cfs). This continues until the water level in the reservoirs is lowered enough to allow the gate to close. Reservoir information was furnished by P. Byrne, NFS (personal communication, 1981).

A check of the reservoir release hydrograph after the October 25-26 flood (Fig. 14c) indicates that when using the stage height of a 'slug' peak, occurring during otherwise low flow, and reading the equivalent discharge on Figure 15, good agreement is found with the known reservoir discharge. This provides a crude calibration of the stage-discharge curve.

4.10 Clast Movement

Clast movement stations were established at transects 5, 11 and 16 of bar complex 6 as described in the procedures section. Plots of the marked clasts are given on Plate 10 and precise locations are tabulated in Appendix E. Photographs of selected localities are shown

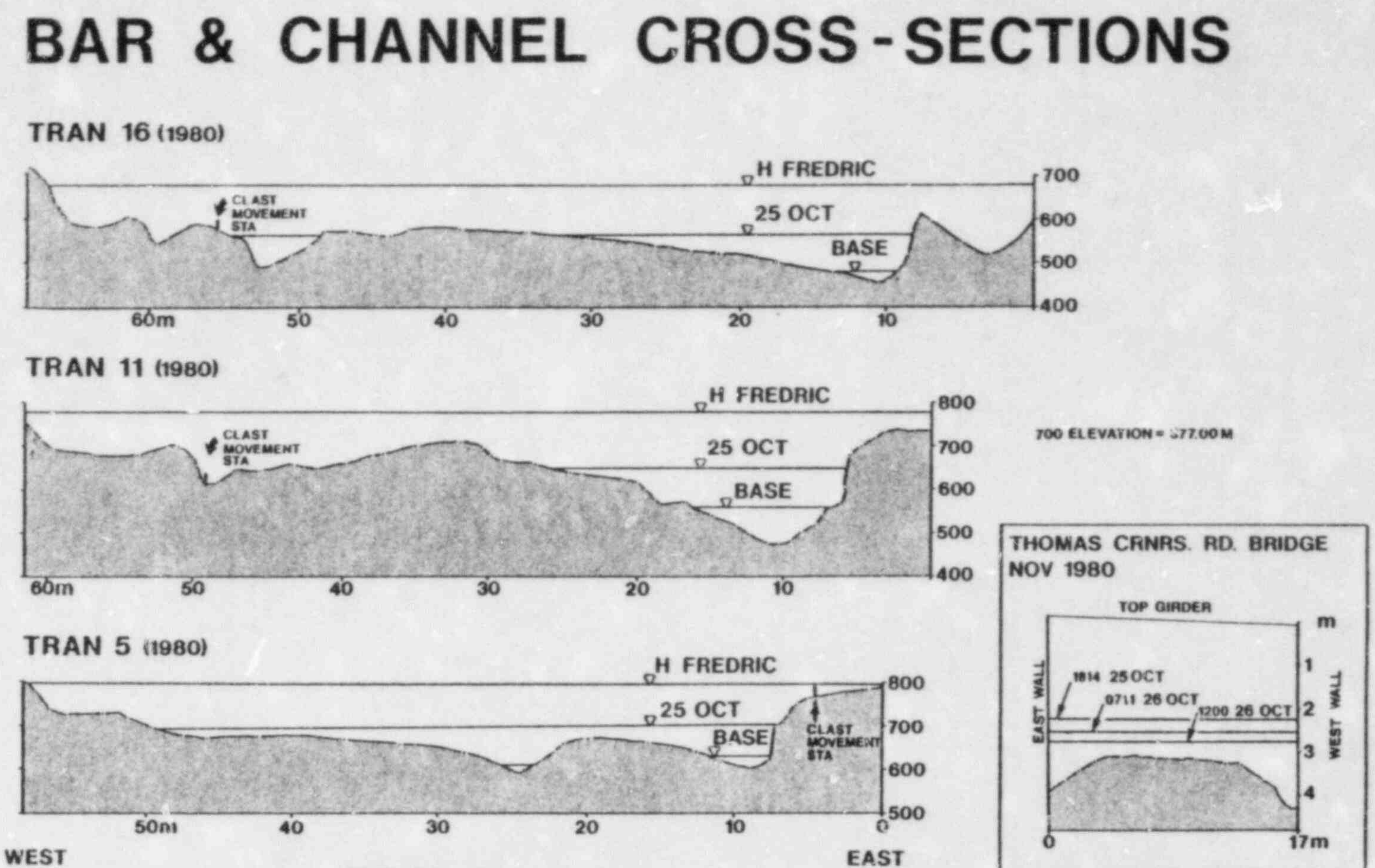


FIGURE 16 Bar and channel cross-sections, bar complex 4-6. Sections were constructed at the locations of the clast movement stations utilizing topography from the bar map (Plate 4). Water-surface elevations are indicated for base-flow, the October 25-26, 1980 flood event, and Hurricane Fredric flooding. Also includel is the flood discharge measuring station at Thomas Corners Road bridge.

as: Figure 17, east side of transect 5; Figure 18, east side of transect 16; and Appendix F, details of the east side of transect 5. A clast movement station marked during 1978 (Fig. 19a; Fig. 14, Boothroyd and others, 1979) was relocated and remarked (Fig. 19b) and one moved clast found (Fig. 19c). Please refer to Figure 3, the morphological change maps of bar complex 4-6; Plate 4, the topographic map; and Figure 16, the bar cross-sections; for details of geometry.

Auguts 11, 1980 Event - Summer flooding after a heavy rain resulted in a stage height peak of 1.58 meters (Fig. 14a) and an estimated discharge of 17.0 m^3sec^{-1} (Fig. 15). Depth of flow over the submerged portions of the transects was not recorded.

Clast movement was confined to bar edges adjacent to the base-flow channels and involved mainly smaller clasts (yellow line markers), although three medium-sized and one large clast did move on transects 5 and 16. The largest clast to move (transect 5) measured 33 cm L-axis and slid about one clast- width forward. The medium-sized clasts on transect 16 moved 802 and 1078 cm respectively. The small clasts on transect 16 recorded the greatest movement, up to 2676 cm away perpendicular to the transect line. This was probably because flow depth was greater over the gently sloping bar surface than at transect 5. The size range of the smaller clasts that moved was 1.5-15 cm L-axis.

October 25-26, 1980 Event - Rapid flooding during and after an intense rainfall resulted in a stage-height peak of 2.39 m, a measured discharge of 46.52 m^3sec^{-1} (after the peak), and an estimated peak discharge of approximately 60 m^3sec^{-1} (Fig. 14c, 15). Most of transect 5 was submerged and maximum depth over the critical movement area was 40-60 cm. The sloping surface of transect 16 was submerged to a maximum depth of 85 cm.

Movement of large clasts at transect 5 was confined to the eastern high-bar surfaces and edges shown in Fig. 17a. The largest clast moved had a L-axis of 40 cm and it traveled 428 cm. This movement is significantly different from that recorded for August 11. Figure 17b shows movement trajectories for some of the large-and medium-sized clasts. The yellow marker line was obliterated in this area and only a few smaller clasts recovered. Maximum movement recorded was 2138 cm.

Transect 16 movement was greater because of greater depth of submergence. All clasts were moved from a 6-meter wide area adjacent to the base-flow channel. No clasts were recovered. They could have been moved downstream into the channel, flipped over so that the paint did not show, have been scoured clean of paint, or have been buried. Along the transect, in areas of shallower water, medium-sized clasts moved a maximum of 3168 cm. Figure 18 shows this part of the transect before movement and trajectories of moved clasts are indicated.

17A

Clast movement station, transect 5, bar complex 4-6. Looking east toward the high bar where most movement occurred during the August and October flood events (area shown in box). Marked line is shown by tape; transect 5 stake by arrow. A small base-flow channel runs through the center. Compare with Plate 4 and Figure 16.

Close-up of part of boxed area in A. Large marked clasts green) are light gray, medium clasts (blue) dark gray. Note the marked line (yellow) and white. Selected movement trajectories are shown. View is downstream and before movement occurred. Scale is 30 cm.

Figure 18. Clast movement station, transect 16, bar complex 4-6. The part of the line shown is on the shoulder of the bar where maximum measured movement occurred on October 25-26, 1980. Markings as in Figure 17; view is downstream, before movement occurred. Selected trajectories are shown. Scale is 30 cm.

9A 1978 clast movement station (transect 8-9) recovered in 1980. View in 1978. Note the tightly-grouped, imbricated clasts (outlined), and the location of clast 49 (arrow) (from Boothroyd and others, 1979), Fig. 14). Downstream is to the left.

9B View in 1980. The tight grouping (outlined) is visible just to the upper left of the scale. A sand and silt drape has partially buried the clasts. Clast 49 is missing.

19C Clast 49 (arrow) relocated downstream of transect 11, on the high point of a new transverse bar (see Fig. 3 and Plate 4 for location). Downstream is to the left. Scale is 30 cm.

Hurricane Fredric Event (Sept. 1979) - Intense rainfall associated with Fredric resulted in a flood discharge estimated to be at least as great as the 1967 peak of 110 m^3sec^{-1} (USGS, 1968). Flow depths over bar-complex 4-6 transects 5, 11 and 16 are shown in Figure 16, which are bar cross-sections. Maximum depth over the highest bar surfaces, as measured by debris levels in trees, was 70-120 cm.

Large volumes of gravel were transported and the geometry of the bars was greatly rearranged as documented by bar mapping (Plate 4) and morphological change diagrams (Fig.3). Most of the clasts marked at stations during the Phase I study were not recovered. The exception was on top of the large transverse bar between transects 7 and 8 as illustrated in Figure 19a,b. Flood flow plucked isolated clasts from the station but did not move the tighter-packed, well-imbricated clasts. Declining flow then deposited a sand and silt drape (Fig. 19b). One of the moved clasts was found on the bar top of a new transverse bar 63 m downstream (Fig. 19c). The clast followed a path directly downstream which was skewed from the direction of bar slipface migration. It was deposited on the highest point of a newly-formed bar where a channel had existed in 1978.

4.11 Buttermilk Valley Sediment Volume

The measurements for volume removed from Buttermilk valley and the Franks Creek/Erdman Brook tributary system are shown in Table 8. The Buttermilk Creek value was derived by measuring the difference from the plateau surface to the channel bottom of the Creek. Tributary valleys were not measured. The Franks Creek/Erdman Brook value was also derived by measuring from the plateau surface to the creek bottom. The upper reach of Erdman, upstream of the railroad tracks, was omitted from the calculation.

The volume of sediment presently in low terraces was derived in a similar manner. Three thicknesses were calculated because of difficulty in measuring an average upper surface of terraces and bars to the accuracy needed for volume calculation. This calculation was done in order to estimate the amount of material, mostly gravel, subject to channel sweep and reincorporation into the active bar system.

TABLE 8

Buttermilk Valley Sediment Volume

Buttermilk Creek	
Total Volume	65,923,331 m^3
Low Terraces	
Base flow - 3 m elevation	1,706,964
0.5 m - 3 m	1,422,470
1.0 m - 3 m	1,137,976
Franks Creek/Erdman Brook	
Total Volume	4,220,274 m^3

5.0 DISCUSSION

5.1 Bar and Channel Geometry

Bar Migration - Changes to bar and channel geometry at bar complex 4-6 were to a great extent the result of migration of large transverse bars in equilibrium with very large floods, in this case the Hurricane Fredric event. The upper transverse bar (BC-4) attempted to migrate forward but the east-side slipface encountered the debris pile and terrace at the kink in the channel (Fig. 3a). The intense turbulence created by this situation caused rapid erosion and removal of terrace gravel. This resulted in formation of a wider bend in the channel (Fig. 3b). The gravel was redistributed onto bars further downstream, effectively recycling the low-active terrace material.

The difference in hydraulic head laterally across the surface of BC-4 with greater head on the west, caused more effective transport of material from the west side of the bar (areas 2, 3; Fig. 3c). The complete bar form migrated downstream approximately 60 m by a combination of stoss-side accumulation (Fig. 4) and bar slipface migration (Fig. 20a). An erosional channel developed where the two bar elements split into different paths (area 2; Fig. 3c). Additions of east side terrace gravel resulted in the vertical accretion and slipface migration of smaller transverse bars on the downstream part of the complex (BC-5).

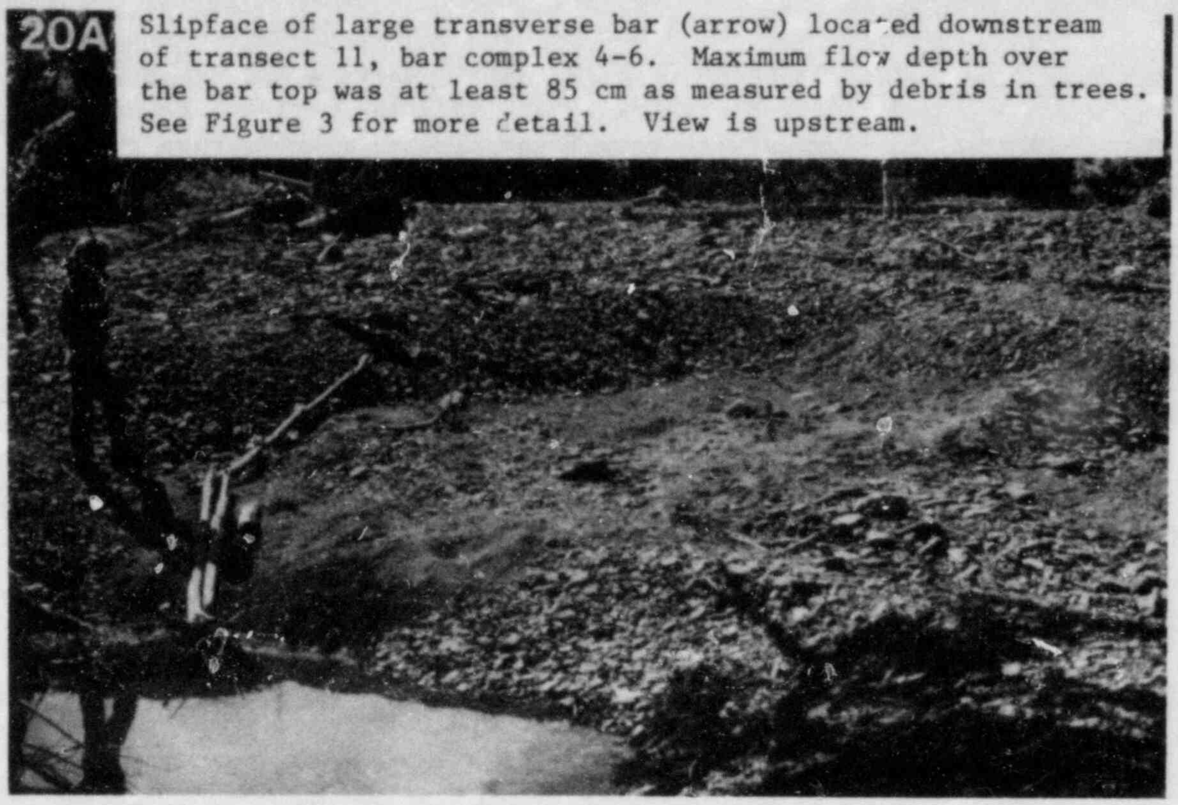
Terraces and Chutes - In addition to removal of terrace material and recycling it back to active bars, active bar gravel was deposited up on the low-active terraces as longitudinal bars during Hurricane Fredric (Fig. 20b). At bar complex 4-6, unvegetated chutes adjacent to active bars were filled and excess gravel deposited on the west-side terrace (area 7, Fig. 3c). Higher elevation chutes on the terraces were activated during peak flooding and gravel longitudinal bars accumlated in them (east side, area 7, Fig. 3c).

Gravel Budget, BC 4-6 - The gross gravel budget for bar complex 4-6 (Table 2) shows a net deficit of about 1160 m^3. More gravel was eroded from terraces and bars than was deposited within the complex. This is a crude estimate and does not represent a precise measurement of the differences between the 1978 and 1980 topographic maps. However, superimposition of the two maps delineates areas of erosion, deposition, no change, and magnitude of elevation difference. Volume changes were determined by planimeter.

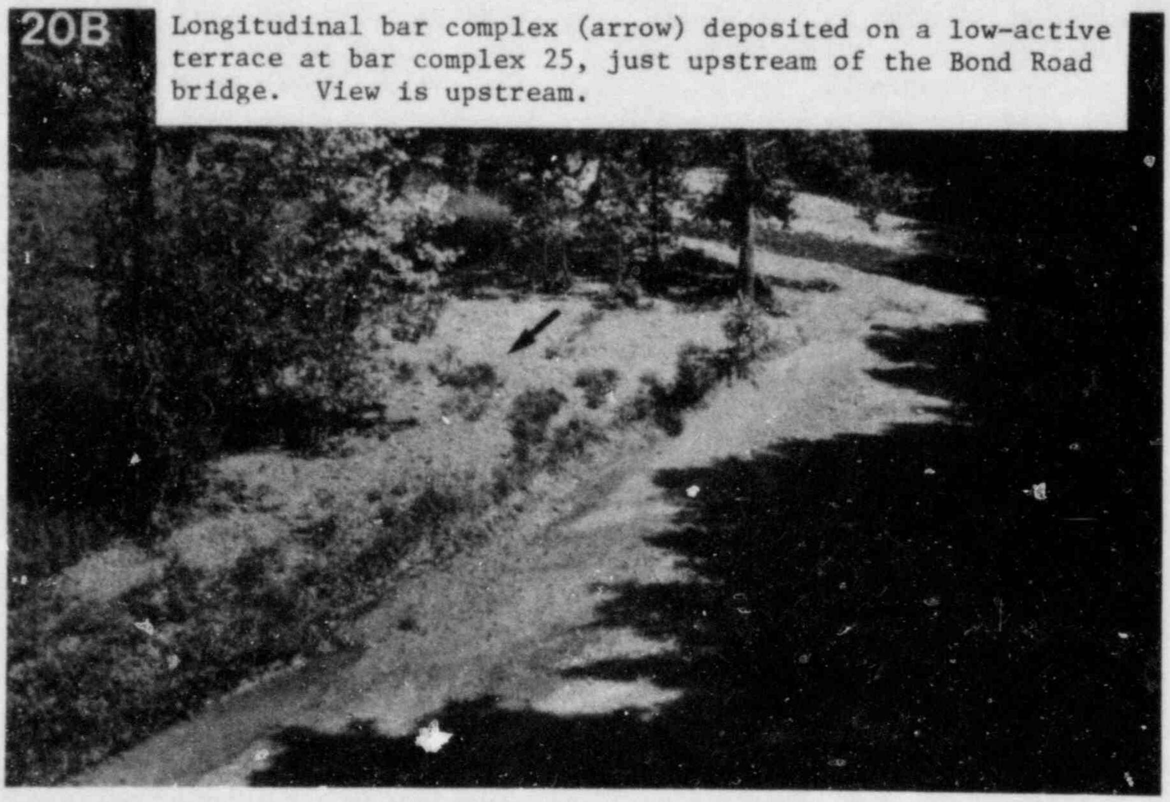
The supposition is that some of the gravel deficit was redeposited within the bar complex 4-6 area, but that the remainder was transported to the next bar complex downstream. Inspection of 1978 photographs of bar complex 6 and visual comparison with the present (summer, 1980) suggests that vertical accretion has occurred.

5.2 Discharge Events and Gravel Transport

Clast Movement - The August 11 flood was probably the threshold event for initiation of movement of medium-sized clasts on the lower bar



20A Slipface of large transverse bar (arrow) located downstream of transect 11, bar complex 4-6. Maximum flow depth over the bar top was at least 85 cm as measured by debris in trees. See Figure 3 for more detail. View is upstream.



20B Longitudinal bar complex (arrow) deposited on a low-active terrace at bar complex 25, just upstream of the Bond Road bridge. View is upstream.

Figure 20. Hurricane Fredric bedload gravel transport.

surfaces. An event of this discharge (9.5 m^3sec^{-1}, estimated) (Fig. 15) occurs several times a year based on the USGS (1968) data (Boothroyd and others, 1979; Fig. 17).

The October 25-26 event (46.52 m^3sec^{-1} measured: 60 m^3sec^{-1} estimated) moved some large clasts on bar edges and shoulders an average of 3 m (Fig. 17,18; Appendix E). This event may be considered to be just above the threshold of movement for large clasts, although not all of them moved. A flood of this discharge falls in the range of events with a one-year recurrence interval (USGS, 1968).

Indirect Measurement - It was impossible to get onto the bar during the flood-peak, high-current velocity nor to observe the flood peak because it occurred at night, no direct velocity-area measurements were made at the clast movements stations. It is possible to calculate bottom shear stress using the known depth of water over the clasts, an estimated water-surface slope, and the well-known DuBoys equation:

$$\Gamma = pds$$

where Γ is boundary shear stress (kg m^{-2}), p the density of the fluid (H_2O), d is the depth of water, and s the water-surface slope. Baker and Ritter (1975) present a graph for estimating threshold of movement of gravel-sized particles knowing the boundary shear stress (or vice versa). This calculation was not done because we have direct measurement of moved clasts at a given creek discharge and can calculate transport rates versus discharge. However, the indirect calculation can be done in the future as a check on other methods.

Gravel Transport Rates - The following calculations use the bar volume changes (Table 2), distances of clast movement (Appendix E), and estimated flood frequency and recurrence interval. All calculations should be regarded as preliminary, open to interpretation, and in need of future refinement.

Transverse bar migration results in the following gravel movement (amount and distance):

850 m^3 moved 60 m (.06 km)

If the Hurricane Fredric event has a 10 year recurrence interval, then movement per year is:

$$\frac{.06 \text{ km per event}}{10} = .006 \text{ km yr}^{-1}$$

The Buttermilk-Bond reach is 4.8 km long, so time to move the gravel bar package through the reach is:

$$\frac{4.8 \text{ km}}{.006 \text{ km yr}^{-1}} = 800 \text{ years}$$

Volume of bar movement per year is:

$$\frac{850\ m^3}{10\ yr} = 85\ m^3yr^{-1}$$

The volume of gravel moved (85 m^3yr^{-1}) as a discrete bar represents only part of the total bar movement over complex 4-6. Other bars are also migrating and it would be necessary to sum their rates and volumes tc arrive at a net amount of gravel bar movement. Individual clasts, especially small sizes, migrate faster and farther than the transverse or longitudinal bar mass and can move to the next bar complex downstream. Thus, the rate and volume of discrete bar movement is only a piece of the total transport package.

Rate and Volume of Clast Movement - Two approaches to estimating clasts movement are: 1) determine a gravel-volume bypassing rate, or 2) determine magnitude of movement of individual clasts.

1) The gravel volume approach relies on the gravel budget deficit of 1160 m^3 (Table 2) and assumes that terrace gravel has moved downstream from bar complex 5 to BC-6, a distance of 130 m (Boothroyd and others, 1979; Fig. 4a).

Volume of gravel moved per year is:

$$\frac{1160\ m^3}{10\ yr} = 116\ m^3yr^{-1}$$

Distance of movement of the gravel package per year is:

$$\frac{130\ m}{10\ yr} = 13\ m\ yr^{-1}\ (.013\ km\ yr^{-1})$$

Time needed to move the gravel through the Buttermilk=Bond reach is:

$$\frac{4.8\ km}{.013\ km\ yr^{-1}} = 369\ years$$

Notice that both the rate of movement and the volume of the package are greater than the discrete bar migration. The bar and the package values should be combined to give a comprehensive rate and volume for bar complex 4-6.

2) The clast movement approach uses data from the clast movement station (Plate 10, Appendix E) for which there are two sets of measurements. The two sets are the October 25-26 event and Hurricane Fredric flooding.

Large clasts moved an average of 3 m during the October 25-26 flood. This event can be considered to have a one-year recurrence interval.

Rate of clast movement (one-year storm): 3 m yr^{-1}
($.003 \text{ km yr}^{-1}$)

Time needed for a clast to move through the Buttermilk-Bond reach is:

$$\frac{4.8 \text{ km}}{.003 \text{ km yr}^{-1}} = 1600 \text{ years}$$

Clast 49 (our only data point) moved 60 m during Hurricane Fredric giving:

Rate of clast movement (10-yr storm): 6 m yr^{-1} ($.006 \text{ km yr}^{-1}$).

Time needed for a clast to move through the reach is:

$$\frac{4.8 \text{ km}}{.006 \text{ km yr}^{-1}} = 800 \text{ years}$$

Clast movement rates have no specific volumes attached to them. Volumes must be derived from other data as discussed in the Buttermilk valley section.

5.3 Discharge Measurements and Transport of Suspended Sediment

Suspended Sediment Supply - Lavery till, Kent till, and associated lacustrine silt and clay (LaFleur, 1979) constitute the fine-grained sediment supply for Buttermilk Creek and tributaries. Erosion of the valley walls by channel incision of alluvial fans, landslides, and erosion of valley bottoms beneath the bar gravel of the tributaries and Buttermilk Creek exposes fine sand, silt, and clay. This material is transported even during minor flood events.

Our grain-size analyses of till samples (Table 3), analysis by Hoffman and others (1980), and inspection of outcrops on the valley walls and at the base of the channels (Fig. 6) indicate that the till is composed of 85-90 percent fine sand, silt and clay by weight. This supports information provided by LaFleur (1979) and Dana and others (1979). In-place density measurements of till in research trench III on the plateau between Erdman Brook and Buttermilk Creek give values up to 117 lbs ft^3 (1.882 g cm^{-3}) (Hoffman and others, 1980).

If the till is 85 percent fine sand, silt, and clay by weight then the unit weight per volume of the fine-grained sediment supply is:

$$1882 \text{ kg m}^{-3} \cdot 0.85 = 1599.7 \ (1600 \text{ kg m}^{-3})$$

Suspended Sediment Discharge - The concentration of suspended material (suspended-material load) measured during flood events (Table 7) in Buttermilk Creek can be used to compute a suspended-sediment discharge. The calculations given below are for the flood values of October 25-26, 1980 (Refer to Figure 4 and Table 7).

1) Peak water discharge (46.52 m^3sec^{-1}) persisted for 6.5 hrs with a suspended-sediment sample (4.4 g l^{-1}) taken at the end of the flattened peak.

Instantaneous sediment discharge (Q_{is}) is:

$$0.0044 \text{ kg } l^{-1} \,.\, 46{,}520 \text{ l sec}^{-1} = 204.688 \text{ kg sec}^{-1}$$

$$(4.4 \text{ g } l^{-1}) \qquad (46.52 \text{ m}^2\text{sec}^{-1})$$

Cumulative sediment discharge (Q_{cums}) for the 6.5 hours (23,400 sec) peak flow is:

$$23{,}400 \text{ sec} \,.\, 205 \text{ kg sec}^{-1} = 4{,}797{,}000 \text{ kg}$$

The equivalent in-place volume (Vol_t) of till needed to supply the sediment is :

$$\frac{4{,}800{,}000 \text{ kg}}{1600 \text{ kg m}^{-3}} = 3000 \text{ m}^3$$

2) A reduced water discharge greater or equal to 20.17 m^3sec^{-1}, occurred over a 11.5 hour time span with a suspended sediment concentration of 1.27 g l^{-1}.

Q_{is}: $0.00127 \text{ kg } l^{-1} \,.\, 20{,}170 \text{ l sec}^{-1} = 25.616 \text{ kg sec}^{-1}$

Q_{cums}: $41{,}400 \text{ sec} \cdot 25.6 \text{ kg sec}^{-1} = 1{,}059{,}840 \text{ kg}$

Vol_t: $\dfrac{1{,}060{,}000 \text{ kg}}{1600 \text{ kg m}^{-3}} = 662.5 \text{ m}^3$

3) A further reduced water discharge of 15.39 m^3sec^{-1} occurred for 5 hours with suspended-sediment discharge of 1.266 g l^{-1}. The calculations are :

Q_{is}: $0.001266 \text{ kg } l^{-1} \cdot 15{,}390 \text{ l sec}^{-1} = 19.5 \text{ kg sec}^{-1}$

Q_{cum}: $18{,}000 \text{ sec} \cdot 19.5 \text{ kg sec}^{-1} = 351{,}000 \text{ kg}$

Vol_t: $\dfrac{172{,}800 \text{ kg}}{1600 \text{ kg m}^{-3}} = 219 \text{ m}^3$

The total volume of till needed to supply the fine-grained material for the October 25-26 event is: 3881 m^3.

The assumed in-place density of till was the largest of the research trench values obtained (Hoffman and others, 1980), but the instantaneous suspended-sediment load values are conservative. The initial sediment sample was obtained after the peak water discharge and most likely after the peak suspended-sediment discharge. The volume of till available will be discussed in the Buttermilk valley section.

5.4 Alluvial Fan Erosion and Sedimentation

As stated previously (Boothroyd and others, 1979), we believe that processes associated with alluvial-fan development are important agents in the widening of Buttermilk Creek and its tributaries. Gravel, sand, and some silt and clay eroded from the upper incised channels are deposited on the fans. Some silt and clay may collect in ponded depressions on the terraces. The stakes placed on the BC-3 fan (Plates 5, 6) were placed there in an attempt to measure the rate and amount of sediment accumulation. A resurvey is needed to assess the accumulation or erosion.

An unknown amount of fine-grained sediment bypasses the fan and is fed directly into Buttermilk Creek and its tributaries as suspended-material load. Data from the NP-3 gaging and sampling station (Plates 1, 2), will help determine the magnitude of this process. Measurement of sediment retained in the NP-3 fan, when subtracted from suspended-sediment cumulative discharge (Q_{cums}), will give a bypassing rate and amount.

5.5 Landslide Processes

Movement of the BC-6 landslide as recorded on Plate 7 and in Table 4 gives an indication of the rate and areal dimension of slumping and earthflow processes that supply sediment to Buttermilk Creek.

Slide Rate and Volume - The lower center of the slide is the actively moving mass (Fig. 7) with an area 50 m wide by 70 m long (slope distance). It is about 3 m thick.

Volume of the moving slide is: 10,500 m^3

The calculated mean value of vertical movement, based on 1978 stakes recovered in 1980, is 3.35 m. Constant movement is assumed for the time period that the Buttermilk low-flow channel is at or near the slide toe. More rapid movement would result if undercutting by large flood events occurred.

Therefore, the rate of downslope movement is about 1.5 m yr^{-1}.

Slope distance down the valley wall from the upper rim to channel floor is 110 m.

The time required for slide material to move from the valley rim down to Buttermilk Creek is:

$$\frac{110 \text{ m}}{1.5 \text{ m yr}^{-1}} = 73.3 \text{ yrs}$$

The average volume per year of material delivered to Buttermilk Creek is:

$$\frac{10,500 \text{ m}^3}{70 \text{ yr}} = 150 \text{ m}^3\text{yr}^{-1}$$

The weight of material per year available for fluvial transport can be derived by using in-place densities of similarly compacted till from the caps of the low-level waste-burial trenches. The lowest trench-cap value (Hoffman and others, 1980) is 104 lbs ft^{-3} (1667 kg m^{-3}).

The weight per year of sediment available for fluvial transport is:

$$1667 \text{ kg m}^{-3} \cdot 150 \text{ m}^3\text{yr}^{-1} = 250,050 \text{ kg yr}^{-1}$$

The amount of gravel and sand is: 37,510 kg yr^{-1} (22.5 m^3yr^{-1})
Fine sand, silt and clay are: 212,540 kg yr^{-1} (127.5 m^3yr^{-1})

Interpretations based on the assumption that calculated yearly averages are valid for a mass-wasting feature, likely to fail catastrophically, should be viewed with some suspicion. A sudden block glide, and subsequent earth-flow of a large segment of the heretofore slowly creeping slide, such as happened in 1977 (Fig. B1, Appendix B), could instantaneously deposit 5000 m^3 of material in Buttermilk Creek. The recurrence interval of this type of event has not yet been determined.

5.6 Reservoir Sedimentation

Limitations - Precise location of shore stakes could not be determined from available maps because the valley-wall contours drawn from photos with heavy forest cover are not accurate. Available aerial photos had too much edge distortion to be useful in accurate delineation of reservoir boundaries. Figures 13a,c and Plate 1 show the former channel thalweg and the pre-reservoir entrenched meander systems. Cross-profiles intersect some of these meander bends. It was difficult to distinguish slump and earthflow deposits from filling by density underflow.

Fluvially-derived Sediment - The volume beneath the delta plains and the fill between the delta front and the first lacustrine cross-profile in front of the delta are used in the following calculations.

1) Reservoir No. 1 (South) - The volume of fill, including delta plain to cross-profile 9/22, is 12515 m^3 (Table 6a, Fig. 13b). Infilling has occurred from 1963 to 1980 (17 yrs).

Volume of infill per year is:

$$\frac{12515 \text{ m}^3}{17 \text{ yrs}} = 736.2 \text{ m}^3\text{yr}^{-1}$$

2) Reservoir No. 2 (North) - The volume of fill, delta plain to cross-profile 50/36, is 6444 m^3 (Table 6b, Fig. 13d).

Volume of infill per year is:

$$\frac{644\ m^3}{17\ yrs} = 379.1\ m^3yr^{-1}$$

Sediment Loss Rate - The drainage basin of the south reservoir (806.8 ha) is almost twice as large as that of the north reservoir (435.8 ha) Table 5). Correspondingly, water discharge and sedimentary material would be greater for the south reservoir. A simple calculation of amount of sediment supplied per year per unit area indicates a sediment loss rate in the drainage basins (Gregory and Walling, 1973).

Drainage basin sediment losses per hectare per year are:

South reservoir: $$\frac{736.2\ m^3yr^{-1}}{806.8\ ha} = 0.91\ m^3ha^{-1}yr^{-1}$$

North reservoir: $$\frac{379.1\ m^3yr^{-1}}{435.8\ ha} = 0.87\ m^3ha^{-1}yr^{-1}$$

The values have not been converted to weights because we do not know the in-place density of the reservoir fill. It is certainly lower than an in-place till density. What is interesting is the good agreement between the two values. The rate derived here has been applied to the total Buttermilk drainage area (see discussion in Buttermilk valley section).

5.7 Buttermilk Valley Denudation

A Simple Denudation Rate - The volume of sediment removed from Buttermilk valley as a function of time can be calculated using the age of terrace 22W (9920 ± 240BP, (Plate 8). This age is assumed to be close to the time of initial incision and downcutting of Buttermilk Creek. The total volume of sediment removed, neglecting tributaries, was 65,923,331 m^3 (Table 8).

The simple denudation rate is:

$$\frac{65{,}923{,}331\ m^3}{10{,}000\ yrs} = 6592\ (6600\ m^3yr^{-1})$$

The denudation value represents the amount of bedload and suspended-load transport per year by Buttermilk Creek necessary to remove valley fill and produce the present configuration. Variations in rate due to short-or long-term climatic change have been ignored.

Evaluation of Denudation Processes - The rates of bedload transport including bar migration and clast movement, and the rates of suspended-load transport can be compared with the simple denudation rate to gain some consensus on the relative value of each type of measurement. Table 9 summarizes the sediment volumes and transport rates derived in the preceding discussion.

1) Gravel Movement - The Buttermilk valley sediment aggregate is composed of about 5 percent gravel, 85 percent fine sand, silt and clay, and 10 percent coarse and medium sand (Table 3) (Hoffman and others, 1980). Using denudation rate and sediment distribution, the volume of each available size can be calculated and a transport rate determined.

Volume of gravel available is:

$$66{,}000{,}000 \text{ m}^3 \cdot 0.05 = 3{,}300{,}000 \text{ m}^3$$

Gravel available per year for transport is:

$$6600 \text{ m}^3\text{yr}^{-1} \cdot 0.05 = 330 \text{ m}^3\text{yr}^{-1}$$

There is temporary storage of gravel in bars and low-active terrace systems (Table 8). The gravel stored in a one meter thick section is 570,000 m^3, and in a two meter section, 1,140,000 m^3.

A comparison of all the derived gravel transport rates reveals that: 1) The gravel bar migration rate plus volume deficit rate agrees quite well with the amount of gravel provided by simple gravel denudation. The bar migration rate is low because it is based on movement of large clasts only. More information is needed on small-clast movement. 2) The amount stored in the bar and terrace system is about 20-35 percent of that made available by denudation per year. This material is recycled at an unknown rate, but the volume deficit for bar complex 4-6 may be a good indication of that rate. This gravel deficit must be up from more gravel-rich units upstream in Buttermilk or in the tributaries.

2) Suspended-sediment Transport - Using the simple denudation rate and selected grain-size distribution of till, the fine-grained material available per year can be calculated.

Volume of fine sand, silt and clay available is:

$$66{,}000{,}000 \text{ m}^3 \cdot 0.85 = 56{,}000{,}000 \text{ m}^3$$

Fine sand, silt and clay available for transport is:

$$6600 \text{ m}^3\text{yr}^{-1} \cdot 0.85 = 5610 \text{ m}^3\text{yr}^{-1}$$

The cumulative suspended-sediment discharge of the October 25-26, 1980 event (one-year storm), a conservatively calculated value, was 69 percent of the simple yearly suspended-sediment denudation rate. Fine-grained material is transported even during small floods and most gravel is not. The total yearly transport of fine-grained material appears to balance that estimated to be eroded from the Buttermilk-Bond reach plus an added, unmeasured contribution from the tributaries and upper Buttermilk Creek. Additional information is needed on the tributary contribution, particularly the Franks Creek drainage.

3) Sediment Loss in the Buttermilk Drainage Basin - The sediment-loss value derived for the reservoir drainage basins (Table 9) can be applied to the total Buttermilk drainage basin. It is understood that the relationship of sediment loss to basin area may not be linear.

The sediment loss per unit area per year in the Buttermilk drainage basin is:

$$7841.5 \text{ ha} \cdot 0.89 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1} = 6979 \text{ m}^3\text{yr}^{-1}$$

The sediment loss result compares will with the simple denudation rate. This larger value is to be expected because it includes the tributary and upper Buttermilk Creek sediment contribution.

5.8 Holocene Landscape Evolution

Buttermilk Fluvial Terraces - The 153 separate terraces (85E, 69W) illustrated on Plates 1 and 8 have been divided into categories according to elevation above active bars. Arrays of terraces also can be grouped according to events that generated them or allowed their preservation after they were formed. The events are site specific. The groups of terraces generated or preserved by each event are shown on Plate 8 (shading patterns).

The low-active terraces are associated with the present processes of Buttermilk Creek and its tributaries. Most of these terraces are subject to recycling into active bars as the lateral sweep of Buttermilk channel occurs. Some terraces may be preferentially preserved as discussed below.

The largest number of terraces that are higher in elevation than the low-active level are associated with the confluence of tributaries with Buttermilk Creek. Gravel transported down the tributaries is deposited as slightly-dipping, fan-shaped bar complexes at the mouths of the tributaries. The fans are skewed in a downstream direction relative to Buttermilk Creek. This is because of redistribution by Buttermilk bedload processes. Continued incision of Buttermilk Creek and the associated tributary leads to the abondonment of the bar complexes. By definition, these bars become terraces. The excess of gravel supplied over transport capacity may temporarily, or permanently, retard the lateral sweep of the Buttermilk channel and destruction of the terrace array.

TABLE 9

Sediment Volumes and Transport Rates

Process	Distance moved	Time thru reach (yr)	Amount: Volume ($m^3 yr^{-1}$)	Amount: Weight ($kg\ yr^{-1}$)	Total volume (m3)
Gravel bar migration	.006 km yr^{-1}	800	85		
Gravel volume deficit	.013 km yr^{-1}	369	116		
Clast movement (1 yr storm)	.003 m yr^{-1}	1600			
Clast movement (10 yr storm)	.006 m yr^{-1}	800			
Suspended sediment					
Instant (Q_{is})			204.7 kg sec^{-1}		
Peak Q_{cums}			3000	4,800,000	
Total Q_{cums}			3881	6,469,627	
Landslide	1.5 m yr^{-1}		150	250,050	10,500
Gravel, Sand			22.5	37,510	
Fs,Si,Clay			127.5	212,540	
Reservoirs					
No. 1 South			736.2		
No. 2 North			379.1		
Buttermilk Valley					
Simple denudation			6600		66,000,000
Basin sediment loss			6979		
Gravel denudation			330		3,300,000
Gravel terraces and bars					570,000 (1 m)
					1,140,000 (2 m)
Fs,Si,Cl denudation			5610		56,100,000

Other terraces are deposited in a similar manner at the base of, and adjacent to, alluvial fans that developed within Buttermilk valley. Some fans are small, such as the BC-3 fan. Others are larger, with upper drainages well-incised into the plateau above Buttermilk valley.

Some terraces at the lower end of the Buttermilk-Bond reach are bedrock-defended. The channel of Buttermilk is incised into Devonian bedrock on the west side of the valley preventing further channel sweep.

We speculate that a third array of terraces, including the set that contains the dated wood fragments and the set that includes the "Racetrack", have been preserved because the Buttermilk channel has remained stable on the east side of the valley for long periods of time. We do not know the cause for this channel behavior.

Tributary Development - The larger tributaries of Buttermilk Creek are inherited from the late-glacial drainage system as noted by Boothroyd and others (1979). The segments of the tributaries aligned parallel to Buttermilk Creek originally flowed as separate streams down the 3 m km^{-1} paleoslope toward Cattaragus Creek. These parallel segments are now entrenched and link with upper drainages that are incised within, or at the margin of, the Holocene alluvial fans of LaFleur (1979) (Unit Haf, Plate 3).

Some of the smaller tributaries head in the uplands adjacent to Buttermilk, but others began as small fans on the Buttermilk valley wall. Headward erosion of the upper drainage results in incision of the Lavery till plateau. Stream capture, such as may have occurred to the Franks/Erdman system, can redirect stream patterns and result in rejuvenation when base-level lowers.

Figure 8 illustrates a range of gradients of longitudinal profiles of streams in the Buttermilk basin from the steep BC-3 alluvial fan, to the lower gradient Buttermilk Creek. The middle example, Franks Creek, can be subdivided into morphologically distinct segments above and below the knickpoints of the Erdman Creek section. The valley above the knickpoints is not being actively incised at the present time. The valley walls appear to have mass-wasted, either by earthflow or soil creep, onto the valley bottom. The flat floor of the valley is not composed of gravel terraces, but consists of hummocky till with tension cracks. The incision will resume as the knickpoints progress up the valley.

Erdman Brook, below the knickpoints, and Franks Creek are undergoing active incision resulting in extreme V-shaped cross-profiles (Fig. 10). Terraces are rare along the Franks Creek segment, but do exist along Erdman Brook. A small fan-shaped bar complex is present at the mouth of Quarry Creek, perhaps the forerunner of a terrace array. The reason for the steeper gradient along this section is unclear. As downcutting continues, both Franks and Erdman valleys can be expected to widen by parallel retreat of slopes because of slumping of wall material and rapid removal by flood events.

Future Evolution - The base-level of Buttermilk Creek is controlled by the elevation of Cattaraugus Creek at the Buttermilk confluence. The Cattaraugus is entrenched in bedrock about one-half kilometer below the confluence, as is Buttermilk near the Bond Road bridge. The bedrock retards downcutting of the active channel. This, in turn, results in a decreased gradient and decreased sediment-transport capacity. The effect of the temporary bedrock base-level is not yet reflected in the gradient of Buttermilk Creek and is interpreted not not to be important over the 'middle' term (tens to hundreds of years).

We believe that tributary lowering and widening will occur somewhat independent of the lowering of Buttermilk Creek. The convex profile of Franks Creek/Erdman Brook is interpreted to mean that it is unstable. It will be subject to continued downcutting and widening even if the base-level at the confluence does not change. This conclusion is speculative and more work remains to be done.

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APPENDIX A

Bulk Sediment Sample Localities

Figure A1. Terrace scarp at BC-3, west bank. Samples are: GS-1, till; GS-2, bar gravel; GS-3, pond silt and clay.

Figure A2. Terrace, transect 16, east bank. Sample GS-10, bar gravel.

Figure A3. Bar complex 4-6, transect 16, top of unit bar. Sample GS-4.

Figure A4. Bar complex 4-6, transect 8, top of transverse bar. Sample GS-5.

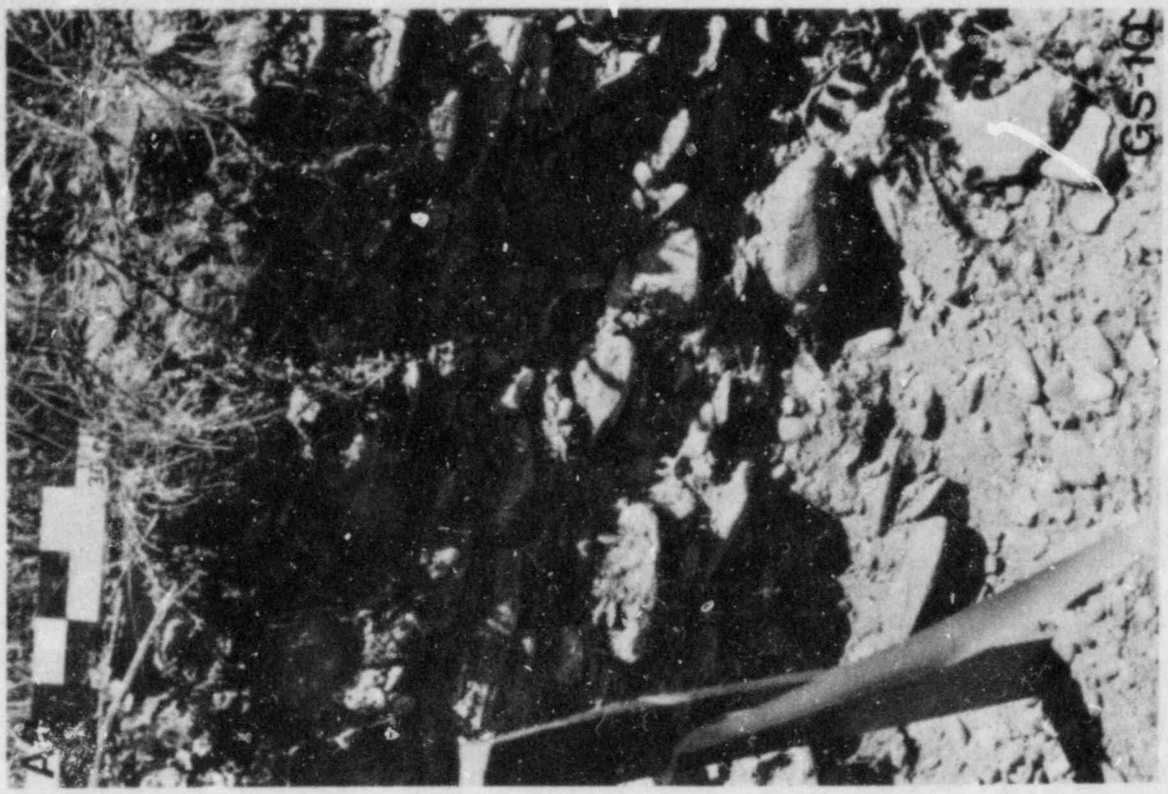
Figure A5. Bar complex 4-6, transect 11, highest point of large transverse bar. Sample GS-6.

Figure A6. Bar complex 4-6, transect 12, shoulder of large longitudinal bar with sand drape. Sample GS-7.

Figure A7. Bar complex 4-6, transect 15, large longitudinal bar. Sample GS-8.

Figure A8. Bar complex 4-6, transect 17, transverse bar crest. Sample GS-9.

Figure A9. Till, exposed in channel bottom at the base of the BC-6 landslide (arrows). Sample GS-11.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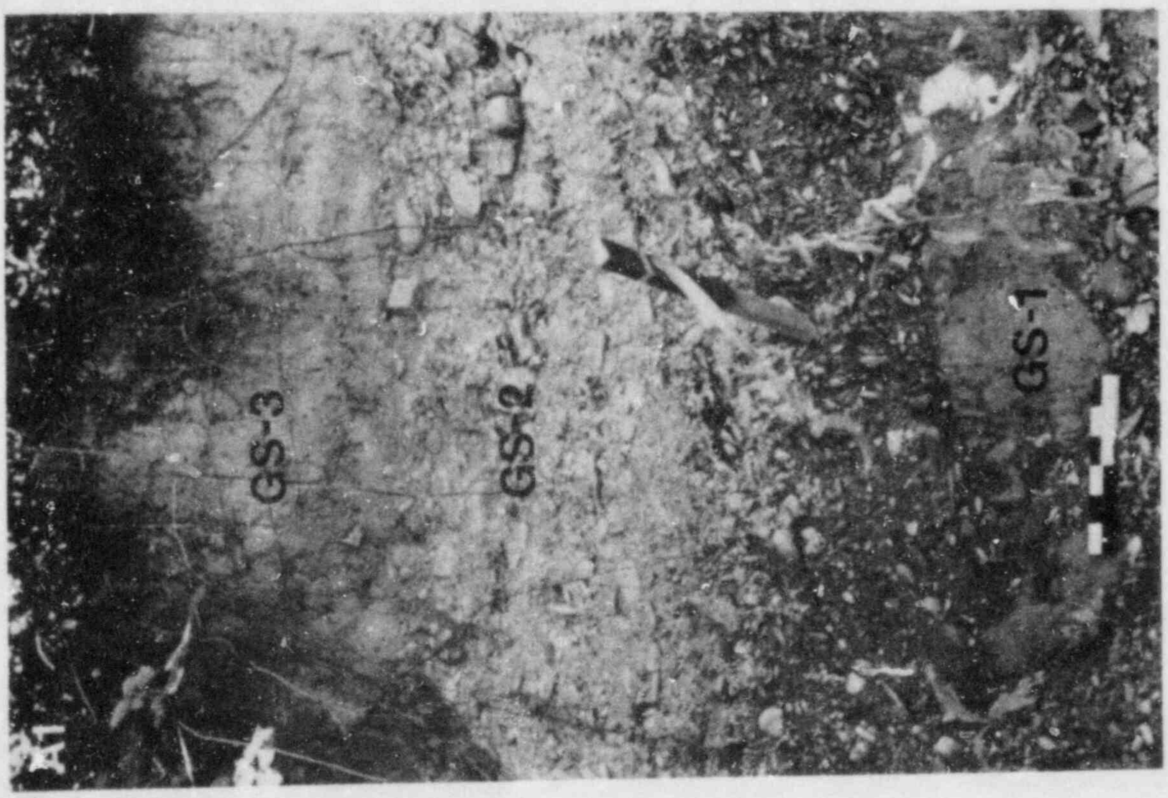
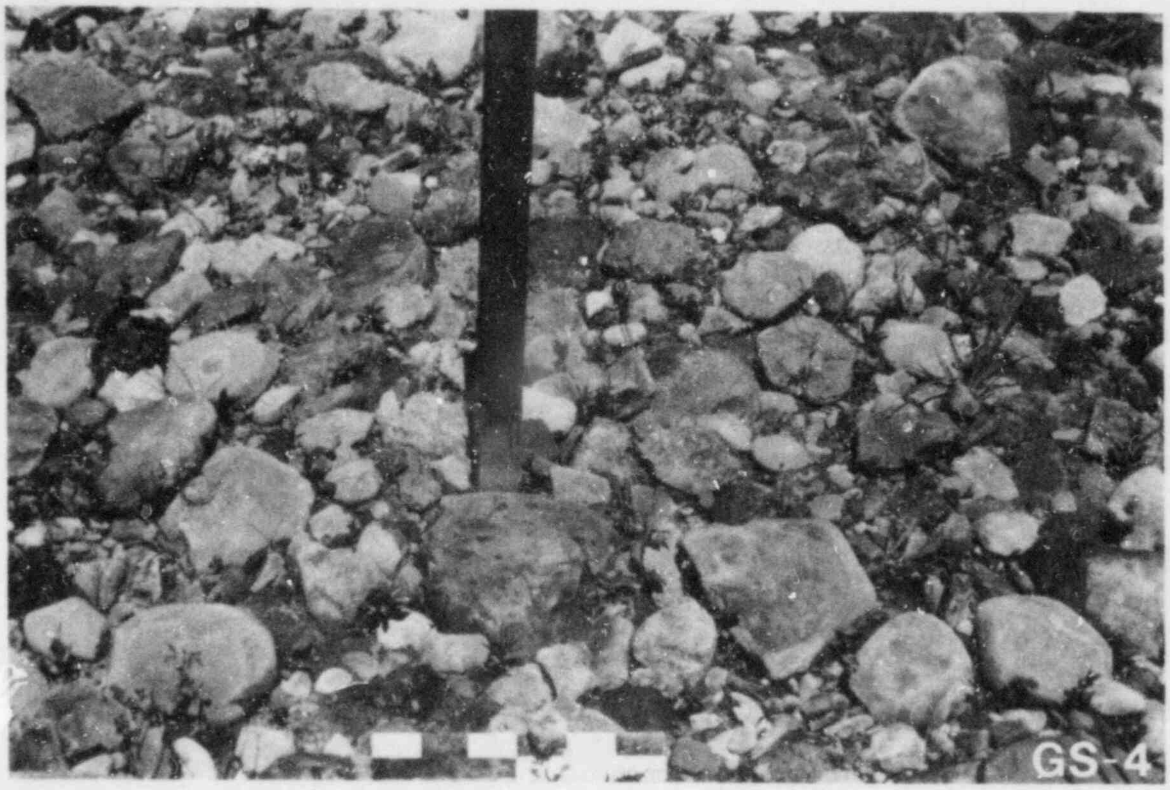

A1
GS-3
GS-2
GS-1



GS-4

A4
GS-5


A5
30 cm


A6


GS


A8
GS 9


A9
CS-11

APPENDIX B

BC-6 Landslide Panoramas

Figure B1. April 1977. Note the recent earthflow deposit in Buttermilk Creek (arrow), and central position of the low-flow channel.

Figure B2. April 1978. Earthflow is partially removed (arrow). Low-flow channel impinges on landslide (left); flood flow partially covers bar surface (right).

Figure B3. April 1980. Post-Fredric bar and channel configuration. The earthflow deposit has been totally removed.

Photographs taken by D. Prudic, USGS.


B1
1977


B2
1978


B3
1980

APPENDIX C

BC-6 Landslide Resurvey

1978 Stake Locations

Surveyed July 23, 1980
Instrument Station #1 (BC-6) Elev. 373.574 m

Station	Azimuth	Horizontal Distance (m)	Elevation (m)
TBM 2	95° 10'	39.93	374.47
3C	206°	33.199	379.916
4C	217°	36.82	381.695
4DB	243° 30'	29.185	376.58
2N	248° 5'	28.268	376.26
3D	239° 3'	36.386	380.82
4D	233° 33'	44.54	384.32
5D	228° 28'	53.156	389.39
5C	211° 2'	47.35	387.48
5UA	198° 57'	44.98	386.86
4UB	206° 13'	42.259	384.38
4UE	193° 25'	47.329	386.29
6AA	193° 58'	63.637	394.84
7U	207° 47'	63.51	396.69
7C	216° 46'	58.776	392.043
6C	211° 21'	58.452	392.97
6D	226° 10'	62.176	391.903
7D	222°	65.786	395.05
8D	220° 12'	77.389	401.64
8C	215° 10'	75.07	400.85
8U	208° 4'	68.517	399.24

APPENDIX D

Buttermilk Fluvial Terrace Locations

Terrace #	Elevation Meters	Distance Down Reach Km
1E (9)	403.2	- .061 - 0
2E (10)	404.1	- .012 - 0
3E (8)	396.5	0 - .061
4E (8)	396.2	.061 - .244
5E (7)	394.7	.061 - .183
6E (4)	386.7	0 - .061
7E (3)	385.5	0 - .244
8E (2)	384.3	0 - .122
9E (2)	383.7	.207 - .366
10E (3)	385.5	.232 - .256
11E (5)	387.9	.305 - .342
12E (6)	391.0	.256 - .329
13E (7)	394.7	.256 - .305
14E (6)	391.0	.281 - .317
15E (7)	393.7	.366 - .427
16E (?)	410.8	.488 - .573
17E (?)	409.6	.488 - .573
18E (2)	377.9 - 376.7	.427 - 1.488
19E (5)	381.25	.549 - .573
20E (4)	380.03	.561 - .585
21E (3)	378.8	.610 - .683
22E (2)	377.9 - 376.7	.427 - 1.488
23E (3)	378.5 - 377.6	.793 - .915
24E (5)	380.3 - 379.7	.793 - .915
25E (2)	376.4	.915 - 1.004
26E (3)	377.6 - 376.9	.915 - 1.004
27E (4)	378.8	.915 - 1.004
28E (7)	383.4	.915 - 1.037

Terrace #	Elevation Meters	Distance Down Reach Km
29E (6)	382.1	.976 - .988
30E (6)	382.1	1.037 - 1.049
31E (5)	381.2	1.037 - 1.22
32E (7)	385.8	1.037 - 1.098
33E (8)	388.8	1.037 - 1.281
34E (7)	385.8	1.281 - 1.403
35E (6)	381.8	1.317 - 1.403
36E (2)	374.2 - 373.6	1.037 - 1.403
37E (5)	379.7	1.342 - 1.549
38E (3)	373.6	1.342 - 1.464
39E (4)	375.15	1.464 - 1.525
40E (3)	373.6	1.525 - 1.586
41E (4)	375.15	1.549 - 1.586
42E (4)	374.5	1.525 - 1.647
43E (3)	373. - 371.8	1.647 - 1.83
44E (2)	369. - 368.1	1.647 - 2.135
45E (5)	375.15	1.647 - 1.891
46E (5)	375.15	1.647 - 1.891
47E (4)	373.	1.952 - 2.074
48E (3)	370.6	1.952 - 2.135
49E (2)	369. - 368.1	1.647 - 2.135
50E (3)	373.6	2.110 - 2.135
51E (5)	375.15	2.110 - 2.135
A52E (6)	377.	1.586 - 1.83
52E (2)	367.2 - 364.5	2.275 - 2.745
53E (3)	367.8	2.375 - 2.476
54E (4)	369.05	2.562 - 2.684
55E (3)	367.3	2.68 - 2.74
56E (4)	368.8	2.71 - 2.87
57E (5)	370.3	2.74 - 2.80
58E (4)	365.75	2.87 - 2.99
A58E (5)	367.3	2.93 - 2.99

Terrace #	Elevation Meters	Distance Down Reach Km
59E (3)	364.84	2.93 - 3.05
60E (2)	364.2	2.93 - 3.05
61E (5)	364.84	3.05 - 3.13
62E (4)	363.3	3.11 - 3.23
63E (3)	362.7	3.17 - 3.29
64E (5)	365.75	3.17 - 3.41
65E (7)	373.4	3.23 - 3.29
66E (2)	359.	3.23 - 3.54
67E (4)	364.2	3.29 - 3.41
68E (5)	365.75	3.17 - 3.41
69E (6)	365.75	3.35 - 3.41
70E (7)	373.4	3.48 - 3.51
71E (3)	359.	3.59 - 3.66
72E (4)	359.7	3.54 - 3.66
73E (5)	361.2	3.59 - 3.68
74E (6)	364.2	3.54 - 3.66
75E (6)	364.54	3.59 - 3.61
76E (4)	359.	3.66 - 3.69
77E (3)	356.6	3.69 - 3.72
78E (5)	359.7	3.69 - 3.72
79E (3)	355.1	3.96 - 4.27
80E (5)	359.7	4.12 - 4.15
1W (2)	382.7	.012 - .055
2W (2/3)	382.7 - 381.86	.109 - .146
3W (2/3)	381.5 - 380.0	.183 - .488
4W (4)	381.25	.366 - .451
5W (5)	384.3 - 382.7	.366 - .488
6W (2)	380.0 - 378.2	.366 - .695
7W (4)	382.2	.488 - .561
8W (5)	383.4 - 381.25	.549 - .707
9W (4)	381.25	.671 - .744
10W (2)	378.2 - 377	.817 - .976

Terrace #	Elevation Meters	Distance Down Reach Km
11W (?)	391.9	1.330 - 1.366
12W (2)	370.5 - 368.4	1.464 - 1.708
13W (3)	372.7 - 370.8	1.342 - 1.708
14W (4)	373.0 - 371.5	1.403 - 1.665
15W (2)	368.0 - 367.5	2.013 - 2.257
16W (3)	369.6 - 369.	1.891 - 2.318
17W (4)	371.2 - 369.6	1.891 - 2.379
18W (2)	366.6 - 366.0	2.318 - 2.501
19W (3)	367.5	2.379 - 2.501
20W (11)	397.0	2.318 - 2.379
21W (10)	396.0 - 395.0	2.318 - 2.501
22W (12)	408.7	2.342 - 2.379
23W (13)	410.2	2.342 - 2.379
24W (11)	397.7	2.379 - 2.501
25W (2)	365.7 - 364.0	2.562 - 2.806
26W (9)	390.5	2.56 - 2.63
27W (10)	393.6	2.56 - 2.63
28W (12)	408.4	2.50 - 2.57
29W (13)	410.8 - 410.4	2.50 - 2.75
30W (10)	395.0	2.68 - 2.74
31W (13)	410.3	2.68 - 2.74
32W (3)	366.5	2.86 - 2.93
33W (2)	366.2 - 365.	2.925 - 3.050
34W (2)	365.	2.92 - 2.99
35W (2)	333. - 331.5	3.05 - 3.30
36W (4)	364.5	3.10 - 3.15
37W (5)	372.1	3.05 - 3.12
38W (6)	373.	3.10 - 3.14
39W (7)	374.2	3.10 - 3.24
40W (8)	377.5	3.08 - 3.12
41W (9)	379.0	3.20 - 3.25
42W (8)	377.4	3.20 - 3.25

Terrace #	Elevation Meters	Distance Down Reach Km
43W (3)	362. - 361.4	3.175 - 3.29
44W (4)	372.	3.325 - 3.45
45W (5)	362.5 - 361.5	3.325 - 3.55
46W (4)	361. - 360.5	3.325 - 3.58
47W (3)	358. - 356.	3.325 - 3.83
48W (2)	357.5 - 356.5	3.325 - 3.83
49W (8)	381.75	3.6 - 3.78
50W (7)	379.	3.77 - 3.84
51W (6)	377.5	3.80 - 3.85
52W (8)	378.8	3.85 - 3.87
53W (7)	377.8	3.90 - 3.96
54W (8)	381.25	3.96 - 3.99
55W (7)	374.5	4.00 - 4.026
56W (12)	397.1	4.026 - 4.087
57W (13)	404.7	4.026 - 4.074
58W (2)	355.3 - 354.7	4.209 - 4.453
59W (3)	357.7	4.209 - 4.331
60W (5)	358.9	4.209 - 4.27
61W (6)	360.5	4.209 - 4.27
62W (9)	385.2	4.12 - 4.27
63W (10)	383.1	4.27 - 4.37
64W (12)	397.1.	4.18 - 4.27
65W (8)	384.3	4.39 - 4.49
66W (10)	383.1	4.39 - 4.636
67W (6)	372.1	4.51 - 4.562
68W (7)	373.6	4.45 - 4.51
69W (8)	376.7	4.51 - 4.575

Terrace #	Elevation Meters	Distance Down Reach Km
83E (4)	356.6	4.39 - 4.42
84E (3)	355.1	4.45 - 4.63
85E (2)	354.2	4.45 - 4.63

APPENDIX E

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 5

Marked: July 15, 1980
Measured: Nov. 6, 1980
(Oct. 25-26 event)
*(Aug. 11 event)

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
420	867	10 D	G	Edge Main Channel						
421	874	11 U	G							
422	898	22 U	G							
423	1028	02 U	G							
424	1126	20 D	G							
425	1154	105 D	G		1110	173 D	70	32	28	03
426	1218	52 U	G							
427	1231	82 U	G							
428	1363	16 U	G							
429	1455	58 U	G	Hi Point Bar	1472	074 U	26	32	22	04
430	1495	86 U	G		1522	239 D	333	35	27	05
431	1524	72 U	G		1550	015 U	62	25	24	05
432	1512	70 D	G		1480	420 D	355	40	38	05
433	1561	141 D	G							
434	1530	281 U	G		1601	135 D	428	40	18	06
435	1588	247 U	G		1616	048 D	300	34	27	03
436	1767	131 U	G	Edge Semi Main	1868	71 U	118	39	30	09
437	1830	000	G		2015	483 D	522	32	20	08
438	1938	16 D	G		*1931 1975	022 D 033 D	04 44	34	24	04
439	2707	110 D	G							
440	3028	101 U	G							
441	3051	06 U	G							
442	3264	66 U	G	Hi Point Bar						
443	3350	62 U	G							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 5

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
444	3236	93 D	G							
445	3371	05 D	G							
446	3455	36 D	G							
447	3529	107 U	G							
448	3790	08 D	G							
449	3775	13 U	G							
450	4272	36 U	G	Filled chute						
451	4618	187 D	G	On Terr.						
452	4624	249 D	G	1/2						
453	693	55 U	B	Main						
454	729	77 U	B	Channel						
455	721	108 U	B	Edge						
456	852	115 U	B							
457	907	42 U	B							
458	939	44 U	B							
459	894	58 U	B							
460	895	60 U	B							
461	849	34 U	B							
462	847	63 U	B							
463	913	04 U	B							
464	924	04 D	B							
465	971	77 U	B							
466	1009	68 U	B		966	010 U	88	28	12	04
467	1009	53 U	B							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 5

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
468	1138	57 U	B	Hi Point						
469	1147	12 U	B	Bar	1004	282 D	335	26	15	03
470	1150	61 D	B							
471	1170	00	B		1065	483 D	498	18	13	06
472	1252	97 U	B		1266	015 D	112	22	16	04
473	1278	104 U	B		1328	231 D	340	20	17	02
474	1287	26 D	B							
475	1283	60 D	B							
476	1348	35 D	B		1259	325 D	307	26	22	08
477	1436	80 U	B		1382	168 D	255	21	17	04
478	1541	23 U	B		1602	307 D	358	23	20	05
479	1621	104 U	B							
480	1598	88 U	B							
481	1621	73 U	B							
482	1609	56 U	B		1750	447 D	525	27	16	05
483	1621	22 U	B		1794	632 D	678	19	14	03
484	1539	23 U	B							
485	1650	08 D	B							
486	1653	110 U	B							
487	1564	268 U	B	Hi Point						
488	1624	237 U	B	Bar						
489	1695	233 U	B							
490	1698	10 D	B							
491	1725	40 U	B		1920	213 D	318	20	15	08
492	1753	30 U	B							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 5

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
493	1798	80 U	B							
494	1829	68 U	B		1950	122 D	230	23	22	05
495	1861	92 U	B	Semi Main	1887	094 U	26	21	18	06
496	1869	78 U	B	Edge	1888	076 U	21	22	15	04
497	1899	05 U	B		*1899	049 D	52	29	18	03
498	1952	59 D	B							
499	2399	50 D	B							
500	2578	49 U	B							
501	2792	13 D	B							
502	2856	24 U	B							
503	2891	28 U	B							
504	2987	35 D	B							
505	3057	81 U	B							
506	3288	98 U	B	Hi Point						
507	3277	13 U	B	Bar						
508	3316	12 U	B							
509	3334	23 U	B							
510	3364	74 U	B							
511	3450	06 D	B							
512	3497	34 D	B							
513	3571	26 D	B							
514	3665	08 D	B							
515	3722	104 U	B							
516	3735	78 U	B							
517	3767	34 U	B							
518	3858	06 U	B							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 5

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
519	4125	00	B	Filled chute						
520	4267	55 D	B							
521	4351	45 D	B	Terr. 1/2						
522	4439	125 D	B							
523	4492	87 D	B							
524	4629	175 D	B							
525	4720	190 D	B							
526	4661	263 D	B							
527	4693	272 D	B							

Measured: Aug. 21, 1980
(Aug. 11 event)
Nov. 6, 1980
*(Oct. 25-26 event)

Clast size	Location	Dist. along line	Dist. downstream	Dist. moved ⊥ to line	Clast Size L	I	S
YLC	Near Base-flow Channel (West)	2505	All Downstream	26	5	1.5	1.0
YLC		2427		70	11	8	5
YLC		2399		39	15	7	4
YLC		2354		83	4	2	1.0
YLC		2339		21	9	8.5	1.0
YLC		2299		12	11	7	2

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 5

Clast size	Location	Dist. along line	Dist. downstream	Dist. moved ⊥ to line	Clast Size L	I	S
YLC		2309		30	7	6	4
YLC		2250		71	5	3.5	1.0
YLC		2252		51	6	4	1.0
YLC		2250		20	6	3	2
YLC	Bar Edge (West)	1889		103	12	8	2
YLC		1833		63	8	4	2
YLC		1825		72	11	6	2
YLC		1539		70	4	1.5	1.0
YLC		1650		99	3.5	3	1.0
YLC		1650		97	3	2	0.5
YLC	Bar Top	1524		17	3.5	3	1.5
YLC		1495		16	5	3.5	1.0
YLC		1455		219	5	2.5	1.5
YLC	Bar Edge (East)	1252		28	4	3	1.0
YLC		1218		98	4	2	1.0
YLC		1170		200	3	2	1.0
YLC		1126		230	3	2	1.0
YLC		1084		289	6	4	3
YLC		1080		30	5	3.5	1.5
YLC		1070		360	3	1.5	0.5
YLC		939		371	3.5	3	1.5
YLC		913		376	3.5	3	0.5
YLC		849		363	5	3.5	2
YLC		867		267	5	4	0.5

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 5

Clast size	Location	Dist. along line	Dist. downstream	Dist. moved ⊥ to line	Clast Size L	I	S
YLC		849		244	3	2.5	2
YLC		913		211	7	5	1.5
YLC		939		96	4	3	1.0
YLC		907		58	5.5	4	1.0
YLC	________	874		53	7	5	1.0
YLC		1530		*254	15	11	4
YLC		942		*1229	4	3	1
YLC		675		*2138	4	3	0.5
YLC		2080		*312	5.5	4.5	1.0

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 11

Marked: July 16, 1980
Measured: Nov. 6, 1980
(Oct. 25-26 event)

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	Clast Size I	Clast Size S
530	3236	100 U	B	Edge Bar						
531	3231	152 U	B	Main Channel						
532	3214	173 U	P							
533	3099	53 D	B							
534	3091	10 U	B							
535	3078	38 U	B							
536	3014	55 U	B							
537	2978	07 U	B							
538	2960	144 D	B							
539	2753	134 D	G							
540	2696	116 U	G							
541	2712	123 U	B							
542	2669	142 U	B							
543	2641	122 U	B							
544	2632	166 U	B							
545	2639	47 U	G							
546	2594	98 U	B							
547	2554	69 U	G							
548	2560	09 D	G							
549	2553	38 U	B							
550	2498	19 U	B							
551	2493	40 D	B							
552	2376	94 U	G							
553	2344	53 U	B							
554	2304	92 U	B							
555	2266	158 U	B							
556	2243	164 U	G							
557	2251	142 U	G							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 11

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
558	2246	115 U	G							
559	2265	110 U	B							
555A	2331	05 D	G							
560	2226	130 U	B							
561	2215	104 U	G							
562	2265	76 U	B							
563	2218	39 U	G							
564	2276	15 U	G							
565	2260	13 U	B							
566	2239	00	B							
567	2273	14 D	B							
5[illegible]	2283	53 D	G							
569	2117	88 U	G							
570	2110	25 U	B							
571	2060	38 D	G							
572	1965	29 U	B							
573	1962	00	B							
574	1917	15 D	B							
575	1867	20 U	G	Hi Point Bar						
576	1869	00	B							
577	1854	25 D	B							
578	1827	53 U	G	Highest						
579	1839	152 D	G							
580	missing									
581	1788	136 D	G							
582	1642	13 U	B							
583	1572	31 U	B							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 11

Clast #	Dist. along line	Dist. upstream/ downstream		Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
584	1539	37	D	G							
585	1503	48	U	G							
586	1550	06	D	B							
587	1435	126	U	G							
588	1399	108	U	G							
589	1222	15	D	B							
49	1791	376	D	G							
590	1179	21	D	B							
591	1119	18	U	B							
592	1127	29	D	G							
593	1134	16	D	B							
594	1098	02	D	B							
595	1075	14	U	B							
596	1080	49	D	G							
597	919	48	U	G	2 %						
598	873	53	D	G							
599	809	95	U	G							
600	795	77	U	B							
601	761	09	U	B							
602	702	16	U	G							
603	636	04	U	B							
604	686	44	U	B							
605	712	106	U	B							
606	725	145	U	G							
607	557	10	D	G							
608	461	29	U	B	Chute						
609	456	24	D	B							
610	470	34	D	G							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 11

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
611	415	04 D	B							
612	390	00	B							
613	368	23 U	B							
614	171	167 U	G							
615	160	41 U	B							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 16

Marked: July 16, 1980
Measured: Nov. 6, 1980
(Oct. 25-26 event)

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
630	4203	14 U	B	Near Main Channel	*4203	802 D	816	21	13	02
631	4118	67 U	B							
632	4092	156 U	B							
633	4082	192 U	G							
634	4006	187 U	B							
635	4010	158 U	B							
636	3955	89 U	B							
637	4003	18 U	B							
638	3940	09 U	B							
639	3920	08 D	B		*3910	1070 D	1078	23	09	03
640	3910	10 D	B							
641	3982	49 U	B							
642	3818	138 D	G							
643	3774	145 U	B							
644	3792	131 U	G							
645	3780	90 U	B							
646	3658	24 D	B							
647	3629	00	B		Not Recovered (After Oct. 25-26 event)					
648	3579	30 U	B							
649	3565	19 D	G							
650	3581	13 D	B		1900	2263 D	3168	16	13.5	01.3
651	3522	50 D	B							
652	3369	32 U	B		2948	1507 D	1600	20.5	16	02
653	3343	17 D	G		3310	558 D	531	27	17.5	04
654	3310	46 D	B							
655	3140	22 U	B							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 16

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
656	3120	15 U	G							
657	3065	152 U	B		2920	130 U	330	21	16	01.5
658	3074	149 U	G							
659	2894	114 U	G							
660	2740	78 U	B							
661	2747	66 U	B							
662	2700	63 U	B							
663	2682	42 U	B							
664	2710	08 U	B							
665	2590	07 U	G							
666	2524	57 U	B							
667	2523	03 U	B							
668	2457	12 D	B							
669	2299	151 U	B	Hi Point						
670	2298	119 U	B	Bar						
671	2303	90 U	G							
672	2256	80 D	G							
673	2282	96 D	G							
674	2210	46 D	B							
675	2194	100 D	B							
676	2152	20 D	B							
677	1966	63 U	G							
678	1938	87 U	B							
679	1920	103 U	B							
680	1900	59 U	B							
681	1703	28 U	B							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 16

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
682	1683	00	B							
683	1670	19 D	B							
683A	1616	16 U	B							
684	1578	131 U	B							
685	1274	364 U	G	Swale						
686	1175	344 U	G							
687	1179	279 U	G							
688	1156	298 U	B							
689	1113	295 U	G							
678A	1979	85 U	B							
690	1158	227 U	G							
691	1160	197 U	G							
692	1177	152 U	G							
693	1156	110 U	B							
694	1211	64 U	G							
695	1195	15 U	G							
696	1132	22 U	G							
697	1118	34 U	B							
698	1110	55 U	B							
699	1077	37 D	B							
700	1068	53 D	G							
701	840	80 U	B							
702	858	46 U	B							
703	836	04 D	G							
704	897	25 D	B							

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 16

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. upstream/ downstream	Dist. moved	Clast Size L	I	S
705	881	61 D	G							
706	808	43 U	B							
707	773	116 U	G	Chute						
708	749	33 U	B							
709	734	22 U	B							
710	724	127 U	B							
711	687	77 U	G							
712	579	14 U	B							
713	563	28 D	B							
714	544	08 D	B							
715	602	89 U	B							
716	596	52 U	G							
717	476	13 U	B							

Measured: Aug. 21, 1980
(Aug. 11 event)
Nov. 6, 1980
*(Oct. 25-26 event)

Clast size	Location	Dist. along line	Dist. downstream	Dist. moved ⊥ to line	Clast Size L	I	S
YLC	Near Base-Flow Channel	3882	All Downstream	18	6	5	2
YLC		3623		19	8	6	2
YLC		3530		177	3	2	1.0
YLC		—		200	5	4	1.0

CLAST MOVEMENT STATIONS
BAR COMPLEX 4-6

Transect 16

Clast #	Dist. along line	Dist. upstream/ downstream	Clast size	Location	Dist. along line	Dist. downstream	Dist. moved ⊥ to line	Clast Size L	I	S
			YLC		3706		218	7	6	1.0
			YLC		4060		599	18	9	1.0
			YLC		3629		996	9	7	1.5
			YLC	Shoulder of Bar	3310		1314	7	4	1.0
			YLC		3196		1472	5	3	1.0
			YLC		3205		1480	4	3	1.0
			YLC		3140		1499	2	1.5	0.5
			YLC		3211		1477	1.5	1.0	0.5
			YLC		3283		1540	2.5	2	1.0
			YLC		3310		1966	8	7	1.0
			YLC		3581		1807	5	3	1.0
			YLC		3056		1722	7	5	3
			YLC		2523		2676	5	4	2
			YLC		1979		*2568	9	6.8	1.3

APPENDIX F

Clast Movement Station
Transect 5, Bar Complex 4-6

Figure F1-4. Bar top, east side.
Sequence is from east (F1) to west (F4). Large marked clasts are light gray (green), medium are dark gray (blue), and transect line is white (yellow). Photos taken July 15, 1980.


F1


F2


F3


F4

C FORM 335 U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG/CR-2862

TLE AND SUBTITLE *(Add Volume No., if appropriate)*
eomorphic Processes and Evolution of Buttermilk Valley nd Selected Trubutaries West Valley, New York

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

UTHOR(S)
.C. Boothroyd, B.S. Timson, L.A. Dunne

5. DATE REPORT COMPLETED
MONTH June | YEAR 1982

ERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
ew York State Geological Survey/State Museum
ew York State Education Department
lbany, New York 12230

DATE REPORT ISSUED
MONTH July | YEAR 1982

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Division of Health, Siting, and Waste Management
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.
FIN B6350
NRC-04-79-105

TYPE OF REPORT

PERIOD COVERED *(Inclusive dates)*

SUPPLEMENTARY NOTES

14. *(Leave blank)*

ABSTRACT *(200 words or less)* Repetitive bar and channel mapping at several scales, clast size and vement measurements, suspended-sediment sampling, and stream gaging of a 5 km reach of ttermilk Creek and selected tributaries at West Valley, New York, were performed to dermine short-term depositional and erosional processes, and long-term valley changes in e vicinity of the Western New York Nuclear Service Center. Changes to bar-and-channel ometry in Buttermilk Creek result from migration of large transverse bars in equilibrium th large floods (i.e. Hurricane Fredric, September 1979) with large amounts of lower rrace gravels being recycled. Downslope movement of landslides by slumping and earthow is a continuous small volumetric sediment source, except for infrequent large scale avity block deposits. Bedload transport, suspended-load sediment transport, and reserir infill rates compare well with the denudation rate (6600 m^3yr^{-1}). Middle-to highel fluvial terraces in Buttermilk Creek are either adjacent to tributary confluences and eserved by an excess of bedload over transport capacity, or survive due to the stable annel on the opposite side of the valley for unknown reasons. Convex longitudinal prole of Franks Creek/Erdman Brook suggests instability with continued rapid downcutting. lley widening occurs by parallel slope retreat. Future lowering of Buttermilk Creek is ntrolled by bedrock floors in Cattaraugus Creek and lower Buttermilk Creek. Tributary wering and widening will continue independent of Buttermilk Creek base level changes.

KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

geomorphology, fluvial processes, sedimentation, landslide, glacial

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