UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

Project Report No. 425

Hydraulic Model Study for Homme Dam Safety Improvements Park River, North Dakota

Conducted for
U.S. Army Corps of Engineers
St. Paul District

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University of Minnesota
St. Anthony Falls Laboratory
and
Barr Engineering Company
Minneapolis, Minnesota

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Table of Contents

Table of Contents (continued)

List of Tables

List of Figures

Table of Contents (continued)

Appendix

1.0 Executive Summary

This report presents the results of a physical model study of the Homme Dam spillway and outlet channel protection. The objectives of the study were to verify the adequacy of the proposed outlet-channel riprap protection, recommend and verify the adequacy of more economical riprap protection, and determine the spillway rating curve. The model study was conducted for the St. Paul District of the Corps of Engineers (COE) at the St. Anthony Falls Laboratory, University of Minnesota.

The study used a 1-to-25-scale model of a center section of the spillway and outlet channel. Two outlet channel protection designs were tested. The study showed that the proposed outlet channel protection (Design 1) withstood the probable maximum flood (PMF) without damage to the spillway structure and with only minor damage to the outlet channel protection. A more economical design of the outlet channel protection (Design 2) was proposed and tested; this design withstood the PMF without damage to the spillway and with only minor damage to the outlet channel protection. The estimated cost savings of implementing Design 2, as compared to Design 1, is $206,000.

Additionally, the spillway rating curve was determined in the model facility by measuring water surface elevations in the approach channel for various discharges. The rating curve measured with the model is similar to that computed by the COE.

2.0 Introduction

The Homme Dam is located on the Park River in northeastern North Dakota's Walsh County, approximately two miles west of the City of Park River. The existing earthen dam and spillway were built in 1950. The existing spillway was designed for a discharge of 23,500 cfs, which is 44 percent of the maximum discharge during the PMF. Based on current dam-safety criteria, it was recommended that the spillway capacity at Homme Dam outlet structures be modified to discharge 53,400 cfs, which is the maximum discharge during the PMF. Modifying the existing spillway was rejected for geotechnical reasons. Therefore, a new structure will be built in the middle of the embankment and the old spillway will be abandoned.

The design of the proposed spillway and outlet channel is included in a Design Memorandum (Reference 1). The proposed spillway consists of a 218-foot-wide reinforced-concrete ogee crest, spillway chute, and stilling basin. The crest for the proposed spillway will be at the same elevation as the existing spillway (elevation 1080). The rectangular spillway chute has an initial slope of 1-to-10 for about 100 feet that changes to 1-to-3 for about 220 feet. The 75-foot-long stilling basin contains two rows of 4.5-foot-high baffle blocks for energy dissipation and a 2-foot-high sloping end sill. The outlet channel protection consists of a riprap-lined trapezoidal channel.

Since the PMF is an extremely rare and relatively short-term phenomenon, the outlet channel protection need not be designed to tolerate the maximum discharge during the PMF for an extended period of time. In addition, since the ultimate objective is protecting the spillway structure itself, some damage to the outlet channel can be tolerated during the PMF. Construction costs can be lowered by using outlet channel protection, which is less extensive than the channel protection required to withstand the maximum discharge during the PMF for an extended period of time. The COE has therefore redesigned the outlet channel protection. This redesigned channel protection requires less riprap than that proposed in the Design Memorandum.

Since limited criteria are available for the channel protection design for short-term and unsteady events, a model study was recommended to verify the proposed channel design. A 1-to-25-scale section model of the spillway and outlet channel was constructed at the University of Minnesota's St. Anthony Falls Laboratory. The model was constructed to represent the center 78 feet of the spillway and the downstream outlet channel. Figure 1 shows the domain of the model as a portion of the spillway and outlet channel.

Two outlet channel protection configurations were tested in the model. The first, Design 1, was developed by the COE using standard design criteria. This outlet channel design consists of a riprap-lined trapezoidal channel that slopes upward at 4 percent for a distance of 205.6 feet and then downward at 0.47 percent to meet the natural riverbed. Figure 1 shows a plan view of the spillway and outlet channel, and Figure 2 shows the profile view of the Design 1 outlet channel protection. Figure 3 shows the Design 1 riprap as installed in the model.

The second channel protection configuration tested, Design 2, was developed by observing the behavior of Design 1 in the sectional model. Figure 4 shows the profile view of the Design 2 outlet channel protection. Figure 5 shows the Design 2 riprap as installed in the model.

Design 1 was tested with the model using step-wise flows for the appropriate time duration to reflect the PMF hydrograph. Design 1 withstood the PMF without damage to the spillway structure and with very little degradation in the outlet channel. The more economical design of the outlet channel protection, Design 2, was therefore tested. In Design 2, 175 lineal feet of riprap was eliminated. Design 2 was tested on a fully erodible channel bed and successfully protected the spillway structure from damage. Degradation of the channel downstream of the protection did occur, but an equilibrium was reached. The most downstream riprap experienced some unraveling; however, the riprap moved downstream and armored the scour slope, thereby protecting further upstream damage.

In this report all dimensions (length, time and discharge) are reported as prototype dimensions to maintain consistency and provide for comparison. In addition, riprap gradations are referred to by the prototype size of the maximum stone diameter in the gradation. For example, the riprap referred to as 30-inch riprap contains stone sizes that vary from 16 inches in diameter to 30 inches in diameter.

3.0 Methods Used

3.1 Model Design

A physical model representing the center 78-foot-wide section of the proposed 218-foot-wide spillway was constructed. Longitudinally, the model extended from the approach channel to the natural riverbed. The model was constructed at a 1-to-25 geometrical scale without distortion. Because gravity and inertial forces are predominant, the Froude number similarity is used (i.e., the model and the prototype Froude numbers are identical). This similarity allows the scale ratios of several flow parameters to be determined, such as:

Length: $\ell_r = \dfrac{\ell_{MODEL}}{\ell_{PROTOTYPE}} = \dfrac{1}{25} = 0.04$

Flow: $Q_r = \left(\ell_r^{5/2}\right)\left(\dfrac{78'}{218'}\right) = \left(0.04^{5/2}\right)\ (.3578) = 1.145x10^{-4}$

Velocity: $U_r = \sqrt{\ell_r} = \sqrt{0.04} = 0.2$

Time: $t_r = \sqrt{\ell_r} = \sqrt{0.04} = 0.2$

An important feature of this study was the modeling of the complete hydrograph for the PMF. The above discharge and time relationships were used to scale the PMF hydrograph, which was further approximated into 15- and 30-minute steps, each of a constant discharge. The PMF hydrograph is shown in Figure 7. The 50-year and 130-year flood hydrographs are included for reference in the Appendix (Figures A-1 and A-2).

For the 1-to-25 scale model, the Reynolds numbers in the model are about 1/122 of prototype Reynolds numbers. In the outlet channel, the prototype Reynolds number during the PMF peak discharge is on the order of:

$$\mathrm{Re} = \frac{VL}{\upsilon} \approx \frac{Q}{B\upsilon} \approx \frac{53400}{218 * 10^{-5}} = 2.4\mathrm{x}10^{7}.$$

The model Reynolds number is therefore about 196,000, meaning the model will exhibit fully rough, turbulent characteristics.

The riprap used in the model study was scaled using a Shields stress comparison. The equation of the bed shear stress (τ_b) is assumed to be:

$$\tau_b = \rho C_f U^2$$

where ρ is the water density, U the average flow velocity, and C_f is a bed friction factor. The dimensionless Shields stress τ^* is:

$$\tau^* = \frac{\tau_b}{(\rho_s = \rho) g D}$$

where ρ_s is the sediment density, g is the acceleration of gravity, and D is the particle diameter. The Shields Stress provides a dimensionless measure of the ratio of the drag force on the particle due to the flow and the force resisting movement of that particle. If the model is to predict riprap movement, the dimensionless Shields stress (τ^*) must be the same in the model and the prototype. Assuming that the friction factor is the same in the model as it is in the prototype, the scale ratio for the riprap diameter can be found.

$$\frac{\rho C_f U^2{}_{PROTOTYPE}}{(\rho_s - \rho) g D_{PROTOTYPE}} = \frac{\rho C_f U^2{}_{MODEL}}{(\rho_s - \rho) g D_{MODEL}}$$

Rearranging and simplifying:

$$\frac{D_{MODEL}}{D_{PROTOTYPE}} = \left(\frac{U_{MODEL}}{U_{PROTOTYPE}} \right)^2$$

Since the velocity scale ratio is:

$$\frac{U_{MODEL}}{U_{PROTOTYPE}} = U_r = \sqrt{\ell_r}$$

Substituting the velocity scale ratio and simplifying yields:

$$D_{MODEL} / D_{PROTOTYPE} = \ell_r$$

Therefore, the riprap scale ratio is the same as the length ratio: 1 to 25. The model particle gradations (scaled to prototype dimensions) are compared to the prototype riprap gradations and shown on Figures 8 through 10. Rounded particles were used as model riprap.

The bedding material and channel sediment underlying the riprap was scaled in a similar manner. The bedding material and sediment gradations are shown on Figures 11 through 14.

The model data are scaled to prototype dimensions for comparison with the actual riprap, bedding, and sediment material. It is apparent that material used in the model is slightly larger and is not as well graded as the field material. The larger mean particle size would reduce the mobility of the model material. Incipient movement would occur at a comparatively higher flow velocity in the model than in the prototype. The use of a more uniform sediment in the model, however, tends to slightly exaggerate the local scour.

The model was used to determine a spillway rating curve by measuring the water surface elevation in the approach channel for various discharges. Staff gages were used to obtain water depths at two lateral locations upstream of the crest—a distance approximately seven times the depth upstream of the crest. The velocity head, h_v, was then calculated using the following equation:

$$h_v = \frac{U^2}{2g} = \frac{\left(\frac{Q}{By}\right)^2}{2g} = \frac{Q^2}{2gB^2y^2}$$

where U is the mean velocity, g is the acceleration of gravity, B is the channel width, and y is the water depth. The sum of the water surface elevation and the velocity head was then plotted against the corresponding discharge.

The model was designed to operate with river water. Inflows were monitored with a calibrated orifice and manometers. The tailwater was controlled using a gate at the downstream end of the model.

For experiment 2, it was assumed that the consolidated till layer shown in the data (Reference 1) was non-erodible. To simulate this non-erodible stratum, the sand was leveled at the required elevation, then stabilized by dusting with Portland cement. This cement blanket was then covered with compacted sand to simulate the erodible channel bottom.

3.2 Model Construction

The model was built according to coordinates and dimensions obtained from drawings provided by the COE (Reference 1.) Dimensional lumber was used as the primary construction material. The ogee crest was constructed using a flexible sheet metal to allow molding for a smoother, more correctly shaped crest. One outlet channel side wall was made using three-quarter-inch-thick Lucite Plexiglas so that a profile view of the outlet channel could be seen.

4.0 Basis for Design

4.1 Experiment 1

The objective of the first experiment was to determine the discharge at which the riprap would begin to advance downstream. The riprap configuration was as shown in Figure 2 (Design 1), except that geotextile was used rather than granular filter. The geotextile was used to reduce the amount of material lost in the event of a sudden riprap failure. A bulkhead was constructed as part of the model at the downstream end of the riprap (Station 8+00). Discharges representing the PMF hydrograph were passed through the model, beginning at 17,000 cfs (Time = 30 hrs), continuing through the PMF peak, and receding to 35,000 cfs (Time = 65 hrs). The experiment was terminated at this time, since it was visually apparent that no additional riprap movement would occur.

4.2 Experiment 2

These changes were made to the model in preparation for the second experiment:

- The bulkhead at Station 8+00 was removed and replaced with compacted sand.
- Granular bedding material was used to more accurately model the design conditions.
- A non-erodible horizontal stratum was placed at elevation 1023. This stratum was meant to model the consolidated till layer that is present under the alluvial channel sediment. The presence of this stratum is based on information provided by the COE (Reference 1). The elevation of this horizontal layer was chosen by the COE staff. The alluvial sediment above this layer was modeled with compacted sand. Figure 14 shows the sand gradation.

4.3 Experiment 3

The final experiment tested the more economical outlet channel protection. This riprap configuration (Design 2) is shown on Figure 4. Features of this configuration include:

- Channel protection between the spillway and station 5+00 remains as previously proposed.
- A 30-inch-thick riprap blanket consisting of riprap with a maximum size of 24 inches was placed between stations 5+00 and 5+25.
- An 18-inch-thick riprap blanket consisting of riprap with a maximum size of 12 inches was placed between stations 5+25 and 5+50.

Also, the non-erodible stratum was removed and the entire bed was replaced with material that would represent the alluvial channel sediment. The gradation of the channel sediment is shown in Figure 14.

5.0 Results

5.1 Experiment 1

In general, the riprap successfully sustained all discharges within the PMF hydrograph. Experimental observations include:

- At the interface of the 24-inch and 12-inch riprap, some of the smaller rock was uplifted and moved downstream. This is shown in a photograph (Figure 15).
- Bulkhead downstream of the riprap may have prevented downstream movement of the riprap.

5.2 Experiment 2

Significant riprap failure did not occur during the PMF. Experimental observations include:

- The sand representing the alluvial channel sediment scoured to the level of the non-erodible till.
- The 12-inch riprap armored the scour slope to form a roughly 10-degree slope angle.
- The smaller individual rocks within the 30-inch riprap blanket just downstream of the spillway was observed to flutter or vibrate during the peak discharges.

The final scour profiles are shown on Figure 2. The data used to develop these profiles is contained in the Appendix. A photograph (Figure 16) shows the downstream edge of the riprap and scour slope.

5.3 Experiment 3

Significant riprap failure did not occur during the PMF. Experimental observations include:

- At the discharge of approximately 17,000 cfs, very little bed movement was observed. For reference, this discharge is greater than the peak discharge of 11,000 cfs, which would occur in the 130-year flood event.
- At the discharge of approximately 24,000 cfs (more than twice that of the 130-year event), the initial formation of a scour hole downstream of the riprap protection was visible.
- At the discharge of approximately 45,400 cfs (85 percent of the PMF peak discharge), scouring of the channel sediment particles continued, but the 12-inch riprap remained stationary.
- At the peak discharge of 53,400 cfs, scour depths of approximately nine feet were observed less than 50 feet downstream from the channel protection. Scour depths of approximately seven feet deep were observed more than 50 feet downstream of the channel protection.
- Scour depths were observed to be deeper adjacent to the model side walls than in the center of the channel.
- Only the 12-inch riprap moved significantly.

Figure 6 shows the change in scour-depth profile elevations along the left wall as a function of time. Figure 4 shows the final scour-depth profiles at each wall and at the center of the channel. Figures 17a and 17b show the final scour at several cross sections. The data used to develop these profiles and cross sections is contained in the Appendix. A photograph (Figure 18) shows the downstream edge of the riprap.

5.4 Spillway Rating Curve

The stage-discharge spillway rating curve was determined by using the model facility. Figure 19 shows the measured rating curve in addition to the rating curve computed by the COE. The data used to develop this rating curve is contained in the Appendix.

5.5 Videotape

A 16-minute videotape supplements this report.

5.6 Cost Savings

The construction cost savings were computed by comparing the cost of the Design 1 outlet channel protection to the cost of the Design 2 outlet channel protection. Approximately $206,000 would be saved by implementing Design 2. The cost computation is shown in Table 1. The cost comparison used the unit prices found in Reference 1. The quantity of each riprap and bedding material is based on the width of 228 feet and the length and layer thickness shown in Figures 2 and 4. The riprap on the channel side slopes is assumed to remain as part of the outlet channel protection.

6.0 Discussion

Three experiments were conducted for three different riprap and bedding configurations. All the experiments modeled the effect of the PMF on the channel protection. The protection was judged adequate if no damage occurred to the spillway during the PMF. Damage could occur to the channel protection without endangering the spillway during the PMF. Some of the channel protection is considered to be sacrificial during the PMF. Additionally, to avoid frequent maintenance, no damage should be allowed to the channel protection during large flood events, such as the 130-year flood.

6.1 Experiment 1

Observations during the first experiment indicated that some of the 12-inch riprap near the interface with the 24-inch riprap was uplifted and moved downstream. This failure of the 12-inch riprap may be due to the larger scale turbulence associated with the larger riprap just upstream of the interface. Therefore, scour may be promoted by a sudden transition from large to small riprap or from riprap to the natural channel sediment. Gradually reducing the riprap size from the large size necessary just downstream of the stilling basin to the natural channel may be a prudent design criterion.

The most downstream riprap blanket was held in place by the bulkhead at the end of the experimental facility. Failure of the 12-inch riprap may have been prevented by this immovable and unerodible boundary condition. For failure of the riprap to occur, the riprap would need to be lifted over the bulkhead, not merely rolled downstream.

6.2 Experiment 2

Observations during the second experiment indicated that the channel bed downstream of the channel protection could scour during the PMF. This scour may proceed to the consolidated till stratum. As this erosion occurred in the model, the 12-inch riprap apparently rolled downstream and armored the scour slope. The resulting slope was observed to be about 10 degrees. Further headcutting or undercutting of the riprap was stopped by this armoring. The Design 1 channel protection adequately protected the spillway with little damage to the channel protection.

As shown in Figure 10, the gradation used for the 12-inch riprap in the model is slightly smaller and is more uniform than the riprap which will be installed in the field. The smaller size will result in incipient motion at a lower velocity than in the field. The behavior of the 12-inch riprap in the model is, therefore, conservative.

As shown in Figure 14, the gradation of the material used to model the channel sediment is larger and more uniform than the actual channel sediment. Scour will, therefore, begin at lower velocities in the field than indicated by the model. Due to the uniformity of the sediment in the model, scour may be exaggerated in the model. During experiment 2, the channel material downstream of the riprap scoured to the non-erodible till. The sediment size difference would, therefore, not alter these results.

It was observed during both of the first two experiments that the smaller particles of the riprap placed just downstream of the stilling basin would occasionally vibrate or flutter. As shown in Figure 8, the gradation of this material is slightly coarser than that in the prototype. Incipient motion of the riprap particles would, therefore, be more likely to occur in the prototype than in the model. Although none of that riprap moved in the model during the PMF, this observation indicates that a smaller gradation in this area might fail.

6.3 Experiment 3

The observations and data gathered during the first two experiments were used to develop criteria for the development of a more economical channel protection design. These criteria are:

- Adjacent riprap blankets should not differ greatly in size. Large riprap should not be placed adjacent to the natural channel bottom, but rather a gradual transition should be made from large- to small-size riprap to the natural channel.

- Because erosion of the channel downstream of the protection could occur, the riprap farthest downstream should be expected to be sacrificed during the PMF.
- The riprap size immediately downstream of the stilling basin is adequate but should not be further reduced.

A profile of the Design 2 channel protection configuration is shown on Figure 4. The major features of this configuration are:

- A 45-inch blanket of 30-inch maximum-size riprap with proper filters should be installed from the downstream edge of the stilling basin to station 5+00. Station 5+00 is the location of a concrete cutoff wall and the downstream end of the 4 percent adverse slope.
- A 30-inch blanket of 24-inch maximum-size riprap with proper filters should be installed between stations 5+00 and 5+25.
- An 18-inch blanket of 12-inch maximum-size riprap with proper filters should be installed between stations 5+25 and 5+50.

The Design 2 channel protection configuration was placed on a fully erodible bed of material that modeled the channel alluvial sediment. The modeling indicated that the Design 2 channel protection configuration performed adequately during the PMF. Scour of the channel bottom occurred downstream of the protection. The scour was somewhat deeper 50 feet downstream of the protection than it was 100 feet downstream. This may be due to the large-scale turbulent eddies generated by the stilling basin and by the riprap. As the flow progresses downstream, these large turbulent eddies decay and their ability to scour the sediment diminishes. The most downstream blanket of riprap acted sacrificially and armored the scour slope. As noted before, the material used to model the 12-inch riprap is smaller and more uniform than the prototype material (see Figure 10). The behavior of the most downstream blanket of riprap is, therefore, conservative.

As much as 12 feet of scour occurred downstream of the channel protection near the channel walls, while as much as 9 feet of scour was observed near the center of the channel. The scour near the walls could be the result of wall effects that might not be present in the prototype. The observed scour in the center of the channel might better represent the scour that would occur in the natural channel. The elevation of this scour is about 1022, which coincidentally is approximately the elevation chosen for modeling the consolidated till stratum in experiment 2. As shown in Figure 14, the material used to model the channel sediment is slightly larger and more uniform than the actual material in the field. The uniformity of the material will tend to exaggerate the scour depth, whereas the larger sediment size may tend to reduce the scour depth.

The Design 2 channel protection configuration tested in the third experiment performed adequately during the PMF even though the downstream channel was allowed to scour deeper than would probably actually occur in the natural channel. It was also observed that the sediment used to model the natural channel did not erode at the discharge of 17,000 cfs, which is greater than the 130-year flood discharge (11,000 cfs).

6.4 Spillway Rating Curve

The spillway rating curve measured in the model was developed using the actual water-surface elevation measurements and the velocity head computed from the measured discharge. Contraction losses that would occur in the prototype were not computed or included. Contraction losses will slightly increase the pool stage for a given discharge. This rating curve consistently predicts slightly higher pool stages than those computed by the COE using estimated coefficients.

7.0 Conclusions

The following conclusions are based on this physical model study of the Homme Dam spillway and outlet channel:

7.1 Design 1 Outlet Channel Protection

- The Design 1 outlet channel protection will adequately protect the spillway during the PMF.
- Scour may occur downstream of the outlet channel protection during the PMF.
- If scour does occur downstream of the outlet channel protection, the riprap will prevent additional headcutting. Only the most downstream 50 feet of riprap will be displaced. The displaced riprap may armor the scour slope at its angle of repose.

7.2 Design 2 Outlet Channel Protection

- The Design 2 outlet channel protection will adequately protect the spillway during the PMF.
- Scour up to 9 feet in depth may occur downstream of the channel protection during the PMF.
- If scour occurs downstream of the outlet channel, the riprap will prevent additional headcutting. Only the most downstream 25 feet of the riprap may be displaced. The displaced riprap may armor the scour slope.
- Little scour will occur in the channel downstream of the channel protection during a discharge of 17,000 cfs, which is greater than the 130-year flood event. At this discharge, no damage to the riprap protection will occur.

7.3 Cost Savings

- The cost savings realized when comparing Design 2 channel protection to the Design 1 channel protection is approximately $206,000.

7.4 Spillway Rating Curve

- The spillway rating curve, as determined by the model, predicts a slightly higher upstream stage for a given discharge when compared to a rating curve computed with estimated coefficients.

8.0 References

1. Design Memorandum and Environmental Assessment, Homme Dam, Park River, North Dakota, Dam Safety Assurance Program, U.S. Army Corps of Engineers, September 1996.

Tables

Table 1

Homme Dam Cost Comparison

Design 1					
Location	Material	Thickness (ft)	Length (ft)	Cost per cubic yard ($)	Cost $
Sta. 294.44-500.00	30" riprap	3.75	205.56	49.70	323,517
	B3 bedding	1	205.56	40.70	70,649
	Filter 3 bedding	0.5	205.56	26.00	22,566
Sta. 500.00-590.00	30" riprap	2.5	90	49.70	94,430
	B3 bedding	1	90	40.70	30,932
Sta.590.00-606.25	30" riprap	2.5	5.25	49.70	5,508
	30" riprap	1.75	5.25	49.70	3,856
	30" riprap	6	5	49.70	12,591
	30" riprap	2	6	49.70	5,036
	30" riprap	2	6	49.70	5,036
	B3 bedding	1	21.875	40.70	7,518
Sta. 606.25-665.00	24" riprap	2	58.75	46.80	46,436
	B3 bedding	1	58.75	40.70	20,192
Sta. 665.00-725.00	12" riprap	1	60	43.3	21,939
	B1 bedding	0.5	60	33.3	8,436
				Total Cost	$678,642

Design 2					
Location	Material	Thickness (ft)	Length (ft)	Cost per cubic yard ($)	Cost ($)
Sta. 294.44-500.00	30" riprap	3.75	205.56	49.70	323,517
	B3 bedding	1	205.56	40.70	70,649
	Filter 3 bedding	0.5	205.56	26.00	22,566
Sta. 500.00-525.00	24" riprap	3	25	46.80	29,460
	B3 bedding	1	25	40.70	8,592
Sta. 525.00-550.00	12" riprap	1.5	25	43.3	13,712
	B1 bedding	0.5	25	33.3	3,515
				Total Cost	$472,191

Design 1 Total Cost =	$678,642
Design 2 Total Cost =	$472,191
Cost Savings =	$206,451

Note: Costs are based on channel bottom width of 228 feet and unit prices listed in Reference 1.

Figures

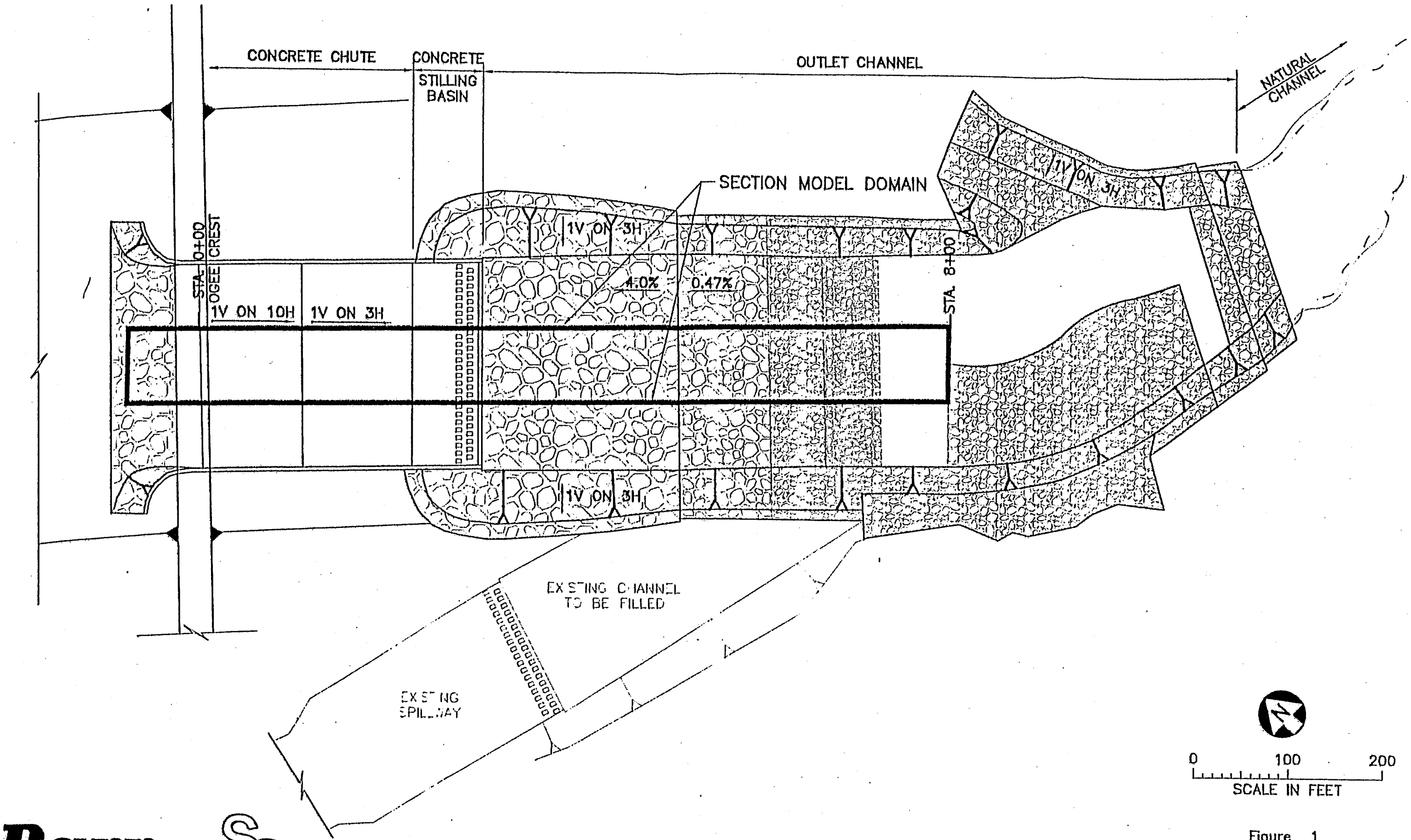

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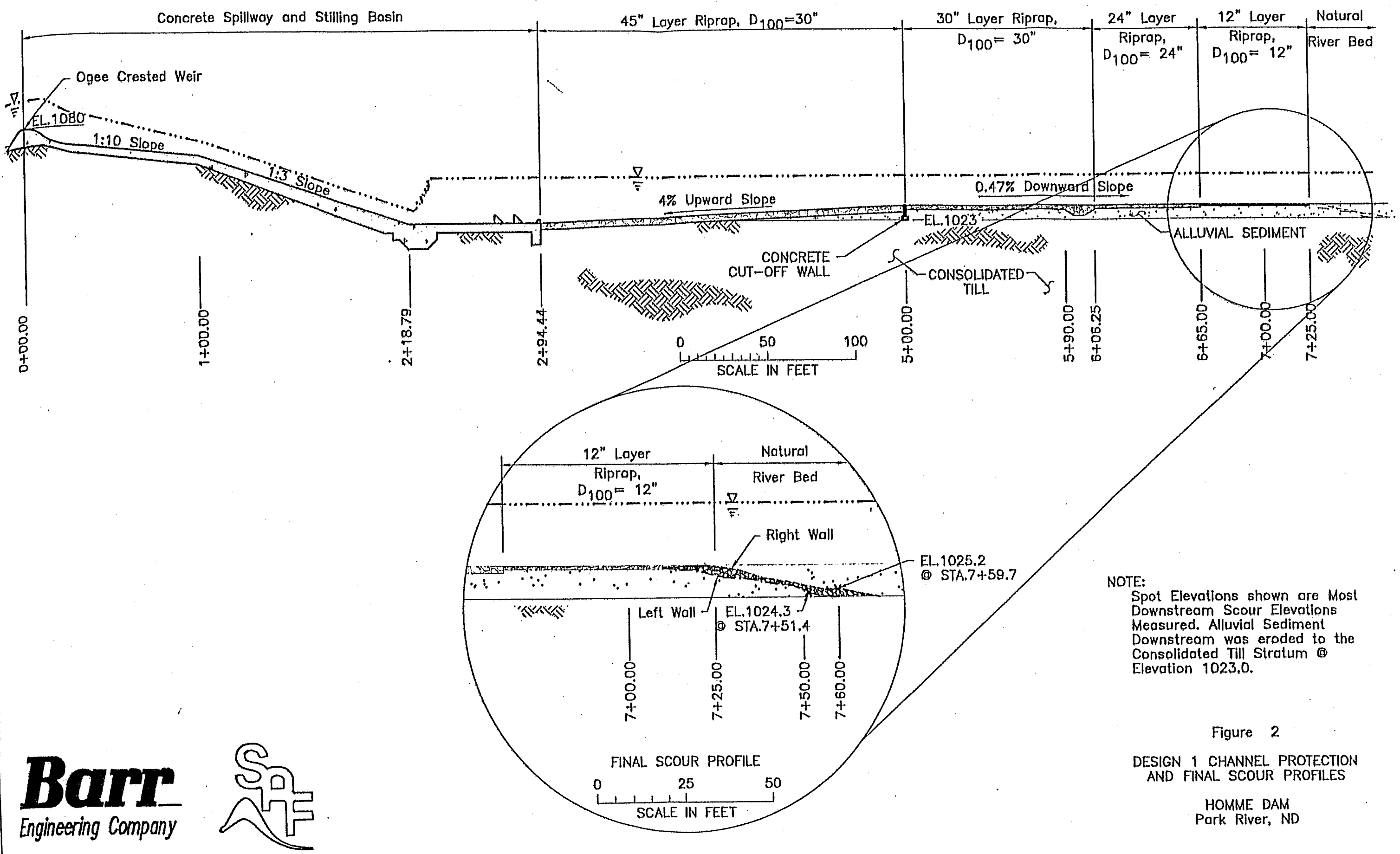
Figure 1

PLAN VIEW

HOMME DAM
Park River, ND

8800_1.DWG 50.00 06/01/1998 14:52:26



NOTE:
Spot Elevations shown are Most Downstream Scour Elevations Measured. Alluvial Sediment Downstream was eroded to the Consolidated Till Stratum @ Elevation 1023.0.

Figure 2

DESIGN 1 CHANNEL PROTECTION AND FINAL SCOUR PROFILES

HOMME DAM
Park River, ND

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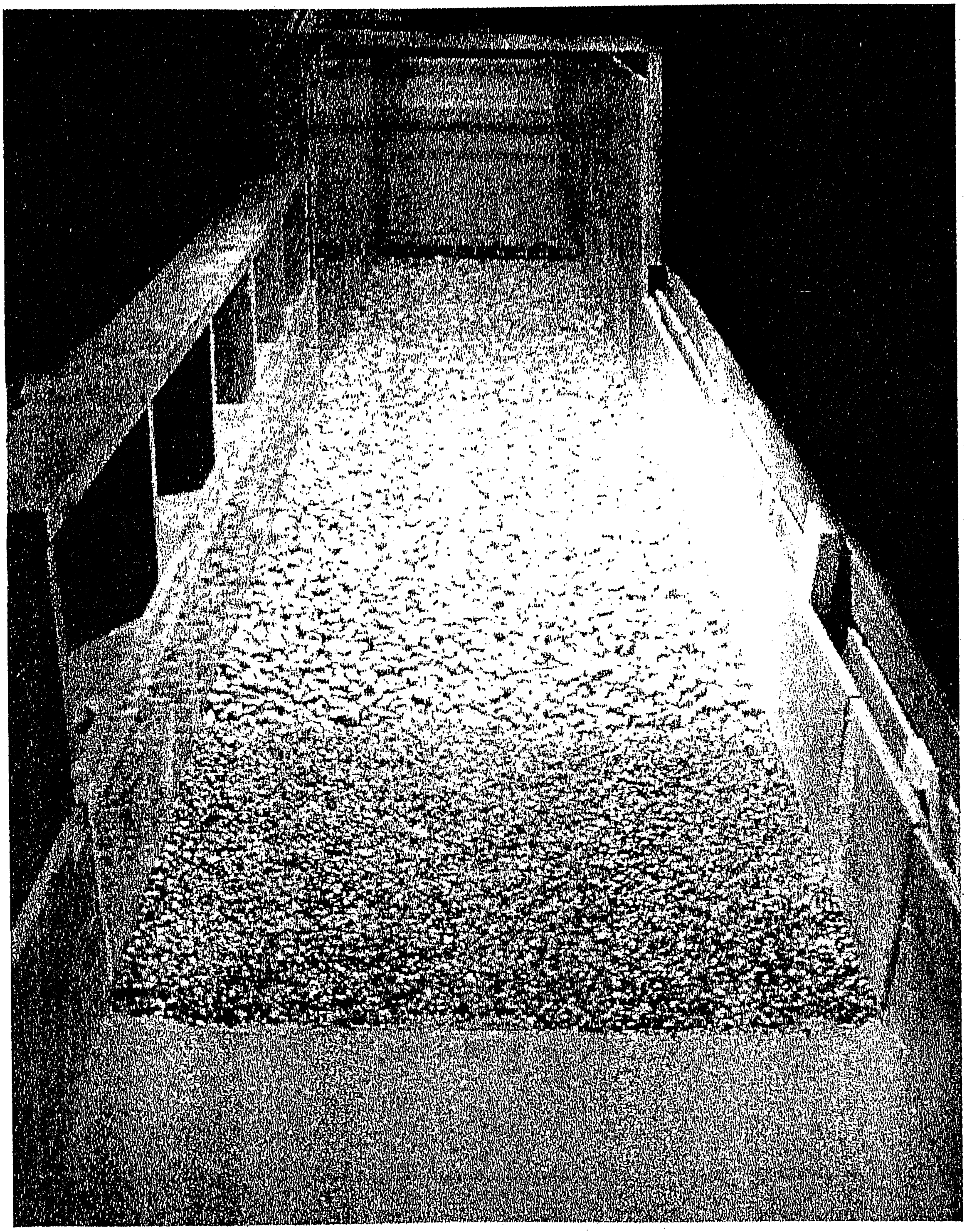

Design 1 Channel Protection

Figure 3

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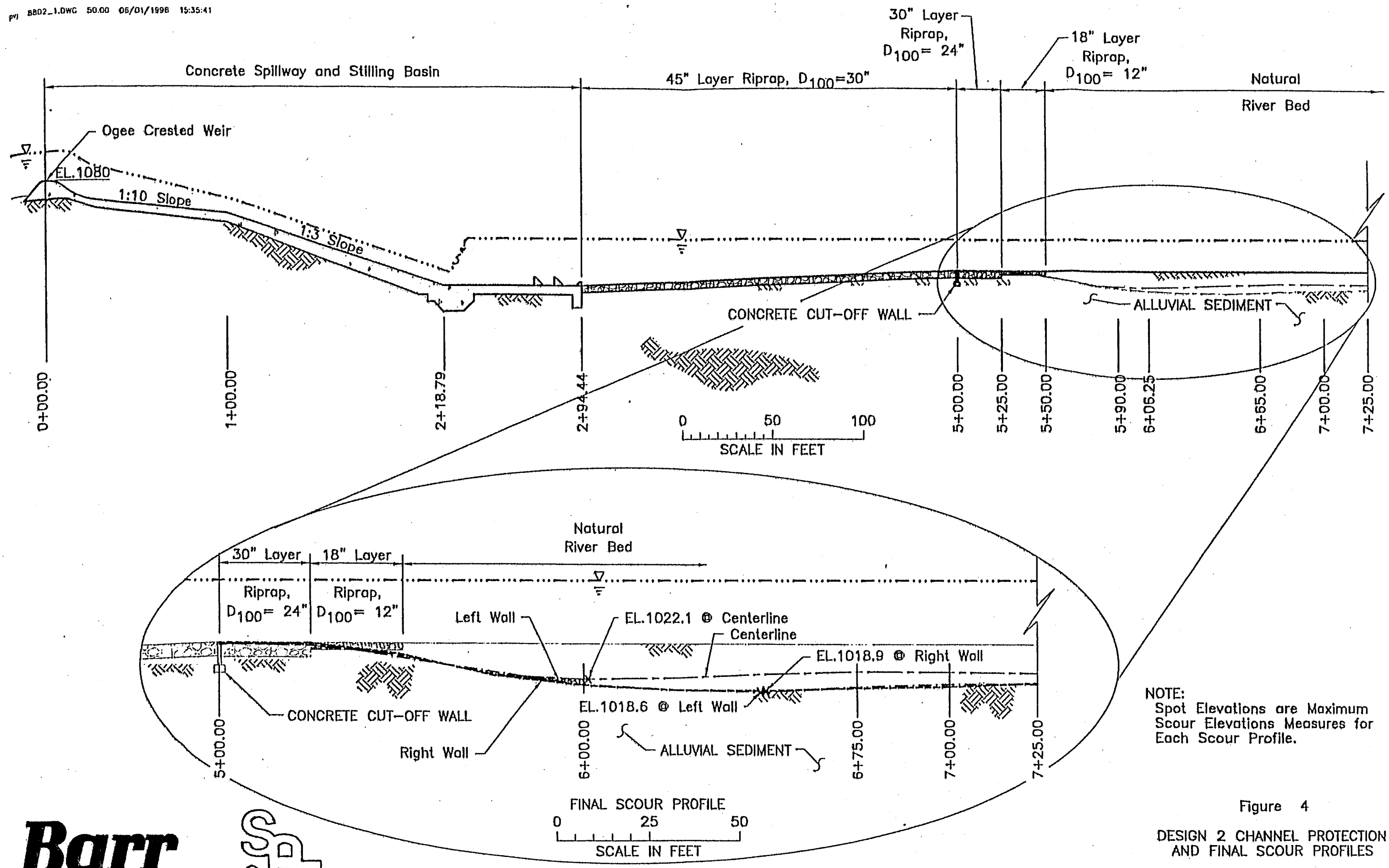

NOTE:
Spot Elevations are Maximum Scour Elevations Measures for Each Scour Profile.

Figure 4

DESIGN 2 CHANNEL PROTECTION
AND FINAL SCOUR PROFILES

HOMME DAM
Park River, ND

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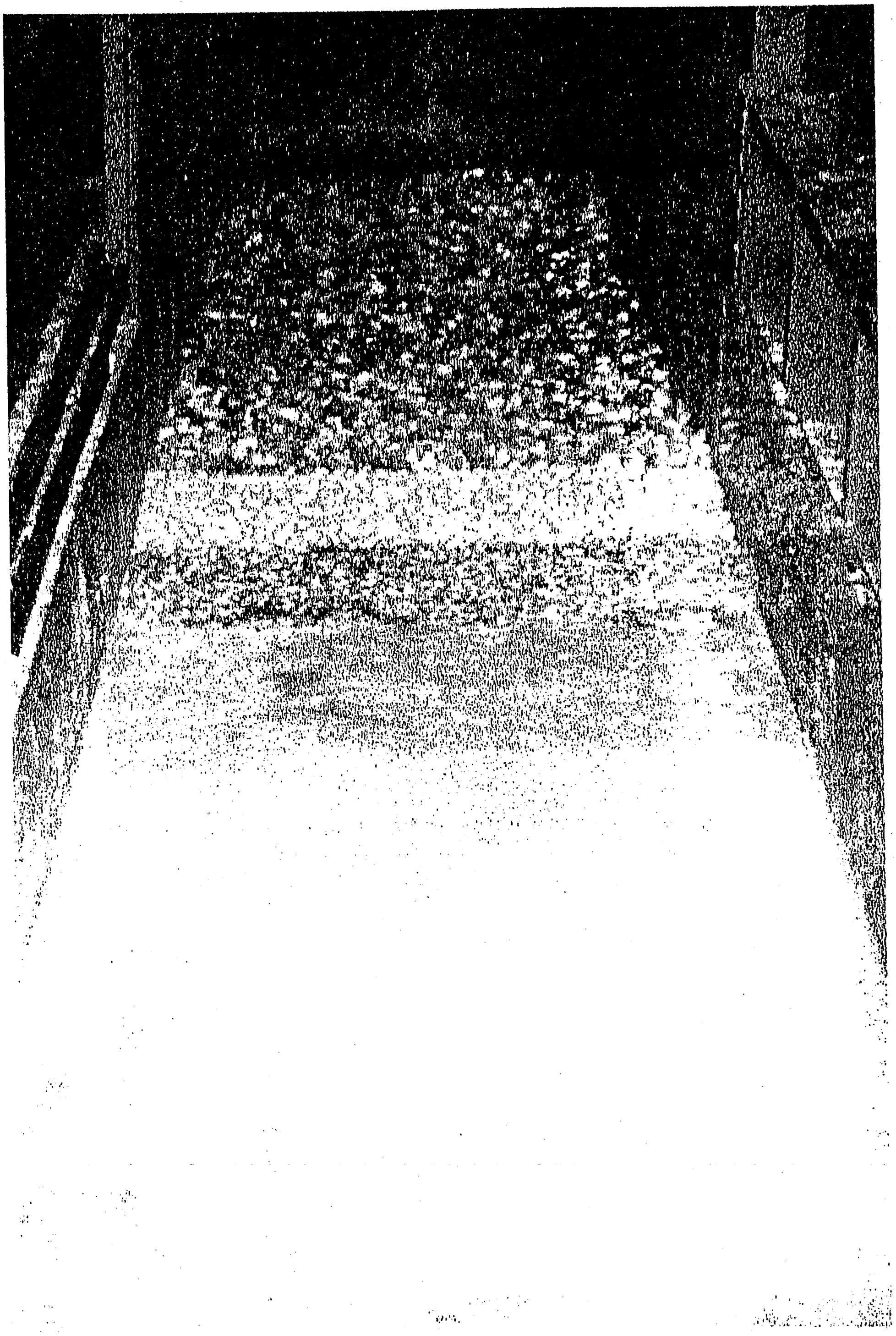

Overhead View Looking Upstream at the Design 2 Channel Protection

Figure 5

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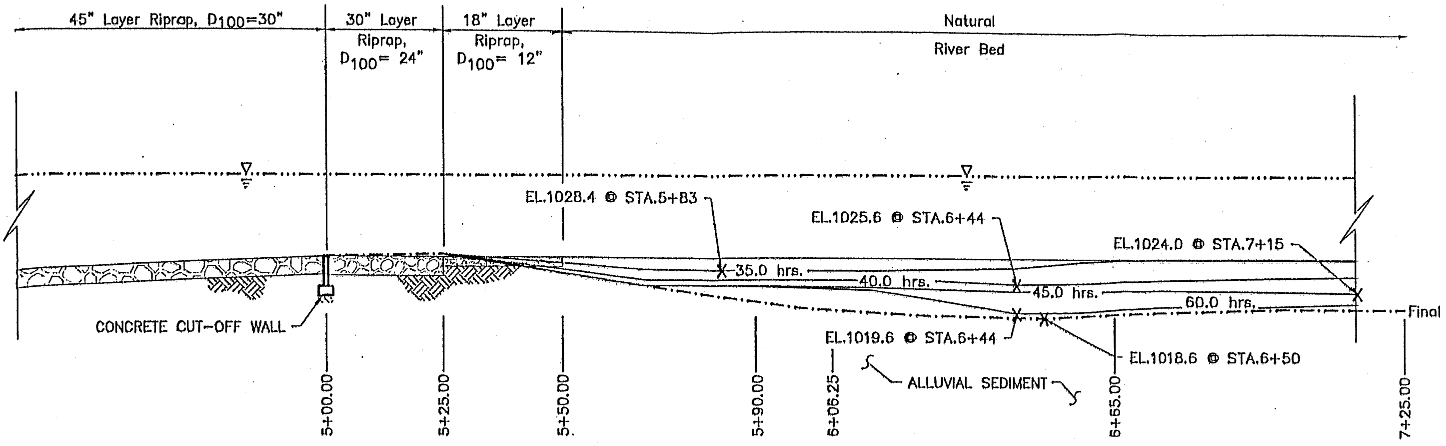

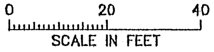

NOTES:
1.) Spot Elevations are the Maximum Scour Elevations for the Scour Profile.

2.) Time Shown with each Profile is from the Beginning of the PMF Hydrograph.

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Figure 6

DESIGN 2 CHANNEL PROTECTION
LEFT WALL SCOUR PROFILE WITH TIME

HOMME DAM
Park River, ND

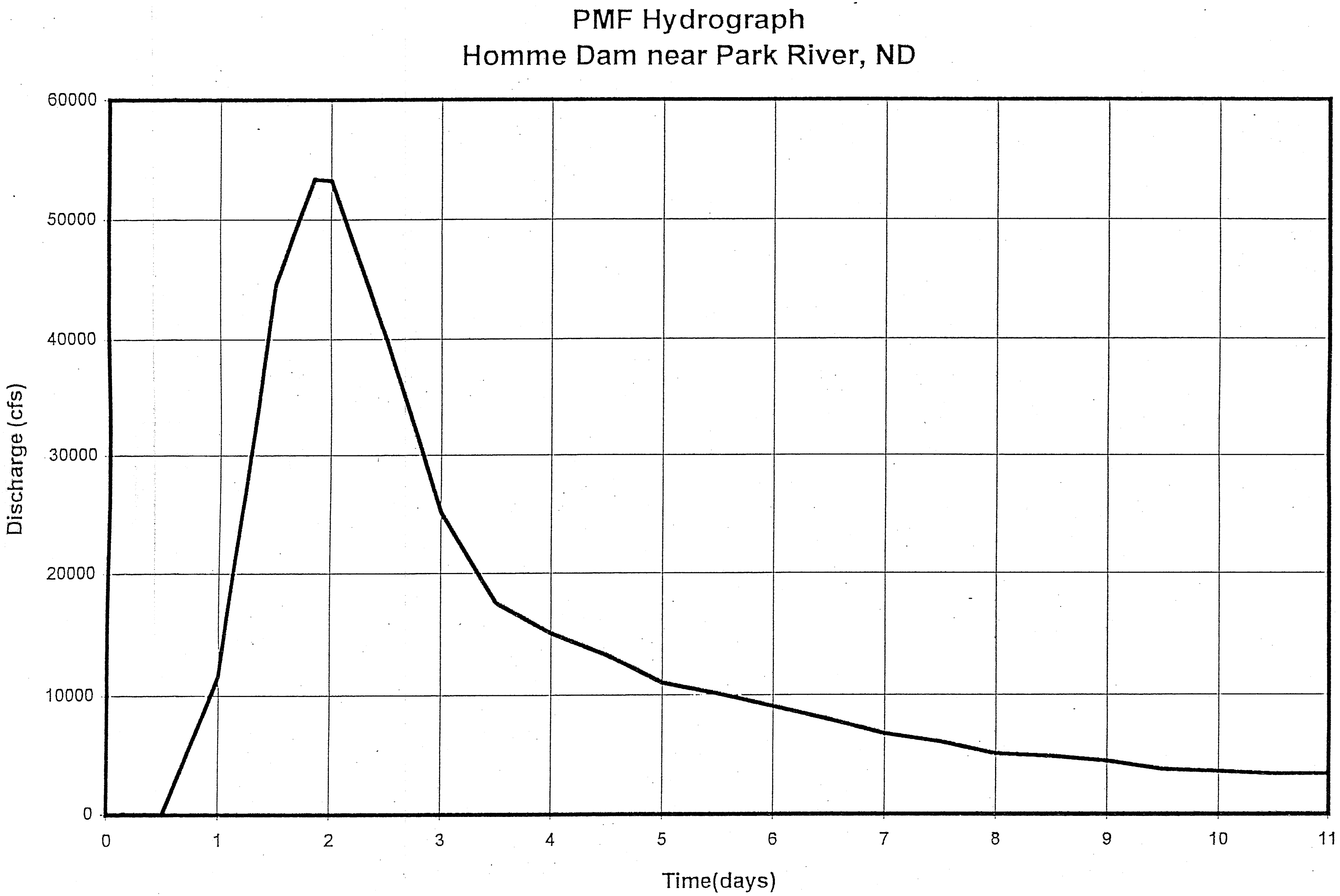

PMF Hydrograph
Homme Dam near Park River, ND
Discharge (cfs)
60000
50000
40000
30000
20000
10000
0
0
1
2
3
4
5
6
7
8
9
10
11
Time(days)

Figure 7

SAFL

	model	prototype					
U.S. Std Sieve Size	Particle Diam.	Particle Diam.	Empty Sieve Mass	Full Sieve Mass	Mass Retained	Percent Retained	Percent Passing
	mm	mm	g	g	g	%	%
11/2	37.50	937.50	818.70	818.7	0.00	0.00	100.00
11/4	31.50	787.50	553.70	729.8	176.10	4.36	95.64
1	25.40	635.00	617.60	2388.5	1770.90	43.82	51.82
7/8	22.40	560.00	548.20	1734.7	1186.50	29.36	22.46
3/4	18.85	471.25	613.60	1382.6	769.00	19.03	3.44
5/8	16.00	400.00	554.40	678.4	124.00	3.07	0.37
PAN	0.00	0.00	341.50	356.4	14.90	0.37	0.00
				sums =	4041.4	100	

COE

Particle Diam.	Particle Diam.	Percent Passing
in	mm	%
30.5	774.70	100.0
23.3	591.06	50.0
17.3	439.34	15.0
15.9	404.88	5.0
0.0	0.00	0.0

30" Riprap Gradation
Homme Dam near Park River, ND

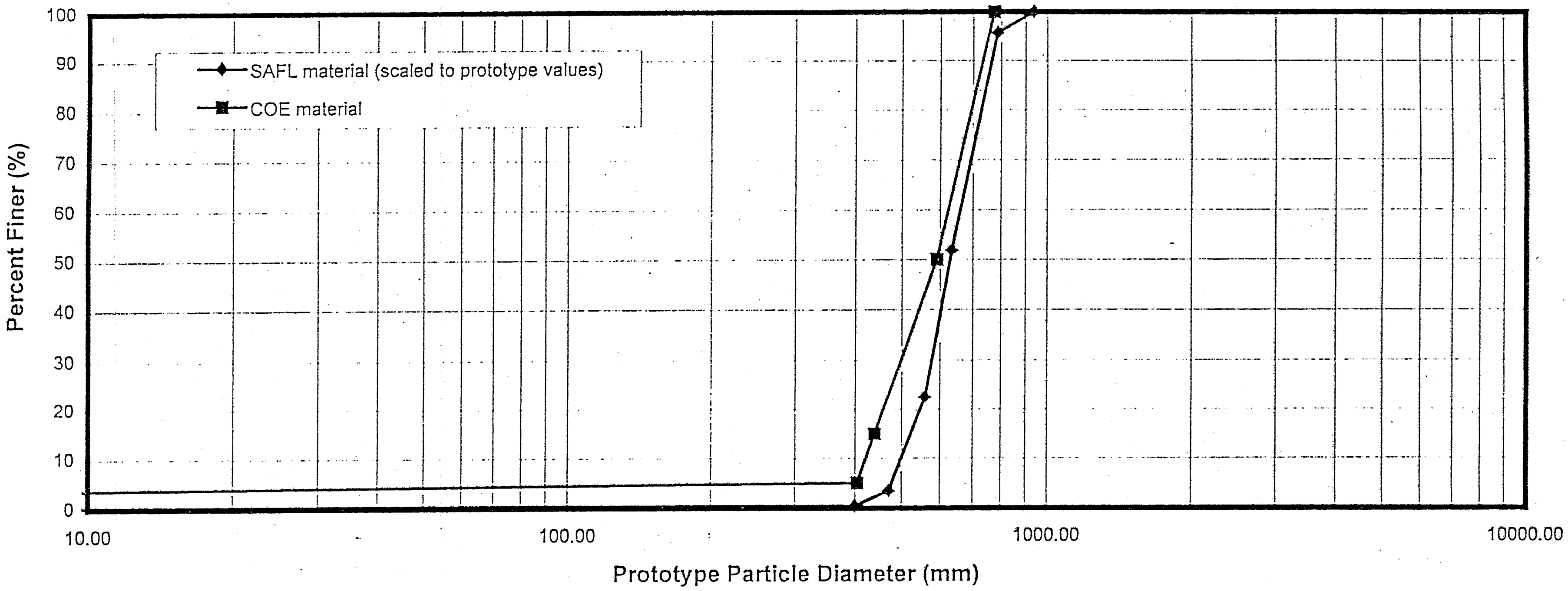


Figure 8

SAFL

	model	prototype					
U.S. Std Sieve Size	Particle Diam.	Particle Diam.	Empty Sieve Mass	Full Sieve Mass	Mass Retained	Percent Retained	Percent Passing
	mm	mm	g	g	g	%	%
11/4	31.50	787.50	553.60	553.6	0.00	0.00	100.00
1	25.40	635.00	617.50	723.8	106.30	3.96	96.04
7/8	22.40	560.00	548.20	1903.3	1355.10	50.42	45.63
3/4	18.85	471.25	613.60	1821.9	1208.30	44.96	0.67
5/8	16.00	400.00	554.30	572.3	18.00	0.67	0.00
7/16	11.2	280.00	552.90	552.9	0.00	0.00	0.00
PAN	0.00	0.00	341.60	341.6	0.00	0.00	0.00
				sums =	2687.7	100	

COE

Particle Diam.	Particle Diam.	Percent Passing
in	mm	%
24.4	620.09	100.0
18.6	472.82	50.0
14.3	363.22	15.0
13.2	336.50	5.0
0.0	0.00	0.0

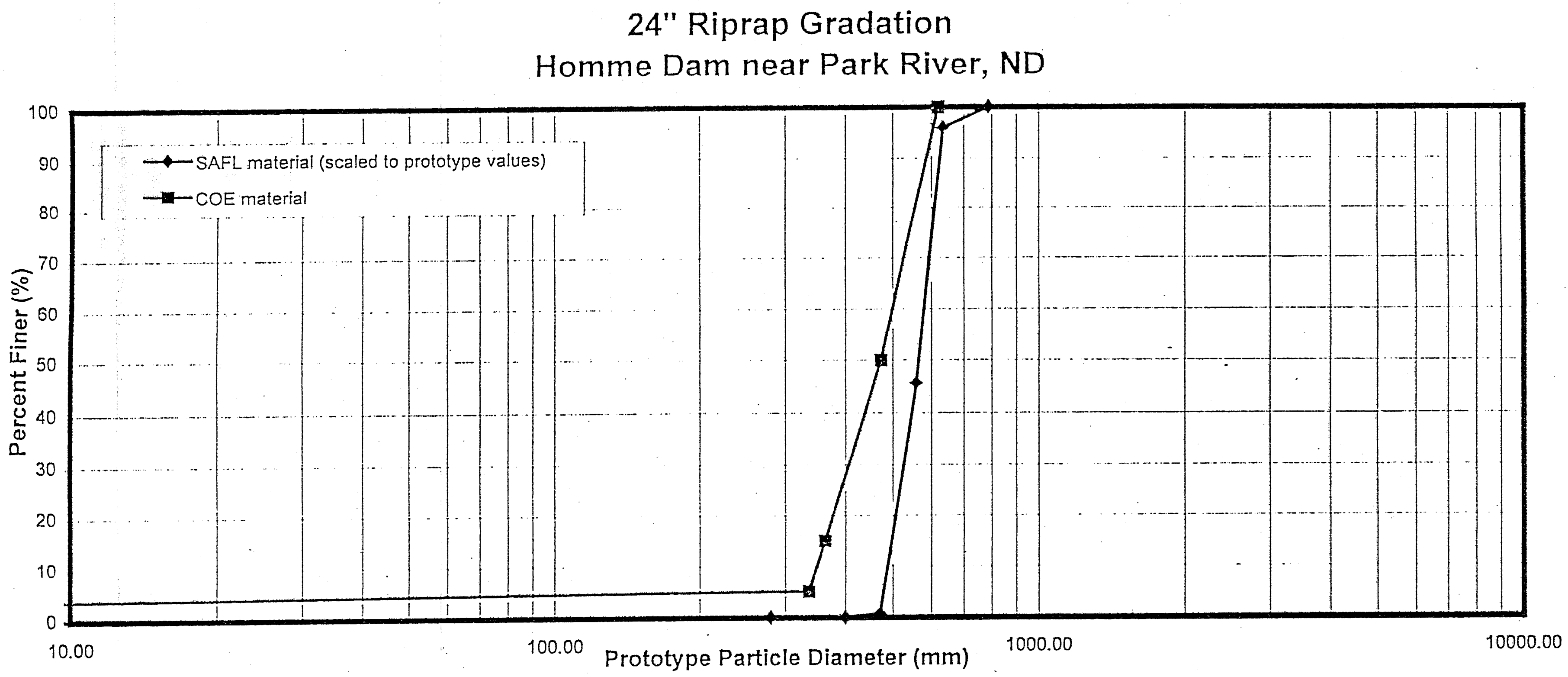


Figure 9

SAFL

	model	prototype					
U.S. Std Sieve Size	Particle Diam.	Particle Diam.	Empty Sieve Mass	Full Sieve Mass	Mass Retained	Percent Retained	Percent Passing
	mm	mm	g	g	g	%	%
7/16	11.2	280.00	554.70	571.3	16.60	1.31	98.69
3/8	9.50	237.50	527.30	1027.4	500.10	39.50	59.19
5/16	8.00	200.00	506.20	1004.6	498.40	39.36	19.82
3 1/2	5.60	140.00	509.80	655.3	145.50	11.49	8.33
6	3.36	84.00	476.30	522.4	46.10	3.64	4.69
10	2.00	50.00	441.80	501.2	59.40	4.69	0.00
PAN	0.00	0.00	341.50	341.5	0.00	0.00	0.00
				sums =	1266.1	100	

COE

Particle Diam.	Particle Diam.	Percent Passing
in	mm	%
13.7	346.96	100.0
9.4	238.23	50.0
7.2	183.16	15.0
6.3	161.04	5.0
0.0	0.00	0.0

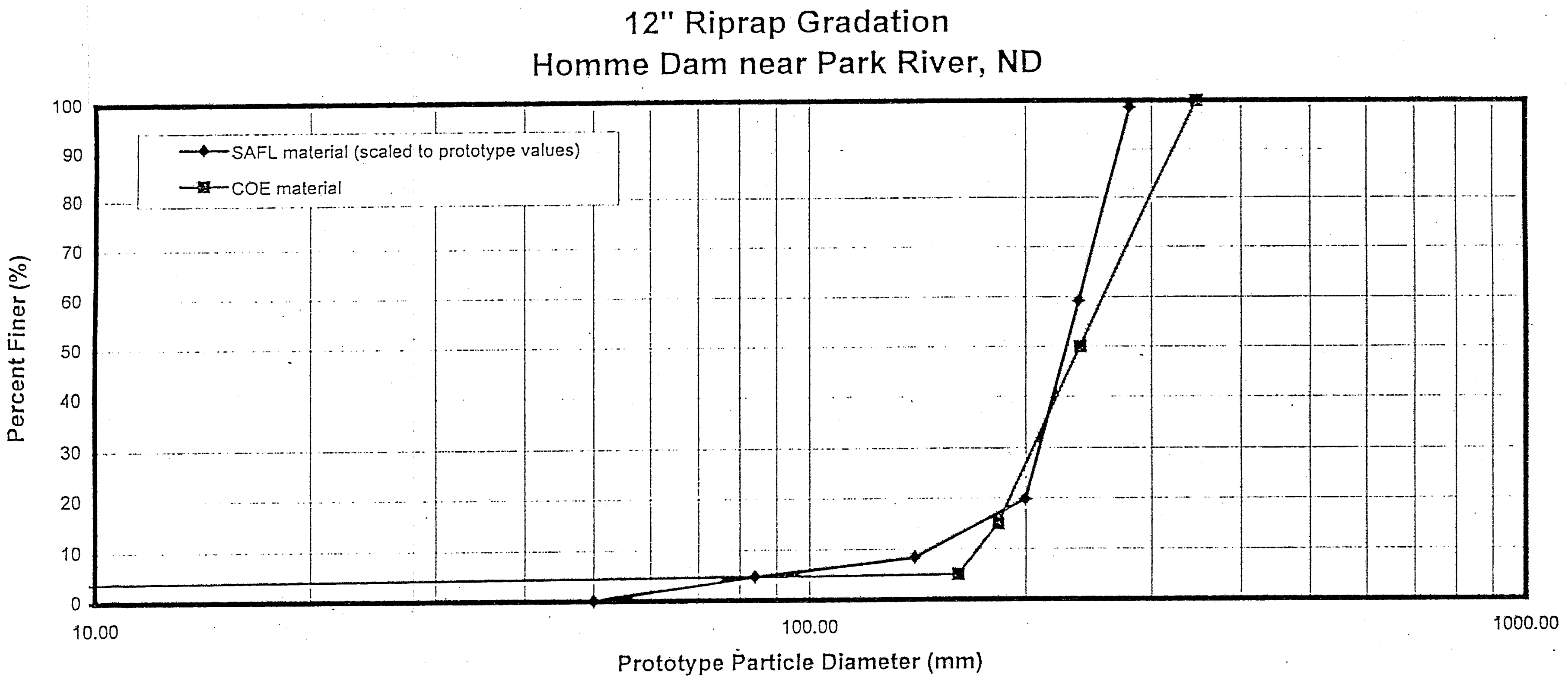

12" Riprap Gradation
Homme Dam near Park River, ND

Figure 10

SAFL

U.S. Std Sieve Size	model Particle Diam.	prototype Particle Diam.	Empty Sieve Mass	Full Sieve Mass	Mass Retained	Percent Retained	Percent Passing
	mm	mm	g	g	g	%	%
5	4.00	100.00	110.49	110.49	0.00	0.00	100.00
7	2.80	70.00	87.50	87.93	0.43	0.99	99.01
10	2.00	50.00	90.26	107.49	17.23	39.48	59.53
14	1.41	35.25	97.34	112.63	15.29	35.04	24.50
18	1.00	25.00	86.74	96.91	10.17	23.30	1.19
20	0.85	21.25	80.14	80.57	0.43	0.99	0.21
25	0.71	17.75	103.86	103.87	0.01	0.02	0.18
35	0.50	12.50	73.10	73.15	0.05	0.11	0.07
50	0.30	7.50	99.99	99.99	0.00	0.00	0.07
PAN	0.00	0.03	46.83	46.86	0.03	0.07	0.00
				sums =	43.64	100	

COE

Particle Diam.	Particle Diam.	Percent Passing
in	mm	%
8.000	203.20	100.0
6.000	152.40	89.5
4.000	101.60	77.5
3.000	76.20	70.5
1.500	38.10	52.5
0.750	19.05	35.0
0.375	9.53	19.0
0.250	6.35	5.5
0.079	2.00	2.5

Type B3 Bedding Material Gradation
Homme Dam near Park River, ND

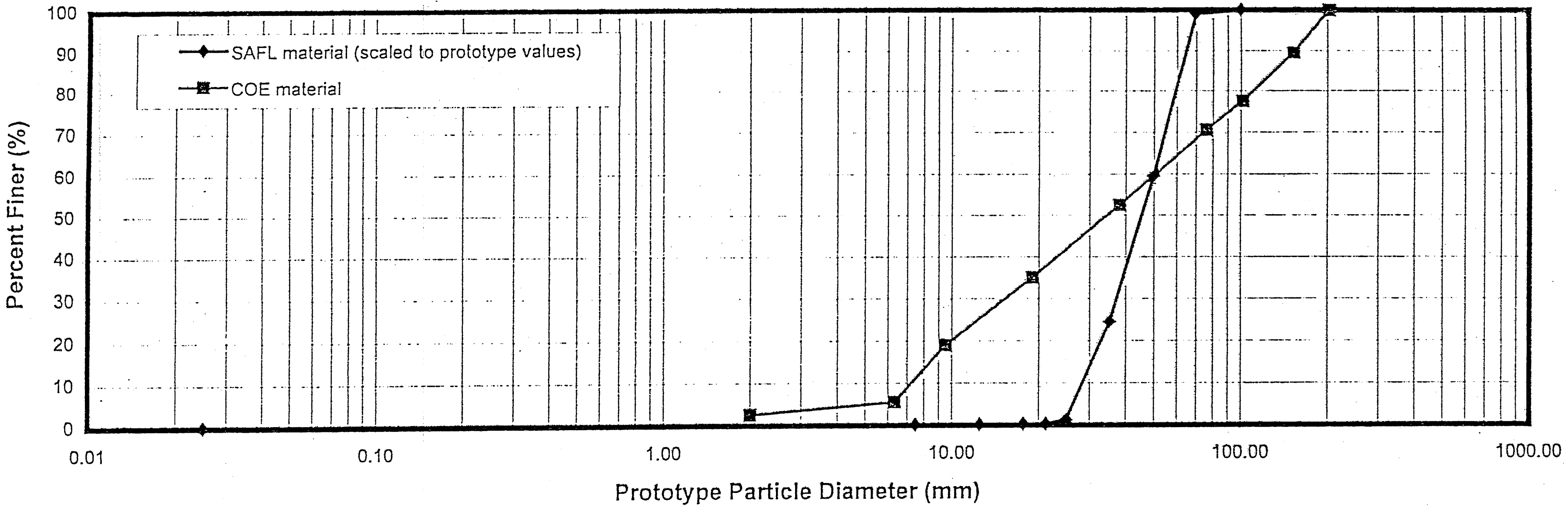


Figure 11

SAFL

U.S. Std Sieve Size	model Particle Diam.	prototype Particle Diam.	Empty Sieve Mass	Full Sieve Mass	Mass Retained	Percent Retained	Percent Passing
	mm	mm	g	g	g	%	%
5/16	8.00	200.00	526.90	527.5	0.6	0.04	99.96
3.5	5.60	140.00	501.90	572.8	70.9	5.26	94.69
5	4.00	100.00	469.90	1063.2	593.3	44.03	50.66
6	3.33	83.18	294.10	547	252.9	18.77	31.89
7	2.80	70.00	489.80	736.8	247	18.33	13.56
10	2.00	50.00	473.60	546.6	73	5.42	8.14
PAN	0.00	0.00	341.60	451.3	109.7	8.14	0.00
				sums =	1347.4	100	

COE

Particle Diam.	Particle Diam.	Percent Passing
in	mm	%
4.000	101.60	100
3.000	76.20	92.5
1.500	38.10	76
0.750	19.05	58.5
0.375	9.53	41
0.187	4.75	23.5
0.079	2.00	5
0.033	0.85	2.5

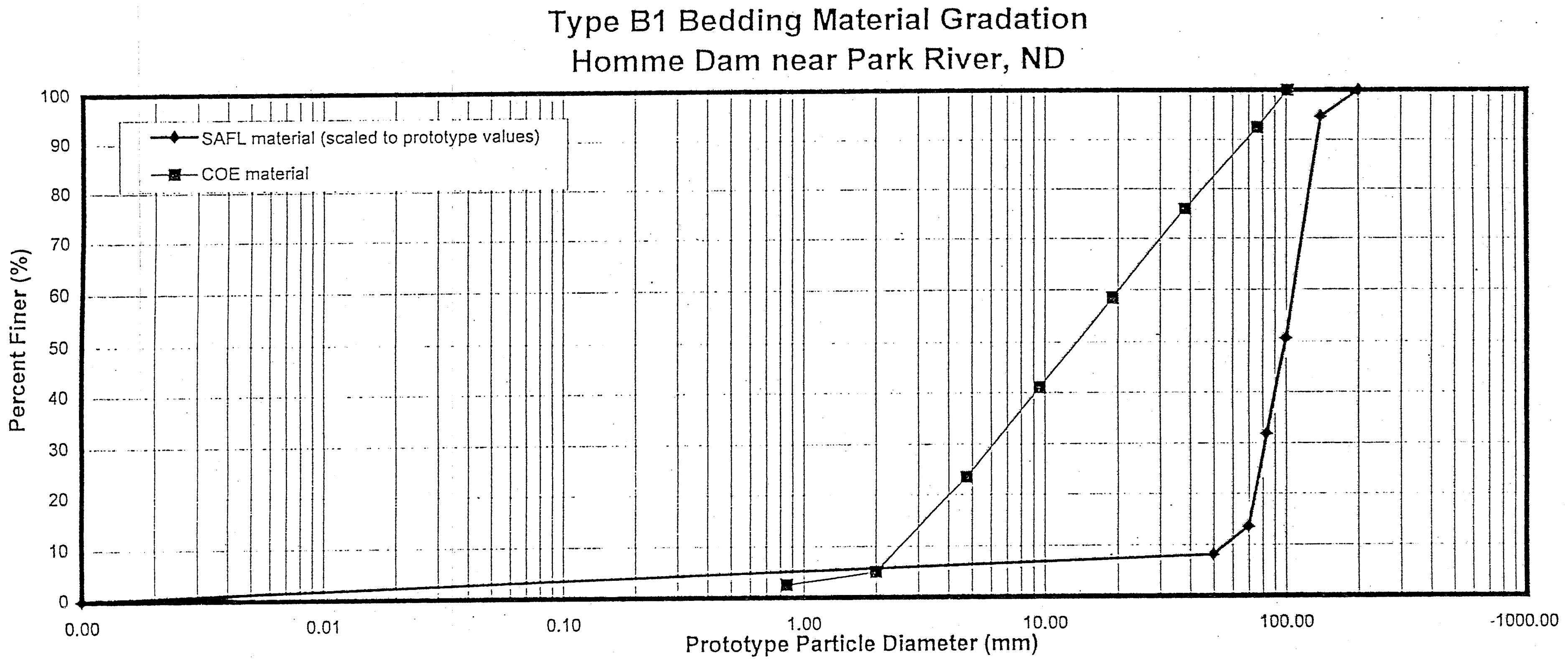


Figure 12

SAFL

	model	prototype					
U.S. Std Sieve Size	Particle Diam.	Particle Diam.	Empty Sieve Mass	Full Sieve Mass	Mass Retained	Percent Retained	Percent Passing
	mm	mm	g	g	g	%	%
5	4.000	100.00	110.49	110.49	0	0.00	100.00
10	2.000	50.00	90.28	90.28	0	0.00	100.00
20	0.850	21.25	80.14	80.18	0.04	0.07	99.93
30	0.600	15.00	107.77	107.78	0.01	0.02	99.91
40	0.425	10.63	101.42	101.86	0.44	0.77	99.14
50	0.300	7.50	100.03	113.44	13.41	23.47	75.67
80	0.180	4.50	95.05	114.1	19.05	33.35	42.32
120	0.124	3.10	86.12	102.14	16.02	28.04	14.28
170	0.088	2.20	80.30	87.68	7.38	12.92	1.37
PAN	0.001	0.03	57.29	58.07	0.78	1.37	0.00
				sums =	57.13	100	

COE

Particle Diam.	Particle Diam.	Percent Passing
in	mm	%
0.750	19.05	100
0.375	9.53	95
0.187	4.75	86
0.079	2.00	64
0.033	0.85	37
0.017	0.43	15.5
0.008	0.21	4
0.006	0.15	2

Filter Type 3 Bedding Material Gradation
Homme Dam near Park River, ND

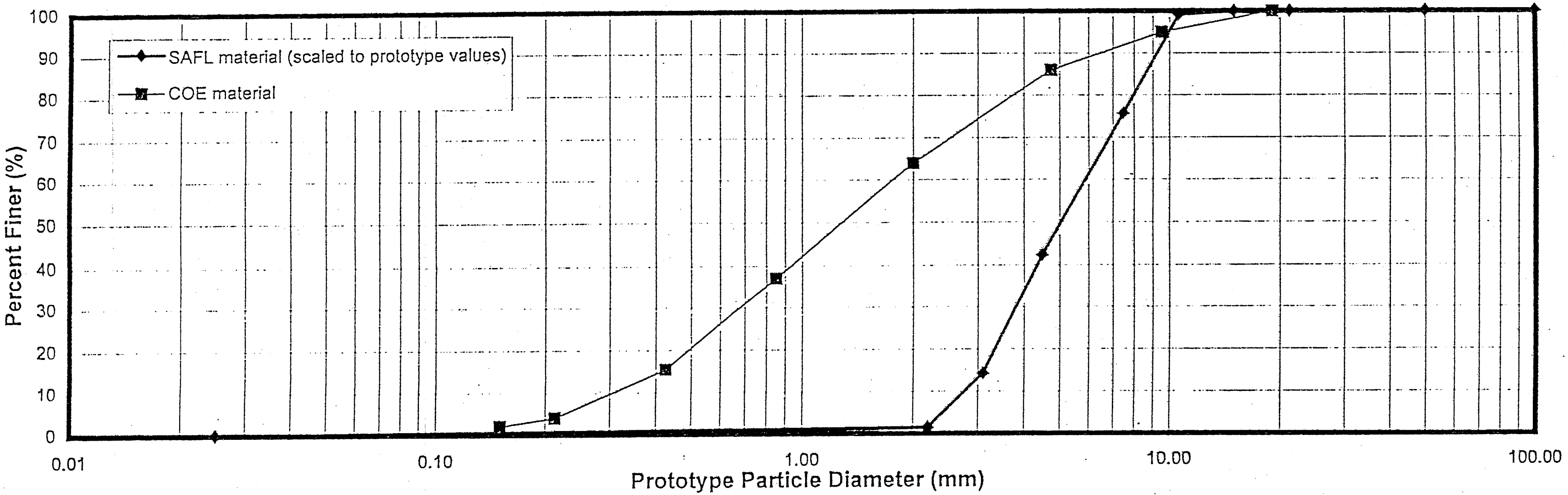


Figure 13

FIELD INFORMATION				
		95-58M	95-59M	95-61M
U.S. Std Sieve Size	Particle Diam.	Percent Passing	Percent Passing	Percent Passing
	mm	%	%	%
3/8	9.53	73	66	80
4	4.75	57	48	67
10	2.00	37	32	42
20	0.85	21	21	21
40	0.43	10	14	11
80	0.18	6	10	7
200	0.08	5	8	6
PAN	0.00	0	0	0

SAFL SEDIMENT							
#3 MODEL		#3 PROTOTYPE		#2 MODEL		#2 PROTOTYPE	
Particle Diam.	Percent Passing	Particle Diam.	Percent Passing	Particle Diam.	Percent Passing	Particle Diam.	Percent Passing
mm	%	mm	%	mm	%	mm	%
1.00	95.76	25.00	95.76	2.00	96.44	50.00	96.44
0.83	94.07	20.83	94.07	1.41	90.99	35.25	90.99
0.71	91.49	17.75	91.49	1.00	80.49	25.00	80.49
0.59	89.24	14.73	89.24	0.83	72.67	20.83	72.67
0.42	75.09	10.43	75.09	0.70	61.83	17.53	61.83
0.30	50.72	7.38	50.72	0.50	28.36	12.50	28.36
0.25	42.91	6.25	42.91	0.30	8.67	7.38	8.67
0.18	32.07	4.38	32.07	0.21	3.50	5.25	3.50
0.15	23.60	3.73	23.60	0.15	1.61	3.73	1.61
0.13	19.17	3.13	19.17	0.00	0.00	0.03	0.00
0.00	0.00	0.00	0.00				

Channel Bed Sediment Gradation
Homme Dam near Park River, ND

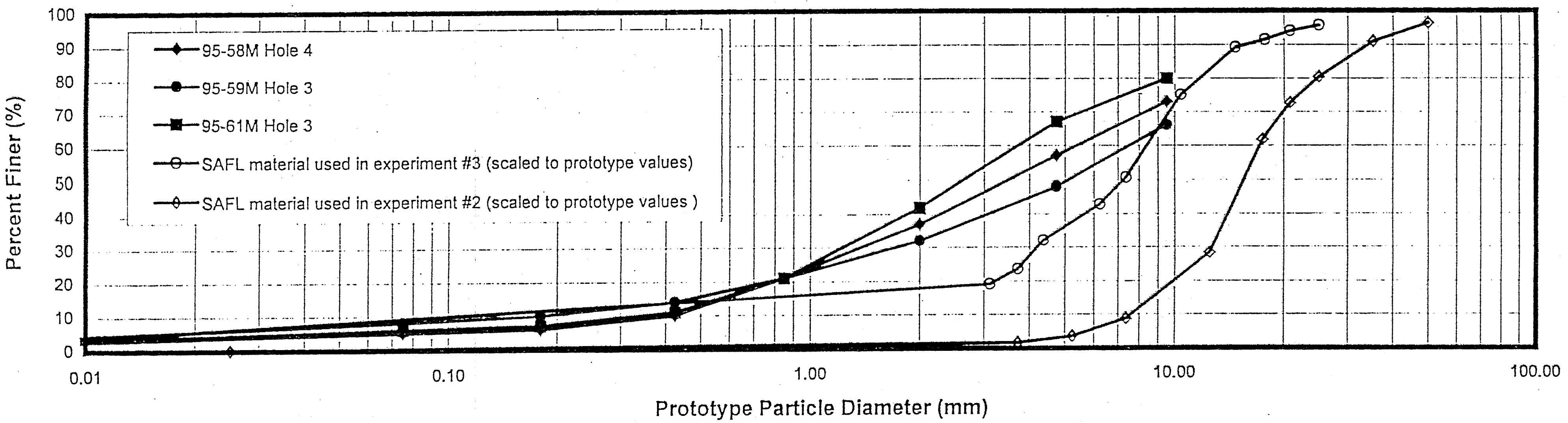
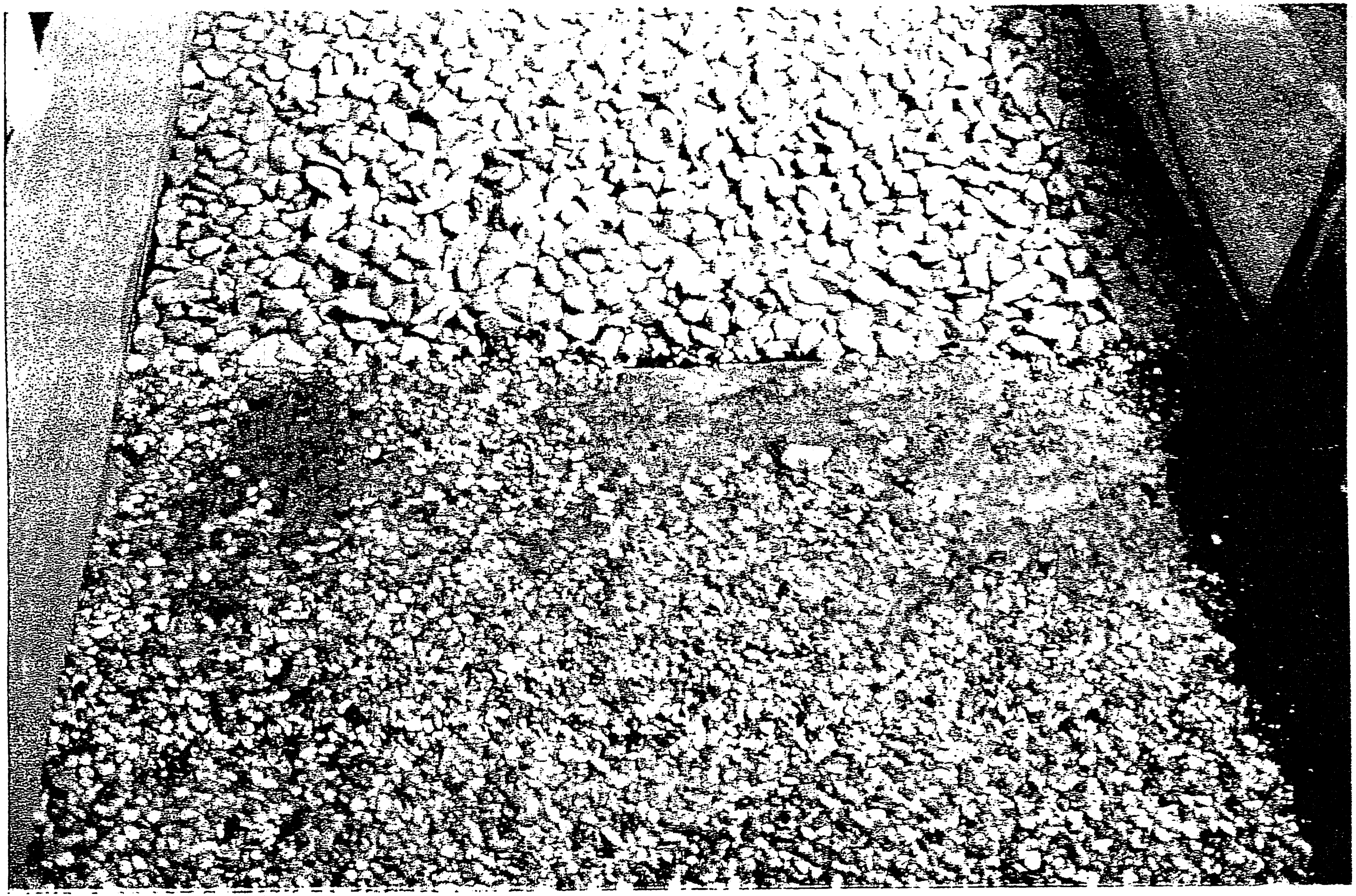
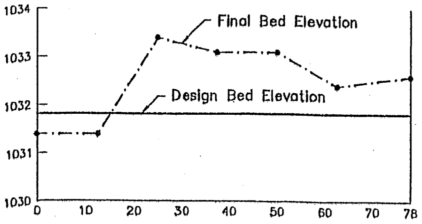


Figure 14

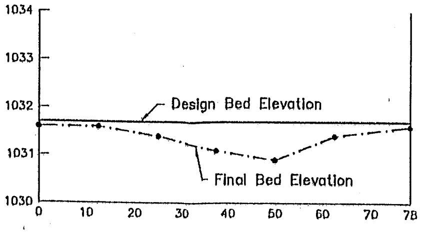


Failure of 12-Inch Riprap Downstream of Interface in Experiment #1

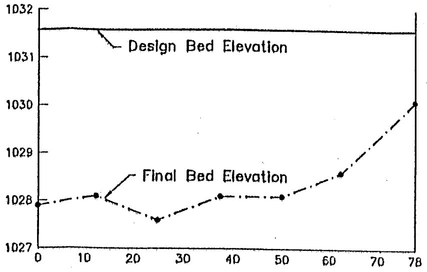
Figure 15



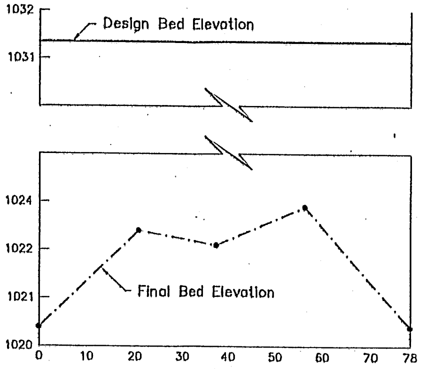
STATION 5+00
Vertical exageration 10x



STATION 5+25
Vertical exageration 10x



STATION 5+50
Vertical exageration 10x



STATION 6+00
Vertical exageration 10x

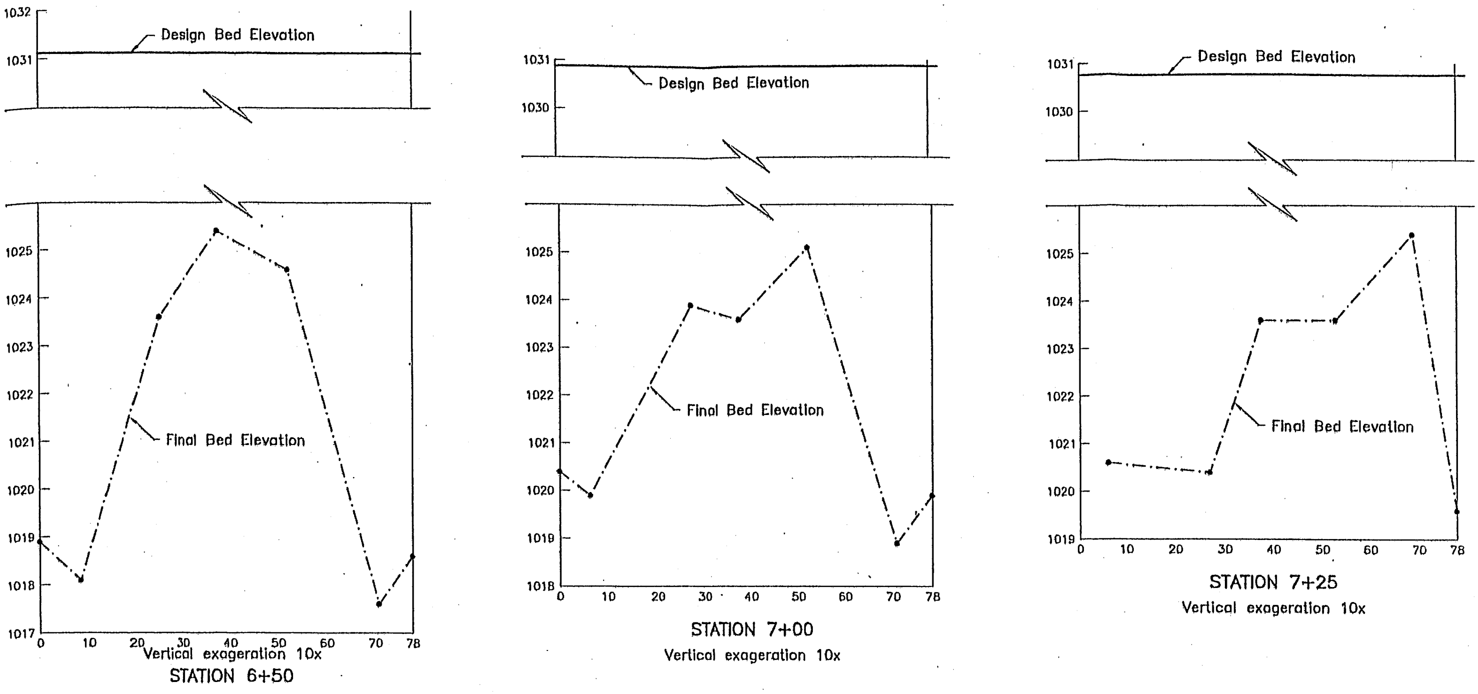
0 20 40
HORIZONTAL SCALE IN FEET

Barr
Engineering Company

Figure 17A

CROSS SECTIONS
SHOWING CHANNEL SCOUR WITH
DESIGN 2 CHANNEL PROTECTION

HOMME DAM
Park River, ND



Vertical exageration 10x
STATION 6+50

STATION 7+00
Vertical exageration 10x

STATION 7+25
Vertical exageration 10x

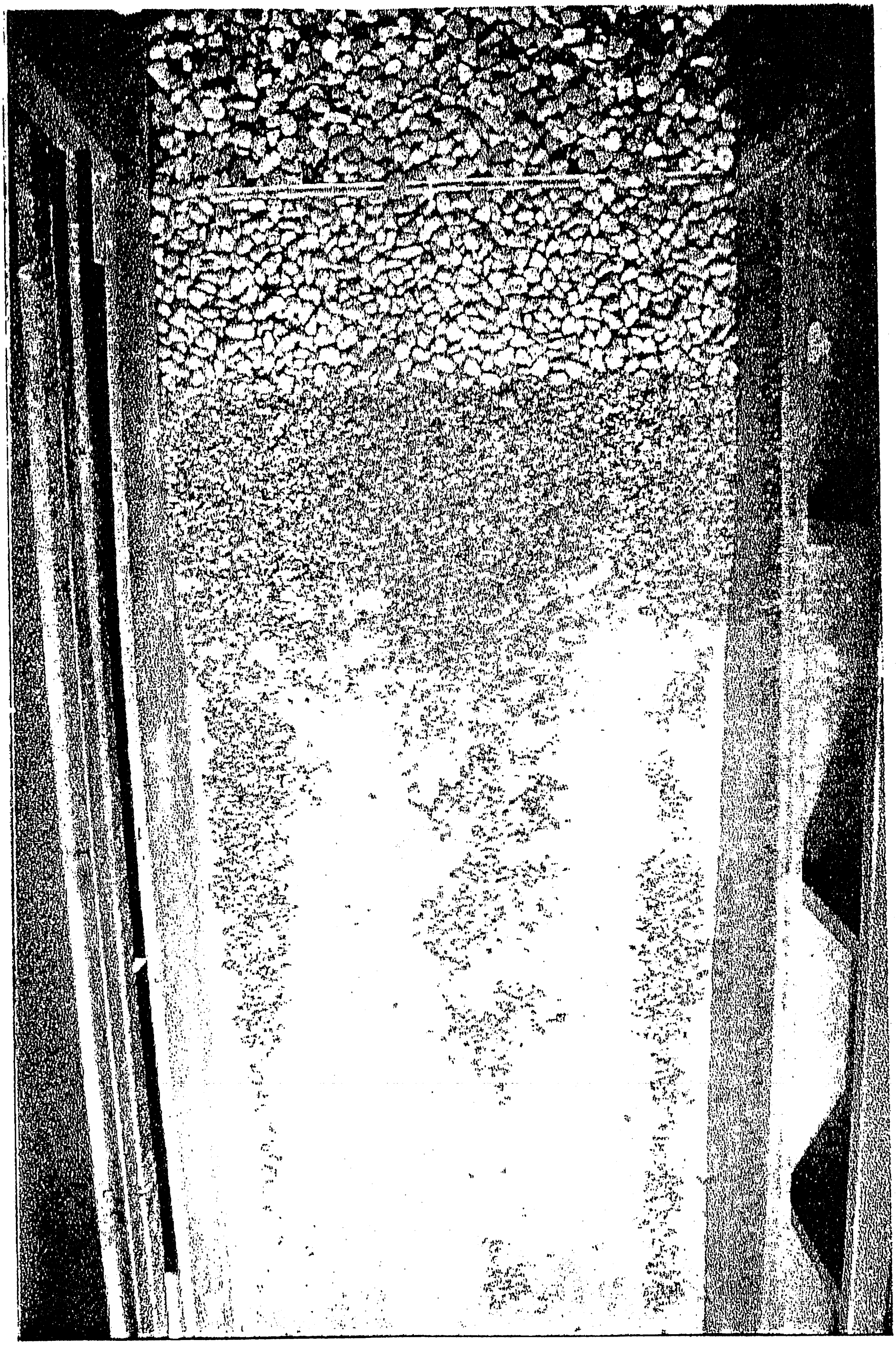
0 20 40
HORIZONTAL SCALE IN FEET

Barr
Engineering Company

Figure 17B

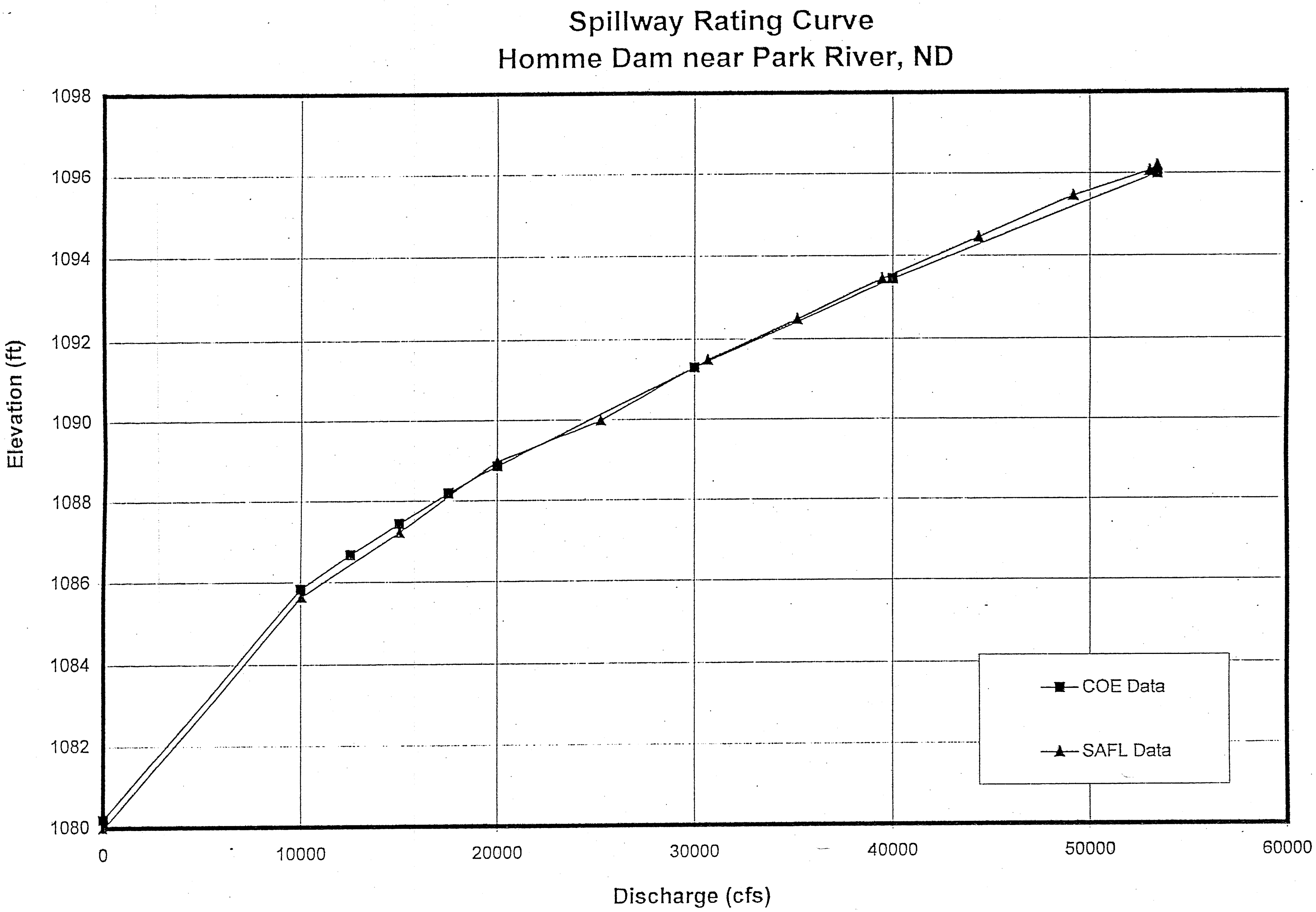
CROSS SECTIONS
SHOWING CHANNEL SCOUR WITH
DESIGN 2 CHANNEL PROTECTION

HOMME DAM
Park River, ND



Overhead View of Design 2 Outlet Channel After Experiment #3

Figure 18



Spillway Rating Curve
Homme Dam near Park River, ND

Figure 19

Appendix

Table A-1

Design 1 – Final Scour Profiles

Left Side		Right Side	
Longitudinal Station (ft.)	Riprap Elev. (ft.)	Longitudinal Station (ft.)	Riprap Elev. (ft.)
709.73	1031.56	722.23	1032.08
713.89	1030.78	726.39	1031.56
718.06	1030.00	730.56	1031.17
722.23	1028.70	734.73	1029.74
726.39	1028.44	738.89	1028.44
730.56	1028.18	743.06	1027.14
734.73	1027.40	747.23	1027.01
738.89	1026.35	751.39	1026.09
743.06	1025.57	755.56	1025.31
747.23	1024.53	759.73	1025.18
751.39	1024.27		

Table A-2

Design 2—Scour Profiles With Time at Left Wall

Longitudinal Station (ft)	Time=30 hrs. Discharge= 24018 cfs Elevation (ft):	Time=35.0 hrs. Discharge= 38429 cfs Elevation (ft):	Time=37.5 hrs. Discharge= 44980 cfs Elevation (ft):	Time=40 hrs. Discharge= 48037 cfs Elevation (ft):	Time=41.25 hrs. Discharge= 49172 cfs Elevation (ft):	Time=42.5 hrs. Discharge= 50308 cfs Elevation (ft):	Time=43.75 hrs. Discharge= 51530 cfs Elevation (ft):	Time=45 hrs. Discharge= 52404 cfs Elevation (ft):	Time=46.25 hrs. Discharge= 53400 cfs Elevation (ft):
567	1031.6	1028.7	1027.7	1026.5	1025.8	1025.3	1025.3	1025.3	1025.3
583	1031.4	1028.4	1027.4	1026.5	1026.5	1025.3	1025.3	1025.3	1025.3
615	1031.3	1028.4	1027.3	1026.4	1025.4	1025.8	1025.8	1024.9	1024.3
644	1031.2	1029.0	1027.0	1025.6	1025.2	1024.7	1024.7	1024.1	1024.1
658	1031.0	1030.3	1028.3	1025.8	1025.3	1025.1	1025.1	1024.3	1023.9
675	1031.0	1031.0	1029.0	1026.6	1026.1	1025.2	1024.9	1024.5	1024.5
715	1031.0	1031.0	1029.5	1027.4	1026.1	1025.2	1024.5	1024.0	1023.5

Longitudinal Station (ft)	Time=47.5 hrs. Discharge= 53400 cfs Elevation (ft):	Time=48.75 hrs. Discharge= 53400 cfs Elevation (ft):	Time=51.25 hrs. Discharge= 51967 cfs Elevation (ft):	Time=53.75 hrs. Discharge= 50220 cfs Elevation (ft):	Time=60 hrs. Discharge= 41486 cfs Elevation (ft):
567	1025.3	1025.3	1025.3	1025.3	1025.3
583	1025.2	1025.2	1024.4	1024.3	1024.3
615	1023.5	1022.7	1021.9	1020.9	1020.1
644	1023.1	1022.2	1021.7	1020.5	1019.6
658	1023.5	1022.8	1021.7	1020.6	1019.8
675	1024.5	1023.9	1023.1	1022.1	1021.0
715	1023.2	1023.2	1022.6	1022.6	1021.7

Table A-3

Design 2—Final Lateral Cross Sections

Lateral (ft.)	Elevation (ft.)
Longitudinal Station 5+00	
0.0	1031.4
12.5	1031.4
25.0	1033.4
37.5	1033.1
50.0	1033.1
62.5	1032.4
78.0	1032.6
Longitudinal Station 5+25	
0.0	1031.6
12.5	1032.6
25.0	1031.4
37.5	1031.1
50.0	1030.9
62.5	1031.4
78.0	1031.6
Longitudinal Station 5+50	
0.0	1027.9
12.5	1028.1
25.0	1027.6
37.5	1028.1
50.0	1028.1
62.5	1028.6
78.0	1030.1

Table A-3

Design 2—Final Lateral Cross Sections (cont.)

Lateral (ft.)	Elevation (ft.)
Longitudinal Station 6+00	
0.0	1020.4
20.8	1022.4
37.5	1022.1
56.3	1022.9
78.0	1020.4
Longitudinal Station 6+50	
0.0	1018.9
8.3	1018.1
25.0	1023.6
37.5	1025.4
52.1	1024.6
70.8	1017.6
78.0	1018.6
Longitudinal Station 7+00	
0.0	1020.4
6.3	1019.9
27.1	1023.9
37.5	1023.6
52.1	1025.1
70.8	1018.9
78.0	1019.9
Longitudinal Station 7+25	
6.25	1020.6
27.08	1020.4
37.50	1023.6
52.08	1023.6
68.75	1025.4
78	1019.6

Table A-4

Design 2—Final Scour Profiles

Station (ft)	Left Wall Elevation(ft)	Centerline Elevation (ft)	Right Wall Elevation (ft)
500	1031.4	1031.6	1031.9
525	1031.9	1031.1	1031.8
550	1027.9	1028.4	1028.9
575	1024.1	1023.4	1023.1
600	1020.6	1022.1	1020.4
625	1019.1	1022.4	1019.1
650	1018.9	1023.4	1018.6
675	1019.9	1024.1	1019.6
700	1020.6	1023.9	1019.9
725	1020.6	1023.6	1020.9

Table A-5

Spillway Rating Curve Data

COE Spillway Rating Curve		Model Spillway Rating Curve	
Discharge (cfs)	Elevation (ft)	Discharge (cfs)	Elevation (ft)
0	1080.2	0	1080.0
10,000	1085.83	10,033	1085.6
12,500	1086.68	15,016	1087.2
15,000	1087.45	19,955	1089.0
17,500	1088.18	25,269	1090.0
20,000	1088.85	30,679	1091.5
30,000	1091.30	35,187	1092.5
40,000	1093.44	39,463	1093.4
53,400	1096.00	44,368	1094.5
		49,170	1095.5
		53,019	1096.1
		53,400	1096.2

Table A-6
Homme Dam Hydrograph Data

50-Year Event	
Time (days)	Discharge (cfs)
0.00	88
0.13	127
0.25	200
0.38	291
0.50	364
0.63	436
0.75	545
0.88	655
1.00	800
1.13	982
1.25	1164
1.38	1382
1.50	1600
1.63	1891
1.75	2255
1.88	2764
2.00	3564
2.13	6910
2.25	8000
2.38	7782
2.50	7273
2.63	6400
2.75	5091
2.88	4218
3.00	3200
3.13	2836
3.25	2473
3.38	2110
3.50	1745
3.63	1455
3.75	1310
3.88	1164
4.00	1018
4.13	891
4.25	855
4.38	800
4.50	745
4.63	727
4.75	691
4.88	655
5.00	618
5.13	589
5.25	582
5.38	575
5.50	567
5.63	560
5.75	553
5.88	545
6.00	538

130-Year Event	
Time (days)	Discharge (cfs)
0.00	0
0.63	800
1.00	1050
1.63	2600
1.75	3000
1.88	3800
2.00	4900
2.13	8800
2.19	10600
2.25	11000
2.31	10900
2.38	10600
2.50	10000
2.63	8400
2.75	6800
2.88	5400
3.00	4200
3.38	2800
3.63	2000
4.00	1400
4.50	1000
5.00	850

PMF Event	
Time (days)	Discharge (cfs)
0.00	0
0.50	0
1.00	11600
1.50	44500
1.85	53400
2.00	53300
2.50	40000
3.00	25100
3.50	17500
4.00	15000
4.50	13200
5.00	11000
5.50	10100
6.00	9000
6.50	7900
7.00	6700
7.50	6000
8.00	5000
8.50	4800
9.00	4400
9.50	3700
10.00	3500
10.50	3300
11.00	3300

Projected 50-Year Hydrograph
Homme Dam near Park River, ND

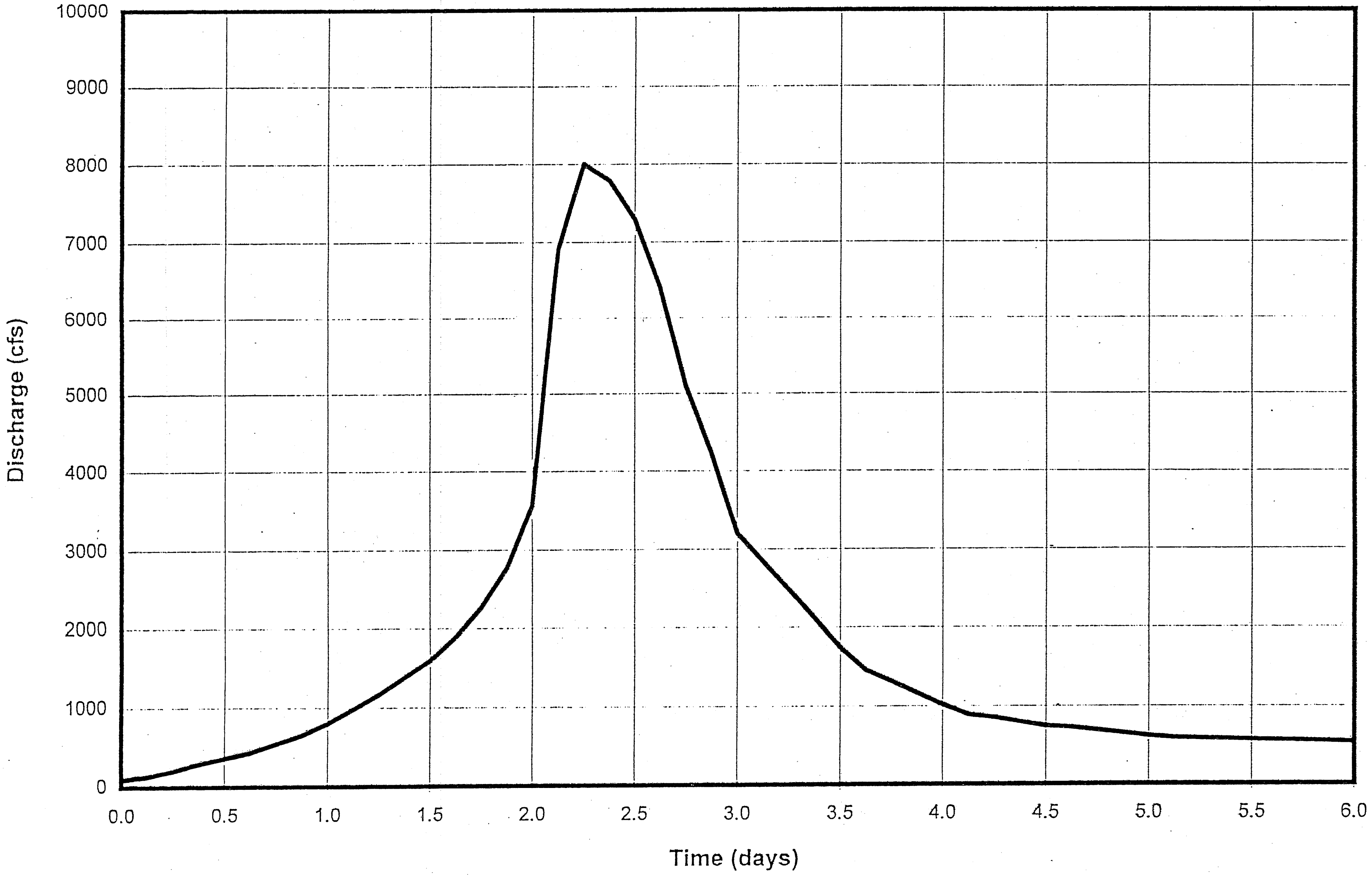
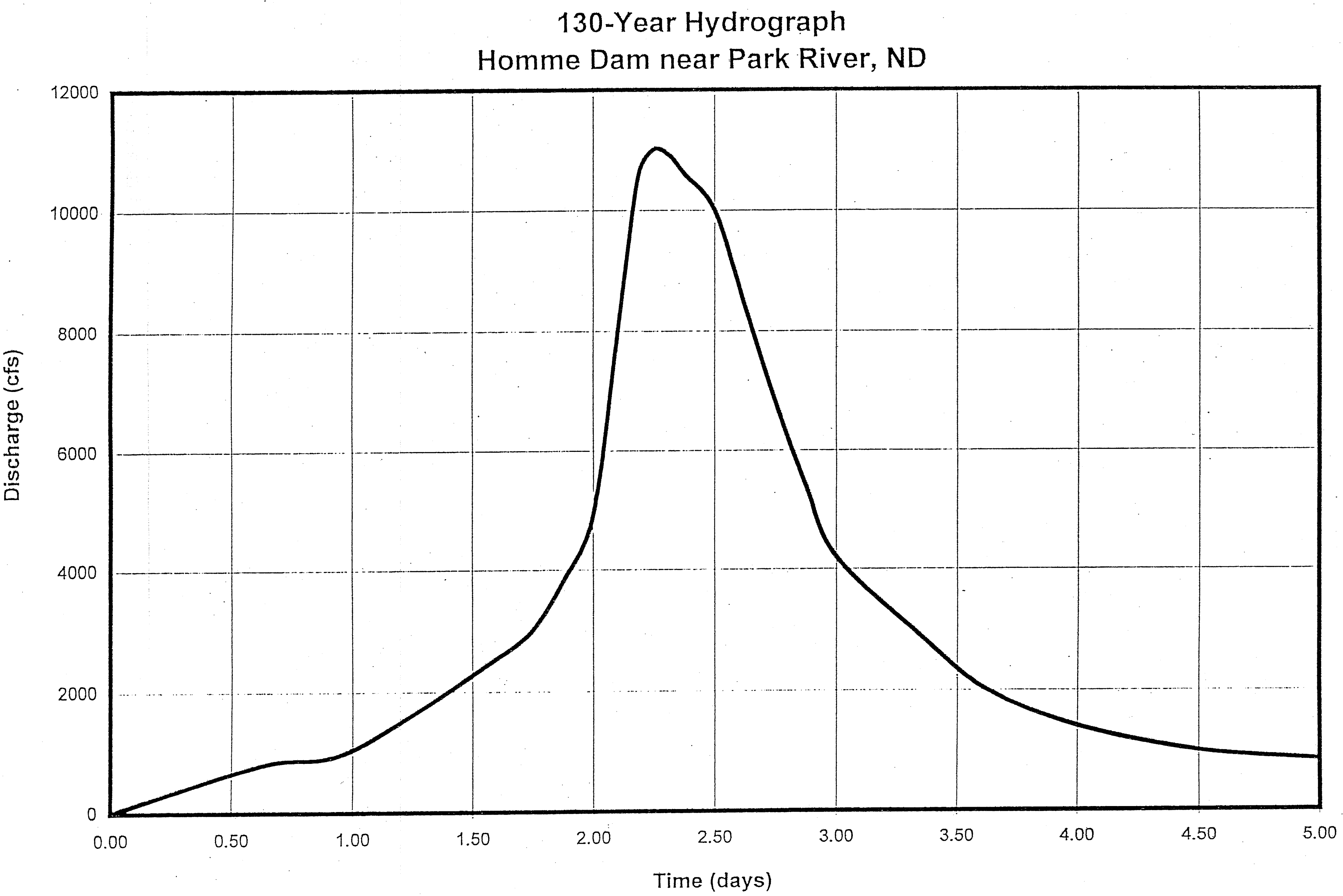


Figure A-1



130-Year Hydrograph
Homme Dam near Park River, ND

Figure A-2

HOMME DAM VIDEO TAPE SUMMARY

(PERIMENT #1 (4-8-98): DESIGN #1 WITH GEOTEXTILE FILTER

--TOP VIEW OF THE SPILLWAY, THE STILLING BASIN WITH HYDRAULIC JUMP, AND THE OUTLET CHANNEL

--SIDE VIEW OF THE OUTLET CHANNEL FROM THE STILLING BASIN TO THE NATURAL RIVER

EXPERIMENT #2 (4-16-98): DESIGN #1 WITH GRANULAR FILTER AND CLAY TILL LAYER

--SIDE VIEW OF THE OUTLET CHANNEL DOWNSTREAM OF THE STILLING BASIN

--SIDE VIEW OF THE OUTLET CHANNEL PANNING DOWNSTREAM TOWARD THE NATURAL RIVER
NOTE: NON ERODIBLE CLAY TILL LAYER BENEATH RIPRAP AND CHANNEL BED SEDIMENT
RIPRAP KEY LOCATED AT THE INTERFACE OF THE 24-INCH AND 30-INCH RIPRAP*

--SIDE VIEW OF THE OUTLET CHANNEL IMMEDIATELY DOWNSTREAM OF THE STILLING BASIN
NOTE: ONE ROCK IS VIBRATING (GENERALLY OCCURS PRIOR TO DOWNSTREAM MOVEMENT)

--TOP VIEW OF THE STILLING BASIN AND THE OUTLET CHANNEL AFTER THE EXPERIMENT
NOTE: FAILURE OF RIPRAP PROTECTION ONLY AT THE RIPRAP/RIVER INTERFACE
FORMATION OF ROUGHLY 10° ANGLE OF REPOSE OF 12-INCH RIPRAP*

EXPERIMENT #3 (5-11-98): DESIGN #2 WITH GRANULAR FILTER AND FULLY ERODIBLE CHANNEL BED

--TOP VIEW OF THE RIPRAP ARRANGEMENT PRIOR TO THE EXPERIMENT
NOTE: TWO 25 FOOT BANDS OF 24-INCH AND 12-INCH RIPRAP*

--SIDE VIEW OF THE OUTLET CHANNEL FROM THE APEX TO THE NATURAL RIVER PRIOR TO THE EXPERIMENT

--SIDE VIEW OF THE OUTLET CHANNEL DOWNSTREAM OF THE APEX AT A DISCHARGE OF 24,018 CFS*
NOTE: INITIAL BED MOVEMENT, MOSTLY CHANNEL BED SEDIMENT

--SIDE VIEW OF THE OUTLET CHANNEL DOWNSTREAM OF THE APEX AT A DISCHARGE OF 31,879 CFS*
NOTE: 1.0 FEET OF SCOUR IN CHANNEL BED*
INITIAL UNRAVELING OF 12-INCH RIPRAP*

--SIDE VIEW OF THE OUTLET CHANNEL DOWNSTREAM OF THE APEX AT A DISCHARGE OF 44,980 CFS*
NOTE: 4.0 FEET OF SCOUR IN CHANNEL BED*
NO SIGNIFICANT FAILURE OF 12-INCH RIPRAP*

--SIDE VIEW OF THE OUTLET CHANNEL DOWNSTREAM OF THE APEX AT A DISCHARGE OF 50,308 CFS*
NOTE: 6 FEET OF SCOUR IN CHANNEL BED*
FAILED 12-INCH RIPRAP RE-ANCHORS ITSELF DOWNSTREAM TO PROVIDE EROSION PROTECTION*

--SIDE VIEW OF THE OUTLET CHANNEL DOWNSTREAM OF THE APEX AT A PEAK DISCHARGE OF 53,400 CFS*
NOTE: 8.75 FEET OF SCOUR IN CHANNEL BED*
ADDITIONAL UNRAVELING OF 12-INCH RIPRAP*

--SIDE VIEW OF THE OUTLET CHANNEL DOWNSTREAM OF THE APEX AT A DISCHARGE OF 41,486 CFS*
NOTE: 11.5 FEET OF SCOUR IN CHANNEL BED*
NO ADDITIONAL MOVEMENT OF 12-INCH RIPRAP*

--SIDE VIEW OF THE OUTLET CHANNEL DOWNSTREAM OF THE APEX AFTER THE EXPERIMENT
NOTE: 12.25 FEET OF SCOUR IN CHANNEL BED*
NO FAILURE OF 24-INCH OR 30-INCH RIPRAP PROTECTION*

--TOP VIEW OF THE OUTLET CHANNEL LOOKING UPSTREAM AFTER THE EXPERIMENT

--TOP VIEW OF THE OUTLET CHANNEL LOOKING DOWNSTREAM FROM THE APEX AFTER THE EXPERIMENT

'LL NUMERICAL VALUES ARE GIVEN IN PROTOTYPE SCALE