**PAP-759**

# Comparison of ACER TM-11 and MacDonald & Langridge-Monopolis Procedures for Estimating Breach Parameters and Peak Breach Outflow

by

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# PEER REVIEW DOCUMENTATION

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Reviewer: Brent W. Mefford Review Date: 4/4/97
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Preparer: I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member: Tony L. Wahl Date: 2/28/97
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D-8560

MEMORANDUM

To: Rodney Danzeisen, Client Liaison, D-8610

From: Tony Wahl, Hydraulic Engineer, D-8560

Subject: Comparison of Procedures for Estimating Embankment Breach Parameters and Peak Breach Outflow

The attached report summarizes the results of my comparative analysis of the ACER TM-11 and MacDonald & Langridge-Monopolis procedures for predicting embankment dam breach parameters and peak breach outflow. The methods were compared using case study data from actual failures of small dams similar to those owned by the BIA. In general there is little systematic difference between the different methods. In a few extreme cases of large reservoirs impounded by very small dams, the ACER TM-11 approach dramatically underpredicts breach widths.

If you have questions regarding the analysis, or need additional information, please give me a call at 236-2000, ext. 446.

**Comparison of ACER TM-11 and MacDonald & Langridge-Monopolis Procedures for Estimating Embankment Breach Parameters and Peak Breach Outflow**

Tony L. Wahl, D-8560

Numerous procedures have been documented in the literature for estimating embankment dam breach parameters and peak breach outflows. ACER TM-11 prescribes the use of the following equations for embankment dams:

| | | |
|---|---|---|
| Average Breach Width: | $BW = 3(h_w)$ | |
| Breach Formation Time: | $TFM = 0.20(BW)$ | (BW in feet, TFM in minutes) |
| | $TFM = 0.011(BW)$ | (BW in meters, TFM in hours) |

BW is the breach width, TFM is the time to failure in hours, and $h_w$ is the depth of water in the reservoir at failure, relative to the breach invert. To determine peak breach outflow, ACER TM-11 recommends the use of these equations to determine input parameters for dam-break analyses performed with SMPDBK or DAMBRK.

MacDonald & Langridge-Monopolis (M&L-M, 1984) compiled case study data from 42 dam failures and used these data to develop predictive equations for the volume of eroded material, breach formation time, and peak breach outflow. Separate equations were developed for "earthfill" and "non-earthfill" dams. Dams constructed with significant portions of rockfill and/or erosion resistant corewalls were classified as "non-earthfill", while dams constructed of homogeneous or zoned earth materials were classified as "earthfill" dams. MacDonald & Langridge-Monopolis's "earthfill" dam equations are as follows:

Volume of Eroded Embankment Material $\quad V_{eroded} = 0.0261(V_w h_w)^{0.769}$

$V_w$ is the volume of water stored above the breach invert at the time of failure. $V_w$ and $V_{eroded}$ are specified in $m^3$ and $h_w$ is specified in meters. $V_w h_w$ is called the "Breach Formation Factor".

Envelope Curve of Times for Breach Development

$t_f = 0.0179(V_{eroded})^{0.364}$ $\quad$ ($t_f$ in hours, $V_{eroded}$ in $m^3$)

Note: The values of $t_f$ computed from this equation are a minimum envelope curve (shortest breach formation time). However, the data used to develop the curve are described as estimates of the **maximum** breach development time.

Peak Breach Outflow

$Q_{peak}$(upper envelope) $= 3.85(V_w h_w)0.411$

$Q_{peak}$(best fit) $= 1.154(V_w h_w)0.412$

Note: The peak flow data used to develop these equations were determined by a variety of methods, including reservoir drawdown measurements, slope-area calculations at downstream cross-sections, etc. Some of these data were obtained a significant distance downstream of the dams, and thus may not accurately represent the peak outflow at the dam.

To assess the applicability of these equations to the analysis of small earthfill dams typical of most BIA structures, I queried a database of 108 dam failures that I have compiled from the literature to obtain a database of small, earthfill dams. This 108-dam database includes the failures documented by MacDonald & Langridge-Monopolis, as well as those cited by Costa (1984), Froehlich (1987, 1995a, 1995b), Singh & Snorrason (1982) and Singh & Scarlatos (1988), among others. I used this reduced dataset to compare the predicted values from the TM-11 and M&L-M equations to observed case study data and to one another. I limited the analysis to earthfill dams with a height of less than 50 ft (15.44 meters) and a storage of less than 10,000 ac-ft ($12.3 \times 10^6$ m$^3$). Both criteria had to be met only if both parameters were documented for a given dam. I also included only dams for which the depth of water above the breach invert ($h_w$) was documented, as this information is necessary to apply the prediction equations. The table on the following page lists the case study data for the 25 dams used in the analysis. An asterisk indicates case studies that were included in the original analysis by MacDonald & Langridge-Monopolis (1984). Both overtopping and piping/seepage failures are present in the dataset.

The seven attached figures summarize the results of the analysis. In general there are few systematic differences between the predictions made by the two methodologies, although both approaches have high uncertainty and in specific cases there are significant differences between the predictions produced by the two methods. Some of these differences will be discussed below.

Figure 1 shows the predicted vs. observed breach widths for the ACER TM-11 equation. There is a great deal of scatter with this relation, and a few very significant outliers. Buffalo Creek Dam[1], Lake Avalon[12], Lower Latham[17], and Goose Creek[6] all have very large breach widths compared to the predicted values. Buffalo Creek Dam was a coal waste embankment which probably was poorly compacted. The other three dams have some of the largest reservoir volumes in the dataset. The only large-reservoir case study that is well-predicted by the TM-11 equation is Wheatland Dam[25].

Figures 2 and 3 show predicted vs. observed breach times using the TM-11 and M&L-M equations. Both equations appear to function as envelope equations, providing the shortest possible breach formation times. As was noted above, the M&L-M equation was developed as a minimum envelope of *maximum* reported breach development times. In contrast, the observed breach times I used to construct this plot are the minimum reported breach times (many case studies have been documented by several researchers, and breach times are not always consistent). Despite this fact, the two breach formation time relations both still function as envelope equations, which is a conservative approach and desirable in most cases. Because it includes a reservoir volume term, the M&L-M equation does provide better predictions for three of the more dramatic outliers on these two plots, dams 12, 17, and 25 (again, three of the larger volume reservoirs in the dataset). The value of any of these breach formation time predictions should be weighed against the fact that a single time parameter cannot adequately describe the mechanics of most breach failures. There are in fact distinct phases of breach failure, such as initiation of breach, deepening of the initial breach channel, and lateral erosion of the embankment. The early phases of the breach are important when warning time is an issue; the time required to reach full breach dimensions is important when peak discharge and maximum inundation levels are of interest.

Figure 4 shows the predicted volume of embankment erosion for the M&L-M equation. This parameter is not predicted by the TM-11 equations and cannot be directly compared to the TM-11 breach width equation, since no prediction of breach side slopes is made. The predicted erosion volumes are widely scattered, but the equation does not appear to be biased relative to the observed erosion volumes in the small-dam dataset. Buffalo Creek Dam is again one of the significant outliers, with a much larger erosion volume observed than predicted. Rito Manzanares Dam[21] has a similar result; it has the smallest reservoir volume in the dataset, and thus has a relatively low predicted erosion volume. Goose Creek Dam[6] on the other hand has a very large reservoir volume and it's erosion volume is overpredicted.

Figure 5 shows the M&L-M peak flow equations (best-fit and upper envelope) compared to the observed peak flows. As noted previously, these observed peak flows may not adequately represent the peak flow at the dam in all cases due to the distance between the dam and the point at which the flow was estimated. The observed data are widely scattered about the best-fit relation, and all points fall well below the upper envelope line.

Figure 6 shows predicted vs. observed peak flows based on the ACER TM-11 equations. In the absence of a complete DAMBRK or SMPDBK analysis for each dam, these peak flows were determined using the following equation:

$$Qpeak = C*B*h_w^{1.5}$$

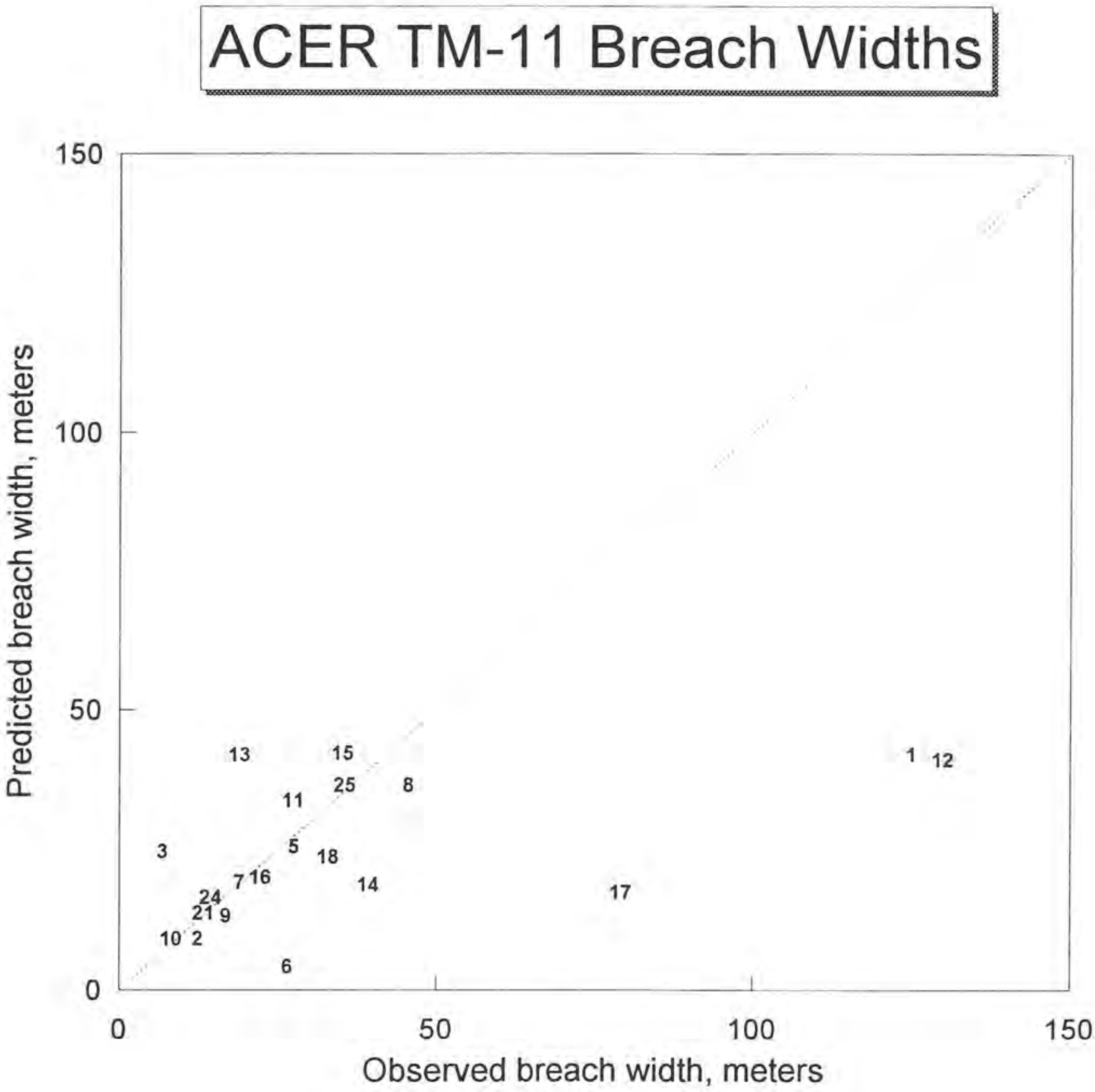
The discharge coefficient, C, was assumed to be 3.0 $ft^{0.5}/s$ (1.66 $m^{0.5}/s$), appropriate for a broad-crested weir flow *without tailwater effects*. The breach width B was determined using the TM-11 breach width equation. The use of $h_w$ implies the assumption of no reservoir drawdown at the time at which the breach width B is obtained. This may be approximately true for the large-reservoir cases, but is probably far from true for the smaller reservoirs. Thus, we should expect these predicted peak outflows to be larger than the observed values in most cases. Figure 6 shows this result, with only two cases of under-prediction (Goose Creek[6] and South Fork Tributary[23]). These two dams were both less than 2 meters high, and thus had relatively small predicted breach widths. The peak flow from Goose Creek Dam was predicted more accurately by the M&L-M equation. The peak flow for South Fork Tributary Dam could not be predicted using the M&L-M equation because the reservoir storage was undocumented.

Figure 7 compares the peak outflows predicted by the TM-11 analysis and the M&L-M equation. This allows a comparison of results for dam failures where the actual peak flows are not documented. Predicted peak flows are in near-agreement for five cases. The TM-11 analysis yields a significantly higher peak flow in 7 cases, and a significantly lower peak flow in 6 cases. The most dramatic difference in predicted peak flow is for Goose Creek Dam.

<u>Conclusions</u>: This analysis shows that both the ACER TM-11 approach and the MacDonald & Langridge-Monopolis equations have high degrees of uncertainty in their ability to predict breach parameters and peak breach outflows for small earthfill dams. Both methods tend to predict conservative, shorter breach times than those observed in the case studies. The ACER TM-11 equation overpredicts and underpredicts breach width about equally, with significant scatter. The few notable exceptions are dramatic underpredictions of breach width for the large-reservoir cases. The M&L-M prediction of volume of embankment material eroded also appears reasonable, with a large amount of scatter. All of the peak flow equations have large scatter, but compare reasonably well with the case study data. The ACER TM-11 equation overpredicts peak discharge in more cases than the M&L-M best-fit equation, but this is likely the result of the assumptions I made in the TM-11 analysis. With more detailed analyses, the peak flows I determined using the TM-11 parameters should be expected to drop. Comparing the peak flow relations to one another, there does not appear to be any systematic difference between them.

## Case Study Data and Predicted Breach Parameters for Small Earthfill Dams (Dam Height < 50 ft; Storage < 10,000 ac-ft)

| | | Dam | Construction | Failure | Observed parameters | | | | | | ACER TM-11 Predictions | | | MacDonald & Langridge-Monopolis Predictions | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $h_w$ | B | $V_w$ | $Q_{peak}$ | $V_{eroded}$ | $t_f$ | BW | TFM | $Q_{peak}$ | $t_f$ | $V_{eroded}$ | $Q_{peak}$ | $Q_{peak,\ envelope}$ |
| | | | | | $m$ | $m$ | $m^3$ | $m^3/s$ | $m^3$ | $hr$ | $m$ | $hr$ | $m^3/s$ | $hr$ | $m^3$ | $m^3/s$ | $m^3/s$ |
| 1 | * | Buffalo Creek, W. Va. | Homogeneous fill, coal waste | Seepage | 14.02 | 125. | 480,000. | 1420. | 318819. | 0.50 | 42.06 | 0.46 | 3665. | 0.39 | 4679. | 753. | 2473. |
| 2 | * | Bullock Draw Dike, Utah | Homogeneous earthfill | Piping | 3.05 | 12.5 | 1,130,000. | | 1353. | | 9.15 | 0.10 | 81.0 | 0.32 | 2779. | 570. | 1872. |
| 3 | * | Frankfurt, Germany | Earthfill | Piping | 8.23 | 6.9 | 350,000. | 79. | 1292. | 0.25 | 24.69 | 0.27 | 968. | 0.31 | 2421. | 529. | 1739. |
| 4 | | Fred Burr, Mont. | Homogeneous earthfill | Piping | 10.20 | | 750,000. | 654. | | | 30.60 | 0.34 | 1655. | 0.40 | 5143. | 792. | 2601. |
| 5 | * | French Landing, Mich. | Homogeneous earthfill | Piping | 8.53 | 27.4 | | 929. | 13762. | 0.58 | 25.59 | 0.28 | 1058. | | | | |
| 6 | * | Goose Creek, S. Carolina | Earthfill | Overtopping | 1.37 | 26.4 | 10,600,000. | 565. | 1070. | 0.50 | 4.11 | 0.05 | 11.0 | 0.48 | 8399. | 1030. | 3381. |
| 7 | | Grand Rapids, USA | Earthfill with clay corewall | Overtopping | 6.40 | 19.0 | 220,000. | | 1800. | 0.50 | 19.20 | 0.21 | 516. | 0.25 | 1396. | 394. | 1296. |
| 8 | * | Hebron, USA | Earthfill | Piping | 12.19 | 45.7 | | | 30812. | 2.25 | 36.57 | 0.40 | 2584. | | | | |
| 9 | | Iowa Beef Processors, WA | Earthfill | Piping | 4.42 | 16.8 | 330,000. | | | | 13.26 | 0.15 | 205. | 0.25 | 1445. | 401. | 1320. |
| 10 | * | Johnston City, Ill. | Homogeneous earthfill | Piping | 3.05 | 8.2 | 575,000. | | 673. | | 9.15 | 0.10 | 81.0 | 0.27 | 1653. | 431. | 1418. |
| 11 | * | Kelly Barnes, Ga. | Homogeneous earthfill | Piping | 11.30 | 27.3 | 505,000. | 680. | 9939. | 0.50 | 33.90 | 0.37 | 2138. | 0.37 | 4095. | 701. | 2303. |
| 12 | | Lake Avalon, N.M. | Earthfill | Piping | 13.70 | 130. | 7,750,000. | 2320. | 81045. | 2.00 | 41.10 | 0.45 | 3460. | 0.84 | 38784. | 2338. | 7659. |
| 13 | * | Lake Frances, Calif. | Homogeneous earthfill | Piping | 14.00 | 18.9 | 865,000. | | 12386. | 1.00 | 42.00 | 0.46 | 3652. | 0.46 | 7304. | 956. | 3138. |
| 14 | | Lake Latonka, Penn. | Homogeneous earthfill | Piping | 6.25 | 39.2 | 1,590,000. | 290. | 9538. | 3.00 | 18.75 | 0.21 | 486. | 0.43 | 6274. | 881. | 2893. |
| 15 | * | Laurel Run, Penn. | Earthfill | Overtopping | 14.10 | 35.1 | 385,000. | 1050. | 19475. | | 42.30 | 0.47 | 3718. | 0.36 | 3941. | 687. | 2256. |
| 16 | | Lawn Lake, Colo. | Homogeneous earthfill | Piping | 6.71 | 22.2 | | 510. | 2402. | | 20.13 | 0.22 | 581. | | | | |
| 17 | | Lower Latham, Colo. | Homogeneous earthfill | Piping | 5.79 | 79.2 | 7,080,000. | 340. | 14268. | 1.50 | 17.37 | 0.19 | 402. | 0.64 | 18656. | 1580. | 5180. |
| 18 | * | Melville, Utah | Zoned earthfill | Piping | 7.92 | 32.8 | | | 10620. | | 23.76 | 0.26 | 879. | | | | |
| 19 | * | North Branch, Penn. | Earthfill | | 5.49 | | | 29. | | | 16.47 | 0.18 | 352. | | | | |
| 20 | * | Otto Run, USA | Earthfill | | 5.79 | | | 60. | | | 17.37 | 0.19 | 402. | | | | |
| 21 | * | Rito Manzanares, N.M. | Homogeneous earthfill | Piping | 4.57 | 13.3 | 24,700. | | 1292. | | 13.71 | 0.15 | 222. | 0.12 | 200. | 139. | 459. |
| 22 | * | Sandy Run, Penn. | Earthfill | Overtopping | 8.53 | | 56,800. | 435. | | | 25.59 | 0.28 | 1058. | 0.19 | 615. | 254. | 836. |
| 23 | * | South Fork Tributary, Penn. | Earthfill | | 1.83 | | | 122. | | | 5.49 | 0.06 | 23.0 | | | | |
| 24 | * | Spring Lake, R.I. | Homogeneous earthfill, clay and gravel | Piping | 5.49 | 14.5 | 135,000. | | 612. | | 16.47 | 0.18 | 352. | 0.21 | 852. | 302. | 995. |
| 25 | * | Wheatland No. 1, Wyo. | Homogeneous earthfill | Piping | 12.20 | 35.4 | 11,500,000. | | 14603. | 1.50 | 36.60 | 0.40 | 2589. | 0.91 | 48054. | 2623. | 8588. |



ACER TM-11 Breach Widths
150
100
50
0
0
50
100
150
Predicted breach width, meters
Observed breach width, meters
13
15
25
8
11
3
5
18
7
16
14
17
24
21
9
10
2
6
1
12


Figure 1

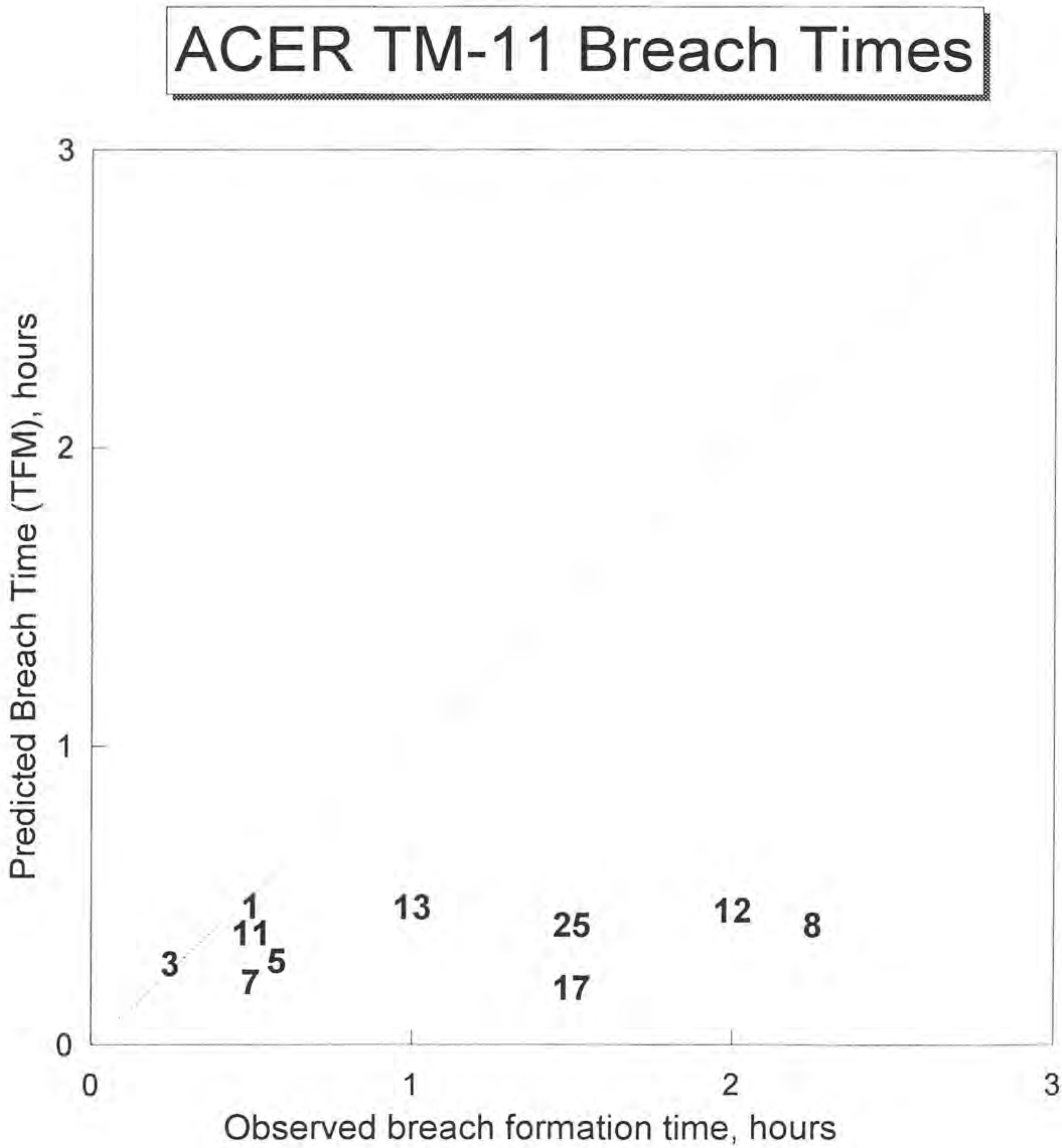
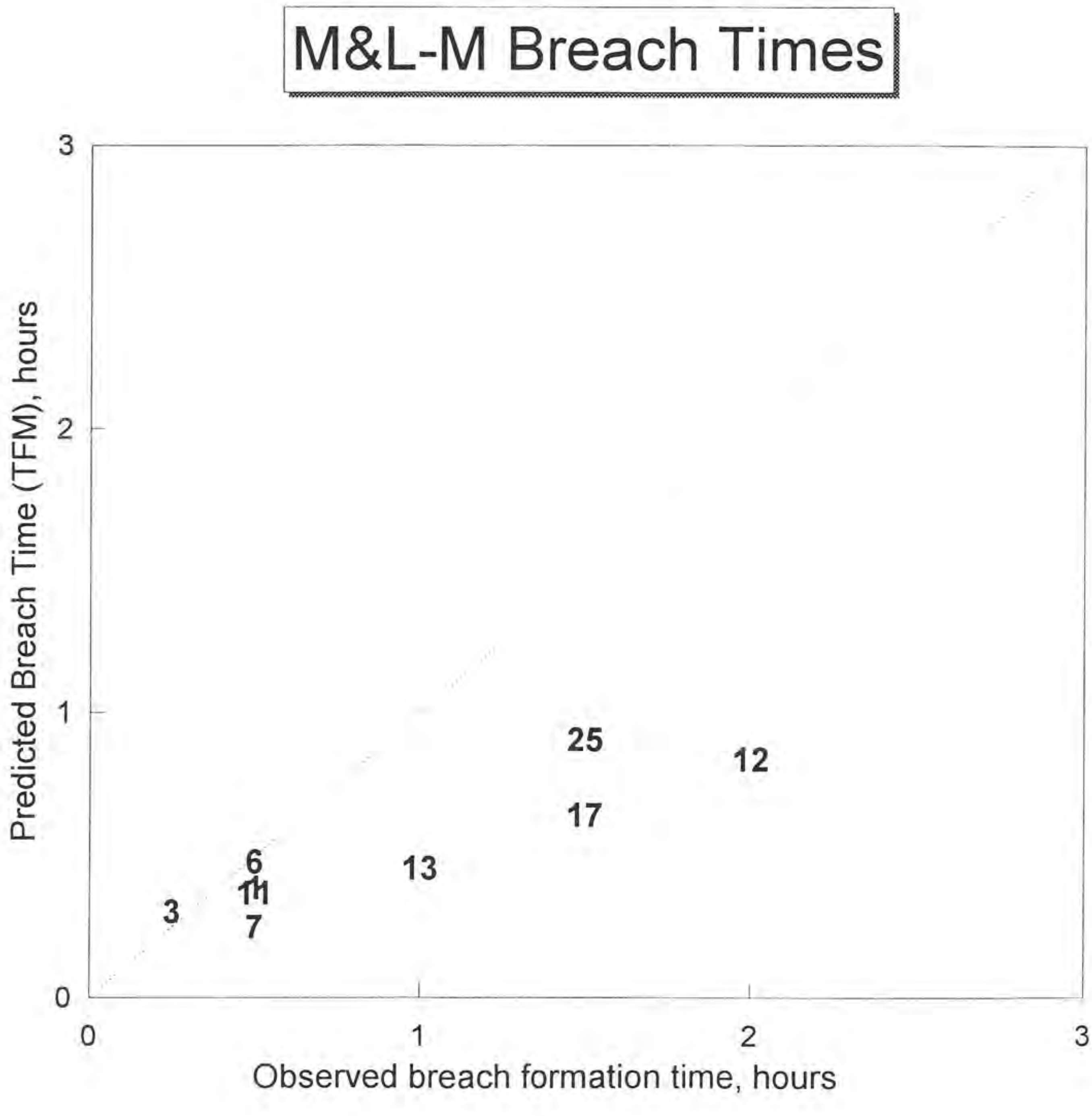

ACER TM-11 Breach Times
3
2
1
0
Predicted Breach Time (TFM), hours
1
13
25
12
8
11
3
5
7
17
0
1
2
3
Observed breach formation time, hours

Figure 2



M&L-M Breach Times
3
2
1
0
0
1
2
3
Predicted Breach Time (TFM), hours
Observed breach formation time, hours
25
12
17
6
13
11
3
7


Figure 3

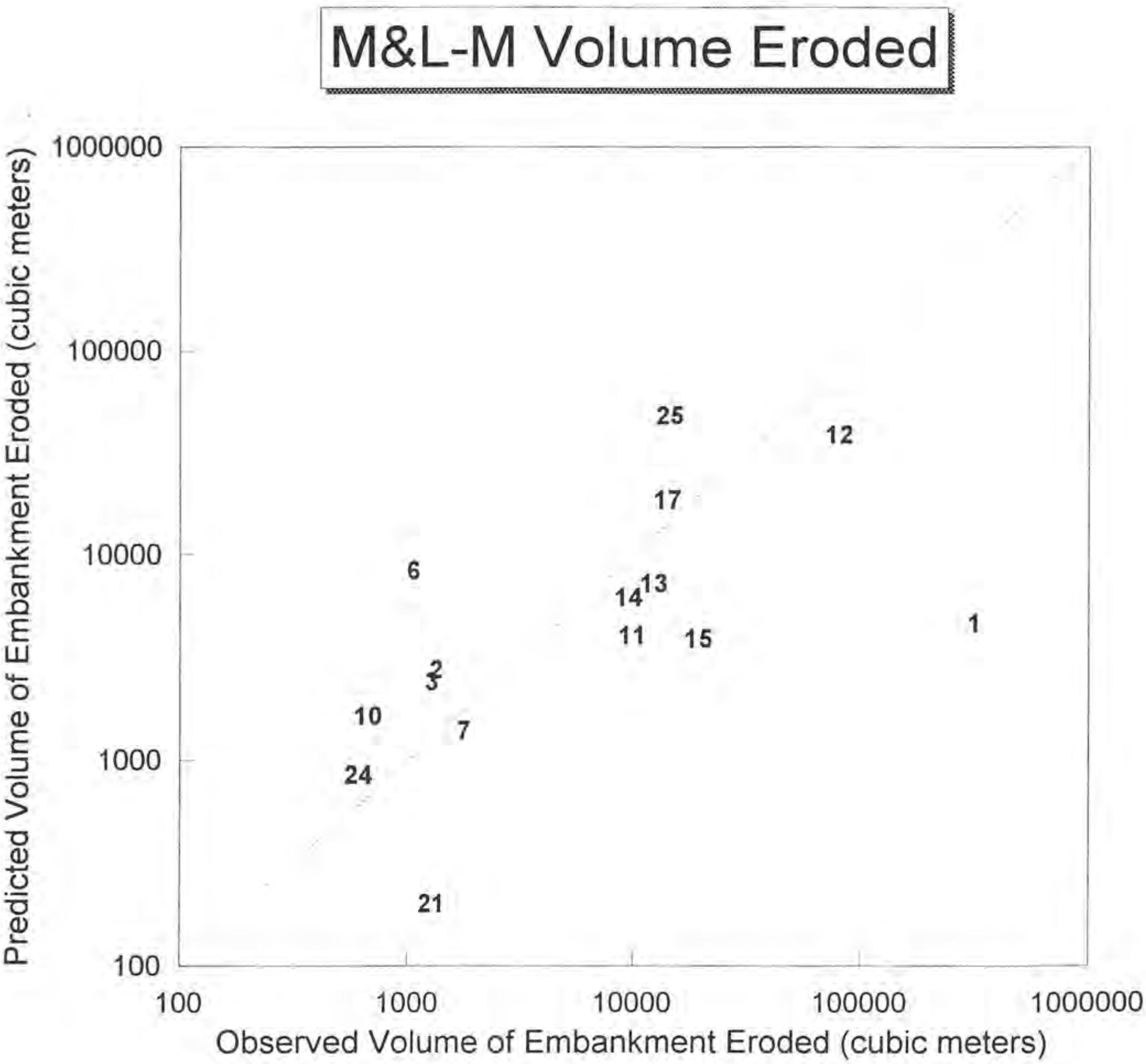

M&L-M Volume Eroded
Predicted Volume of Embankment Eroded (cubic meters)
Observed Volume of Embankment Eroded (cubic meters)
1000000
100000
10000
1000
100
100
1000
10000
100000
1000000
25
12
17
6
14
13
1
11
15
2
3
10
7
24
21

Figure 4

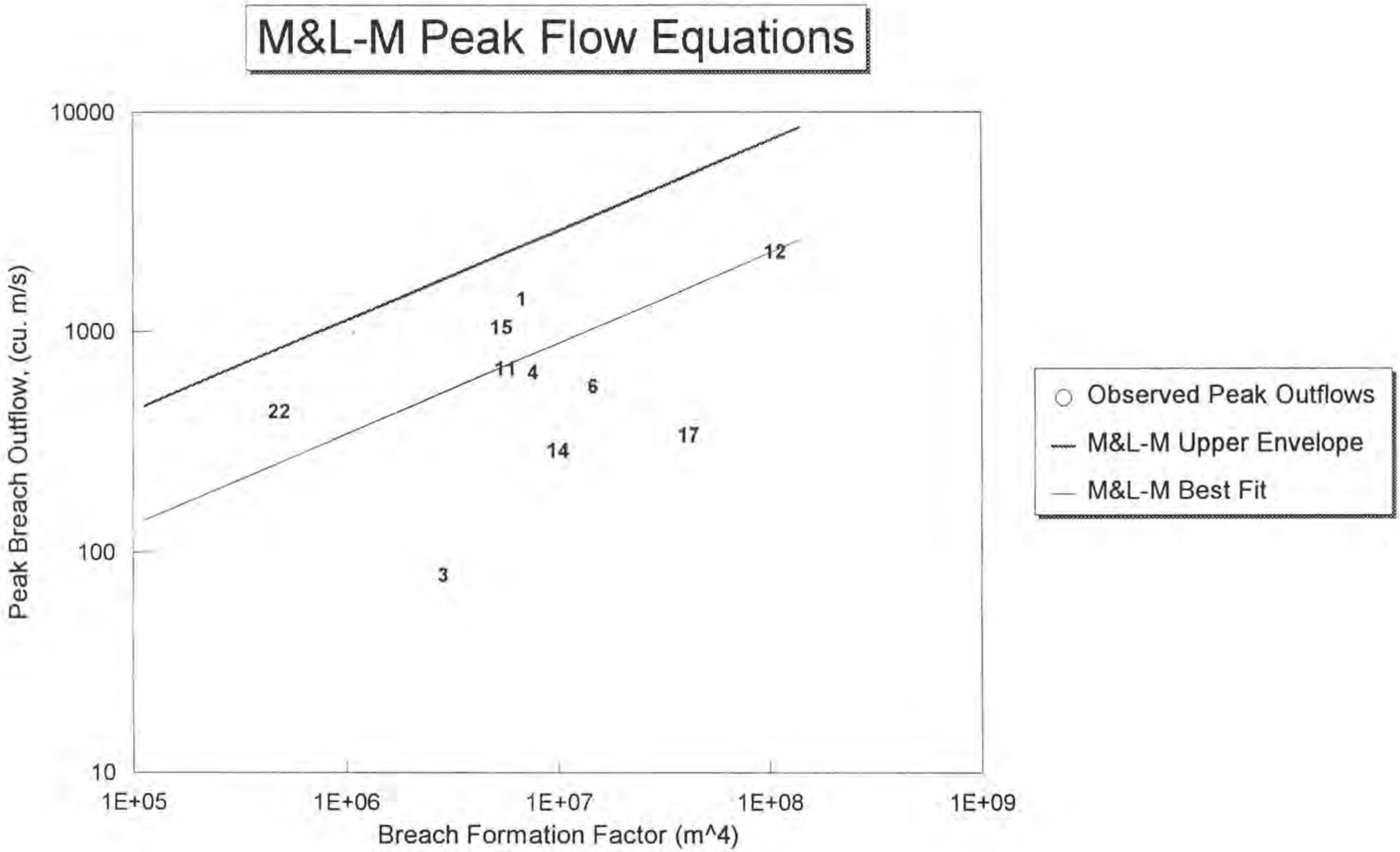

M&L-M Peak Flow Equations
10000
1000
100
10
Peak Breach Outflow, (cu. m/s)
1E+05
1E+06
1E+07
1E+08
1E+09
Breach Formation Factor (m^4)
12
1
15
11
4
6
22
17
14
3
Observed Peak Outflows
M&L-M Upper Envelope
M&L-M Best Fit

Figure 5

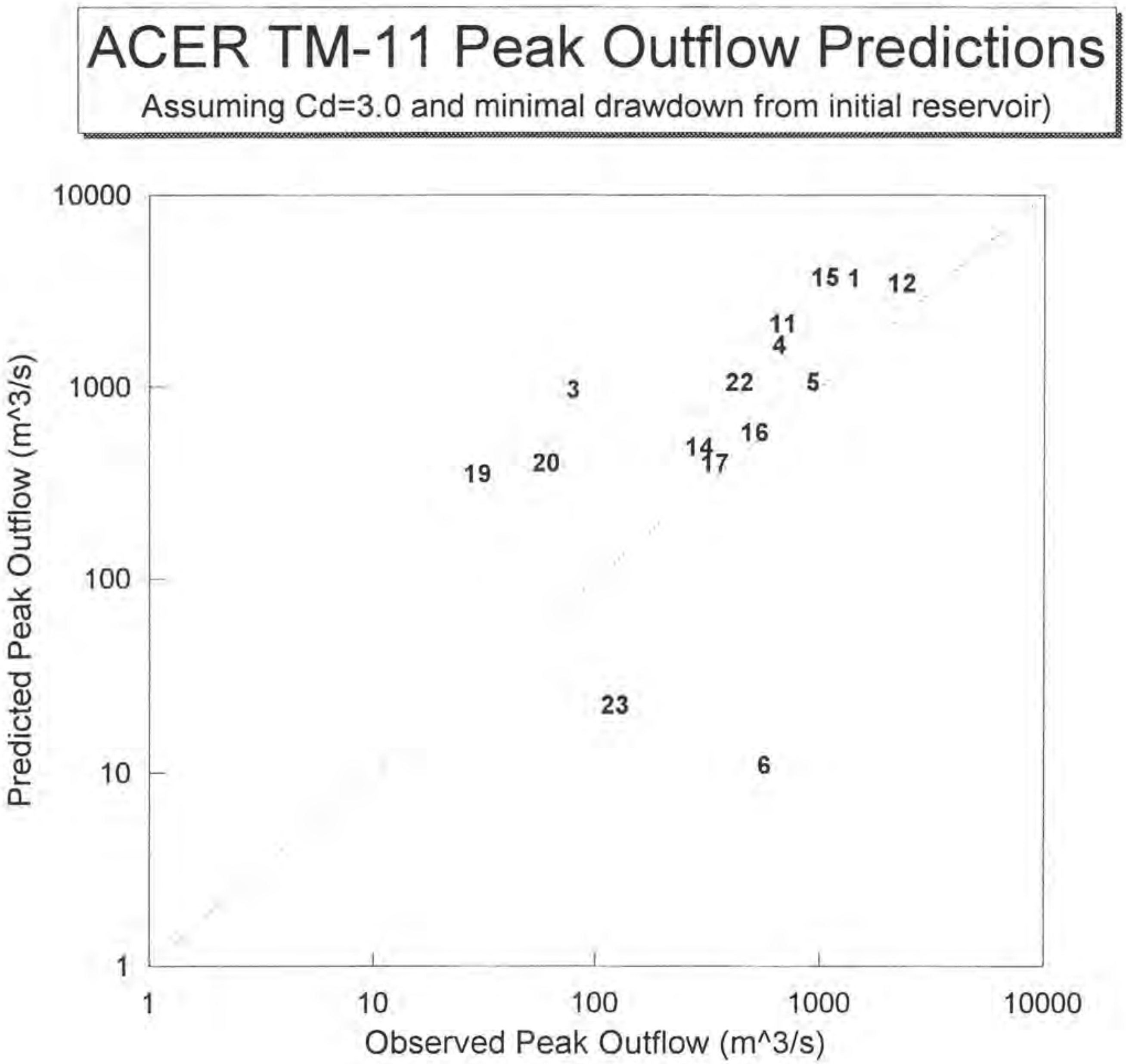

ACER TM-11 Peak Outflow Predictions
Assuming Cd=3.0 and minimal drawdown from initial reservoir)
Predicted Peak Outflow (m^3/s)
Observed Peak Outflow (m^3/s)
10000
1000
100
10
1
1
10
100
1000
10000
15
1
12
11
4
3
22
5
16
14
17
19
20
23
6

Figure 6

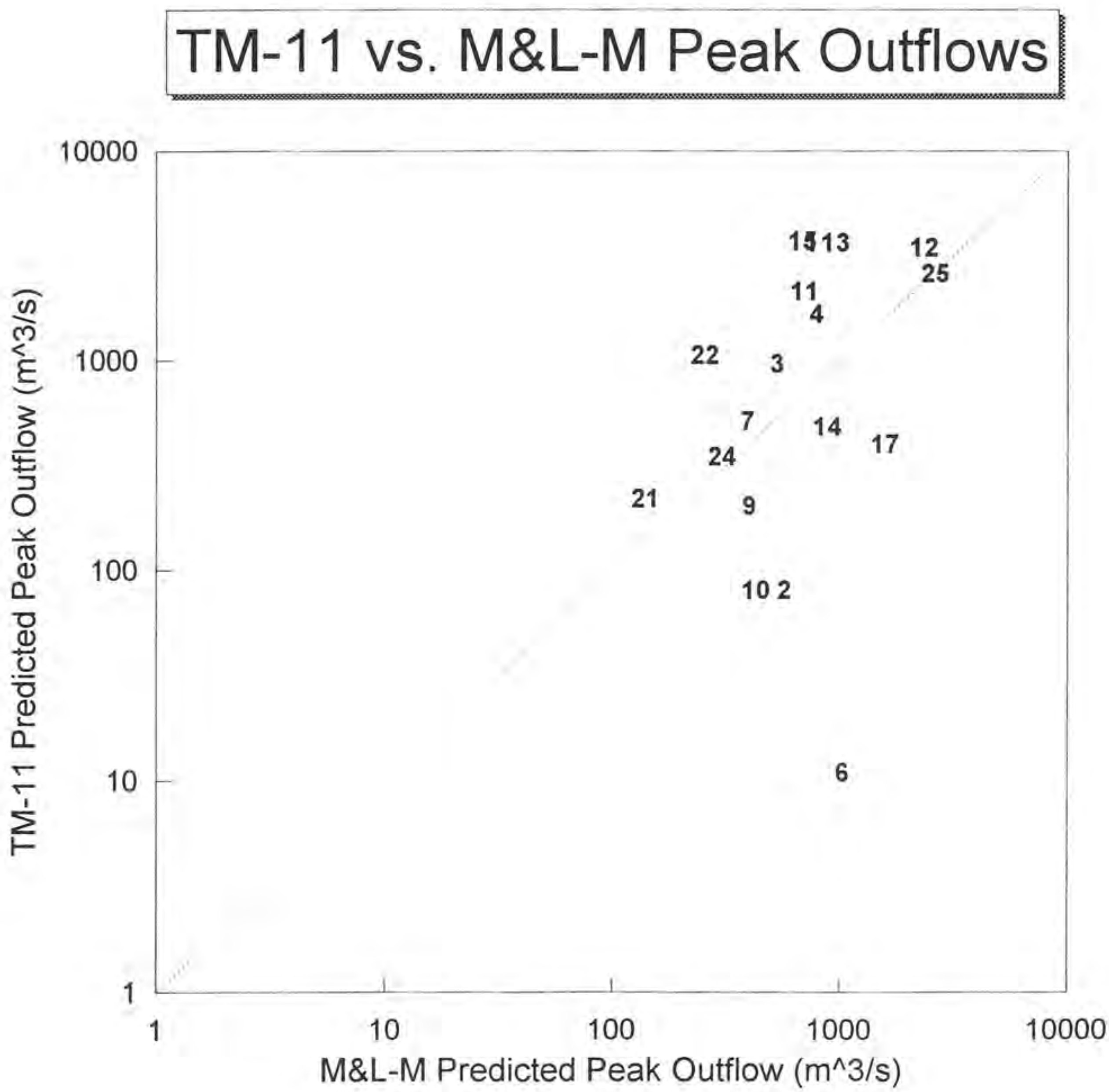

TM-11 vs. M&L-M Peak Outflows
10000
1000
100
10
1
1
10
100
1000
10000
TM-11 Predicted Peak Outflow (m^3/s)
M&L-M Predicted Peak Outflow (m^3/s)
15
13
12
25
11
4
22
3
7
14
17
24
21
9
10
2
6

Figure 7