# <u>Hydrological Study of Thundering Brook Drainage Basin In Killington, Vt.</u>

Sarah King
Kathleen Donna
Geomorphology
University of Vermont
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**Abstract**

In Killington, Vermont, there is a section of the Appalachian Trail that needs to be moved. Its present location poses hazardous conditions for its hikers and for the land. This location causes many hikers to go out of their way to view the beautiful Thundering Brook Falls, which has no designated trail to it, resulting in damage to the surrounding natural resources, such as destruction of vegetation and an increase in soil erosion. In order to relocate this section of the trail, it needs to go by the falls, to pass through a marsh, via a boardwalk, and connect to the rest of the trail. Unfortunately, the Thundering Brook and nearby Ottauquechee River flood this marsh and the boardwalk built here must be high enough to be above the largest flood this area could have. In order to calculate this flood height, 27 flood records from streams around Vermont were collected and graphed on log/probability paper, discharge versus probability of occurrence. From each of these graphs, the discharges of the 2 yr., 5 yr., 10 yr., 25 yr., 50 yr., 100 yr., and 200 yr. flood intervals were estimated. These discharges were then plotted on log/log paper, discharge versus drainage basin area. The size of the drainage basin of Thundering Brook was calculated using a USGS map, and found to be 10.3 square miles. Using this area, the discharges for each of the flood intervals were estimated. These discharges were then put into the Manning Equation, which was rewritten in terms of depth, to determine the depth of water in the marsh during each flood interval. In order to account for possible errors in determining the type of stream channel, the Manning Coefficients of 0.015, 0.035, and 0.055 were used. For 0.015, 0.035, and 0.055, the 2 year flood interval depths were 0.23 feet, 0.38 feet, and 0.50 feet, respectively, while the 200 year flood interval depths were 0.35 feet, 0.59 feet, and 0.77 feet, respectively. The maximum height of 0.77 feet will be used to determine the height of the boardwalk across the marsh of Thundering Brook and the Ottauquechee River.

## Introduction

The Appalachian Trail (AT) is used by thousands of people every year. Currently, a section of this trail runs along Thundering Brook Road in Killington, Vermont (Fig. 1). The town does not want people walking along this road because it could be dangerous. The current trail location passes near Thundering Brook Falls, but does not go directly by it (Fig. 2). Many people who hike on this section of the Appalachian Trail will hike over to view the falls. The US Forest Service, which maintains a 1000 ft. corridor along the AT, has decided to relocate this section of the Appalachian Trail because of the town concerns and the natural resource damage occurring near Thundering Brook Falls due to the lack of a designated trail location near the falls. The proposed relocation of the trail would no longer follow Thundering Brook Road, but would be located along Thundering Brook Falls, across a marsh, across the Ottauquechee River and then across River Road to connect with the current trail location (Fig. 3). Since the proposed relocation of the trail crosses a marsh, a boardwalk must be built to provide dry conditions for hiking. For the design of the boardwalk, a hydrological study of the drainage basin had to be completed in order to estimate the maximum height of the 200 year flood stage.

## Methodology

The hydrological study of Thundering Brook drainage basin began with the measurement of the drainage area size using the Pico Peak USGS topographic map. The drainage area was 10.3 square miles. A topographic survey of the study area was completed using a Leitz total station and a Leitz data collector. To determine the maximum height of the 200 year flood stage using the probability analysis of flood records method, the peak discharge records of 27 Vermont streams with flow records from 13 to 85 years, were located on the USGS website (USGS, 2001). These records were entered into an Excel spreadsheet, ranked by descending peak discharges, exceedence probabilities were calculated, and plotted on normal probability paper. From these graphs, the peak discharge of the 2 yr., 5 yr., 10 yr., 25 yr., 50 yr., 100 yr., and 200 yr. recurrence interval floods for each Vermont gaged stream was estimated. These peak discharges were plotted on log/log graph paper vs. the drainage basin areas. The peak discharge for each recurrence interval for the study area was estimated using these discharge/area relation graphs. The water level depth for each recurrence interval was determined by applying the estimated peak discharge values for the study area into the Manning Equation. The Manning Equation is $Q=[A(R)^{2/3}(S)^{1/2}(1.49)]/n$ where Q is equal to discharge, A is equal to area, R is equal to the hydraulic radius, S is equal to the slope, 1.49 is a conversion factor for units in feet, and n is equal to the Manning Coefficient, which is representative of stream characteristics. Since the area (A) and hydraulic radius (R) are unknown, these values were put in terms of depth. The Manning Equation became $Q=[(w*d)(\{w*d\}/w+2d\})^{2/3}(S)^{1/2}(1.49)]/n$, where d equals depth and w equals width. A sensitivity test was performed using different ‘n’ values for the Manning Coefficient, to account for possible errors in determining the type of stream channel. The different values for the Manning Coefficient that were used were 0.015, 0.035 and 0.055. The water level depth for the 200 yr. recurrence interval will be used to determine the minimum height of the proposed boardwalk.

**Data**

The peak discharge/drainage basin area relationship is needed to generalize flood experiences over geographic areas, due to the differences in the flood experience and flood potential that exist among various lithologic and topographic types (Leopold et al, 1992). The Excel spreadsheets of peak discharge records (Table 1), and these plots on normal probability paper (Fig. 4) are examples of the first stage of a probability analysis of flood records. The peak discharge of the 2 yr., 5 yr., 10 yr., 25 yr., 50 yr., 100 yr., and 200 yr. recurrence interval flood for each Vermont gaged stream was estimated (Tables 2 - 8). The peak discharge vs. drainage basin area plots illustrate the peak discharge/drainage basin area relationship (Figs. 5 - 11). The estimated peak flows of

Thundering Brook drainage basin, applied to the Manning Equation, result in a narrow range of flood depths. The values used in the Manning Equation were: measured S equals 0.0105, Q changes with each flood recurrence interval, n equals 0.035, which represents a winding natural stream (Dunne and Leopold, 1998), and w equals 529 feet, determined from the cross-section of the topographic survey (Table 2). The range of flood depths, calculated using the Manning Coefficient of 0.035, are listed in an Excel spreadsheet (Table 9). The various water level depths are illustrated on cross-sections of the study area for each recurrence interval flood (Figs. 12 and 13). The depth analysis sensitivity test, using the Manning Coefficient 'n' values 0.015 and 0.055, illustrate the error involved for the study area (Tables 10 and 11). This analysis was done to determine the extremes of a misjudgment in assuming the stream characteristics in the study area. The water level depth for the 200 yr. recurrence interval, 0.77 ft., using the Manning Coefficient of 0.055, will be used to determine the minimum height of the proposed boardwalk, as this is most conservative.

**Discussion**

The flood-prediction method of probability analysis of flood records is an estimate of peak discharges from a variety of drainage basin areas (Dunne and Leopold, 1998). The 200 yr. recurrence interval peak discharge is extrapolated from the graphs because there is no 200 year peak discharge record available. The 100 yr. recurrence interval peak discharge is also extrapolated, but the historic records available are close to a 100 year record. As stated in the National Research Council, "…in the United States stream flow records of greater than 100 years are meager, and most records are considerably shorter. Consequently, any method for estimating probabilities of floods rarer than about the 100-year flood must include some form of extrapolation, a process that can, at best, introduce errors and, at worst, strain credulity" (National Research Council, 1988: 2). A methodology, though, that analyzes a range of floods and their estimated probabilities is preferred to a methodology that analyzes a single, major flood that represents an upper limit (National Research Council, 1988).

Another flood-prediction technique uses the unit hydrograph to determine the time distribution of runoff throughout the storm (Dunne and Leopold, 1998). The unit hydrograph illustrates one inch of storm runoff that would be generated from a rainstorm of uniform intensity over a specific period of time. An advantage to the unit hydrograph method is that flood peak predictions can be made using only a short period of record of rainfall and runoff, and the results can be regionalized for other ungauged basins, which is also the case for the probability analysis method. The unit hydrograph method was a more sophisticated method than was needed for the hydrological study of Thundering Brook drainage basin.

In the probability analysis method, the use of the Manning Equation and the range of water level depths calculated using three different Manning Coefficients (Table 12), illustrates the weakness of the final step of the methodology. The application of the Manning Equation to natural rivers is not straightforward (USACE, 2002), because the procedure assumes that “the roughness coefficient is known; the roughness coefficient does not vary with stage; the cross-section does not change markedly with stage; the energy slope is known; and the flow is steady and uniform” (Bevin and Carling, 1989: 87). By applying the different “n” values to the Manning Equation, three water level depths were found. The deepest, 0.726 feet, will be used in the proposed boardwalk design, therefore, a reliable boardwalk height should be achieved.

**Summary**

At Thundering Brook and Ottauquechee River, the flood water depths were estimated using interpreted flow data from gaged streams across Vermont. Using measured data from a location on the Ottauquechee River, in the study area, the width and depth were applied to the Manning Equation. The calculated discharge was 245.3 cfs, which equals the bank full discharge, or the 1.5 year recurrence interval flood. This discharge was compared to the calculated 2 year recurrence interval flood discharge of

460 cfs.  The bank full discharge was slightly lower than the 2 year recurrence interval flood discharge.  This would be expected since the recurrence interval years and peak flow discharges have a direct linear relationship; as the recurrence interval year increases, the peak flow discharge increases.  This suggests that using flow data, from many different gaged streams, to interpret one that does not have multiple years of recorded data, is an acceptable flood-prediction method.

**Bibliography**

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USACE (2002) www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1601/c-5.pdf <http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1601/c-5.pdf>

USGS (2002) http://water.usgs.gov/vt/nwis/peak?…

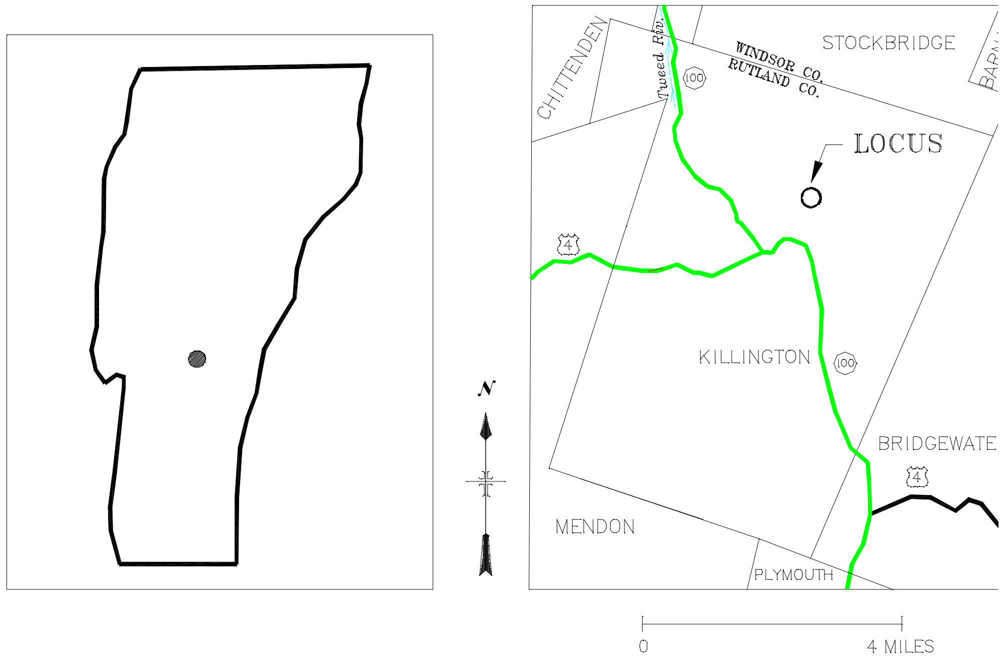



Figure 1: Location Map of Killington, Vt.

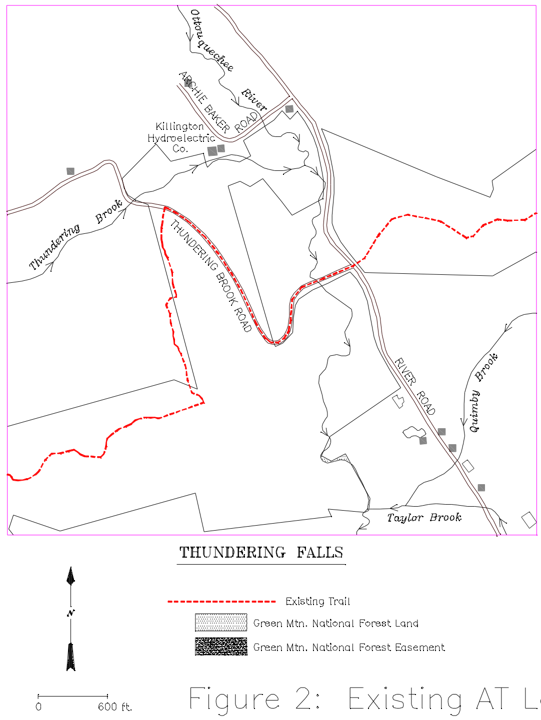



Figure 2: Existing AT Location

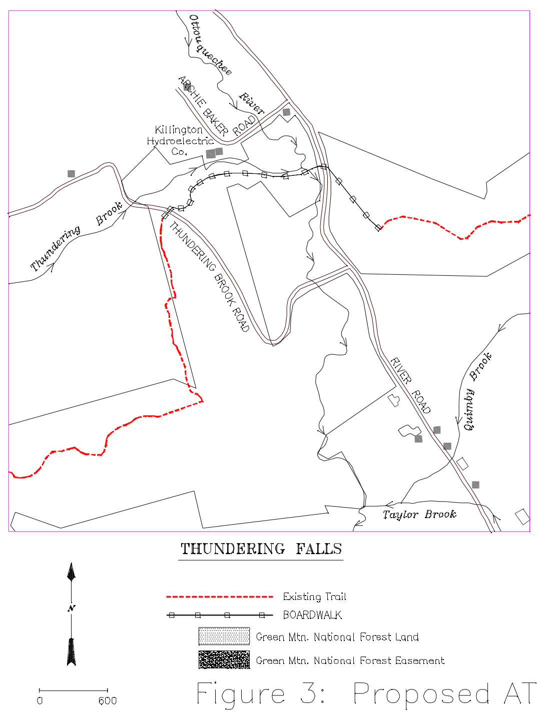



Figure 3: Proposed AT Relocation

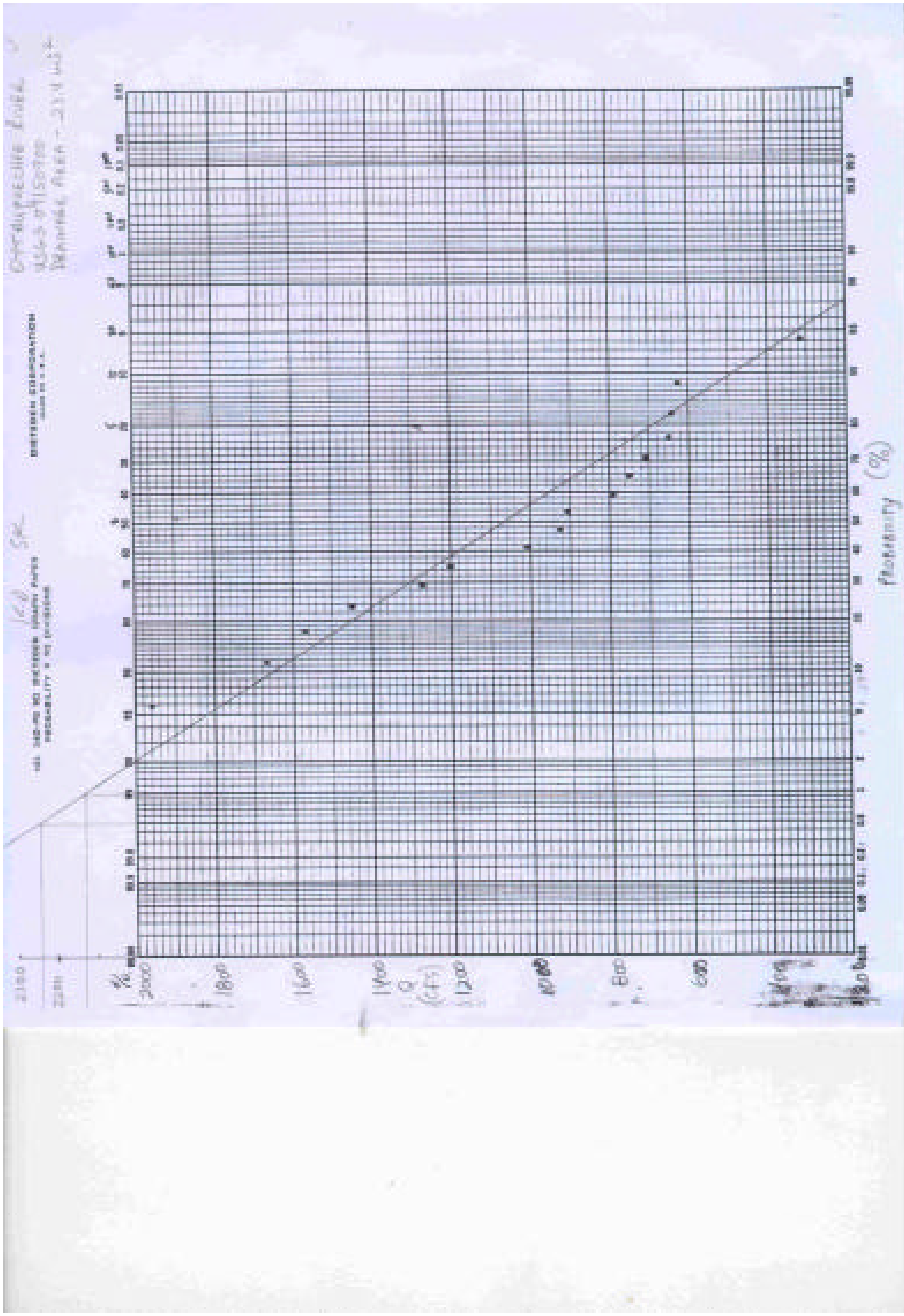


Figure 4:  Example of Discharge vs Probability Plot

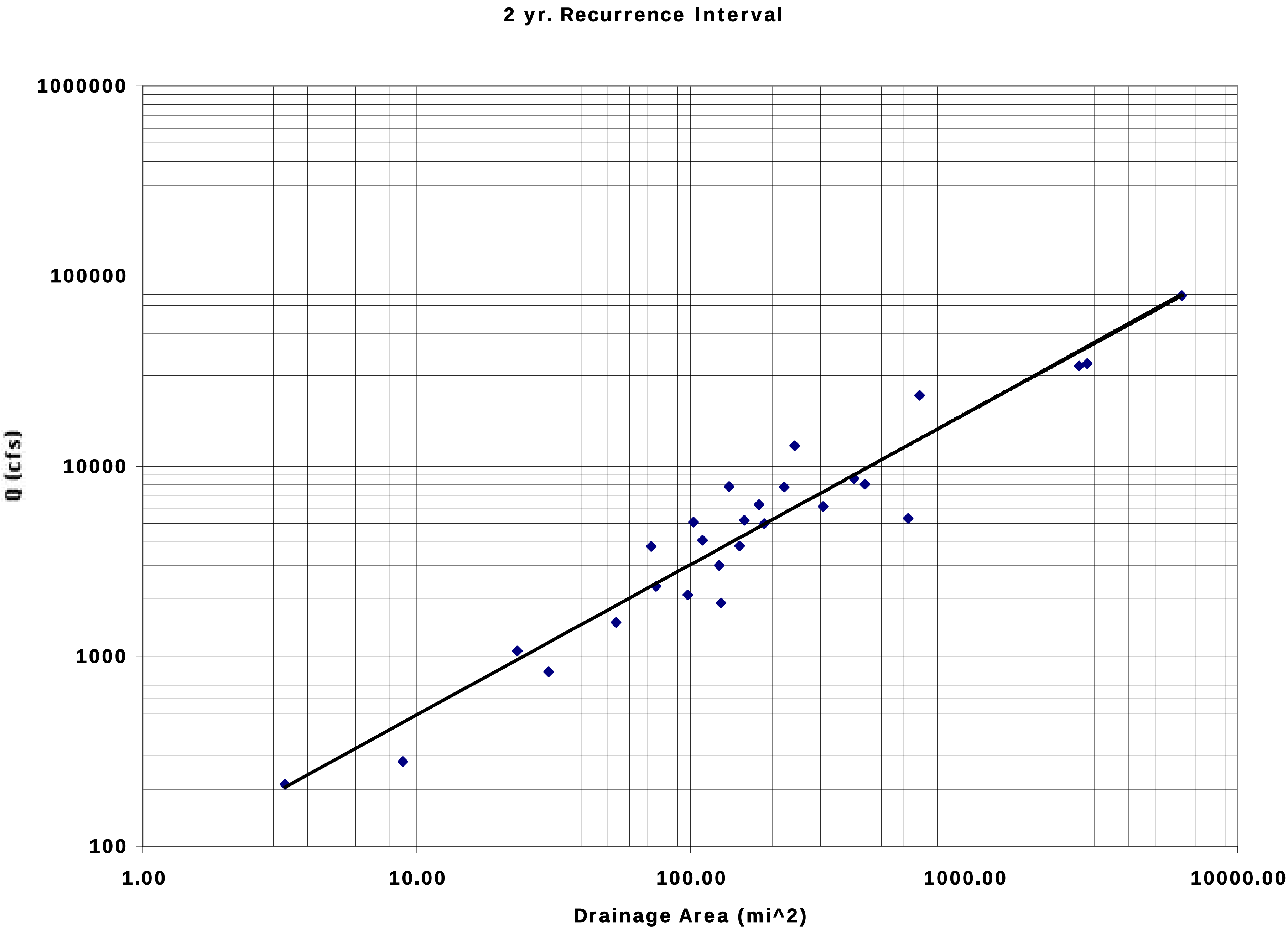


Figure 5:  Peak Discharge vs Drainage Basin Area for 2 yr. Recurrence Interval

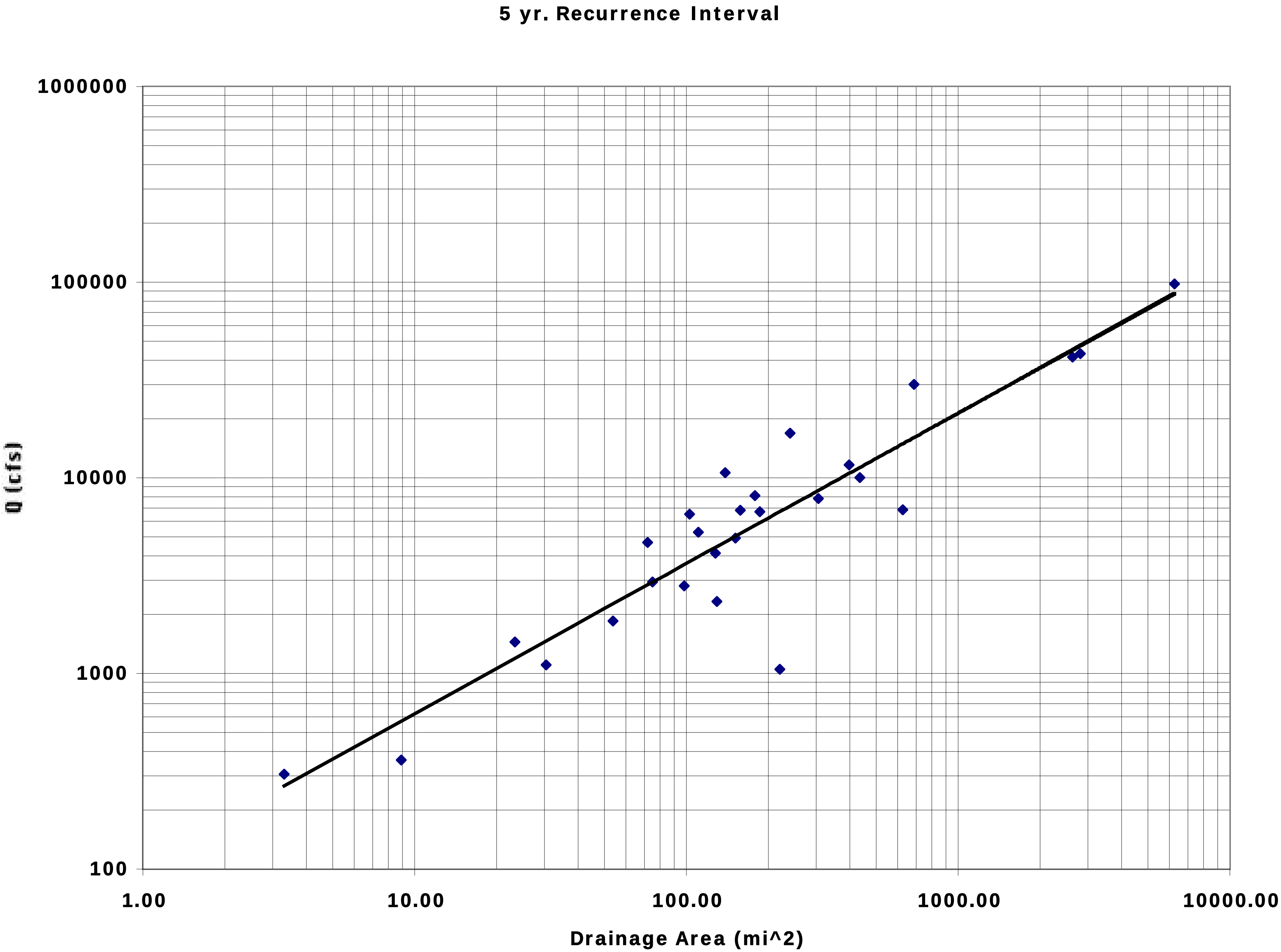


Figure 6: Peak Discharge vs Drainage Basin Area for 5 yr. Recurrence Interval

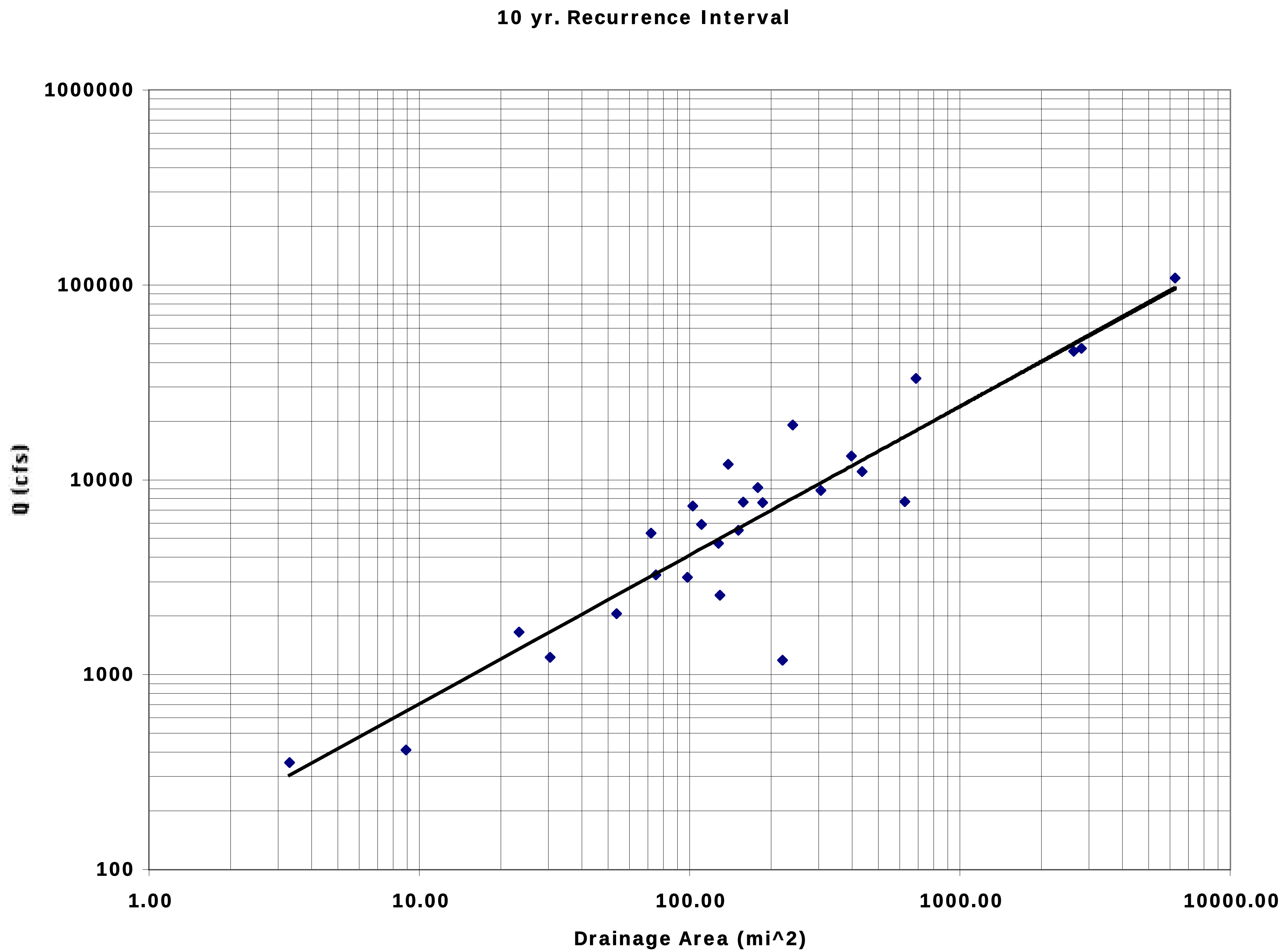


Figure 7: Peak Discharge vs Drainage Basin Area for 10 yr. Recurrence Interval

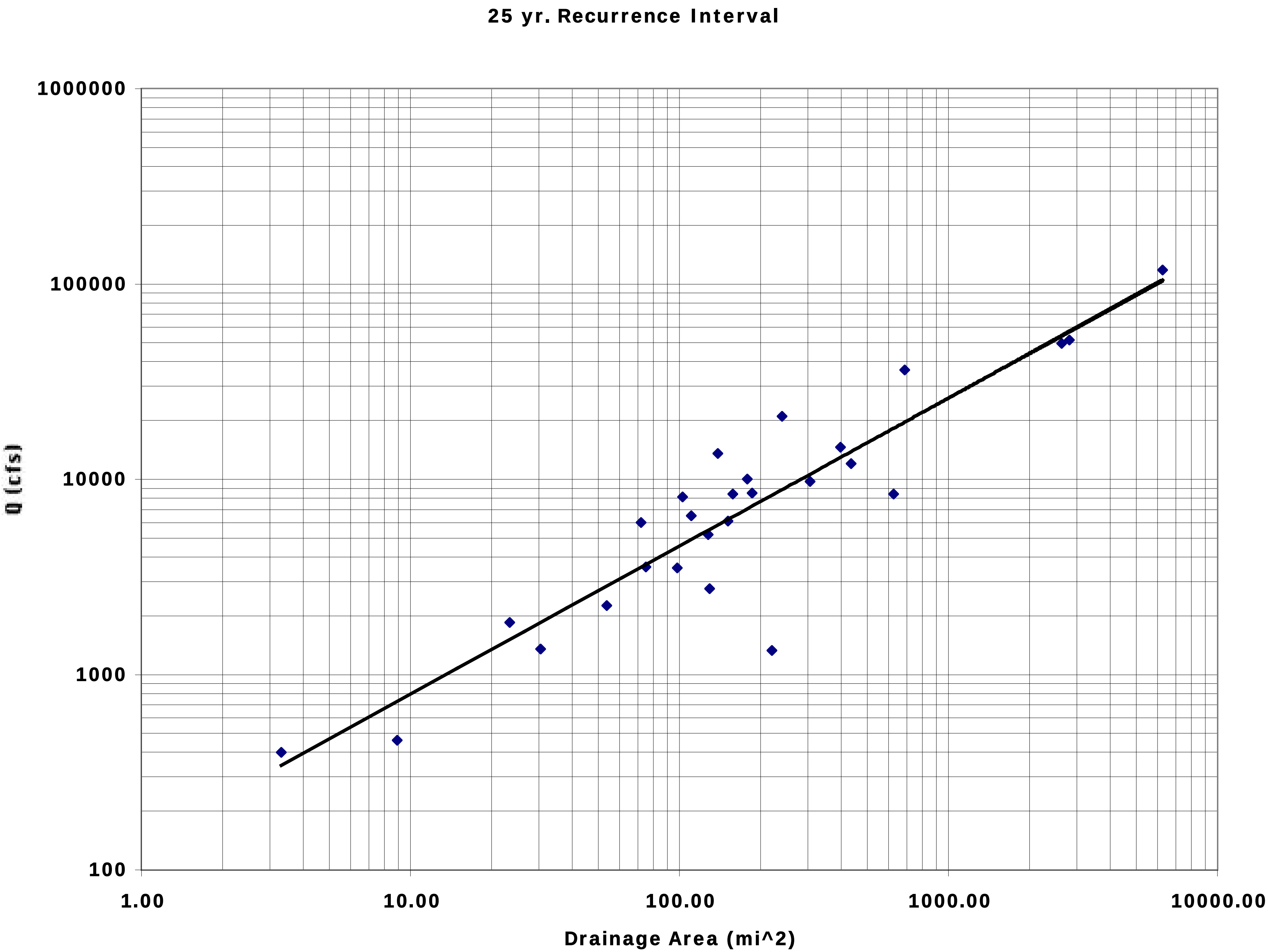


Figure 8: Peak Discharge vs Drainage Basin Area for 25 yr. Recurrence Interval

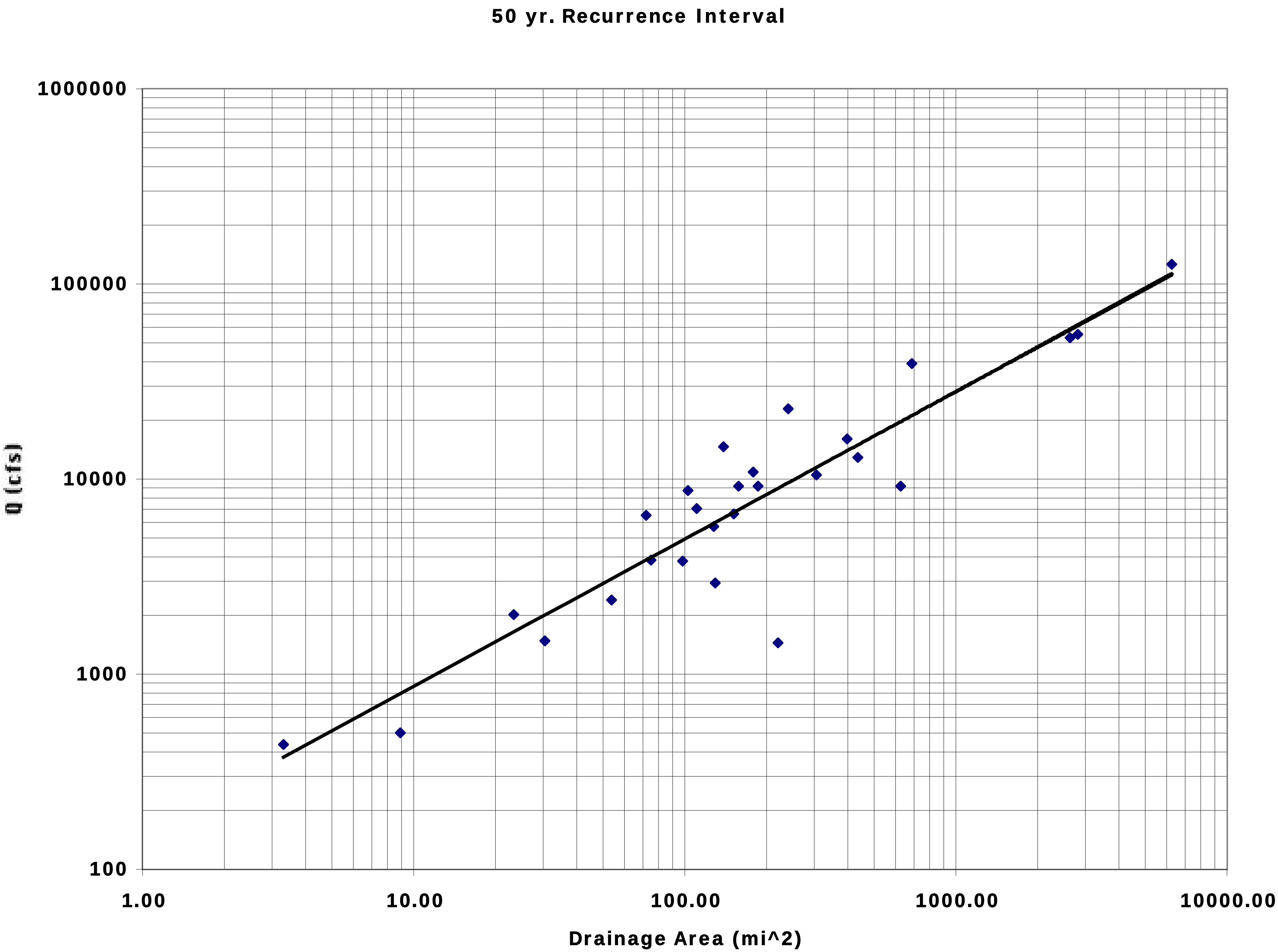



Figure 9:  Peak Discharge vs Drainage Basin Area for 50 yr. Recurrence Interval

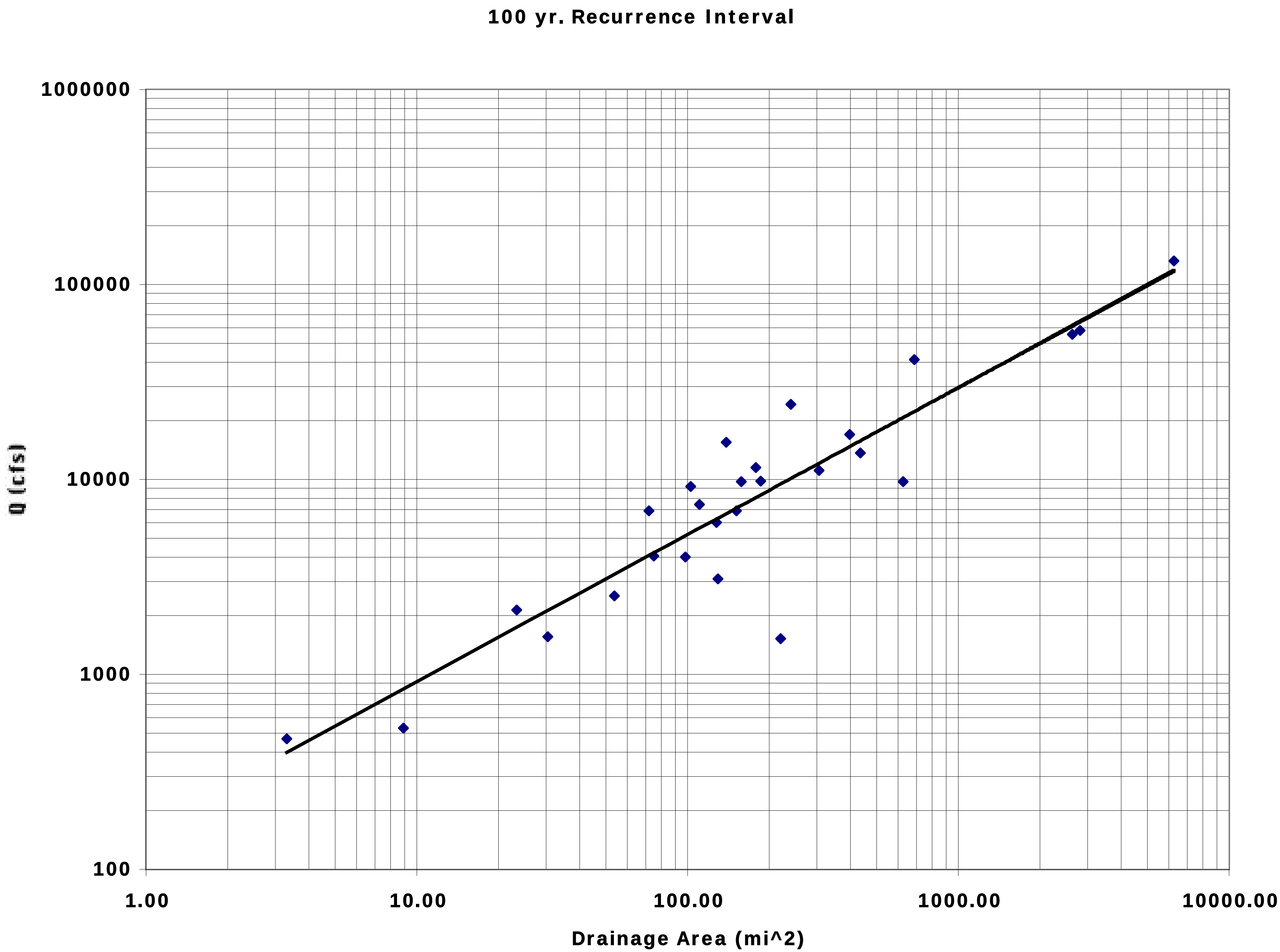


Figure 10: Peak Discharge vs Drainage Basin Area for 100 yr. Recurrence Interval

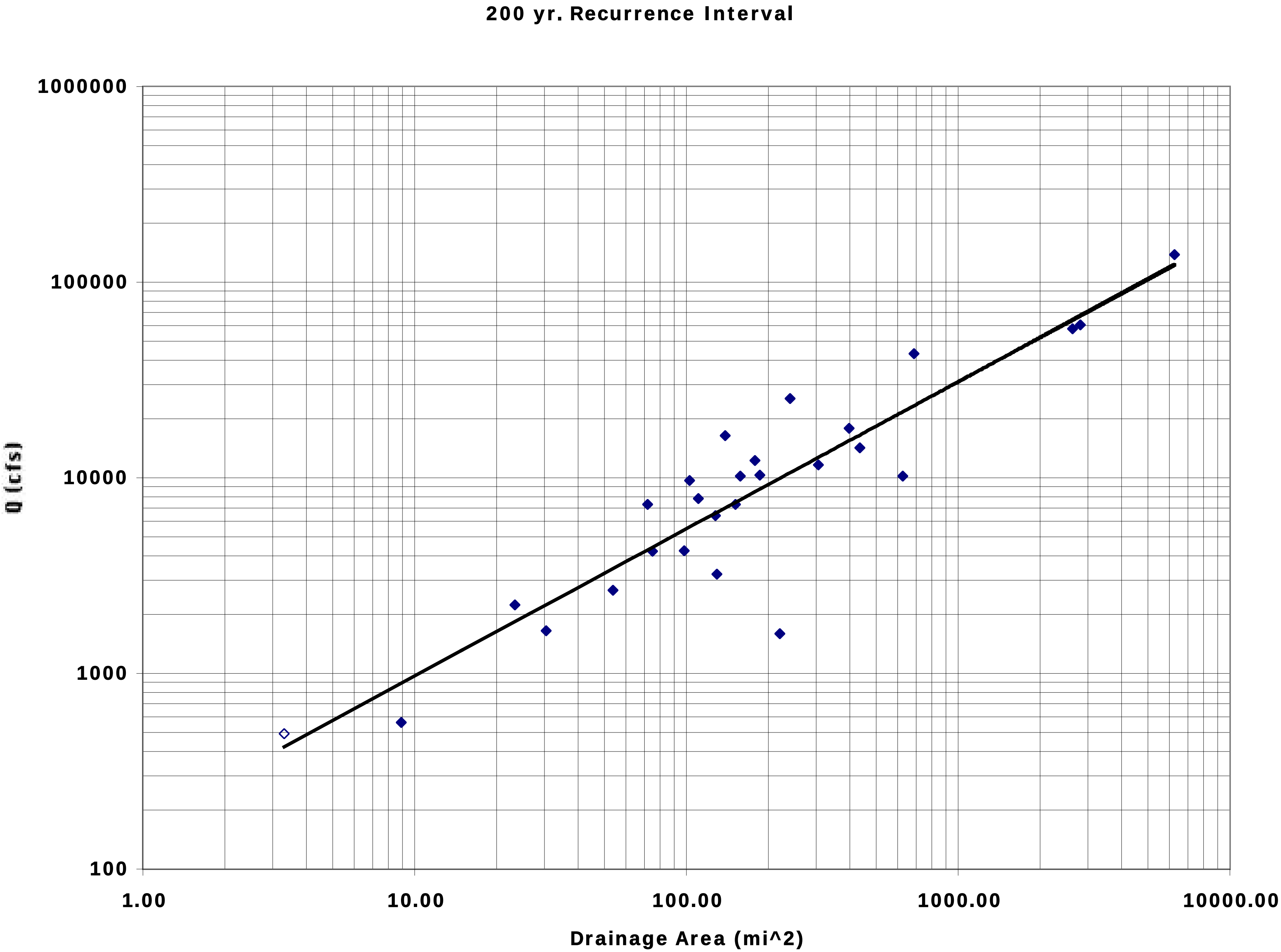
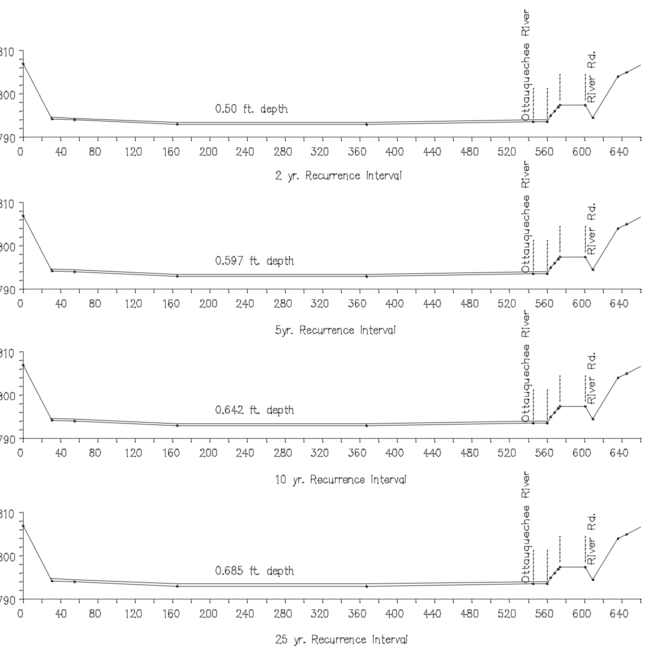
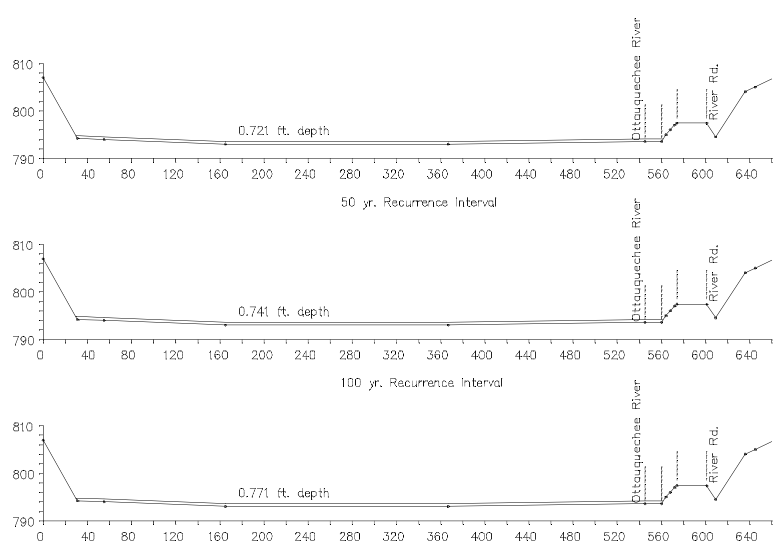



Figure 11: Peak Discharge vs Drainage Basin Area for 200 yr. Recurrence Interval




Scale: 1" = 80 ft. (horizontal), 1" = 20 ft. (vertical)

Figure 12: Thundering Brook Drainage Basin Cross-Section
2 – 25 yr. Recurrence Interval




Scale: 1" = 80 ft. (horizontal), 1" = 20 ft. (vertical)

Figure 13: Thundering Brook Drainage Basin Cross-Section
50–200 yr. Recurrence Interval

**Table 1: Example of a Vt. Stream Peak Discharge Record**
**Ottauquechee River near West Bridgewater, VT**
**USGS 01150900 Drainage area: 23.4 sq.mi.**

| Water Year | Streamflow (cfs) | Rank | Recurrence Interval T=(n+1)/m | Probability P=1/T (%) |
|---|---|---|---|---|
| 1996 | 1960 | 1 | 17.000 | 5.882 |
| 2000 | 1670 | 2 | 8.500 | 11.765 |
| 1998 | 1570 | 3 | 5.667 | 17.647 |
| 1993 | 1450 | 4 | 4.250 | 23.529 |
| 1987 | 1270 | 5 | 3.400 | 29.412 |
| 1999 | 1200 | 6 | 2.833 | 35.294 |
| 1986 | 1010 | 7 | 2.429 | 41.176 |
| 1988 | 928 | 8 | 2.125 | 47.059 |
| 1994 | 918 | 9 | 1.889 | 52.941 |
| 1989 | 791 | 10 | 1.700 | 58.824 |
| 1992 | 753 | 11 | 1.545 | 64.706 |
| 1997 | 702 | 12 | 1.417 | 70.588 |
| 1990 | 655 | 13 | 1.308 | 76.471 |
| 1985 | 646 | 14 | 1.214 | 82.353 |
| 1991 | 629 | 15 | 1.133 | 88.235 |
| 1995 | 318 | 16 | 1.063 | 94.118 |

Table 2: Peak Discharge of 2 yr Recurrence Interval

| Stream Gage Location | USGS # | Streamflow (cfs) | Drainage Area (mi^2) |
|---|---|---|---|
| Kent Brook | 1150800 | 211 | 3.31 |
| East Orange Branch | 1139800 | 279 | 8.95 |
| Ottauquechee River | 1150900 | 1065 | 23.40 |
| Ayers Brook | 1142500 | 825 | 30.50 |
| East Branch Passumpsic River | 1133000 | 1500 | 53.80 |
| Saxtons River | 1154000 | 3780 | 72.20 |
| Moose River | 1134500 | 2325 | 75.20 |
| Wells River | 1139000 | 2100 | 98.40 |
| Williams River | 1153500 | 5050 | 103.00 |
| Walloomsac River | 1334000 | 4060 | 111.00 |
| Moose River | 1135000 | 3000 | 128.00 |
| Ompompanoosuc River | 1141500 | 1900 | 130.00 |
| Mad River | 4288000 | 7800 | 139.00 |
| Batten Kill | 1329000 | 3790 | 152.00 |
| Black River | 1153000 | 5190 | 158.00 |
| West River | 1155500 | 6250 | 179.00 |
| Poultney River | 4280000 | 4975 | 187.00 |
| Ottauquechee River | 1151500 | 7750 | 221.00 |
| White River | 1142000 | 12800 | 241.00 |
| Otter Creek | 4282000 | 6100 | 307.00 |
| Winooski River | 4286000 | 8600 | 397.00 |
| Passumpsic River | 1135500 | 8000 | 436.00 |
| Otter Creek | 4282500 | 5300 | 628.00 |
| White River | 1144000 | 23500 | 690.00 |
| Connecticut River | 1138500 | 33500 | 2644.00 |
| Connecticut River | 1139500 | 34500 | 2825.00 |
| Connecticut River | 1156500 | 78850 | 6266.00 |

Study Area - Drainage Area: 10.3 mi^2 - Streamflow: 460 cfs

Manning Equation:

S = 794.21 ft. - 794.00 ft. / 20 ft.

R = A/P

P = w+2(d)

Q = AR^2/3 S^1/2 (1.49) / n

S = 0.0105

460 ft^3/s = (529 ft (d)) ((529 ft (d))/(529 ft+2d))^2/3 (0.0105)^1/2 (1.49) / 0.035

16.1 ft^3/s = 80.76749 ft (d) ((529 ft (d))/(529 ft+2d))^2/3

d = 0.38 ft.

**Table 3: Peak Discharge of 5 yr Recurrence Interval**

| Stream Gage Location | USGS # | Streamflow (cfs) | Drainage Area (mi^2) |
|---|---|---|---|
| Kent Brook | 1150800 | 305 | 3.31 |
| East Orange Branch | 1139800 | 360 | 8.95 |
| Ottauquechee River | 1150900 | 1445 | 23.40 |
| Ayers Brook | 1142500 | 1100 | 30.50 |
| East Branch Passumpsic River | 1133000 | 1850 | 53.80 |
| Saxtons River | 1154000 | 4650 | 72.20 |
| Moose River | 1134500 | 2925 | 75.20 |
| Wells River | 1139000 | 2800 | 98.40 |
| Williams River | 1153500 | 6500 | 103.00 |
| Walloomsac River | 1334000 | 5250 | 111.00 |
| Moose River | 1135000 | 4100 | 128.00 |
| Ompompanoosuc River | 1141500 | 2325 | 130.00 |
| Mad River | 4288000 | 10600 | 139.00 |
| Batten Kill | 1329000 | 4900 | 152.00 |
| Black River | 1153000 | 6790 | 158.00 |
| West River | 1155500 | 8100 | 179.00 |
| Poultney River | 4280000 | 6700 | 187.00 |
| Ottauquechee River | 1151500 | 1049 | 221.00 |
| White River | 1142000 | 16900 | 241.00 |
| Otter Creek | 4282000 | 7810 | 307.00 |
| Winooski River | 4286000 | 11600 | 397.00 |
| Passumpsic River | 1135500 | 10000 | 436.00 |
| Otter Creek | 4282500 | 6840 | 628.00 |
| White River | 1144000 | 30000 | 690.00 |
| Connecticut River | 1138500 | 41250 | 2644.00 |
| Connecticut River | 1139500 | 43000 | 2825.00 |
| Connecticut River | 1156500 | 98000 | 6266.00 |

**Study Area - Drainage Area: 10.3 mi^2 - Streamflow: 620 cfs**

| | | | | | | |
|---|---|---|---|---|---|---|
| Manning Equation: | | | S = 794.21 ft. - 794.00 ft. | | | R = A/P |
| | | | | 20 ft. | | P = w+2(d) |
| | Q = AR^2/3 S^1/2 (1.49) | | S = 0.0105 | | | |
| | n | | | | | |
| | 620 ft^3/s = (529 ft (d)) ((529 ft (d))/(529 ft+2d))^2/3 (0.0105)^1/2 (1.49) | | | | | |
| | | | 0.035 | | | |
| | 21.7 ft^3/s = 80.76749 ft (d) ((529 ft (d))/(529 ft+2d))^2/3 | | | | | |
| | d = 0.46 ft. | | | | | |

Table 4: Peak Discharge of 10 yr Recurrence Interval

| Stream Gage Location | USGS # | Streamflow (cfs) | Drainage Area (mi^2) |
|---|---|---|---|
| Kent Brook | 1150800 | 352 | 3.31 |
| East Orange Branch | 1139800 | 410 | 8.95 |
| Ottauquechee River | 1150900 | 1645 | 23.40 |
| Ayers Brook | 1142500 | 1225 | 30.50 |
| East Branch Passumpsic River | 1133000 | 2050 | 53.80 |
| Saxtons River | 1154000 | 5300 | 72.20 |
| Moose River | 1134500 | 3250 | 75.20 |
| Wells River | 1139000 | 3150 | 98.40 |
| Williams River | 1153500 | 7320 | 103.00 |
| Walloomsac River | 1334000 | 5890 | 111.00 |
| Moose River | 1135000 | 4700 | 128.00 |
| Ompompanoosuc River | 1141500 | 2550 | 130.00 |
| Mad River | 4288000 | 12000 | 139.00 |
| Batten Kill | 1329000 | 5500 | 152.00 |
| Black River | 1153000 | 7640 | 158.00 |
| West River | 1155500 | 9100 | 179.00 |
| Poultney River | 4280000 | 7600 | 187.00 |
| Ottauquechee River | 1151500 | 1180 | 221.00 |
| White River | 1142000 | 19100 | 241.00 |
| Otter Creek | 4282000 | 8800 | 307.00 |
| Winooski River | 4286000 | 13200 | 397.00 |
| Passumpsic River | 1135500 | 11000 | 436.00 |
| Otter Creek | 4282500 | 7720 | 628.00 |
| White River | 1144000 | 33000 | 690.00 |
| Connecticut River | 1138500 | 45500 | 2644.00 |
| Connecticut River | 1139500 | 47250 | 2825.00 |
| Connecticut River | 1156500 | 108000 | 6266.00 |

Study Area - Drainage Area: 10.3 mi^2 - Streamflow: 700 cfs

Manning Equation:

S = 794.21 ft. - 794.00 ft. / 20 ft.

R = A/P

P = w+2(d)

Q = AR^2/3 S^1/2 (1.49) / n

S = 0.0105

700 ft^3/s = (529 ft (d)) ((529 ft (d))/(529 ft+2d))^2/3 (0.0105)^1/2 (1.49) / 0.035

24.50 ft^3/s = 80.76749 ft (d) ((529 ft (d))/(529 ft+2d))^2/3

d = 0.490 ft.

Table 5: Peak Discharge of 25 yr Recurrence Interval

| Stream Gage Location | USGS # | Streamflow (cfs) | Drainage Area (mi^2) |
|---|---|---|---|
| Kent Brook | 1150800 | 398 | 3.31 |
| East Orange Branch | 1139800 | 460 | 8.95 |
| Ottauquechee River | 1150900 | 1840 | 23.40 |
| Ayers Brook | 1142500 | 1350 | 30.50 |
| East Branch Passumpsic River | 1133000 | 2250 | 53.80 |
| Saxtons River | 1154000 | 5980 | 72.20 |
| Moose River | 1134500 | 3550 | 75.20 |
| Wells River | 1139000 | 3500 | 98.40 |
| Williams River | 1153500 | 8100 | 103.00 |
| Walloomsac River | 1334000 | 6500 | 111.00 |
| Moose River | 1135000 | 5200 | 128.00 |
| Ompompanoosuc River | 1141500 | 2750 | 130.00 |
| Mad River | 4288000 | 13500 | 139.00 |
| Batten Kill | 1329000 | 6100 | 152.00 |
| Black River | 1153000 | 8400 | 158.00 |
| West River | 1155500 | 10000 | 179.00 |
| Poultney River | 4280000 | 8500 | 187.00 |
| Ottauquechee River | 1151500 | 1325 | 221.00 |
| White River | 1142000 | 21000 | 241.00 |
| Otter Creek | 4282000 | 9700 | 307.00 |
| Winooski River | 4286000 | 14600 | 397.00 |
| Passumpsic River | 1135500 | 12000 | 436.00 |
| Otter Creek | 4282500 | 8400 | 628.00 |
| White River | 1144000 | 36200 | 690.00 |
| Connecticut River | 1138500 | 49500 | 2644.00 |
| Connecticut River | 1139500 | 51500 | 2825.00 |
| Connecticut River | 1156500 | 117300 | 6266.00 |

Study Area - Drainage Area: 10.3 mi^2 - Streamflow: 780 cfs

Manning Equation:

$$S = \frac{794.21 \text{ ft.} - 794.00 \text{ ft.}}{20 \text{ ft.}}$$

R = A/P

P = w+2(d)

$$Q = \frac{AR^{2/3} S^{1/2} (1.49)}{n}$$

S = 0.0105

$$780 \text{ ft}^3/\text{s} = \frac{(529 \text{ ft } (d)) ((529 \text{ ft } (d))/(529 \text{ ft}+2d))^{2/3} (0.0105)^{1/2} (1.49)}{0.035}$$

$$27.30 \text{ ft}^3/\text{s} = 80.76749 \text{ ft } (d) ((529 \text{ ft } (d))/(529 \text{ ft}+2d))^{2/3}$$

d = 0.522 ft.

| Table 6: Peak Discharge of 50 yr | Recurrence Interval | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | Drainage | | | |
| Stream Gage | | Streamflow | Area | | | |
| Location | USGS # | (cfs) | (mi^2) | | | |
| Kent Brook | 1150800 | 435 | 3.31 | | | |
| East Orange Branch | 1139800 | 500 | 8.95 | | | |
| Ottauquechee River | 1150900 | 2010 | 23.40 | | | |
| Ayers Brook | 1142500 | 1475 | 30.50 | | | |
| East Branch Passumpsic River | 1133000 | 2400 | 53.80 | | | |
| Saxtons River | 1154000 | 6500 | 72.20 | | | |
| Moose River | 1134500 | 3825 | 75.20 | | | |
| Wells River | 1139000 | 3800 | 98.40 | | | |
| Williams River | 1153500 | 8700 | 103.00 | | | |
| Walloomsac River | 1334000 | 7030 | 111.00 | | | |
| Moose River | 1135000 | 5700 | 128.00 | | | |
| Ompompanoosuc River | 1141500 | 2925 | 130.00 | | | |
| Mad River | 4288000 | 14600 | 139.00 | | | |
| Batten Kill | 1329000 | 6600 | 152.00 | | | |
| Black River | 1153000 | 9185 | 158.00 | | | |
| West River | 1155500 | 10850 | 179.00 | | | |
| Poultney River | 4280000 | 9200 | 187.00 | | | |
| Ottauquechee River | 1151500 | 1440 | 221.00 | | | |
| White River | 1142000 | 22800 | 241.00 | | | |
| Otter Creek | 4282000 | 10490 | 307.00 | | | |
| Winooski River | 4286000 | 16000 | 397.00 | | | |
| Passumpsic River | 1135500 | 12850 | 436.00 | | | |
| Otter Creek | 4282500 | 9200 | 628.00 | | | |
| White River | 1144000 | 39000 | 690.00 | | | |
| Connecticut River | 1138500 | 53000 | 2644.00 | | | |
| Connecticut River | 1139500 | 55000 | 2825.00 | | | |
| Connecticut River | 1156500 | 125900 | 6266.00 | | | |
| | | | | | | |
| Study Area - Drainage Area: 10.3 mi^2 - Streamflow: 850 cfs | | | | | | |
| | | | | | | |
| Manning Equation: | | | S = 794.21 ft. - 794.00 ft. | | | R = A/P |
| | | | | 20 ft. | | P = w+2(d) |
| | Q = AR^2/3 S^1/2 (1.49) | | S = 0.0105 | | | |
| | n | | | | | |
| | 850 ft^3/s = (529 ft (d)) ((529 ft (d))/(529 ft+2d))^2/3 (0.0105)^1/2 (1.49) | | | | | |
| | | | 0.035 | | | |
| | 29.75 ft^3/s = 80.76749 ft (d) ((529 ft (d))/(529 ft+2d))^2/3 | | | | | |
| | d = 0.550 ft. | | | | | |

Table 7: Peak Discharge of 100 yr Recurrence Interval

| Stream Gage Location | USGS # | Streamflow (cfs) | Drainage Area (mi^2) |
|---|---|---|---|
| Kent Brook | 1150800 | 467 | 3.31 |
| East Orange Branch | 1139800 | 530 | 8.95 |
| Ottauquechee River | 1150900 | 2128 | 23.40 |
| Ayers Brook | 1142500 | 1560 | 30.50 |
| East Branch Passumpsic River | 1133000 | 2525 | 53.80 |
| Saxtons River | 1154000 | 6900 | 72.20 |
| Moose River | 1134500 | 4025 | 75.20 |
| Wells River | 1139000 | 4000 | 98.40 |
| Williams River | 1153500 | 9200 | 103.00 |
| Walloomsac River | 1334000 | 7420 | 111.00 |
| Moose River | 1135000 | 6000 | 128.00 |
| Ompompanoosuc River | 1141500 | 3075 | 130.00 |
| Mad River | 4288000 | 15500 | 139.00 |
| Batten Kill | 1329000 | 6900 | 152.00 |
| Black River | 1153000 | 9690 | 158.00 |
| West River | 1155500 | 11500 | 179.00 |
| Poultney River | 4280000 | 9780 | 187.00 |
| Ottauquechee River | 1151500 | 1525 | 221.00 |
| White River | 1142000 | 24200 | 241.00 |
| Otter Creek | 4282000 | 11090 | 307.00 |
| Winooski River | 4286000 | 17000 | 397.00 |
| Passumpsic River | 1135500 | 13600 | 436.00 |
| Otter Creek | 4282500 | 9720 | 628.00 |
| White River | 1144000 | 41000 | 690.00 |
| Connecticut River | 1138500 | 55500 | 2644.00 |
| Connecticut River | 1139500 | 58000 | 2825.00 |
| Connecticut River | 1156500 | 132000 | 6266.00 |

Study Area - Drainage Area: 10.3 mi^2 - Streamflow: 890 cfs

Manning Equation:

$$S = \frac{794.21\ \text{ft.} - 794.00\ \text{ft.}}{20\ \text{ft.}}$$

R = A/P

P = w+2(d)

$$Q = \frac{AR^{2/3}\, S^{1/2}\, (1.49)}{n}$$

S = 0.0105

$$890\ \text{ft}^3/\text{s} = \frac{(529\ \text{ft}\ (d))\ ((529\ \text{ft}\ (d))/(529\ \text{ft}+2d))^{2/3}\ (0.0105)^{1/2}\ (1.49)}{0.035}$$

$$31.15\ \text{ft}^3/\text{s} = 80.76749\ \text{ft}\ (d)\ ((529\ \text{ft}\ (d))/(529\ \text{ft}+2d))^{2/3}$$

d = 0.566 ft.

Table 8: Peak Discharge of 200 yr Recurrence Interval

| Stream Gage Location | USGS # | Streamflow (cfs) | Drainage Area (mi^2) |
|---|---|---|---|
| Kent Brook | 1150800 | 492 | 3.31 |
| East Orange Branch | 1139800 | 560 | 8.95 |
| Ottauquechee River | 1150900 | 2240 | 23.40 |
| Ayers Brook | 1142500 | 1650 | 30.50 |
| East Branch Passumpsic River | 1133000 | 2650 | 53.80 |
| Saxtons River | 1154000 | 7300 | 72.20 |
| Moose River | 1134500 | 4200 | 75.20 |
| Wells River | 1139000 | 4225 | 98.40 |
| Williams River | 1153500 | 9680 | 103.00 |
| Walloomsac River | 1334000 | 7800 | 111.00 |
| Moose River | 1135000 | 6375 | 128.00 |
| Ompompanoosuc River | 1141500 | 3200 | 130.00 |
| Mad River | 4288000 | 16400 | 139.00 |
| Batten Kill | 1329000 | 7300 | 152.00 |
| Black River | 1153000 | 10190 | 158.00 |
| West River | 1155500 | 12200 | 179.00 |
| Poultney River | 4280000 | 10300 | 187.00 |
| Ottauquechee River | 1151500 | 1590 | 221.00 |
| White River | 1142000 | 25400 | 241.00 |
| Otter Creek | 4282000 | 11600 | 307.00 |
| Winooski River | 4286000 | 17850 | 397.00 |
| Passumpsic River | 1135500 | 14200 | 436.00 |
| Otter Creek | 4282500 | 10200 | 628.00 |
| White River | 1144000 | 43000 | 690.00 |
| Connecticut River | 1138500 | 57500 | 2644.00 |
| Connecticut River | 1139500 | 60400 | 2825.00 |
| Connecticut River | 1156500 | 138000 | 6266.00 |

Study Area - Drainage Area: 10.3 mi^2 - Streamflow: 950 cfs

Manning Equation:

S = 794.21 ft. - 794.00 ft. / 20 ft.

R = A/P

P = w+2(d)

Q = AR^2/3 S^1/2 (1.49) / n

S = 0.0105

950 ft^3/s = (529 ft (d)) ((529 ft (d))/(529 ft+2d))^2/3 (0.0105)^1/2 (1.49) / 0.035

33.25 ft^3/s = 80.76749 ft (d) ((529 ft (d))/(529 ft+2d))^2/3

d = 0.588 ft.

**Table 9: Depth Calculations Using 0.035 Manning Coefficient**

| 2 yr. interval | | 5 yr. interval | | 10 yr. interval | | 25 yr. interval | | 50 yr. interval | | 100 yr. interval | | 200 yr. interval | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation |
| 0.10 | 1.739644 | 0.35 | 14.02708 | 0.440 | 20.53571 | 0.470 | 22.92023 | 0.520 | 27.12315 | 0.530 | 27.99734 | 0.550 | 29.77874 |
| 0.12 | 2.357259 | 0.36 | 14.36246 | 0.442 | 20.69142 | 0.472 | 23.0829 | 0.522 | 27.29711 | 0.532 | 28.17351 | 0.552 | 29.95928 |
| 0.14 | 3.047638 | 0.36 | 14.701 | 0.444 | 20.84759 | 0.474 | 23.24603 | 0.524 | 27.4715 | 0.534 | 28.35011 | 0.554 | 30.14027 |
| 0.16 | 3.807105 | 0.37 | 15.04269 | 0.446 | 21.00424 | 0.476 | 23.40961 | 0.526 | 27.64634 | 0.536 | 28.52715 | 0.556 | 30.32168 |
| 0.18 | 4.632625 | 0.37 | 15.3875 | 0.448 | 21.16135 | 0.478 | 23.57366 | 0.528 | 27.82162 | 0.538 | 28.70464 | 0.558 | 30.50353 |
| 0.20 | 5.521636 | 0.38 | 15.73543 | 0.450 | 21.31892 | 0.480 | 23.73816 | 0.530 | 27.99734 | 0.540 | 28.88256 | 0.560 | 30.68581 |
| 0.22 | 6.471928 | 0.38 | 16.08645 | 0.452 | 21.47697 | 0.482 | 23.90312 | 0.532 | 28.17351 | 0.542 | 29.06092 | 0.562 | 30.86853 |
| 0.24 | 7.48157 | 0.39 | 16.44056 | 0.454 | 21.63548 | 0.484 | 24.06853 | 0.534 | 28.35011 | 0.544 | 29.23972 | 0.564 | 31.05168 |
| 0.26 | 8.54885 | 0.39 | 16.79775 | 0.456 | 21.79445 | 0.486 | 24.2344 | 0.536 | 28.52715 | 0.546 | 29.41896 | 0.566 | 31.23526 |
| 0.28 | 9.672238 | 0.40 | 17.15799 | 0.458 | 21.95389 | 0.488 | 24.40072 | 0.538 | 28.70464 | 0.548 | 29.59863 | 0.568 | 31.41927 |
| 0.30 | 10.85035 | 0.40 | 17.52128 | 0.460 | 22.11379 | 0.490 | 24.56749 | 0.540 | 28.88256 | 0.550 | 29.77874 | 0.570 | 31.60371 |
| 0.32 | 12.08193 | 0.41 | 17.8876 | 0.462 | 22.27416 | 0.492 | 24.73472 | 0.542 | 29.06092 | 0.552 | 29.95928 | 0.572 | 31.78858 |
| 0.34 | 13.36584 | 0.41 | 18.25694 | 0.464 | 22.43498 | 0.494 | 24.9024 | 0.544 | 29.23972 | 0.554 | 30.14027 | 0.574 | 31.97389 |
| 0.36 | 14.701 | 0.42 | 18.62928 | 0.466 | 22.59627 | 0.496 | 25.07054 | 0.546 | 29.41896 | 0.556 | 30.32168 | 0.576 | 32.15962 |
| 0.38 | 16.08645 | 0.42 | 19.00463 | 0.468 | 22.75802 | 0.498 | 25.23912 | 0.548 | 29.59863 | 0.558 | 30.50353 | 0.578 | 32.34578 |
| | | 0.43 | 19.38295 | 0.470 | 22.92023 | 0.500 | 25.40815 | 0.550 | 29.77874 | 0.560 | 30.68581 | 0.580 | 32.53237 |
| | | 0.43 | 19.76425 | 0.472 | 23.0829 | 0.502 | 25.57764 | | | 0.562 | 30.86853 | 0.582 | 32.71939 |
| | | 0.44 | 20.14851 | 0.474 | 23.24603 | 0.504 | 25.74757 | | | 0.564 | 31.05168 | 0.584 | 32.90683 |
| | | 0.44 | 20.53571 | 0.476 | 23.40961 | 0.506 | 25.91796 | | | 0.566 | 31.23526 | 0.586 | 33.09471 |
| | | 0.45 | 20.92586 | 0.478 | 23.57366 | 0.508 | 26.08879 | | | | | 0.588 | 33.28301 |
| | | 0.45 | 21.31892 | 0.480 | 23.73816 | 0.510 | 26.26007 | | | | | | |
| | | 0.46 | 21.71491 | 0.482 | 23.90312 | 0.512 | 26.43179 | | | | | | |
| | | | | 0.484 | 24.06853 | 0.514 | 26.60396 | | | | | | |
| | | | | 0.486 | 24.2344 | 0.516 | 26.77658 | | | | | | |
| | | | | 0.488 | 24.40072 | 0.518 | 26.94965 | | | | | | |
| | | | | 0.490 | 24.56749 | 0.520 | 27.12315 | | | | | | |
| | | | | | | 0.522 | 27.29711 | | | | | | |

| Table 10: Depth Calculations Using 0.015 Manning Coefficient | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 yr. interval | | 5 yr. interval | | 10 yr. interval | | 25 yr. interval | | 50 yr. interval | | 100 yr. interval | | 200 yr. interval | |
| d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation |
| 0.10 | 1.739644 | 0.255 | 8.276713 | 0.275 | 9.386209 | 0.295 | 10.55076 | 0.315 | 11.76909 | 0.325 | 12.39805 | 0.340 | 13.36584 |
| 0.11 | 2.039094 | 0.256 | 8.330859 | 0.276 | 9.44314 | 0.296 | 10.61041 | 0.316 | 11.8314 | 0.326 | 12.46166 | 0.341 | 13.43139 |
| 0.13 | 2.693601 | 0.257 | 8.385146 | 0.277 | 9.500209 | 0.297 | 10.6702 | 0.317 | 11.89383 | 0.327 | 12.52541 | 0.342 | 13.49706 |
| 0.15 | 3.418938 | 0.258 | 8.439573 | 0.278 | 9.557415 | 0.298 | 10.73011 | 0.318 | 11.9564 | 0.328 | 12.58928 | 0.343 | 13.56287 |
| 0.17 | 4.211778 | 0.259 | 8.494141 | 0.279 | 9.614758 | 0.299 | 10.79017 | 0.319 | 12.0191 | 0.329 | 12.65328 | 0.344 | 13.6288 |
| 0.19 | 5.069339 | 0.260 | 8.54885 | 0.280 | 9.672238 | 0.300 | 10.85035 | 0.320 | 12.08193 | 0.330 | 12.71741 | 0.345 | 13.69486 |
| 0.21 | 5.989248 | 0.261 | 8.603699 | 0.281 | 9.729855 | 0.301 | 10.91067 | 0.321 | 12.1449 | 0.331 | 12.78168 | 0.346 | 13.76105 |
| 0.23 | 6.969442 | 0.262 | 8.658688 | 0.282 | 9.787608 | 0.302 | 10.97112 | 0.322 | 12.20799 | 0.332 | 12.84607 | 0.347 | 13.82737 |
| | | 0.263 | 8.713817 | 0.283 | 9.845498 | 0.303 | 11.03171 | 0.323 | 12.27121 | 0.333 | 12.91059 | 0.348 | 13.89381 |
| | | 0.264 | 8.769085 | 0.284 | 9.903524 | 0.304 | 11.09243 | 0.324 | 12.33456 | 0.334 | 12.97524 | 0.349 | 13.96038 |
| | | 0.265 | 8.824493 | 0.285 | 9.961687 | 0.305 | 11.15328 | 0.325 | 12.39805 | 0.335 | 13.04002 | 0.350 | 14.02708 |
| | | 0.266 | 8.880041 | 0.286 | 10.01999 | 0.306 | 11.21427 | 0.326 | 12.46166 | 0.336 | 13.10492 | 0.351 | 14.0939 |
| | | 0.267 | 8.935727 | 0.287 | 10.07842 | 0.307 | 11.27538 | 0.327 | 12.52541 | 0.337 | 13.16996 | 0.352 | 14.16085 |
| | | 0.268 | 8.991553 | 0.288 | 10.13699 | 0.308 | 11.33664 | 0.328 | 12.58928 | 0.338 | 13.23512 | 0.353 | 14.22793 |
| | | 0.269 | 9.047517 | 0.289 | 10.19569 | 0.309 | 11.39802 | 0.329 | 12.65328 | 0.339 | 13.30042 | | |
| | | 0.270 | 9.10362 | 0.290 | 10.25454 | 0.310 | 11.45953 | 0.330 | 12.71741 | 0.340 | 13.36584 | | |
| | | 0.271 | 9.159862 | 0.291 | 10.31351 | 0.311 | 11.52118 | 0.331 | 12.78168 | | | | |
| | | 0.272 | 9.216241 | 0.292 | 10.37262 | 0.312 | 11.58296 | | | | | | |
| | | 0.273 | 9.272759 | 0.293 | 10.43187 | 0.313 | 11.64487 | | | | | | |
| | | 0.274 | 9.329415 | 0.294 | 10.49125 | 0.314 | 11.70692 | | | | | | |

**Table 11: Depth Calculations Using 0.055 Manning Coefficient**

| 2 yr. interval | | 5 yr. interval | | 10 yr. interval | | 25 yr. interval | | 50 yr. interval | | 100 yr. interval | | 200 yr. interval | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation | d (ft) | Manning Equation |
| 0.35 | 14.02708 | 0.575 | 32.0667 | 0.620 | 36.35339 | 0.6830 | 42.70949 | 0.700 | 44.494 | 0.740 | 48.80683 | 0.750 | 49.90977 |
| 0.36 | 14.701 | 0.576 | 32.15962 | 0.621 | 36.45107 | 0.6831 | 42.71991 | 0.701 | 44.59987 | 0.740 | 48.81781 | 0.751 | 50.0206 |
| 0.38 | 16.08645 | 0.577 | 32.25265 | 0.622 | 36.54886 | 0.6832 | 42.73032 | 0.702 | 44.70585 | 0.740 | 48.82879 | 0.752 | 50.13153 |
| 0.40 | 17.52128 | 0.578 | 32.34578 | 0.623 | 36.64675 | 0.6833 | 42.74073 | 0.703 | 44.81193 | 0.740 | 48.83977 | 0.753 | 50.24256 |
| 0.42 | 19.00463 | 0.579 | 32.43902 | 0.624 | 36.74475 | 0.6834 | 42.75115 | 0.704 | 44.9181 | 0.740 | 48.85075 | 0.754 | 50.35369 |
| 0.44 | 20.53571 | 0.580 | 32.53237 | 0.625 | 36.84286 | 0.6835 | 42.76156 | 0.705 | 45.02438 | 0.741 | 48.86174 | 0.755 | 50.46492 |
| 0.46 | 22.11379 | 0.581 | 32.62583 | 0.626 | 36.94106 | 0.6836 | 42.77198 | 0.706 | 45.13076 | 0.741 | 48.87272 | 0.756 | 50.57624 |
| 0.48 | 23.73816 | 0.582 | 32.71939 | 0.627 | 37.03937 | 0.6837 | 42.7824 | 0.707 | 45.23724 | 0.741 | 48.88371 | 0.757 | 50.68766 |
| 0.50 | 25.40815 | 0.583 | 32.81306 | 0.628 | 37.13779 | 0.6838 | 42.79282 | 0.708 | 45.34381 | 0.741 | 48.8947 | 0.758 | 50.79918 |
| | | 0.584 | 32.90683 | 0.629 | 37.23631 | 0.6839 | 42.80324 | 0.709 | 45.45049 | 0.741 | 48.90569 | 0.759 | 50.9108 |
| | | 0.585 | 33.00072 | 0.630 | 37.33493 | 0.6840 | 42.81366 | 0.710 | 45.55727 | 0.741 | 48.91668 | 0.760 | 51.02251 |
| | | 0.586 | 33.09471 | 0.631 | 37.43366 | 0.6841 | 42.82408 | 0.711 | 45.66415 | 0.741 | 48.92767 | 0.761 | 51.13433 |
| | | 0.587 | 33.1888 | 0.632 | 37.53249 | 0.6842 | 42.8345 | 0.712 | 45.77112 | 0.741 | 48.93866 | 0.762 | 51.24623 |
| | | 0.588 | 33.28301 | 0.633 | 37.63143 | 0.6843 | 42.84493 | 0.713 | 45.8782 | 0.741 | 48.94965 | 0.763 | 51.35824 |
| | | 0.589 | 33.37731 | 0.634 | 37.73047 | 0.6844 | 42.85535 | 0.714 | 45.98538 | | | 0.764 | 51.47035 |
| | | 0.590 | 33.47173 | 0.635 | 37.82961 | 0.6845 | 42.86578 | 0.715 | 46.09265 | | | 0.765 | 51.58255 |
| | | 0.591 | 33.56625 | 0.636 | 37.92886 | 0.6846 | 42.8762 | 0.716 | 46.20003 | | | 0.766 | 51.69485 |
| | | 0.592 | 33.66088 | 0.637 | 38.02821 | 0.6847 | 42.88663 | 0.717 | 46.30751 | | | 0.767 | 51.80724 |
| | | 0.593 | 33.75561 | 0.638 | 38.12766 | 0.6848 | 42.89706 | 0.718 | 46.41508 | | | 0.768 | 51.91974 |
| | | 0.594 | 33.85046 | 0.639 | 38.22722 | 0.6849 | 42.90749 | 0.719 | 46.52276 | | | 0.769 | 52.03233 |
| | | 0.595 | 33.9454 | 0.640 | 38.32688 | | | 0.720 | 46.63053 | | | 0.770 | 52.14502 |
| | | 0.596 | 34.04045 | 0.641 | 38.42665 | | | 0.721 | 46.7384 | | | 0.771 | 52.2578 |
| | | 0.597 | 34.13561 | 0.642 | 38.52652 | | | | | | | | |

Table 12: Summary of Manning Coefficients

| | | | |
|---|---|---|---|
| n = 0.015 | | Manning Equation | |
| | d | Value | Q |
| | (ft) | (ft^3/s) | (ft^3/s) |
| 2 yr. interval | 0.230 | 6.90 | 460 |
| 5 yr. interval | 0.274 | 9.30 | 620 |
| 10 yr. interval | 0.294 | 10.50 | 700 |
| 25 yr. interval | 0.314 | 11.70 | 780 |
| 50 yr. interval | 0.331 | 12.75 | 850 |
| 100 yr. interval | 0.340 | 13.35 | 890 |
| 200 yr. interval | 0.353 | 14.25 | 950 |
| | | | |
| n = 0.035 | | Manning Equation | |
| | d | Value | Q |
| | (ft) | (ft^3/s) | (ft^3/s) |
| 2 yr. interval | 0.380 | 16.10 | 460 |
| 5 yr. interval | 0.460 | 21.70 | 620 |
| 10 yr. interval | 0.490 | 24.50 | 700 |
| 25 yr. interval | 0.522 | 27.30 | 780 |
| 50 yr. interval | 0.550 | 29.75 | 850 |
| 100 yr. interval | 0.566 | 31.15 | 890 |
| 200 yr. interval | 0.588 | 33.25 | 950 |
| | | | |
| n = 0.055 | | Manning Equation | |
| | d | Value | Q |
| | (ft) | (ft^3/s) | (ft^3/s) |
| 2 yr. interval | 0.500 | 25.30 | 460 |
| 5 yr. interval | 0.597 | 34.10 | 620 |
| 10 yr. interval | 0.642 | 38.50 | 700 |
| 25 yr. interval | 0.685 | 42.90 | 780 |
| 50 yr. interval | 0.721 | 46.75 | 850 |
| 100 yr. interval | 0.741 | 48.95 | 890 |
| 200 yr. interval | 0.771 | 52.25 | 950 |