



Technical Memorandum

To: Marvin Hora, Doug Hall and Mark Tomasek, Minnesota Pollution Control Agency
From: Tim Anderson, Barr Engineering Co.
Subject: Final Basin Hydrology Technical Memorandum
Date: December 17, 2003
Project: 23/62-853 BASN 008
c: Greg Wilson, Hal Runke

Overview and Introduction to Basin Hydrology

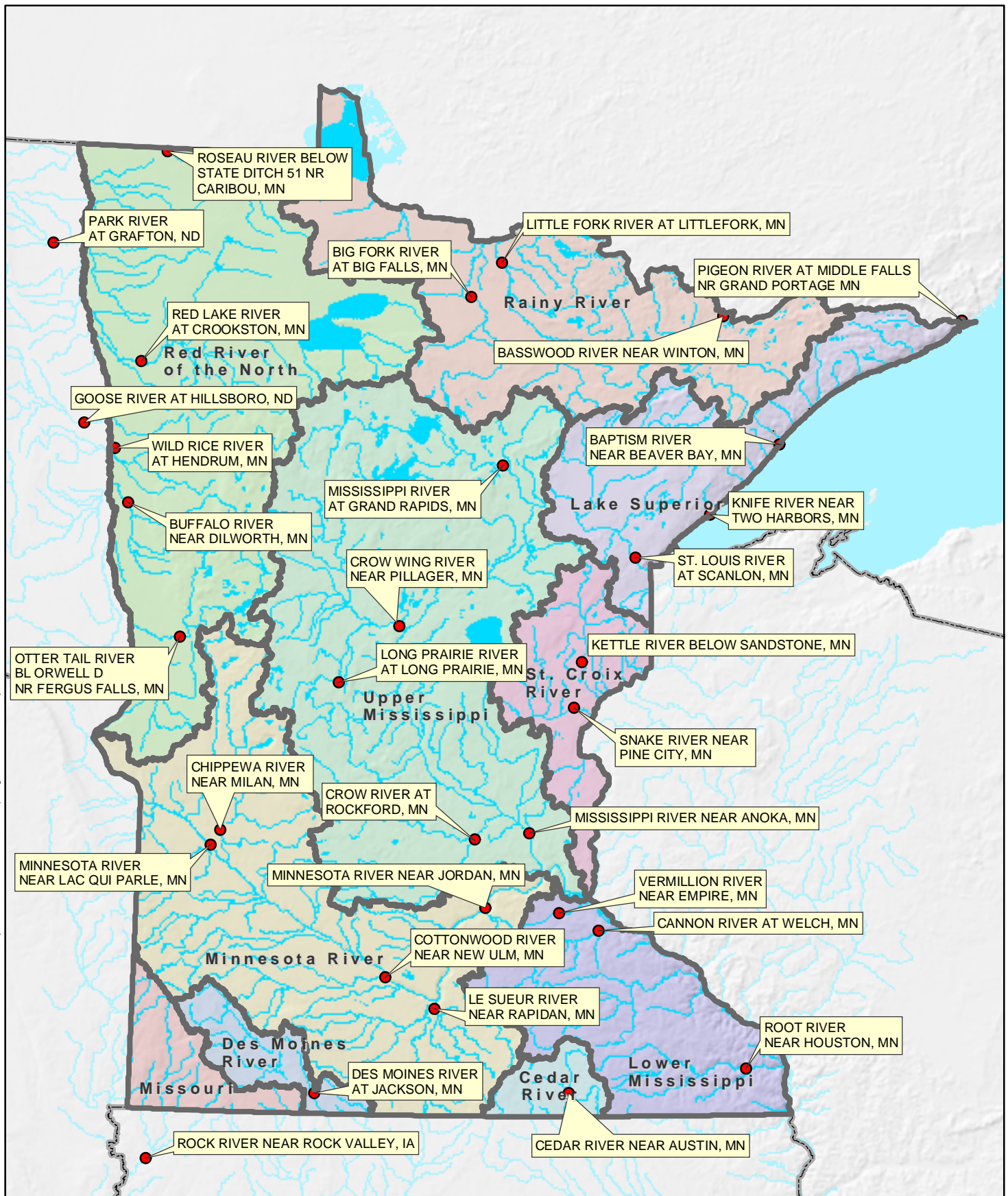
The objective of the Detailed Phosphorus Assessment Study is to estimate the sources of phosphorus for the 10 major basins for three flow scenarios within the State of Minnesota. These basins are shown in Figure 1. The flow scenarios are:

- Dry year
- Average year
- Wet year

The estimate of phosphorus loading, especially from non-point sources, requires the estimate of flows and rainfall that correspond to each of the three flow scenarios. The identification of three flow conditions will allow for the comparison of point and non-point phosphorus sources during the varied climatic and flow conditions that occur across Minnesota. The mass of phosphorus from non-point sources is generally higher during high runoff years than for average or dry years. Therefore, the proportion of the total phosphorus mass in the drainage system originating from point sources (e.g. waste water treatment plants) should be lower in wet years due to greater mass originating from non-point sources.

The Basin Hydrology portion of this study has two objectives:

- The identification of dry, average and wet years conditions for each basin, including the estimation of flow and precipitation
- Selecting years that are representative of these conditions



Major Basins
USGS Stations

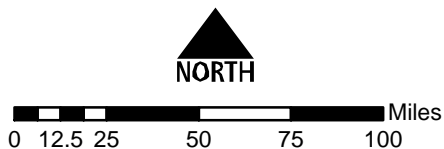


FIGURE 1
Major Basins with USGS
Flow Gaging Stations

The methods used for each of these objectives are discussed below.

Watershed Basin Characteristics

The ten major drainage basins within Minnesota vary greatly in their characteristics. Table 1 provides a summary of some of the characteristics of each basin. As shown in the table, there is a significant variability of runoff and precipitation across the state. There is also a significant difference in land cover between basins, particularly between the southwest and northeast parts of the state. Each basin is described in more detail below.

Cedar River

The Cedar River basin in Minnesota consists of approximately 1000 square miles and is drained by the Winnebago, Shell Rock and Cedar Rivers, all of which flow into the State of Iowa and ultimately to the Mississippi River. The major cities in this Basin are Albert Lea and Austin and the dominate land use is tilled agriculture. The USGS gage near Austin, on the Cedar River measures flow for 399 square miles of this Basin.

Des Moines River

The Des Moines River Basin consists of the headwater areas of both the East and West Fork of the Des Moines River in southwest Minnesota. The Basin is about 1500 square miles, mostly made up of row crops. The cities of Jackson and Windom are within this Basin along with the northern ½ of the City of Worthington. The USGS gage at Jackson, on the West Fork of the Des Moines River, measures flow for 1250 square miles of this Basin.

Lake Superior

The Lake Superior Basin drains about 6,150 square miles of northeast Minnesota. Approximately 3646 square miles of the basin drain to the St. Louis River, which enters Lake Superior at Duluth. The Nemadji River drains 278 square miles of Minnesota, south of Duluth before it enters Wisconsin and ultimately reaches Lake Superior at Superior, Wisconsin. The remaining 2,226 square miles of the Minnesota's Lake Superior Basin drains via many small streams and rivers along the North Shore of Lake Superior. The major land cover types within this basin are forest, lakes and wetlands. Duluth, Two Harbors, and many of the Iron Range cities are located in this Basin. The Lake Superior Basin produces the most runoff (12.44 inches annually, on average) even though three of

TABLE 1
Basin Characteristics

| Basin | Area (Sq Miles)* | Average Precipitation (1979-2002) | Average Runoff (1979-2002) | Land Cover Percentages** | | | | | |
|-------------------|------------------|-----------------------------------|----------------------------|--------------------------|--------------|---------------------|-------------------|--------------------|-------------|
| | | | | Urban | Forested | Tilled Agricultural | Pasture/Grassland | Wetland/Open Water | Other |
| Cedar River | 1,028 | 32.06 | 9.80 | 3.4% | 3.3% | 83.4% | 6.2% | 3.7% | 0.0% |
| Des Moines River | 1,535 | 27.98 | 5.68 | 1.8% | 1.8% | 79.9% | 11.0% | 5.5% | 0.0% |
| Lake Superior | 6,149 | 29.11 | 12.44 | 1.4% | 57.1% | 2.6% | 3.5% | 33.3% | 2.1% |
| Lower Mississippi | 6,317 | 33.29 | 10.28 | 2.4% | 15.4% | 52.2% | 24.8% | 5.1% | 0.1% |
| Minnesota River | 14,943 | 28.14 | 5.61 | 2.2% | 4.6% | 72.7% | 12.6% | 7.8% | 0.1% |
| Missouri | 1,782 | 27.16 | 5.25 | 1.5% | 1.0% | 78.9% | 16.0% | 2.6% | 0.0% |
| Rainy River | 11,236 | 26.20 | 8.01 | 0.4% | 41.4% | 2.0% | 2.3% | 52.5% | 1.3% |
| Red River | 17,741 | 23.29 | 3.42 | 0.7% | 12.0% | 54.6% | 8.8% | 23.8% | 0.2% |
| St. Croix River | 3,528 | 30.61 | 9.71 | 1.3% | 36.8% | 10.8% | 20.6% | 30.1% | 0.2% |
| Upper Mississippi | 20,100 | 28.07 | 6.87 | 3.5% | 29.1% | 20.2% | 16.7% | 29.7% | 0.7% |
| State Wide | 79,202 | 27.39 | 6.83 | 1.9% | 22.7% | 38.1% | 12.0% | 24.7% | 0.6% |

*Drainage area within Minnesota

**Based on USGS National Land Cover Database (1992)

the other basins receive more precipitation. Flow data from four USGS gage locations were used to assess runoff from this area.

Lower Mississippi

The Lower Mississippi consists of approximately 6,300 square miles of area draining to the Mississippi River below the River's confluence with the St. Croix River. The Lower Mississippi is the only non-headwaters basin. The Upper Mississippi, Minnesota and St. Croix Basins flow into the Mississippi River above the Lower Mississippi. Rivers that drain the Lower Mississippi Basin include the Zumbro, Root, Cannon and Vermillion Rivers. The major land cover is agricultural, although there are significant forest areas in the hilly bluff lands along the major river systems. The Cities of Rochester, Winona, Owatonna, Faribault and Red Wing are in this Basin. The southern suburbs of the Metropolitan area, including most of Lakeville are also in this Basin. This Basin receives the greatest annual average precipitation. During the period of 1979-2002, the basin received an average 33.3 inches annually. Flow data from three USGS gage locations were used to assess direct runoff from this area.

Minnesota River

The Minnesota River Basin is composed of 16,950 square miles, of which 1,668 are in South Dakota, 5 in North Dakota and 338 are in Iowa. The USGS gage near Jordan measures flow from about 16,200 square miles (or 96 percent) of the Basin. The Minnesota River drains into the Mississippi River upstream of St. Paul. Major tributaries of the Minnesota include the Pomme De Terre, Chippewa, Lac Qui Parle, Yellow Medicine, Redwood, Cottonwood, Watonwan, Blue Earth and Le Sueur Rivers. The vast majority of the land is in agricultural land uses. Cities included in this basin are Mankato, Redwood Falls, St. Peter, Morris, Marshall, Fairmont and the southwest suburbs of the Twin Cities. Flow data from five USGS gage locations were use to assess runoff from this area.

Missouri River

The Missouri River Basin is composed of 1,782 square miles in extreme southwestern Minnesota. The main rivers draining this Basin are the Little Sioux, Rock, and Pipestone. These river systems flow into Iowa and South Dakota. The only long term gaging record in this watershed is on the Rock River near Rock Valley, Iowa. Approximately 95 percent of this basin has agricultural land uses. Cities within this basin include Pipestone, Luverne and part of Worthington.

Rainy River

The Rainy River Basin consists of approximately 11,240 square miles of area in Minnesota draining to the Rainy River and Lake of the Woods on the Canadian border. Much of the Boundary Waters Canoe Area Wilderness is within this Basin. A significant part of the area tributary to Rainy River and Lake of the Woods are in Canada. Major land cover types within this basin include forest, lakes and wetlands. Rivers that drain this basin include the Little Fork, Big Fork and Basswood Rivers. Cities within this basin include Ely, International Falls, Warroad and Baudette. Flow data from three USGS gage locations were used to assess runoff from this area.

Red River of the North

The Red River of the North Basin in Minnesota consists of 17,741 square miles of area. The Red River of the North Basin receives the least amount of rainfall on average and also produces the least runoff of the ten basins. The Red River of the North flows north along the western boundary of the state. Approximately one-half of the watershed area to the Red River of the North at the Canadian border is in North Dakota.

Major river systems that flow to the Red River in Minnesota include the Bois De Sioux, Ottertail, Buffalo, Wild Rice, Sandhill, Red Lake, Snake, Tamarac and Roseau Rivers. The land cover of the eastern portions of the basin includes significant lake, wetland and forested areas while the western portion is mostly tilled farm land. Cities in the basin include Moorhead, East Grand Forks, Crookston, Roseau, Detroit Lakes, Fergus Falls and Thief River Falls. Flow data from seven USGS gage locations were used to assess runoff from this area.

St. Croix River

The St. Croix River Basin in Minnesota drains a 3,528 square mile area of mixed land use in the east central part of the state. An additional 4,200 square miles of watershed to the St. Croix River is in Wisconsin. Rivers that drain this basin include the Kettle, Snake and Sunrise Rivers. The St. Croix watershed includes the extreme eastern portions of the Twin City area. Other cities in this basin include Moose Lake, Sandstone, Hinckley, North Branch, Taylors Falls and Stillwater. Flow data from two USGS gage locations were used to assess runoff from this area.

Upper Mississippi River

The Upper Mississippi River Basin consists of the area tributary to the Mississippi River upstream of the confluence of the St. Croix River, not including the area tributary to the Minnesota River. This basin is 20,100 square miles and is a transition zone between agricultural areas to the south and west and forest and open water/wetland areas to the north. Major river systems that are tributary to the Upper Mississippi include the Crow, Sauk, Rum, Long Prairie, Red Eye, Crow Wing and Pine rivers. This basin also contains the majority of the Minneapolis-St. Paul Metropolitan area. Other cities in this basin include St. Cloud, Little Falls, Brainerd, Hutchinson, Alexandria, Grand Rapids and Bemidji. Flow data from five USGS gage locations were used to assess runoff from this area.

Available River Discharge and Precipitation Data

Precipitation and river discharge data were collected and analyzed as part of this portion of the project.

River Discharge Data

Mean monthly discharge data were collected from the USGS for 32 gaging stations across Minnesota and neighboring states. Figure 1 shows the location of the gages where data was collected. The stations were selected based on their length of record and the location of the gage within each of the ten basins. The Mississippi River near Anoka gage and Minnesota near Jordan gage are included in Figure 1 but were not directly used in deriving the flow values related to the dry, wet and average years. Measurements at these gages represent flow from nearly the entire Upper Mississippi and Minnesota basins, respectively. Because of the large size of these basins, USGS data from smaller watersheds within these basins were used so that regional runoff patterns could be better estimated.

Precipitation Data

Basin-wide precipitation data were made available from the State Climatology Office of the Minnesota Department of Natural Resources. The data consisted of monthly values calculated from a grid-based archive of historical monthly precipitation totals for the period of 1892 – 2002. These data consisted of estimated monthly total precipitation over each watershed, in inches, for each of the ten basins. The data were totaled by water-year (October – September) for use in this study. Data for the period of 1979 – 2002 water years were used in this study. Table 2 provides the minimum,

maximum and average number of precipitation gages used to develop the grids for the 1979-2002 period. Figures 2 and 3 show the distribution of precipitation gages for the months with the minimum and maximum number, respectively, of gages used to develop the grids.

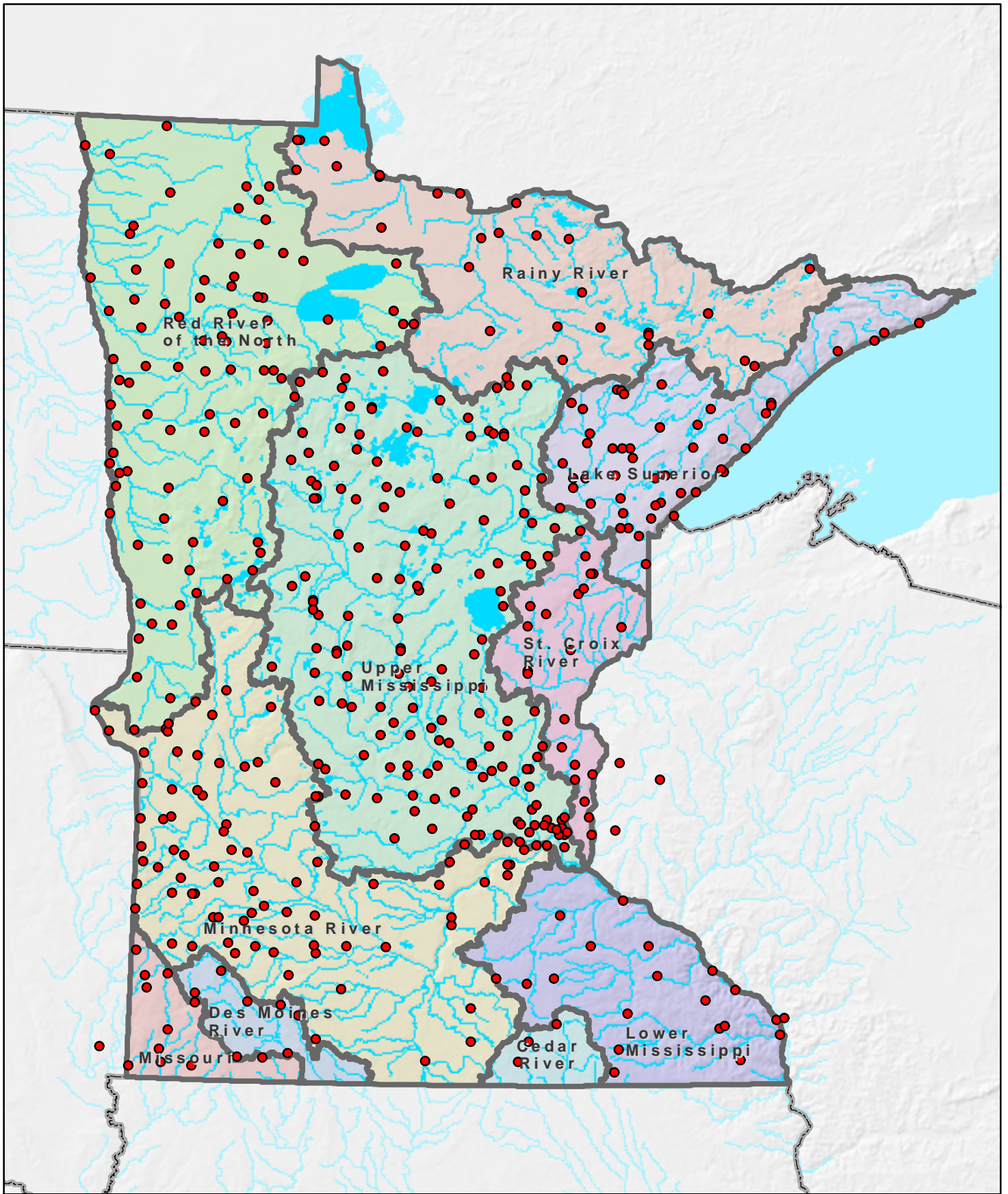
Table 2

| | Cedar River | Des Moines River | Lower Mississippi | Minnesota River | Missouri River | Rainy River | Red River of the North | St. Croix River | Lake Superior | Upper Mississippi | Total |
|---------|-------------|------------------|-------------------|-----------------|----------------|-------------|------------------------|-----------------|---------------|-------------------|-------|
| Average | 15 | 22 | 83 | 226 | 22 | 44 | 142 | 64 | 56 | 339 | 1014 |
| Minimum | 2 | 2 | 18 | 65 | 3 | 25 | 36 | 21 | 40 | 165 | 480 |
| Maximum | 39 | 49 | 150 | 416 | 41 | 66 | 246 | 118 | 71 | 591 | 1632 |

Number of Precipitation Gages

Approach and Methodology for Calculation of Basin Runoff Volumes

The phosphorus load estimates in this study were determined for low, average and high flow conditions, for each of the ten basins. A characteristic of most of the basins is that water is received from upstream basins (such as the Lower Mississippi which receives flow from the Minnesota, St. Croix and Upper Mississippi basins) or water flows into the basin from neighboring states or provinces. Therefore, flow and phosphorus data measured at the “outlet” of the basin will include both water and phosphorus originating from outside of Minnesota or from other upstream Minnesota basins. For example, 53 percent of the watershed area of the Red River of the North (which is the border between North Dakota and Minnesota), at the Manitoba border, is in the State of North Dakota. The Lake Superior and Rainy River basins do not have a defined single outlet point at all, since both discharge from lakes that share a boundary with multiple states and/or provinces. Since this study is only concerned with phosphorus contributions from Minnesota, a methodology was developed to estimate only Minnesota’s contribution of water.



- Rain Gage Locations
- ▭ Major Basins



0 12.5 25 50 75 100 Miles

FIGURE 2
Minimum Number of Rain Gages
Used for Rainfall Analysis
(480 Total, February, 1987)

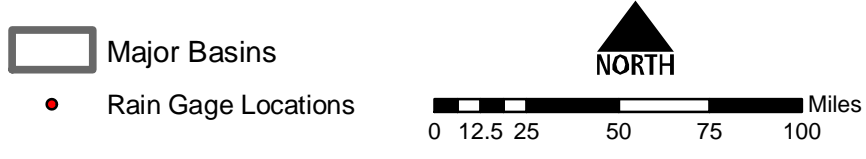
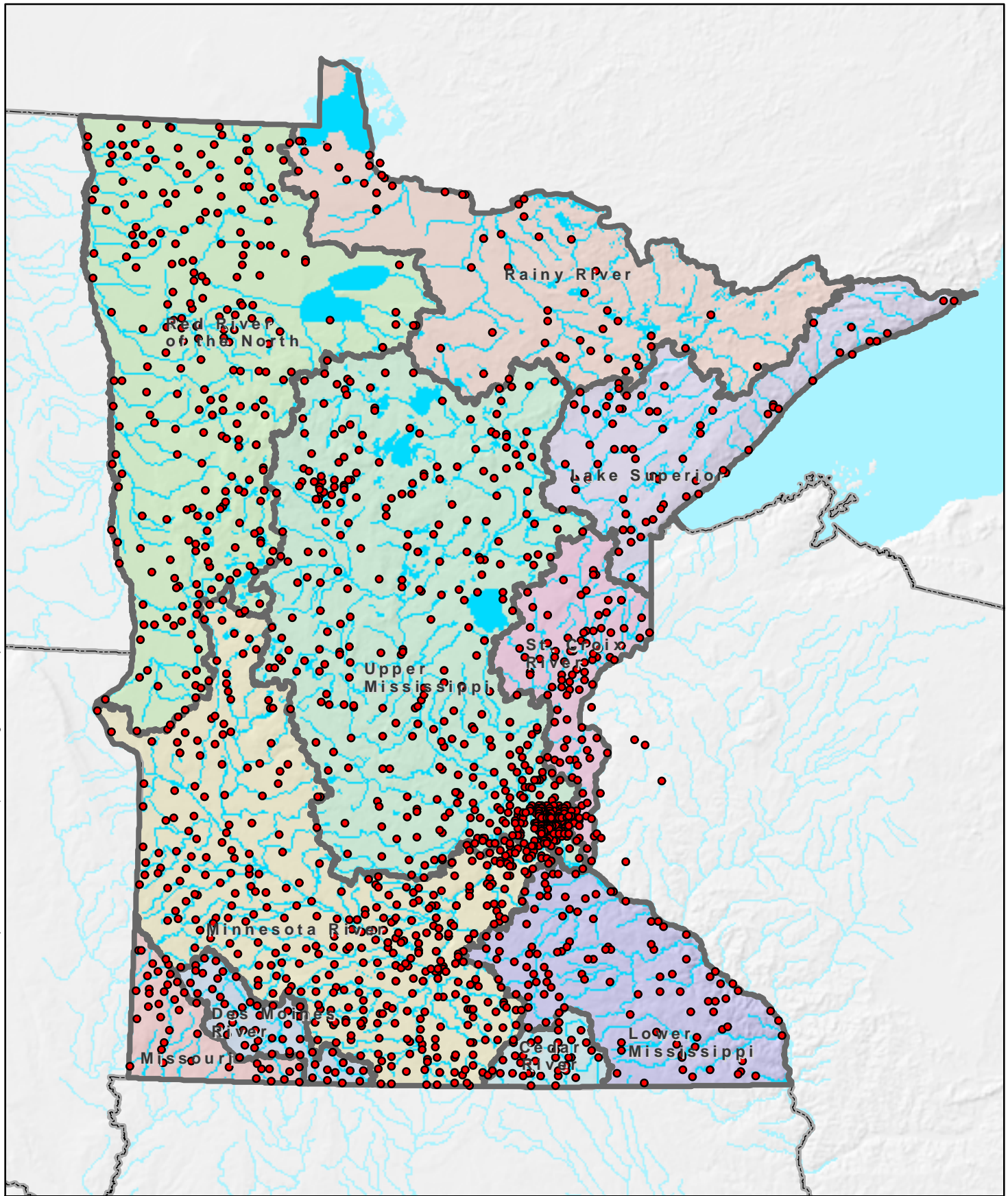


FIGURE 3
Maximum Number of Rain Gages
Used for Rainfall Analysis
(1632 Total, June, 1994)

Runoff from the Minnesota portions of the ten basins were calculated using state-wide flow maps for the three flow conditions. Each map consists of a state-wide 1 km x km grid of values representing runoff in inches. The resulting maps are shown in Figures 4, 5 and 6. Using these grids, runoff averages over the basins were determined. The methods used to develop these maps are described below.

River Discharge Data

Monthly mean stream flow data were collected from the United States Geologic Survey for 27 gaging stations in Minnesota, two in North Dakota and one in Iowa for a total of 30 gages. Annual runoff in inches, for each gage was determined by summing the monthly mean flows for each water year (October – September) and dividing by the contributing watershed area to arrive at runoff in inches per year. The watershed areas were delineated using the Minnesota Department of Natural Resources Division of Waters Watershed Basin (1995) GIS Layer. This layer was developed using data from USGS 1:24,000 Quadrangle Maps. The percent of the area of the major basins that drain to the gages used are summarized in Table 3.

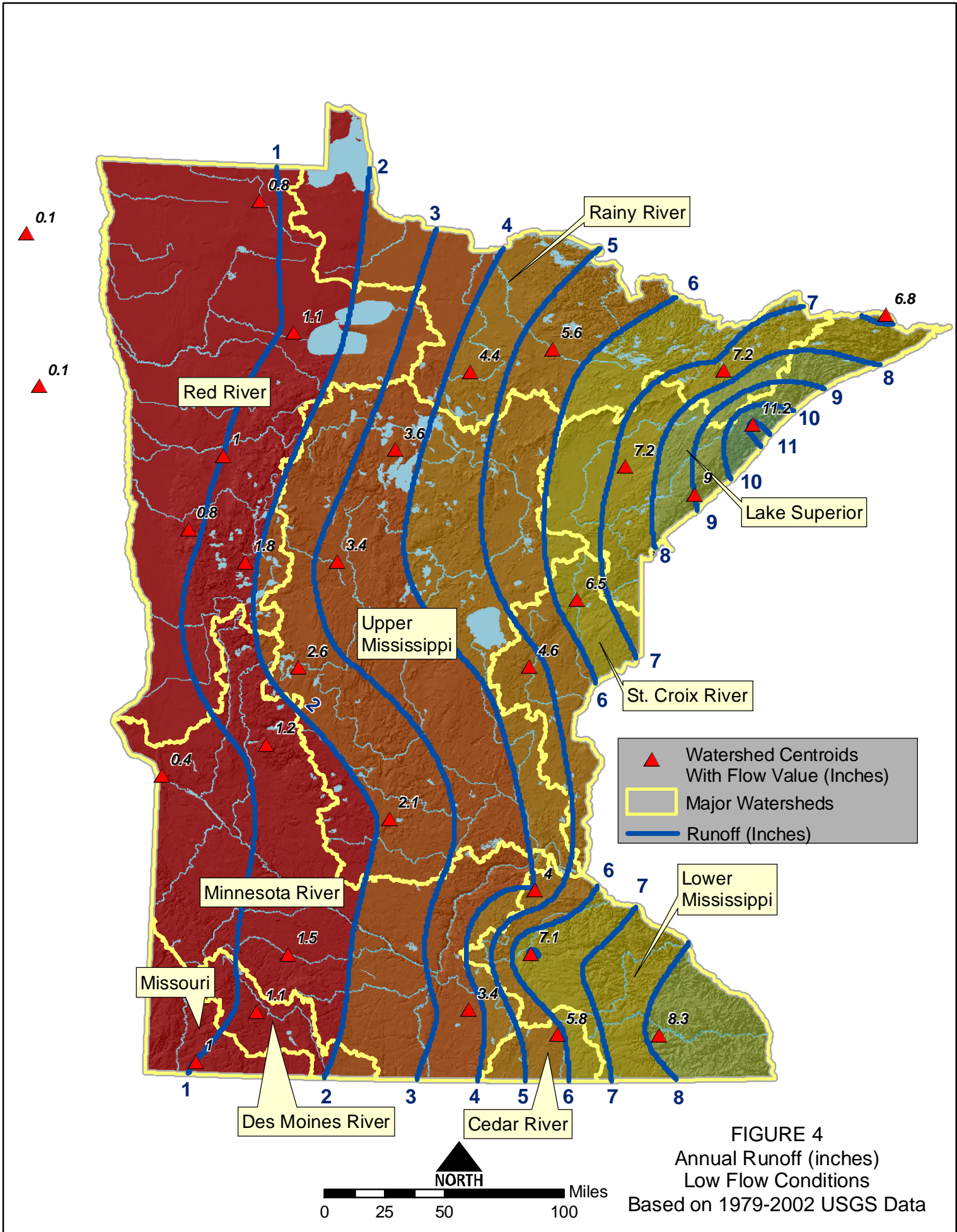
Development of Frequency Curves

The result of these computations was a table of annual runoff values, in inches over each of the 30 watersheds. These data were used to develop two frequency curves for each of the 30 gages and were based on these following periods of record:

1. Using all water years data were available
2. Using water years 1979 – 2002

For curve one, the time period of available flow data varied greatly. Some gages had data available for up to 100 years and others only a dozen or so years. The second curve was developed to reflect current climatic and drainage conditions. During the 1979-2002 period, a complete record of data was available for most of the gages used. This shorter period also reflected current watershed drainage characteristics and climatic trends. Because of these reasons, the 1979-2002 record was used to develop the runoff maps. Table 4 provides general statistics on the gages used, including the length of record.

The frequency curves were developed using a statistical analysis of the annual basin flows adopted from *Guidelines for Determining Flood Flow Frequency*, Bulletin #17B, U.S. Water Resources



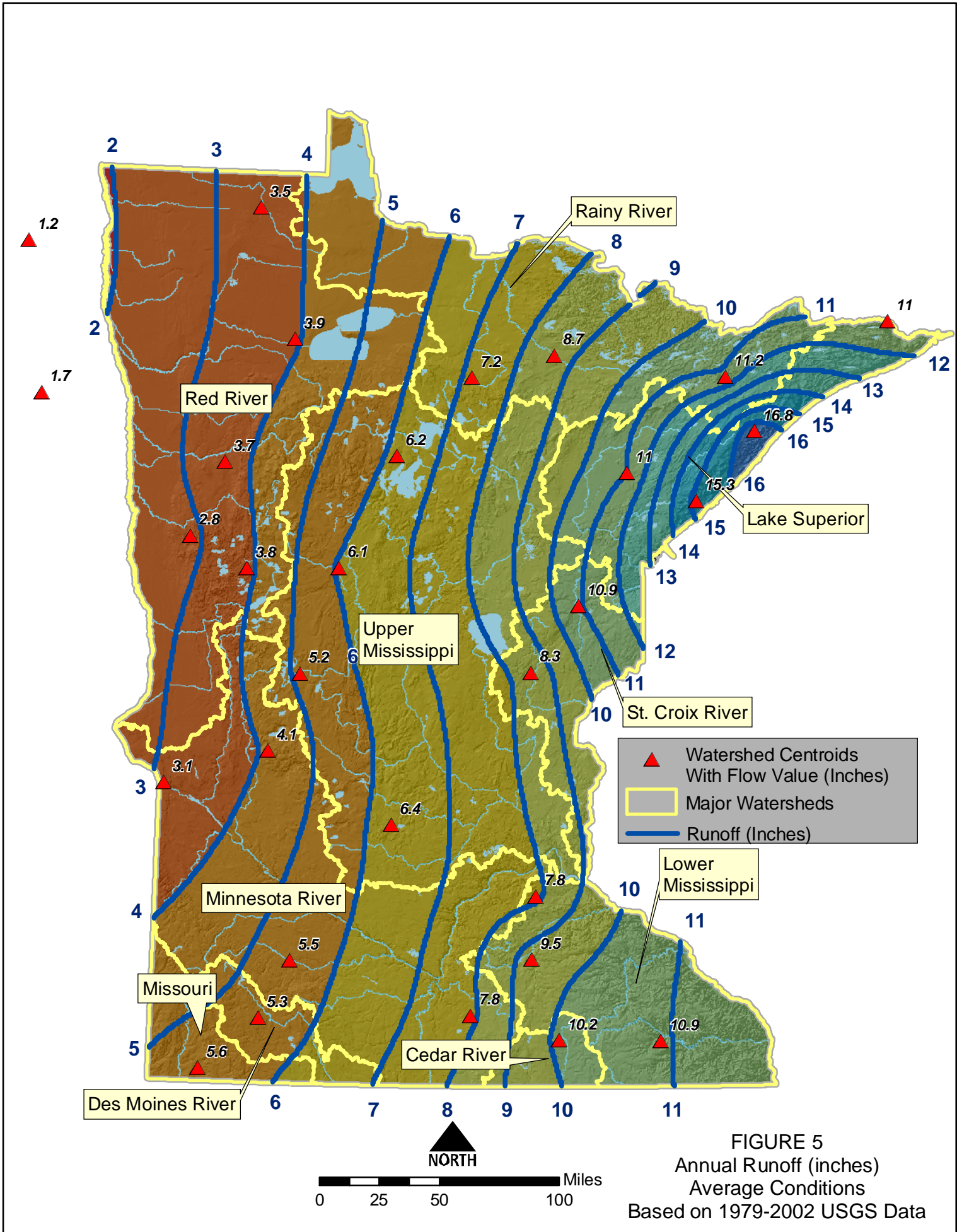


FIGURE 5
 Annual Runoff (inches)
 Average Conditions
 Based on 1979-2002 USGS Data

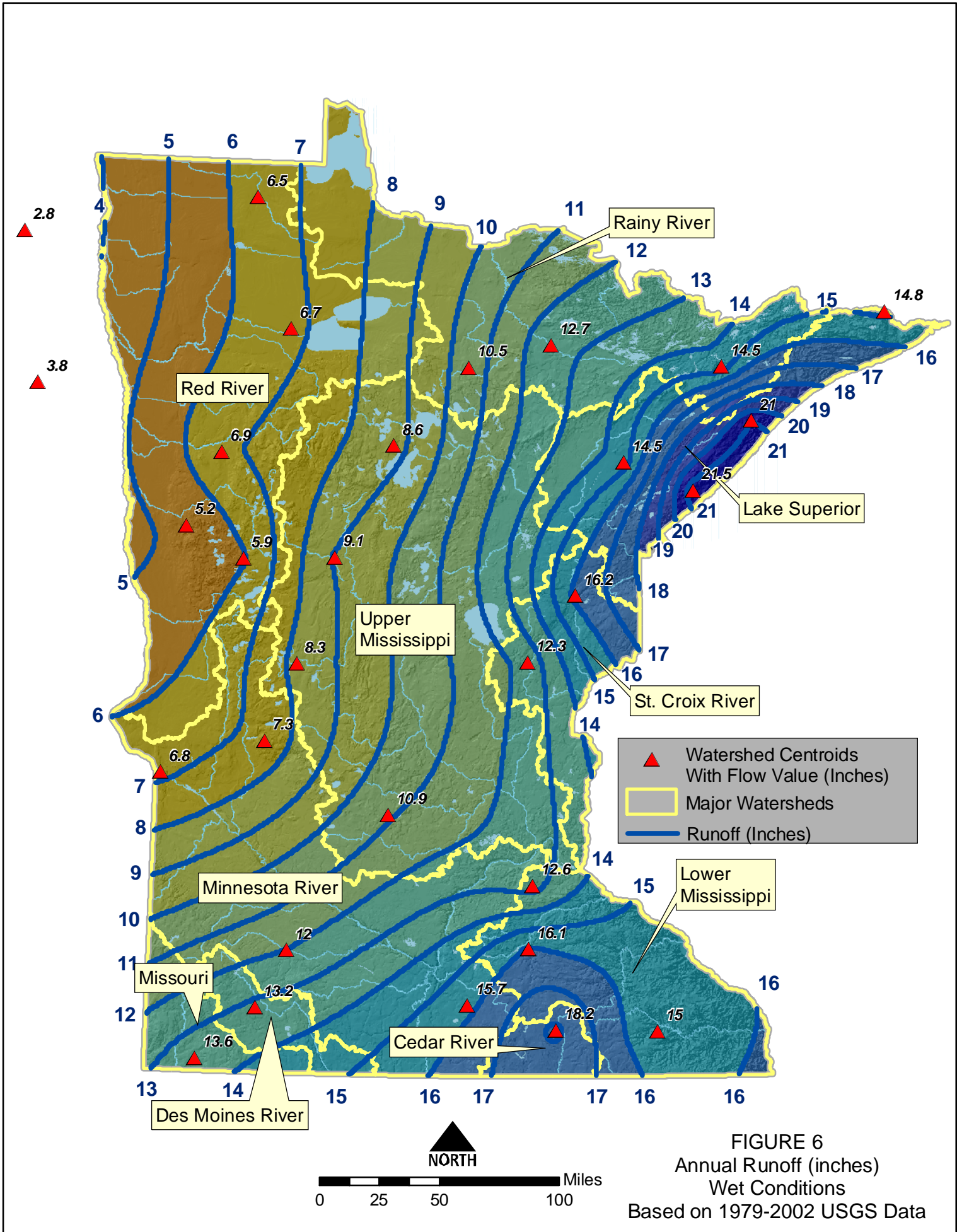


FIGURE 6
 Annual Runoff (inches)
 Wet Conditions
 Based on 1979-2002 USGS Data

Table 3
Gage Watershed Summary

| USGS Gage | Major Basin | Major Basin Area Within Minnesota (Sq. Miles) | Contributing Watershed Area Within Minnesota (Sq. Miles) | Percent of Total Basin Area |
|--|--------------------------|---|--|-----------------------------|
| CEDAR RIVER NEAR AUSTIN | Cedar River | 1,028 | 399 | 38.8% |
| TOTAL CEDAR RIVER BASIN GAGES | | 1,028 | 399 | 38.8% |
| DES MOINES RIVER AT JACKSON | Des Moines River | 1,536 | 1,250 | 81.4% |
| TOTAL OF DES MOINES RIVER BASIN GAGES | | 1,536 | 1,250 | 81.4% |
| BAPTISM RIVER NEAR BEAVER BAY | Lake Superior | 6,149 | 140 | 2.3% |
| KNIFE RIVER NEAR TWO HARBORS | Lake Superior | 6,149 | 84 | 1.4% |
| PIGEON RIVER AT MIDDLE FALLS NR GRAND PORT | Lake Superior* | 6,149 | 241 | 3.9% |
| ST. LOUIS RIVER AT SCANLON | Lake Superior | 6,149 | 3,430 | 55.8% |
| TOTAL OF LAKE SUPERIOR BASIN GAGES | | 6,149 | 3,895 | 63.3% |
| CANNON RIVER AT WELCH | Lower Mississippi | 6,317 | 1,340 | 21.2% |
| ROOT RIVER NEAR HOUSTON | Lower Mississippi | 6,317 | 1,250 | 19.8% |
| VERMILLION RIVER NEAR EMPIRE, MN | Lower Mississippi | 6,317 | 129 | 2.0% |
| TOTAL OF LOWER MISSISSIPPI BASIN GAGES | | 6,317 | 2,719 | 43.0% |
| CHIPPEWA RIVER NEAR MILAN, MN | Minnesota River | 14,933 | 1,880 | 12.6% |
| COTTONWOOD RIVER NEAR NEW ULM, MN | Minnesota River | 14,933 | 1,300 | 8.7% |
| LE SUEUR RIVER NEAR RAPIDAN, MN | Minnesota River | 14,933 | 1,110 | 7.4% |
| MINNESOTA RIVER NEAR LAC QUI PARLE, MN* | Minnesota River | 14,933 | 2,398 | 16.1% |
| TOTAL OF MINNESOTA RIVER BASIN GAGES | | 14,933 | 6,688 | 44.8% |
| ROCK RIVER NEAR ROCK VALLEY, IA* | Missouri River | 1,782 | 917 | 51.5% |
| TOTAL OF MISSOURI RIVER BASIN GAGES | | 1,782 | 917 | 51.5% |
| BASSWOOD RIVER NEAR WINTON | Rainy River | 11,236 | 1,740 | 15.5% |
| BIG FORK RIVER AT BIG FALLS | Rainy River | 11,236 | 1,480 | 13.2% |
| LITTLE FORK RIVER AT LITTLEFORK | Rainy River | 11,236 | 1,680 | 15.0% |
| TOTAL OF RAINY RIVER BASIN GAGES | | 11,236 | 4,900 | 43.6% |
| BUFFALO RIVER NEAR DILWORTH | Red River of the North | 17,741 | 975 | 5.5% |
| OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS | Red River of the North | 17,741 | 1,740 | 9.8% |
| RED LAKE RIVER AT CROOKSTON | Red River of the North | 17,741 | 5,270 | 29.7% |
| ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU | Red River of the North | 17,741 | 1,420 | 8.0% |
| WILD RICE RIVER AT HENDRUM | Red River of the North | 17,741 | 1,560 | 8.8% |
| GOOSE RIVER AT HILLSBORO, ND** | Red River of the North** | 17,741 | 0 | 0.0% |
| PARK RIVER AT GRAFTON, ND** | Red River of the North** | 17,741 | 0 | 0.0% |
| TOTAL OF RED RIVER OF THE NORTH BASIN GAGES | | 17,741 | 10,965 | 61.8% |
| KETTLE RIVER BELOW SANDSTONE | St. Croix River | 3,528 | 868 | 24.6% |
| SNAKE RIVER NEAR PINE CITY | St. Croix River | 3,528 | 958 | 27.2% |
| TOTAL OF ST. CROIX RIVER BASIN GAGES | | 3,528 | 1,826 | 51.8% |
| CROW RIVER AT ROCKFORD, MN | Upper Mississippi | 20,100 | 2,640 | 13.1% |
| CROW WING RIVER NEAR PILLAGER, MN | Upper Mississippi | 20,100 | 3,300 | 16.4% |
| LONG PRAIRIE RIVER AT LONG PRAIRIE, MN | Upper Mississippi | 20,100 | 434 | 2.2% |
| MISSISSIPPI RIVER AT GRAND RAPIDS, MN | Upper Mississippi | 20,100 | 3,370 | 16.8% |
| TOTAL OF UPPER MISSISSIPPI GAGES | | 20,100 | 9,744 | 48.5% |

*Portion of Watershed is outside of Minnesota

**Watershed is not in Minnesota

Table 4
USGS Gages Used in Analysis

| STATION NAME | STATION NUMBER | NUMBER OF YEARS DATA AVAILABLE | WATER YEARS FLOW DATA AVAILABLE |
|--|----------------|--------------------------------|---|
| BAPTISM RIVER NEAR BEAVER BAY, MN | 4014500 | 61 | 1931-1947, 1950-1993 |
| BASSWOOD RIVER NEAR WINTON, MN | 5127500 | 70 | 1932-1987,1939-2002 |
| BIG FORK RIVER AT BIG FALLS, MN | 5132000 | 67 | 1929-1979, 1983-1993, 1998-2002 |
| BUFFALO RIVER NEAR DILWORTH, MN | 5062000 | 71 | 1932-2002 |
| CANNON RIVER AT WELCH, MN | 5355200 | 53 | 1912-1913, 1932-1971, 1992-2002 |
| CEDAR RIVER NEAR AUSTIN, MN | 5457000 | 63 | 1910-1914, 1945-2002 |
| CHIPPEWA RIVER NEAR MILAN, MN | 5304500 | 65 | 1938-2002 |
| COTTONWOOD RIVER NEAR NEW ULM, MN | 5317000 | 68 | 1912-1913, 1936-1937, 1939-2002 |
| CROW RIVER AT ROCKFORD, MN | 5280000 | 76 | 1910-1911, 1913-1917, 1931,1935-2002 |
| CROW WING RIVER NEAR PILLAGER, MN | 5247500 | 33 | 1969-1986, 1988-2002 |
| DES MOINES RIVER AT JACKSON, MN | 5476000 | 67 | 1936-2002 |
| GOOSE RIVER AT HILLSBORO, ND | 5066500 | 69 | 1932, 1935-2002 |
| KETTLE RIVER BELOW SANDSTONE, MN | 53367000 | 35 | 1968-2002 |
| KNIFE RIVER NEAR TWO HARBORS, MN | 4015330 | 28 | 1975-2002 |
| LE SUEUR RIVER NEAR RAPIDAN, MN | 5320500 | 59 | 1940-1945, 1950-2002 |
| LITTLE FORK RIVER AT LITTLEFORK, MN | 5131500 | 79 | 1912-1916, 1929-2002 |
| LONG PRAIRIE RIVER AT LONG PRAIRIE, MN | 5245100 | 31 | 1972-2002 |
| MINNESOTA RIVER NEAR JORDAN, MN | 5330000 | 68 | 1935-2002 |
| MINNESOTA RIVER NEAR LAC QUI PARLE, MN | 5301000 | 56 | 1943-1994, 1999-2002 |
| MISSISSIPPI RIVER AT GRAND RAPIDS, MN | 52110000 | 105 | 1884-1888, 1901-1909, 1912-2002 |
| MISSISSIPPI RIVER NEAR ANOKA, MN | 5288500 | 71 | 1932-2002 |
| OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS, MN | 5046000 | 72 | 1931-2002 |
| PARK RIVER AT GRAFTON, ND | 5090000 | 71 | 1932-2002 |
| PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTAGE MN | 4010500 | 79 | 1924-2002 |
| RED LAKE RIVER AT CROOKSTON, MN | 5079000 | 101 | 1902-2002 |
| Rock River near Rock Valley, IA | 6483500 | 54 | 1949-2002 |
| ROOT RIVER NEAR HOUSTON, MN | 5385000 | 71 | 1910-1917,1931-1983,1991-2000 |
| ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU, MN | 5112000 | 45 | 1921-1930, 1933, 1937, 1941-1943, 1973-2002 |
| SNAKE RIVER NEAR PINE CITY, MN | 5338500 | 41 | 1914-1917, 1952-1981, 1992-2002 |
| ST. LOUIS RIVER AT SCANLON, MN | 4024000 | 94 | 1909-2002 |
| VERMILLION RIVER NEAR EMPIRE, MN | 5345000 | 30 | 1943, 1974-2002 |
| WILD RICE RIVER AT HENDRUM, MN | 5064000 | 58 | 1945-2002 |

Council, Sept. 1981. The Weibull plotting position method, described in this reference, were implemented to assign an exceedence probability (the probability of the flow being greater than or equal to a value) to every annual flow record in the time series. The probabilities were then plotted on semi-log paper to fit a trend line to the data. Different statistical equations were analyzed to determine which equation best describes the data. The frequency curves were then based on the best-fit equation, typically a Pearson Type III distribution.

Typically, frequency analysis using the methodology described above, is used for annual flood peaks rather than total annual runoff. Another statistical technique described in Bulletin #17B is the development of flow duration curves to define flow conditions. This method is commonly used in the analysis of low flow conditions. Flow duration curves are usually developed using a time step of less than a year (in this study, a year time step was used), frequently using a one day time step. A comparison between using flow-duration curves and frequency analysis was made and is shown in Table 5. The results presented in the table show only a small difference between the values derived from the two methods. Since flow-duration curves are usually fit by eye rather than a statistical distribution it was decided to use the frequency analysis which would provide objectivity in the selection of runoff values for the low, average and high runoff years.

The frequency curves for each of the watersheds are in Appendix A. The curves show that for gages in the south and west portions of the state, the period of 1979-2002 flows were consistently above the long-term period of record. The frequency curves for much of Northeast Minnesota, particularly the Rainy River, the North Shore of Lake Superior, and St. Croix River basins did not show this trend. The curves indicate that there is a general trend of decreasing runoff from east to west. Lake Superior Basin has the highest runoff in the state of Minnesota, with the Baptism River watershed having the highest values within that basin, with average runoff of 15.3 inches. Runoff in the Red River of the North Basin had the least runoff, with the Buffalo River Watershed having 2.8 inches of runoff in an average year which is lowest of the Minnesota gages used in this analysis. However, the two watersheds in the North Dakota portions of the Red River Watershed have average runoff of less than 2 inches. Decreasing runoff from east to west also occurs in southern Minnesota, but the trend is less dramatic than in the north. The Root River in extreme southeast Minnesota has nearly 11 inches of runoff for the period of 1979-2002, The Rock River in southwest Minnesota and

Table 5
Comparison of Frequency and Duration Analysis on Runoff Values

| Watershed | Major Basin | Values from Frequency Plots (inches) Average | | | Values from Duration Curves (inches) Average | | | Difference (inches) Average | | |
|--|-------------------------|--|------------|-------------|--|------------|-------------|--------------------------------|--------------|--------------|
| | | Low Flow | Flow | High Flow | Low Flow | Flow | High Flow | Low Flow | Flow | High Flow |
| CEDAR RIVER NEAR AUSTIN | Cedar River | 5.8 | 10.2 | 18.2 | 5.2 | 10.3 | 16.7 | 0.6 | -0.1 | 1.5 |
| DES MOINES RIVER AT JACKSON | Des Moines River | 1.1 | 5.3 | 13.2 | 0.6 | 5.9 | 10.5 | 0.5 | -0.6 | 2.7 |
| BAPTISM RIVER NEAR BEAVER BAY | Lake Superior | 11.2 | 16.8 | 21.0 | 10.0 | 17.2 | 20.6 | 1.2 | -0.4 | 0.4 |
| KNIFE RIVER NEAR TWO HARBORS | Lake Superior | 9.0 | 15.3 | 21.5 | 9.0 | 15.8 | 19.7 | 0.0 | -0.5 | 1.8 |
| PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTAGE MN | Lake Superior | 6.8 | 11.0 | 14.8 | 6.5 | 10.9 | 14.3 | 0.3 | 0.1 | 0.5 |
| ST. LOUIS RIVER AT SCANLON | Lake Superior | 7.2 | 11.0 | 14.5 | 6.9 | 11.1 | 15.1 | 0.3 | -0.1 | -0.6 |
| CANNON RIVER AT WELCH | Lower Mississippi River | 7.1 | 9.5 | 16.1 | 7.0 | 9.8 | 13.7 | 0.1 | -0.3 | 2.4 |
| ROOT RIVER NEAR HOUSTON | Lower Mississippi River | 8.3 | 10.9 | 15.0 | 8.8 | 10.5 | 16.5 | -0.5 | 0.4 | -1.5 |
| VERMILLION RIVER NEAR EMPIRE, MN | Lower Mississippi River | 4.0 | 7.8 | 12.6 | 3.9 | 7.5 | 12.0 | 0.1 | 0.3 | 0.6 |
| CHIPPEWA RIVER NEAR MILAN, MN | Minnesota River | 1.2 | 4.1 | 7.3 | 1.1 | 3.7 | 7.2 | 0.1 | 0.4 | 0.1 |
| COTTONWOOD RIVER NEAR NEW ULM, MN | Minnesota River | 1.5 | 5.5 | 12.0 | 1.1 | 5.4 | 11.1 | 0.4 | 0.1 | 0.9 |
| LE SUEUR RIVER NEAR RAPIDAN, MN | Minnesota River | 3.4 | 7.8 | 15.7 | 2.5 | 8.1 | 14.0 | 0.9 | -0.3 | 1.7 |
| MINNESOTA RIVER NEAR LAC QUI PARLE, MN | Minnesota River | 0.4 | 3.1 | 6.8 | 0.7 | 2.6 | 7.1 | -0.3 | 0.5 | -0.3 |
| ROCK RIVER NEAR ROCK VALLEY, IA | Missouri River | 1.0 | 5.6 | 13.6 | 1.0 | 5.6 | 12.5 | 0.0 | 0.0 | 1.1 |
| BASSWOOD RIVER NEAR WINTON | Rainy River | 7.2 | 11.2 | 14.5 | 6.5 | 11.2 | 14.0 | 0.7 | 0.0 | 0.5 |
| BIG FORK RIVER AT BIG FALLS | Rainy River | 4.4 | 7.2 | 10.5 | 4.3 | 6.8 | 10.9 | 0.1 | 0.4 | -0.4 |
| LITTLE FORK RIVER AT LITTLEFORK | Rainy River | 5.6 | 8.7 | 12.7 | 5.6 | 8.8 | 12.5 | 0.0 | -0.1 | 0.2 |
| BUFFALO RIVER NEAR DILWORTH | Red River of the North | 0.8 | 2.8 | 5.2 | 0.9 | 2.5 | 5.2 | -0.1 | 0.3 | 0.0 |
| GOOSE RIVER AT HILLSBORO, ND | Red River of the North | 0.1 | 1.7 | 3.8 | 0.1 | 1.3 | 3.9 | 0.0 | 0.4 | -0.1 |
| OTTER TAIL RIVER BL ORWELL D NR FERGUS F | Red River of the North | 1.8 | 3.8 | 5.9 | 1.8 | 3.9 | 5.9 | 0.0 | -0.1 | 0.0 |
| PARK RIVER AT GRAFTON, ND | Red River of the North | 0.1 | 1.2 | 2.8 | 0.1 | 1.1 | 2.7 | 0.0 | 0.1 | 0.1 |
| RED LAKE RIVER AT CROOKSTON | Red River of the North | 1.1 | 3.9 | 6.7 | 0.7 | 4.1 | 6.6 | 0.4 | -0.2 | 0.1 |
| ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU, MN | Red River of the North | 0.8 | 3.5 | 6.5 | 0.7 | 3.5 | 6.4 | 0.1 | 0.0 | 0.1 |
| WILD RICE RIVER AT HENDRUM | Red River of the North | 1.0 | 3.7 | 6.9 | 1.0 | 3.5 | 7.4 | 0.0 | 0.2 | -0.5 |
| KETTLE RIVER BELOW SANDSTONE | St. Croix River | 6.5 | 10.9 | 16.2 | 6.0 | 11.2 | 15.1 | 0.5 | -0.3 | 1.1 |
| SNAKE RIVER NEAR PINE CITY | St. Croix River | 4.6 | 8.3 | 12.3 | 4.3 | 7.5 | 12.3 | 0.3 | 0.8 | 0.0 |
| CROW WING RIVER NEAR PILLAGER, MN | Upper Mississippi River | 3.4 | 6.1 | 9.1 | 3.3 | 6.0 | 9.0 | 0.1 | 0.1 | 0.1 |
| CROW RIVER AT ROCKFORD, MN | Upper Mississippi River | 2.1 | 6.4 | 10.9 | 1.1 | 7.0 | 10.4 | 1.0 | -0.6 | 0.5 |
| LONG PRAIRIE RIVER AT LONG PRAIRIE, MN | Upper Mississippi River | 2.6 | 5.2 | 8.3 | 2.3 | 5.2 | 8.2 | 0.3 | 0.0 | 0.1 |
| MISSISSIPPI RIVER AT GRAND RAPIDS, MN | Upper Mississippi River | 3.6 | 6.2 | 8.6 | 3.2 | 5.6 | 8.7 | 0.4 | 0.6 | -0.1 |
| Average | | 3.8 | 7.2 | 11.4 | 3.5 | 7.1 | 11.0 | 0.250 | 0.037 | 0.433 |
| Standard Deviation | | | | | | | | 0.370 | 0.352 | 0.901 |

Northwest Iowa has an average runoff of 5.6 inches. Increases in runoff are more dramatic moving south as flows approach high flow conditions.

From the frequency curves developed for the 1979-2002 water year period, runoff values from the 90 (dry year), 50 (average year) and 10 (wet year) percent probability were determined. The 90 percent value means that, on average, 90 percent of the years will have runoff exceeding this value. The 50 percent value shows the runoff amount that would be exceeded one-half the years on average. The 10 percent value is the flow which would be exceeded only 10 percent of the years. The 90 and 10 percent probabilities were selected because they do not represent extreme events; rather they represent typical dry and wet periods for the basins (a 1 in 10 chance of occurring on any given year).

Development of Runoff Maps from Frequency Data

The centroid of the watershed for each of the 30 USGS gages was determined. The resulting X and Y coordinates of the centroid (in UTM Coordinates) were determined and were assigned the runoff values for the watershed. The centroid (essentially, the center of the watershed) was used rather than the gage location since the centroid best represents the average characteristics of the watershed. The gage is most often at an extreme point in the watershed and its location would not necessarily best represent the watershed upstream.

A table was constructed with the UTM coordinates and runoff values. This table was imported into Surfer Software and interpolated using the Kriging routine to create three state-wide 1 kilometer x 1 kilometer grids representing the dry, average and wet condition runoff values. The resulting Surfer grid files were imported into ArcView Spatial Analyst extension and were overlain with the boundaries of the major basins. The result was an estimation of the wet, average and dry condition flow volumes based on the 10, 50 and 90 percentile frequencies, respectively.

One of the benefits of using runoff grids is that average runoff for smaller ungaged watersheds within each of the larger basins could be estimated. Runoff from smaller watersheds is a necessary input for some of the non-point source phosphorus computations. Because of the differences in rainfall and land cover across Minnesota, runoff characteristics are likely to be different for smaller watersheds compared to runoff recorded for the larger basin gages.

Precipitation Frequency Curves

Frequency curves were also developed for the basin-wide precipitation data. The data were summarized by water year and the same methodology used to develop the flow – frequency curves were also used for the precipitation. The curves are shown in Appendix B.

Results of Flow and Precipitation Computations

Maps showing the state-wide runoff values are shown in Figures 4, 5 and 6. Table 6 shows the 10 basin-wide averages develop from these maps for the wet, average and dry conditions. The averages were estimated by using ArcView Spatial Analyst to overlay the basin boundaries with the runoff grids discussed in the previous section. The average of the grid (cell) values within each basin was used as the basin-wide average for each condition. Table 6 also provides a summary of basin wide average precipitation for the wet, average and dry years based on the frequency determinations. Also shown in Table 6 is the percent runoff calculated using the ratio of runoff to rainfall.

Note that, in general, the year in which the 10th percentile wet year flow volume occurred will not necessary coincide with the year in which the 10th percentile wet year precipitation amount was observed. River discharge is not only a function of precipitation, but is affected by a number of hydrologic conditions such as drought and floods occurring in preceding years. For example, if the preceding year was much dryer than normal, much of the current year's rainfall (even though above average) may be used in refilling lake and wetland basins and replenishing soil moisture. The intensity of rainfall is another factor in the generation of runoff. For a given amount of precipitation, more of it will runoff if the precipitation occurs during a heavy thunderstorms rather than rain falling during a gentle day-long shower.

Therefore, there may be below-normal flow in years where precipitation is above-average. In this study it was assumed that the 10th percentile flow does occur in the same year that the 10 percentile rainfall occurs. The same assumption was made for the 50 and 90th percentile years. This simplifying assumption had to be made to facilitate a direct comparison between the three flow scenarios examined.

TABLE 6
Basin-Wide Runoff and Precipitation

| Basin | Dry Conditions | | | Average Conditions | | | Wet Conditions | | |
|-------------------------|----------------------|--------------------|-------------------|----------------------|--------------------|-------------------|----------------------|--------------------|-------------------|
| | Rainfall (inches) | Runoff (inches) | Percent Runoff | Rainfall (inches) | Runoff (inches) | Percent Runoff | Rainfall (inches) | Runoff (inches) | Percent Runoff |
| Cedar River | 27.5 | 5.6 | 20.4% | 32.1 | 9.8 | 30.6% | 41.3 | 17.5 | 42.4% |
| DesMoines River | 22.0 | 1.4 | 6.4% | 28.0 | 5.7 | 20.3% | 36.8 | 13.4 | 36.4% |
| Lake Superior | 25.5 | 7.9 | 30.8% | 29.1 | 12.4 | 42.7% | 35.1 | 16.7 | 47.7% |
| Lower Mississippi | 27.0 | 7.1 | 26.5% | 33.3 | 10.3 | 30.9% | 39.8 | 15.6 | 39.1% |
| Minnesota River | 22.1 | 1.9 | 8.7% | 28.1 | 5.6 | 19.9% | 34.8 | 11.2 | 32.2% |
| Missouri River | 21.1 | 1.0 | 4.6% | 27.2 | 5.3 | 19.3% | 35.6 | 12.8 | 36.0% |
| Rainy River | 22.4 | 4.8 | 21.4% | 26.2 | 8.0 | 30.6% | 32.1 | 11.4 | 35.6% |
| Red River | 18.6 | 1.1 | 5.7% | 23.3 | 3.4 | 14.7% | 28.9 | 6.1 | 21.1% |
| St. Croix River | 23.7 | 5.6 | 23.7% | 30.6 | 9.7 | 31.7% | 37.6 | 14.3 | 38.1% |
| Upper Mississippi River | 22.6 | 3.6 | 15.8% | 28.1 | 6.9 | 24.5% | 34.3 | 10.4 | 30.5% |

To: Marvin Hora, Doug Hall and Mark Tomasek, Minnesota Pollution Control Agency
From: Tim Anderson, Barr Engineering Co.
Subject: Final Basin Hydrology Technical Memorandum
Date: December 17, 2003
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The representative years for low, average and high flows for each basin are summarized in Table 7. The years selected typically had annual flow volumes within ½ inch of the 90, 50 and 10th percentile frequency values for representative gages in each Basin. However, there were cases, especially in the Lower Mississippi basin, where the volume differences exceed the ½ inch value. These representative years were used to select the time frame when phosphorus and TSS data collected would best reflect the wet, average and dry flow conditions.

TABLE 7
 Representative Years for Low, Average and High Flow Conditions

| Major Watershed | Representative Years | | |
|-------------------------|------------------------|------------------------|---------------------------|
| | Low Flow | Average Flow | High Flow |
| Cedar River | 1988, 1989, 1990, 2002 | 1995, 1997, 1998 | 1983, 1999, 2001 |
| Des Moines River | 1988, 1989, 1990, 2000 | 1985, 1987, 1991, 1999 | 1983, 1984, 1994 |
| Lake Superior | 1988, 1990, 1998 | 1985, 1991, 1993, 1995 | 1978, 1983, 1996 |
| Lower Mississippi River | 1996, 2002 | 1994, 1998 | 1973, 1974, 1993 |
| Minnesota River | 1981, 1990, 2000 | 1985, 1998, 1999 | 1986, 1997, 2001 |
| Missouri River | 1989, 1990, 1991, 2000 | 1980, 1987, 1992, 1999 | 1983, 1984, 1997 |
| Rainy River | 1977, 1980, 2002 | 1992, 1993, 1997 | 1974, 1975, 1996, 2001 |
| Red River of the North | 1988, 1989, 1990, 1991 | 1993, 1994, 1995, 2002 | 1997, 1998, 2001 |
| St. Croix River | 1980, 1987, 1988, 1998 | 1994, 1995, 1999 | 1978, 2001, 2002 |
| Upper Mississippi | 1989, 1990, 2000 | 1982, 1995, 2002 | 1985, 1997, 2001 |

Flow Variability and Uncertainty

As part of the frequency analysis, the 95 percent confidence intervals for the curves were developed. For example, the confidence intervals indicate that there is a 95 percent probability the 10 percent (wet year) flow falls between the range shown on the curves (see curves in Appendix A and Appendix B). In general, when the period of record is longer, the confidence interval becomes narrower.

A comparison was also made of the interpolated grid data for the three runoff conditions with actual values for the watersheds that are entirely within the state of Minnesota. This comparison is shown in Table 8. The last three columns represent the difference between the value from the frequency curves and that predicted from the grid. The difference in high flows had the highest standard deviation and also the highest absolute difference (-1.2 inches for the St. Louis River). The average flows had the best overall match. The Big Fork River Watershed had the best fit, with nearly identical values for all three flow conditions.

Recommendations for Future Refinements

One of the problems encountered when developing this flow analysis is that some of the USGS gages were discontinued. The collection of current data at some locations would provide valuable flow data for calculation of phosphorus loadings and also more accurate estimation of annual flows. Gages where reestablishment of continuous flow monitoring is recommended are listed below:

- Baptism River near Beaver Bay
- Big Fork River at Big Falls
- Root River near Houston
- Zumbro River at Zumbro Falls

It is also recommended that one or two smaller watersheds within the metropolitan area be continuously gaged. Currently only the Vermillion River in the south suburbs has a long-term, uninterrupted record.

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Minnesota Department of Natural Resources, GIS Data Deli Website. <http://ftp.dnr.state.mn.us/>

Greg Spoden; Minnesota Department of Natural Resources Division of Waters State Climatology Office.

Guidelines for Determining Flood Flow Frequency, Bulletin #17B, U.S. Water Resources Council, Sept. 1981

USGS National Land Cover Database, 1992. <http://seamless.usgs.gov>,
<http://landcover.usgs.gov/natl/landcover.html>

Table 8

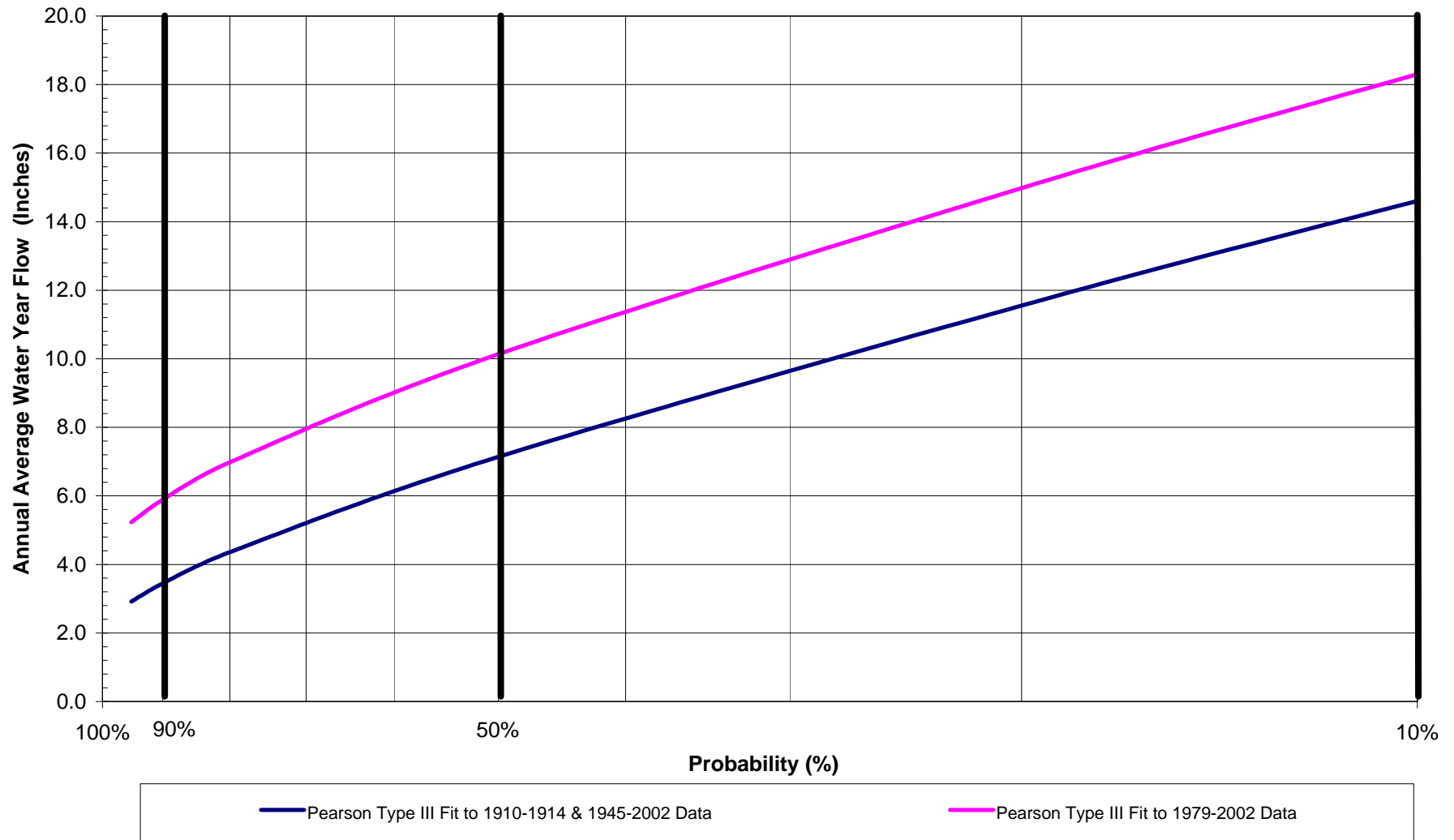
Comparison of Runoff Calculated from State-Wide Grids and Frequency Curves for Watersheds Entirely Within Minnesota (Runoff in Inches)

| Watershed | Major Basin | Values from State-Wide Runoff Map (inches) | | | Values from Frequency Plots (inches) | | | Difference (inches) | | |
|--|-------------------------|--|--------------|-------------|--------------------------------------|--------------|-------------|---------------------|---------------|---------------|
| | | Low Flow | Average Flow | High Flow | Low Flow | Average Flow | High Flow | Low Flow | Average Flow | High Flow |
| CEDAR RIVER NEAR AUSTIN | Cedar River | 5.9 | 10.0 | 17.7 | 5.8 | 10.2 | 18.2 | -0.115 | 0.183 | 0.520 |
| DES MOINES RIVER AT JACKSON | Des Moines River | 1.2 | 5.5 | 13.1 | 1.1 | 5.3 | 13.2 | -0.131 | -0.153 | 0.120 |
| BAPTISM RIVER NEAR BEAVER BAY | Lake Superior | 10.7 | 16.2 | 20.5 | 11.2 | 16.8 | 21.0 | 0.470 | 0.608 | 0.535 |
| KNIFE RIVER NEAR TWO HARBORS | Lake Superior | 9.0 | 15.1 | 21.1 | 9.0 | 15.3 | 21.5 | -0.027 | 0.159 | 0.354 |
| ST. LOUIS RIVER AT SCANLON | Lake Superior | 7.3 | 11.6 | 15.7 | 7.2 | 11.0 | 14.5 | -0.137 | -0.580 | -1.235 |
| ROOT RIVER NEAR HOUSTON | Lower Mississippi River | 7.9 | 10.9 | 15.8 | 8.3 | 10.9 | 15.0 | 0.390 | -0.028 | -0.783 |
| VERMILLION RIVER NEAR EMPIRE, MN | Lower Mississippi River | 4.3 | 8.0 | 13.0 | 4.0 | 7.8 | 12.6 | -0.320 | -0.219 | -0.374 |
| CHIPPEWA RIVER NEAR MILAN, MN | Minnesota River | 1.4 | 4.3 | 7.8 | 1.2 | 4.1 | 7.3 | -0.191 | -0.236 | -0.480 |
| COTTONWOOD RIVER NEAR NEW ULM | Minnesota River | 1.5 | 5.5 | 12.1 | 1.5 | 5.5 | 12.0 | 0.037 | 0.018 | -0.110 |
| CROW WING RIVER NEAR PILLAGER, MN | Minnesota River | 3.1 | 5.8 | 8.7 | 3.4 | 6.1 | 9.1 | 0.280 | 0.314 | 0.400 |
| LE SUEUR RIVER NEAR RAPIDAN, MN | Minnesota River | 3.8 | 8.0 | 15.8 | 3.4 | 7.8 | 15.7 | -0.425 | -0.249 | -0.103 |
| BASSWOOD RIVER NEAR WINTON | Rainy River | 7.8 | 12.0 | 15.6 | 7.2 | 11.2 | 14.5 | -0.581 | -0.831 | -1.098 |
| BIG FORK RIVER AT BIG FALLS | Rainy River | 4.4 | 7.2 | 10.5 | 4.4 | 7.2 | 10.5 | 0.025 | -0.015 | -0.018 |
| LITTLE FORK RIVER AT LITTLEFORK | Rainy River | 5.5 | 8.6 | 12.3 | 5.6 | 8.7 | 12.7 | 0.134 | 0.096 | 0.378 |
| BUFFALO RIVER NEAR DILWORTH | Red River of the North | 0.9 | 3.0 | 5.5 | 0.8 | 2.8 | 5.2 | -0.118 | -0.194 | -0.293 |
| OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS | Red River of the North | 1.8 | 3.9 | 6.4 | 1.8 | 3.8 | 5.9 | 0.030 | -0.148 | -0.483 |
| RED LAKE RIVER AT CROOKSTON | Red River of the North | 1.5 | 4.1 | 7.0 | 1.1 | 3.9 | 6.7 | -0.386 | -0.242 | -0.287 |
| ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU | Red River of the North | 0.9 | 3.5 | 6.4 | 0.8 | 3.5 | 6.5 | -0.120 | -0.009 | 0.072 |
| WILD RICE RIVER AT HENDRUM | Red River of the North | 1.1 | 3.6 | 6.5 | 1.0 | 3.7 | 6.9 | -0.109 | 0.098 | 0.415 |
| KETTLE RIVER BELOW SANDSTONE | St. Croix River | 6.4 | 10.7 | 15.7 | 6.5 | 10.9 | 16.2 | 0.138 | 0.229 | 0.515 |
| SNAKE RIVER NEAR PINE CITY | St. Croix River | 4.8 | 8.6 | 12.8 | 4.6 | 8.3 | 12.3 | -0.209 | -0.310 | -0.486 |
| CANNON RIVER AT WELCH | Upper Mississippi River | 5.8 | 9.1 | 15.5 | 7.1 | 9.5 | 16.1 | 1.294 | 0.446 | 0.572 |
| CROW RIVER AT ROCKFORD | Upper Mississippi River | 2.3 | 6.3 | 10.8 | 2.1 | 6.4 | 10.9 | -0.214 | 0.122 | 0.087 |
| LONG PRAIRIE RIVER AT LONG PRAIRIE | Upper Mississippi River | 2.4 | 5.1 | 8.2 | 2.6 | 5.2 | 8.3 | 0.157 | 0.103 | 0.128 |
| MISSISSIPPI RIVER AT GRAND RAPIDS | Upper Mississippi River | 3.6 | 6.3 | 9.1 | 3.6 | 6.2 | 8.6 | 0.048 | -0.093 | -0.495 |
| MISSISSIPPI RIVER NEAR ANOKA** | Upper Mississippi River | 3.5 | 6.8 | 10.4 | 4.4 | 7.0 | 9.9 | 0.862 | 0.198 | -0.452 |
| Average | | 4.2 | 7.7 | 12.1 | 4.2 | 7.7 | 12.0 | 0.030 | -0.028 | -0.100 |
| Standard Deviation | | | | | | | | 0.395 | 0.302 | 0.504 |

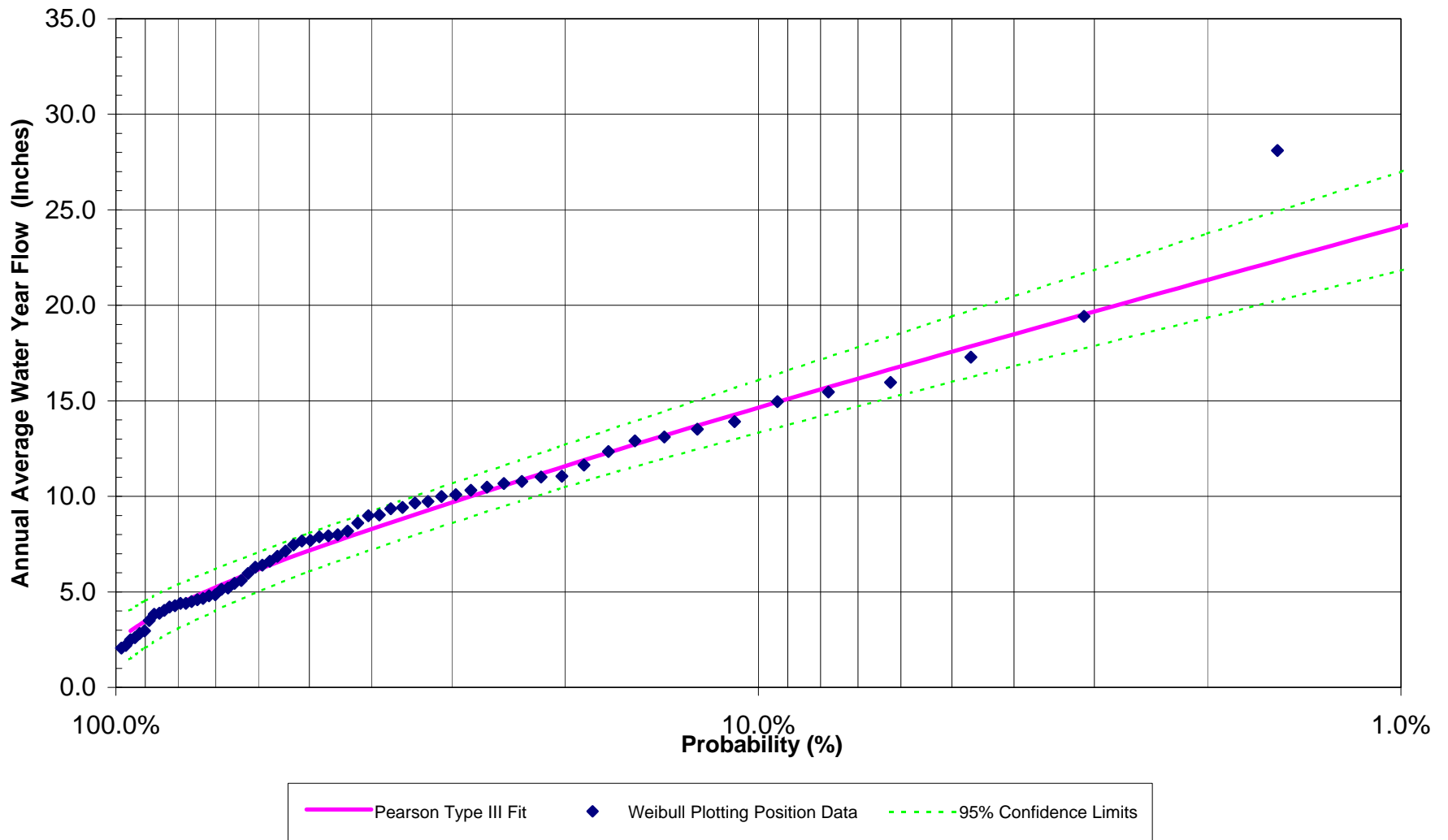
**Data not used in the development of state-wide runoff maps

Appendix A: Flow – Frequency Curves

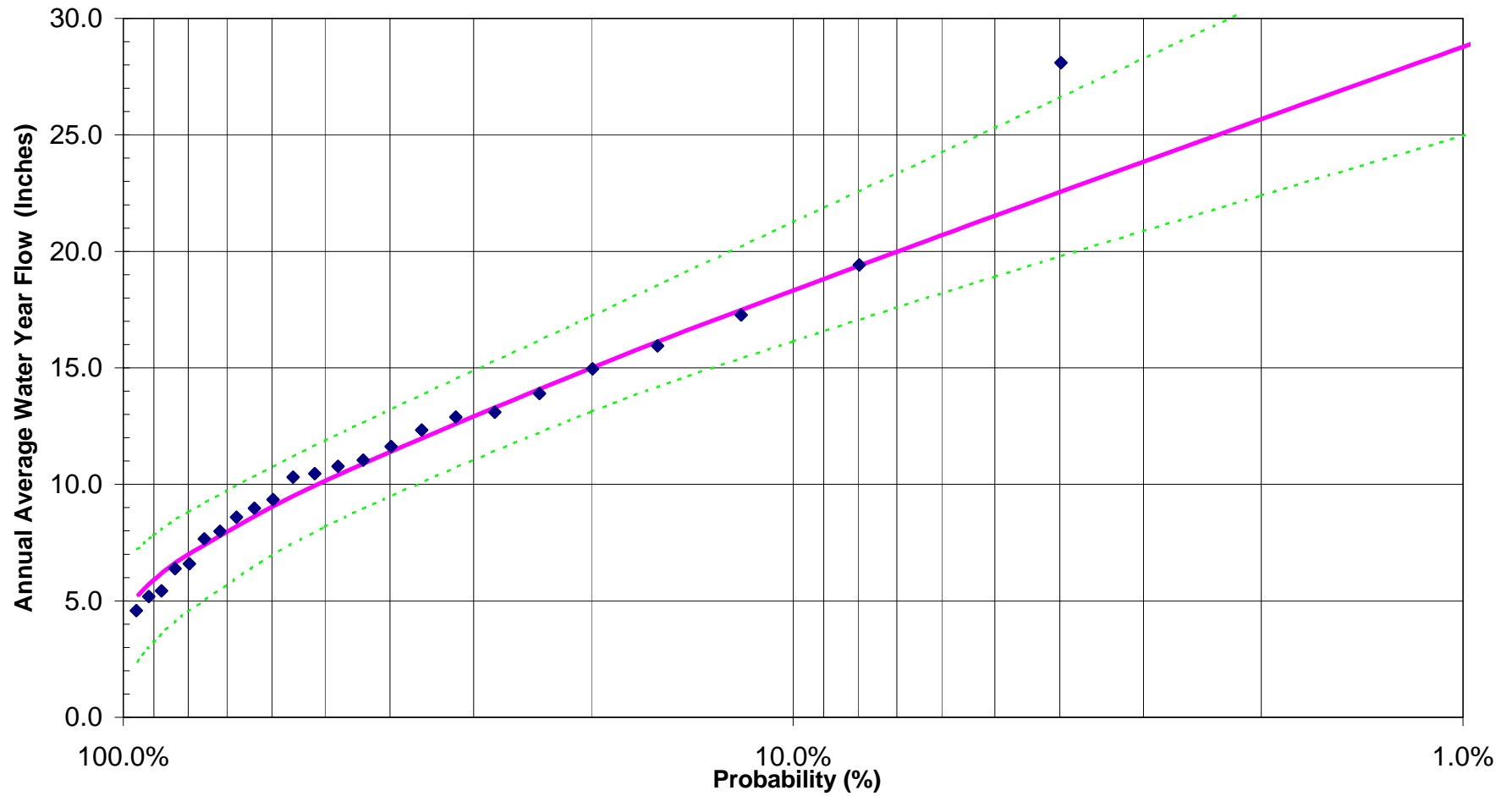
USGS 05457000 CEDAR RIVER NEAR AUSTIN, MN Annual Average Flow Frequency Analysis



USGS 05457000 CEDAR RIVER NEAR AUSTIN, MN Average Flow Frequency Analysis (1945-2002)

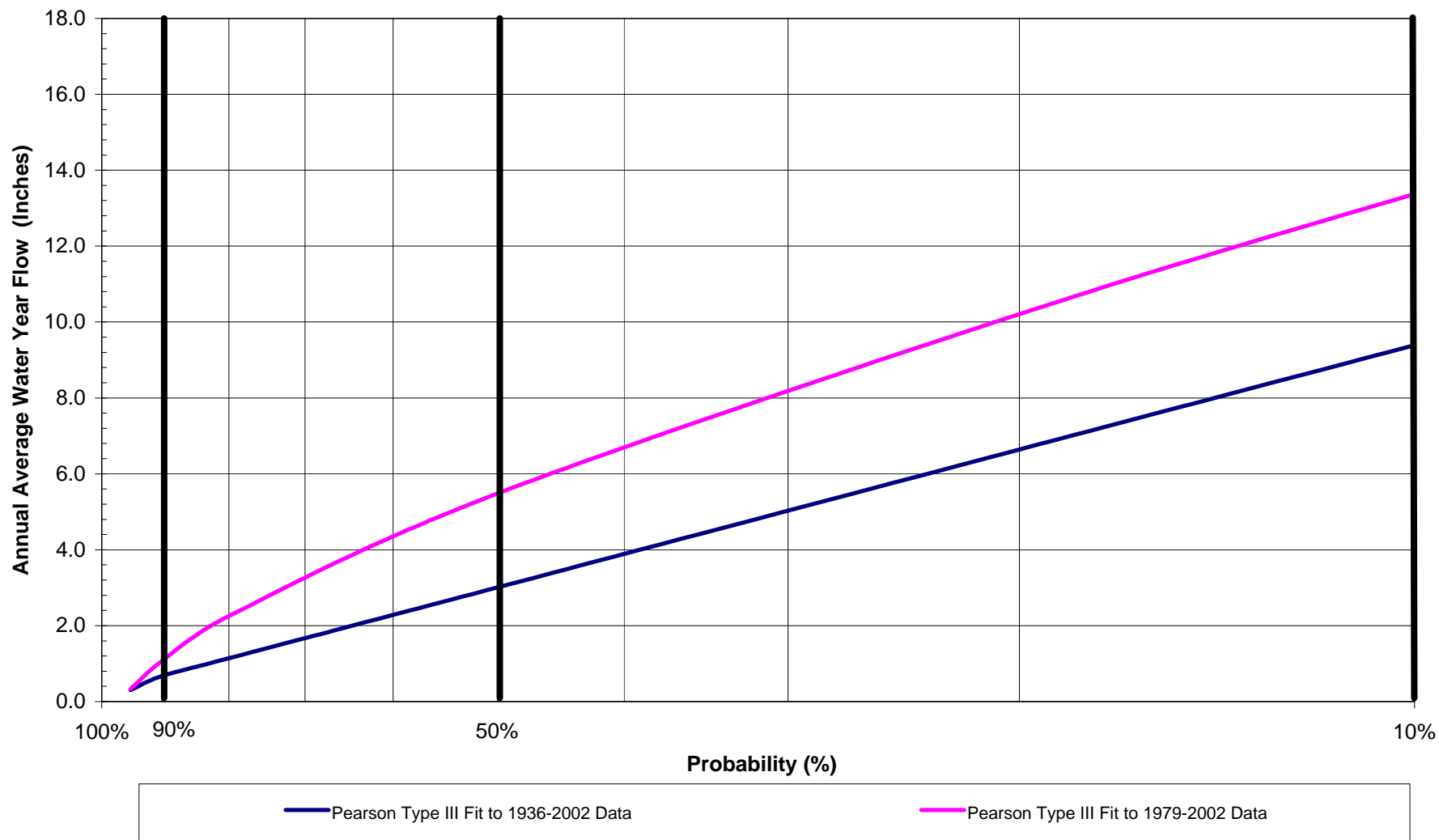


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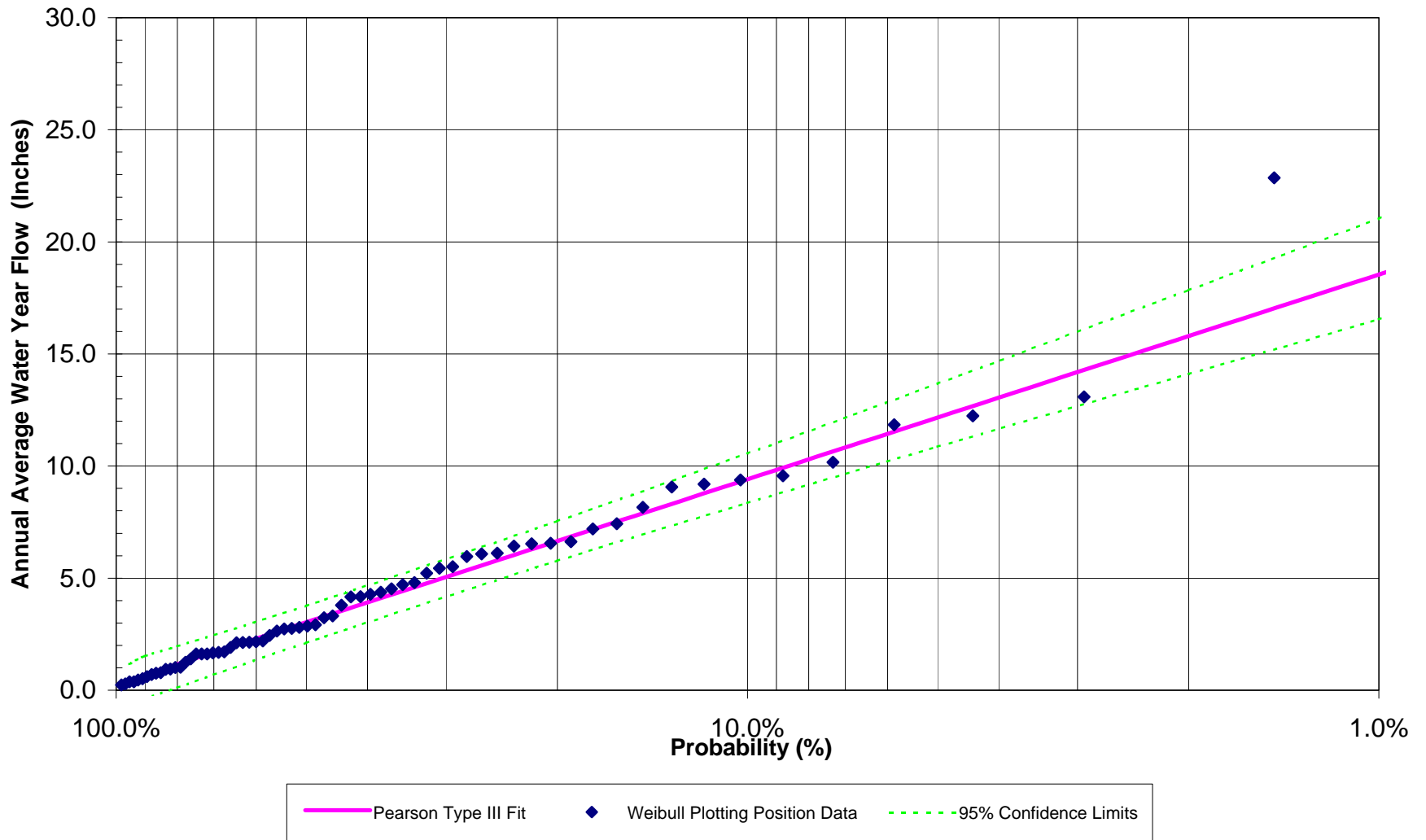


— Pearson Type III Fit ◆ Weibull Plotting Position Data - - - 95% Confidence Limits

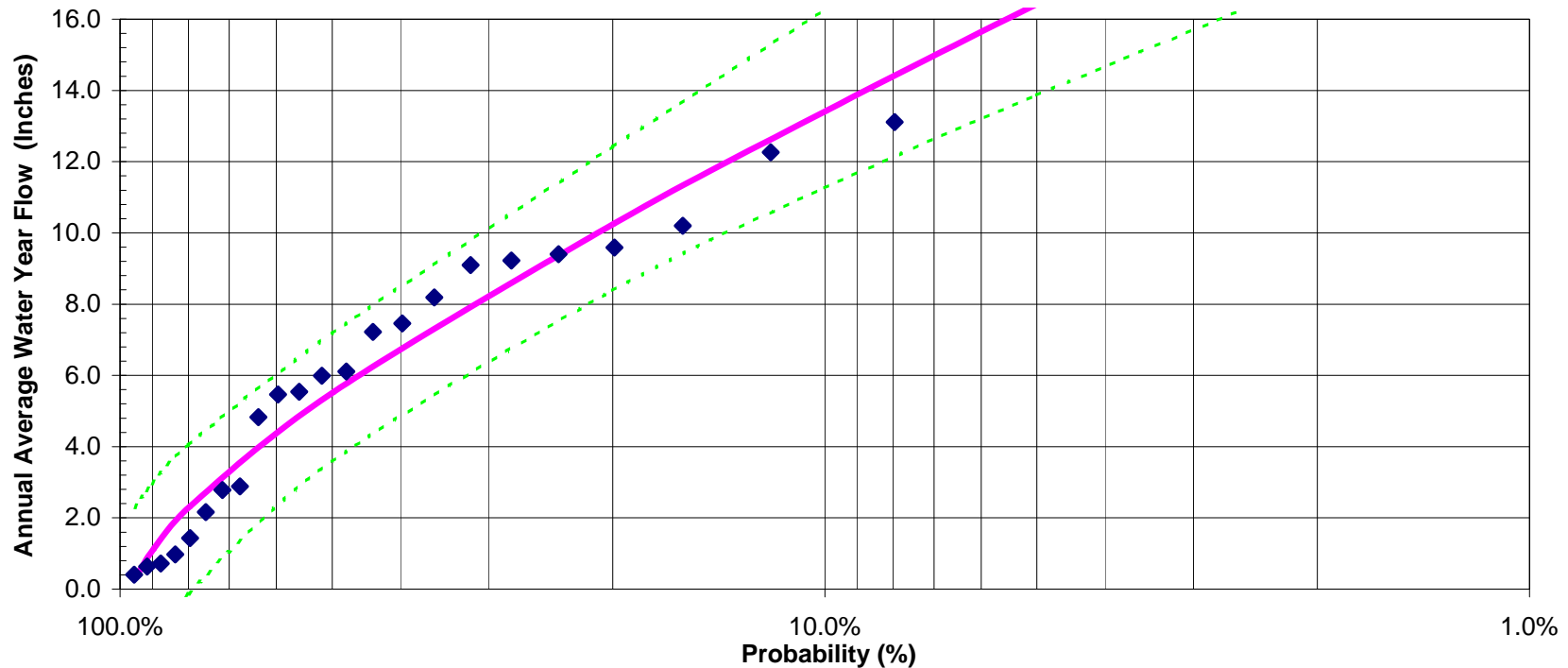
USGS 05476000 DES MOINES RIVER AT JACKSON, MN Annual Average Flow Frequency Analysis



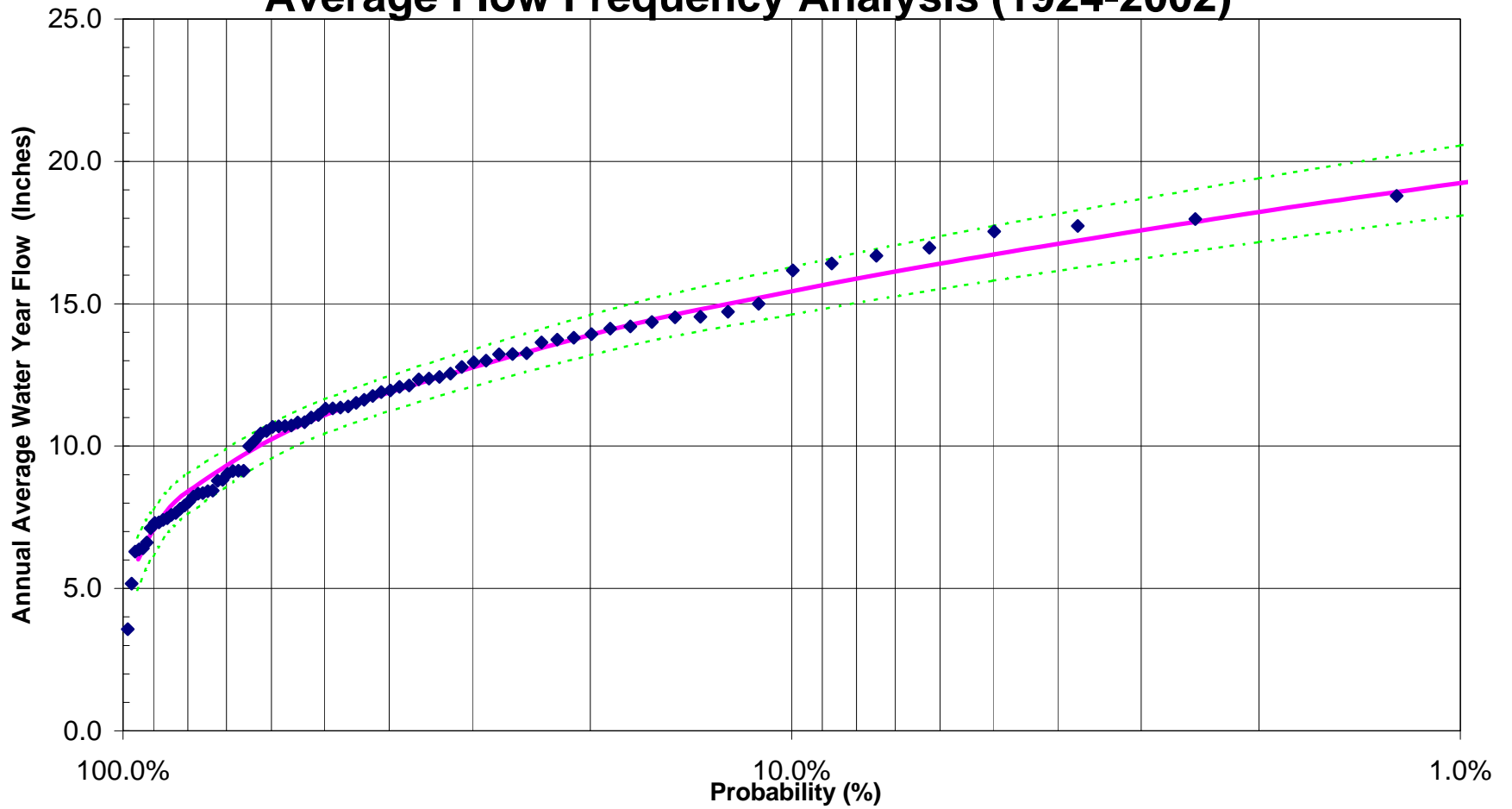
USGS 05476000 DES MOINES RIVER AT JACKSON, MN Average Flow Frequency Analysis (1936-2002)



USGS 05476000 DES MOINES RIVER AT JACKSON, MN Average Flow Frequency Analysis (1979-2002)

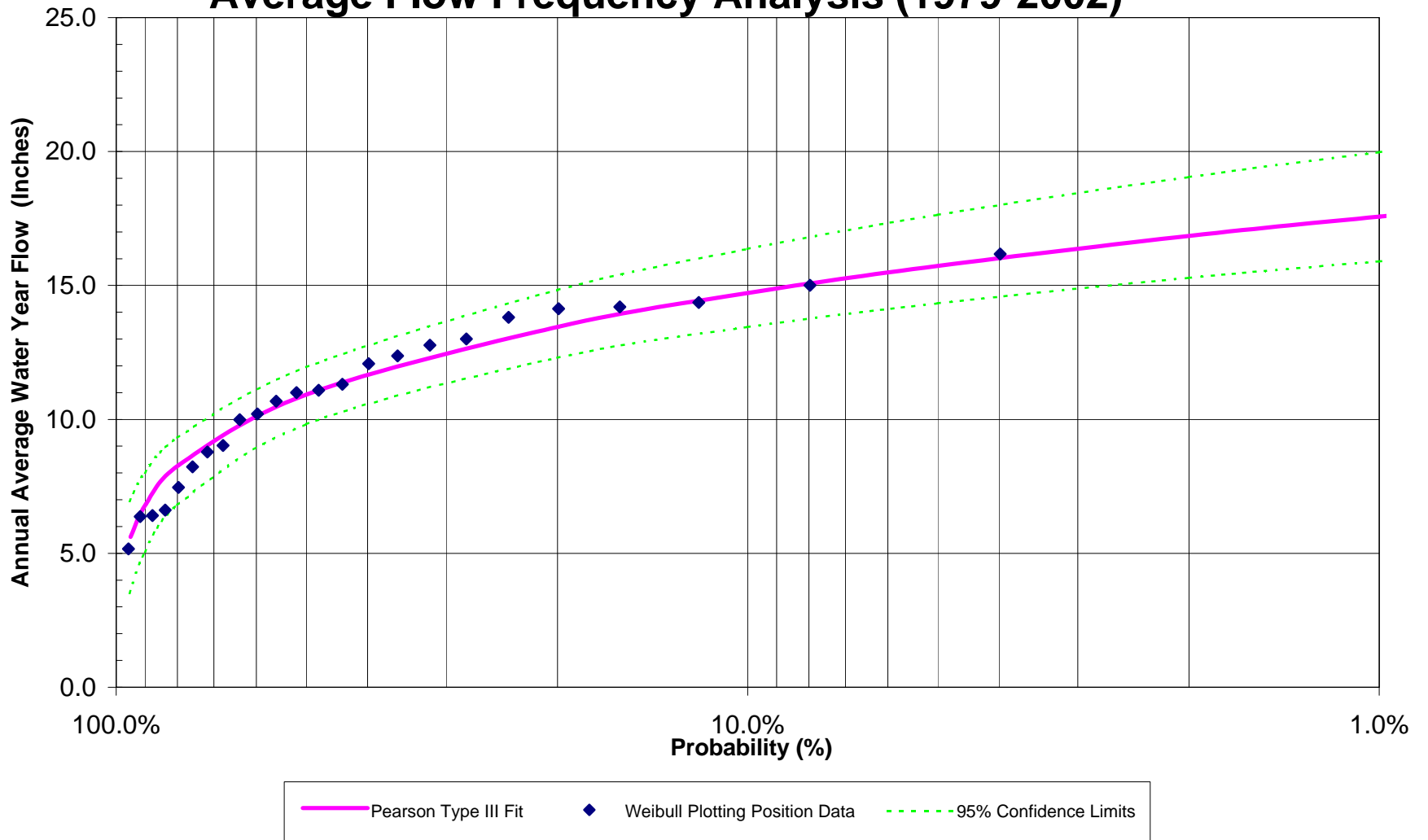


USGS 04010500 PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTAGE MN Average Flow Frequency Analysis (1924-2002)



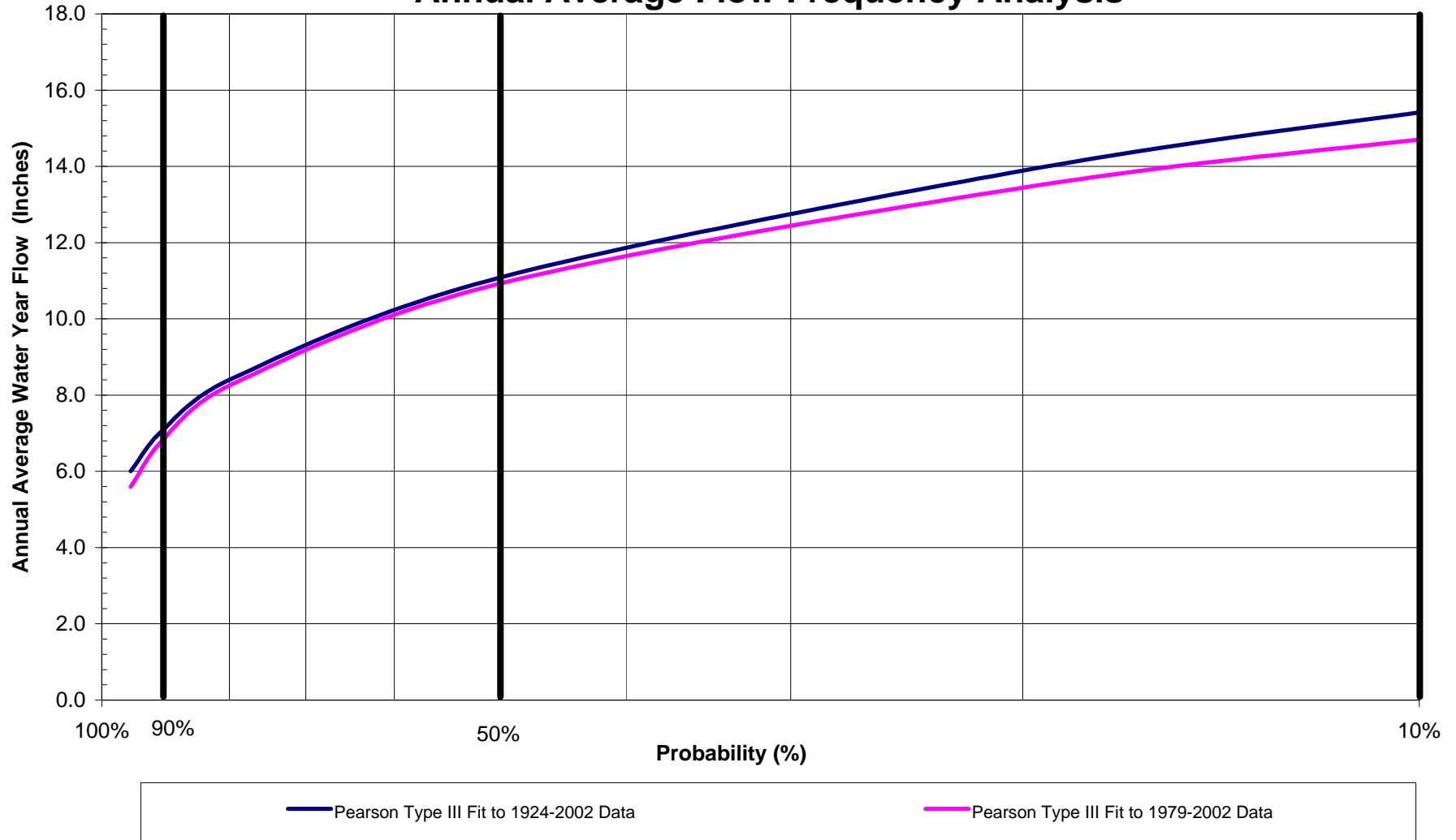
— Pearson Type III Fit ◆ Weibull Plotting Position Data - - - 95% Confidence Limits

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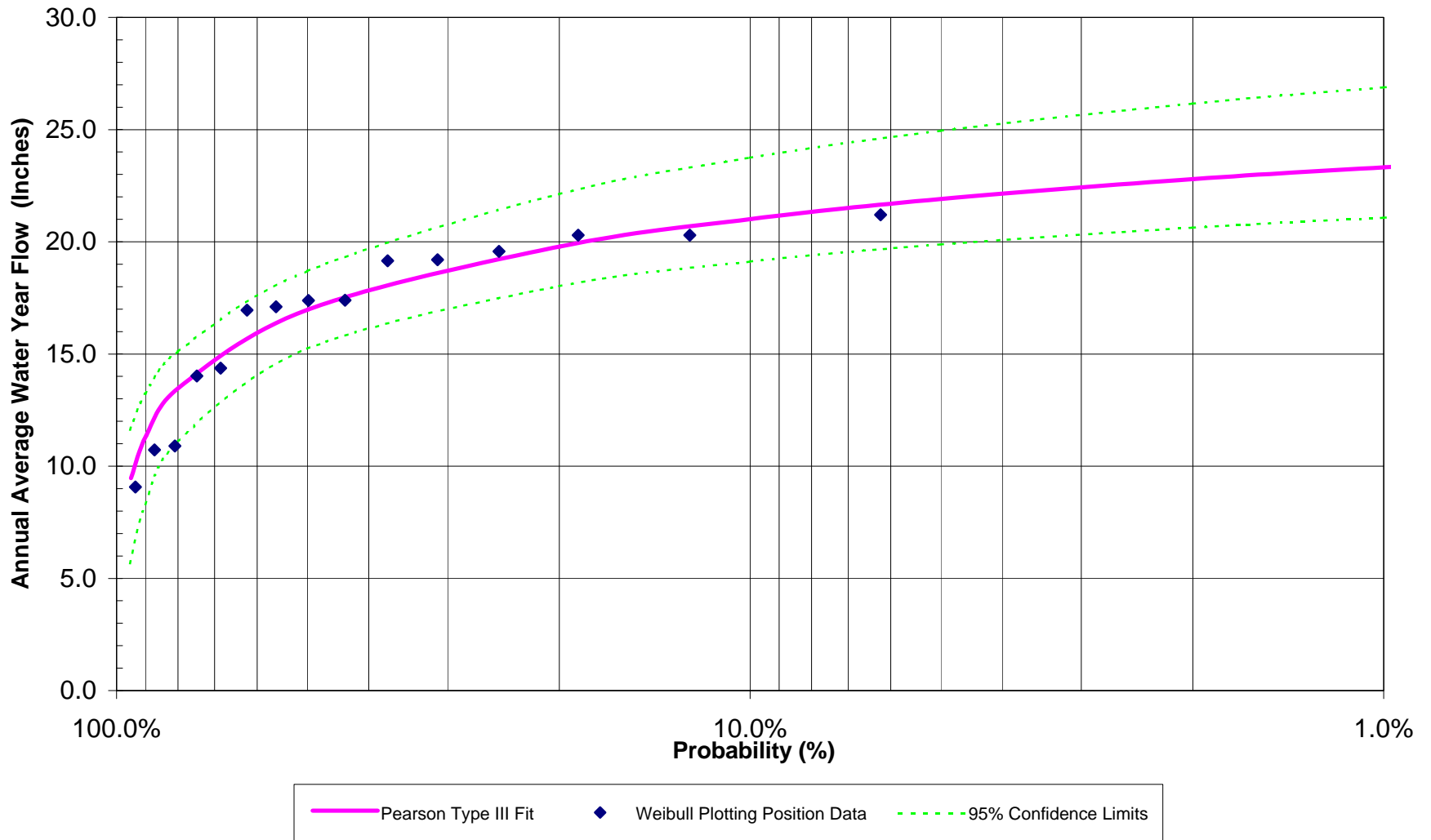


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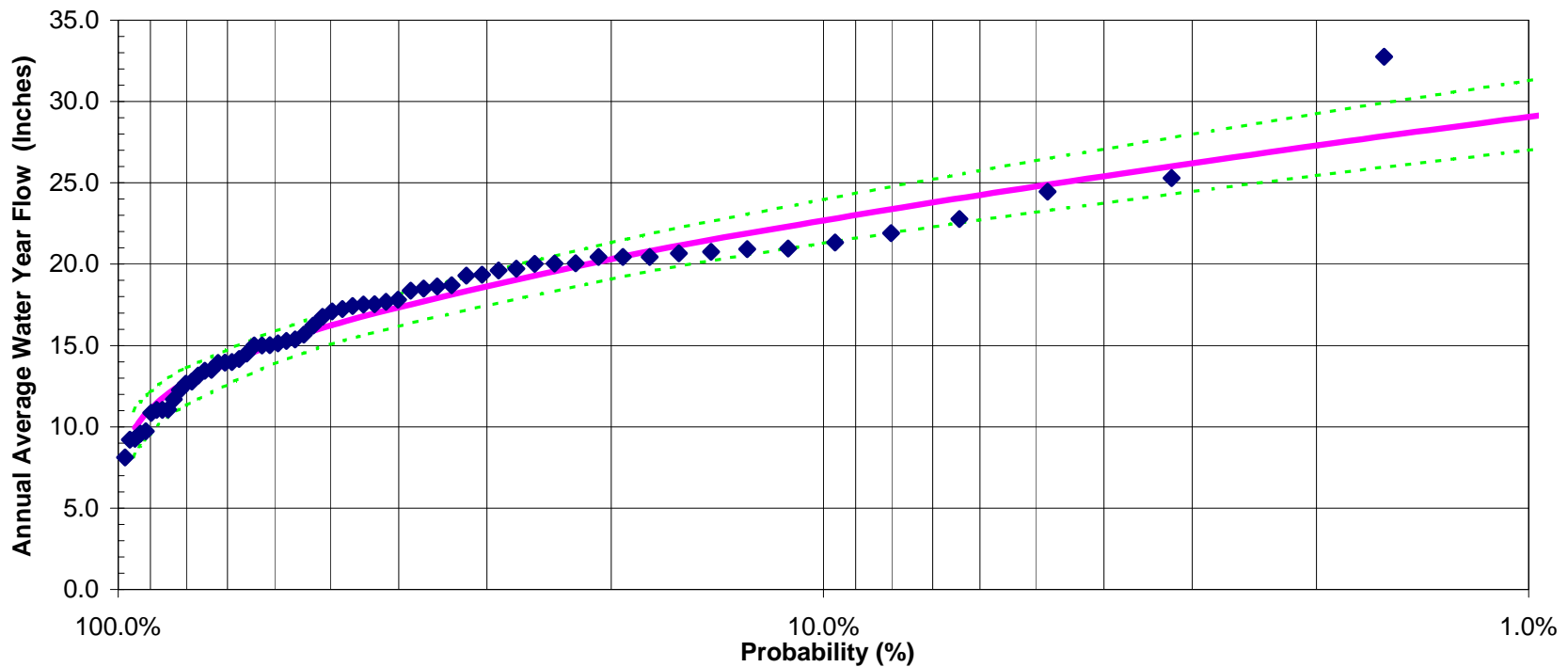
Annual Average Flow Frequency Analysis



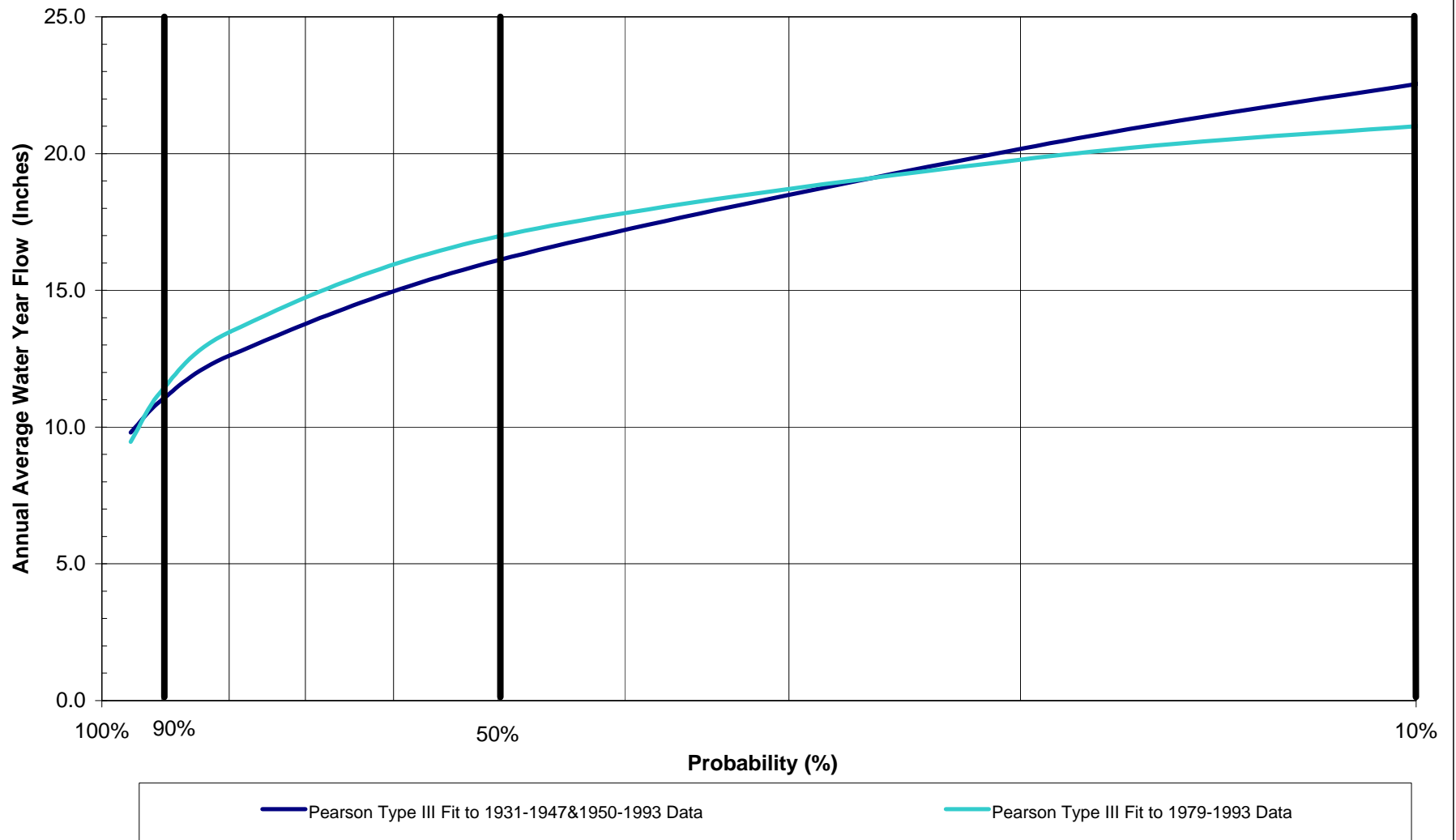
USGS 04014500 BAPTISM RIVER NR BEAVER BAY, MN Average Flow Frequency Analysis (1979-1993)



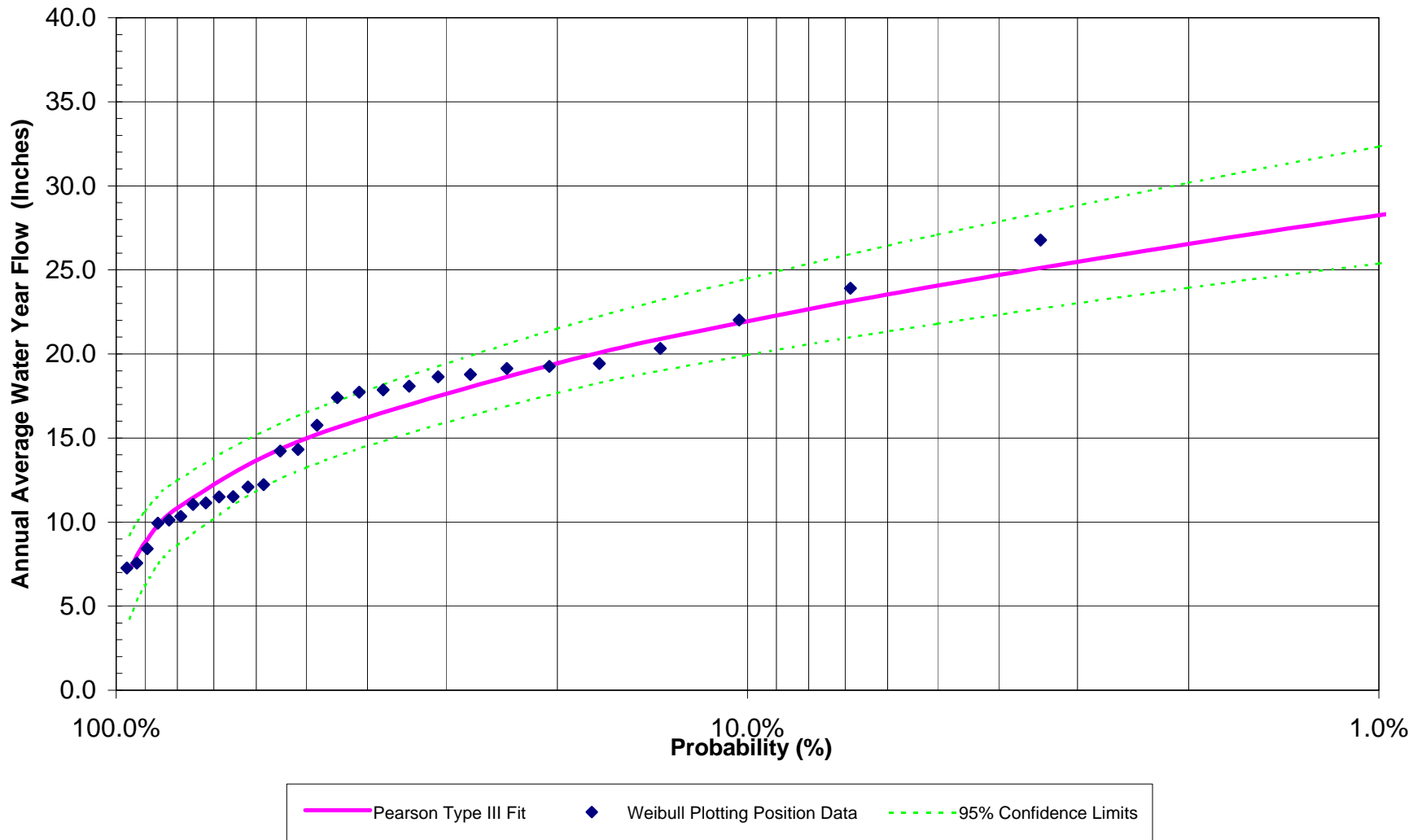
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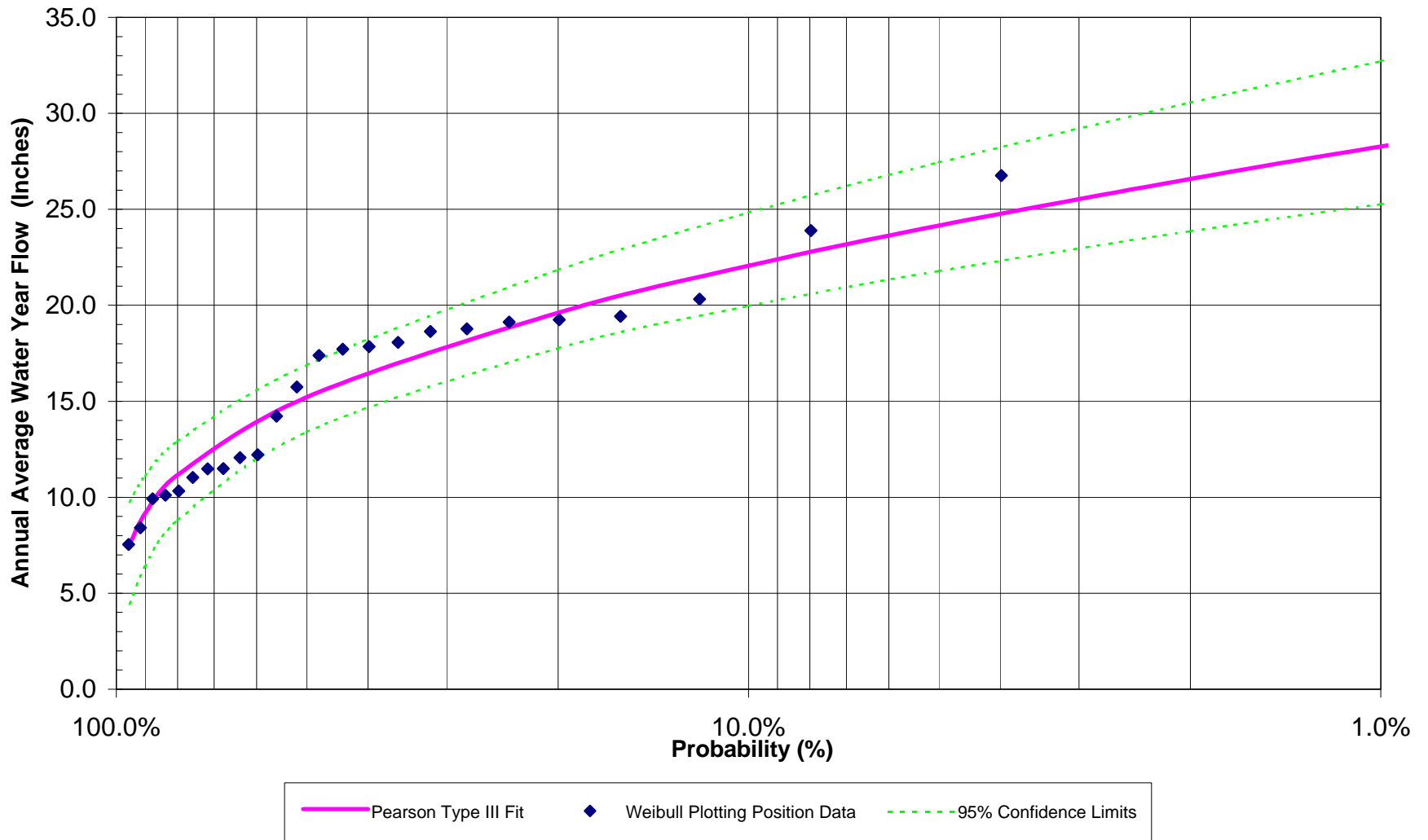
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USGS 04015330 KNIFE RIVER NEAR TWO HARBORS, MN Average Flow Frequency Analysis (1975-2002)

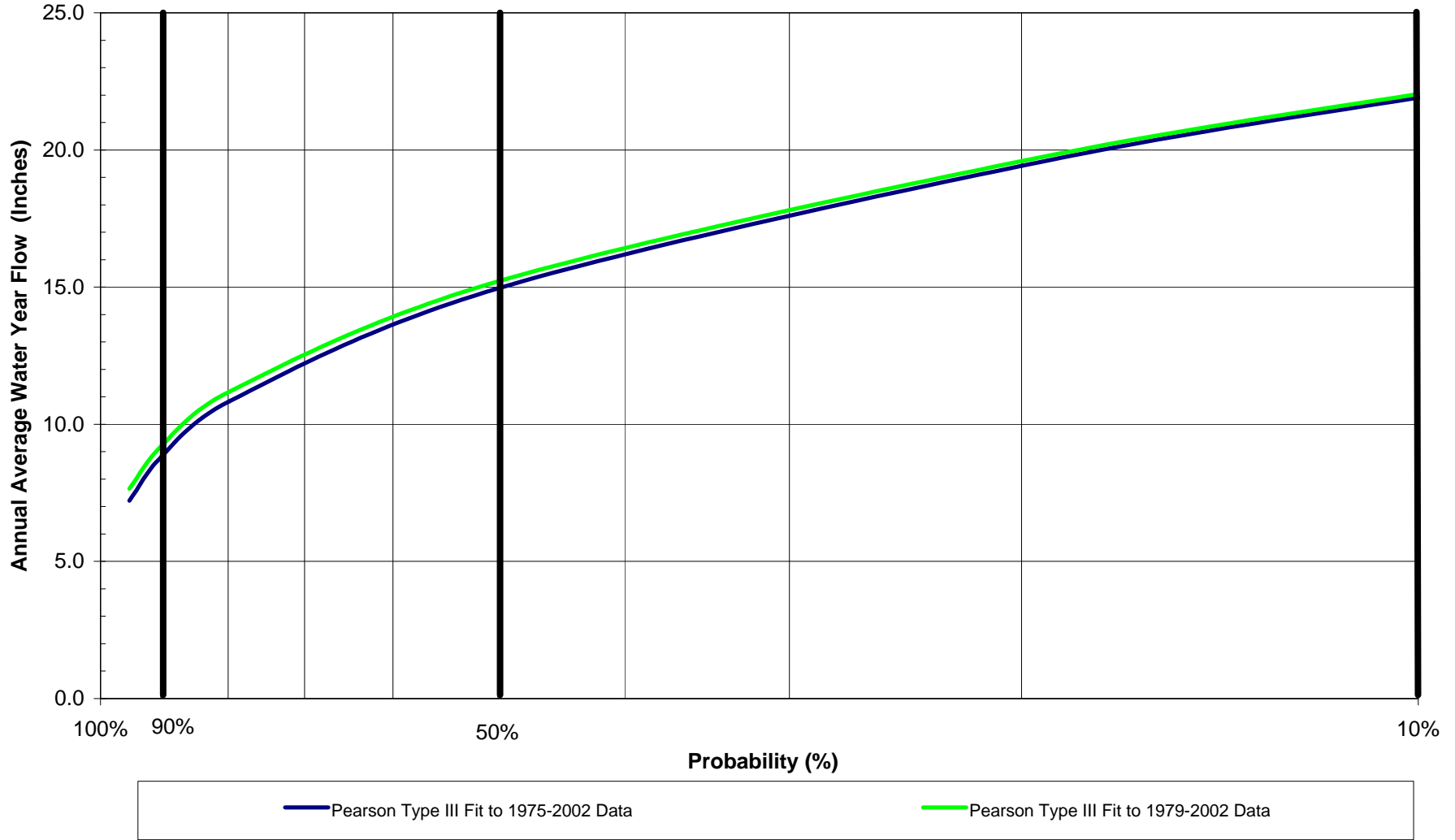


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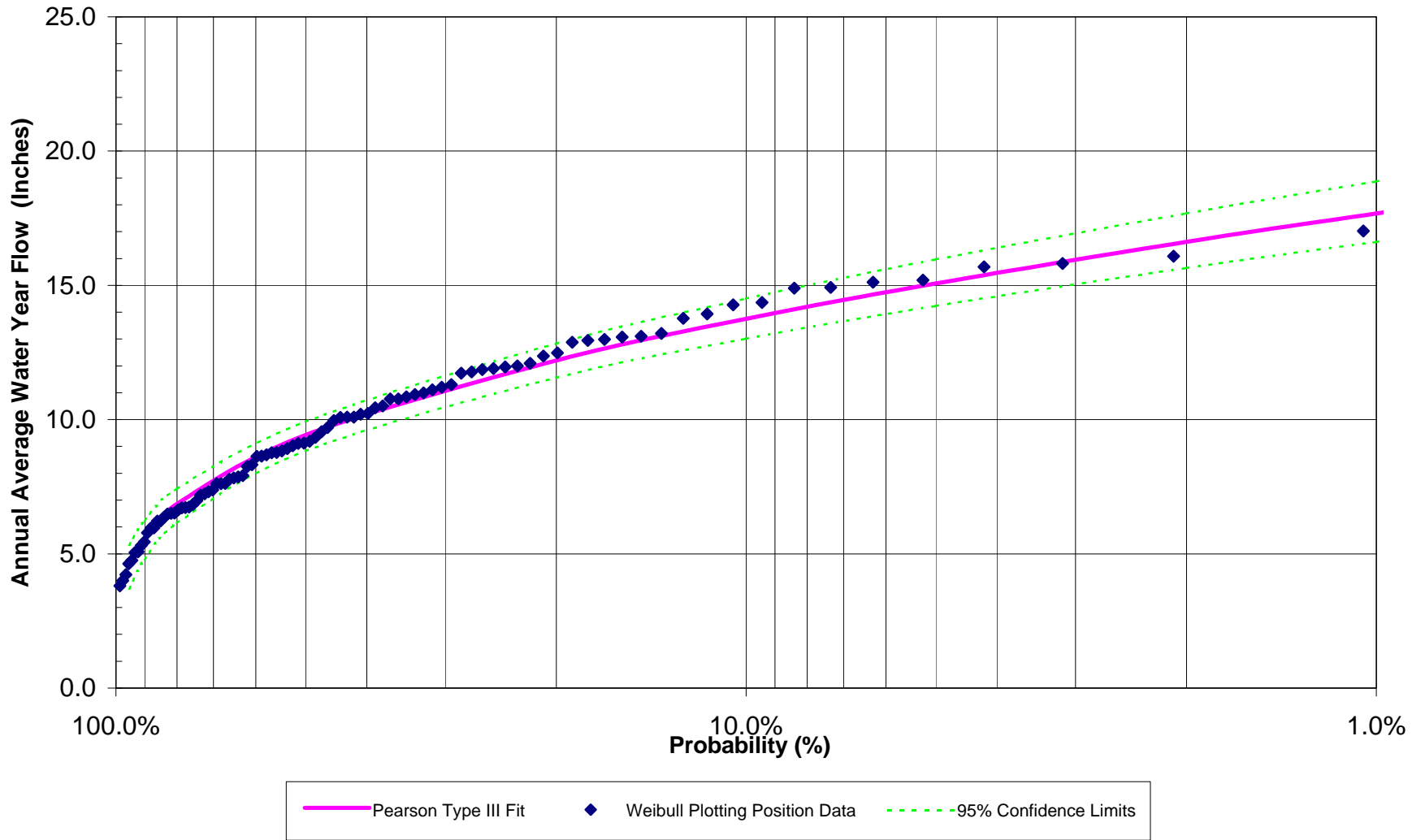


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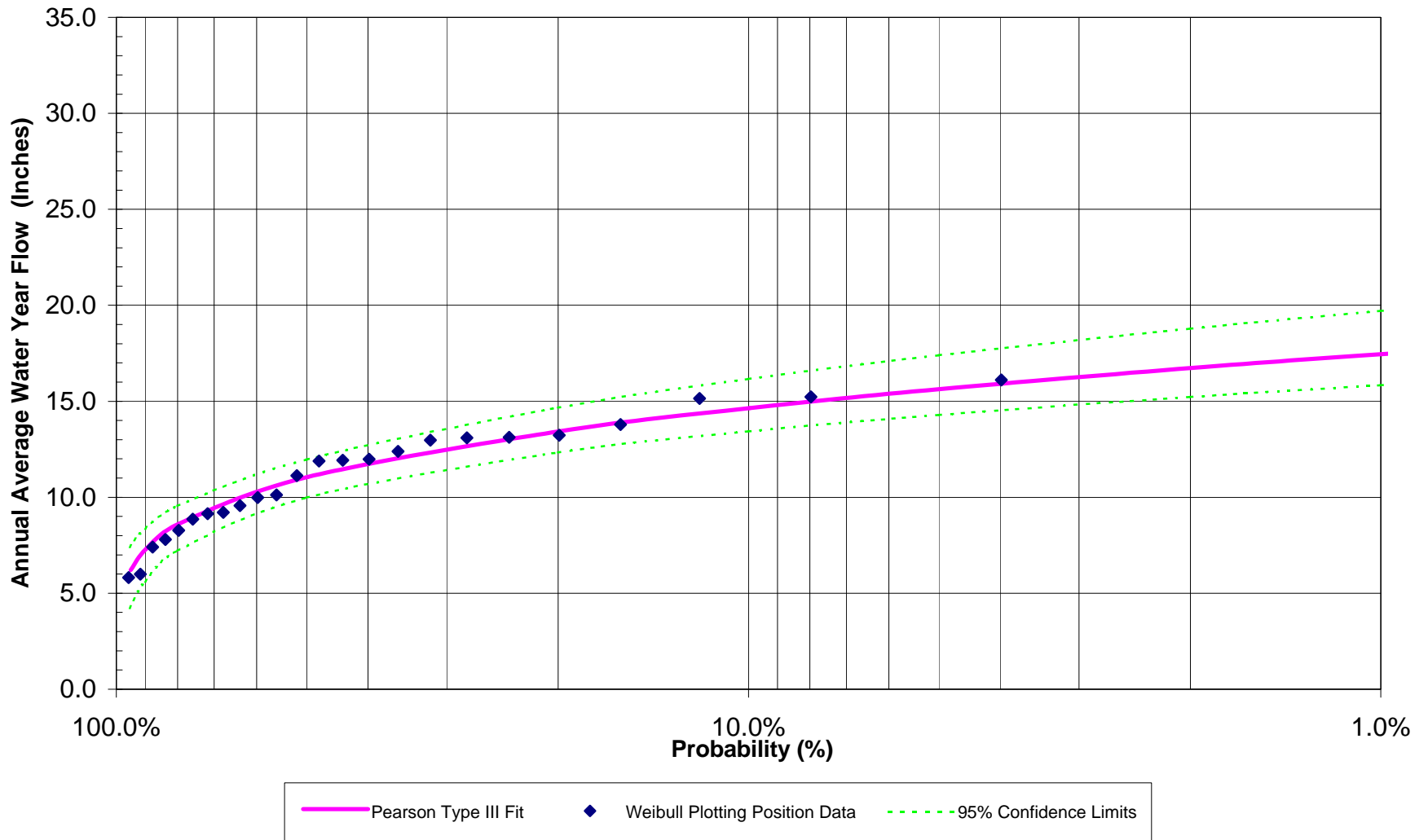
Annual Average Flow Frequency Analysis



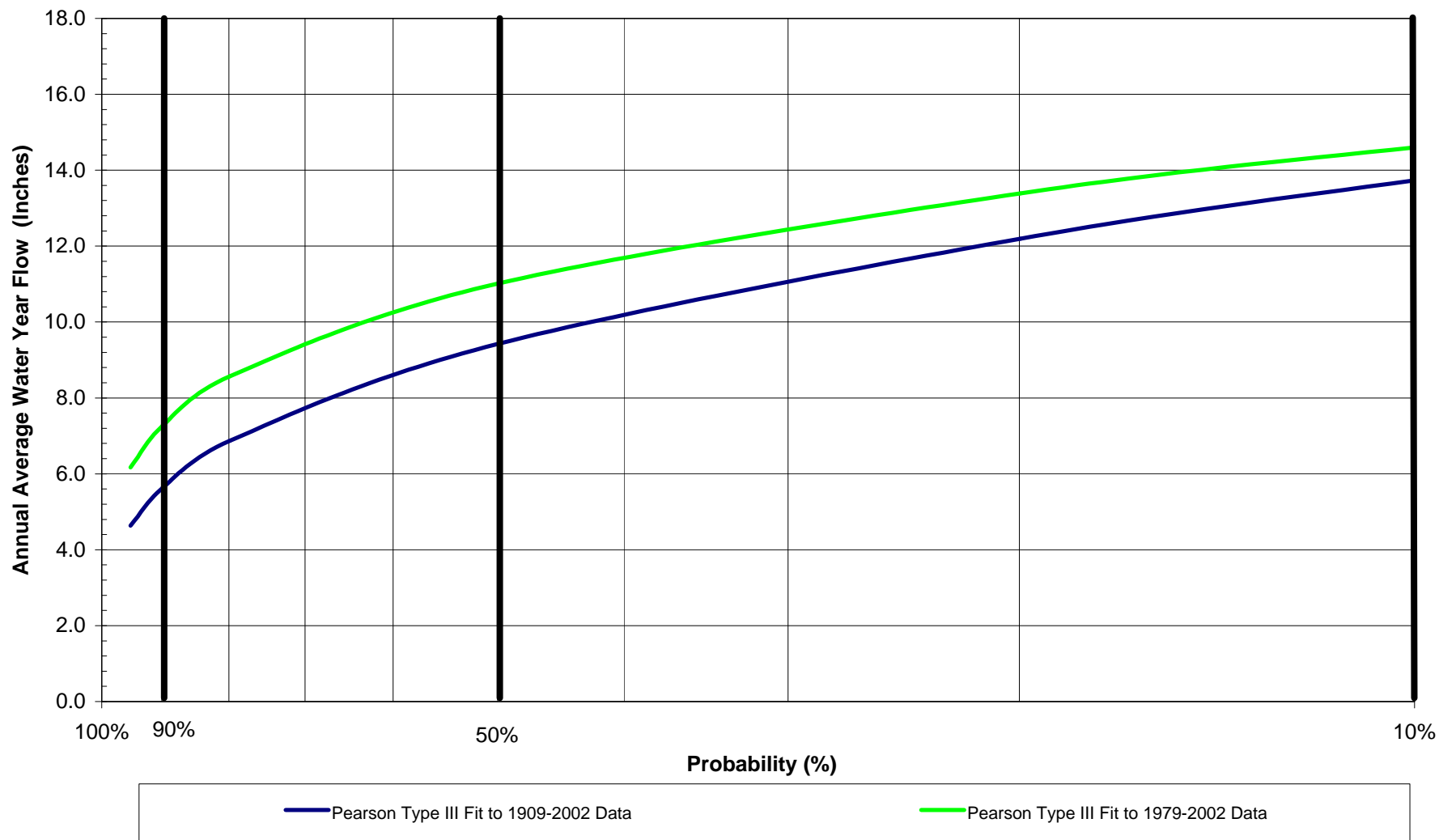
USGS 04024000 ST. LOUIS RIVER AT SCANLON, MN Average Flow Frequency Analysis (1909-2002)



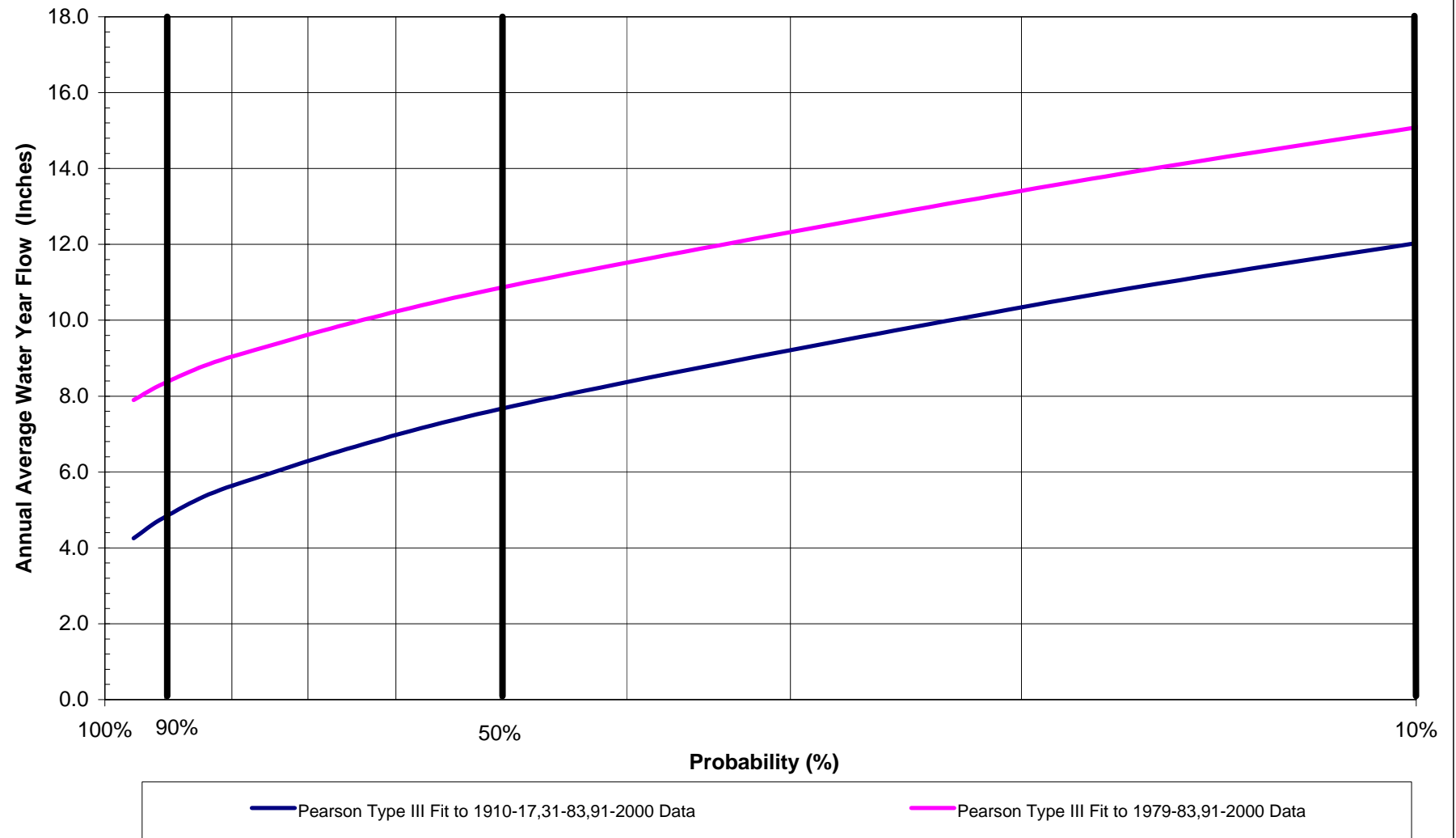
USGS 04024000 ST. LOUIS RIVER AT SCANLON, MN Average Flow Frequency Analysis (1979-2002)



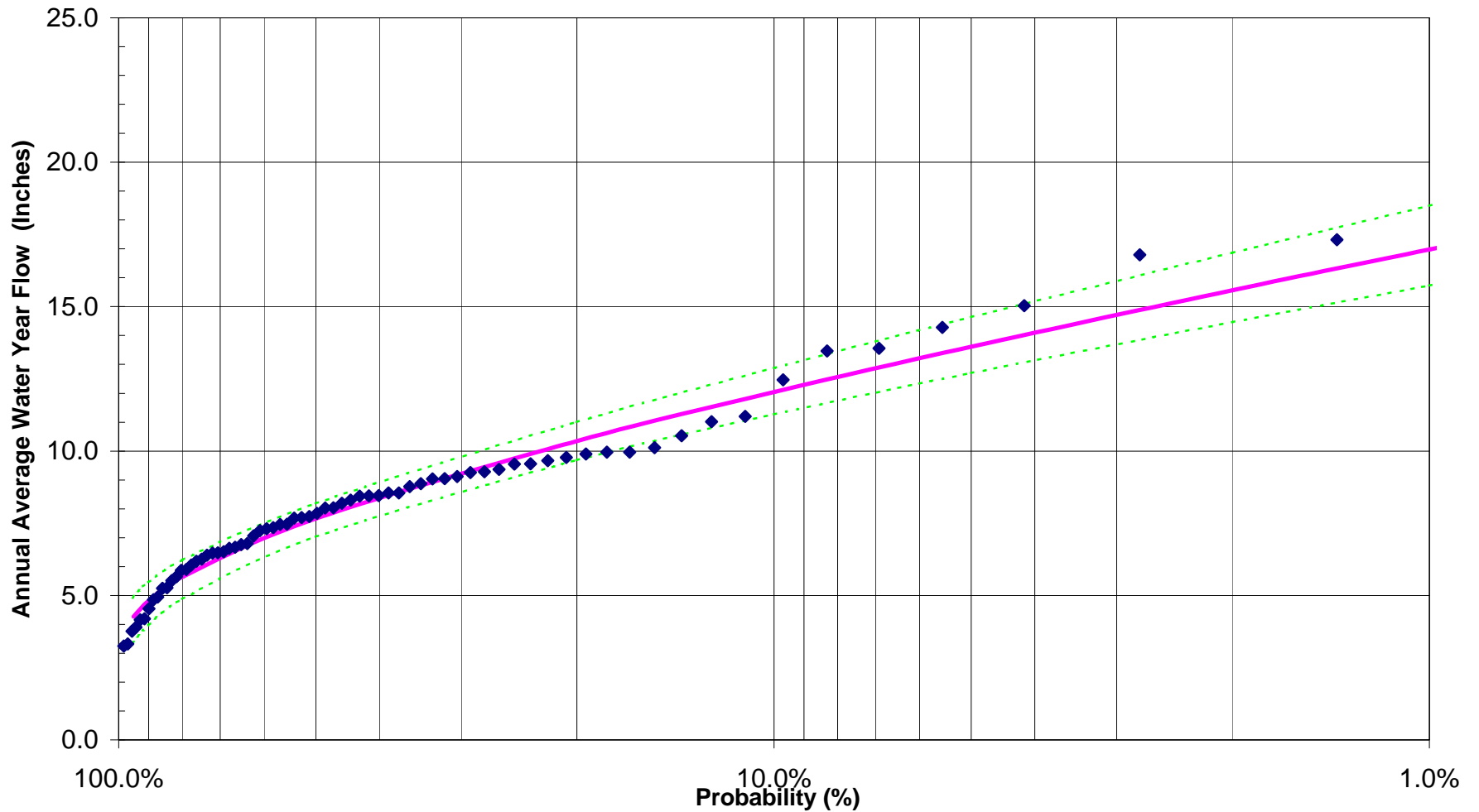
USGS 04024000 ST. LOUIS RIVER AT SCANLON, MN Annual Average Flow Frequency Analysis



USGS 05385000 ROOT RIVER NEAR HOUSTON, MN Annual Average Flow Frequency Analysis

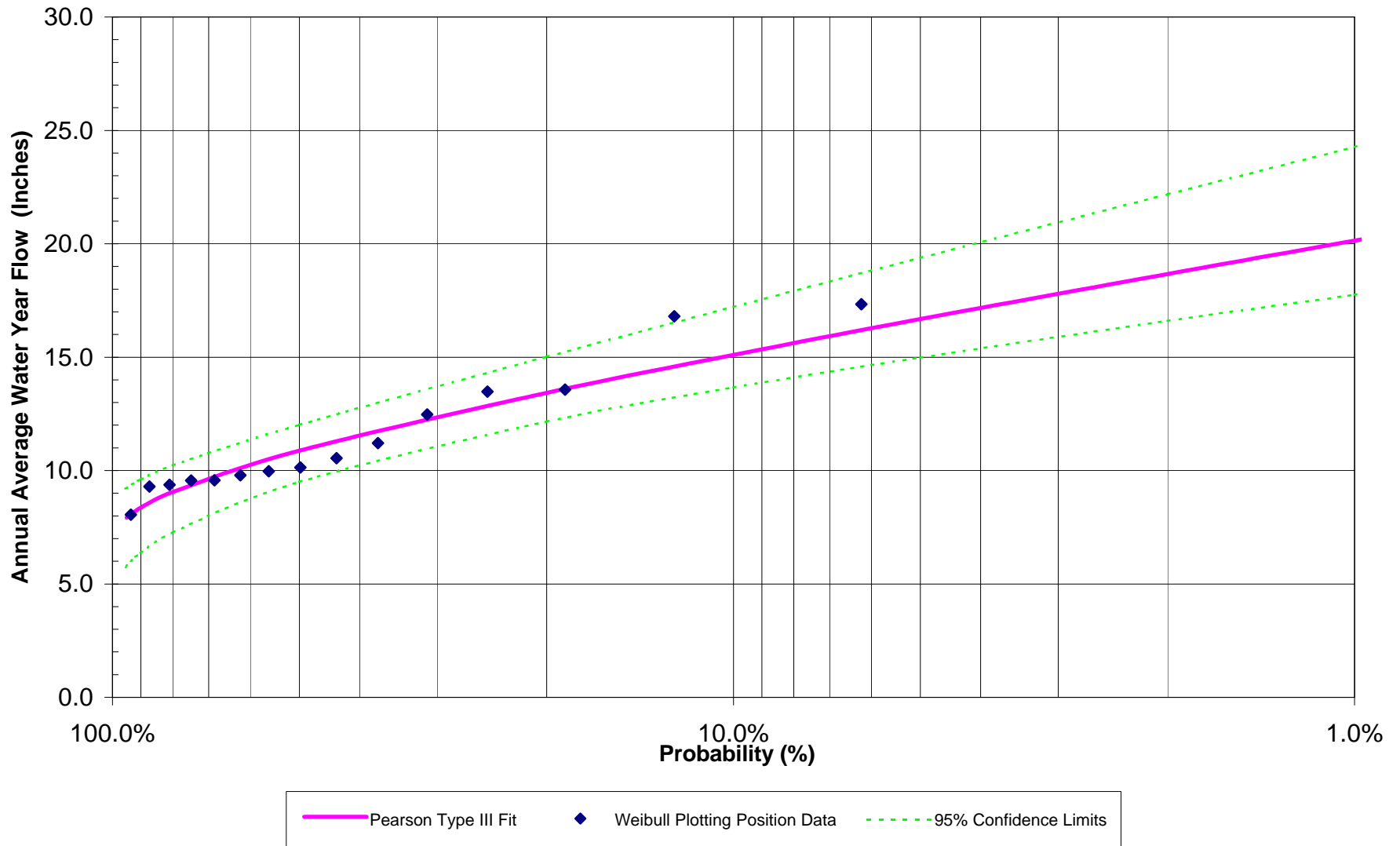


USGS 05385000 ROOT RIVER NEAR HOUSTON, MN Average Flow Frequency Analysis (1910-1917, 1931-1983, 1991-2000)

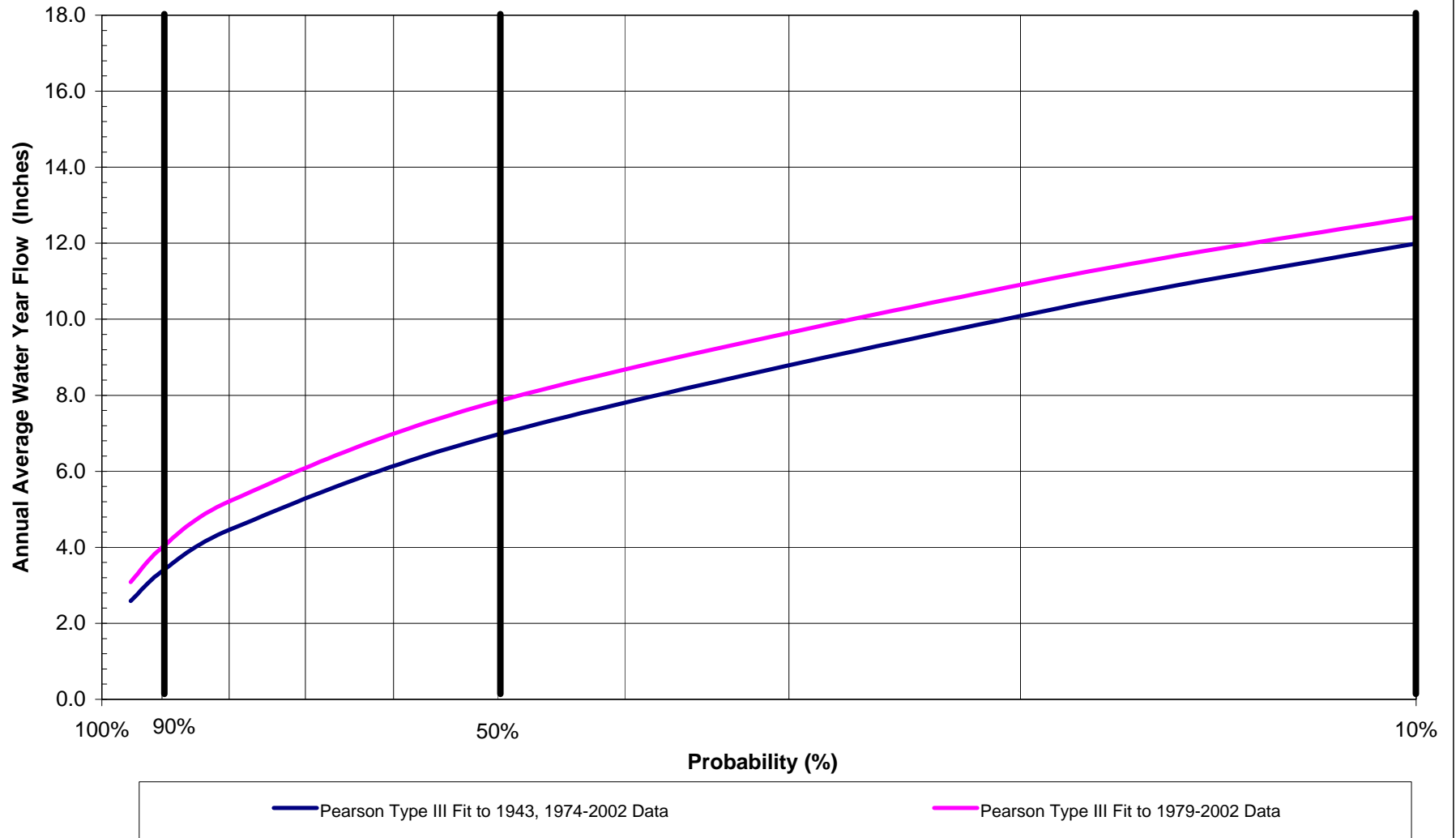


— Pearson Type III Fit ◆ Weibull Plotting Position Data - - - 95% Confidence Limits

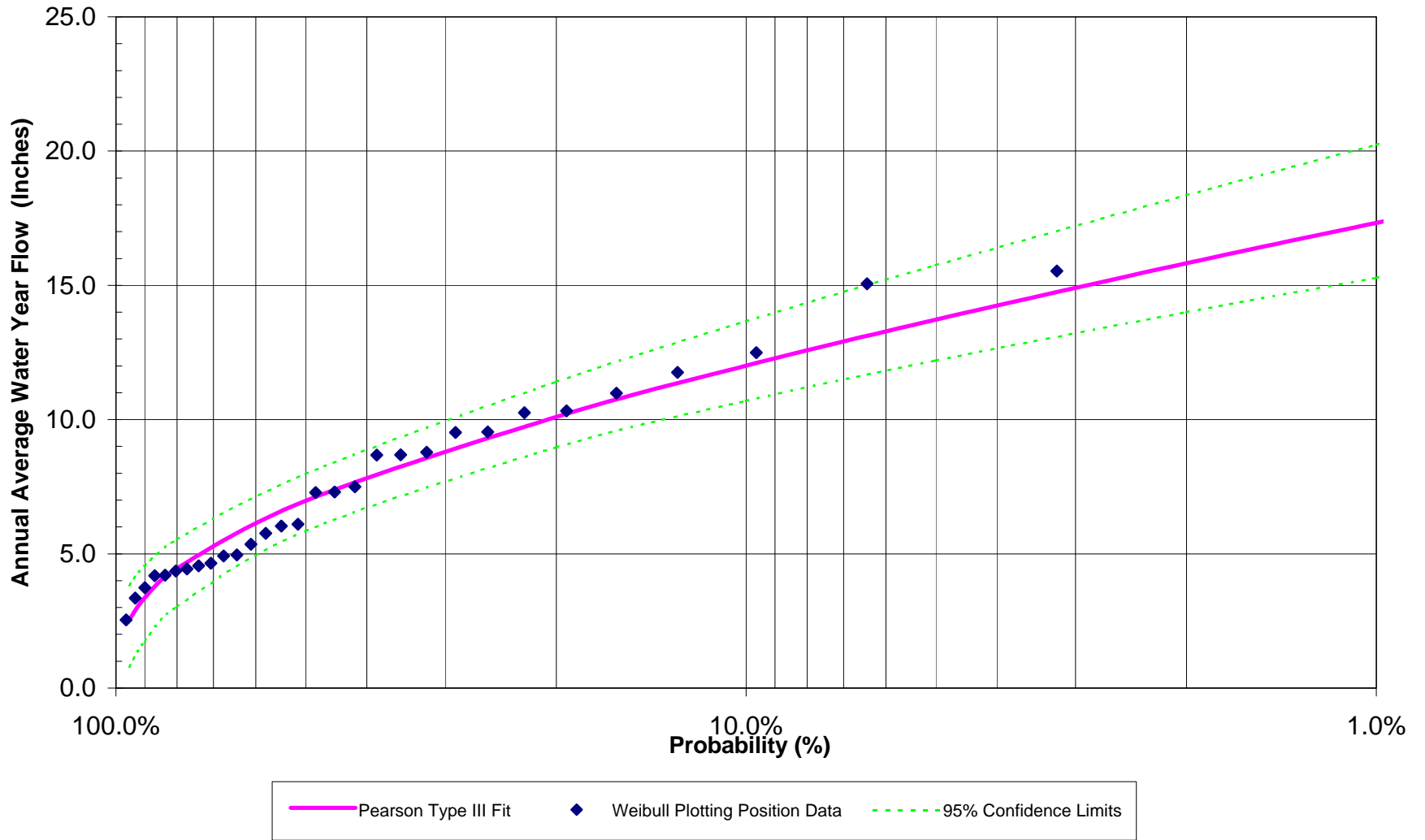
USGS 05385000 ROOT RIVER NEAR HOUSTON, MN Average Flow Frequency Analysis (1979-1983&1991-2000)



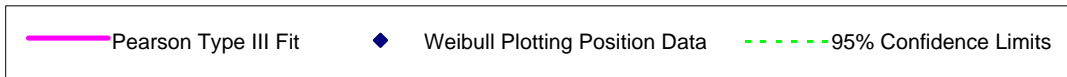
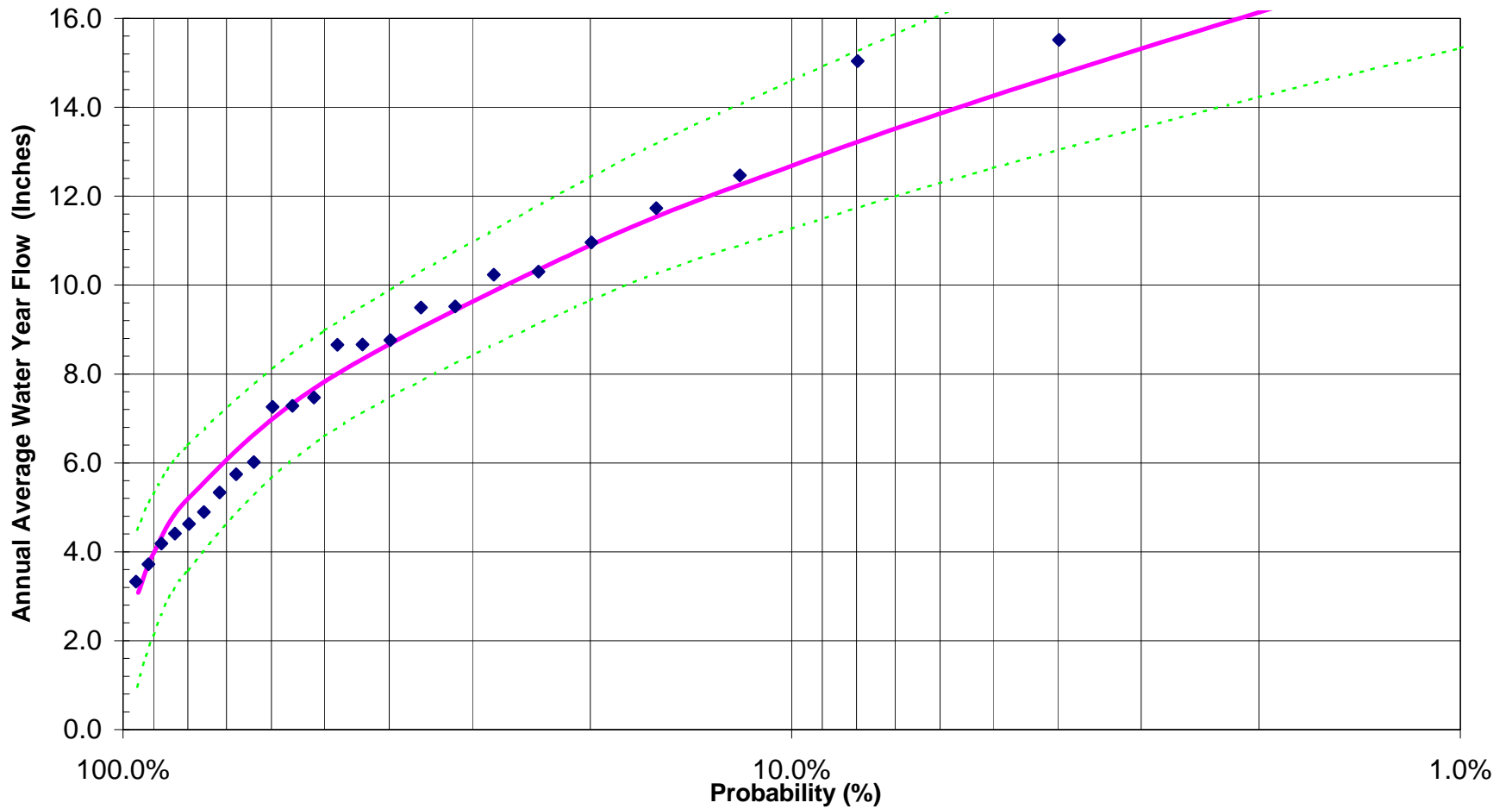
USGS 05345000 VERMILLION RIVER NEAR EMPIRE, MN Annual Average Flow Frequency Analysis



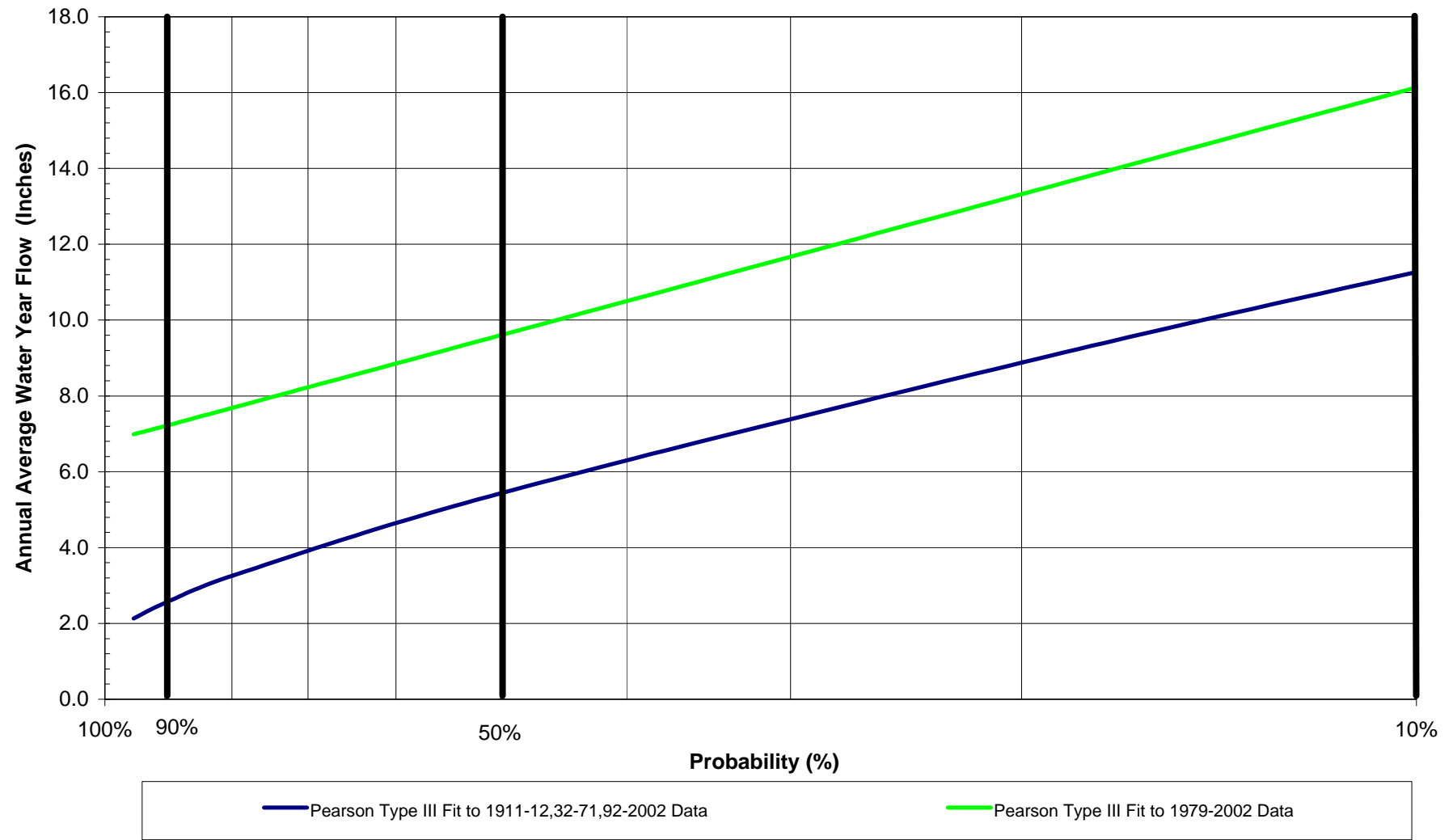
USGS 05345000 VERMILLION RIVER NEAR EMPIRE, MN Average Flow Frequency Analysis (1943, 1974-2022)



USGS 05345000 VERMILLION RIVER NEAR EMPIRE, MN Average Flow Frequency Analysis (1979-2002)

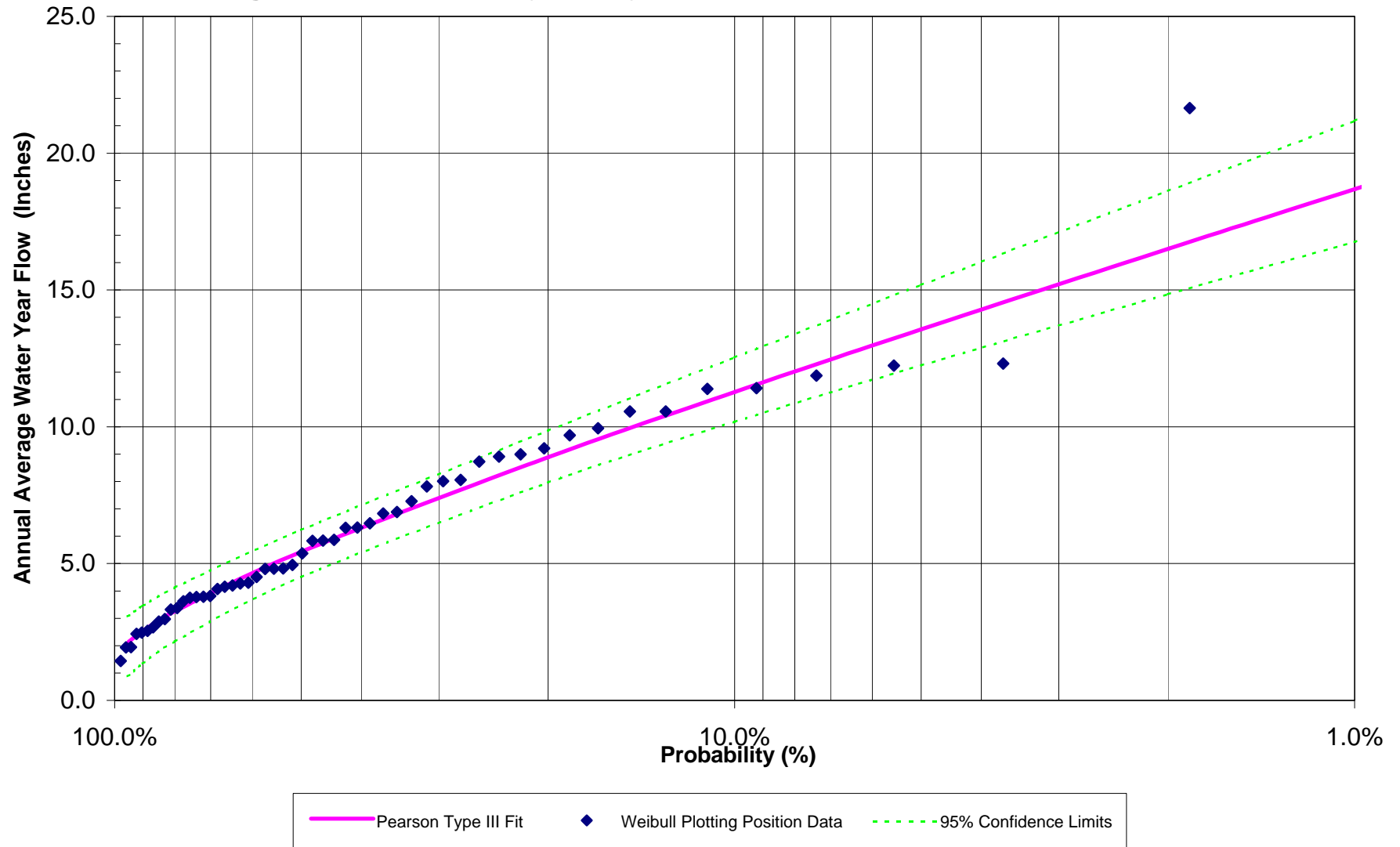


USGS 05355200 CANNON RIVER AT WELCH, MN Annual Average Flow Frequency Analysis

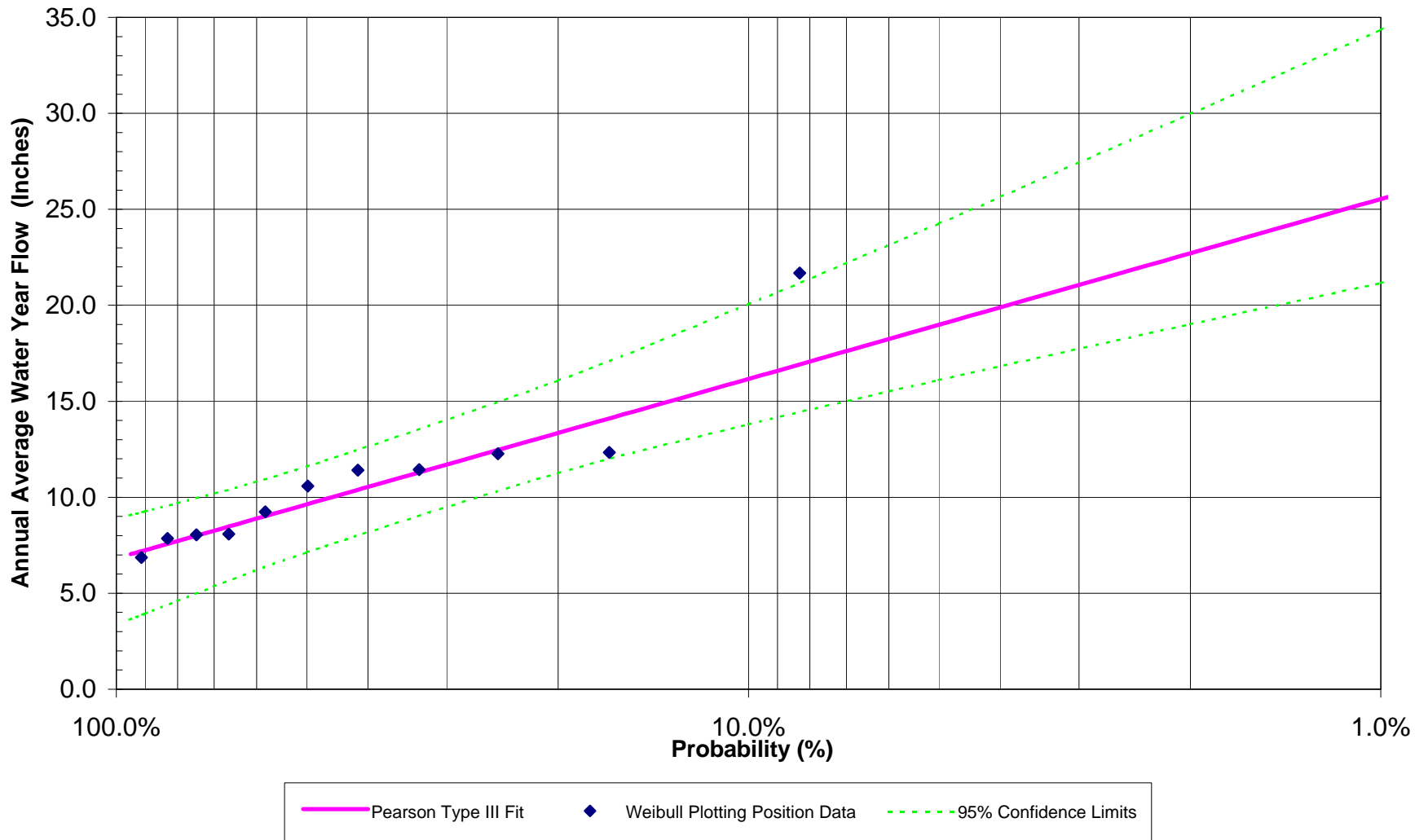


USGS 05355200 CANNON RIVER AT WELCH, MN

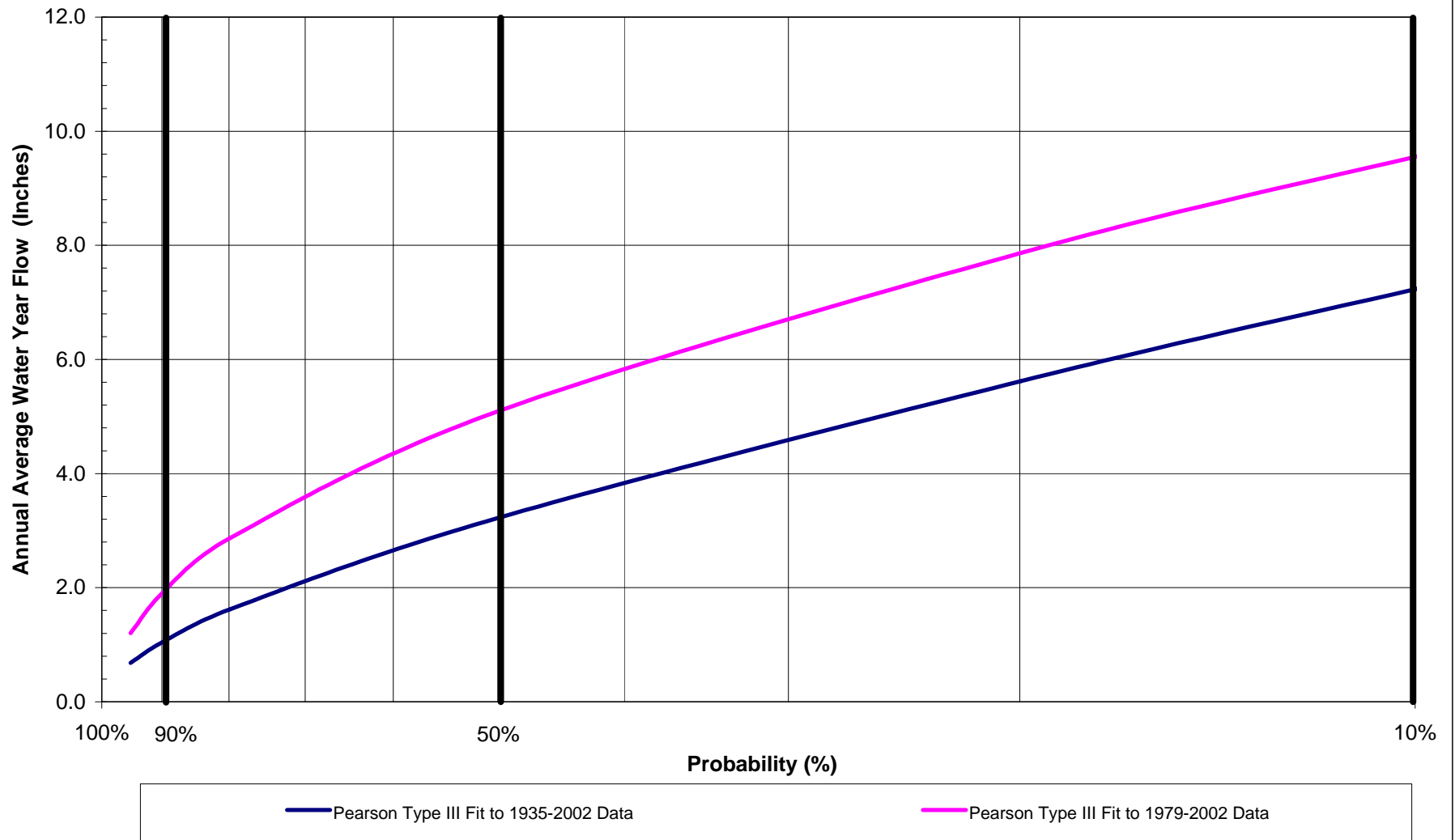
Average Flow Frequency Analysis (1911-1912,1932-1972 & 1992-2002)



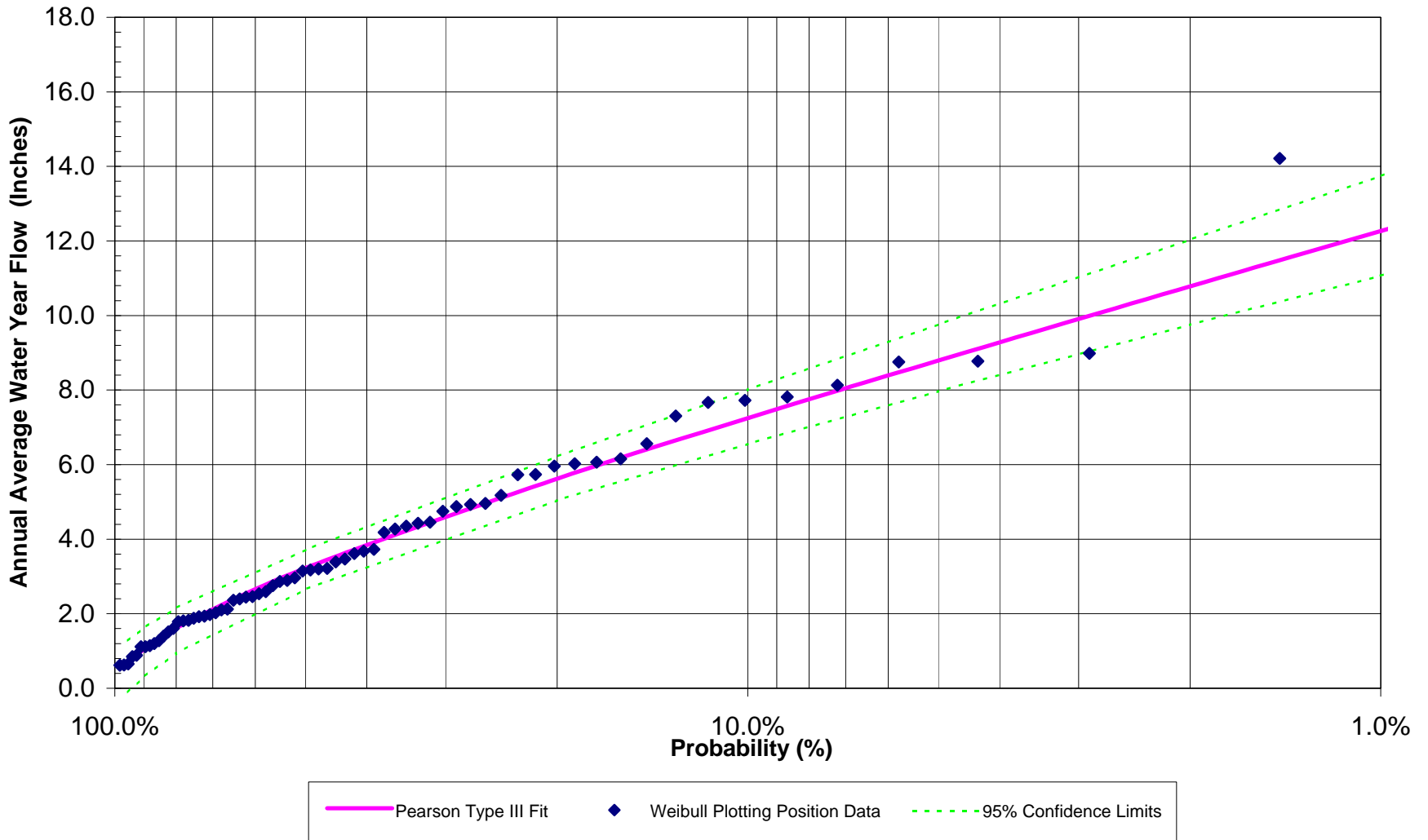
USGS 05355200 CANNON RIVER AT WELCH, MN Average Flow Frequency Analysis (1992-2002)



USGS 05330000 MINNESOTA RIVER NEAR JORDAN, MN Annual Average Flow Frequency Analysis

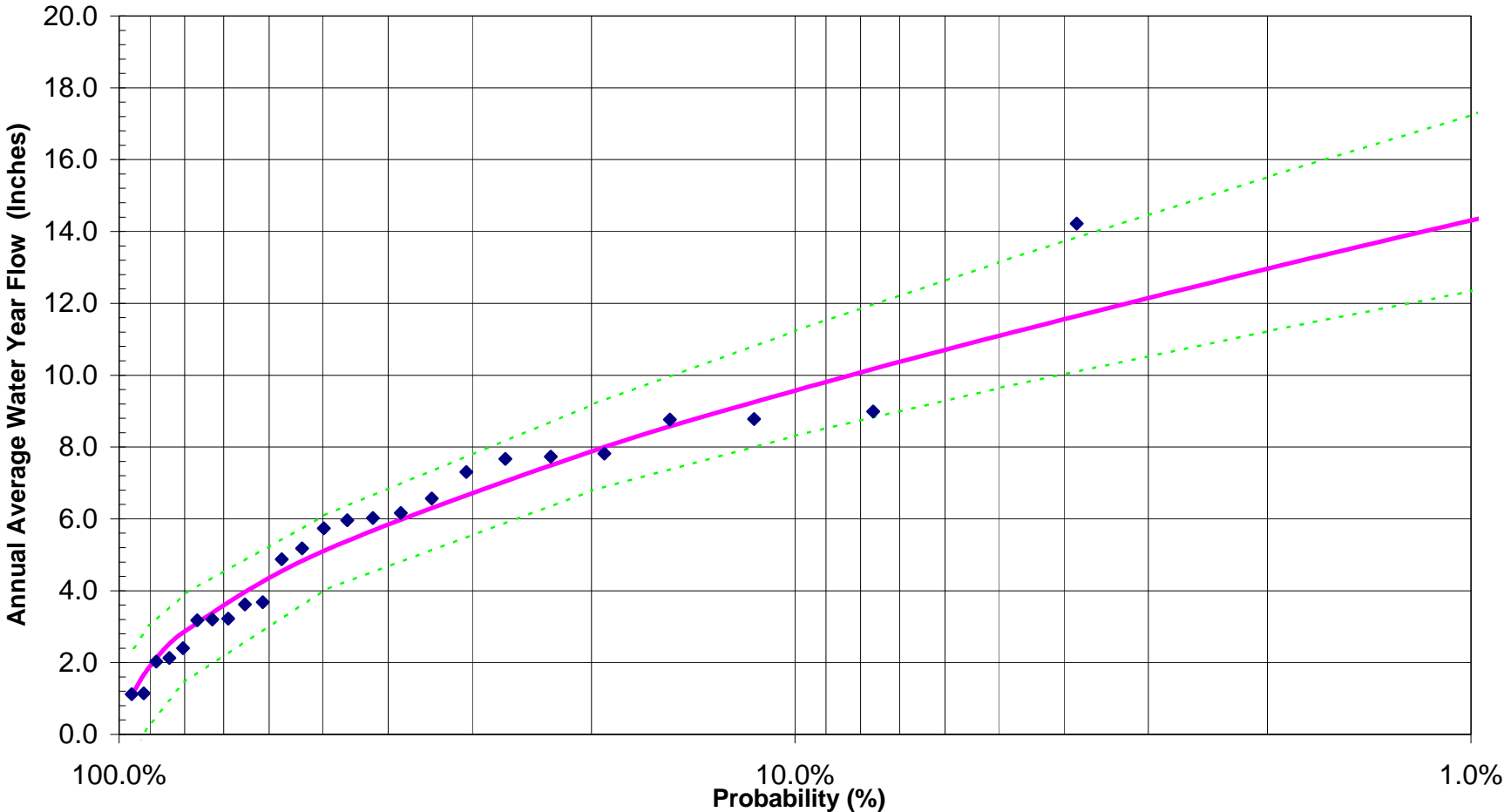


USGS 05330000 MINNESOTA RIVER NEAR JORDAN, MN Average Flow Frequency Analysis (1935-2002)



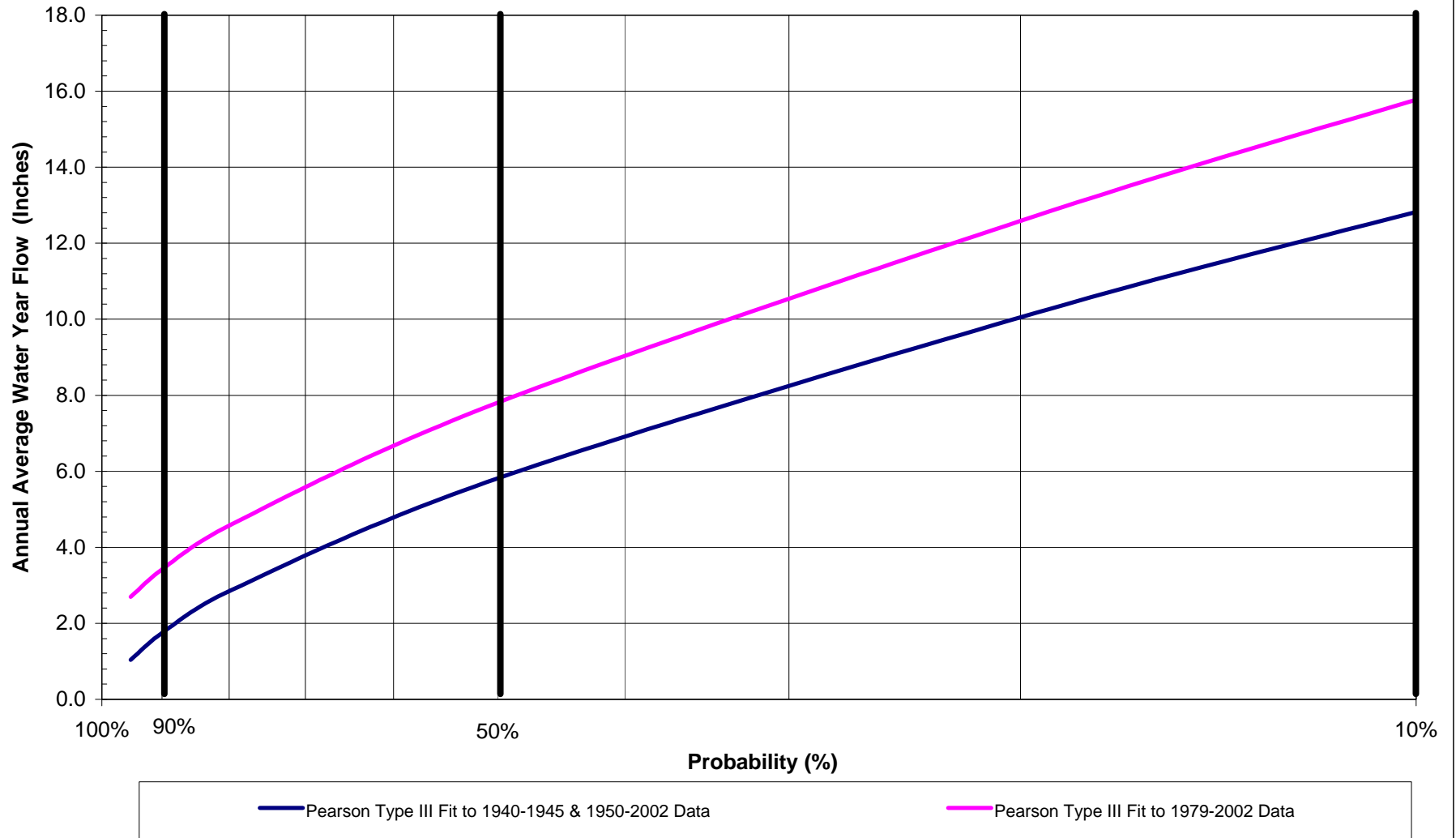
USGS 05330000 MINNESOTA RIVER NEAR JORDAN, MN

Average Flow Frequency Analysis (1979-2002)

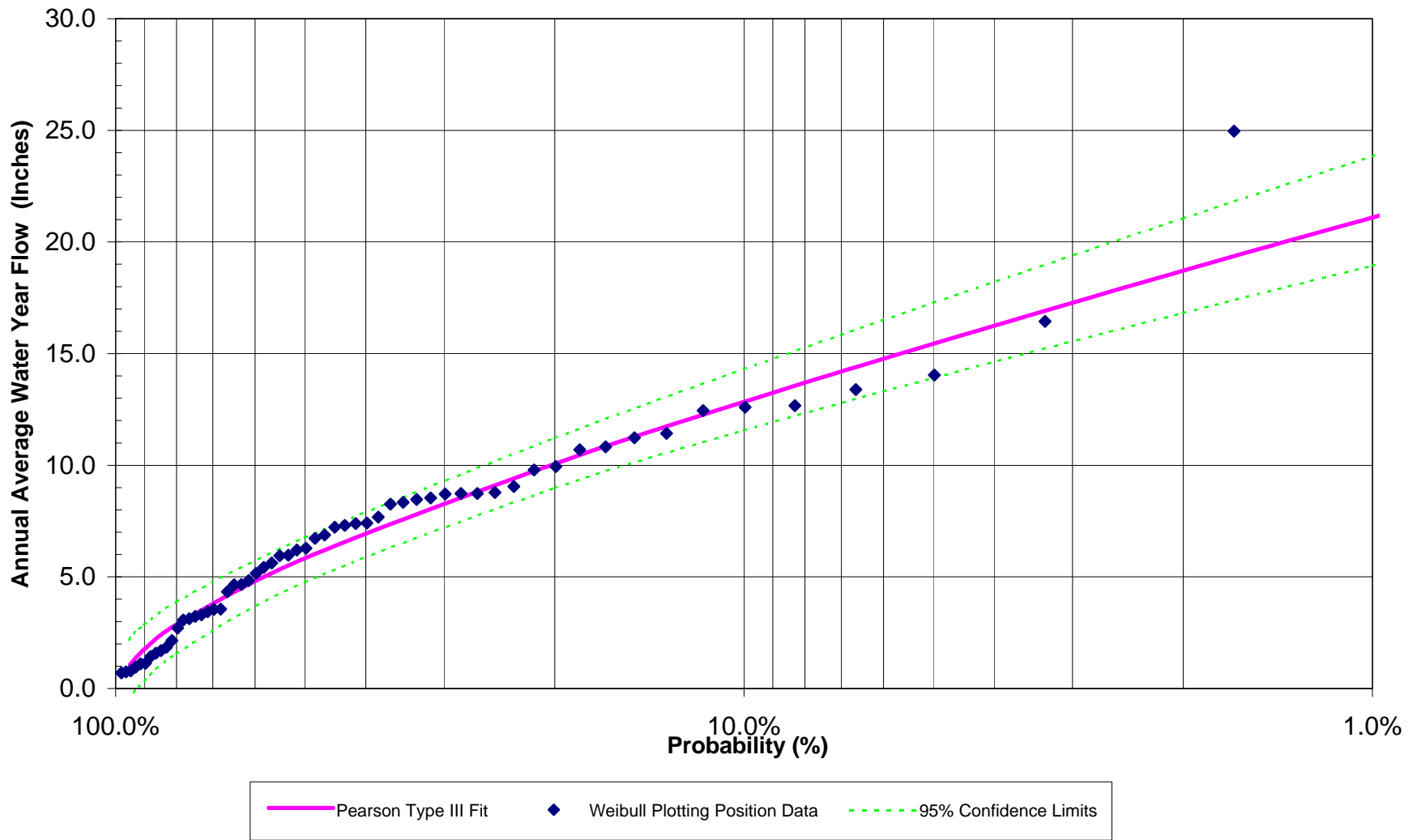


— Pearson Type III Fit
 ◆ Weibull Plotting Position Data
 - - - 95% Confidence Limits

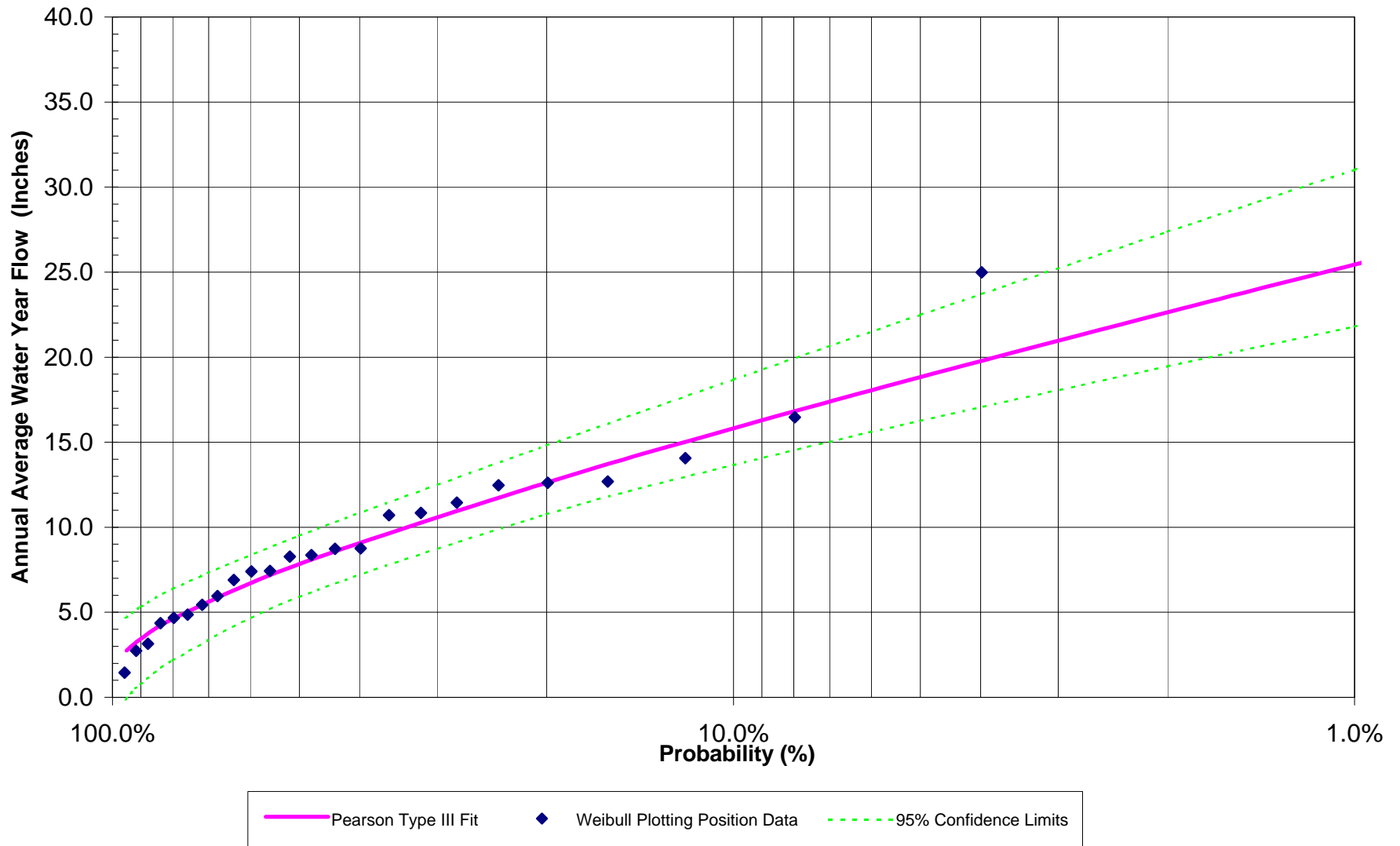
USGS 05320500 LE SUEUR RIVER NEAR RAPIDAN, MN Annual Average Flow Frequency Analysis



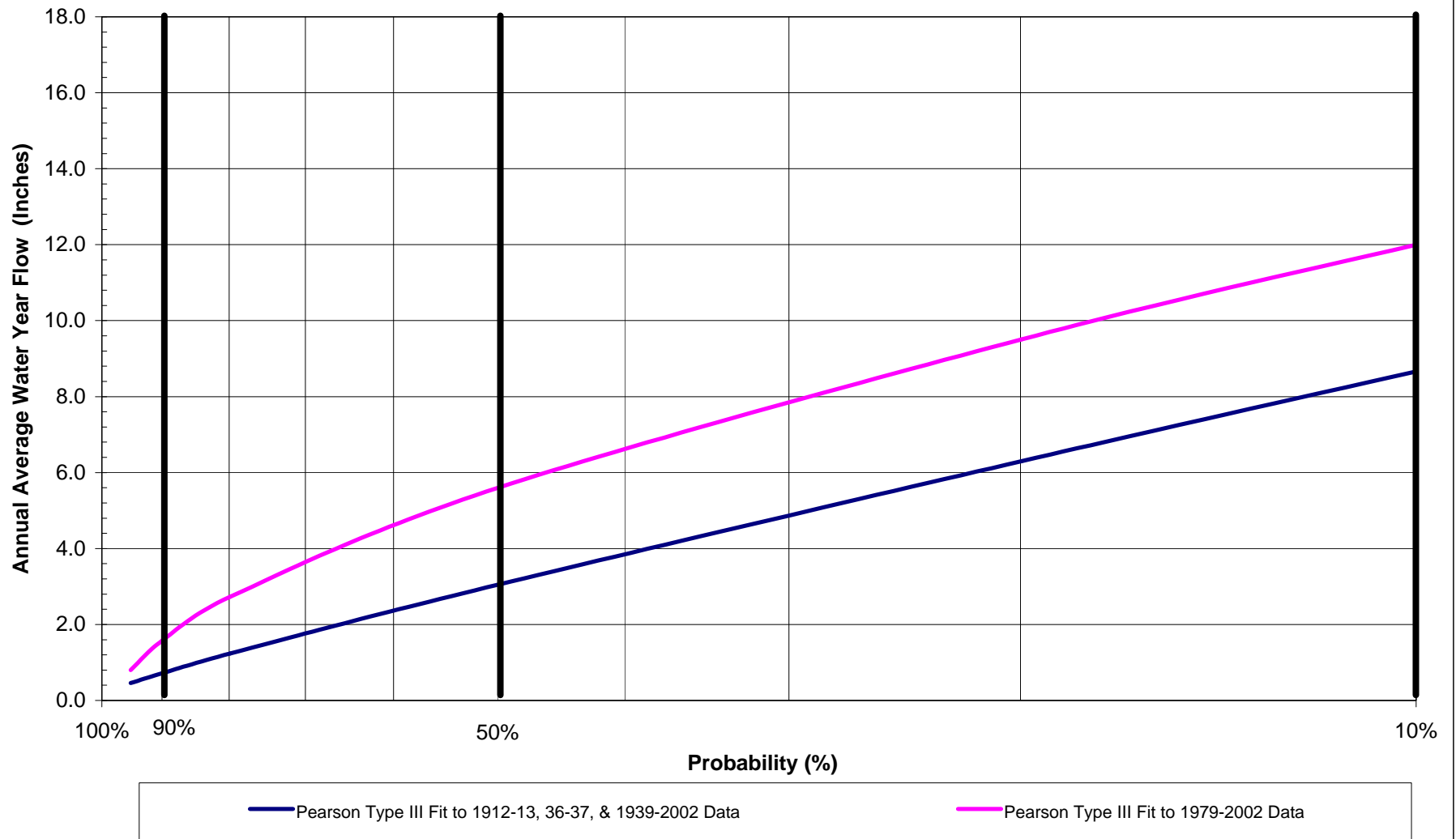
USGS 05320500 LE SUEUR RIVER NEAR RAPIDAN, MN Average Flow Frequency Analysis (1940-1945&1950-2002)



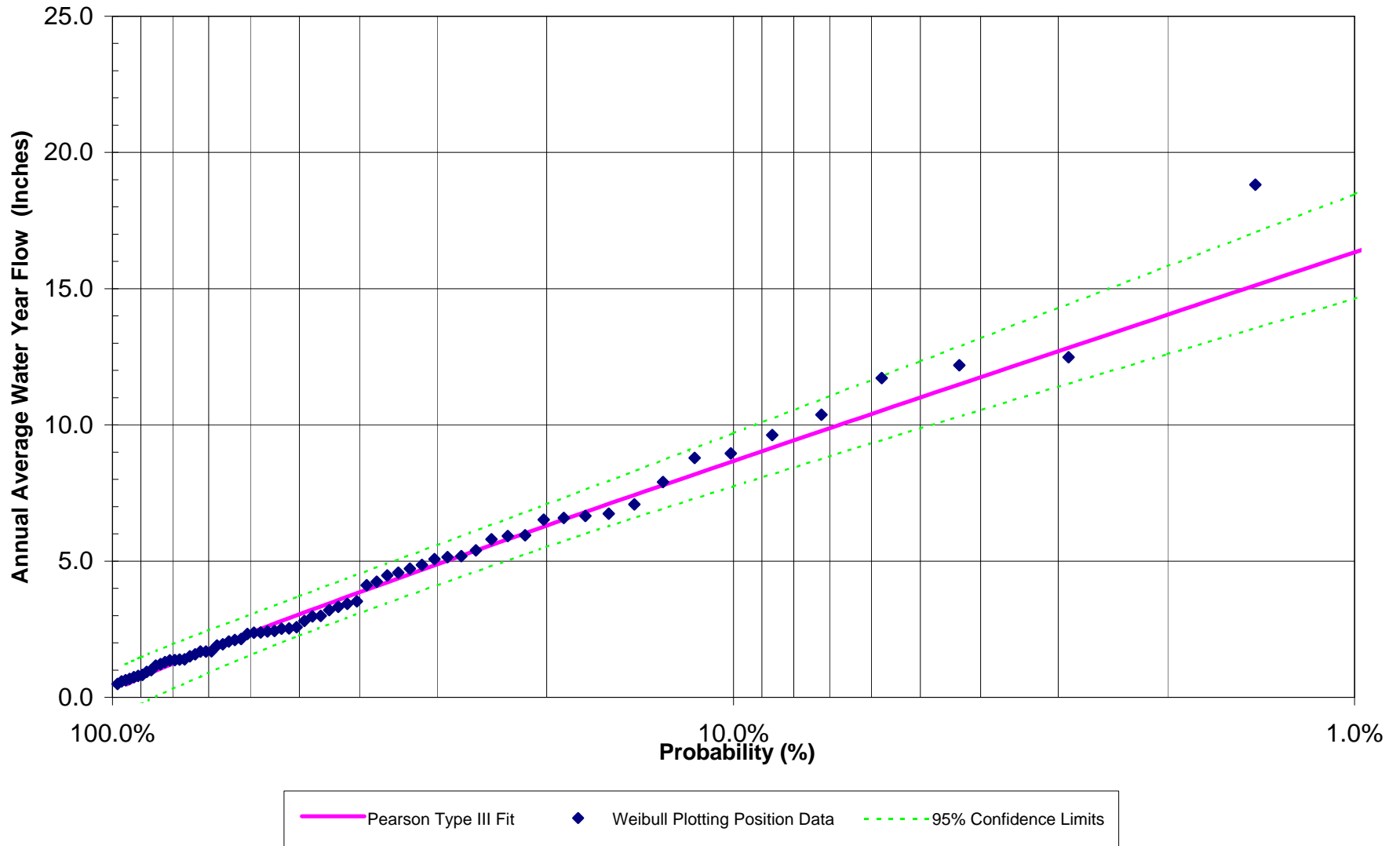
USGS 05320500 LE SUEUR RIVER NEAR RAPIDAN, MN Average Flow Frequency Analysis (1979-2002)



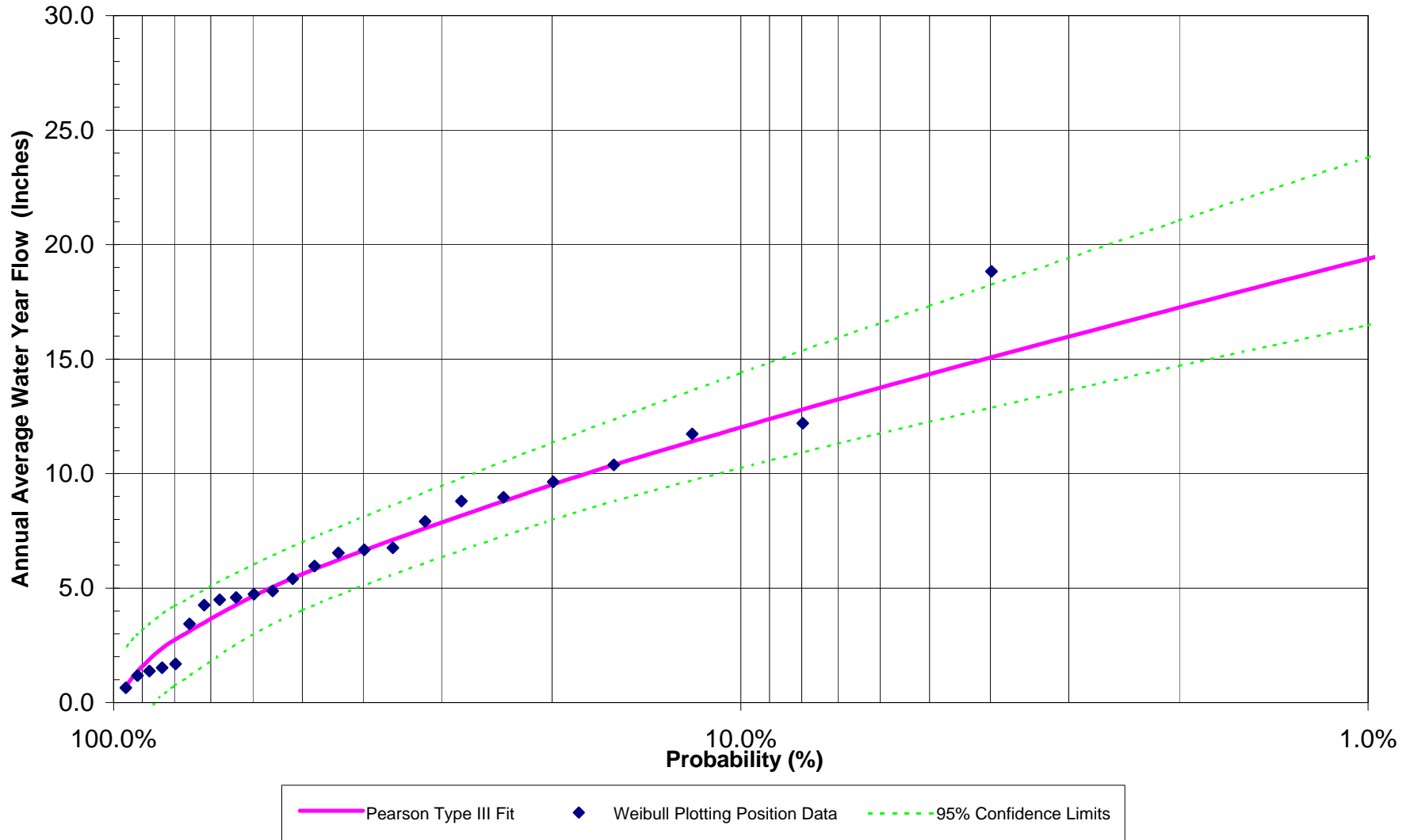
USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN Annual Average Flow Frequency Analysis



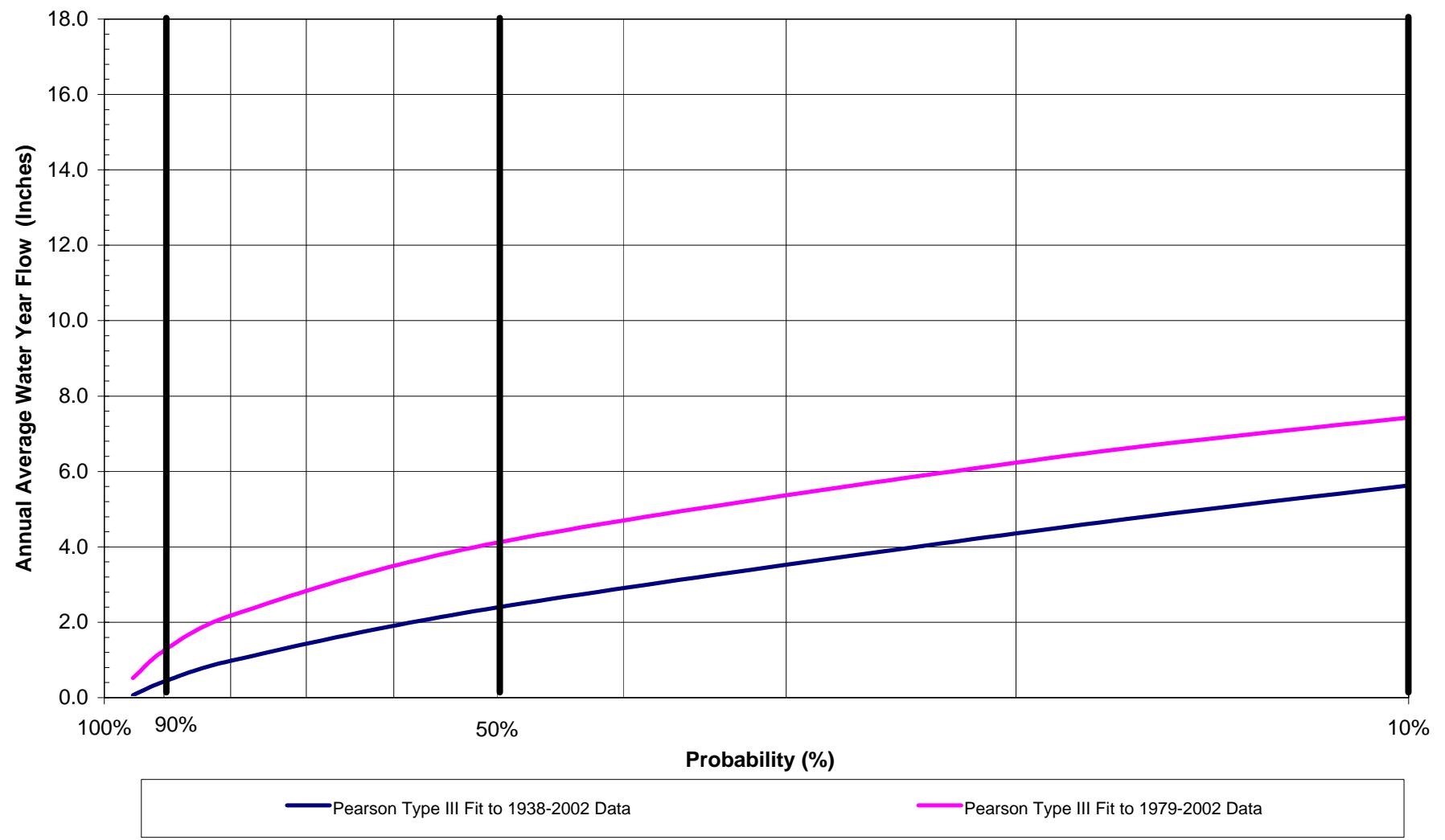
USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN Average Flow Frequency Analysis (1912-13,36-37,39-2002)



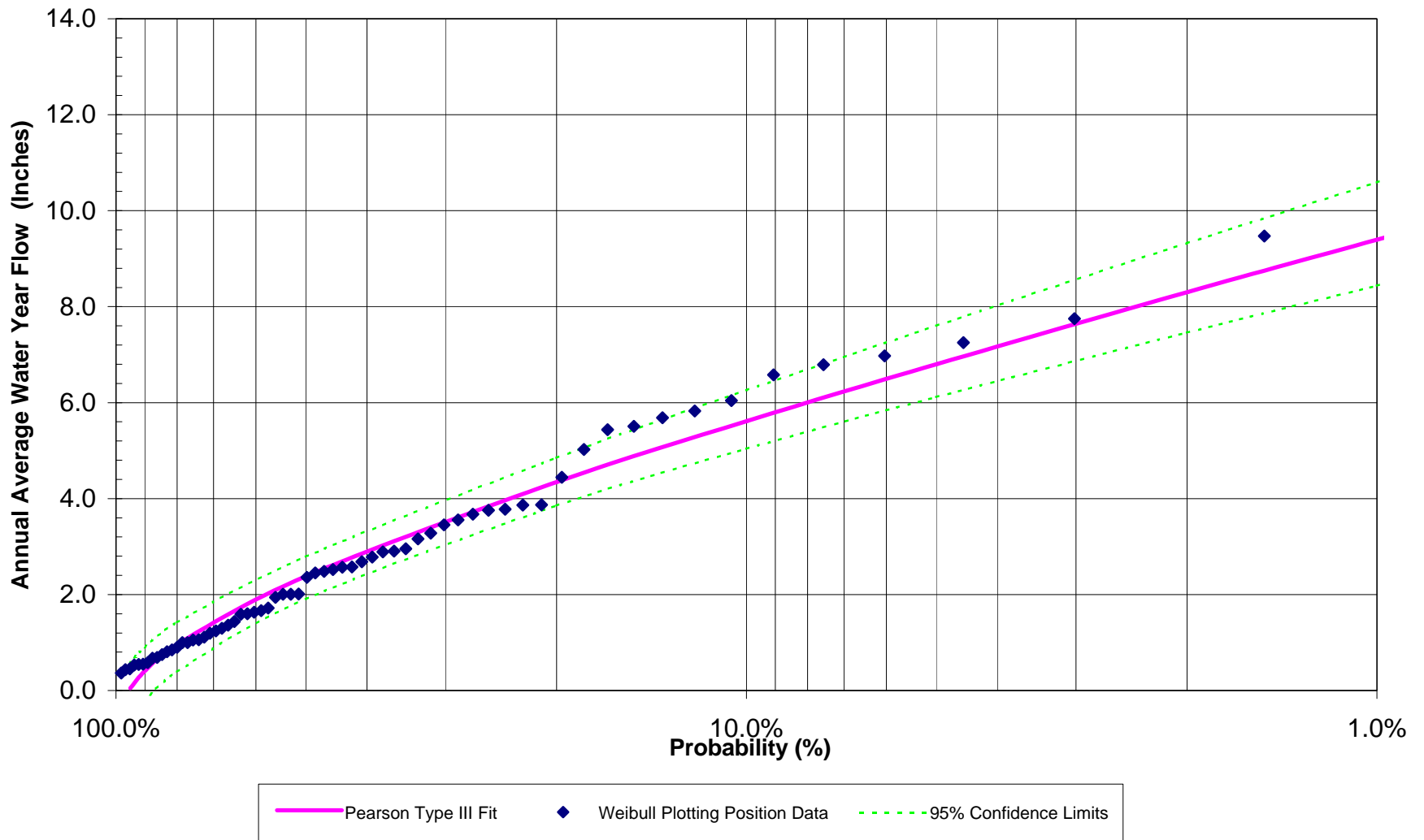
USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN Average Flow Frequency Analysis (1979-2002)



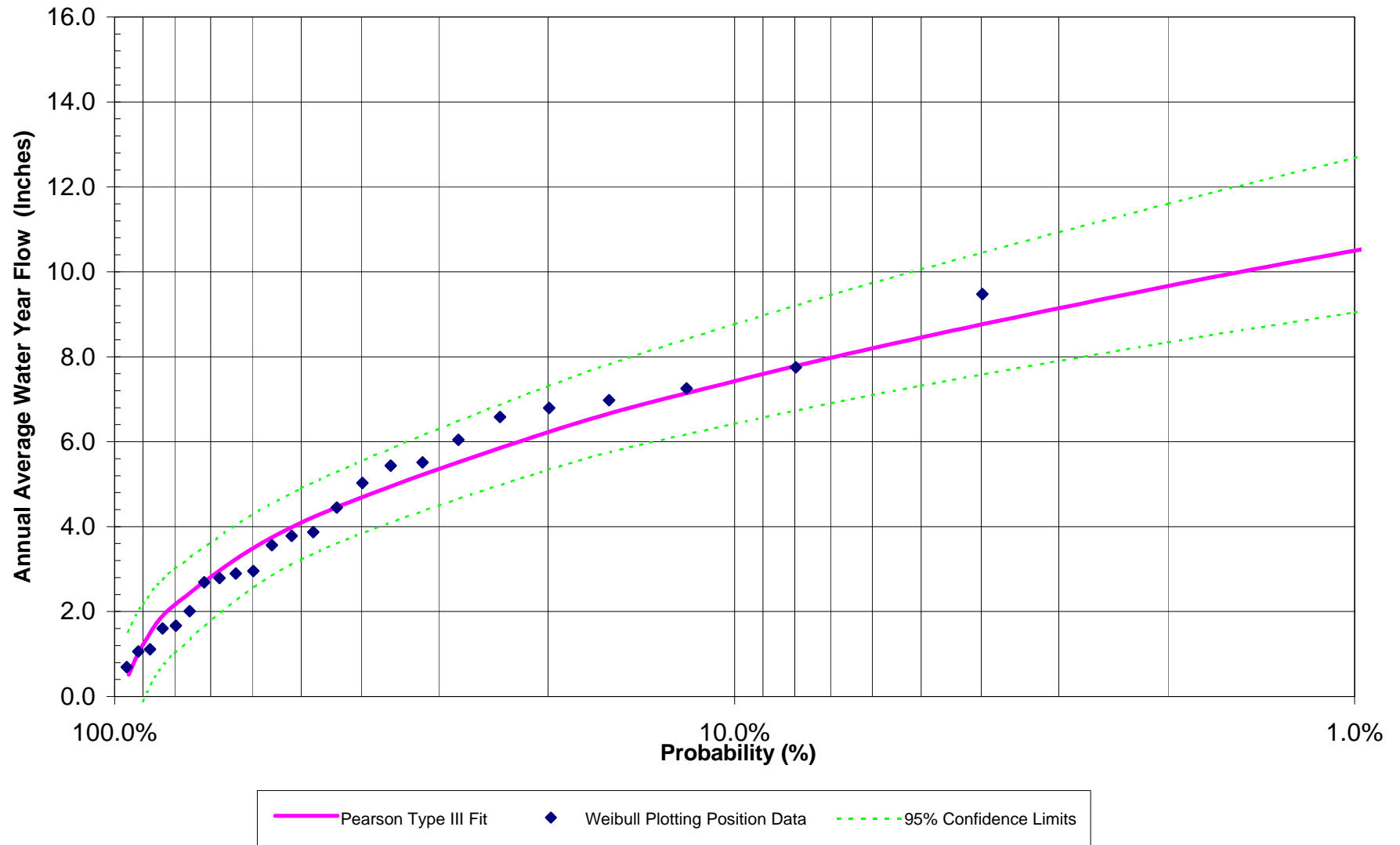
USGS 05304500 CHIPPEWA RIVER NEAR MILAN, MN Annual Average Flow Frequency Analysis



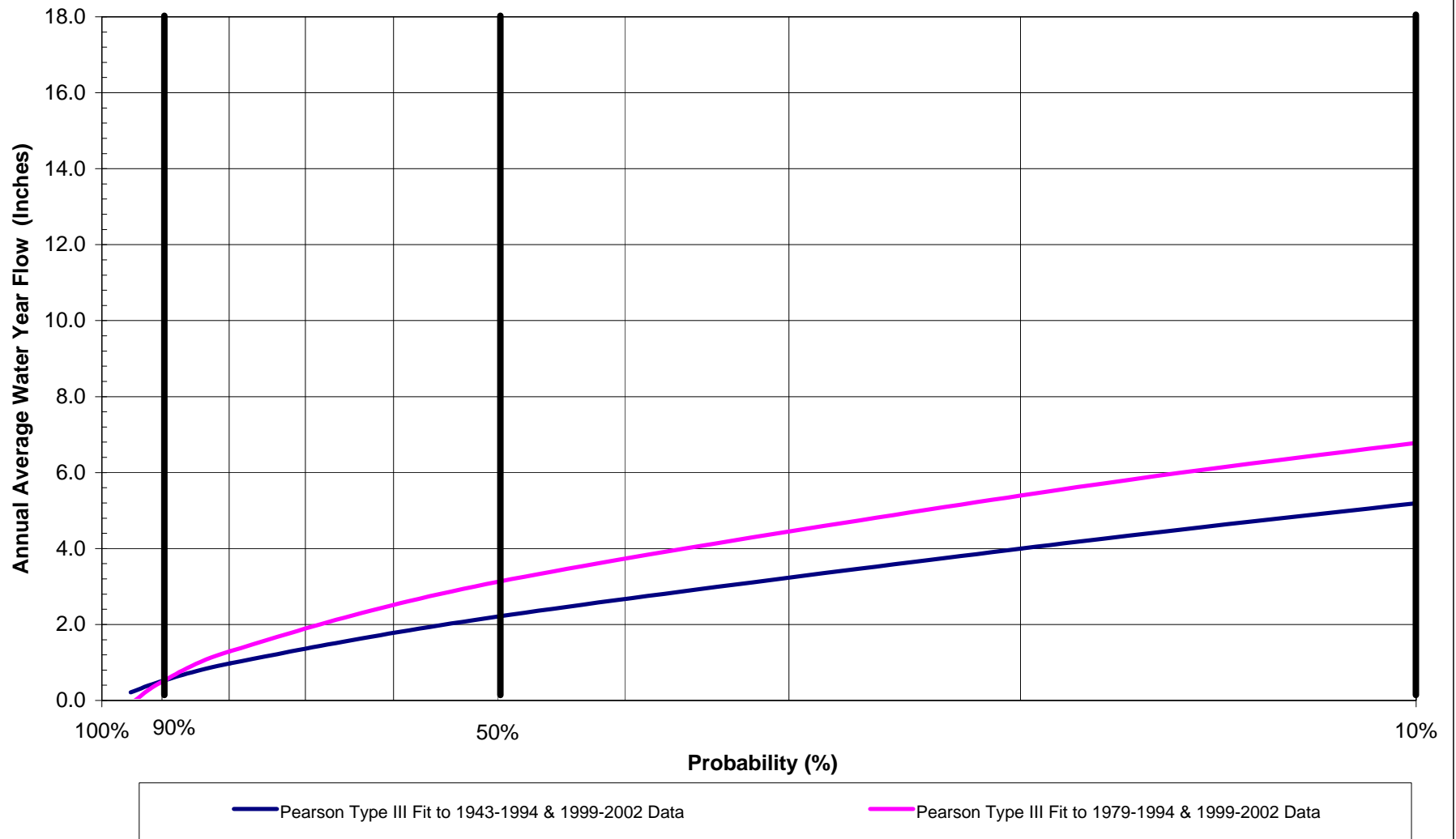
USGS 05304500 CHIPPEWA RIVER NEAR MILAN, MN Average Flow Frequency Analysis (1938-2002)



USGS 05304500 CHIPPEWA RIVER NEAR MILAN, MN Average Flow Frequency Analysis (1979-2002)

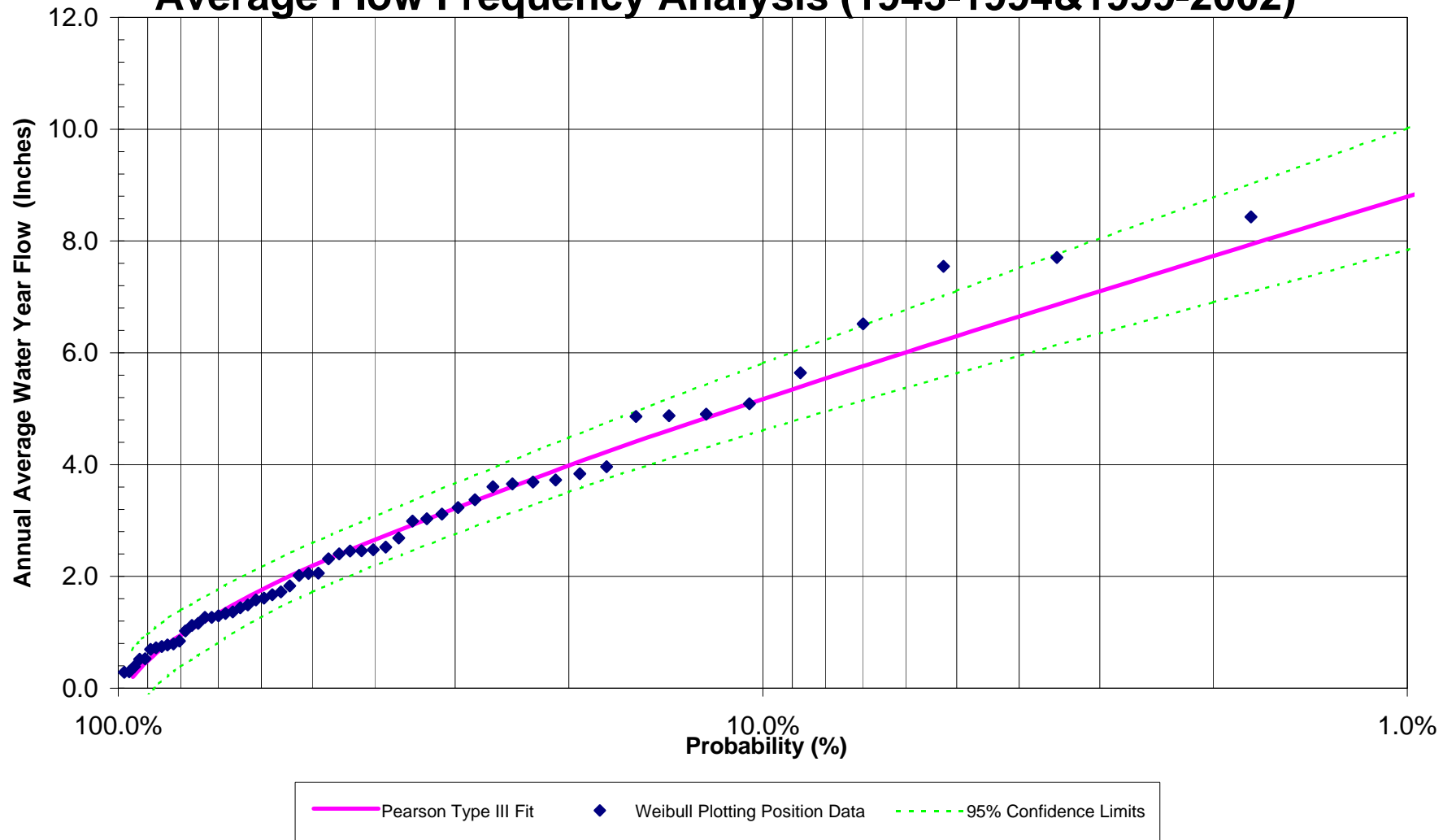


USGS 05301000 MINNESOTA RIVER NEAR LAC QUI PARLE, MN Annual Average Flow Frequency Analysis

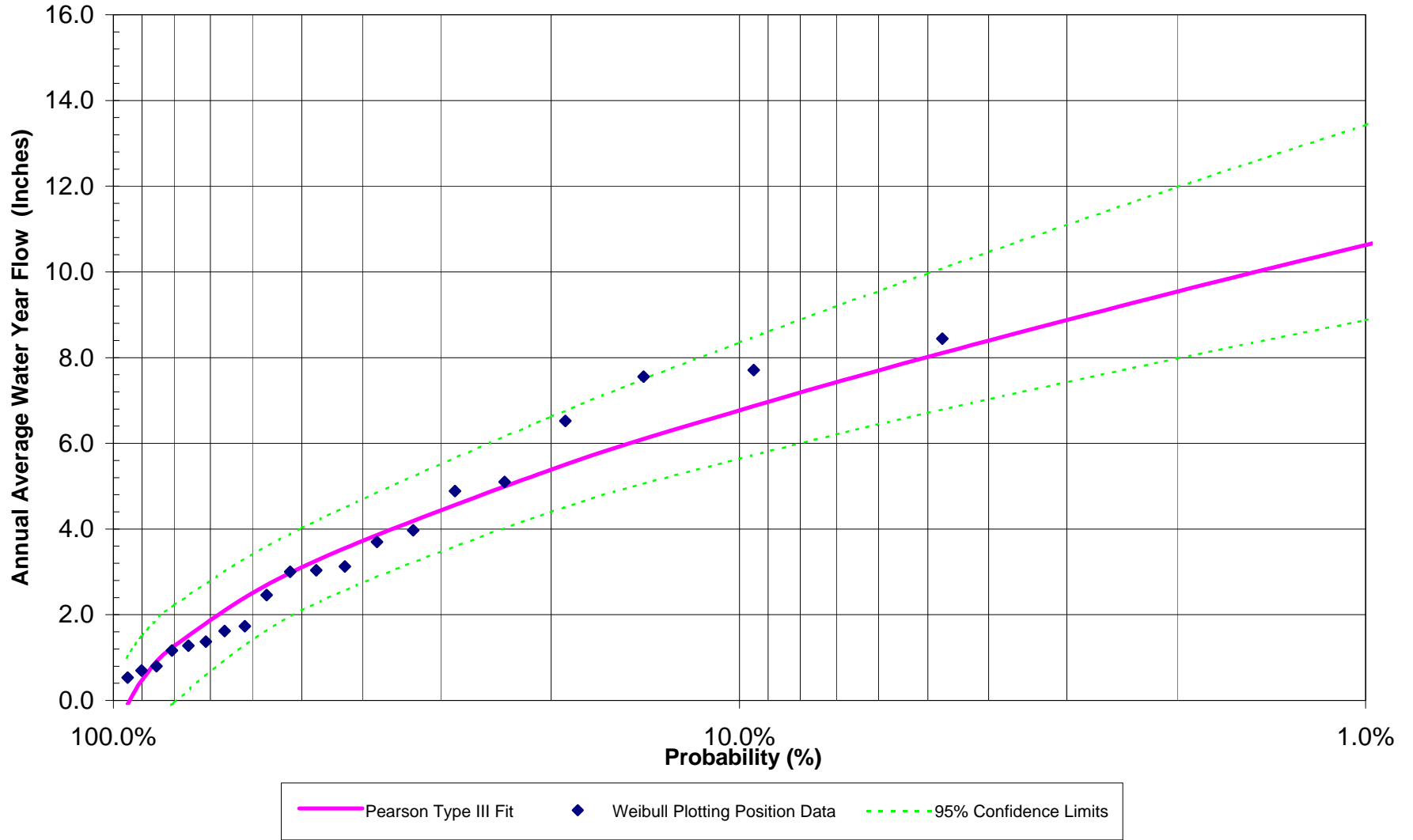


USGS 05301000 MINNESOTA RIVER NEAR LAC QUI PARLE, MN

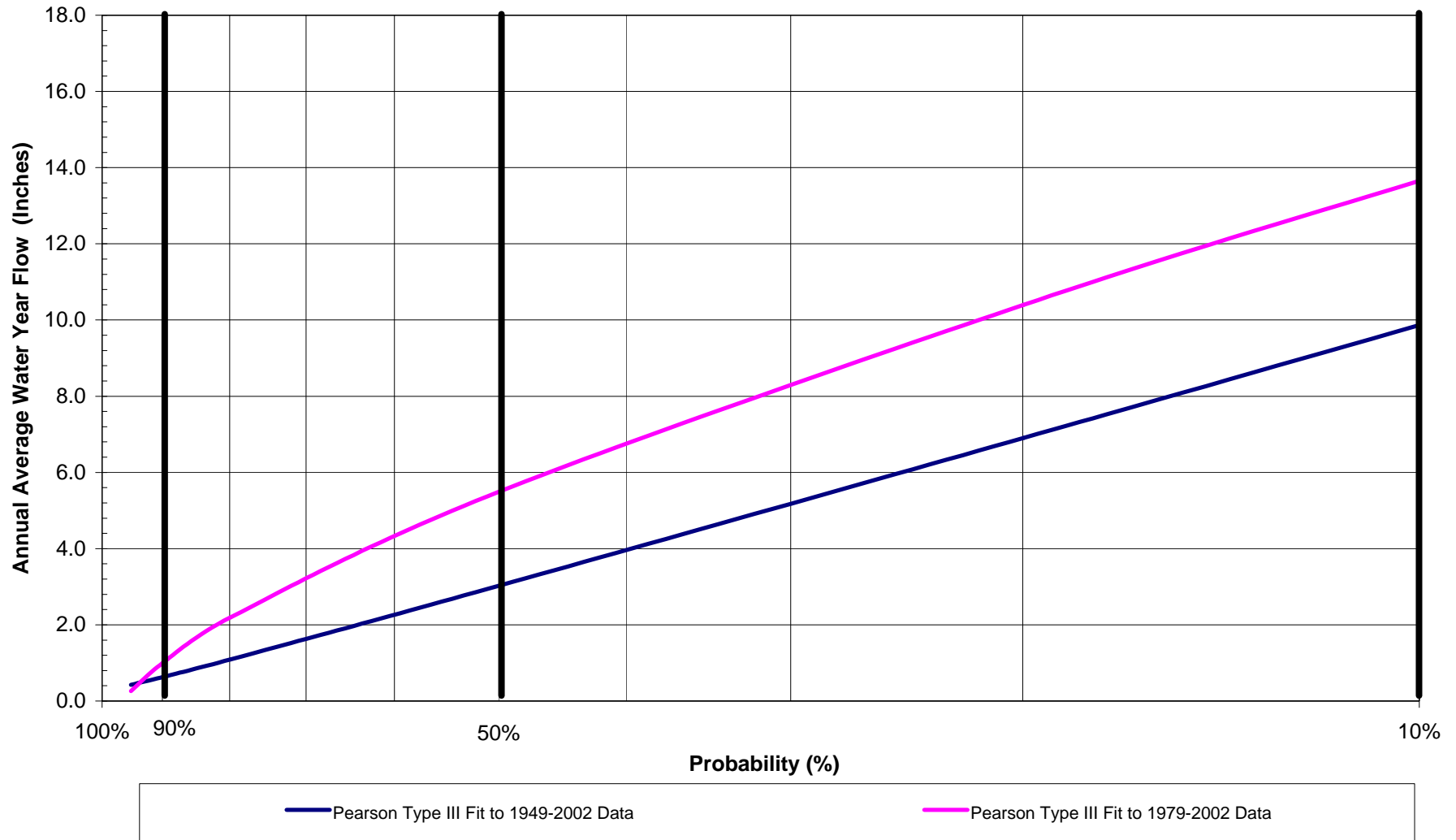
Average Flow Frequency Analysis (1943-1994&1999-2002)



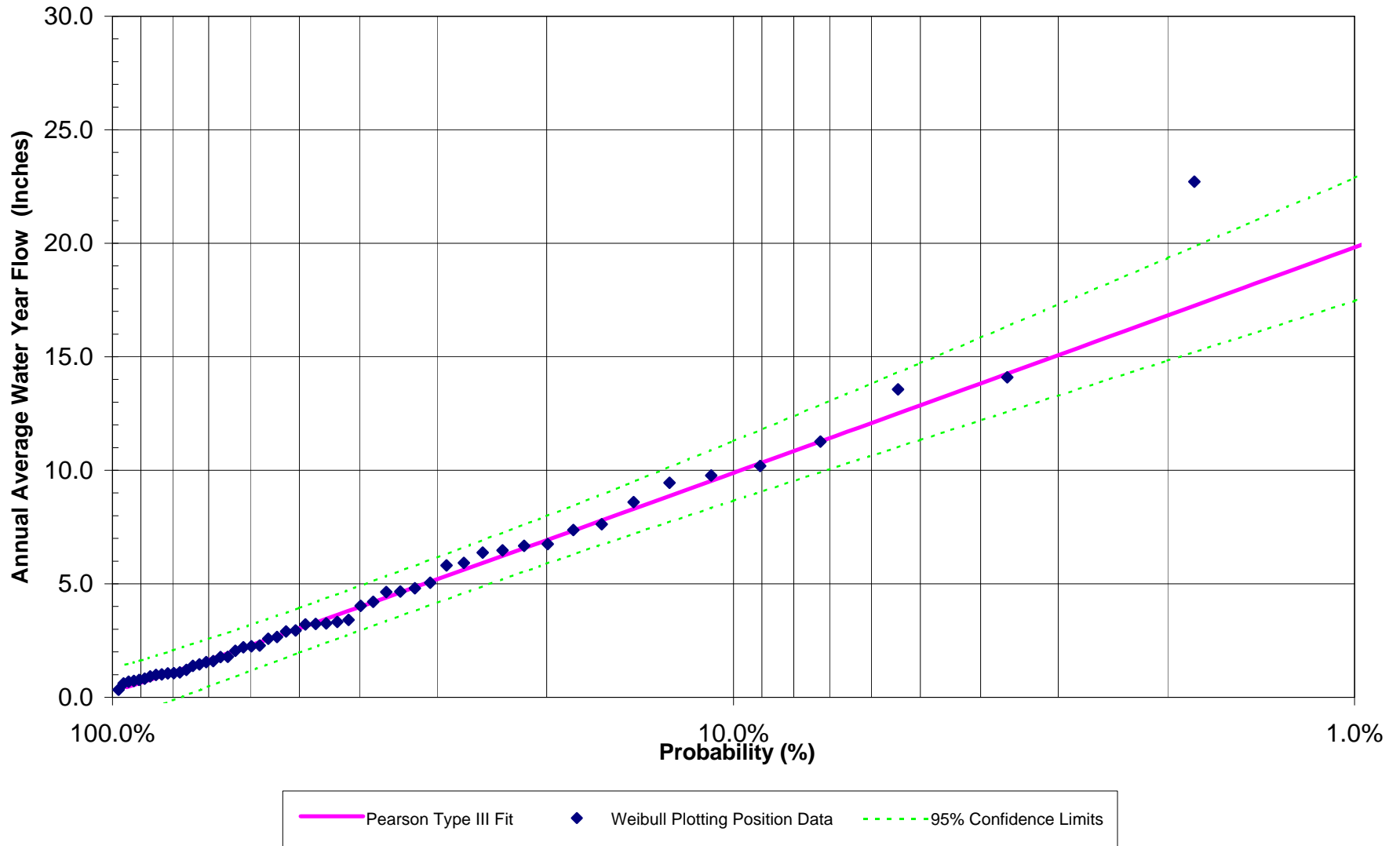
USGS 05301000 MINNESOTA RIVER NEAR LAC QUI PARLE, MN Average Flow Frequency Analysis (1979-1994&1999-2002)



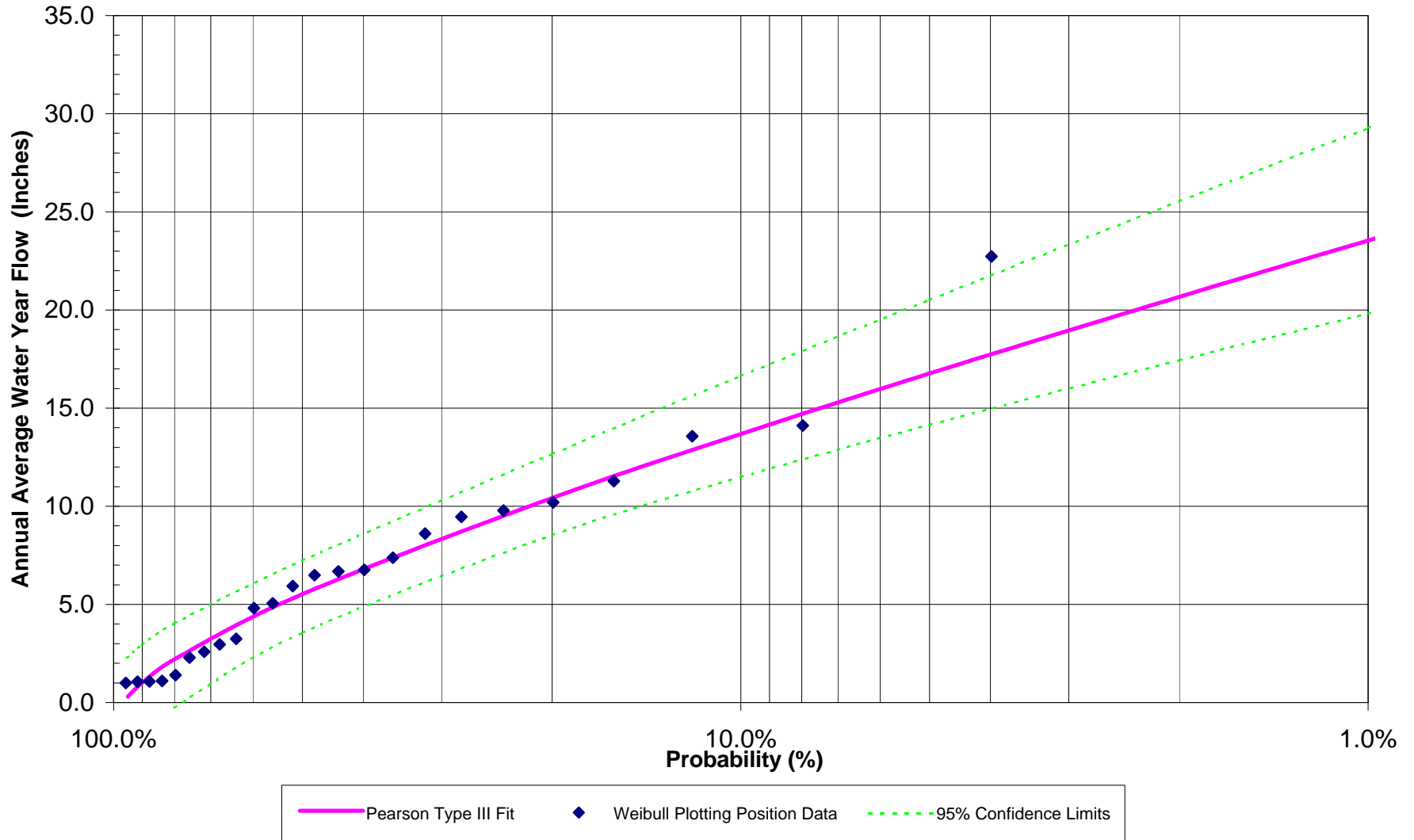
USGS 06483500 Rock River near Rock Valley, IA Annual Average Flow Frequency Analysis



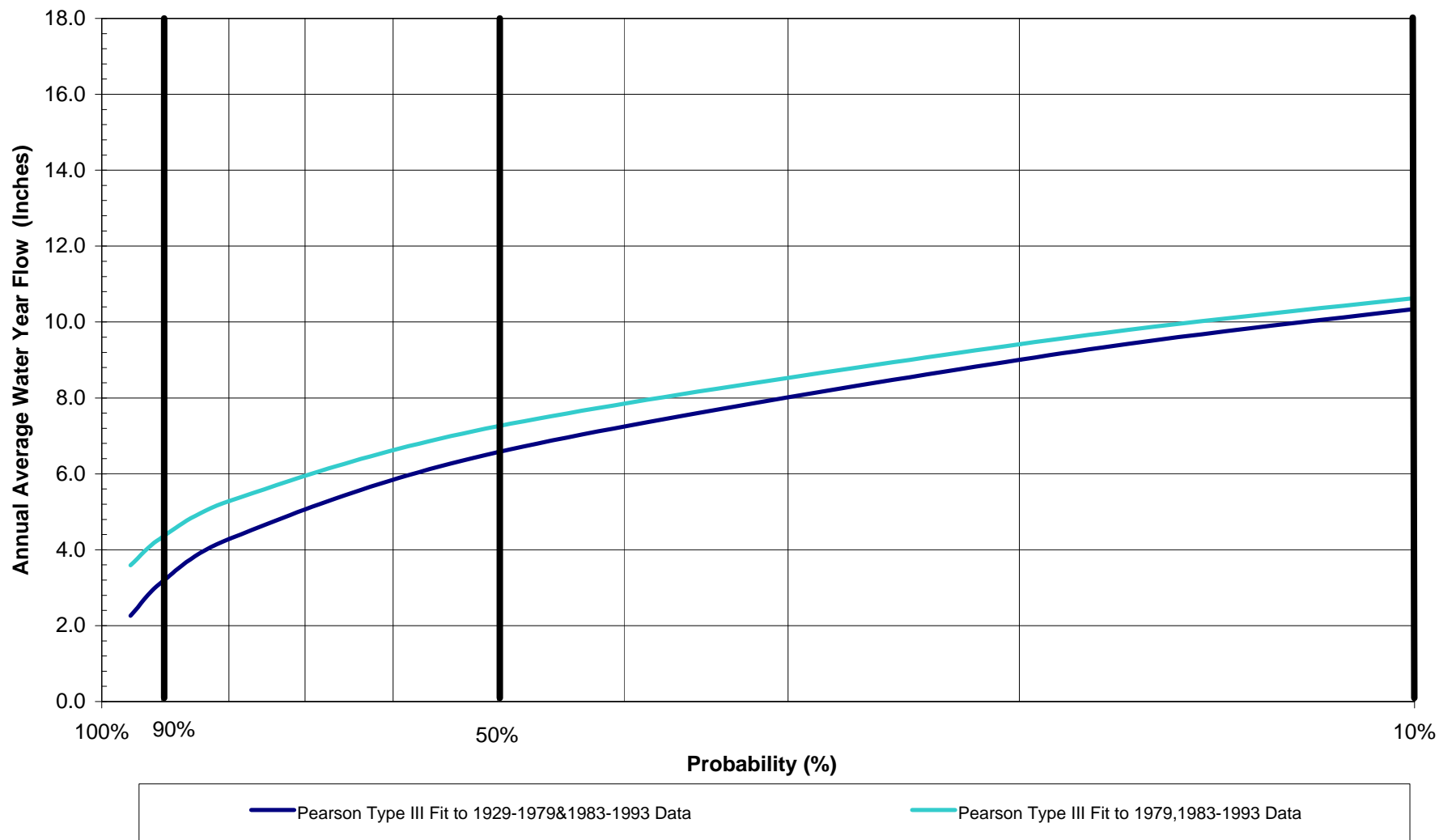
USGS 06483500 Rock River near Rock Valley, IA Average Flow Frequency Analysis (1949-2002)



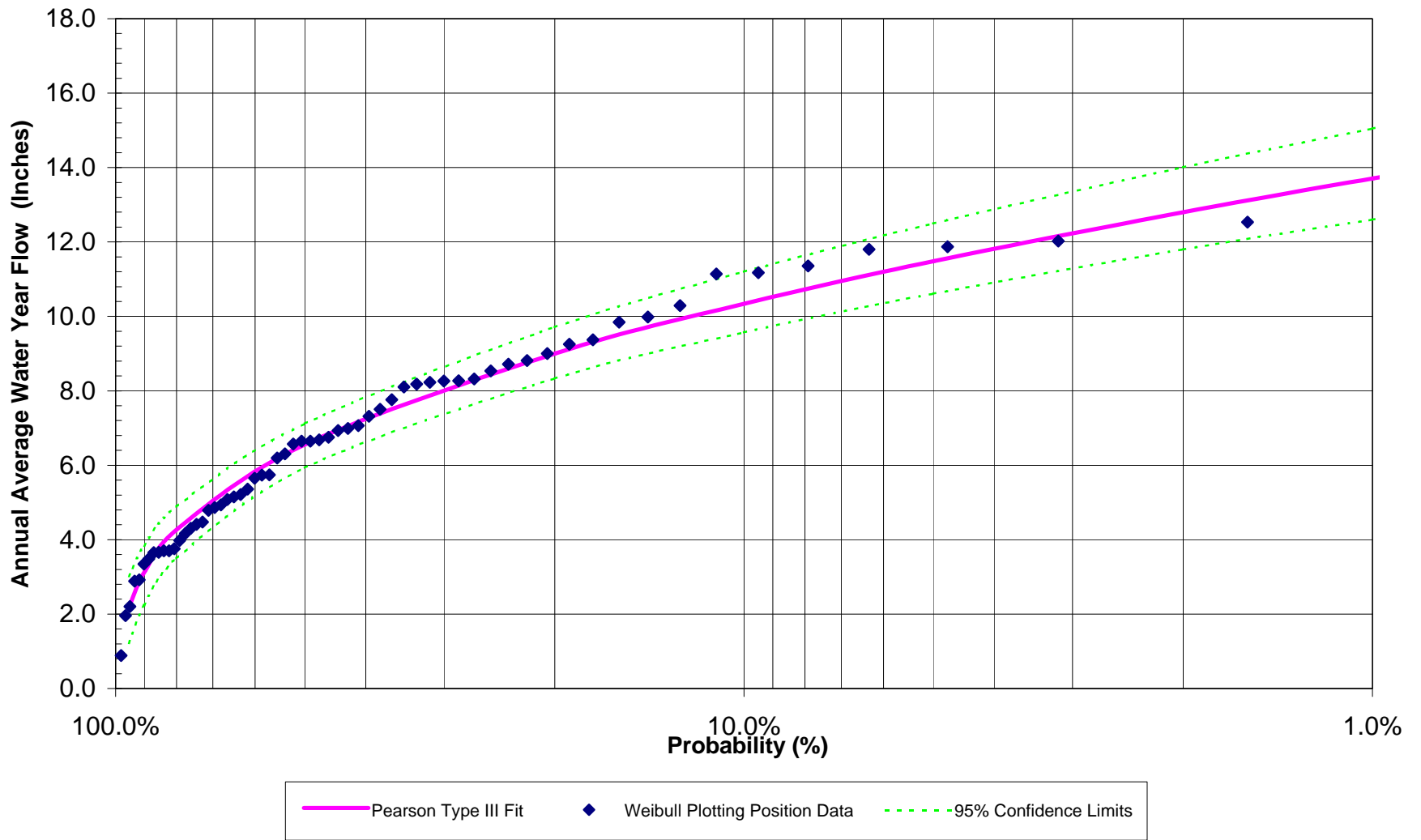
USGS 06483500 Rock River near Rock Valley, IA Average Flow Frequency Analysis (1979-2002)



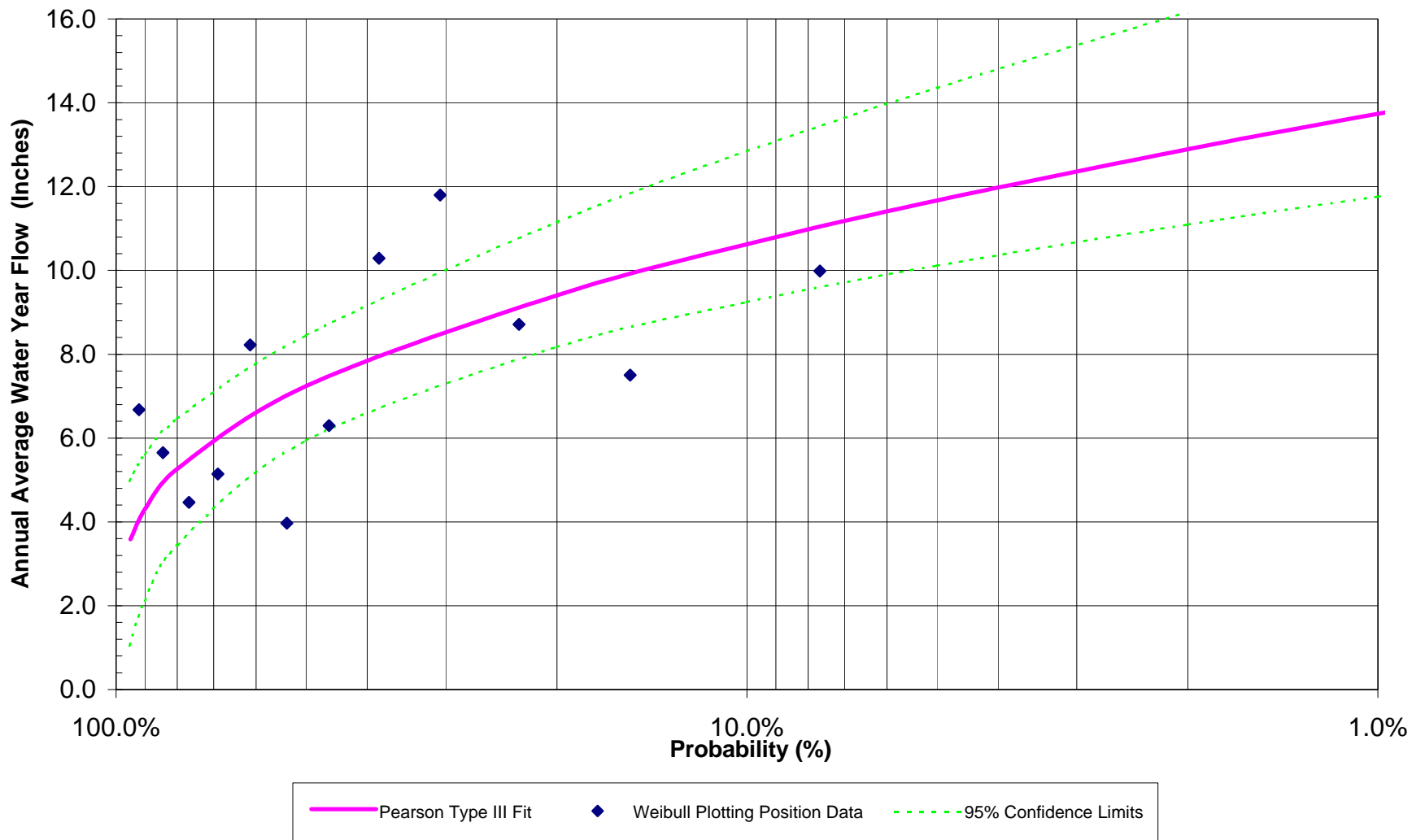
USGS 05132000 BIG FORK RIVER AT BIG FALLS, MN Annual Average Flow Frequency Analysis



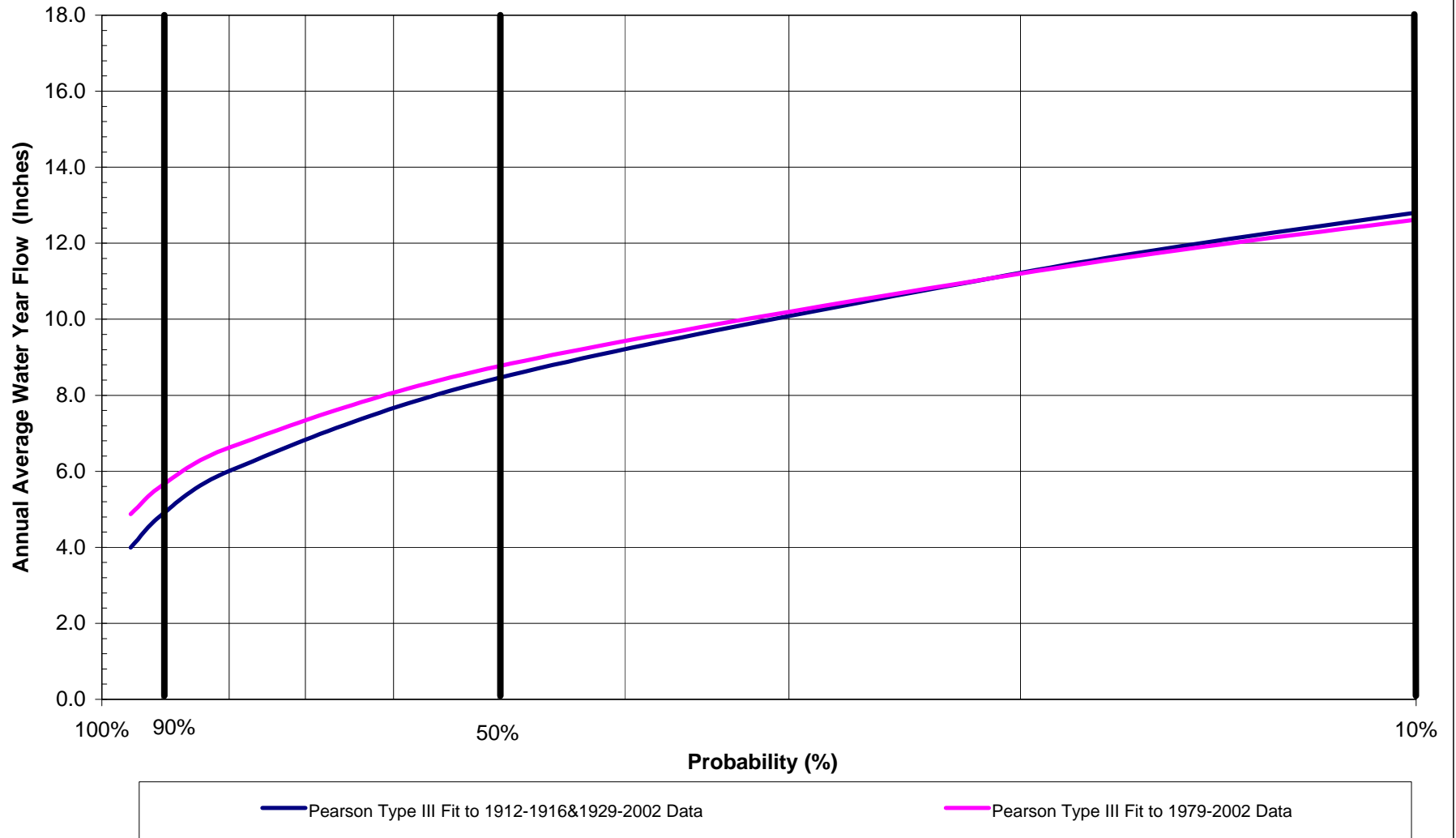
USGS 05132000 BIG FORK RIVER AT BIG FALLS, MN Average Flow Frequency Analysis (1929-1979&1983-1993)



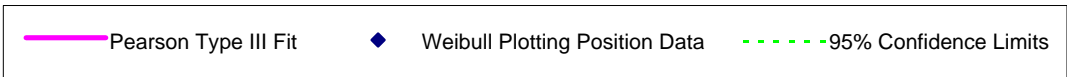
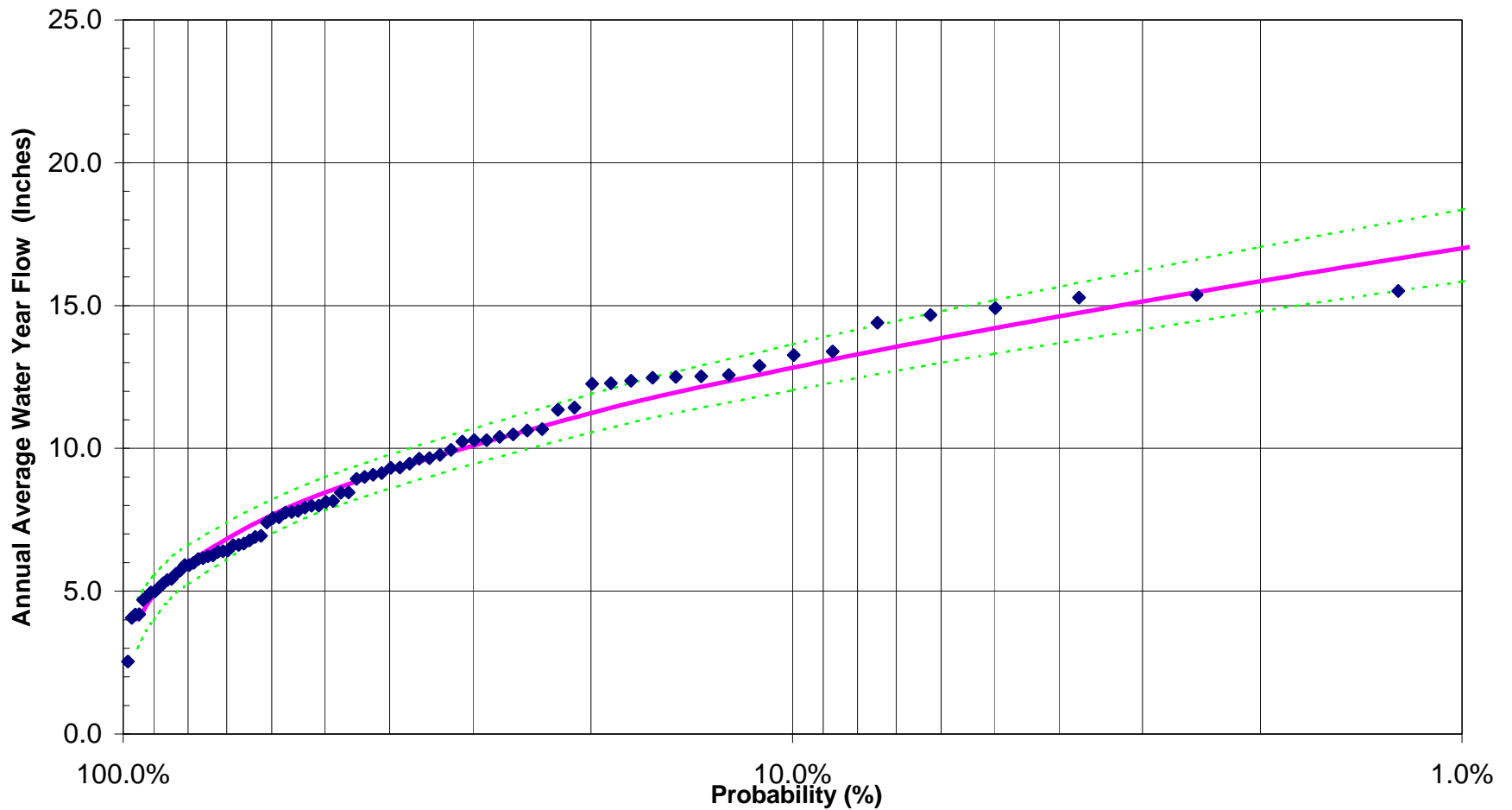
USGS 05132000 BIG FORK RIVER AT BIG FALLS, MN Average Flow Frequency Analysis (1979,1983-1993)



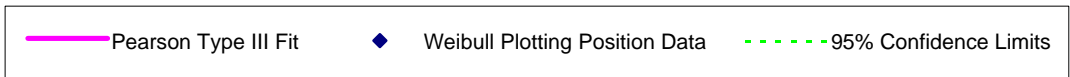
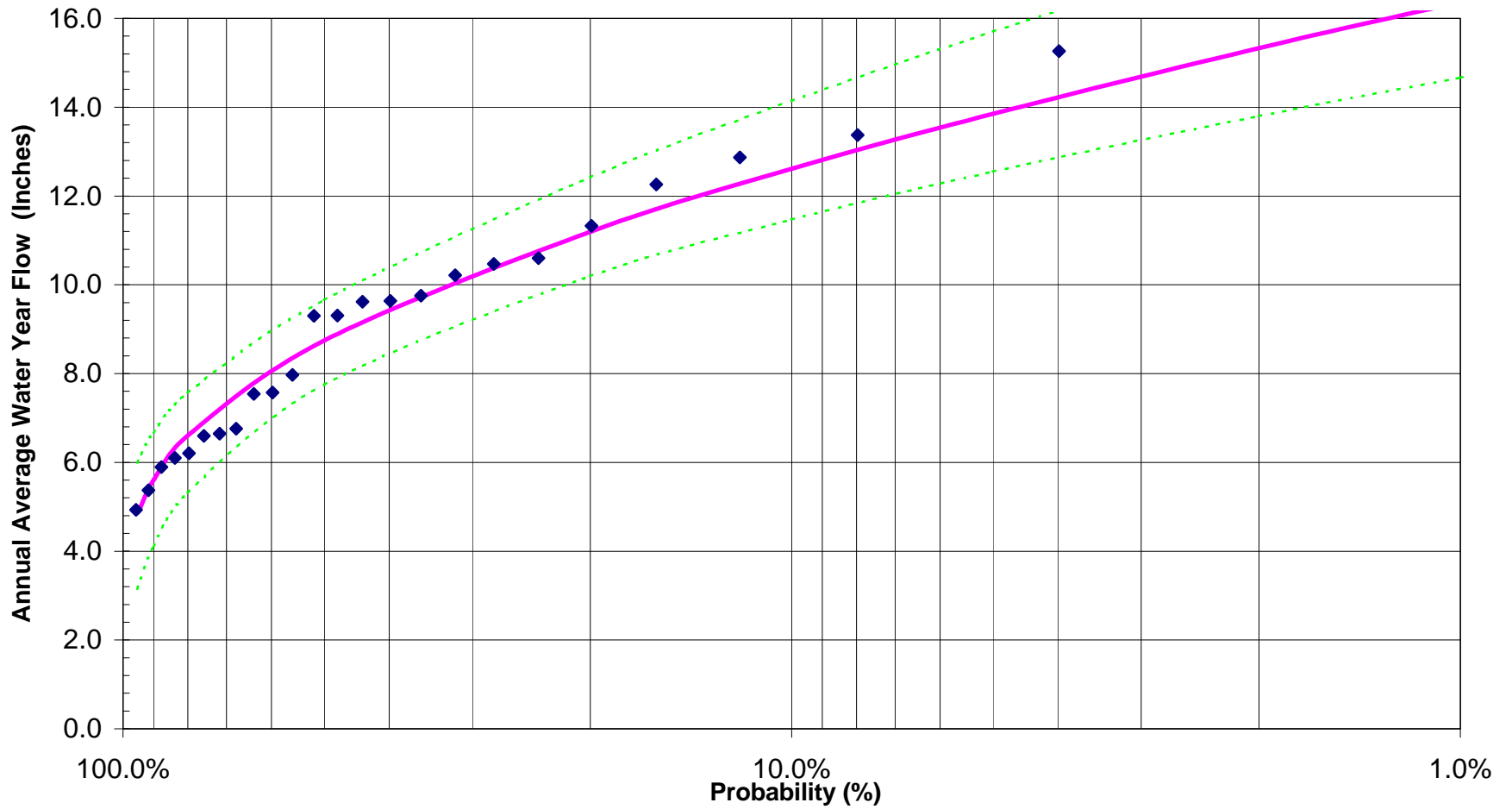
USGS 05131500 LITTLE FORK RIVER AT LITTLEFORK, MN Annual Average Flow Frequency Analysis



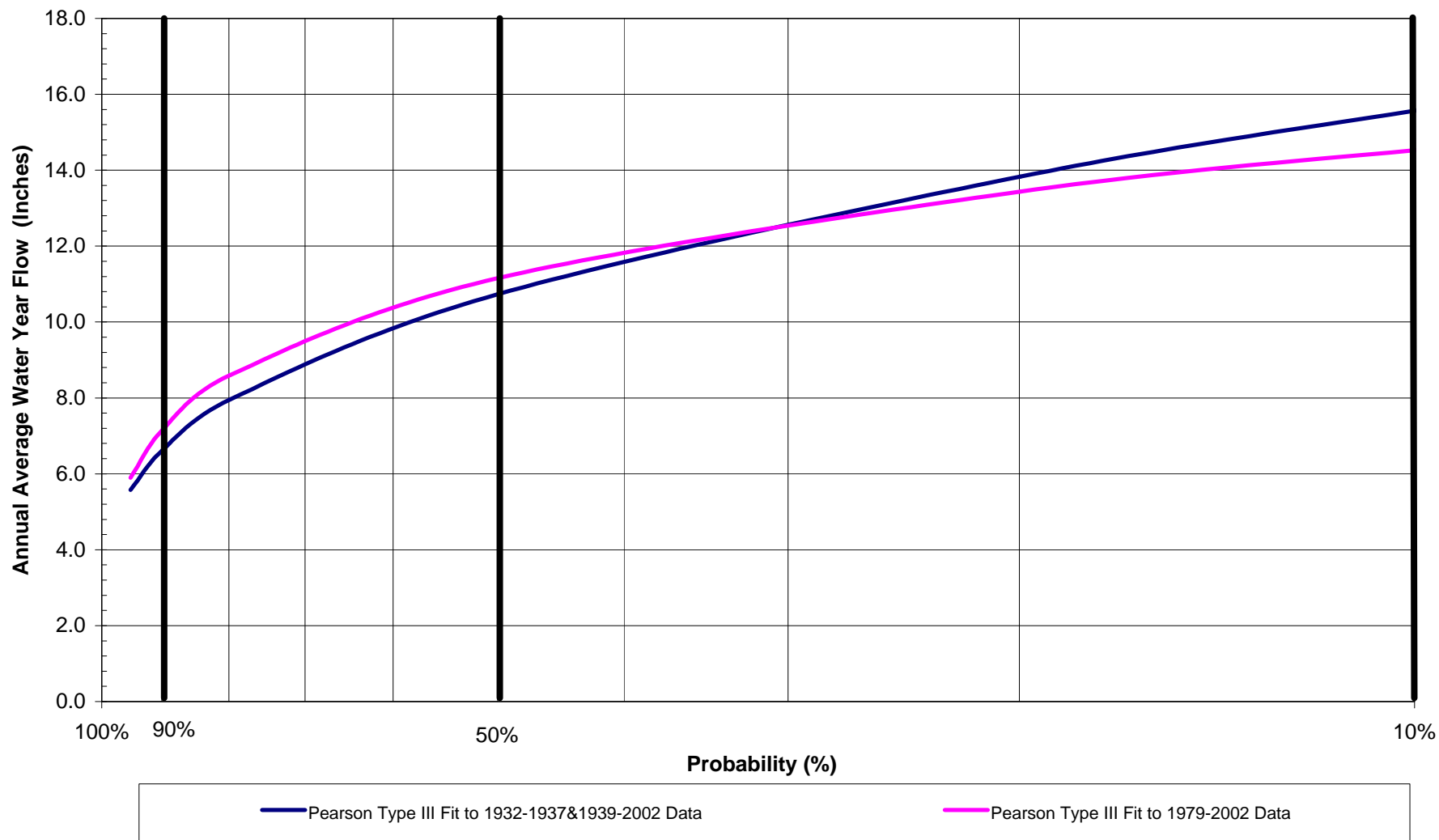
USGS 05131500 LITTLE FORK RIVER AT LITTLEFORK, MN Ave Flow Frequency Analysis (1912-1916&1929-2002)



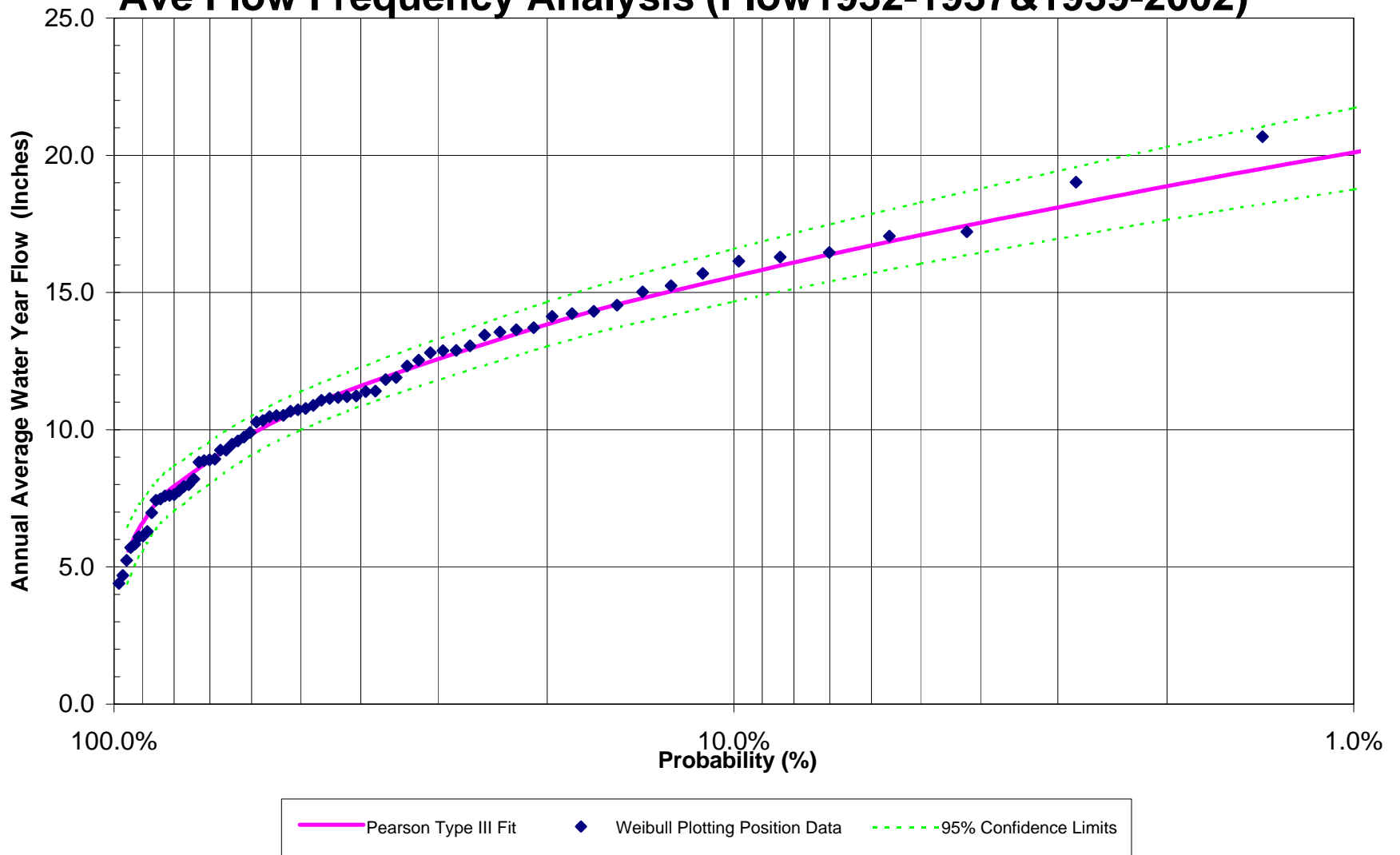
USGS 05131500 LITTLE FORK RIVER AT LITTLEFORK, MN Average Flow Frequency Analysis (1979-2002)



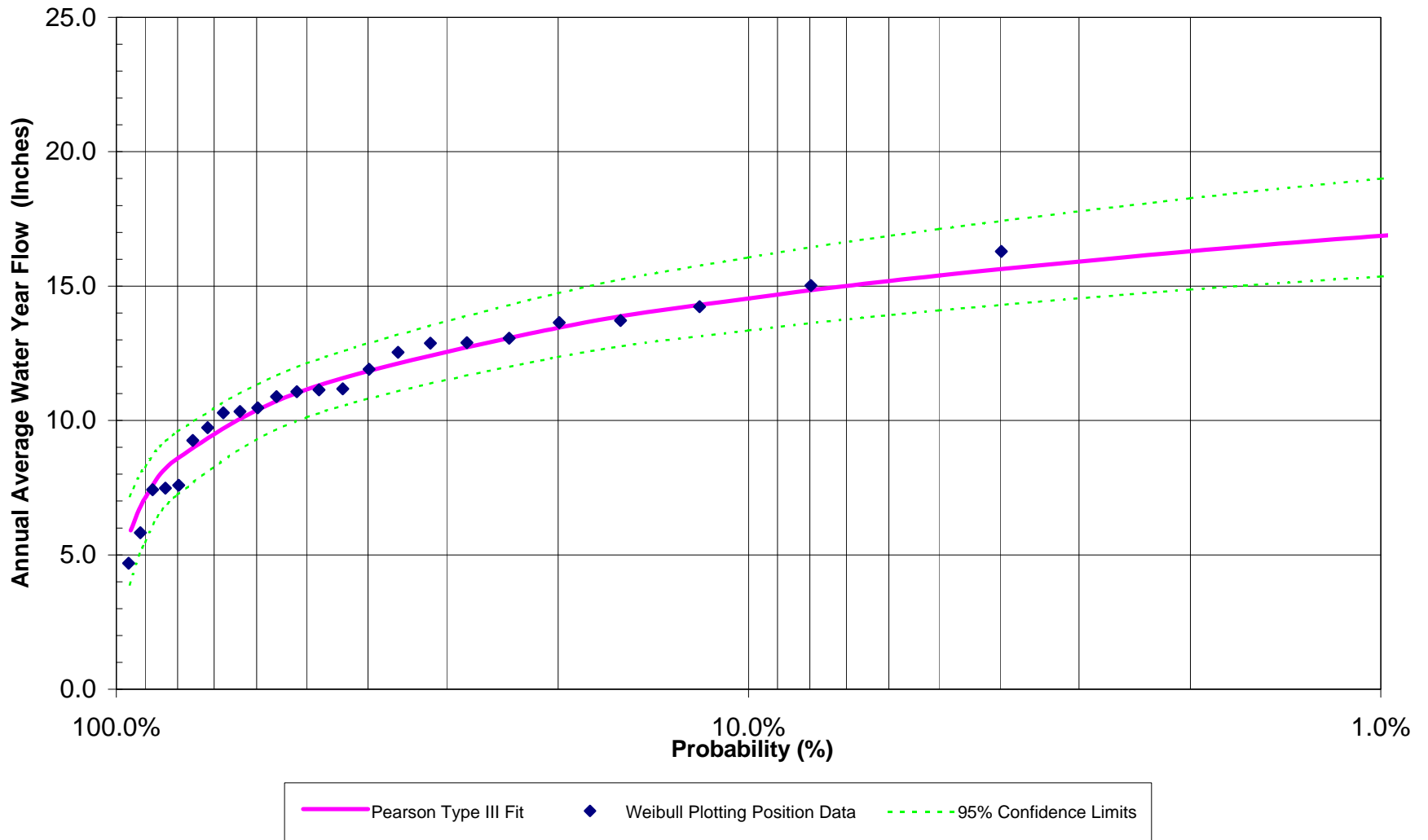
USGS 05127500 BASSWOOD RIVER NEAR WINTON, MN Annual Average Flow Frequency Analysis



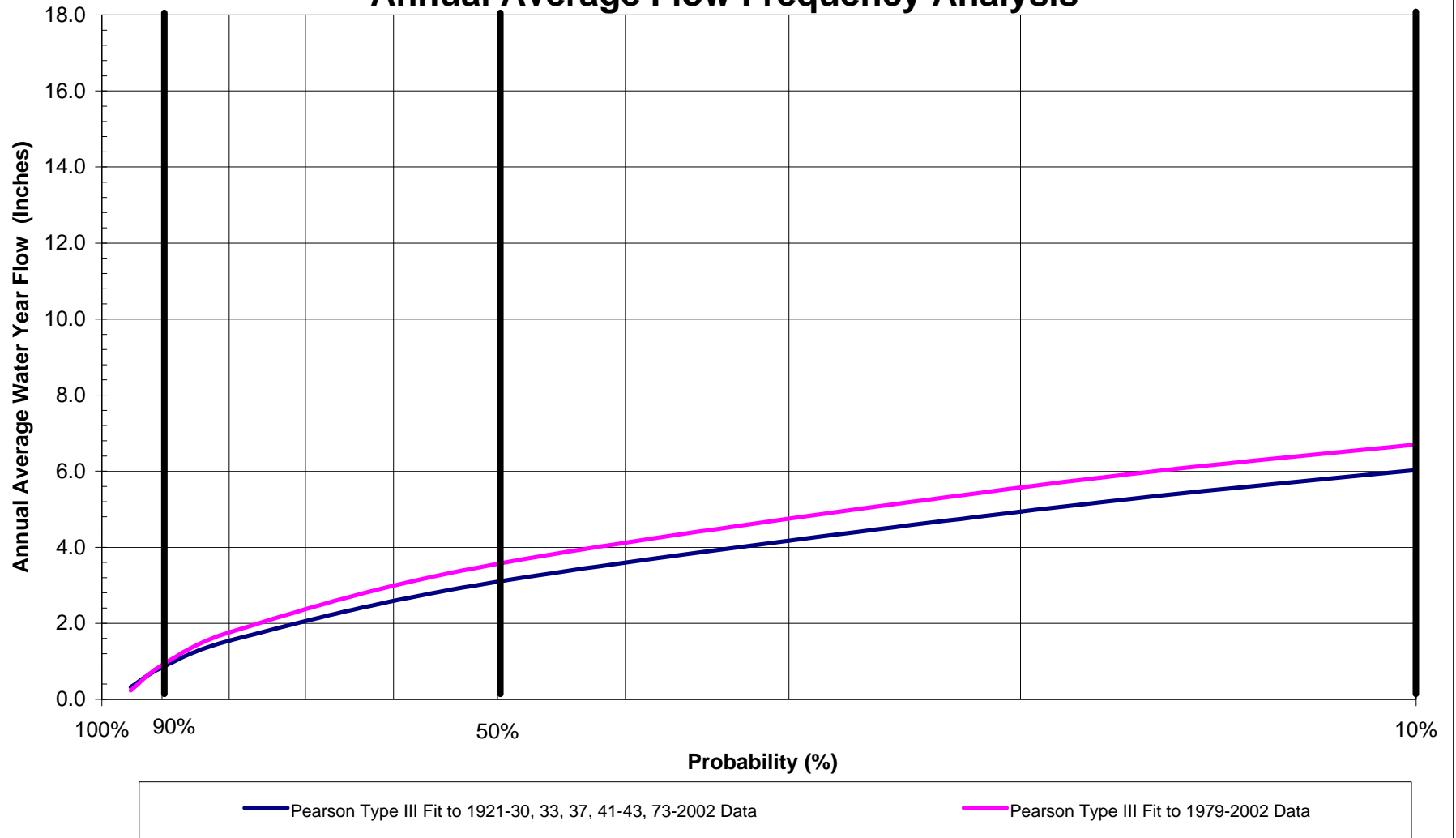
USGS 05127500 BASSWOOD RIVER NEAR WINTON, MN Ave Flow Frequency Analysis (Flow1932-1937&1939-2002)



USGS 05127500 BASSWOOD RIVER NEAR WINTON, MN Average Flow Frequency Analysis (1979-2002)

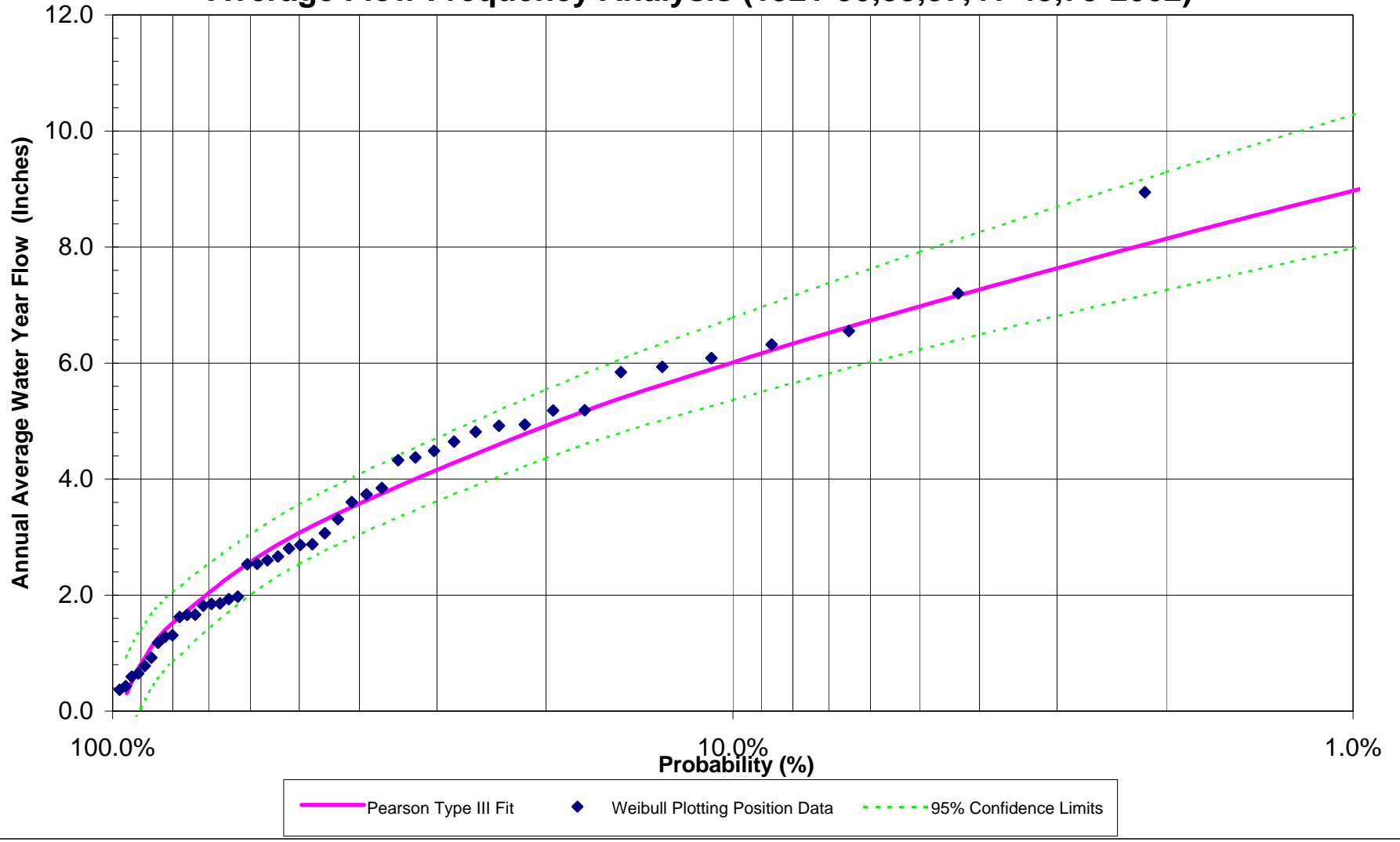


USGS 05112000 ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU, MN Annual Average Flow Frequency Analysis

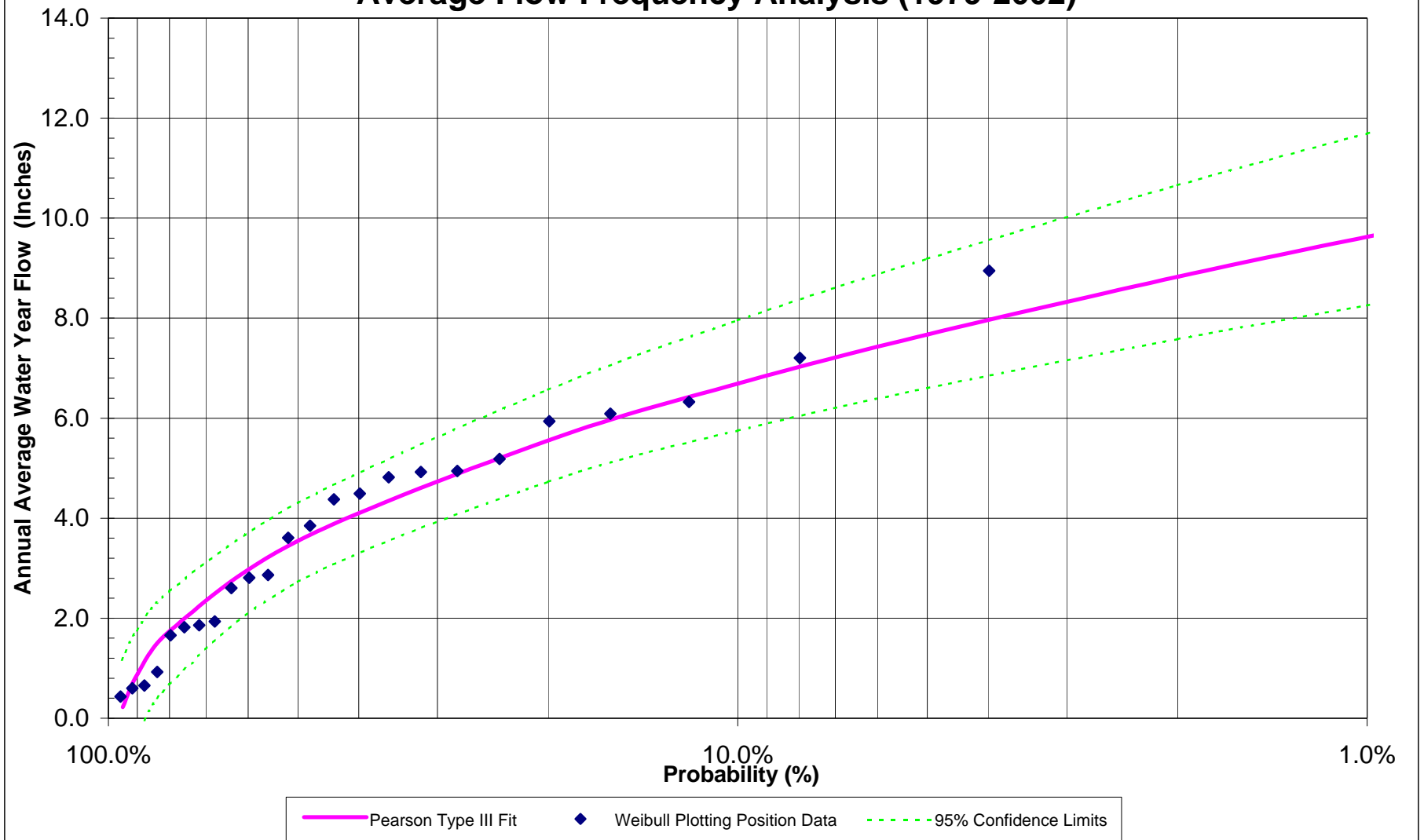


USGS 05112000 ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU, MN

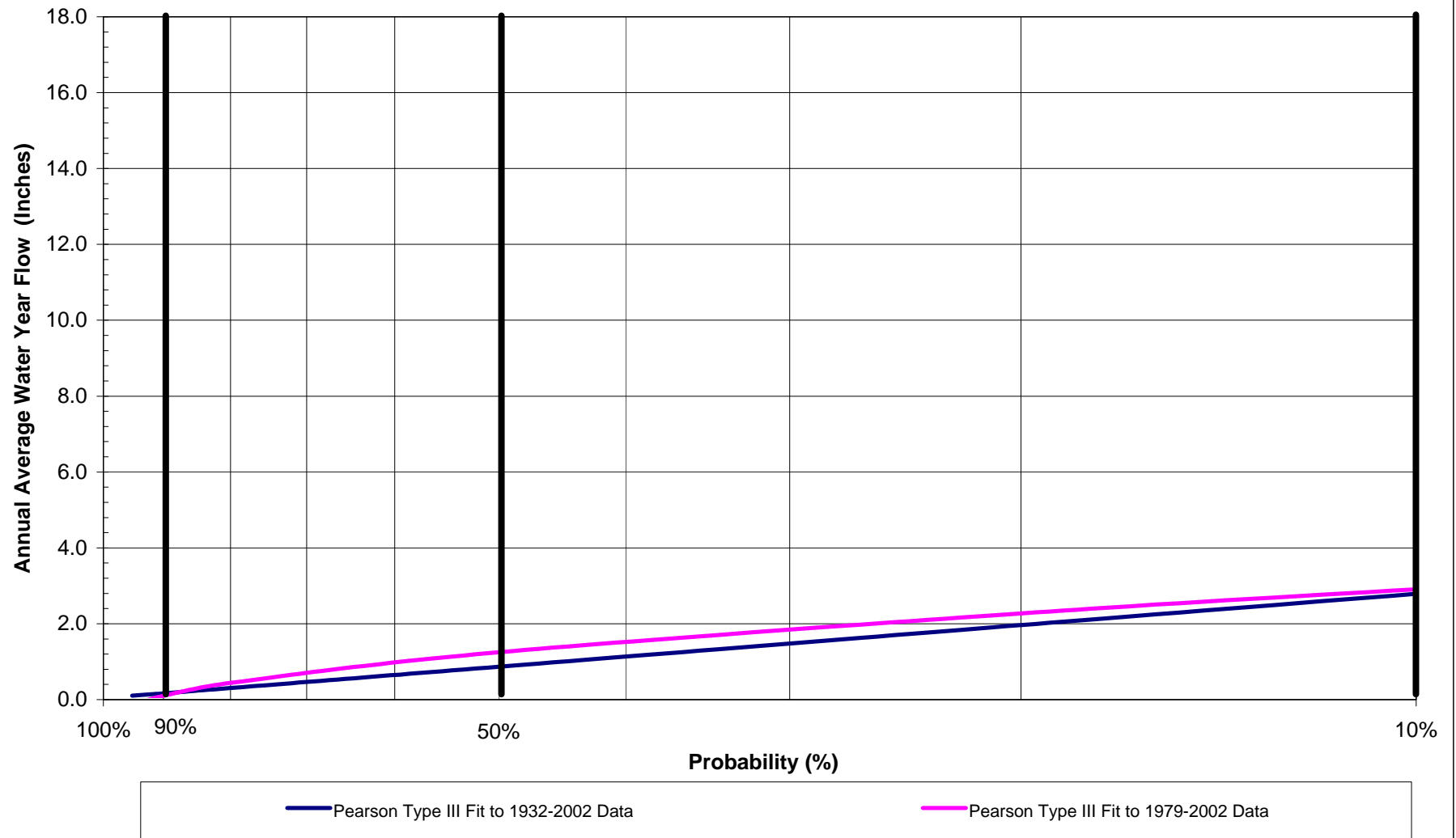
Average Flow Frequency Analysis (1921-30,33,37,41-43,73-2002)



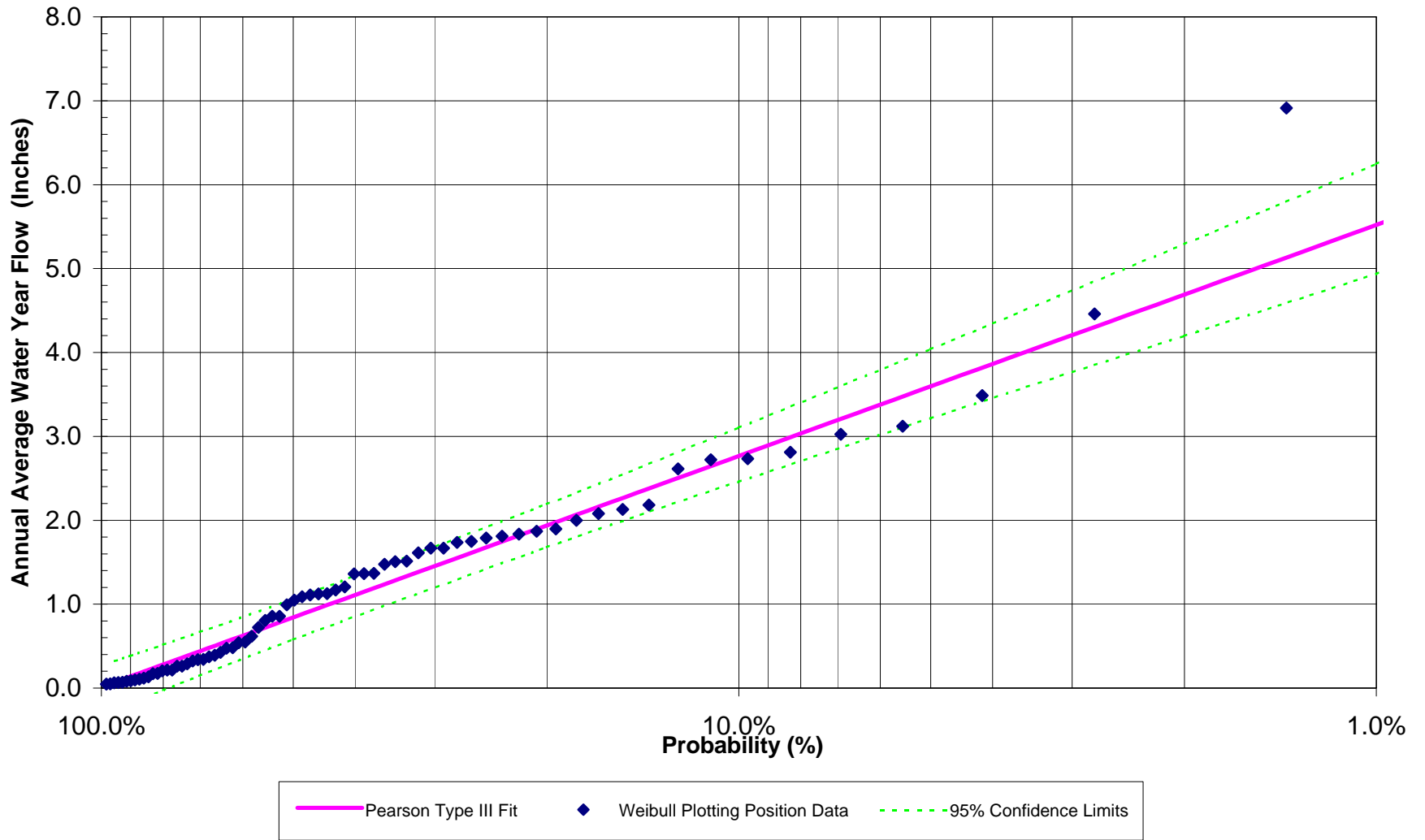
**USGS 05112000 ROSEAU RIVER BELOW STATE DITCH 51 NR
CARIBOU, MN
Average Flow Frequency Analysis (1979-2002)**



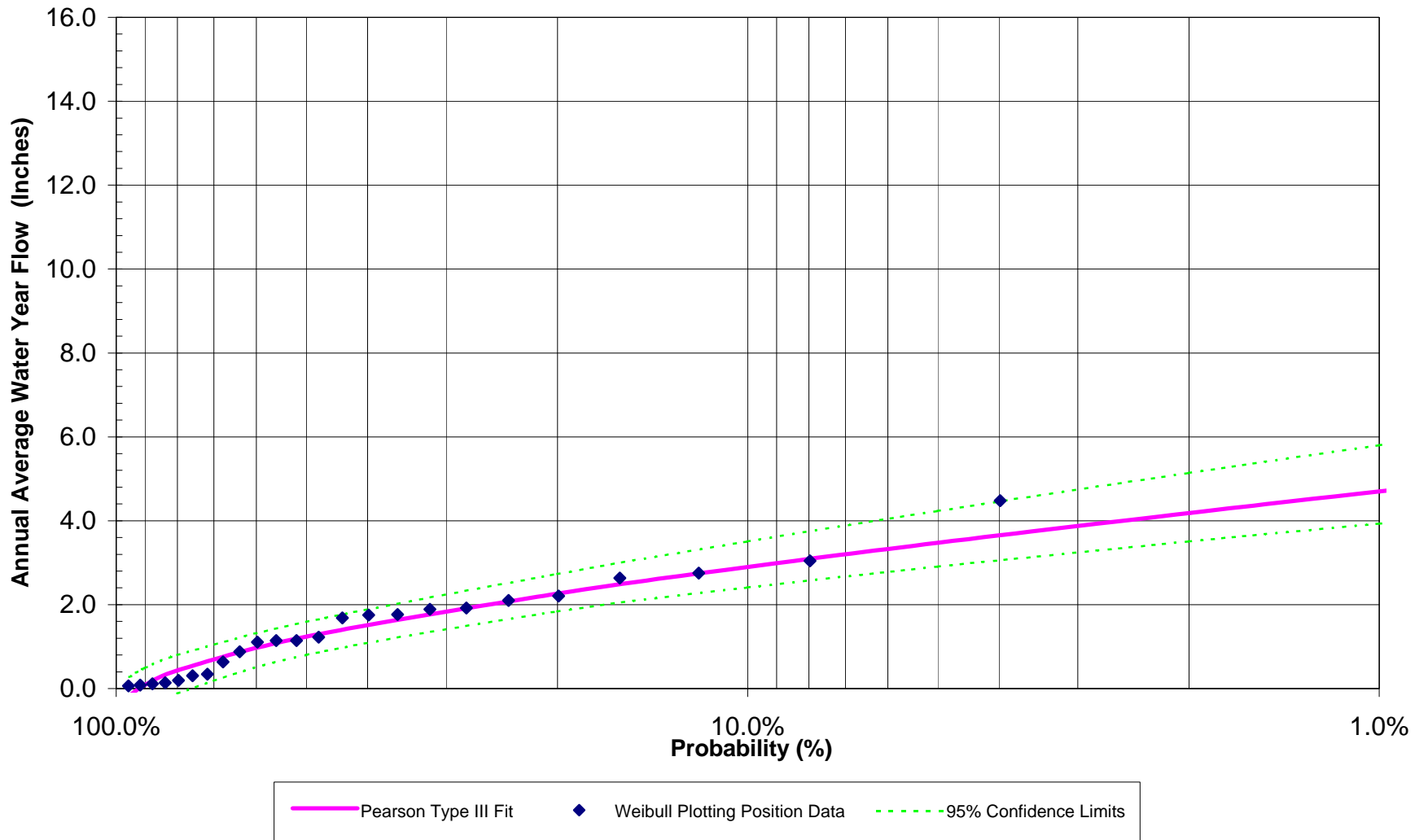
USGS 05090000 PARK RIVER AT GRAFTON, ND Annual Average Flow Frequency Analysis



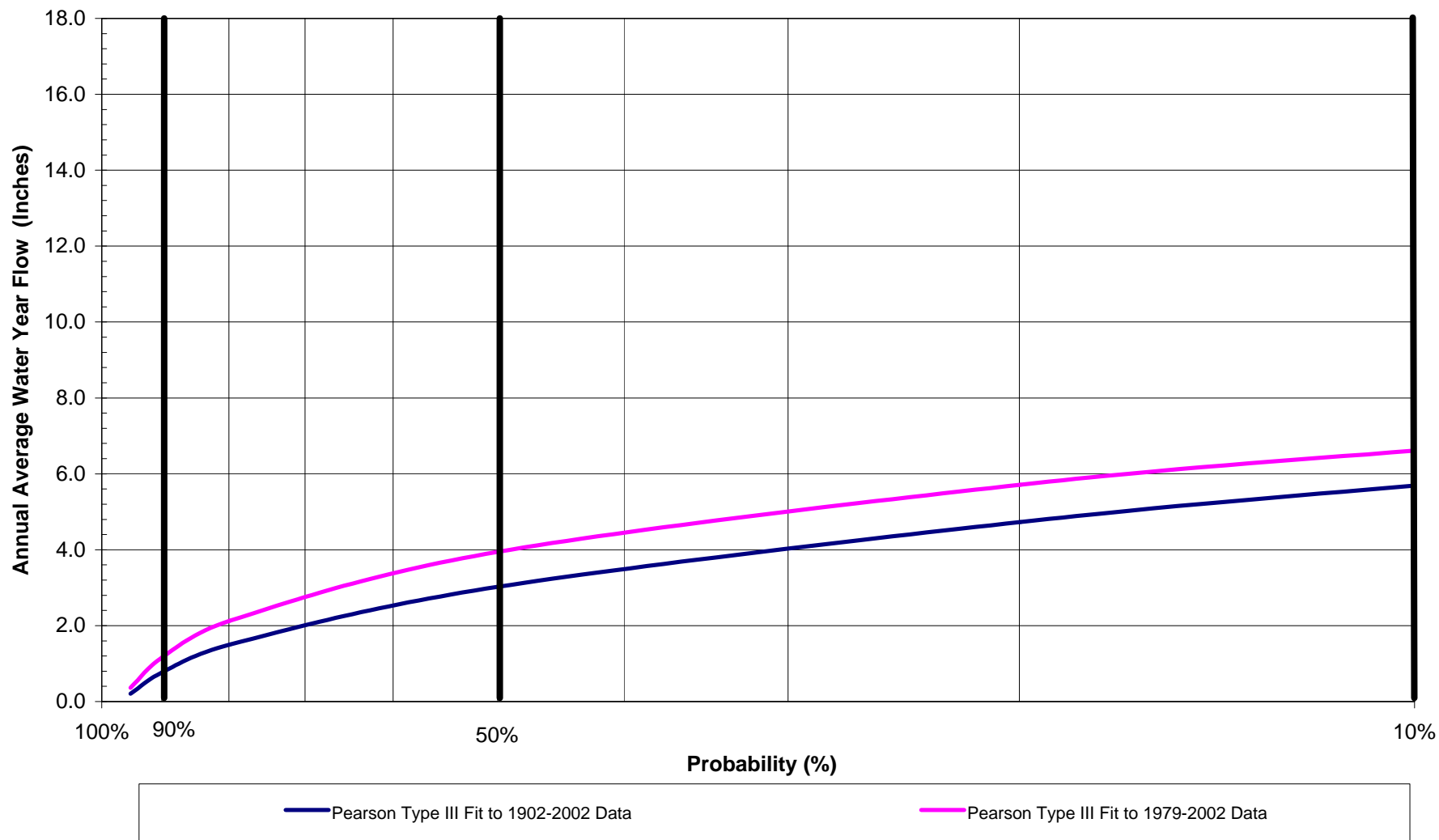
USGS 05090000 PARK RIVER AT GRAFTON, ND Average Flow Frequency Analysis (1932-2002)



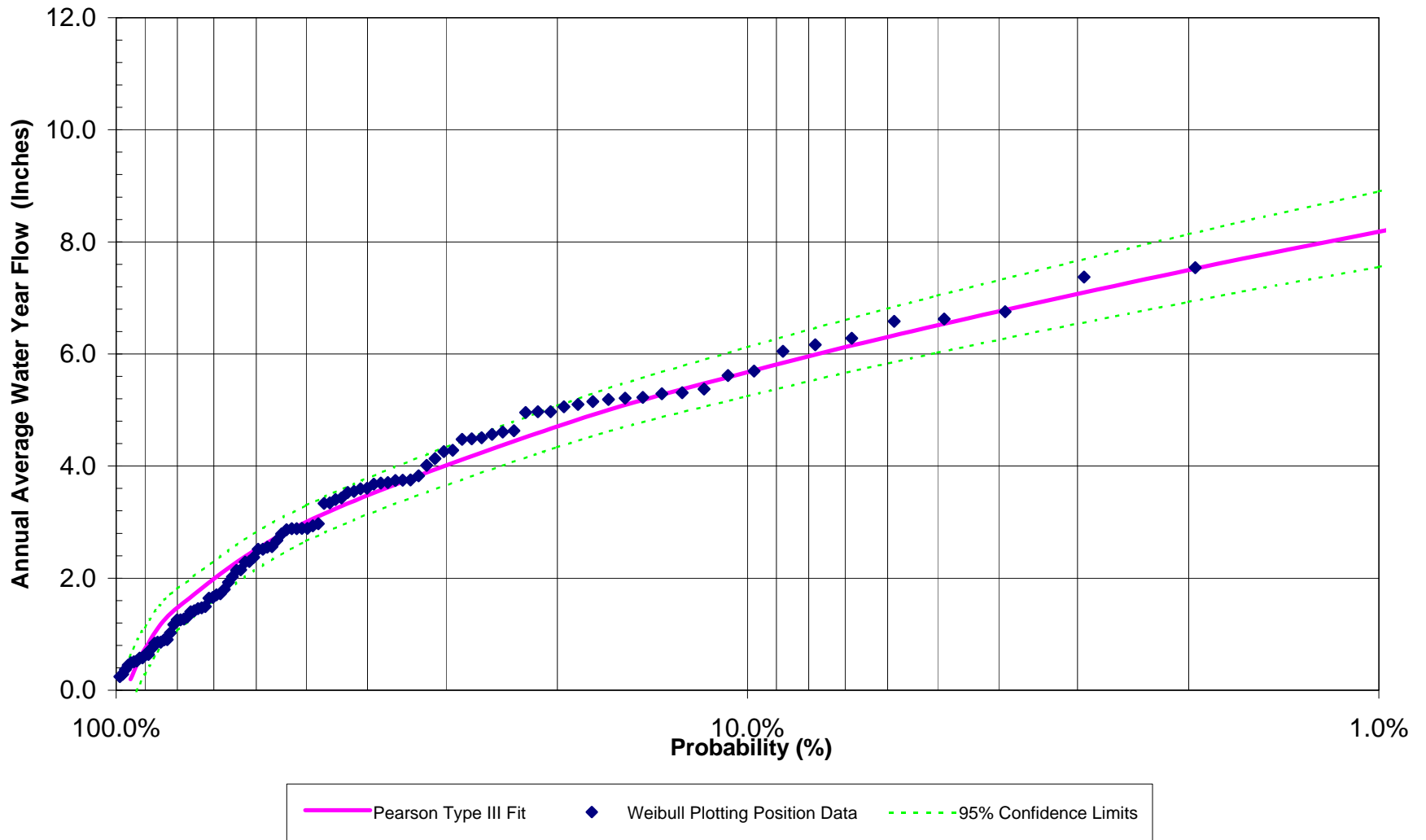
USGS 05090000 PARK RIVER AT GRAFTON, ND Average Flow Frequency Analysis (1979-2002)



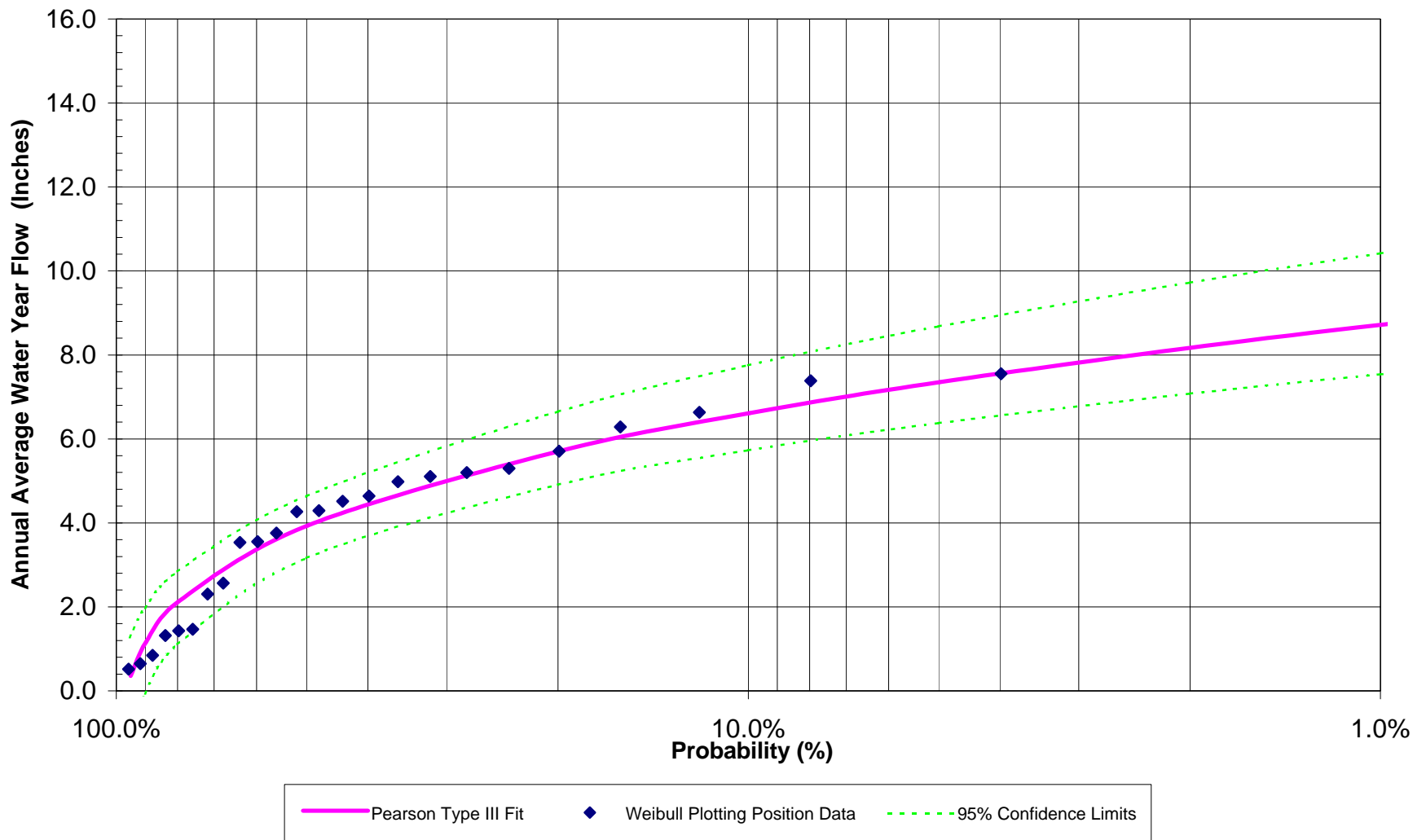
USGS 05079000 RED LAKE RIVER AT CROOKSTON, MN Annual Average Flow Frequency Analysis



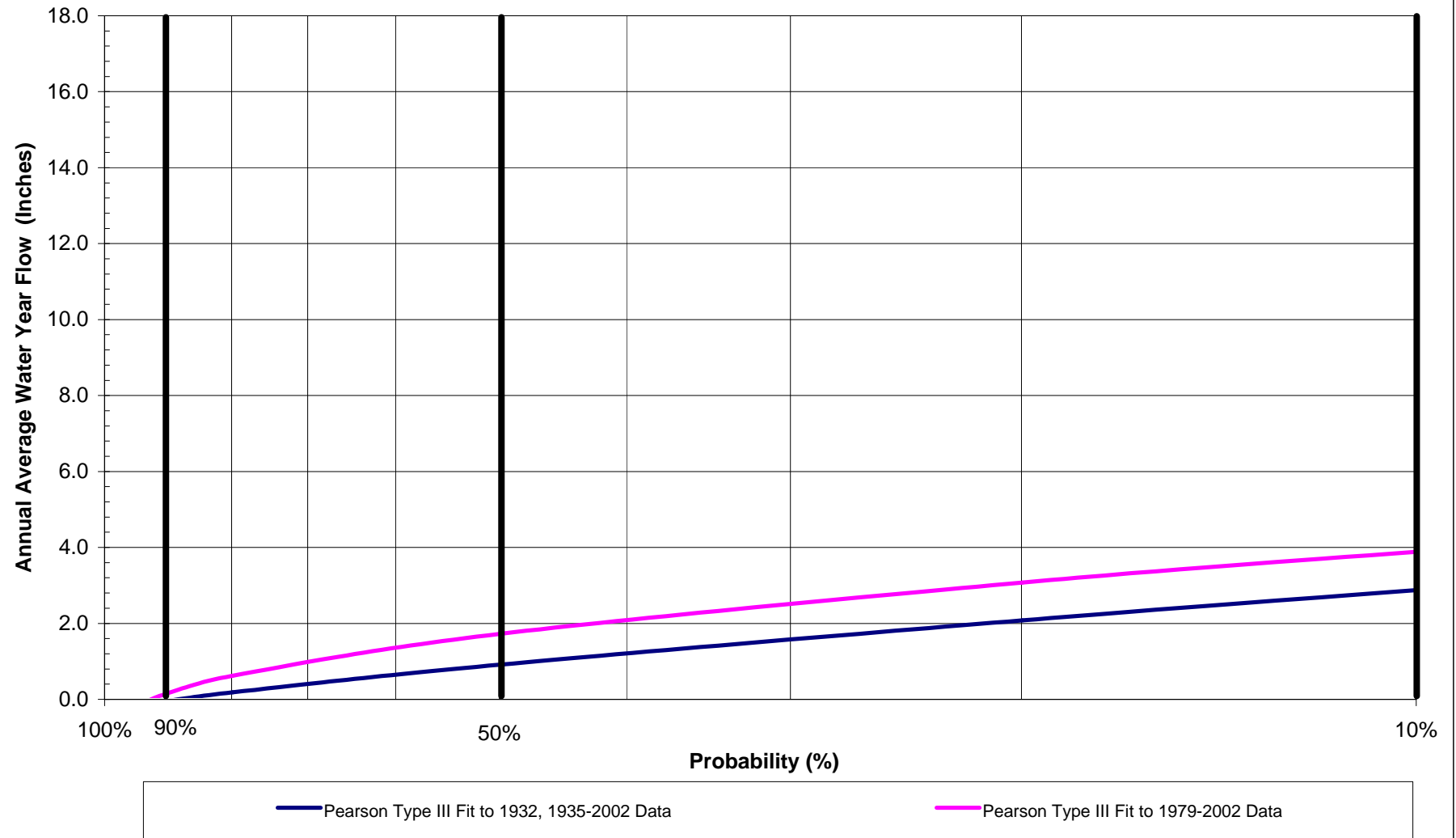
USGS 05079000 RED LAKE RIVER AT CROOKSTON, MN Average Flow Frequency Analysis (1902-2002)



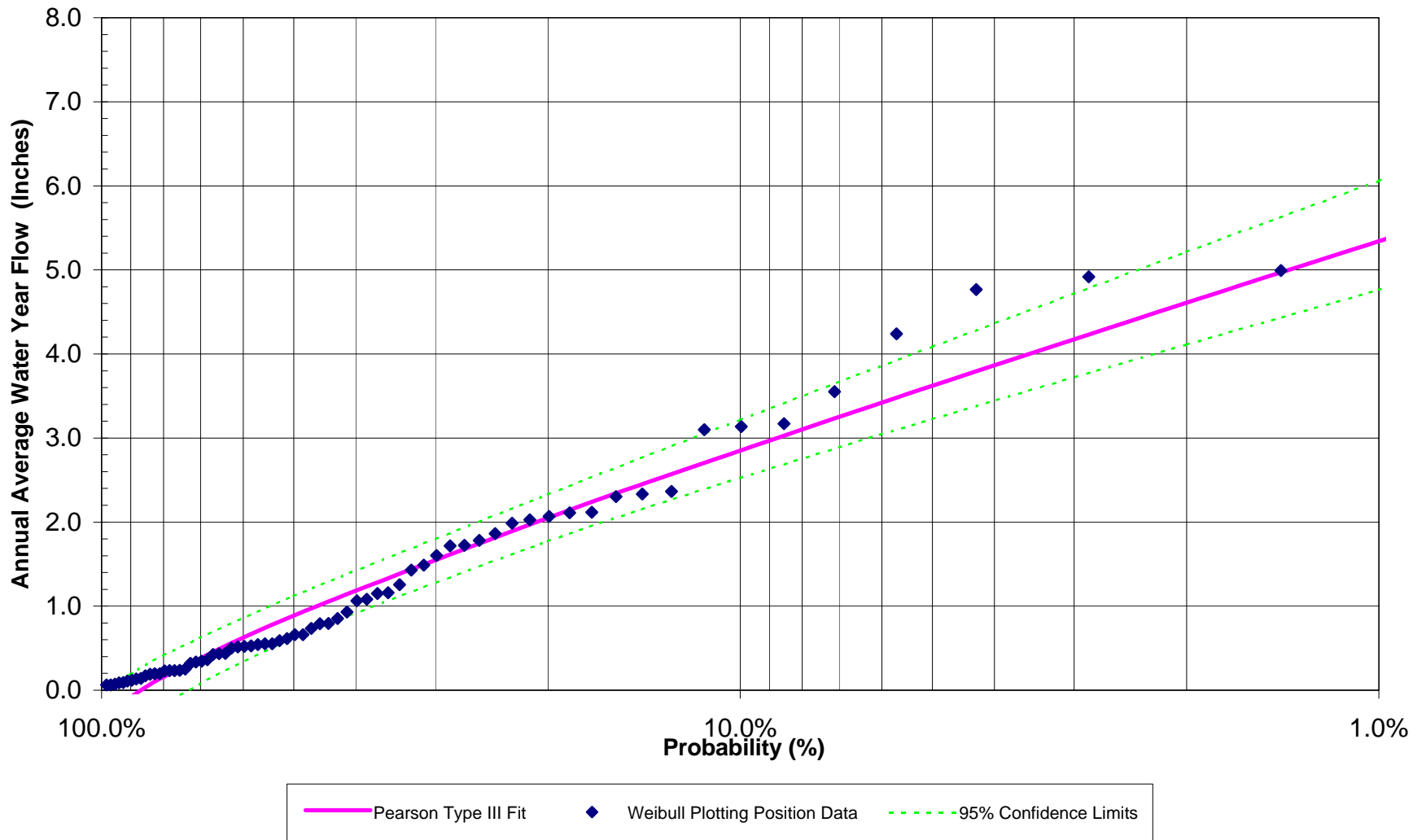
USGS 05079000 RED LAKE RIVER AT CROOKSTON, MN Average Flow Frequency Analysis (1979-2002)



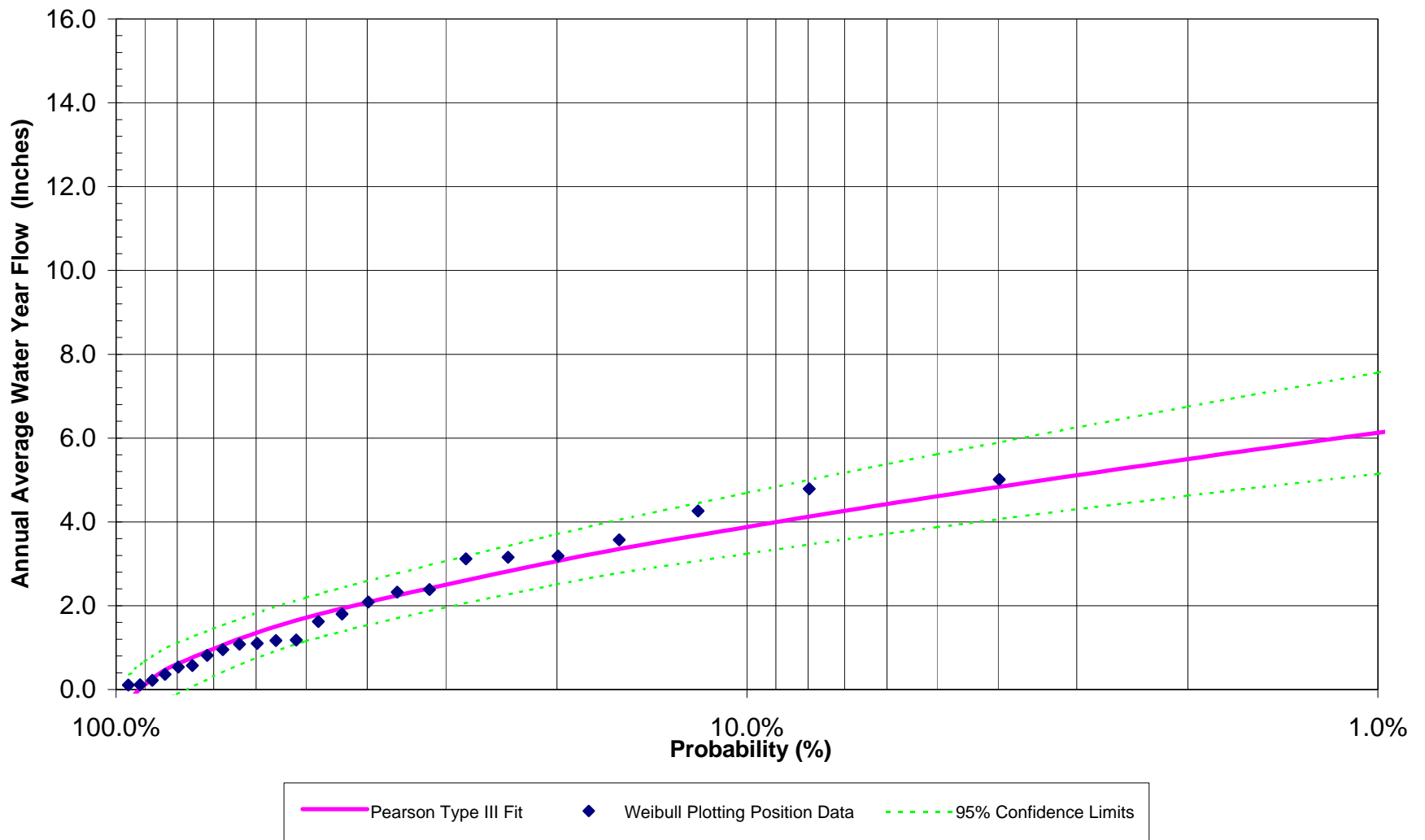
USGS 05066500 GOOSE RIVER AT HILLSBORO, ND Annual Average Flow Frequency Analysis



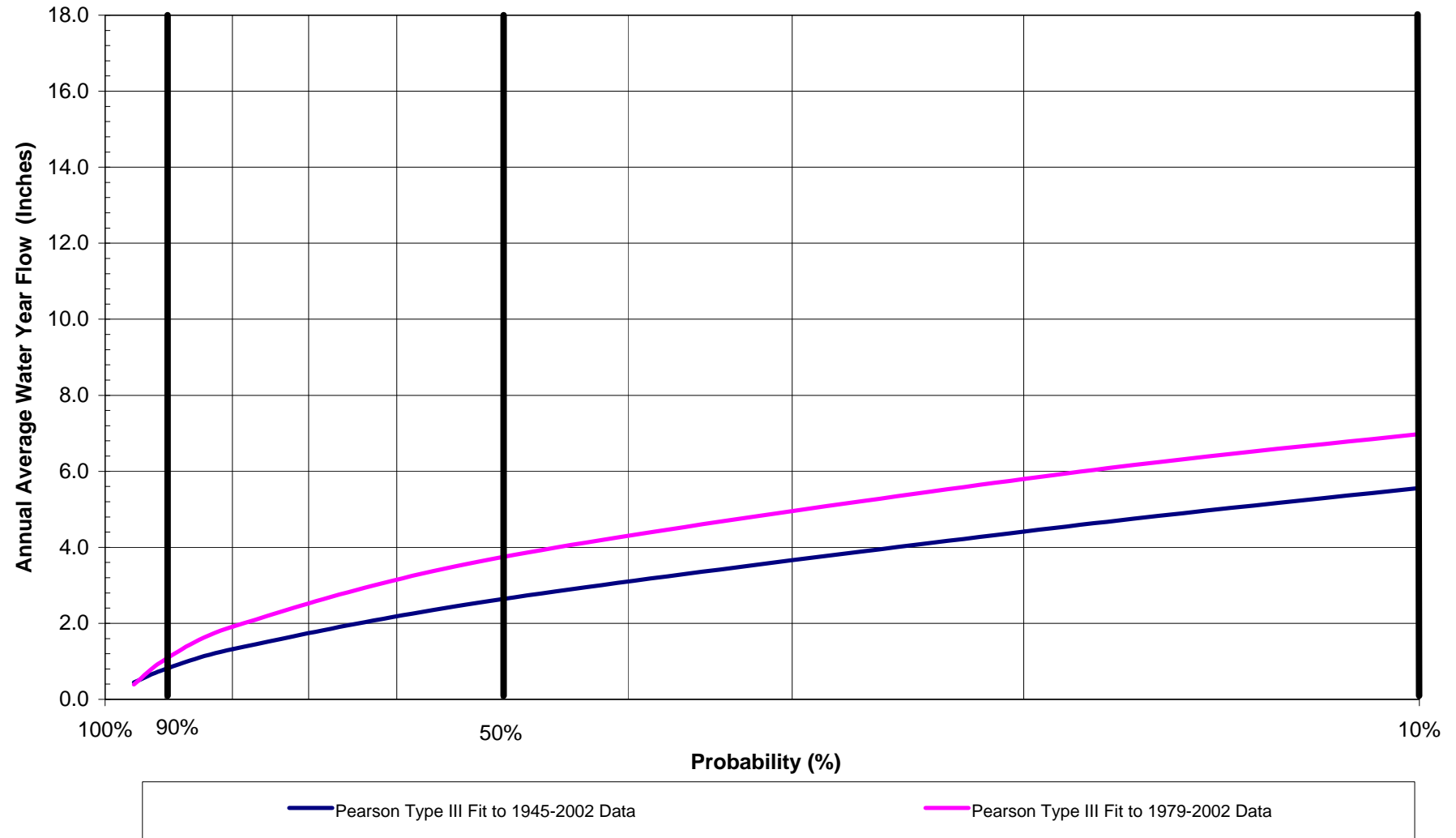
USGS 05066500 GOOSE RIVER AT HILLSBORO, ND Average Flow Frequency Analysis (1932, 1935-2002)



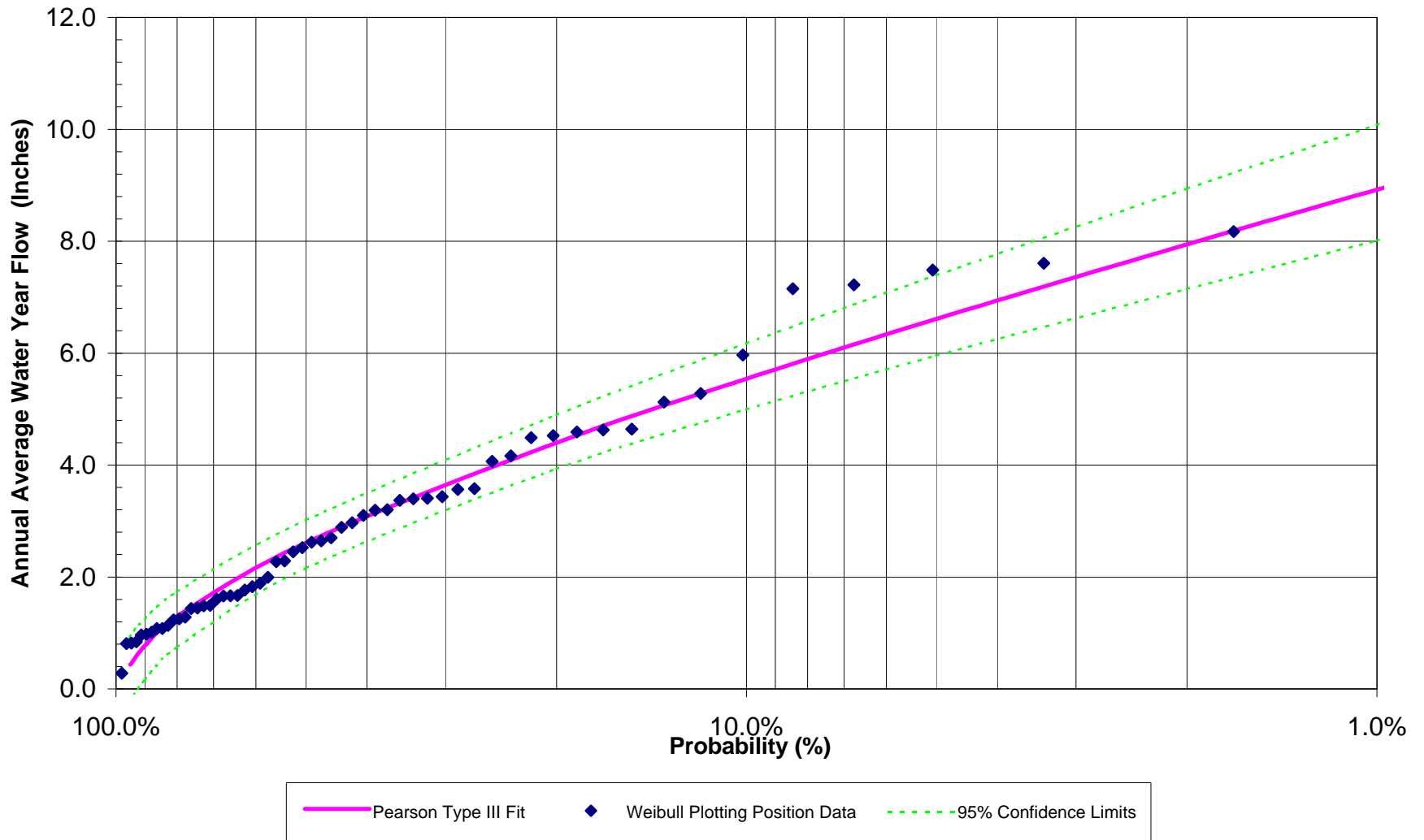
USGS 05066500 GOOSE RIVER AT HILLSBORO, ND Average Flow Frequency Analysis (1979-2002)



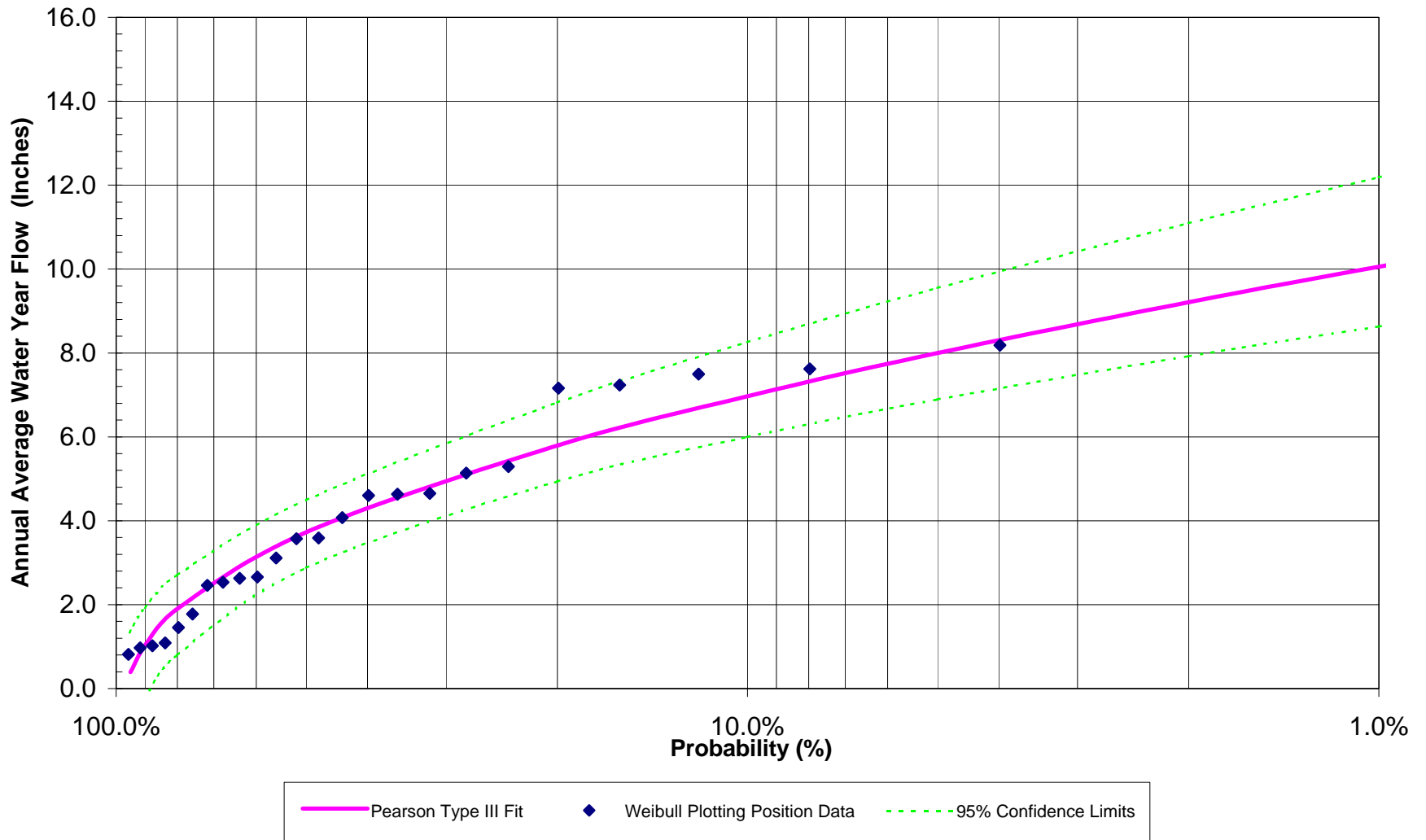
USGS 05064000 WILD RICE RIVER AT HENDRUM, MN Annual Average Flow Frequency Analysis



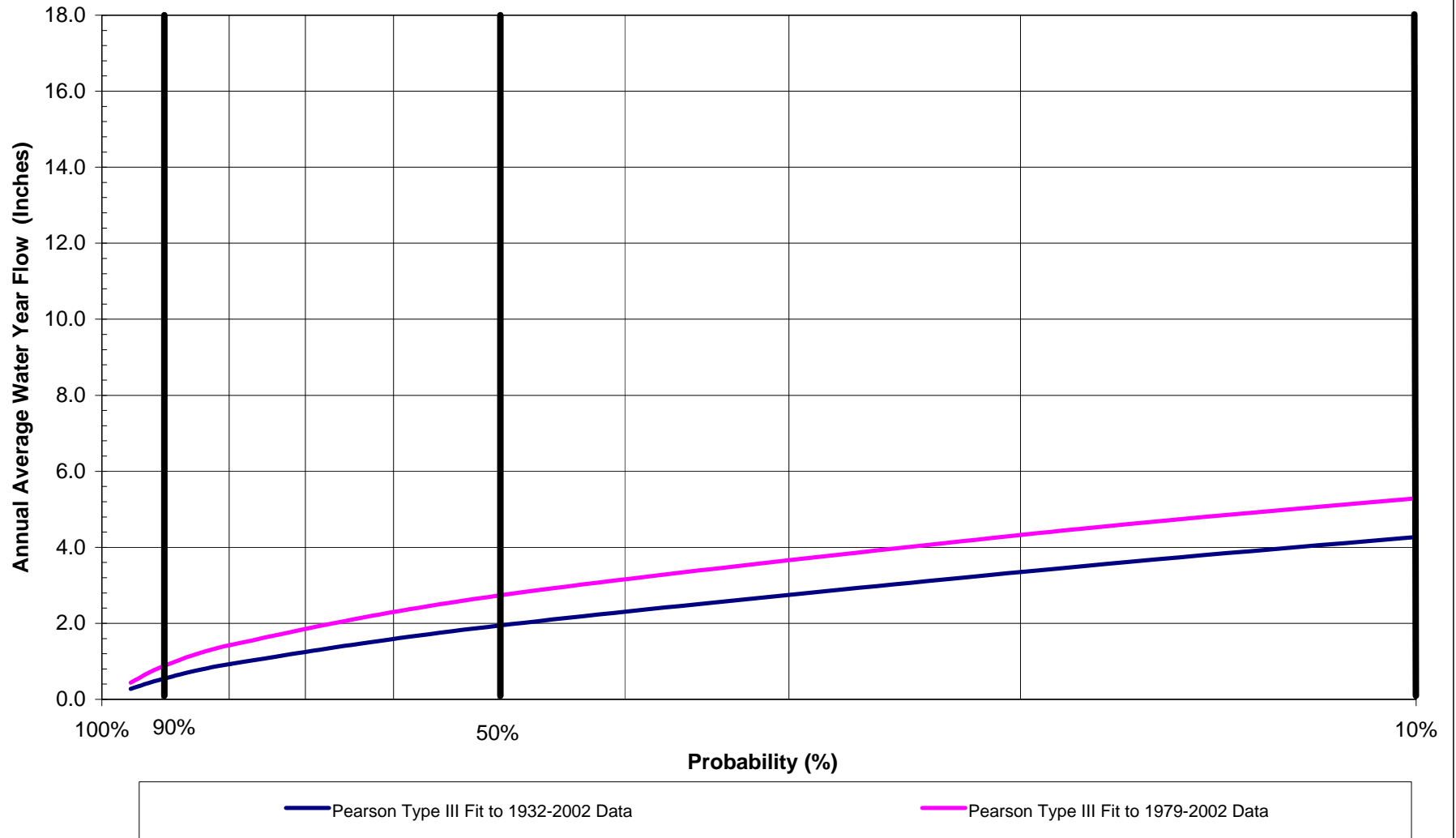
USGS 05064000 WILD RICE RIVER AT HENDRUM, MN Average Flow Frequency Analysis (1945-2002)



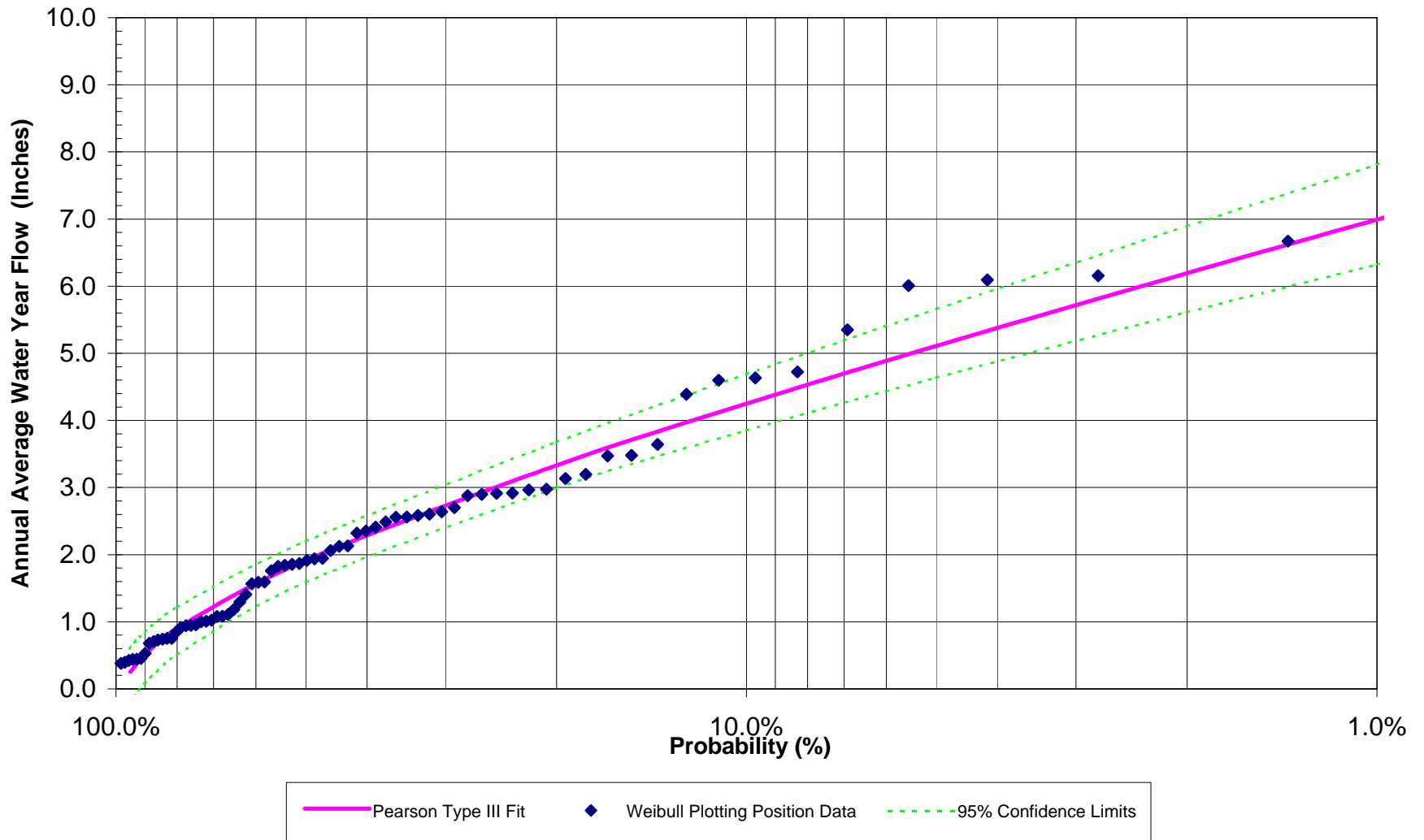
USGS 05064000 WILD RICE RIVER AT HENDRUM, MN Average Flow Frequency Analysis (1979-2002)



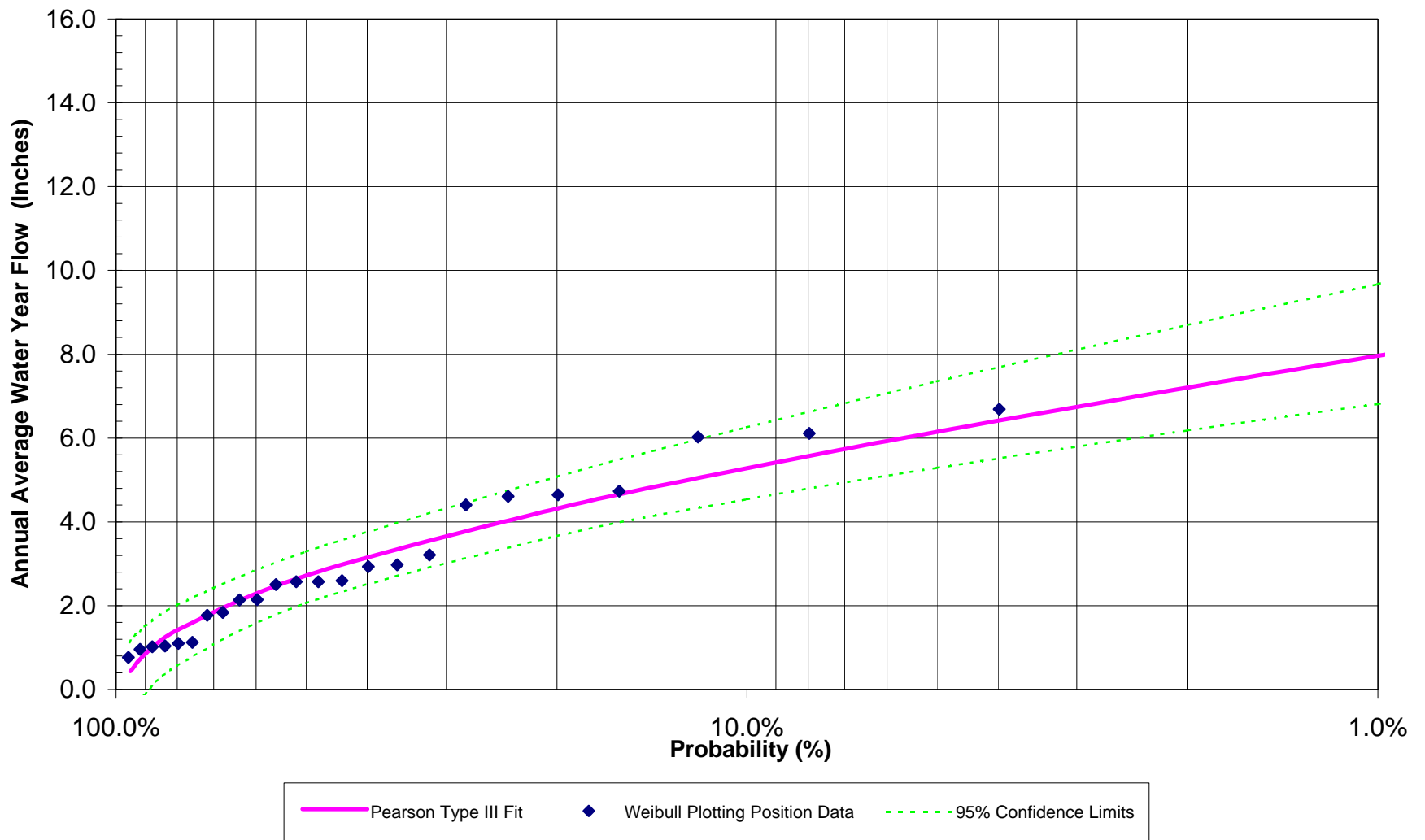
USGS 05062000 BUFFALO RIVER NEAR DILWORTH, MN Annual Average Flow Frequency Analysis



USGS 05062000 BUFFALO RIVER NEAR DILWORTH, MN Average Flow Frequency Analysis (1932-2002)

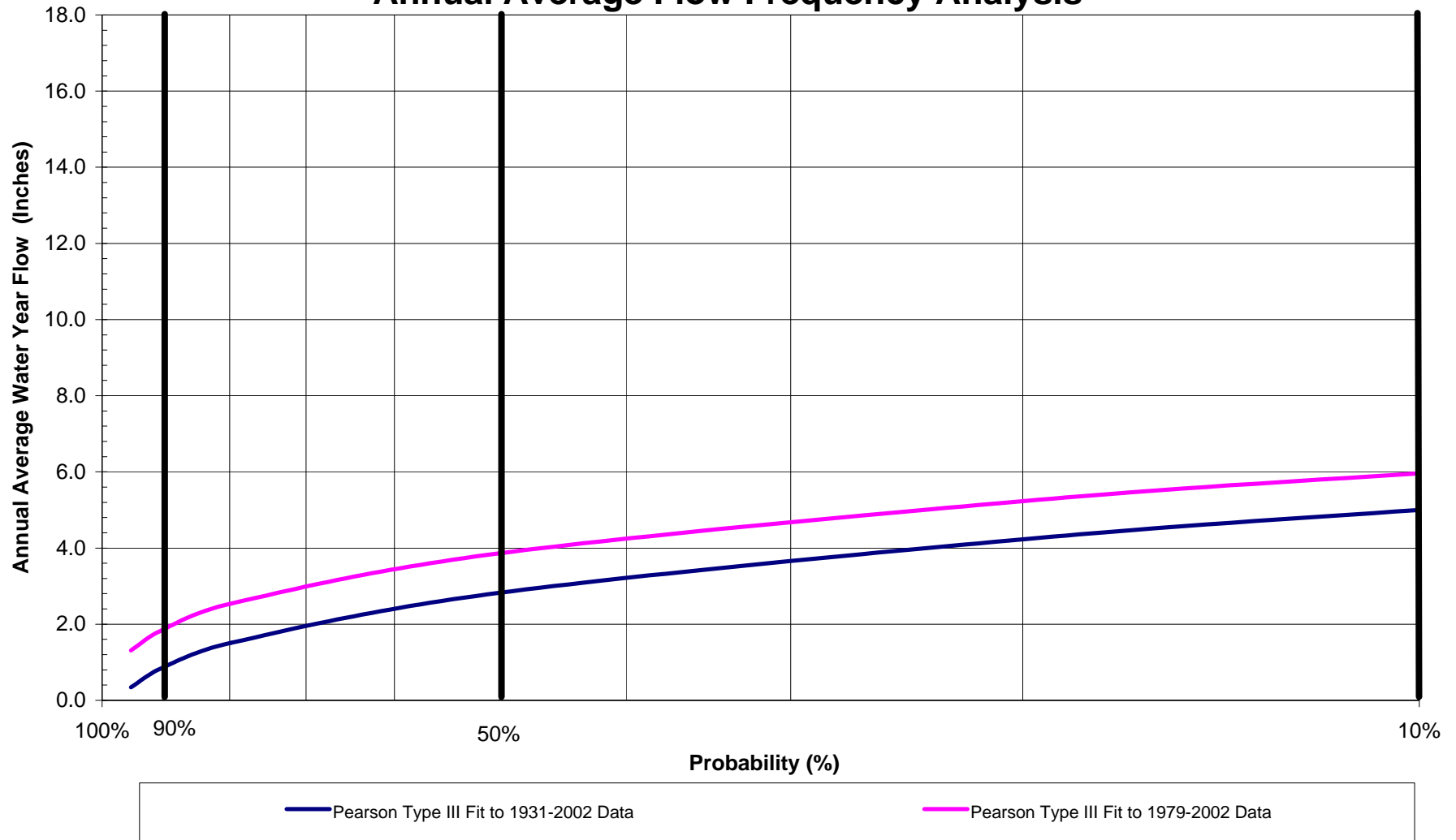


USGS 05062000 BUFFALO RIVER NEAR DILWORTH, MN Average Flow Frequency Analysis (1979-2002)

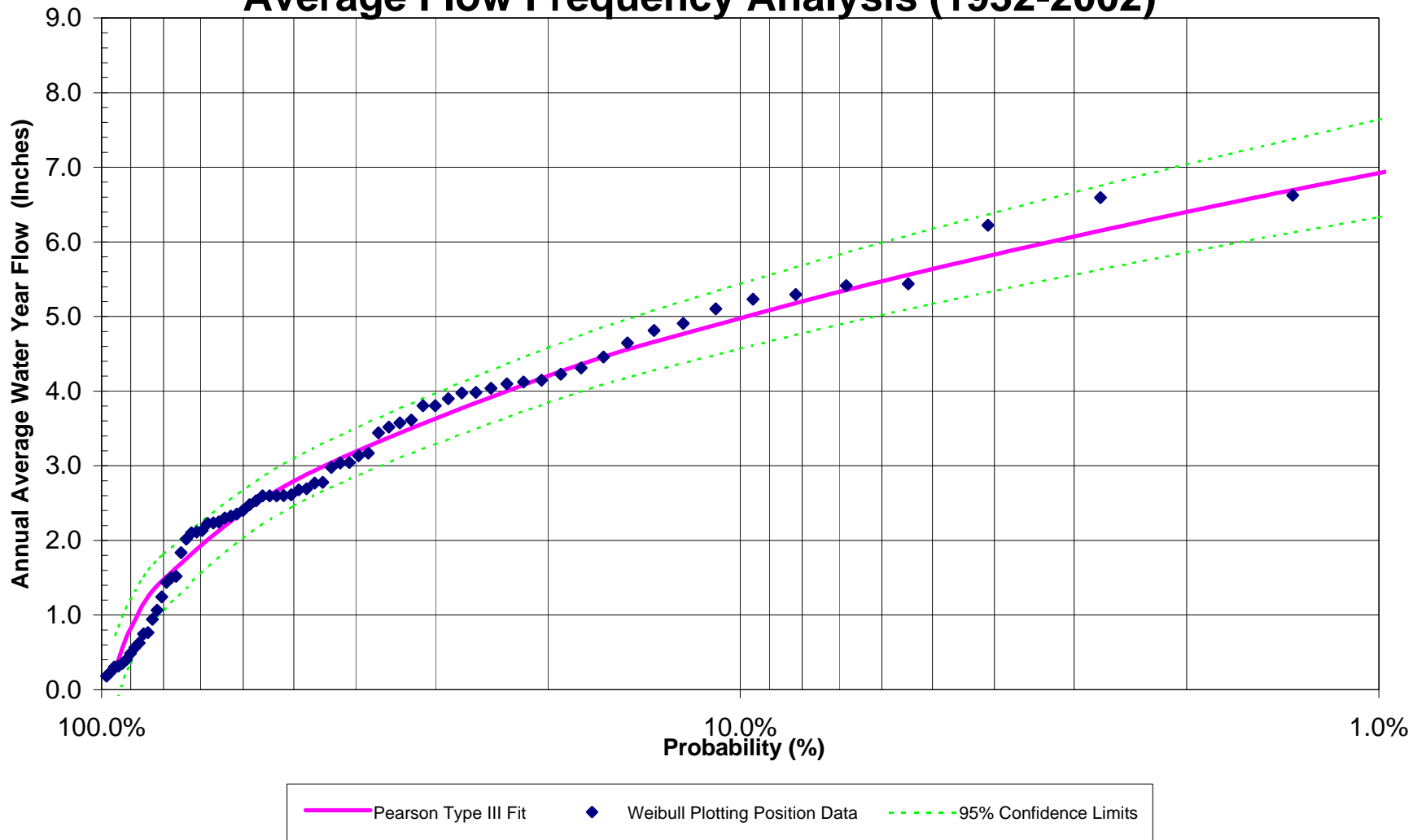


USGS 05046000 OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS, MN

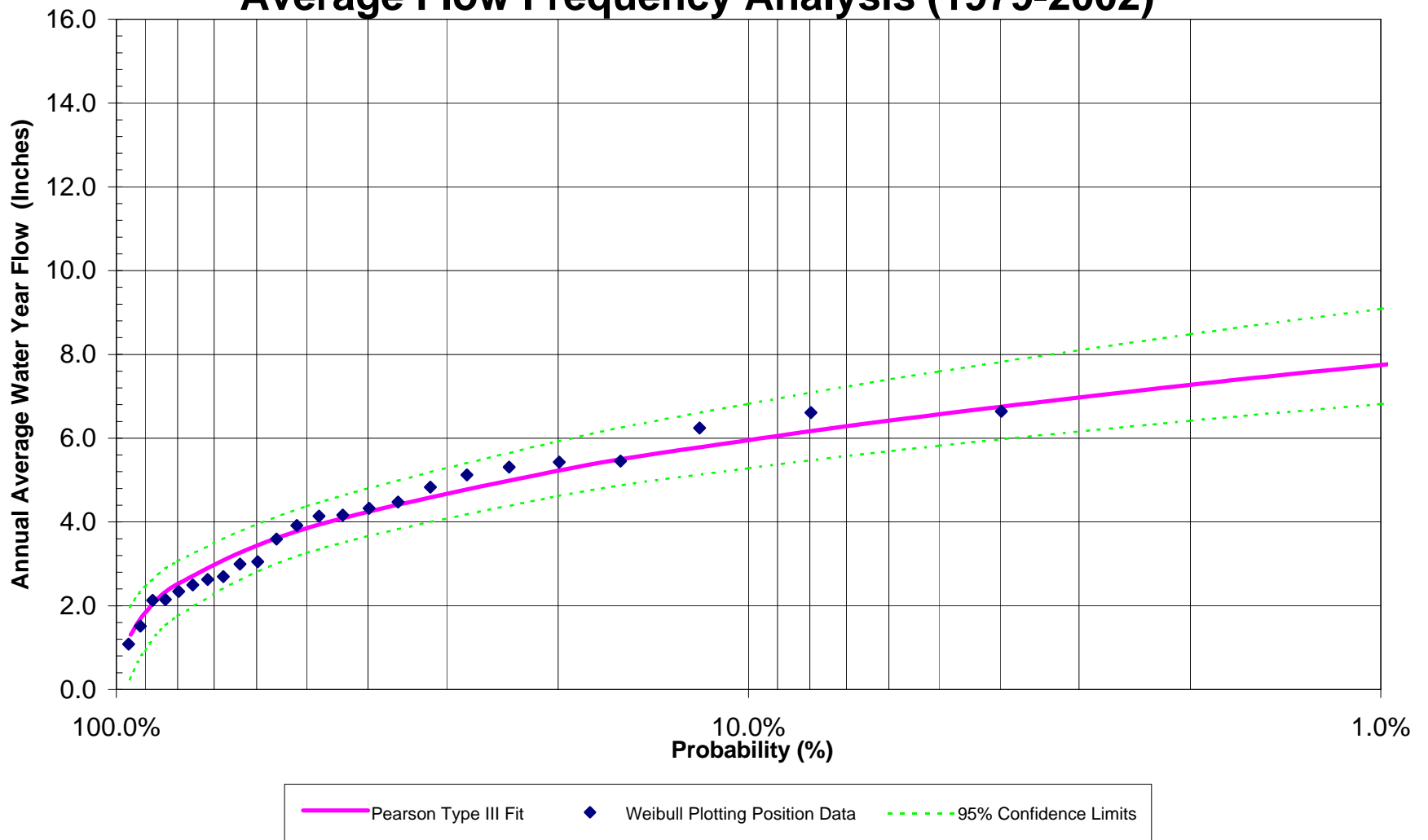
Annual Average Flow Frequency Analysis



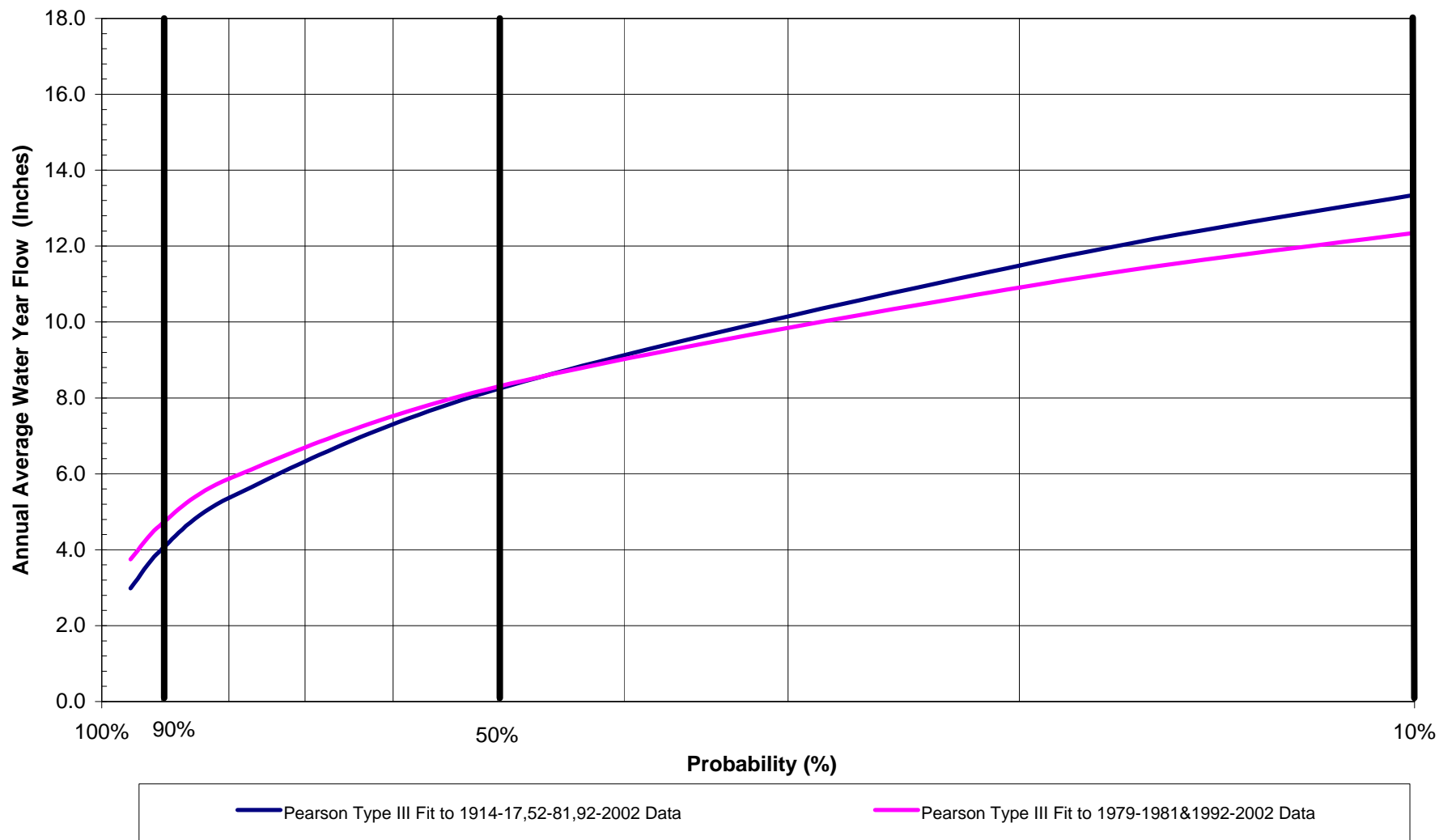
USGS 05046000 OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS, MN Average Flow Frequency Analysis (1932-2002)



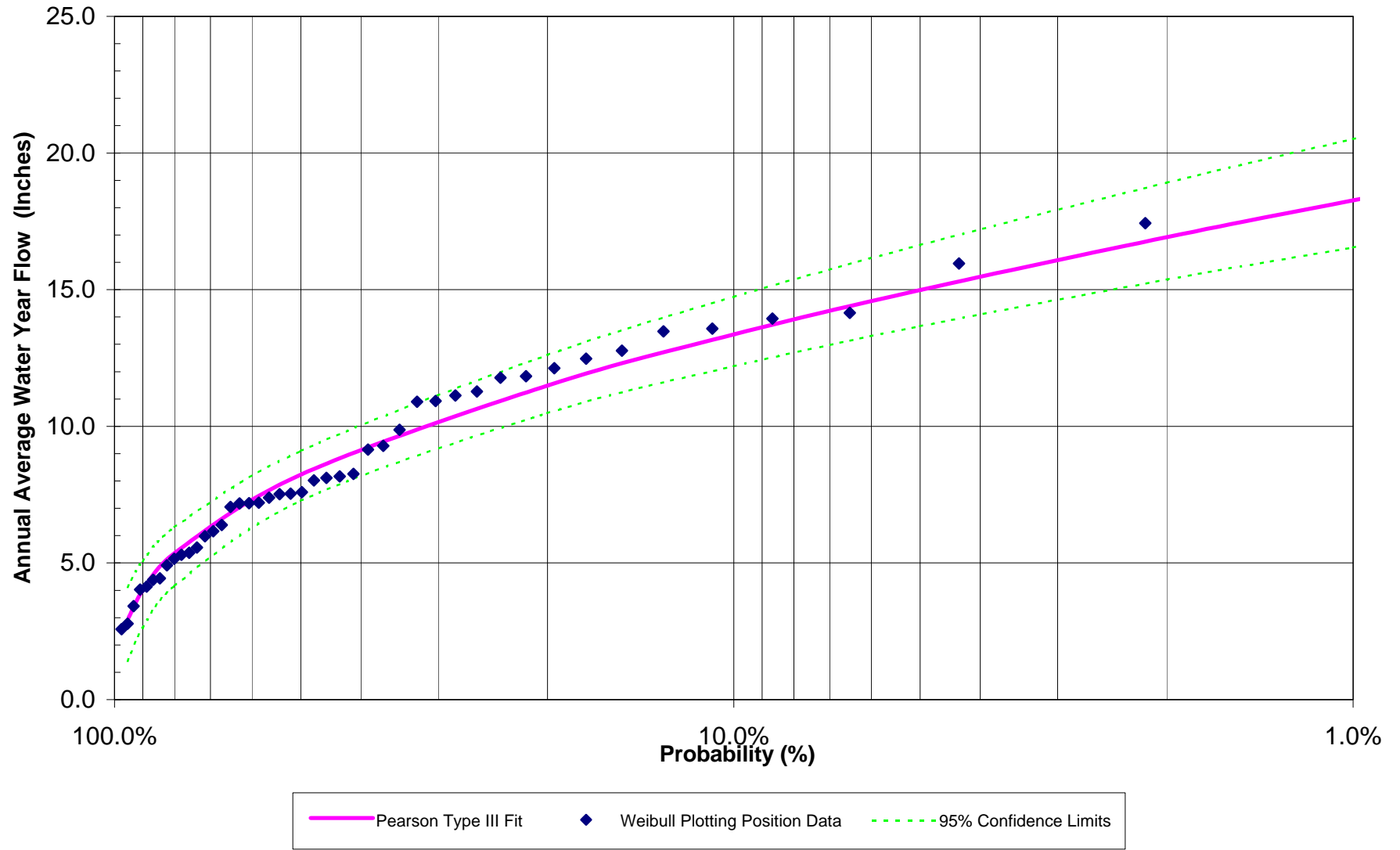
USGS 05046000 OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS, MN Average Flow Frequency Analysis (1979-2002)



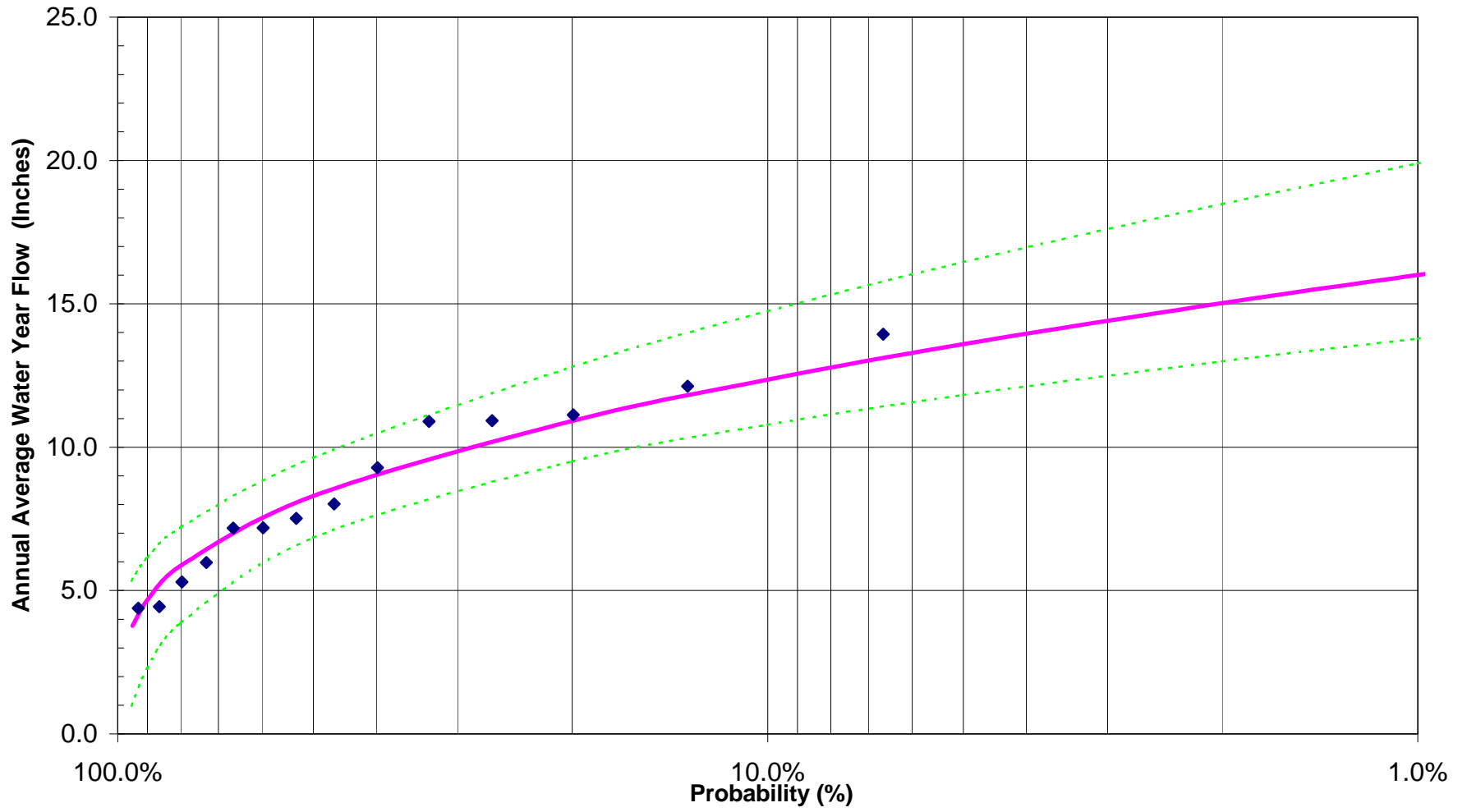
USGS 05338500 SNAKE RIVER NEAR PINE CITY, MN Annual Average Flow Frequency Analysis



USGS 05338500 SNAKE RIVER NEAR PINE CITY, MN Average Flow Frequency Analysis (1914-17,52-81,92-2002)

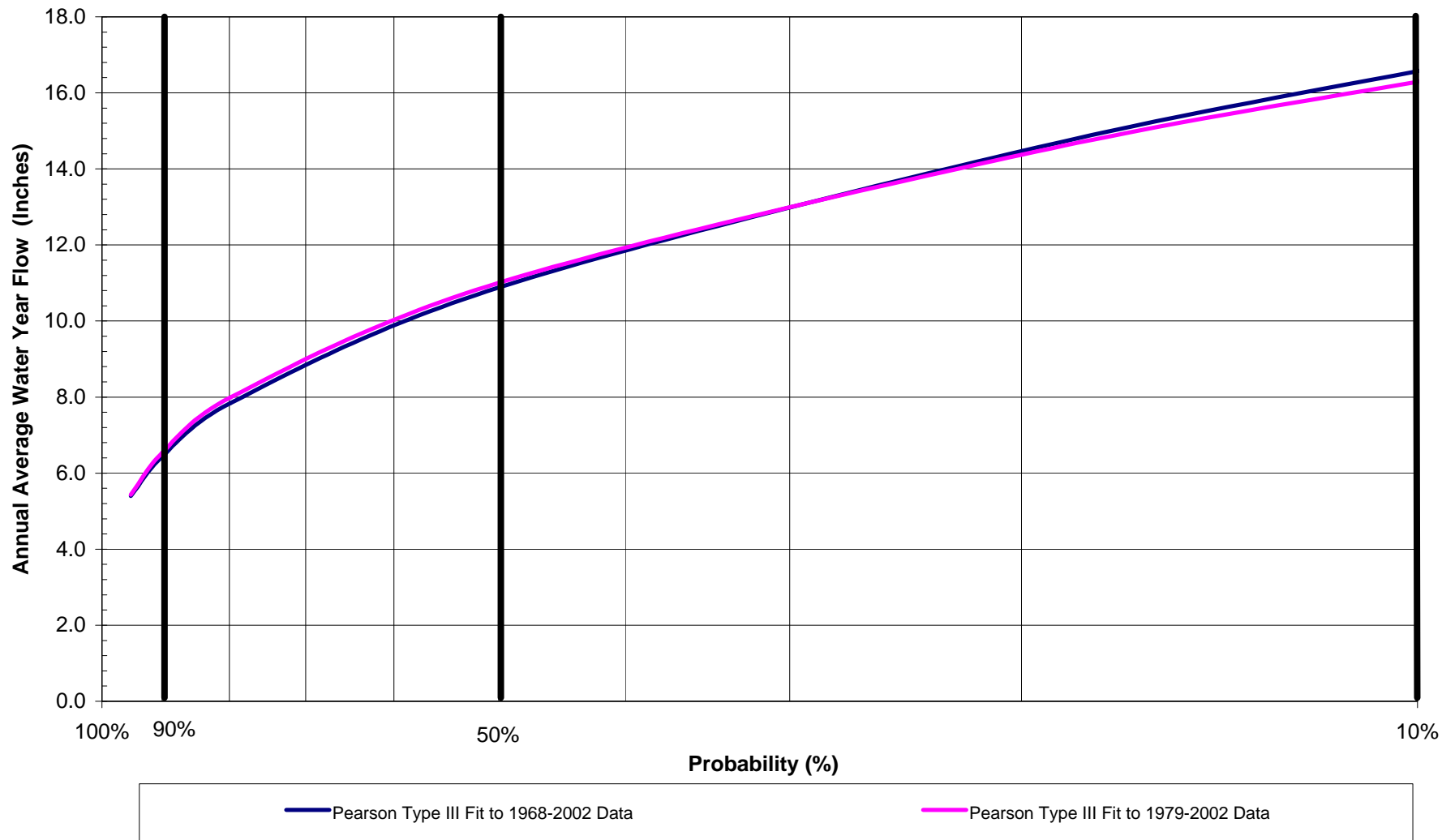


USGS 05338500 SNAKE RIVER NEAR PINE CITY, MN Average Flow Frequency Analysis (1979-1981&1992-2002)

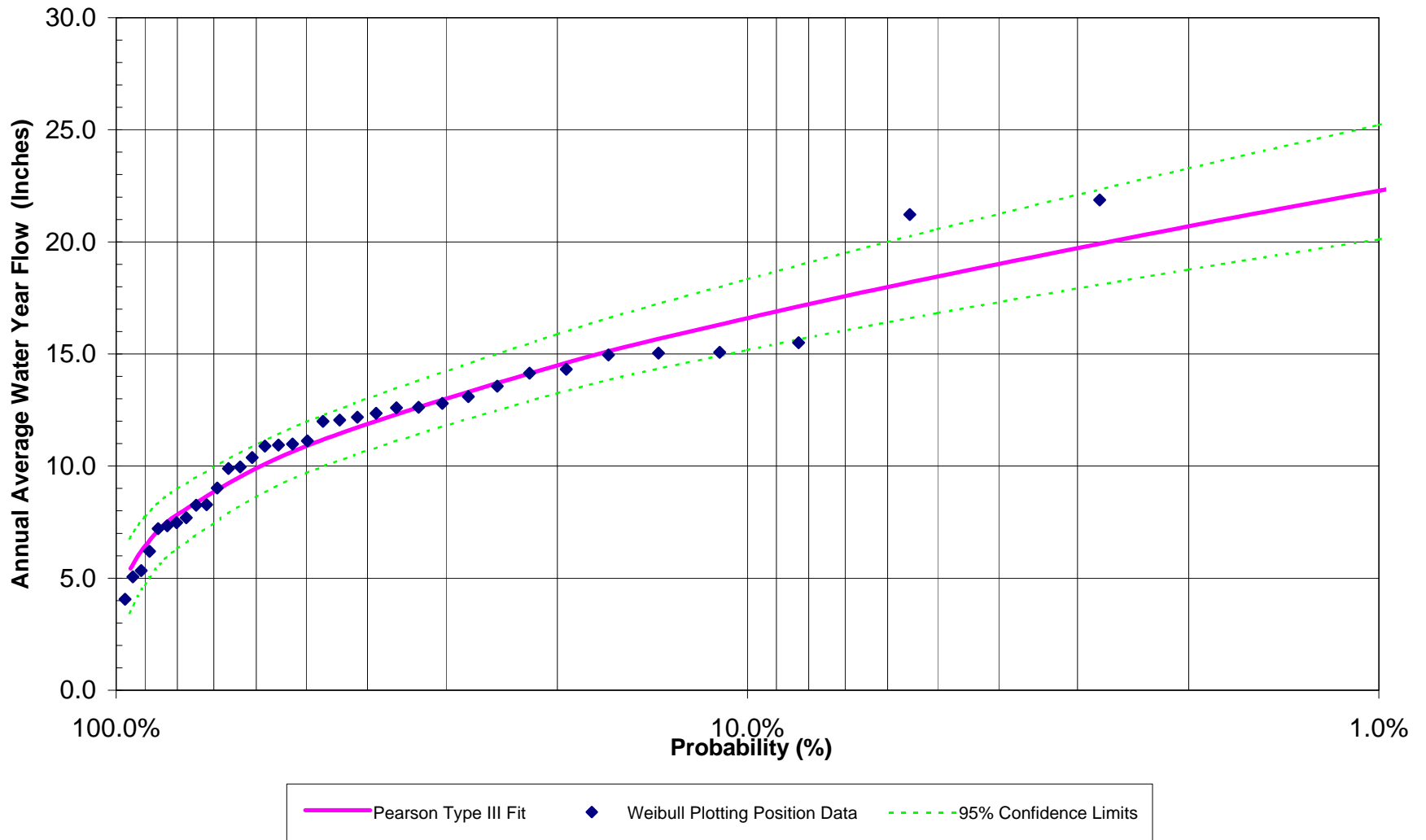


— Pearson Type III Fit ◆ Weibull Plotting Position Data - - - 95% Confidence Limits

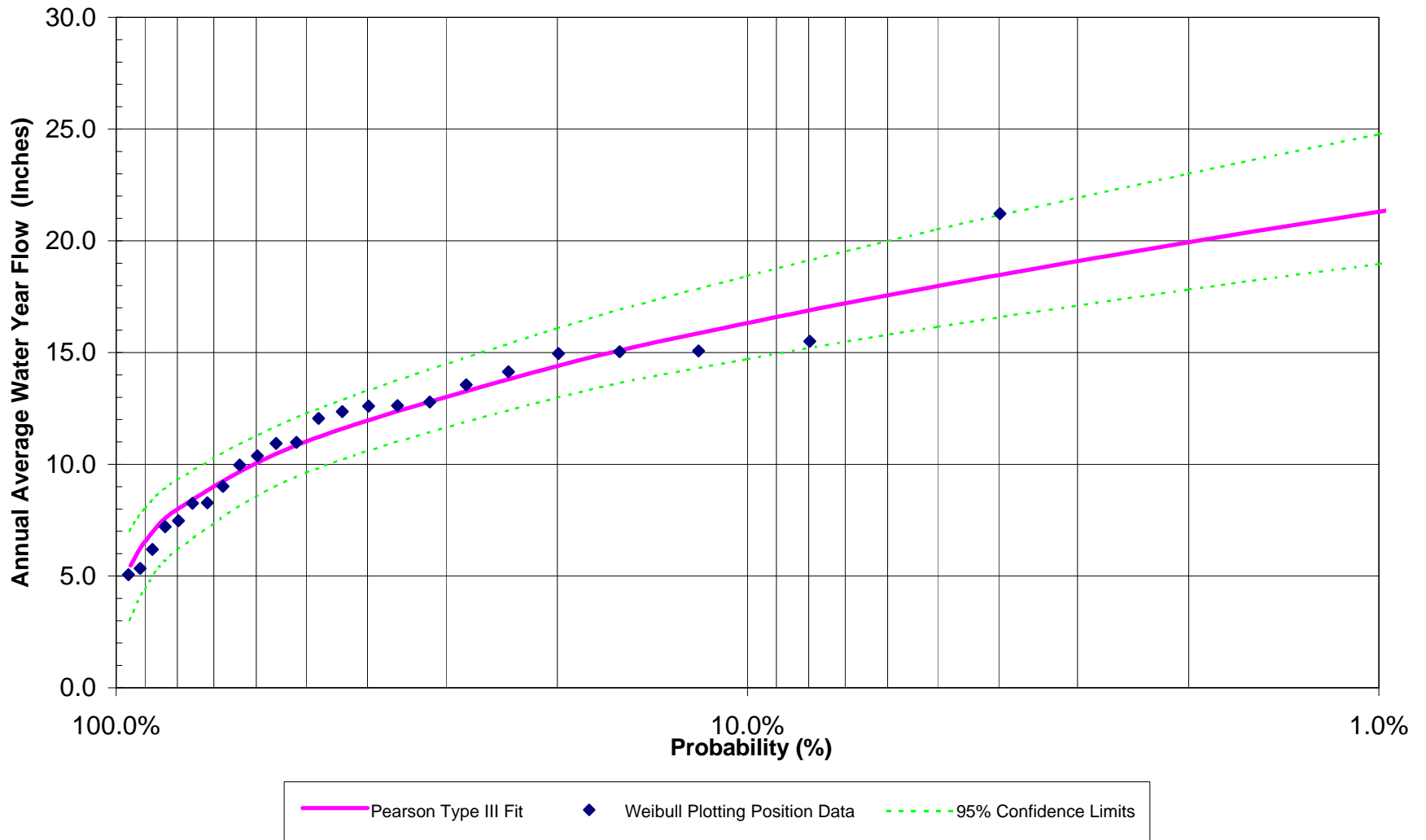
USGS 05336700 KETTLE RIVER BELOW SANDSTONE, MN Annual Average Flow Frequency Analysis



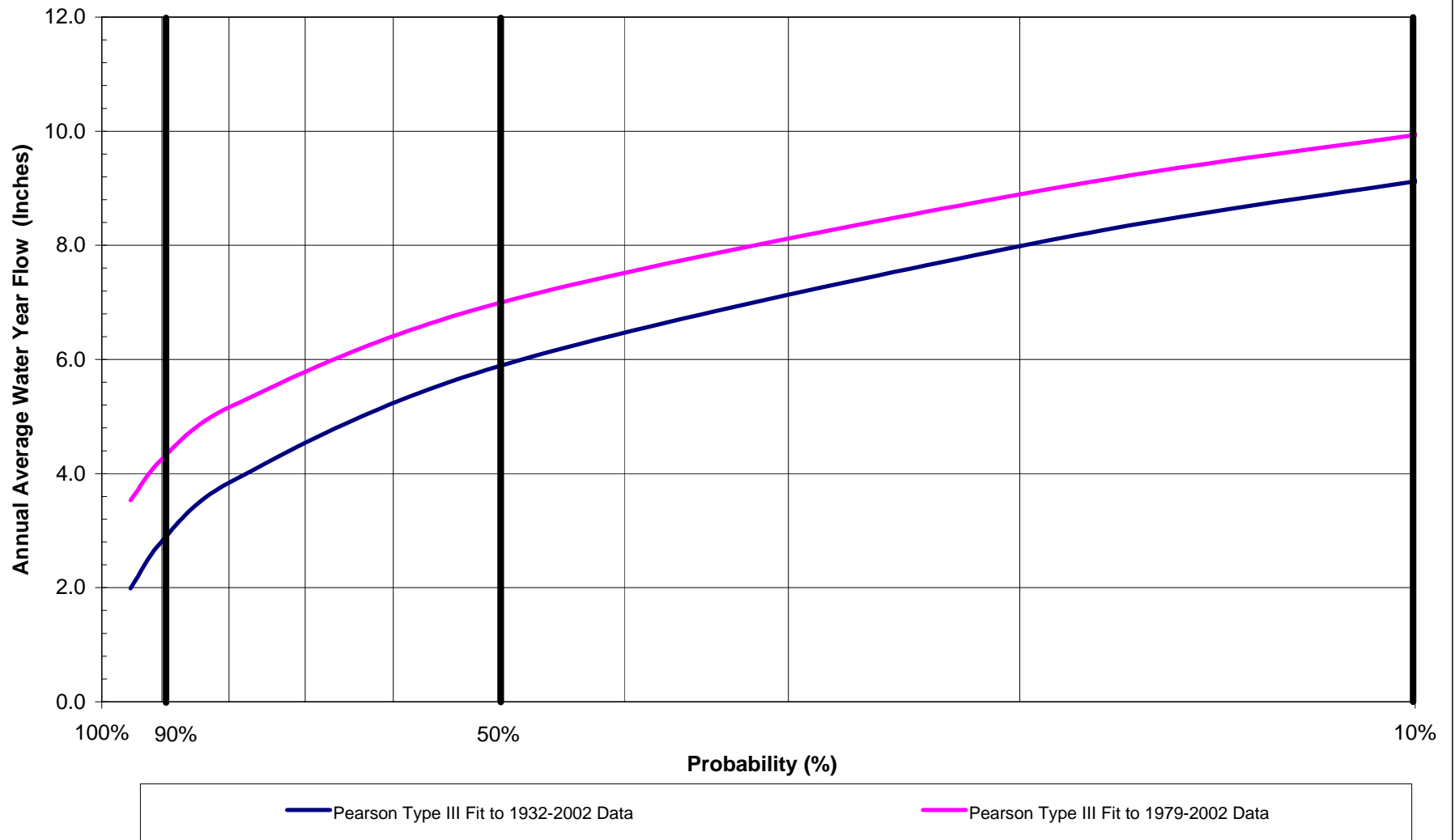
USGS 05336700 KETTLE RIVER BELOW SANDSTONE, MN Average Flow Frequency Analysis (1968-2002)



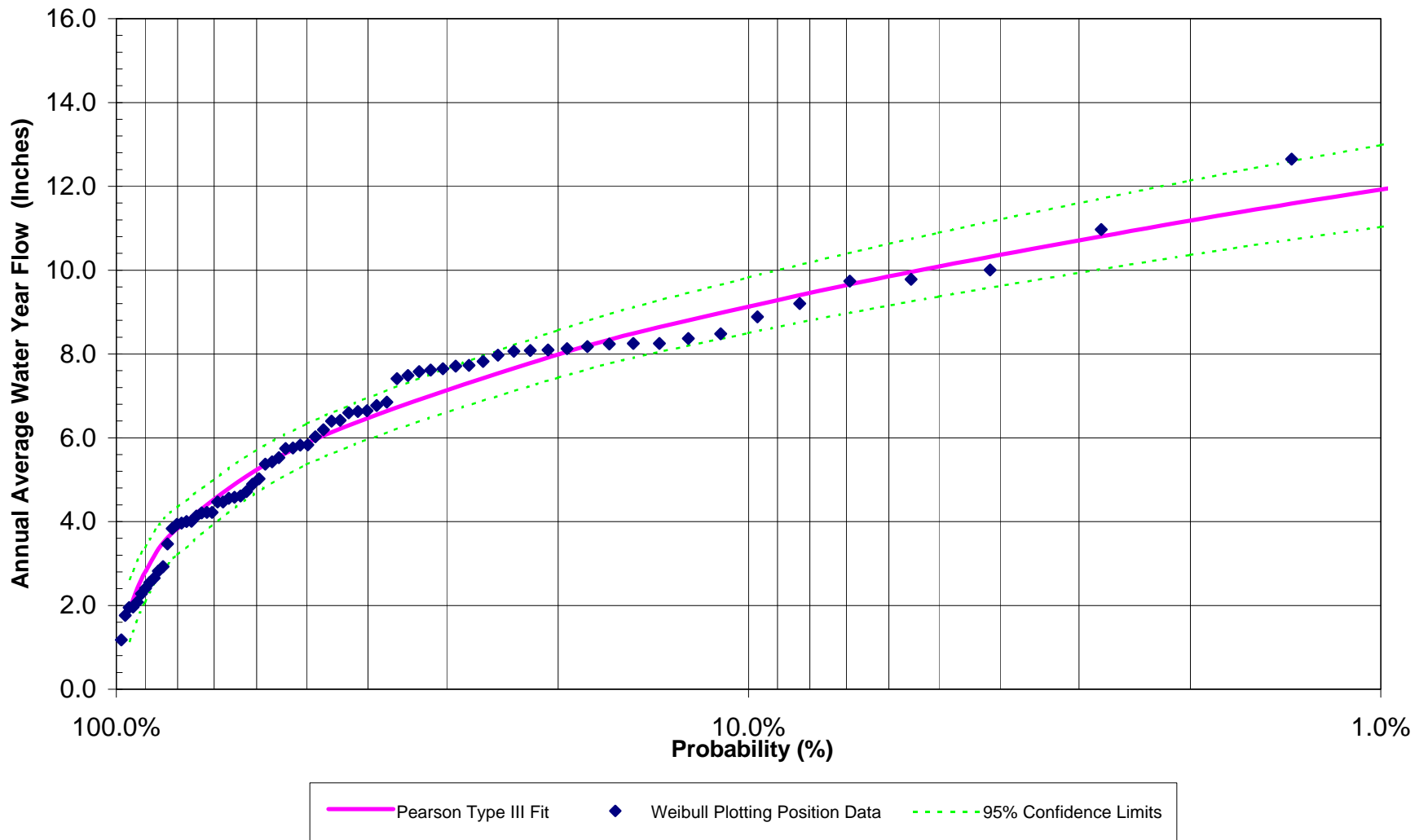
USGS 05336700 KETTLE RIVER BELOW SANDSTONE, MN Average Flow Frequency Analysis (1979-2002)



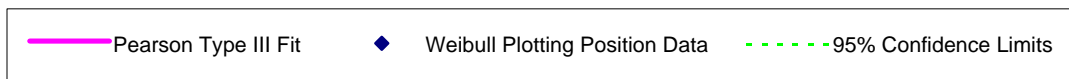
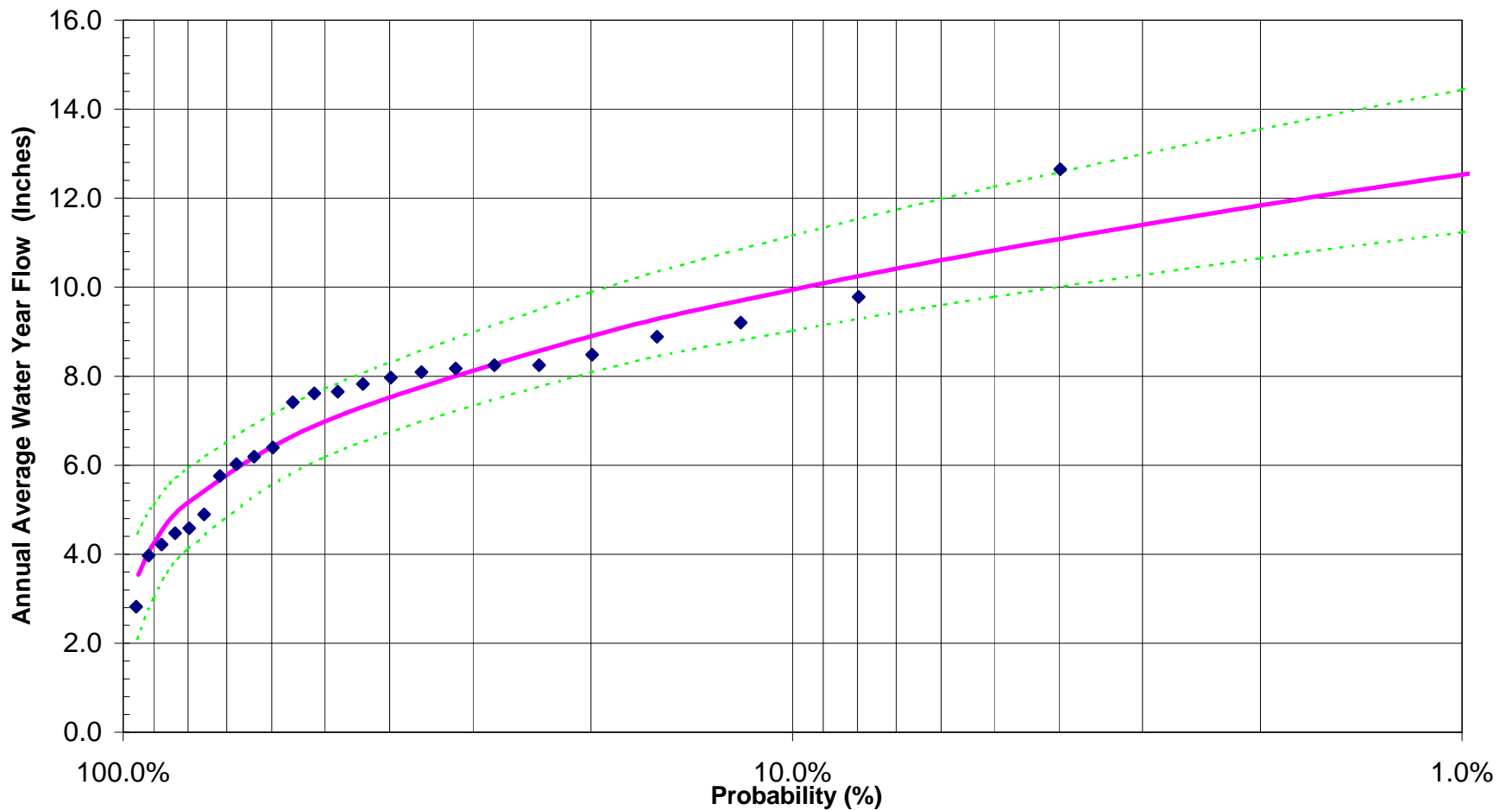
USGS 05288500 MISSISSIPPI RIVER NEAR ANOKA, MN Annual Average Flow Frequency Analysis



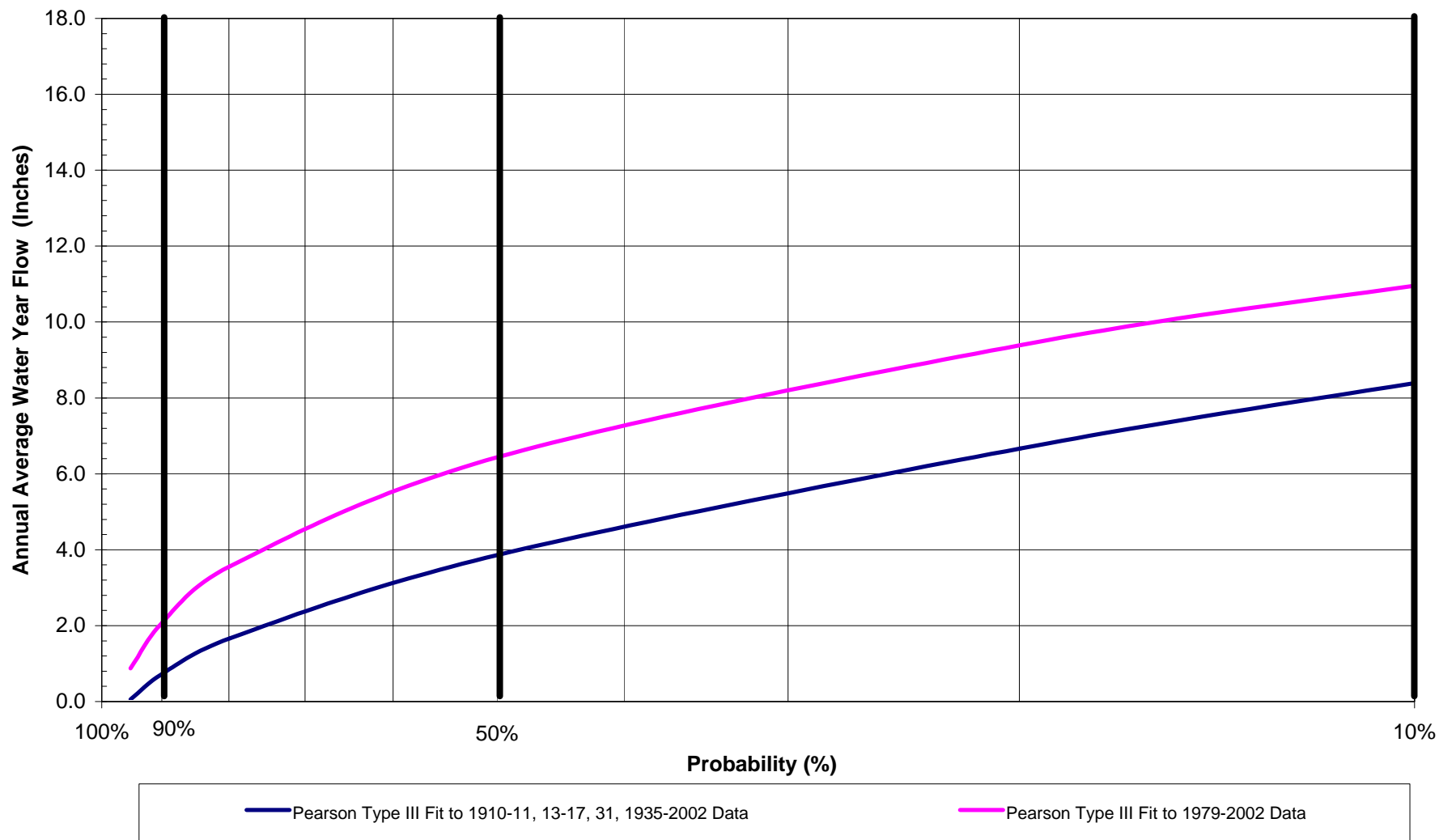
USGS 05288500 MISSISSIPPI RIVER NEAR ANOKA, MN Average Flow Frequency Analysis (1932-2002)



USGS 05288500 MISSISSIPPI RIVER NEAR ANOKA, MN Average Flow Frequency Analysis (1979-2002)

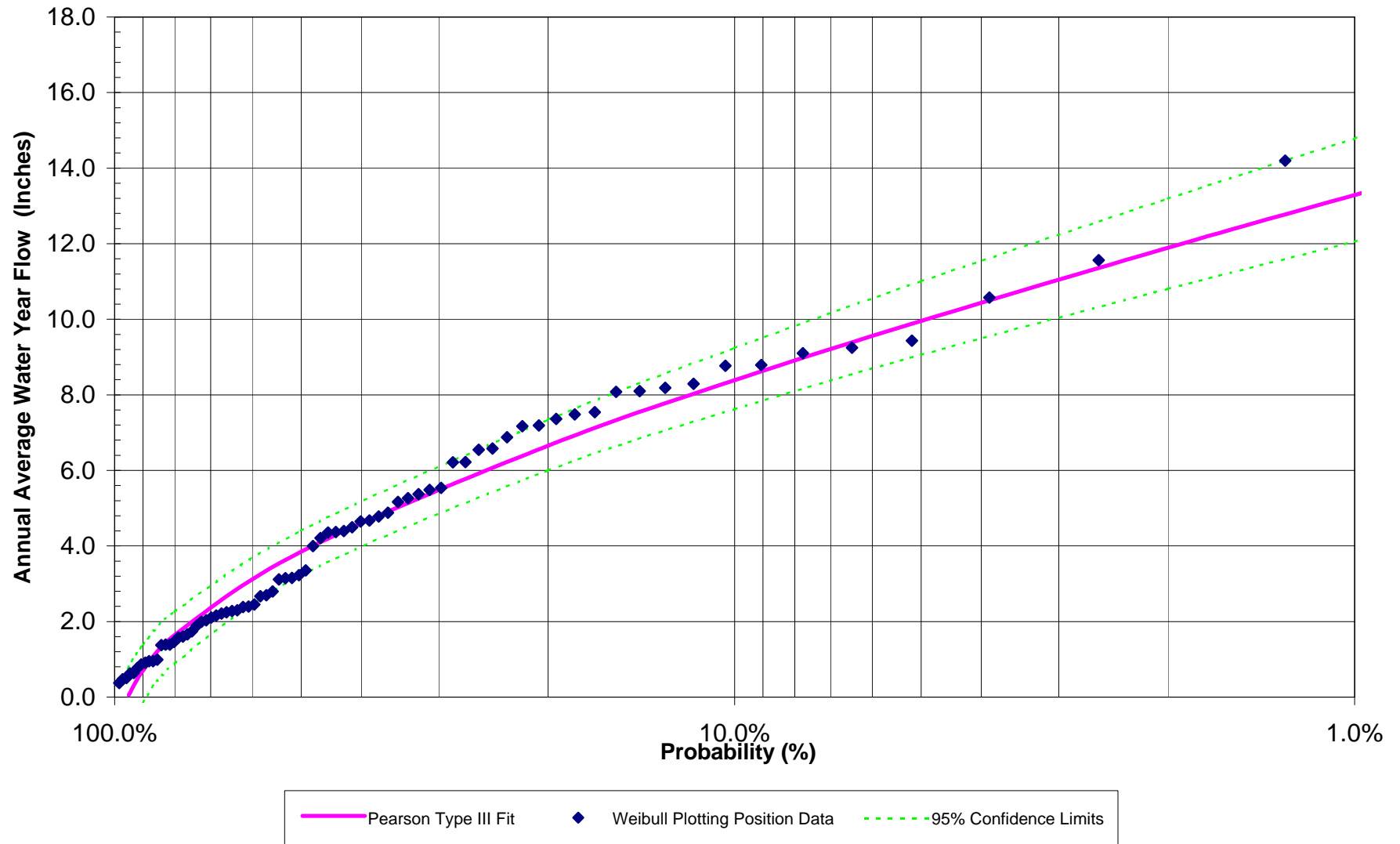


USGS 05280000 CROW RIVER AT ROCKFORD, MN Annual Average Flow Frequency Analysis

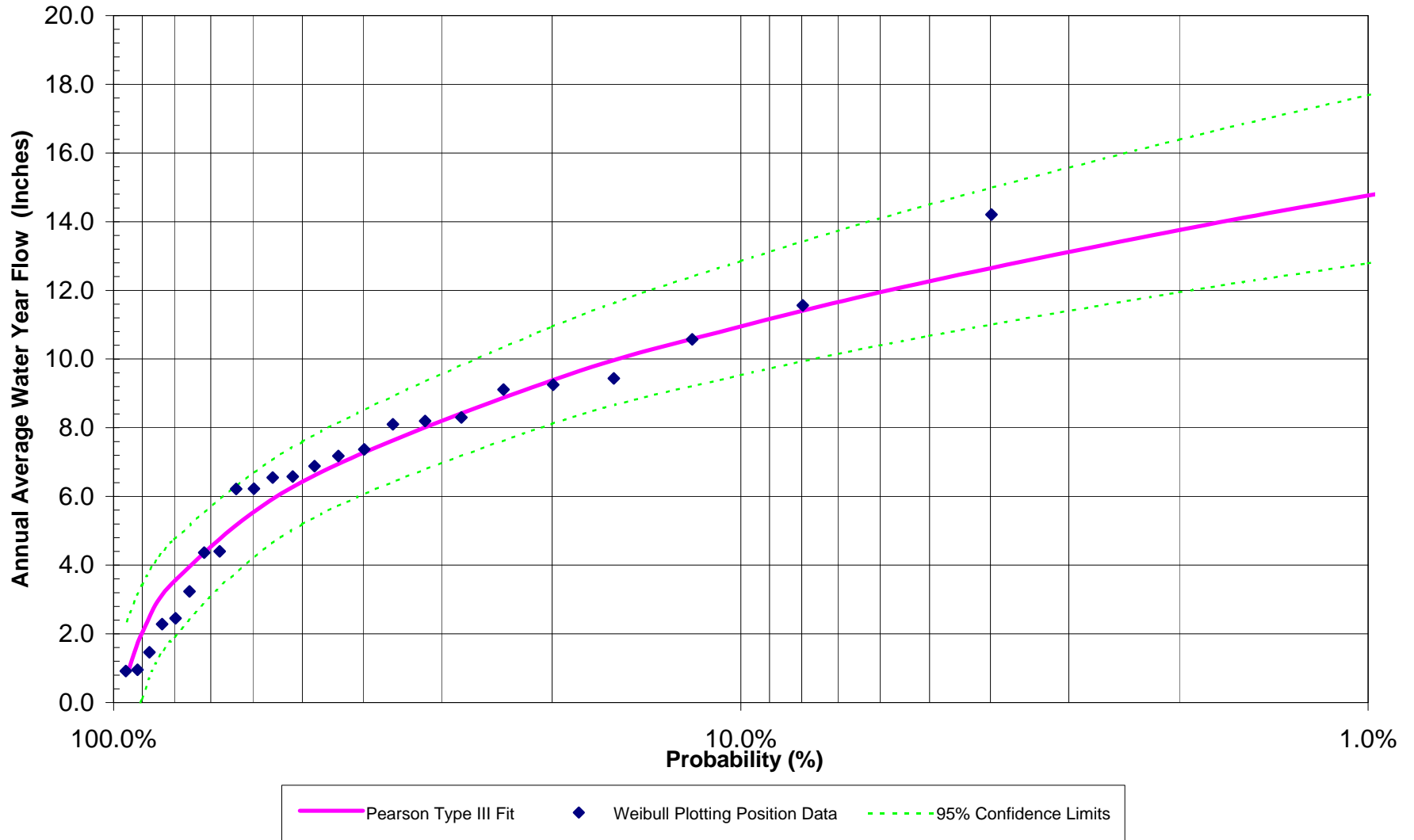


USGS 05280000 CROW RIVER AT ROCKFORD, MN

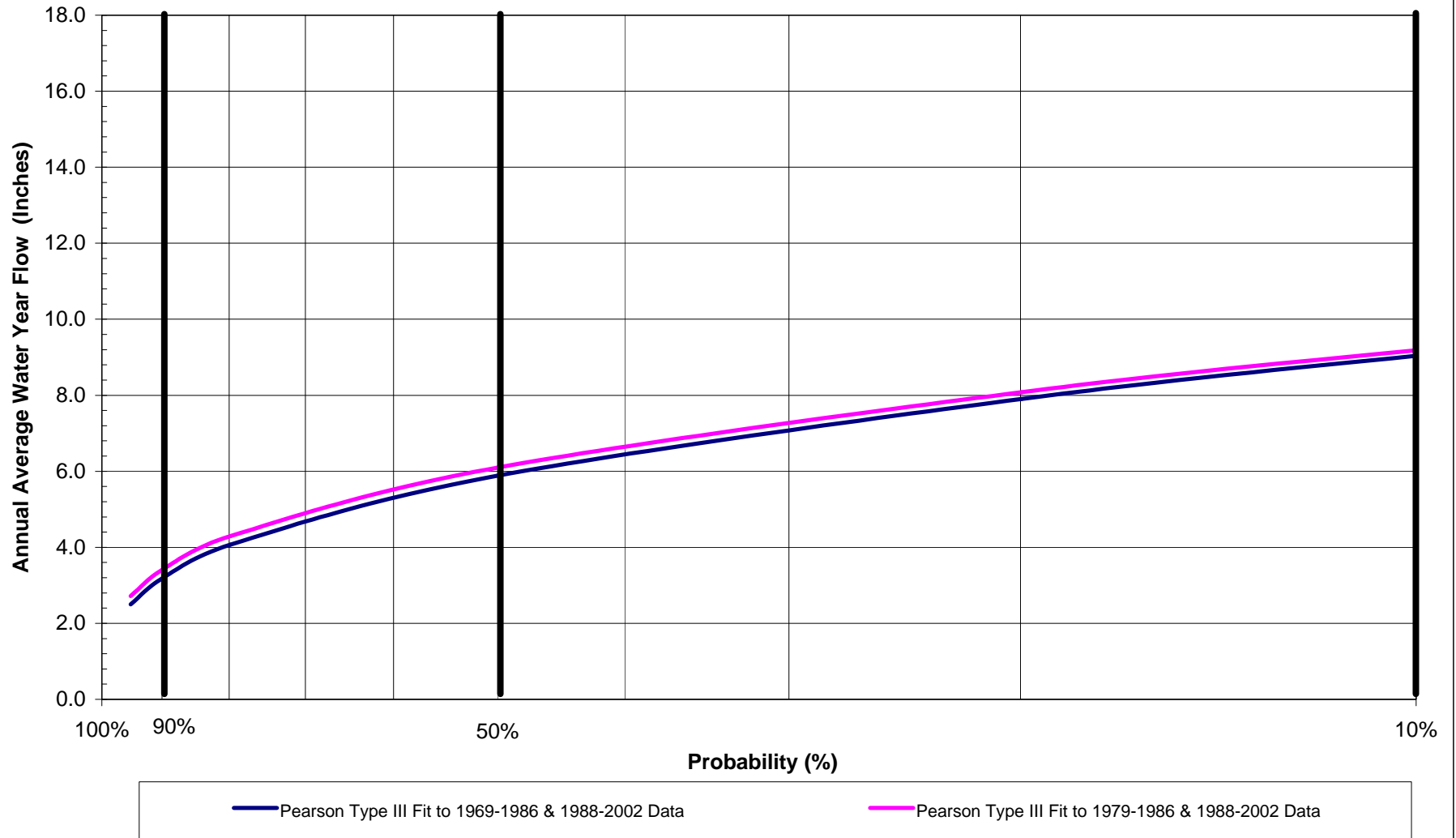
Average Flow Frequency Analysis (1910-11, 13-17, 31, 1935-2002)



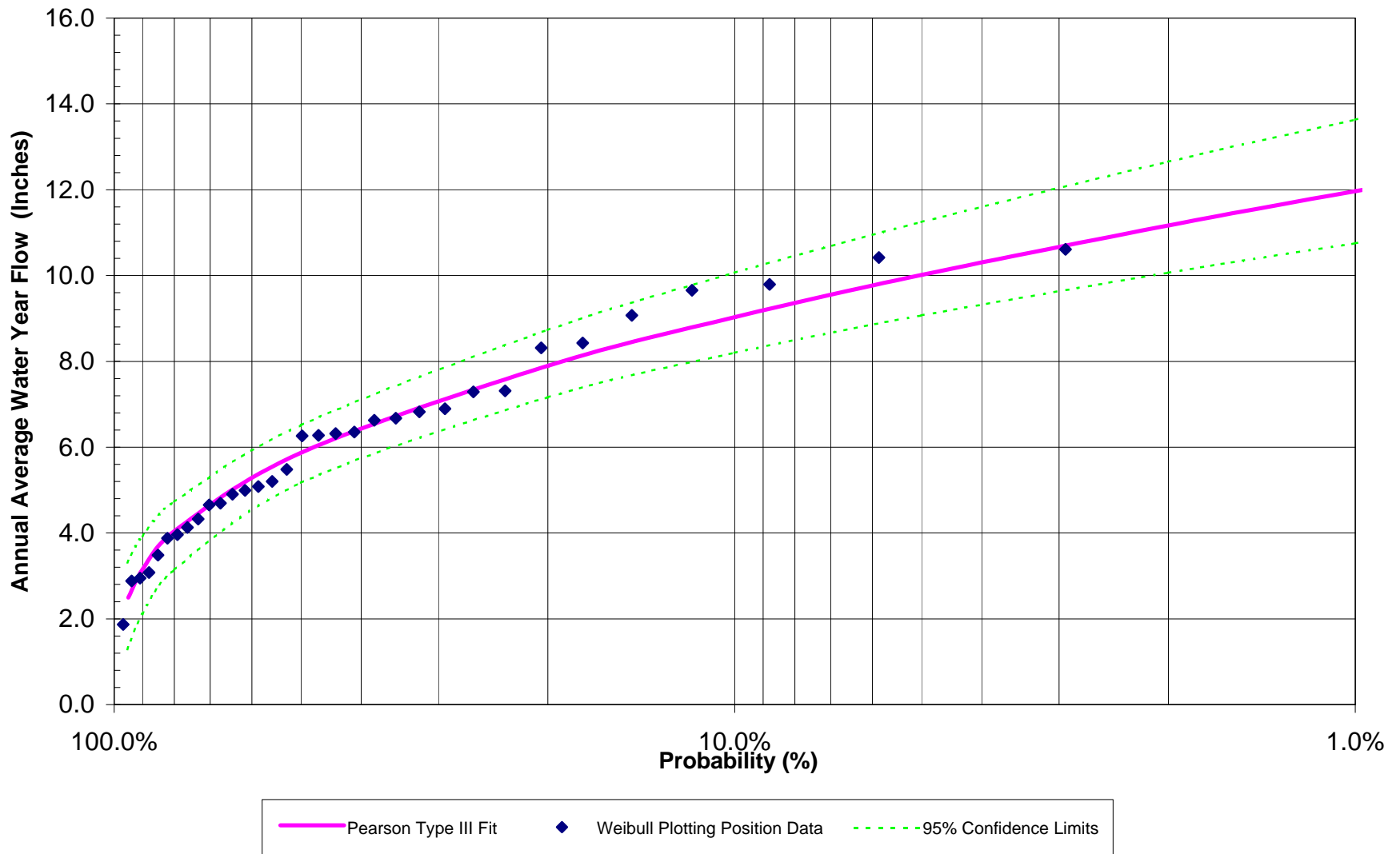
USGS 05280000 CROW RIVER AT ROCKFORD, MN Average Flow Frequency Analysis (1979-2002)



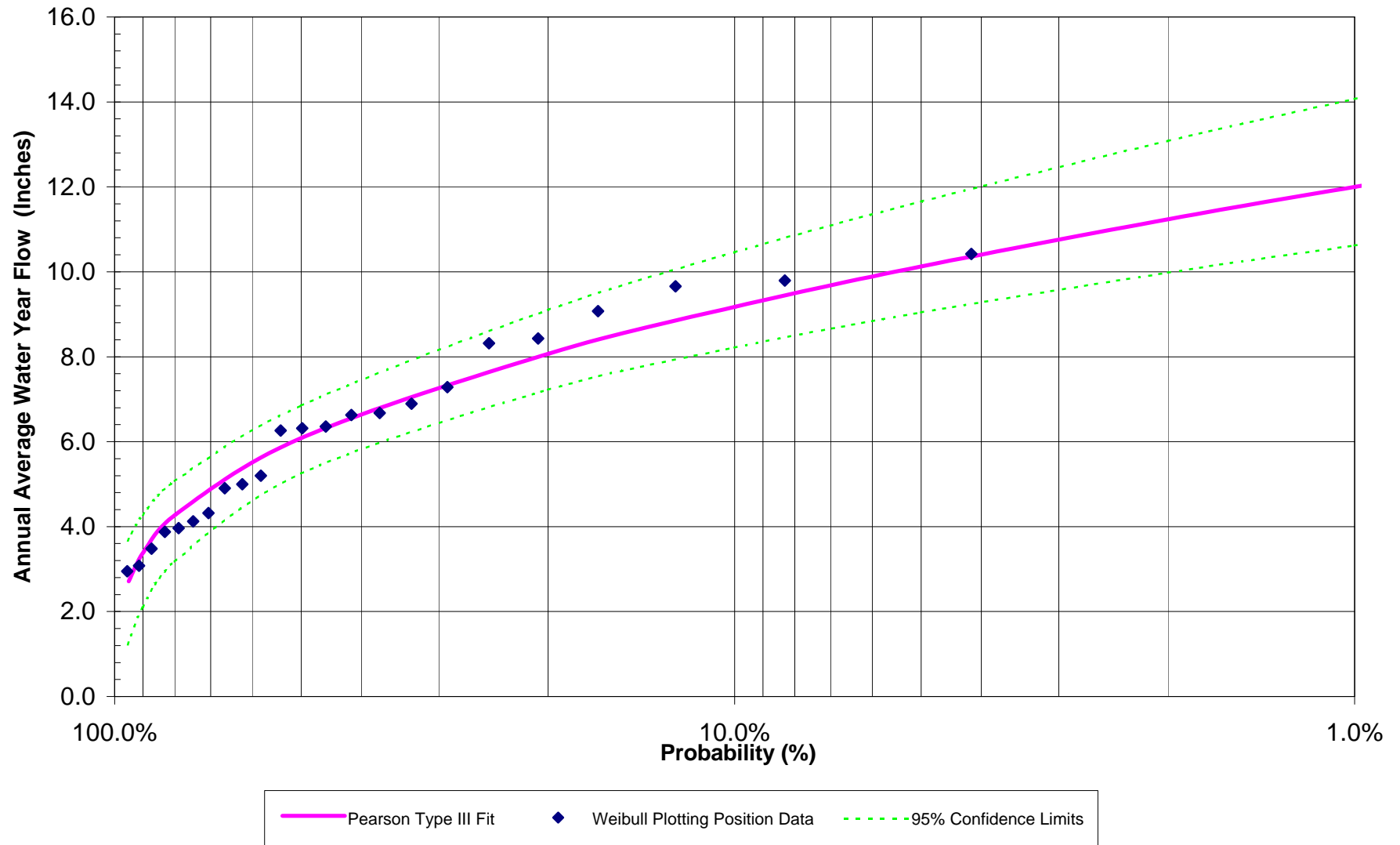
USGS 05247500 CROW WING RIVER NEAR PILLAGER, MN Annual Average Flow Frequency Analysis



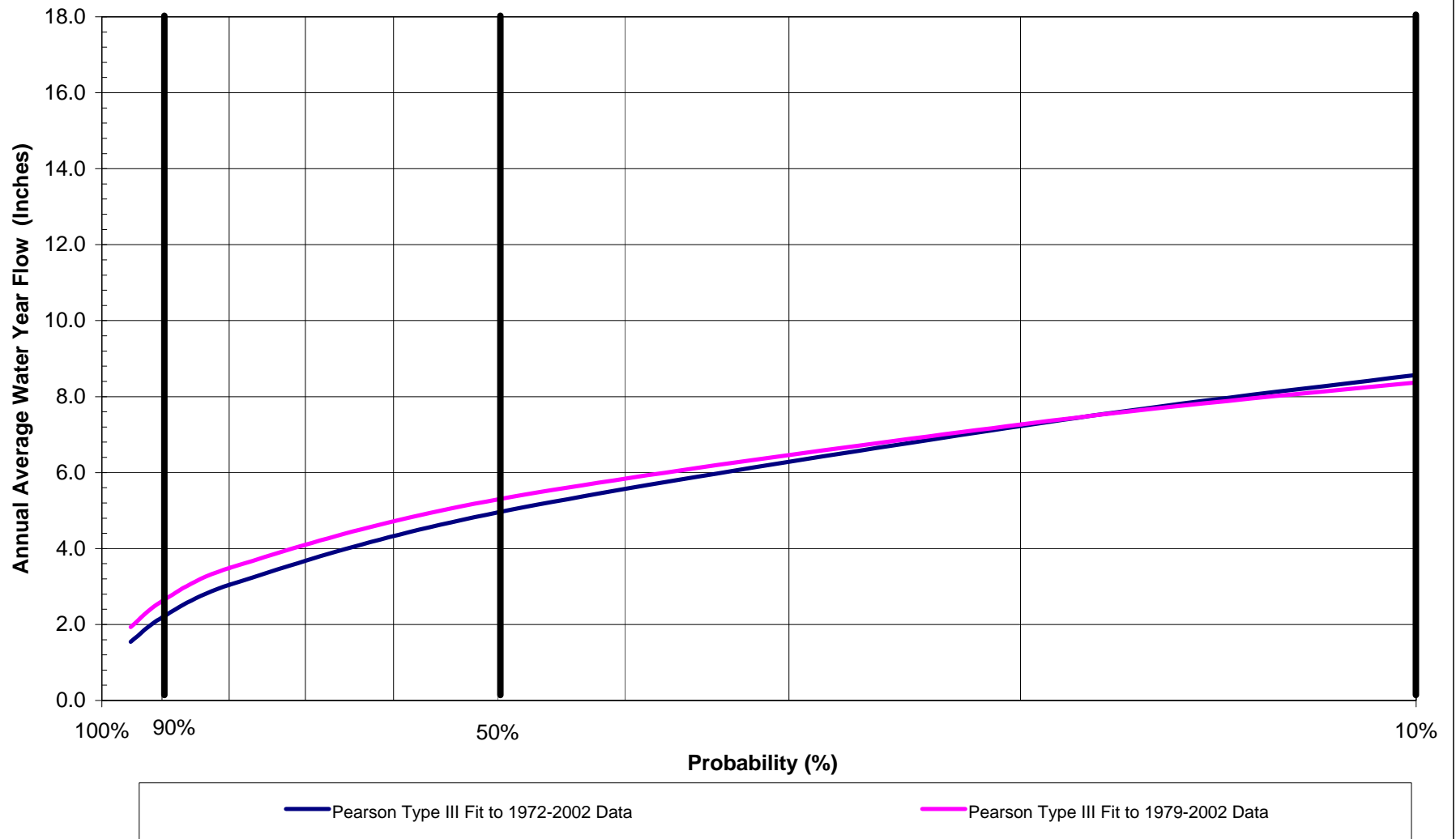
USGS 05247500 CROW WING RIVER NEAR PILLAGER, MN Average Flow Frequency Analysis (1969-1986&1988-2002)



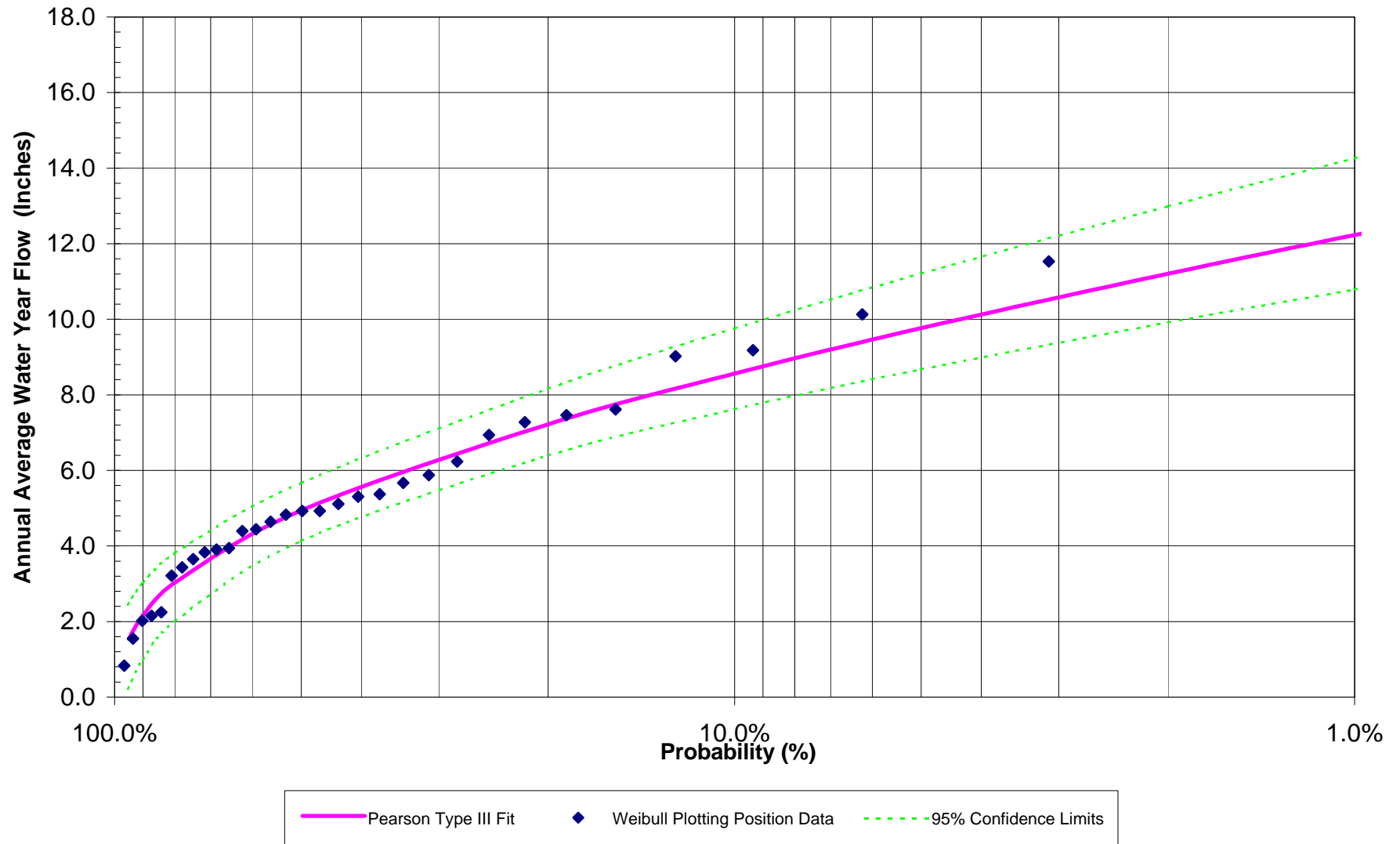
USGS 05247500 CROW WING RIVER NEAR PILLAGER, MN Average Flow Frequency Analysis (1979-1986&1988-2002)



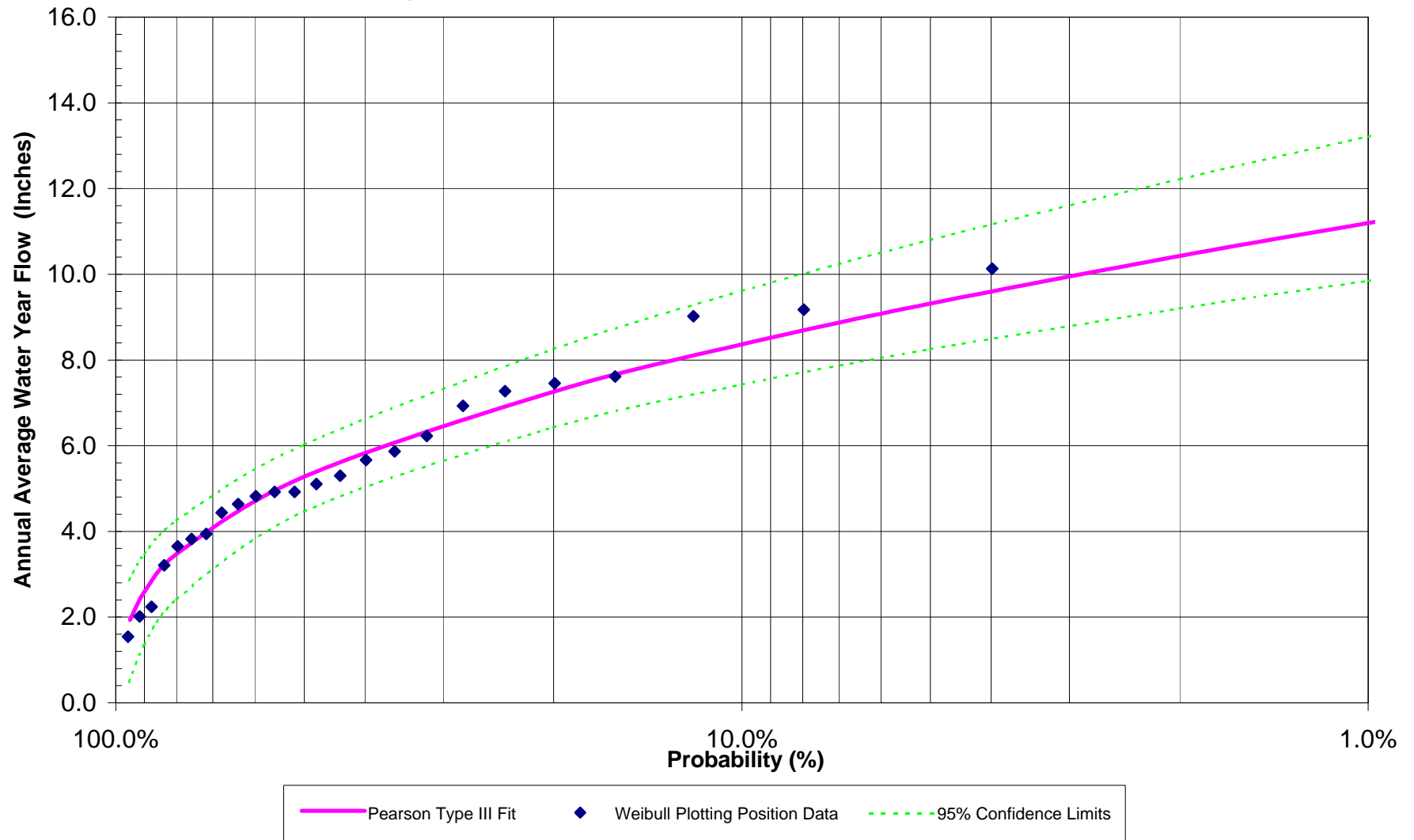
USGS 05245100 LONG PRAIRIE RIVER AT LONG PRAIRIE, MN Annual Average Flow Frequency Analysis



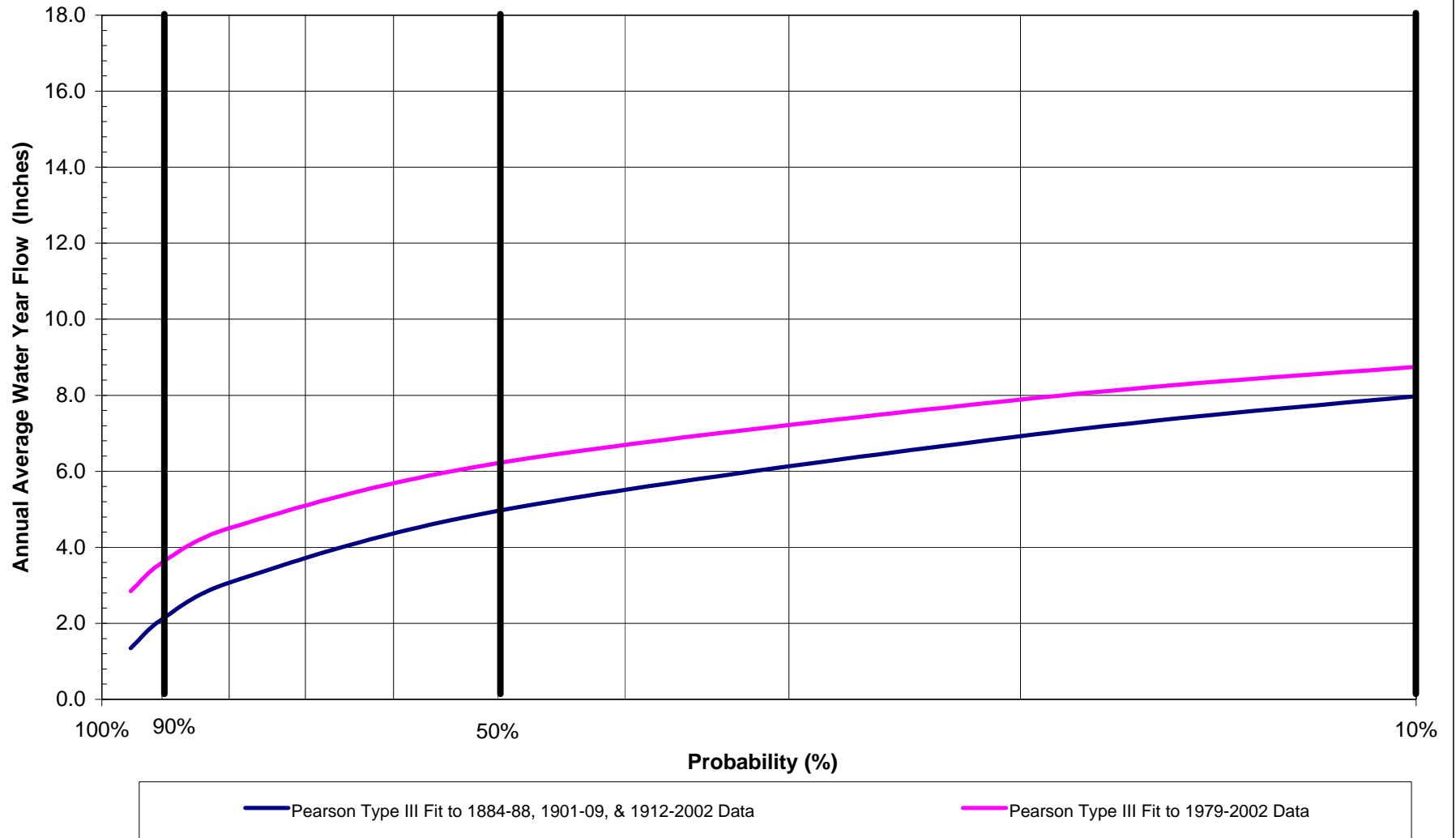
USGS 05245100 LONG PRAIRIE RIVER AT LONG PRAIRIE, MN Average Flow Frequency Analysis (1972-2002)



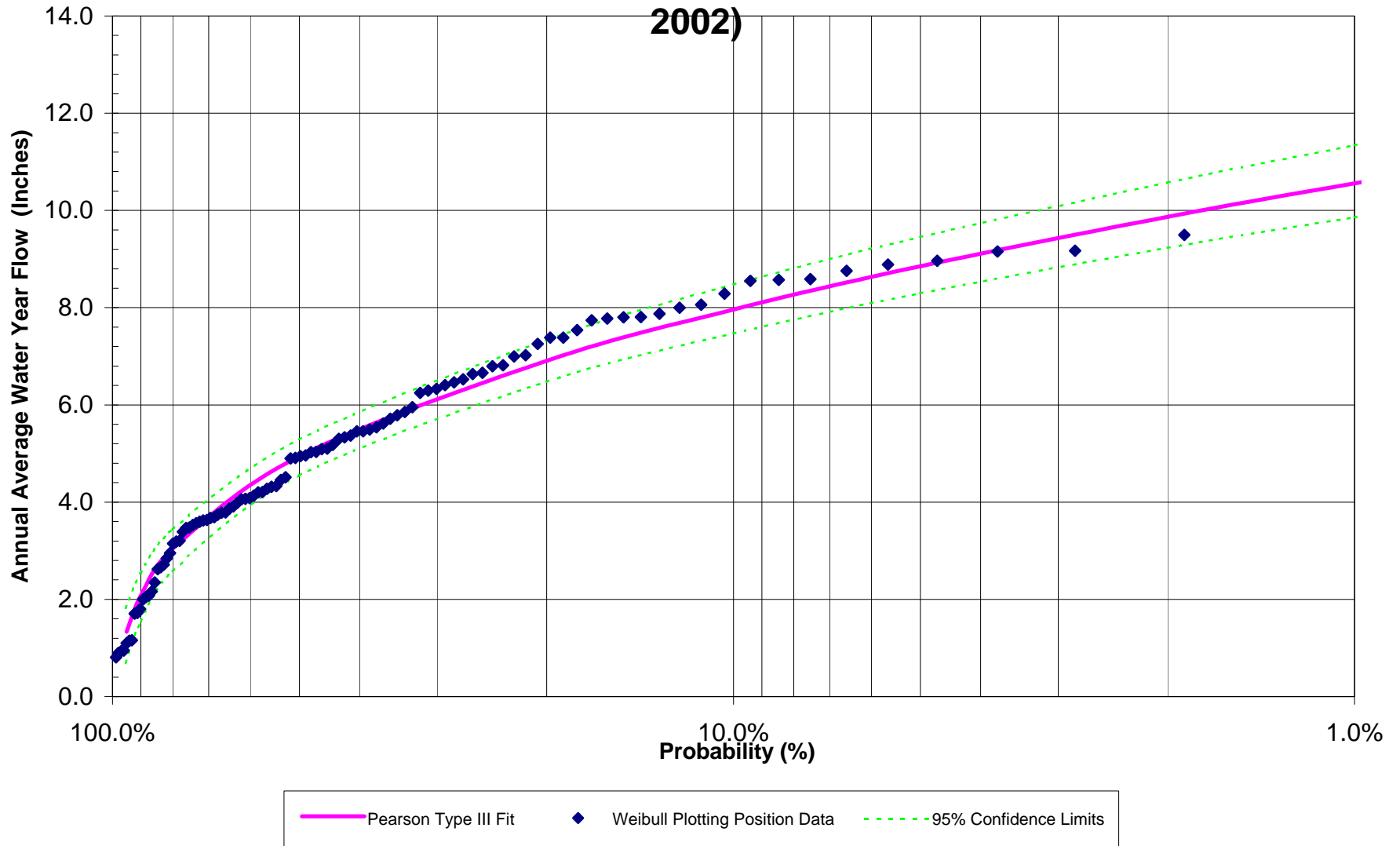
USGS 05245100 LONG PRAIRIE RIVER AT LONG PRAIRIE, MN Average Flow Frequency Analysis (1979-2002)



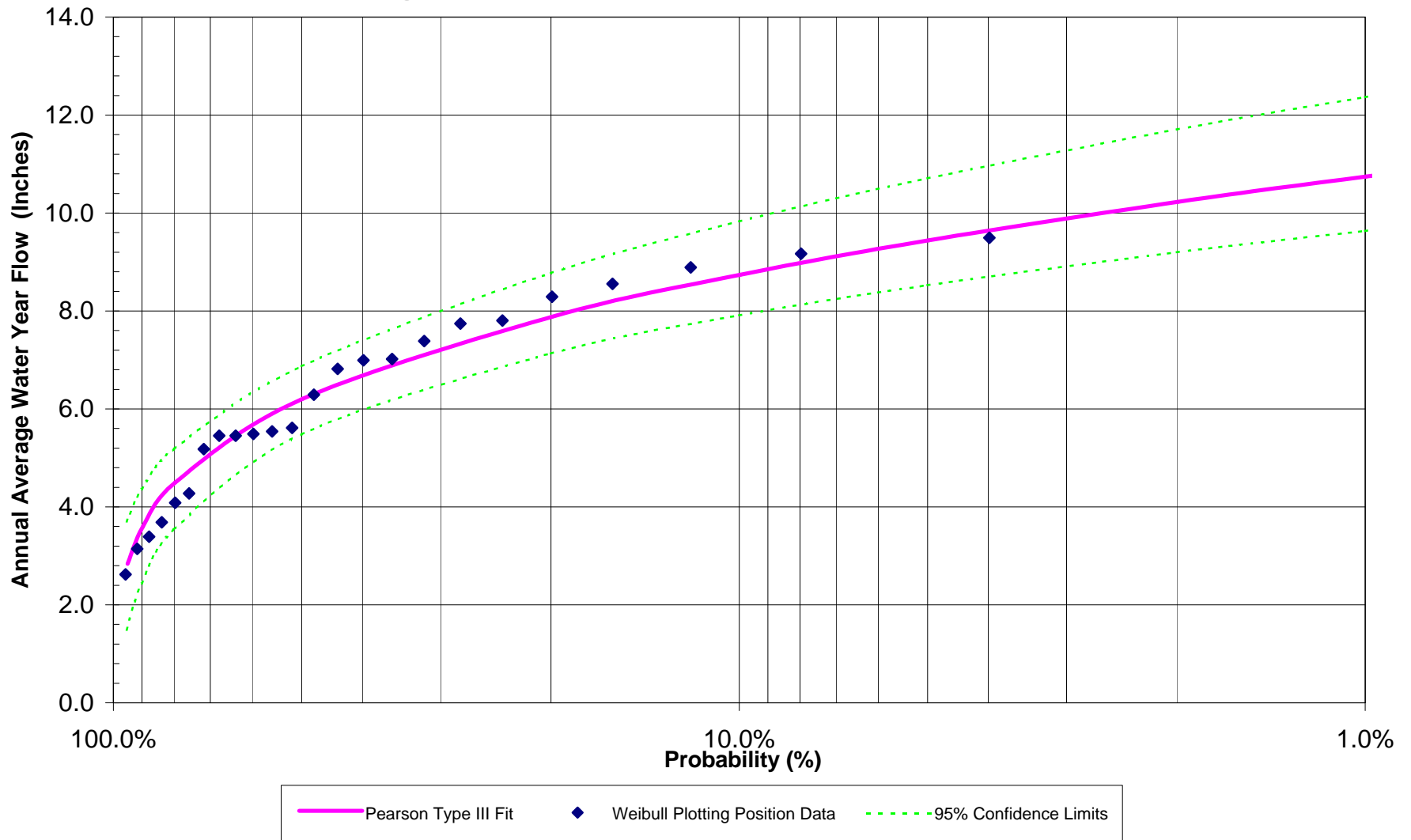
USGS 05211000 MISSISSIPPI RIVER AT GRAND RAPIDS, MN Annual Average Flow Frequency Analysis



USGS 05211000 MISSISSIPPI RIVER AT GRAND RAPIDS, MN Average Flow Frequency Analysis (1884-88, 1901-09, & 1912- 2002)

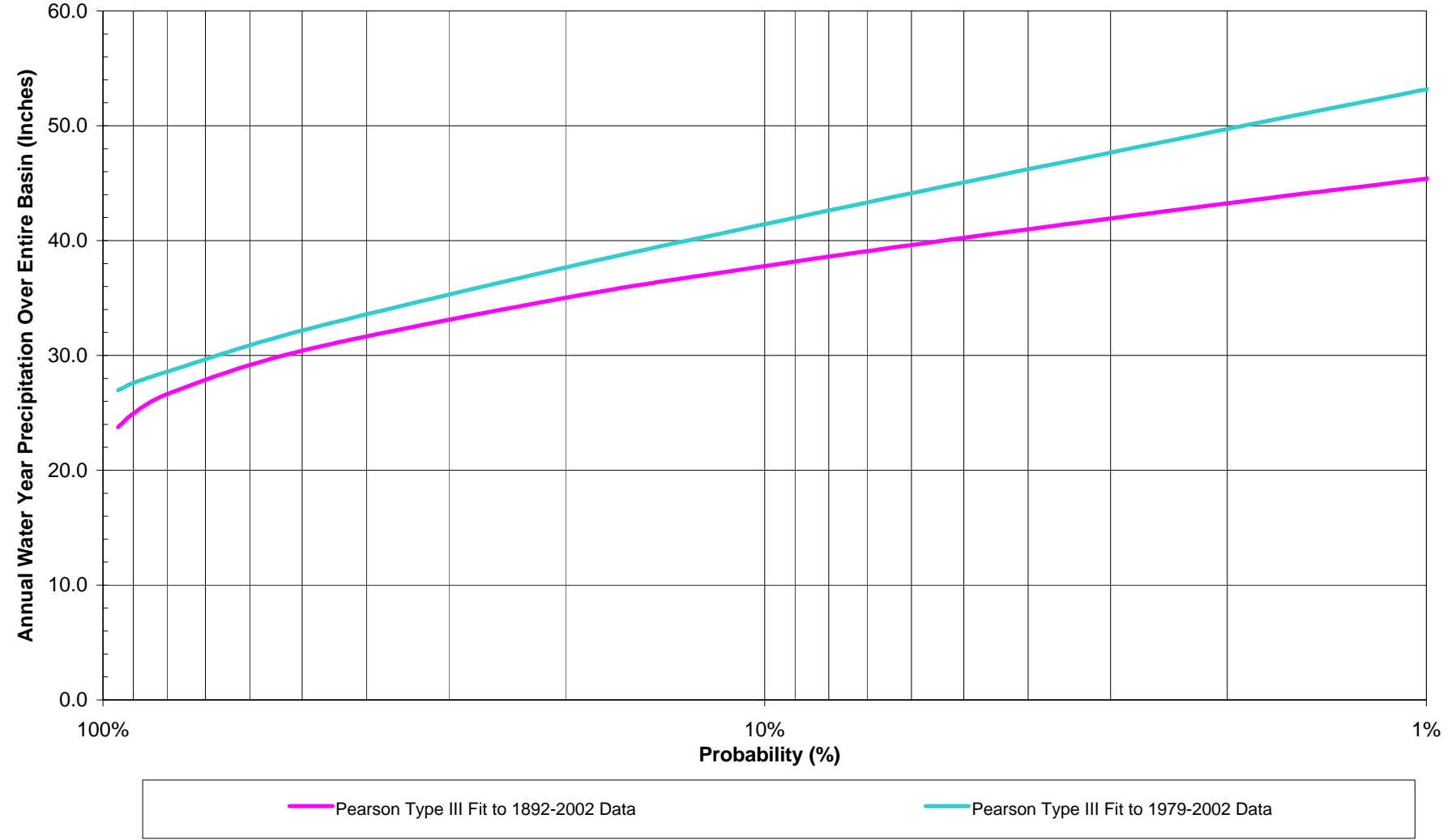


USGS 05211000 MISSISSIPPI RIVER AT GRAND RAPIDS, MN Average Flow Frequency Analysis (1979-2002)

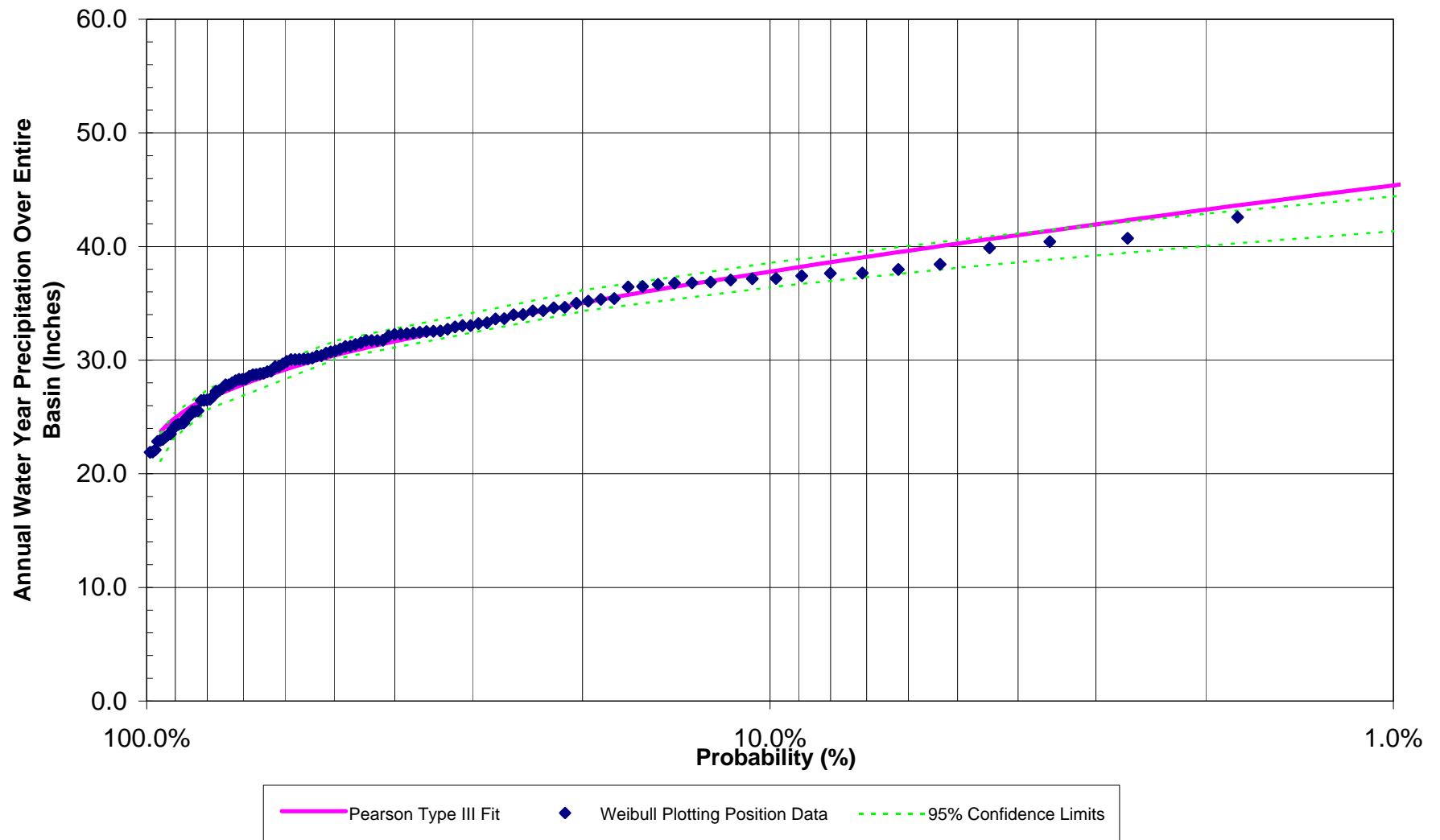


Appendix B: Precipitation – Frequency Curves

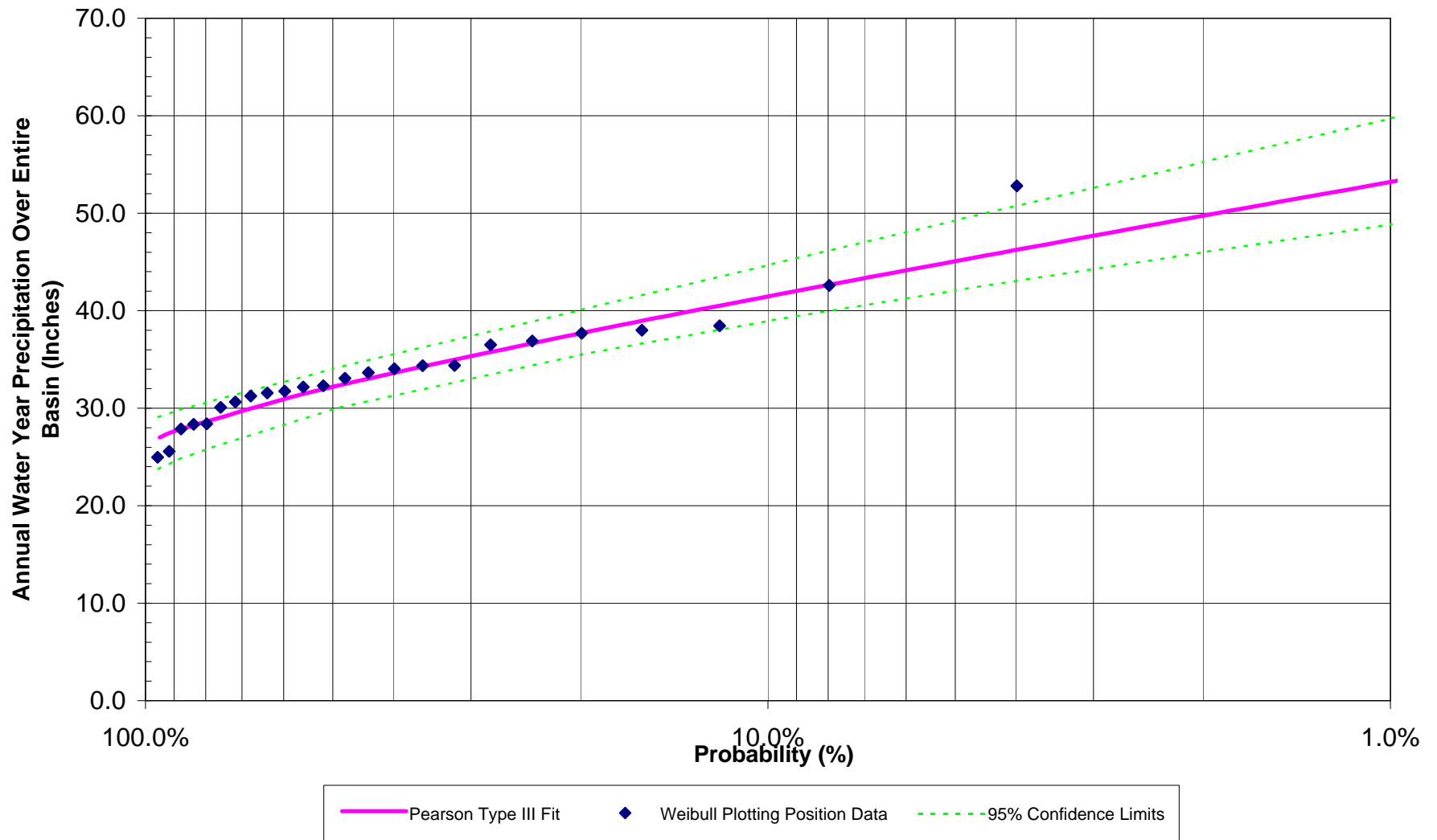
Cedar River Basin Precipitation Frequency Analysis



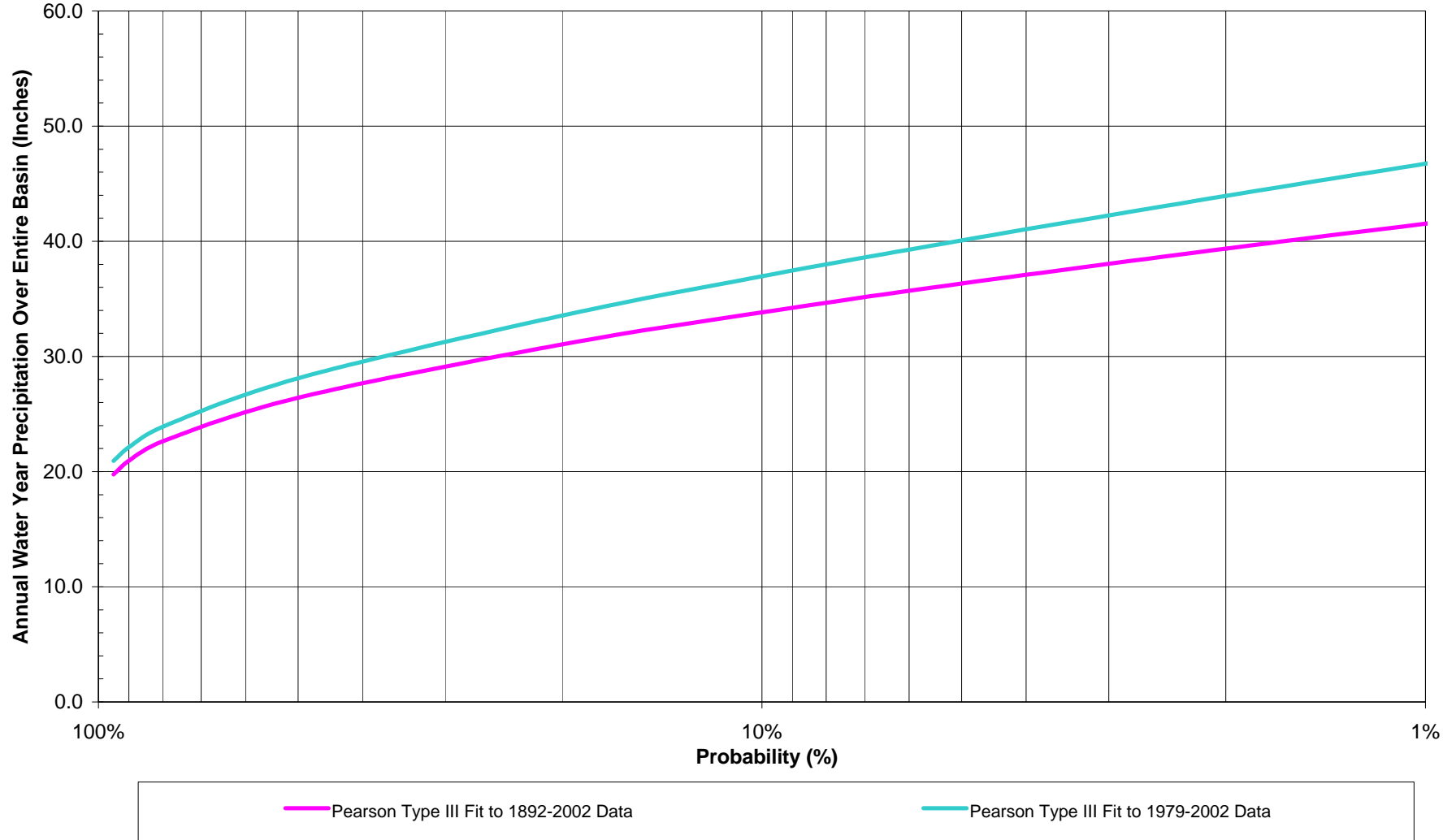
Cedar River Basin Precipitation Frequency Analysis (1892-2002)



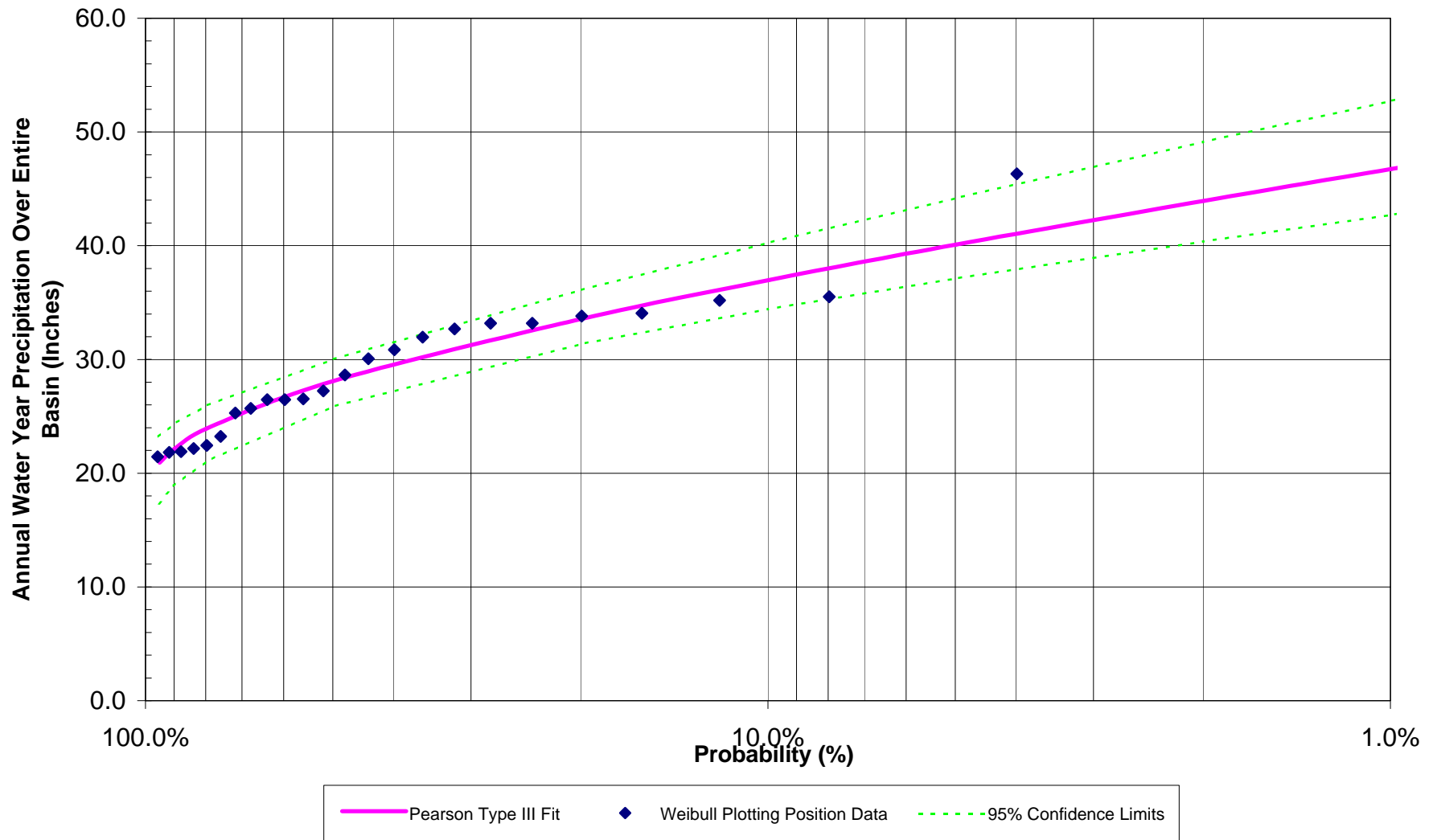
Cedar River Basin Precipitation Frequency Analysis (1979-2002)



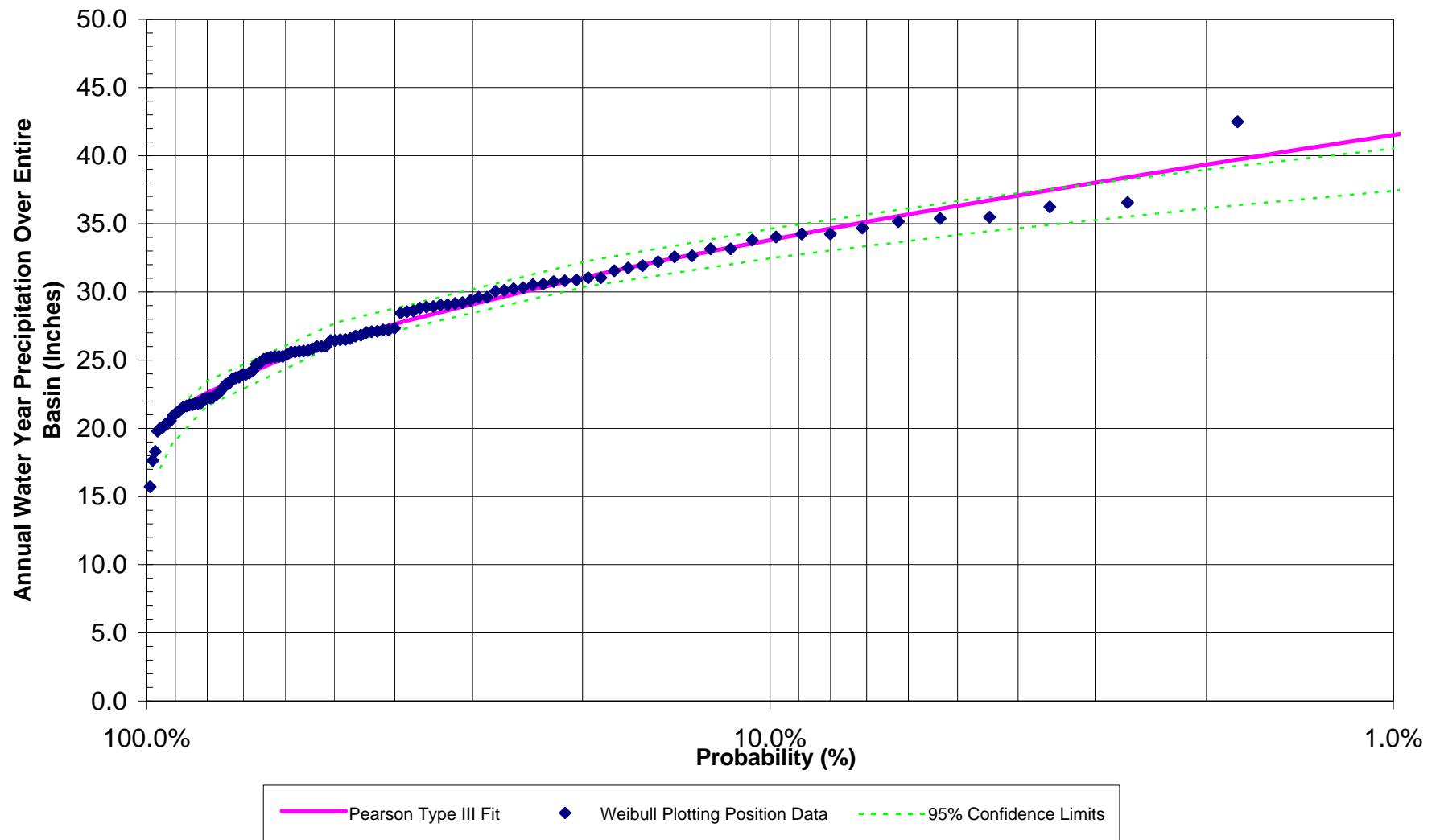
DesMoines River Basin Precipitation Frequency Analysis



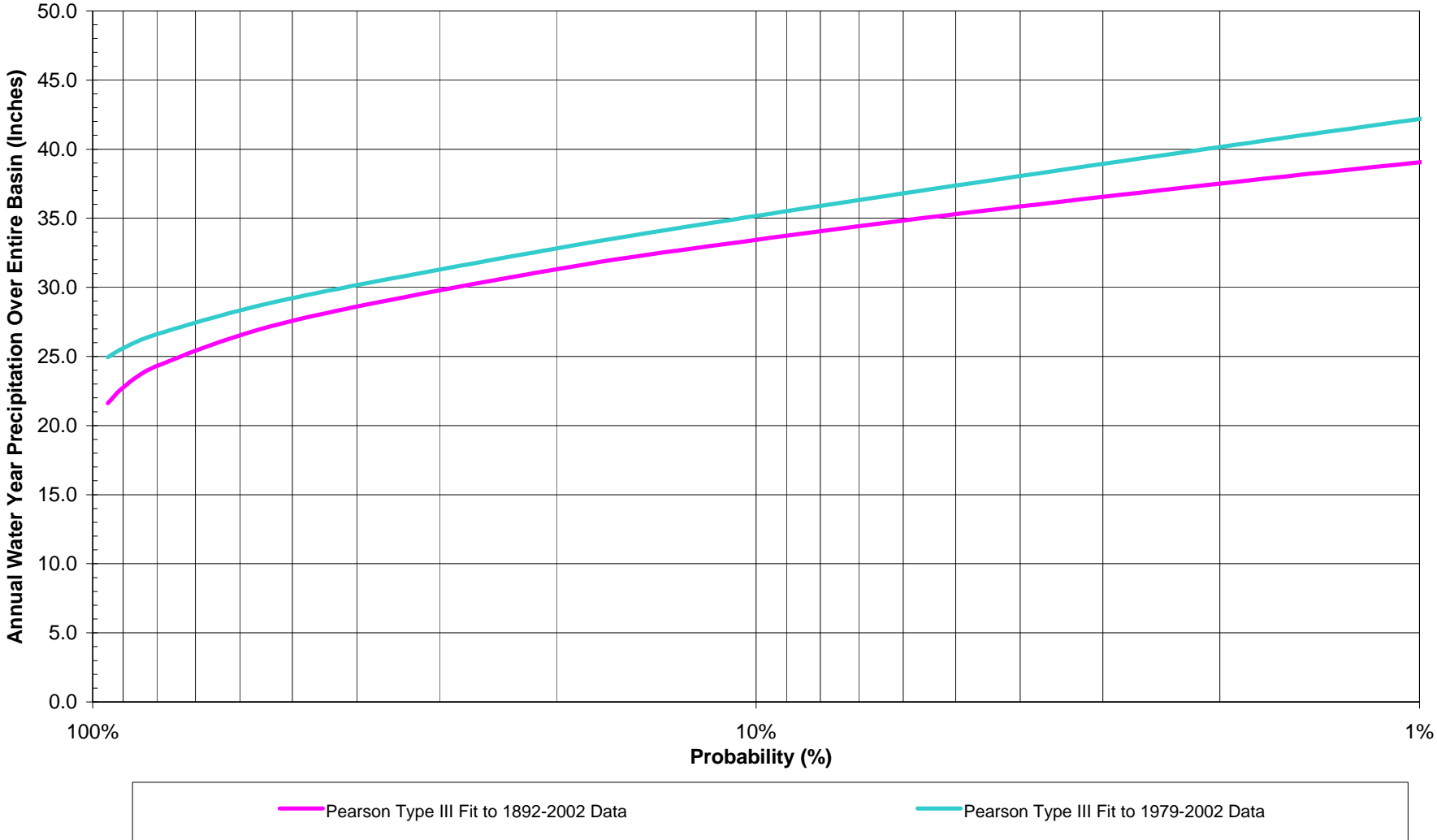
DesMoines River Basin Precipitation Frequency Analysis (1979-2002)



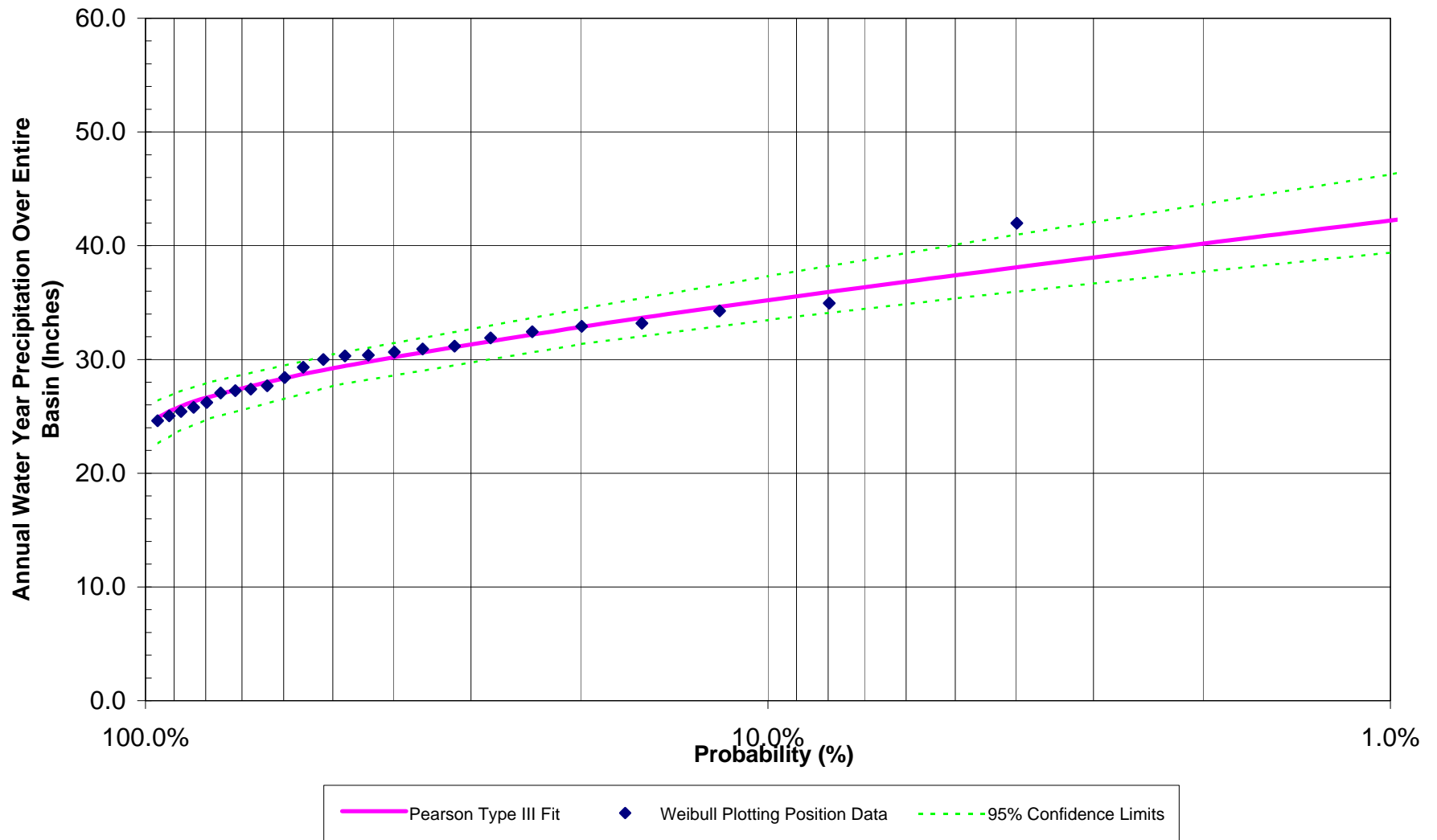
DesMoines River Basin Precipitation Frequency Analysis (1892-2002)



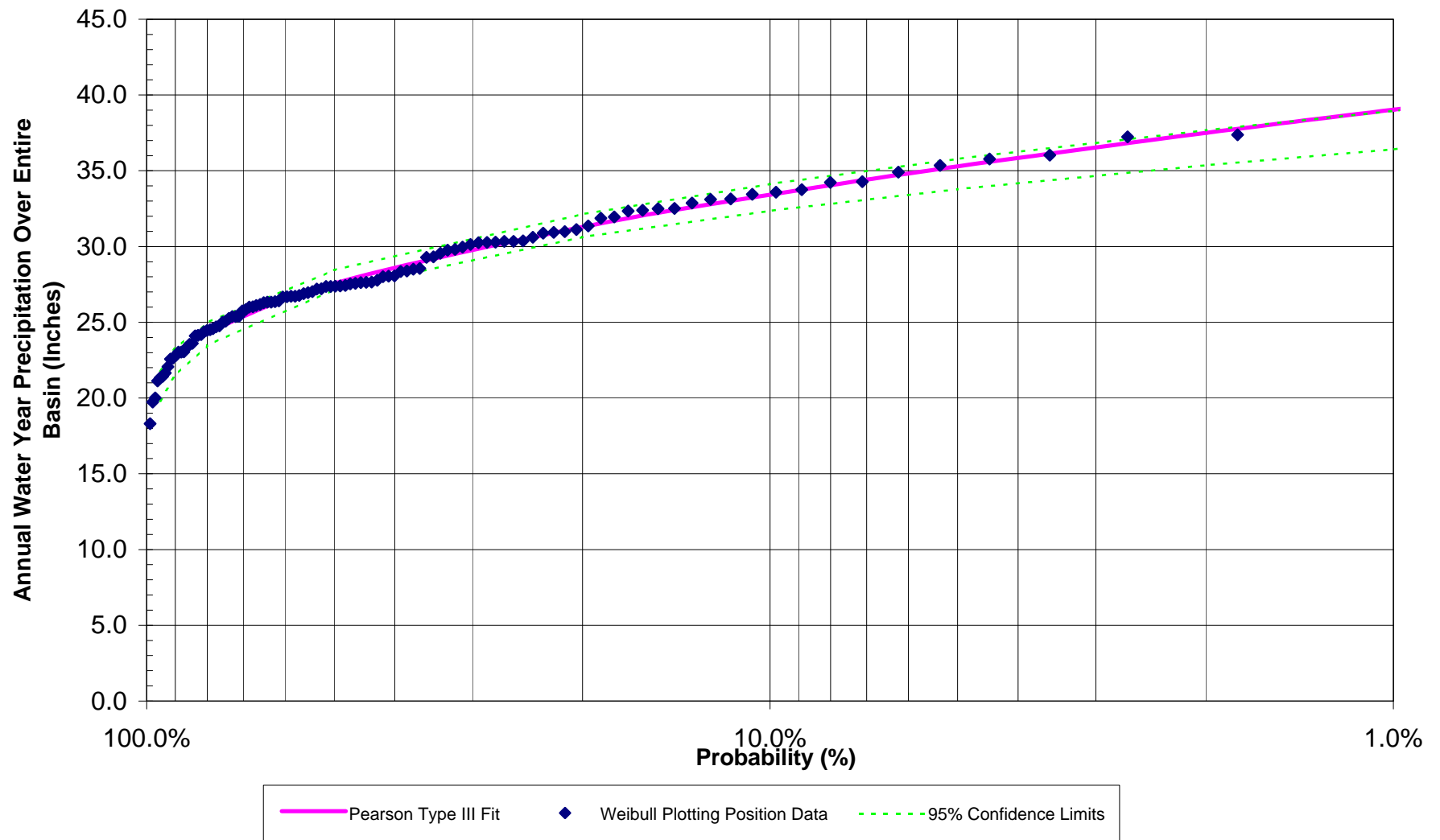
Lake Superior River Basin Precipitation Frequency Analysis



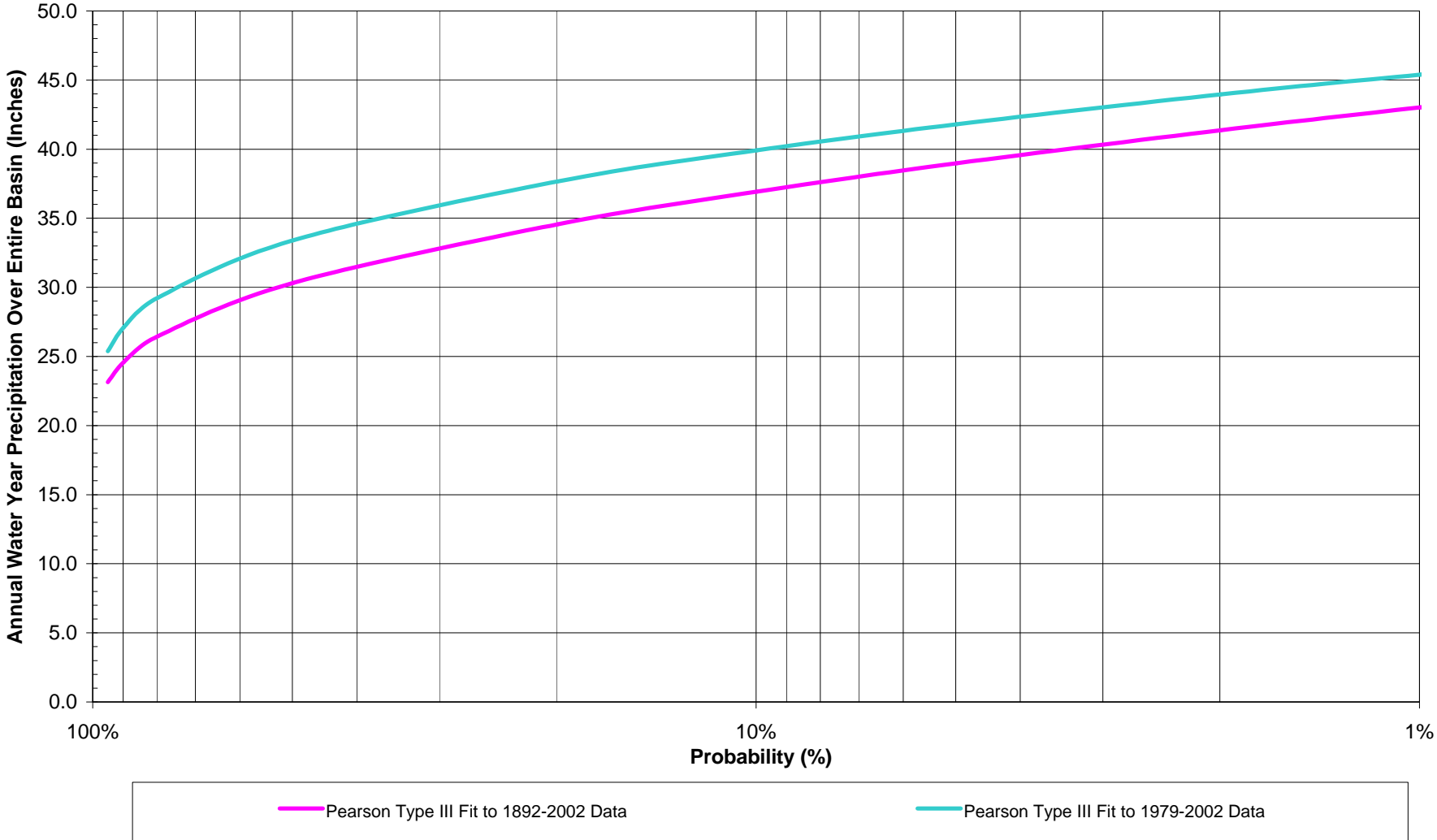
Lake Superior River Basin Precipitation Frequency Analysis (1979-2002)



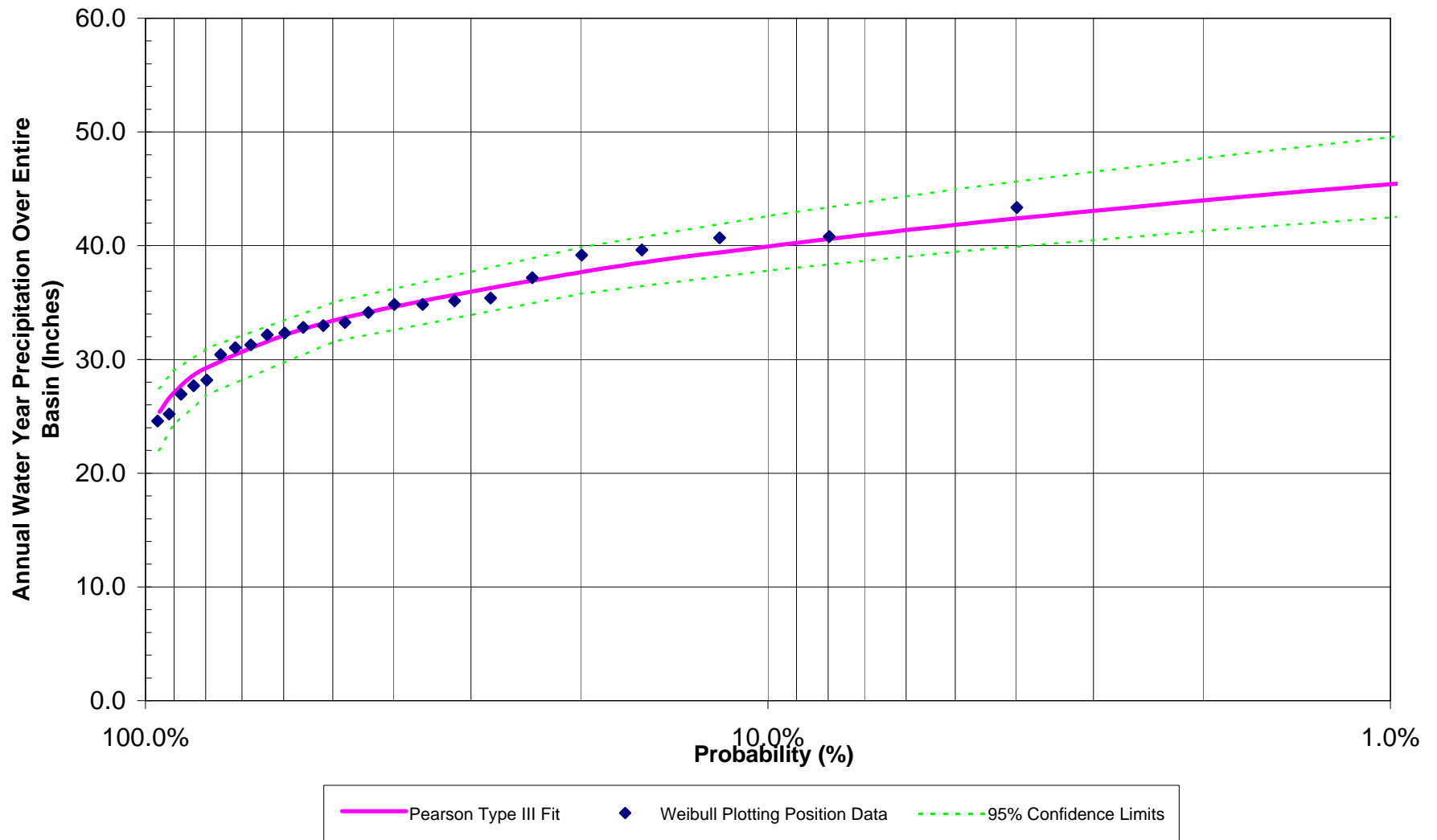
Lake Superior River Basin Precipitation Frequency Analysis (1892-2002)



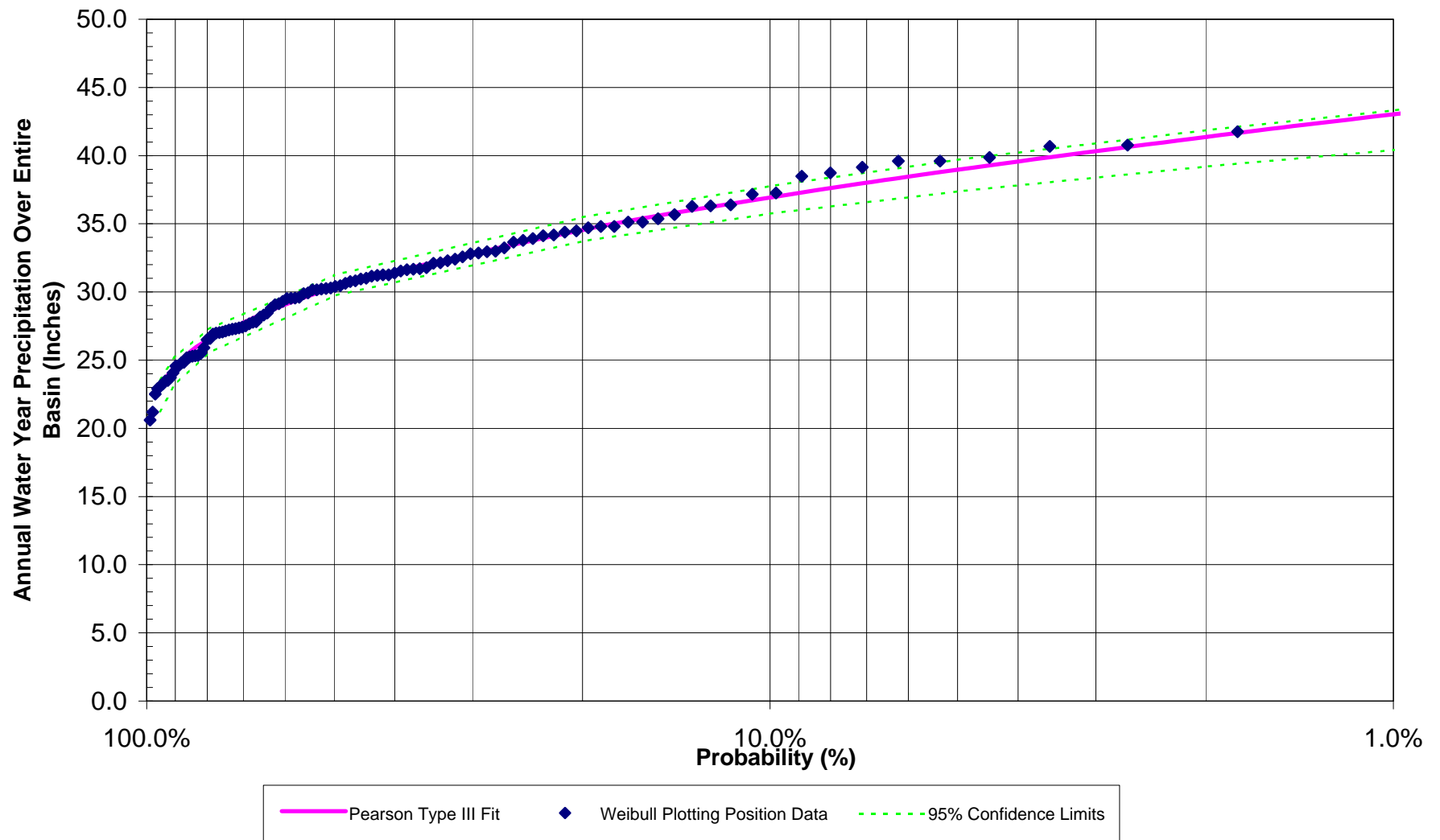
Lower Mississippi River Basin Precipitation Frequency Analysis



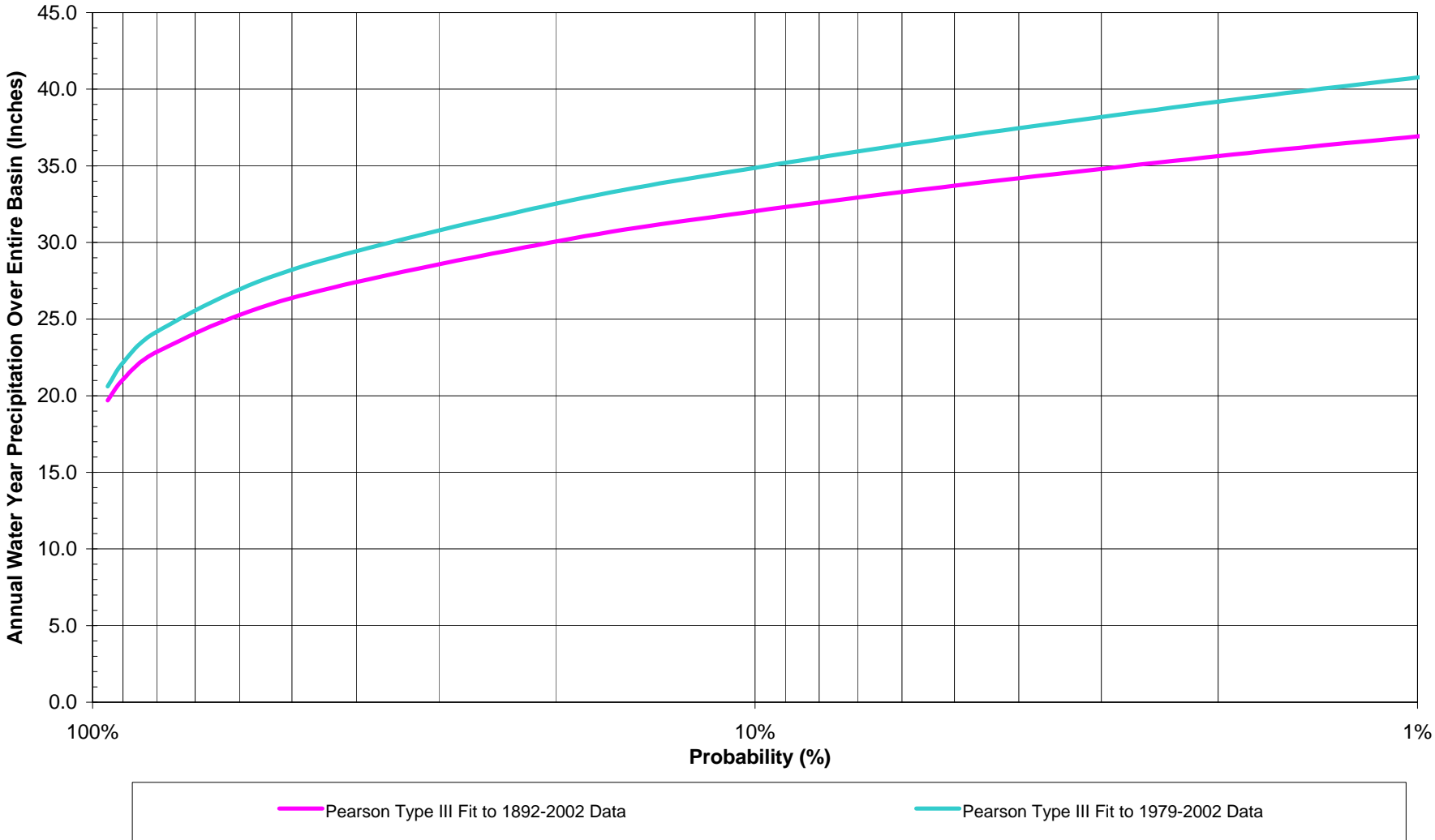
Lower Mississippi River Basin Precipitation Frequency Analysis (1979-2002)



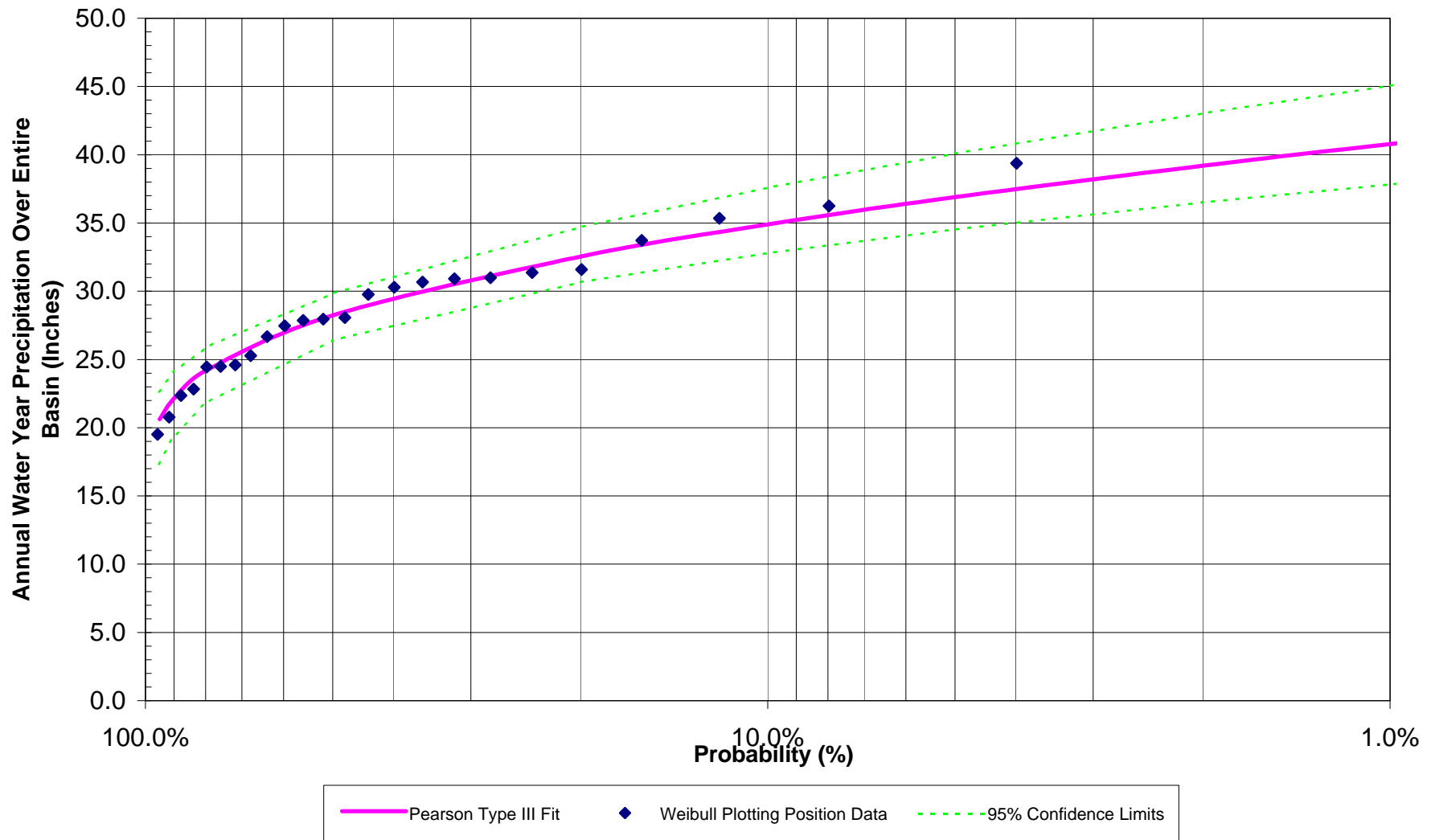
Lower Mississippi River Basin Precipitation Frequency Analysis (1892-2002)



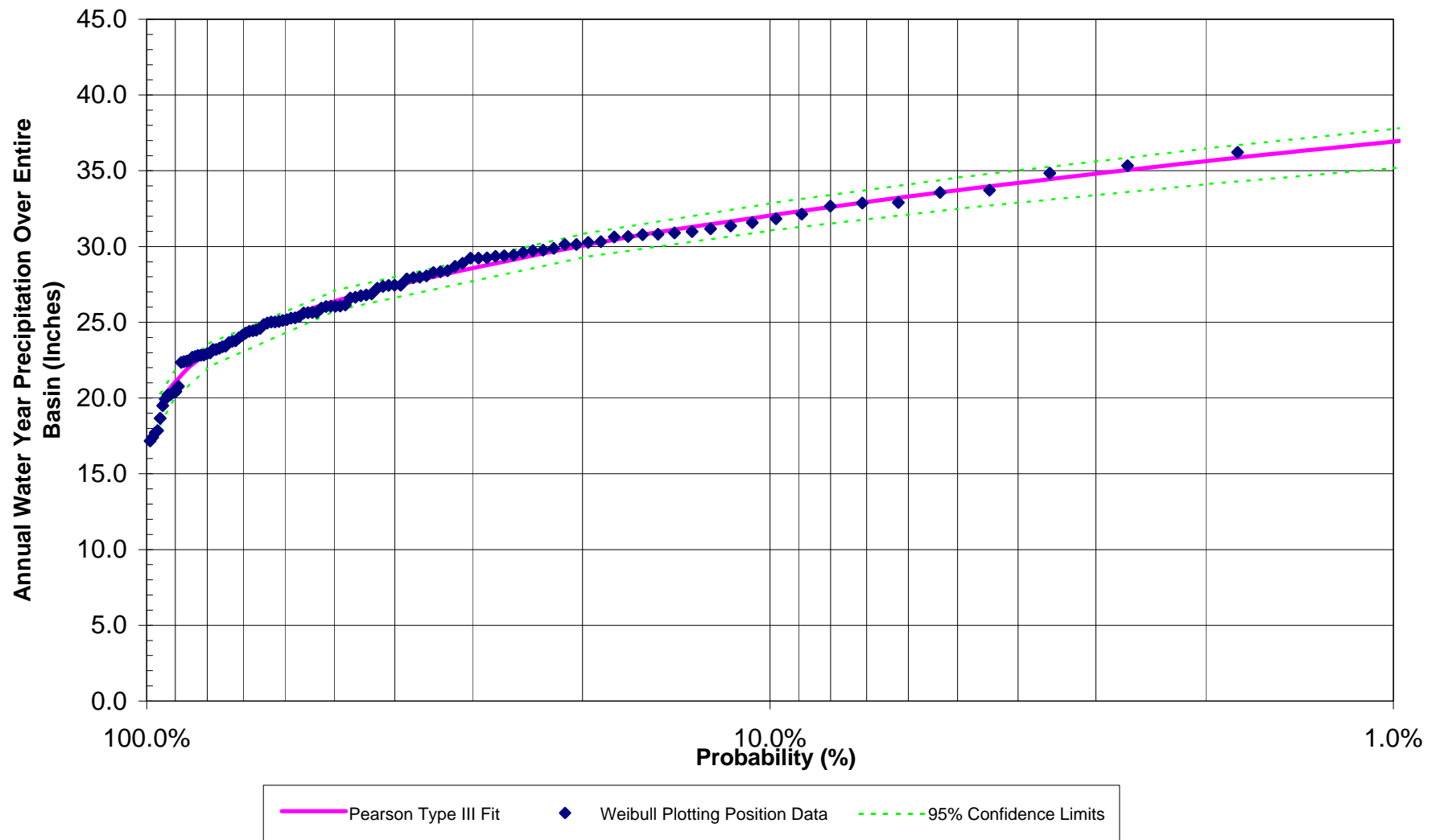
Minnesota River Basin Precipitation Frequency Analysis



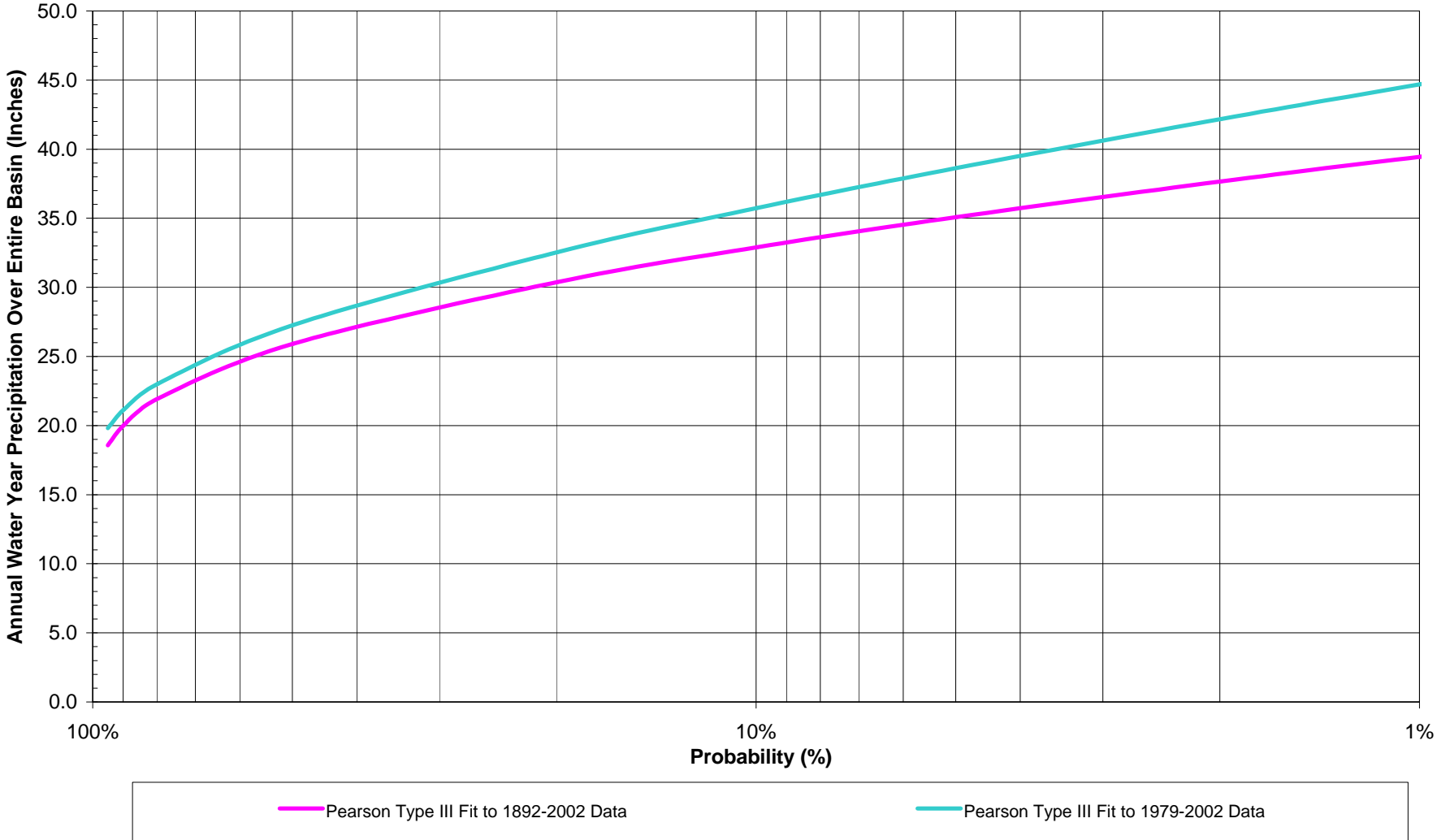
Minnesota River Basin Precipitation Frequency Analysis (1979-2002)



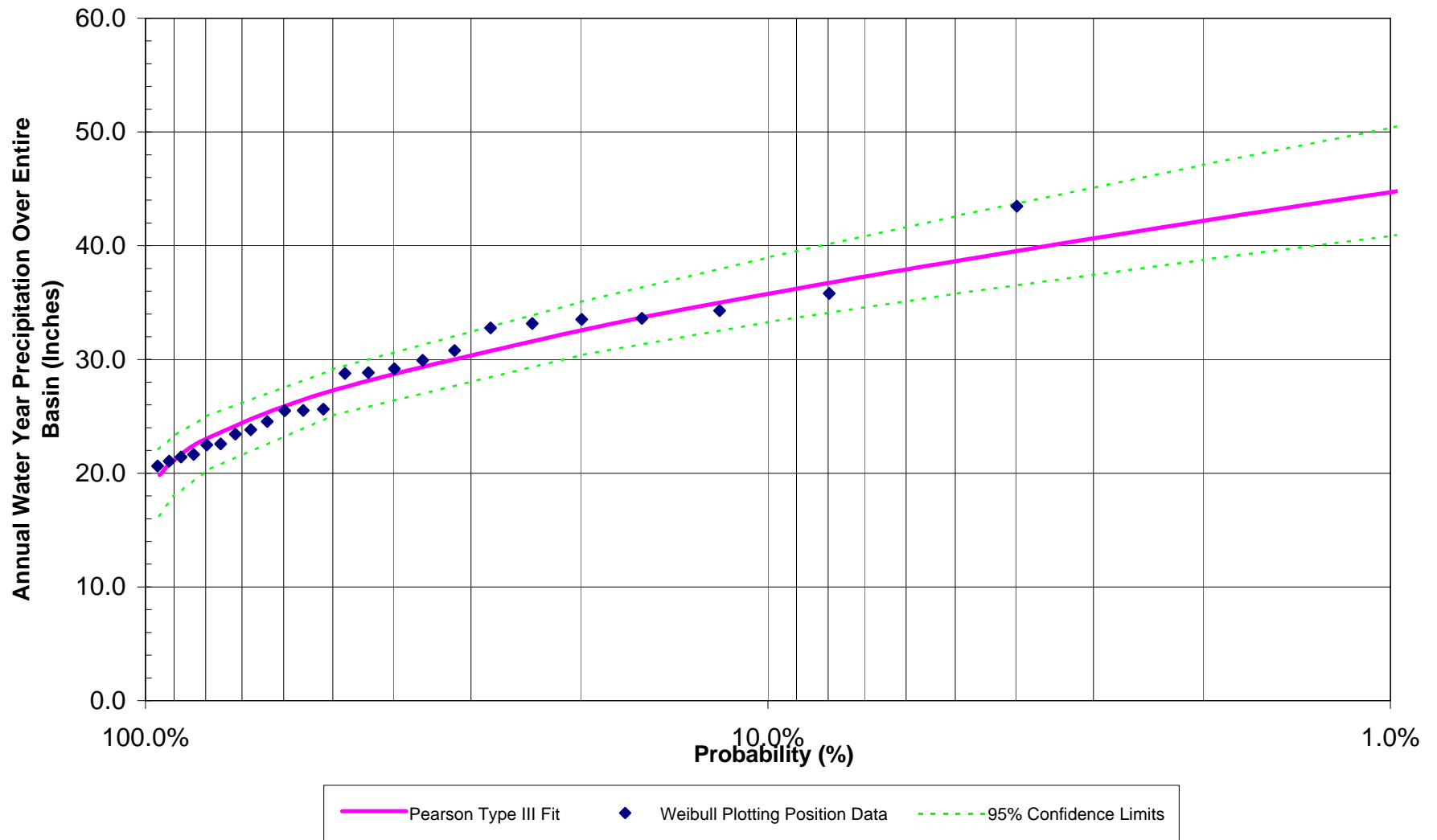
Minnesota River Basin Precipitation Frequency Analysis (1892-2002)



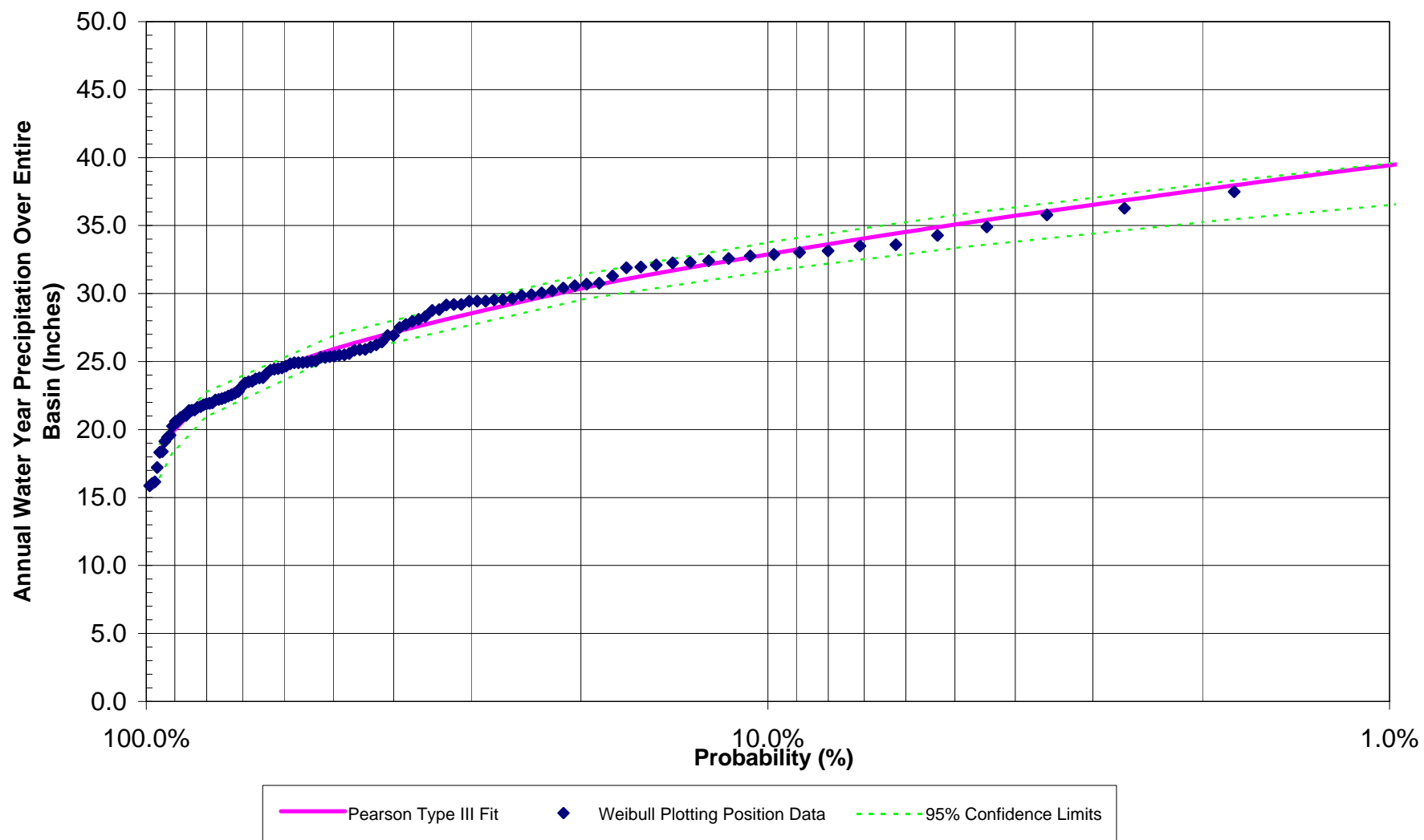
Missouri River Basin Precipitation Frequency Analysis



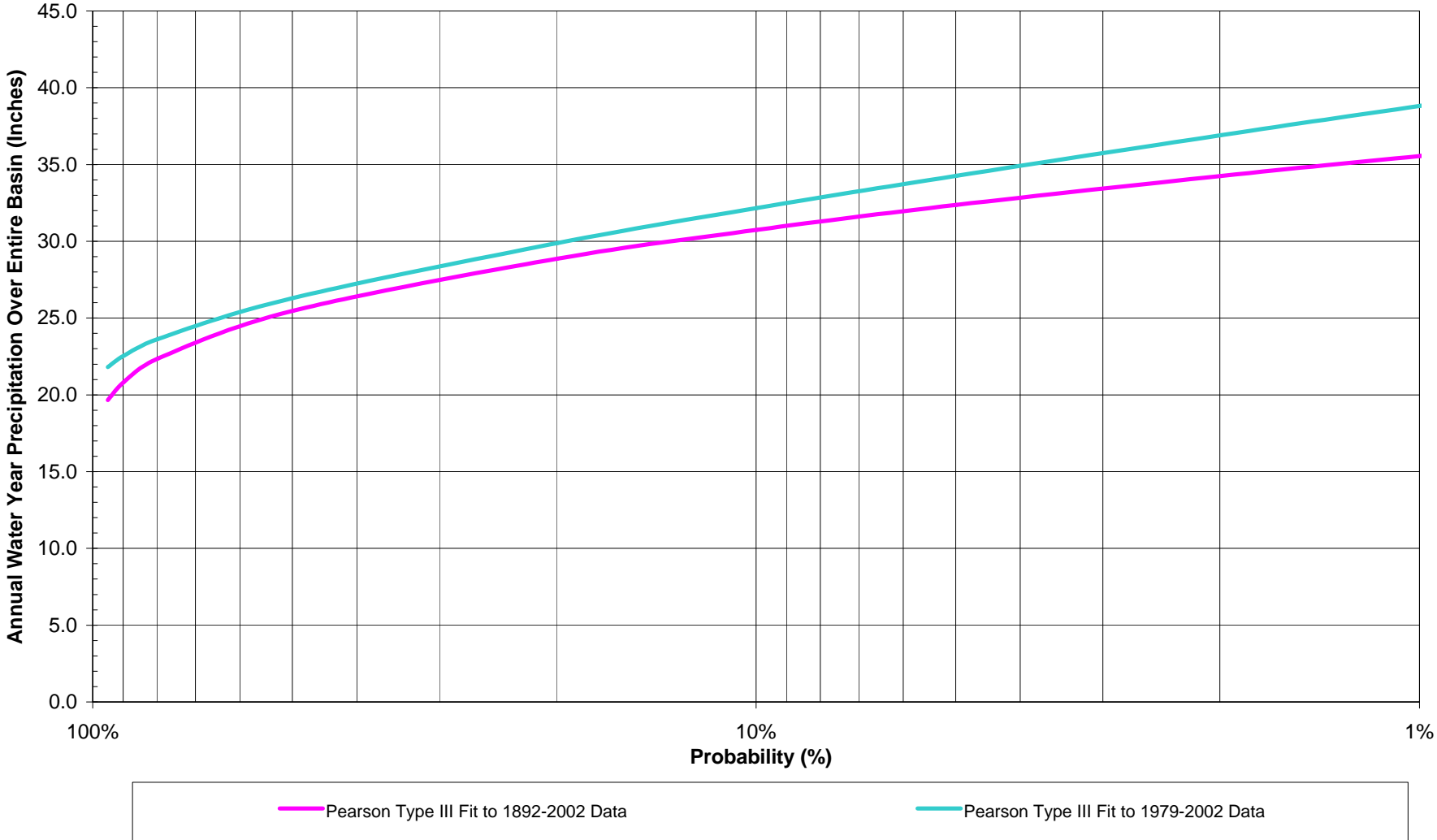
Missouri River Basin Precipitation Frequency Analysis (1979-2002)



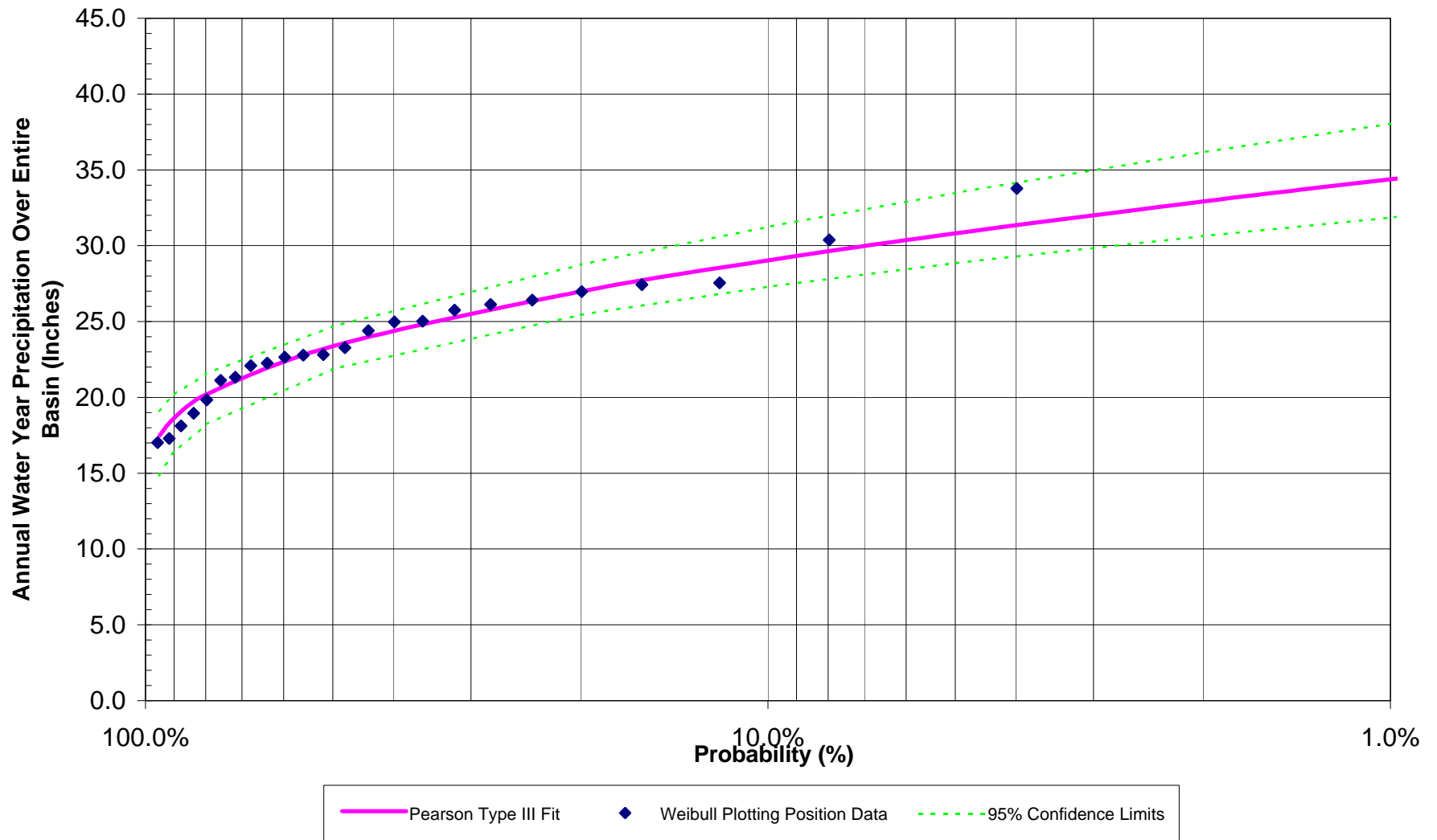
Missouri River Basin Precipitation Frequency Analysis (1892-2002)



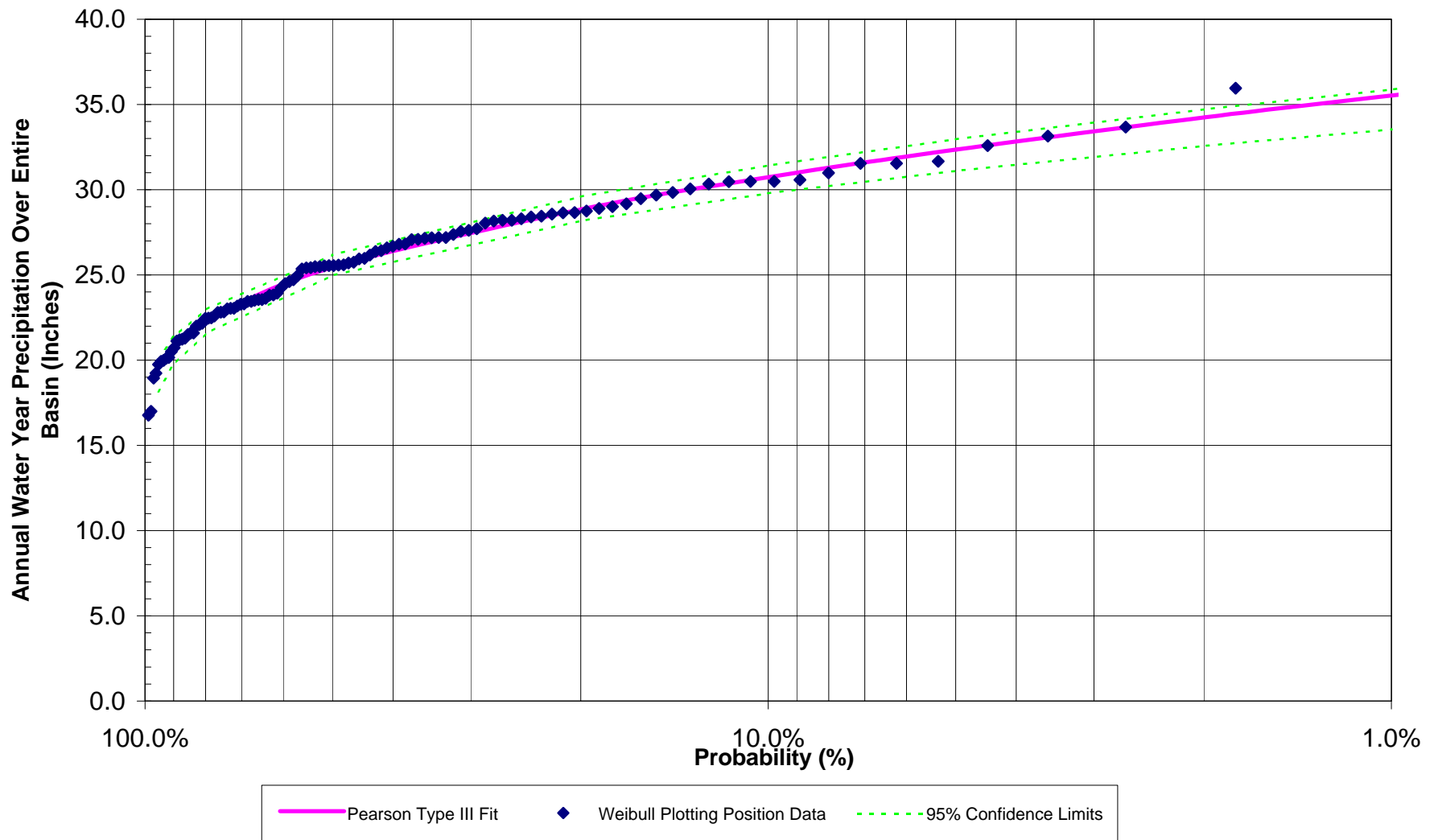
Rainy River Basin Precipitation Frequency Analysis



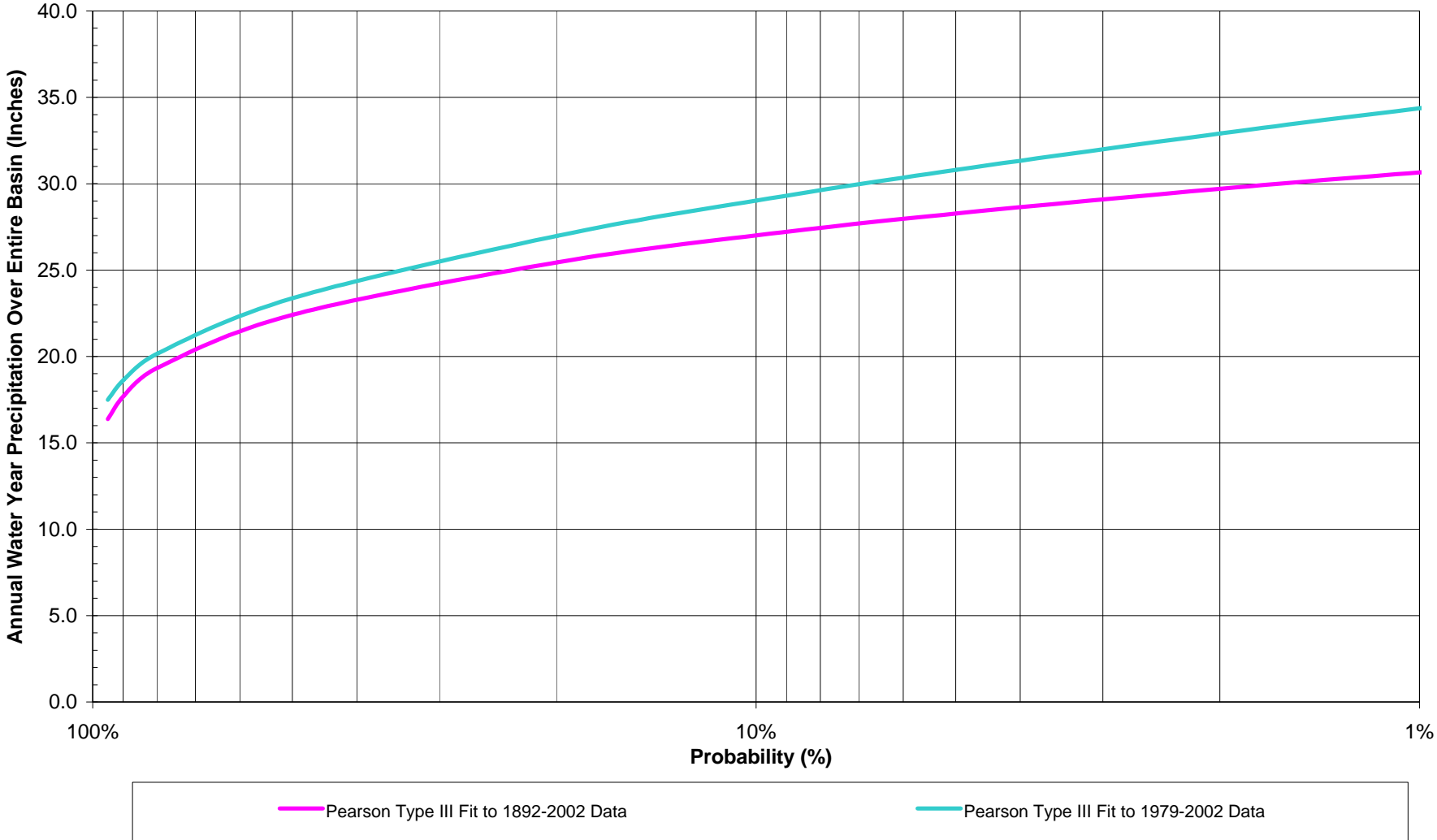
Red River Basin Precipitation Frequency Analysis (1979-2002)



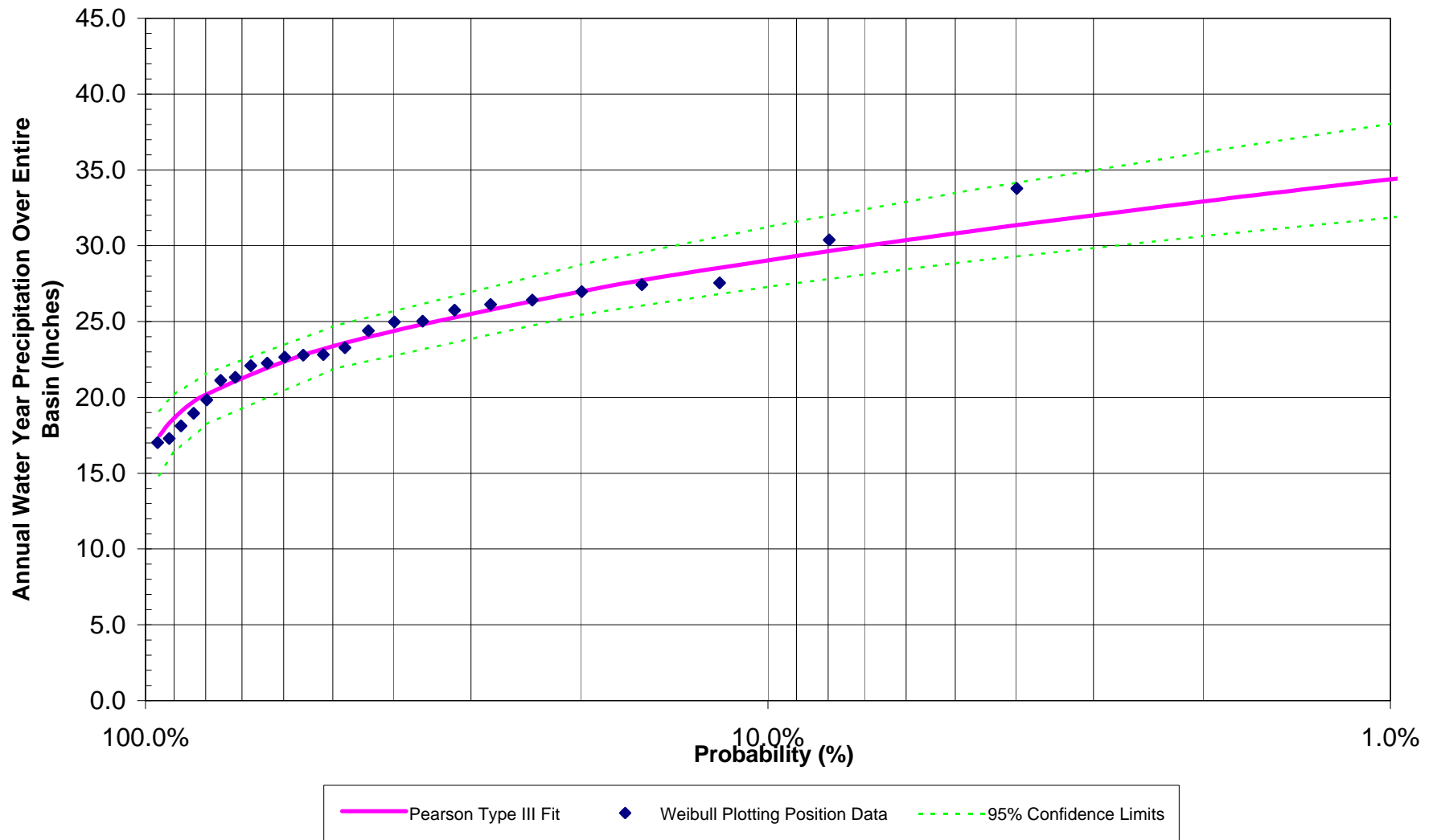
Rainy River Basin Precipitation Frequency Analysis (1892-2002)



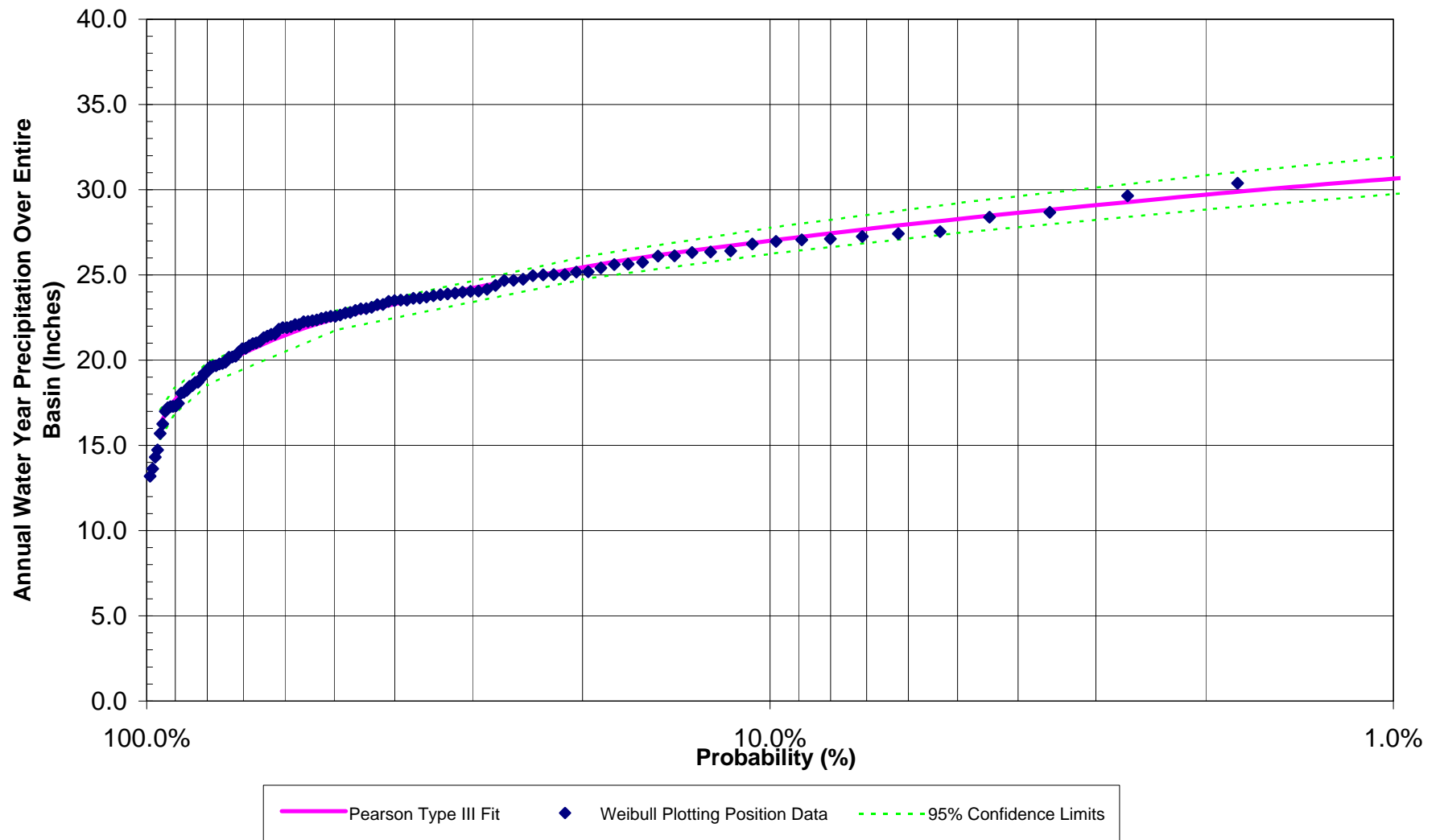
Red River Basin Precipitation Frequency Analysis



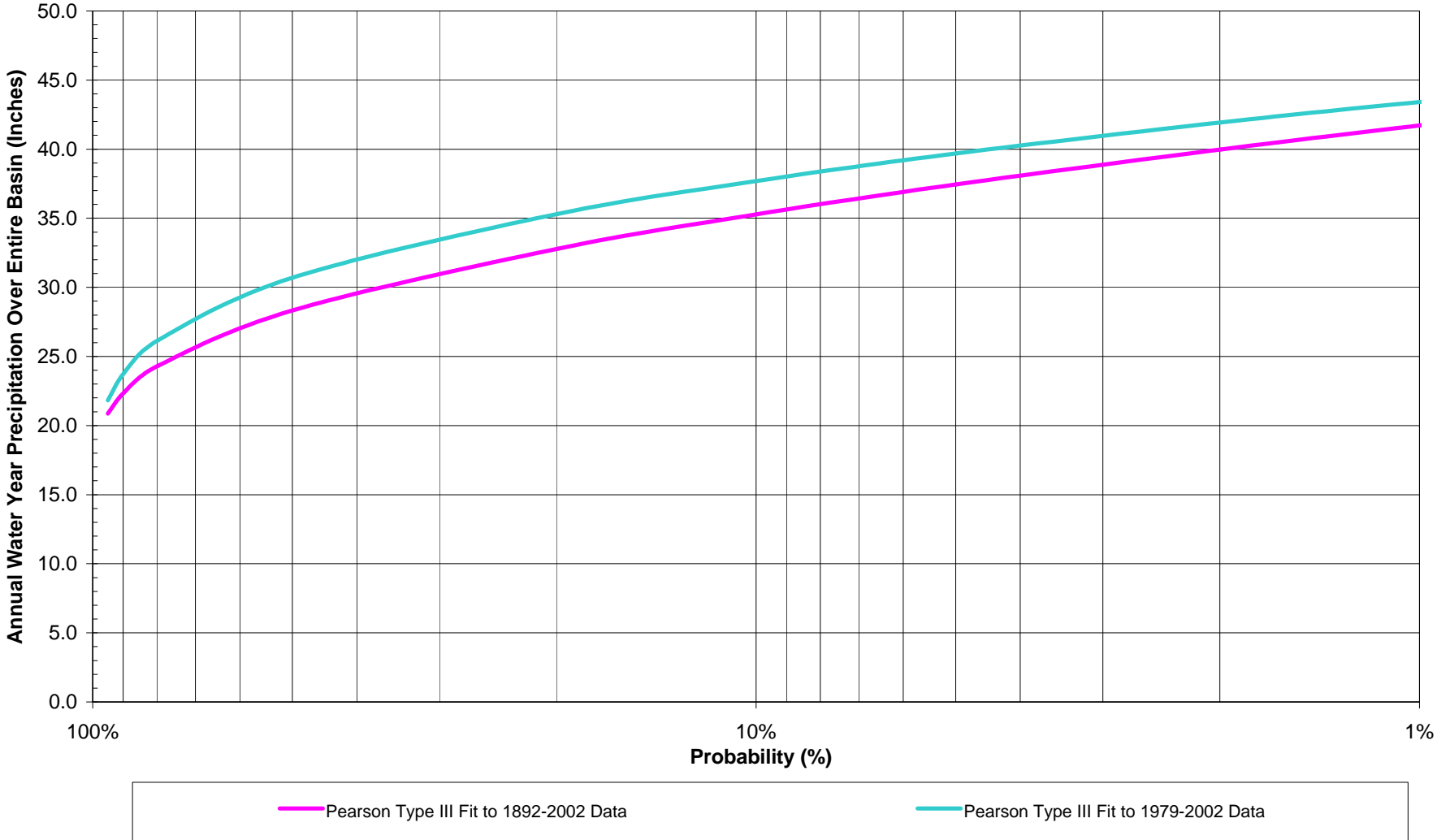
Red River Basin Precipitation Frequency Analysis (1979-2002)



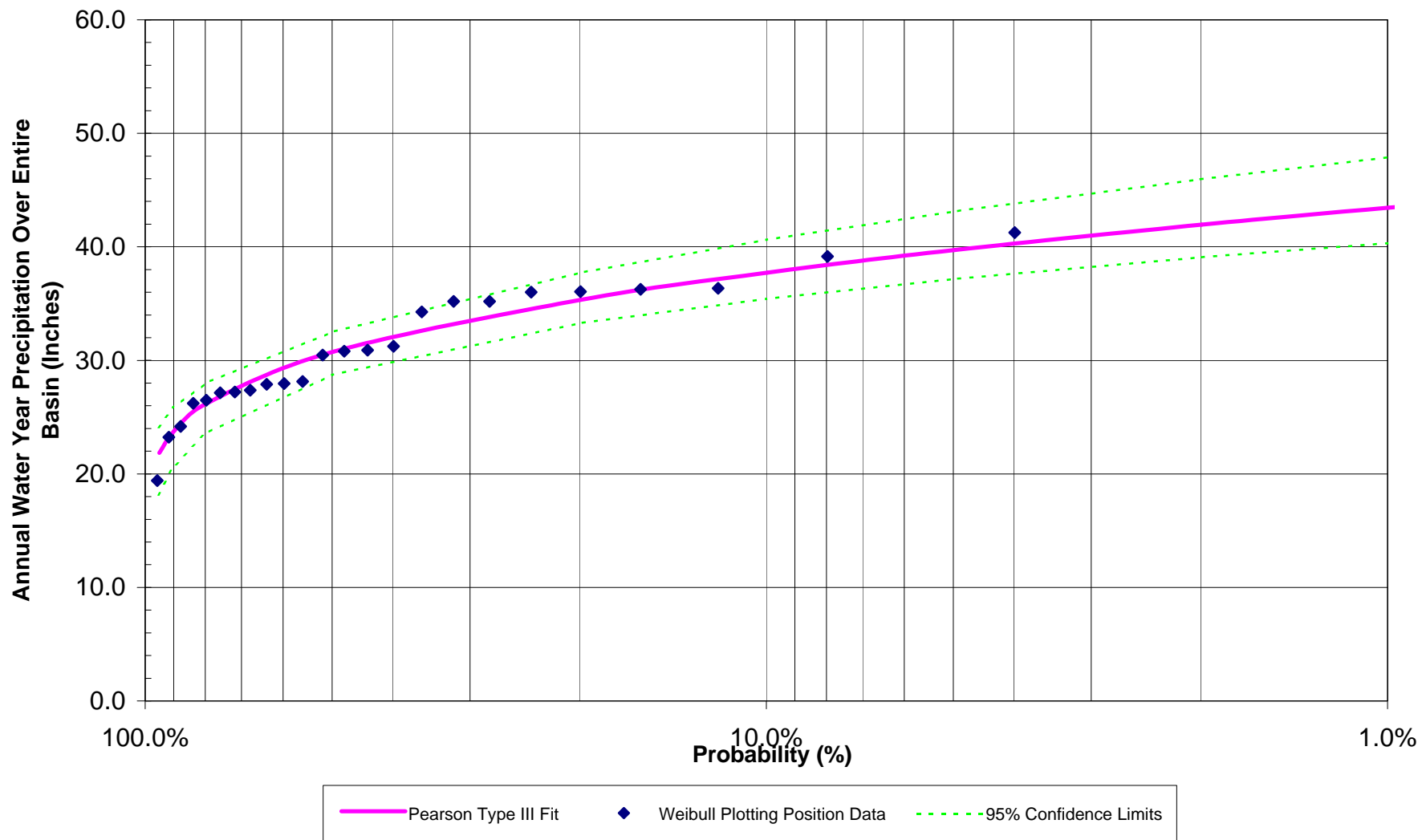
Red River Basin Precipitation Frequency Analysis (1892-2002)



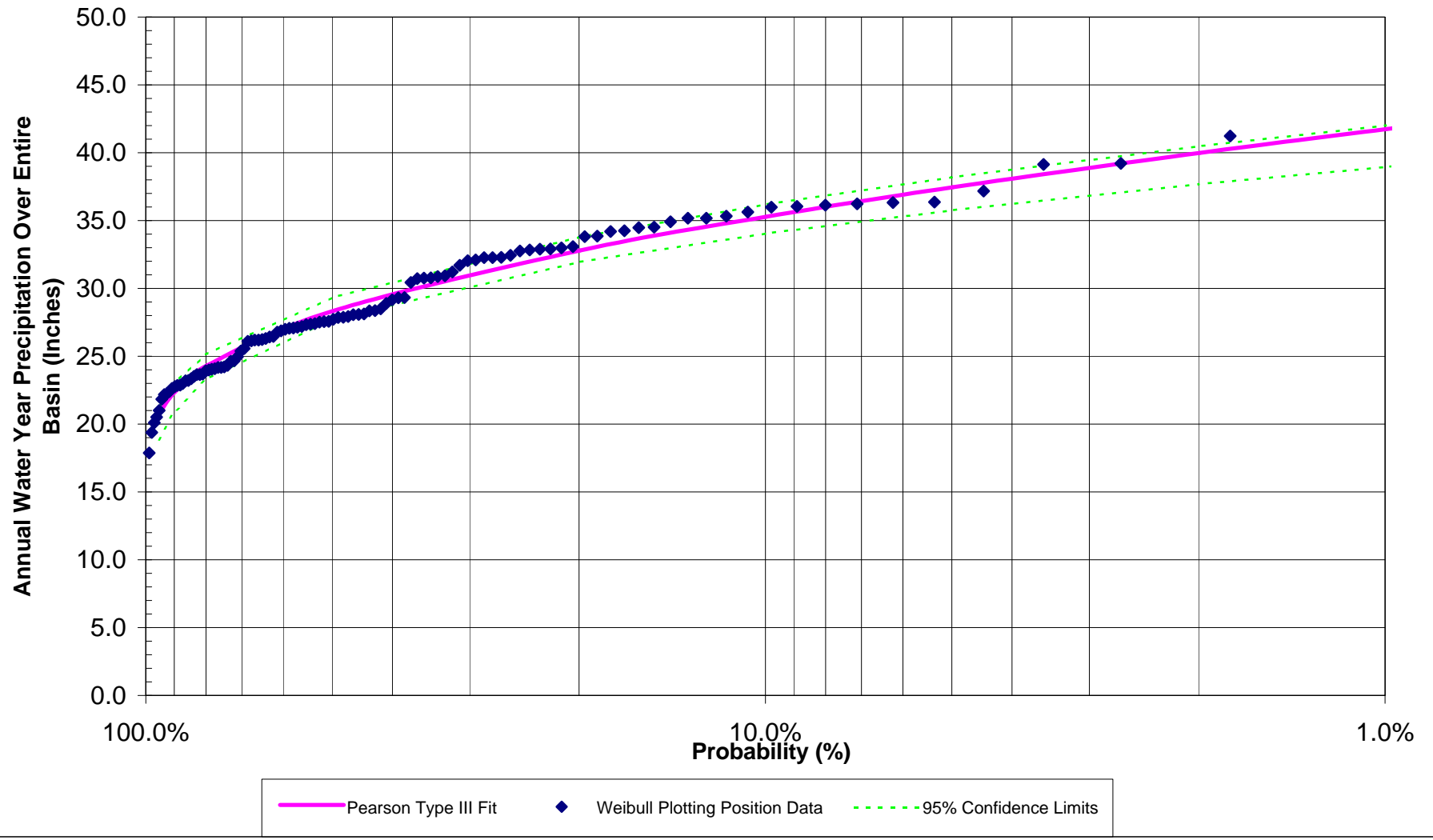
St. Croix River Basin Precipitation Frequency Analysis



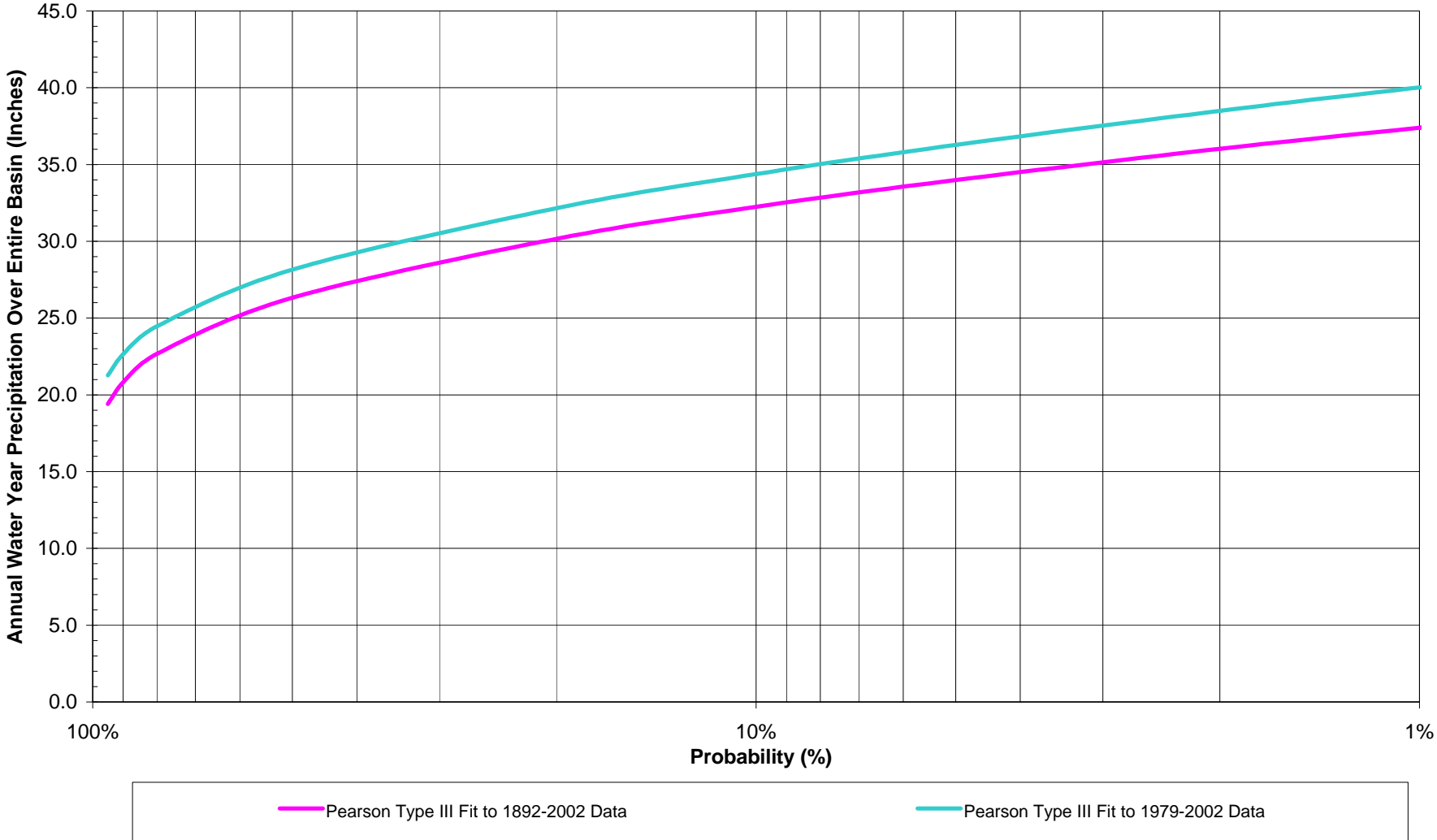
St. Croix River Basin Precipitation Frequency Analysis (1979-2002)



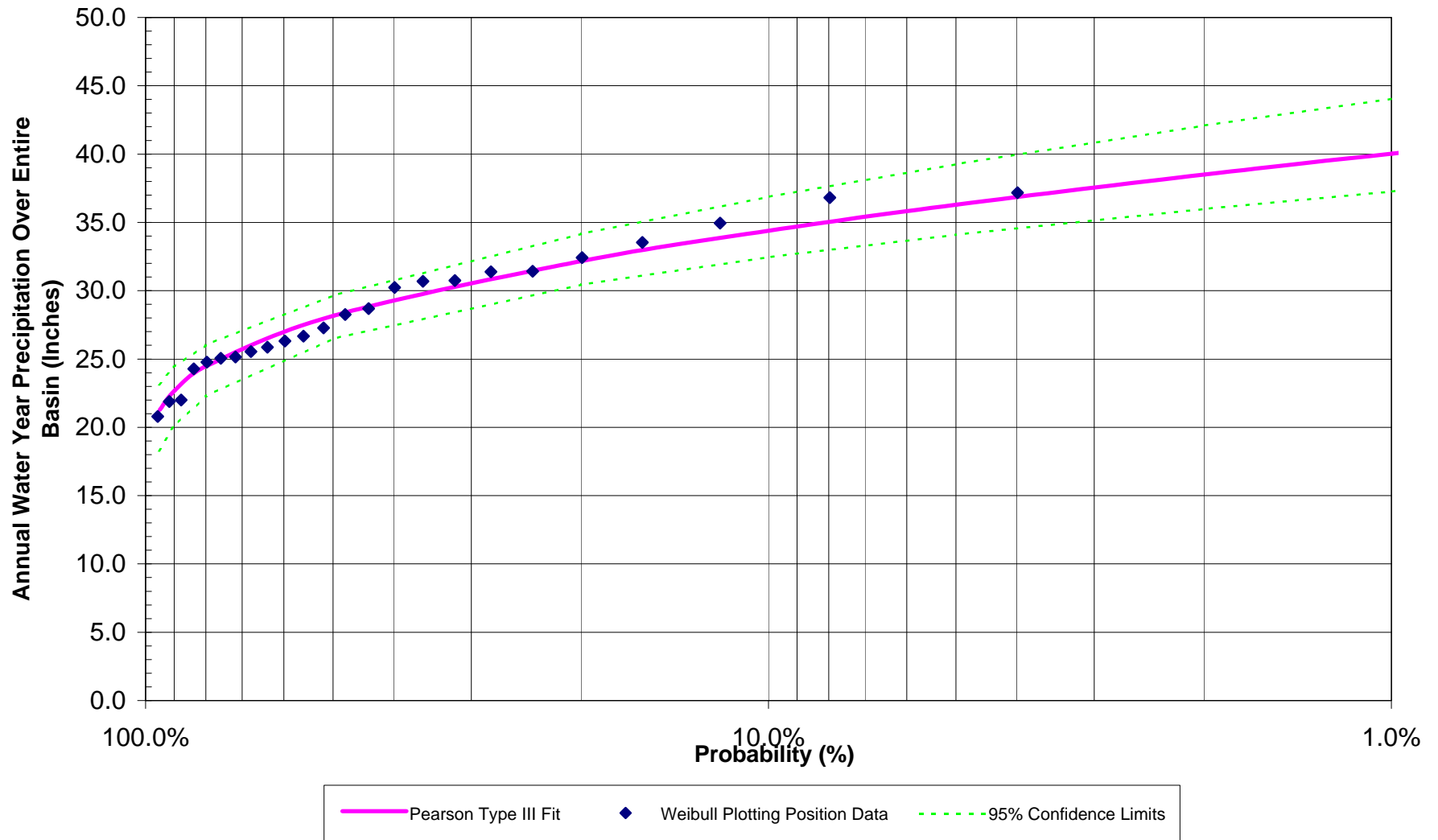
St. Croix River Basin Precipitation Frequency Analysis (1892-2002)



Upper Mississippi River Basin Precipitation Frequency Analysis



Upper Mississippi River Basin Precipitation Frequency Analysis (1979-2002)



Upper Mississippi River Basin Precipitation Frequency Analysis (1892-2002)

