OCS Study MMS 2000-007

Estimation of Oil Spill Risk From Alaska North Slope, Trans-Alaska Pipeline, and Arctic Canada Oil Spill Data Sets

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MMS U.S. Department of the Interior
Minerals Management Service
Alaska Outer Continental Shelf Region

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Errata

Location	change	to
Page 2, 5th complete paragraph	at the 1 percent level of confidence	at p=0.011*
Page 2, 5th complete paragraph	at the 17 percent level of confidence	at p=0.12
Page 99, 1st complete paragraph	at the 1 percent level of confidence	at p=0.011*
Page 99, 1st complete paragraph	at the 17 percent level of confidence	at p=0.12

PROJECT ORGANIZATION

Hart Crowser, Inc., study team:

Thomas K. Noyes	Principal in charge
Jeffery L. Mach	Project manager
	Oil spill data collection
	Oil production, pipeline throughput, pipeline mileage data collection
	Oil spill notification requirements research
	Database manager
	Primary report author
Robert L. Sandefur	Data analysis
	Calculation of oil spill rates
	Report author – Analysis of Data and Calculation of Oil Spill Risk Rate
Jean H. Lee	Oil spill data research and collection
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EXECUTIVE SUMMARY

The Minerals Management Service Alaska Outer Continental Shelf Region commissioned Hart Crowser, Inc. (Hart Crowser) to collect and analyze data to provide an estimation of oil spill risk from Alaska North Slope, Trans-Alaska Pipeline (TAPS), and Arctic Canada oil industry activities.

To populate the database needed to perform statistical calculations, data on oil spills of 100 barrels (4,200 gallons) and greater related to oil industry exploration, construction, development, production, transportation, and storage activities from within eight study areas including the Alaska North Slope, TAPS, and Arctic Canada were collected from industry, government, and commercial sources. Supporting data on annual crude oil production, pipeline mileages, and quantities of crude oil transported by pipeline or tank vessel in the study areas were gathered. Current and historical oil spill reporting criteria in effect in the study areas also were identified.

The oil spill data were collated and evaluated for comprehensiveness and completeness. Attempts were made to validate the data with government regulatory authorities to which the responsible party for a spill was required to report. The reliability of the volumes of spills of 500 barrels (21,000 gallons) and greater was evaluated based on how the spill volume was determined and supporting documentation. The statistical robustness and appropriateness of using the collected oil spill data, and the validity of using potential estimators to evaluate oil spill risks from Beaufort Sea Outer Continental Shelf (OCS) development were evaluated. Finally, an oil spill rate was calculated using the optimum data set, which was corrected for an observed time trend in the spill rate.

Overall, 126 oil spills in Alaska and Canada were identified which met the study criteria. All of these spills occurred between 1970 and September 1999. The most recent spill occurred in 1997. There are 28 spills of 500 barrels and greater and 14 spills of 1,000 barrels (42,000 gallons) or greater. Another 95 spills in the study areas also were identified, but were not included in the subsequent analysis because insufficient information existed to allow a conclusive determination as to whether the spills met the study criteria.

Hart Crowser identified 126 spills of 100 barrels and greater that met the study criteria. Of these spills, 111 occurred in Alaska and 15 in Canada. The Alaskan oil spills most frequently are associated with highway tank vehicle accidents and operations support facilities, followed by spills related to construction camps, operations support facilities, and pipelines. Spills associated with oil production processing facilities, oil production wells, pipeline pump stations, and exploration activities also were identified. No spills meeting the study criteria were identified for the Alaska Onshore North Slope (ONS), National Petroleum Reserve Alaska (NPRA), or Beaufort Sea study areas. Oil spills meeting the study criteria were identified in each of the Canadian study areas. Canadian spill were most frequently associated with oil exploration activities, oil production wells, and oil production processing facilities. Spills from highway tank vehicles, pipelines, and vessels also were identified.

Data on the Alaska oil spills were considered to be comprehensive and complete because more than 60 percent of the spill records appeared in two or more data sets. The Canadian data are more suspect in terms of being comprehensive and complete. Less than 15 percent of the Canadian spills appeared in the two data sets obtained. Canadian data since approximately 1980 are considered good, but anecdotal report and the lack of records provides suspicion that the data is not comprehensive. Because of the small number of Canadian oil spills and relatively small amount of Canadian oil production, the Canadian data were not included in the subsequent statistical analysis. For both the Alaskan and Canadian oil spill data, the volumes assigned for the spills of 500 barrels and larger are reliable, but must be considered as general estimates in most cases. Documentation for these spills often does not describe how the spill volume was determined.

The Alaska oil spill data was sufficiently comprehensive and complete to conduct statistical analyses and estimate oil spill risk rates. A series of box and cumulative frequency plots of the Alaska spill data were constructed to analyze the data and determine trends. Exploratory data analysis on relevant independent variables indicated little statistical difference in terms of spills that occurred within the Alaska ONS, East of NPRA, and TAPS study areas. A general check on the fluctuation of the data set indicated spill occurrence to be quite random. There appeared to be little difference in the size of spills associated with the various facilities, with the exception of pipelines, which had larger spills. Analysis of variance by oil type showed that, in general crude oil spills tend to be larger than other types of oil spills.

A statistical analysis of individual spill volumes by study area, facility type, oil type, affected media, and spill cause combined did not indicate any particularly interesting correlation. Annualized groupings of spills, where total spill volumes by year were accumulated and plotted on a cumulative frequency plot, showed a mixture of several populations. Re-plotted on a logarithmic scale, a single lognormal population emerged. A count of the number of spills per year in the database is showed a possible Poisson distribution, but that hypothesis was not tested.

When spill size was plotted by year to see if regulatory or reporting requirements had a significant affect, it appeared that in the period from 1975 to 1979 there were a considerable number of large spills, and then the number of spills dropped to a more or less constant rate. The year of 1977 is significant because crude oil production on North Slope and operation of TAPS began in the middle of that year. However, the years of 1978 and 1979 visually fit with years of 1975 and 1977 better than breaking the data at 1977. The 1975 to 1979 period appears to have the most number of spills.

When Alaskan spill data were plotted on a yearly basis, it appears that prior to 1977, spill rates were considerably greater than in the subsequent years. When re-plotted on a logarithmic scale, it is apparent that prior to 1980 spill rates were considerably greater than after 1980.

Hart Crowser calculated oil spill risk rates based on the number of spills and on volume. Hart Crowser calculated a rate based on volume because of the greater visual variability in the data. The statistical significance of this visual analysis showed a highly statistically significant correlation with spill rate and year if all of the Alaska spill data is included. If data earlier than 1980 is excluded, then there is still a correlation between spill rate and year that is significant at the 1 percent level of confidence. However, if data earlier than 1985 is excluded, then there is a correlation between spill rate and year, which is significant at the 17 percent level of confidence.

Hart Crowser concluded that spill rate is the best variable to use in predicting the volume of further oil spills and that a rate of approximately 52 gallons of oil spilled per million barrels of crude oil produced will be the average, if trends that started in 1980 continue. This rate is subject to considerable uncertainty in the mean (± 50% at the 95% level of confidence) and the value derived from the logarithmic distribution is 66 gallons of oil spilled per million barrels of crude oil produced as opposed to 52 gallons of oil spilled per million barrels of crude oil produced. These two values agree within the standard deviation of the means. The 95 percent logarithmic confidence limits on spills for a given year are ± 465 percent at the 95 percent level of confidence. Hart Crowser is more inclined to believe the logarithmic values than the untransformed values, because the cumulative frequency of the data is more lognormal than normal. These very wide confidence limits and individual yearly values are consistent with the small number of data points available for this prediction.

Hart Crowser also calculated oil spill risk rates based on the number of spills of a given volume per million barrels of crude oil produced (spills/MMBbl), using data from 1978 through 1999. Hart Crowser found these rates to be:

- 0.0053 spills/MMBbl, ±24 percent, for spills of 100 barrels and greater;
- 0.00093 spills/MMBbl, ±58 percent, for spills of 500 barrels and greater;
- 0.00039 spills/MMBbl, ±89 percent, for spills of 1,000 barrels and greater; and
- 0.000078 spills/MMBbl, ±200 percent, for spills of 10,000 barrels and greater.

INTRODUCTION

In the development of environmental analyses for proposed Outer Continental Shelf (OCS) Beaufort Sea oil exploration and development off of Alaska's North Slope, the U.S. Department of the Interior Minerals Management Service (MMS) OCS Region uses national OCS statistics to estimate the likelihood that large oil spills of 1,000 barrels (42,000 gallons) or larger will occur as a result of oil exploration, construction and development, production, and transportation activities. These national statistics primarily are from the Gulf of Mexico and do not include pipeline spills inshore of the OCS, in state waters, or on land. The MMS Alaska OCS Region desires to estimate oil spill frequency based on Alaska North Slope and Canadian Arctic, rather than Gulf of Mexico oil exploration, construction and development, production, and transportation experience.

The MMS contracted Hart Crowser to gather data and provide oil spill risk occurrence estimators for OCS Beaufort Sea oil exploration and development based on Alaska North Slope and Canadian Arctic statistics. More specifically, the scope of work directed Hart Crowser to:

- Identify, obtain relevant supporting information, and collate data for crude oil and diesel oil spills of 100 barrels and greater related to oil and gas exploration, construction, development, production, transportation, and storage from within the following study areas:
    - U.S. Beaufort Sea;
    - Canadian Beaufort Sea;
    - National Petroleum Reserve Alaska (NPRA);
    - Alaska Onshore North Slope (ONS) East of NPRA;
    - Trans-Alaska Pipeline System, not including the Valdez Marine Terminal;
    - Onshore McKenzie River Delta;
    - Canadian High Arctic Islands; and
    - Norman Wells.

- Compare data sets from different sources for the same area to increase the comprehensiveness and completeness of the data.

- Identify the oil spill reporting criteria in effect for oil spills in the study areas and validate the oil spill data with the regulatory authority to which the responsible party for the spill was required to report.

- Describe the overall comprehensiveness and completeness of the collected oil spill data.

- Evaluate the reliability of the volumes of spills of 500 barrels and greater, based on how the spill volume was determined and supporting documentation.

- Obtain and collate data on crude oil production, pipeline throughput, tanker shipments, and pipeline mileage by year for the Alaska and Canada study areas.

- Examine the appropriateness of using the collected oil spill data to evaluate oil spill risks from Beaufort Sea OCS development, partly in the context of prior MMS uses and statistical evaluations of oil spill rates for OCS use.

- Consider the statistical robustness and validity of potential oil spill risk estimators, including the:

    - Effect of one or more spills on the estimators;
    - Size of the data set for spills of 100 barrels or more and 500 barrels or more;
    - Rationale for including or excluding intentional spills;
    - Effect of incomplete pipeline life cycles in the data set;
    - Correlation of pipeline mileage and/or oil production or throughput volumes with spillage;
    - Differences in size of onshore and offshore oil spill data subsets;
    - Magnitude of the record (i.e., number and volumes of spills) used to calculate oil spill risk estimators versus that used by Anderson and LaBelle (1994); and
    - Postulated differences, or lack thereof, in onshore and offshore oil spill risk factors.

- Calculate onshore and offshore oil spill rates using the optimum data sets and including corrections for time trends in spill rates, if statistically appropriate.

- Prepare draft and final reports and technical summaries concerning the study, and appendices containing the oil spill and supporting data sets.

METHODS

Oil Spill Data Collection

Alaskan Oil Spill Data

Hart Crowser gathered the Alaskan oil spill data used in this study using information contained in electronic spreadsheet and database files, and from written records. The data was obtained from federal and state agencies, major Alaskan oil industry companies, and one commercial source. Methods used to gather these data are described below.

The MMS Alaska OCS Office provided Hart Crowser with Alaska oil spill data gathered prior to the study by MMS from:

- BP Exploration (Alaska) Inc. (BP);
- ARCO Alaska Inc. (ARCO);
- Alyeska Pipeline Service Company (Alyeska);
- U.S. Department of the Interior and Alaska Department of Natural Resources, Alaska Joint Pipeline Office (JPO);
- U.S. Department of the Interior Bureau of Land Management (BLM), Alaska Office of Special Projects;
- Alaska Department of Environmental Conservation (ADEC); and
- The Oil Spill Intelligence Report (OSIR).

Hart Crowser contacted each of the data sources listed above, except OSIR, by telephone to obtain updated or additional oil spill data. Hart Crowser also contacted the U.S. Environmental Protection Agency (EPA), Alaska Operations Office by telephone and the National Response Center, Washington, D.C., in writing, to obtain available data on Alaskan oil spills meeting the study criteria.

Hart Crowser identified the location of potentially useful files from inquiries made to knowledgeable ADEC staff. Hart Crowser researchers traveled to ADEC's Fairbanks and Valdez offices, and gathered oil spill data, supporting information, and documentation directly from the active and archived oil spill files in those offices. Hart Crowser also searched for Alaskan oil spill data on the Internet and in the collection of the Alaska State Library in Juneau, which contains documents from the ADEC's former library.

Canadian Oil Spill Data

Hart Crowser contacted the following organizations by telephone and inquired about the availability of oil spill data for the Canadian study areas:

- Department of Indian Affairs and Northern Development (DIAND; also known as Indian and Northern Affairs Canada); Toronto, Ontario offices;
- National Energy Board Canada (NEB); Edmonton, Alberta offices;
- Environment Canada (EC), Prairie and Northern Region; Yellowknife, Northwest Territories office;
- Coast Guard Canada (CGC); Ottawa, Ontario office; and

- Government of the Northwest Territories (GNWT); Environmental Protection Service (EPS); Yellowknife, NWT office.

Oil spill records also were contained in the OSIR summary provided by MMS and reviews of the OSIR *Oil Spills: International Summary and Review 1978-1981* and *Oil Spills: International Summary and Review 1982-1985* were conducted to look for Canadian oil spills that met the study criteria. Hart Crowser also searched the Internet for documents that contained information on Canadian oil spills meeting the study criteria.

Oil Spill Data Evaluation and Collation

Alaskan and Canadian oil spill records were initially transferred from existing electronic files, or were entered directly from written records, into Microsoft Excel® spreadsheets. Each spreadsheet contained oil spill records from a specific source. Each spreadsheet was reviewed and those spill records that were judged to meet the study criteria were transferred into a Microsoft Access 97® database. This database contained all of the oil spill records subsequently used in the study. Spreadsheets and databases were maintained exclusively by the project data manager.

The spill records in the database containing all of the records were sorted to identify individual spills appearing in more than one data set. In cases where a spill record was found only in one of the data sets, the other relevant data sets Hart Crowser had obtained were cross checked to determine if they contained a similar spill record that had not been included in the database for some reason. Spill records were added to or deleted from the database of all spill records based on information found in the data sets, in written records, or interviews with knowledgeable individuals concerning specific spills.

Hart Crowser also assembled a database of oil spills that were excluded from the study because Hart Crowser could not determine whether these spills met the study criteria. Hart Crowser did not attempt to assemble a listing of all spill records reviewed and included in, or excluded from, the study.

Using the database of all oil spill records included in the study, Hart Crowser then assembled a collated database of the oil spills. Records from different data sets for an individual spill were compared with one another, and a single spill record for the collated database was created based on all of the records for the spill. Differences in individual spill records among the different data sets, including spill date, location description, spiller identity, oil type, and spill quantity were reconciled as much as possible by comparing the data in the different records and making inquiries about particular spills to the owners of the spill records or to individuals knowledgeable about the spill. Where differences between spill records for the same spill continued to exist, deference for use in the collated database was given to the data in the regulatory agency spill records. Where different spill dates were found among data sets, a single date was used in the collated database, typically the date used in the ADEC's databases or that agency's records. Where different oil spill quantities were reported in different data sets or where the spill quantity was reported as a range, a range was used in the collated database, using the range of spill quantities found among the data sets.

<u>Oil Spill Data Comprehensiveness and Completeness</u>

Hart Crowser felt that it would assemble the most comprehensive and complete data possible, within the time and resource limits of the study, by obtaining oil spill data from as many sources as possible. To that end, Hart Crowser contacted organizations that were believed or known to have oil spill records relevant to the study. Included in the search for oil spill data relevant to the study were regulatory agencies that had or have legal requirements for oil spill reporting and cleanup; major oil exploration, production, and pipeline operating companies; and the OSIR, commercial publication specializing in oil spill information. Because Hart Crowser knew that ADEC's oil and hazardous substance spill databases were incomplete, reviews of document files were conducted in an attempt to gather comprehensive and complete data for the study.

Hart Crowser analyzed the list of collated spills to determine how many spills appeared in two or more data sets. Whether a particular oil spill was found in more than one data set, whether the data for a particular spill was substantially the same between data sets, and whether data required for the study was found among the data sets was used as a guide in judging the comprehensiveness and completeness of the data. Hart Crowser also evaluated whether there was a correlation between the size of oil spills versus the occurrence of the spills in multiple databases for oil spills in the Alaskan and Canadian study areas, as a potential indicator of whether larger spills are more likely to be recorded.

Reliability of Oil Spill Volume Determinations

During reviews of the written oil spill records from Alaska and Canada Hart Crowser researchers searched for information in the records indicating how oil spill volume determinations had been made to allow Hart Crowser to gauge the reliability of the spill volumes contained in the records.

Oil Spill Notification Requirement Data Collection

United States and Alaska Notification Requirements
Hart Crowser reviewed copies of current and historical federal and Alaska statutes and regulations in the Alaska Court System Law Library and the Alaska State Library at Juneau. The MMS provided Hart Crowser with additional information on oil spill notification requirements in Alaska.

Canadian Notification Requirements
Hart Crowser reviewed copies of current statutes and regulations obtained from the Canada Department of Justice and the GNWT. Some historical statutes and regulations also were obtained and reviewed. Hart Crowser also interviewed representatives of the GNWT EPS and the NEB concerning current and historical oil spill notification requirements.

Crude Oil Production and Transportation Data Collection

Alaska Crude Oil Production, and Pipeline Mileage and Throughput Data
The Alaska Department of Natural Resources (ADNR), Division of Oil and Gas was contacted to obtain annual crude oil production and pipeline throughput statistics. ADNR obtains production data monthly from the Alaska Oil and Gas Conservation Commission (AOGCC) and publishes annual summary statistics as part of its periodic publication, *Historical and Projected Oil and Gas Consumption*.

The JPO was contacted to obtain the mileages of "regulated pipelines" (i.e., those pipelines regulated by the U.S. Department of Transportation and by right-of-way leases issued by the State of Alaska or the BLM). Hart Crowser consulted the *Trans-Alaska Pipeline Atlas, Prudhoe Bay to Valdez (Alyeska, 1993)* to obtain the mileage of the TAPS.

Telephone inquiries were made to ARCO and BP staff members at the respective companies' Anchorage headquarters and the individual oil production units concerning the mileages of the smaller field gathering lines (also called cross-country lines) in the individual production units. The field gathering lines, typically ranging in size from 8 to 30 inches in diameter, run from oil production pads to processing facilities and from processing facilities to sale oil pipelines or to Pump Station 1.

Throughputs for individual oil sales pipelines were calculated from the annual crude oil production quantities of the particular North Slope oil fields or operating units as reported in ADNR's *Historical and Projected Oil and Gas Consumption*. Annual TAPS throughputs were obtained directly from *Historical and Projected Oil and Gas Consumption*.

Canadian Crude Oil Production, Pipeline Mileage and Throughput, and Tanker Transport Quantity Data

Hart Crowser contacted the NEB to obtain crude oil production, pipeline mileage and throughput, and tanker transport quantity data for the Canadian Arctic study areas.

Alaska and Canadian crude oil production, pipeline mileage, and pipeline throughput or other transportation data were entered into a Microsoft Access® database application and have been provided to MMS separately from this report.

Oil Spill Data Statistical Analysis and Estimation of Spill Risk

Statistical analysis began after collation of the oil spill data. The basic statistical approach used in the study consisted of visual review all of the data using cumulative frequency and box plots. Conclusions inferred from visual analysis of the data were verified by linear methods including linear regression and analysis of variance. In all statistical analyses, there is some type of balancing between a reasonable number of samples, which allow statistical inference to be made and relevant independent variables. Review of the oil spill data indicated that not all data fields had enough repeated entries to provide useful statistical results. Relevant variables selected were study area, spill date, facility type, oil type, spill cause, and affected media.

Units used in this study are those provided in the data. Oil production was expressed in millions of barrels per year, the volume of spills were expressed in U.S. gallons, volumetric spill rates were expressed in U.S. gallons per millions of barrels produced, and numerical spill rates were expressed as the number of spills at or above a specific size divided by millions of barrels of crude oil produced.

To increase the number of repeated entries in data fields, minor typographical inconsistencies in the facility type and oil type data fields were standardized. The data contained a number of explanations for the causes of spills. However, there was enough consistency to allow some of spill causes to be combined into a new variable, which was called spill cause common. The spill cause common variable contained facility piping leaks, facility tank leaks, facility explosions, pipeline leaks, tank vehicle accidents, and unspecified spill causes, along with one production well leak.

Visual review of the oil spill data from both Canadian and U.S. sources indicated that, in general, only maximum estimated spill volumes were available for the size of the oil spills. Maximum spill volume also is conservative. Consequently, the maximum spill size was used as the dependent variable for all analyses.

The statistical analysis of the oil spill data and the estimation of oil spill risk rates was conducted using Microsoft® Windows 2000® beta build 2128 using the MKS toolkit (which emulates a Unix Korn shell under Windows®) and the public domain statistics package "R"[1], running on a Pentium II 300Mhz computer. After initial re-formatting of the data from Microsoft® Excel® spreadsheets, a single batch file was used to assure that results obtained in the study could be reproduced Between the initial analysis and the final analysis presented here, new versions of Windows 2000® (final release), the "R" statistics package and Microsoft® Excel® became available and were installed on the computer used to conduct the analysis. To verify that none of the software changes had an affect on the results, the initial data set was rerun and identical results obtained.

[1] A description of this statistics package can be found on the Internet at http://www.ci.tuwien.ac.at/.

RESULTS

Oil Spill Data Collection

Alaskan Oil Spill Data

Alaskan oil spill data obtained from the MMS consisted of:

- BP electronic database files of oil spills in the Prudhoe Bay Unit Western Operating Area (1989 through 1996), Duck Island (Endicott) Unit (1989 through 1996), and Milne Point (1994 through 1996);

- ARCO electronic spreadsheet files of oil spills for the Prudhoe Bay Unit Eastern Operating Area (1977 through 1996), Kuparuk River Unit (1977 through 1985 and 1986 through 1996), and Kuparuk River Unit exploration (1986 through 1996);

- Alyeska printed summary report of oil spills greater than 1000 barrels along the TAPS from 1977 to 1989;

- JPO electronic database of oil spills along the TAPS (1970 through 1994);

- BLM printed reports of oil spills along the TAPS during 1981 and 1982;

- ADEC electronic text and spreadsheet files of oil spills from the agency's current oil and hazardous substances spill database (July 1995 to February 1997) and an earlier oil and hazardous substances spill database (1971 to July 1995);

- An unattributed printed summary of oil spills over 378.5 liters (100 gallons) on Alaska's North Slope and along TAPS from 1970 to 1981[2]; and

- An electronic spreadsheet summary of Alaskan and Canadian oil spills of 100 barrels or greater, from 1978 through 1997, as reported by the OSIR.

- An MMS report that no oil spills of 100 barrels or larger have occurred in the Alaska Beaufort Sea study area.

From inquiries to these same organizations, except to the OSIR, Hart Crowser obtained updated or additional oil spill data from:

- Alyeska; an electronic spreadsheet file containing all oil spills of 100 barrels and greater from the company's oil spill database to September 1999; and

- ADEC; an electronic spreadsheet containing all oil spills in ADEC's current oil and hazardous substance spill database to September 1999.

[2] MMS reported that they obtained the summary from BLM. Hart Crowser believes this summary may be an ADEC work product, because a copy of it was found in the agency's Fairbanks office files, and it is familiar to the report's primary author who worked for ADEC in Fairbanks at the time it was prepared.

Additional oil spill data was not received in response to inquiries and requests made to ARCO, BP Exploration (Alaska), EPA, BLM, or the National Response Center.

A review of *Oil Spills: International Summary and Review 1978-1981* and *Oil Spills: International Summary and Review 1982-1985*, which were produced by the publishers of the OSIR, yielded no additional oil data for the study.

No data concerning oil spills of 100 barrels and greater within the National Petroleum Reserve in Alaska (NPRA) were obtained from any sources. Inquiries to the BLM, the agency with surface management and protection responsibilities in NPRA since 1977, did not yield any oil spill data. Hart Crowser's review of two publications that discussed oil exploration activities in NPRA also did not identify any oil spills that met the size threshold for inclusion in this study and analysis[3].

Canadian Oil Spill Data Collection

Hart Crowser's inquiries seeking Canadian oil spill data either yielded no oil spill records or resulted in referrals to the GNWT EPS. From the GNWT EPS, Hart Crowser obtained a tabular summary of all oil spills of 100 barrels and larger that are included in the GNWT EPS oil spill database. The database has been maintained since 1985 and contains spill records back to 1971. Hart Crowser identified oil spills in the GNWT EPS database that met the study criteria and obtained the written records for those spills from the GNWT EPS.

Oil spill records also obtained oil spill data from the OSIR summary provided by MMS. This data was confirmed by Hart Crowser's reviews of *Oil Spills: International Summary and Review 1978-1981* and *Oil Spills: International Summary and Review 1982-1985*.

Reviews of EC's *Summary of Spill Events in Canada, 1974 – 1983* and *Summary of Spill Events in Canada, 1984 – 1995* and DIAND's Northern Oil and Gas Annual Reports for 1992 through 1998 yielded no data on specific spills for inclusion in the study.

Documentation of Oil Spills of 500 Barrels and Larger

Hart Crowser obtained some form of written supporting documentation from the ADEC and GNWT files for 24 of 28 oil spills identified that had a volume of 500 barrels or greater. Those spills are listed in Table 1.

Oil Spill Data Evaluation and Collation

Collation of the Alaskan and Canadian oil spill data sets resulted in the identification of 126 oil spills that met the study criteria for spill location, relation to oil industry activity, and were 100 barrels or greater. Of the 126 collated spills, 111 occurred in Alaska between 1970 and September 1999, and 15 in Canada between 1973 and September 1999. The most recent oil spills of 100 barrels or greater in both Alaska and Canada occurred in 1997. Also, of the 126 oil spills, 28 spills were 500 barrels and greater and 14 spills are 1,000 barrels or greater. Of the 28 oil spills that are 500 barrels or greater, 23 occurred in Alaska and 5 in Canada. The collated list of spills was provided to MMS as a Microsoft Access® database application and, because of its size, is provided in Appendix A rather than as a table here.

[3] Hanley *et. al*. 1981 and Gryc 1985.

TABLE 1 DOCUMENTATION FOR SPILLS OF 500 BARRELS AND LARGER						
Study Area	**Date**	**Facility Operator**	**Oil Type**	**Spill Location**	**Maximum Spill Quantity (Gallons)**	**Documentation Obtained?**
AK-Onshore North Slope (E. of NPRA)	06/03/71	ARCO	Jet/Turbine Fuel	Prudhoe Bay Unit, ARCO airfield	45,000	No
AK-Onshore North Slope (E. of NPRA)	07/16/73	ARCO	Diesel Fuel/Heating Oil	Itkillik River Unit 1	40,000	Yes
AK-Onshore North Slope (E. of NPRA)	06/20/79	Chevron USA	Jet/Turbine Fuel	Cape Beaufort	40,000	Yes
AK-Onshore North Slope (E. of NPRA)	07/15/82	Wien Air Alaska	Jet/Turbine Fuel	Deadhorse Airport	100,000	Yes
AK-Onshore North Slope (E. of NPRA)	07/28/89	Conoco	Crude Oil	Milne Point Unit, Central Processing Facility	38,850	No
AK-Onshore North Slope (E. of NPRA)	08/25/89	ARCO	Crude Oil	Kuparuk River Unit, Drill Site 2-U	25,326	Yes
AK-Onshore North Slope (E. of NPRA)	12/10/90	ARCO	Crude Oil	Lisburne Unit, Drill Site L-5	25,200	No
AK-Onshore North Slope (E. of NPRA)	08/17/93	ARCO	Crude Oil and Produced Water	Kuparuk River Unit CPF 1	28,350	Yes
AK-Onshore North Slope (E. of NPRA)	09/26/93	BP	Crude Oil	Prudhoe Bay Unit, Gathering Center 2	27,305	Yes
AK – TAPS	02/07/75	Alyeska Pipeline	Diesel Fuel/ Heating Oil	TAPS Galbraith Camp	100,000	Yes
AK – TAPS	06/11/75	Alyeska Pipeline	Diesel Fuel/ Heating Oil	TAPS Galbraith Camp	60,000	Yes
AK – TAPS	09/18/75	Alyeska Pipeline	Diesel Fuel/ Heating Oil	TAPS Franklin Bluffs Camp	30,000	Yes
AK – TAPS	12/17/75	Alyeska Pipeline	Diesel Fuel/ Heating Oil	Surfcote	70,000	Yes

TABLE 1 DOCUMENTATION FOR SPILLS OF 500 BARRELS AND LARGER						
Study Area	**Date**	**Facility Operator**	**Oil Type**	**Spill Location**	**Maximum Spill Quantity (Gallons)**	**Documentation Obtained?**
AK – TAPS	12/31/75	Alyeska Pipeline	Diesel Fuel/ Heating Oil	TAPS Prospect Camp	100,000	Yes
AK – TAPS	01/28/76	Alyeska Pipeline	Diesel Fuel/ Heating Oil	TAPS Galbraith Camp	40,000	Yes
AK – TAPS	05/08/77	Alyeska Pipeline	Gasoline	TAPS Galbraith Camp Bladder Farm	35,000	No
AK - TAPS	07/08/77	Alyeska Pipeline	Crude Oil	TAPS Pump Station 8	200,000	Yes
AK – TAPS	07/19/77	Alyeska Pipeline	Crude Oil	TAPS MP 26, Check Valve 7	110,000	Yes
AK – TAPS	02/15/78	Alyeska Pipeline	Crude Oil	TAPS MP 458, Steele Ck	672,000	Yes
AK – TAPS	06/10/79	Alyeska Pipeline	Crude Oil	TAPS MP 166, Atigun Pass	300,000	Yes
AK – TAPS	06/15/79	Alyeska Pipeline	Crude Oil	TAPS MP 734	168,000	Yes
AK – TAPS	01/01/81	Alyeska Pipeline	Crude Oil	TAPS MP 114.6, Check Valve 23	100,000	Yes
AK – TAPS	04/20/96	Alyeska Pipeline	Crude Oil	TAPS MP 539.7, Check Valve 92	34,076	Yes
CANADA - Beaufort Sea	09/18/85	Esso.	Diesel Fuel/ Heating Oil	Esso Rig #7, W. of Pelly Island	103,000	Yes
CANADA - High Arctic Islands	04/06/75	Pan-Arctic Oils	Jet/Turbine Oil	Drake D-73 Well Site	22,817	Yes
CANADA - Norman Wells	09/07/86	Esso Resources Canada Ltd.	Crude Oil	Imperial Oil Tank #53 Mainland, Sahtu Region	21,136	Yes
CANADA - Norman Wells	05/04/92	Interprovincia l Pipelines	Crude Oil	Norman Wells Pipeline, 25 km N of Ft Simpson	26,420	Yes
CANADA - Norman Wells	05/05/97	Imperial Oil.	Crude Oil	Transfer line: CPF to Tank 401	63,000	Yes

Another 95 spills, 77 in Alaska and 18 in Canada, were excluded from the study because Hart Crowser could not obtain sufficient information about them to determine whether or not they met the study criteria. The lack of information on the quantity of oil spilled, the location of the spill, or who spilled the oil were the most common reasons that prevented determinations of whether or not any of these spills should be included. A table of these spills was provided to MMS separately from this report. As discussed further, later in the report, Hart Crowser does not believe that the lack of data for the Alaskan oil spills invalidates the database of collated oil spills used to estimate oil spill risk because of the comprehensiveness of the Alaskan oil spill data and a low probability that these spills would be included in the study if complete data on them were available

Notwithstanding the spills excluded from the collated spill database because of incomplete data, Hart Crowser judged the Alaskan oil spill to be very comprehensive. Alaskan oil spill data was obtained from ten data sets. More than 60 percent of the Alaskan spills appeared in two or more data sets. Spills of 500 to 999 barrels and 1,000 barrels and larger were present in two or more data sets at a higher percentage than spills of 100 to 499 barrels.

Although some data elements, such as latitude and longitude and how the spill quantity was determined, are missing from most spill records, the data for the Alaskan spills also is mostly complete.

Overall, Hart Crowser is not confident that the Canadian oil spill data is comprehensive, because only two data sets were obtained for Canadian oil spills and there was a much lower rate of occurrence of the spill records in both of these data sets. Data sets from only the GNWT EPS and the OSIR were obtained for the Canadian oil spills, and less than 15 percent of the spills appear in both the data sets. The Canadian data is mostly complete, with the same data elements missing from some records as in the Alaskan data sets.

Oil Spill Notification Requirements

Current and historical oil spill notification requirements were identified for the United States, Alaska, Canada, and the Northwest Territories. Two sets of government agency oil spill notification requirements exist in both the Alaskan and the Canadian Arctic study areas: Federal requirements and State or Territorial requirements. In addition, the State and Federal rights-of-way for the TAPS in Alaska contain oil spill notification stipulations. Current oil spill notification requirements within the study areas are summarized in Table 2. The current and historical regulatory oil spill notification requirements are discussed further in the Discussion section of this report.

TABLE 2
CURRENT OIL SPILL NOTIFICATION REQUIREMENTS IN STUDY AREAS

Agency	Required For	Initial Verbal Report	Written Report
United States Government			
U.S. Coast Guard	All oil spills in or threatening marine navigable waters of the United States	Immediately upon knowledge. Spills may be reported to the National Response Center (NRC).	None required, but may be requested.
U.S. Environmental Protection Agency	All oil spills in or threatening navigable fresh waters of the United States	Immediately upon knowledge. Spills may be reported to the NRC.	Required, if requested or if spill is from a facility that is required to have an SPCC plan and spill is ≥1,000 gallons or is second spill in 12 months.
U.S. Department of the Interior, Minerals Management Service	All oil spills in offshore marine waters.	Immediately to the NRC Immediately to MMS Regional Supervisor for spills ≥1 barrel.	May be requested for spills of <1 barrel. Written report to MMS Regional Supervisor required for all spills of ≥1 barrel, within 15 days after spill has been stopped.
U.S. Department of Transportation	All oil spills from regulated pipelines	Immediately	Required within 30 days on DOT form 7000-1.
Federal land management agencies	Spills on Federal mineral leases, pipeline rights-of-way, and lands	As required by lease or permit	As required by lease or permit
State of Alaska			
Alaska Department of Environmental Conservation	All oil spills ≥ 1 gallon to lands or waters in Alaska	Immediately for: • Spills of >55 gallons solely to land outside of impermeable containment • Any amount to water Within 48 hours for: • Spills of 10 to 55 gallons solely to land • Spills >55 gallons to impermeable containment	Monthly, for spills of 1 to 10 gallons solely to land Within 15 days of end of cleanup, or as requested, for all other spills.

TABLE 2
CURRENT OIL SPILL NOTIFICATION REQUIREMENTS IN STUDY AREAS

Agency	Required For	Initial Verbal Report	Written Report
Alaska Oil and Gas Conservation Commission	Oil spills of ≥10 barrels from an oil drilling, production, injection, or abandonment operation in Alaska	Immediately	Preliminary report within 5 days after release; final report within 30 days after release
Alaska Department of Natural Resources	Spills on State mineral leases, pipeline rights-of-way, and lands	As required by lease or permit	As required by lease or permit
Canada Federal Government and Government of the Northwest Territories			
GNWT EPS (Serves as single point of spill notification for: • National Energy Board • Environment Canada • Department of Indian Affairs and Northern Development • Coast Guard Canada, and • Inuvialuit Lands Administration)	Oil spills of 100 liters (26.4 gallons) and larger.	Immediately	Within 15 days after end of cleanup

Crude Oil Production, Pipeline Mileage, Pipeline Throughput, Canadian Tanker Shipment, and Data

Alaskan and Canadian Crude Oil Production

Data obtained for crude oil production in the Alaska study areas are presented in Table 3. Data obtained for crude oil production in the Canadian study areas are presented in Table 4.

Alaskan Pipeline Mileages and Throughputs

The mileages of "regulated pipelines" (i.e., those pipelines regulated by the U.S. Department of Transportation and right-of-way leases issued by the State of Alaska or the BLM) were obtained from the Joint Pipeline Office (JPO). The mileage of the TAPS was obtained from the *Trans-Alaska Pipeline Atlas, Prudhoe Bay to Valdez*. The mileages for these pipelines in the Alaskan study areas are presented in Table 5.

Comprehensive data on the mileages of field gathering lines through the years could not be collected within the time and resource constraints of this study. The limited data on field gathering line mileages for the Alaskan study area that were collected are presented in Table 6.

Throughputs for the regulated pipelines in the Alaskan study areas are presented in Table 7.

Canadian Pipeline Mileage, Pipeline Throughput, and Tanker Shipment Volumes

The Norman Wells Pipeline is the only pipeline larger than a field gathering line that has operated and continues to operate in all of the Canadian study areas. The Norman Wells Pipeline runs from a pump station at Norman Wells, Northwest Territories to the Interprovincial Pipeline in Zama, Alberta, a distance of 540.0 miles. The Norman Wells Pipeline has operated from 1985 to the present.

Annual throughputs for the Norman Wells Pipeline, as well as the volumes of oil that have been shipped by tanker from other locations in the Canada study areas are presented in Table 8.

Oil Spill Data Statistical Analysis and Estimation of Spill Risk

Hart Crowser found the Alaska oil spill data to be sufficiently robust and valid to conduct statistical analyses and estimate oil spill risk rates. A cumulative frequency plot of the Alaska spill size data showed a bow characteristic of lognormal data. When these limited number of data points were re-plotted on a lognormal scale, it appeared that two lognormal populations could reasonably describe this population. A cumulative frequency plot of the Canadian oil spill size data on a lognormal basis indicated more or less the same distribution as the Alaskan data, when a plot of both the Alaskan and Canadian data were overlaid. The Canadian data was not used in further analysis because of doubts about its completeness, the fact that 15 points were below the 30 point empirical rule for number of samples, and the fact that the 112 Alaska data points would overpower the 15 Canadian points.

Exploratory data analysis on relevant independent variables indicated little statistical difference in terms of spills that occurred within the Alaska (ONS), East of NPRA, and the TAPS study areas. This lack of statistical difference was confirmed by an analysis of variance in which no statistically significant difference between the two populations was found. Although there appeared to be some type of a cycling trend in the data, with the lowest number of spills occurring in March, and the highest volume of spills occurring in July, a linear regression on month showed no statistically significant correlation.

TABLE 3
CRUDE OIL PRODUCTION FOR ALASKAN STUDY AREAS

Oil Field	Study Area	Year	Production (MMBbl)
Duck Island (Endicott)	ALASKA – Beaufort Sea	1986	0.011
		1987	8.799
		1988	37.933
		1989	36.938
		1990	38.596
		1991	42.521
		1992	43.084
		1993	40.753
		1994	35.769
		1995	34.437
		1996	27.663
		1997	22.928
		1998	18.629
Badami	ALASKA – Onshore North Slope (E. of NPRA)	1998	0.731
Kuparuk River	ALASKA – Onshore North Slope (E. of NPRA)	1981	1.092
		1982	32.406
		1983	39.882
		1984	46.208
		1985	80.013
		1986	95.272
		1987	103.705
		1988	111.146
		1989	109.770
		1990	107.206
		1991	113.571
		1992	118.506
		1993	115.166
		1994	111.795
		1995	106.999
		1996	99.459
		1997	95.971
		1998	96.281
Milne Point	ALASKA – Onshore North Slope (E. of NPRA)	1985	0.704
		1986	4.709
		1987	0.040
		1988	0.000
		1989	3.715
		1990	6.628
		1991	7.457
		1992	6.947
		1993	6.764

TABLE 3
CRUDE OIL PRODUCTION FOR ALASKAN STUDY AREAS

Oil Field	Study Area	Year	Production (MMBbl)
		1994	6.678
		1995	8.692
		1996	14.101
		1997	18.954
		1998	20.419
Point McIntrye	ALASKA – Onshore North Slope (E. of NPRA)	1981	0.002
		1982	0.208
		1983	0.087
		1984	0.294
		1985	1.123
Point McIntrye	ALASKA – Onshore North Slope (E. of NPRA)	1986	3.594
		1987	16.657
		1988	16.103
		1989	14.830
		1990	15.873
		1991	14.653
		1992	13.981
		1993	18.549
		1994	50.710
		1995	65.166
		1996	75.563
		1997	73.705
		1998	61.950
Prudhoe Bay	ALASKA - Onshore North Slope (E. of NPRA)	1969	0.277
		1970	1.193
		1971	1.157
		1972	0.922
		1973	0.944
		1974	2.170
		1975	2.870
		1976	4.604
		1977	115.258
		1978	397.679
		1979	468.412
		1980	555.648
		1981	555.620
		1982	559.389
		1983	561.148
		1984	562.269
		1985	586.590
		1986	561.767
		1987	586.555
		1988	578.686

TABLE 3
CRUDE OIL PRODUCTION FOR ALASKAN STUDY AREAS

Oil Field	Study Area	Year	Production (MMBbl)
		1989	522.869
		1990	486.235
		1991	486.706
		1992	456.490
		1993	409.690
		1994	374.318
		1995	340.439
		1996	312.609
		1997	284.001
		1998	252.825

TABLE 4
CRUDE OIL PRODUCTION FOR CANADIAN STUDY AREAS

Oil Field	Study Area	Year	Production (MMBbl)
Amauligak	CANADA - Beaufort Sea	1986	0.317
Bent Horn	CANADA - High Arctic Islands	1985	0.186
		1986	0.047
		1987	0.216
		1988	0.346
		1989	0.273
		1990	0.151
		1991	0.205
		1992	0.178
		1993	0.358
		1994	0.333
		1995	0.231
		1996	0.249
Norman Wells	CANADA - Norman Wells	Pre-1949	2.812
		1949	0.182
		1950	0.193
		1951	0.288
		1952	0.351
		1953	0.329
		1954	0.361
		1955	0.395
		1956	0.441
		1957	0.421
		1958	0.500
		1959	0.459
		1960	0.496
		1961	0.577
		1962	0.671
		1963	0.698
		1964	0.654
		1965	0.753
		1966	0.856
		1967	0.796
		1968	0.678
		1969	0.878
		1970	0.954
		1971	1.030
		1972	0.959
		1973	1.022
		1974	0.999
		1975	1.074
		1976	1.004
		1977	0.984
		1978	1.064
		1979	0.943
		1980	1.022
		1981	1.069
		1982	1.090
		1983	1.066
Norman Wells	CANADA - Norman Wells	1984	1.099
		1985	6.580
		1986	8.876
		1987	9.652
		1988	10.908
		1989	11.253
		1990	11.578
		1991	11.912
		1992	11.640
		1993	11.257
		1994	10.888
		1995	10.679
		1996	10.265
		1997	9.968
		1998	9.824

TABLE 5
REGULATED PIPELINE MILEAGES FOR ALASKAN STUDY AREAS

Pipeline Name	Starting Point	Ending Point	Operational	Mileage
Trans-Alaska Pipeline	TAPS Pump Station 1	Valdez Marine Terminal	1977 - present	799.8
Badami Sales Oil	Badami Production Facility	Endicott Sales Oil Pipeline	1998 - present	34.3
Endicott Sales Oil	Endicott Production Facility	TAPS Pump Station 1	1986 - present	25.0

Kuparuk Sales Oil	Kuparuk Central Processing Facility 1	TAPS Pump Station 1	1986 to present	30.0
Kuparuk Extension	Kuparuk Central Processing Facility 2	Kuparuk Central Processing Facility 1	1983 - present	9.2
Lisburne Sales Oil	Lisburne Production Facility	TAPS Pump Station 1	1985 - present	5.3
Milne Point Sales Oil	Milne Point Central Production Facility	Kuparuk Sales Oil Pipeline	1985 – 1987, 1989 to present	10.5
Oliktok Pipeline	Kuparuk Central Processing Facility 1	TAPS Pump Station 1	1981 – 1986	30.0

Table 6
FIELD GATHERING PIPELINE MILEAGES FOR ALASKA STUDY AREAS

Oil Production Unit	Study Area	Year	Mileage
Endicott	AK - Beaufort Sea	1986 - present	3.5
Kuparuk River	AK - Onshore North Slope (E. of NPRA)	1994	36.3
		1997	132.9
		1998	132.9
Prudhoe Bay - Eastern Operating Area (ARCO)	ALASKA - Onshore North Slope (E. of NPRA)	1994	88.7

TABLE 7
PIPELINE THROUGHPUTS FOR ALASKAN STUDY AREAS

Pipeline Name	Study Area	Mileage	Year	Throughput (MMBbl)
Trans-Alaska Pipeline	AK - Trans-Alaska Pipeline System	799.8	1977	112.315
			1978	397.149
			1979	467.939
			1980	554.934
			1981	556.067
			1982	591.142
			1983	600.859
			1984	608.836
			1985	649.887
			1986	665.435
			1987	716.662
			1988	744.108
			1989	688.062
			1990	654.551
			1991	665.175
			1992	639.390
			1993	591.220
			1994	579.320
			1995	555.939
			1996	525.565
			1997	487.017
			1998	440.482
Badami Sales Oil	AK - Onshore North Slope (E. of NPRA)	34.3	1998	0.731
Endicott Sales Oil	AK – Beaufort Sea	6.0	1986	0.011
	AK - Onshore North Slope (E. of NPRA)	19.0	1987	8.799
			1988	37.933
			1989	36.938
			1990	38.596
			1991	42.521
			1992	43.084
			1993	40.753
			1994	35.769
			1995	34.437
			1996	27.663
			1997	22.928
			1998	19.360
Kuparuk Extension and Oliktok Pipelines	AK - Onshore North Slope (E. of NPRA)	39.2	1981	1.092
			1982	32.406
			1983	39.882
			1984	46.208
			1985	80.717
			1986	99.981
Kuparuk Extension and Kuparuk Sales Oil Pipelines	AK - Onshore North Slope (E. of NPRA)	39.2	1987	143.705
			1988	111.146
			1989	113.485
			1990	113.834
			1991	120.728
			1992	125.453
			1993	121.930
			1994	118.473
			1995	115.691

TABLE 7
PIPELINE THROUGHPUTS FOR ALASKAN STUDY AREAS

Pipeline Name	Study Area	Mileage	Year	Throughput (MMBbl)
Kuparuk Extension and Kuparuk Sales Oil Pipelines	AK - Onshore North Slope (E. of NPRA)	39.2	1996	113.560
			1997	114.925
			1998	116.700
Lisburne Sales Oil	AK - Onshore North Slope (E. of NPRA)	5.3	1985	1.123
			1986	3.594
			1987	16.657
			1988	16.103
			1989	14.830
			1990	15.873
			1991	14.653
			1992	13.981
			1993	9.750
			1994	7.785
			1995	6.277
			1996	5.139
			1997	3.416
			1998	2.800
Milne Point Sales Oil	AK - Onshore North Slope (E. of NPRA)	10.5	1985	0.704
			1986	4.709
			1987	0.040
			1988	0.000
			1989	3.715
			1990	6.628
			1991	7.457
			1992	6.947
			1993	6.764
			1994	6.678
			1995	8.692
			1996	14.101
			1997	18.954
			1998	20.419

TABLE 8
PIPELINE THROUGHPUTS AND TANKER SHIPMENT VOLUMES FOR CANADIAN STUDY AREAS

Oil Field	Study Area	Transport Method	Mileage	Year	Volume (MMBbl)
Norman Wells	CANADA - Norman Wells	Norman Wells Pipeline	540.0	1985	6.580
				1986	8.876
				1987	9.652
				1988	10.908
				1989	11.253
				1990	11.578
				1991	11.912
				1992	11.640
				1993	11.257
				1994	10.888
				1995	10.679
				1996	10.265
				1997	9.968
				1998	9.824
Bent Horn	CANADA - High Arctic Islands	Tanker	NA	1985	0.186
				1986	0.047
				1987	0.216
				1988	0.346
				1989	0.273
				1990	0.151
				1991	0.205
				1992	0.178
				1993	0.358
				1994	0.333
				1995	0.231
				1996	0.249
Amauligak	CANADA - Beaufort Sea	Tanker	NA	1986	0.317

TABLE 8
PIPELINE THROUGHPUTS AND TANKER SHIPMENT VOLUMES FOR CANADIAN STUDY AREAS

A general check on the fluctuation of the data set, as seen in a plot of the logarithm of thespill size versus the day of the month indicated spill occurrence to be quite random. There was little trend seen in the median of the data for a box plot of the logarithm of the spill size versus the year, with the exception of 1979, which was higher. However, an analysis of variance of this data showed no statistically significant difference between the years. There appeared to be little difference in the size of spills between the types of spills associated with the various facilities, with the exception of pipelines, which had larger spills. Analysis of variance by oil type showed that, in general crude oil spills tend to be larger than other types of oil spills.

Cumulative frequency plots by selected independent variables show that:

- Spills within the TAPS study area appears to be a fairly clear mixture of two lognormal populations;
- Spills within the ONS study area shows more bowing, indicating perhaps a single population;
- Spills from tank vehicles exhibit little apparent variability in a box plot, which is more or less consistent with the fact that a tank vehicle spill should be expected to have a firm upper limit;
- Spills from facility piping exhibit a bow, but no clear break in population;
- Spills from pipeline leaks indicate what may be a single lognormal population and, in general, appear to be the largest in quantity;
- Spills from facility tank leaks exhibit a single lognormal population;
- Spills from unspecified causes also exhibit a single lognormal population; and
- Spills from other causes had such a small number of data points that no definite conclusions could be drawn, but overlaying the figure for unspecified causes indicated that these two spill cause categories can probably reasonably be lumped together as a single population for statistical analysis.

Cumulative frequency plots of the logarithms of spill volume versus oil type showed that the data for spills involving:

- Diesel fuel data appears to be a mixture of two lognormal populations;
- Crude oil data appears to be a mixture of two lognormal populations;
- Gasoline data appears to show a single lognormal population with one possible outlier, which is consistent with a mixture of two lognormal populations; and
- Turbine and jet fuel data also shows what may be a mixture of two lognormal populations.

Cumulative frequency plots of the logarithms of spill volume versus the type of facility where a spill occurred showed that the data for spills from:

- Highways are very similar to the tank vehicle spills, which is entirely consistent with the assumption that most, if not all, highway spills are from tank vehicles;
- Support facilities was a bowed lognormal population;
- Production facilities appear to show a single lognormal population;
- Construction camps appear to show a mixture of two lognormal populations; and

- Pipelines could be interpreted as a single lognormal population.

Cumulative frequency plots of the log of spill volume versus the affected environmental media showed that spills:

- Affecting land is a mixture of two lognormal populations;
- Affecting land and water shows a mixture of two lognormal populations;
- Contained within a secondary containment area, appeared to be a single lognormal population; and
- Where the affected media was unspecified appears to be a single lognormal population.

There were no spills that affected water only.

A statistical analysis of individual spill volumes by study area, facility type, oil type, affected media and spill cause combined did not indicate any particularly interesting correlation. Annualized groupings of spills, where total spill volumes by year were accumulated and plotted on a cumulative frequency plot, showed a mixture of several populations. Re-plotted on a logarithmic scale, a single lognormal population emerged. A count of the number of spills per year in the database is showed a possible Poisson distribution, but that hypothesis was not tested.

When spill size was plotted by year to see if regulatory or reporting requirements had a significant affect, it appeared that in the period from 1975 to 1979 there were a considerable number of large spills, and then the number of spills dropped to a more or less constant rate. The year of 1977 is significant because crude oil production on North Slope and operation of TAPS began in the middle of that year. However, the years of 1978 and 1979 visually fit with years of 1975 and 1977 better than breaking the data at 1977. The 1975 to 1979 period appears to have the most number of spills.

When Alaskan spill data were plotted on a yearly basis, it appears that prior to 1977, spill rates were considerably greater than in the subsequent years. When re-plotted on a logarithmic scale, it is apparent that prior to 1980 spill rates were considerably greater than after 1980.

Hart Crowser calculated oil spill risk rates based on the number of spills and on volume. Hart Crowser calculated a rate based on volume because of the greater visual variability in the data. The statistical significance of this visual analysis showed a highly statistically significant correlation with spill rate and year if all of the Alaska spill data is included. If data earlier than 1980 is excluded, then there is still a correlation between spill rate and year that is significant at the 1 percent level of confidence. However, if data earlier than 1985 is excluded, then there is a correlation between spill rate and year, which is significant at the 17 percent level of confidence.

Hart Crowser concluded that spill rate is the best variable to use in predicting the volume of further oil spills and that a rate of approximately 52 gallons of oil spilled per million barrels of crude oil produced will be the average, if trends that started in 1980 continue. This rate is subject to considerable uncertainty in the mean (± 50% at the 95% level of confidence) and the value derived from the logarithmic distribution is 66 gallons of oil spilled per million barrels of crude oil produced as opposed to 52 gallons of oil spilled per million barrels of crude oil produced. These two values agree within the standard deviation of the means. The 95 percent logarithmic confidence limits on spills for a given year are ± 465 percent at the 95 percent level of confidence. Hart Crowser is more inclined to believe the logarithmic values than the untransformed values, because the cumulative frequency of the data is more lognormal than normal. These very wide confidence limits and individual yearly values are consistent with the small number of data points available for this prediction.

Hart Crowser also calculated oil spill risk rates based on the number of spills of a given volume per million barrels of crude oil produced (spills/MMBbl), using data from 1978 through 1999. Hart Crowser found these rates to be:

- 0.0053 spills/MMBbl, ±24 percent, for spills of 100 barrels and greater;
- 0.00093 spills/MMBbl, ±58 percent, for spills of 500 barrels and greater;
- 0.00039 spills/MMBbl, ±89 percent, for spills of 1,000 barrels and greater; and
- 0.000078 spills/MMBbl, ±200 percent, for spills of 10,000 barrels and greater.

DISCUSSION

Oil Spill Data Collection

Alaska Oil Spill Data

Hart Crowser believed that ADEC would be the best potential source of oil spill records for Alaska because, since the Department was established in 1971, the agency has received reports, investigated, and overseen the cleanup of oil spills in Alaska. Hart Crowser received and reviewed copies of electronic spreadsheet files from ADEC and from the MMS that contained data on oil spills from a past (1986 – 1995) and a current (1995 – present) agency oil and hazardous substance spill database.

Through inquiries to ADEC staff, Hart Crowser researchers identified the location of relevant written oil spill files, and then traveled to ADEC's Fairbanks and Valdez offices, to review those files. During the file reviews, Hart Crowser sought to identify oil spills that met the study criteria, record pertinent data from the spill records, and obtain documentation from the files for spills of 500 barrels or greater.

With respect to ADEC's oil spill files and databases, Hart Crowser researchers observed that:

- Not all reported oil spills prior to July 1995 have been entered into ADEC's current oil and hazardous substance spill database, which has been used since July 1995. In 1996, ADEC attempted to have all historical oil and hazardous substance spill information reviewed and entered into the database. However, the project was not conducted for several reasons, including the large number of historical records and the incomplete status of many historical records.

- Not all reported oil spills were entered into the older ADEC Northern Regional Office oil and hazardous substance spill database, which was used from approximately 1986 to July 1995. Hart Crowser found several oil spill reports in the agency's files that met the criteria for inclusion in this study, but which were not included in the agency's database.

- Most initial and final oil spill reports and most other spill documentation do not describe how spill quantities were determined. In most cases, spill quantities appeared to be estimates. Some estimates are more accurate because the quantity of oil that may have been spilled is known (e.g., the capacity of a tank vehicle and the amount of oil that remained inside after an accident). Some spill estimates are calculated based on the size of the hole that allowed oil to escape, the pressure of the oil within the pipe or tank, the known or estimated duration of the leak, and the amount of oil recovered during spill cleanup. In other cases, spill sizes are rough estimates because the rate and duration of oil loss could not be accurately determined and the amount of oil recovered was not documented.

- Some oil spill reports contained incomplete information that did not allow them to be included in the study database. For oil spill records where the quantity of oil spilled, the location of the spill, or a connection to oil industry activities was not given or could not be determined, data on the spill was recorded, but the spill was not included in the study.

Canadian Oil Spill Data

Hart Crowser's inquiries to Canadian government agencies for oil spill data resulted in referrals to the Government of the Northwest Territories, Environmental Protection Service (GNWT EPS) in Yellowknife, Northwest Territories. The GNWT EPS appears to be the sole repository of Canadian oil spill data for the areas of interest in this study. Hart Crowser was prepared to travel to Yellowknife and review the GNWT EPS oil spill files. However, GNWT EPS staff assured Hart Crowser that all requested oil spill documentation available in the agency's files would be transmitted to Hart Crowser.

The GNWT EPS has maintained an oil and hazardous substance spill database since the early 1980s. Hart Crowser first obtained summary reports of oil spills of 100 barrels and larger from the agency's database, then obtained all written documentation from GNWT EPS for those oil spills that Hart Crowser determined either met or might meet the study criteria.

Hart Crowser also reviewed two summary reports of oil spills covering the years 1974 through 1995, published by Environment Canada, and seven Northern Oil and Gas Annual Reports from 1992 to 1998, published by the Department of Indian Affairs and Northern Development (DIAND, also known as Indian and Northern Affairs Canada) to look for additional data on oil spills associated with oil industry activities in the Canadian Arctic.

A summary of oil spills as reported by the OSIR, supplied by the MMS was reviewed for potential data on oil spills in the Canadian study areas. Data in this summary was found to correspond to information OSIR's publications, *Oil Spills: International Summary and Review 1978-1981* and *Oil Spills: International Summary and Review 1982-1986*.

<u>Evaluation and Collation of Oil Spill Data</u>

Different oil spill data sets (i.e., oil spill data obtained from different sources) were compared with one another to evaluate the overall comprehensiveness and completeness of the data and to develop a single collated list of oil spills. To develop the collated list of spills, the spill records from the different data sets were compared with one another and data for each spill was combined into a single record for each spill. Differences in data between spill records in the different data sets, including reported spill dates, locations, responsible parties, oil type, and spill quantity were reconciled. Where different oil spill quantities were reported in two or more different data sets, or the spill quantity was reported as a range, the spill quantity was reported as a range in the collated list of spills.

The database for the oil spill records included in the study includes data fields for:

- Record source (the organization where an oil spill record was obtained);
- Study area (designating which of the eight study areas a spill occurred within);
- Spill date;
- Facility type (ten categories of facility types were developed by Hart Crowser; one type was assigned to each spill report);
- Facility operator (company or organization that operates the facility where the spill occurred);
- Spiller (company or organization named as responsible for the spill);
- Spill name (if a spill is commonly referred to by a name);
- Oil type (six categories of oil types were developed by Hart Crowser;

one type was assigned to each spill report);

- Location (a brief description of where the spill occurred);
- Latitude and longitude;
- Spill cause (a brief description of what caused the spill);
- Low and high spill quantity (in gallons);
- How the spill quantity was determined; and
- Affected environmental media.

The facility type categories attempt to designate the facility where the spill occurred to allow analysis by this field. The facility type categories are:

- Construction camp;
- Exploration support facility;
- Exploration well site;
- Highway;
- Operations support facility;
- Pipeline;
- Pipeline pump station;
- Production processing facility;
- Production well site; and
- Unspecified.

The oil type field categories assigned are:

- Crude oil;
- Crude oil and produced water;
- Diesel/heating oil;
- Gasoline;
- Jet/turbine fuel; and
- Unspecified.

Because of their similarities, diesel fuel and heating oil, and jet fuel and turbine fuel, were combined into single categories.

The affected media field records whether an individual oil spill affected land, water, or both. Spills contained in buildings, on gravel pads, or in impoundments such as secondary containment structures were included in the all-record and collated spill databases. These spills were designated as having affected "land" with a subsequent notation of how the spill was contained.

Data in the record source, study area, and facility type fields were assigned by Hart Crowser, based on information in the spill records, answers to inquiries, or personal knowledge. Data in fields such as facility operator, spiller, spill name, oil type, spill location descriptions, and the units of measure used in oil spill quantity were standardized as much as possible among the data sets to facilitate comparisons of individual spills between data sets.

The collated database includes the same data fields as the database for all spills, with the exception that the record source field was eliminated and multiple fields were added to indicate the sources of the records for each spill.

The Alaskan oil spills observed most frequently are associated with highway tank vehicle accidents related to TAPS and North Slope oil field construction and operations support, followed by spills related to construction camps, other operations support facilities, and pipelines. Spills associated with oil production processing facilities, oil production wells, pipeline pump stations, and exploration activities also were identified. The most frequent oil spills of 100 barrels and greater in the Canadian study areas were associated with oil exploration activities, oil production wells, and oil production processing facilities. Highway tank vehicle and pipeline spills also were identified.

As mentioned in the results section of the report, 77 oil spills in Alaska and 18 in Canada were not included in the study because Hart Crowser could not obtain sufficient information about them to determine whether or not they met all of the study criteria. These excluded spills do not detract from the validity of the oil spill data used to estimate oil spill risk. Spills of 100 barrels and larger occur relatively infrequent, and because of this, they are more readily noticed and are better reported to government agencies either by the responsible party or other people who see them or clean them up. These spills also are more highly publicized in news stories. Evidence that oil spills of 100 barrels and larger are well reported can be seen in the high frequency that their spill records appear in more than one data set.

The spills on the excluded list tend to be those for which there no corroborating evidence in other data sets to help in determining whether to include an individual spill or not. All but one oil spill excluded from the study database appear only in one data set. Where Hart Crowser was able to obtain additional information about spills on the excluded list, the information Hart Crowser obtained has eliminated spills from further consideration, rather than added spills to the study database. No spills from the list of excluded spills have been added to the database. Further research could be conducted to completely determine whether any of the remaining spills on the excluded list should be included in the study. However, there appears to be a low probability that sufficient data on these other spills would be uncovered or that many additional oil spills would be added to the study database by that further research.

Oil Spill Data Comprehensiveness and Completeness

For the period from 1970 through September 1999, the Alaskan oil spill data appears to be comprehensive. However, Hart Crowser is not confident that the same can be said for the Canada data. It appears that the Alaskan spills are better documented than those in Canada. The Alaskan spill data was obtained from ten different government agency, industry, and commercial sources. The different sources largely corroborated each other on more than 60 percent of the spills and helped to provide complete data for most spills. Spills reported in only one data set appear to exist either because the spiller is a party who did not provide data for this study or because the spill was reported by one party but not another because of differences in the estimated spill quantity. The comprehensiveness and completeness of the Alaskan spill data prior to the early 1970s is the most suspect, because ADEC was not fully functional and agencies such as JPO did not exist. Data on older oil spills may exist in the archived files of extinct State or Federal environmental pollution agencies, such as the Alaska Department of Health and Welfare or the Federal Water Pollution Control Agency.

To see if there were differences between the size of a spill and its appearance in two or more data sets, the spills from the correlated spill database were compared against the various data sets to determine how many of the spills appeared in two or more data sets. Spills were divided into three basic size categories: 100 to 499 barrels, 500 to 999 barrels, and 1,000 barrels and larger. Table 9 presents the results of that evaluation. Overall, and individually, the Alaskan and Canadian data showed trends indicating that larger spills were more likely to occur in multiple data sets. The Canadian data showed greater differences between the 100 to 499 barrel and the other spill size categories, but with so few data points, Hart Crowser would not draw any conclusions from the Canadian data alone.

TABLE 9 CORRELATION OF SPILL SIZE AND OCCURRENCE IN MULTIPLE DATA SETS			
Spill Location and Size	**Number of Spills**	**Number of Spills in Multiple Data Sets**	**Percent of Spills in Multiple Data Sets**
Alaska ≥100 - 499 bbls	87	54	62
Alaska ≥500 - 999 bbls	12	8	67
Alaska ≥1,000 bbls	12	9	75
Canada ≥100 - 499 bbls	10	0	0
Canada ≥500 - 999bbls	3	1	33
Canada ≥1,000 bbls	2	1	50
All spills ≥100 - 499 bbls	97	54	56
All spills ≥500 - 999 bbls	15	9	60
All spills ≥1,000 bbls	14	10	71

Hart Crowser is not confident that the Canadian oil spill data is adequately comprehensive. Hart Crowser's conclusion is based on the fact that only two data sets, from the GNWT EPS and the OSIR, were obtained, and of 15 spills, only 2 spills (15 percent) are found in both data sets.

The collated list of Alaskan oil spills, as well as the list of spills not included in the database, was provided to the ADEC for data validation. Because virtually all of the Canadian oil spill data came from the GNWT EPS, the collated Canadian data was sent to Environment Canada for validation. Hart Crowser did not receive responses from ADEC or Environment Canada concerning the validity of the oil spill data before the completion of this report.

Reliability of Oil Spill Volume Determinations

Hart Crowser obtained copies of written oil spill reports from agency files for 24 of the 28 spills identified in Alaska and Canada that met the study criteria and were 500 barrels or greater. Documentation for these 24 oil spills, either in reports filed by the responsible party or a government agency report, typically do not describe how the spill quantity was determined.

The quantity of oil involved in most spills is an estimate, because the exact rate and duration of the oil discharge is not known. For some spills, such as from tanks, tank vehicles, or tank vessels, the quantity of oil in the tank, vehicle, or vessel prior to the spill and the quantity of oil offloaded or remaining in the tank, vehicle, or vessel after the spill frequently is known, allowing a fairly accurate estimate of the spill size. Spills that occur in containment areas also can be accurately determined. However, leaks from aboveground tanks lacking, or with incomplete secondary containment may go undetected for a long period of time. The rate and duration of leaks from buried tanks, piping, and pipeline systems may be even more difficult or impossible to determine with good accuracy. Engineering calculations compared to measurements of how much oil is recovered during cleanup may provide the best method to estimate the spill's size, and may yield an estimate accurate only to an order of magnitude. The size of spills from aboveground pipelines in Alaska and Arctic Canada also can be difficult to estimate, because the pipelines cross remote, uninhabited areas and it can be hours or days before facility workers or security surveillance patrols discover a spill. Even in pipeline systems equipped with leak detection instrumentation, a leak may occur at a rate less than the instrumentation can detect. Finally, not all of the spilled oil may be discovered or recovered, making it difficult to estimate the size of a spill with much accuracy.

Of the 28 oil spills that are 500 barrels and greater, 8 involve pipeline leaks and 8 involve facility piping leaks. These types of spills are the most difficult to accurately estimate the size of because they may go undetected for long periods of time, the rate of spillage can be difficult to determine, and not all of the oil may be discovered or accounted for in cleanup. Two of the 28 spills involved facility explosions. The size of the spills associated with these explosions can be reasonably estimated because the time and rate of spillage can be calculated with some certainty. Another 7 of the 28 spills involve tank leaks, which also can be estimated with reasonable certainty because the quantity of oil involved in a spill can be accurately estimated from tank capacities, the tanks involved in these spills are located above ground, and, in most instances, the spills occurred within secondary containment areas. The final 3 of the 28 spills are from unspecified causes, and an assessment of the accuracy of the spill estimate cannot be made without further information.

Alaska Statutes, Title 46, Chapter 03, Section 758 (A.S. 46.03.758), enacted in 1977, authorizes state courts to assess civil penalties, based the quantity and toxicity of the oil, and the type of environment, against parties found that are found guilty of illegally discharging oil. This provision commonly is referred to as the "dollars per gallon" penalty. Depending on the toxicity of the oil and the type of environment involved, the basic penalties range from less than $1.00 to $10.00 per gallon. If gross negligence or intentional discharge is involved in the spill, or if the spiller fails to take reasonable steps to control, contain, and cleanup the spill, fines can be increased by a factor of five. ADEC adopted regulations in April 1978, found in Alaska Administrative Code, Title 18, Chapter 75, Article 6 (18 AAC 75.605 - 75.670), that establish a schedule to be used in calculating proposed fines under A.S. 46.03.758.

In addition to the civil fine provisions of A.S. 46.03.758, A.S. 46.030.759 establishes civil penalties for discharges of crude oil larger than 18,000 gallons. Under the crude oil penalty provisions, the court can assess a guilty party $8.00 per gallon for the first 420,000 gallons (1,000 barrels) spilled and $12.50 for every gallon over 420,000 gallons, regardless of the type of environment. Both statutory provisions allow a penalty to be reduced for every gallon of oil recovered and for mitigating circumstances. The provisions of A.S. 46.030.758 also allow the court to reduce a fine for an oil spill of less than 18,000 gallons to less than $500.

Because the dollar per gallon penalty provisions of A.S. 46.03.758 and 46.03 .759 apply only after a party has been found guilty of the illegal discharge of oil in a civil suit, a penalty can be reduced for specific reasons, and civil suits against oil spillers in Alaska are rare, ADEC does not routinely expend the effort to develop legally defensible estimates of the quantity of oil involved in each oil spill. In administrative enforcement actions that ADEC may take following an oil spill, such as a Compliance Order by Consent, any monetary restitution paid to the State as part of the Order may be based on the dollar per gallon penalty provisions and schedule, but are negotiated as part of settling a potential legal action.

No data concerning oil spills within the NPRA were obtained. Hart Crowser inquiries to BLM , the agency with surface management and protection responsibilities in NPRA since 1977, did not yield any oil spill data. Two publications that discussed oil exploration activities in NPRA did not identify any specific spills that met the size threshold for inclusion in this study and analysis[4]. Hanley[5] wrote that when the Navy resumed oil exploration activities in NPRA in 1974, that there were chronic problems, which included minor fuel spills. He also states that

[4] Hanley *et. al*. 1981 and Gryc 1985.
[5] Hanley *et. al*. 1981, page 195.

while several fuel spills of 800 to 1,000 gallons in size occurred during the U.S. Department of the Interior's exploration program beginning in 1977, spills of that size or larger had not occurred more recently (1979-1980)[6]. Gyrc[7] wrote that there were a few minor fuel leaks and spills at drill sites and from mobile trains during the Department of the Interior's exploratory activities from 1977 to 1982.

Current and Historical Oil Spill Notification Requirements

United States Federal Oil Spill Notification Requirements

Federal oil spill notification requirements exist under the Federal Water Pollution Control Act (FWPCA), as amended by the Clean Water Act (CWA) amendments and the Oil Pollution Act of 1990 (OPA). Notification requirements also exist under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended.

The FWPCA, enacted in 1948, prohibited the discharge of oil to the navigable waters. However, it was not until enactment of the CWA in 1972 that amendments were added which began to require notification of the U.S. Government for discharges of oil to the waters of the United States. Further amendments, which did not significantly change the notification requirements, were made in the CWA of 1977. Finally, OPA enacted in 1990 has further strengthened the FWPCA's oil spill notification requirements and penalties.

Section 311(b)(6) of the CWA[8] requires notification be made to the appropriate U.S. Government agency by the owner, operator, or person in charge of a vessel or an onshore or offshore facility that discharges oil into the navigable waters of the United States. EPA and the Coast Guard share oil spill notification and cleanup oversight or response responsibilities, based on whether the spill occurs in inland or marine waters. The Coast Guard has adopted oil discharge notification regulations that apply to vessels[9]. The EPA first adopted oil discharge notification regulations in September 1970. Prior to that time, there was no federal requirement to report oil spills promptly[10]. These regulations, found in 40 CFR 110, require that the owner, operator, or person in charge of a vessel or an onshore or offshore facility notify EPA when oil is discharged to the waters of the United States in a quantity that will be harmful[11]. The regulations define harmful quantity as the amount of oil that violates water quality standards or causes a film or sheen upon or discoloration of the surface of the water or adjoining shorelines or causes a sludge or emulsion to be deposited beneath the surface of the water or adjoining shorelines. It is known as the "sheen regulation." EPA revised 40 CFR 110 in April 1987. These revisions modified the requirement that a spill be reported when the quantity of oil <u>will</u> be harmful, to when the quantity of oil <u>may</u> be harmful, and specified appropriate reporting requirements in terms of whether the discharge occurs in the territorial sea, the contiguous zone, or beyond 12 miles.

In 1997, the MMS also established oil spill notification requirements, under the authority of the CWA, for offshore oil for owners and operators of oil handling, storage, or transportation facilities that are located offshore of the coast line. The MMS requires the operator of an offshore facility to report to the NRC all oil spills from their facility, another offshore facility,

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[6] Hanley *et. al*. 1981, page 207.
[7] Gyrc 1985, page C54.
[8] 33 USC 1321(b)(5)
[9] 33CFR 151.15 Reporting Requirements.
[10] Federal Register, Volume 50, Page 9776 (50 FR 9776), March 11, 1985.
[11] See 40 CFR 110.6.

and from unknown origins. An offshore facility operator also must report all spills known or thought to be 1 barrel or more in size from their facility also must be reported directly to the MMS, and a written follow-up report must be filed with MMS within 15 days after the spillage has stopped.

The CWA of 1972 established a criminal penalty for failure to notify the government of a discharge of oil. Upon conviction for a violation of the discharge notification requirement, the court could impose up to a $10,000 fine and, for a person, up to 1 year imprisonment[12]. These penalties were increased by OPA in 1990, making failure to report a discharge of oil a Class D felony, with a maximum penalty of a $250,000 fine and up to 5 years imprisonment for a person. OPA also added a maximum penalty of $250,000 fine and 15 years imprisonment, for a person convicted of multiple violations, and increased the maximum fine for an organization to $500,000.

Enactment of CERCLA in 1980 extended U.S. Government notification requirements to oil releases on land, provided that a discharge contains a hazardous substance identified by the Act above the established reportable quantity for the substance (e.g., the discharge of oil containing 10 pounds or more of benzene). The notification regulation adopted by EPA under CERCLA is found as part of the National Contingency Plan[13]. Discharge notifications to meet the requirements of either the FWPCA, for the Coast Guard or EPA, or CERCLA can be made through the NRC , a national clearinghouse, operated by the U.S. Coast Guard, for reporting all types of pollution incidents. The original penalty established in CERCLA for failure to report a discharge of a hazardous substance was a maximum fine of $10,000 and, for a person, up to 1 year imprisonment. In 1986, Congress increased the CERCLA's penalties for failure to make the required notification, making the fine a maximum of $250,000 and increasing the imprisonment penalty to 3 years, with a maximum of 5 years for a second violation.

Alaska Oil Spill Notification Requirements

Alaska's current oil spill notification requirements, found in Title 18, Chapter 75, Section 300 (18 AAC 75.300), set out requirements for the reporting of both oil and hazardous substances spills based on the material, the quantity spilled, and whether the spill affects land or water. These notification requirements have been in effect, in much the same form, since April 1977. The underlying statutory authority for the regulation is found in Alaska Statutes Title 46, Chapter 03, Section 755 (AS46.03.755) Discharge Reporting, enacted by the Alaska Legislature in 1976.

Failure to report an oil spill as required by 18 AAC 75.300 and AS 46.03.755 is a Class A misdemeanor and, upon conviction, is punishable by:

- A $5,000 fine and up to 1 year imprisonment, if the defendant is a person; or

- A $200,000 fine or up to two times the pecuniary gain or loss that would be realized by the defendant as a result of the violation, if the defendant is an organization. From 1978 to 1990, the maximum fine for an organization was $100,000.

Prior to the adoption of 18 AAC 75.300 in 1977, Alaska's oil spill notification requirement was found in older Alaska Department of Health and Welfare (ADHW) regulations which extended

[12] 33 USC 1321 (b)(5).
[13] 40 CFR 300.405 (b) Discovery or Notification.

back to at least 1959[14]. The ADHW was the agency with primary responsibility for administering Alaska's environmental laws prior to the Alaska Legislature's creation of ADEC in 1971. The ADHW regulation required only the submittal of a written report for an oil spill within three days. No spill volume was specified in the notification requirement. The underlying statutory authority for the regulatory notification requirement appears to be general statutory prohibitions on environmental pollution[15] and nuisances[16]. Penalties for failure to notify the state of an oil spill were a $100 to $500 fine and imprisonment of up to 30 days.

The Alaska Oil and Gas Conservation Commission (AOGCC) adopted regulations in 1980 that require the immediate notification of the AOGCC for uncontrolled accidental losses of oil that occur from oil drilling, production, injection, and abandonment activities. The existing regulations require notification for releases of greater than ten barrels. Prior to November 1999, the requirement called for the notification of any accidental loss. The penalties for failure to report an accidental loss to the AOGCC are the same as the penalties for failure to report a spill to the ADEC.

TAPS Right-of-Way Stipulations

Both the State of Alaska and the federal right-of-way leases for the TAPS contain nearly identical notification requirements for oil spills from construction and operation of the pipeline. State of Alaska Stipulation 2.13.1 prohibits discharges of oil or other pollutants in violation of state law or regulations and requires the immediate reporting of any discharge to the Pipeline Coordinator and other state officials required by law to be given notice. State Stipulation 2.13.2 requires immediate notice of any spill or leakage from the pipeline, the Valdez Marine Terminal, and any storage or refueling facility and equipment to the Pipeline Coordinator and other state officials required by law to be given notice. An oral notification must be confirmed in writing as soon as possible.

Federal Stipulation 2.13.1 prohibits the discharge of oil into or upon the navigable waters of the United States, adjoining shorelines, or waters of the contiguous zone in violation of FWPCA as amended or the laws and regulations of the State of Alaska. The stipulation requires the immediate notification of discharges to the Department of the Interior Authorized Officer and other state and federal officials required by law to be notified. Federal Stipulation 2.13.2 requires immediate notice be given of any spill or leakage from the pipeline, the Valdez Marine Terminal, and any storage facility to the Authorized Officer and other state and federal officials required by law to be given notice. An oral notification must be confirmed in writing as soon as possible.

Other Federal and State Notification Requirements

Federal and state land management agencies, including the BLM; Department of the Interior, Fish and Wildlife Service (USFWS); and the Alaska Department of Natural Resources also routinely require notification of spills that occur on lands under their administration. These notification requirements, similar to the TAPS right-of-way stipulations described above, typically are included as conditions of mineral leases, pipeline rights-of-way, and land use

[14] 7 AAC 01.02.04.501(h)
[15] AS 46.03.710, and AS 46.05.170 prior to 1971. See 3Ch 120 SLA 1971.
[16] AS 46.10.010 prior to 1971.

permits issued by the agencies. Because these types of notification requirements are not found in statutes or regulations, their current and historical requirements are not described in this report.

Canadian Notification Requirements

In Canada, statutes and regulations are first published in the Canada Gazettes and then consolidated every decade or so. Although consolidated statutes and regulations are cited, according to the Canada Department of Justice, consolidated statutes and regulations are not currently considered the official version. When consolidation occurs, the original year of enactment and early amendments are not necessarily carried forward. Information currently available from the regulatory agencies and the Canada Department of Justice was obtained, but further research into the full history of Canada's oil spill notification requirements would require time-consuming research in the annual Canada Gazettes.

The latest consolidation of Canada's statutes occurred in 1985 and is named the Revised Statutes of Canada (R.S.C.). The most recent consolidation of the regulations occurred in 1978 and is named the Consolidated Regulations of Canada (C.R.C.). Lowercase "c" is the abbreviation for chapter and lowercase "s" is the abbreviation for section in the regulations. Statutory Orders and Regulations (S.O.R.) refer to the regulations enacted between consolidations. Specific acts and accompanying regulations that contain oil spill notification requirements are discussed below.

Fisheries Act

The Fisheries Act (R.S.C. 1985, c. F-14.81) is the primary federal means of managing water resources by protecting fish and fish habitat in Canadian waters. This Act originally was enacted no later than 1973. The current Fisheries Act sets penalties as high as $1 million in fines and three years in jail, depending on which offense is alleged, and whether the prosecution proceeds by way of a summary proceeding or by indictment.

Canada Oil and Gas Operations Act

The Canada Oil and Gas Production and Conservation Act, which was amended by the Canada Petroleum Resources Act (which also repealed the Canada Oil and Gas Act), became the Canada Oil and Gas Operations Act (R.S.C. 1985, c. O-7)**.** The Canada Oil and Gas Operations Act was enacted no later than 1979. According to definitions in this Act, "'former regulations' means the Canada Oil and Gas Land Regulations made pursuant to the Public Lands Grants Act and the Territorial Lands Act and includes orders made pursuant to those Regulations."

Section 25 of the Oil and Gas Operations Act includes the duty to report spills:

> "Where a spill occurs in any area to which this Act applies, any person who at the time of the spill is carrying on any work or activity related to the exploration for or development or production of oil or gas in the area of the spill shall, in the manner prescribed by the regulations, report the spill to the Chief Conservation Officer."

Liability is assigned to persons involved, to the extent determined, according to the degree of fault or negligence proved against them.

Canada Oil and Gas Drilling and Production Regulations (C.R.C. 1978, c.1517) are part of the Territorial Lands Act and were adopted no later than 1978. These regulations govern oil and natural gas drilling and production procedures. If an accident occurs, such as a well flowing out of control, or any breaks or leaks in tanks or pipelines from which any serious loss of oil occurs, the license owner/operator must report to the Oil Conservation Engineer immediately by telegraph, telephone or radio, with subsequent letter confirmation. Violations of the regulations can result in cancellations of licenses, permits, or leases. A "serious loss of oil" has not been defined in the regulations or in subsequent guidance issued by the NEB.

Canada Oil and Gas Drilling Regulations (SOR/79-82), adopted in 1979, are part of the Canada Oil and Gas Operations Act, and primarily address oil and natural gas drilling programs. If a significant event occurs, such as a spill, notification to the Chief Safety Officer or the Chief Conservation Officer is required. A "significant event" has not been defined in the regulations or in subsequent guidance. Failure to report a spill is considered an offense and the penalties for a violation are assumed to be as described in the Act.

Canada Oil and Gas Operations Regulations (SOR/83-149), adopted in 1983, also are part of the Canada Oil and Gas Operations Act and primarily govern operating license requirements. These regulations also require oil spills to be reported. Penalties are not included in this regulation, but are assumed to be as described in the Act.

The Canada Oil and Gas Production and Conservation Regulations (SOR/90-791), adopted in 1990 under the Canada Oil and Gas Operations Act, govern oil and natural gas production sites and the production of oil and natural gas. These regulations require the reporting of a "serious accident or event," such as a spill, to the Chief Safety Officer or the Chief Conservation Officer. Failure to report is considered an offense; penalties are assumed to be as described in the Act. The phrase, a "serious accident or event" is not defined in the regulations or in subsequent guidance issued by the NEB.

Canada Oil and Gas Installation Regulations (SOR/96-118), adopted in 1996, under the Canada Oil and Gas Operations Act, also govern the operations of oil and natural gas installations. These regulations require the reporting, "of any situation or event involving any danger or accident to a person or property, including…explosion, loss of well control, hydrocarbon or toxic fluid spills, or significant damage to a pipeline, equipment or an installation." Spill reports are to be given to the Chief Safety Officer. Failure to report is considered an offense; penalties are assumed to be as described in the Act. The phrase, "any situation or event involving any danger or accident" has not been further defined by the NEB.

Arctic Waters Pollution Prevention Act

The Arctic Waters Pollution Prevention Act (R.S.C. 1985, c. A-12) was enacted either in 1970 or 1989. Two different information sources provided two different dates for its enactment. This federal statute requires that "a deposit of waste" in arctic waters above the 60th parallel to be reported forthwith to a pollution prevention officer. Failure to make a report can result in a fine up to $5,000 for a person or up to $100,000 for a ship. The Canada Shipping Act applies to waters below the 60th parallel.

Regulations pertaining to oil spills under the Arctic Waters Pollution Prevention Act include the Arctic Waters Pollution Prevention Regulations (C.R.C. 1978, c.354). The regulations expanded the reporting requirements to include "any undertaking on the mainland or islands of the Canadian arctic or in the arctic waters that, by reason of any accident or other occurrence, is in danger of causing any deposit of waste." Deposits of industrial waste are allowed, "if the industrial waste is of a type and in a quantity and is deposited under conditions authorized by or under the Oil and Gas Production and Conservation Act, the Territorial Lands Act or the Public Lands Grants Act, whichever is applicable." Current limits of liability are:

- For a pipeline operation, "an amount equal to the product of $500 and the volume, measured in barrels, of the section of the pipeline between the shut-off valves located on either side of the point in the pipeline from which the deposit of waste originates, divided by 7;"

- For an operation engaged in exploring for, developing or exploiting oil and gas, $40 million. This $40 million limit has four amendment citations for 1979, 1980, and 1981; and

- For ships (ship and cargo owners), an amount determined by multiplying 2,000 gold francs by the tonnage to a maximum of 210 million gold francs.

Canada Shipping Act

The Canada Shipping Act (R.S.C. 1985, c. S-9.97) empowers the government to enact regulations that require reporting of discharges. The Act controls ship-borne pollution in all Canadian waters and fishing areas, except waters within certain zones under the Arctic Waters Pollution Prevention Act. Pollution from ships engaged in oil and gas exploration, production, or processing in areas under the Oil and Gas Production and Conservation Act also are exempted from the Canada Shipping Act.

Pollutant Discharge Reporting Regulations (SOR/95-351) were adopted in 1995 under the Canada Shipping Act. They replaced earlier regulations by the same name, adopted in 1992 (SOR/92-211). According to the 1995 version, immediate reporting is required when "the discharge is prohibited by the Act, the Arctic Waters Pollution Prevention Act or regulations made under these Acts." The report must be made to a pollution prevention officer where the discharge of a pollutant occurs. In 1998, an amendment was made including reporting by "an operator of an oil handling facility." Penalties are not described and are assumed to be similar to the Arctic Waters Pollution Prevention Act.

The Onshore Pipeline Regulations

The Onshore Pipeline Regulations (SOR/89-303), adopted in 1989, as part of the National Energy Board Act, apply to onshore pipelines constructed, operated or abandoned after June 30, 1989. The regulations require the reporting of uncontained spillage of oil in excess of 1.5 cubic meters (approximately 397 gallons). Penalties are not discussed.

The Northwest Territories Waters Act

The Northwest Territories Waters Act (R.S.C. 1992 c. 39), enacted in 1992, requires the reporting of unlawful deposits of waste. Currently, every person who is guilty of an offense, including not reporting an oil spill, and liable on summary conviction may be fined up to $100,000 dollars and/or be imprisoned for a term not exceeding 1 year. The associated regulations, the Northwest Territories Waters Regulations (SOR/93-303), were adopted in 1993 and govern applications for licenses to use water or deposit waste. Licenses are generally required for oil and gas exploration, production and transportation activities.

Inter-Agency Spill Reporting Working Agreement

In addition, in 1992, a letter of agreement was set up concerning response to spills in the Northwest Territories between Indian and Northern Affairs Canada, Environment Canada, National Energy Board, Government of the Northwest Territories, Canadian Coast Guard (Transport Canada), and the Inuvialuit Lands Administration. The letter of agreement clarified which agency would take the lead in each spill. This working agreement is currently being updated to include the Government of Nunavut.

Crude Oil Production, Pipeline Mileage and Throughput, and Tanker Transport Quantities

Crude oil production statistics were readily available for the study areas from the State of Alaska and the NEB. The AOGCC closely tracks crude oil production throughout Alaska. The Commission requires the monthly reporting of crude oil, natural gas, and natural gas liquid production and injection statistics by all oil field operators. The ADNR Division of Oil and Gas publicly reports the AOGCC statistics on a regular basis in their periodic publication, *Historical and Projected Oil and Gas Consumption*. The NEB closely tracks crude oil production in Canada, and production statistics were readily provided by that agency.

Mileages for the larger pipelines including the TAPS, the Norman Wells Pipeline, and the sales oil pipelines on Alaska's North Slope were readily available from ADNR, in Alaska, and the NEB, in Canada. Each pipeline is built on an individual right-of-way, granted by ADNR, which specifies the pipeline's length. The NEB was able to furnish the length of the Norman Wells Pipeline from the agency's regulatory records.

The regulatory agencies in Alaska and Canada do not keep records of the mileages of the smaller pipelines, termed field gathering lines or cross-country lines, that run from production well pads to processing facilities, and, in some cases, from processing facilities to one of the larger pipelines. Construction and operation of the field gathering lines are allowed as part of the surface-use provisions of the mineral lease for oil production. In some cases, wetland fill or surface use permits are issued, but Hart Crowser could locate no comprehensive compilation of the current or historical mileages for these pipelines. One suggestion Hart Crowser received for gathering data on the smaller pipelines on Alaska's North Slope was to obtain a scale map of the oilfields and then measure all of the pipelines. This approach to gathering the data was not feasible given the time and resource constraints of the project, and it would not have provided the historical data that MMS sought. Hart Crowser obtained field gathering line mileage data from a single year for two Alaskan North Slope oil fields, which ARCO gathered in response to a request for data on these smaller pipelines from the U.S. Department of Transportation. However, the company did not have any historical compilations of field gathering line data that they could provide for the study.

Throughput data for the larger Alaskan pipelines were calculated using the crude oil production throughput table in ADNR's publication, *Historical and Projected Oil and Gas Consumption*. Because of the organization of the table and knowing the layout of the pipelines, the individual pipeline throughputs by year were readily calculated. TAPS throughput by year was taken directly from a table in *Historical and Projected Oil and Gas Consumption*. The NEB supplied throughput for the Norman Wells Pipeline and tanker shipment volumes from the agency's regulatory records. Hart Crowser was able to corroborate these volumes in other reports, such as the DIAND Northern Oil and Gas Annual Reports.

Oil Spill Data Statistical Analysis and Estimation of Spill Risk

Consideration was given to the statistical robustness and validity of potential oil spill risk estimators. Because there are a limited number of data points, the statistical parameters estimated are subject to considerable uncertainty. Large variations in statistically estimated parameters are characteristic in the analysis of rare events, such as oil spills of 100 barrels and greater. In cases where a limited amount of data exists, the only way to decrease the uncertainty in these parameters is to gather additional data. In the case of this study, to decrease the uncertainty, additional data would need to be gathered over a longer time period of time. For this study, the number and study area distribution of oil spills of 100 barrels and greater and 500 barrels and greater are shown in Table 10. Because there are so few Canadian spills, all of the Canadian study areas have been combined in the table.

Table 10
Number And Distribution Of Oil Spills In Study Areas

Study Area	Number of Spills 100 - 499 bbls	Number of Spills ≥500 bbls
Alaska - Onshore North Slope (E. of NPRA)	32	9
Alaska - TAPS	56	14
Canada - all study areas	10	5

The single oil spill that was caused intentionally, the February 1978 Steele Creek oil spill along the TAPS, was included in the statistical analysis and risk estimation. Intentional spills should be included in the estimation of potential oil spill risk because the sabotage of facilities is a real potential source of spills. A large percentage of TAPS and all pipelines on the Alaska North Slope are installed above ground, often in locations that provide relatively little protection against sabotage.

All of the pipelines included in the study are in the midst of their useful lives. The risk of an oil spill might be expected to increase with the age of the pipeline. However, the effect of incomplete lifecycles on the potential for oil spills from pipelines is difficult to gauge with any precision or accuracy because there are many other factors other than age that also affect the risk of a spill from any particular pipeline. Some of these other factors affecting oil spill risk include:

- The potential for corrosion or erosion of a particular pipeline, especially a field gathering line, which is related to the amount of sand and saltwater in the oil the pipeline carries and on the number of elbows in the pipeline;

- Engineering, construction, and monitoring of the condition of pipelines installed in ground susceptible to settling or other ground movement; and

- The type and amount of maintenance of the pipeline.

Hart Crowser evaluated whether the number or volume of oil spills should be correlated to oil production, pipeline mileage, pipeline throughput, or some other variable in calculating oil spill risk. Oil production was chosen for use in the risk estimates because oil production is well documented each year, it allows a simple calculation of spill rate, and it allows direct comparison with calculations of oil spill rates in other studies. Hart Crowser decided against using pipeline mileage because it was difficult to obtain pipeline mileage data for the smaller field gathering pipelines, and especially mileages over time. In addition, other factors that could affect the potential for a spill or the size of a spill from a pipeline are not accounted for using mileage alone. These factors include pipeline diameter, potential for corrosion or erosion, potential for damage by earth movement or other causes including sabotage, pipeline age, and pipeline maintenance. Hart Crowser also decided against the use of pipeline throughput as the variable because annual throughput data is not readily available for the smaller pipelines and, while eliminating pipeline diameter as a spill risk factor, pipeline throughput does not take into account the other potential risk factors already mentioned in connection with pipeline mileage.

All of the spill data used in the analysis is from onshore oil spills. No offshore spills were identified in the Alaskan study areas and only two offshore spills were identified in the Canadian study areas. Almost certainly there are some differences in the risk factors between onshore and offshore oil spills. However, because so few offshore oil spills were identified as part of this study, there is not enough statistical data to determine any differences.

In comparison to Anderson and LaBelle (1994), this study gathered and used data on oil spills with a lower quantity threshold: 100 barrels and larger compared to 1,000 barrels and larger. This study also gathered and used data on different sources of oil spills than Anderson and LaBelle. The sources of spills included in the Anderson and LaBelle study and the number of spills identified for these sources were:

- Offshore oil drilling and production platforms located in the U.S. Outer Continental Shelf, 11 spills;
- Offshore pipelines located in the U.S. Outer Continental Shelf, 12 spills;
- Tankers transporting crude oil in worldwide coastal and offshore waters, 213 spills;
- Tankers transporting crude oil in U.S. coastal and offshore waters, 38 spills;
- Tankers transporting Alaska North Slope crude oil, 10 spills; and
- Barges transporting petroleum products in U.S. coastal, offshore, and inland waters, 153 spills.

This study gathered and used data on oil spills related to oil and gas exploration, construction, development, production, storage, and transportation in specific Alaskan and Canadian study areas. The sources of spills included in this study and the number of spills identified among these spill types are:

- Construction Camps, 21 spills, all in Alaska;
- Exploration Support Facilities, 3 spills, 2 of which were in Alaska;
- Exploration Well Sites, 4 spills, 1 of which was in Alaska;
- Highways; 37 spills, 36 of which were in Alaska;
- Operations Support Facilities, 18 spills, all in Alaska;
- Pipelines, 11 spills, 10 of which were in Alaska;
- Pipeline Pump Stations, 5 spills, all in Alaska;
- Production Processing Facilities, 13 spills, 10 of which were in Alaska;
- Production Well Sites, 11 spills, 7 of which were in Alaska;
- Unspecified Source, 1 spill in Alaska; and
- Vessel Leak, 2 spills in Canada.

Hart Crowser first constructed a cumulative frequency plot of the data for the size of Alaskan spills, as shown in Figure 1. To facilitate easy plotting of the data analysis figures, abbreviations were used for different variables as shown in Table 11. Figure 1 shows a bow characteristic of lognormal data. Therefore, the data were re-plotted on a lognormal scale, as shown in Figure 2. For the limited number of data points, it appears that two lognormal populations could reasonably describe this population. In Figure 2, two lines approximating the two lognormal populations are shown. The higher population is more linear than the lower. This is typical in lognormal data because of the greater proportional effect of rounding and data errors at low values. Lines showing the approximate theoretical distributions are shown only in Figure 2 to avoid biasing the reader.

A cumulative frequency plot of the Canadian oil spill size data also was constructed on a lognormal basis, as shown in Figure 3. Overlaying the Alaskan and Canadian plots indicated more or less the same distribution. The Canadian data was not used in further analysis because of doubts about its completeness, the fact that 15 points were below the 30 point empirical rule for number of samples, and the fact that the 112 Alaska data points would overpower the 15 Canadian points. The use of only Alaskan data also appears consistent with Anderson and LaBelle (1994), who state that "U.S. … rates will better reflect the magnitude of spill occurrence under U.S. regulatory and operational controls, and the individual spill and production records are readily available." However, Hart Crowser also redid the analysis using the total oil spill data set (with Alaskan and Canadian crude oil production for rates). The results were statistically the same as for the Alaskan data alone. The rerun of all the combined Alaskan and Canadian data is included as Appendix B to the report.

Because the Alaskan data was more or less a mixture of two lognormal populations, exploratory data analysis on the relevant independent variables was conducted, as shown in Figures 4 through 10. These figures present box plots on a logarithmic basis for the dataset and show the median, quartile values, and outlying points. In Figure 4, it can be seen that there appears to be little statistical difference in terms of spills that occurred within the ONS and in the TAPS study areas. This lack of statistical difference between the ONS and TAPS study areas was confirmed by an analysis of variance in which no statistically significant difference between the two populations was found.

In Figure 5, which shows spill size versus month, some type of a cycling trend in the data may be interpreted, with the lowest number of spills occurring in March, and the highest volume of spills occurring in July. However, a linear regression on month showed no statistically significant correlation. A statistically significant correlation at the 99 percent level of confidence was confirmed by a logarithmic analysis of the data as presented in Table 12. As a general check on the fluctuation of the data set, logarithmic spill size versus the day of the month also was plotted, as shown in Figure 6. This particular dataset appears to be quite random. Once again, an analysis of variance, as seen in Table 13, showed no statistically significant difference between days.

Figure 7 is a box plot of the logarithm of the spill size versus the year. With the exception of 1979, there appears to be little trend in median of the data. An analysis of variance of this data showed no statistically significant difference in the years. Figure 8 shows the logarithm of spill size versus facility type. In general, there appears to be little difference between the types of spills associated with the various facilities with the exception of pipelines. An analysis of

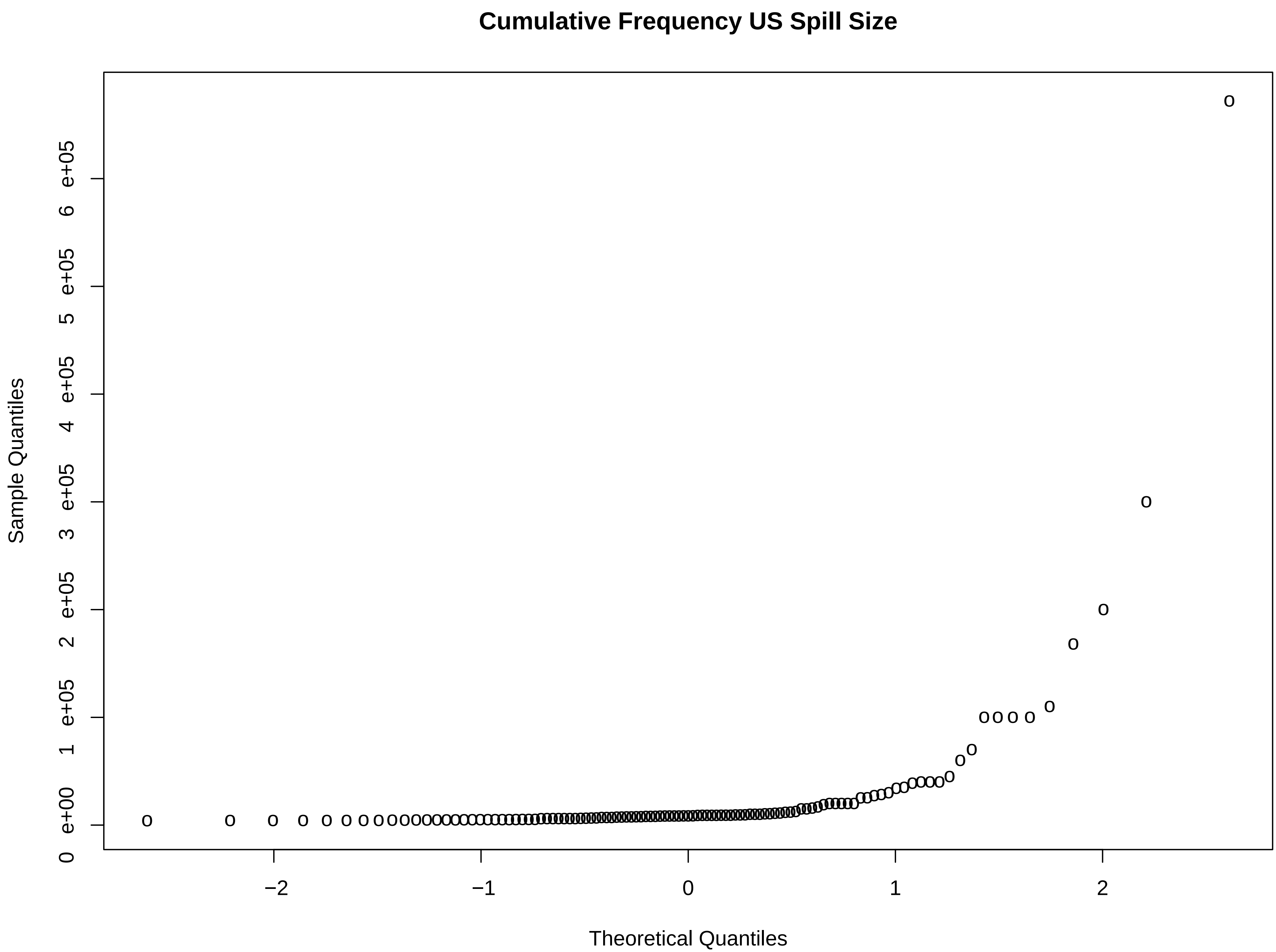

Cumulative Frequency US Spill Size
Sample Quantiles
0 e+00
1 e+05
2 e+05
3 e+05
4 e+05
5 e+05
6 e+05
−2
−1
0
1
2
Theoretical Quantiles
Figure 1

TABLE 11
ABBREVIATIONS USED IN FIGURES

Variable	Abbreviation
Study Areas	
ALASKA – Trans Alaska Pipeline System	TAPS
ALASKA – Onshore North Slope (E. of NPRA)	ONS
CANADA - Beaufort Sea	CBS
CANADA - Onshore Mackenzie River Delta	CMRD
CANADA - Norman Wells	CNW
CANADA - High Arctic Islands	CHAI
Facility Type	
Construction Camp	CC
Exploration Support Facility	SF
Exploration Well Site	PRD
Highway	HWY
Operations Support Facility	SF
Pipeline	PIPE
Pipeline Pump Station	PIPE
Production Processing Facility	PRD
Production Well Site	PRD
Unspecified	U
Spill Cause	
Facility Explosion	O
Facility Piping Leak	FP
Facility Tank Leak	FT
Human Error	U
Pipeline Leak	PL
Production Well Leak	O
Tank Vehicle Accident	TV
Unspecified Cause	U
Vessel Leak	VL
Oil Type	
Crude Oil	CO
Diesel Fuel or Gasoline	D
Diesel Fuel/Heating Oil	D
Gasoline	G
Turbine/Jet Fuel	TF
Unspecified	U
Affected Media	
Land	L
Land and Water	WL
Retained in secondary containment, on facility pad, or in impoundment	R
Unspecified	U

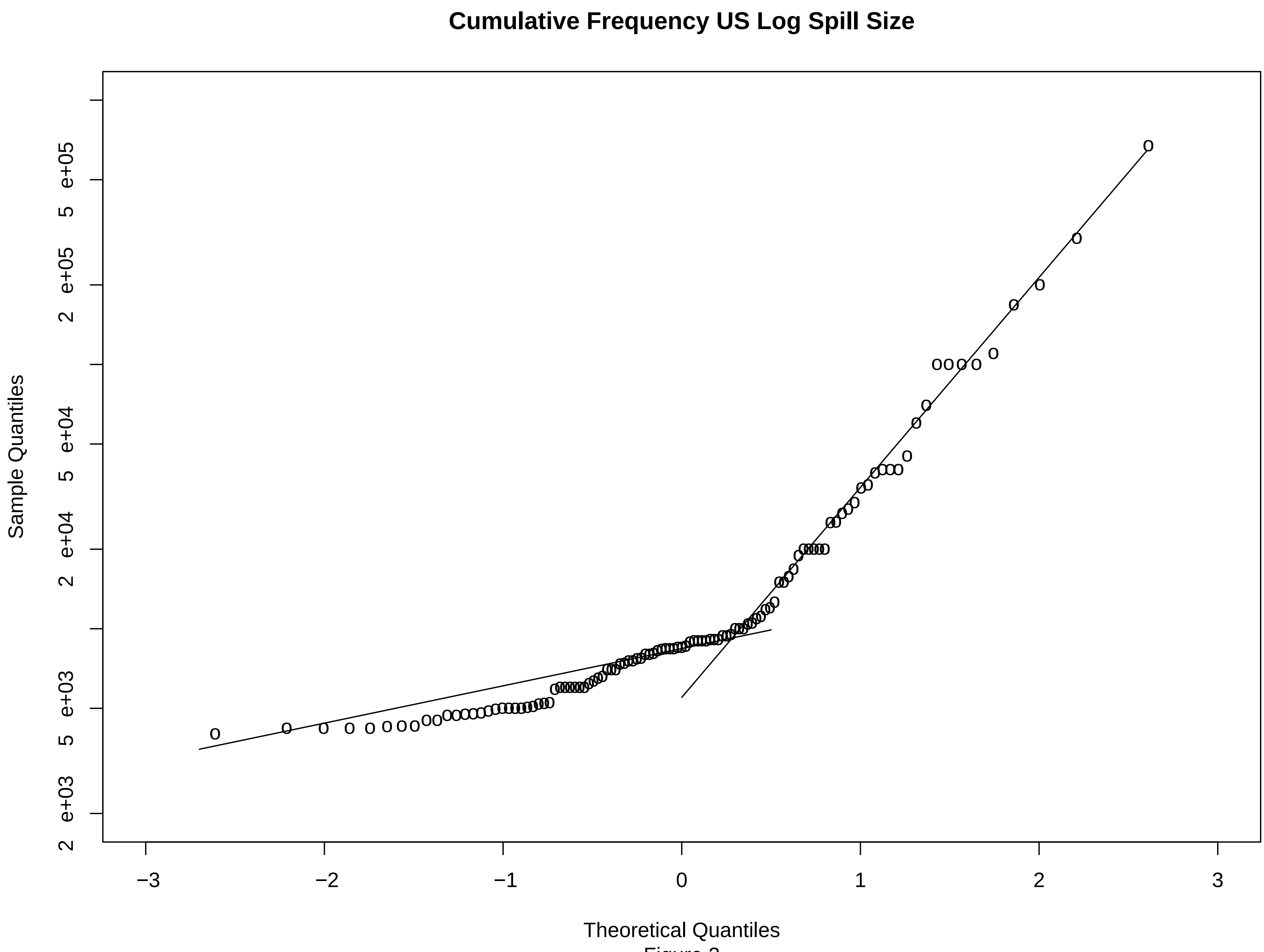
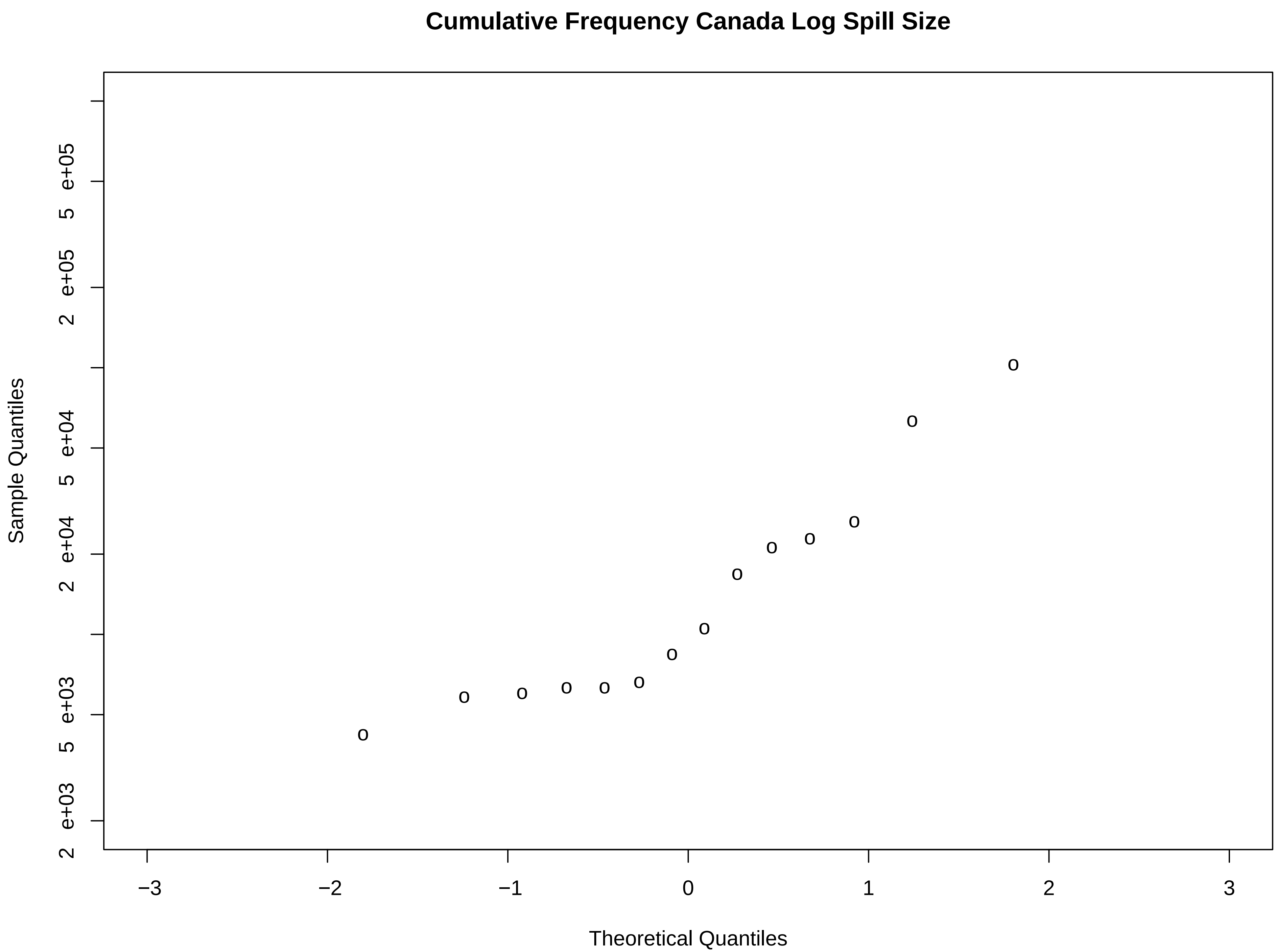

Cumulative Frequency US Log Spill Size
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
Theoretical Quantiles
−3
−2
−1
0
1
2
3

Figure 2


Cumulative Frequency Canada Log Spill Size
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles
Figure 3

Log US Spill Size vs StudyAREA Box plot

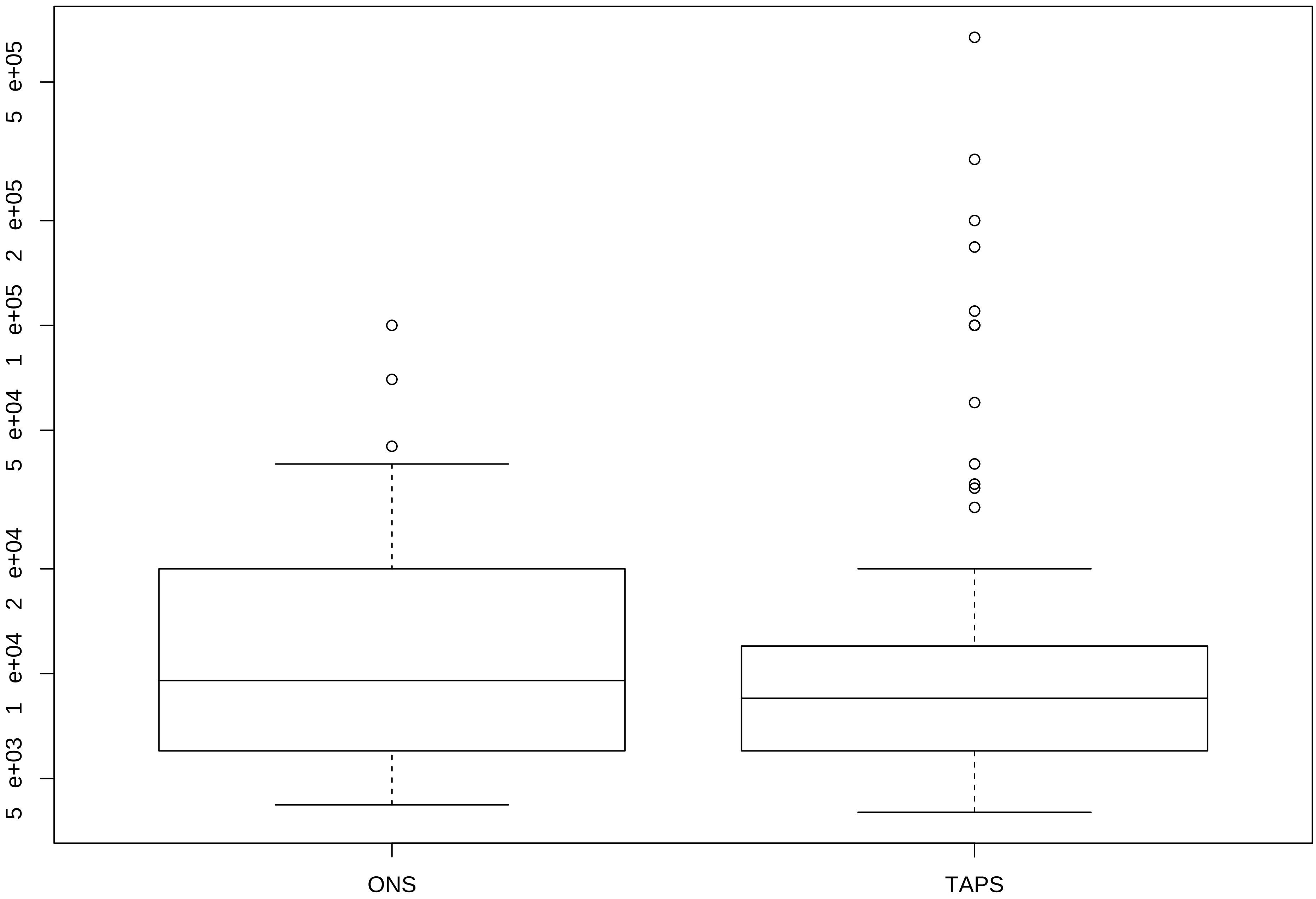


Figure 4

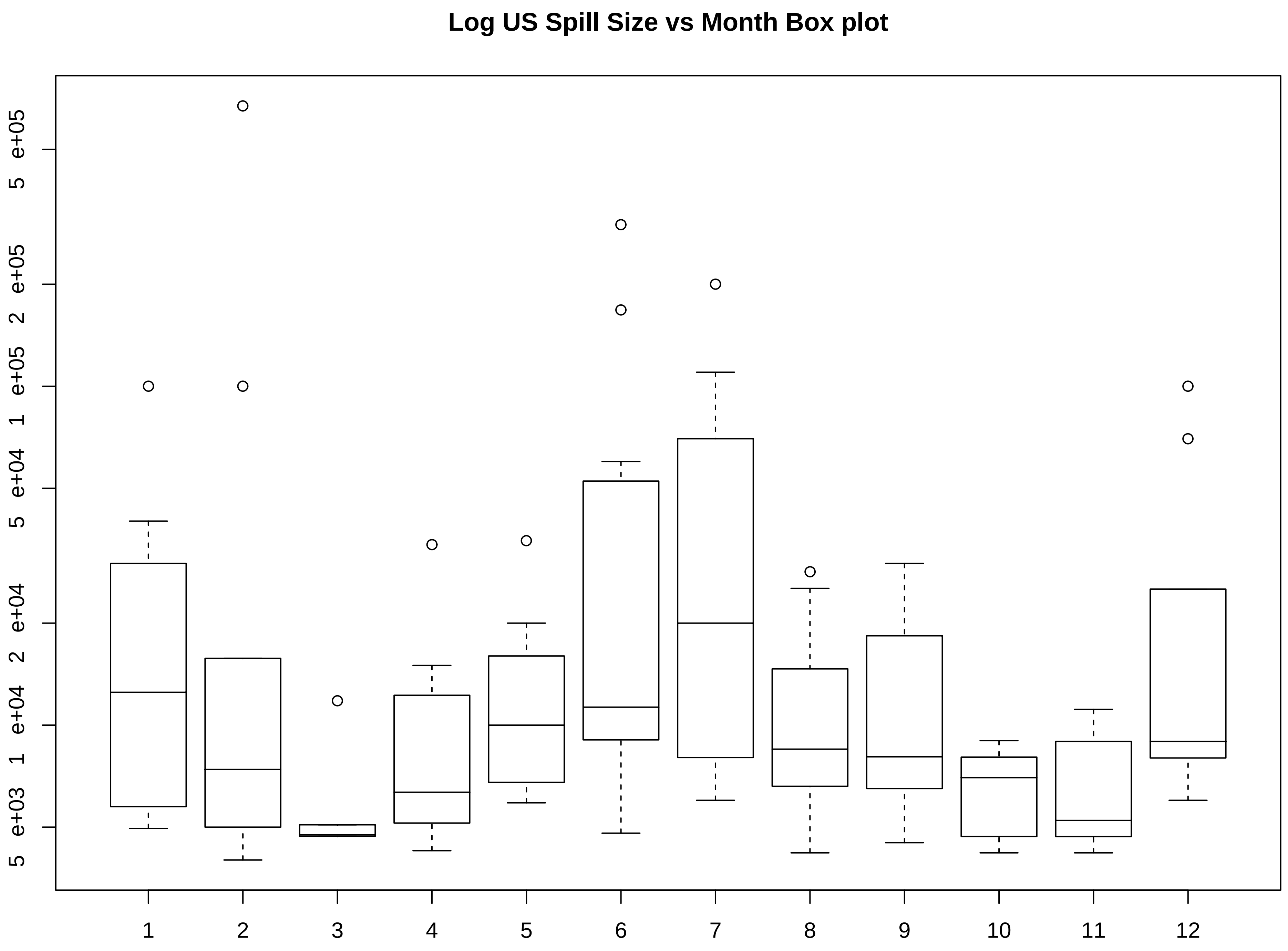

Log US Spill Size vs Month Box plot
5 e+05
2 e+05
1 e+05
5 e+04
2 e+04
1 e+04
5 e+03
1
2
3
4
5
6
7
8
9
10
11
12

Figure 5

TABLE 12
ANALYSIS OF VARIANCE OF INDIVIDUAL SPILL EVENTS BY MONTH

```
lm(formula = log(SpillHigh) ~ Amonth)

Residuals:
      Min          1Q      Median        3Q       Max
  -1.5185     -0.5982     -0.1919    0.4648    3.7786

Coefficients:
                 Estimate Std     Error    t value    Pr(>|t|)
(Intercept)        9.0550        0.3667     24.693    <2e ***
AmonthAug          0.1406        0.4614      0.305    0.7612
AmonthDec          0.5858        0.4781      1.225    0.2234
AmonthFeb          0.5844        0.4889      1.195    0.2348
AmonthJan          0.5256        0.5021      1.047    0.2978
AmonthJul          1.1059        0.4691      2.357    0.0204 *
AmonthJun          0.9399        0.4614      2.037    0.0443 *
AmonthMar         -0.3980        0.5681     -0.701    0.4852
AmonthMay          0.2361        0.4691      0.503    0.6159
AmonthNov         -0.3103        0.4614     -0.672    0.5029
AmonthOct         -0.3147        0.5186     -0.607    0.5454
AmonthSep          0.1712        0.5186      0.330    0.7420

Signif. codes:  0  `***'  0.001  `**'  0.01  `*'  0.05  `.'  0.1  ` '  1

Residual standard error:  0.9702 on 99 degrees of freedom
Multiple R-Squared:  0.2087,     Adjusted R-squared:  0.1207
F-statistic:  2.373 on 11 and 99 degrees of freedom,      p-value:  0.01195
```

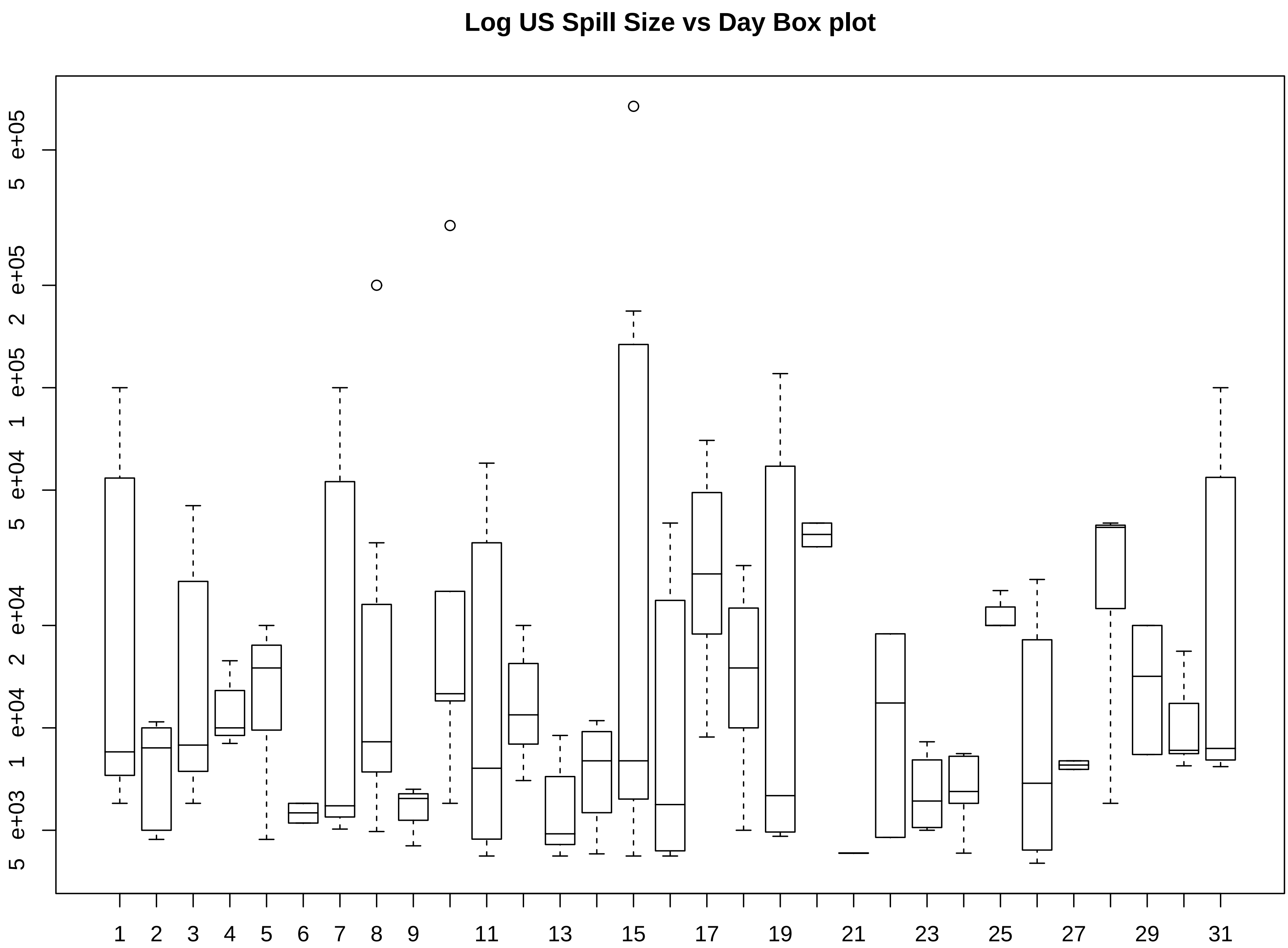

Log US Spill Size vs Day Box plot
5 e+05
2 e+05
1 e+05
5 e+04
2 e+04
1 e+04
5 e+03
1
2
3
4
5
6
7
8
9
11
13
15
17
19
21
23
25
27
29
31

Figure 6

TABLE 13
ANALYSIS OF VARIANCE OF INDIVIDUAL SPILL EVENTS BY YEAR

lm(formula = log(SpillHigh) ~ Ayear)

Residuals:

Min	1Q	Median	3Q	Max
-1.98124	-0.51387	-0.09211	0.34085	2.95913

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	9.23968	0.57207	16.151	<2e-16 ***
AyearY71	1.47474	1.14414	1.289	0.2009
AyearY72	0.66381	1.14414	0.580	0.5633
AyearY73	0.14848	0.80903	0.184	0.8548
AyearY74	0.11242	0.80903	0.139	0.8898
AyearY75	0.43975	0.63465	0.693	0.4903
AyearY76	-0.18432	0.68375	-0.270	0.7881
AyearY77	0.43562	0.64538	0.675	0.5015
AyearY78	1.21921	0.80903	1.507	0.1355
AyearY79	1.84654	0.75678	2.440	0.0168 *
AyearY80	-0.50826	0.80903	-0.628	0.5315
AyearY81	0.09226	0.70064	0.132	0.8955
AyearY82	0.39884	0.75678	0.527	0.5995
AyearY83	-0.38340	0.70064	-0.547	0.5857
AyearY84	-0.59703	0.75678	-0.789	0.4324
AyearY85	-0.10958	0.75678	-0.145	0.8852
AyearY86	-0.67908	0.72362	-0.938	0.3507
AyearY87	-0.08202	0.90452	-0.091	0.9280
AyearY88	-0.34575	0.90452	-0.382	0.7032
AyearY89	0.27484	0.68375	0.402	0.6887
AyearY90	0.27524	0.80903	0.340	0.7345
AyearY92	-0.25248	1.14414	-0.221	0.8259
AyearY93	0.15640	0.67081	0.233	0.8162
AyearY94	-0.59251	0.80903	-0.732	0.4660
AyearY96	1.19667	1.14414	1.046	0.2986
AyearY97	-0.58789	0.80903	-0.727	0.4694

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 0.9909 on 85 degrees of freedom
Multiple R-Squared: 0.2914, Adjusted R-squared: 0.08294
F-statistic: 1.398 on 25 and 85 degrees of freedom, p-value: 0.1303

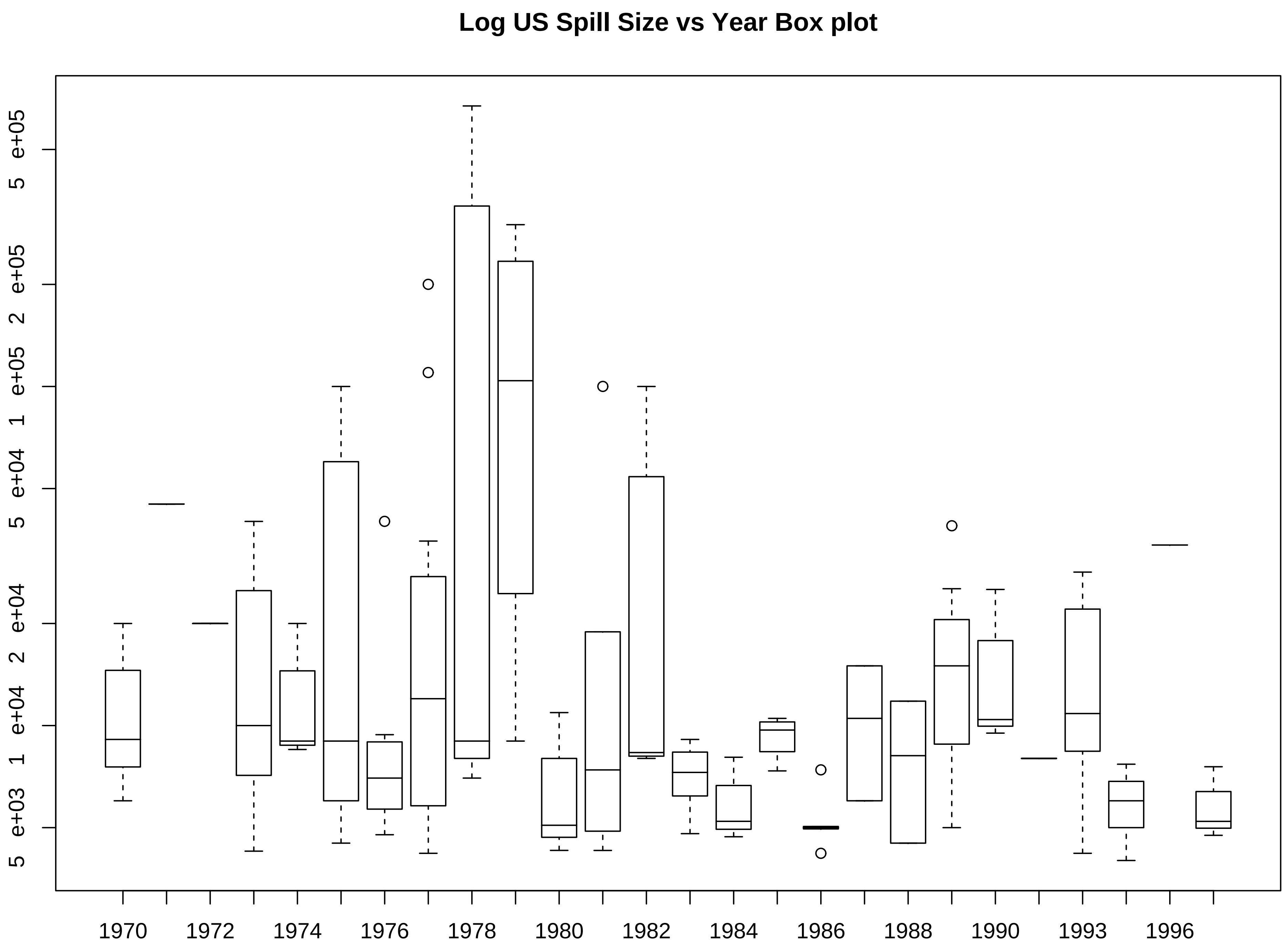

Log US Spill Size vs Year Box plot
5 e+05
2 e+05
1 e+05
5 e+04
2 e+04
1 e+04
5 e+03
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1993
1996

Figure 7

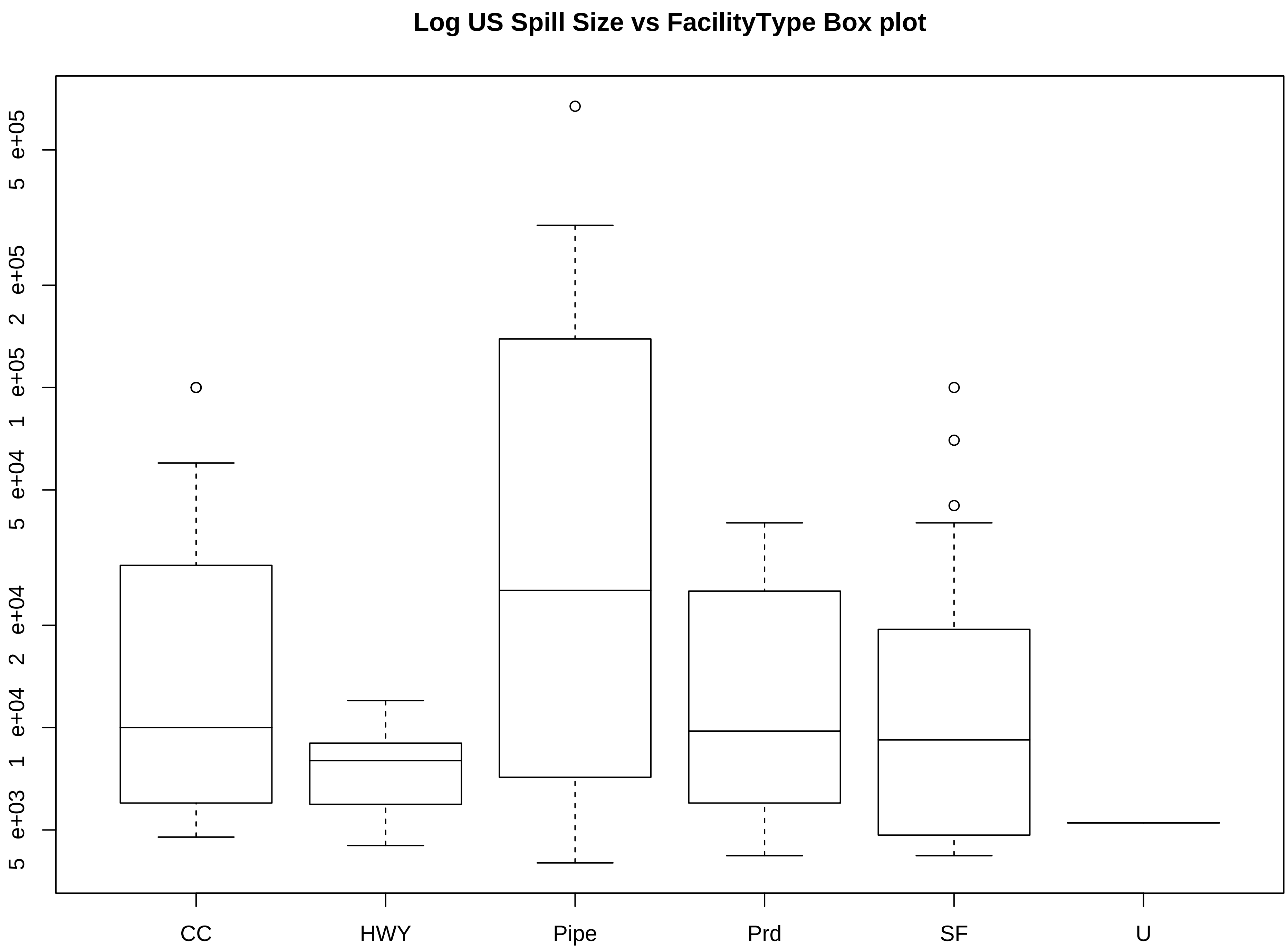

Log US Spill Size vs FacilityType Box plot
5 e+05
2 e+05
1 e+05
5 e+04
2 e+04
1 e+04
5 e+03
CC
HWY
Pipe
Prd
SF
U

Figure 8

variance of facility type showed that there was a statistically significant difference for pipelines. This analysis of variance is given in Table 14.

Figure 9 shows spill size versus oil type. An analysis of variance by oil type, presented in Table 15, showed that, in general it appears that crude oil spills tend to be larger than other types of oil spills.

Figure 10 is a box plot of the logarithm of the spill size versus affected media.

In performing a statistical analysis of the data, it is important to look at the cumulative frequency plots by selected independent variables. This is done in Figures 12 through 33. Figure 11 is a box plot of the logarithm of the spill size versus the spill cause. In general, those spills associated with pipelines appear to be largest. Figures 12 and 13 show cumulative frequency plots for the two different areas. The TAPS study area, Figure 12, appears to be a fairly clear mixture of two lognormal populations. The ONS study area shows less of a break, indicating perhaps a single population.

Figures 14 through 19 show cumulative frequency plots of the logarithm of the spill size versus the spill cause combined. In Figure 14, which is a plot of spills from tank vehicles, there is little apparent variability. This is more or less consistent with the fact that a tank vehicle spill should be expected to have a firm upper limit. Facility piping, as shown in Figure 15, shows a bow but no clear break in population. Pipeline leaks, Figure 16, show what may be a single lognormal population. Facility tank leaks, Figure 17, shows a single lognormal population. Unspecified spill causes, Figure 18, show a single lognormal population. Other spill causes, Figure 19, have such a small number of data points that no definite conclusions may be drawn. In general, overlaying all of the figures on one another indicates that they can probably reasonably be lumped together as a single population for statistical analysis.

Figures 20 through 23 show cumulative frequency plots of the logarithms of spill volume versus oil type. Figure 20, for diesel fuel, appears to be a mixture of two lognormal populations. Figure 21, for crude oil, again appears to be a mixture of two lognormal populations. Figure 22, for gasoline, shows a single lognormal population with one possible outlier. Again, this is consistent with a mixture of two lognormal populations. Figure 23, for turbine and jet fuel, again shows what may be a mixture of two lognormal populations. Figure 24 is two data points and is of little interest. However, Figure 24 overlies Figure 23 quite nicely.

Figures 25 through 29 show cumulative frequency plots of the logarithms of spill volume versus facility type. Figure 25, for highways, is very similar to the tank vehicle spills and is entirely consistent with the assumption that most highway spills are from tank vehicles. Figure 26, for support facilities, shows a bowed lognormal population. Figure 27, for production facilities, seems to show a single lognormal population. Figure 28, for construction camps, appears to show a mixture of two lognormal populations. Figure 29, for pipelines, may be interpreted as a single lognormal population.

TABLE 14
ANALYSIS OF VARIANCE OF SPILL EVENTS BY FACILITY TYPE

lm(formula = SpillHigh ~ FacilityType)

Residuals:

Min	1Q	Median	3Q	Max
-106588	-12983	-2454	1515	561412

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	24772	14786	1.675	0.096822 .
FacilityTypeHWY	-17237	18605	-0.927	0.356306
FacilityTypePipe	85815	22906	3.746	0.000293 ***
FacilityTypePrd	-9663	21764	-0.444	0.657953
FacilityTypeSF	-4765	21170	-0.225	0.822357
FacilityTypeU	-19522	69350	-0.282	0.778878

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 67760 on 105 degrees of freedom
Multiple R-Squared: 0.2025, Adjusted R-squared: 0.1645
F-statistic: 5.332 on 5 and 105 degrees of freedom, p-value: 0.0002088

lm(formula = log(SpillHigh) ~ FacilityType)

Residuals:

Min	1Q	Median	3Q	Max
-2.06337	-0.56860	-0.02809	0.29790	3.06059

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	9.6056	0.2056	46.728	<2e-16 ***
FacilityTypeHWY	-0.7116	0.2587	-2.751	0.0070 **
FacilityTypePipe	0.7518	0.3185	2.361	0.0201 *
FacilityTypePrd	-0.2601	0.3026	-0.860	0.3920
FacilityTypeSF	-0.2361	0.2943	-0.802	0.4243
FacilityTypeU	-1.0396	0.9642	-1.078	0.2834

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 0.942 on 105 degrees of freedom
Multiple R-Squared: 0.2088, Adjusted R-squared: 0.1711
F-statistic: 5.542 on 5 and 105 degrees of freedom, p-value: 0.0001436

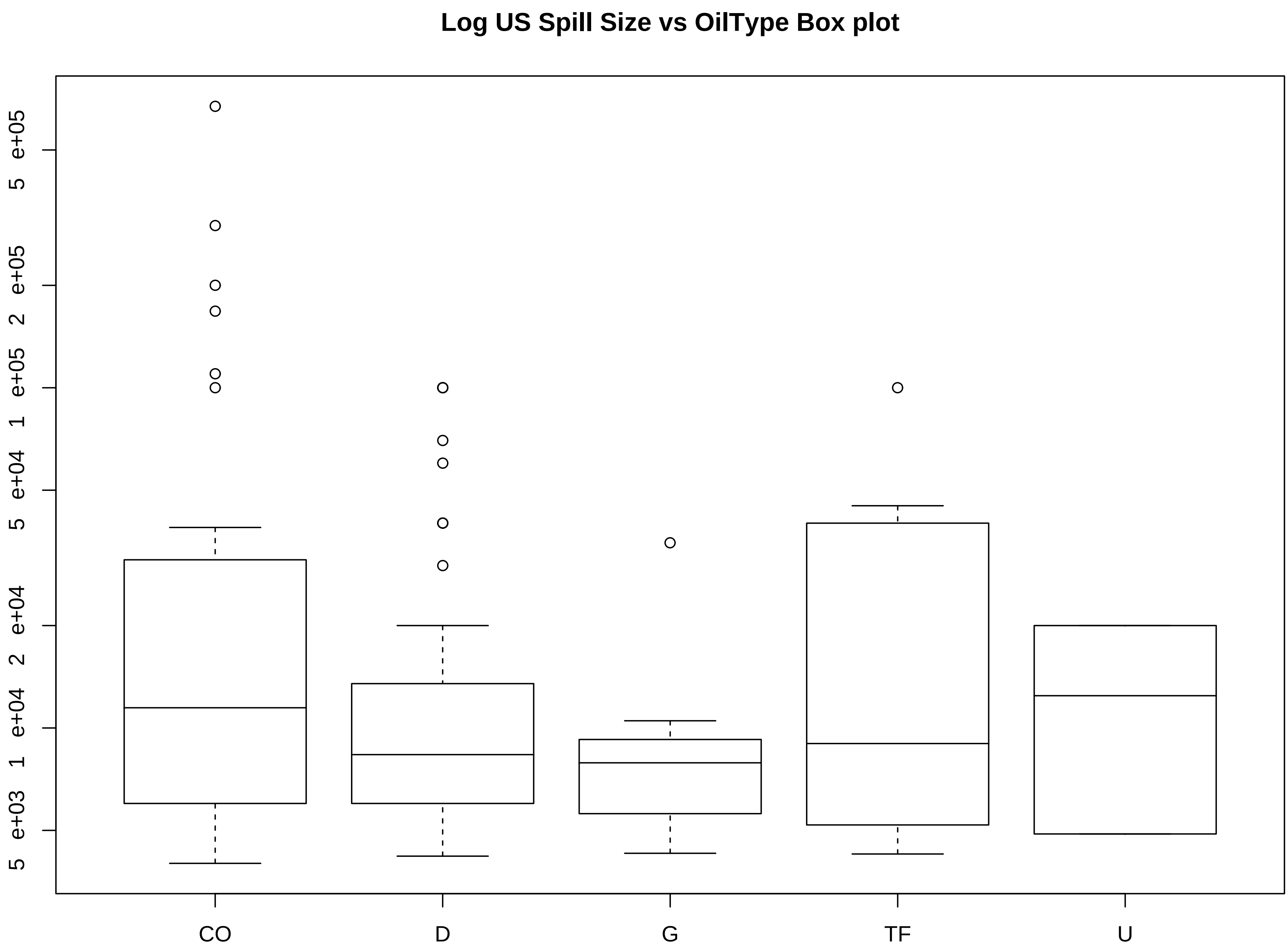

Log US Spill Size vs OilType Box plot
5 e+05
2 e+05
1 e+05
5 e+04
2 e+04
1 e+04
5 e+03
CO
D
G
TF
U

Figure 9

TABLE 15
ANALYSIS OF VARIANCE OF INDIVIDUAL SPILL EVENTS BY OIL TYPE

lm(formula = SpillHigh ~ OilType)

Residuals:

Min	1Q	Median	3Q	Max
-55174.6	-18358.6	-8205.8	-605.8	612825.4

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	59175	12851	4.605	1.15e-05 ***
OilTypeD	-43569	16162	-2.696	0.00817 **
OilTypeG	-49513	24607	-2.012	0.04674 *
OilTypeTF	-35682	26336	-1.355	0.17835
OilTypeU	-46734	52985	-0.882	0.37976

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 72690 on 106 degrees of freedom
Multiple R-Squared: 0.07324, Adjusted R-squared: 0.03827
F-statistic: 2.094 on 4 and 106 degrees of freedom, p-value: 0.08667

lm(formula = log(SpillHigh) ~ OilType)

Residuals:

Min	1Q	Median	3Q	Max
-1.4988	-0.6814	-0.2326	0.3960	3.6252

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	9.7928	0.1793	54.627	<2e-16 ***
OilTypeD	-0.5730	0.2255	-2.542	0.0125 *
OilTypeG	-0.7958	0.3433	-2.318	0.0224 *
OilTypeTF	-0.3314	0.3674	-0.902	0.3691
OilTypeU	-0.5946	0.7391	-0.804	0.4230

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 1.014 on 106 degrees of freedom
Multiple R-Squared: 0.07436, Adjusted R-squared: 0.03943
F-statistic: 2.129 on 4 and 106 degrees of freedom, p-value: 0.08229

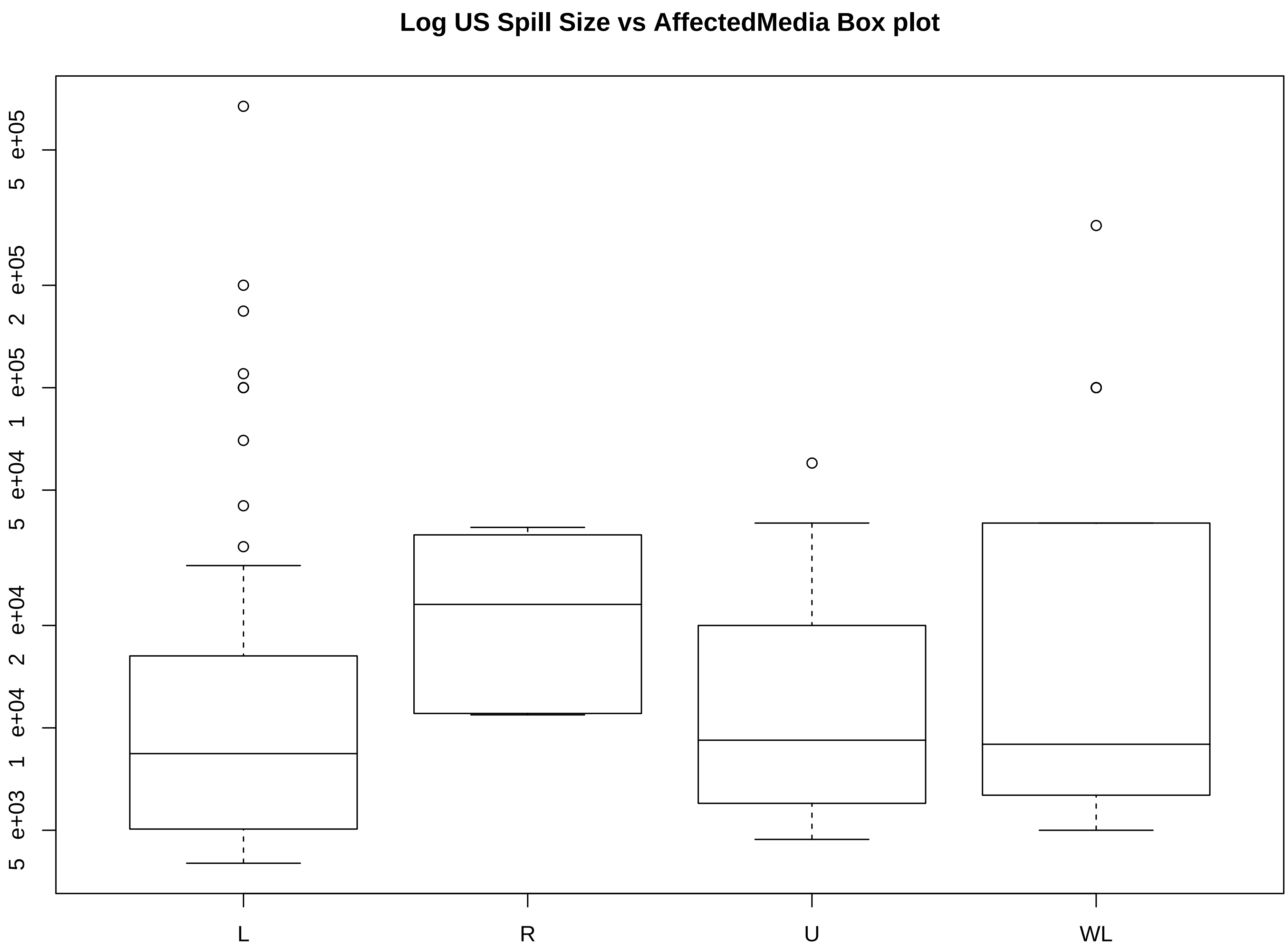

Log US Spill Size vs AffectedMedia Box plot
5 e+05
2 e+05
1 e+05
5 e+04
2 e+04
1 e+04
5 e+03
L
R
U
WL

Figure 10

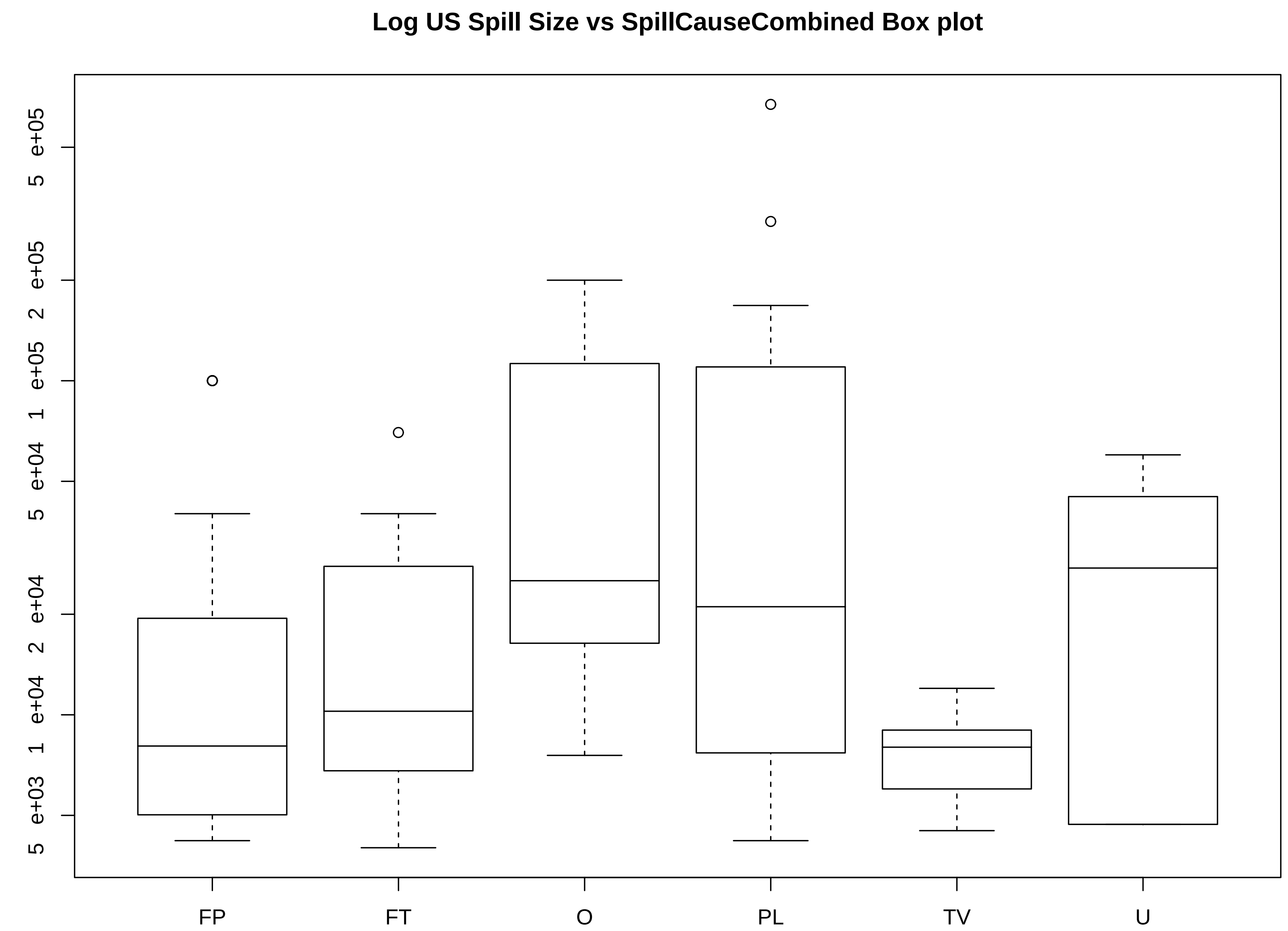
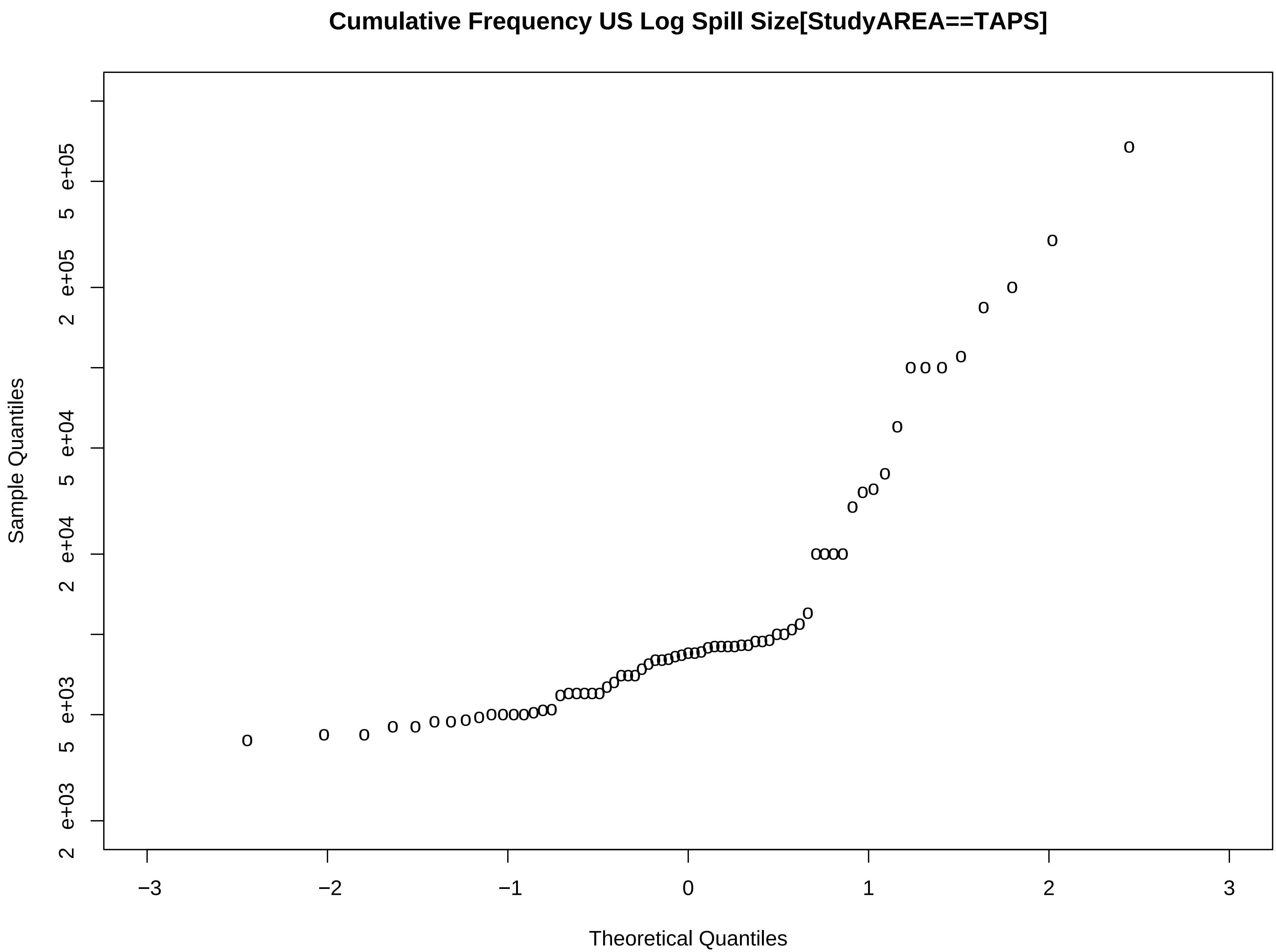
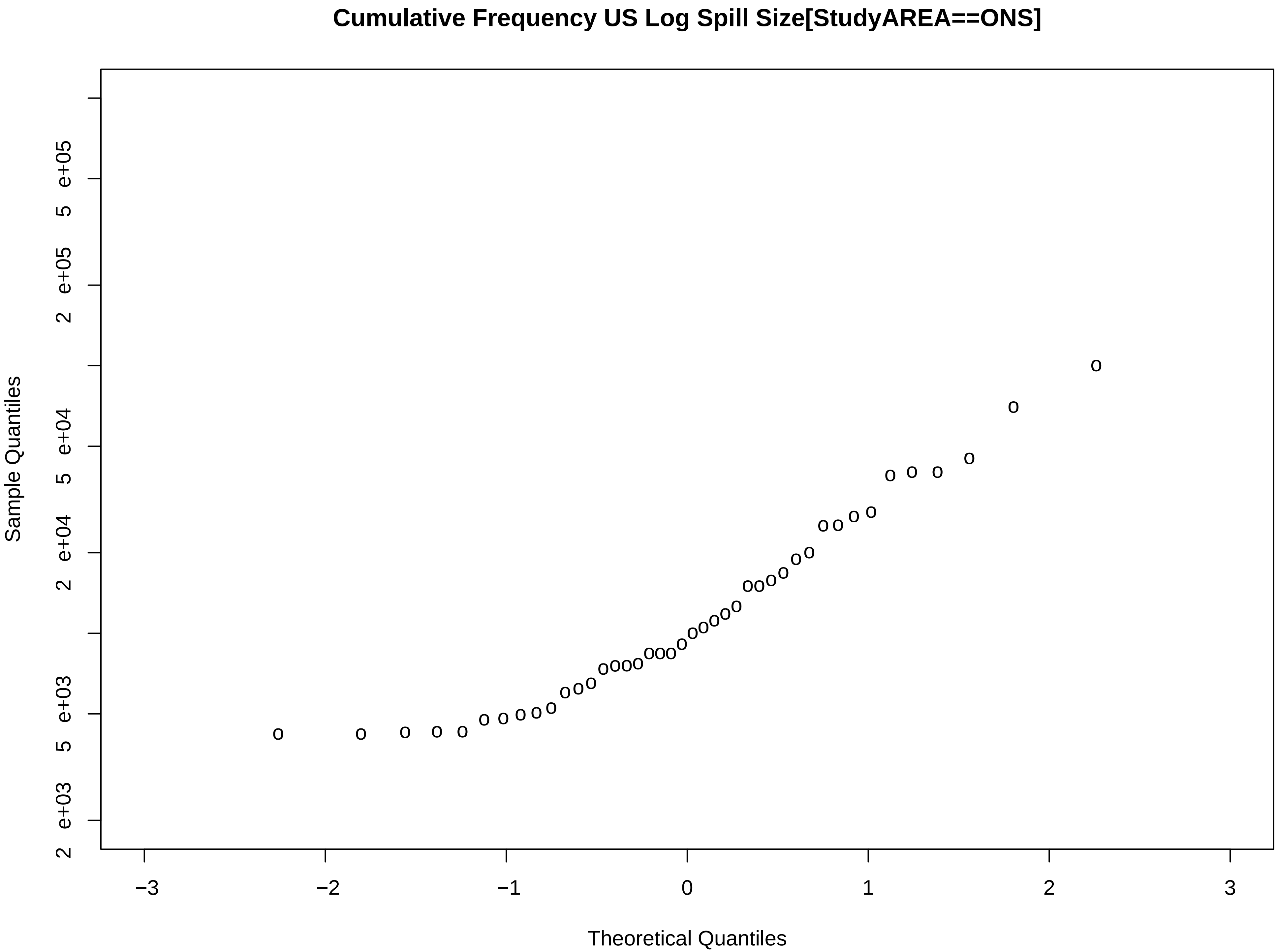

Log US Spill Size vs SpillCauseCombined Box plot
5 e+05
2 e+05
1 e+05
5 e+04
2 e+04
1 e+04
5 e+03
FP
FT
O
PL
TV
U

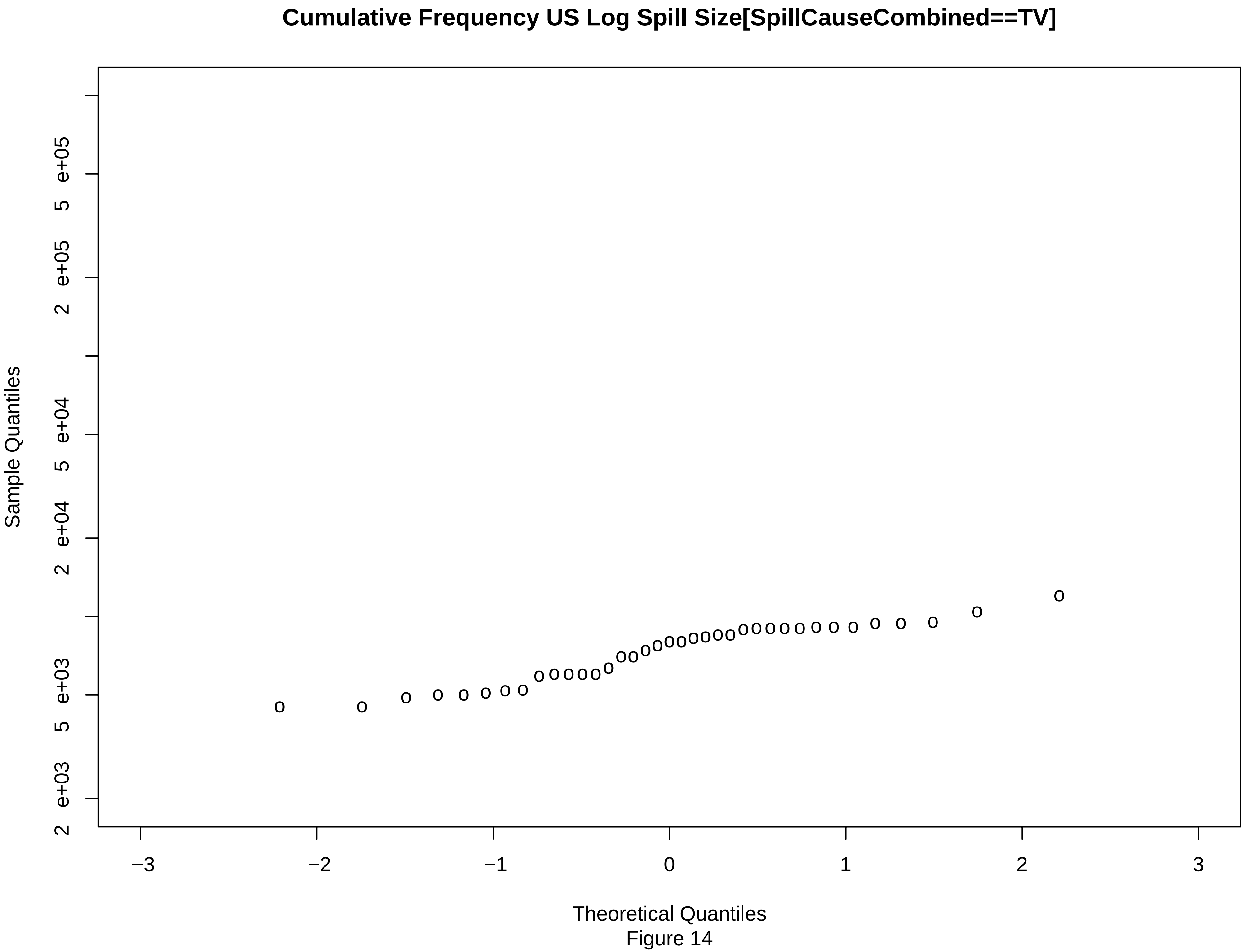
Figure 11

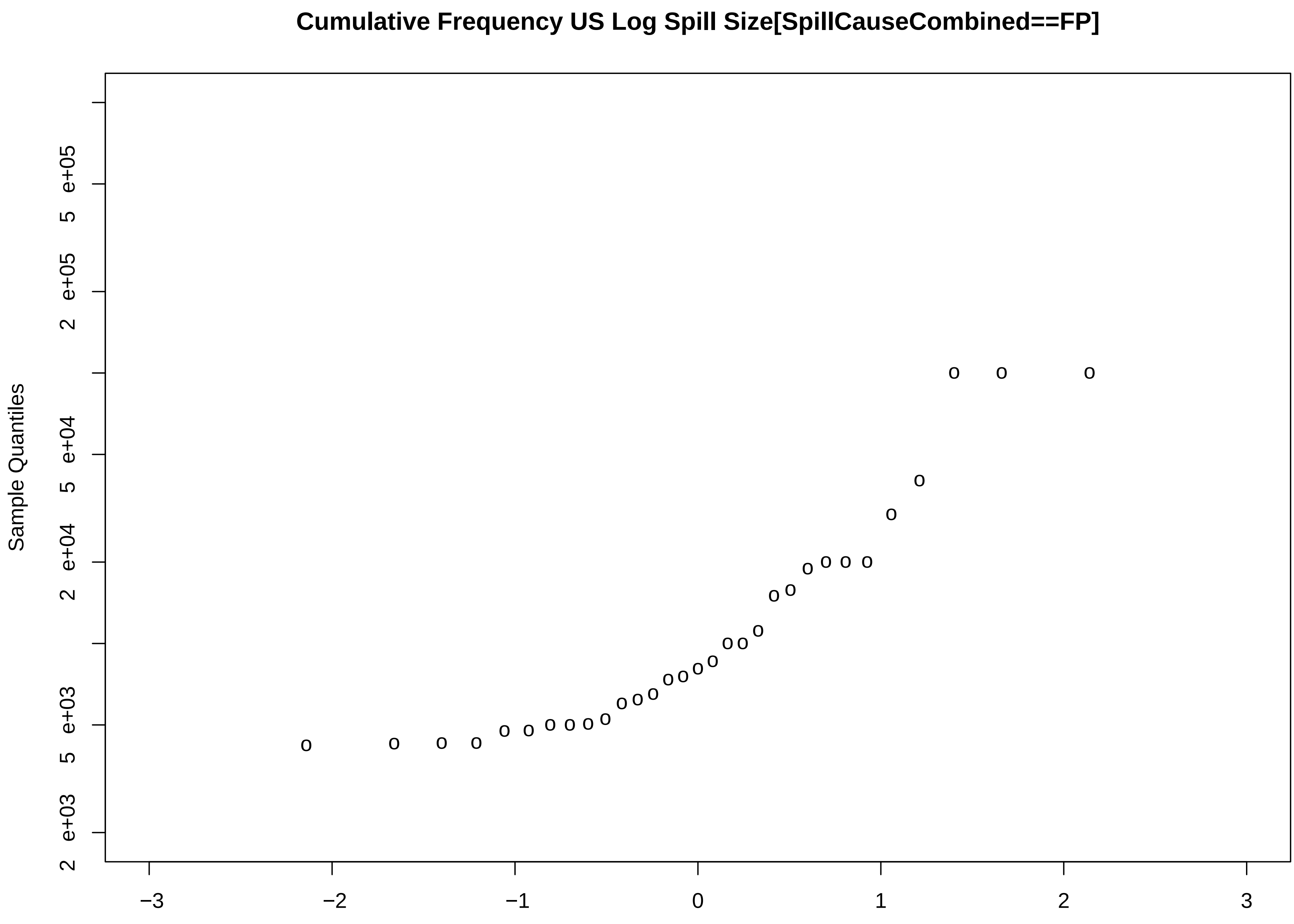


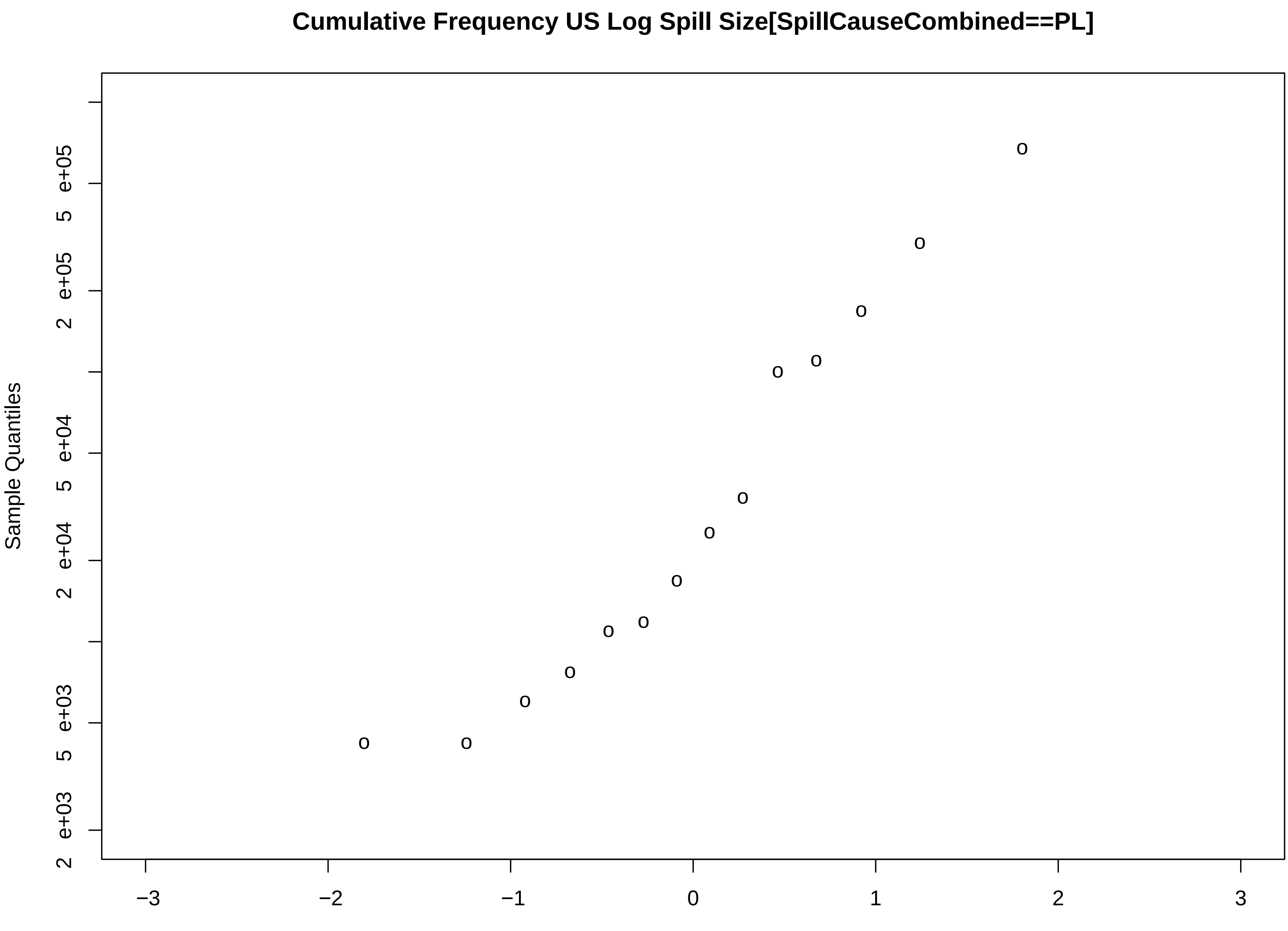
Cumulative Frequency US Log Spill Size[StudyAREA==TAPS]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles

Figure 12


Cumulative Frequency US Log Spill Size[StudyAREA==ONS]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
Theoretical Quantiles
−3
−2
−1
0
1
2
3
Figure 13


Cumulative Frequency US Log Spill Size[SpillCauseCombined==TV]
Sample Quantiles
5 e+05
2 e+05
5 e+04
2 e+04
5 e+03
2 e+03
−3
−2
−1
0
1
2
3
Theoretical Quantiles
Figure 14


Cumulative Frequency US Log Spill Size[SpillCauseCombined==FP]
Sample Quantiles
Theoretical Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Figure 15



Cumulative Frequency US Log Spill Size[SpillCauseCombined==PL]
Sample Quantiles
Theoretical Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3

Figure 16

Cumulative Frequency US Log Spill Size[SpillCauseCombined==FT]

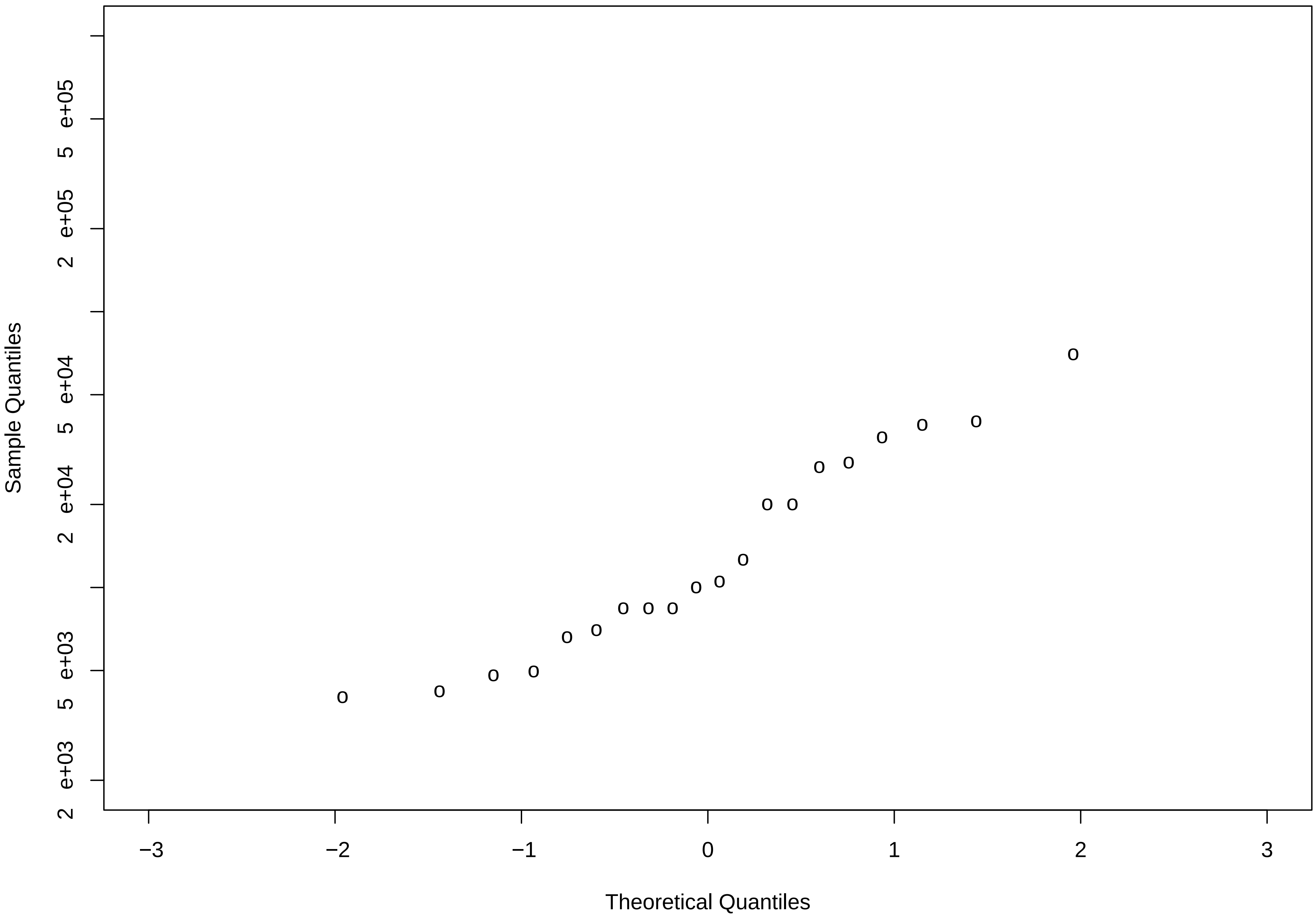


Figure 17

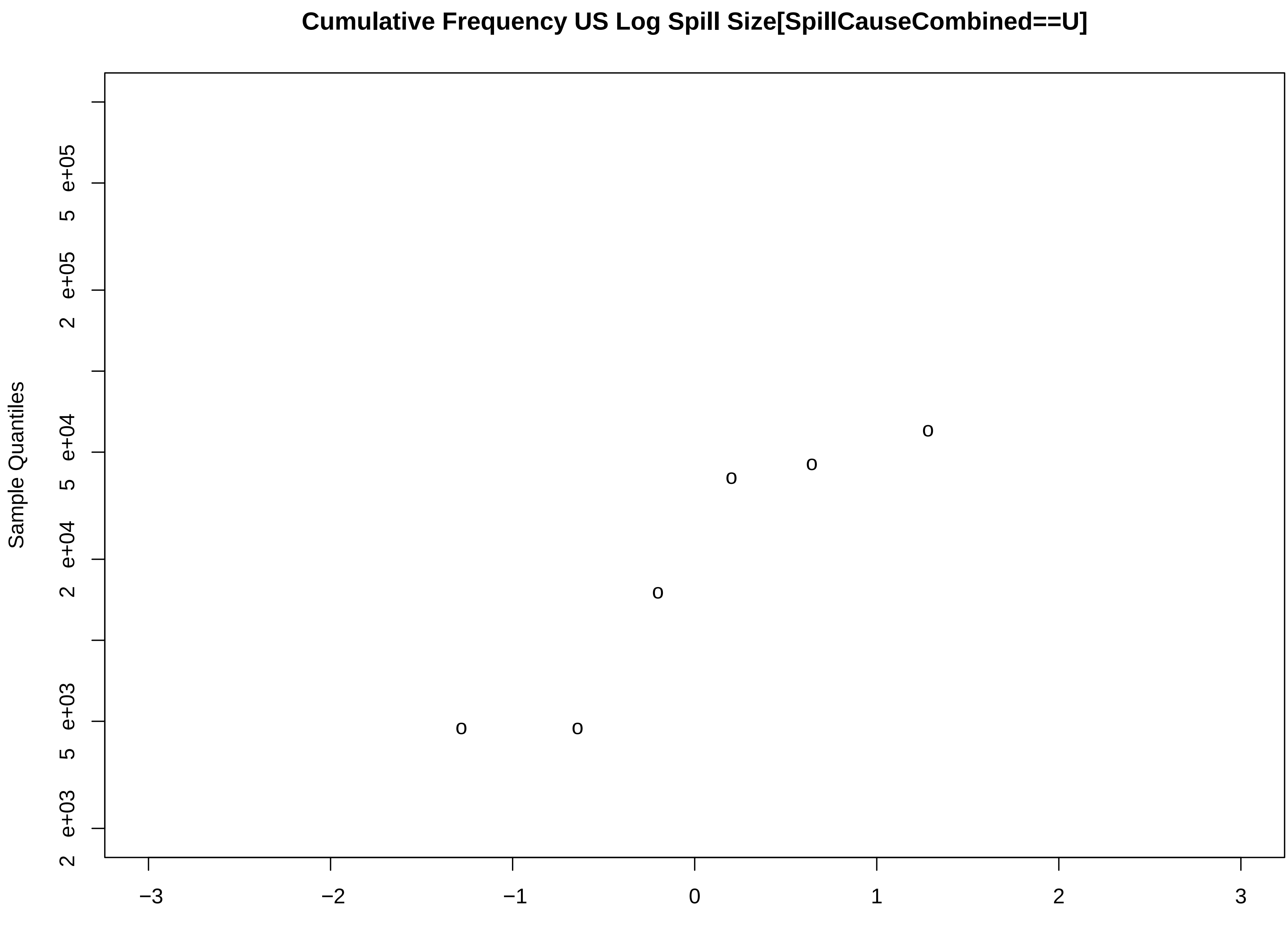
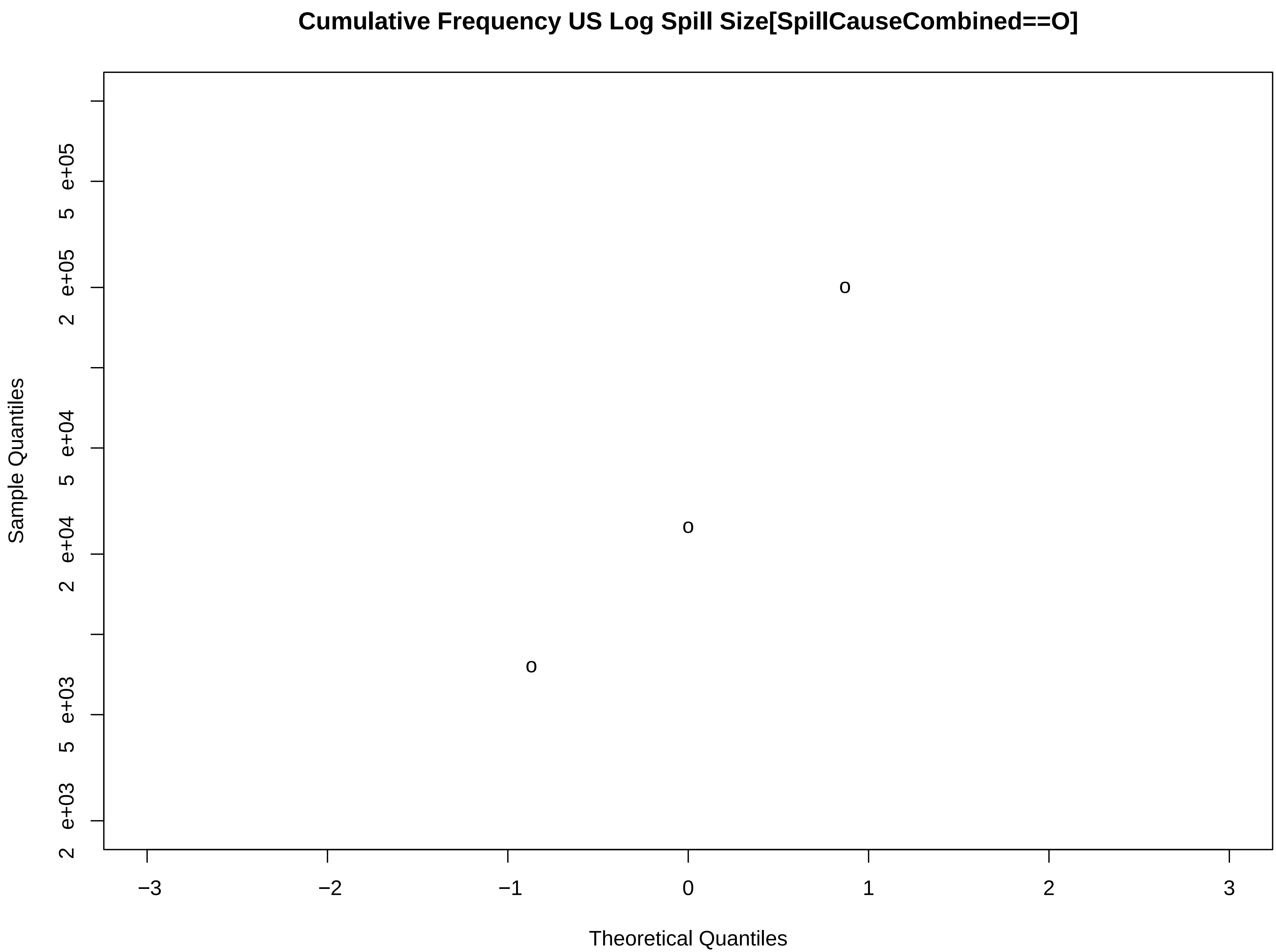

Cumulative Frequency US Log Spill Size[SpillCauseCombined==U]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles

Figure 18


Cumulative Frequency US Log Spill Size[SpillCauseCombined==O]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles
Figure 19

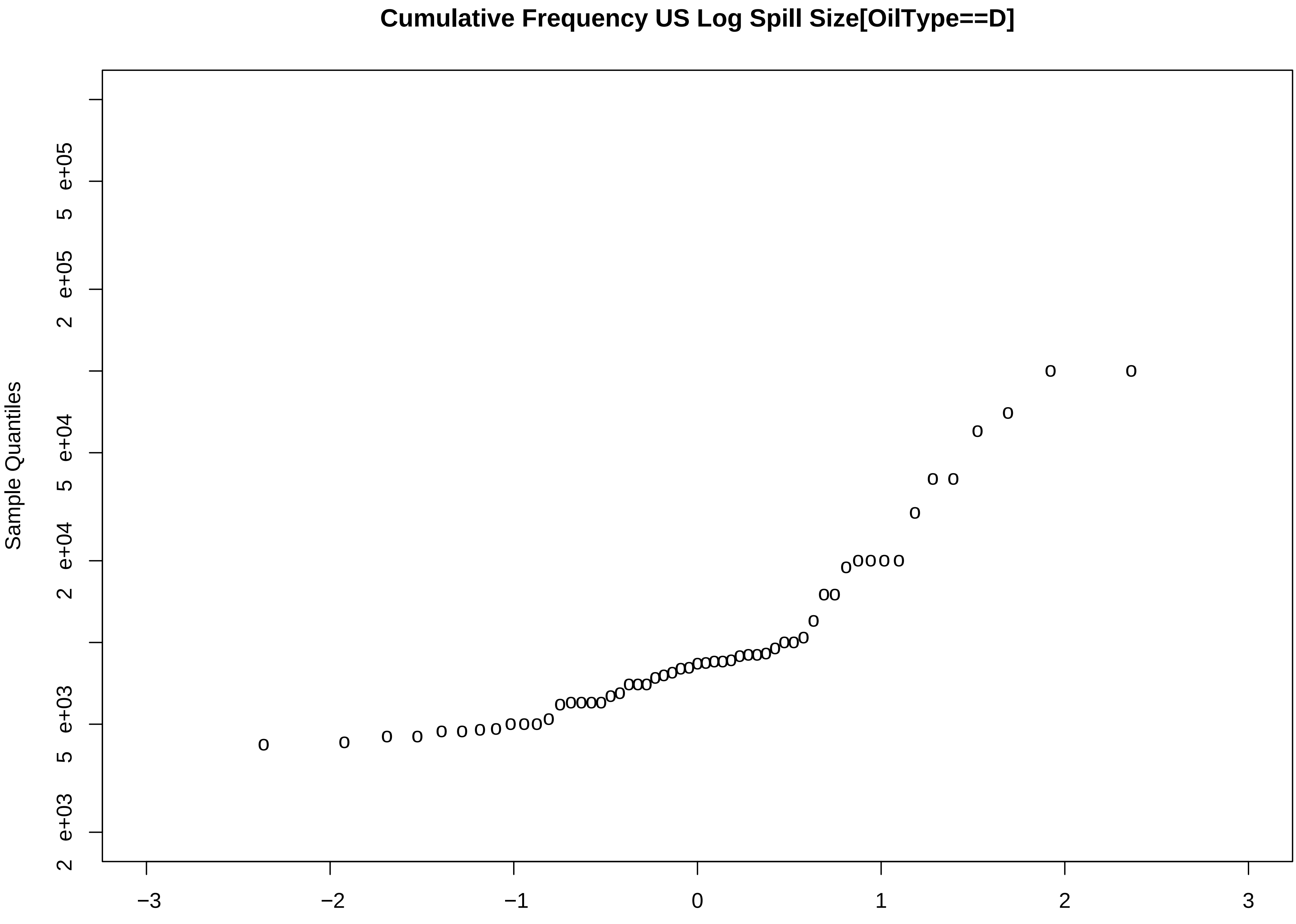

Cumulative Frequency US Log Spill Size[OilType==D]
Sample Quantiles
Theoretical Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3

Figure 20

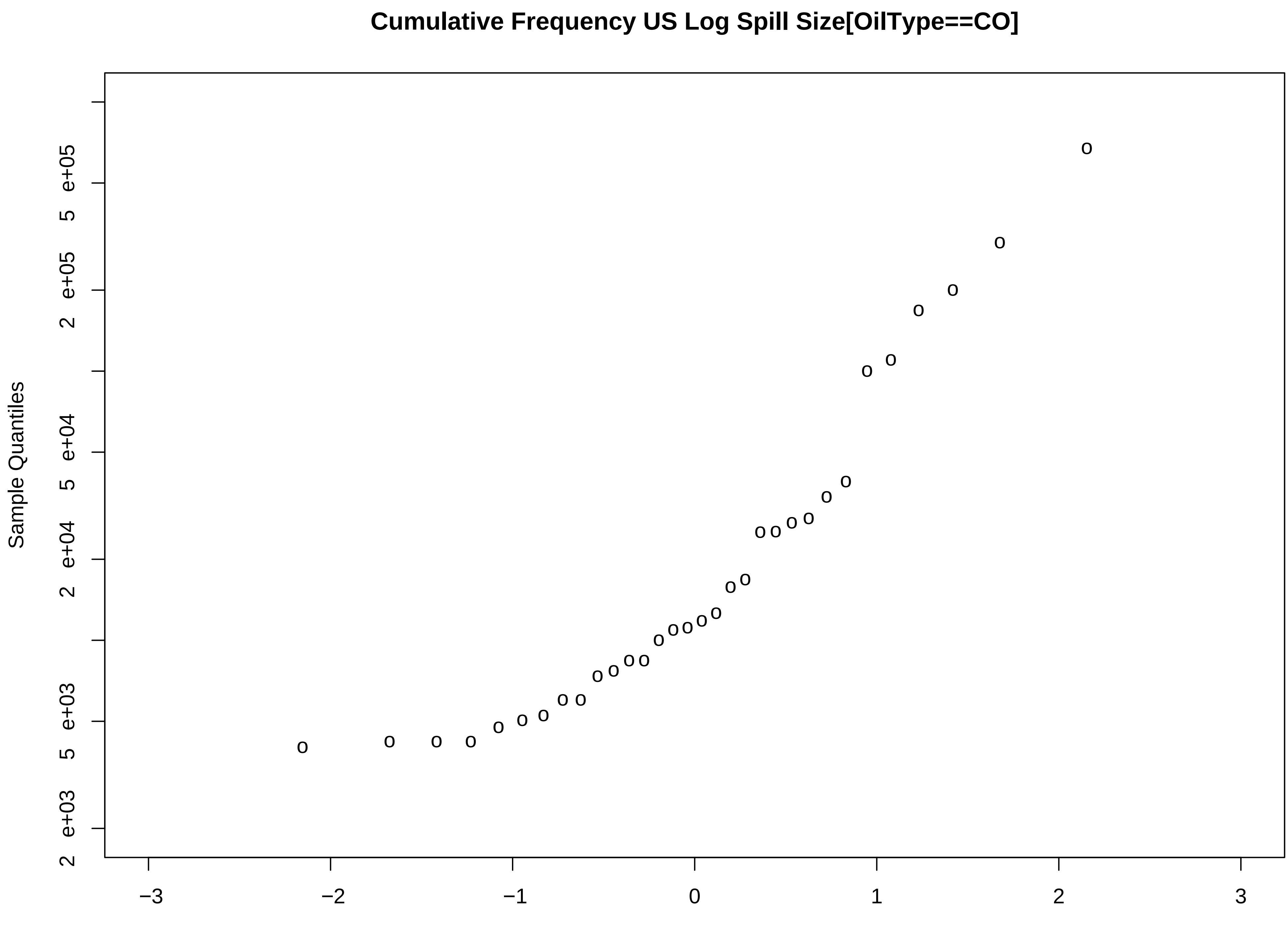

Cumulative Frequency US Log Spill Size[OilType==CO]
Sample Quantiles
Theoretical Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3

Figure 21

Cumulative Frequency US Log Spill Size[OilType==G]

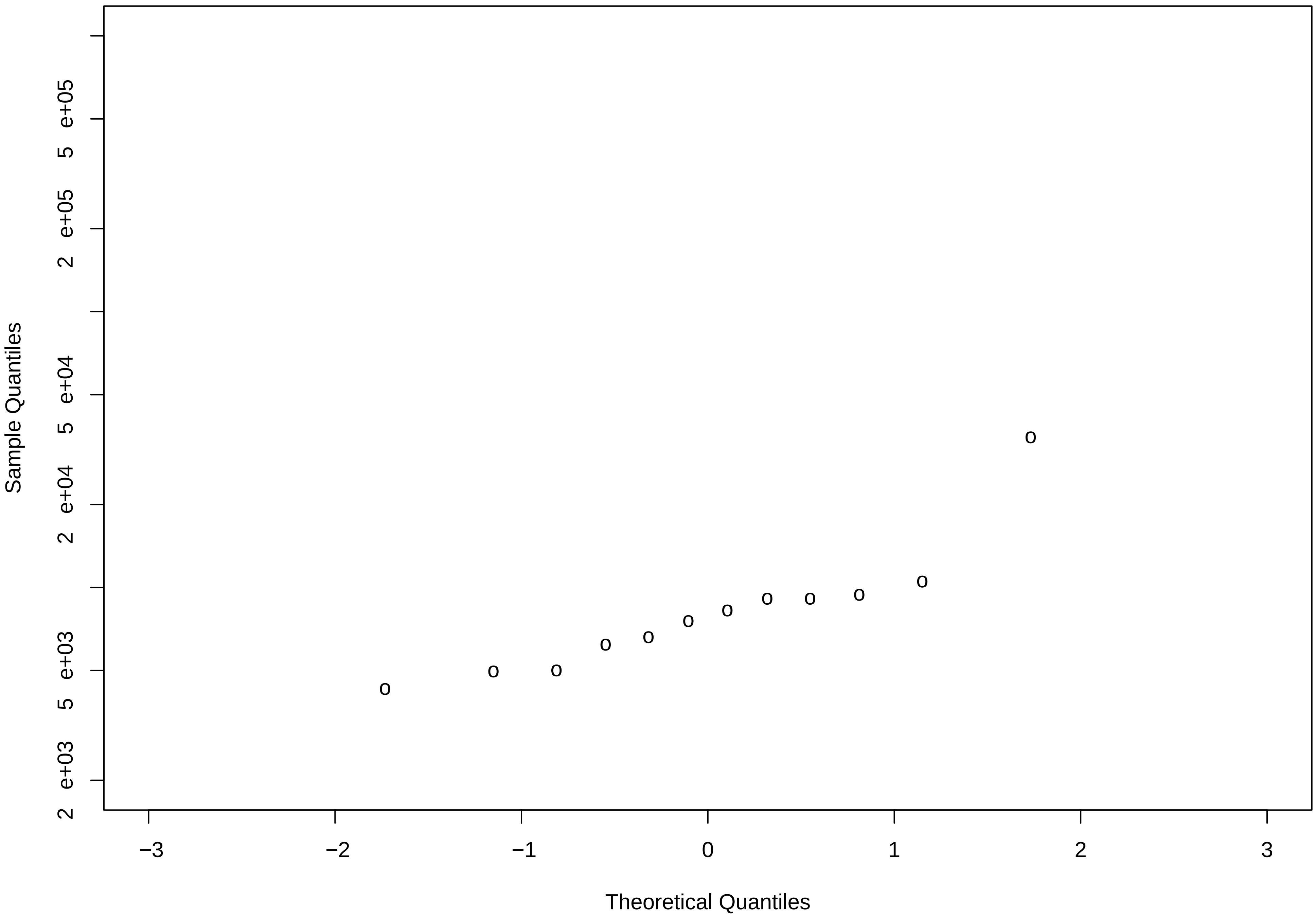


Figure 22

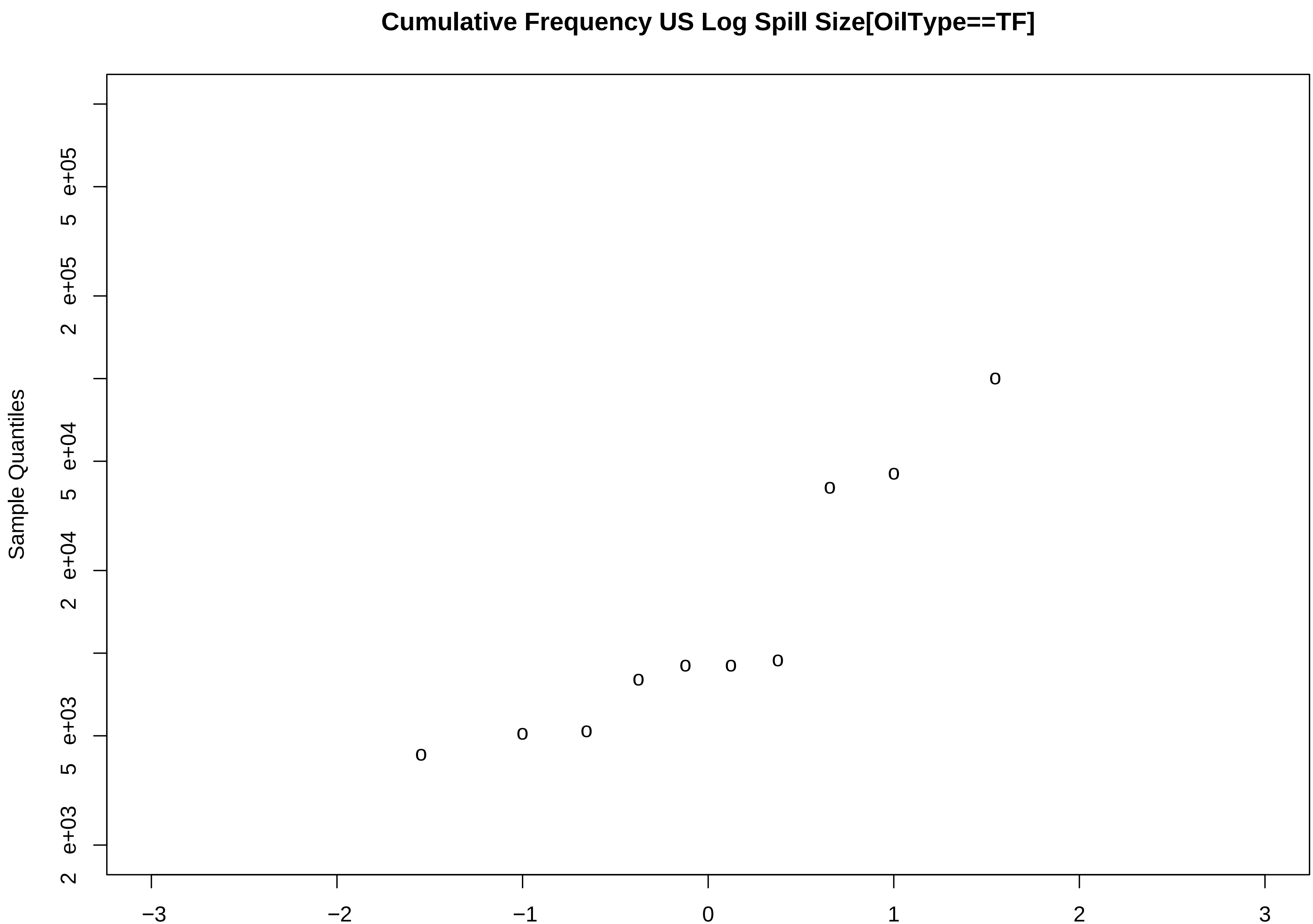

Cumulative Frequency US Log Spill Size[OilType==TF]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles

Figure 23

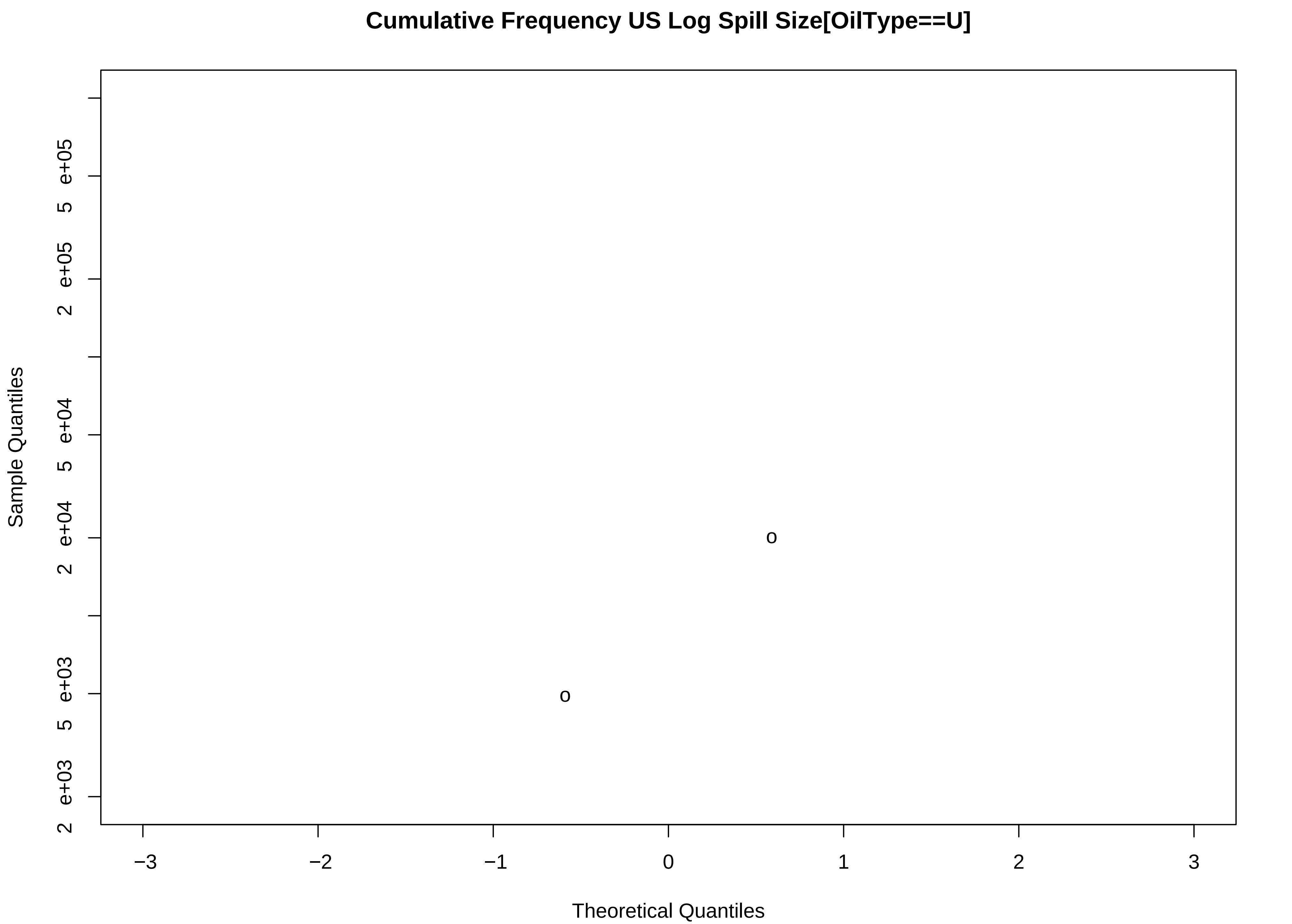
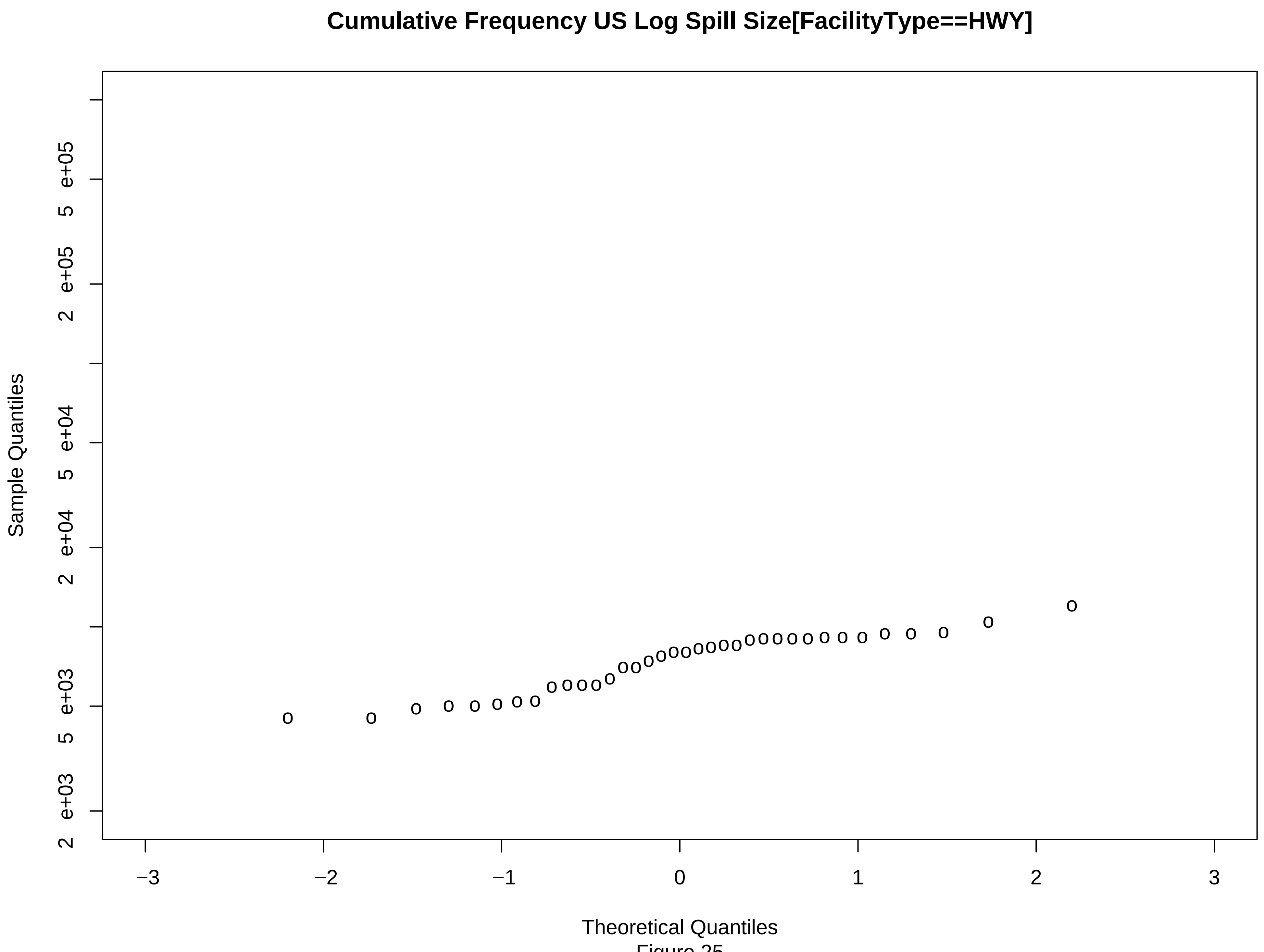
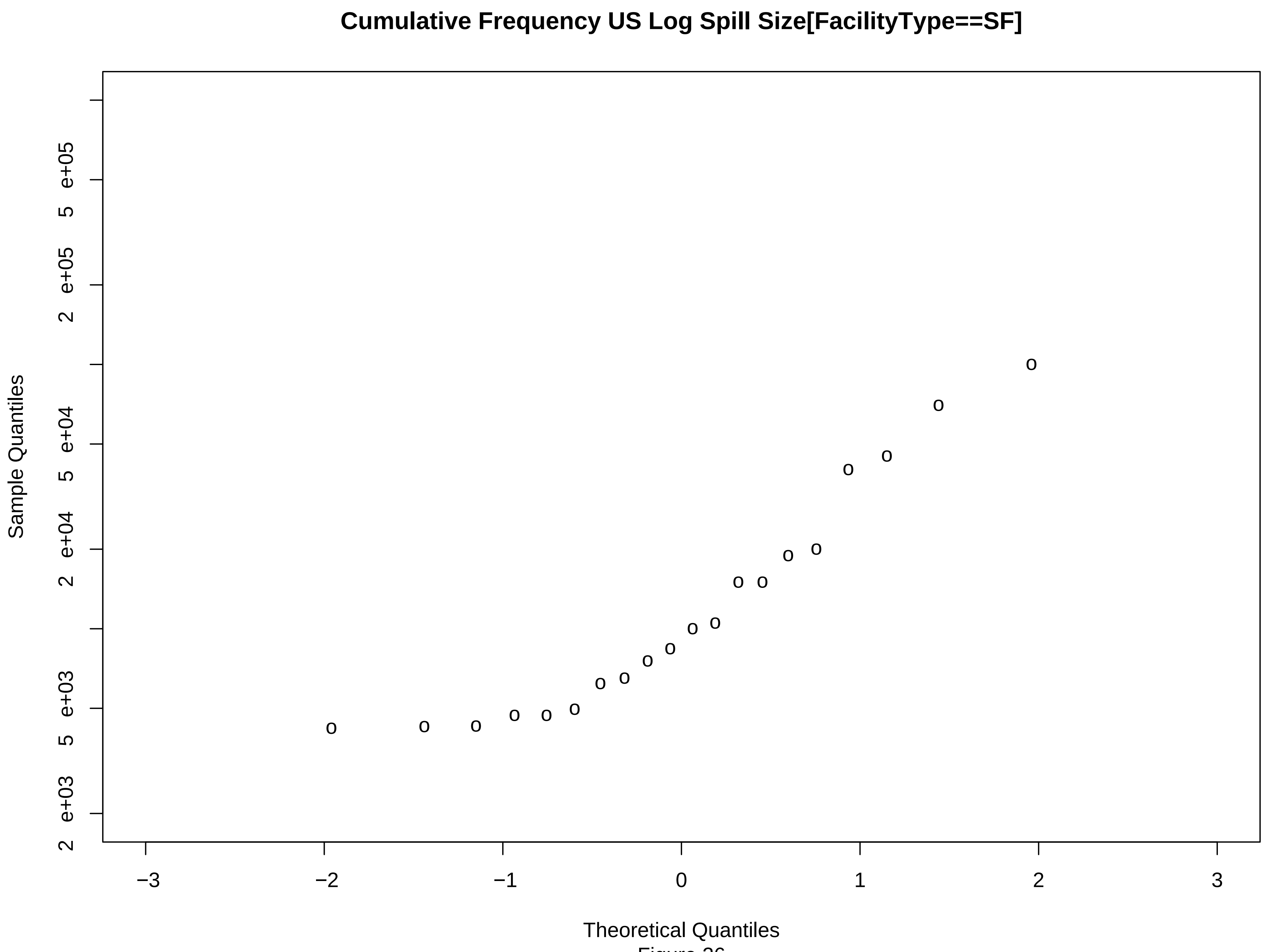

Cumulative Frequency US Log Spill Size[OilType==U]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
Theoretical Quantiles
−3
−2
−1
0
1
2
3

Figure 24


Cumulative Frequency US Log Spill Size[FacilityType==HWY]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles
Figure 25


Cumulative Frequency US Log Spill Size[FacilityType==SF]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles
Figure 26

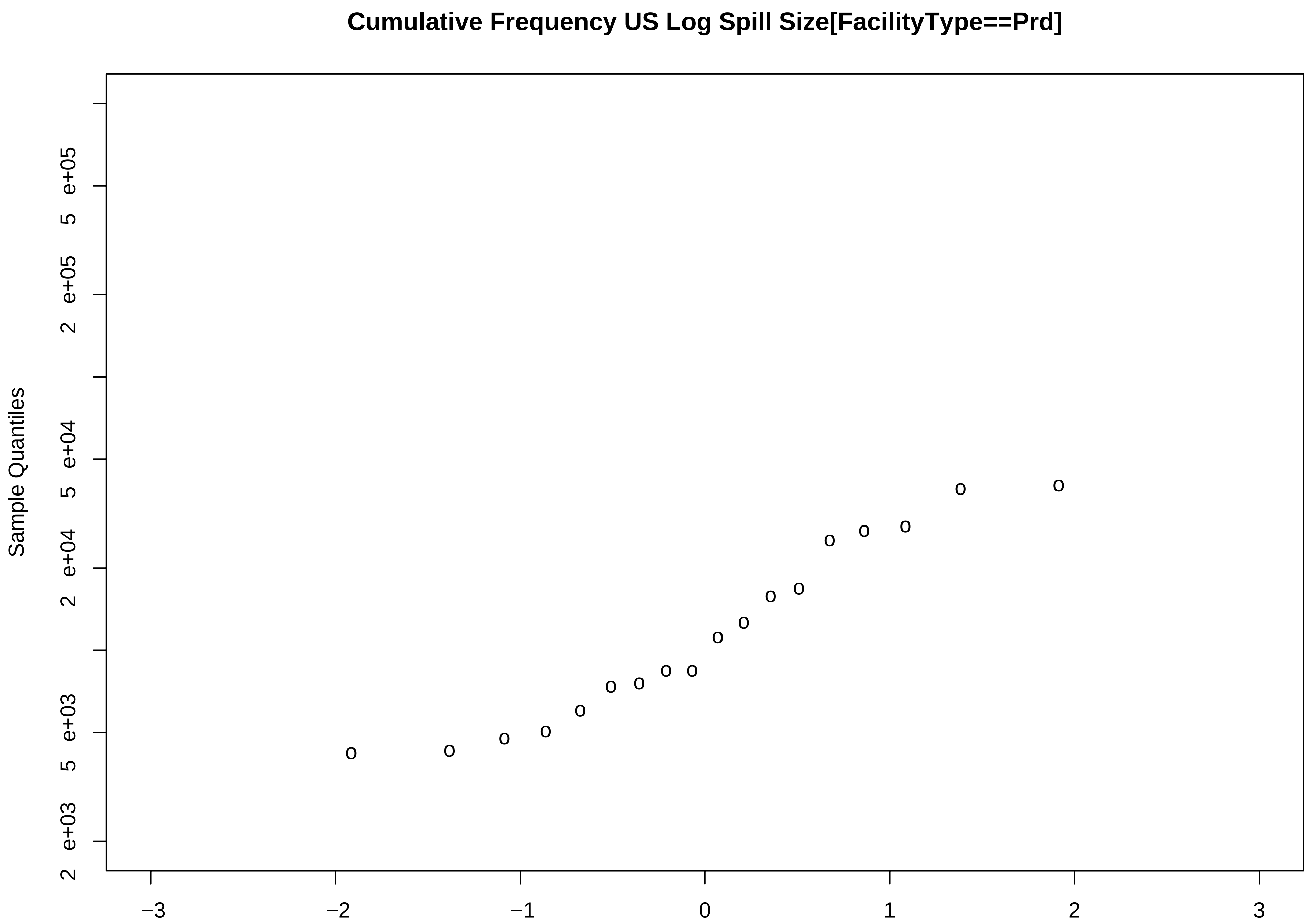
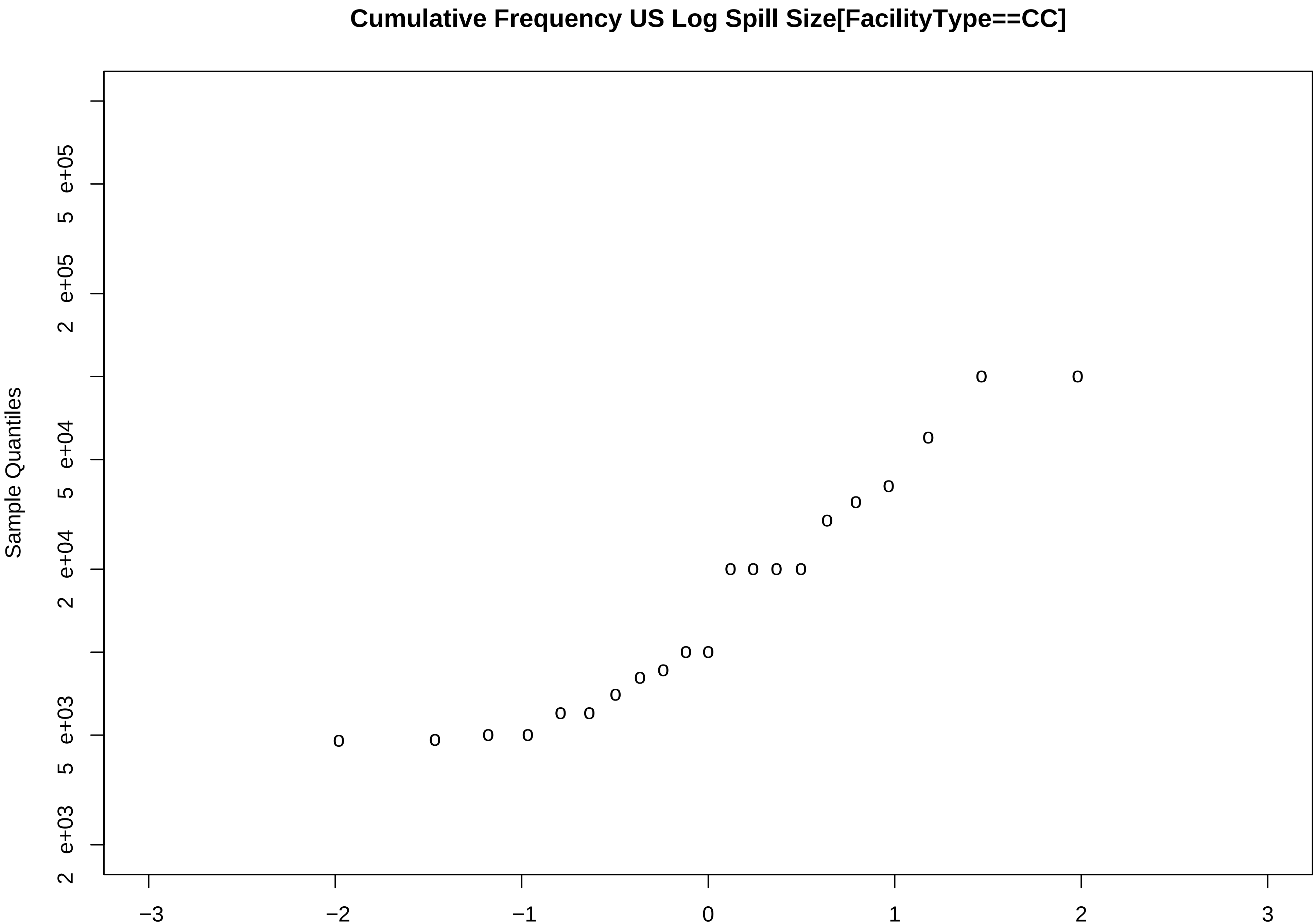
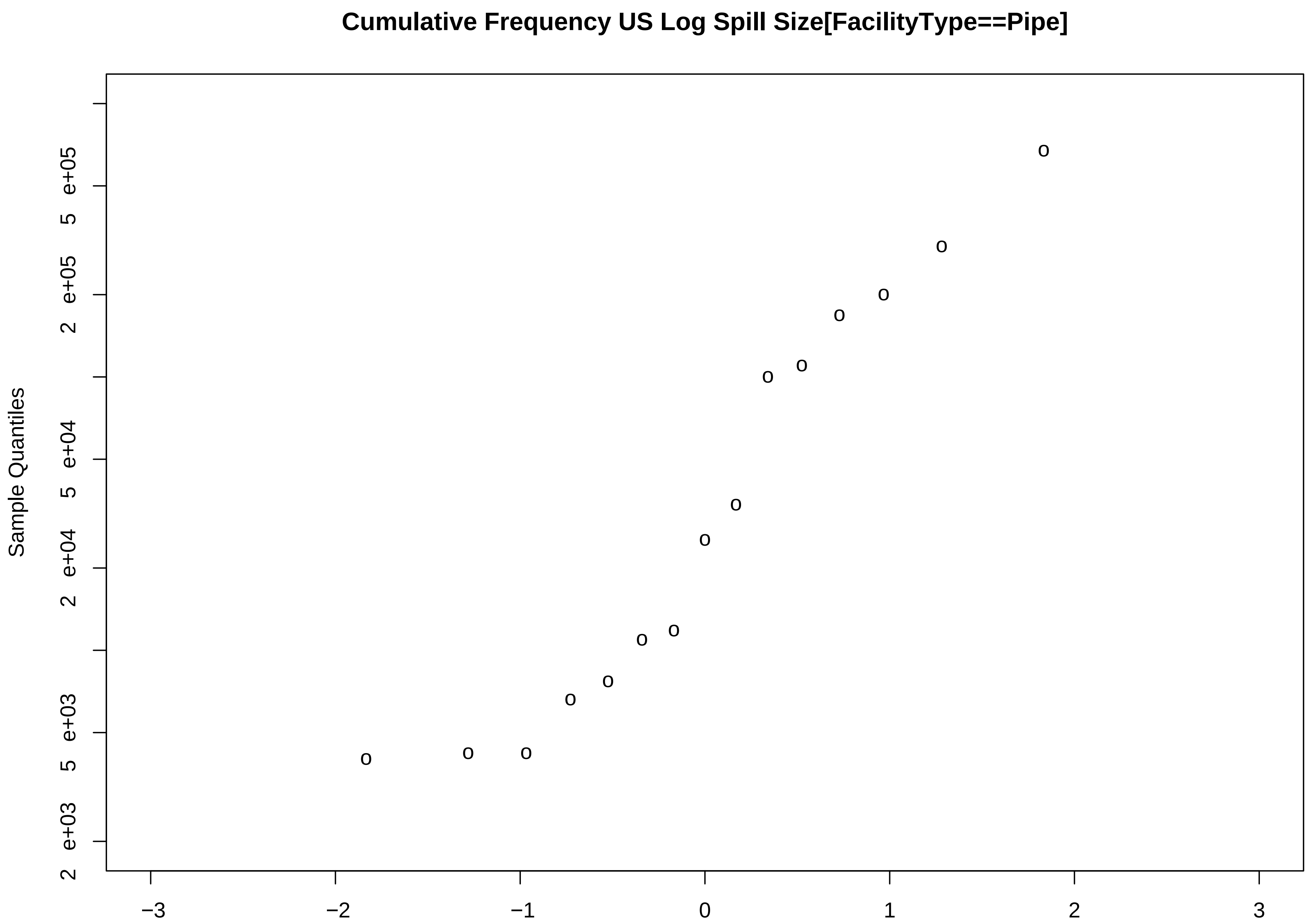

Cumulative Frequency US Log Spill Size[FacilityType==Prd]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles

Figure 27


Cumulative Frequency US Log Spill Size[FacilityType==CC]
Sample Quantiles
Theoretical Quantiles
−3
−2
−1
0
1
2
3
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
Figure 28


Cumulative Frequency US Log Spill Size[FacilityType==Pipe]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles
Figure 29

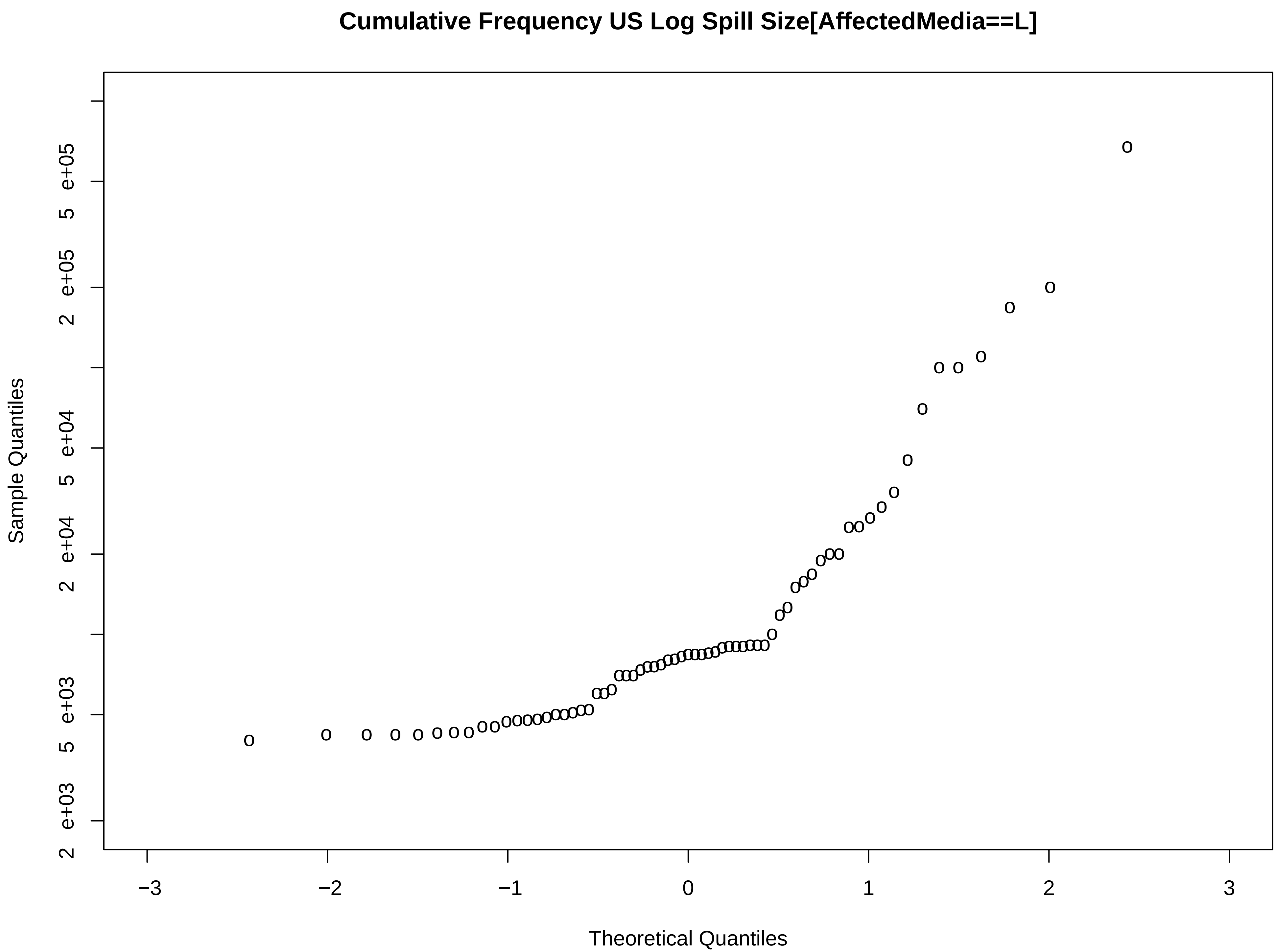
Figures 30 through 33 show the logarithms of spill volume versus affected media. Figure 30, for land, shows a mixture of two lognormal populations, while Figure 31, for unspecified values, seems to be a single lognormal population. Figure 32, for land and water, shows a mixture of two lognormal populations. Figure 33, for those spills retained on a facility pad, in an impoundment, or within a secondary containment area, appears to be a single lognormal population.

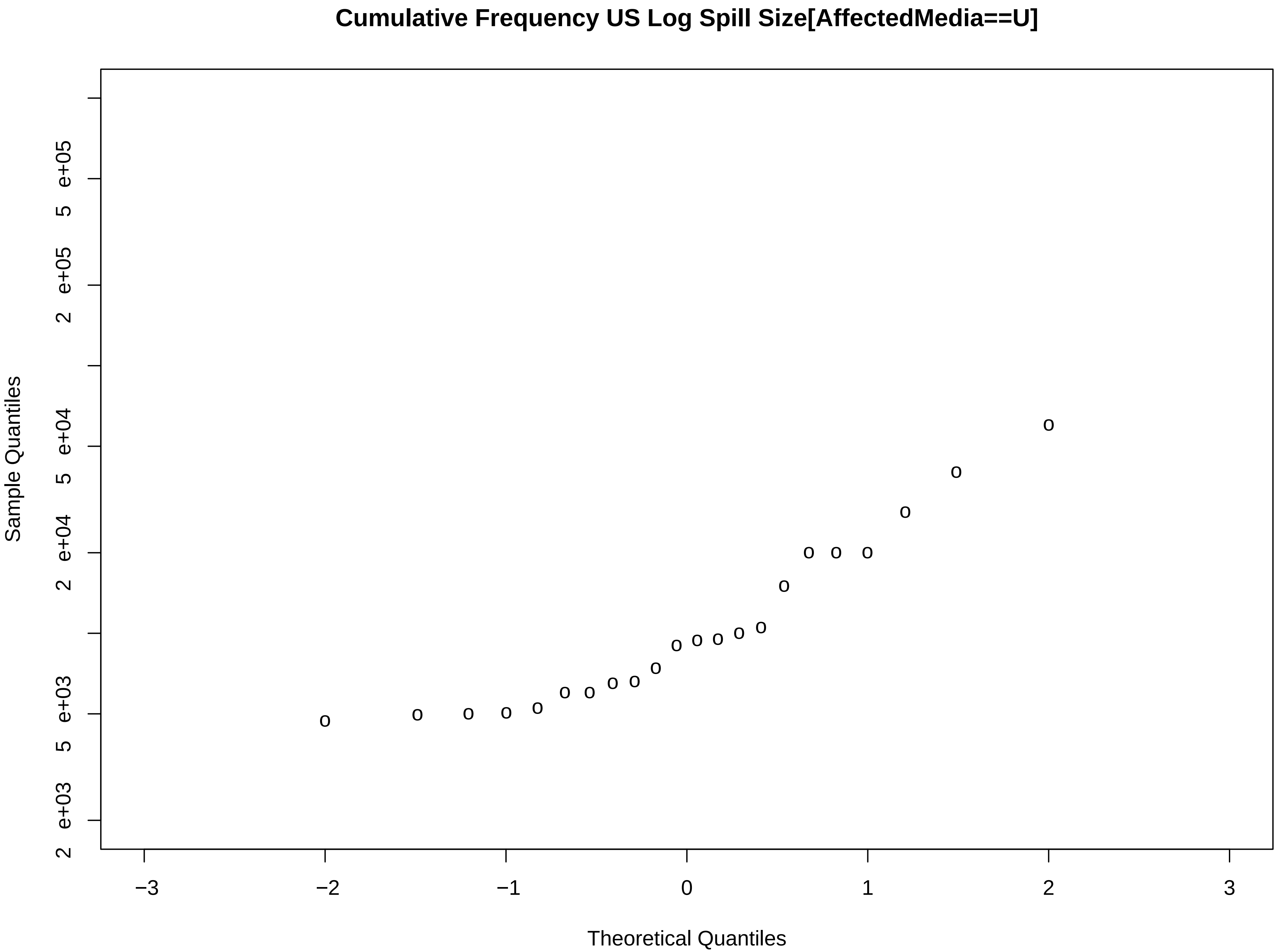
It is of interest to note that it is possible to globally interpret all of the spills as composed of two lognormal populations, one of which is average and the other that is larger. Hart Crowser conducted a statistical analysis on individual spill volumes by study area, facility type, oil type, affected media and spill cause combined, and did not find any particularly interesting correlation. Hence, the next phase of the analysis looked at annualized groupings of spills. Total spill volumes by year were accumulated and plotted on a cumulative frequency plot, as shown in Figure 34. This shows a mixture of several populations.

If the data are re-plotted on a logarithmic scale, a single lognormal population emerges. This is shown in Figure 35. A count of the number of spills per year in the database is tabulated in Figure 36. This distribution is possibly Poisson; however, this hypothesis was not tested. A more interesting way of looking at the data to see if regulatory or reporting requirements have significantly affected spills is shown in Figure 37, where spill size is plotted by year. As can be seen by examining Figure 37, it appears that in the period from 1975 to 1979 there were a considerable number of large spills, and then after that, the number of spills dropped to a more or less constant rate. This same data is shown on a logarithmic scale in Figure 38. .Again, it appears that spills were relatively constant between 1969 and 1975, and from 1980 onward. It must be noted that 1977 is significant because crude oil production on North Slope and TAPS operation started in the middle of that year. However, the years of 1978 and 1979 fit with years of 1975 and 1977 visually better in Figure 38 than breaking the data at 1977. The number of spills as shown in Figure 39 again shows a larger number in the period from 1975 to 1980. On a count basis (Figure 39), there is some evidence that 1975,1976 and 1977 are a single high group. This corresponds well to the peak years of TAPS construction and development and construction of the North Slope oil fields. When the number of spills are grouped by 5-year periods (arbitrarily starting on years ending in 0 and 5 for calculation convenience), as shown in Figures 40 and 41, it appears that the 1975 to 1979 period was the highest. This same conclusion is confirmed by Figure 42, which shows a count of spills by 5-year groups. The 1975 to 1979 period appears to have the most number of spills.

Calculated Oil Spill Risk Rates

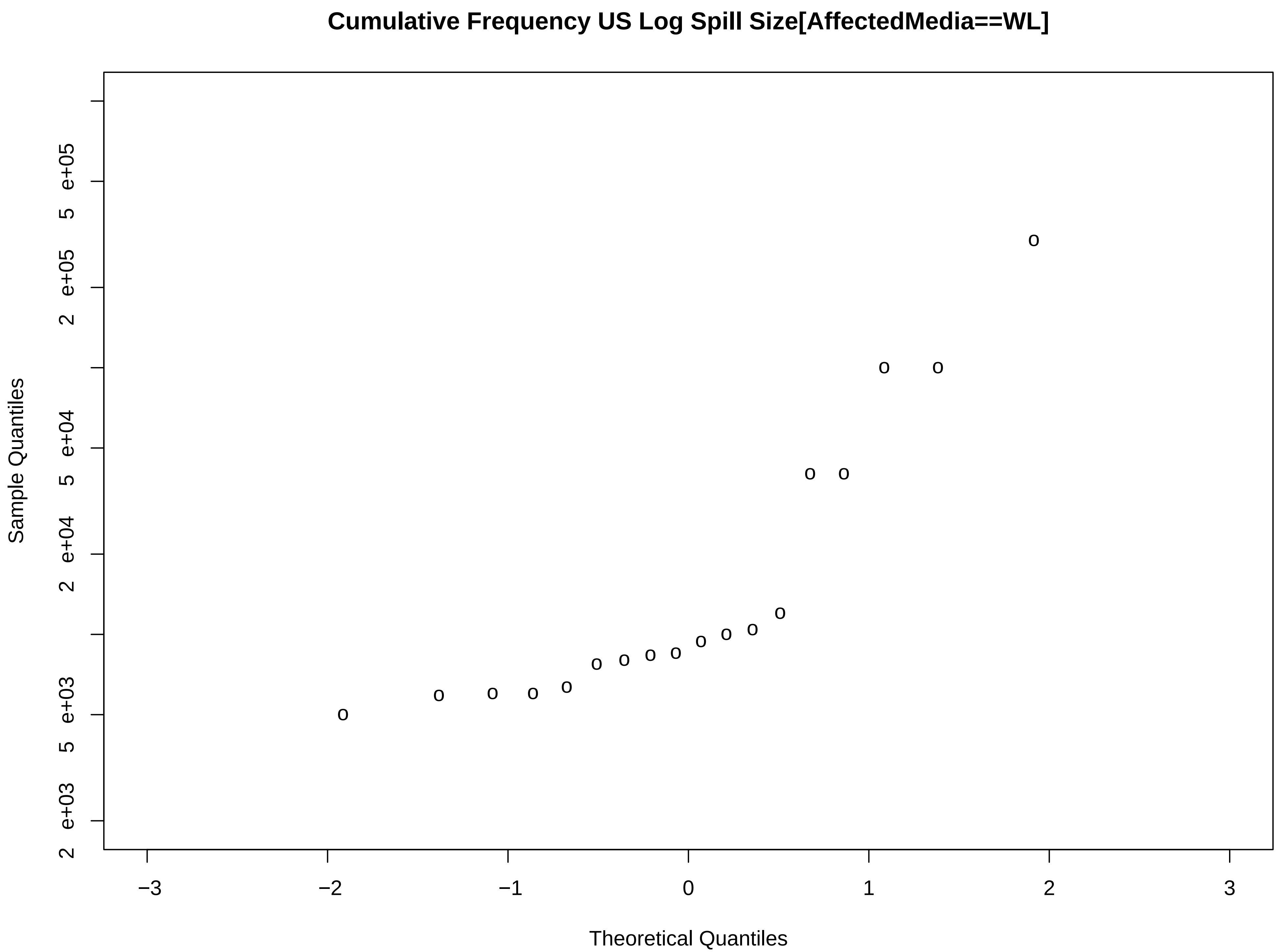
Another way of investigating the data is on a rate basis. For a rate-basis type of investigation, some variable, which can be reasonably expected to correlate with the quantity being measured, is added to the dataset for analysis. In the case of the Alaskan oil spill data, total volume spilled divided by production was selected. As noted earlier, the units for this spill rate are U.S. gallons per million barrels produced. Because it was anticipated that a logarithmic analysis would give better results, 2,000 gallons was added to the total spill volume on each year for analysis. The rate data used are presented in Table 4, with assumptions of 450 million barrels of crude oil production for the Alaska - ONS study area and 9.924 million barrels of crude oil production for the Canada - Norman Wells study area for 1999. The value of 2,000 gallons is close to one-half of the minimum oil spill volume included in this analysis. A cumulative frequency plot of this variable is shown in Figure 43. This figure was not found to be particularly useful, so the data were re-plotted on a logarithmic basis as shown in Figure 44. Figure 44 shows what may be a mixture of three lognormal populations. When these data are plotted on a yearly basis, as shown in Figure 45, it appears that prior to 1977, spill rates were considerably greater than in the subsequent years. Because of the low value of the spill rate after 1980, it is not possible to draw any conclusions


Cumulative Frequency US Log Spill Size[AffectedMedia==L]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles
Figure 30



Cumulative Frequency US Log Spill Size[AffectedMedia==U]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles

Figure 31



Cumulative Frequency US Log Spill Size[AffectedMedia==WL]
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
−3
−2
−1
0
1
2
3
Theoretical Quantiles

Figure 32

Cumulative Frequency US Log Spill Size[AffectedMedia==R]

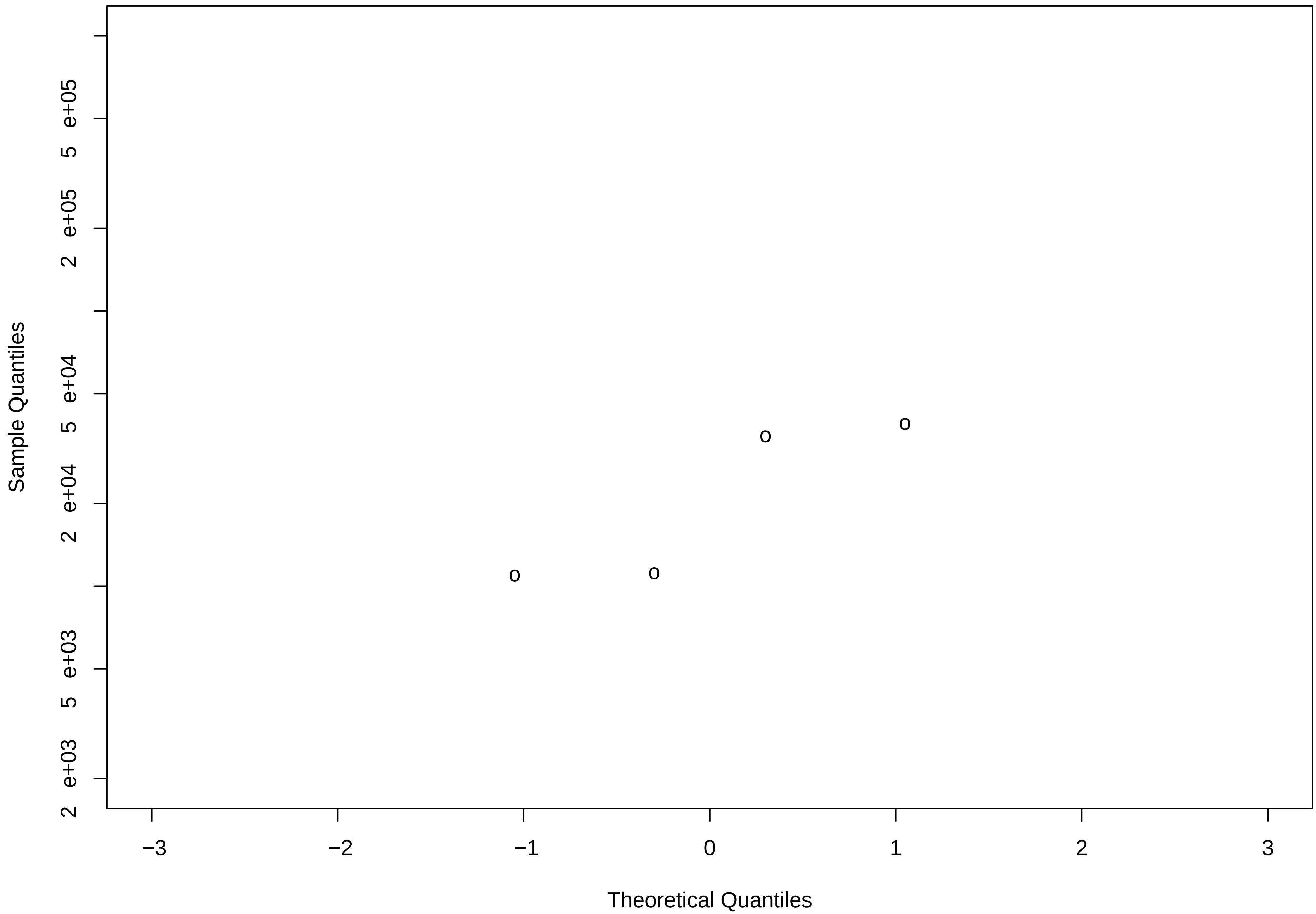


Figure 33

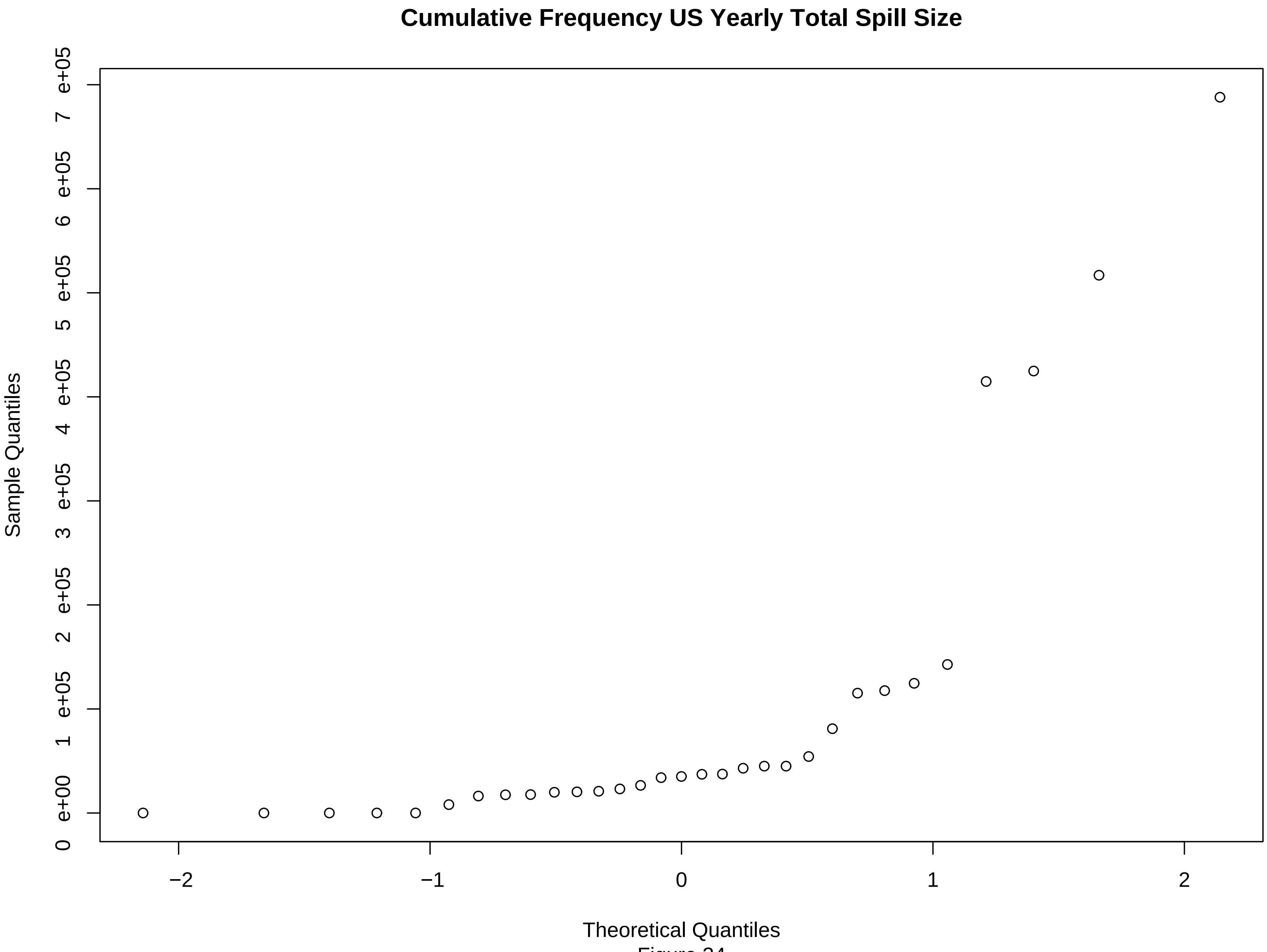

Cumulative Frequency US Yearly Total Spill Size
Sample Quantiles
0 e+00
1 e+05
2 e+05
3 e+05
4 e+05
5 e+05
6 e+05
7 e+05
−2
−1
0
1
2
Theoretical Quantiles

Figure 34

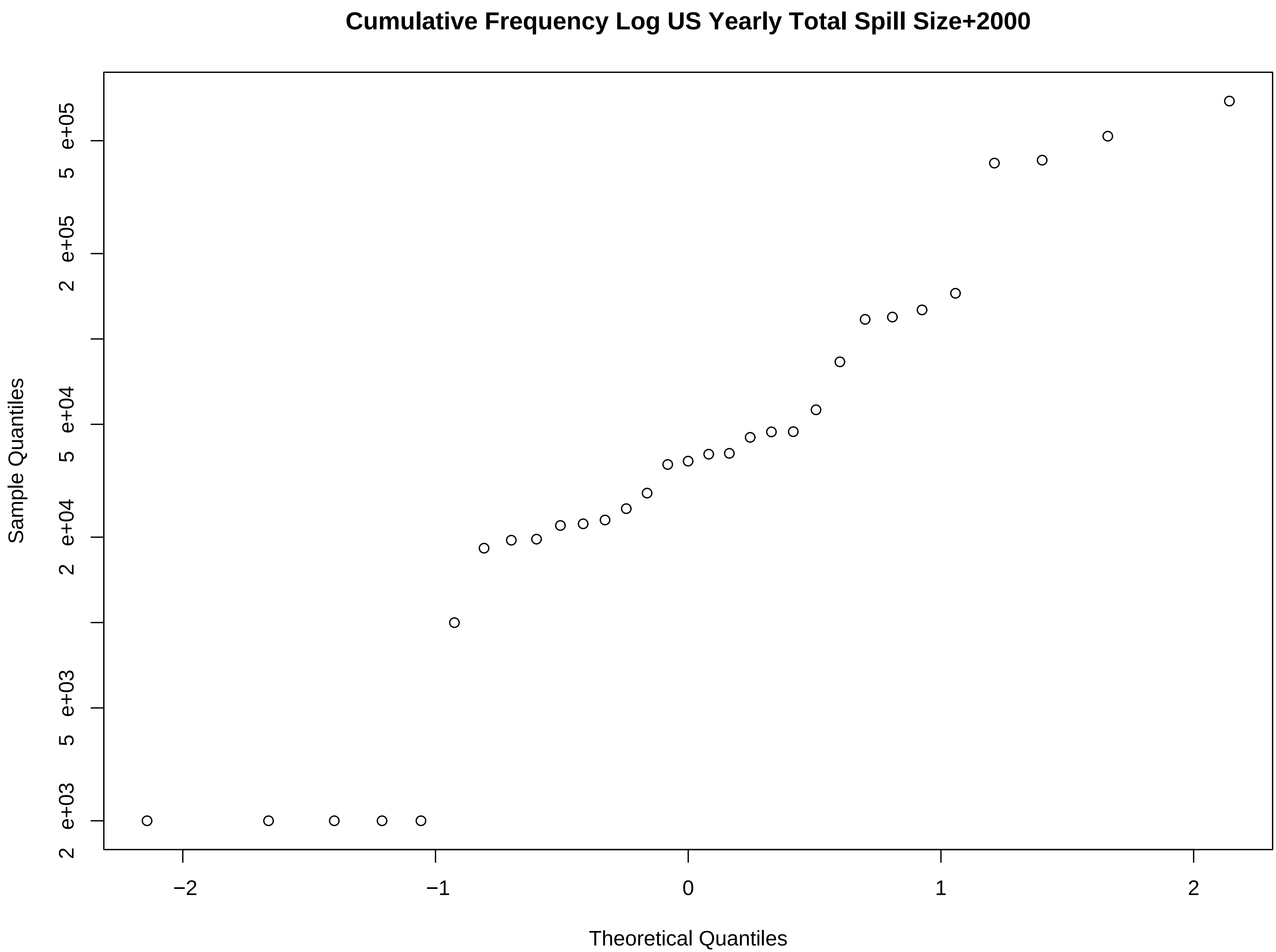
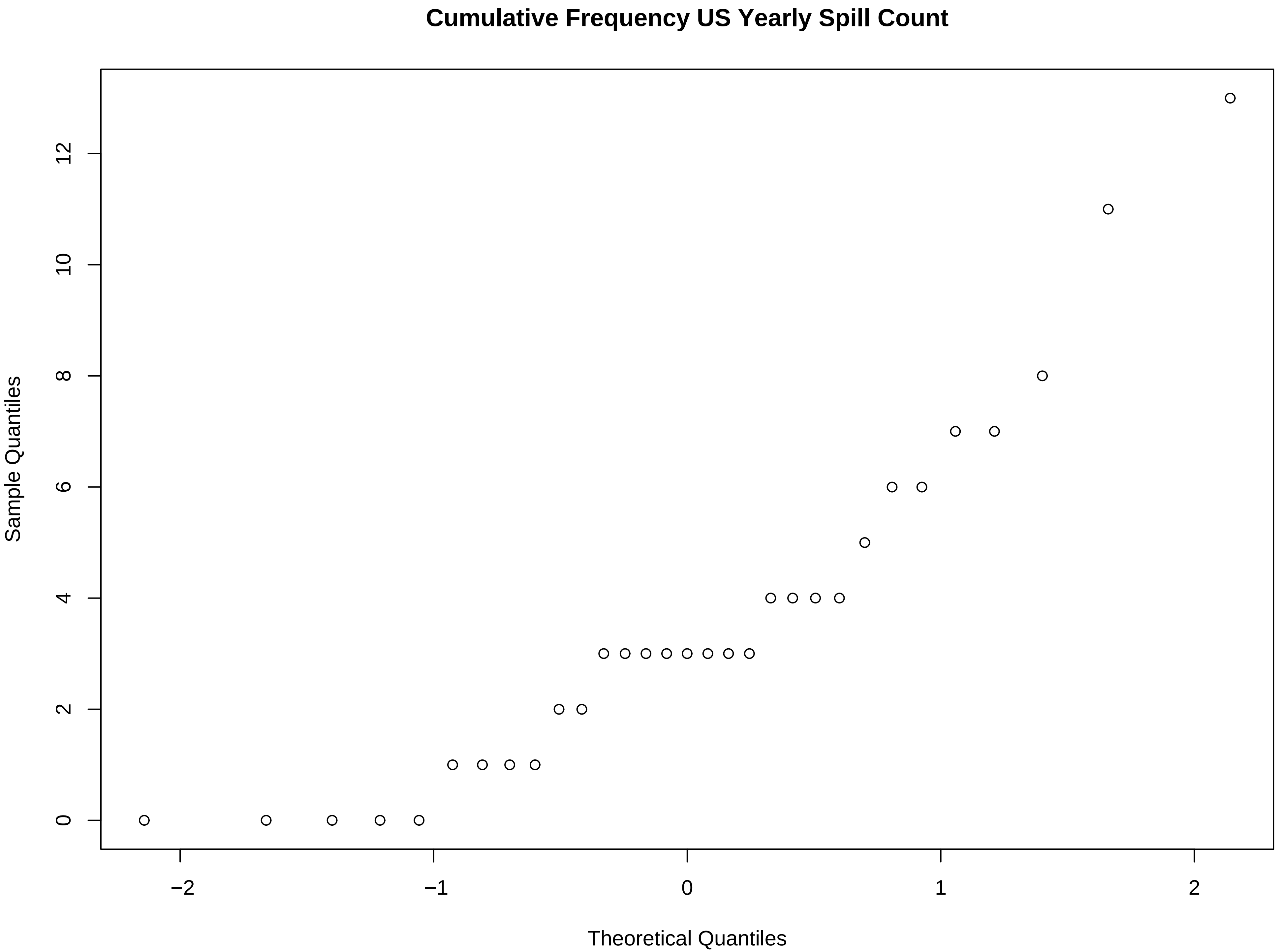
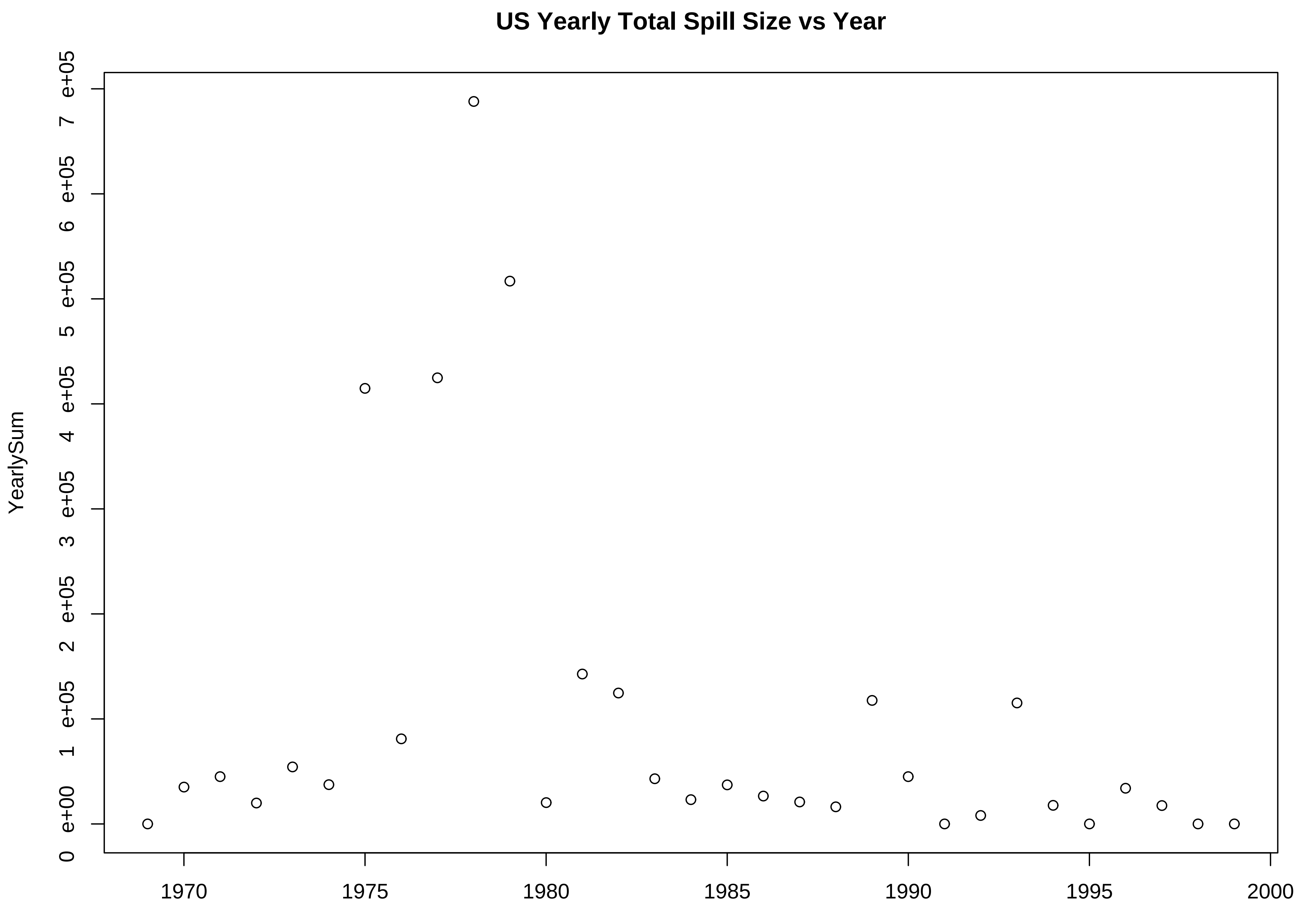

Cumulative Frequency Log US Yearly Total Spill Size+2000
Sample Quantiles
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
Theoretical Quantiles
−2
−1
0
1
2

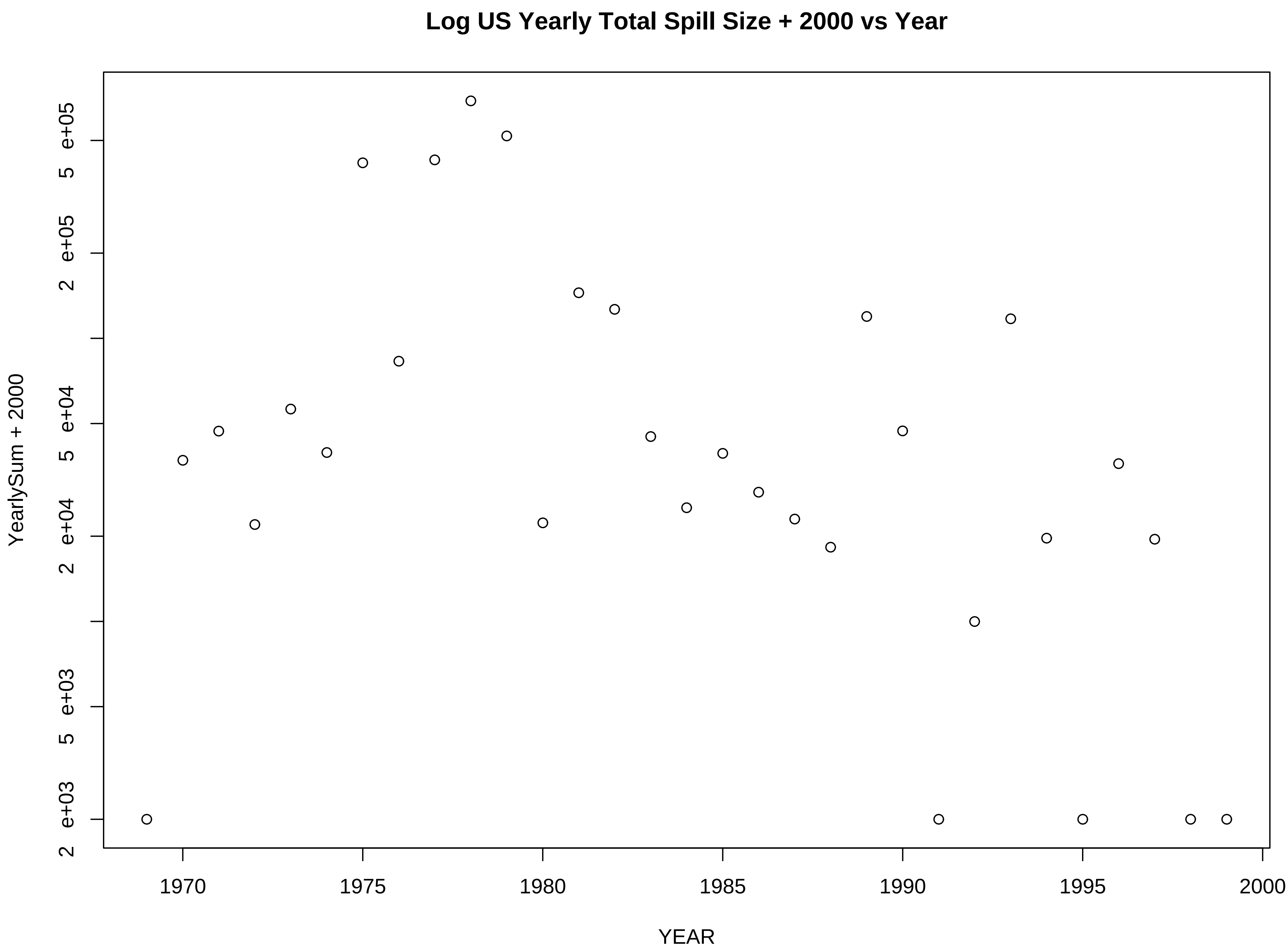
Figure 35

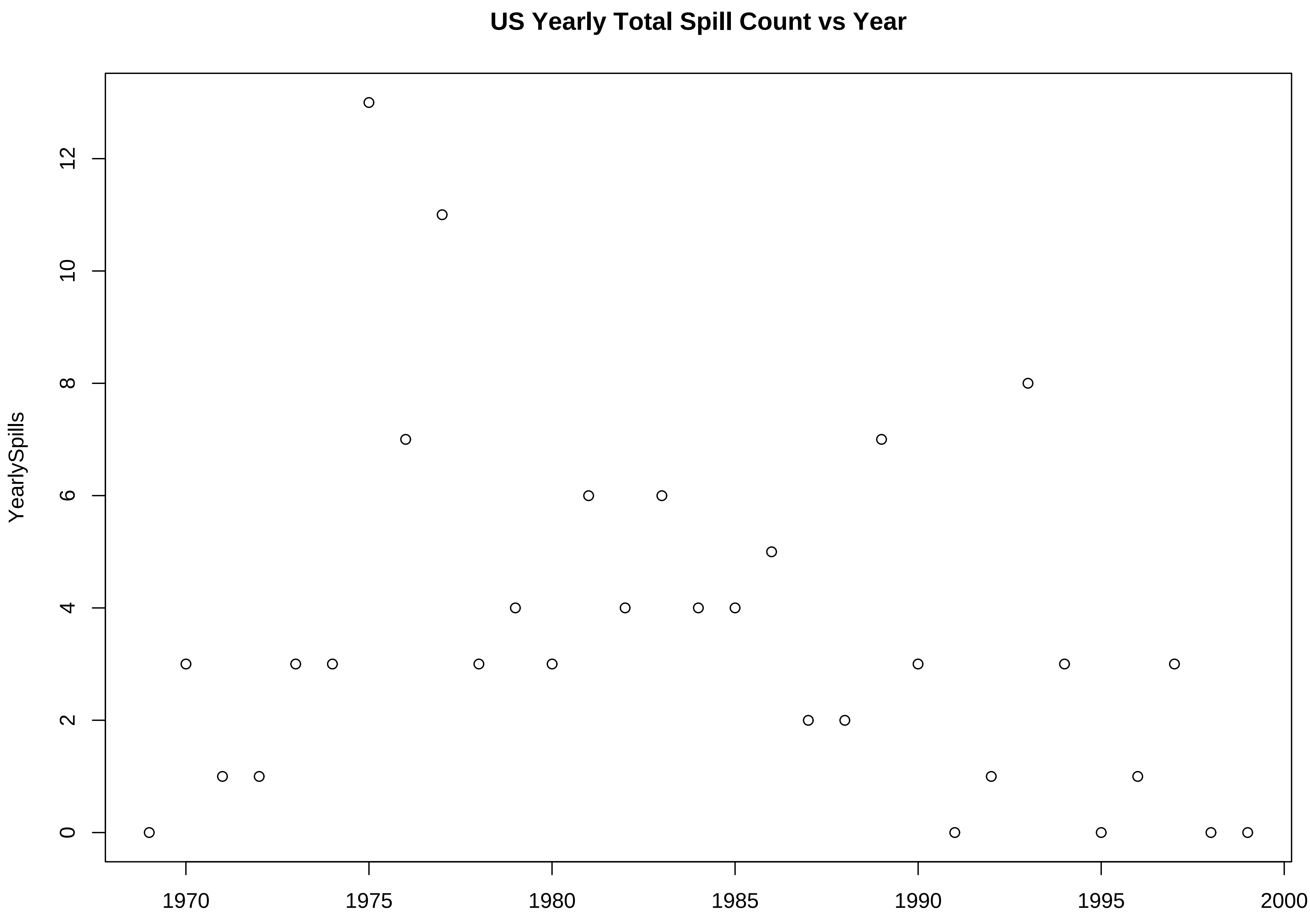


Cumulative Frequency US Yearly Spill Count
Sample Quantiles
0
2
4
6
8
10
12
−2
−1
0
1
2
Theoretical Quantiles

Figure 36


US Yearly Total Spill Size vs Year
YearlySum
0 e+00
1 e+05
2 e+05
3 e+05
4 e+05
5 e+05
6 e+05
7 e+05
1970
1975
1980
1985
1990
1995
2000
YEAR
Figure 37


Log US Yearly Total Spill Size + 2000 vs Year
YearlySum + 2000
5 e+05
2 e+05
5 e+04
2 e+04
5 e+03
2 e+03
1970
1975
1980
1985
1990
1995
2000
YEAR
Figure 38


US Yearly Total Spill Count vs Year
YearlySpills
0
2
4
6
8
10
12
1970
1975
1980
1985
1990
1995
2000
YEAR
Figure 39

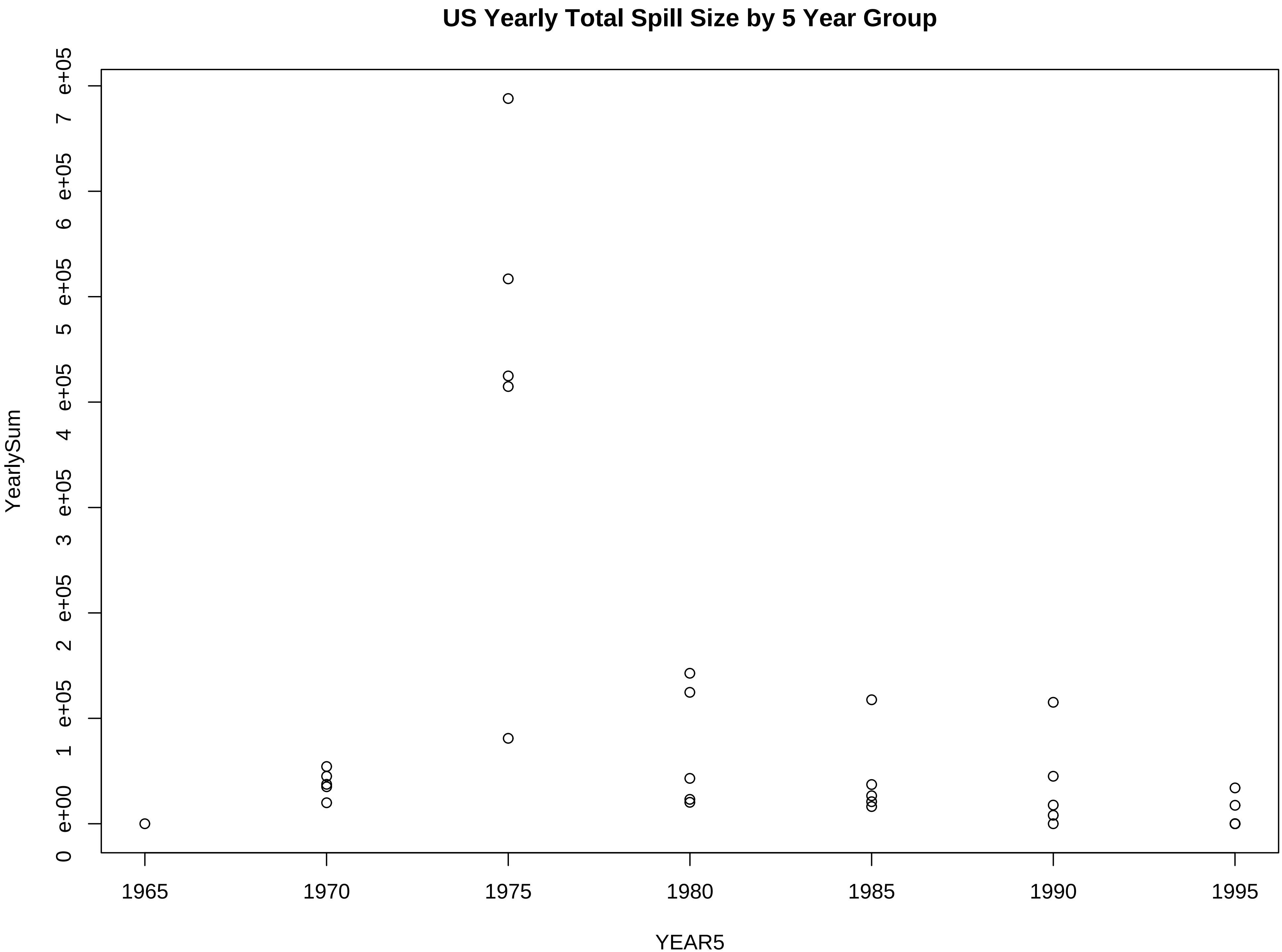

US Yearly Total Spill Size by 5 Year Group
YearlySum
0 e+00
1 e+05
2 e+05
3 e+05
4 e+05
5 e+05
6 e+05
7 e+05
1965
1970
1975
1980
1985
1990
1995
YEAR5

Figure 40

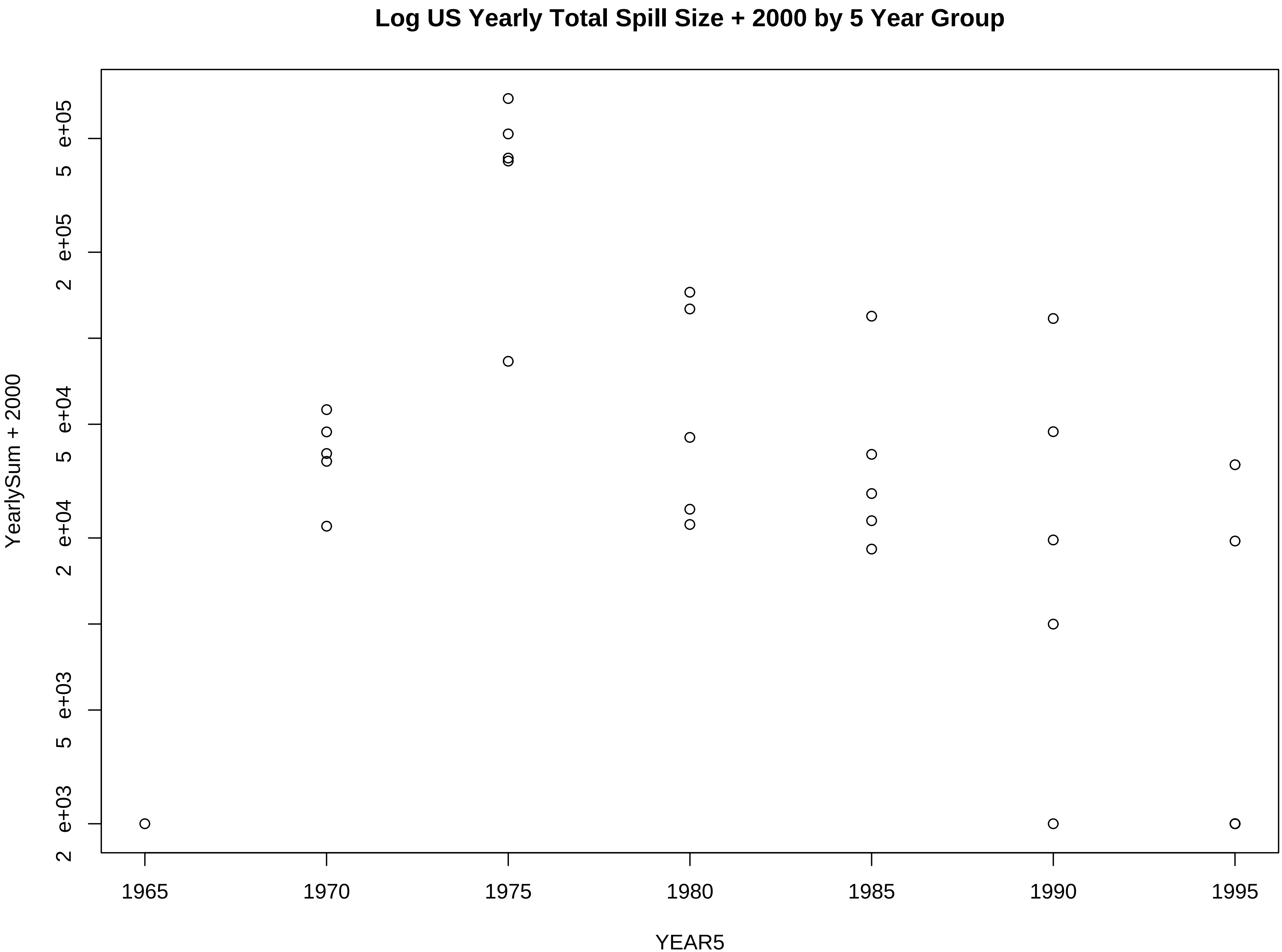
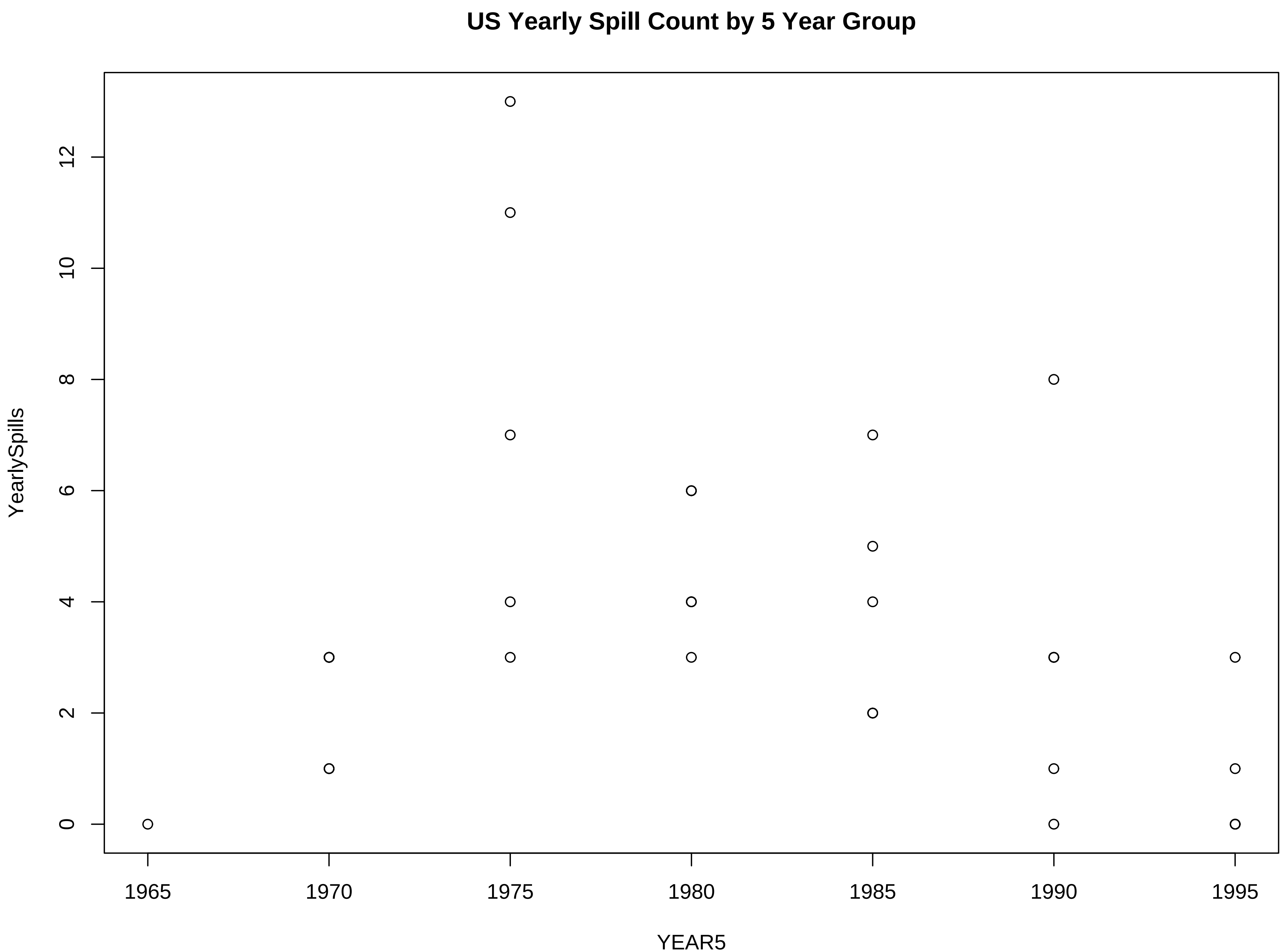
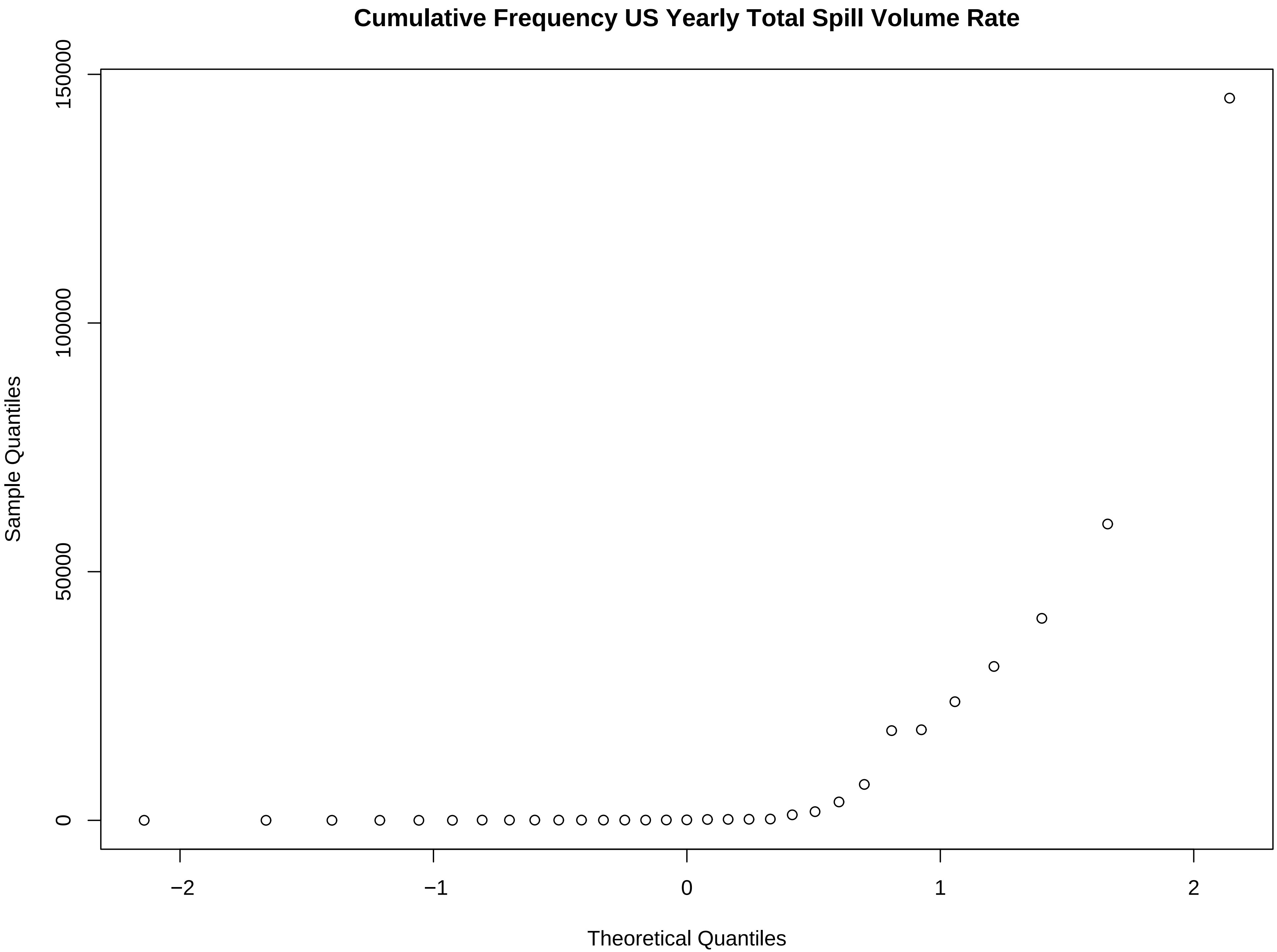

Log US Yearly Total Spill Size + 2000 by 5 Year Group
YearlySum + 2000
2 e+03
5 e+03
2 e+04
5 e+04
2 e+05
5 e+05
1965
1970
1975
1980
1985
1990
1995
YEAR5

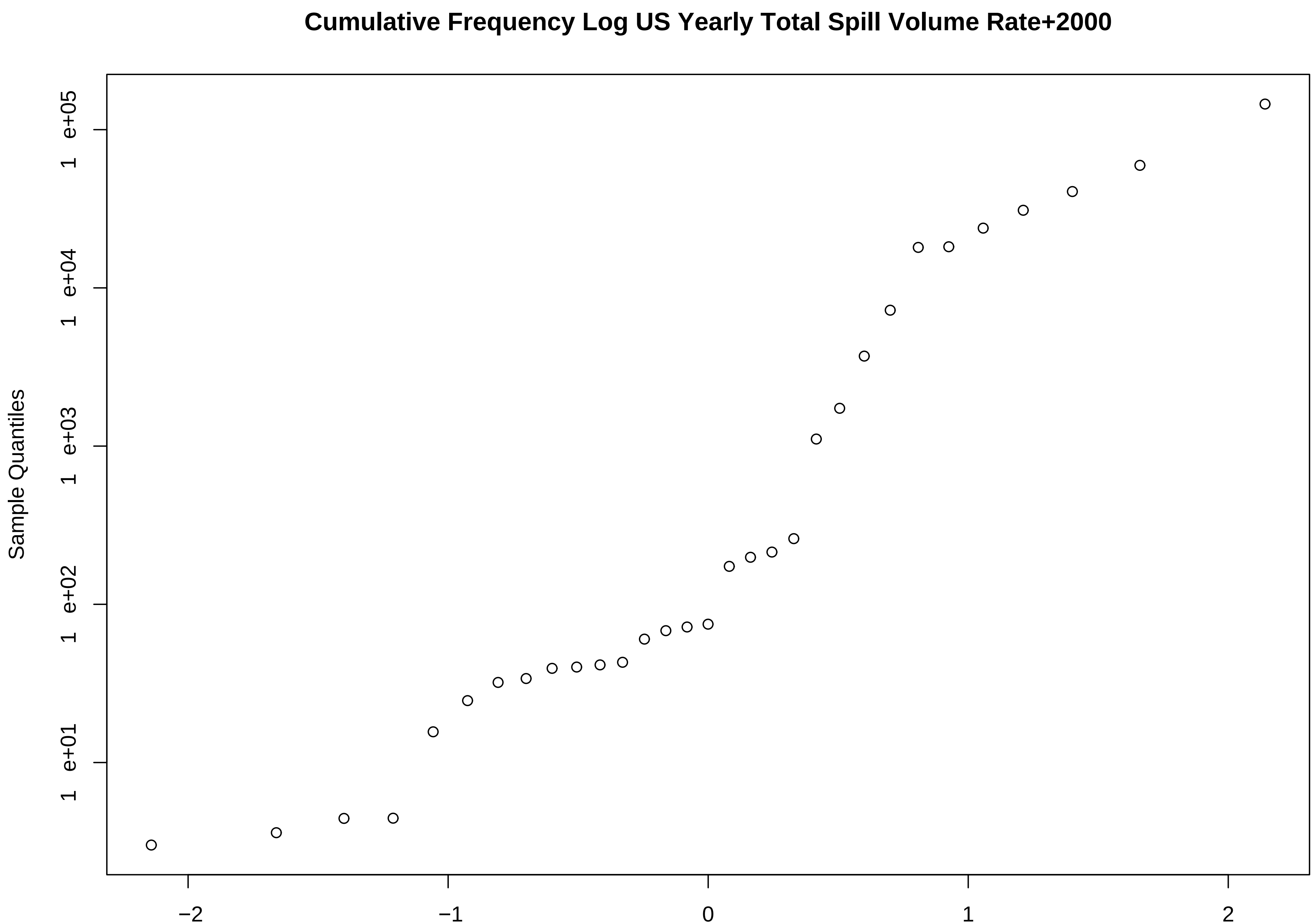
Figure 41



US Yearly Spill Count by 5 Year Group
YearlySpills
0
2
4
6
8
10
12
1965
1970
1975
1980
1985
1990
1995
YEAR5

Figure 42


Cumulative Frequency US Yearly Total Spill Volume Rate
Sample Quantiles
150000
100000
50000
0
−2
−1
0
1
2
Theoretical Quantiles
Figure 43


Cumulative Frequency Log US Yearly Total Spill Volume Rate+2000
Sample Quantiles
1 e+05
1 e+04
1 e+03
1 e+02
1 e+01
−2
−1
0
1
2
Theoretical Quantiles
Figure 44

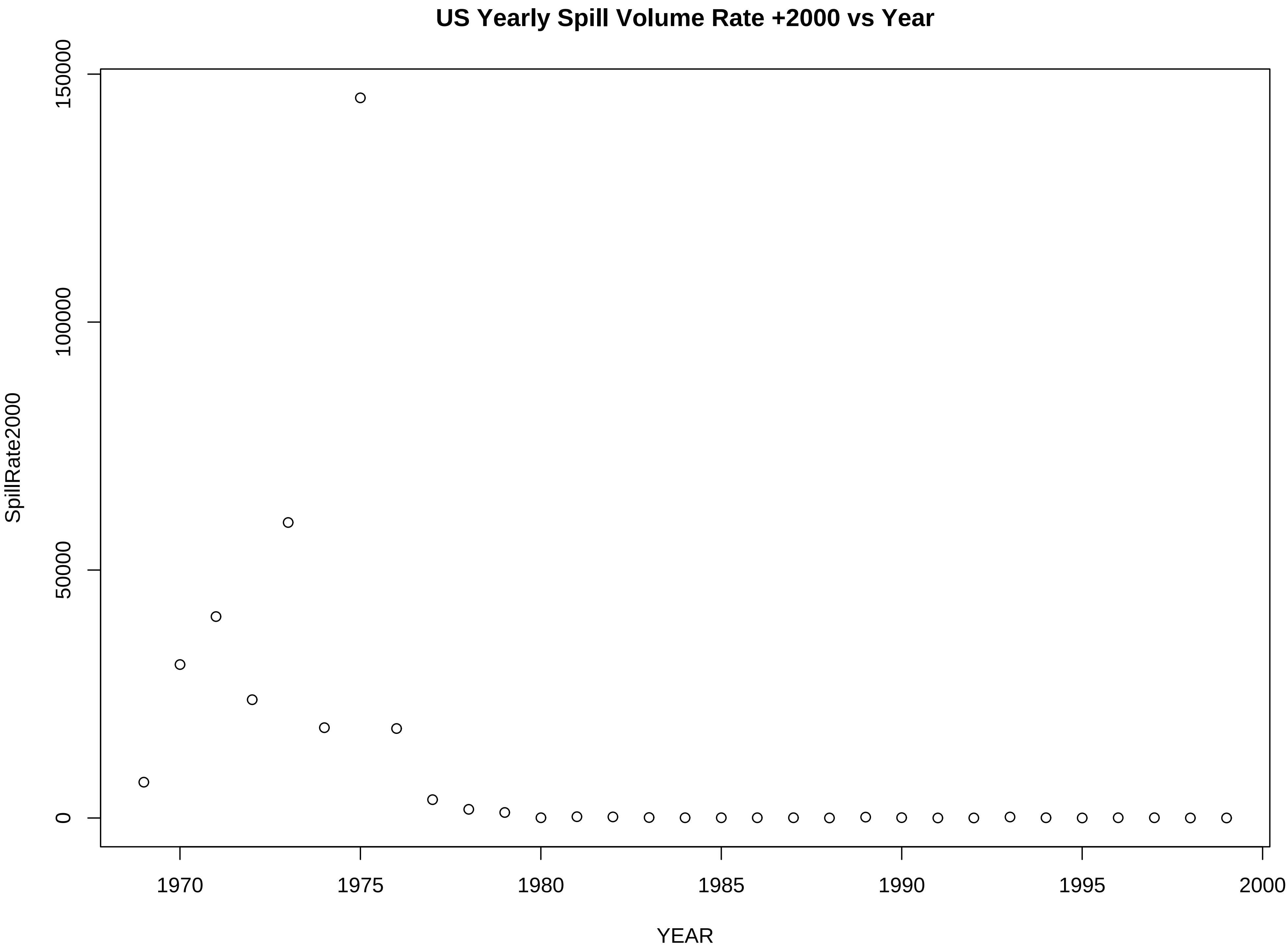

US Yearly Spill Volume Rate +2000 vs Year
SpillRate2000
150000
100000
50000
0
1970
1975
1980
1985
1990
1995
2000
YEAR

Figure 45

from Figure 45. When the data in Figure 45 is re-plotted on a logarithmic scale, as shown in Figure 46, a rather clear picture emerges that prior to 1980 spill rates were considerably greater than after 1980. This figure also indicates that the 5-year groupings used in Figures 40 through 43 were statistically reasonable.

Hart Crowser selected an oil spill risk rate based on volume, rather than a rate based on the more traditional variable of number of spills of a given size or above, because of the greater visual variability and a possible trend. This difference is shown in Figure 39 relative to Figure 46. The statistical significance of this visual analysis is confirmed in Tables 16, 17, and 18, which show that there is a highly statistically significant correlation between spill rate and year, if all of the Alaska spill data is included. If data earlier than 1980 is excluded, then there is still a correlation between spill rate and year that is significant at the 1 percent level of confidence. However, if data earlier than 1985 is excluded, then there is a correlation between spill rate and year, which is significant at the 17 percent level of confidence.

For a relatively small dataset where the theoretical distribution is not known and there is the possibility of missing data, it is Hart Crowser's normal practice to require a level of significance of greater than 99 percent before conclusions are drawn. Hart Crowser concluded that spill rate is the best variable to use in predicting the volume of further oil spills. An average rate of approximately 52 gallons of oil spilled per million barrels of crude oil produced was calculated based on the trend that started in 1980. This rate is subject to considerable uncertainty in the mean (± 50% at the 95% level of confidence). A spill rate derived from the logarithmic distribution was 66 gallons as opposed to 52 gallons. These two values agree within the standard deviation of the means. The 95 percent logarithmic confidence limits on spills for a given year are ± 465 percent at the 95 percent level of confidence. These values are summarized in Table 19. (Note that values in Table 19 have not been rounded. It should be noted that all of the uncertainty in rate is statistically accurate to less than one significant figure.) Hart Crowser is more inclined to believe the logarithmic values than the untransformed values, because the cumulative frequency of the data is more lognormal than normal (see Figures 47 and 48). These very wide confidence limits and individual yearly values are consistent with the small number of data points available for this prediction. Hart Crowser believes it is unlikely that further accuracy will be achieved by additional analysis.

The volumetric oil spill risk rate does not completely describe the statistical system and, accordingly, Hart Crowser also investigated the oil spill count rate (i.e., the number of oil spills over a particular volume threshold per million barrels of crude oil produced). Oil spill and oil production data from 1978 through 1999 (with 1999 production assumed 450 million Bbl) were used because to correspond to the observed trend in oil spills. A plot of the spill count rate from the database is shown in Figure 49. Figure 49 shows 4 points aligned along the bottom, and consequently, is not very useful for visual analysis. To enhance the variability at the low end of the scale, Hart Crowser constructed a logarithmic plot of the same data. However, because of the zeros in the database, some positive constant had to be added to the spill rate. At first, Hart Crowser used a constant of 0.1 spills per million barrels of crude oil produced and obtained the plot shown in Figure 50. This figure shows only slight variability at the low spill rate. The constant was then adjusted to 0.01 spills per million barrels of crude oil produced and the results obtained are plotted in Figure 51. This shows a clear picture of no spills where there was no production in 1969, but a considerable spill count rate from 1970 to 1976. In 1977, the spill count rate started to drop, and from 1978 through 1990 the spill rate appeared visually

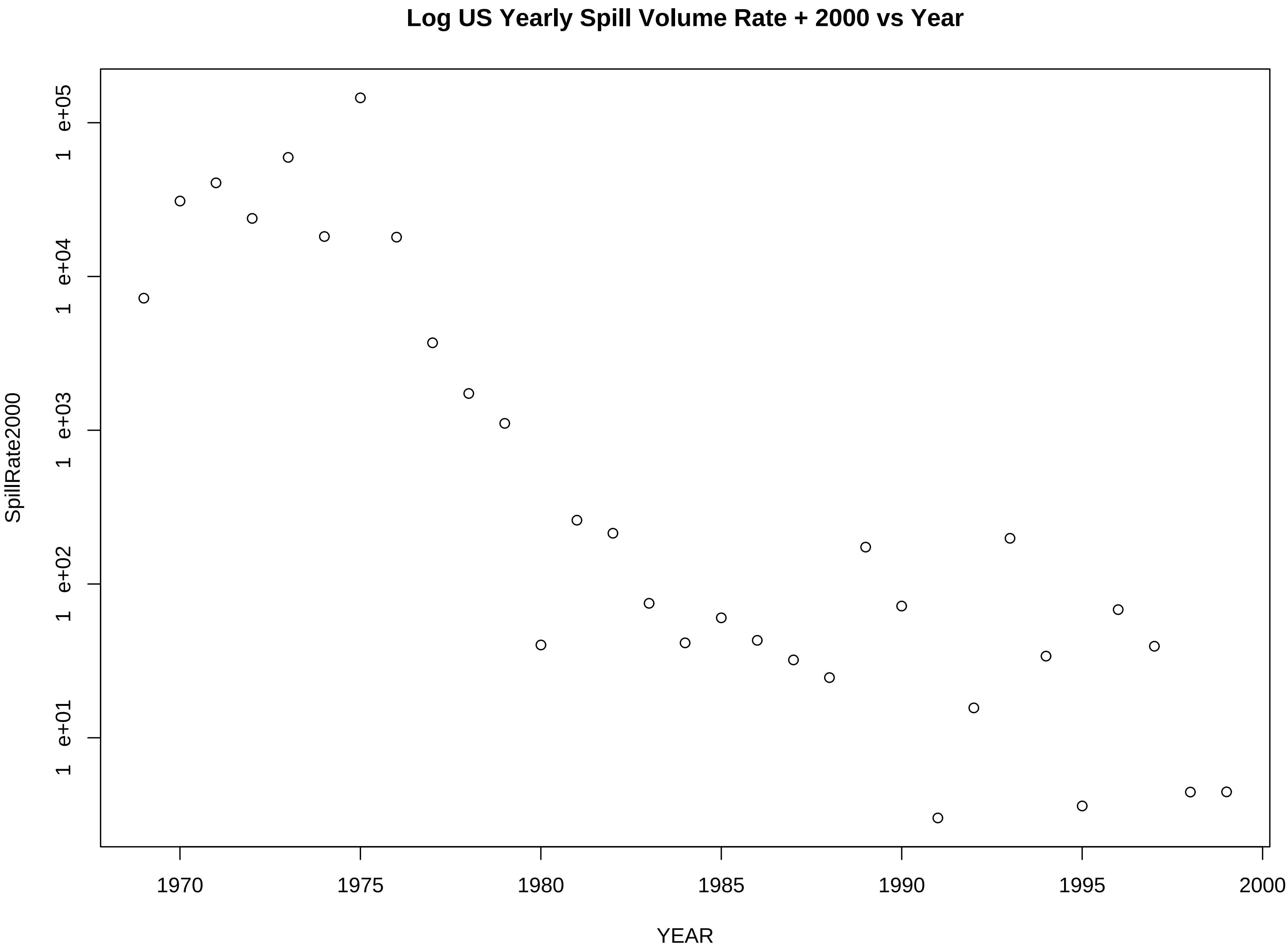

Log US Yearly Spill Volume Rate + 2000 vs Year
SpillRate2000
1 e+05
1 e+04
1 e+03
1 e+02
1 e+01
1970
1975
1980
1985
1990
1995
2000
YEAR
Figure 46

TABLE 16
LINEAR REGRESSION OF ANNUAL SPILL RATE BY YEAR

```
lm(formula = SpillRate2000 ~ YEAR)

Residuals:
     Min          1Q       Median       3Q        Max
  -26398      -12028        -5194     4267     120515

Coefficients:
               Estimate Std      Error     t value     Pr(>|t|)
(Intercept)      2957488.0   1022113.8       2.894    0.00716 **
YEAR               -1485.0       515.2      -2.882    0.00736 **

Signif. codes:  0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error:  25660 on 29 degrees of freedom
Multiple R-Squared:  0.2227,        Adjusted R-squared:  0.1959
F-statistic:  8.308 on 1 and 29 degrees of freedom,        p-value: 0.007357


lm(formula = log(SpillRate2000) ~ YEAR)

Residuals:
     Min          1Q       Median       3Q        Max
 -3.2463     -1.2667       0.1449   0.9728     3.3947

Coefficients:
               Estimate Std      Error     t value     Pr(>|t|)
(Intercept)      622.15336    63.01039       9.874    8.80e-11 ***
YEAR              -0.31071     0.03176      -9.784    1.08e-10 ***

Signif. codes:  0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error:  1.582 on 29 degrees of freedom
Multiple R-Squared:  0.7675,        Adjusted R-squared:  0.7595
F-statistic:  9572 on 1 and 29 degrees of freedom,        p-value: 1.082e-010
```

TABLE 17
LINEAR REGRESSION OF ANNUAL SPILL RATE FOR YEARS GREATER THAN 1979

lm(formula = SpillRate2000[YEAR > 1979] ~ YEAR[YEAR > 1979])

Residuals:

Min	1Q	Median	3Q	Max
-84.16	-48.53	-25.04	17.36	147.75

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	11358.290	5498.812	2.066	0.0536

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 71.27 on 18 degrees of freedom
Multiple R-Squared: 0.1897, Adjusted R-squared: 0.1447
F-statistic: 4.214 on 1 and 18 degrees of freedom, p-value: 0.05492

lm(formula = SpillRate2000[YEAR > 1979] ~ YEAR[YEAR > 1979])

Residuals:

Min	1Q	Median	3Q	Max
-2.2798	-0.6379	-0.1724	0.8531	2.1637

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	257.47120	89.97904	2.861	0.0104 *

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 1.166 on 18 degrees of freedom
Multiple R-Squared: 0.3067, Adjusted R-squared: 0.2682
F-statistic: 7.962 on 1 and 18 degrees of freedom, p-value: 0.0113

TABLE 18
LINEAR REGRESSION OF ANNUAL SPILL RATE FOR YEARS GREATER THAN 1984

lm(formula = SpillRate2000[YEAR > 1984] ~ YEAR[YEAR > 1984])

Residuals:

Min	1Q	Median	3Q	Max
-51.642	-35.062	-26.014	8.212	149.345

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	5766.308	7152.998	0.806	0.435

Residual standard error: 60.09 on 13 degrees of freedom
Multiple R-Squared: 0.0468, Adjusted R-squared: -0.02653
F-statistic: 0.6382 on 1 and 13 degrees of freedom, p-value: 0.4387

lm(formula = log(SpillRate2000[YEAR > 1984]) ~ YEAR[YEAR > 1984])

Residuals:

Min	1Q	Median	3Q	Max
-2.2792	-0.7141	-0.2578	0.9137	2.1644

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	257.47368	152.95508	1.683	0.116

Residual standard error: 1.285 on 13 degrees of freedom
Multiple R-Squared: 0.1753, Adjusted R-squared: 0.1118
F-statistic: 2.762 on 1 and 13 degrees of freedom, p-value: 0.1204

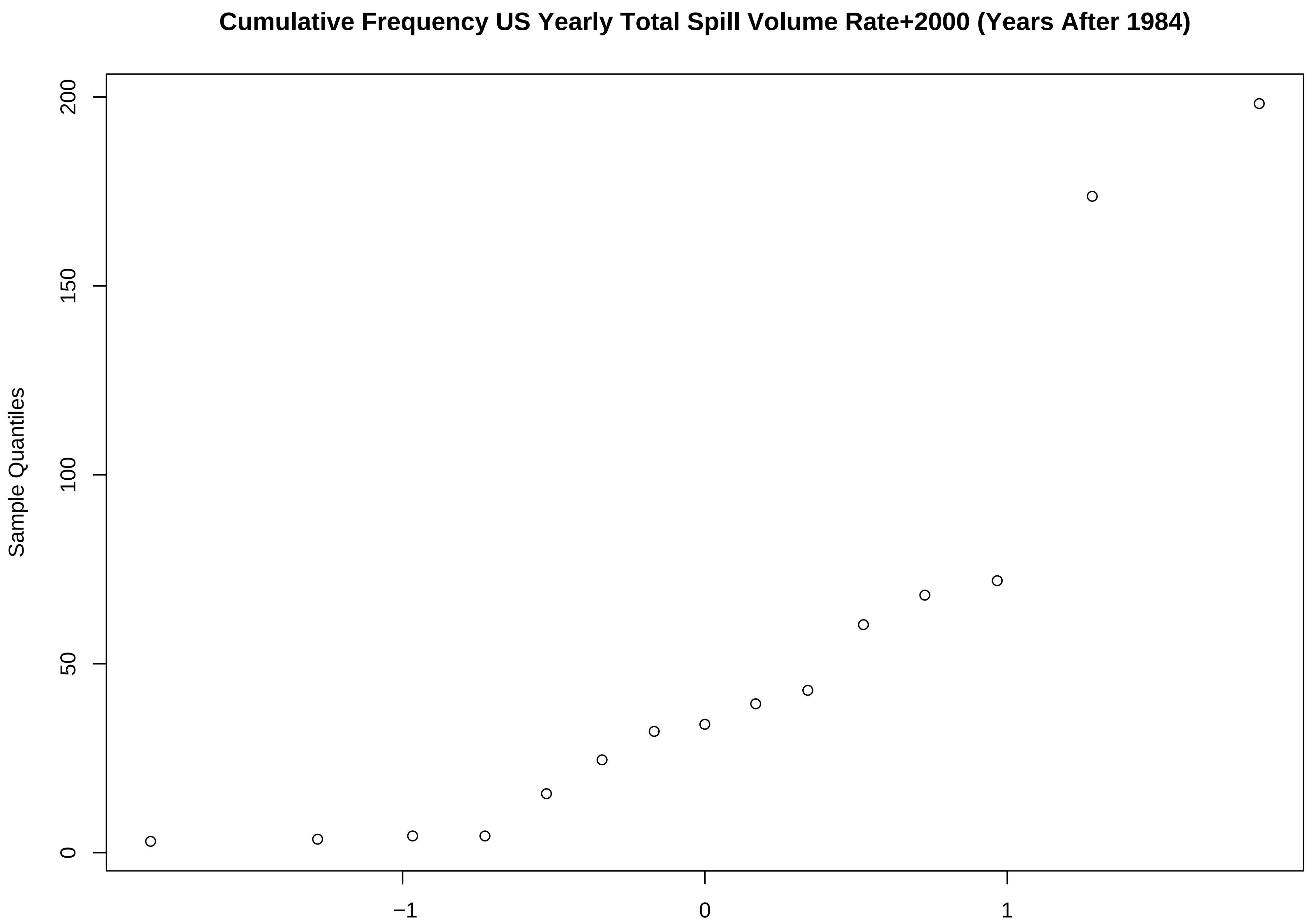
TABLE 19
CALCULATION OF MEANS AND EXPECTED UNCERTAINTIES OF ANNUAL SPILL RATE FOR YEARS GREATER THAN 1984

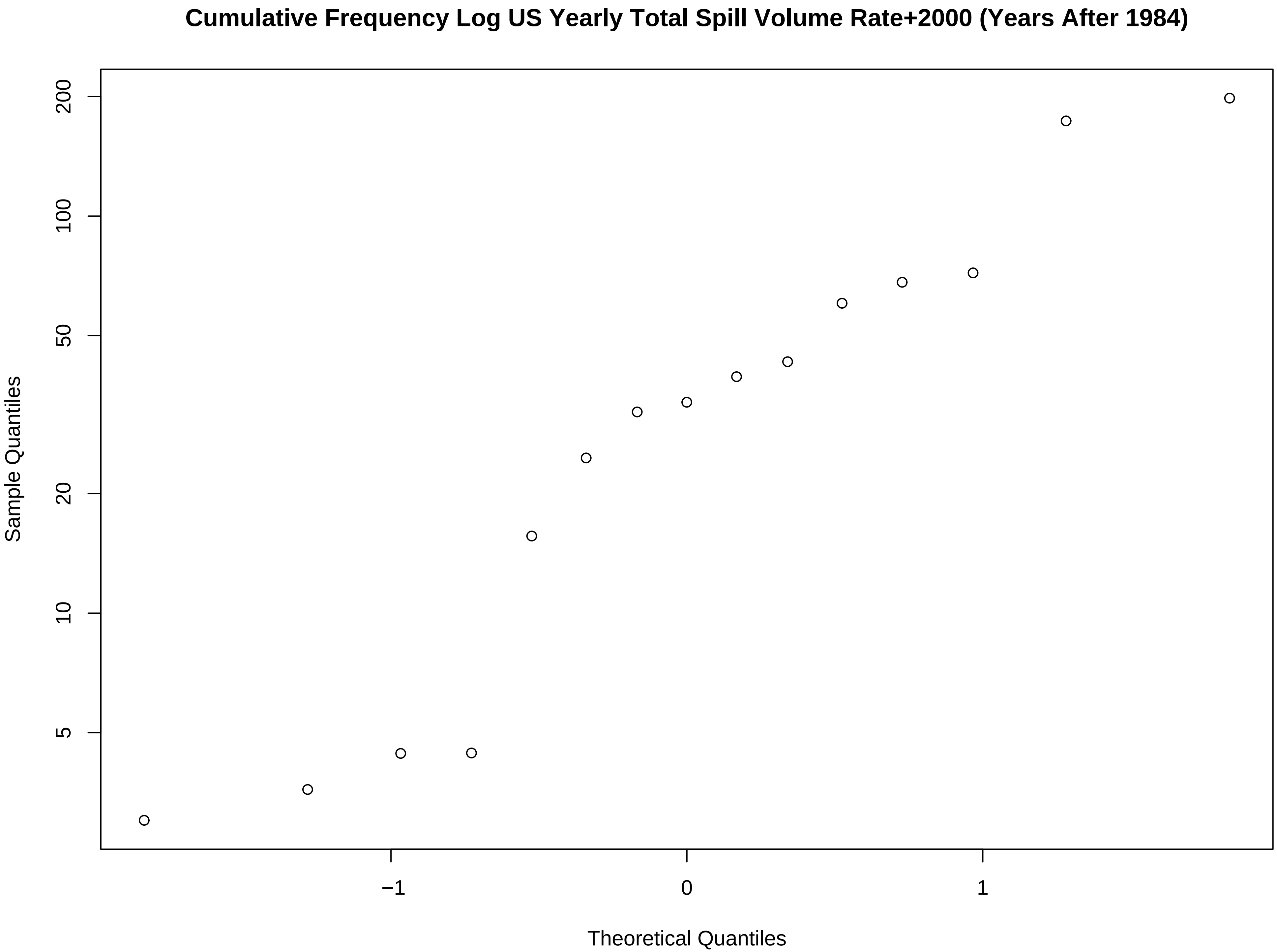
A. Arithmetic mean of annualized spill rate = 51.7813 gallons spilled per million barrels produced

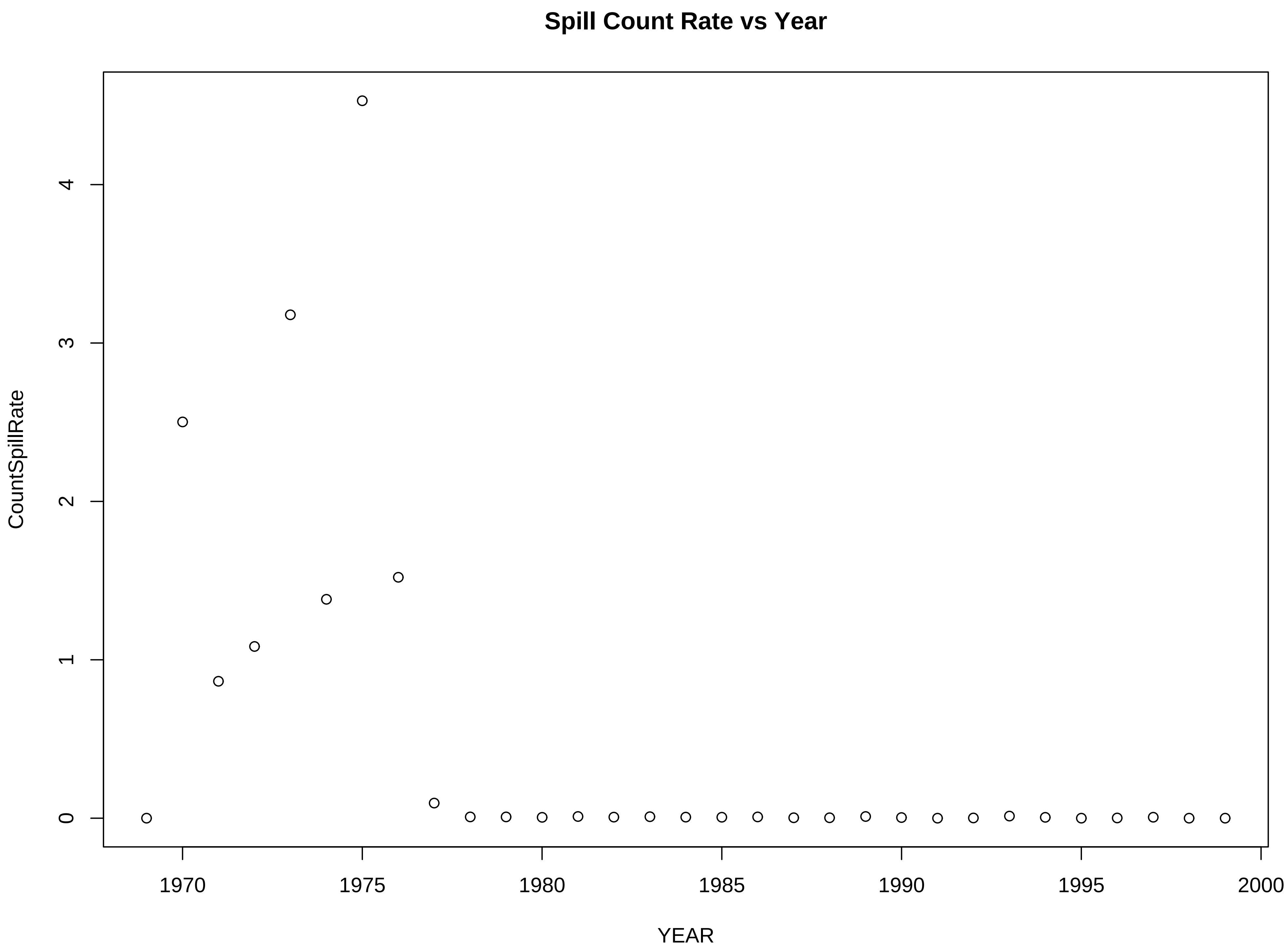
B. Approximate arithmetic 95% confidence limits on the mean of annualized spill rate = 51.21935%

C. Lognormal mean annualized spill rate = 65.50743 gallons spilled per million barrels produced

D. Approximate logarithmic 95% confidence limits on annualized spill rate 465.4103 %


Cumulative Frequency US Yearly Total Spill Volume Rate+2000 (Years After 1984)
Sample Quantiles
200
150
100
50
0
−1
0
1
Theoretical Quantiles
Figure 47


Cumulative Frequency Log US Yearly Total Spill Volume Rate+2000 (Years After 1984)
Sample Quantiles
200
100
50
20
10
5
−1
0
1
Theoretical Quantiles
Figure 48


Spill Count Rate vs Year
CountSpillRate
0
1
2
3
4
1970
1975
1980
1985
1990
1995
2000
YEAR
Figure 49

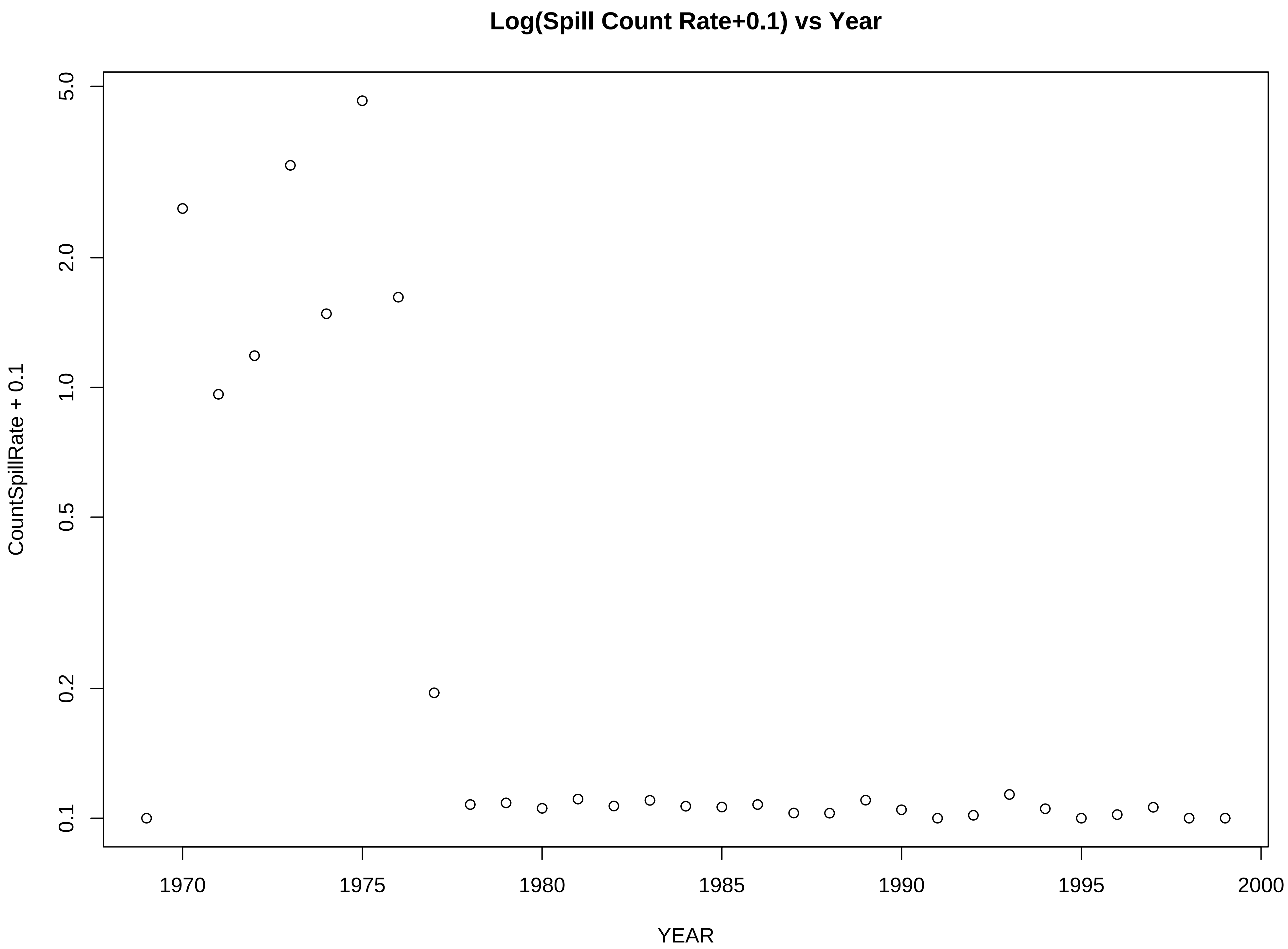

Log(Spill Count Rate+0.1) vs Year
CountSpillRate + 0.1
5.0
2.0
1.0
0.5
0.2
0.1
1970
1975
1980
1985
1990
1995
2000
YEAR

Figure 50

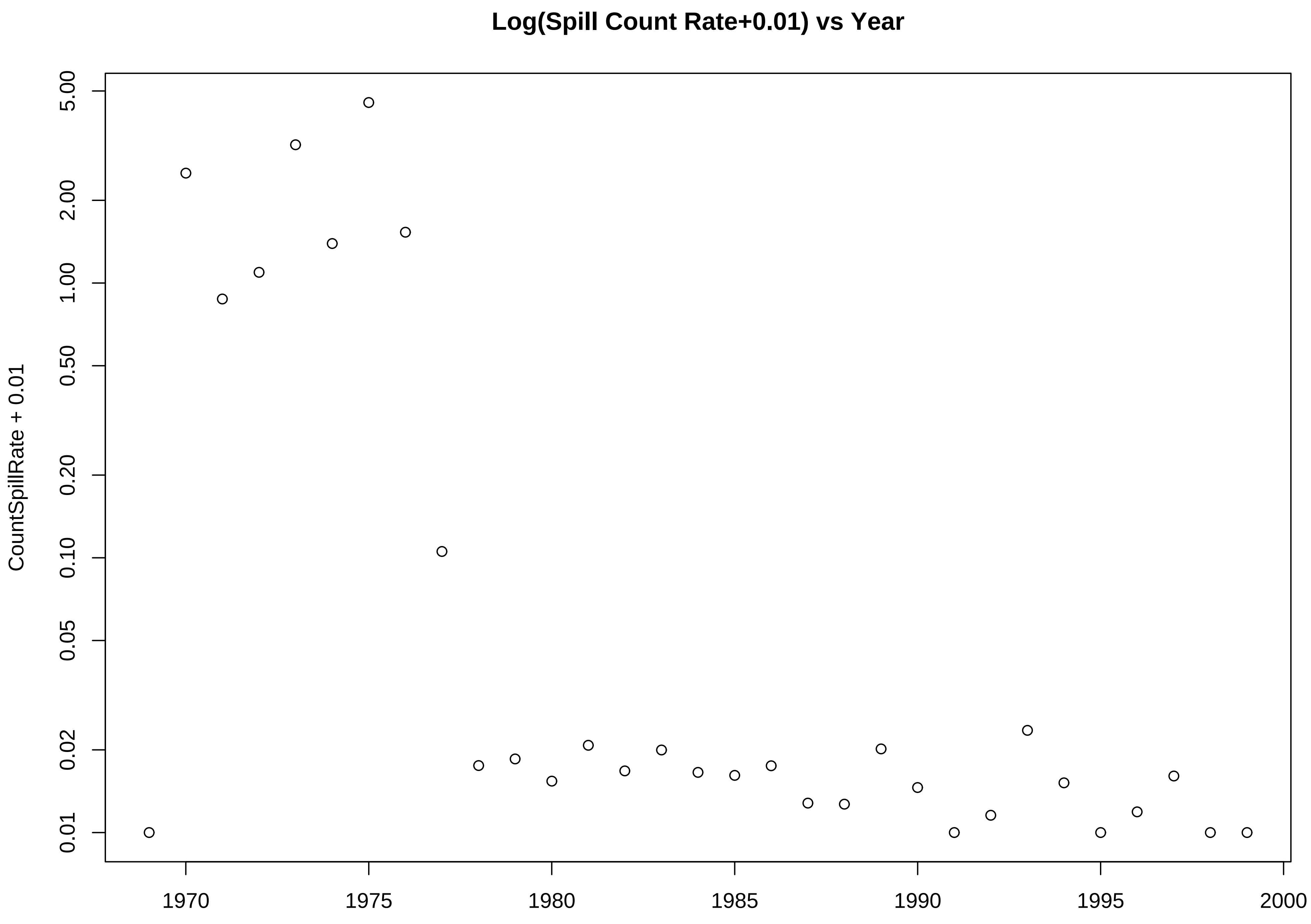

Log(Spill Count Rate+0.01) vs Year
CountSpillRate + 0.01
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01
1970
1975
1980
1985
1990
1995
2000
YEAR

Figure 51

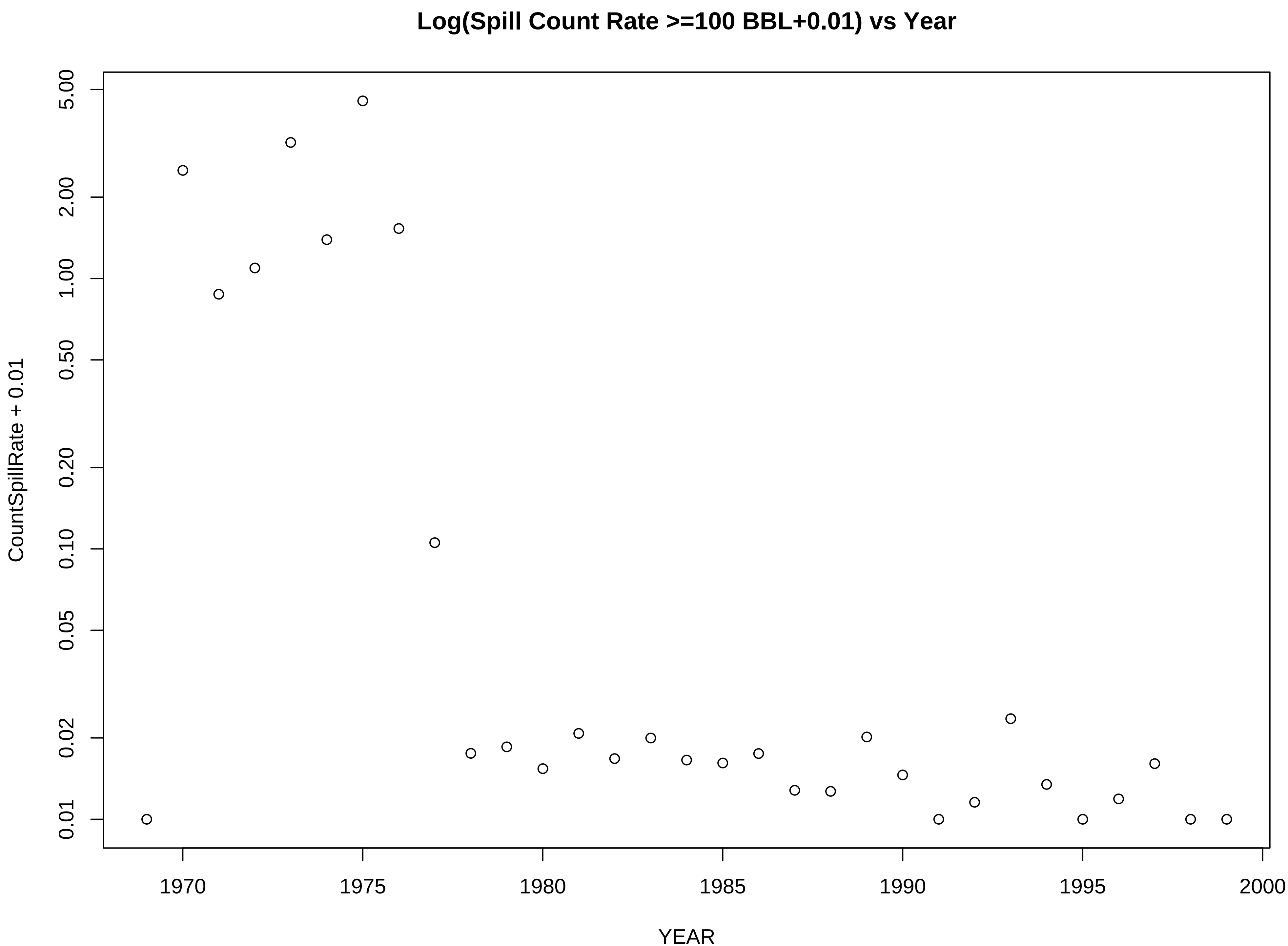
constant, although one might argue that the period from 1978 through 1986 had a lower variability than the period from 1987 through 1999.

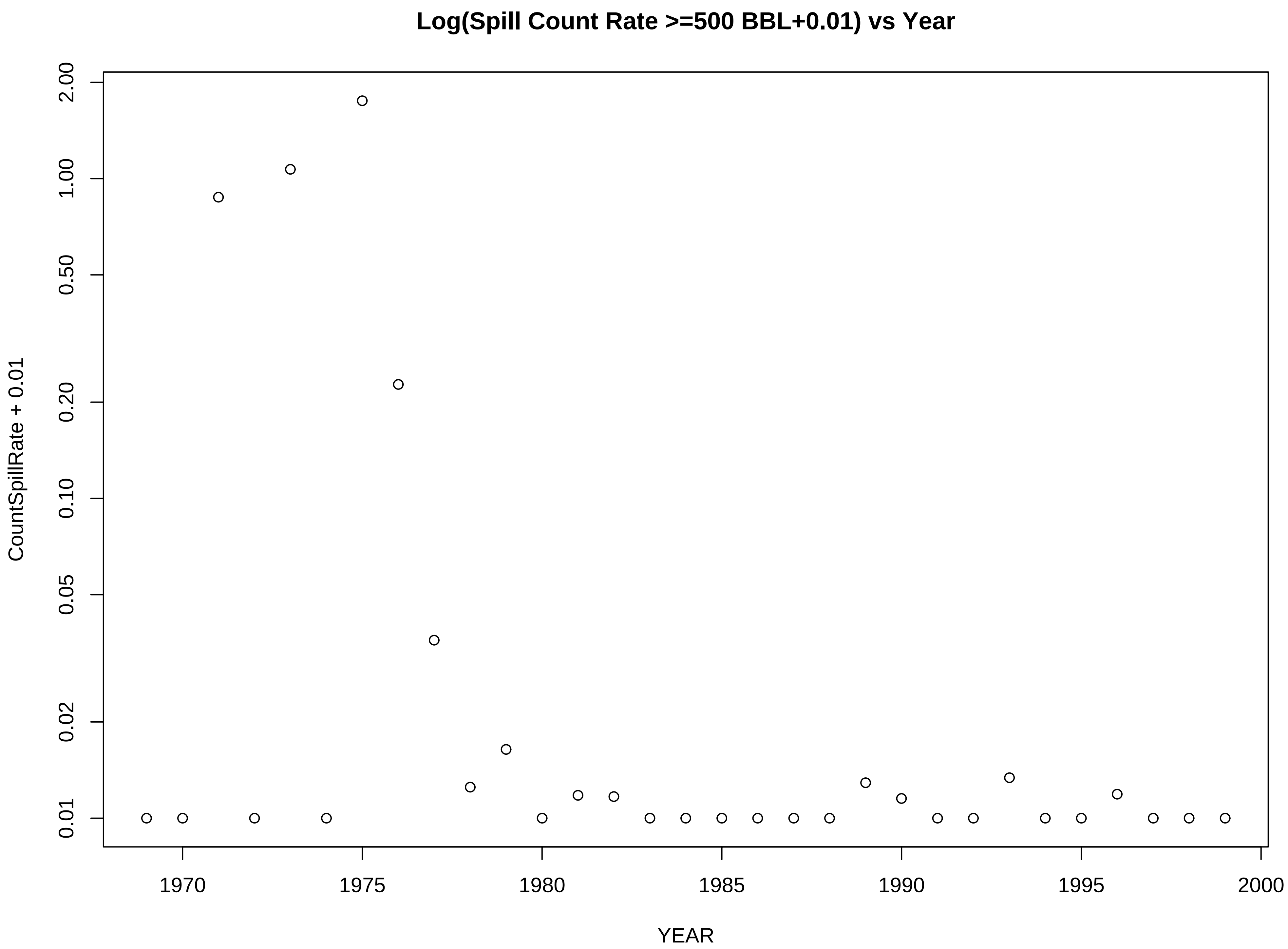
When dealing with the spill count rate, one of the methods to quantify the differences in spill sizes is to provide a certain minimum threshold and only count spills above those volumes. Spill count rates for minimum spill sizes of 100, 500, 1,000 and 10,000 barrels are shown in Figures 52, 53, 54, and 55. Again, the arbitrary constant of 0.01 spills per million barrels of crude oil produced was added to the values to enhance the assessment of variability for the very low rates. As can be seen by examining these figures, the period from 1978 until 1990 was relatively statistically homogeneous. Results of spill count and total production are summarized in Table 20. Based on the visual analysis of Figures 49 through 55, it appeared that spill count rate has been constant. Under this assumption that the spill count rate has been relatively constant, the spill count rate for spills greater than various sizes may be estimated by simply counting the number of spills. Using the fact that the variance of a counted quantity is that quantity, approximate confidence limits may be calculated as shown in Table 10. For example, the total count of all spills from 1978 on is 68. Dividing by the total production, a rate of 0.0053 spills per million barrels produced is obtained, and using the approximate 95 percent limits of the counted quantity, a 95 percent confidence limit of plus or minus 24 percent is obtained. (24% = 2 sqrt (68)/68 * 100; were 2 is the approximate t statistic for 95 percent confidence).

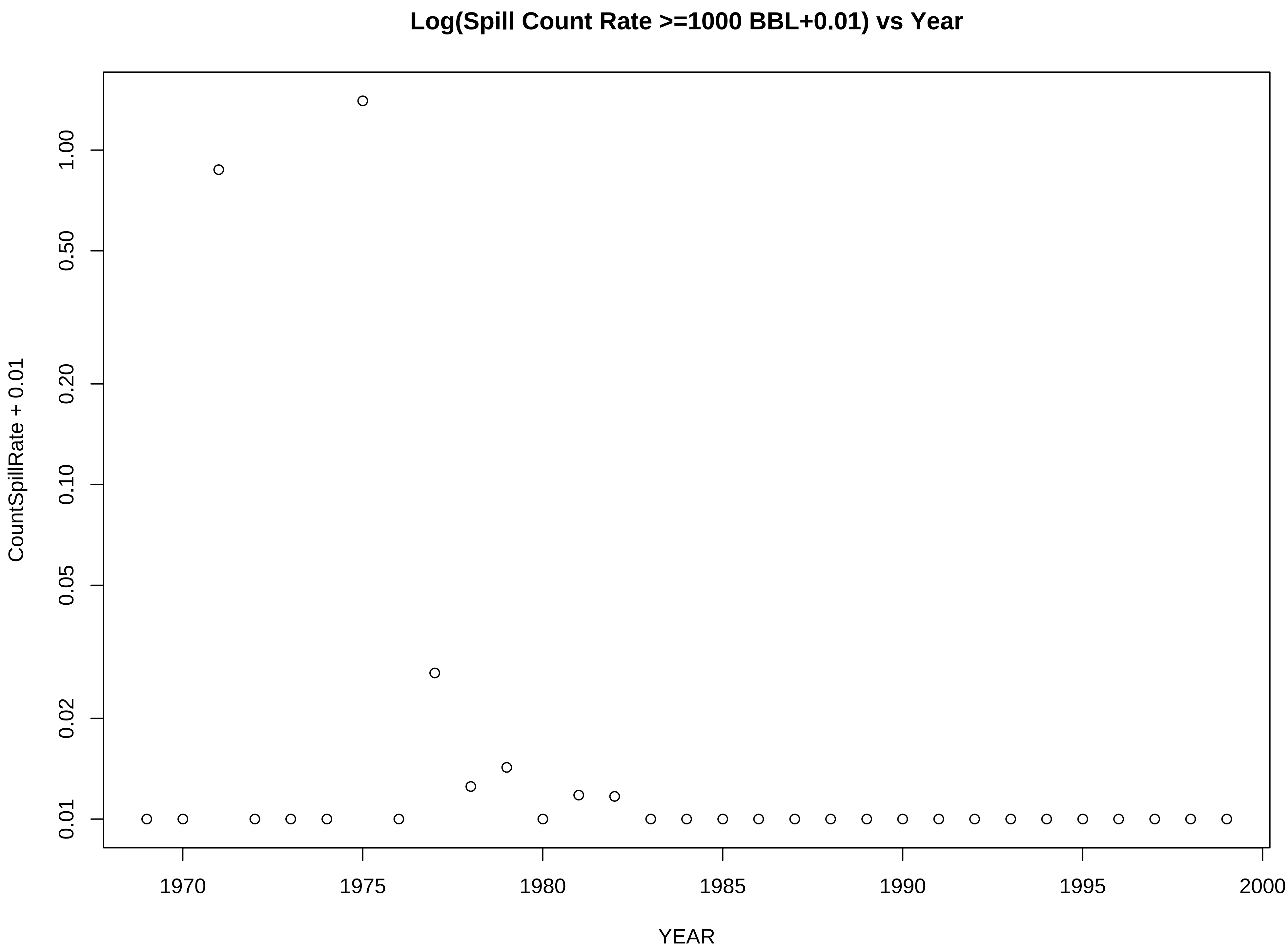
TABLE 20
OIL SPILL RISK RATE BY COUNT WITH ASSOCIATED UNCERTAINTIES
DATA FROM 1978-1999

Spill Size (Bbl)	**Number of Spills**	**Total Crude Oil Production** (MMBbl)	**Calculated Risk Rate** (Spills/MMBbl)	**Approximate 95% Confidence Limits** (%±)
≥100	68	12,854	0.0052902	24
≥500	12	12,854	0.0009336	58
≥1,000	5	12,854	0.0003890	89
≥10,000	1	12,854	0.0000778	200

As a smaller number of spills are available, the rate, of course, decreases and the uncertainty increases. In the case of spills over 10,000 barrels, the rate is 0.00008 spills per million barrels produced and the approximate 95 percent confidence limits are plus or minus 200 percent.


Log(Spill Count Rate >=100 BBL+0.01) vs Year
CountSpillRate + 0.01
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01
1970
1975
1980
1985
1990
1995
2000
YEAR
Figure 52


Log(Spill Count Rate >=500 BBL+0.01) vs Year
CountSpillRate + 0.01
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01
1970
1975
1980
1985
1990
1995
2000
YEAR
Figure 53


Log(Spill Count Rate >=1000 BBL+0.01) vs Year
CountSpillRate + 0.01
1.00
0.50
0.20
0.10
0.05
0.02
0.01
1970
1975
1980
1985
1990
1995
2000
YEAR
Figure 54

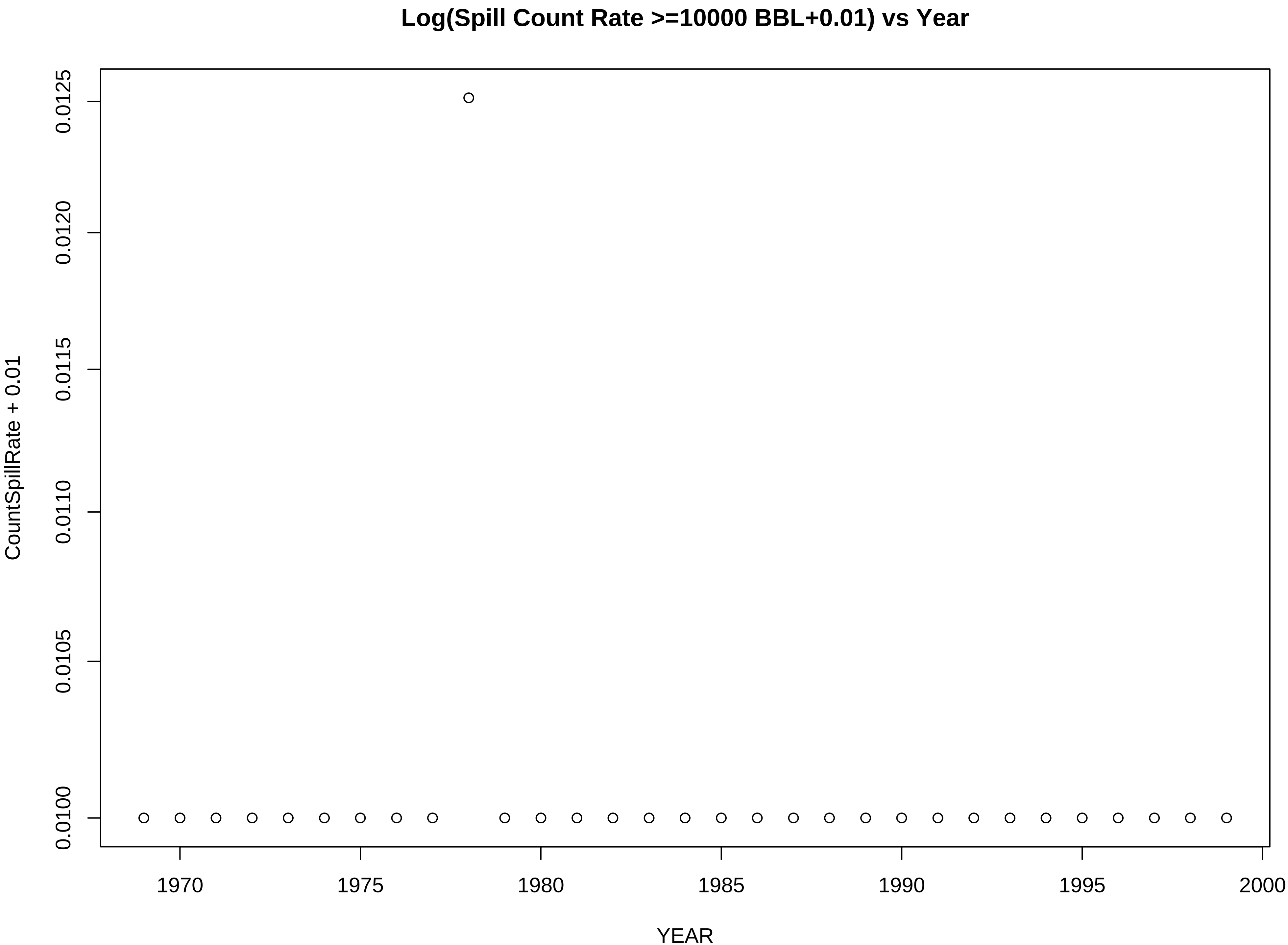

Log(Spill Count Rate >=10000 BBL+0.01) vs Year
CountSpillRate + 0.01
0.0100
0.0105
0.0110
0.0115
0.0120
0.0125
1970
1975
1980
1985
1990
1995
2000
YEAR

Figure 55

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APPENDIX A - COLLATED ALASKA AND CANADA INDIVIDUAL OIL SPILL DATA USED IN STUDY

COLLATED LIST OF OIL SPILLS OF 100 BARRELS AND LARGER FROM ARCTIC ALASKA AND CANADA STUDY AREAS

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-ONS[1]	02/23/70	Highway	Mobile Oil Drilling	Diesel Fuel/Heating Oil	Approx 11 miles east of BP Prudhoe Bay base camp	Tank Vehicle Accident	7,000	9,100	Unspecified	Land
AK-ONS	06/03/71	Operations Support Facility	ARCO Alaska, Inc.	Jet/Turbine Fuel	Prudhoe Bay Unit, ARCO airfield	Unspecified		45,000	Unspecified	Land - retained within secondary containment area
AK-ONS	01/05/72	Operations Support Facility	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Prudhoe Bay Unit, ARCO airfield	Facility Piping Leak - human error, valve left open	15,000	20,000	Unspecified	Land

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-ONS	04/14/73	Operations Support Facility	ARCO Alaska, Inc.	Jet/Turbine Fuel	Prudhoe Bay Unit, ARCO airfield	Facility Piping Leak - nozzle failure		4,262	Unspecified	Land
AK-ONS	07/16/73	Exploration Well Site	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Itkillik River Unit 1	Unspecified		40,000	Unspecified	Land and Water
AK-ONS	12/17/75	Operations Support Facility	Surfcote	Diesel Fuel/Heating Oil	Prudhoe Bay Surfcote Camp (Slope Camp)	Facility Tank Leak - unspecified cause	60,000	70,000	Unspecified	Land
AK-ONS)	06/20/79	Exploration Support Facility	Chevron USA	Jet/Turbine Fuel	Cape Beaufort	Facility Tank Leak - rupture due to frost action		40,000	Unspecified	Unspecified
AK-ONS	11/21/80	Production Well Site	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Prudhoe Bay Unit, Drill Site 5, Well 16	Facility Piping Leak - line break		4,284	Unspecified	Land
AK-ONS	04/24/81	Operations Support Facility	ARCO Alaska, Inc.	Gasoline	Prudhoe Bay Unit, Crude Oil Topping Unit	Facility Piping Leak - human error, valve left open		4,282	Unspecified	Land
AK-ONS)	08/22/81	Operations Support Facility	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Prudhoe Bay Unit, Crude Oil Topping Unit, Fuel Storage Tanks	Facility Piping Leak - faulty connection	18,000	18,900	Unspecified	Land - retained within secondary containment area
AK-ONS	07/15/82	Operations Support Facility	Wien Air Alaska	Jet/Turbine Fuel	Wien Air Terminal, Deadhorse Airport	Facility Piping Leak - unspecified cause	30,000	100,000	Unspecified	Land

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-ONS	10/31/82	Operations Support Facility	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Prudhoe Bay Operations Center, Diesel Storage Tank	Facility Tank Leak - human error, overfilled	6,300	8,400	Unspecified	Land - retained within secondary containment area
AK-ONS	06/19/83	Construction Camp	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Kuparuk Construction Camp	Facility Tank Leak - tank fell off supports		4,800	Unspecified	Land - retained within secondary containment area
AK-ONS	07/27/83	Operations Support Facility	North Slope Borough Service Area 10	Gasoline	North Slope Borough Service Area 10 facility	Facility Piping Leak - line break		7,550	Unspecified	Land
AK-ONS	08/09/83	Operations Support Facility	ARCO Alaska, Inc.	Gasoline	Prudhoe Bay Unit, Crude Oil Topping Unit	Facility Piping Leak - human error		6,200	Unspecified	Land - retained on facility pad
AK-ONS	06/02/85	Operations Support Facility	ARCO Alaska, Inc.	Crude Oil	Prudhoe Bay Operations Center	Facility Piping Leak - unspecified cause		10,000	Unspecified	Land
AK-ONS	11/14/85	Operations Support Facility	ARCO Alaska, Inc.	Gasoline	Prudhoe Bay Unit, Crude Oil Topping Unit fuel terminal	Facility Tank Leak - human error, overfilled		10,500	Unspecified	Unspecified
AK-ONS	11/15/85	Production Processing Facility	Conoco, Inc.	Crude Oil	Milne Point Unit, Central Processing Facility holding pit	Facility Piping Leak - faulty valve		7,350	Unspecified	Land - retained within secondary containment area

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-ONS	11/6/1984	Unspecified	Sohio	Crude Oil	Unspecified	Facility Piping-Leak		5,250	Unspecified	Unspecified
AK-ONS	01/08/86	Operations Support Facility	ARCO Alaska, Inc.	Gasoline	Prudhoe Bay Unit, Crude Oil Topping Unit	Facility Tank Leak - human error, overfilled		4,957	Unspecified	Unspecified
AK-ONS	10/16/86	Operations Support Facility	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Prudhoe Bay Unit, Crude Oil Topping Unit	Facility Piping Leak - line break		4,200	Unspecified	Land
AK-ONS	11/07/86	Production Processing Facility	ARCO Alaska, Inc.	Crude Oil	Kuparuk River Unit, Central Processing Facility 1 Seawater Flood Module	Facility Piping Leak - faulty valve		5,040	Unspecified	Unspecified
AK-ONS	01/05/87	Operations Support Facility	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Prudhoe Bay Unit, ARCO airfield	Facility Piping Leak - human error, valve left open		15,000	Unspecified	Land
AK-ONS	03/30/88	Pipeline	ARCO Alaska, Inc.	Crude Oil/Produced Water	Prudhoe Bay Unit, Drill Site 3 to Flow Station 2	Pipeline Leak - corrosion	11,800	11,802	Unspecified	Land
AK-ONS	01/24/89	Exploration Support Facility	Unspecified	Diesel Fuel/Heating Oil	7-Mile Camp	Facility Piping Leak - line break	4,500	6,500	Unspecified	Unspecified
AK-ONS	02/04/89	Production Processing Facility	BP Exploration (Alaska)	Crude Oil	Prudhoe Bay Unit, Gathering Center 2	Facility Piping Leak - faulty valve	3,150	15,750	Unspecified	Land
AK-ONS	04/18/89	Operations Support Facility	Prudhoe Bay Hotel	Diesel Fuel/Heating Oil	Prudhoe Bay Hotel, behind hotel	Unspecified		15,000	Unspecified	Unspecified

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-ONS	07/28/89	Production Processing Facility	Conoco, Inc.	Crude Oil	Milne Point Unit, Central Processing Facility	Facility Tank Leak - overfill	34,650	38,850	Unspecified	Retained within secondary containment
AK-ONS	08/25/89	Pipeline	ARCO Alaska, Inc.	Crude Oil	Kuparuk River Unit, Drill Site 2-U	Pipeline Leak - corrosion of block valve	14,280	25,326	Unspecified	Land
AK-ONS)	11/08/89	Production Well Site	ARCO Alaska, Inc.	Crude Oil	Kuparuk River Unit Drill Site 2-G, Well 4	Facility Piping Leak - line break	7,140	11,130	Unspecified	Contained on pad and in reserve pit
AK-ONS	12/10/90	Production Well Site	ARCO Alaska, Inc.	Crude Oil	Lisburne Unit, Drill Site L-5	Facility Explosion	7,400	25,200	Unspecified	Land - contained on gravel pad
AK-ONS	06/10/93	Production Processing Facility	ARCO Alaska, Inc.	Crude Oil	Lisburne Unit, Lisburne Production Center	Facility Tank Leak - high level alarm failure		12,600	Unspecified	Land - flare pit and tundra
AK-ONS	8/17/1993	Production Processing Facility	ARCO Alaska, Inc.	Crude Oil/Produced Water	Kuparuk River Unit CPF 1	Tank Leak - Corrosion		28,350	Unspecified	Unspecified
AK-ONS	08/30/93	Production Processing Facility	BP Exploration (Alaska)	Crude Oil	Prudhoe Bay Unit, Gathering Center 1, Skid 312	Facility Tank Leak - human error, overfill		8,400	Unspecified	Land - retained within secondary containment area
AK-ONS	09/26/93	Production Processing Facility	BP Exploration (Alaska)	Crude Oil	Prudhoe Bay Unit, Gathering Center 2	Facility Tank Leak - overflow due to pump failure		27,305	Unspecified	Land - contained on facility pad

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-ONS	11/13/93	Production Processing Facility	BP Exploration (Alaska)	Crude Oil	Prudhoe Bay Unit, Dead Crude Storage Tank 1801	Facility Tank Leak - human error		4,200	Unspecified	Land - retained within secondary containment area
AK-ONS	12/24/93	Production Processing Facility	BP Exploration (Alaska)	Crude Oil	Prudhoe Bay Unit, Gathering Center 2, Tank 8511	Facility Tank Leak - overflow due frozen components	7,560	8,400	Unspecified	Land - retained within secondary containment
AK-ONS	12/30/93	Production Well Site	ARCO Alaska, Inc.	Crude Oil	Prudhoe Bay Unit, Drill Site 5, Well 23	Pipeline Leak - line break, corrosion	15,750	16,800	Unspecified	Land - gravel pad and tundra
AK-ONS	05/10/94	Production Well Site	ARCO Alaska, Inc.	Crude Oil	Pt. McIntyre, Drill Site 1	Pipeline Leak - valve failure	3,360	6,000	Unspecified	Land
AK-ONS	10/31/94	Pipeline	ARCO Alaska, Inc.	Crude Oil	Kuparuk River Unit, Junction of Drill SIte1Y and 1R flowlines	Pipeline Leak - corrosion	2,520	7,692	Unspecified	Land
AK-ONS	03/26/97	Production Well Site	ARCO Alaska, Inc.	Crude Oil	Prudhoe Bay Unit, Drill Site 16 Well 18	Facility Piping Leak - line break		4,746	Unspecified	Land
AK-ONS	05/19/97	Production Well Site	ARCO Alaska, Inc.	Diesel Fuel/Heating Oil	Prudhoe Bay Unit, Drill Site 10	Production Well Leak - Leaking Well Plug		7,560	Unspecified	Land
AK-TAPS[2]	07/25/70	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Prospect Camp	Facility Tank Leak - bear damaged bladder		20,000	Unspecified	Unspecified

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-TAPS	12/01/70	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Happy Valley Camp "A"	Facility Piping Leak - line break		6,000	Unspecified	Land and Water
AK-TAPS	05/04/73	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Happy Valley Camp	Facility Tank Leak - human error, valve left open	8,000	10,000	Unspecified	Land and Water
AK-TAPS	05/29/74	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Toolik Camp	Facility Tank Leak - bladder leaked	5,000	20,000	Unspecified	Land
AK-TAPS	06/26/74	Highway	NA	Diesel Fuel/Heating Oil	Richardson Hwy MP 230	Tank Vehicle Accident		9,000	Unspecified	Unspecified
AK-TAPS	11/08/74	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 235	Tank Vehicle Accident		8,500	Unspecified	Land and Water
AK-TAPS	01/11/75	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Five Mile Camp	Facility Piping Leak - line break		10,000	Unspecified	Unspecified
AK-TAPS	02/07/75	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Galbraith Camp (N. side of camp)	Facility Piping Leak - line break	62,500	100,000	Unspecified	Land and Water
AK-TAPS	03/05/75	Operations Support Facility	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Van Horn Rd Facility, Fairbanks	Human error		4,700	Unspecified	Unspecified
AK-TAPS	04/03/75	Highway	NA	Diesel Fuel/Heating Oil	Ferry Access Road, S. Bank of Yukon R	Tank Vehicle Accident		6,000	Unspecified	Land
AK-TAPS	05/28/75	Construction Camp	Alyeska Pipeline Service Co.	Crude Oil	TAPS Happy Valley Camp A	Tank Vehicle Leak - unspecified cause		6,000	Unspecified	Unspecified

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-TAPS	06/11/75	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Galbraith Camp	Unspecified		60,000	Unspecified	Unspecified
AK-TAPS	08/24/75	Highway	NA	Diesel Fuel/Heating Oil	Elliott Hwy MP 60.5	Tank Vehicle Accident		6,000	Unspecified	Land and Water
AK-TAPS	08/30/75	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Toolik Camp (Between Barracks 12 & 13)	Facility Piping Leak - line break		8,590	Unspecified	Land
AK-TAPS	09/09/75	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 279 (Approx. 3.6 mi N. of Galbraith Camp)	Tank Vehicle Accident		4,500	Unspecified	Land
AK-TAPS	09/18/75	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Franklin Bluffs Camp (Shop #2)	Facility Piping Leak - equipment damage		30,000	Unspecified	Land
AK-TAPS	12/14/75	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 130 (1 mi. S. of Gobbler's Knob)	Tank Vehicle Accident		9,000	Unspecified	Land
AK-TAPS	12/31/75	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Prospect Creek Camp (NE of Laundry Bldg)	Facility Piping Leak - line break	40,000	100,000	Unspecified	Land and Water
AK-TAPS	01/28/76	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Galbraith Camp	Facility Piping Leak - fitting leak		40,000	Unspecified	Land and Water
AK-TAPS	02/22/76	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Pump Station 8 Construction Camp	Facility Piping Leak - valve leak		4,765	Unspecified	Land

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-TAPS	04/08/76	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 125.5 (Bonanza Creek)	Tank Vehicle Accident		6,340	Unspecified	Land and Water
AK-TAPS	06/23/76	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Five Mile Camp	Facility Piping Leak - line break	4,000	5,000	Unspecified	Land
AK-TAPS	07/01/76	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 290.1	Tank Vehicle Accident	4,000	8,500	Unspecified	Land
AK-TAPS	10/23/76	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 307.5	Tank Vehicle Accident		7,000	Unspecified	Land
AK-TAPS	11/02/76	Highway	NA	Jet/Turbine Fuel	Dalton Hwy MP 155.8	Tank Vehicle Accident		9,400	Unspecified	Land and Water
AK-TAPS	01/18/77	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Franklin Bluffs Camp	Facility Piping Leak - line break		5,000	Unspecified	Land
AK-TAPS	05/08/77	Construction Camp	Alyeska Pipeline Service Co.	Gasoline	TAPS Galbraith Camp (Airport Bladder Farm)	Facility Tank Leak - catastrophic failure	16,000	35,000	Unspecified	Retained within secondary containment
AK-TAPS	05/10/77	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 241.5	Tank Vehicle Accident		12,000	Unspecified	Land and Water
AK-TAPS	05/12/77	Construction Camp	Alyeska Pipeline Service Co.	Unspecified	TAPS Franklin Bluffs Camp	Facility Piping Leak - line leak		20,000	Unspecified	Unspecified
AK-TAPS	07/08/77	Pipeline Pump Station	Alyeska Pipeline Service Co.	Crude Oil	TAPS Pump Station 8 (TAPS MP 489.2)	Facility Explosion	12,600	200,000	Unspecified	Land

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-TAPS	07/09/77	Pipeline Pump Station	Alyeska Pipeline Service Co.	Gasoline	TAPS Pump Station 6	Facility Tank Leak - UST leak		6,600	Unspecified	Unspecified
AK-TAPS	07/19/77	Pipeline	Alyeska Pipeline Service Co.	Crude Oil	TAPS MP 26 (Check Valve 7)	Pipeline Leak - equipment damage	42,000	110,000	Unspecified	Land
AK-TAPS	07/25/77	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Prospect Camp	Facility Piping Leak - line break		20,000	Unspecified	Unspecified
AK-TAPS	08/15/77	Pipeline Pump Station	Alyeska Pipeline Service Co.	Crude Oil	TAPS Pump Station 9 (TAPS MP 548.7)	Pipeline Leak - bypass failure		4,200	Unspecified	Land
AK-TAPS	10/11/77	Pipeline	Alyeska Pipeline Service Co.	Crude Oil	TAPS Check Valve 68A (TAPS MP 433.4)	Pipeline Leak - loose fitting		4,200	Unspecified	Land
AK-TAPS	12/30/77	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 237(Approx. 4.5 mi S. of Chandalar)	Tank Vehicle Accident	7,500	7,735	Unspecified	Land and Water
AK-TAPS	02/12/78	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Glennallen Camp	Facility Tank Leak - human error, overfill		7,000	Unspecified	Land
AK-TAPS	02/15/78	Pipeline	Alyeska Pipeline Service Co.	Crude Oil	TAPS MP 458 (N OF RGV 73)	Pipeline Leak - intentional sabotage	500,000	672,000	Unspecified	Land
AK-TAPS	10/04/78	Highway	NA	Jet/Turbine Fuel	TAPS Pump Station 6 Access Road	Tank Vehicle Accident		9,000	Unspecified	Land
AK-TAPS	06/10/79	Pipeline	Alyeska Pipeline Service Co.	Crude Oil	TAPS MP 166 (N. side of Atigun Pass)	Pipeline Leak - line break	63,000	300,000	Unspecified	Land and Water

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-TAPS	06/15/79	Pipeline	Alyeska Pipeline Service Co.	Crude Oil	TAPS MP 734	Pipeline Leak - line break	12,600	168,000	Unspecified	Land
AK-TAPS	08/31/79	Highway	NA	Jet/Turbine Fuel	Richardson Hwy MP 238	Tank Vehicle Accident	4,500	9,000	Unspecified	Land
AK-TAPS	03/19/80	Highway	NA	Jet/Turbine Fuel	Richardson Hwy MP 243	Tank Vehicle Accident		5,081	Unspecified	Land
AK-TAPS	05/12/80	Pipeline Pump Station	Alyeska Pipeline Service Co.	Crude Oil	TAPS Pump Station 10	Pipeline Leak - faulty valve	10,000	10,920	Unspecified	Retained within secondary containment
AK-TAPS	01/01/81	Pipeline	Alyeska Pipeline Service Co.	Crude Oil	TAPS MP 114.6 (Check Valve 23)	Pipeline Leak - valve leak	42,000	100,000	Unspecified	Land
AK-TAPS	05/07/81	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 5.5 (Lost Creek)	Tank Vehicle Accident	2,500	5,900	Unspecified	Land and Water
AK-TAPS	11/13/81	Highway	NA	Unspecified	Dalton Hwy MP 357.8	Tank Vehicle Accident	2,000	4,881	Unspecified	Land
AK-TAPS	12/03/81	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 273, 0.2 mi north of creek	Tank Vehicle Accident		8,900	Unspecified	Land
AK-TAPS	05/24/82	Highway	NA	Gasoline	Dalton Hwy MP 120	Tank Vehicle Accident		8,250	Unspecified	Land
AK-TAPS	12/15/82	Highway	NA	Jet/Turbine Fuel	Dalton Hwy MP 20	Tank Vehicle Accident	7,800	8,000	Unspecified	Land
AK-TAPS	06/08/83	Highway	NA	Gasoline	Dalton Hwy MP 165	Tank Vehicle Accident		9,100	Unspecified	Land
AK-TAPS	08/14/83	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 11.5	Tank Vehicle Accident		7,000	Unspecified	Land

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-TAPS	08/29/83	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 125	Tank Vehicle Accident		8,350	Unspecified	Land and Water
AK-TAPS	03/02/84	Operations Support Facility	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Van Horn Rd Facility, Fairbanks	Unspecified		4,700	Unspecified	Land
AK-TAPS	09/02/84	Construction Camp	Alyeska Pipeline Service Co.	Diesel Fuel/Heating Oil	TAPS Pump Station 5 Construction Camp	Facility Piping Leak - line break		8,064	Unspecified	Land
AK-TAPS	10/23/84	Highway	NA	Jet/Turbine Fuel	Dalton Hwy MP 22	Tank Vehicle Accident		5,188	Unspecified	Land
AK-TAPS	09/17/85	Highway	NA	Gasoline	Dalton Hwy MP 320	Tank Vehicle Accident	3,000	9,400	Unspecified	Unspecified
AK-TAPS	02/02/86	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 156.5	Tank Vehicle Accident		5,000	Unspecified	Unspecified
AK-TAPS	02/16/86	Highway	NA	Diesel Fuel or Gasoline	Dalton Hwy MP 349	Tank Vehicle Accident	7,158	7,400	Unspecified	Unspecified
AK-TAPS	07/06/87	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 45	Tank Vehicle Accident	2,828	6,000	Unspecified	Unspecified
AK-TAPS	11/16/88	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 188.3	Tank Vehicle Accident		4,500	Unspecified	Land
AK-TAPS	09/15/89	Highway	NA	Gasoline	Dalton Hwy MP 77	Tank Vehicle Accident		5,000	Unspecified	Land and water
AK-TAPS	04/13/90	Highway	NA	Diesel Fuel/Heating Oil	Elliott Hwy MP 44.5	Tank Vehicle Accident	2,000	9,500	Unspecified	Unspecified

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
AK-TAPS	08/02/90	Highway	NA	Diesel Fuel/Heating Oil	Elliott Hwy MP 24	Tank Vehicle Accident	5,700	10,416	Unspecified	Land and Water
AK-TAPS	09/27/92	Highway	NA	Diesel Fuel/Heating Oil	Dalton Hwy MP 248.2	Tank Vehicle Accident		8,000	Unspecified	Land and Water
AK-TAPS	06/08/93	Highway	NA	Gasoline	Dalton Hwy MP 165	Tank Vehicle Accident		9,100	Unspecified	Land
AK-TAPS	02/26/94	Pipeline Pump Station	Alyeska Pipeline Service Co.	Crude Oil	TAPS Pump Station 10 (Tank 209)	Facility Tank Leak - overfill		4,000	Unspecified	Land
AK-TAPS	04/20/96	Pipeline	Alyeska Pipeline Service Co.	Crude Oil	TAPS MP 539.7 (Check Valve 92)	Pipeline Leak - loose fitting	33,619	34,076	Unspecified	Land
AK-TAPS	11/11/97	Highway	NA	Diesel fuel/Heating Oil	Dalton Hwy MP 289	Tank Vehicle Accident		5,217	Unspecified	Land
CND-BS[3]	08/31/83	Exploration Support Vessel	Esso Resources Canada Ltd.	Diesel Fuel/Heating Oil	Beaufort Sea off Esso Caisson	Vessel Leak - Accident		6,605	Estimated	Water
CND-BS	09/18/85	Exploration Well Site	Esso Resources Canada Ltd.	Diesel Fuel/Heating Oil	Esso Rig #7, west of Pelly Island	Facility Tank Leak - equipment damage	102,480	103,000	Unspecified	Water
CND-HAI[4]	04/06/75	Exploration Well Site	Pan-Arctic Oils Ltd.	Jet/Turbine Oil	Drake D-73 Well Site	Facility Tank Leak - equipment damage		22,817	Unspecified	Land
CND-HAI	02/28/79	Exploration Support Facility	Pan-Arctic Oils Ltd.	Gasoline	Banks Island Passage Point Airstrip	Facility Tank Leak - equipment damage		6,005	Unspecified	Land

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
CND-NW[5]	06/21/73	Exploration Well Site	Imperial Oil	Crude Oil	Imperial Oil, Goose Island	Facility Piping Leak - human error		4,200	Unspecified	Land
CND-NW	10/01/78	Production Well Site	Imperial Oil	Crude Oil	Imperial Oil, Goose Island	Facility Tank Leak - overfill		10,500	Unspecified	Land
CND-NW	10/16/81	Production Processing Facility	Esso Resources Canada Ltd.	Crude Oil	No description	Facility Tank Leak - unspecified cause		12,000	Unspecified	Unspecified
CND-NW	07/31/82	Production Well Site	Esso Resources Canada Ltd.	Crude Oil	Imperial Oil Bear Island Production Dock	Vessel Leak - Overfill	4,200	5,812	Unspecified	Water
CND-NW	09/07/86	Production Processing Facility	Esso Resources Canada Ltd.	Crude Oil	Imperial Oil Tank #53 Mainland	Facility Piping Leak - equipment damage	21,000	21,136	Unspecified	Land
CND-NW	07/31/91	Production Well Site	Esso Resources Canada Ltd.	Crude Oil	Imperial Oil, Well O-41X, Bear Island	Facility Piping Leak - equipment damage	4,200	6,300	Unspecified	Land and Water
CND-NW	08/05/91	Production Well Site	Esso Resources Canada Ltd.	Crude Oil	Imperial Oil, Across from Well B-40	Facility Piping Leak - corrosion		6,300	Unspecified	Land and Water
CND-NW	08/20/91	Production Processing Facility	Esso Resources Canada Ltd.	Crude Oil	Imperial Oil Tank #53 Mainland	Facility Tank Leak - equipment damage	8,400	16,800	Unspecified	Land
CND-NW	05/04/92	Pipeline	Interprovincial Pipelines (NW) Ltd	Crude Oil	Norman Wells Pipeline, 25 km N of Ft Simpson	Pipeline Leak - corrosion	528	26,420	Unspecified	Land

Study Area	Spill Date	Facility Type	Facility Operator	Oil Type	Spill Location	Spill Cause	Low Spill Quantity (Gallons)	High Spill Quantity (Gallons)	How Quantity Determined	Affected Media
CND-NW	05/05/97	Production Well Site	Imperial Oil Resources Ltd.	Crude Oil	Imperial Oil, Transfer line from Central Processing Facility to Tank 401	Facility Piping Leak - corrosion	21,136	63,000	Unspecified	Land
CND-OMD[6]	02/09/83	Highway	NA	Diesel Fuel/Heating Oil	Atkinson Point, Inuvik Region	Tank Vehicle Accident		8,406	Estimated	Land

Abbreviations:

1. AK-ONS = Alaska – Onshore North Slope (East of NPRA)
2. AK-TAPS = Alaska – Trans-Alaska Pipeline System
3. CND-BS = Canada – Beaufort Sea
4. CND-HAI = Canada – High Arctic Islands
5. CND-NW = Canada – Norman Wells
6. CND- OMD = Canada – Onshore McKenzie River Delta

APPENDIX B – STATISTICAL ANALYSIS AND OIL SPILL RATE CALCULATIONS USING ALASKAN AND CANADIAN SPILL DATA

Appendix B presents key statistical analyses and calculations of oil spill risk estimates using both the Alaskan and the Canadian data. The analysis and calculations presented in the main body of the report use only the Alaskan oil spill data because of doubts about the comprehensiveness of the Canadian data. The following table shows how the table and figures presented in this appendix correspond to the tables and figures in the main text

Appendix B Tables and Figures	**Comparable Main Text Tables and Figures**
Appendix B, Table 12	Table 12
Appendix B, Table 13	Table 13
Appendix B, Table 14	Table 14
Appendix B, Table 15	Table 15
Appendix B, Table 16	Table 16
Appendix B, Table 17	Table 17
Appendix B, Table 18	Table 18
Appendix B, Table 19	Table 19
Appendix B, Table 20	Table 20
Appendix B, Figure 5	Figure 5
Appendix B, Figure 6	Figure 6
Appendix B, Figure 8	Figure 8
Appendix B, Figure 9	Figure 9
Appendix B, Figure 10	Figure 10
Appendix B, Figure 11	Figure 11

APPENDIX B TABLE 12
ANALYSIS OF VARIANCE OF INDIVIDUAL SPILL EVENTS BY MONTH

lm(formula = log(SpillHigh) ~ Amonth)

Residuals:

Min	1Q	Median	3Q	Max
-1.5250	-0.6354	-0.1991	0.5093	3.9188

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	9.177535	0.348172	26.359	<2e-16 ***
AmonthAug	-0.002824	0.431133	-0.007	0.9948
AmonthDec	0.463255	0.467121	0.992	0.3234
AmonthFeb	0.321720	0.457587	0.703	0.4834
AmonthJan	0.403027	0.492389	0.819	0.4148
AmonthJul	0.759831	0.442518	1.717	0.0887 .
AmonthJun	0.690284	0.442518	1.560	0.1216
AmonthMar	-0.520539	0.561410	-0.927	0.3558
AmonthMay	0.317429	0.442518	0.717	0.4746
AmonthNov	-0.432825	0.449488	-0.963	0.3376
AmonthOct	-0.307075	0.478516	-0.642	0.5223
AmonthSep	0.387448	0.478516	0.810	0.4198

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 0.9848 on 114 degrees of freedom
Multiple R-Squared: 0.1499, Adjusted R-squared: 0.06791
F-statistic: 1.828 on 11 and 114 degrees of freedom, p-value: 0.05704

APPENDIX B TABLE 13
ANALYSIS OF VARIANCE OF INDIVIDUAL SPILL EVENTS BY YEAR

lm(formula = log(SpillHigh) ~ Ayear)

Residuals:

Min	1Q	Median	3Q	Max
-1.9087	-0.5397	-0.1999	0.3477	3.2591

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	9.23968	0.58824	15.707	<2e-16 ***
AyearY71	1.47474	1.17648	1.254	0.2130
AyearY72	0.66381	1.17648	0.564	0.5739
AyearY73	-0.11285	0.77817	-0.145	0.8850
AyearY74	0.11242	0.83190	0.135	0.8928
AyearY75	0.46516	0.64821	0.718	0.4747
AyearY76	-0.18432	0.70308	-0.262	0.7937
AyearY77	0.43562	0.66363	0.656	0.5131
AyearY78	0.91927	0.77817	1.181	0.2403
AyearY79	1.36937	0.74407	1.840	0.0687 .
AyearY80	-0.50826	0.83190	-0.611	0.5426
AyearY81	0.10094	0.70308	0.144	0.8861
AyearY82	0.20467	0.74407	0.275	0.7838
AyearY83	-0.36843	0.68978	-0.534	0.5944
AyearY84	-0.59703	0.77817	-0.767	0.4448
AyearY85	-0.59703	0.77817	-0.767	0.4448
AyearY86	-0.44606	0.72045	-0.619	0.5372
AyearY87	-0.08202	0.93009	-0.088	0.9299
AyearY88	-0.34575	0.93009	-0.372	0.7109
AyearY89	0.27484	0.70308	0.391	0.6967
AyearY90	0.27524	0.83190	0.331	0.7415
AyearY91	-0.16443	0.83190	-0.198	0.8437
AyearY92	0.34486	0.93009	0.371	0.7116
AyearY93	0.15640	0.68978	0.227	0.8211
AyearY94	-0.59251	0.83190	-0.712	0.4780
AyearY96	1.19667	1.17648	1.017	0.3116
AyearY97	0.01189	0.77817	0.015	0.9878

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 1.019on 99 degrees of freedom
Multiple R-Squared: 0.2098, Adjusted R-squared: 0.002265
F-statistic: 1.011 on 26 and 99 degrees of freedom, p-value: 0.4619

APPENDIX B TABLE 14
ANALYSIS OF VARIANCE OF SPILL EVENTS BY FACILITY TYPE

lm(formula = log(SpillHigh) ~ FacilityType)

Residuals:

Min	1Q	Median	3Q	Max
-101327	-13520	-2618	1517	566673

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	24772	14074	1.760	0.080927 .
FacilityTypeHWY	-17214	17621	-0.977	0.330582
FacilityTypePipe	80555	21402	3.764	0.000260 ***
FacilityTypePrd	-6020	18480	-0.326	0.745191
FacilityTypeSF	-6011	19676	-0.305	0.760535
FacilityTypeU	-19522	66012	-0.296	0.767941

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 64490 on 120 degrees of freedom
Multiple R-Squared: 0.1888, Adjusted R-squared: 0.155
F-statistic: 5.586 on 5 and 120 degrees of freedom, p-value: 0.0001158

lm(formula = log(SpillHigh) ~ FacilityType)

Residuals:

Min	1Q	Median	3Q	Max
-2.05240	-0.57235	-0.04463	0.29790	3.07156

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	9.6056	0.2037	47.146	< 2e-16 ***
FacilityTypeHWY	-0.7077	0.2551	-2.774	0.00641 **
FacilityTypePipe	0.7409	0.3098	2.391	0.01835 *
FacilityTypePrd	-0.1679	0.2675	-0.627	0.53157
FacilityTypeSF	-0.1679	0.2675	-0.627	0.53157

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 0.9337 on 120 degrees of freedom
Multiple R-Squared: 0.1957, Adjusted R-squared: 0.1622
F-statistic: 5.839 on 5 and 120 degrees of freedom, p-value: 7.302e-005

APPENDIX B TABLE 15
ANALYSIS OF VARIANCE OF INDIVIDUAL SPILL EVENTS BY OIL TYPE

lm(formula = log(SpillHigh) ~ OilType)

Residuals:

Min	1Q	Median	3Q	Max
-45192	-21626	-9833	-1831	622808

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	49192	10720	4.589	1.10e-05 ***
OilTypeD	-32359	14077	-2.299	0.0232 *
OilTypeG	-39812	22051	-1.805	0.0735 .
OilTypeTF	-25760	23532	-1.095	0.2758
OilTypeU	-36751	50283	-0.731	0.4663

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 69480on 121 degrees of freedom
Multiple R-Squared: 0.05081, Adjusted R-squared: 0.01943
F-statistic: 1.619 on 4 and 121 degrees of freedom, p-value: 0.1738

lm(formula = log(SpillHigh) ~ OilType)

Residuals:

Min	1Q	Median	3Q	Max
-1.4072	-0.6652	-0.2570	0.4371	3.7168

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	9.7012	0.1552	62.522	<2e-16 ***
OilTypeD	-0.4518	0.2037	-2.218	0.0285 *
OilTypeG	-0.7269	0.3192	-2.278	0.0245 *
OilTypeTF	-0.1876	0.3406	-0.551	0.5828
OilTypeU	-0.5029	0.7278	-0.691	0.4909

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 1.006 on 121 degrees of freedom
Multiple R-Squared: 0.05921, Adjusted R-squared: 0.02811
F-statistic: 1.904 on 4 and 121 degrees of freedom, p-value: 0.1141

APPENDIX B TABLE 16
LINEAR REGRESSION OF ANNUAL SPILL RATE BY YEAR

lm(formula = SpillRate2000 ~ YEAR)

Residuals:

Min	1Q	Median	3Q	Max
-19642	-7815	-3212	1946	95670

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	1853064.4	769111.6	2.409	0.0226 *
YEAR	-930.3	387.7	-2.400	0.0231 *

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 19300 on 29 degrees of freedom
Multiple R-Squared: 0.1657, Adjusted R-squared: 0.1369
F-statistic: 5.759 on 1 and 29 degrees of freedom, p-value: 0.0205

lm(formula = log(SpillRate2000) ~ YEAR)

Residuals:

Min	1Q	Median	3Q	Max
-3.1563	-0.9427	0.0793	0.7122	3.4422

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	534.83199	60.10058	8.899	8.68e-10 ***
YEAR	-0.26666	0.03029	-8.803	1.10e-09 ***

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 1.509 on 29 degrees of freedom
Multiple R-Squared: 0.727, Adjusted R-squared: 0.7183
F-statistic: 77.49 on 1 and 29 degrees of freedom, p-value: 1.096e-009

APPENDIX B TABLE 17
LINEAR REGRESSION OF ANNUAL SPILL RATE FOR YEARS GREATER THAN 1979

```
lm(formula = SpillRate2000[YEAR > 1979] ~ YEAR[YEAR > 1979])

Residuals:
        Min          1Q      Median        3Q        Max
    -108.29      -43.46      -31.44     78.44     138.80

Coefficients:
                     Estimate Std      Error     t value     Pr(>|t|)
(Intercept)           11826.906     6090.759       1.942     0.068 .
YEAR[YEAR > 1979]        -5.898        3.061      -1.927     0.070 .

Signif. codes:  0  `***'  0.001  `**'  0.01  `*'  0.05  `.'  0.1  ` '  1

Residual standard error:  71.07on 13 degrees of freedom
Multiple R-Squared:  0.1093,          Adjusted R-squared:  0.0476
F-statistic:  1.595 on 1 and 13 degrees of freedom,          p-value: 0.02288
```

```
lm(formula = log(SpillRate2000[YEAR > 1979]) ~ YEAR[YEAR > 1979])

Residuals:
        Min          1Q      Median        3Q        Max
   -2.03886    -0.88628     0.07833   0.74709    2.03006

Coefficients:
                     Estimate Std      Error     t value     Pr(>|t|)
(Intercept)           237.57204     88.57378       2.682     0.0152 *
YEAR[YEAR > 1979]      -0.11743      0.04452      -2.638     0.0167 *

Signif. codes:  0  `***'  0.001  `**'  0.01  `*'  0.05  `.'  0.1  ` '  1

Residual standard error:  1.148 on 18 degrees of freedom
Multiple R-Squared:  0.2788,          Adjusted R-squared:  0.2387
F-statistic:  6.957 on 1 and 18 degrees of freedom,          p-value:  0.01672
```

APPENDIX B TABLE 18
LINEAR REGRESSION OF ANNUAL SPILL RATE FOR YEARS GREATER THAN 1984

lm(formula = SpillRate2000[YEAR > 1984] ~ YEAR[YEAR > 1984])

Residuals:

Min	1Q	Median	3Q	Max
-74.56	-38.57	-33.27	44.19	122.46

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	10762.149	8460.510	1.272	0.226
YEAR[YEAR > 1984]	-5.364	4.247	-1.263	0.229

Residual standard error: 71.07 on 13 degrees of freedom
Multiple R-Squared: 0.1093, Adjusted R-squared: 0.04076
F-statistic: 1.595 on 1 and 13 degrees of freedom, p-value: 0.2288

lm(formula = log(SpillRate2000[YEAR > 1984]) ~ YEAR[YEAR > 1984])

Residuals:

Min	1Q	Median	3Q	Max
-1.99331	-1.10423	0.09609	0.75313	2.15364

Coefficients:

	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	315.36040	146.73039	2.149	0.0510 .
YEAR[YEAR > 1984]	-0.15644	0.07366	-2.124	0.0534 .

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 1.233 on 13 degrees of freedom
Multiple R-Squared: 0.12576, Adjusted R-squared: 0.2005
F-statistic: 4.511 on 1 and 13 degrees of freedom, p-value: 0.05344

APPENDIX B TABLE 19
CALCULATION OF MEANS AND EXPECTED UNCERTAINTIES OF ANNUAL SPILL RATE FOR YEARS GREATER THAN 1984

A. Arithmetic mean of annualized spill rate = 77.34 barrels spilled per million barrels produced

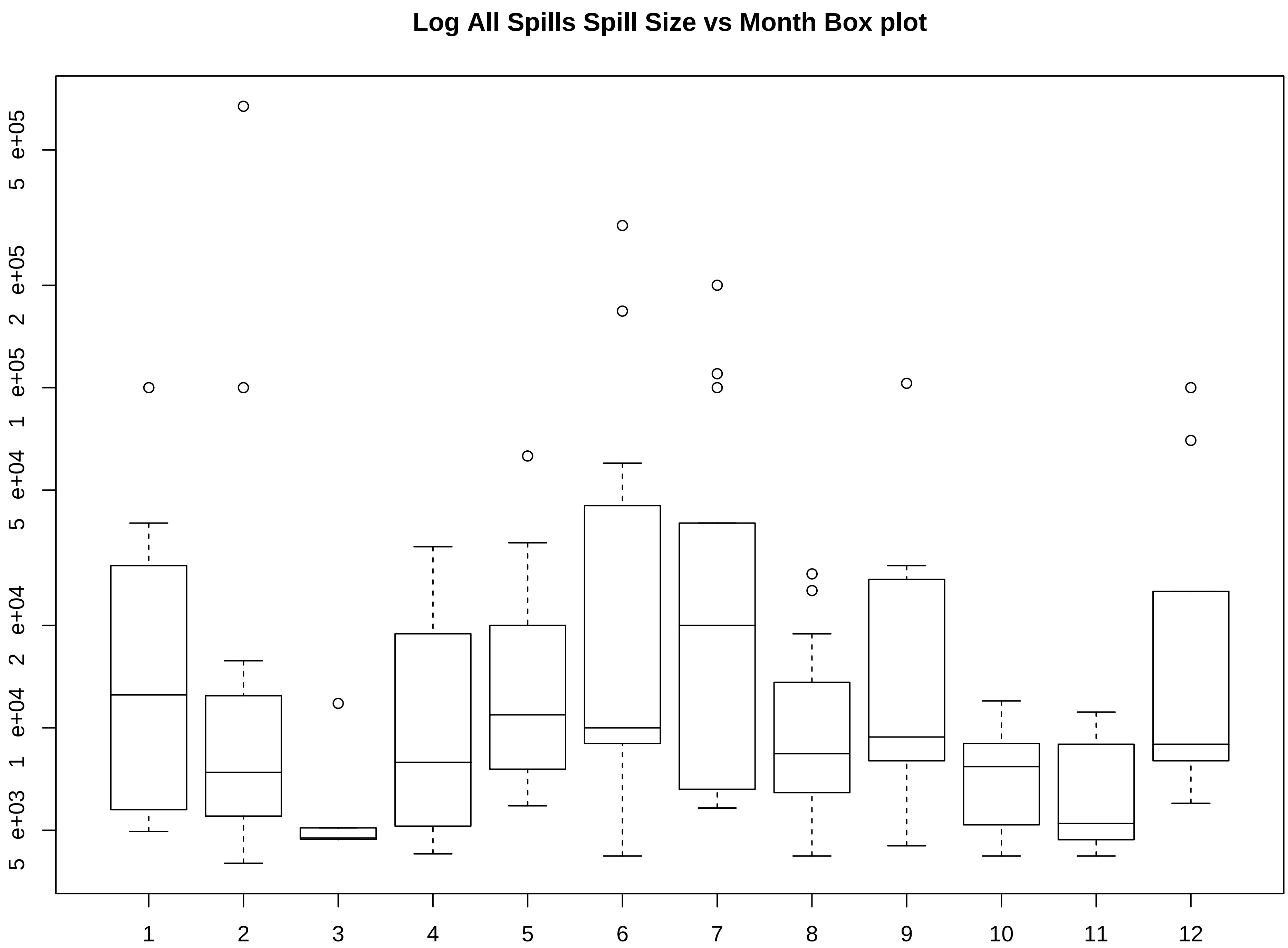
B. Approximate arithmetic 95% confidence limits on the mean of annualized spill rate = 72.56 %

C. Lognormal mean annualized spill rate = 107.11 barrels spilled per million barrels produced

D. Approximate logarithmic 95% confidence limits on annualized spill rate 476.95 %

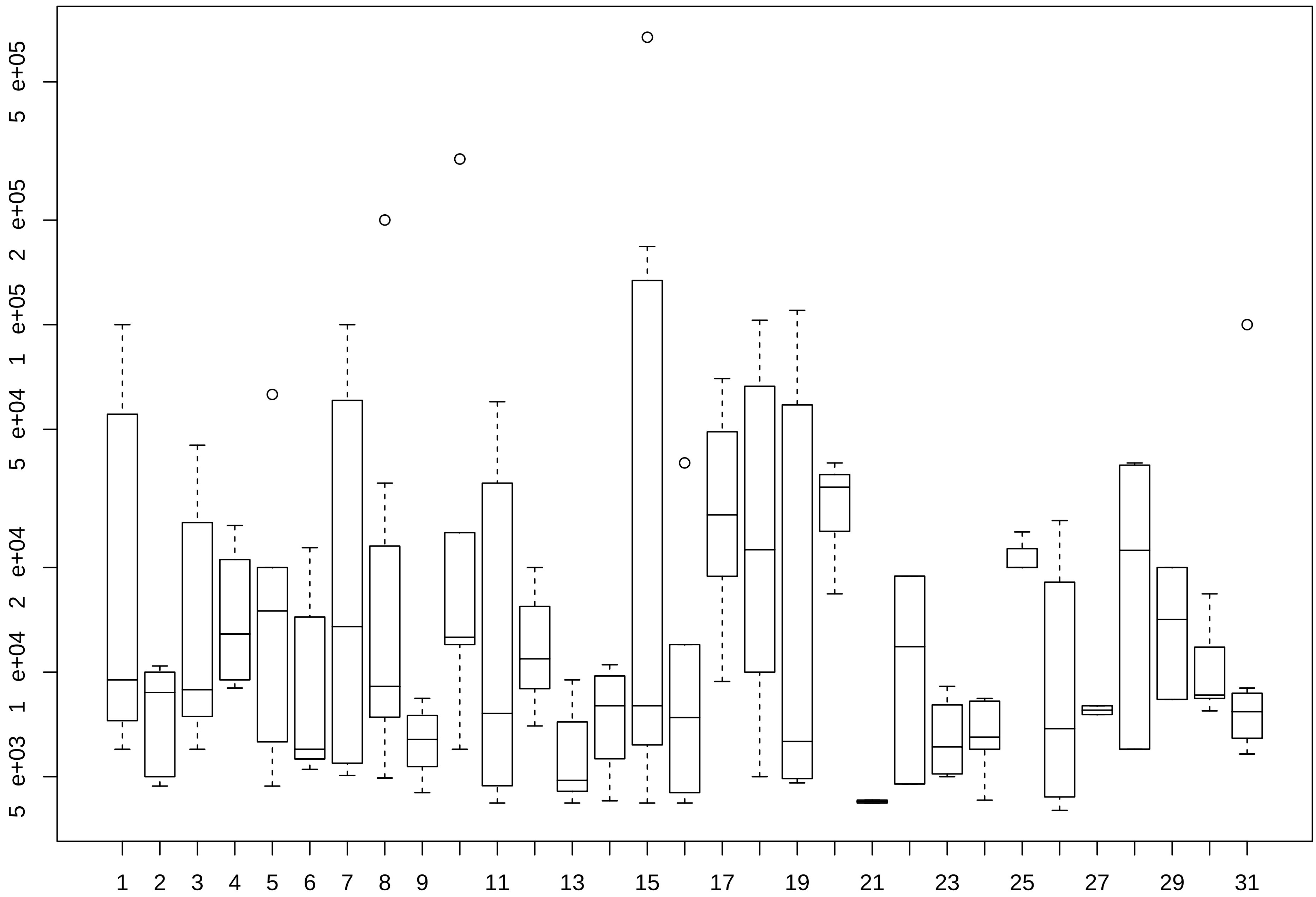
APPENDIX B TABLE 20
OIL SPILL RISK RATE BY COUNT WITH ASSOCIATED UNCERTAINTIES
DATA FROM 1978-1999

Spill Size (Bbl)	**Number of Spills**	**Total Crude Oil Production** (MMBbl)	**Calculated Risk Rate** (Spills/MMBbl)	**Approximate 95% Confidence Limits** (%±)
≥100	81	13,019	0.0062217	22
≥500	16	13,019	0.0012290	50
≥1,000	7	13,019	0.0005377	76
≥10,000	1	13,019	0.0000768	200

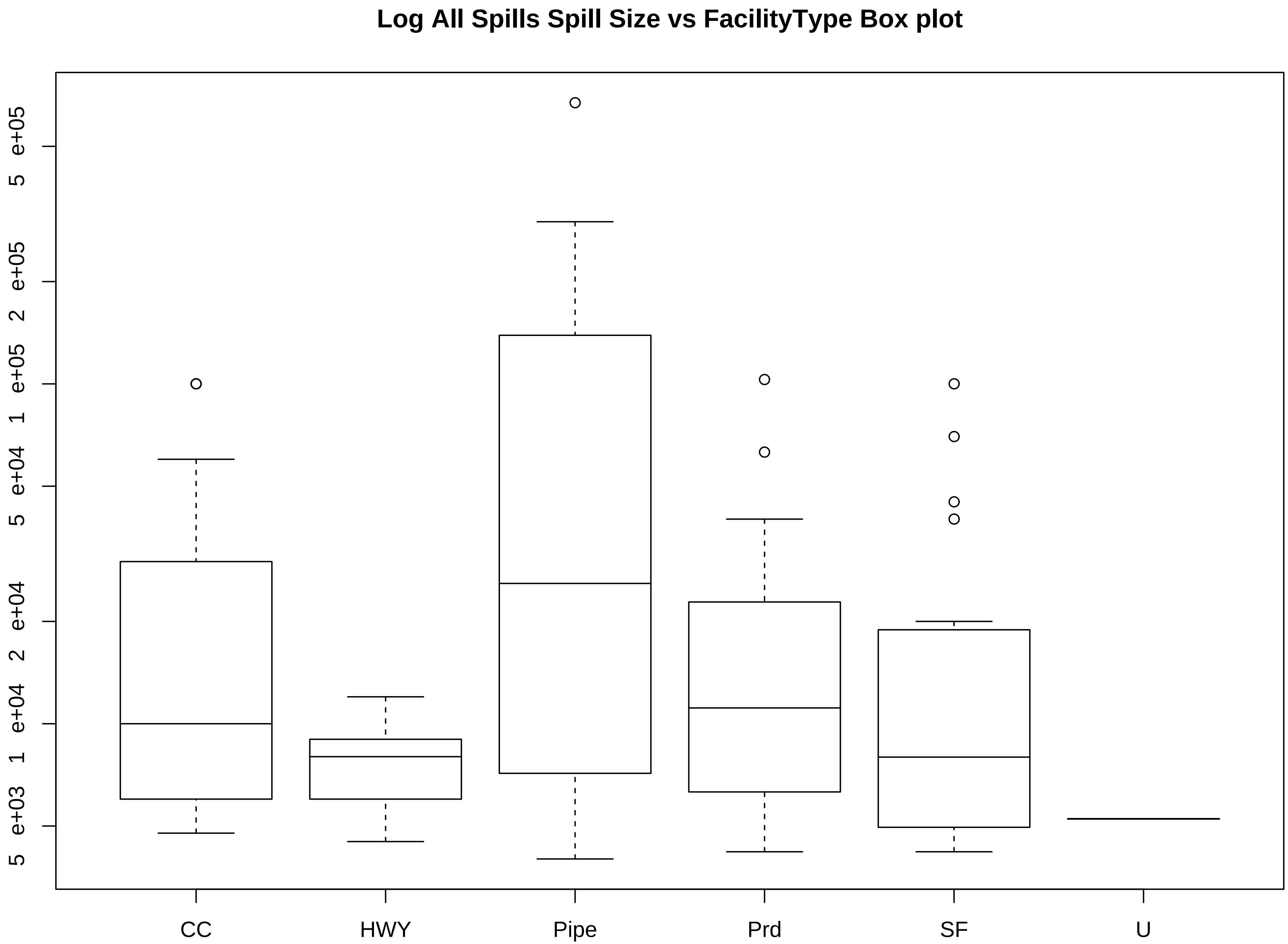


Appendix B Figure5

Log All Spills Spill Size vs Day Box plot

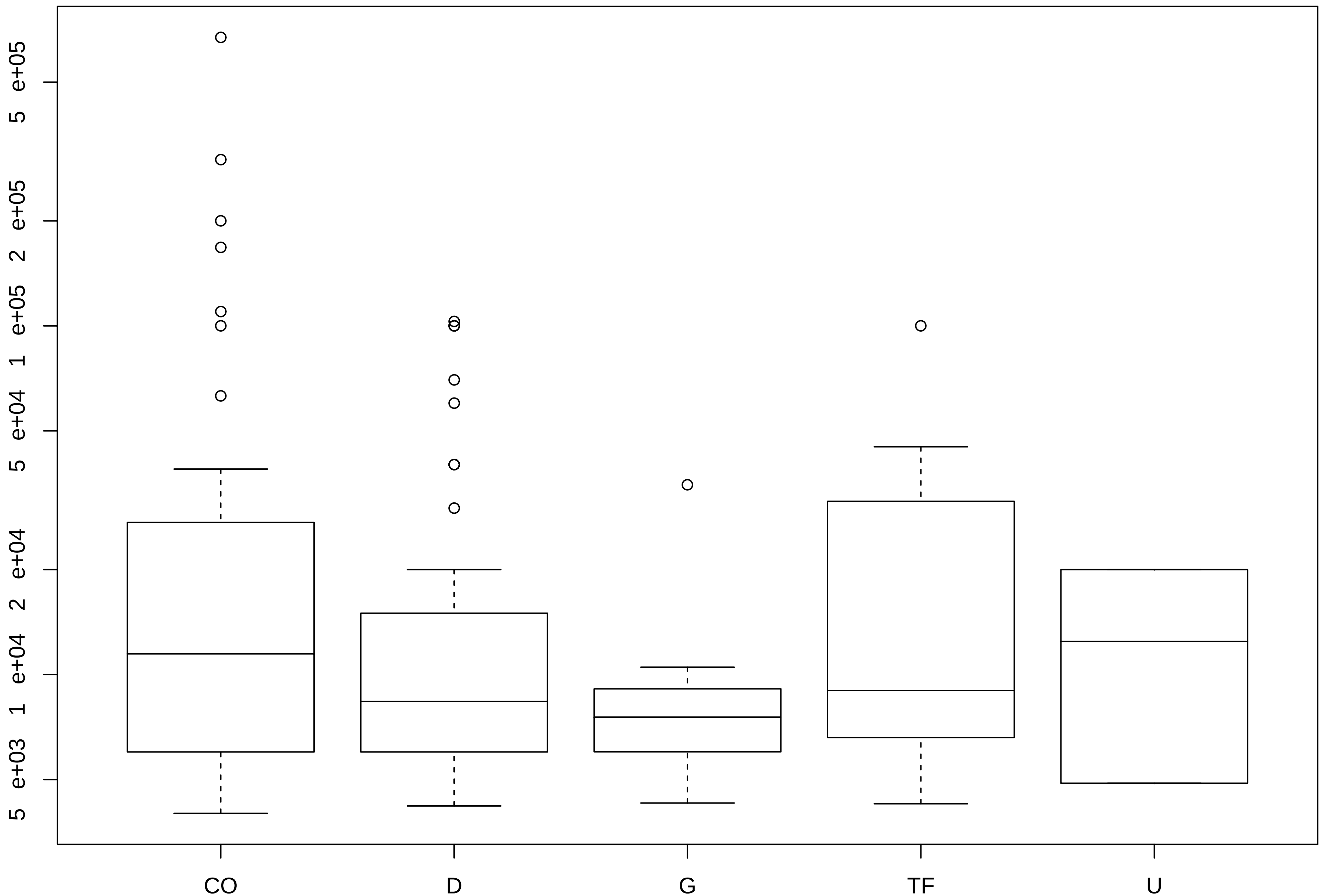


Appendix B Figure6

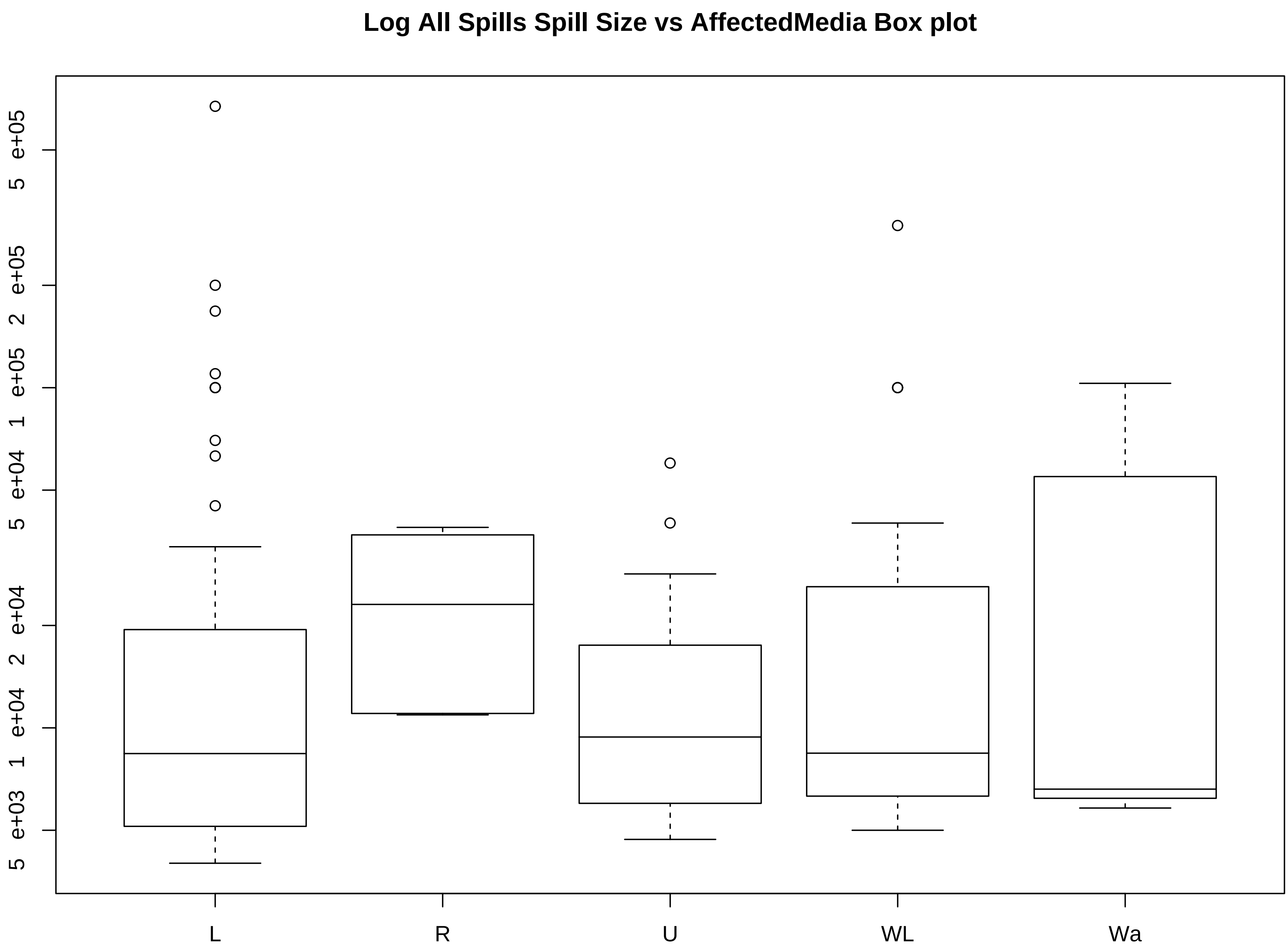


Appendix B Figure8

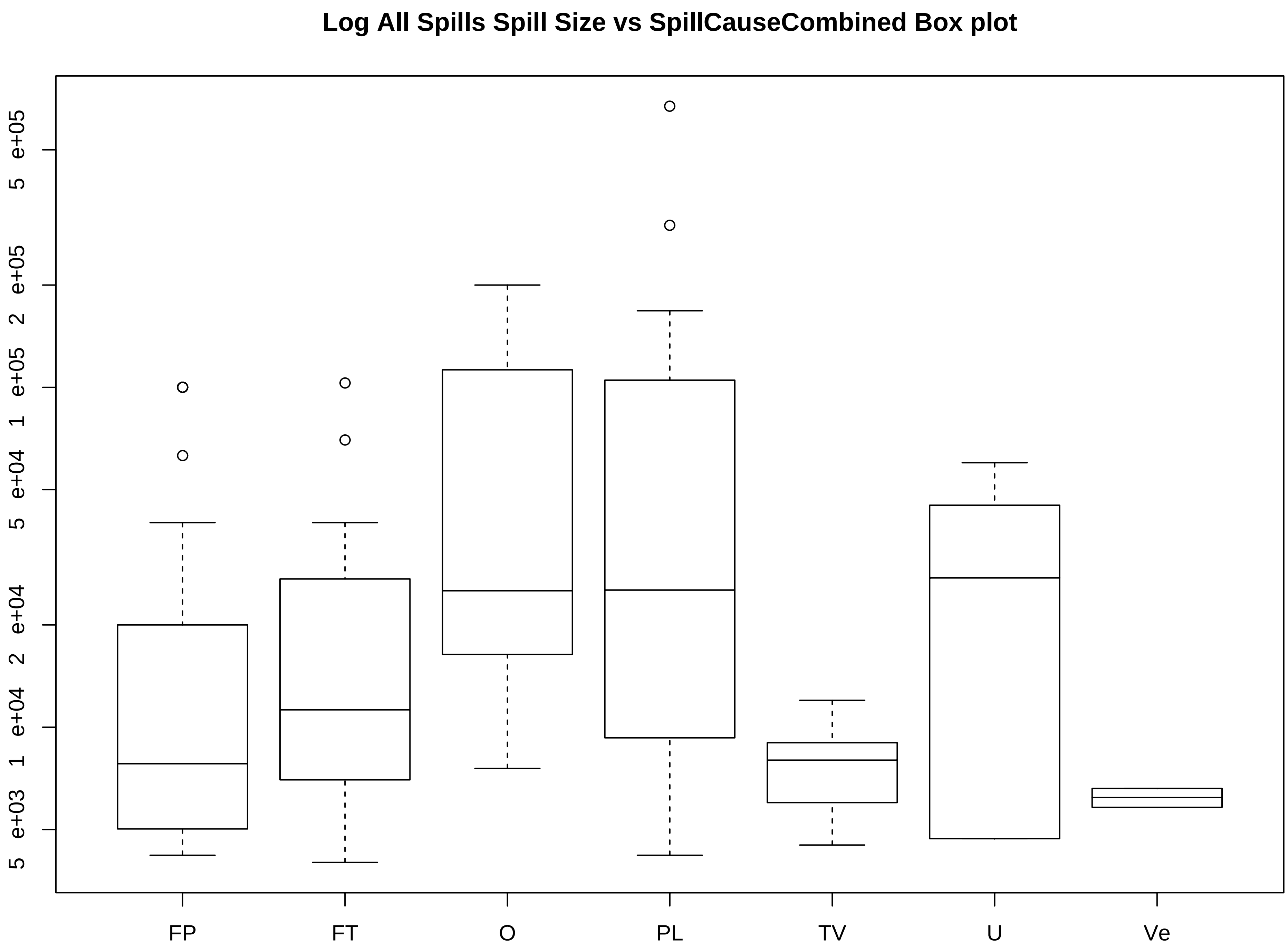
Log All Spills Spill Size vs OilType Box plot



Appendix B Figure9



Appendix B Figure10



Appendix B Figure11