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TECHNICAL REPORT No. 18

AN ANALYSIS OF RECORDED COLORADO RIVER BOATING ACCIDENTS IN GLEN CANYON FOR 1980, 1982, AND 1984, AND IN GRAND CANYON FOR 1981 THROUGH 1983

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June 1986

NATIONAL PARK SERVICE/UNIVERSITY OF ARIZONA
National Park Service/Bureau of Reclamation
Interagency Agreement No. 4-AA-40-01930
CONTRIBUTION NO. 053/02

FOREWORD

In 1975, a study was initiated by the United States Department of the Interior's Bureau of Reclamation (BUREC) to determine the potential for increasing power generation capabilities of existing BUREC hydroelectric facilities (i.e. dams). Among those dams identified as prime candidates for cost-effective power generation upgrading was Glen Canyon Dam, located on the Colorado River near Page, Arizona.

A product of the subsequent study to increase power generation at Glen Canyon Dam (referred to as the "peaking-power" study) was an environmental assessment report, released in 1981, which stated that the proposed method and consequences of upgrading the dam's power generation capability would have no significant detrimental impact on the downstream riverine environment. Public reaction to this conclusion and to the peaking-power study in general was strongly negative, prompting the Secretary of the Interior to authorize a more extensive study of the long-term, downstream effects of Glen Canyon Dam operation.

In 1982, Interior Department agencies, consisting of the Bureau of Reclamation, National Park Service, U.S. Geological Survey, and U.S. Fish and Wildlife Service, in conjunction with other public and private natural resource agencies and entities, initiated the Glen Canyon Environmental Studies (GCES), in response to the Secretary's order. The two principal GCES goals are: (1) to determine how current flow regimes, based on dam releases, impact the downstream riverine environments in Glen and Grand canyons, particularly the effects of low flows on recreational boating and fishing, and (2) to identify how dam operation could be altered, within the operating constraints of water commitments and power demands, to improve the downstream riverine environments and conditions of their use for recreational and scientific purposes.

The GCES project, funded with Glen Canyon Dam power generation revenues, addresses four major subject areas associated with the downstream environments: (1) aquatic and terrestrial biology, (2) hydrology and sediment transport, (3) river-based recreation, and (4) dam operation (i.e. flow release) scenarios.

ACKNOWLEDGMENTS

This study would not have been possible without the assistance and support of many individuals and organizations. Staff members, both current and former, of the Resource Management Division of Grand Canyon National Park (GRCA) provided much in the way of river-related data, technical and logistical support for study activities, valuable river management insight, and report direction and editing. In particular, river rangers and others within the River Subdistrict Office, both past and present, deserve special recognition.

Also recognized for their assistance and support of the study are staff members of the Resource Management Division of Glen Canyon National Recreational Area (GLCA). The rangers at Lees Ferry deserve special recognition. The cooperation and assistance rendered by all GRCA and GLCA employees contacted during or involved in the study is greatly appreciated.

Financial support for the study was provided by the Bureau of Reclamation. River flow data essential to the study was provided by Bureau staff members in the Salt Lake City office. Bureau staff members in both the Salt Lake City and Denver offices assisted the study greatly in the areas of direction and content review. The information and assistance provided by all BUREC employees associated with the study is also greatly appreciated.

Many of the commercial river companies operating in Glen and Grand canyons cooperated with or participated in the study. Their help provided study researchers with invaluable, first-hand data and experience on boating conditions and accident situations/occurrences. Management of the cooperating companies deserve our thanks for their assistance. Boat crews of these companies deserve special recognition and have our most sincere appreciation for their help and tolerance of our presence.

Members of Heberlein - Baumgartner Research Services (HBRS) of Madison, WI also deserve thanks for their valuable input and interest in the study.

Special thanks go to Lupe Hendrickson, of the Cooperative National Park Resources Studies Unit (CPSU) at the University of Arizona, for her editorial contributions.

A distinct possibility exists that some individual(s) who contributed to the study sometime during its course may have been forgotten or neglected in these acknowledgments. For those of you in this category, we apologize and offer a note of thanks for your help.

ABSTRACT

Recorded boating accidents for three boating seasons on the Glen and Grand Canyon sections of the Colorado River (between Glen Canyon Dam and Diamond Creek) are analyzed to determine whether a significant correlation existed between accident occurrence and river flow level at the times and locations of the occurrences. Accident populations of each study section were analyzed separately because of marked differences in the nature of boating use and associated accidents between the sections.

The study period for the ~17-river-mile, non-whitewater, Glen Canyon section covered the calendar years of 1980, 1982, and 1984. The study period for the ~225-river-mile, whitewater, Grand Canyon section covered 1981 through 1983. Choice of years in each study period was based on the number of recorded accidents, available records on total boating use, and diversity of flows.

River flows occurring during the study periods, measured in cubic feet per second (cfs), were divided into four categories or ranges: Low, < 9,000 cfs; Medium, 9,000 to 15,999 cfs; High, 16,000 to 31,500 cfs; and Flood, > 31,500 cfs. The total boat populations of each study section, counted or estimated as both individual boats and boat-days, were matched with hourly dam releases broken down into the four flow ranges. An expected number of accidents in each range was computed and compared with the corresponding number of total observed accidents in each range.

The Glen Canyon section had 29 recorded accidents for 27,747 known boat-days, resulting in an overall accident rate per boat-day of 0.104 percent. The exact number of boats to use this section of the Colorado during the study period is not known, although it is estimated to be at least 20,000.

Chi-Square testing of the Glen Canyon accident population showed the accident distribution by flow-range to be non-random (not merely the result of chance) for the complete study period ($X^2 = 10.967$, df = 3, $P < 0.05$). Almost twice the expected number of accidents occurred during High range flows while less than a third of expected accidents occurred during Medium range flows.

A descriptive analysis of some flow and several non-flow characteristics of the Glen Canyon accident population, including water-surface conditions and operator error, suggests that certain patterns of accident occurrence exist. However, these hypotheses were not supported statistically by the available data.

The Grand Canyon section, with 40 recorded accidents for 7,727 known boats, had an overall accident rate per boat of 0.52 percent. Total Grand Canyon boat-days for the study period are estimated at over 75,000, giving an accident rate per boat-day of ~0.05 percent.

The distribution of Grand Canyon accidents by flow-range was random (i.e. essentially due to chance) ($X^2 = 5.206$, df = 3, $P > 0.05$). However, over 60 percent of all Grand Canyon accidents (25 of 40) occurred at five rapids (Crystal, Horn Creek, Badger Creek, Grapevine, Lava Falls). Crystal Rapid, which accounted for 11 accidents, showed association with flow ($X^2 = 15.338$, df = 3, $P < 0.05$) and with boat type, principally motor rafts ($X^2 = 8.130$, df = 3, $P < 0.05$).

Although not statistically supported by the available data, noteworthy occurrence trends appeared at Horn Creek, Grapevine, and Lava Falls. All five Horn Creek accidents occurred between 7,000 and 10,850 cfs, suggesting that this rapid was most dangerous below 11,000 cfs during the study period. Grapevine and Lava Falls each had three accidents occurring in narrow ranges or bands of flow. These were 22,600 to 27,900 cfs for Grapevine and 9,100 to 12,750 cfs for Lava Falls, suggesting that these rapids were most dangerous in the High and Medium flow ranges respectively, during the study period.

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INTRODUCTION

Study Purpose

This study of recorded boating accidents which occurred on the Colorado River in two National Park Service (NPS) areas below Glen Canyon Dam and above Lake Mead was undertaken to determine if a significant correlation existed between accident occurrence and flow level at the time and location of each accident.

Study Areas and Time Periods

The study area, a distance of approximately 240 river miles, was located between Glen Canyon Dam, in Glen Canyon, and Diamond Creek in Grand Canyon. This area was broken down by administrative jurisdiction into the Glen Canyon National Recreation Area (Glen Canyon) section and the Grand Canyon National Park (Grand Canyon) section. Because of the marked differences in the nature of boating use and associated accidents between the sections, the accident populations for each study section were analyzed separately.

The ~17-river-mile, non-whitewater, Glen Canyon section was located between the dam and the confluence of the Paria River with the Colorado, about one mile downstream of Lees Ferry. The whitewater Grand Canyon section, covered approximately 225 river miles and was located between Lees Ferry and Diamond Creek.

The time periods for each study section, calendar years 1980, 1982, and 1984 for Glen Canyon and 1981 through 1983 for Grand Canyon, were chosen for their diversity of flows, the number of accidents recorded, and the records available on total boating use.

DATA COLLECTION

Data Sources

Glen Canyon

Three sources of data were used in the study of Glen Canyon boating accidents: (1) accident reports compiled by NPS personnel on both U.S. Coast Guard and NPS forms, (2) total boat population on the river during the study period (compiled from Glen Canyon Ranger reports), and (3) hourly flow releases at the dam for each of the 1,000 days in the Glen Canyon study period, supplied by the Bureau of Reclamation (BUREC) Office in Salt Lake City. There were no Glen Canyon boating records (or recorded accidents) for 95 days of the study period.

Grand Canyon

The study of Grand Canyon boating accidents used four sources of data: (1) accident reports compiled by NPS personnel on the standard NPS Case Incident Record, (2) river trip checkout sheets completed at Lees Ferry by Grand Canyon personnel for each of the 2281 separate trips launched during the study period, (3) hourly dam releases for each of the 1,095 days of the Grand Canyon study period, and (4) BUREC generated flow routings for Grand Canyon, used to determine flows for the time and place of each accident.

Data Types

Boating Accident Reports

For each study section, boating accidents were defined as those incidents involving boats on the river which resulted in notable equipment damage or loss and/or personal injury requiring medical attention, as recorded on the NPS Case Incident Record or Coast Guard style accident report forms. All accident/incident reports used in the study (henceforth referred to as accident reports) contained information on the date, time, and location of the accident. These three accident related variables were the minimum required to determine a flow for the time and location of the accident. Any river-related accident reports which lacked this information were not included in the analysis for association with flow.

Thirty-three Glen Canyon accidents were recorded during the 1980, 1982, 1984 study period. Four of the 33 study period accident reports described accidents or incidents clearly caused by operator negligence or not directly associated with the river. These were also not included in the study analysis. In Grand Canyon, 47 accidents were recorded during the 1981 through 1983 study period. Seven of the 47 study period accident reports did not describe equipment damage or personal injury occurring in a boat while navigating the river and were not included. Examples of excluded reports for both study sections included on-river illnesses, speeding/reckless driving (Glen Canyon), hiking, and swimming related accidents.

For Glen Canyon, non-flow related accident variables provided on all of the Coast Guard forms (15 of the 29 usable accident reports) and on a few of the NPS reports were not analyzed. No data was available on these same variables for the total Glen Canyon boat population. The number of reports which recorded this information were insufficient to produce statistically significant analyses of relevant factors such as operator experience, weather, and wind. This information is descriptively summarized later in this report.

Boat Populations

The boat population of the Glen Canyon section was almost entirely composed of one boat type, the hard-shelled (as opposed to inflatable) motorboat. Summing the boat counts made by Lees Ferry Rangers on their daily Visitation Logs produced the total Glen Canyon population. A log was supplied for each day during the study period except as noted above.

The boat population of the Grand Canyon section was composed of five known boat types: motor, oar, and paddle rafts, dories, and kayaks. Totals for each boat type were determined by summing the number of each type listed on each river trip checkout sheet for the study period.

Flow Figures

Flow data used in the analysis of Glen Canyon accidents consisted of the hourly releases at the dam for each day of the Glen Canyon study period. These releases represented the flow values used for both the accident and non-accident, Glen Canyon boat populations.

The average speed of flow throughout the ~17-mile-long Glen Canyon section is approximately 4 to 5 miles per hour. The flow at each accident location was calculated by dividing the river mile location of the accident by 4.5 and then subtracting that figure from the time of the accident. The dam release at the resulting time was used as the flow for the time and place of the accident.

In Grand Canyon, Glen Canyon Dam releases were again used to represent flow values for the non-accident boat population. This was necessitated by the inability to reliably determine the precise location of any Grand Canyon river trip boat after launching from Lees Ferry, and because all dam releases affect flows in Grand Canyon. While it is true that dam-release variations (i.e. flow fluctuations) are attenuated during the course of travel through Grand Canyon and flow volumes throughout the canyon vary somewhat at any given time, these circumstances are not considered significant enough to preclude the use of dam releases as baseline flow values (i.e. flow-range boat-hours) for the Grand Canyon boat population during the study period.

For each Grand Canyon accident, BUREC provided flow data in the form of a flow routing for the day of the accident. These flow routings consisted of measured and estimated hourly flows at twelve locations within Grand Canyon (starting at Lees Ferry and ending at Diamond Creek) and were generated by BUREC's computerized Streamflow Synthesis and Reservoir Regulation (SSARR) Colorado River flow model. The flows at the time and place of each Grand Canyon accident were then determined using these routings.

At the start of this study, river flows, measured in cubic feet per second (cfs), were divided into four categories and a range was established for each category. These categories and their respective ranges, used throughout the study, are: Low, < 9,000 cfs; Medium, 9,000 to 15,999 cfs; High, 16,000 to 31,500 cfs; and Flood, > 31,500 cfs.

DATA ANALYSIS

For both the Glen Canyon and Grand Canyon sections of the river, the total boat populations, counted as both individual boats and boat-days, and the hourly flows were converted to boat-hours for each of the four flow ranges. In this conversion, it was necessary to use all 24 hours of each daily flow regime because of the following circumstances:

> Almost all Grand Canyon river trips were from 5 to 18 days long, in contrast to the one day trips predominant in Glen Canyon. Although trips are on the river only during daylight hours (7:00 A.M. to 7:00 P.M.), it was impossible to determine precisely where any particular trip or boat was at any particular time after launching from Lees Ferry. This situation prevented using the SSARR flow model to match trips only with daylight flows, which would require knowing how many boats were at or near each of the 12 locations (where flows are measured or estimated) at every hour. Since this was impossible, all 24 hours of dam releases were used for each day that trips were on the river. Although this method is not precise, it consistently produces the proper proportion of boat-hours in each flow range, thereby correctly weighting dam releases in proportion to use.

Statistical Analysis

The non-parametric Chi-Square Test for Association was used to test for a flow-accident relationship because of the very low (0.5 percent or less) accident rates in both study sections. Chi-Square testing is typically used to test for association among variables of an event with a low incidence rate (Glass 1984).

The Chi-Square analysis used here involved comparing the percent of annual and study-period dam releases to which all boats in a study section were exposed in each of the four flow ranges, (i.e. boat-hours), with the percent of total accidents occurring in each flow-range during the same time period. Statistically similar distributions of accident occurrence and boat-hours would indicate that the distribution of accidents by flow-range was the result of chance and/or the influence of unknown factors, a situation which will henceforth be referred to as random. A non-random distribution would indicate that some factor, possibly flow, is associated with accident occurrence.

It should be noted that different breakdowns of flows might change the conclusions reached here as to whether or not accidents were randomly distributed with respect to flow or flow ranges. However, we believe that both the flow-range analysis approach and the ranges selected for use in the study are reasonable and proper, in that they generally reflect the categories of flow levels recognized by experienced Glen/Grand Canyon boaters.

The percentage of total annual and study period boat-hours in each of the four flow ranges was determined as follows:

(1) For each day of a study period, the hourly dam releases furnished by BUREC were manually categorized into each flow-range.

(2) The number of boats on the river each day of the study period was determined.

(3) Total boat-hours and percentages were calculated by multiplying steps (1) and (2).

a. For Glen Canyon, ranger-supplied, daily boat counts, together with corresponding daily flow-range hours, were entered into a microcomputer statistical package which then computed the total boat-hours per flow-range and percentages of total boat-hours per flow-range for the study period.

b. For Grand Canyon, the NPS-supplied, river-use data file, giving launch date, boat numbers and types, and takeout date (at Diamond Creek) was also computerized and then merged with the same flow-range hours file used for Glen Canyon boats to produce the total boat-hours per flow-range and corresponding percentages. Grand Canyon daily boat counts were derived from the river use file and then matched with the corresponding daily hours in each flow-range during this process.

The flow-range boat-hours needed for this analysis were first computed on a daily basis by multiplying the total number of boats on the river (in each study section) for that day times the number of hours of that day in each flow-range. For example, if 50 boats were on the river on a day when the river was in each of the four flow ranges for six hours, this day would produce 300 boat-hours in each range. Total annual and study period boat-hours for each study section were summations of the daily figures.

ANALYSIS RESULTS

Glen Canyon

The percentages of total boat-hours and accidents, and recorded vs. expected accidents in each flow-range for Glen Canyon are shown in Table 1. Of the 29 recorded study-period accidents, 20.69 percent (6) occurred during Low flows, 6.90 percent (2) occurred during Medium flows, 68.96 percent (20) occurred during High flows, and 3.45 percent (1) occurred during Flood flows.

Table 1. Percent of total Glen Canyon boating accidents vs. percent of total boat-hours in each flow-range, and recorded vs. expected Glen Canyon boating accidents by flow-range for 1980, 1982, and 1984.

	Flow Range			
	Low	Medium	High	Flood
Percent of total Glen Canyon accidents	20.69	6.90	68.96	3.45
Percent of total boat-hours in flow-range	30.00	24.79	39.83	5.38
Recorded accidents	6.00	2.00	20.00	1.00
Expected accidents	8.70	7.19	11.55	1.56

$X^2 = 10.967$ df = 3 $P < 0.05$

Chi-Square analysis of the accident distribution required converting the percentage of total boat-hours in each flow-range to whole numbers representing expected accidents. This was accomplished by multiplying the total boat-hours percentage in a given range by the total number of study period accidents. The distributions of expected and recorded accidents were then statistically compared.

For the High flow-range, the number of recorded accidents was almost twice the expected number. For the Medium range, recorded accidents were less than a third of the expected number. The relationship between recorded and expected accidents for Glen Canyon is graphically displayed in Figure 1.

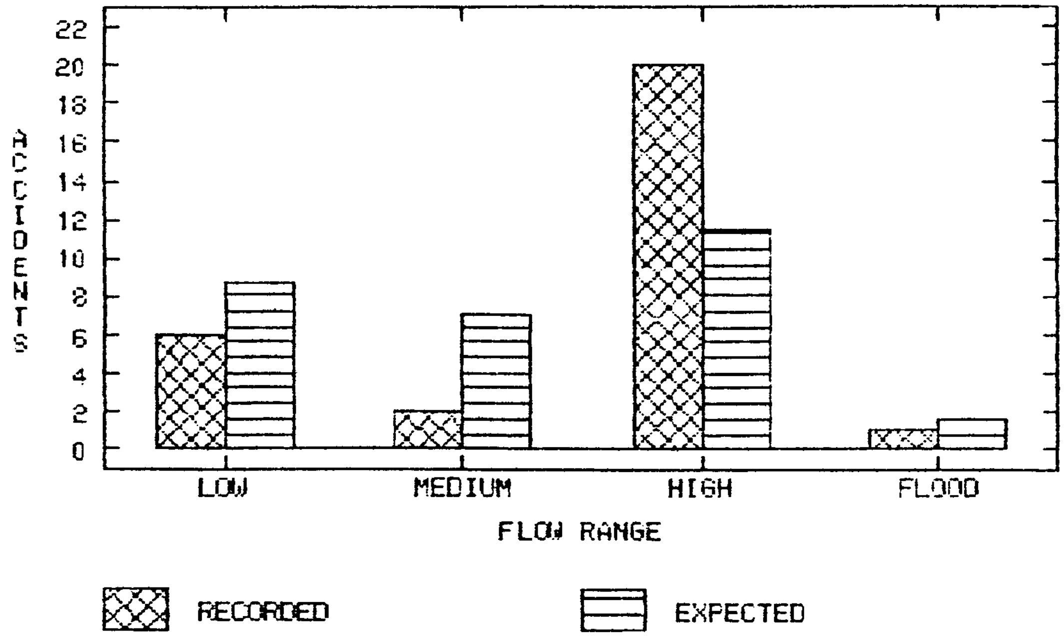

Figure 1. Recorded vs. expected Glen Canyon boating accidents by flow-range for 1980, 1982, and 1984.

Chi-Square analysis of the recorded vs. expected Glen Canyon accident distributions for the complete study period produced a Chi-square value of 10.967. Combining this value with the appropriate three degrees of freedom indicated that the distribution of recorded accidents across the flow ranges was not merely the result of chance or the effects of some unknown factor(s). Some factor or factors including flow, influenced accident occurrence within the flow ranges over the course of the study period. This resulted in a "non-random" distribution of accidents across the ranges, thereby demonstrating an association at the 0.05 level of significance, between accident occurrence and flow-range during the course of the study period in Glen Canyon.

Analysis of the annual Glen Canyon accident distributions indicated that each was random (all P's > 0.05). This result, which may have been caused by the small number of annual accidents, led to the use of data for the complete study period only in the analysis for association with flow. As shown in Table 1, collectively, the accidents display an overall non-random distribution in relation to flow.

Although desirable, assuming that the other non-flow related variables such as operator experience, wind, boat or motor condition, etc., remain constant across flow ranges, or balance out, was not possible for the following reasons: (1) the post-hoc, correlational design of the study does not allow for such an assumption, (2) it was impossible to attain a random sample or to randomly assign events to groups, and (3) much of the data, both flow and non-flow related, is inconsistent, incomplete, and inherently biased. Although the availability and consistency of these data were insufficient to support a statistical analysis, enough information was contained in all of the Glen Canyon reports to warrant a descriptive analysis.

The descriptive analysis revealed that high winds were reported at the time and place of nine of the 29 Glen Canyon accidents, although only seven accident reports indicated that high winds may have contributed to the accident. The river surface was recorded as being rough or very rough for these same nine accidents.

Strong river current was reported for 17 accidents. Our analysis has shown that 20 accidents occurred during high flows and one during flood flows. Water conditions were characterized as being rough, very rough, or having strong current in 19 of the accident reports. However, only 12 reports specifically indicated that these water conditions may have contributed to accident occurrence. The combination of bad weather (cloudy, rain), high winds, and rough water/strong current occurred in four reports.

Descriptive analyses of boat-related variables revealed that four accidents were considered to have been at least partially caused by overloading or improper weight distribution. One of these resulted in the two fatalities reported during the study period. Equipment failure was indicated as having contributed to or been the principal cause of nine accidents. Strong current or rough water was also cited as a major contributing factor in eight of these nine accidents.

Operator error was listed as a probable cause in 11 accidents. This error entailed bad judgment and/or carelessness in boat operation. Examples included producing boat-swamping wakes and, in two instances, anchor dragging from the bow.

Analysis of overall Glen Canyon accident occurrence by location revealed that eight accidents occurred on the mile of river between Lees Ferry and the Paria/Colorado confluence, six occurred 3.0 to 3.5 miles upstream of the Ferry and two each occurred 5.5 miles, 9.0 miles, and 12.0 miles upstream of Lees Ferry.

Six of the eight accidents associated with equipment failure and strong current/rough water occurred between Lees Ferry and the Paria confluence. Seven of the nine accidents related to equipment failure occurred in this section of the river. All nine accidents related to high winds occurred between 3.0 miles and 12.0 miles upstream of Lees Ferry, with four of these occurring in the 3.0 to 3.5 mile area.

The overall non-random distribution of accidents appears to result from the number of accidents occurring in the Medium flow-range, which was considerably lower than expected, and the number occurring in the High flow-range, which was considerably higher than expected. A possible interpretation of this distribution is that boaters were much more likely to have problems which resulted in accidents during high flows and much less likely to get into accident producing situations during medium and low flows.

In an attempt to confirm the adequacy of the flow ranges used in this study, an alternative flow-range scenario consisting of 2,000 cfs increments, starting at 1,000 cfs and ending at 45,000 cfs (the approximate minimum and maximum flow levels at which Glen Canyon accidents occurred during the study period), was constructed to tally or redistribute the Glen Canyon accidents. The idea was to compare generally the percentage of total flow hours in each 2,000 cfs increment in which accidents occurred, with the percentage of total accidents in that increment.

The new accident distribution produced consisted of two groups and two isolated occurrences (at 14,000 cfs and 43,200 cfs). The first group consisted of seven accidents fairly evenly spaced between 2,000 and 10,000 cfs. The second accident group consisted of 20, occurring between 17,000 and 27,000 cfs. Seven of the second group were fairly evenly spaced between 17,000 and 25,000 cfs. The remaining 13 occurred between 25,000 and 27,000 cfs, with 12 of these recorded in 1984.

At first, the clustering of such a large percentage of the total study-period accidents (13 of 29, or ~45%) in a very narrow band of flow appeared to be anomalous. But when hourly dam releases for 1984 were checked for the occurrence of flows in the 25,000 to 27,000 cfs range, it was found that approximately 60 percent of the releases fell within that narrow range. At least half of the remaining 1984 releases (~20 percent of total) were within only a few thousand cfs of this range. Therefore, at least 80 percent of the hourly releases for 1984 were in the High range, with 75 percent of these occurring between 25,000 and 27,000 cfs. The balance of 1984 releases were in the Flood stage, during which time the remaining 1984 accident occurred. This result tends to imply a random distribution of accidents in 1984 with respect to flow, and to confirm the adequacy and validity of the four flow ranges used here for comparing the percentages of total boat-hours and accidents in each range. Overall, however, the fact that 69 percent of all Glen Canyon accidents occurred during High range flows, which accounted for only 40 percent of total boat-hours, suggests some connection between flows and accident occurrence in this range (16,000 to 31,500 cfs).

Total Boating Use and Accidents

During the three years of this study, 27,747 boat-days were reported to have occurred on the Glen Canyon section of the Colorado River. The exact number of boats to use the river during the study period was not available. It should however, be similar to the total boat-days figure, as nearly all Glen Canyon boat use consisted of one-day fishing trips. A few boats were used for sight-seeing and research trips. Twenty-nine of these 20,000+ boats were involved in a recorded boating accident. The overall accident rate per boat-day is 0.104 percent, which translates to one recorded accident for every 957 boat-days on this section of the river. How this rate compares to other American rivers with similar recreational boating use is not known.

The annual boating use and number of accidents for Glen Canyon is shown in Table 2.

Table 2. Annual boating use and number of boating accidents in Glen Canyon for 1980, 1982, and 1984.

	Year		
	1980	1982	1984
Total reported boat-days	5,548	14,442	7,757
Recorded boating accidents	8	8	13
Accident rate	0.144% (1:694)	0.055% (1:1805)	0.168% (1:597)

Summary and Conclusions

This study was initiated to determine whether any significant correlation existed between boating accident occurrence on the Colorado River in Glen Canyon and the flow level at the time and place of each accident.

The study area is that ~17 mile, non-whitewater section of the Colorado River between Glen Canyon Dam and the confluence with the Paria River, approximately 1 river mile downstream of Lees Ferry. The study period consisted of the calendar years 1980, 1982, and 1984.

The three sources of data used in the study were: (1) National Park Service boating accident reports in two forms, the standard Case Incident Record and the U.S. Coast Guard type report, (2) the daily boat counts made by Lees Ferry NPS Rangers, and (3) hourly dam releases for all 1000 days of the study period.

Twenty-nine officially recorded accidents were used in the study. Fourteen were recorded on NPS Case Incident Records and the remaining 15 on the NPS version of the Coast Guard Boating Accident Report. Recorded information varied greatly but all reports contained a usable date, time, and location for the reported accident.

The available total boat use and hourly flow data were combined to form boat-hours and corresponding expected accidents for each of the four flow ranges. This was then compared to the number of recorded accidents in each flow-range. The lack of data on non-flow characteristics of the total Glen Canyon boat population and insufficient comparable data for the accident population, prevented the calculation of appropriate baseline figures for analyzing the effects of non-flow characteristics on boating accident occurrence. Information contained in the descriptive analyses of some flow (water-surface conditions and current strength) and several non-flow-related characteristics (such as wind and operator error) of the Glen Canyon accident population suggests that certain patterns of accident occurrence exist. These hypotheses cannot be adequately supported statistically by the available data. Statistical analysis of Glen Canyon boating accidents was therefore restricted to relating accident distribution among the assigned flow ranges to total boat-hours in each range.

Chi-Square testing was used to check for association between accident occurrence and flow-range. Data were analyzed for the 3-year study period only.

The accident distribution by flow-range for the entire study period was found to be non-random ($X^2 = 10.967$, df = 3, $P < 0.05$), with almost twice the expected number of accidents occurring during High range flows and less than a third of expected accidents occurring during Medium range flows. This result tends to imply that Glen Canyon boats or boaters are most susceptible to High range flows and least susceptible to Medium range flows, as both the Low and Flood ranges had similar numbers of recorded and expected accidents.

As indicated earlier, the use of different flows for the flow ranges used here, or the use of an alternate flow-range scenario, might result in a very different distribution of accidents. However, it is felt that the ranges used were appropriate and reasonable.

Applying a different flow-range scenario, consisting of 2,000 cfs increments, to 1984 Glen Canyon accidents, confirmed the random nature of the 1984 accident distribution and, at least in part, served to confirm the adequacy of the four-flow-range approach used in this study.

Although flow-related trends have appeared for boating-accident occurrence in Glen Canyon, the small number of recorded accidents and the lack of sufficient information on pertinent accident-related variables suggests that these results should be used carefully in reaching management decisions.

Grand Canyon

The percentages of total boat-hours and accidents in each flow-range for Grand Canyon are shown in Table 3. Of the total study-period accidents, 22.50 percent occurred during Low flows, 35.00 percent occurred during Medium flows, 25.00 percent occurred during High flows, and 17.50 percent occurred during Flood flows.

Table 3. Percent of total Grand Canyon boating accidents vs. percent of total boat-hours in each flow-range, and recorded vs. expected Grand Canyon boating accidents by flow-range for 1981 through 1983.

	Flow Range			
	Low	Medium	High	Flood
Percent of total Grand Canyon accidents	22.50	35.00	25.00	17.50
Percent of total boat-hours in flow-range	28.87	25.01	35.53	10.59
Recorded accidents	9.00	14.00	10.00	7.00
Expected accidents	11.56	10.00	14.20	4.24

$X^2 = 5.206$ df = 3 $P > 0.05$

The relationship between recorded and expected accidents for Grand Canyon is graphically illustrated in Figure 2.

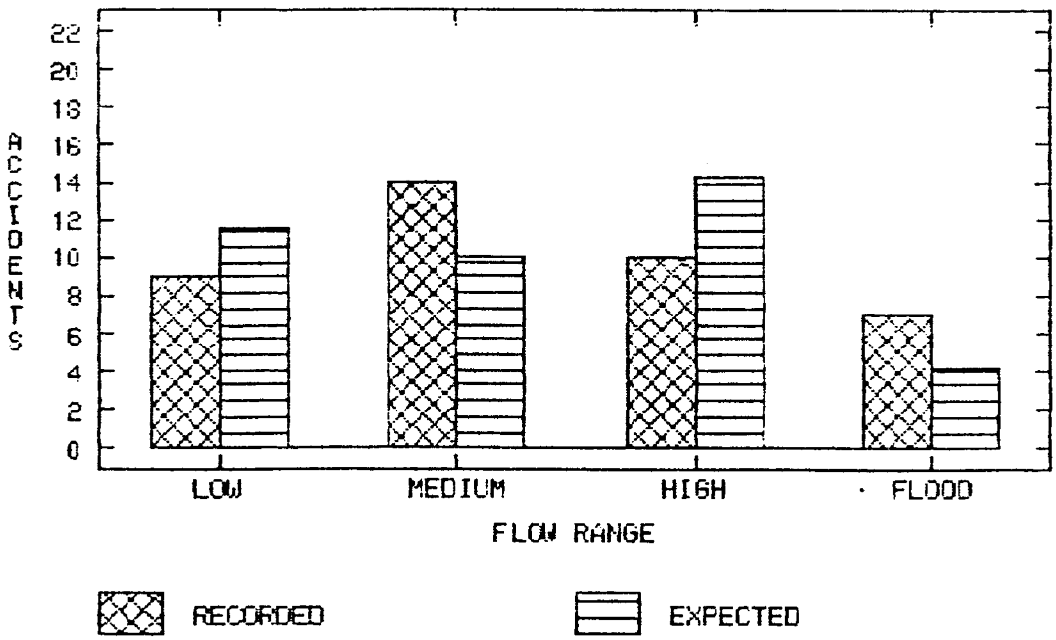

Figure 2. Recorded vs. expected Grand Canyon boating accidents by flow-range for 1981, 1982, and 1983.

Chi-Square analysis of the recorded vs. expected accident distributions for the complete study period in Grand Canyon showed the recorded accident distribution by flow-range to be random ($X^2 = 5.206$, df = 3, $P < 0.05$). Analysis of the annual Grand Canyon accident distributions indicated a random distribution for each year: 1981: $X^2 = 5.135$, df = 2, $P > 0.05$, 1982: $X^2 = 0.828$, df = 2, $P > 0.05$, and 1983: $X^2 = 3.047$, df = 3, $P > 0.05$. As with Glen Canyon, this result led to the use of data for the complete study period only in the analysis for association with flow.

Although the annual and overall distributions of accidents by flow-range were random, there were sufficient data on boat type and accident location to enable testing these variables for any relationship with accident occurrence.

Boat Type vs. Flow

Data were available on five types of boats used on the Colorado River in Grand Canyon: motor, oar, and paddle rafts; dories; and kayaks. The distributions of recorded and expected accidents according to boat type and flow-range are presented in Table 4.

Table 4. Boating accident distribution by boat type/flow relationship for Grand Canyon, 1981 through 1983.

Flow-Range	Motor Rec.	Motor Exp.	Dory Rec.	Dory Exp.	Oar Rec.	Oar Exp.	Paddle Rec.	Kayak Rec.
Low	3	5.87	0	0.83	5	4.08	1	0
Medium	7	5.03	1	0.74	5	3.51	0	1
High	5	6.46	2	1.13	3	4.98	0	0
Flood	6	3.64	0	0.31	1	1.44	0	0

$X^2 = 7.260$ df = 6 $P > 0.05$ (oar, motor, dory)

$X^2 = 3.651$ df = 3 $P > 0.05$ (oar, motor)

Individual Chi-Square tests for the motor raft, dory, and oar raft categories showed their respective accident distributions among the flow ranges to be random (all P's > 0.05). Paddle rafts and kayaks each accounted for only 1 of the 40 total recorded accidents in the study period, too small a number to be statistically analyzed for association with flow. A component analysis for association was done only on the oar, motor, and dory categories. As indicated at the bottom of Table 4, association between accidents involving these three boat types and flow level at the time of their occurrence was not demonstrated. Another component analysis using only the motor and oar raft categories also produced no association between boat type and flow level (see bottom of Table 4).

The distribution of boat-hours by flow-range for each boat type is shown in Table 5. Overall, the boat types had similar exposures to each flow-range during the study period, indicating that their distribution among the ranges was essentially random. The hard-shelled boats (dories and kayaks) tended to be on the river more during High range flows than the soft-shelled boats (i.e. inflatable rafts) and less during Flood flows. The flow-range percentages of each boat type generally reflect the corresponding aggregate boat-hour percentages for each flow-range shown at the bottom of the table.

Table 5. Percent of total boat-hours for each boat type in each flow-range for Grand Canyon, 1981 through 1983.

Boat Type	Flow-Range Low	Medium	High	Flood
Oar Raft	29.1	25.0	35.6	10.3
Motor Raft	27.9	24.0	30.8	17.3
Paddle Raft	31.1	27.1	34.5	7.3
Dory	27.7	24.5	37.6	10.2
Kayak	29.0	25.5	38.7	6.8
Aggregate percent of total boat-hours	28.9	25.0	35.5	10.6

Accident Location

Location was also analyzed as a factor in Grand Canyon boat accidents. Of the 40 accidents recorded during the 3-year study period, 13 occurred in both 1981 and 1982, and 14 occurred in 1983. All 40 occurred at 20 rapids of which Crystal and Badger Creek were the only two with recorded accidents in all three years. Twenty-five of the 40 accidents occurred at five rapids: Crystal (river mile(RM) 98) = 11, Horn Creek (RM 90) = 5, Badger Creek (RM 8) = 3, Grapevine (RM 82) = 3, and Lava Falls (RM 179) = 3.

The accident distribution by flow was similar for 1981 and 1982, with almost all of the 13 accidents for each year occurring in the Low and Medium ranges. The 1983 distribution was markedly different from those of '81 and '82, as all 14 accidents were equally distributed in the High and Flood ranges. Post-dam record high flows (> 92,000 cfs) occurred during the peak rafting season (May through September) of 1983 while both 1981 and 1982 had considerably lower, fluctuating flows during this period when most (~75 percent) of the annual boating use in Grand Canyon occurs.

In an effort to determine possible influences on accident occurrence with respect to flow and location, several location characteristics, for which data were available, were examined. These included dominant geologic strata, channel type, vertical drop, navigational-difficulty rating, and boat type. Accident locations with corresponding characteristics are shown in Table 6.

Of the five major accident locations (Crystal, Horn Creek, Badger Creek, Grapevine, and Lava Falls rapids) all except Badger are geologically composed of igneous-metamorphic or volcanic strata. Badger accounted for only three of the 25 accidents occurring at these five rapids. Therefore, 22 (88 percent) of these accidents occurred in rapids formed by non-sedimentary strata. Overall, 30 of the 40 recorded Grand Canyon accidents occurred in rapids formed in non-sedimentary strata. A breakdown of accident locations by geologic sections of the river shows the following groupings:

Non-Sedimentary Sections

Location	#Accidents
Upper Granite Gorge (RM 77 - 117)	24
Middle Granite Gorge (RM 127 - 137)	2
Volcanic Strata Rapids (RM 65, 179)	4
Total	30

Sedimentary Sections

Location	#Accidents
Marble Canyon (Lees Ferry(LF) - RM 52)	5
Sedimentary Strata Rapids below Marble Canyon (RM 52, 72, 75, 143)	4
Unknown Location (LF - Phantom Ranch)	1
Total	10

The unknown location accident involved a private party who abandoned their oar-powered trip at Phantom Ranch (RM 88) during the flood stage flows of 1983. The exact location of this particular accident was not crucial since the flows between Lees Ferry and Phantom Ranch were virtually constant at ~61,000 cfs during the entire time this trip was on the river.

Table 6. Accident location variables for Grand Canyon boating accidents during 1981, 1982, and 1983. Vertical Drop is the change in elevation from the beginning to the end of a rapid. Flow Range: 1 = Low, 2 = Medium, 3 = High, 4 = Flood. * = no data. R. = Rapid. S = Sedimentary, V = Volcanic, S-G = Schist-Granite, H-G = Hornblende-Granite. Strt. = Straight.

Accident Location	Dominant Strata	Channel Type	Vertical Drop	Flow Range	Difficulty Rating[1]	Boat Type
Crystal R.	S-G	Bend	17'	2	9.5	Oar
"	"	"	"	"	"	Motor
"	"	"	"	"	"	"
"	"	"	"	1	10	Oar
"	"	"	"	"	"	"
"	"	"	"	3	8.5	"
"	"	"	"	4	10	Motor
"	"	"	"	"	"	"
"	"	"	"	"	"	"
"	"	"	"	"	"	"
"	"	"	"	"	"	"
Horn Creek R.	S-G	Strt.	10'	1	10	Paddle
"	"	"	"	"	"	Oar
"	"	"	"	2	8	"
"	"	"	"	"	"	Motor
"	"	"	"	"	"	"
Badger Creek R.	S	Strt.	15'	1	7	Motor
"	"	"	"	"	"	Oar
"	"	"	"	3	5	Dory
Grapevine R.	S-G	Strt.	18'	3	8	Motor
"	"	"	"	"	"	"
"	"	"	"	"	"	"
Lava Falls R.	V	Strt.	37'	2	10	Oar
"	"	"	"	"	"	"
"	"	"	"	"	"	Kayak
House Rock R.	S	Strt.	10'	2	7	Motor
24.5 Mile R.	"	Bend	9'	3	5	Dory
Nankoweap R.	"	"	25'	4	3	Motor
Lava Canyon R.	V	Strt.	4'	1	3	"
Unkar R.	S	Bend	25'	3	6	Oar
Nevills R.	"	"	15'	2	"	"
Sockdolager R.	S-G	Strt.	19'	3	9	Motor
River mile 79[2]	"	"	*	1	*	Oar
Above Phantom	*	*	*	4	*	"
Hermit R.	S-G	Strt.	15'	3	9	Motor
Boucher R.	"	Bend	13'	2	4	"
River mile 99.5	"	"	*	3	5	"
Bedrock R.	H-G	Strt.	7'	2	8	Dory
Tapeats R.	Diabase	"	15'	1	7	Motor
Kanab Creek R.	S	"	*	2	3	"

[1] Stevens 1983.
[2] May be the same as Sockdolager Rapid.

The navigational difficulty assigned to Grand Canyon rapids is based on the Western (or American) scale of river-rapid rating. This scale ranges from 1 to 10 with a rating of 1 indicating an easily run rapid and 10 indicating an extremely difficult and dangerous (sometimes unrunnable) rapid. The ratings are made largely from the perspective of oar-powered boats (Interagency 1980; Stevens 1983).

The average navigational difficulty for the five major accident locations was 9, and ~6 for the other 15 locations. For the geologic river sections listed above, these figures are:

Marble Canyon locations	~6
Upper Granite Gorge locations	~9
Middle Granite Gorge locations	~7-8
Volcanic strata rapids (RM 65, 179)	~8 (10 for Lava)
Sedimentary strata rapids below Marble Canyon (RM 52, 72, 75, 143)	~4-5

Relating flow level to the five major accident locations provides perhaps the most interesting combination of known accident variables. Each location is discussed separately.

Chi-Square analysis of the recorded accident distribution by flow-range for Crystal Rapid showed it to be non-random ($X^2 = 15.338$, df = 3, $P < 0.05$). In order to compute expected accident values for each of the five major Grand Canyon locations, the assumption was made (as stated earlier) that the flows at each location were essentially the same as those released at Glen Canyon Dam. This premise is not entirely accurate because of attenuation and temporal delay of flows through the canyon. However, it was necessary for this analysis because of the inability to pinpoint boat locations at any given time.

All 11 Crystal Rapid accidents involved only motor and oar rafts, and an analysis of these accidents by boat type showed a non-random distribution of motor raft accidents among the flow ranges ($X^2 = 16.052$, df = 3, $P < 0.05$) and a random distribution of oar raft accidents ($X^2 = 1.142$, df = 3, $P > 0.05$). Five of the seven motor raft accidents at Crystal Rapid occurred in Flood range flows. Oar raft accidents at Crystal were fairly evenly distributed among the four flow ranges.

Testing Crystal Rapid accidents as a group for a possible relationship between boat type and flow showed an association between these variables ($X^2 = 8.130$, df = 3, $P < 0.05$). The association appears to have been primarily the result of the high number of motor raft accidents in the Flood flow-range. Five of the 11 Crystal accidents occurred during the 1983 spills. All five accidents involved large motor rafts and occurred at flows between 61,200 and 70,500 cfs during one week in June. There were considerable equipment loss and damage, many injuries, and one fatality.

While Crystal Rapid was a problem for motor rigs at flood flows, Horn Creek Rapid appeared to have been most dangerous during low and medium flows. All five accidents there occurred in flows between 7,000 and 10,850 cfs. Note that this spread involves both the Low and Medium flow ranges.

With only five accidents occurring in two flow ranges, Chi-Square analysis of Horn Creek Rapid accidents would not have been statistically valid. Therefore, no testing for association with flow was done for the Horn Creek location. However, the grouping of all five accidents (involving motor, oar, and paddle rafts) in flows between 7,000 and 10,850 cfs strongly suggests that Horn Creek was most dangerous, during the study period, at flows below 11,000 cfs regardless of boat type. Horn Creek is considered by experienced river runners to be most dangerous between 4,000 and 10,000 cfs (Stevens 1983).

Badger Creek, Grapevine, and Lava Falls rapids each had three recorded accidents during the study period, too small a number on which to base credible conclusions, statistical or otherwise. The circumstances of accident occurrence at each location may, however, provide useful information.

Two of the three Badger Creek Rapid accidents occurred between 6,000 and 7,000 cfs, the other at 28,200 cfs. All three Grapevine Rapid accidents occurred in the High flow-range, between 22,600 and 27,900 cfs during the summer of 1983. Two occurred at 27,900 cfs and all three involved rafts (two motor, one oar). Like Horn Creek, it would appear that Grapevine was most dangerous during the study period within a narrow band of flows, in this case in the High range.

The three recorded Lava Falls Rapid accidents all occurred in the Medium flow-range (9,100 to 12,750 cfs) during the summer of 1982. Two of these three accidents involved oar rafts. These circumstances could suggest that Lava Falls was most dangerous in Medium range flows during the study period.

Analysis of the channel type variable revealed that there is a similar distribution (22 vs. 17) between straight channel alignments and those on a bend among all locations.

Vertical drop figures indicate that there is an average drop of ~18′ for the five major accident locations, and slightly greater than 14′ for the 15 individual accident locations. This may in part explain the difference in the average difficulty rating for the two location groups. Vertical drops, as well as some other variables were not available for some locations.

Summary Statistics

During the 3 years of this study, 7,727 boats were launched from Lees Ferry in 2281 separate trips, resulting in over 75,000 boat-days on the river. Approximately 40 of the 7,727 study-period boats were involved in 40 accidents recorded, by the Park Service at Grand Canyon, as having occurred during navigation of the river. The overall accident rate per boat was ~0.52 percent, which translates to one of every 193 boats launched from Lees Ferry. The rate per boat-day was ~0.05 percent. The rate per trip was 1.75 percent, indicating that one trip in 57 had a recorded accident. The accident rate by boat type for Grand Canyon is shown in Table 7. Table 8 ranks the Grand Canyon boat types by population size and accident rate.

Table 7. Total boating population vs. accident population by boat type in Grand Canyon, 1981 through 1983.

	Oar	Motor	Kayak	Dory	Paddle
Total Population	3,685	2,172	1,353	343	174
Accident Pop.	14	21	1	3	1
Accident Rate	0.38% (1:263)	0.97% (1:103)	0.074% (1:1353)	0.88% (1:114)	0.58% (1:174)

Table 8. Population size and accident rate rankings by boat type for Grand Canyon, 1981 through 1983.

Boat Type	Population Size	Accident Rate
Oar	1	4
Motor	2	1 (highest)
Kayak	3	5
Dory	4	2
Paddle	5	3

Comparing the population sizes and accident rates of each boat type showed that the 2,172 motor rafts had the highest accident rate. This rate was almost three times greater than the second lowest rate of the 3,685 oar rafts. Oar and motor rafts combined accounted for 76 percent of the total boats and 87 percent of the total recorded accidents. Dories, with the second lowest number of boats (343), had the second highest accident rate. Kayaks had the lowest accident rate and third largest number of boats (1,353). Although there are wide variations among the boat types, it is important to remember that the overall reported accident rate is still very small (< 1 percent).

Summary and Conclusions

This study was initiated to determine whether any significant correlation existed between boating accident occurrence on the Colorado River in Grand Canyon and the flow level at the time and place of each accident.

The study area covered the ~225 mile, whitewater section of the river between Lees Ferry and Diamond Creek. The Grand Canyon study period included National Park Service recorded accidents for the calendar years of 1981 through 1983. Forty boating accident reports were used in the study; all contained the essential information on the date, time, and location of the accident.

Chi-Square testing was used to check accident distributions by boat type, location, and flow level because the 40 recorded accidents (from a population of 7,727 boats) produce such a low incidence rate that more powerful statistical techniques could not be applied. Variables tested were flow, boat type and accident location. Other accident related variables were eliminated for lack of supporting data.

The accident distribution by flow-range for the complete Grand Canyon study period was found to be random. An analysis of the complete boat type/flow relationship for the entire Grand Canyon study section found the distributions of each boat type to be similar and random with respect to flow.

The 40 recorded accidents used in the study occurred at 20 different locations, all of which were rapids. Twenty-five accidents occurred at five rapids (Crystal = 11; Horn Creek = 5; Badger Creek, Grapevine, Lava Falls = 3 each). Crystal Rapid was tested for association with flow-range and showed a non-random distribution of accidents. In addition, it showed an association between boat type and flow.

The accident totals for each of the other four major accident locations were too small to be meaningfully tested for association with flow. Descriptive analyses of these locations suggested that Horn Creek Rapid was most dangerous below 11,000 cfs during the study period; Grapevine Rapid could be considered especially dangerous during High range flows, and Lava Falls Rapid during Medium range flows. Badger Creek Rapid showed no discernible patterns.

The overall results of this analysis indicate that there is no demonstrable association between flow and recorded boating accident occurrence on the Colorado River in Grand Canyon National Park during the years of 1981 through 1983. However, certain Grand Canyon accident locations do show association or suggest some connection between flow and accident occurrence. Crystal Rapid between 60,000 and 70,000 cfs and Horn Creek Rapid below 11,000 cfs are the best examples.

The overall accident rate is low and data on other accident related variables, such as operator experience and weather conditions, are lacking. Under these circumstances it is very possible that variables other than flow may have significant impacts on accident occurrence. Without data on these associated variables, it is difficult to assess the relative effect of one or two.

The analysis of all accident related data used in the study and verbal information gained from well-informed sources strongly suggested that many more accidents occur in both study sections than are actually recorded. This situation may provide impetus for additional boating accident research. However, with the present very low accident rate, the number of additional accidents that may be identified would have to be considerable in order for the results of this study to change significantly.

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