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# Cooperative National Park Resources Studies Unit 

## ARIZONA

TECHNICAL REPORT No. 16
SIMULATING THE EFFECTS OF GLEN CANYON DAM RELEASES ON GRAND CANYON RIVER TRIPS
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## COOPERATIVE NATIONAL PARK RESOURCES STUDIES UNIT <br> University of Arizona/Tucson - National Park Service

The Cooperative National Park Resources Studies Unit/University of Arizona (CPSU/UA) was established August 16, 1973. The unit is funded by the National Park Service and reports to the Western Regional Office, San Francisco; it is located on the campus of the University of Arizona and reports also to the Office of the Vice-President for Research. Administrative assistance is provided by the Western Archeological and Conservation Center, the School of Renewable Natural Resources, and the Department of Ecology and Evolutionary Biology. The unit's professional personnel hold adjunct faculty and/or research associate appointments with the University. The Materials and Ecological Testing Laboratory is maintained at the Western Archeological and Conservation Center, 1415 N. 6th Ave., Tucson, Arizona 85705.

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\text { April } 1986
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NATIONAL PARR SERVICE/UNIVERSITY OF ARIZONA National Park Service/Bureau of Reclamation Interagency Agreement No. 4-AA-40-01930

The controversy over peaking power studies at Glen Canyon Dam in Page, Arizona, has prompted the Secretary of the Interior to initiate a program to evaluate the long-term impacts of the dam's operation on the downstream environment. In 1982, the Bureau of Reclamation, National Park Service, and U.S. Fish and Wildlife Service joined forces to investigate two basic aspects: (1) how the present flow patterns impact the riverine environment (especially how low flows affect rafting and fishing); and (2) how the dam operation could be improved for the benefit of all concerned (boaters, flora, fauna, and beaches) within the constraints of water commitments and power demand.

This project is funded by revenue from power generation at Glen Canyon Dam. Four areas are being studied: aquatic and terrestrial biology, sediment and hydrology, recreation, and operation. Overall, there are forty-two separate studies.

## ACRNOHLEDGMENTS

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## ABSTRACT

The Bureau of Reclamation and the National Park Service are cooperatively sponsoring a series of studies to determine the downstream impacts of various release patterns from Glen Canyon Dam. In order to reflect the impact of fluctuating Glen Canyon Dam releases on Grand Canyon river trips, the Shechter-Lucas Wilderness Use Simulation Model has been modified. The model now simulates changes in flow as predicted by the Streamflow Synthesis and Reservoir Regulation computer flow model for the Colorado River. The two models have been linked to provide data on the impacts of alternative dam releases on river trips, including data on delays at rapids, encounters with other parties, and the time available for visiting attraction sites. Comparison and analysis of the model's outputs provide data on the effects of alternative scenarios on river trips through Grand Canyon National Park.

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## INTRODUCTION

The Bureau of Reclamation and other federal agencies are cooperatively sponsoring a series of studies to determine the downstream impacts of various release patterns from Glen Canyon Dam. This particular study modified the Lucas-Shechter Wilderness Use Simulation Model (WUSM) to simulate the effects of dam releases on river trips through Grand Canyon National Park. The output of the Streamflow Synthesis and Reservoir Regulation (SSARR) model for the Colorado River, which computes river flow for 11 downstream locations based on hourly dam releases, was used as input into the WUSM. The effects of river flow on river trips which could and could not be simulated, as well as some of the limitations of this computer model, are discussed in this section. The methods discussion briefly describes how the WUSM works. Nine alternative flow scenarios are tested on the model against May and July launch schedules.

Releases from Glen Canyon Dam control the flow of the Colorado River through Grand Canyon National Park to Lake Mead. The effects of these releases are most pronounced nearest the dam. Lees Ferry, approximately 16 river miles from the dam, is as close as Grand Canyon river trips come to the dam. Even at this point there is some attenuation of river flow. A particular dam release may take up to 24 hours to reach Phantom Ranch, 88 miles below Lees Ferry, and over 2 days to reach Diamond Creek, at river mile 225. Figure 1 illustrates river flow as affected by Glen Canyon Dam releases. In Figure 1a note that it takes 4 hours for a peak dam release to arrive at Lees Ferry. Figure 1b shows the minimum and maximum daily fluctuations at 12 locations on June 18, 1979, as well as the river flow at these locations at 12:00 noon.

There are a number of direct effects of dam releases upon river trips. The most obvious is the fluctuation of the river level. The volume of water released also affects the velocity of the river flow, which increases in proportion to the volume of water released. These velocities influence the speed of travel of boating parties on the river. Rapids become unsafe and/or unnavigable at either extreme of volume or velocity. At low water, rocks are exposed and boats run the danger of being grounded between or upon them, or more serious accidents can occur. At high water and velocity, the turbulence of the water and size of the waves are so great that serious injury can occur to passengers and/or equipment.

We studied the effects of dam releases ranging from 1,000 to 35,000 efs. Because of fluctuations in volume of flow, the volume and/or velocity can be significantly different at different points along the river at any one time (see Figure 1). The WUSM incorporates all 11 flow stations of the SSARR model, thereby simulating fluctuating flows at all points along the river.


Figure 1. The effects of dam releases on river flow through Grand Canyon National Park. (a) Glen Canyon Dam releases over a 48 hour period, and the flow measured at Lees Ferry in cubic feet per second (cfs). (b) Colorado River flow on June 18, 1979 at 12:00 noon, and the minimum and maximum daily flows, at Glen Canyon Dam and 11 downstream locations.

One effect of fluctuating flows not incorporated into the WUSM is the impact of radical changes in releases over a short period of time. When releases drop or rise very quickly, there are effects which are not quantified, and therefore not simulated. What is simulated are the flows at specific locations at specific times, independent of the flow of the previous hour. In other words, it is not important to the model whether the river is rising or falling, rather it is the flow at a particular location at a specific time which is of primary interest. Another effect which is not simulated is the beaching of boats which can occur when the river level falls drastically during the night, and the boat is not in deep enough water. This has been a problem in the past, and is not included in the simulation model. Models are not exact replicas of real systems; many aspects of real life are omitted or drastically simplified. The WUSM incorporates as many of the salient features of Grand Canyon river trips as possible.

This model has approximately 3000 lines of computer code which attempt to reproduce the conditions of the "real world." In most computer models, simplifying assumptions must be made, for there are simply too many variables to include in a model. The validity of the model is discussed in Appendix A. Important assumptions about river trips made by the model are discussed. In addition, this model is dependent upon random number generation in order to produce events, As a result, one event is dependent upon a previous event, and therefore, the results of one simulation can not be subjected to parametric statistical analysis. However, two simulations can be compared parametrically, since two simulations are independent of each other.

## METHODS

The WUSM was originally designed for wilderness trail systems, under the premise that user satisfaction in wilderness areas was inversely proportional to the number of encounters with other parties. It is designed to simulate travel, both for hikers and horseback riders, through a wilderness trail system. Its primary outputs are: (1) the number of encounters with other parties; (2) the locations where they occur; and (3) the use of campsites, attraction sites, and trail segments

For this study, we have added lines of code which made it possible to include the effects of river flow on simulated raft trips. The trail system is the Colorado River through Grand Canyon National Park. It includes the river from Lees Ferry to Diamond Creek (approximately 225 river miles) and all possible hiking stops. These 225 miles were divided into 199 river segments. Separating river segments are campsites, attraction sites, and other possible stops. In all, there are 110 attraction sites and 140 campsites. All river segments and attraction sites have an associated travel or visit time. These times were originally obtained by Shelby \& Nielsen (1976 a-d).

The original WUSM had two types of users, hikers and riders. Underhill and Xaba (1983) changed this to oars and motors. The single trailhead is Lees Ferry, and the two exit points are Whitmore Wash and Diamond Creek. River trip lengths are from 5 to 18 days; 5 to 11 days for motor trips, and 12 to 18 days for oar trips. Simulated trips have preplanned itineraries, which is unlike actual trips. All Grand Canyon river trips are permitted by the National Park Service (NPS) for a specified length of time. However, within that trip's duration, the party is free to choose where it camps and what attraction sites it visits. The WUSM is unable to do this, so preplanned itineraries are its first assumption. River trip itineraries were developed by a computer program which utilized actual frequency of use data from 1980-1983 for Grand Canyon river trips (Underhill \& Xaba 1983). Therefore the itineraries used in the model are representative of typical trips taken in Grand Canyon, and the launch schedule is the actual one administered by the NPS.

The WUSM simulates party launches from Lees Ferry according to a launch schedule (the number of trips, their trip duration and the type oar or motor). Parties proceed downstream according to their itineraries (which are chosen at random based on trip duration and mode of travel). Encounters, use of all segments, campsite arrival times and various other data are recorded after each simulated week. The program simulates five weeks: during the first two, parties proceed downstream to initialize the run; for the remaining three, all encounters and use levels are recorded.

The effects of river flow are felt in the navigability of rapids and the speed of river travel. The first step in measuring the effects of flow is to determine the flow of the river at the location where a party is located. The SSARR model computes river flow for 11 downstream locations. The river was divided into 11 reaches, one for each station, with the midpoint between two consecutive stations dividing two reaches. River segments were assigned to a flow station according to which reach the river segment was located. For example, the Little Colorado flow station is located at river mile 61.6, which is river segment 60. The Hance Rapid station is located at river mile 77.1, or river segment 76. Therefore river segments 60 through 68 were assigned to the Little Colorado Station, and segments 69 through 76 went to the Hance Rapid station (see Table 1).

Table 1. Name, location and referenced river segments to 11 flow stations.

| Name/Location | Starting Segment | Ending |
| :--- | ---: | :---: |
| Lees Ferry | 1 | 4 |
| Badger | 5 | 14 |
| Lo Mile | 15 | 40 |
| Little Colorado | 41 | 68 |
| Hance Rapid | 69 | 80 |
| Grand Canyon/Phantom | 81 | 87 |
| Upper Granite | 88 | 106 |
| Bedrock Rapid | 107 | 135 |
| Last Chance | 136 | 158 |
| Lava Falls | 159 | 181 |
| Trail Canyon | 182 | 199 |

The flow at a river segment is determined by the date and time that a party is at that segment. For example, if a river party arrived at segment 1 at 10 am on Monday, July 2, the model checks the Lees Ferry flow station to determine the flow at that time. This flow is then used to compute a speed factor. Speed factors were different for oar and motor parties, as shown below. Straight-line interpolation was done by the model

Oar Speed Factors Motor Speed Factors

| 1,000 cfs | 3.0 | 2.0 |
| ---: | :---: | :---: |
| 5,000 cfs | 2.0 | 1.7 |
| 16,500 cfs | 1.0 | 1.0 |
| 35,000 cfs | 0.8 | 0.8 |

between these four flow values. Since the base travel times in the model were for a steady flow of 16,500 cfs, the factor for this flow was 1.0 . Data collected during the study indicated that at higher flows, both motor and oar trips increased their speed proportionately. Lower flows slowed oar trips more than motor trips. This is probably due to the fact that a motor can be run at high speed for a long period of time, unlike an oarsmen. Upriver winds also contribute to slower oar travel.

For simulated oar trips, travel times on the river and at attraction sites are 1.75 times longer than for motor trips (computed by Underhill \& Xaba 1983). For oar trips, the speed of travel is computed by multiplying the speed factor, the travel time, and 1.75. For motor trips, speed of travel is the product of the speed factor and the travel time.

River flow also determines whether a particular river segment is traversable. Of the 199 river segments, 24 are rapids where delays occur below a particular flow level. When faced with low flow at a rapid, it is up to the boatman to determine whether the party walks around the rapid while he navigates the boats through; they wait for higher water; or they float the river segment without hesitation. The variables in this decision process include the rising or falling of the river over the next few hours, their trip length, time of day, and location Data were not collected on these variables, such that the model was not programmed to make this decision A second assumption was made: all parties in the model would handle a delay at a rapid exactly the same way. Two ways were programmed, so two simulations were run for each flow alternative. The first method was as follows: If a party was scheduled to travel a rapid at a water level below that shown in Table 3 for that boat type, the party waited for one hour, during which time the passengers either walked around the rapid or decided to run the rapid at the present level. After one hour, the boats proceeded through the rapid according to the time allotted for that river segment. This was called the WALK routine. The second method skipped the WALK routine: the party waited for the water to rise above the benchmark flows shown in Table 3, regardless of how long the wait.

The data from these two simulations were combined to present results during which half of the time the party waited for higher water, and half of the time the party walked around the rapid. In some cases, this meant waiting 4 or more hours. Actual river trips use both these methods, and others, in handling delays at rapids. However, averaging these two methods provided an illustration of the effects of low flow scenarios on river trips, and was useful for purposes of comparison.

Tables 2 and 3 contain flow information gathered by the "expert witness" method of data collection. Because low river flows did not occur during the summer rafting season in the course of this study, we had to rely on surveys of, and conversations with, boatmen who had a minimum of five years experience on the river. They were judged to be in a position to know river conditions at low water and thus be expert witnesses.

Rapids are assigned to 7 classes based on their characteristics at particular flows. Most rapids are Class 1; above 1,000 efs, motors, oars and dories can be successfully navigated through them. Classes 2 through 7 are assigned to rapids where delays will occur if the flow was below that listed for that boat type for that class of rapid. There were 24 rapids in classes 2 through 7.

Table 2. Rapid class benchmark flows in cfs.

|  | Oars | $\underline{\text { Motors }}$ | Dories |  |
| :--- | :---: | :---: | :---: | :---: |
| Class 1: | $1000-$ | $1000-$ | $1000-$ (No effects) | 3000 |
| Class 2: | 2500 | 4000 | 5000 |  |
| Class 3: | 2500 | 6000 | 6000 |  |
| Class 4: | 3500 | 5000 | 5000 |  |
| Class 5: | 2000 | 5500 | 6500 | 3000 |
| Class 6: | 550 |  |  |  |
| Class 7: Impassable for all between 4000 and 10000 |  |  |  |  |

Whether a particular rapid is navigable or not is the judgment of the individual boatman. For example, a few oarsmen claimed that the entire river was navigable by an oar boat when dam releases were as low as 1,000 cfs on a continual basis. Others disagreed sharply, suggesting that they were forced to wait or walk around rapids at flows higher than shown in Table 3. Therefore, the data in Table 3 were based on the average of approximately 35 surveys. When comparing alternative flow scenarios, the absolute numbers, although important, were not critical. Any change in the data would produce similar changes in all of the alternatives.

Table 3. Flows (in cfs), by boat type, below which delays occur at rapids.

|  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
| Rapid | Class | Oars | Motors | Dories |
|  |  |  |  |  |
| Badger | 3 | 2500 | 4000 | 5000 |
| Soap Creek | 4 | 3500 | 6000 | 6000 |
| House Rock | 6 | 5500 | 6500 | 3000 |
| $24.5 / 25$ Mile | 3 | 2500 | 4000 | 5000 |
| Kwagunt | 3 | 2500 | 4000 | 5000 |
| Unkar | 2 | 2500 | 3000 | 6000 |
| Hance | 4 | 3500 | 6000 | 6000 |
| Sockdolager | 2 | 2500 | 3000 | 6000 |
| Grapevine | 2 | 2500 | 3000 | 6000 |
| Zoroaster | 2 | 2500 | 3000 | 6000 |
| Horn | 7 |  | $4000-10000$ |  |
| Granite | 5 | 2000 | 5000 | 5000 |
| Hermit | 5 | 2000 | 5000 | 5000 |
| Ruby | 3 | 2500 | 4000 | 5000 |
| Serpentine | 2 | 2500 | 3000 | 6000 |
| Waltenberg | 5 | 200 | 5000 | 5000 |
| Forster | 2 | 2500 | 3000 | 6000 |
| Fossil | 2 | 2500 | 3000 | 6000 |
| Bedrock | 4 | 3500 | 6000 | 6000 |
| Deubendorff | 4 | 3500 | 6000 | 6000 |
| Tapeats | 2 | 2500 | 3000 | 6000 |
| Upset | 3 | 2500 | 4000 | 5000 |
| Lava | 5 | 2000 | 5000 | 5000 |
| 212 Mile | 2 | 2500 | 3000 | 6000 |

Two simulations were run for each flow scenario. Data were produced for each simulated week, so there were six weeks of data for each of the five alternatives. Three of these six weeks used the WALK routine, and the remaining three had the parties wait for higher, safer water. Two months were simulated. The July 1984 schedule, which launched 186 trips in five weeks, represented the peak summer months of June, July and August. The May 1984 schedule, which launched 127 trips in five weeks, represented the other high use months of May and September. October through April are low use months. The July data and the May data were analyzed and compared separately; the July data are discussed first under Results.

This has been only a brief discussion of how the original Wilderness Use Simulation Model, and the Colorado River flow modification works. More information can be obtained in Shechter (1975), Shechter \& Lucas (1978), Underhill \& Xaba (1983), Underhill et al. (1986), and Borkan (1986).

## RESULTS

Results from the July and May launch schedules are analyzed separately in this section. The July schedule is discussed first.

## July Launch Schedule

The peak rafting season in Grand Canyon National Park is the summer months of June, July, and August. In July 1984, 186 trips were launched from Lees Ferry (see Table 4).

## July Flow Scenarios

Presently, an agreement exists between the Bureau of Reclamation and the National Park Service that the minimum dam release during June, July and August not fall below 3000 cfs. Of the five alternative flow scenarios tested, none violated this condition. The alternative scenarios included hourly dam releases for both weekdays and weekends; traditionally, weekend releases are lower than weekday releases. For each month of each flow scenario, the SSARR flow computed river flow at 11 downstream locations. These were based on hourly dam releases, consisting of 5 days of weekday flows then 2 days of weekend flows for three weeks. The flows that were selected for the model were from the middle of this period, starting on a Sunday, and ending on a Saturday, insuring that the full effect of the scenario was felt along the entire length of the river.

Each of the five flow scenarios had a dam release prescription for each of the twelve months of the year. Within each month, every week was identical. The July flow scenario for alternatives two and five was identical, so for the remainder of this report, the results of alternative 2 represent both alternatives 2 and 5. The range of releases for the four July alternatives is listed below in cfs. If a range of releases is noted, than the alternative was a fluctuating scenario.

|  | weekdays | weekends |
| :--- | :--- | :--- |
| Alternative 1: | 12,750 constant | 12,750 constant |
| Alternatives $2 \& 5:$ | $6,600-31,500$ | $3,600-23,400$ |
| Alternative 3: | $8,500-25,000$ | $8,500-26,700$ |
| Alternative 4: | 25,000 constant | 25,000 constant |

Figures $2-5$ show the hourly releases for both weekdays and weekends for all four alternatives. These releases are not used by the model: it is routings of these releases through the SSARR model to the 11 flow stations which are used. However, these releases determine the downstream flow of the Colorado River through Grand Canyon National Park. The model has been modified to reflect their effects on the number of encounters, delays at rapids, and time for attraction site visits.

Table 4. July 1984 launch schedule showing number of days and type of propulsion for each trip launched on any one day. *= private trip; **= NPS patrol trip; *** research trip. Total number of boats launched in July by type: oar: 271; motor: 180; paddle: 10; kayak: 119; dory: 17.

| SUNDAY | MONDAY | TUESDAY | WIEDMESDAY | THURSDAY | FRIDAY | SATURDAY |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| JULY 1 <br> 6 motor <br> 6 motor <br> 9 motor <br> 13 oar* <br> 13 oar <br> 14 dory | $\quad 2$ 5 motor 6 motor 12 oar 13 oar 13 oar 13 oar* | 6 motor <br> 6 motor <br> 7 motor <br> 7 motor <br> 7 motor <br> 8 motor <br> 9 motor <br> 12 oar <br> 18 oar* | 6 motor <br> 7 motor <br> 7 motor <br> 8 motor <br> 8 motor <br> 8 motor* <br> 9 motor | $\begin{gathered} 5 \\ 6 \\ 6 \\ 6 \\ \text { motor } \\ \text { motor } \end{gathered}$ | $\begin{gathered} 6 \\ 8 \text { motor } \\ 8 \text { motor } \end{gathered}$ | ```7 motor 8 motor 8motor 8motor 8motor 14 oar 14 oar*``` |
| ```8 6 \text { motor} motor motor 8motor 12 oar 13 oar 18 oar*``` | $\quad$ $\quad 9$ <br> 5 motor <br> 6 motor <br> 7 <br> 8 motor <br> 8 motor <br> 9 motor <br> 12 oar <br> 13 oar** <br> 18 oar* | $\quad 10$ 7 motor 7 9 motor 9 motor 12 oar* 13 oar | 11 <br> 6 motor <br> 6 <br> 6 motor <br> 7 <br> 8 motor <br> 8 motor <br> 9 motor <br> 9 motor <br> 18 oar * | $$ | $\begin{array}{\|c\|} \hline 13 \\ 6 \text { motor } \\ 7 \text { motor } \\ 12 \text { oar } \end{array}$ | 7 motor <br> 8 motor <br> 8 motor <br> 14 oar* |
| 15 <br> 6 motor <br> 6 motor <br> 7 motor <br> 13 oar <br> 14 oar* <br> 13 oar | 16 <br> 5 motor <br> 12 oar <br> 12 oar <br> 12 oar* <br> 12 oar <br> 14 oar | ```17 motor motor motor motor 12 oar* 15 oar*``` | $\begin{aligned} & \quad 18 \\ & 6 \text { motor } \\ & 9 \text { motor } \\ & 9 \text { motor } \\ & 12 \text { oar } \\ & 12 \text { oar } \end{aligned}$ | $$ | ```20 8 motor 8 motor 17 oar``` | ```21 8 motor motor 8motor motor 13 oar*``` |
| 22 6 motor 13 oar 13 oar 13 dory* | 23 <br> 5 motor <br> 6 motor <br> 8 motor <br> 12 oar <br> 13 oar <br> 13 oar <br> 18 dory | 24 7 motor 8 motor 8 motor 8 motor 9 motor 13 oar 18 oar* | $\begin{aligned} & 25 \\ & 6 \text { motor } \\ & 9 \text { motor } \\ & 12 \text { oar } \\ & 18 \text { oar } \end{aligned}$ | $\begin{array}{\|l\|} \hline 26 \\ 6 \text { motor } \\ 7 \\ 8 \text { motor } \\ 8 \text { motor } \\ 13 \text { oar ** } \\ 14 \text { oar** } \end{array}$ | 6 motor <br> 7 motor <br> 12 oar <br> 12 oar* <br> 14 oar | 28 8 motor 8 motor 8 motor 18 oar* |
| 29 6 motor 6 motor 7 motor 13 oar 14 oar* 14 oar | 30 5 motor 9 motor 12 oar 12 oar 18 oar* | $\begin{aligned} & 31 \\ & 7 \text { motor } \\ & 7 \text { motor } \\ & 8 \text { motor } \\ & 8 \text { motor } \\ & 9 \text { motor } \\ & 16 \text { oar } \end{aligned}$ | $\begin{aligned} & \hline \text { AUGUST } 1 \\ & 6 \text { motor } \\ & 8 \text { motor } \\ & 9 \text { motor } \\ & 12 \text { oar } \\ & 12 \text { oar*** } \\ & 18 \text { oar* } \end{aligned}$ | ```2 motor motor motor* 12 oar``` | $\begin{array}{\|c} \hline 3 \\ 8 \text { motor } \\ 12 \text { oar } \\ 18 \text { dory } \end{array}$ | 6 motor <br> 7 motor <br> 8 motor <br> 8 motor <br> 8 motor <br> 8 motor <br> 13 oar* <br> 14 oar |



Figure 2. Alternative 1 - July hourly dam releases.


Figure 3. Alternatives $2 \& 5$ - July hourly dam releases.


Figure 4. Alternative 3 - July hourly dam releases.


Figure 5. Alternative 4 - July hourly dam releases.

## Comparison of July alternatives by the model

Tables 5 through 9 compare the effects of these four scenarios on encounters with other parties, mean campsite arrival times, time available for attraction site visits, and delays at rapids. All four alternatives were run twice through the WUSM; this provided data for six weeks. Half of this data used the WALK routine explained earlier; the second half had the party wait for higher water, regardless of how long the wait. The exception to this rule was Horn Creek. Some of the May alternatives would have delayed parties there for days, and possibly for the entire simulation, since the flow at Horn never would have exceeded 10,000 cfs or fallen below 4,000 cfs. Therefore, for the purposes of comparison, when a party was delayed at Horn Creek, the WALK routine was always used. It is not important that in reality one can not walk around Horn Creek Rapid. The idea was that the party was delayed by low water: Then, because boatmen knew higher flows were not forthcoming, the trip proceeded.

Many of the following tables involve encounters between parties. A party is defined as a group of one or more boats with passengers, launching under one permit on the same day. An encounter is defined as one party coming in contact with another party. The four kinds of encounters are meeting, overtaking, visual, and camp. Meeting encounters occur when one party encounters another at an attraction site. Overtaking encounters occur on the river and at attraction sites, when one party passes another party. Visual encounters are when one party sees another party at a different location. Camp encounters occur when one party camps with another party at a campsite. It is important to note that, first, double counting could and did occur, as noted in the tables; and second, visual encounters are counted when one party sees the boats of another party, whether or not their passengers are present. For example, if a party is up canyon at Havasu, and another party floats by Havasu, two visual encounters are recorded (one for each party), yet the one party did not witness it because they were up canyon, away from the river.

Table 5 provides data on the average number of encounters per party at selected attraction sites. This table is read in the following manner: At Redwall Cavern during alternative 1, a party there encountered on the average 0.60 other parties ( 6 times out of 10 a party will share Redwall Cavern with another party.). These were on-site encounters (meeting plus overtaking). A party at Redwall under Alternative 1 saw on the average 0.71 other parties float by Redwall Cavern ( 7 out of 10 times they saw another party float by while at Redwall.). These are off-site (or visual) encounters. Double counting occurred in the data for table 5: a party could arrive at Redwall, and encounter another party, which recorded one meeting encounter at Redwall. When this party left and returned to the river again, a visual encounter was recorded. This visual encounter was recorded twice, once at Redwall and once on river segment 37 , the segment directly after Redwall. Although visual encounters were overcounted, the degree of overcounting was similar for all alternatives, and therefore not crucial to the comparison.

Table 5. Average number of encounters per party per visit to selected attraction sites, by July alternative. $N=218$ parties. On-site encounters are with another party at the same attraction site (meeting plus overtaking). Off-site encounters are visual encounters where a party at the attraction site sees another party either on the river or at an adjacent campsite. There was some double counting of off-site encounters.

| Location | July Flow Alternative |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | \#1 |  | \#2, \#5 |  | *3 |  | \# 4 |  |
|  | $\begin{aligned} & \text { on- } \\ & \text { site } \end{aligned}$ | offsite | on- site | off- <br> site | $\begin{aligned} & \text { on- } \\ & \text { site } \end{aligned}$ | off- <br> site | $\begin{aligned} & \text { on- } \\ & \text { site } \end{aligned}$ | off- <br> site |
| Redwall |  |  |  |  |  |  |  |  |
| Cavern | 0.60 | 0.71 | 0.70 | 0.81 | 0.66 | 0.73 | 0.93 | 0.88 |
| Nankoweap |  |  |  |  |  |  |  |  |
| Canyon | 0.31 | 1.65 | 0.40 | 1.58 | 0.35 | 1.61 | 0.45 | 1.66 |
| Little |  |  |  |  |  |  |  |  |
| Colorado River | 1.89 | 1.63 | 2.00 | 1.10 | 2.39 | 2.04 | 2.80 | 2.17 |
| Unkar | 0.50 | 2.06 | 0.45 | 1.73 | 0.77 | 2.02 | 0.68 | 1.68 |
| Phantom |  |  |  |  |  |  |  |  |
| Ranch | 0.60 | 1.03 | 0.86 | 1.18 | 0.74 | 1.12 | 0.84 | 1.30 |
| Elves Chasm | 1.15 | 1.10 | 1.82 | 1.67 | 1.47 | 1.41 | 1.46 | 1.34 |
| Deer Creek | 1.60 | 1.92 | 1.84 | 2.12 | 1.69 | 2.23 | 2.20 | 2.30 |
| Havasu Canyon | 3.09 | 2.75 | 2.60 | 2.69 | 2.39 | 2.66 | 2.85 | 2.52 |
| Totals | 9.74 | 12.85 | 10.67 | 12.88 | 10.46 | 13.82 | 12.21 | 13.85 |

Not all of the 218 parties which figure in Table 5 visited all eight of the attraction sites. Redwall and Deer Creek had visitation rates of $90 \%$ or more, whereas Unkar's visitation rate was approximately a $50 \%$ visitation rate. These eight locations are some of the most popular on the river.

Alternative 1 had the least number of attraction site encounters, whereas alternative 4 had the most. The difference between alternatives 1, 2 , and 3 was less than $10 \%$ for both on- and off-site encounters, Alternative 4 had less than $10 \%$ more off-site encounters than any of the other alternatives, but $25 \%$ more on-site encounters than alternative 1.

Table 6 provides data about campsite arrival times. Since the WUSM works with fixed itineraries, once a trip was launched there could be no adjustments in its schedule. This data can be analyzed in a number of ways. The average arrival time suggests how much extra time could be spent visiting attraction sites. The standard deviation and the percent of arrivals between $3: 00 \mathrm{pm}$ and $6: 00 \mathrm{pm}$ suggested how much variation existed in the times of campsites arrivals. Ideally, most river trips should be in camp by $6: 00 \mathrm{pm}$, however, given the nature of this model, there were always arrivals at odd hours. The important point is that the more arrivals between $3: 00 \mathrm{pm}$ and $6: 00 \mathrm{pm}$ the better.

Table 6. Campsite arrival times, by July alternative.

|  |  | July Flow Alternative |  |
| :--- | :---: | :---: | :---: | :---: |

As can be seen in Table 6, alternative 4, with constant releases of $25,000 \mathrm{cfs}$, had the earliest mean arrival time, the smallest standard deviation, and the most arrivals between 3:00 and 6:00 pm. This suggested that extra time could be spent at attraction sites. The mean arrival times for all other scenarios were an hour or more later. The standard deviations, as well as the percent of arrivals, followed this same pattern.

The WUSM was unable to identify a fast trip, allowing for more time at attraction sites, from a slow trip. The base visit times to attraction sites were obtained by Underhill \& Xaba (1983), and reflect the average amount of time spent at each site by river parties, which always is sufficient for a good visit. So, it was not that the other alternatives allowed insufficient time for attraction site visits, but rather that either the number of visits or their length would have to be reduced.

Table 7 shows overall encounters per party per day. These figures are expressed in averages and medians. Often, the averages were higher than the medians due to the distribution of encounters, most parties encounter few others, some encountered many. By comparing this table with Table 14 in the May scenarios, it can be seen that encounter levels overall were more dependent on the number of launches than upon river flow. The average number of encounters were very similar for all four scenarios.

Table 7. Average number of encounters per party per day, by July alternative.

| July Elow Alternative |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | \#1 | 2.*5 | * 3 | \#4 |
| River \& attraction site encounters |  |  |  |  |
| Average no. of parties per day | 49 | 49 | 49 | 49 |
| Average no. of river and attraction site encounters (encts.) per party per day (pppd) | 4.55 | 4.35 | 4.43 | 4.69 |
| Median no. of river encts. pppd | 3.0 | 2.8 | 2.9 | 2.8 |
| Average no. of visual encts. pppd | 4.33 | 4.64 | 4.69 | 4.67 |
| Median no. of visual encts. pppd | 3.1 | 3.6 | 3.6 | 3.5 |
| Camp Encounters |  |  |  |  |
| Average no. of parties in camp per day | 44.5 | 44.5 | 44.5 | 44.5 |
| Average no. of camp encts. pppd | 0.74 | 0.70 | 0.79 | 0.79 |
| Median no. of camp encts. pppd | 0.00 | 0.00 | 0.00 | 0.00 |
| Percent of nights camped alone | 55.4\% | 54.1\% | 51.2\% | 51.6\% |
| Average no. of visual encts. pppd | 0.85 | 0.91 | 0.85 | 0.87 |
| Median no. of visual encts. pppd | 0.00 | 0.00 | 0.00 | 0.00 |

The use of campsites was difficult to simulate with the WUSM. On the river, boatmen exchange information on which campsites they planned to use. If they come to their planned site and it is occupied, they often proceed downstream to the next available campsite. The model is unable to make this kind of decision. However, campsite use was based upon actual frequencies of use, and can be thought of as first choice campsites. As a result, the number of campsite encounters is likely to be overcounted. The percent of nights camped alone shown in Table 7 was used for comparison, in addition to average encounters at campsites. All were very similar.

Table 8 shows the average number of the four kinds of encounters per week, counted once as seen by an observer. Most output matrices in the model count encounters twice, once for each party involved. The first item to notice in Table 8 is that the number of visual encounters roughly equals the sum of all other encounters combined. This is because visual encounters occur at all locations, whereas other kinds of encounters are recorded only at one or two different location types (river segments, attraction sites or campsites). These kinds of encounters are differentiated by the WUSM because wilderness research suggests that different kinds of encounters have different effects upon wilderness users. It is unclear whether this is the case with Grand Canyon floaters.

The difference in the total number of encounters occurring per week was small, as shown in Table 8. In fact, there was less than a $5 \%$ difference between the lowest (alternative 2), and the highest (alternative 4). Alternative 1 had comparatively high camp encounters and overtaking encounters, yet low meeting and visual encounters. One can conclude from Tables 7 and 8 that all four July scenarios had very little effect upon encounter rates as experienced by simulated river trips.

Table 8. Number of encounters per week, as seen by an observer, by July alternative.

|  | July Flow Alternative |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | \#1 | \#2, \#5 | \#3 | \# 4 |
| Meeting Encounters | 279 | 312 | 313 | 339 |
| Overtaking Encounters | 514 | 445 | 458 | 473 |
| Visual Encounters | 876 | 949 | 951 | 962 |
| Camp Encounters | 167 | 110 | 124 | 125 |
| Totals | 1836 | 1816 | 1846 | 1899 |

The potential delays at rapids caused by low dam releases were major measures of the effect of river flow on river trips as simulated by the WUSM. Since there were no delays at rapids under any of the July scenarios, it can be safely concluded that according to this model, none of the July alternatives would delay any party due to low river flow. Unlike the May scenarios, which had delays at rapids, only the bottom half of this table is shown below. The percent of all overtaking encounters which occurred at these rapids was included since when parties are delayed, and they bottleneck at a rapid, overtaking encounters are recorded. Likewise, when parties are delayed, visual encounters are recorded. These percentages are included here to provide a baseline from which to examine other alternatives.

Table 9. Statistics about delays and encounters at rapids, by July alternative. RAPIDS: Badger, Soap Creek, House Rock, 24.5/25 Mile, Kwagunt, Unkar, Hance, Sockdolager, Grapevine, Zoroaster, Horn Creek, Granite, Hermit, Ruby, Serpentine, Waltenberg, Forster, Fossil, Bedrock, Deubendorff, Tapeats, Upset, Lava Falls, 212 Mile.

|  |  | July Elow Alternative |
| :--- | :--- | :--- | :--- | :--- |

July Summary
Although there were five alternatives, two were identical (numbers 2 and 5), therefore Tables 5 through 9 have data for four different alternatives. The overall picture for the four alternative July scenarios indicated that their effects on river trips did not vary greatly. Encounter rates did vary among the scenarios, as did the mean campsite arrival times. Alternative 4, with constant releases of $25,000 \mathrm{cfs}$, had the most time available for attraction site visits, yet it consistently had the highest number of encounters. Alternative 1, with constant releases of $12,750 \mathrm{cfs}$, had the lowest level of encounters, and the shortest time available for attraction site visits. Alternatives 2 (5) and 3 fluctuated releases, and were in the middle range. Table 10 provides summary data about each of the four different alternatives.

Table 10. Summary of the effects of the July alternatives on simulated river trips.

|  |  | July Flow Alternative |  |
| :--- | :---: | :---: | :---: | :---: |
| Times \& Rapids |  |  |  |
| Average reduction (increase) |  |  |  |
| in attraction site visit time |  |  |  |
| (in minutes) |  |  |  |

## May Launch Schedule

Although the peak summer rafting season was June, July and August, a significant number of both commercial and private trips rafted the Colorado River through Grand Canyon National Park during the spring and fall. In fact, in May 1984, 127 trips launched from Lees Ferry. A similar number launched in September. Therefore the non-summer month of May was simulated in order to determine the effects of different releases on significant numbers of parties.

May Flow Scenarios
The non-summer months had no restriction on minimum dam discharges, with three of the five scenarios having releases at or below 3,000 cfs. Therefore, as expected, there were many more delays at rapids, and significantly slower travel through the canyon.

Table 11 shows the May launch schedule. During the first two weeks, an average of 18.5 trips were launched each week, whereas during the final three weeks, an average of 29.67 trips were launched each week. This uneven distribution in the number of trips launched per week did have an effect on the model's outputs. The average number of encounters, as counted by the model, were more representative of the latter three weeks, than the first two weeks. The overall effects of river flow on river trips, however, remained the same.

Although there were fewer trips launched in May than July, the percentage of boats in each boat type remained the same, with oars outnumbering motors almost two to one.

The May release prescriptions for each of the five alternatives are summarized below. Again, weekday and weekend flow prescriptions are described, with the minimum and maximum flow for the day, or the volume of the constant release. These flows are all stated in cfs.

|  | weekdays | weekends |
| :--- | :---: | :---: |
| Alternative 1: | 10,000 constant | 10,000 constant |
| Alternative 2: | $2,200-13,500$ | $3,000-10,700$ |
| Alternative 3: | $8,000-11,300$ | $8,000-11,500$ |
| Alternative 4: | $1,000-31,000$ | $1,000-30,000$ |
| Alternative 5: | $3,000-20,900$ | $3,000-10,800$ |

Figures 6 through 10 are bar charts which show the hourly dam releases for weekday and weekend flows for all five May scenarios.

Table 11. May 1984 launch schedule showing number of days and type of propulsion for each trip launched on any one day. * = private trip; \#\# = NPS patrol trip; \#\#\# $_{\text {\# }}$ = research trip. Total number of boats launched in May by type: oar: 211; motor: 108; paddle: 5; kayak: 59; dory: 14.

| SUNDAY | MONDAY | TUESDAY | WEDNESDAY | THURSDAY | FRIDAY | SATURDAY |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| MAY 1 <br> 7 motor 11 motor* | 7 motor 18 oar | 14 oar 18 oar* | 6 motor <br> 9 motor <br> 18 oar* | 5 17 oar* | $$ | $\left\lvert\,\right.$ |
| 6 motor <br> 13 oar <br> 18 oar* | 8 motor <br> 15 oar <br> 18 oar* | 10 7 motor 18 oar* | 11 <br> 9 motor <br> 12 oar* | $\begin{array}{\|c\|} \|c\| \\ 12 \\ 18 \\ \text { oar } \\ 18 \\ \text { oar.****** } \end{array}$ | $\begin{gathered} 13 \\ 6 \text { motor } \\ 18 \text { oar* } \end{gathered}$ |  |
| 15 <br> 6 motor 7 motor 16 dory <br> 18 oar" | 16 <br> 8 motor <br> 12 oar <br> 12 oar <br> 15 oar* <br> 18 oar*** | 7 motor 17 <br> 9 motor <br> 13 oar <br> 18 oar* | 18 <br> 6 motor <br> 9 motor <br> 17 oar* | 19  <br> 8 motor <br> 13 oar <br> 14 oar <br> 16 dory <br> 18 oar | $\begin{array}{\|l} \mid \quad 20 \\ 6 \\ \text { motor } \\ 10 \\ \text { motor } \\ 12 \\ \text { oar } \\ 16 \\ \text { oar } \end{array}$ | $\begin{array}{\|c}  \\ 21 \\ 8 \text { motor } \\ 8 \text { motor } \\ 8 \text { motor } \\ 18 \text { oar* } \end{array}$ |
| $\begin{aligned} & 22 \\ & 6 \text { motor } \\ & 6 \text { motor } \\ & 13 \text { oar } \\ & 15 \text { dory } \\ & 18 \text { oar } \end{aligned}$ | ```2 3 motor 12 oar 13 oar 14 oar 15 oar*``` | $\begin{aligned} & 24 \\ & 7 \text { motor } \\ & 9 \text { motor } \\ & 9 \text { motor } \\ & 18 \text { oar } \end{aligned}$ | $\begin{gathered} 25 \\ 6 \text { motor } \\ 8 \text { motor } \\ 8 \text { motor } \\ 13 \text { oar } \end{gathered}$ | $\|c\|$ <br> 5 <br> 5 motor <br> 10 <br> 14 <br> 14 motor | 27 <br> 8 motor <br> 12 oar | 28 <br> 7 <br> 7 <br> 7 <br> 8 motor <br> 8 <br> 8 motor <br> 8 |
| $\begin{aligned} & 29 \\ & 6 \text { motor } \\ & 6 \text { motor } \\ & 14 \text { oar } \end{aligned}$ | 30 <br> 6 motor <br> 8 motor <br> 8 motor <br> 12 oar <br> 18 oar* | 31 <br> 7 motor <br> 8 motor <br> 9 motor <br> 13 oar <br> 13 oar* <br> 14 oar | JUNE 1 <br> 7 motor <br> 8 motor <br> 8 motor <br> 9 motor <br> 12 oar <br> 14 oar* | 2 6 motor 7 16 motor | $$ |  |



Figure 6. Alternative 1 - May hourly dam releases.


Figure 7. Alternative 2 - May hourly dam releases.


Figure 8. Alternative 3-May hourly dam releases.


Figure 9. Alternative 4 - May hourly dam releases.


Figure 10. Alternative 5 - May hourly dam releases.

Comparison of the May alternatives by the model
Tables $12-17$ follow the same format as previously shown for July. The WALK routine was utilized for one three-week simulation, and in the second three-week simulation, the parties waited at rapids when the flow caused a delay until the river flow was above the benchmark flow for that boat type. Again at Horn Creek, all parties that were delayed utilized the WALK routine. These data were then combined in the following tables.

Table 12 provides the attraction site encounter data. The average number of encounters experienced per party at these attraction sites was similar among all May alternatives. Alternative 2 had the lowest numbers of on and off-site encounters, while alternative 5 had the highest number of on-site encounters, and alternative 4 had the highest number of visual, or off-site encounters. The overall differences between the alternatives were greater than in the July scenarios, with alternative 5 having $36 \%$ more on-site encounters than alternative 4. Alternative 4 had $11 \%$ more off-site encounters than alternative 2. The overall level of encounters at attraction sites was less than experienced by July parties.

Table 12. Average number of encounters per party per visit to selected attraction sites, by May alternative. $N=178$ Parties. On-site encounters are with another party at the same attraction site (meeting plus overtaking). Off-site encounters are visual encounters where a party at the attraction site sees another party either on the river or at an adjacent campsite. There was some double counting of off-site encounters.

|  | May Flow Alternative |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | \# 1 |  | \#2 |  | \#3 |  | * 4 |  | \#5 |  |
|  | $\begin{aligned} & \text { on- } \\ & \text { site } \end{aligned}$ | off- <br> site | $\begin{aligned} & \text { on- } \\ & \text { site } \end{aligned}$ | off- <br> site | $\begin{aligned} & \text { on- } \\ & \text { site } \end{aligned}$ | off- <br> site | onsite | off- <br> site | $\begin{aligned} & \text { on- } \\ & \text { site } \end{aligned}$ | off- <br> site |
| Location |  |  |  |  |  |  |  |  |  |  |
| Redwall <br> Cavern | 0.75 | 0.81 | 0.57 | 0.76 | 0.68 | 0.73 | 0.36 | 0.55 | 0.64 | 0.62 |
| Nankoweap Canyon | 0.23 | 1.40 | 0.20 | 1.16 | 0.29 | 1.12 | 0.20 | 1.29 | 0.15 | 1.25 |
| Little Colorado River | 0.91 | 1.30 | 0.95 | 1.29 | 1.39 | 1.15 | 0.98 | 0.77 | 1.87 | 1.51 |
| Unkar | 0.27 | 1.48 | 0.27 | 1.17 | 0.20 | 1.35 | 0.22 | 2.51 | 0.34 | 1.45 |
| Phantom Ranch | 0.63 | 0.76 | 0.65 | 0.70 | 0.72 | 0.96 | 0.73 | 0.95 | 0.79 | 1.03 |
| Elves Chasm | 1.05 | 1.05 | 0.92 | 1.00 | 0.72 | 0.93 | 0.77 | 0.92 | 1.03 | 0.98 |
| Deer Creek | 1.39 | 1.63 | 1.15 | 1.52 | 1.58 | 1.80 | 1.03 | 2.15 | 1.22 | 1.65 |
| Havasu | 2.13 | 1.93 | 2.25 | 2.00 | 2.32 | 1.97 | 1.72 | 1.53 | 2.22 | 2.07 |
| Totals | 7.36 | 10.36 | 6.96 | 9.60 | 7.90 | 10.01 | 6.05 | 10.67 | 8.26 | 10.56 |

Campsite arrival times were similar for four of the five alternatives shown in Table 13. Due to the lower flows, travel was slower on the river. Consequently, the mean campsite arrival times were later in the day. These later arrivals implied that less time could be spent at attraction sites. For these four alternatives (numbers 1, 2, 3, and 5), an average of two hours would have to be subtracted from attraction site visits for each day in order to obtain a mean arrival time of $4: 30 \mathrm{pm}$.

Alternative 4 had an early mean campsite arrival time, 3:09 pm. However, only ten percent of all arrivals under this alternative were in camp between $3: 00$ and $6: 00 \mathrm{pm}$. The standard deviation for alternative 4 was 490 minutes, or approximately 8 hours, and therefore the average reduction in attraction site visits per day under this alternative could not be computed accurately. Parties were arriving at all hours of the day and night, due to the substantial delays at rapids, and slow travel on the river resulting from low river flow. Obviously, parties could not afford to be so delayed; they would adjust their schedule for much less attraction site visit time, and not wait for the water to rise, thereby running rapids at higher risk.

Table 13. Campsite arrival times, by May alternative. = see text.

|  | May Flow Alternative |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | \# 1 | \#2 | *3 | * 4 | * |
| Number of campsite arrivals (approx.) | 1725 | 1725 | 1725 | 1725 | 1725 |
| Average arrival time | 6:39pm | 6:32 pm | 6:46pmi | 3:09pm | 6:05pm |
| Standard Deviation (in minutes) | 164 | 271 | 224 | 490 | 210 |
| Percent of arrivals between 3:00 \& 6:00pm | 32.4\% | 24.4\% | 25.7\% | 10.2\% | 37.1\% |
| Difference between mean arrival time of 4:30 pm and actual | 129 | 122 | 136 | -81 | 95 |
| Average reduction in attraction site visits per day | 129 | 122 | 136 | * | 95 |

Differences in the average number of encounters experienced per party per day were quite small among the May alternatives (see Table 14). The average number of river and attraction site encounters per party per day varied between 3.48 and 3.67 , a difference of approximately $5 \%$. The average number of visual encounters per party per day from the river and attraction sites varied from 3.78 to 4.01 , a difference of approximately $6 \%$. The only large difference was in the average number of visual encounters per party per day from camp, where alternative 4 had almost twice as many as the other four. This is again attributed to the odd hours at which parties arrived at camp.

Table 14. Average number of encounters per party per day, by May alternative.


The average number of encounters per week, counted once as seen by an observer, were similar for four of the five alternatives (see Table 15). Alternative 4 had the least meeting encounters and the most overtaking, visual, and camp encounters. The high number of overtaking
encounters resulted from the many delays at rapids, and the high number of visual encounters were due to parties arriving at attraction sites and campsites at odd hours, thereby sighting parties more often. Although the counts were accurate, they did not accurately represent what would happen under this scenario. River parties running the river under alternative 4 would adjust their itineraries such that they would remain on a diurnal schedule. For the other four alternatives, the average number of encounters per week were similar, ranging from 1354 to 1424, a difference of around 5\%. The proportion of encounters in each of the four categories was also similar.

Table 15. Number of encounters per week, as seen by an observer, by May alternative.


Simulated parties experienced many delays at rapids when operating under the May flow alternatives (see Table 16). These delays at rapids often forced parties to wait at locations which were neither campsites nor attraction sites, Delays at rapids force parties to bottleneck at locations where they encounter other parties also delayed. The boatman has three options: (1), he can risk running the passengers through the rapid at a low, and possibly unsafe flow; (2), he can walk the passengers around the rapid; or (3), he could wait until the flow is higher. If he waits, the remaining trip itinerary has to be changed.

At the extremes, alternative 1, with a constant flow of 10,000 cfs, was just high enough to prevent delays. Alternative 4, with low releases most hours of the day, produced delays at all 24 rapids. Parties under alternatives 2, 3 and 5 experienced delays predominantly at Horn Creek, where the WALK routine was always used. The percentage of all overtaking encounters for alternative 4 was much higher than the others, resulting from the encounters with other parties also delayed.

Table 16. Delays and encounters at 24 rapids, by May alternative. $N=178$ parties. TPD: Total number of parties delayed; THD: Total number of hours delayed.

| Rapid | \#1 | May Flow Alternative |  |  |  |  |  | * 5 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\# 2-\$ 3$ |  |  |  | * 4 |  |  |  |
|  | THD | TPD | THD | TPD | THD | TPD | THD | TPD | THD |
| Badger $\quad \frac{0}{0}$ | 0 | 0 | 0 | 0 | 0 | 37 | 42 | 0 | 0 |
| Soap Creek 0 | 0 | 4 | 4 | 0 | 0 | 3 | 6 | 5 | 5 |
| House Rock 0 | 0 | 63 | 109 | 0 | 0 | 85 | 133 | 31 | 55 |
| 24.5/25 Mile 0 | 0 | 3 | 7 | 0 | 0 | 100 | 338 | 0 | 0 |
| Kwagunt 0 | 0 | 0 | 0 | 0 | 0 | 74 | 359 | 0 | 0 |
| Unkar 0 | 0 | 0 | 0 | 0 | 0 | 38 | 158 | 0 | 0 |
| Hance 0 | 0 | 0 | 0 | 0 | 0 | 35 | 228 | 0 | 0 |
| Sockdolager 0 | 0 | 0 | 0 | 0 | 0 | 9 | 9 | 0 | 0 |
| Grapevine 0 | 0 | 0 | 0 | 0 | 0 | 14 | 31 | 0 | 0 |
| Zoroaster 0 | 0 | 0 | 0 | 0 | 0 | 7 | 8 | 0 | 0 |
| Horn 0 | 0 | 102 | 102 | 137 | 137 | 143 | 143 | 51 | 51 |
| Granite 0 | 0 | 0 | 0 | 0 | 0 | 11 | 39 | 0 | 0 |
| Hermit 0 | 0 | 0 | 0 | 0 | 0 | 7 | 7 | 0 | 0 |
| Ruby 0 | 0 | 0 | 0 | 0 | 0 | 15 | 49 | 0 | 0 |
| Serpentine 0 | 0 | 0 | 0 | 0 | 0 | 5 | 19 | 0 | 0 |
| Waltenberg 0 | 0 | 4 | 6 | 0 | 0 | 58 | 142 | 1 | 2 |
| Forster 0 | 0 | 5 | 6 | 0 | 0 | 87 | 230 | 0 | 0 |
| Fossil 0 | 0 | 0 | 0 | 0 | 0 | 48 | 95 | 0 | 0 |
| Bedrock 0 | 0 | 34 | 64 | 0 | 0 | 62 | 234 | 24 | 52 |
| Deubendorff 0 | 0 | 17 | 31 | 0 | 0 | 52 | 168 | 11 | 32 |
| Tapeats 0 | 0 | 4 | 8 | 0 | 0 | 44 | 94 | 1 | 2 |
| Upset 0 | 0 | 0 | 0 | 0 | 0 | 70 | 237 | 0 | 0 |
| Lava Falls 0 | 0 | 2 | 2 | 0 | 0 | 66 | 415 | 0 | 0 |
| 212 Mile 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 0 | 0 |
| Number of rapids <br> where delays occurred |  |  |  |  |  |  |  |  |  |
| Total no. of delays 0 |  | 229 |  | 137 |  | 1076 |  | 124 |  |
| Total hours delayed |  | 335 |  | 137 |  | 3190 |  | 199 |  |
| Average no. of hours delayed per party |  |  | 1.88 |  | 0.77 |  | 17.92 |  | 1.12 |
| Percent of all visual encounters which occurred | 6.6\% |  | 6.3\% |  | 6.5\% |  | 6.8\% |  | 6.8\% |
| Percent of all overtaking encts. which occurred | 4.6\% |  | 16.3\% |  | 15.7\% |  | 23.5\% |  | 6.1\% |

## Hay Summary

Alternative 5 had the most campsite arrivals between 3:00 and $6: 00 \mathrm{pm}$, and consequently called for the smallest reduction in the length or amount of attraction site visits in order to achieve a mean campsite arrival time of $4: 30 \mathrm{pm}$. Alternative 1, with a constant release of 10,000 cfs, had no delays at rapids. Alternative 3 only delayed parties at Horn, whereas 2 and 5 delayed parties at a number of other rapids. Alternative 4 had an average delay, per party, of 18 hours. Alternative 1 had the least number of encounters per party per day ( 8.69 ), whereas alternative 4 had the most (9.69). Encounter rates per party per day for alternatives 1, 2, 3 and 5 were all very similar. Table 17 provides summary data from the simulation of river trips running under the five May alternatives.

Table 17. Summary of the effects of the May alternatives on simulated river trips. " = exact amount not determined, highest of all alternatives.

| Times and Delays | May Flow Alternative |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | * | *2 | * | \# 4 | \#5 |
| Average reduction in |  |  |  |  |  |
| attraction site visits <br> (in minutes) | 129 | 122 | 136 | * | 95 |
| Mean campsite arrival times | 6:39pm | 6:32pm | 6:46pm | 3:09 pm | 6:05pm |
| Percent of arrivals between |  |  |  |  |  |
| Number of delays at rapids | 0 | 229 | 137 | 1076 | 124 |
| Total hours delayed | 0 | 335 | 137 | 3190 | 199 |
| Average time spent delayed per party delayed (hours) | 0 | 1.88 | 0.77 | 17.92 | 1.12 |
| Encounters |  |  |  |  |  |
| 8 attraction sites - on-site | $\begin{array}{r} 7.36 \\ 10.36 \end{array}$ | $\begin{aligned} & 6.96 \\ & 9.60 \end{aligned}$ | $\begin{array}{r} 7.90 \\ 10.01 \end{array}$ | $\begin{array}{r} 6.05 \\ 10.67 \end{array}$ | $\begin{array}{r} 8.26 \\ 10.56 \end{array}$ |
| Average number of river and attraction site encounters |  |  |  |  |  |
| PPPD - on-site <br>  - off-site | $\begin{aligned} & 3.60 \\ & 3.78 \end{aligned}$ | $\begin{aligned} & 3.63 \\ & 3.87 \end{aligned}$ | $\begin{aligned} & 3.62 \\ & 3.78 \end{aligned}$ | $\begin{aligned} & 3.48 \\ & 3.91 \end{aligned}$ | $\begin{aligned} & 3.67 \\ & 4.01 \end{aligned}$ |
| Average camp encounters PPPD | 0.53 | 0.61 | 0.54 | 0.66 | 0.56 |
| - off-site | 0.78 |  | 0.78 | 1.64 | 0.87 |
| Total average number of encounters experienced PPPD | 8.69 | 9.06 | 8.72 | 9.69 | 9.11 |

## DISCUSSIOI

Simulation of the dam release alternatives revealed a number of trends. First, the lower the dam release, the slower a party traveled on the river, and consequently the less time that was available for attraction site visits. A component of slow travel time which was not incorporated in the WUSM was the human dimensions of low river flow. For oar parties on the river, this entails more rowing on the part of the boatmen. Upriver winds combined with low river flow, can bring oar travel to a standstill. For motor parties, low river flow requires longer use of the motor and greater use of fuel, subjecting passengers to more motor noise and odor. The chance of breakdown is also increased not only because of more motor use, but also because more rocks are exposed at lower river flow. Low river flow means more time on the river, less time at attraction sites and secondary effects on the motors and oarsmen

A second trend was that as the flow got lower, more delays occurred at rapids. Although delays may be overstated by the simulation model, they occurred. How a boatman on the river responds to these delays is an individual decision Most trips, particularly commercial trips, must stay on a schedule. Schedule concerns are generally greater for shorter trips than longer trips. Since it is possible that certain rapids are more dangerous at low flows, a boatman concerned about staying on schedule needs to be particularly careful in navigating these rapids at low flows.

A third trend concerned encounters. For the most part, the number of encounters that a party experienced was more dependent upon the launch schedule than upon the river flow. Tests done previously with this simulation model have shown that encounter levels could be reduced $25 \%$ and more by spreading the number of launches evenly throughout the week, and not launching trips of the same length on the same day (Underhill, Xaba \& Borkan 1986). Except in cases of parties delayed at a particular location, fluctuating flows tended to produce a lower rate of encounters on the average than did steady high flows. This may be due to the tendency of fluctuating; variable flows to space parties out, whereas steady flows keep everybody going along at roughly the same rate.

All five July scenarios produced similar encounter levels at the attraction sites used for comparison (Redwall, Nankoweap, Little Colorado, Unkar, Phantom, Elves, Deer Creek and Havasu). Alternative 1, with a constant release of 12,750 cfs produced the least attraction site encounters, both on- and off-site. Alternatives 2 and 5, which were the same, produced similar rates to alternative 3. These three scenarios fluctuated releases. Alternative 4 had the highest attraction site encounter level.

The steady release of 25,000 ofs in alternative 4 maximized the amount of time available for attraction site visits. In fact, this alternative provided one hour or more additional attraction site visit time per day over the other July scenarios. Additional time for attraction site visits implies less time on the river. Nevertheless, the higher the river flow, the more time that was available for attraction site visits. Alternatives 2, 3 and 5 produced more attraction site visit time than alternative 1, which produced the least.

Encounter rates per party per day for the four July scenarios were similar. They all produced approximately 9 encounters per day, with an additional 1.5 at camp. The nine encounters were divided equally between on-site and off-site (visual) encounters. It can be concluded from this model that these four scenarios had no significant effect upon the average number of encounters experienced per party per day. Likewise, the number of the four types of encounters occurring per week under each of the four scenarios was also similar.

There were no delays at rapids as a result of the four July flow scenarios. Apparently the fluctuating scenarios which could have delayed parties at rapids never produced a flow below the benchmark values at a rapid where a party was located.

Thus, one could conclude that according to the results of the July 1984 launch schedule subject to these four alternative flow regimes, all were satisfactory. There were differences in the amount of time available for attraction site visits, as well as very slight differences in encounter rates.

For the May scenarios, the picture was quite different. The May scenarios were included since a significant number of commercial and private parties raft the Canyon during the off-season. This is a time when the Bureau traditionally operates the dam at lower release levels, so the effects of river flow on river trips, particularly delays at rapids, can occur quite commonly.

Attraction site encounter rates under the May alternatives were similar. Alternative 4 had the least on-site and the most off-site encounters. However, since alternative 4 had parties arriving in camp at all hours of the day and night, parties were also visiting attraction sites at odd hours, thereby not encountering other parties. The May alternatives, on the average, had two or three less encounters per visit at attraction sites than did the July alternatives. This supports the argument that encounter levels are more dependent upon the number of parties launched than upon river flow.

The average number of encounters experienced per party per day was also similar among the alternatives, averaging approximately 7.5 encounters per party per day on the river and at attraction sites. In camp, a party encountered an average of an additional 1.4 parties. Again, the May alternatives provided approximately 1.5 (20\%) less encounters per party per day than did the July scenarios.

The number of encounters per week, as seen by an observer, was also similar for four of the five alternatives. For alternatives 1, 2, 3 and 5, encounters per week for all parties on the river averaged between 1354 and 1424 encounters per week, almost 500 less than in July. Alternative 4 had 1740 encounters per week, with 1014 of these as visual encounters, 250 - 300 more than the other four scenarios. This was again a result of parties being on the river at odd hours.

The analysis of the May data clearly indicated that alternative 4 produced more delays at rapids than any other alternative studied. It also reduced the available attraction site visit time the most. In order to achieve a mean campsite arrival time of $4: 30 \mathrm{pm}$, all trips operating under these May alternatives would need to reduce their attraction site visit time by a minimum of 90 minutes per day. It was difficult to determine precisely how much parties would have to reduce attraction site visit time for alternative 4. Large schedule changes would have to be made in order to keep a party on a diurnal schedule under this alternative.

Recall that the WUSM works on fixed itineraries, which, based on an average flow of $16,500 \mathrm{cfs}$, provided sufficient time for each attraction site visit, and a number of visits each day. Therefore, even when attraction site visit times are shortened by as much as two hours per day, there is still time for visits. Likewise, longer trips have more time for attraction site visits than shorter trips.

The major issue with the May scenarios was the delays at rapids. Looking back at Table 16, alternative 1, with a constant release of 10,000 cfs, did not delay parties at rapids. Alternative 3 only delayed parties at Horn Creek, where 137 out of 178 parties ( $77 \%$ of all parties) arrived when the flow was between 4,000 and 10,000 cfs. Since the WALK routine was always used, each party was delayed one hour. Alternative 5 delayed parties at Soap Creek, House Rock, Horn, Bedrock, Deubendorff, and Tapeats, with 124 parties delayed for a total of 199 hours (averaging 67 minutes of delay for the entire trip per party delayed). Fifty-one of these delays occurred at Horn Creek. Alternative 2 delayed parties at Soap Creek, House Rock, 24.5/25 Mile, Horn, Waltenberg, Forster, Bedrock, Deubendorff, and Tapeats, with 229 parties delayed for 335 hours (averaging 113 minutes delay per party, of which 102 were at Horn). Alternative 4 delayed parties at every rapid, an average of 18 hours for an entire trip.

Results from the model indicated that the May scenario for alternative 4 had greater impacts upon river trips than any other scenario tested. The other four May alternatives affected river trips in terms of time at attraction sites, encounters with other parties, and delays at rapids. However the effects were marginal compared to alternative 4.

## Discussion of Dam Release Alternatives

Simulation of these 9 alternatives for the months of July and May provides information with which to evaluate the five full-year dam release alternatives. These were developed with realistic constraints in mind, including water commitments to the Lower Basin States of the Colorado River Compact; maintaining adequate storage in Lake Powell above Glen Canyon Dam;
dealing with spring runoff; and the need to generate and sell electricity. The five alternatives have monthly dam release prescriptions, most of which involve fluctuations. However all 5 provide the same annual flow past Glen Canyon Dam into Grand Canyon.

The turbines at Glen Canyon Dam are designed to produce "peak" power. They are to generate more or less electricity on demand. The great advantage of this capability is the ability to respond to times of peak electrical demand, typically from noon until the early evening. Fluctuating dam releases are a direct result of the amount of electric power generation. As shown in Figures 4 through 12, the highest dam releases are during the afternoon. In this section, the five alternatives are evaluated according to the results of the simulation model.

Alternative 1 has no daily fluctuations of flow from Glen Canyon Dam. The power plant would be base loaded for the year, with a different release prescription for each month. These base load flows would be a low of 8,300 cfs in March to a high of 14,600 cfs in January. The effects of these flow scenarios on river trips would be (1) slow river travel; (2) reduced attraction site visit times; and (3) no delays at rapids, with the exception of Horn Creek.

Alternative 2 uses the full fluctuating potential of the dam, with daily releases from 1,000 to 31,500 cfs between September and May, and from 3,000 to 31,500 during June through August. This alternative maximizes power generation by providing the ability to fluctuate dam releases, hence power generation, all year round. As indicated by previous evaluations, this alternative would provide (1) less encounters than a high, steady flow alternative; (2) less attraction site visit time than a high, steady flow alternative, particularly during the non-summer months; and (3) delay parties at rapids during the non-summer months.

Alternative 3 also seeks to maximize electric power generation from the turbines, however it does not utilize the full potential of the dam. Daily fluctuations are between 8,000 and 25,000 ofs all year round. This scenario was in the middle range for alternatives tested. It would (1) only delay parties at Horn Creek; (2) provide more time at attraction sites than some alternatives, yet less than a high, steady release; and (3) provide a mid-range level of encounters. Its most salient feature is that it brings up the lower end to 8,000 cfs.

Alternative 4 maximizes electrical generation from September through May, with releases during this time between 1,000 and 31,500 cfs. June through August would have a steady, high release of 25,000 cfs. The May scenario under this alternative was the least acceptable of all alternatives studied, producing more delays at rapids than any other scenario. These delays, combined with low river flow, resulted in slow travel through the canyon. In contrast to the May scenario, the summertime releases of 25,000 cfs provided the most time for attraction site visits, yet the highest number of encounters. It was hypothesized by the Glen Canyon Environmental Study that the release of 25,000 ofs during the summer months represented an optimal situation for commercial river runners. This
high release did not delay parties at rapids and provided the most time at attraction sites. Encounter rates for parties operating during this high, steady flow were slightly higher than for parties running the river at other flow levels.

Alternative 5 is designed to provide a stable spawning, incubation and initial growth period for the trout in the Lees Ferry fishery. The remainder of the year maximizes electrical generation. The scenario is: from November to April releases fluctuate between 6,000 and 10,000 cfs; April, May, September, and October between 1,000 and 31,500 cfs; and June through August between 3,000-31,500 cfs. Releases which fluctuate down to 1,000 cfs have the greatest effects on river trips as simulated by this model. Delays at rapids combined with slow river travel reduces attraction site visit time significantly. Also, safety is of ten compromised by running rapids at dangerous flows in order to keep on schedule.

If fewest delays at rapids, most time at attraction sites, and least encounters with other parties are the objectives with which these alternatives should be evaluated, then alternatives with high releases are preferable over low releases; constant releases are preferable over fluctuating releases; and small fluctuations are preferable over large fluctuations. Therefore, none of the scenarios are optimal for river recreation. The summer months of alternative 4, as hypothesized by the Bureau of Reclamation, best meet the above criteria. However the nonsummer months of that alternative are not preferable. Many parties raft the canyon in May and September, when fluctuations would be between 1,000 to 31,500 cfs. Alternative 3, with fluctuations between 8,000 and 25,000 cfs, would be more preferable than the non-summer months of alternative 4. Alternative 1, which would base load the dam year round, would be next; alternative 5 would be next, and alternative 2 would be the least preferable.

## SUMMARY \& CONCLUSIONS

The Lucas-Shechter Wilderness Use Simulation Model has been modified to reflect the effects of fluctuating Glen Canyon Dam releases on Grand Canyon river trips. The output of the Streamflow Synthesis and Reservoir Regulation flow model for the Colorado River, which computed river flow for 11 downstream locations based on hourly Glen Canyon Dam releases, was used as input into the WUSM. In this manner, the flow of the river could be determined for all 199 river segments which simulated parties floated, and the effects of river flow on parties on the river could be simulated.

The effects which were simulated included how river flow affected speed of travel, delayed parties at rapids, and impacted encounter rates. Effects which were not simulated included the amount of rowing or motoring, motoring noise, upriver winds, possible breakdowns or accidents, potential beaching of boats due to the river volume falling drastically overnight,
the availability of campsites, and complex river velocity effects due to severe fluctuations.

The relationship between river flow and speed of travel was fairly simple, the higher the flow, the faster a party traveled on the river. Delays at rapids were not quite as simple. Data were collected from experienced boatmen regarding particular rapids, and the flows at which they felt that all other things being equal, they would wait for higher water rather than risk taking passengers through. Data were collected for oar, motor and dory boat types. Twenty-four rapids were identified, and divided into six classes. Each class had its own combination of benchmark flow values for each of the three boat types at which that rapid would delay a party.

Delays at rapids are handled by boatmen in different ways depending on time of day, weather, scheduling, and other factors outside the realm of this simulation model. Therefore, the model was programmed with a decision rule which made all boatmen in the model exactly the same in the way they handled a delay at a rapid. Two three-week simulation runs were made for each flow alternative. These two simulations differed on how they handled a party delayed at a rapid. In the first simulation, the party waited for one hour, and then ran the rapid, regardless of the flow. During this hour the passengers either walked around the rapid, or they simply decided that they could not afford to wait. The second simulation had the party wait for the water to rise above the benchmark flow for that boat type. These data were then combined. Although this is not how an actual river trip was run, it is useful for the purpose of comparing alternative flow scenarios.

Encounter rates were once again found to be more dependent upon the number of parties on the river than upon river flow. Although there were differences in encounter rates among the alternatives in each of the two months simulated, the differences were small.

Simulation of the July 1984 launch schedule ( 186 parties in five weeks) was accomplished by using this schedule and SSARR routings of the five July alternative dam release scenarios in the model. Two of these scenarios were identical, so four alternatives were run in the model. These alternatives varied between fluctuating and steady releases. The constant release of 25,000 ofs provided the most time available for attraction site visits. Encounter rates under this alternative were consistently higher than the other alternatives, but only by a small percentage. The constant release of 12,750 ofs provided the least attraction site visit time, also the least number of encounters experienced per party per day. Alternative 2 and 5 fluctuated releases between 3,600 and $31,500 \mathrm{cfs}$, and alternative 3 fluctuated releases between 8,500 and $25,000 \mathrm{cfs}$. These fluctuating release scenarios were very similar in terms of number of encounters produced and the time available for attraction site visits. All July alternatives simulated did not delay any parties at rapids, and all allowed ample time for attraction site visits.

Simulation of the May 1984 launch schedule of 127 parties in five weeks produced different data than that obtained by the July schedule. The May scenario for alternative 1 was a constant release of 10,000 cfs. This alternative produced the least average number of encounters experienced per party per day of all the May alternatives. The other four alternatives fluctuated releases. Alternative 5, with fluctuations between 3,000 and 20,900 cfs had the best campsite arrival time of $6: 05 \mathrm{pm}$, calling for a reduction of 95 minutes from attraction site visits per day. Alternatives 1, 2 and 3 were similar in their campsite arrival time, calling for an average reduction of approximately 129 minutes per day in attraction site visits. Alternative 4 fluctuated releases between 1,000 and 31,000 cfs, with most hours of the day releasing between 1,000 and $3,000 \mathrm{cfs}$. This alternative produced delays at all 24 rapids, an average of 18 hours per party. The three other alternatives delayed parties at rapids as well, however, on the average only one or two hours total. Alternative 4 had the greatest effects on river trips compared to any other scenario tested. The low dam release prescriptions of this alternative caused low river flow, requiring much more time on the river and less at attraction sites, and possibly forcing parties to run rapids at unsafe water levels in order to stay on schedule.

This study is not designed to reflect the preferences of river managers or recreationists in Grand Canyon National Park, nor is it able to make specific recommendations about Glen Canyon Dam releases. Rather, it has shown that alternative dam releases affect river trips in different ways. While the steady, high flow of 25,000 cfs, as in the July scenario for alternative 4, provided the most time to visit attraction sites, it also provided the highest encounter rates. Alternative 4's May scenario produced delays at all 24 rapids, requiring parties operating under this regime to alter their schedules to allow more time on the river, and less at attraction sites. The May alternative 4 fluctuated releases between 1,000 and 31,000 cfs; whereas the July alternative 4 called for a constant release of 25,000 cfs. They resemble each other only in number.

We may conclude from this simulation model that the May scenario for alternative 4 would necessitate large schedule changes on the part of river trips, more so than any other alternative studied. The three fluctuating scenarios for May would cause some delays at rapids, whereas the constant release of $10,000 \mathrm{cfs}$ in May delayed no parties. July alternatives evaluated produced similar encounter levels, yet the constant release of 25,000 cfs produced the most time available for attraction site visits. In evaluating other flow scenarios, the simple rules are that (1) the higher the flow, the more time that is available for attraction site visits, (2) the lower the flow, the greater number of parties delayed at rapids, and (3) the greater the number of parties launched, the greater the encounter rates.

The Wilderness Use Simulation Model has been shown to be an effective tool for evaluating the effects of alternative Glen Canyon Dam releases on Colorado River raft trips through Grand Canyon National Park.

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## APPENDIX: MODEL VALIDITY

Table 18 compares encounters at five selected attraction sites, the average number of encounters experienced per party per day (excluding visual), and the percent of nights camped alone. The comparison is between Park Service patrols from 1980-1983, Shelby's data collection in 1975, Underhill's model from 1982, various trips from 1985, and this model. All trips were taken between April and October.

Table 18. Comparison of actual river trip encounter data with simulation model results: 1975 - 1985. * = Base run by Underhill, 29 parties per week, $36 \%$ oar, $64 \%$ motor. ** $=$ averaged May and July scenarios, 16,500 ofs constant release. *** = July had 186 launches, May had 127 launches.

|  | Shell by | Patrol | Patrol | Patrol | Model | Patrol | Trips | Model |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1975 | 1980 | 1981 | 1982 | 1982* | 1983 | 1985 | 1984** |
| N | 41 | 5 | 10 | 10 | 87 | 10 | 10 | 198*** |
| Redwall |  |  |  |  |  |  |  |  |
| Cavern | 0.43 | 0.60 | 1.10 | 0.64 | 0.55 | 0.75 | 0.71 | 0.75 |
| Little |  |  |  |  |  |  |  |  |
| Colorado | 0.63 | 0.80 | 1.30 | 1.64 | 1.26 | 1.80 | 2.00 | 1.86 |
| Elves Chasm | 0.63 | 0.60 | 1.90 | 1.91 | 0.58 | 2.86 | 1.00 | 1.19 |
| Deer Creek | 0.67 | 1.00 | 1.70 | 1.90 | 1.09 | 2.63 | 3.50 | 1.68 |
| Havasu |  |  |  |  |  |  |  |  |
| Canyon | 0.67 | 1.00 | 2.10 | 2.22 | 2.35 | 3.12 | 2.13 | 2.61 |
| Encts/Day | 3.40 | 3.20 | 2.74 | 2.45 | 2.54 | 3.19 | 4.00 | 4.15 |
| \% Nights |  |  |  |  |  |  |  |  |
| Camped Alone | 0.91 | 0.84 | 0.75 | 0.81 | 0.63 | 0.62 | 0.80 | 0.61 |

The validity of the model for campsite selection and use was reported in Underhill and Xaba (1983). Table 3 of that report compared user logs turned in by permit holders with the base model on seventeen campsites. These seventeen campsites were ranked for both the logs and the model. Spearman's Rho test (Ranking Comparability Test) gave a value of 0.87, showing a high relationship between the two rankings. Unfortunately, user logs were no longer required after 1983, therefore this test could not be reproduced. However, at this point the model has shown that it accurately simulates use and encounter levels on the Colorado River through Grand Canyon National Park.
$4$

