Computer Simulation for Rafting Traffic on the Colorado River

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Abstract. A computer program called the Grand Canyon River Trip Simulator (GCRTSim) has been developed for use by managers at the Grand Canyon National Park. GCRTSim consists of a database, simulator, and extensive analysis tools. The database will eventually contain approximately 500 trip diaries, collected in 1998 and 1999, that report stops for activities and camping along 226 miles of the Colorado River corridor within the park. The simulator provides park managers with the opportunity to set prospective launch schedules for rafting trips and simulate rafting seasons using these launch calendars. Both the trip diary database and the results of the simulations can be analyzed using graphing tools. The analysis can provide insight into use levels that could impact both the recreational experiences and resources along the Colorado River corridor.

Key words: Colorado River, Grand Canyon National Park, rafting, simulation, management, launch schedule, model.

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INTRODUCTION

The 1989 Colorado River Management Plan (National Park Service 1989) governs the recreational rafting traffic on the Colorado River within Grand Canyon National Park. This document provides guidance for park managers in charge of supervising and governing both commercial and noncommercial river rafting use. To help supplement the ability of managers to understand the complex human-environment interactions in this setting, a team of faculty and students from the University of Arizona's School of Renewable Natural Resources, and from Northern Arizona University's Department of Mathematics and Statistics (senior author's previous affiliation), have worked since April 1998 to develop the Grand Canyon River Trip Simulator Project (GCRTSim) (Bieri 2001, Cherry 1997, Gimblett et al. 2000).

The goal of GCRTSim is two fold: (1) to improve understanding of the current rafting traffic conditions, and (2) to predict possible outcomes of changes to the current set of rafting traffic regulations. To accomplish the first objective, we collected trip diaries from rafting parties, and used these data to inform the National Park Service (NPS) about the use frequency of various camping and attraction sites. The data from these trip reports, coupled with extensive expert interviews, were used to develop an artificial-intelligence and statistical-based computer simulation model of rafting traffic along the Colorado River (Brian and Thomas 1985, Jalbert 1990, 1991, O'Brien and Roberts 2000, Roberts 1998, Shelby and Nielsen 1976a, 1976b, 1976c, 1976d). The simulator can approximate the behavior of rafting trips under a wide range of natural or imposed conditions. Thus, GCRTSim can consider how a proposed set of new regulations would influence an imaginary launch schedule, and simulate river trips over multiple seasons. The resultant data can subsequently be analyzed to provide insight into the potential consequences proposed set of new regulations. The intent is to provide NPS managers with more information about existing conditions on the Colorado River, and enable them to gain insight into the potential consequences of any new proposed management actions.

Computers have provided a venue for investigating human recreational use since the mid-1970's (Bishop and Gimblett 1999, Borkan and Underhill 1989, Schechter 1975, Schechter and Lucus 1978, Underhill et al. 1986, Van Wagendonk 1979). With recent advances in computing, and the development of artificial intelligence algorithms, the potential to make real progress in this area has grown immensely. While a natural "next step" in the management of natural resources is to take advantage of the potential offered by these recent advances, to date little has been done in this arena. Some recent work has developed a related intelligent-agent based program to study the interactions between jeep tours, bicyclists and hikers in a recreational setting in Sedona, Arizona (Gimblett et al. 1996). Our efforts have been to design a computer simulation model that examines the complex interactions between humans and the natural environment. Each rafting trip is designed as an intelligent agent, imbued with the intelligence to respond dynamically to its environment and to modify its plans accordingly. This represents a new approach for managers in the National Park system, in that we are able to combine statistical analysis, artificial intelligence and tools from mathematical modeling in a cutting edge fashion.

METHODS

Data Collection Methodology

To develop a detailed picture of river use, we needed to gain an understanding of: (1) the popularity of various camping and attraction sites along the Colorado River corridor; and, (2) how various trip leaders make decisions about where to stop, when to stop, and how long to remain at a given location. To obtain this information, trip leaders were asked to complete trip itineraries during the 1998 and 1999 rafting seasons. These itineraries listed the time in and time out for each location (250 sites between the launch area at Lee's Ferry and the end of the Park's tracking of river use at Diamond Creek). The trip diaries represent trips of all lengths and propulsion types (i.e., motorized or non-motorized).

The authors worked with various constituent groups to help gain support for this data collection effort. To reach private boaters, presentations were given at the annual meetings the Grand Canyon Private Boater Association, and email notification was sent to their members, encouraging participation in our study. In addition, the permit office at the Grand Canyon National Park sent information directly to permit holders. At orientation on the day of launch, the ranger at Lee's Ferry provided our survey materials to the permit holders.

To reach the commercial trips, presentations were given at Grand Canyon River Outfitters Association meetings. The outfitters made individual decisions as to how to implement their support of this project. Some, for example, required their guides to complete trip reports. Others distributed the trip reports to their guides with a request to participate. The authors also met with the Grand Canyon River Outfitters Association to solicit support of the river guide community (a summary of the meeting dates and locations can be found at http://mathcs.holycross.edu/~croberts/research). Although completing the trip diaries was optional, we recognize that the data collected are, nonetheless, far more comprehensive than anything previously available. A statistical analysis is currently underway to more precisely determine the extent to which this database is representative and reasonable.

During 1998, more than 15 river guides were interviewed to learn as much as possible about the logic employed by a river guide when taking a trip down the Colorado River. These guides, recommended by the Grand Canyon River Outfitters Association, the Private Boaters Association and the Grand Canyon River Guides Association, collectively represented many years of experience running the Colorado River, either privately (i.e., non-commercially) or as guides for commercial outfitters. They had experience at various river flow regimes and with all types of watercraft (e.g, oars, paddle boats, dories, motor boats). Questions were open-ended and extensive. For example, to understand how a guide might choose a campsite, we asked questions such as, "When do you start thinking about camping for the evening?", "What campsites do you like and why?", "Which ones do you try to avoid and why?", and "List every factor that goes into the selection process of choosing a campsite, and explain why each factor is important." The result was a complex matrix of possibilities for campsite selection based on several scenarios or situations that might be faced by a river guide. The scenarios could either be the result of human interactions and decisions, or could be the result of responding to the natural environment. For example, a trip might avoid a campsite because a conversation earlier in the day revealed that another trip was planning to select that site (result of a human interaction and decision); alternatively, a trip might avoid a campsite because when they arrive, a recent rainfall has rendered the area too small for their group size (result of responding to the natural environment).

Simulation Engine Development

The simulation engine represents a hybrid program that uses statistical data from the trip diary database, along with artificial-intelligence algorithms developed from the expert interview process. As development of the simulation engine proceeded, additional analysis of the database, or additional querying of expert guides, has been utilized as needed. The simulation engine is constructed as an object-oriented system that uses elements of fuzzy logic in the decision structure (Gimblett et al. 2000, Manneville et al. 1989, Reghis and Raventa 1998, Tecuci and Dybala 1998). Fuzzy logic is an artificial-intelligence construct that permits a decision to be made by weighing several factors or variables in an appropriate manner. Fuzzy logic theory provides a robust and full range of decision-making tools that are suitable for capturing much of the nuances inherent in making complex decisions in the natural environment of the Colorado River. For example, when a trip is choosing a campsite, the current conditions of the river and the individual trip play a role, as does the campsite's historical popularity. Fuzzy logic takes into account all these factors and weighs them appropriately, so that each trip's campsite decision represents a reasonable outcome for that particular set of circumstances.

A launch schedule (e.g, the current launch schedule or a prospective calendar created by the user) is entered into the simulation engine, which outputs simulated trips from Lee's Ferry. These simulated trips execute days on the river by choosing attraction sites for hikes or other activities, stopping for lunch, and selecting an appropriate campsite each night. Certain trips must be at given locations on certain times (e.g., some trips exchange passengers at Phantom Ranch), and the trips are managed by the simulator to meet these fixed points as scheduled. Moreover, a sophisticated planning algorithm helps each simulated trip plan out an optimal schedule that will include stops at key attraction sites and ensure that campsite selections are appropriate. A comprehensive record is developed for each simulated trip, including where and when it encounters other trips, where it chooses to engage in an activity or to stop for camp, and the duration of time spent engaged in each activity or camp stop.

Simulation Engine Use

After running a simulation, the created database can be queried to investigate outcomes of that particular launch schedule. For example, one could query the top 10 attraction sites, and compare the simulation output with data from the real 1998 and/or 1999 trip diaries, to observe if any major differences exist. There are a number of standard and non-standard queries possible to help the user of GCRTSim judge whether the outcome of a simulation represents an improvement over the current conditions in Grand Canyon National Park.

GCRTSim has the ability to run simulations representing new prospective launch calendars. It is also possible for the user to manipulate other conditions along the river corridor. For example, the user could restrict camping or activities at any number of sites. In this instance, a user could compare data from the 1998 trip diaries, as well as from simulations run off of the 1998 launch schedule, both with or without the added camping/activity restrictions. A judgement could then be made about the possible consequences of such a management action on the dynamics of the river rafting traffic on the Colorado River.

RESULTS

The Grand Canyon River Trip Simulator Project (GCRTSim) can create numerous types of graphs and charts from a database (real or simulated) to provide insight into Colorado River rafting traffic dynamics. To help illustrate some of the uses for GCRTSim, it is important to note that the trip report database represents a wealth of valuable information. Approximately 500 trip diaries were collected, representing about a 50% return rate for the commercial and 30% return rate for private trips. To date, only the 1998 trip reports are available for analysis. Not only is it useful to examine the "real data" from trip reports, but comparisons are also possible between these "real data" and various simulation runs. Simulations were run using a launch calendar regarded as typical by the 1989 Colorado River Management Plan. Simulations were run at both 100% and 50% use levels. Comparisons were made between the simulations and real data, and the results are presented herein. It must be noted that the 1998 trip reports represent approximately 40% of the actual launches, whereas a simulation of 100% use level represents a complete launch calendar. At the 50% use level, half of the launches were removed from the standard launch calendar, the remainder of which represents an even cut of all trip types.

The authors caution the reader that the results presented here are illustrative only. It would be unwise to draw conclusions regarding management of future launch schedules based soley on data presented in this paper. First, the 100% and 50% use levels were arbitrarily created and cannot be presumed to necessarily illustrate management decision scenarios. Second, in order to evaluate the potential impact of an alternative scenario (such as a 50% use level), it is necessary to examine multiple outputs from the simulation model – only a few such indicators are presented here. The graphs simply illustrate the types of output that are available to users of the simulation model.

A user can easily compare the popularity among key attraction and camping sites along the river corridor. In Figure 1, the most popular attraction sites are presented from each of three data sets: (1) the "real" data from the 1998 trip reports, (2) the "simulated" data from 100% use level, and (3) the "simulated" data from 50% use level. Thus, it appears that key attraction sites remain popular, regardless of the number of trips on the river (Fig. 1). Simulated trips chose the same top attraction

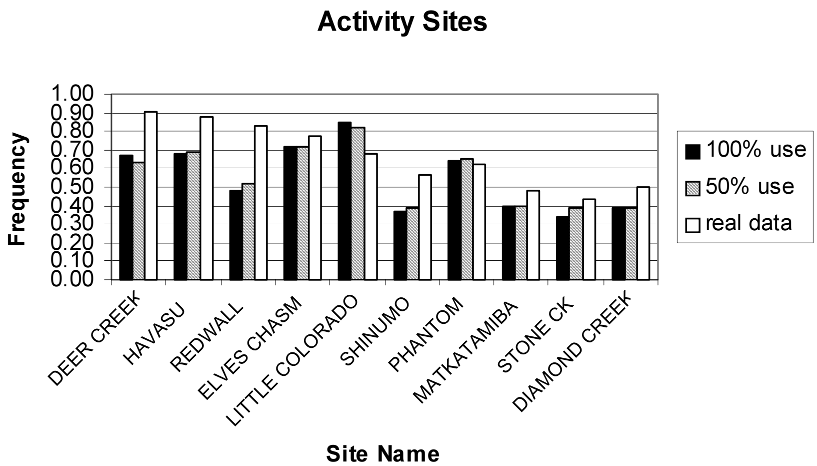

Figure 1. Comparison of recreational visitation at 10 key attraction sites along the Colorado River corridor within the Grand Canyon National Park. Real data corresponds to trip diaries collected during the 1998 river running season. The 100% and 50% results arise from simulations conducted from scenarios representing 100% use and a 50% reduction in people, boats and user days.

sites, but at a lower frequency, than that reported in the real data. Some of this error can be explained by the fact that the real data does not represent full river use. Still, efforts are underway to refine the model to better reflect current conditions on the river. Data, such as is presented in Figure 1, provides some insight into how reducing the number of launches might affect the selection of attraction sites. Again, the historical popularity of these sites keep them as key attractions, regardless of the use level, although the amount of use does change. It is interesting to note that this same dynamic does not hold for campsites. While the popularity of some campsites remain high under any use level, others fall into less use when there is less competition on the river.

Comparison between "Real" and "Simulated" Data

An important distinction between "real" and "simulated" data is illustrated in Figures 2a and b. In each case, graphs show the distribution of all trips along the river corridor on a particular day. The horizontal axis shows river mile, while the vertical axis represents the number of trips reported to be at each location on that particular day. Clearly, several trips were on the river 15 July, but we did not receive trip reports from all parties. While the complete launch schedule simulation does not match up perfectly with the trip diary data, it still provides an accurate representation for the distribution of parties along the river corridor. Note that the real data are incomplete, whereas the simulated data represent a complete scenario where every trip is repre-

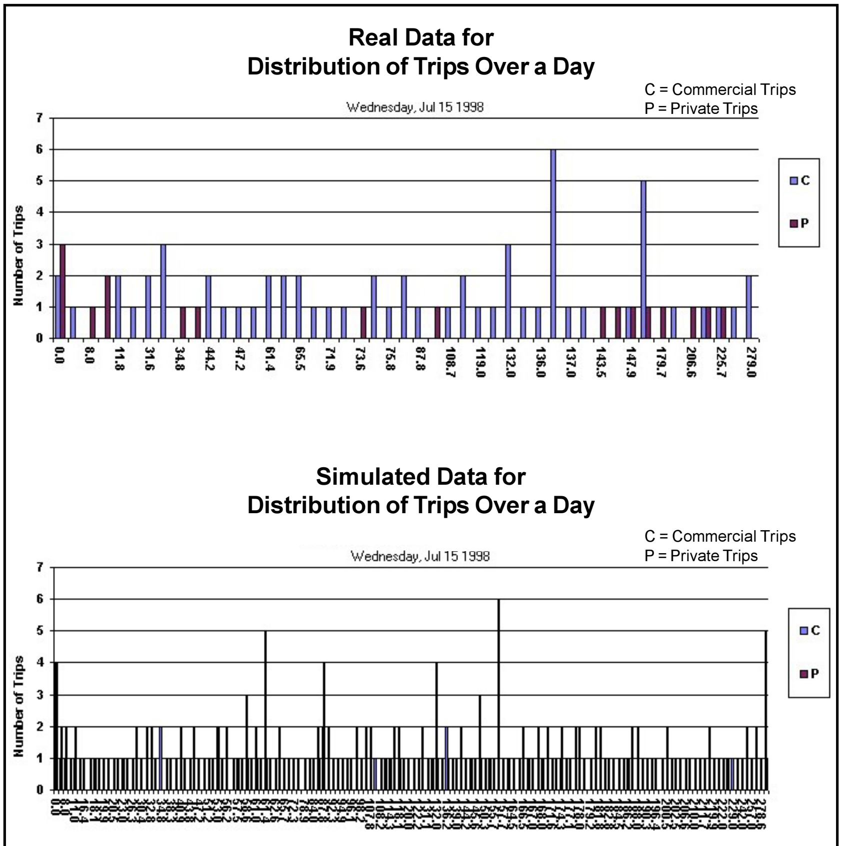

Figure 2a-b. **a**. Distribution of rafting trips along the Colorado River corridor within the Grand Canyon National Park over one day, as reported in diaries collected during the 1998 river running season ("real data"). The horizontal axis marks the river mile, and the vertical axis indicates the number of trips reported to be at that river mile on July 15, 1998. Note that not all trips on the river submitted a trip diary. **b**. Distribution of rafting trips along the Colorado River corridor within the Grand Canyon National Park over one day; results are from a simulation of a scenario that represents the typical 100% use-level ("simulated data"). The horizontal axis marks the river mile, and the vertical axis indicates the number of trips that were simulated as being at that river mile on July 15, 1998.

sented. The higher peaks represent more trips having been at those locations on that same day.

15-day Trips

All of the records for 15-day trips (using real data) were compiled to illustrate an "average" 15-day trip on the river; these data were used to generate simulated 15-day trips at both the 100% and 50% use levels (Fig. 3). The slope of the lines provides a sense of trip velocity as they travel down the river. Comparisons among the lines on this graph indicate the accuracy of our simulator. For example, the slope of the line for the real data and the 100% simulation data are closely matched. After day 10, however, the real data average trip speed is slower, and the average trip location distance is less than the simulated data. This disparity suggests that the simulation might have some error that accumulates to become obvious only after running trips of more than 10 days.

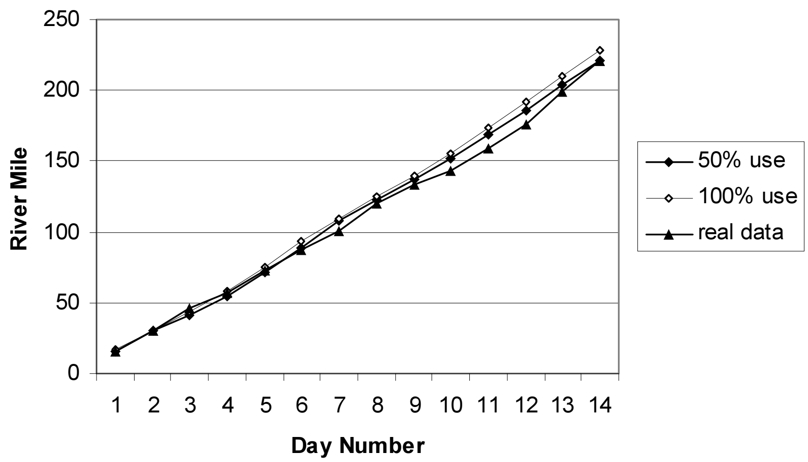

Figure 3. The average trip profile for rafting trips of 15-day duration. This graph provides a comparison between the real data and various simulated scenarios. It can be used both to calibrate the simulator in the development stage and also as a tool for interpreting outcomes of multiple scenarios.

Trips of Varying Lengths

We next provide output that takes the average of all the trips, not just those of 15-day duration (Fig. 4). Each line captures the average location of each trip on a daily basis, but also represents trips of many different lengths. The anomalous decrease after day 6 is not due to trips backtracking along the river, but rather shows the effects of shorter trip lengths that travel the entire river corridor (all 250 miles) in six or seven days. These trips, because of early completion, are then removed from the data set. A more useful query might involve separating out shorter, motorized trips for individual analysis. On day-7, only trips that are greater than or equal to seven days are shown. The simulation provides an indication that it is capturing the real data flow of rafting trips in some sort of "average" sense. The similarities between Figures 3 and 4 suggest a certain robustness in the simulator's ability to capture the basic flow of rafting traffic on the Colorado River. The simulator appears, however, to result in trip itineraries that are further down river than the real data indicates. This is another area of focus for improving the next version of our simulator.

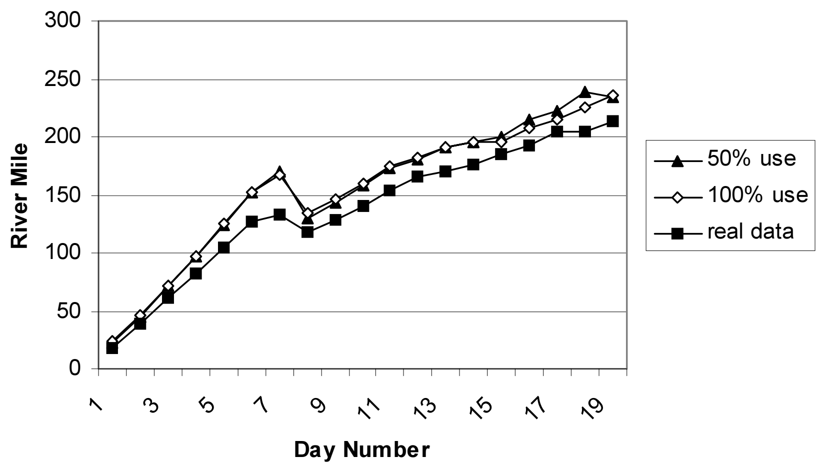

Figure 4. The average trip profile for trips of all lengths. This provides a comparison between real data and various simulated scenarios.

In addition to specific queries, GCRTSim provides a comprehensive report that can be compared to Management Objectives established in the Colorado River Management Plan (National Park Service 1989). These management objectives are the guidelines that the National Park Service employs in order to evaluate proposed launch scenarios and determine whether or not a given scenario results in acceptable river traffic conditions. For example, one management objective specifies that there should be an 80% probability that a trip will make contact with seven or fewer river parties per day, with up to 90 minutes in sight of less than 125 other people (National Park Service 1989). A simulation run based on a 100% use level, showed that this particular management objective resulted in an average probability of 54.53% that party contacts will remain within the management standards. A simulation run based on a 50% use level, resulted in an average probability of 91.09% that party contacts will remain within the management standards. Queries such as these will enable users of GCRTSim to better judge alternative management scenarios.

DISCUSSION AND CONCLUSIONS

GCRTSim, in addition to being a repository for an extensive database of trip reports completed during 1998 and 1999, is also an integrated statistical and artificial intelligence-based computer simulator that models complex, dynamic human-environment interactions in the Colorado River corridor. It will be used by managers at Grand Canyon National Park to help understand the potential impact of various alternative management scenarios for rafting trips on the Colorado River.

These results are preliminary because the 1999 trip diary data are not yet available, and additional improvements and refinements for the simulation engine are still underway. The real test will be subsequent to this, when the model is used extensively to examine potential outcomes of various alternative launch schedules. The insight that can be provided by GCRTSim is expected to be a valuable contribution to a complex situation: managing rafting traffic on the Colorado River in an optimal way for both recreators and for the natural resource itself. For up-to-date information on the status of this project, visit the websites at http://mathcs.holycross.edu/~croberts/research or http://odin.math.nau.edu/~msl.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the team members involved in this project: Dr. Terry Daniel, Dr. Michael I. Ratliff, Micheal Meitner, Susan Cherry, Doug Stallman, Rian Bogle, Rob Allred, Joanna Bieri, Gary O'Brien and Dana Kilbourne. This project would not be possible without funding from the Grand Canyon National Park, the University of Arizona and Northern Arizona University (including the NAU-NASA Space Grant). The authors also wish to thank the countless people who have contributed to our understanding of the complex nature of running rafting trips down the Colorado River. This includes Linda Jalbert, Laurie Domler and others from Grand Canyon National Park, the Grand Canyon River Outfitters Association, the Grand Canyon Private Boaters Association, the Grand Canyon River Guides and several social science researchers involved with the Grand Canyon National Park.

LITERATURE CITED

Bieri, J.A., and C.A. Roberts. 2000. Using the Grand Canyon River Trip Simulator to Test New Launch Schedules on the Colorado River. AWIS Magazine, Association for Women in Science, Washington DC. 29: 6-10.

Bishop, I.D., and H.R. Gimblett. 1999. Management of Recreational Areas: Geographic Information Systems, Autonomous Agents and Virtual Reality. Environment and Planning B. Planning and Design 2000 27: 423-435.

Borkan, R.E., and A.H. Underhill. 1989. Simulating the Effects of Glen Canyon Dam Releases on Grand Canyon River Trips. Environmental Management 13: 347-354.

Brian, N.J., and J.R. Thomas. 1984. The 1983 Colorado River Beach campsite inventory. National Park Service Division of Resource Management, Grand Canyon National Park, Grand Canyon, 56 pp.

Cherry, S. 1997. Modeling of River Trips on the Colorado River in Grand Canyon National Park. Unpublished Paper. School of Renewable Natural Resources. University of Arizona. Tucson, Arizona.

National Park Service. 1989. Colorado River Management Plan. U.S. Department of the Interior.

Gimblett, H.R., C.A. Roberts, T. Daniel, M. Mitner, S. Cherry, D. Kilbourne, M. Ratliff, D. Stallman, R. Bogle. 2000. Intelligent Agent Modeling for Simulating and Evaluating River Trip Scheduling Scenarios for the Grand Canyon National Park. Pages 245-275. *in* H.R. Gimblett H.R. (ed.) Integrating GIS and Agent based modeling techniques for Understanding Social and Ecological Processes, Oxford Press, London.

Gimblett, H.R., B. Durnota and R.M. Itami. 1996. Spatially Explicit Autonomous Agents for Modeling Recreation Use in Complex Wilderness Landscapes. Complex International Journal 3.

Jalbert, L.M. 1990. Monitoring Visitor Distribution and Use Patterns Along the Colorado River Corridor: River Contact Survey and Attraction Site Monitoring. Resource File in Grand Canyon Science Center, Grand Canyon National Park. 47pp.

Jalbert, L.M. 1991. Monitoring Visitor Distribution and Use Patterns Along the Colorado River Corridor: River Contact Survey and Attraction Site Monitoring. Resource File in Grand Canyon Science Center, Grand Canyon National Park. 32pp.

Jalbert, L.M. 1992. The Influence of Discharge on Recreational Values including Crowding and Congestions and Safety in Grand Canyon National Park. Division of Resources Management in Cooperation with Glen Canyon Environmental Studies. Grand Canyon National Park.

Jalbert. L.M. 1993. Colorado River Management; Resource Monitoring Program: Recreational Impacts to Camp and Attraction Site Quality, River Rehabilitation and Visitor Experience, Program Summary. Resource File in Grand Canyon Science Center, Grand Canyon National Park. 14pp.

Kaplinski, M., J. Hazel, M. Manone, R. Parnell and A. Dale. 1998. Colorado River sediment storage in Grand Canyon during calendar year 1997, Final Report to the U.S. Bureau of Reclamation, Grand Canyon Monitoring and Research Center, Flagstaff, AZ, 65 pp.

Kearsley, L., and R. Quartaroli. 1997. Effects of a beach/habitat building flow on campsites in Grand Canyon: Final Report of Applied Technology Associates for the Glen Canyon Environmental Studies, 18 pp.

Manneville, P., N. Boccara, G.Y. Yichniac and R. Bidaux. 1989. Cellular Automata and Modeling of Complex Physical Systems. Springer, New York.

O'Brien, G.O., J. Jansen, K.S. Thompson, A.R. Potochnik and K.J. Burke. 1997. Effects of the Effects of Continuous High Flows and Daily Fluctuating Flows from Glen Canyon Dam on Grand Canyon Beaches, 1997 and 1998: A Continuation of a Repeat Photography Study by Grand Canyon River Guides, Inc. (Adopt-a-Beach Program) Administrative report for Grand Canyon Monitoring And Research Center by the Grand Canyon River Guides Adopt-a-Beach program.

O'Brien, Gary and C.A. Roberts. 2000. Evaluation of river beach carrying capacity information utilized by the Grand Canyon River Trip Simulator: Analysis and recommendations for future study. Unpublished Paper. Northern Arizona University. Flagstaff, AZ.

Reghis, M., and E. Reventa. 1998. Classical and fuzzy concepts in mathematical logic and applications. CRC Press, Boca Raton.

Roberts, C.A, 1998. Expert Interviews with Grand Canyon River Guides. Unpublished Paper. Available at CPFS, Northern Arizona University. Flagstaff, AZ.

Schechter, M. 1975. Simulation model of wilderness area use. Resources for the Future, Washington, D.C. pp. 172.

Shelby, B., and J.M. Nielsen. 1976a. Design and Method of the Sociological Research in the Grand Canyon. Technical Report No. 1, Colorado River Research Program Report Series, U.S. Department of Interior, National Park Service.

Shelby, B., and J.M. Nielsen. 1976b. Motors and Oars in the Grand Canyon. Technical Report No. 2, Colorado River Research Program Report Series, U.S. Department of Interior, National Park Service.

Shelby, B., and J.M. Nielsen. 1976c. Use levels and Crowding in the Grand Canyon. Technical Report No. 3, Colorado River Research Program Report Series, U.S. Department of Interior, National Park Service.

Shelby, B., and J.M. Nielsen. 1976d. Private and Commercial Trips on the Grand Canyon. Technical Report No. 4, Colorado River Research Program Report Series, U.S. Department of Interior, National Park Service.

Shechter, M., and R.L. Lucus. 1978. Simulation of Recreational Use for Park and Wilderness Management. Johns Hopkins University Press for Resources for the Future, Inc., Washington, D.C. 220 pp.

Tecuci, G., and T. Dybala. 1998. Building intelligent agents: an apprenticeship multi-strategy learning theory, methodology, tool and case studies. Academic Press, San Diego.

Underhill, A. H., A.B. Xaba and R.E. Borkan. 1986. The Wilderness Simulation Model Applied to Colorado River Boating in Grand Canyon National Park, USA. Environmental Management. 10: 367-374.

Van Wagendonk, J. W. 1979. Use of a wilderness simulator for management decisions. Proceedings of the 1st Conference of Scientific Research in the National Parks. Transactions and Proceedings Series 5: 1039-1040.

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