WATER QUALITY ANALYSES OF THE COLORADO RIVER CORRIDOR OF GRAND CANYON

Brock Tunnicliff and Stanley K. Brickler
University of Arizona

ABSTRACT

Water quality research of the Colorado River corridor of Grand Canyon examines important relationships between densities of fecal coliform bacteria in surface water and underlying bottom sediments. Surface water sampling alone does not accurately reflect baseline water quality status of natural recreational waters, as sediments often harbor microbial densities in several orders of magnitude of overlying waters. Water-based recreation activities and natural wave and current processes can resuspend sediment and associated microbial populations, including enteric pathogens. Data show significant associations between surface water and bottom sediment microbial populations, demonstrating the importance of a combined sampling approach to water quality analyses.

INTRODUCTION

During the late 1960s and early 1970s, the Colorado River through Grand Canyon reached international acclaim as the premier white water recreational river in America. The narrow 225-mile river corridor of Grand Canyon provided water-based recreational opportunities in a wilderness-type setting with challenging white water, spectacular tributary watercourses, attractions of cultural and natural history, and abundant camping beaches. The popularity of Colorado River float trips resulted in intensive and near recreation capacity use by river runners. Concern regarding the phenomenal growth of commercial and private river trip participation led to research to assess relationships between river recreation and the Canyon environment.

The first evaluations (1973-1975) of microbial water quality in the Colorado River corridor led the National Park Service (NPS) to conclude that generally unpolluted conditions existed (NPS, 1979); management recommended treatment of all drinking water from the river or side creeks but had not identified any particular water quality hazards. Early water quality investigations in the Canyon examined only surface waters of the Colorado River and tributaries; researchers and management did not recognize nor examine critical associations between recreational activities, surface water quality, and bottom sediment microbial densities. Research elsewhere has established that bottom sediments can provide a microbial habitat where enteric organisms,* including pathogens, can persist and concentrate (Van Donsel and Geldreich, 1971 and Hendricks, 1971), representing a latent potential to dramatically degrade surface microbial water quality if resuspended by currents, wave action, or recreational activities (Motschall, 1976; Winslow, 1976; and McKee, 1977).

Fecal contamination from warm-blooded animals, including man, is the source of enteric organisms in surface waters and bottom sediments; baseline water quality analyses of recreational waters seek to define water quality status through examination of the distribution and quantity of fecal contamination in the resource. The objective of recreational water quality analyses is to identify potential water quality hazards that may affect the user and facilitate management decisions to protect users. User impacts on water quality may be implicated in recreational water quality surveys but are supplementary findings of research designed primarily to determine potential resource impacts on users.

Research conducted by the University of Arizona in 1978 and 1979 in the Colorado River corridor of Grand Canyon was designed to examine associations between river recreation activities and water quality. Baseline profiles of selected water parameters were 1) established for the Colorado River and the lower confluent reaches of 26 tributaries (Figure 1) and 2) evaluated for potential impacts on river runners based on the pattern of their water use and contact. Evaluations of potential impacts were facilitated by selection of sample sites representing varying types of recreation activities and use intensities. Research analyses concentrated on microbial water quality parameters; detection and quantification of microbial contamination of surface waters and bottom sediments through an examination of densities of enteric organisms was an essential approach leading to the understanding of water quality hazards associated with river running recreation.

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*Enteric organisms live in the intestines of warm-blooded animals and are excreted in fecal matter; may be pathogenic or nonpathogenic.

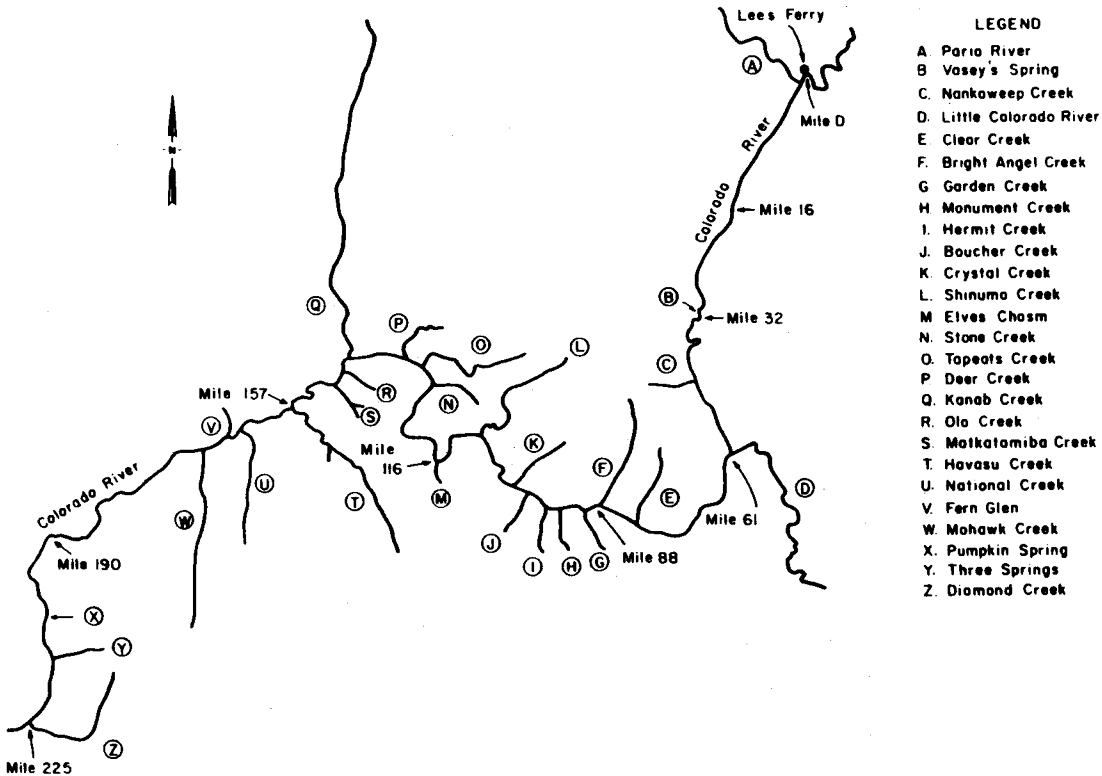

Figure 1. Colorado River and Tributaries through Grand Canyon.

In the scope of this study, the Colorado River corridor refers to that central gorge of the Grand Canyon through which the Colorado River flows and to those accessible, adjacent areas visited frequently by river trips. Tributaries to the Colorado River supersede the limits of the river corridor and potentially can have multiple impacts on river water quality corresponding to watershed characteristics and land use. Factors such as soil erosiveness, the presence of domestic stock, or recreational use determine the quality of runoff from the watersheds which influences the quality of the Colorado River. Tributary influences are potentially pronounced during the summer season when monsoon rains can have a flushing effect on watersheds.

Associated with watershed flushing are microbial contaminants; Motschall (1976) and Patterson (1977) found increased fecal coliform* densities in surface waters following storm runoff events in southern Arizona. Fecal contamination by domestic stock, wildlife, communities, or recreationists on tributary watersheds miles or a few feet from the Colorado River can ultimately influence the River water quality through flushing processes.

Colorado River corridor research was designed to detect variations in water quality which potentially reflect the diversity of tributary watershed influences.

RESEARCH APPROACH

Water quality analyses of the Colorado River corridor occurred during the 1978 and 1979 river running seasons. Examination of the extensive river corridor necessitated analyses in the field. Travel through the Grand Canyon was via research rafts in a series of six float trips, April through September, in 1978, and two float trips, July and August, in 1979; 82 field days occurred in 1978 and 22 field days occurred in 1979.

A total of 497 water quality samples were collected over two seasons from the Colorado River along the 225-mile stretch from Lees Ferry to Diamond Creek, the launch and take-out points of the research trips. The confluent reaches (within approximately 200 yards of the Colorado River) of 26 side creeks in the river corridor were also sampled in 1978; nine tributaries were sampled in 1979. Additional samples collected from upstream locations on some side creeks increased the tributary sample site total to 33 in 1978 and to 13 in 1979 for a two-season total of 165 individual tributary samples.

Selected microbial, physical, and chemical parameters were measured to determine baseline water quality status in the Colorado River corridor of Grand Canyon. Research emphasis was on microbial water quality; physical and chemical parameters were measured to facilitate evaluation of the microbial profiles. Microbial parameters included two groups of enteric indicator organisms, fecal coliform (FC) and fecal streptococcus (FS) bacteria. Physical parameters included turbidity and water and air temperature; chemical determinations included alkalinity, hardness, phosphate, nitrate, chloride, total dissolved solids, and pH.

University of Arizona research in Grand Canyon examined FC and FS densities in Colorado River and tributary surface waters and FC densities in river and tributary bottom sediments. Surface water bacteria densites were determined in the field using membrane filter (MF) methodologies for microbiological analyses (Standard Methods, 1975); MF techniques were adaptable to field research procedures. Bottom sediment bacteria densities were determined by two variations of the most probably number method (MPN), a multiple fermentation tube technique which was not readily adaptable to field research. In 1978, a technique of storing bottom sediment samples intact on ice for up to 14 days was developed and successfully tested and used. Bottom sediment samples collected in the field were stored on ice until transport out of the Canyon to a laboratory for MPN analyses. For the 1979 research phase, the MPN methodology and apparatus were modified to allow in-the-field analyses.

Sample designs for the Colorado River and tributaries were distinct. Two designs were employed to assure representative analyses of the river. A fixed site design identified river sample points located in a pattern to detect influences of tributary inflows, current irregularities, and light and intensive recreational use on Colorado River water quality; surface water and bottom sediment samples were collected at fixed sites. A time series sample design complemented the fixed site design by assuring comprehensive sampling of the Colorado River surface waters through time; surface water samples were collected at 0800, 1200, and 1800 hours each day at the location of the research rafts at the specified period.

Tributaries were sampled by a fixed site design. Multiple sites were located at Hermit Creek, Elves Chasm, Deer Creek, and Havasu Creek to detect potential water quality associations with intensive recreational use. Surface water and bottom sediment samples were collected from selected tributaries.

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*Fecal coliforms are a group of enteric bacteria native to the gut of warm-blooded animals and which are excreted in feces. Rarely pathogenic, fecal coliform densities are measured as indicators of fecal contamination. Arizona state water quality standards specify allowable limits of fecal coliform occurrence; the bacteria are especially prominent in the human digestive system.

Surface water fecal contamination levels in the Colorado River corridor are consistently low as indicated by the 1978 log mean FC densities of 2.1 FC/100 ml (N = 424) in the River, and 3.6 FC/100 ml (N = 189) in 26 tributaries, and the 1979 log mean FC densities of 2.4 FC/100 ml (N = 73) in the River and 8.0 FC/100 ml (N = 26) in 11 tributaries. An arid climate prevails in the Grand Canyon environment and surface water flow processes infrequently translocate fecal matter and organisms from watershed surfaces to the stream channel.

RESEARCH FINDINGS

The most important finding of the research is detection of a significant difference between the distributions of enteric organisms in surface waters and bottom sediments of the Colorado River corridor (Figure 2). Surface waters of the River and tributaries are generally free of significant concentrations of FC bacteria indicating waters which are acceptable* for full and partial body recreational contact, an expected status based on previous analyses (NPS, 1979) and the natural, wildland characteristics of most of the tributary watersheds. Exceptions to this general surface water finding may be expected during periods of watershed flushing from storm water runoff; these potentials are discussed later.

In contrast to surface waters, the bottom sediments of the Colorado River and tributaries harbor generally high concentrations of FC bacteria (Figure 2), a status unsuspected even as a potential in previous management or research perspectives of Colorado River corridor water quality. Grand Canyon is essentially a natural environment managed as a preserve for wilderness purposes, e.g., wildlife habitat, scenic values, educational values, and backcountry recreation. Water quality impacts, such as sewage outfalls, population centers, feedlot drainages, and intensive agriculture, are not evident within the Canyon system and surface waters appear to be generally free of significant contamination; consequently, two questions arise: 1) what is the source of fecal contamination in the bottom sediments; and 2) what is the significance of bottom sediment contamination? These issues are examined in turn.

SOURCE OF FECAL CONTAMINATION IN SEDIMENTS

FC bacteria by definition are enteric organisms native to warm-blooded animals; in Grand Canyon and the tributary watershed system, aquatic sources of FC bacteria are virtually nonexistent. Ultimately, the source of enteric organisms as represented by FC bacteria in Colorado River corridor bottom sediments must be terrestrial warm-blooded animals, i.e., wildlife, livestock, and humans. Analyses of FC/FS ratios** (0.10 for the Colorado River, 1978, and collectively 0.06 for 26 tributaries, 1978) indicate that animals, rather than humans, are the predominant source of fecal contamination in the River corridor. Chances of human fecal contamination have been minimized by NPS policy, initiated in 1978, requiring river trips to carry out human sewage, ending a practice of beach burial. Wildlife and livestock sources of enteric organisms cannot be discounted as a water quality concern as many enteric diseases infect both man and wildlife. Human impacts on water quality must also not be overlooked as river parties are not completely effective in containing their wastes, the wastes of 250,000 to 300,000 Grand Canyon hikers per year are not totally controlled, and tributaries can introduce uncontrolled human wastes from outside Grand Canyon National Park.

Rainfall events which lead to overland flow can more directly impact water quality. Samples following a September 1978 storm event in Grand Canyon detected a sudden increase in Colorado River FC densities from near mean levels to a peak of 1165 FC/100 ml as the River waters became turbid with storm water runoff. Watershed flushing which accompanies summer rainfall events in Grand Canyon can temporarily and severely impact surface water quality and river runners should be alert to this potential when utilizing River or tributary waters influenced by storm water runoff, usually characterized by increased turbidity.

In 1978 at least, day to day translocation processes, which account for consistently low levels of FC contamination in River corridor surface waters, are probably more important than infrequent rainfall events in moving enteric organisms from watersheds to stream sediments as is reflected in the gradual and continual buildup of FC densities in bottom sediments. The 1978 log mean FC density of 2.1 FC/100 ml in the Colorado River translates to approximately 12 million FC bacteria passing any given point along the river channel every second assuming a typical midsummer flow of 20,000 cfs and homogeneous distribution of bacteria in the water column; this ball park figure indicates that sufficient numbers of bacteria exist in the River to lead to bottom sediment concentrations of up to 48,000 FC/100 ml (maximum detectable FC density with techniques used).

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*State and federal water quality standards for recreational use allow up to 200 FC/100 ml for full body contact and 1000 FC/100 ml for partial body contact as log mean values of samples collected within 30 days.

**FC bacteria are prevalent in human feces; FS bacteria are prevalent in other warm-blooded animal feces. FC/FS ratios 4:1 are indicative of human sources of contamination; ratios 0.7 are suggestive of nonhuman sources.

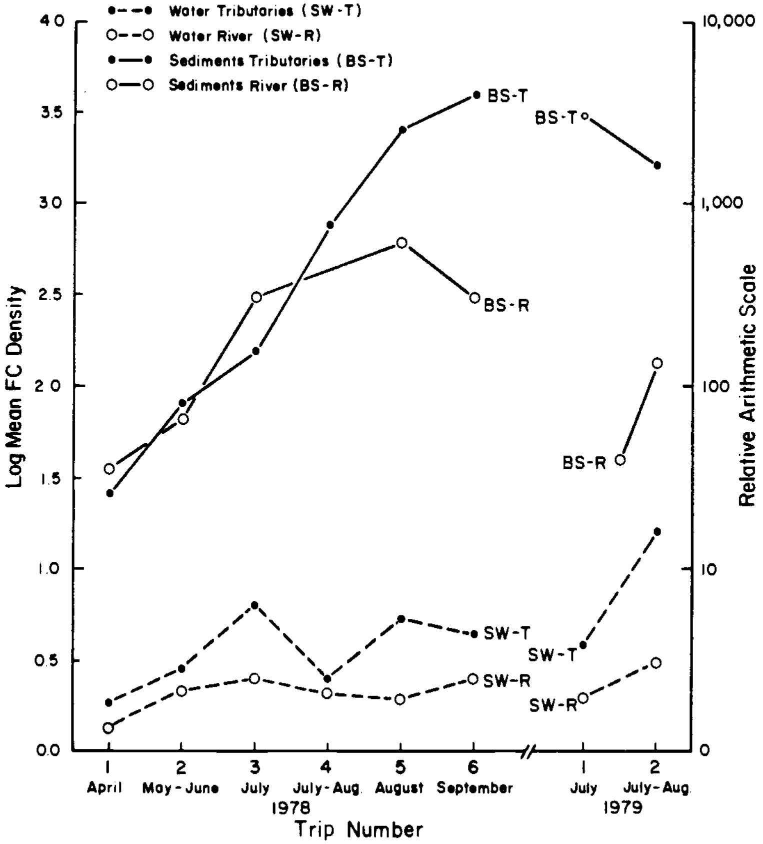

Figure 2. FC Densities in Surface Waters and Bottom Sediments of Both the Colorado River and its Tributaries during 1978 and 1979 Research Trips.

Plotted values are log mean FC densities for each research trip representing all corresponding trip samples.

Sediments provide substrate and nutrients to which microorganisms can adhere and persist (Hendricks and Morrison, 1974); cold water temperatures (6-12°C) in the Colorado River facilitate persistence through a reduction of metabolic rates. Mechanisms which translocate bacteria to the sediments are not clearly understood. Potentially, sediments serve as filters removing bacteria from the surface waters which pass over and through the sediments. Bacterial survival within the sediments would lead to increasing FC densities as streamflow processes continuously added bacteria.

SIGNIFICANCE OF BOTTOM SEDIMENT CONTAMINATION

Bottom sediment concentrations of enteric organisms constitute potential water quality hazards to river runners and other Colorado River corridor visitors. A number of river running and natural activities can resuspend bottom sediments in the overlying waters; associated with sediment resuspensions will be concentrations of enteric organisms leading to degradation of surface water quality. Several avenues of intermixing surface waters and sediments occur in Grand Canyon, including: 1) recreational water play activities; 2) boat and motor actions near beaches; 3) bathing; 4) wading for drinking, cooking water collection; 5) dish scrubbing with sediments; and 6) wave and current actions on Colorado River beaches.

Of the river running activities, water play and the handling of water for drinking and cooking purposes have the most critical water quality associations. Water play activities particularly in confined tributary pools can lead to widespread sediment resuspension. In August 1979, samples from the pool at Elves Chasm showed bottom sediment FC densities of 9200 FC/100 ml and surface water FC densities of 4810 FC/100 ml. Elves Chasm is a Colorado River tributary popular as a swimming site; approximately 50 river runners were active in the pool site at the time of the August sample.

Drinking and cooking water are often utilized by river runners without regard for 1) sediments introduced during collections or 2) proper treatment, practices which advocate unnecessary water quality risks.

The danger of bottom sediment concentrations of enteric organisms in the Colorado River corridor cannot be quantified in terms of relating specific FC densities to specific hazard levels but they clearly represent a previously unknown and unsuspected water quality hazard beyond that detected from surface water analyses alone. During the 1972 and 1979 river seasons, outbreaks of Shigellosis, a severe gastrointestinal disease caused by an enteric pathogen, occurred among river runners, requiring investigations by the Federal Center for Disease Control, Atlanta, Georgia (Merson et al., 1974). Pathogens were isolated from victims of the disease but the pathogen's source has not been determined; water could not be ruled out as a potential carrier. Research by the University of Arizona has identified bottom sediments as potential reservoirs of enteric pathogens within the Colorado River corridor system.

CONCLUSIONS

Surface waters in the Colorado River corridor of Grand Canyon are generally of high quality; FC densities are predominately low, rarely indicating a recreational contact hazard associated with surface waters.

Colorado River corridor bottom sediments are a latent source of concentrated microbial contamination to overlying surface waters, but have not previously been considered or indexed as a water quality criterion. Contamination occurs when sediments are resuspended by current or wave action or recreational activities, creating a surface water quality hazard. Research in 1978 and 1979 identified sediments as a water quality entity and hazard in Grand Canyon; monitoring of the river or side streams must include bottom sediment analyses to accurately evaluate baseline water quality status in the Canyon.

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